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Aerospace Senior Design Project, In-Orbit Manufacturing Process of Electronic Enclosures

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Abstract – In Orbit Manufacturing Process of Electronic Enclosures

This report presents the final design of A-MOD's groundbreaking in-orbit electronic enclosure manufacturing device. The detailed design, encompassing analysis, specifications, and component specifics, showcases the feasibility of the proposed system. With objectives met, the report navigates through the concept of operations, validation and verification processes, critical design of mechanical and electrical components, software integration, performance specifications, and a comprehensive risk assessment. A-MOD's design revolutionizes space technology by proposing a device capable of manufacturing electronic enclosures in orbit, reducing costs and optimizing resources. Thorough validation and verification procedures ensure the system's adherence to stringent requirements, covering precision, quality, thermal resilience, and power efficiency, providing confidence in the robustness of the design. The critical design section highlights the meticulous mechanical design, detailing overall dimensions, manufacturing head specifics, and material storage mechanisms supported by CAD models and simulations. Although secondary in focus, the electrical design section outlines essential aspects, emphasizing wiring, off-the-shelf electrical components, and microcontroller usage, contributing to the system's overall efficiency. The performance specifications provide crucial metrics for evaluating efficiency in terms of mass, time, power consumption, and production quantity, with an enclosure test case serving as a benchmark for raw material optimization. The detailed risk assessment identifies potential challenges, emphasizing preventive actions and continuous testing and research, instilling confidence in the system's reliability. In essence, A-MOD's report offers a deep dive into groundbreaking space technology, presenting a design and a vision for the future of in-orbit manufacturing. The comprehensive insights and innovative solutions detailed in this report make it a must-read for space technology enthusiasts, researchers, and professionals seeking cutting-edge advancements in space manufacturing capabilities. The four most significant benefits of A-MOD's design to society and potential customers are its cost efficiency, rapid prototyping capabilities, reduced environmental impact, and enhanced space exploration capabilities. These advantages collectively position the in-orbit electronic enclosure manufacturing device as a transformative technology with broad implications for the space industry and beyond.

Document Update

Revision	Effective Date	Description of Changes
1.0	09/05/2023	MCR
2.0	09/25/2023	SRR & SDR
3.0	10/23/2023	PDR
4.0	10/21/2023	CDR
5.0	12/11/2023	FDR

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Also, we thank The Aerospace Corporation for assigning the senior design projects and providing industry mentors from their staff. It was great having the company help us complete the project for a real-life problem they are trying to solve. Dr. Vinay Goyal and Dr. Jacob Rome led the effort and helped organize the program—special thanks to Dr. Mason Hickman for being our team's mentor. Dr. Hickman has been a big help in reviewing assignments, explaining how things work in the industry, and pointing us in the right direction.

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Chapter 1 – Mission Concept

1.1 Motivations

1.1.1 Project Importance

Satellite orbital manufacturing stands out as a transformative advancement in the aerospace industry. To alleviate the problems of aging satellites and costly spacewalk upgrades, this project aims to do so in a way that allows for reduced efforts needed for launching and would be cost-effective due to its reduced robustness in space. While traditional satellite manufacturing involves extensive resources and transportation, eliminating atmospheric launch's immense energy and logistical challenges translates to reaching these goals. The straights can be manufactured with components more specific to their purpose because they no longer need to withstand launch loads. Furthermore, each part manufactured in orbit can be lighter, use fewer materials, and serve its intended purpose better. This resilience translates to an extended operational lifetime and reduced maintenance requirements, ultimately increasing the return on investment for satellite missions.

1.1.2 Aerospace Corporation Relevance

Within the Aerospace Corporation company, conceptual design studies play a pivotal role. This project resonates deeply with the company's ethos, aligning with pursuing future-oriented endeavors. By engaging in collaborations that delve into uncharted technological territories, the company showcases its commitment to innovation and progress. This project's uniqueness lies in its ability to offer a fresh outlook that would be distinct from the ongoing initiatives within the corporation.

The design of modules that foster space-based construction and the adaptation of 3D printing to micro-gravity environments would be the cornerstones of this mission. This pursuit would bring forth an array of challenges, both technical and logistical, as well as challenges from a science and engineering perspective that haven't been dealt with before, which is what would prompt more innovative solutions.

1.1.3 Student Relevance

For the students involved, this project offers a unique experience. By participating in conceptual design studies with the Aerospace Corporation, the students gain exposure to real-world challenges and innovation. Their contribution holds the promise of fresh perspectives, with the ability to hone their skills as a group to help them achieve their common goal.

1.2 Mission Description

The Aerospace Corporation has tasked the Kennesaw State University (KSU) aerospace senior design class with developing designs for technology demonstrators for an "On-orbit satellite factory." The plan is to design a modular "factory" on Earth to demonstrate three operations broken down into three missions. The Missions are as follows: (1) "Use polymer extrusion additive manufacturing (AM) to manufacture a plate, embed copper wire onto the plate, place a sensor (or second wire or connector) nearby, electrically join the components via soldering or other durable mechanisms, encapsulate the part and demonstrate continuity"; (2) "Using a pair of robot arms, select compatible connectors from inventory, connect them, and demonstrate mechanical and electrical performance"; and, (3) Use a laser cutter to manufacture parts in a microgravity environment. This team aims to tackle mission 1 of the satellite factory.

1.2.1 Problem Description

Mission 1 of the satellite factory's target is to design a module that can manufacture some base components and use them to assemble more complex systems in orbit. The module is to be hosted by the BCT X-Sat Venus Class bus. This mission aims to use polymer extrusion to manufacture housing and plates to embed wires, sensors, and connectors in said plate and then assemble components with premade circuits and computers in orbit. This mission plans to highlight how new additive manufacturing techniques and autonomous manufacturing can be used in on-orbit manufacturing.

The team, known as the Aerospace Microgravity Orbital Designers (A-MOD), intends to develop a payload module capable of manufacturing an electronic enclosure in a microgravity environment. The module will interface with the X-Sat Venus class bus and will be capable of making parts in orbit. Polymer extrusion or other additive manufacturing techniques will be utilized to create an enclosure for electronics. Wires and a sensor will be embedded into the enclosure. A-MOD is tasked with developing the conceptual design for the unit to achieve the aforementioned objectives in microgravity. This will require designing custom parts and integrating off-the-shelf mechanisms such as a robotic arm and 3D printer.

1.2.2 Assumptions

To make this project successful, the following assumptions are made:

1. The satellite will provide the communication systems. There is no reason to create an earth-to-space communication system for the manufacturing unit.
2. Someone else will provide and integrate Software to drive the mechanisms. The project's scope is only the conceptual design of the manufacturing system and does not involve writing the software to control it.
3. Zero gravity/ space environment is the primary design consideration.
4. The entire cargo bay and power supply within the satellite bus are available for the AM unit.
    a. Cargo volume
        i. 1 array: 20.5” × 16.4” × 27.0”
        ii. 2 arrays: 17.0” × 16.4” × 27.0”
    b. Payload Mass Capability: 70 kg
    c. Solar array power
        i. 1 array: 222W
        ii. 2 arrays: 444W
    d. Energy storage: 10.2 Ah
5. An atmosphere with maintained in the payload compartment by the X-Sat bus.
6. The temperature will be maintained by the X-Sat bus.

1.2.3 Available Resources

KSU campus resources, as well as team members' resources, are available. KSU provides students access to the library, computers, maker space, and other resources. Group members are willing to use personal resources as necessary, such as 3D printers, wires, welders, and soldering supplies. The KSU library provides students with an extensive research database and the inter-library loan program for free access to content outside the University System of Georgia (USG) library system. Campus computers are also available, as well as SolidWorks and Matlab software. The maker space is a small workshop available to students and consists of 3D printers, laser cutters, lathes, and mills. George has a 3D printer, welder, soldering iron, and spare parts that the team can use. Hunter can also utilize a 3D printer that he owns. In addition to the above resources, The Aerospace Corporation supplies mentors for each student team and documents related to in-orbit manufacturing.

1.2.4 Project Merits

The project will use current wiring and 3D printing technology to create an additive manufacturing (AM) process for electronic enclosures. The AM process proposed can be a starting point for future manufacturing operations in space. One aspect of an in-orbit satellite factory is showing that an electronic enclosure can be manufactured and assembled in space.

Technological advances have driven down the cost of 3D printers and other AM processes. Utilizing the current technology and adapting it to the mission of producing electronic enclosures will be possible in space. Creating components in space will save components from the harsh launching loads and make parts lighter, and fewer materials will be needed. The impact may help make the next generation of space equipment more affordable in the coming decades.

1.3 A Systems Engineering Approach

The project will be completed in five steps. The first is to establish design requirements. Some requirements are given based on the X-Sat Venus class's cargo and power capacity. Other conditions, such as electromagnetic interference (EMI), thermal, and other environmental factors, will need to be researched. The second step is to design the unit to meet the requirements. The design will involve inventing custom parts and integrating off-the-shelf components like a 3D printer and robotic arm. The third step is to analyze the layout to determine if it will meet the requirements. Simulations and estimations of the electrical load will be required to complete this step. The fourth step will be to conduct a trade study showing the advantages and disadvantages of both a single and double solar array. The last step is to create a prototype model of an electronic enclosure that could be made using the designed manufacturing unit.

1.3.1 Gantt Chart

The team has outlined its milestones in the proposed Gantt chart shown in Figure 1. Once each stage is completed, the team presses forward to the next milestone. This will ensure that the group meets its objectives and goals. The chart shows that the project will be divided into two phases; the first phase is the design phase. In the design phase, the team will understand the needs and goals and then transition to designing a solution. After the design phase, the second phase will begin. This Phase is the Review phase. In this phase, the team will determine the validity of the design.

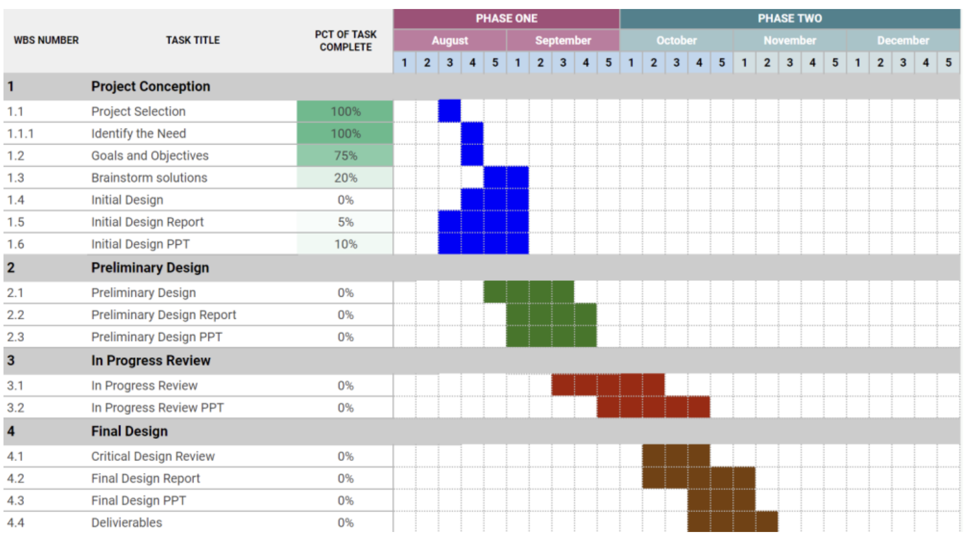


Figure 1 Gantt Chart

1.3.2 Systems Engineering

In the two phases of this project, the team focuses on four main milestones: the project conception, preliminary design, in-progress review, and the final design. Each of these milestones has its own set of objectives to meet. In the first milestone, the team needs to complete an initial design. The team must lay out initial ideas and possible solutions in this design. This includes identifying the needs and defining the goals. In this step, the team will come up with possible solutions.

Once the initial design report and presentation are done, the team will move on to the preliminary design portion of phase one. The team solidifies their ideas into a design that accomplishes the project's needs. The team will need to ensure the design fits the requirements. The team will decide which of the ideas proposed will be the best for the mission.

After the preliminary design review (PDR) is finished, the team moves to the project's next phase. In the review phase, the team will evaluate their preliminary design. It would have met the requirements in the previous step, yet in this phase, the design will need to complete the system requirements of the mission.

The next milestone is the final design, encompassing the critical design review (CDR) and final design review (FDR). To pass the CDR, the design must undergo varying testing to prove that the components work together under the conditions of the space environment. They are wrapping up the project with the final design report, which will be the proposal for the Aerospace Crop. With a model of the design as the deliverables.

1.4 A-MOD Mission

A. Team Name

Aerospace Microgravity Orbital Designers (A-MOD).

B. Vision

Unleashing the potential of space manufacturing.

C. Mission

To create a design that demonstrates the use of additive manufacturing in orbit to construct electronic enclosures.

D. Logo

Figure 2 Team Logo

Figure 2 is the A-MOD logo, which encompasses the different aspects of the vision held by the team. The black circle represents the Earth, the blue process surrounding it represents the outer atmosphere where the satellite will be orbiting the world, and the stars represent space, where this endeavor will occur. The grid floor adds to the aspect of 3-D printing in zero gravity. The blue and yellow metric lines represent the analysis and progress of the project being carefully measured and thought out.

E. Goals

1. To create an additive manufacturing (AM) process for electronic enclosures
2. To show that an electronic enclosure can be manufactured and assembled in space.
3. To reduce costs and the efforts needed for launch.
4. To help make the next generation of space equipment more affordable in the coming decades.

F. Objectives

1. Build an electronic enclosure made of extruded polymer, utilizing AM techniques, which would ultimately be compatible with lighter and hardware connectors.
2. Embed wires and two sensors into enclosures that were made
3. Ensure these enclosures withstand outer space's EMI and temperature cycles.

Chapter 2 - System Requirements and Definitions

2.1 System Definition

2.1.1 Units

During this project, the US standard System will be employed as the foundation for reviewing and defining the systems within this process for dimensioning and modeling. The rest will be done using the International System (SI). The appendix will contain the pertinent units essential to the work done.

2.1.2 Team Architecture

A. Customer and Stakeholders

There are three stakeholders in this project: (1) The Aerospace Corporation, (2) Kennesaw State University, and (3) The Aerospace Microgravity Orbital Designers (A-MOD). The Aerospace Corporation will act as the customer. Table 1 and Table 2 explain the responsibilities and duties of the stakeholder and the customer.

Table 1 Stakeholder needs, roles, and effectiveness

Stakeholder	Needs and Expectations	Role	Measure of Effectiveness
Aerospace Corporation	Have product align with the Aeospace Corportion's mission and vision. Equip students with technical expertise in the manufacturing field.	Align with the Aerospace Corporation's mission and vision. Offer students specialized knowledge in manufacturing and microgravityapplications. The Aerospace Corporation will offer ongoing support throughout the project's development. This support will encompass conducting reviews at key milestones and offering guidance in the students' approach.	The project will go through the process of reaching the milestones set by assigned managers from the Aerospace Corporation.
Kennesaw State University	Enable students to gain valuable knowledge that. will benefit their future professional endeavors.	The university will provide students with the necessary resources to achieve the projects goal, whilst students continue to abide by their code of conduct as well as professionalism.	The evaluation criteria given byDr. Vijay Goyal, will be used for guidance. Students will be exposed to the processes of systems engineering and manifacturing in order to aid in their learning path as engineers.
A-MOD	Enhance the Student Experience. Cultivate Relationships. Fulfill Stakeholder Expectations.	Comply with the expecttions of the stakejolders, while learning	This collaboration between the Aeospace Corporation and Kennesaw State University allows students to experince what solving engineering problems in the real-world is like. This allows them to expand their knowledge and view their work from a different perspective.

Table 2 Customer needs, roles, and effectiveness

Customer	Expectations	Role	Measure of Effectiveness
Aerospace Corporation	Develop electronic enclosures made up of extruded polymer, that can withstand temperature cycles in space.	The Aerospace Corporation will provide the team with guidance via mentors, as well as expose them with industry experience.	If satisfaction is achieved, the project life cycle may be further developed.

B. Team Personnel Roles & Responsibilities

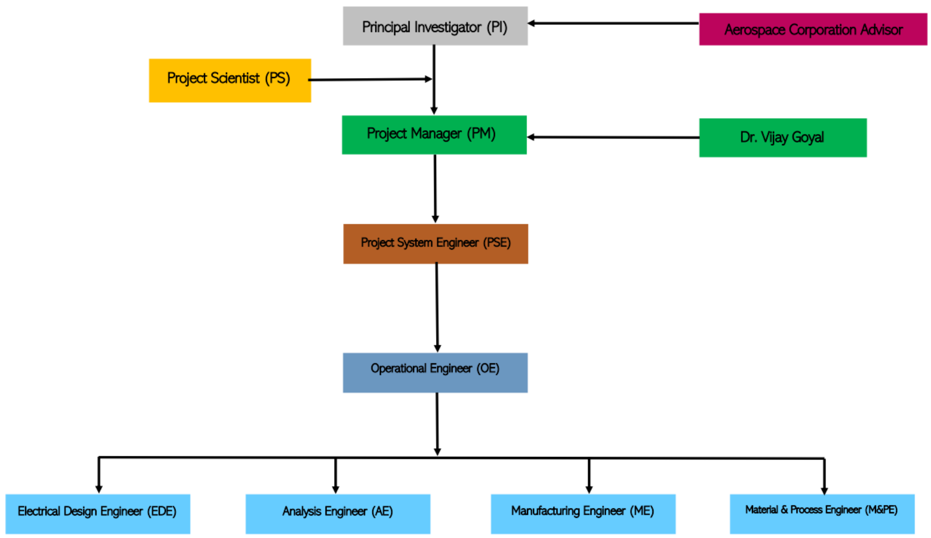


Figure 3 A-MOD Operational Model

Figure 3 shows the A-MOD team, which consists of three mechanical engineering students, one professor, and a mentor from the Aerospace Corporation. The assigned roles are as follows:

1. Dr. Mason Hickman is the **Aerospace Corporation Advisor.** He is responsible for (1) providing A-MOD feedback on the project, (2) communicating with PI and team members, and (3) keeping the Aerospace Corporation up to date on the project.

2. Dr. Vijay Goyal is the **Principal Investigator (PI).** He will be responsible and accountable for (1) the success of the mission, (2) the project's execution within the cost and schedule, (3) delegating day-to-day operation, (4) maintaining communication with the Aerospace Corporation Advisor, and (5) working with the Project Program Manager (PM).

3. Ms. Audrey Yewo, Mr. George Pitcock, and Mr. Hunter O'Neal will be **Project System Engineers (PSE)**. They will be responsible for (1) maintaining coordination between all of the system components, (2) defining the interfaces between the components, and (3) developing a System Engineering Management Plan consistent with the mission.

2.1.3 Project Layout

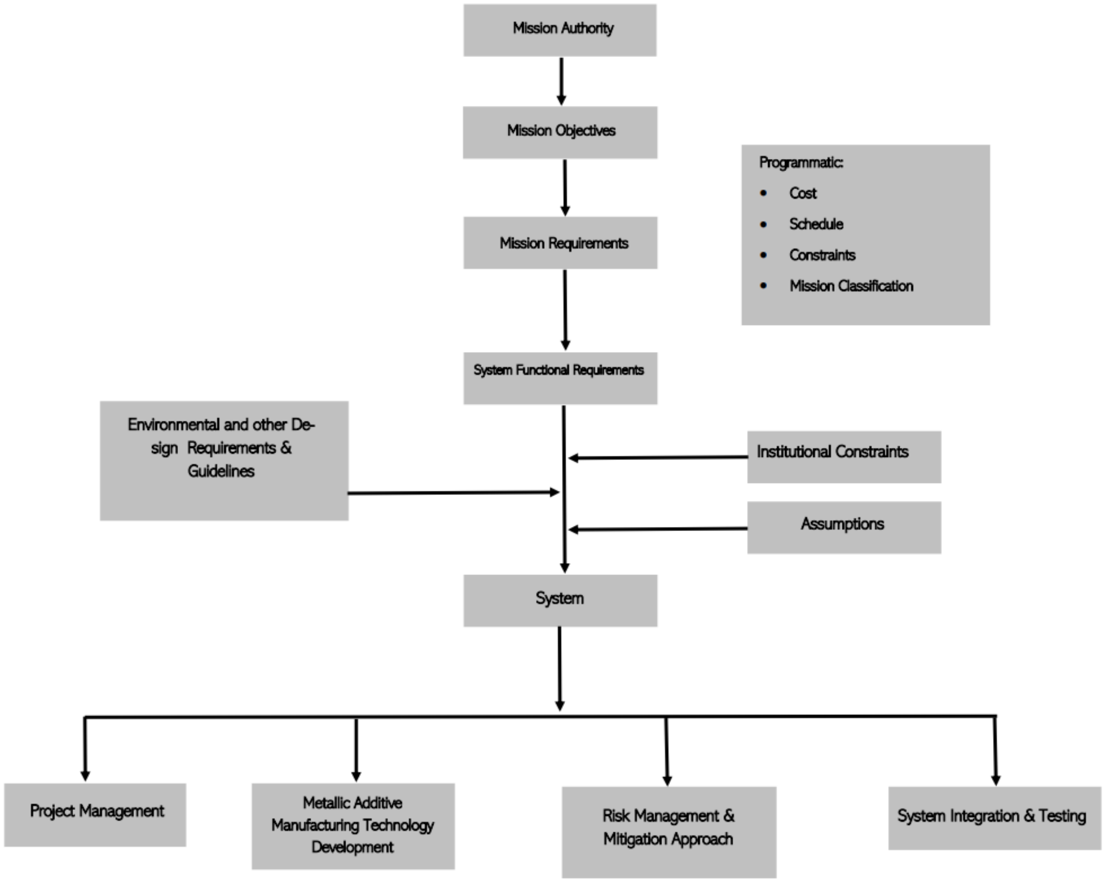


Figure 4 Project Layout

The project layout, showcased in Figure 4, shows the four main ways the team aims to achieve the needs of the stakeholders. A more detailed description of the overall objective is outlined in Chapter 1 – Mission Concept. Here, the four main aspects will be explained.

1. Project Management: Emphasis on managing time, cost, and other business aspects while adhering to project objectives. More details addressing the systems engineering management plan can be found in 2.2.1 Work Breakdown Structure.

3. Risk Assessment and Mitigation: Identify all conceivable risks associated with each component. This entails evaluating potential hazards, categorizing their gravity and occurrence frequency, and developing a risk mitigation strategy for each identified risk. This ongoing process will persist throughout the entire system's life cycle.

4. Systems Integration and Testing: This stage in the system's life cycle depends on the Aerospace Corporation's choice to proceed with further development. Throughout this phase, adjustments will be made to the prototype to align it with the testing and validation criteria. It is important to note that this process exists independently of A-MOD's mission requirements.

2.1.4 Interface Documentation

Documentation for each section will follow the given identification number:

1xx Documents related to the project management area

2xx Documents link to the polymer extrusion AM Process

3xx Documents related to the Risk Assessment and Mitigation Plan

These tables are given in Appendices **B** to **D**. Table 3 summarizes these documents.

Table 3 A-MOD Codification

Number	Title
101	Tasks for Each Milestone
102	Leaders and Support per Task
103	Schedule
104	Cost Analysis
301	Quantittive Analysis Table

2.2 Management Plan

The management plan consists of three main sections: the work breakdown structure, shown in Figure 5; the project life cycle, shown in Figure 6; and the schedule, shown in Figure 7. By adhering to the procedures laid out in each area, the team will be able to ensure they are on track.

2.2.1 Work Breakdown Structure

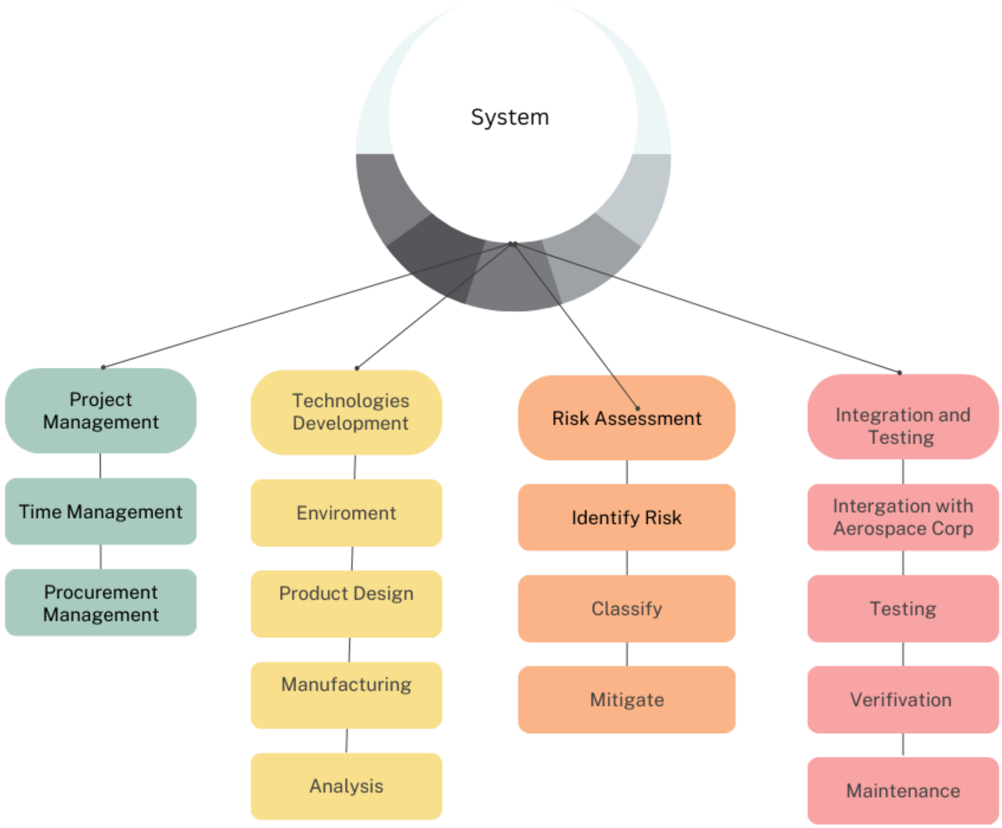


Figure 5 Work Breakdown Chart

1. Project management encompasses time management, planning, focus areas, and team organization. This branch is divided into two parts.
    a. Time Management: How the team will dedicate their time to the different parts. These are the questions that Time Management will focus on. This will allow the team to stay on track. The Gantt chart in Figure 7 will be the guide for the project's timeline.
    b. Procurement Management: What the team will need for the project. The different supplies needed and how they will be provided.
2. Technologies Development involves researching existing technologies that can be modified to perform the required task.
    a. Environment: Understanding what conditions the system will have to operate in and planning for what problems might arise.
    b. Product Design: The team must design a system demonstrating the viability of manufacturing electronics in orbit. The design must be autonomous and low maintenance. It must be cost-effective compared to manufacturing the same components on Earth.
    c. Manufacturing: This is the point at which the team will look at how manufacturable the design would be. The team will also look at the different parts that must be custom-made or could be bought premade.
    d. Analysis: The team will analyze the design thus far.

3. Risk Assessment The team will identify the potential risk, classify each servility, and determine how to mitigate the risk.
   a. Identify Risk: Defining the possible problems of the system.
   b. Classify: The team will determine how much said problem will affect the mission and how frequently the problem may arise.
   c. Mitigate: The team will plan countermeasures to correct the problem if it occurs and how to prevent it from happening.
4. The Aerospace Corporation will mainly do integration and Testing.

2.2.2 Project Life Cycle

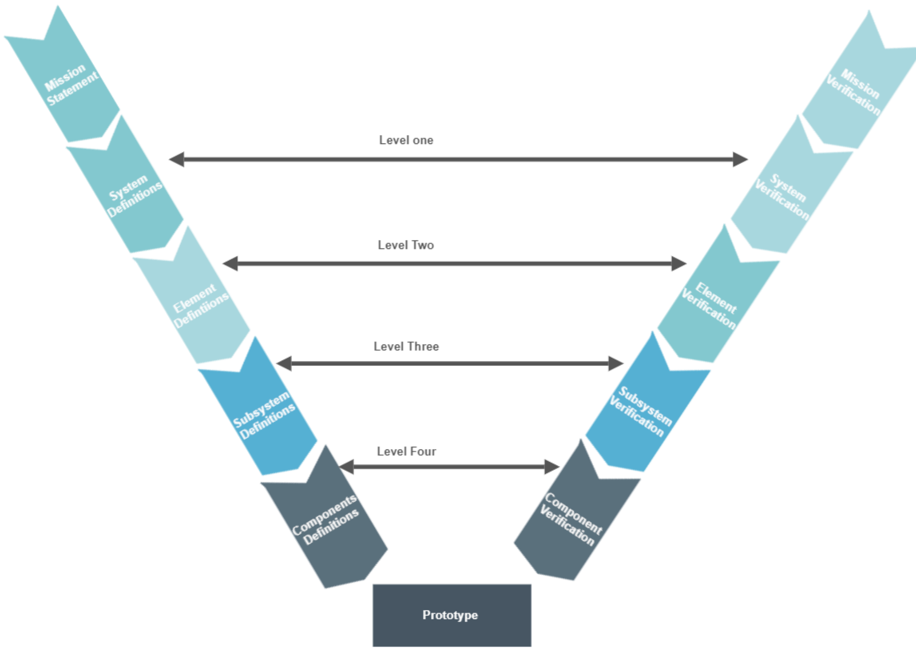


Figure 6 V Diagram

Figure 6 shows the progression of the project from design to operation. In the context of this course, we will focus on the left side of the chart. The left side of the V is the concept and design part of the project. The right side shows the verification part of the project. This site is going to be handed over to The Aerospace Corp.

2.2.3 Schedule

The schedule for this project is just a rough estimate of the time frame of the course. The following is just a projected timeline shown in Figure 7.

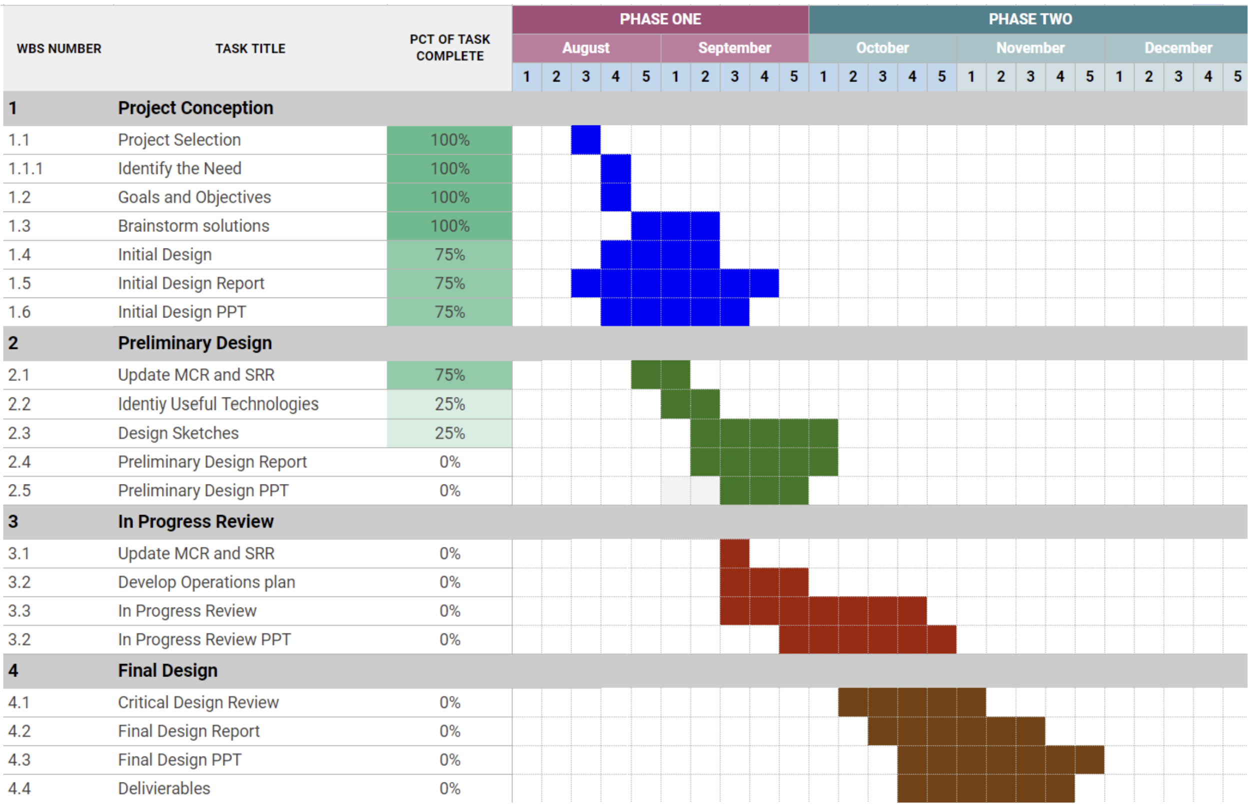


Figure 7 Gantt Chart

2.3 Additive Manufacturing Technology Development

2.3.1 System Overview

The A-MOD team will create electronic enclosures in outer space, with support from the Aerospace Corporation throughout this project. The primary objective of this project is to employ an adapted additive manufacturing (AM) process to produce these electronic enclosures in a microgravity setting. This approach aligns well with the stakeholders' requirements because it addresses the need for their current mission.

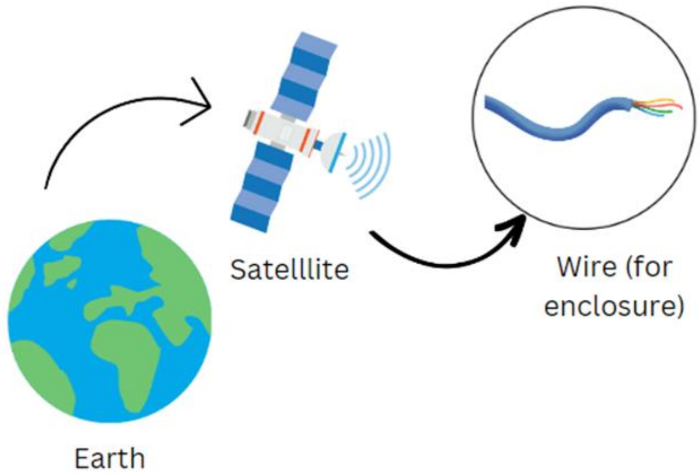


Figure 8 Concept of Idea

Figure 8 shows the idea of the developmental process post-launch of the satellite regarding space manufacturing.

A. Operation Scenario

1. Aerospace Corporation defines the need for enclosures.
2. The team creates a model of what is needed.
3. Part undergoes an additive manufacturing process.

B. Real-Time Operation

This product will undergo human supervision throughout parts manufacturing to minimize errors.

C. Nonreal-Time Operation

The A-MOD team will develop the system and 3D model of the prototype with guidance from the Aerospace Corporation.

2.3.2 Useful and Available Technologies

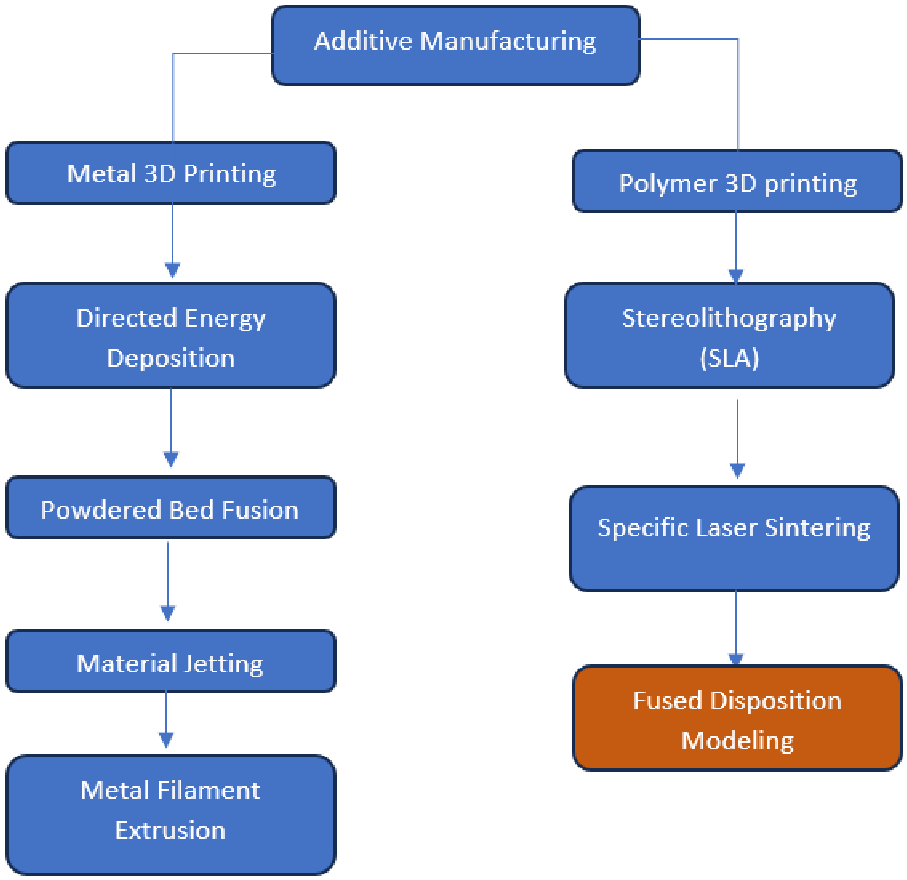


Figure 9 Method Tree

Upon investigation into AM, metal 3D printing is a promising option. Figure 9 compares the methods behind the two properties. Metal 3D printing can be broken down into powder-based or solid-based printing. With Powdered-based printing, the medium starts as a powder and solidifies into metal parts through curing. On the other hand, solid based on printing, the material starts as a solid filament and then is soften to be extruded. Each type has advantages and disadvantages, as explored in this section.

1. Powder-based 3D Printing is the most common form of metal 3D printing. It was the first viable method based on the stock for printing to be powder. Then, energy is applied, fusing the powder into a solid metal part.
    a. Directed Energy Deposition (DED) is like a traditional polymer 3D printer. Instead of using filament, the Directed Energy Deposition uses powder. So, the printer is set up like a conventional 3D printer, except it would have a large container of powder to dispense onto a hot end that fuses the powder together.
    b. Powder Bed Fusion is the basic style of powdered-based printers. It has a bed packed with metal powder, and a laser or arc is needed to melt and bond the powder. After each layer, more powder is applied, and the process is repeated till a complete part is made.
    c. Material Jetting is like the directed energy deposition method; however, the material must undergo heat treatment. The process starts like the DED method, except for the powder being dispensed with a binder agent, which is built up. After the part is done printing, a

firing process must be done. Material jetting lays out the powder with a binding compound, requiring other equipment to cure it.

2. Solid Based is just as it sounds. The “raw material” starts as a solid and then is softened to form a part. In this case, the “raw material" is called filament; it is usually a roll of processed material that can be softened to be extruded from a nozzle.
    a. Metal Filament Extrusion is the fastest-growing way to print metal. It uses traditional polymer filaments with a high concentration of metal flakes. After the print, the polymer must be melted, and the metal bonds together to form a solid metal part.

Another option is polymer 3D printing. It uses the same principle as metal 3D printing and manufactures polymer parts. Polymer 3D printing, unlike metal 3D printing, can be broken down into three types: resin-based, powdered-based, and solid-based. Powdered and solid-based polymer printing is just like metal printing apart from the high power required to print.

1. Resin-based polymer printing is simple and relatively quiet, with few moving parts. With this style of printing, a liquid polymer known as resin is used. The resin is cured when energy is applied. Power can be supplied in a variety of different ways.
    a. Stereolithography (SLA) is the oldest form of 3D printing. SLA is only used with polymer because the print material starts as a liquid. The resin is held in a vat and cured with a light source. This allows for very fine layers and complex parts to be made.
2. Powder-based polymer is just like its metal counterpart. In this case, polymer powder is used as feedstock and cured by adding energy. As stated, less fuel is required to fix the polymer powder than the metal powder.
    a. Specific Laser Sintering is a powder-based printing method. It is the same process as powder bed fusion, only with polymer powder. As the name suggests, a laser provides the energy for the curing process.
3. Solid-based polymer printing is widely used for hobbyist printing. It uses rolls of polymer with defined dimensions, heats it to its glass transition temperature, and then extrudes it through a nozzle.
    a. Fused Disposition Modeling (FDM) is what most people think of when you say 3D printing. It is a standard and reliable method to produce polymer parts. It feeds a solid stock through a hot end where the polymer softens and can be forced through a nozzle.

For the application the team seeks, the whole system will be confined by the power of the given bus. With that in mind, the team has planned to go with polymer printing due to its lower power requirements. This will also allow the team to decrease costs since polymer printing is less expensive than metal printing.

2.3.3 Preliminary Concept of Operation

A-MOD’s present invention will enable the manufacture of electronic enclosures in orbit. The device will use additive manufacturing processes to create the part. The initial concept involves the following processes: (1) fuse deposition modeling (FDM) with a polymer filament; (2) a wire routing process for laying individual wires throughout the enclosure; (3) a soldering process for soldering wires together; (4) assembly process replacing electronic components such as sensors, plugs, and PCBs into the enclosure; and (5) process for applying faraday tape around the outside of the enclosure. Depending on the enclosure's design, these five processes can be done in any order. Furthermore, each process involves a separate mechanism or effector that can be deployed anytime. The device will comprise five effector heads for each of the processes as follows: (1) an FDM printing head with extruder and hot end; (2) A wire dispenser for placing wires within the enclosure and cutting them at length; (3) a soldering head with a soldering tip and rosin core solder dispenser; (4) robotic fingers for placing components; and (5) a faraday tape dispenser that can apply the faraday tape and cut to length. It should be noted that each effector mechanism is modular in the unit and can switch between any of the five heads.

The manufacturing process depends on the design; however, a conventional enclosure may use the following method:

1. apply a layer of faraday tape to the base.
2. build up the enclosure halfway with the FDM printing head. The design should allow features for wires, connectors, PCBs, and plugs.
3. Robotic fingers can place the components in the correct locations within the enclosure.
4. The soldering head comes through and solders the wires as required per the design.
5. The FDM printing head finishes the enclosure by printing over the internal components.
6. The foil tape dispenser applies faraday tape to the top and sides of the enclosure.
7. The enclosure is now finished and ready for verification, then onto the installation.

The five end effector mechanisms may be installed on a typical 3D printer gantry where software chooses which end effector to use at which time. Another method is establishing a robotic arm next to the printer base where each effector is interchangeable with the robotic arm's end. More details can be worked out using this initial concept as more analysis is done on parts available within the satellite's available space.

2.4 System Requirements

2.4.1 Level 1 and 2 Requirements

To develop a successful product, system requirements must be met. The level one and level two conditions are:

1. The system shall use an additive manufacturing process in a zero-gravity environment.
   a. The system shall manufacture parts from raw materials and assemble components.
   b. The system shall Operate under the thermal cycles of space and control temperature within the unit.
   c. The system shall manufacture electronic enclosures with multiple parts, wires, and sensors embedded into it.
   d. The device to be made in orbit shall be designed with the system in mind and what it's capable of manufacturing.
2. The system shall operate within power, volume, and weight constraints.
   a. Power shall be drawn from the X-Sat Venus class bus.
      i. One wing: 222W
      ii. Two wings: 444W
   b. The system weight shall be equal to or less than 70 kg.
   c. The system shall fit entirely within the X-Sat Venus class bus.
      i. One wing: 20.5” × 16.4” × 27.0”
      ii. Two wings: 17.0” × 16.4” × 27.0”
   d. The system shall construct enclosures for electronics no larger than 6” × 6” × 2”
   e. Temperature Range -170°C to 120°C

The level one requirement provides the framework between the project's objectives and the system to be designed. Level one includes the initial concepts and the primary goal of the mission. These are the top-level functions that the system must meet to achieve the objectives. The level two requirements lay the groundwork for preliminary design. It shows how the system must perform and the primary constraints for integrating it into the space vehicle. Both level one and level two requirements must be met for this Project to have a successful product.

2.4.2 Traceability of Requirements

Each requirement is traceable to a particular level. The SSR establishes level one and level two requirements. Level one is the highest level and most important. Level one is the mission's primary goal, and the product succeeds if this level criteria are met. The path to meeting the level one requirement requires subsequent levels that provide a way to meet the main goals. Level two requirements are established to help verify the accomplishment of level one. Furthermore, level two provides more details on what the system must meet, and if the product meets these objectives, then it should be fine to complete the development goals. The requirements are organized into levels to show that each level builds on each other to meet the emissions goals. Level two conditions must be met before level one can be accomplished. Because each requirement is traceable to a level, it provides a smooth path for design and moving to and from each level, ensuring each condition is met correctly.

2.4.3 Operation Success Criteria

The success criteria are defined and assessed using the following steps:

1. The unit receives a part file or G code from ground control.
2. The part is manufactured and assembled in orbit.
3. The manufactured enclosure Must meet the criteria it was designed for.
    a. Functional criteria of the part means that it performs the function it was designed for. An enclosure may house wires that relay a signal between a sensor and a plug.
    b. Environmental criteria means that the part can function in a space environment. The enclosure can operate under thermal cycling and is shielded from EMI interference.
4. The part must be transferred from the unit to be installed.
5. The unit must reset to manufacture a new part.

If the device does not meet the aforementioned criteria, it is considered failed, and the design will have to be updated and reevaluated so you can meet the criteria. Examples of failure may include:

1. Files not received or corrupted
2. The manufacturing process fails.
    a. Layers of the manufacturing material don't adhere or pull apart.
    b. solder joints are not electrically sound.
    c. components need to be found.
    d. holes or tears in the EMI shielding
3. Part is completed but is distorted and does not fit in the attended application.
4. Raw materials are misplaced or lost in the zero-gravity environment.

2.4.4 Tools for Analysis

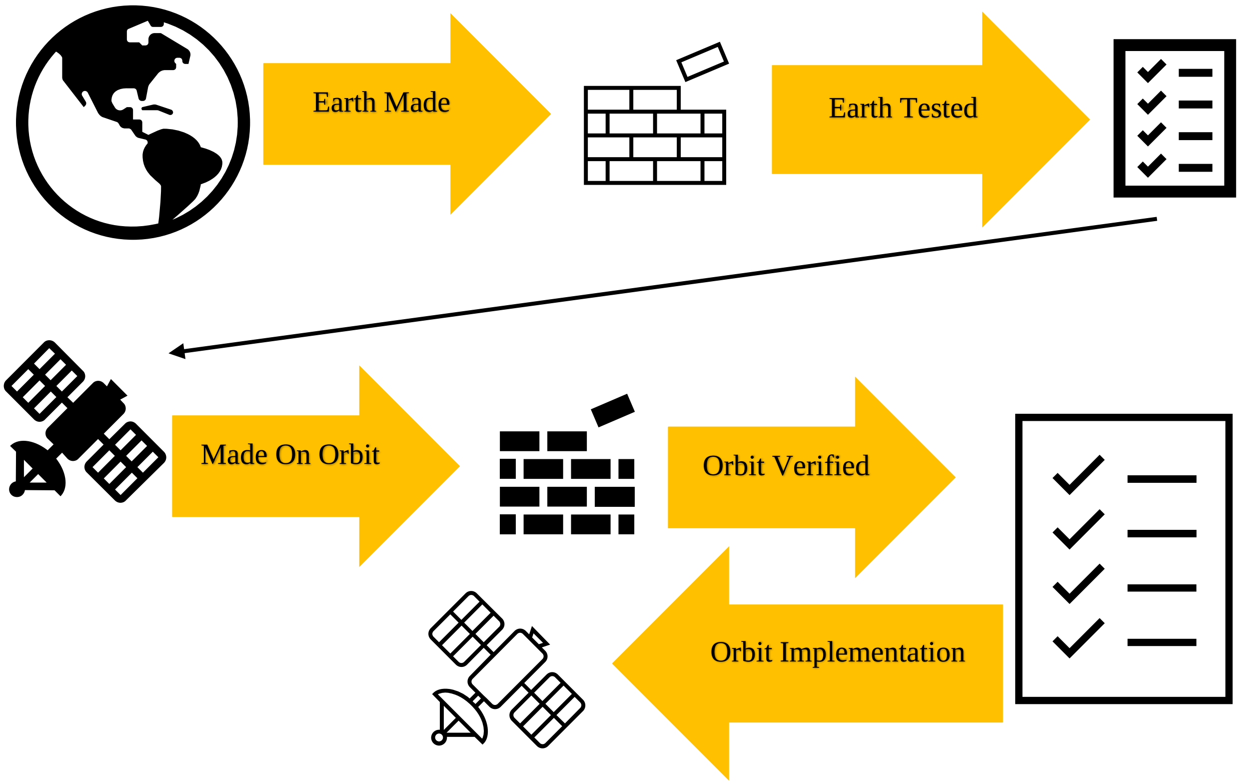


Figure 10 Analysis Flow

Figure 10 shows the test verification and implementation plan. A duplicate unit is created and remains on Earth permanently while another unit is manufactured to be sent to orbit. The earth-based unit is intended to duplicate the devices to be manufactured to be tested on earth. An enclosure is produced on earth using the manufacturing device, and the part is earth-tested. When the part passes the test, commands can be sent to the orbit-based manufacturing unit to produce the final part. Once created, the piece is examined to verify its success. Then, it can be implemented for its intended purpose and space vehicle.

2.5 Validation Test Plan

2.5.2 Hardware Test Plan

During the Fall 2023 semester, A-MOD will make a sample of an enclosure that the manufacturing system could create. This prototype is for demonstration purposes, and we'll show that making a functional enclosure using the additive above manufacturing processes is possible. The sample product will involve an embedded sensor plug and wiring within an FDM 3D-printed housing wrapped in faraday tape.

A-MOD will use only AM processes That will work in a microgravity environment. If the sample prototype is successfully made, it will show that these AM processes are possible in space. It should be noted that an actual test of the device is within a natural microgravity environment.

Chapter 3 – Preliminary Design

3.1 Updated System Requirements

This chapter will cover the preliminary design for A-MOD's manufacturing system, and the initial trade studies and what resulted from the design will be mentioned.

3.1.1 Levels 1 through 4 System Requirements

The A-MOD team has successfully identified the range of requirements, encompassing system requirements, performance criteria, and other interface specifications. These requirements were necessary when it came to guiding the phases of the design process. These requirements remain flexible and open to revisions, depending on feedback from The Aerospace Corporation or the acquisition of new information. Any possible alterations will be assessed so they meet stakeholder expectations.

<u>1. The system shall use an additive manufacturing process in zero-gravity environments.</u>

1A. The system shall manufacture parts from raw materials and assemble components.

1A-1. The manufacturing process should maintain quality standards.

1A-1A. It should include automated checks and inspections at critical stages to validate the manufactured parts' dimensional accuracy and material properties.

1A-2A It must have a comprehensive database or inventory system that accurately catalogs all the necessary components.

1A-2. The system should be able to align and connect components accurately.

1A-2A System should incorporate precision alignment sensors.

1A-2A. Analog Ferrous Metal Detection sensors will be utilized.

1A-5. The assembly process should ensure the integrity and durability of the final product.

1A-5A. The system should implement quality assurance protocols to verify that the assembled product meets or exceeds industry standards.

1B. The system shall operate under the thermal cycles of space and control temperature within the unit.

1B-1. It should have insulation to protect internal components from extreme temperature fluctuations.

1B-1A. The system should be equipped with temperature-resistant materials and components.

1B-2A. The insulation should be strategically placed to cover all critical components and subsystems, ensuring uniform protection across the system.

1B-3A. Heat dissipation methods should be used to regulate and maintain optimal operating temperatures.

1B-4B. A minimum test range of -20 °C to +75°C is required for electronic assemblies.

1C. The system shall manufacture electronic enclosures with multiple parts, wires, and sensors embedded into it.

1C-1. The system should incorporate precise fitting and fastening solutions to ensure the secure and stable assembly of all electronic components within the enclosure.

1D-1A. Limitations and constraints of the manufacturing process should be considered when in zero-gravity environments.

1C-2C. FDM printing with a dimensional tolerance of ± 0.15% and a lower limit of ± 0.2 mm.

2. The System shall operate within power, volume, and weight constraints.

2A. Power shall be drawn from the X-Sat Venus class bus.

2A-1. The system's power distribution should be planned according to the specific power outputs from the wings.

2A-1A. Dual wing power should generate 444W of power for the system.

2A-2A. The system must include effective power management strategies to utilize available power efficiently.

2A-3A. It should mitigate the risk of power fluctuations or failures, maintaining the system's functionality and stability.

2B. The choice of materials should be such that they contribute to keeping the system's overall weight within the specified limit without compromising functionality or structural integrity.

2B-1. Lightweight and high-strength materials should be prioritized.

2B-1B. The system weight shall be equal to or less than 70 kg.

2C. The system shall fit within the X-Sat Venus class bus.

2C-1. Must allow for flexible arrangements and placements of components for space.

2C-1C. For a single wing, the system dimensions should not exceed 20.5” × 16.4” × 27.0.”

2C-2C. For two wings, the system dimensions should not exceed 17.0” × 16.4” × 27.0.”

2D. The system must ensure all constructed enclosures adhere to the specified size limits.

2D-1. The design of the enclosures should prioritize efficient utilization of the internal space while staying within the size constraints.

2D-1DE enclosures for electronics should be no larger than 6” × 6” × 2.”

2E. The system must incorporate effective temperature control measures to ensure that internal components remain within the specified temperature range.

2E-1. Materials used in the system should be selected based on their ability to perform reliably under these conditions.

2E-1A. Temperature Range -170°C to 120°C

These requirements were later categorized into four primary areas of focus. The four focus areas are functional, environmental, manufacturing, and design. With these four areas of emphasis, the team was able to sum up the previous requirements so that five main criteria could be derived from them. Below is the breakdown of these four main focus areas and how the requirements were derived from them.

Functional Requirements: The system shall use an additive manufacturing process in a zero-gravity environment (1). The system shall manufacture parts from raw materials and assemble components (2). The system shall manufacture electronic enclosures with multiple parts, wires, and sensors embedded into it (3).

Environmental Requirements: The system shall maintain an internal temperature between 0 to 50 degrees Celsius (1). The system shall be shielded from EMI (2). The system shall maintain an atmosphere in the device (3).

Manufacturing Requirements: The device shall make enclosures from polymer filament (1). The device shall be able to reach the build plate with all the manufacturing heads (2). The device shall be capable of manufacturing enclosures with different layouts and functions (3).

Design Requirements: The device shall be made to be carried by the X-Sat Venus class bus (1). The device shall be powered by the X-Sat Venus class bus (2). The device shall maintain the temperature in the unit to operate efficiently (3). The device shall be capable of manufacturing various unique enclosures (4).

The team could extrapolate the reliability criteria from functional requirements one and two. Both requirements require the machine to print and assemble components reliably in a microgravity environment. The third functional requirement is to meet the criteria of versatility. With the device able to house multiple parts and sensors and its storage, it can manufacture several types of enclosures for various applications. For all three of the environmental requirements, they all lead to the reliability of the device. The device must have all three requirements to maintain peak operation and be cost-effective. For manufacturing requirement number one, the device must use polymer filament to conserve power. This was the rationale behind the requirements and how the criteria of power efficiency were chosen. The manufacturing requirement number two leads the way into the device's reliability. The device must be able to perform all manufacturing functions to be reliable. The manufacturing requirement number three leads the way into versatility. This requirement refers to the functional requirement number three as well. The device needs to be able to manufacture a variety of different enclosures to meet the various needs of other satellites and foreign missions. Design requirement number one means that the mass and volume of the device are restricted to the limit set by the X-Sat Venus class bus. These constraints read way to the mass and the device's volume criteria. The requirement that the device be hosted by the X-Sat Venus class bus means that it shall be powered by the Venus class bus as well, which gives the constraint of the power leading into the criteria of power efficiency. The third design requirement is to ensure the system's reliability, which gives way to the reliability criteria. The four design requirements reflect the device's versatility to meet various missions. As spoken before, this gives way to the requirements of versatility.

3.1.2 Traceability of Requirements

Implementing level one and two requirements is imperative for the project to yield a successful product. The level one requirement establishes the foundational connection between the project's objectives and the system's design. At the same time, the level two requirements serve as the basis for the preliminary design. They specify the performance expectations of the system and the primary constraints associated with its integration into the space vehicle.

3.2 Trade Studies

The team was able to each come up with their designs and one design from a combination of ideas. The following section shows the pros and cons of each creation.

3.2.1 Preliminary Trade Studies

Design 1, shown in Figure 11, comprises a gantry system with a stationary base. The gantry can move in the x, y, and z directions like most 3D printers. Five end effectors are mounted to the gantry to perform various manufacturing operations. The end effectors can also be referred to as manufacturing heads and operate as follows: (1) FDM 3D printing head creates the part geometry using a plastic material; (2) A wire dispensing head lays copper wire in the desired locations within the enclosure; (3) a soldering head fuses the wires and components for an electrical connection; (4) robotic finger can place components within the enclosure such as plugs, sensors, and relays; and, (5) a tape dispensing head applies foil tape to the outside of the encloser to shield the circuits from EMI. Furthermore, the machine can do the five operations in any order.

Design 1 is similar in function to most FDM 3D printers. Therefore, the performance of the preliminary design is estimated based on the performance of a similar-sized FDM 3D printer. The power consumption of most printers is between 50W and 150W, which is well below the maximum power available from the bus (Bardwell, n.d.). This will mean that power will be left for the other process on board the machine. Furthermore, A-MOD looked at the mass of compatible printers. The Creality CR-10 is 14kg, but the final design will weigh more with the additional manufacturing heads and raw materials (Dwamena, 2023). The basic computer-aided design (CAD) rendering shown in Figure 11 proves the concept will meet the volume requirements. Furthermore, the design has minimal moving parts, aiding the concept's reliability. Still, further, the design could be more varied in versatility because it has only 3 degrees of freedom in the gantry and can only manufacture parts layer by layer. It cannot modify a section of that already printed layer. The concept does have the unsolved problem of applying the EMI shielding tape to the bottom of the enclosure.

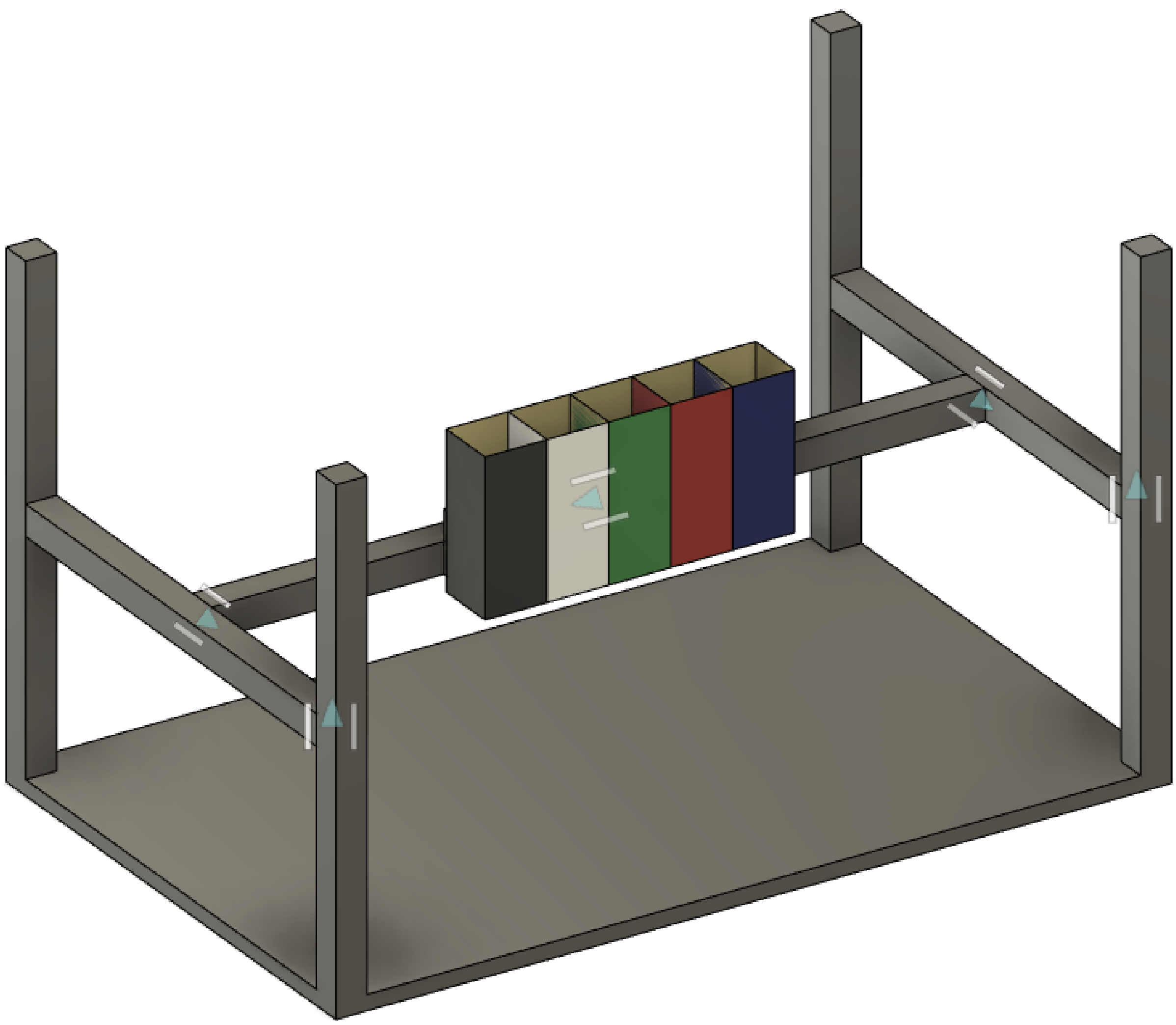


Figure 11 Design Concept 1

Design 2; This Design implements the idea of a removable 3D printing bed or build plate into each manufactured part. This approach also includes an EMI shielding layer within the removable build plate, which is a definitive solution to the persistent issue of applying faraday tape to the enclosure's underside. While in operation, the base is fixed to a moving mechanism that moves the entire part in the X, Y, and Z directions. The enclosure will move under an end effector applying the necessary additive manufacturing operations. This not only streamlines the manufacturing process but also enhances the overall efficiency of the production cycle. Moreover, the build plate has embedded mounting features, enabling the seamless and secure fixation of the finished enclosure. This design concept can also be seen in Figure 12.

The advantage of this design is that it meets the volume restrictions, with a maximum volume of 15.7” × 13.58” × 19.7”. It is also quite versatile due to its removable base connecting the parts. Some downsides to this design include high power consumption due to heavier weight and the system's lack of reliability when fitting the legs after being printed.

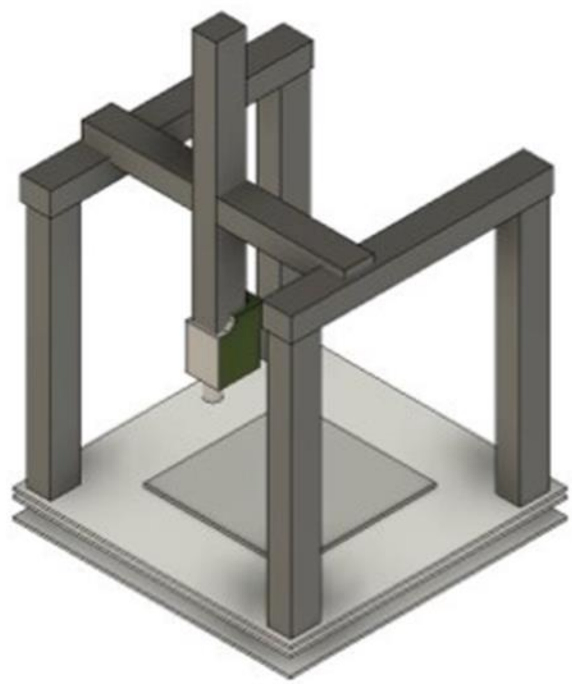


Figure 12 Design Concept 2

Design 3 uses a robotic arm outfitted with removable end effectors, shown in Figure 13. The base robotic arm is a Mecademic Meca500 series (Mecademic Industrial Robotics, n.d.). There will be an attachment for polymer extrusion, wire laying, soldering iron, and an EMI tape head. The Meca500 only has a mass of 5 kg yet takes a max power of 200 W. The interchangeable end effectors will add more mass and, more importantly, add more power drawn. Each head will be stored on the side of the print bed for ease of changing roles. The supporting equipment needed for this design will take up space, weight, and power. However, the tradeoff will be incredibly versatility.

This design's advantage is that the manufacturing and assembly methods will be in one device. The downside is that the device will take up a lot of space and power. The design will have a low mass, yet it cannot lift large objects. The arm's energy can be varied to save power, yet it will give off excess heat that must be managed. The design is based on a proven, reliable manufacturing design. However, the system will be more complex with the removable end effectors.

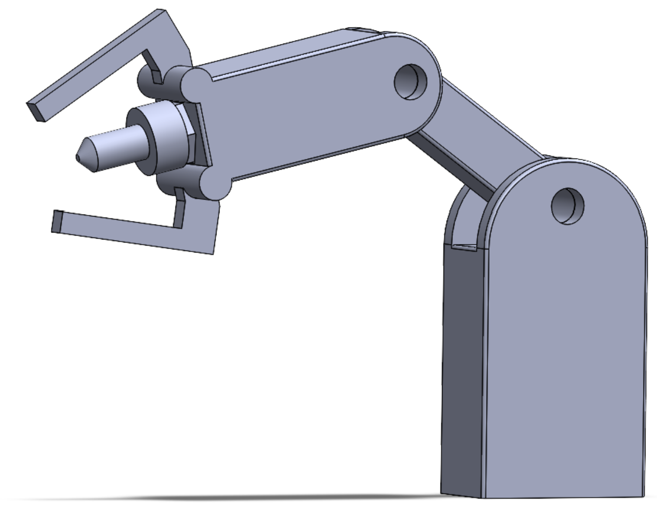


Figure 13 Design Concept 3

Design 4 is a combination of design 1 and 2 and is shown in Figure 14. The five different end effectors are mounted on a gantry system, as in design 1. However, the removable build plate is used from design 2. The build plate is incorporated into every part that is produced. The features that a removable build plate adds are as follows: (1) the removable build plate incorporates an EMI shielding layer, which solves the problem of applying faraday tape to the bottom of the enclosure; (2) the removable build plate includes a generic circuit with a plug that a custom enclosure is built off of; and, (3) the build plate includes mounting features for securing the finished enclosure in the desired application. It should be noted that each time the machine produces an enclosure, a build plate is used up because it becomes an integral part of the enclosure. Furthermore, build plates are supplied and stored in a magazine to be loaded each time a part is manufactured.

Design 4 is very similar to Design 1 in many design criteria, but it has a few advantages. The incorporated printing platforms save manufacturing steps because the basic circuitry is premade. Reducing the steps to manufacture in space increases reliability and power efficiency. Fewer steps mean less power to produce a part and fewer instances of error. However, there are some drawbacks. The design requires storage for the extra build plates, reducing the total volume available and increasing the total mass of the machine. Versatility is also decreased because all the enclosers are limited to the same footprint and generic starting circuit. Furthermore, it should be noted that the removable bases solve the EMI shielding problem from Concept 1. By incorporating a metallic material into the bases, the bottom of the enclosures is protected from EMI radiation.

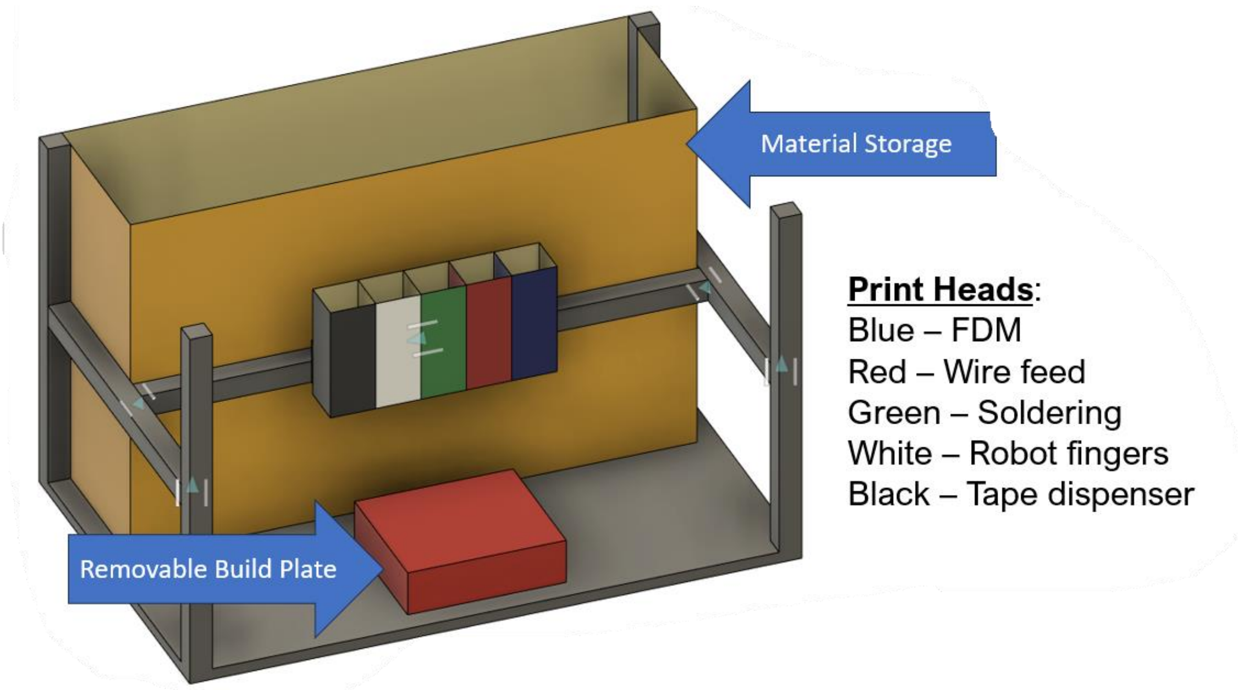


Figure 14 Design Concept 4

3.2.2 Design Metrics

Moving forward with the four designs, the team used a ranking system to weigh the criteria for selecting the best design. Table 4 shows each criterion and how they compare in terms of importance. A more detailed analysis of the Metrics can be found in Appendix A.

Table 4 Weighing Criteria

	Power Efficiency	Mass	Volume	Reliability	Versatility	Total	Weight
Power Efficiency	----	1	0.25	0	1	2.25	0.20
Mass	0	---	0	0	1	1	0.09
Volume	0.75	1	---	0	1	2.75	0.25
Reliability	1	1	1	---	1	4	0.36
Versatility	0	1	0	0	---	1	0.09

The order ranking shows the importance of each criterion concerning the other. They are as follows:

1. Reliability: The device must work in a space environment with minimal malfunctions. Secondly, the system should be simple, the fewer moving parts, the better
2. Volume: The X-Sat Bus has dimensions that cannot be changed, so the device must fit within 17.0 in × 16.4 in × 27.0 in

3. Power Efficiency: The X-Sat Bus has strict parameters with a power of 444 Watts at max and can only store 10.2 Ah with its battery.
4. Mass: The X-Sat Bus has a limited payload of 70 kg
5. Versatility: The device must be able to manufacture custom electronic enclosures.

Once the criteria have been weighed, a decision matrix, Table 5, can be constructed to determine the best design. The Matrix will narrow the designs to one that will move on to the next phase; a more detailed analysis of the Matrix can be found in Appendix A.

Table 5 Design Decision Matrix

Orbit Manufacturing								
Metrics	Weight	Design 1	Design 2		Design 3		Design 4	
		Datum	Score	Weight	Score	Weight	Score	Weight
Power	0.23	0	-1	-0.23	-1	-0.23	1	0.23
Mass	0.07	0	-1	-0.07	0	0	-1	-0.07
Volume	0.24	0	0	0	0	0	-1	-0.24
Reliability	0.36	0	-1	-0.36	0	0	1	0.36
Versatility	0.02	0	0	0	1	0.02	-1	-0.02
Total	**1**	**0**	**-0.66**		**-0.21**		**0.26**	

3.3 Preliminary Design

This section explains the reasoning for deciding the initial design. A brief explanation of the chosen design and how it meets the established requirements is included. Further details of how the winning design was chosen will be shown.

3.3.1 The Chosen Design

The chosen concept is Design 4, combining the 1st and 2nd designs from 3.2.1 Preliminary Trade Studies. The first and third designs employ novel ideas that The Aerospace Corporation is looking for to solve the presented problem. The other designs are acceptable; however, it is believed that the 4th design will outperform the alternatives with the most excellent ease of meeting the requirements.

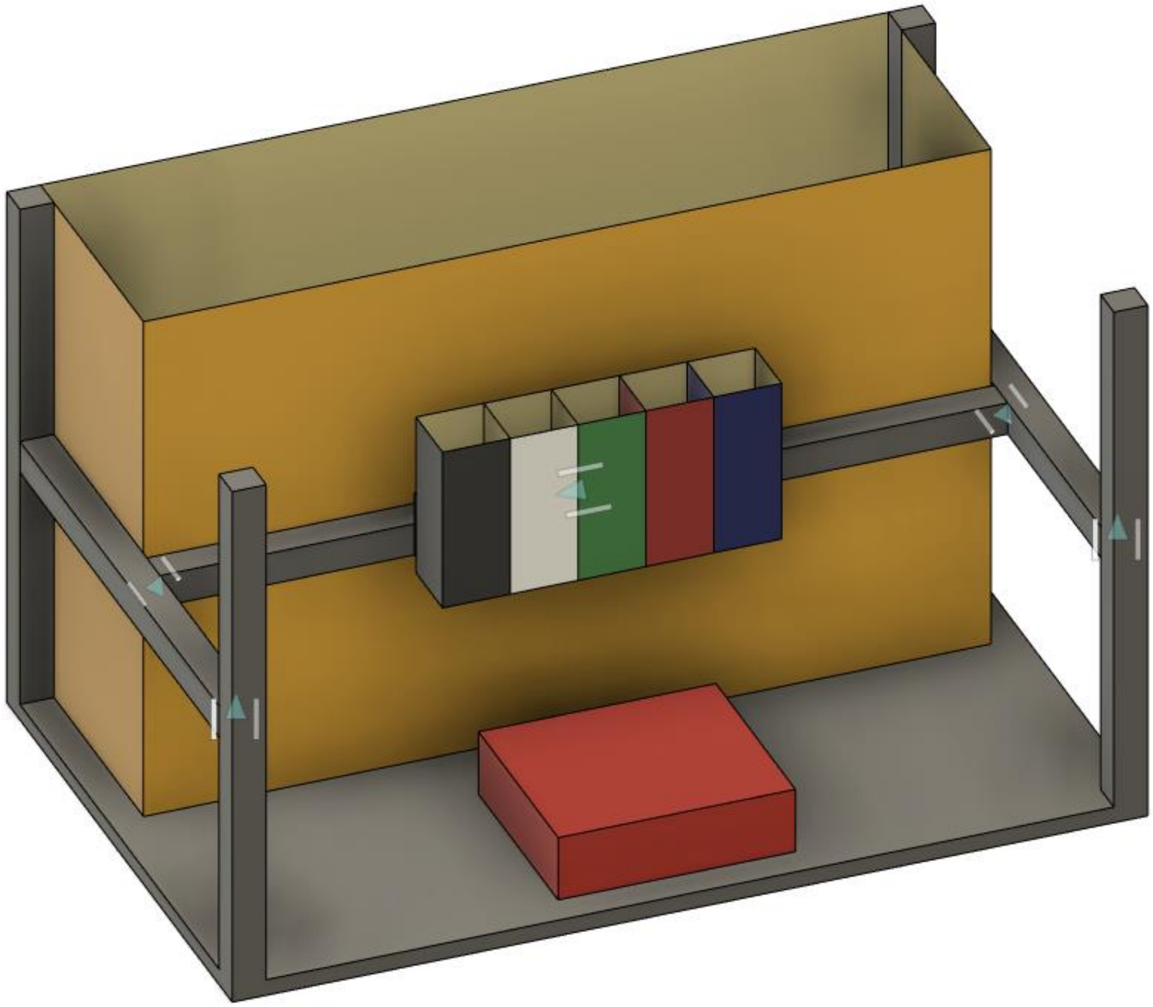


Figure 15 Preliminary Design

The overall design will resemble many 3D printers, like the Creality CR-10 or Prusa printers. The focus is to use data from other 3D printers and equal parts to estimate the weight and size of the design. Furthermore, the power requirements for each of the five manufacturing operations will be calculated based on similar devices on the market. Still further, the storage capacity of each raw material will be estimated. The above estimates are outlined in the next chapter.

The gantry frame, shown in gray in Figure 15, will be made of lightweight and dimensionally stable material. The frame needs to remain accurate throughout all temperature ranges. The proposed design dimensions are 16.4” × 17” × 27”, precisely those of the X-SAT bus with two wings. Staying within the two solar wing dimensions provides the maximum power.

Now, referring to Figure 15, each component will be explained. The Frame shown in gray is composed of the base and gantry segments. The symbol shown as an arrow with parallel bars represents a linear sliding joint. The sliders allow for three degrees of freedom at the printheads for the x, y, and z directions. In the current configuration shown in Figure 15, any of the five end effectors can reach a 6” × 7” × 3” space above the build plate, which exceeds the enclosure requirement of 6” × 6” × 2”. A-MOD may limit the printable size to 6” × 6” × 2” as the design develops to conserve raw material storage space. The orange box represents raw material storage; rolls of FDM filament, solder, tape, wire, build plate magazine, and extra components will be stored here. The red box represents the removable build plate. The five end effectors are mounted to the gantry and are labeled as follows: (Blue) FDM print head; (Red) wire feeding mechanism; (Green) soldering mechanism; (White) robot fingers for placing extra electrical components; and (Black) faraday tape dispenser for EMI shielding. Furthermore, it should also be noted that the model represented in Figure 15 is to scale.

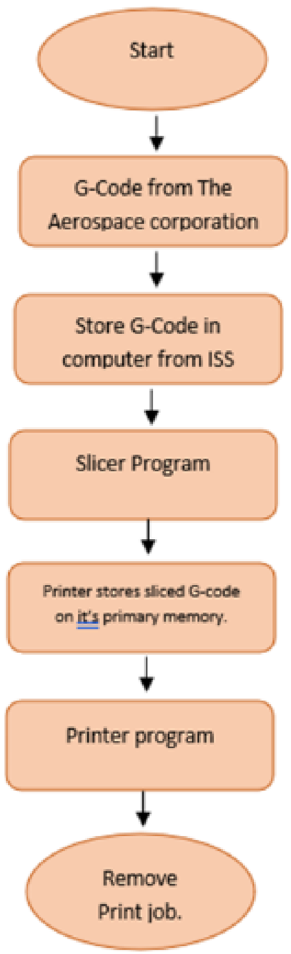


Figure 16 Print Process

The printing process starts with preparation, including attaching the removable print bed to the printer's mechanism. The electronic enclosure design is then uploaded into the system, and specific parameters, such as material composition and structural specifications, are configured to ensure the production of durable and precisely crafted enclosures. Once the configuration is complete, the printer executes the printing process. The general printing process flow can be seen in Figure 16.

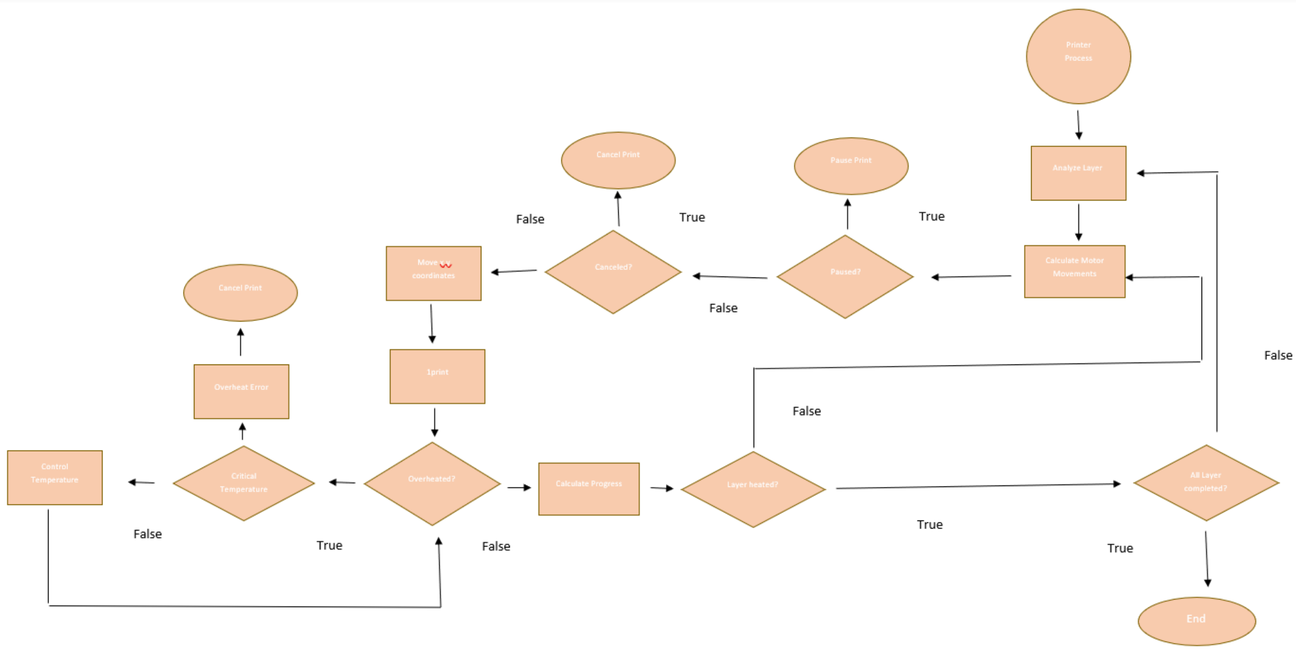


Figure 17 Print Firmware

As shown in Figure 17, the printing process starts with a CAD file and a signal sent to manufacturing. A new print bed will then be loaded, where the different print heads for FDM, wiring, and soldering will work on it. After those printing processes, including the EMI shielding already built into the print base, the mechanism is removed, and the procedures repeat.

3.3.2 Concept of Operations

When a command is sent to the manufacturing unit, the process starts by loading a new printing base from the magazine. The FDM printing head takes over and creates geometry to guide the next step. The robotic fingers then place any extra components the encloser design requires, like sensors and plugs. Then, the wire feed mechanism places the wire in the correct locations, followed by the soldering mechanism that electrically connects the wire to the generic PCB base and other components. The FDM print head starts again to cover the circuitry by the upper half of the enclosure. It should be noted that this process can be repeated to make multi-layered circuits. By following this approach, custom enclosers and internal circuits can be made. The final step uses the tape dispenser to apply foil tape to the top and sides of the enclosure. Applying tape to the bottom is unnecessary because metallic EMI shielding is built into the printing base. After completing the validation test plan and quality control checks, the finished part is ready for use.

3.4 Validation Test Plan

The validation tests aim to determine whether the device is operating at its peak. The test plan consists of tests to gauge the device's performance. The machine will be tested in three areas: accuracy, strength of parts, and function.

1. Accuracy: This test will use a cube 1 inch × 1 inch × 1 inch. The cube will then be measured for how close the cube's dimensions are to 1 inch × 1 inch × 1 inch. If the cube fails, a calibration will need to be done.
2. Strength: This will test the printed parts for their quality; the device will print three test pieces for three different tests. The test includes tensile, shear, and compression tests. Each test will be done by printing three samples for each test.

3. Function: This will test if the completed part works. The test will consist of assembling the enclosure with all the sensors and wires connected. The test will see if the function can perform a basic test of the circuit. The test will ensure that the wiring is not damaged, and that the sensor or other connector is aligned.

3.4.1 Test Print Demos

The test that needs to be done will require a few test prints to ensure the device is ready for operation. The test prints will demonstrate different properties that the part will need to be functional. These test prints will include the following:

1. A 1 inch × 1 inch × 1 inch cube
2. Tensile test coupon
3. Shear test coupon
4. Compression test coupon
5. A layer adhesion test
6. A demonstration parts

3.4.2 Interpretation of Test Results

Once the test has been completed, the following questions will be answered:

1. Did the part function as needed, mechanically, electrically, and structurally?
2. Was the performance of the part satisfactory?
3. Did the EMI hold up to the radiation?
4. Was there any ware on the part that will cause concern?
5. Did the part function as predicted?
6. Are there any changes that will need to be made to the test in the future?

3.4.3 Maintenance, Reparability, & Upgradability

The system should be maintained at regular intervals by an astronaut. They must clean the nozzle on the polymer extruder and the soldering iron head for excess solder and refill the supplies. The simple repairs will be done in the same fashion as the maintenance of the system. The upgrades of the system will be explored at a later date.

Chapter 4 – Critical Design

4.1 Introduction

This chapter focuses on A-MOD's proposed design for a device to manufacture electronic enclosures in orbit. This Critical Design Review (CDR) demonstrates the feasibility of said design by showing analysis, drawings, specifications, and details of components. Furthermore, the CDR will also discuss testing and verification, future development, materials, and system overview. A final design solution will be presented with the capabilities and limitations of the system.

4.1.1 CDR Objectives

The purpose of the CDR section of this report is to describe the details of the design and compare it with the requirements set out in the requirements review and preliminary design process.

The objectives of the CDR are:

1. Describe the details of the chosen design and ensure a thorough review.
2. Ensure the design meets all Chapters 2 and 3 requirements.
3. Describe the design specifications, such as weight, cost, storage capacity, volume, and production capacity.
4. Guide future design development, custom controls, and software required.
5. Describe how the product will operate.
6. Define Test plans such as vibration, temperature, EMI, and another environmental tests.

4.2 Concept of Operations

This section is intended to clarify the manufacturing process of an enclosure. Shown in

Figure 18 is the method used to create one enclosure. The explanation of each stage is as follows: (1) g-code is loaded onto the machine; the g-code is the software file that creates the particular enclosure needing to be manufactured; (2) The base is loaded into the fixture and ready to be used as a build surface; (3) the FDM print head creates the first few layers of the geometry of the enclosure making locations for the components inside; (4) auxiliary parts are installed into the voids from step 3; (5) wire is installed into the wire groves left in step 3; (6) the soldering station electrically connects the wires, plugs and aux components; (7) the FDM printer generates the remaining layers to finish the enclosure geometry; (8) the EMI tape is applied to the outside of the enclosure, and (9) the completed unit is ready for service.

A variety of enclosure designs can be created. Therefore, this process could be modified slightly to accommodate different enclosure designs. If no auxiliary parts are needed, then step 4 is skipped. Also, depending on the enclosure design, multiple layers of circuits could be required. Therefore, after step 6, the process can be looped back to step 3 to generate a plurality of circuit layers.

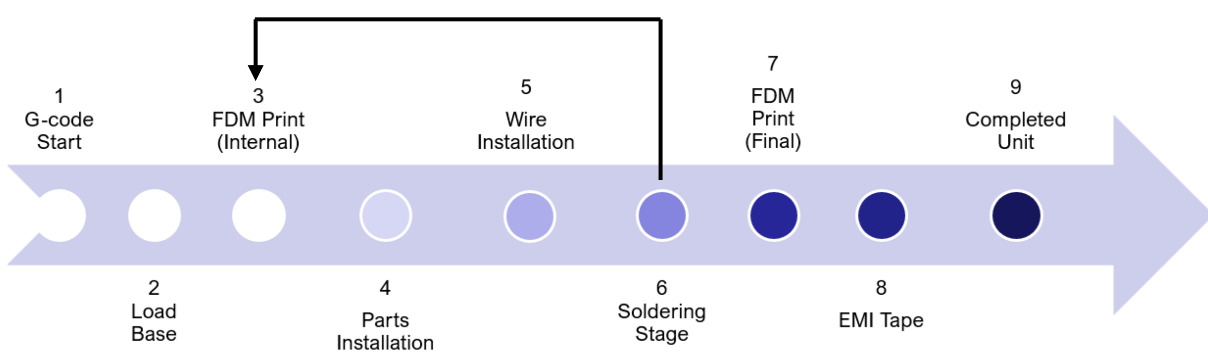


Figure 18 Operation Process

4.3 Validation and Verification

The system must meet the requirements outlined in section 3.1.1 Levels 1 through 4 System Requirements. Therefore, it will undergo validation. Validation will come through either testing, analysis, or inspection. Validation through testing will be done under a controlled environment, in which the system will be given inputs to see if the outputs are as designed. The analysis will be validated through software, either through simulation of the parts or through calculations. Lastly, the validation through inspection will be carried out by visual observations. The following Table 6 shows how each requirement will be validated.

Table 6 Requirement Validation

Requirements	Rationale	Validation	Method
The system shall manufacture parts from raw materials and assemble components	Manufacturing and assembling a finished product is essential for reducing the cost of systems in space	A prototype must be completed to test the manufacturing function, and assembling components will be tested	Testing
The manufacturing process should maintain quality standards	Due to the precision needed for satellites to function correctly, quality must be maintained throughout production	Prototypes of the electronic enclosures would need to be manufactured by A working prototype, and accuracy will be examined	Inspection
The system should be able to align and connect components accurately	The sensors in the system require accurate and precise connections to function properly	Testing on the robotic arm and soldering arm will need to be carried out	Testing
The assembly process should ensure the integrity and durability of the final product	The enclosures will need to be manufactured to handle the environments they will be implemented in	Analysis can be performed on CAD models to ensure they can handle the loads and forces upon them	Analysis
The system shall operate under the thermal cycles of space and control temperature within the unit	The enclosures must operate in the varying temperatures of a space environment	Testing of prototyping closures and analysis of CAD models would need to be run to ensure materials will work in the environment	Testing and Analysis
The system must include effective power management strategies to utilize available power efficiently	With the limited power capacity of the satellite Bus, energy conservation will be integral to success	Testing must be done on the device's electronics to ensure adequate power usage	Testing
The system must ensure all constructed enclosures adhere to the specified size limits	With limited space in satellites and other spacecraft craft, precise and consistent enclosures must be manufactured	Once a prototype is made and the function of manufacturing and assembly is tested, the consistency across multiple prototyped enclosures will need to be inspected	Inspection

4.4 Critical Design

4.4.1 Mechanical Design

Overall dimensions of the Machine

It is essential to the use and functionality of the product that the machine meets the volume requirements. The X-Sat bus constrains the device's overall size and shape. Also, it is essential to use all the available space so that the maximum amount of materials can be stored on board for the best use of the on-orbit factory. Therefore, overall dimensions, shape, and layout are determined first through a basic CAD model. Then, the various components and sub-systems are designed to fit the prescribed volume for each part. The overall size shown in Figure 19 fits precisely within the X-sat Bus with two arrays. Furthermore, the space allowance for each manufacturing head is 2 × 2.5 × 5 inches. The allotment for the fixture plate is 6 × 7 × 2 inches. The allowance for the material storage is 7.75 × 15.9 × 25 inches—the figure labels each block, showing the location of parts and subassembly.

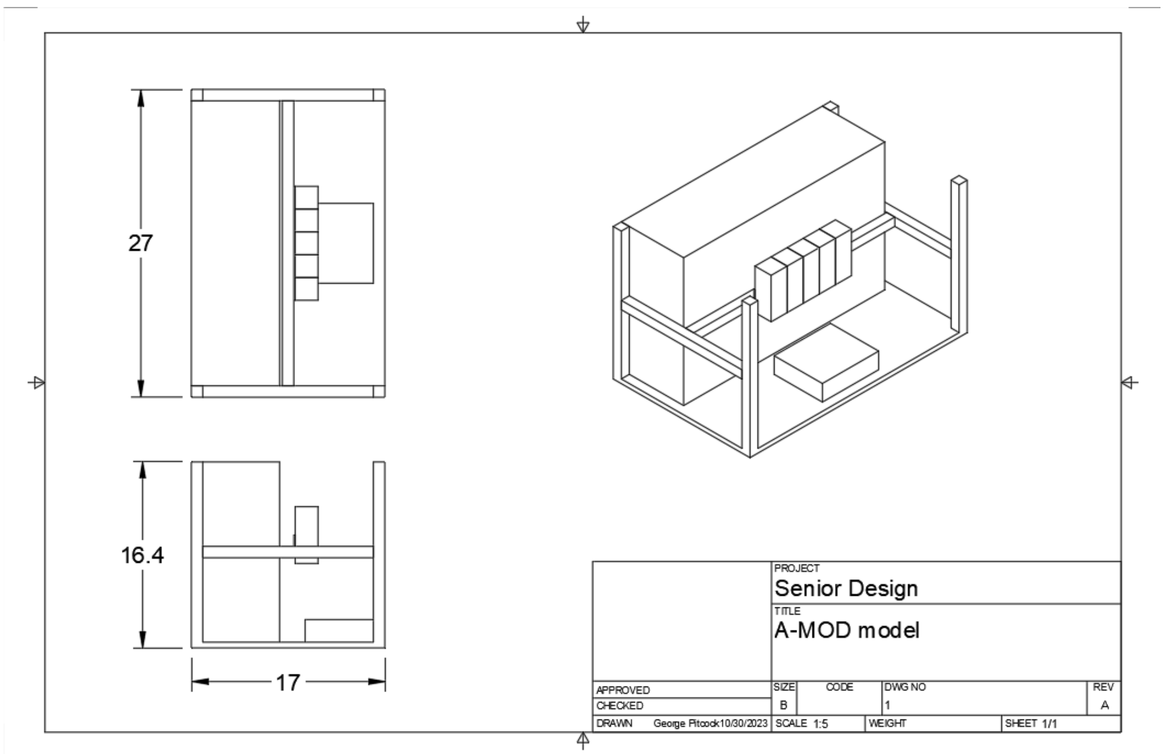
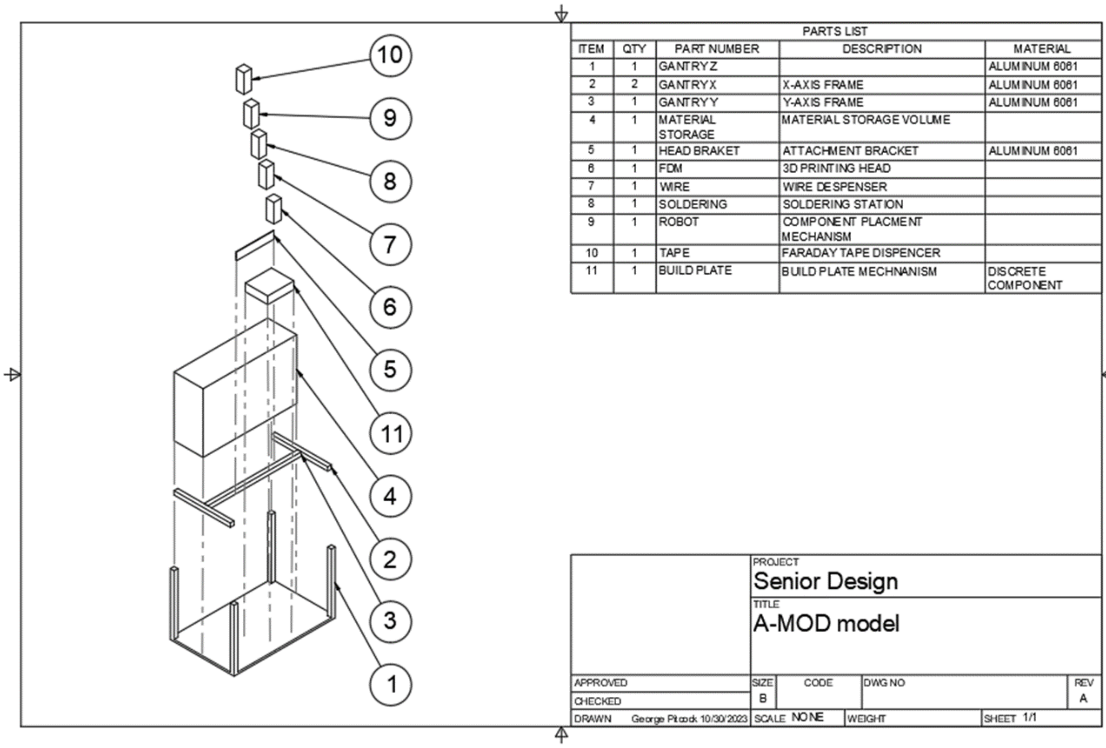


Figure 19 Overall Dimensions



PARTS LIST				
ITEM	QTY	PART NUMBER	DESCRIPTION	MATERIAL
1	1	GANTRYZ		ALUMINUM 6061
2	2	GANTRYX	X-AXIS FRAME	ALUMINUM 6061
3	1	GANTRYY	Y-AXIS FRAME	ALUMINUM 6061
4	1	MATERIAL STORAGE	MATERIAL STORAGE VOLUME	
5	1	HEAD BRAKET	ATTACHMENT BRACKET	ALUMINUM 6061
6	1	FDM	3D PRINTING HEAD	
7	1	WIRE	WIRE DESPENSER	
8	1	SOLDERING	SOLDERING STATION	
9	1	ROBOT	COMPONENT PLACMENT MECHANISM	
10	1	TAPE	FARADAY TAPE DISPENCER	
11	1	BUILD PLATE	BUILD PLATE MECHNANISM	DISCRETE COMPONENT

Figure 20 Assembly and Part Labels

Manufacturing Head Design

This section will conduct a detailed breakdown of the manufacturing heads and the gantry system. The analysis will entail each manufacturing head's mass, dimensions, power consumption, and function. Detailed CAD and overview models will be used for each manufacturing head. The below figure, Figure 21 Gantry Arm, shows the overview of the gantry system with the manufacturing heads installed.

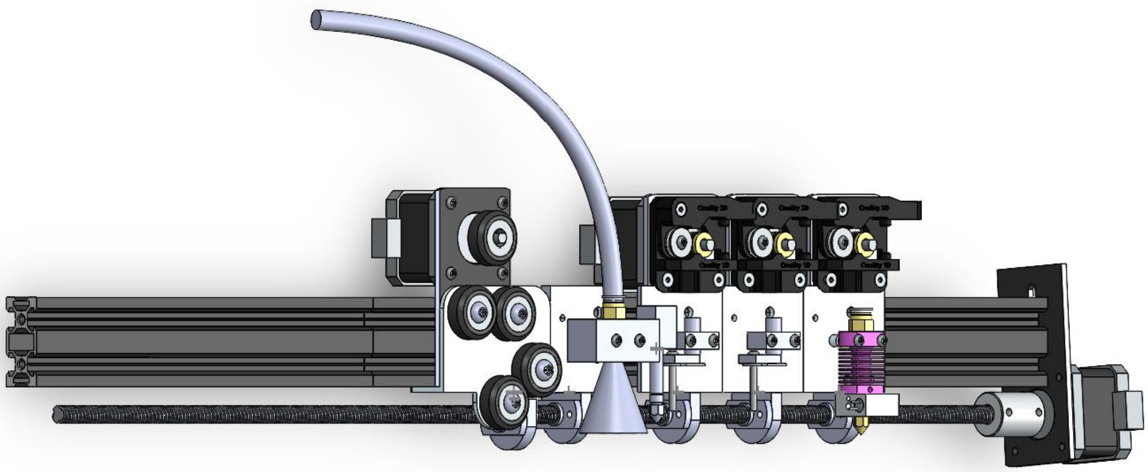


Figure 21 Gantry Arm

As the figure, Figure 21 Gantry Arm, shows, the five manufacturing heads from right to left are the polymer FDM print head, the wire feed head, the soldering head, the robotic suction head, and the EMI tape dispensing head. The end effectors will be attached to the gantry and allowed to slide along the gantry by the stepper motor and threaded rod below the gantry arm.

The polymer FDM printing head comprises commercially available Creality Ender 3 components. However, they are fitted to the gantry arm and assembled using custom-fabricated back plates. Figure 22 shows a detailed model of the print head. For the polymer printing head, we'll use one 40-34 stepper motor and a 40-watt heating element to soften a polymer-based filament to extrude to build up the enclosures. A breakdown of the specifications for the motor and heater can be found in Appendix F, as well as a bill of material.

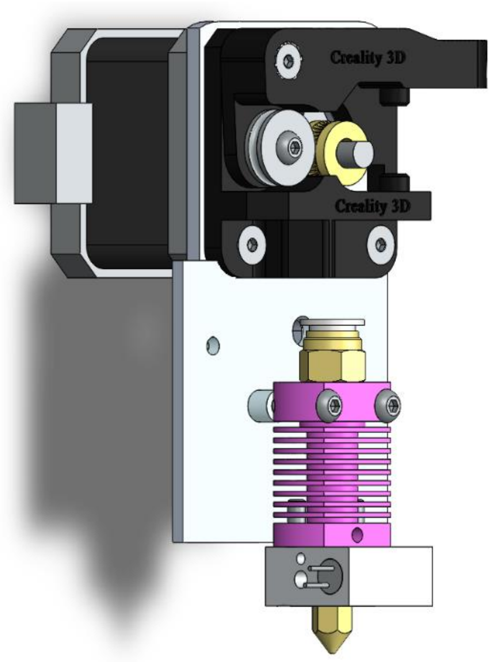


Figure 22 FDM Polymer Print Head

The wire feed end effector will set the non-insulated 110 copper wire into the channels that are made by the FDM manufacturing head. The data sheet for wire can be located in Appendix D – Wire Data Sheet. The wire feed will use the same 40-34 stepper motor as the polymer FDM print head. Figure 23 shows a detailed CAD model of the end effector. Most components of the wire feed are custom-made. A bill of materials will be listed in Appendix F -Specifications and Bill of Materials. (Micro Swiss, n.d.)

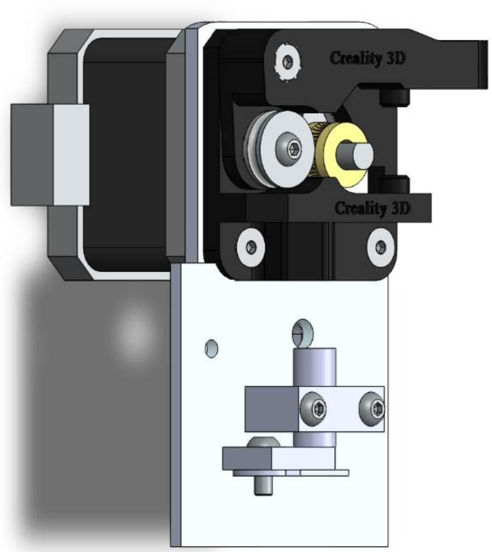


Figure 23 Wire Feed Manufacturing Head

The soldering end effector is simply a modified wire feed and effector. A heating element was added to the side to melt the solder to create electrical connections. The purpose of the soldering end effector is to distribute a set amount of solder and heat the wire to melt the solder and make the connections. Figure 24 shows the completed CAD model of the soldering manufacturing head. Detailed specifications with the bill of materials can be found in Appendix F -Specifications and Bill of Materials.

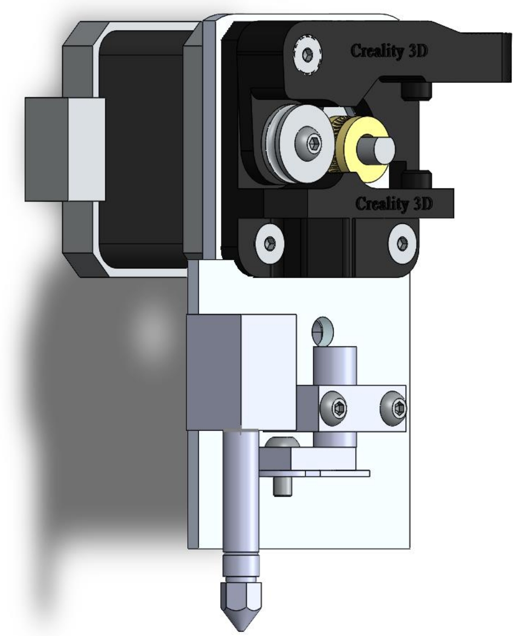


Figure 24 Soldering Iron Manufacturing Head

The robotic suction head was chosen for its simplistic design and the low number of moving parts, this aids in its reliability. The robotic suction head will use the difference in the pressure within the satellite with the vacuum of space to create suction to hold parts in place and transfer them to the working area. As Figure 25 shows most of the components will be custom-made apart from the valve that connects the tube to the outside environment, which is not shown in the figure. The constraint of this design translates to our parts having a smooth surface for the suction head to attach to.

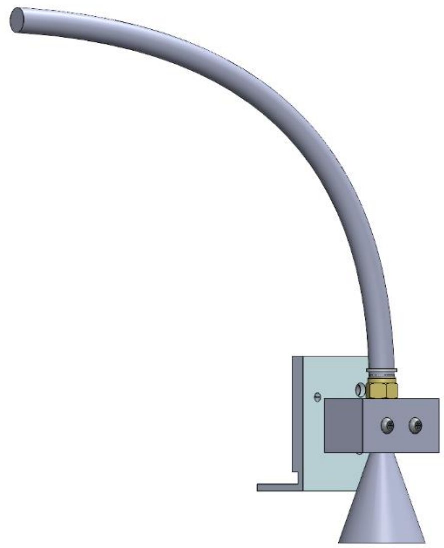


Figure 25 Suction Graber

The EMI tape dispensing end effector will use Nickel Copper Faraday tape, data sheet provided in Appendix E – Nickle Copper Faraday Tape Data Sheet. The purpose of the tape is to shield the components from the harmful radiation of its environment. The tape dispenser uses the 40-34 stepper motor; the data sheet and bill of materials to distribute the tape to the part can be found in Appendix F -Specifications and Bill of Materials. Figure 26 shows a detailed CAD model of the manufacturing head.

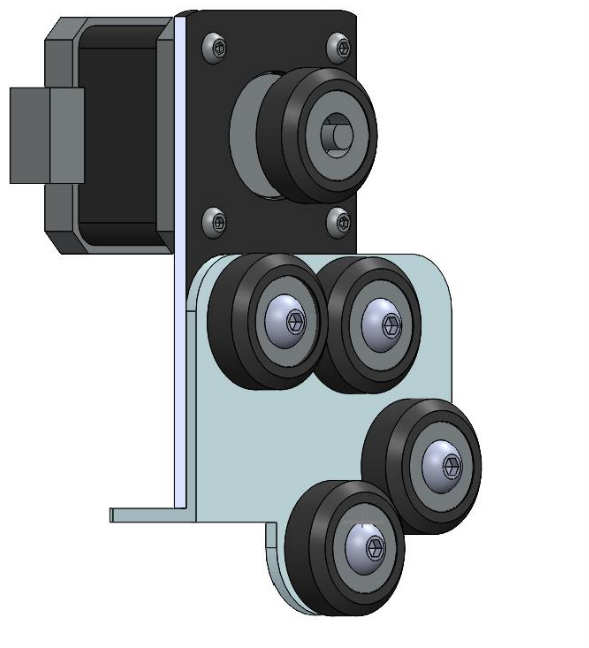


Figure 26 EMI Tape Dispenser

One central element has persisted with all the designs shown above: the stepper motor attached to the back plate. The stepper motor is attached to the rear plate with a M3 × 18 mm flathead screw. The material for the screw is alloyed steel. Figure 27 shows the SolidWorks simulation performed on the part to ensure it could handle a torque of 0.04 Nm. That torque is derived from the 40-34 stepper motor. The torque of 0.04 Nm is the torque the motor can apply, so in a worse-case situation, only one screw holding the motor to the back plate is what the simulation represents.

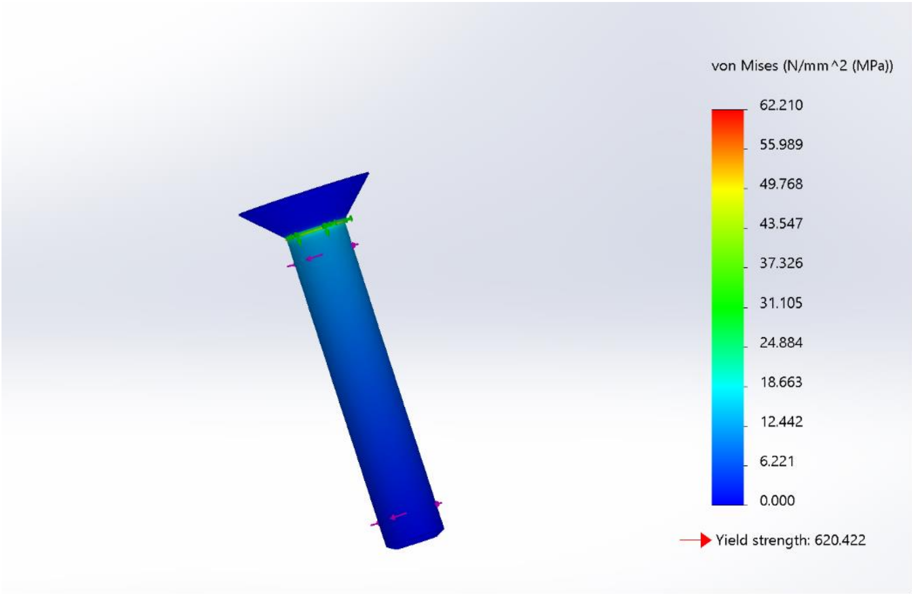


Figure 27 Screw Torque Simulation

The maximum stress on the screw is 62.2 MPa, as the chart to the right of the screw shows. The screw has a yield strength of 620.4 MPa, as shown below in the diagram. This indicates that the screw will not fail under the worst-case conditions.

Material Storage Mechanism

Storage Mechanism

The material storage mechanism for this system is divided into three main parts: the auxiliary dispensers, the base plate storage, and a compartment for the building materials. This allows for the distribution of each component in an orderly manner.

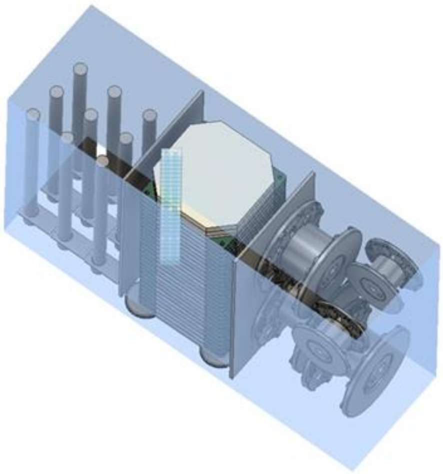


Figure 28 Material Storage

Auxiliary Dispenser

The auxiliary dispenser compartment on the left of the storage unit consists of 16 dispensers, of which eight are for sensors, while the other eight are for plugs. Each tube has the storage capacity to hold up to 20 sensors or plugs.

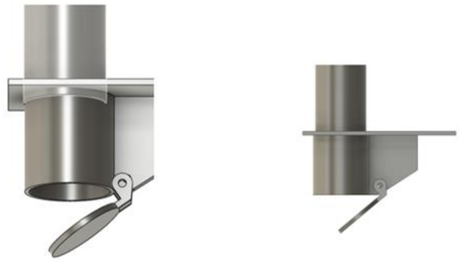


Figure 29 Auxiliary Dispenser

Base Plate Storage

This gantry system can hold 25 base plates in total. These plates will be stored in the center of the storage box and wheeled out through the four gears near the bottom of the stack so that they may be used.

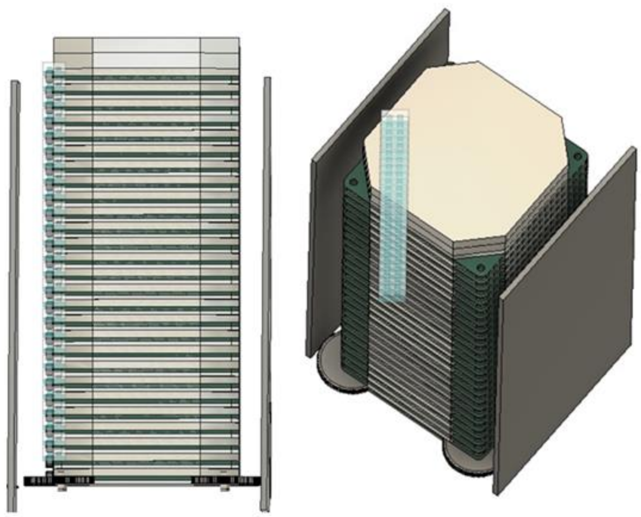


Figure 30 Base Plate Storage

Building Material Storage

Lastly, the building material storage compartment consists of two large FDM spools that take up to 562.5 m each, both for a total of 1,125m. One large spool for the wire can also hold up to 350 m. Then, stacked on top of those are two small spools for the solder and the EMI tape, which can hold 338 m of solder and 250m of EMI tape, respectively.

Figure 31 Building Material Storage

4.3.2 Electrical Design

For the AMOD team, mechanical design is a greater focus since the team comprises mechanical engineers; however, the electrical design will be more of an outline for future electrical engineers. The focus of this section is the basic breakdown of the wiring, off-the-shelf electrical components, and what needs more detailed work by an electrical engineer. First, the wires that will be run to the end effectors. Although each head is different, they fall into either drawing 7.2 watts or 47.2 watts of power. The end effectors that draw 7.2 watts of power need a wire with a minimum gauge of 12 ran to them. Meanwhile, the end effectors that require 47.2 watts need a wire of 18 gauge or more. So, to make the manufacture of the device streamlined, a wire of gauge 12 should be used to run to all the end effectors. The calculations for the wire gauge can be found in Appendix G – Wire Gauge Calculations.

The controls of the end effectors will be an off-the-shelf microcontroller. The SparkFun Red-V is shown in Figure 32. The microcontroller will be responsible for the stepper motors for the manufacturing heads and the motion in the Z-axis and Y-axis. The microcontroller will also program the heating elements in the FDM polymer print and soldering iron manufacturing heads.

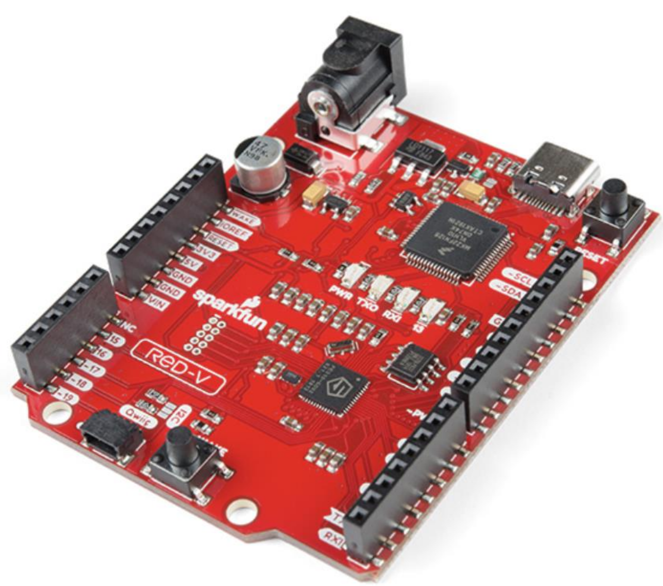


Figure 32 Red-V Microcontroller

The Red-V will be used with the 40-34 stepper motors, as shown in Figure 33. The motors will be used in four manufacturing heads to move the gantry in the three axes of motion. The 40-34 engine consumes 7.2 watts of power, is powered by 4.8 volts, and has a current rating of 1.5 amperes. The motor produces 0.04 Nm of torque.

Figure 33 40-34 Stepper Motor

4.5 Software

4.5.1 System Overview

In this system, the software is used in a way that allows one to work and alter the different printheads of the gantry and the removable base. The firmware provides the ability to utilize sensors for precision, check temperatures, and control the additive manufacturing process by the end user. This is done to allow users to monitor the system and keep up with its status, which allows for better production from the system.

4.5.2 CSCI Wide Design Decisions

The print process starts remotely, with the end user adjusting essential functions before the print commences. Files for the print will load from a G-code. This G-code will allow the system to slice and print the designed component in the preferred configuration setting. The advantage of this remote option is the ability to transfer these files directly to the printer instead of manually saving them before uploading. Any errors will be notified through the printer's interface. This process can further be seen in Figure 34

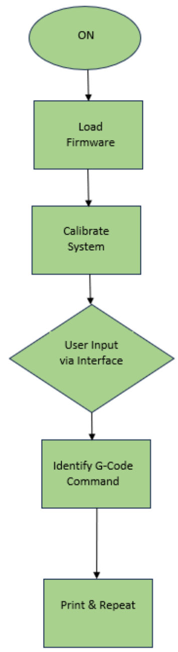


Figure 34 Main Firmware Algorithm

For this system, the firmware Creality, which is reliable, is used. Still, the firmware and software are typically tailored to work seamlessly with their hardware, which this system possesses regarding its FDM print head component, as referenced earlier in the document. Specifically, Ender 3 from the series was used as its advantage in how it possesses open-source designs and firmware. This allows multiple individuals to modify and customize the printer, contributing to developing firmware updates and even hardware modifications. Additionally, added buffering commands will enable the printer to handle minor hiccups or delays in communication without affecting the print quality. This software is very versatile and also allows users to upgrade within its series.

4.5.3 Concept of Execution

At the beginning of the print job, the end user will have the G-Code instructions plugged into the computer via USB. This will allow for remote control. As demonstrated in Figure 35.

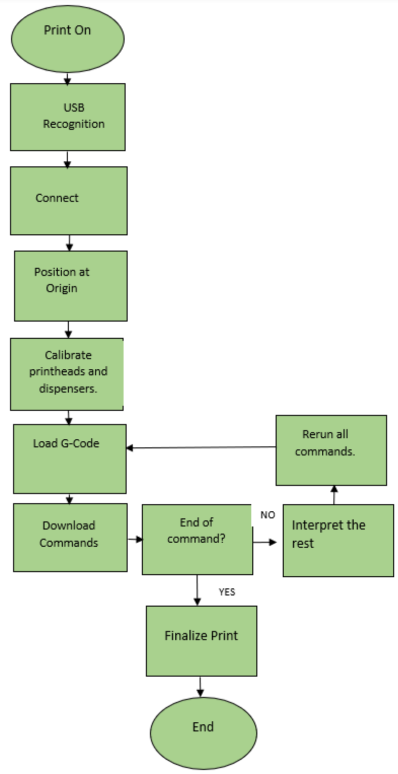


Figure 35 Print Process Diagram

Next, when everything is activated following this connection, the software will choose which effectors to use at which time. For accuracy, the extruder position will also be calibrated to meet the point of origin using 3D cartesian coordinates. This will then lead to the system ensuring the temperature is within range before and during printing. Once this is done, the G-Code command/instructions will be sent to the computer to Commands include:

- Multi-printhead movements
- EMI Shielding
- Auxiliary Dispensing sensors
- Print Base removal.

Once prompted for more instructions, the end user can loop the process with these commands. Each parameter will have the chance to be assessed in terms of progress, with the option to stop and restart the process. After the performance, the algorithm will review the final commands and complete the print.

4.6 Performance Specifications

The performance of the present apparatus is contingent upon the project's primary purpose, manufacturing electronic enclosures in orbit. Therefore, it is necessary to design an enclosure test case to represent the average enclosure that could be manufactured. Like a desktop 3D printer can produce an infinite variety of geometries, so can this machine. The enclosure test case is only an example of what an enclosure could look like. Furthermore, the test case is designed to consume the average amount of raw material used to manufacture enclosures. The test case can then be used as a benchmark for the production quantity, helping to drive the amount of raw material on board and the design of the material storage system.

The following specifications are derived from the materials and time required to manufacture the test case. See more details on the Test case design in 4.6.1 Enclosure Test Case.

Table 7 Performance Metrics

Metric	Value	Requirement
Mass of 1 unit	587 g	N/A
Mass of Product	38 kg	70 kg
Time to Manufacture 1 unit	15 hours	N/A
Power Required for One unit	650 Wh	N/A
Average Power Consumption	50 W	444 W
Production Quantity	25 units	N/A

The metrics listed in Table 7 are defined as follows:

- Mass of 1 unit: Mass of the average electronic enclosure or mass of test case
- Mass of product: Total mass of the entire machine. This would be everything installed inside the X-SAT bus
- Time to Manufacture: total time needed to produce the enclosure test case
- Power Required for One unit: This is the time needed to produce the enclosure test case
- Average power consumption: This is the average power consumed during production. There may be highs and lows around this point
- Production Quantity: The total number of enclosures the factory can produce with the amount of raw materials on board

4.6.1 Enclosure Test Case

It should be noted that specialized electrical engineers did not design the test case. Instead, the test case is helpful as an example, and future electronic designers can use A-MOD's system to design and manufacture functional electronic enclosures needed for in-space machinery. Furthermore, the test case exemplifies how the manufacturing process works. It shows how the base, wires, aux components, and plastic enclosure interact.

Figure 36 shows the enclosure base plate. All manufacturing processes are built on the base plate, and the base plate becomes part of the finished product. Twenty-five base plates are stored in a magazine within the material storage section of the device. When manufacturing of a new enclosure begins, a base plate is loaded onto the fixture plate and held in place while the rest of the enclosure is built on top. The base has a generic circuit already made into it and comes with the 37-pin D sub connector already in place. Details on the D sub-connector can be found in Appendix B – Filtered D-Sub Connector Data Sheet. Further, the base also includes EMI protection.

The base featured in this Design is made from a 1/8 inch thick 6061-T6 aluminum plate on the bottom, and layered on top of that is an eighth-inch thick printed circuit board that includes the generic circuit. Also, a 1/4-inch tall perimeter is made out of conductive material on the outside that's electrically connected to the aluminum base. The electrical connection is crucial for creating a Faraday cage for EMI protection. Then, the D-sub connector is mounted on the side. Pins of the D-sub connector are connected to circuits within the generic base. The base provides pads for hardware and custom circuits to communicate so that various enclosures can be built on top. The advantage of having premade bases that become part of the enclosures is it saves space and energy in the final design by simplifying the manufacturing process. It should also be noted that the enclosure base has four holes, so it is ready to be installed on space machinery.

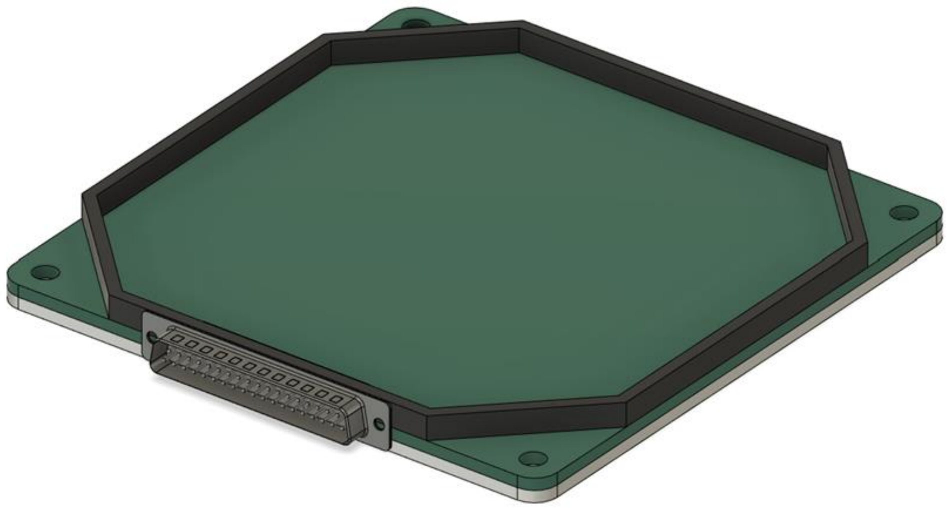


Figure 36 Print and Enclosure Base Model

Once manufacturing begins on the generic base, the FDM printing head begins building the geometry of the enclosure. The initial geometry layers may include channels and inserts for installing wires and exhilarating parts. Figure 37 shows how a partially printed enclosure may look with internal geometry for wires and auxiliary components. These grooves and holes provide a place to locate wires and hold them in place in a microgravity environment. Furthermore, inserts are made into the base so that auxiliary parts can be snapped and placed so they don't move in microgravity and stay in place so the soldering station can solder the connections. When all connections are fused in this layer, the machine prints over the installed wires and parts to encase them in the closure. Depending on the enclosure's design, the device may create multiple wiring layers and components.

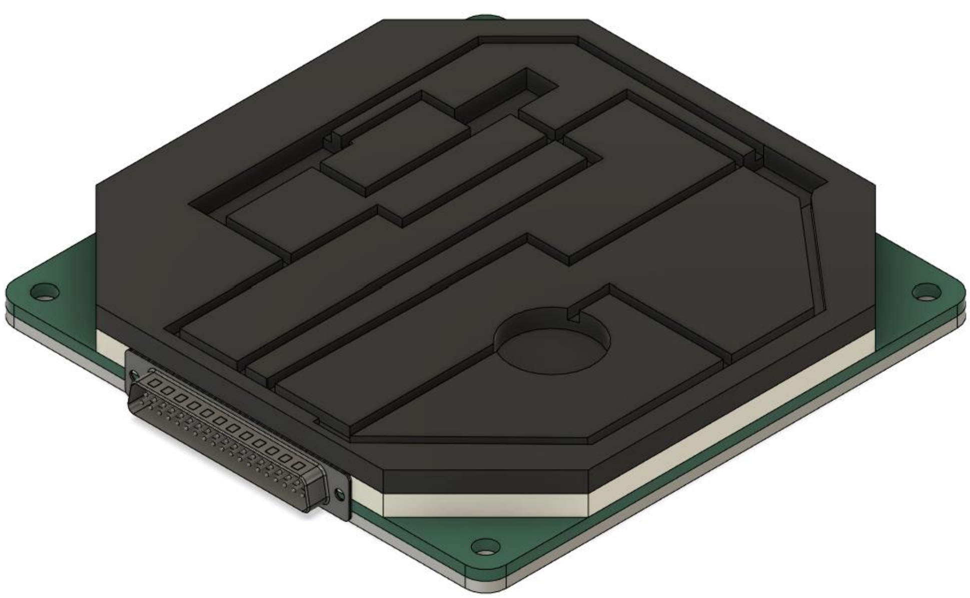


Figure 37 Partially Manufactured Enclosure

The extra space inside the enclosure must be filled somehow to print the preceding layers. 3D printing processes achieve this using something called infill. Infill is when additional material is built up in rows within solid sections. This saves on the needed material because it's not 100% reliable. The infill can be adjusted, and because there's very little strength required from an enclosure in microgravity, the infill percentage can be small. For the test case A-MOD, use an infill percentage of 5%. Figure 38 is a screen capture from Creality slicing software used to cut the prototype enclosure. The infill grid is yellow; this figure only shows layers up to halfway inside the enclosure. Furthermore, this slicing software estimates the factoring time and amount of plastic material used in the closure.

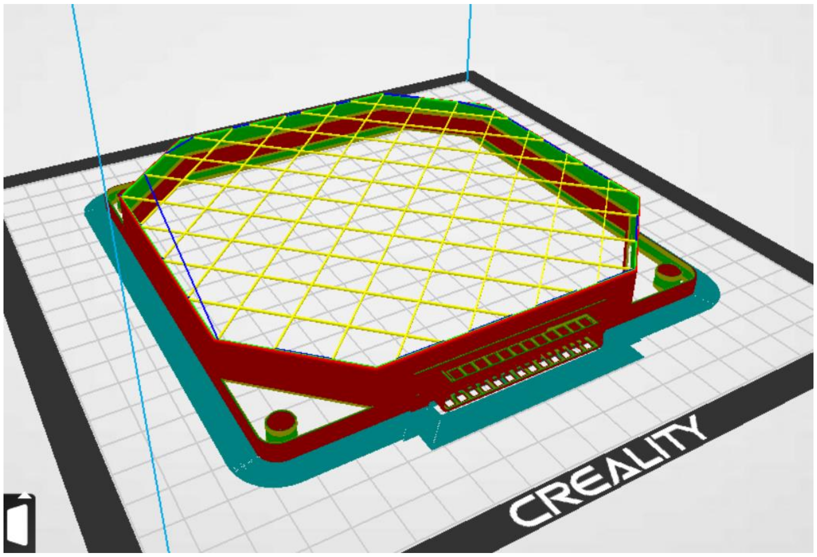


Figure 38 Slicer Layer Visualization

EMI tape is wrapped around the final geometry and Figure 39 shows the completed enclosure. An electrical engineer with experience in space equipment is needed to design the generic circuit boards within the base. Furthermore, electrical expertise is required to develop the machine's enclosures. By using the A-MOD-designed process and device, engineers can create custom enclosures within orbit.

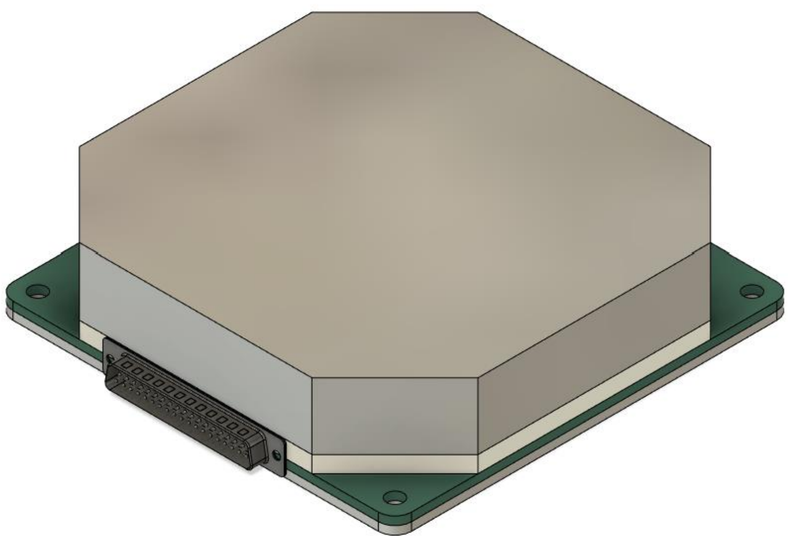


Figure 39 Completed Enclosure

Table 8 Test Case Materials

	QTY	MASS
Base	1	370 g
FDM	37 m	112 g
Solder	0.5 m	7 g
Wire	12 m	58 g
EMI Tape	1.6 m	12 g
Aux Parts	4	28 g

Table 8 highlights the materials used in one test case. These figures estimate the total amount of material needed to be stored on board. The definitions of the materials are as follows:

- Base: Printing base and enclosure base with D-sub connector and generic circuit board
- FDM: The material used in Fused Deposition Modeling makes up the enclosure's structure and geometry
- Solder: Solder electrically connects the wires, plugs, and auxiliary components. The solder data sheet is found in Appendix C – Solder Data Sheet
- Wire: This is used to connect components within the enclosure electrically. The wire used is 0.032” diameter copper. More details are found in Appendix D – Wire Data Sheet
- EMI Tape: Tape covers the enclosure's top and sides and protects it from electromagnetic interference. The tape chosen is shown in Appendix E – Nickle Copper Faraday Tape Data Sheet
- Aux Parts: Auxiliary parts, such as sensors, plugs, and relays, could be installed into an enclosure

A-MOD’s different methods to determine the amount of material used in an average enclosure. Slicing software was used to estimate the amount of FDM material by loading the geometry of the finished enclosure. The amount of solder wire and axillary parts was determined based on personal experience working on similar enclosures for aerospace applications. An electrical engineer must review these numbers and help make more accurate predictions. The amount of EMI tape used is based on the model geometry. By adding all these materials up, the final model and weight of the materials can be estimated for the finished machine.

4.6.2 Enclosure material

The chosen material for 3D printing the enclosure is polychlorotrifluoroethylene (PCTFE). PCTFE is a high-performance polymer known for its excellent chemical resistance, low gas permeability, and thermal stability. However, no evidence exists that this polymer has been used in FDM 3D printing. A method for 3D printing PCTFE may need to be developed (Curbell Plastics, n.d.).

To consider the use of PCTFE or any other material for 3D printing satellite parts in space, there are several factors to take into account:

1. **Weight and Volume Constraints**: Materials for 3D printing in space must be lightweight to minimize launch costs. PCTFE is known for its low density, which can be advantageous.

2. **Thermal Stability**: PCTFE is known for its high thermal stability, which could be important for applications in space where temperature variations can be extreme. This characteristic may help in maintaining the structural integrity of the printed parts.

4. **Chemical Resistance**: PCTFE's excellent chemical resistance could be beneficial in harsh space environments where exposure to various elements and radiation is a concern.

5. **Permeability to Gases**: If the satellite parts need to maintain a specific internal atmosphere or pressure, the low permeability of PCTFE to gases could be advantageous.

6. **Mechanical Properties**: The mechanical properties of PCTFE should be considered to ensure that the printed parts meet the required strength and durability standards.

7. **Compatibility with Other Materials**: Since the manufacturing process involves using multiple materials and the printed parts need to interface with other components, the compatibility of PCTFE with these materials should be evaluated.

Furthermore, detailed information on PCTFE and its various properties can be found in Appendix H - PCTFE (polychlorotrifluoroethylene) Data Sheet

4.7 Risk Assessment

For this project, a simplified risk assessment focuses on each stage of the manufacturing process. Each item is one step of orbit operations. A-MOD looks at the likelihood and impact of each step going wrong. The risk assessment highlights where additional effort is needed. The high-risk items may require more research and design to mitigate the risk. The manufacturing steps that are analyzed in the risk assessment are as follows:

1. G-code
2. Load base
3. FDM Printing (Internal geometry)
4. Aux Parts installation
5. Wire installation
6. Soldering stage
7. FDM Printing (final geometry)
8. EMI Tape
9. Completed Part

Using the chart, each item is ranked in likelihood and impact. The ranking system is 1 to 3, 3 being the most severe. Preventive actions are listed as well. Restarting the software means that the code is stopped and continued at the beginning. Testing and research means those processes and components need more attention and design effort. Verification for item 9 may require some verification stage that plugs into the enclosure and verifies that it functions appropriately before being in service.

Table 9 Risk Assessment Table

Item	**Risk**	**Impact**	**Likelihood**	**Preventive Actions**
(1) g-code	Software malfunction	1	1	Restart software
(2) Base	Base magazine and reloader Jam	2	1	Testing and research
(3) FDM	The filament doesn’t adhere properly	1	3	discard part and restart the prosses
(4) Aux parts	Dispenser jam or misplaced part	2	3	Testing and research
(5) Wire	Wire is misplaced	3	2	Testing and research
(6) soldering	There is no continuity through joint	2	2	Testing and research
(7) FDM	The filament doesn’t adhere properly	1	3	discard part and restart

(8) EMI tape	Tapes don't adhere, or mechanism jams	1	2	Redundant layers
(9) Completed part	The completed part does not perform correctly	1	3	Verification stage

Table 10 is an easy-to-read visualization of the risk assessment. Before delivery of the final product, everything should be in the green. Furthermore, a more detailed and interdisciplinary risk assessment may be required. This will serve the purposes of the project and highlight areas that still need work.

Table 10 Risk Assessment Chart

Likelihood		Impact: Negligible	Impact: Moderate	Impact: Catostrophic
Likelihood	Likely	(3) FDM Printing (Internal geometry) (7) FDM Printing (Final geometry)	(4) Aux Parts Installation	
	Possible	(8) EMI Tape	(6) Soldering stage	(5) Wire Instalation
	Unlikely	(1) g-code	(2) Load base	(9) Completed part
		Negligible	Moderate	Catostrophic
		Impact		

Chapter 5 – Final Design Review

5.1 Functional Review

To round out this report, the team will discuss the functional review of the device. The helpful review will be broken into two main sections: 5.1.1 Requirement Review and 5.1.2 Mission Objective Review. In the section of requirement review, we'll go through the validation on the validation test plan as laid out previously in section 3.4. As for the mission objective review; this section will dig into how the device meets the mission and objectives that the team had set before them in Chapter 1.

5.1.1 Requirement Review

In this section, the final design review of the requirements in Table 6 will be revisited and expounded upon whether they were met or if further testing and research need to be done on the device.

Table 11 Requirement Review

Requirements	Rationale	Validation
The system shall manufacture parts from raw materials and assemble components.	Manufacturing and assembling a finished product is essential for reducing the cost of systems in space.	The device has been designed to be able to accomplish this. However, further research into the support systems to maintain temperature, atmosphere, and the device needs to be done.
The manufacturing process should maintain quality standards	Due to the precision needed for satellites to function correctly, quality must be maintained throughout production	Further research into an observation system will need to be done to ensure consistent quality throughout
The system should be able to align and connect components accurately	The sensors in the system require accurate and precise connections to function properly	The device, when programmed correctly, will be able to perform this task successfully
The assembly process should ensure the integrity and durability of the final product	The enclosures will need to be manufactured to handle the environments they will be implemented in	a prototype of the device will need to be made and conditions simulated while printing a prototype piece to test the durability of a final enclosure
The system shall operate under the thermal cycles of space and control temperature within the unit	The enclosures must work in the varying temperatures of a space environment	with proper insulation and any support system, the device will be able to maintain temperature within the unit
The system must include effective power management strategies to utilize available power efficiently.	With the limited power capacity of the satellite Bus, energy conservation will be integral to success.	The device will be equipped with state-of-the-art electronics and electrical engineers to configure it most efficiently when brought on.
The system must ensure all constructed enclosures adhere to the specified size limits.	With limited space in satellites and other spacecraft craft, precise and consistent enclosures must be manufactured.	The device we need to include an observation system to ensure consistency

5.1.2 Mission Objective Review

The A-MOD team had three objectives they wanted to demonstrate with the project of in-orbit manufacturing of electronic enclosures. The aim and goal of the project were laid out in section 1.4 A-MOD Mission. The goal was to show that an electronic enclosure can be manufactured and assembled in space. The team broke that goal into three objectives:

1) Build an electronic enclosure made of extruded polymer, utilizing AM techniques
2) Embed wires and two sensors into enclosures
3) Ensure these enclosures withstand outer space's EMI and temperature cycles

The A-MOD team devised a design to meet these objectives, and here's how. The design had to incorporate a polymer hot end to satisfy the aim of using extrude parliament AM techniques. The team chose a direct drive system for the polymer hot end and a standard heating element that can reach temperatures of 280°C. The team also selected a type of polymer suitable for this mission, PCTFE (polychlorotrifluoroethylene). This material is already used in aerospace applications. However, further research into making it 3D printable needs to be conducted. As for the second objective, the device is designed with a wire feed head and robotic suction hand. This allows wires and sensors to be placed into the enclosure. And ask for the connection of the wires and sensors. The device has a soldering head, dispensing material, and a soldering iron. The last objective was the EMI take the dispensing head, which was designed to enable EMI shielding to be applied to the enclosure—the design of the removable base plates allowed for EMI protection at the bottom of the enclosures. The selection of the polymer material of PCTFE also enables the enclosures to sustain the temperature cycles of space.

5.3 Cost Summary

The cost summary delineates expense distribution within a specific project, focusing on various materials essential for its execution. The most significant portion of the budget is allocated to Fused Deposition Modeling (FDM), which is $535.34 and accounts for 40.18% of the total cost. FDM is a widely used additive manufacturing technology that involves layering material to create three-dimensional objects—the substantial investment in FDM serves as a foundational element and one of the primary manufacturing processes.

Following closely is the allocation for wire, which costs $314.04 and constitutes 23.57% of the total cost. Wires are crucial in this project, as they establish electrical connections for the enclosures. This expenditure highlights the significance of connectivity within the project, emphasizing the importance of a reliable and efficient wiring system. Solder costs $324.96 and contributes 24.39%, indicating the necessity for secure and durable connections between electronic components, essential for the overall functionality and reliability of the project.

The remaining percentages are attributed to specific components such as the robotic finger, which costs $57.42 (4.31%), and EMI tape, which costs $100.5 (7.54%). The robotic finger expense focuses on the mechatronic aspect due to the intricate manipulation and interaction project. With its electromagnetic interference mitigating properties, the EMI tape is essential due to its properties against unwanted interference. The detailed cost breakdown provides valuable insights into the project's priorities, with each material's significance reflecting its role in the overall execution and success of the endeavor. The total cost, amounting to $1,332.36, underscores the financial scope of the project.

5.4 Improvements and Recommendations

5.4.1 Technology Readiness Level

The Technology Readiness Level (TRL) assessment systematically evaluates the readiness and maturity of each component within the proposed gantry system designed for additive manufacturing in space. The TRL ratings will be used to quantitatively measure the technological advancement and robustness of various elements integral to the project (Manning, 2023).

The gantry is at the system's heart, achieving an impressive TRL Level 6. This indicates a high technological readiness level, suggesting that the gantry design has undergone substantial testing and validation, making it well-prepared for application in a space environment. The gantry frame's lightweight and dimensionally stable composition, combined with the three degrees of freedom at the printheads, showcases a mature and reliable technology capable of withstanding the challenges of space conditions.

The individual components of the gantry system also possess high TRL ratings. The FDM Print Head, Solder Head, and Wire Feed mechanisms all exhibit a Level 5 readiness. This means these components have undergone extensive testing in relevant environments, indicating high confidence in their performance and reliability. Although rated at Level 3, the Auxiliary Dispenser signifies a technology in the early stages of development but shows promise for further advancement.

The Base Plate Magazine, Build Material Compartment, and Robotic Finger components are each assigned a TRL Level 4. This suggests that these elements have undergone testing in a relevant environment and are approaching a mature stage, with further refinement anticipated as the project progresses.

Overall, the TRL ratings provide a comprehensive snapshot of the technological readiness of each crucial aspect of the proposed gantry system, paving the way for a systematic and informed development path as the mission advances toward its goals of in-space electronic enclosure manufacturing.

5.4.2 Recommendations

Strategic recommendations are proposed to enhance performance, functionality, and overall maturity to advance the Technology Readiness Levels (TRL) of the various components of the gantry system.

Starting with the gantry, which is currently rated at Level 6, structural design and stability improvements are crucial to achieve a Level 7 rating. This involves rigorous analysis and refinement of materials, considering their durability in harsh space conditions. Furthermore, implementing fail-safes can enhance reliability, ensuring the gantry maintains precision and accuracy throughout temperature fluctuations and operational cycles of space. Currently, at Level 5, the FDM Print Head can progress to Level 6 by optimizing its design for a broader range of materials and printing conditions. This may involve refining nozzle technology, temperature control, and extrusion mechanisms. Compatibility with a broader spectrum of materials enhances the versatility of the gantry system, making it adaptable to diverse mission requirements.

The Solder Head, also at Level 5, can advance to Level 6 by exploring automated calibration features. This improvement enhances user-friendliness and reduces the need for manual adjustments, making the gantry system more efficient and accessible. Automatic calibration contributes to consistent and precise soldering, ensuring the reliability of electronic components in space. Currently, at Level 5, the Wire Feed can move to Level 6 by integrating sensors for real-time monitoring and adjustment of wire feed speed. Real-time feedback will enable adaptive control, ensuring optimal wire placement and connectivity. This advancement contributes to the overall reliability and quality of the electronic enclosures produced by the gantry system.

The Auxiliary Dispenser, rated at Level 3, can progress to Level 4 by developing and integrating additional functionalities. This may include variable dispensing rates, precision control, or multi-material dispensing capabilities. Increasing the versatility of the dispenser enhances its utility, making it a more integral part of the gantry system. For the Base Plate Magazine, currently at Level 4, design modifications should be considered to improve the efficiency of material loading and unloading. This may involve implementing automated mechanisms for material handling, reducing human intervention, and streamlining the overall operation of the gantry system.

The Build Material Compartment at Level 4 can move to Level 5 by exploring advanced materials or storage methods. This ensures compatibility with a broader range of materials, extending the capabilities of the gantry system and enabling it to adapt to evolving mission requirements. Finally, the Robotic Finger, currently at Level 4, can advance to Level 5 by refining its design to improve functionality and agility. This may involve enhancements in gripping mechanisms, precision control, and adaptability to electronic components. An improved robotic finger would contribute to the overall effectiveness of the gantry system in assembling electronic enclosures in space.

By systematically addressing these recommendations, the gantry system can progress to higher TRL levels, signifying increased readiness and reliability for the unique challenges posed by space-based additive manufacturing.

5.5 Conclusion

In conclusion, the Critical Design Review (CDR) has successfully outlined A-MOD's proposed design for an in-orbit electronic enclosure manufacturing device. The comprehensive analysis, drawings, specifications, and component details presented in this report demonstrate the feasibility of the design. The objectives of the CDR, including a thorough review of the chosen layout, adherence to requirements, and guidance for future development, have been achieved.

The Concept of Operations elucidates the intricate manufacturing process, highlighting critical stages from loading the g-code to completing the electronic enclosure. A versatile system capable of accommodating various enclosure designs has been outlined, allowing for flexibility in the manufacturing process.

Validation and Verification procedures, as detailed in Table 6, ensure that the system meets stringent requirements for manufacturing precision, quality, component alignment, assembly integrity, thermal resilience, and power efficiency. These procedures, encompassing testing, analysis, and inspection, validate the robustness of A-MOD's design.

The Critical Design section provides a detailed examination of the Mechanical Design, emphasizing the machine's overall dimensions, manufacturing head designs, and material storage mechanisms. The CAD models and simulations instill confidence in the mechanical integrity and reliability of the system.

Though a secondary focus, Electrical Design outlines essential aspects such as wiring, off-the-shelf electrical components, and microcontroller usage. A systematic approach ensures streamlined control of manufacturing heads and motion axes.

The Software section elucidates the system overview and critical software design decisions, emphasizing remote control through G-code, firmware selection, and an algorithmic execution process. Integrating reliable firmware, such as Creality, ensures smooth operation and adaptability.

Performance specifications in Table 7 provide crucial metrics for evaluating the system's efficiency in mass, time, power consumption, and production quantity. The Enclosure Test Case serves as a benchmark, representing the average enclosure that could be manufactured and aiding in optimizing raw material storage.

The Risk Assessment, presented in Tables 9 and 10, identifies potential challenges in the manufacturing process, emphasizing the importance of preventive actions and continuous testing and research to mitigate risks.

In summary, A-MOD's critical design for an in-orbit electronic enclosure manufacturing device demonstrates innovation, precision, and adaptability. The outlined specifications, validated procedures, and risk mitigation strategies position the system as a viable solution for manufacturing electronic enclosures in space.

Appendix A – Ranking Criteria and Design Matrix

For Table 3.1, the breakdown of the ranking is as follows.

	Power Efficiency	Mass	Volume	Reliability	Versatility	Total	Weight
Power Efficiency	----	1	0.25	0	1	2.25	0.20
Mass	0	---	0	0	0.75	0.75	0.07
Volume	0.75	1	---	0	1	2.75	0.25
Reliability	1	1	1	---	1	4	0.36
Versatility	0	0.25	0	0	---	0.25	0.02

The table compares the row to the column. A score of 1 means that the row is more important than the column. A score of 0 means that the column is more important than the row. If the team believes that the row and column are close in importance, a quarter system will be used. This means that scores of 0.25 and 0.75 are comparable in extent, but the one with a score of 0.75 is a little more important.

This section will discuss the reasoning of each row vs. column.

Power Efficiency is more important than the mass of the device since the limit on the power is more problematic than the limit on the mass. Compared to the volume, volume wins out since the limit on space available on the bus is 16.4” × 17” × 27”. However, it is a close call on whether the volume is more critical than power efficiency; this is where the quarter system comes in. The volume constraint for the bus is more problematic than the power efficiency, so a score of 0.25 is given here. When power efficiency is compared to reliability, reliability comes out on top, scoring 0. The device can be as efficient as possible, but it's useless if it cannot work consistently. Lastly, power efficiency is more important than versatility. Since this design will only be used as a demonstration model, it does not need to print a variety of enclosers.

Mass gets a score of 0 when compared to power efficiency since the limit on the power is more problematic than the limit on the mass. Mass also receives a score of 0 when compared to volume. The system's total mass is not as constrained as the bus's strict volume requirements of 16.4” × 17” × 27”. When mass is compared to reliability, reliability wins out since the ability to be consistent is more important than the system's mass. Mass and versatility are close in the ranking of importance; however, mass wins out over versatility. This is denoted by the score of 0.75; since this design will only be used as a demonstration model, it does not need to print a variety of enclosers.

Volume compared to power efficiency achieves a score of 0.75. The two are close in terms of importance, yet the volume is just a bit more critical than power efficiency. Volume, when compared to mass, gets a score of 1. The bus is stricter with the space requirements than the mass. The score of 0 is given when volume is compared to reliability. The device’s size does not matter if it cannot consistently work as intended. When volume is compared to versatility, volume wins out. The score of 1 is given because this is a demonstration model and does not need to print a variety of enclosers.

Reliability is more important than power efficiency, so it scores 1 in the ranking order. When reliability is compared to mass, reliability beats out mass since the ability to be consistent is more important than the system's mass. Reliability, compared to volume, archives a score of 1; the device’s size does not matter if it cannot consistently work as intended regarding whether reliability is more important than versatility. Reliability gets a score of 1 because this is a demonstration model and does not need to print a variety of enclosers. As opposed to if the device will consistently work.

Versatility archives a score of 0 when compared to power efficiency. Since this design will only be used as a demonstration model, it does not need to print a variety of enclosers. When versatility is compared to mass, it gets a score of 0.25. This means that the two are close in terms of importance. However, the mass is more important than the versatility of the device. The mass is more important since it comes from the limits of the bus used. Compared to volume, the versatility gets a score of 0 since the volume requirements of 16.4” × 17” × 27” of the bus are strict limits. Lastly, when versatility is compared to reliability, reliability wins out since the function of the devices is paramount to versatility.

For Table 3.2, the breakdown of the Design Matrix is as follows.

Orbit Manufacturing								
Metrics	Weight	Design 1	Design 2		Design 3		Design 4	
		Datum	Score	Weight	Score	Weight	Score	Weight
Power	0.23	0	-1	-0.23	-1	-0.23	1	0.23
Mass	0.07	0	-1	-0.07	0	0	-1	-0.07
Volume	0.24	0	0	0	0	0	-1	-0.24
Reliability	0.36	0	-1	-0.36	0	0	1	0.36
Versatility	0.02	0	0	0	1	0.02	-1	-0.02
Total	**1**	**0**	**-0.66**		**-0.21**		**0.26**	

A-MOD is used to design one as the datum to compare the other designs. The scores are -1, 0, or 1. The score of -1 denotes that the design is worse than the datum. A score of 0 indicates that the design is about the same as the datum. A score of 1 denotes that the design is better than the datum. The weight is then multiplied by the score. The total will tell the best design after all of them have been added together. A positive total score will signal that the design is better than the datum. At the same time, a negative score will mean that the design is worse than the datum. The team decided on using design one as the datum since it is similar to a regular 3D printer. This makes it easier to compare it to the other design since there is much data on known printers, and assumptions can be made easier on this design.

As design 2 compares to the datum, it receives a score of -1 for power and mass; in this case, they are closely related. This was decided because the added mass will increase power consumption. Since the design has more mass added than a traditional 3D printer, it will have more mass and consume more power than the datum. When design two is compared to the datum in terms of volume, it gets a score of 0. The design meets the volume requirements for the bus, so it is on par with the datum. Design 2 receives a score of -1 for reliability since it adds complexity to the design. Lastly, the versatility of design 2 is similar to the datum, so it archives a score of 0.

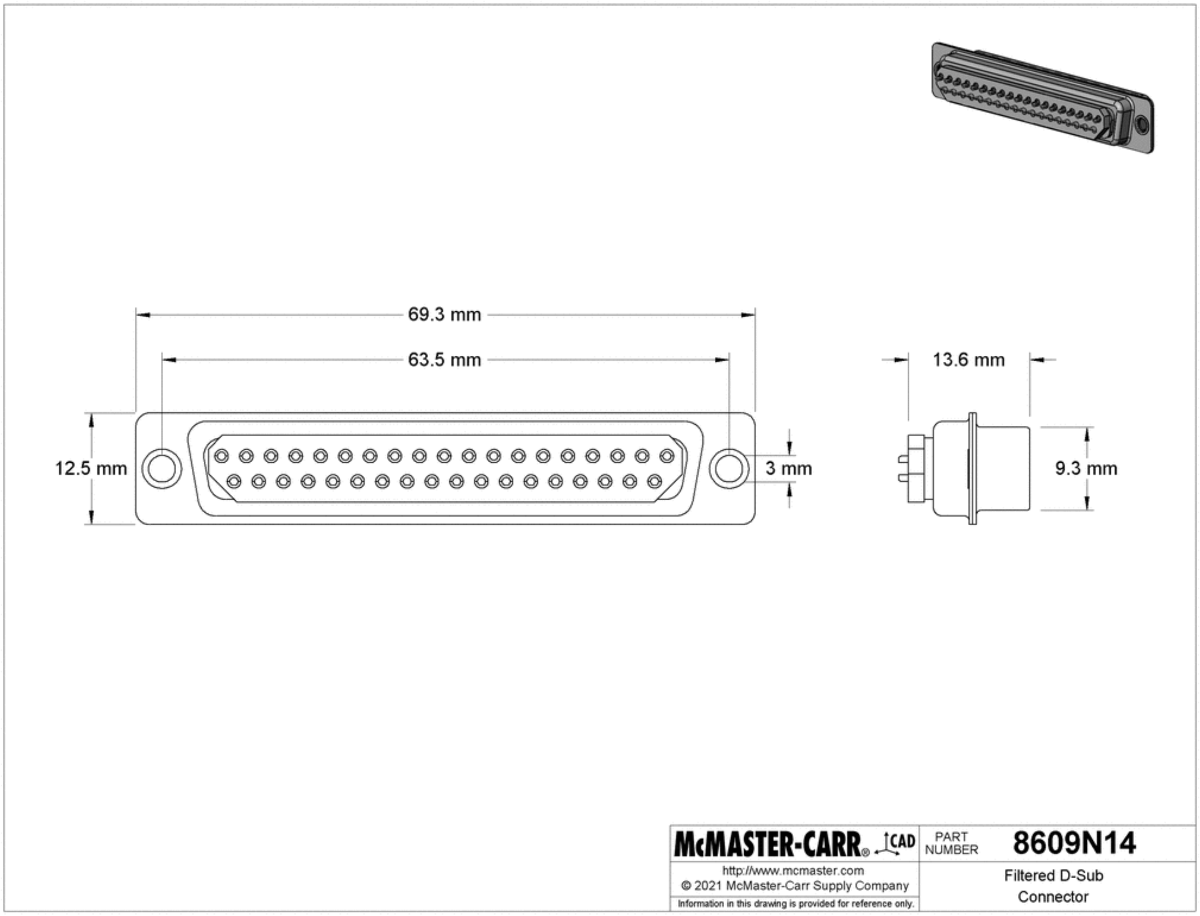
For design 3, the power needed for the arm will be more than the datum, so it receives a score of -1. Regarding the design's mass, the arm has less mass than a traditional 3D printer, yet the removable end effector will add more mass. After considering that, they will have about the same mass, so the score is 0. The same goes for the volume of the design. Initially, it is lower than a traditional 3D printer, but the end effectors add volume. This leads to a score of 0. With design 3, the reliability does not improve or worsen, so it also receives a score of 0. The design is more versatile than the datum since it has more degrees of freedom; it was given a score of 1.

For design 4, the device only needs a little power since some parts are made into the print bed. For this reason, it was given a score of 1. The design does add more mass than the datum, so it receives a -1 for mass. The space needed for the materials is also increased in this design compared to the datum, so it archives a score of -1. The method increases the device's reliability since the sensors and wires are already in place. For this reason, it receives a score of 1. The versatility of this design is less than the datum since the print bed is predetermined, and new enclosures can only be printed if the print bed is changed. For this reason, it archives a score of -1.

Appendix B – Filtered D-Sub Connector Data Sheet

Connection Type	Computer
Computer Connection Type	DB37
Electrical Connector Component	Plug
Gender	Male
Shape	Straight
Shielding	Shielded
Wire Connection Type	Solder
For Wire Gauge	20
Maximum Voltage	250V AC
Maximum Current	7.5A
Interference Reduction @ Frequency	4 dB @ 1 GHz
Housing Material	Nickel-Plated Steel
Shield Material	Ferrite Ceramic
Temperature Range	-60° F to 220° F
Mounting Holes	
Number of	2
Diameter	3 mm
Protections Provided	EMI, RFI
Specifications Met	UL 94 V-0
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/17/2023, 233 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	People's Republic of China
Schedule B	854420.0000
ECCN	EAR99

With a ferrite filter block surrounding their contacts, these connectors control and reduce electromagnetic (EMI) and radio frequency (RFI) interference. They have solder cup terminals that hold wire leads in place when you're soldering them, helping you create a stable connection.


69.3 mm
63.5 mm
13.6 mm
12.5 mm
3 mm
9.3 mm
McMASTER-CARR
CAD
PART NUMBER
8609N14
http://www.mcmaster.com
© 2021 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Filtered D-Sub Connector

Appendix C – Solder Data Sheet

Product Attribute	Attribute Value
Manufacturer:	AIM - American Iron and Metal
Product Category:	Solder
RoHS:	N
Product:	Solder
Type:	Wire, Water Soluble
Alloy:	Sn60/Pb40
Description/Function:	Water Soluble Flux Wire
Diameter:	0.032 in
Core Size:	2 %
Package Type:	Spool
Size:	1 lb
Contains Lead:	Yes
Brand:	AIM
Product Type:	Solder
Factory Pack Quantity:	48
Subcategory:	Solder & Equipment
Unit Weight:	1.261 lbs

TECHNICAL DATA SHEET

Solder plus Support

OAJ WATER SOLUBLE CORED WIRE

FEATURES

- Excellent Wetting Properties
- High Activity Level
- Reduces Oxidation of Solder Iron Tip
- Residue Washes Easily with DI Water Alone
- Excellent Thermal Transfer

DESCRIPTION

OAJ Flux Cored Solder Wire has been formulated with an innovative amine neutralized halide-activator system. This novel system offers a high activation level that provides rapid oxide removal and maximum capillary action, resulting in faster wetting on all surface finishes and plating. OAJ flux residues MUST be removed after soldering. IPC flux classification – ORH1.

STANDARD AVAILABILITY

OAJ Cored Wire is available in Sn/Pb, SAC305 and SN100C® alloys. Other alloys, diameters and spool sizes may be available upon request.

APPLICATION

Solder iron tip temperature should be between 350° - 400°C (650° - 750°F) for Sn63, Sn62 and Sn60 alloys, 370° - 425°C (700° - 800°F) for SN100C®, Sn/Ag and Sn/Ag/Cu (SAC305, SAC405, CASTIN, etc.) alloys.

HANDLING & STORAGE

Time	Conditions
3 years	Cool < 30°C (< 86°F) Dry < 75%Rh

Store cored wire in a clean, dry area away from moisture and sunlight. Avoid freezing.

CLEANING

Post-process residues can remain in place up to 8 hours*. Flux residue can be removed with normal tap water @ 38° - 60°C (100° - 140°F) with a DI water final rinse. Use of a pressurized spray cleaning system is suggested, but is not required.

*Environment and application dependent

SAFETY

Use with adequate ventilation and proper personal protective equipment. Refer to the accompanying Safety Data Sheet for any specific emergency information. Do not dispose of any hazardous materials in non-approved containers.

TECHNICAL DATA SHEET

Solder plus Support

TEST DATA SUMMARY

Name	Test Method	Results	
IPC Flux Classification	J-STD-004	ORH1	
IPC Flux Classification	J-STD-004B 3.3.1	ORH1	
Name	**Test Method**	**Results**	**Image**
Copper Mirror	J-STD-004B 3.4.1.1 IPC-TM-650 2.3.32	High - > 50% Removal	
Corrosion	J-STD-004B 3.4.1.2 IPC-TM-650 2.6.15	Major Corrosion	Uncleaned
Quantitative Halides	J-STD-004B 3.4.1.3 IPC-TM-650 2.3.28.1	≥ 2.0% Typical	
Qualitative Halides, Silver Chromate	J-STD-004B 3.5.1.1 IPC-TM-650 2.3.33	Halides Detected	
Qualitative Halides, Fluoride Spot	J-STD-004B 3.5.1.2 IPC-TM-650 2.3.35.1	None Detected	
Surface Insulation Resistance	J-STD-004 3.4.1.4 IPC-TM-650 2.6.3.3	>100MΩ	Cleaned
Surface Insulation Resistance	J-STD-004B 3.4.1.4 IPC-TM-650 2.6.3.7	>100MΩ	Cleaned
Flux Solids, Nonvolatile Determination	J-STD-004B 3.4.2.1 IPC-TM-650 2.3.34	100% Typical	
Acid Value Determination	J-STD-004B 3.4.2.2 IPC-TM-650 2.3.13	104 ± 2.68 Typical	
Visual	J-STD-004B 3.4.2.5	White Solid	
Wetting	J-STD-005A 3.9 IPC-TM-650 2.4.45	PASS	
Fluoride	J-STD-004B IPC-TM-650	PASS	
Flux Spreading	J-STD-004B 3.7.2 IPC-TM-650 2.6.14.1	PASS	
Metal/Flux Content	J-STD-005A 3.4 IPC-TM-650 2.2.20	98% / 2%	
Spread	J-STD-004B 3.7.2 IPC-TM650 2.4.46	PASS	
Cleanliness	TM125-03	PASS	

Appendix D – Wire Data Sheet

Material	110 Copper
Shape	Wire
Appearance	Mirror-Like
Diameter	0.032"
Diameter Tolerance	-0.0004" to 0.0004"
Tolerance Rating	Standard
Yield Strength	Not Rated
Tensile Strength	29,000 psi
Temper	Not Rated
Temper Rating	Softened (Annealed)
Hardness	Not Rated
Hardness Rating	Not Rated
Heat Treatable	No
Mechanical Finish	Polished
Specifications Met	ASTM B3
Container Type	Spool
Container Net Weight	1 lb.
Warning Message	Physical and mechanical properties are not guaranteed. They are intended only as a basis for comparison and not for design purposes.
Length	315 ft.
Additional Specifications	SDS Wire Gauge Conversion Chart
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/10/2022, 224 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	United States
USMCA Qualifying	No
Schedule B	740819.0000
ECCN	EAR99

This wire is polished to a mirror-like finish. Offering high electrical conductivity and formability, 110 copper is 99.9% pure. Also known as ETP copper, it's often used as grounding wire. It has a soft temper and will stay in place when bent.

Appendix E – Nickle Copper Faraday Tape Data Sheet

Product Attribute	Attribute Value	
Manufacturer:	Laird Performance Materials	
Product Category:	Adhesive Tapes	
RoHS:	Details	
Product:	Tapes	
Type:	Conductive	
Description/Function:	Nickel / Copper conductive fabric tape with pressure-sensitive adhesive	
Color:	Gray	
Material:	Nickel, Copper Coated Polyester	
Adhesive Type:	Acrylic	
Width - in:	0.98 in	
Width - mm:	25 mm	
Length - in:	65.62 ft	
Length - mm:	20 m	
Brand:	Laird Performance Materials	
Packaging:	Roll	
Product Type:	Tape	
Factory Pack Quantity:	1	
Subcategory:	Supplies	
Tensile Strength:	7.5 Kgf / 25 mm	
Thickness:	0.075 mm	

Unit Weight:	5.073865 oz

Laird TECHNOLOGIES

Innovative **Technology** for a **Connected** World

86750 Nickel/Copper Fabric Tape

NI/CU POLYESTER CONDUCTIVE FABRIC TAPE

Laird Technologies' Conductive Fabric Tape 86750 product is made of metallized fabric (polyester Ni/Cu) coated with a pressure sensitive adhesive. These products can be used as EMI/RFI shielding and grounding tape, which would meet market requirements.

FEATURES

RoHS

- RoHS compliant
- Halogen-free per IEC-61249-2-21 standard
- Low surface resistivity of < 0.03 Ω/□ provides excellent conductivity
- Shielding effectiveness of 70 dB across a wide spectrum of frequencies

MARKETS

ecoGREEN

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- Servers
- Printers
- Laptop computers

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Asia: +86.755.2714.1166

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Laird TECHNOLOGIES

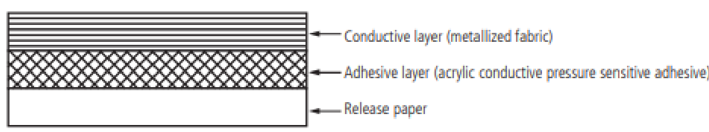
Innovative **Technology** for a **Connected** World

86750 Nickel/Copper Fabric Tape

Item	Unit	Value	Test Method
Thickness	mm	0.075 mm ± 0.015	-
Peel Adhesion	Kgf / 25 mm	>0.9	PSTC 101*
Shear Adhesion			ASTM D4935
at R.T.	Hrs	>72	PSTC 107#
at 80°C	Hrs	>3	PSTC 107#
Tensile Strength	Kgf / 25 mm	>7.5	
Operation Temperature	°C	0-80	
Surface Resistivity (Fabric Side)	Ω/□	<0.03	ASTM F390
Z-axial Resistance	Ω	<0.03	
Shielding Effectiveness+			ASTM D4935
at 100 MHz	dB	70	
at 1 GHz	dB	75	
Package Dimensions (Max. Width: 1000 mm)	M	W: Dimension by Customer Spec L: Standard Length of 20 M	
Shelf Life (Under 23°C/65% R.H.)		Six Months	

*:Test Method A, dwell time 30 min. #:Contact area 25 mm by 25 mm +:Typical value

COMPOSITION OF PRODUCT



APPLICATION TECHNIQUES

1. Bond strength is dependent upon the amount of adhesive-to-surface contact developed. Firm application pressure develops better adhesive contact & thus improves bond strength.
2. To obtain optimum adhesion, the bonding surfaces must be clean, dry and well unified. A typical surface cleaning solvent is isopropyl alcohol. Use proper safety precautions for handling solvents.
3. Ideal tape application temperature range is 21°C to 38°C. Initial tape application to surfaces at temperatures below 10°C is not recommended because the adhesive becomes too firm to adhere readily. However, once properly applied, low temperature holding is generally satisfactory.

EMI-DS-FOF-86750 1112

Appendix F -Specifications and Bill of Materials

Bill Of Materials for the polymer hot-end manufacturing head

ITEM NO.	PART NUMBER	QTY.
1	nozzle	1
2	Heat block	1
3	Heater	1
4	Radiator	1
5	Pneumatic joint	1
6	M3×18 Flush Head Screw	6
7	Direct drive made	1
8	42-34 motor	1
9	E housing 2	1
10	E idler tensioner	1
11	624U pillow	1
12	E gear	1
13	M3X16 Pan Head Screw	2
14	M3X8 Pan Head Screw	1

Bill of Materials for the wire feed manufacturing head.

ITEM NO.	PART NUMBER	QTY.
1	Direct drive made	1
2	42-34 motor	1
3	E housing 2	1
4	E idler tensioner	1
5	624U pillow	1
6	E gear	1
7	M3×18 Flush Head Screw	4
8	M3X8 Pan Head Screw	2
9	Wire guide	1
10	Wire cutting	1
11	Wire blade	1
12	M3X16 Pan Head Screw	2

Bill of Materials for the soldering manufacturing head.

ITEM NO.	PART NUMBER	QTY.
1	Direct drive made	1
2	42-34 motor	1
3	E housing 2	1
4	E idler tensioner	1
5	624U pillow	1
6	E gear	1
7	M3×18 Flush Head Screw	4
8	M3X8 Pan Head Screw	2
9	Wire guide	1
10	Wire cutting	1
11	Wire blade	1
12	Solder	1
13	M3X16 Pan Head Screw	2

Bill of Materials for the robotic suction head.

ITEM NO.	PART NUMBER	QTY.
1	Robotic mount	1
2	Suction	1
3	Pneumatic joint	1
4	Tube	1
5	M3X25 pan	2

Bill of Materials for the EMI tape dispensing head.

ITEM NO.	PART NUMBER	QTY.
1	E plate	1
2	Rollers	2
3	F688 pillow	4
4	Wheel	3
5	New X axis bracket	1
6	42-34 motor	1
7	m5	4
8	M3X16 Pan Head Screw	4

The 40-34 stepper motor

Company	CREALITY 3D
Part Number	4004100017

Gross Weight	0.226kg
Step Angle	1.8
Holding Torque	4kg. cm
Rated Voltage	4.8Volt
Rated Current:	1.5A/Phase
Form Factor	NEMA 17

The heating element

Voltage	24 V
Power	40 W
Dimensions	6 × 20 mm

Appendix G – Wire Gauge Calculations

In the following equations

A is the cross-sectional area of the wire in inches squared

I am the current through the wire in amps

ϱ is the conductivity of the wire

L is the length of the wire in feet

V is the voltage of the wire in volts

For the manufacturing head that requires 7.2 Watts, the current is 1.5 Amps, and the voltage is 4.8 Volts.

For each case, 25 feet is used as the maximum length of wire needed, and the wire material is copper. ($\varrho = 69.7 \times 10^{-8}$ Ω in).

$$A = (I \times \varrho \times 2L)/(V)$$

$$A = (1.5 \times 69.7 \times 10^{-8} \times 2 \times 25)/(4.8)$$

$$A = 0.005091 \text{ in2}$$

That cross-sectional area corresponds to a 12-gauge wire.

For the manufacturing heads that draw 47.2 Watts of power, the current and voltages are 1.7 amps and 24 volts, respectively. The rest of the equations are the same.

$$\text{availableA} = (I \times \varrho \times 2L)/(V)$$

$$A = (1.67 \times 69.7 \times 10^{-8} \times 2 \times 25)/(24)$$

$$A = 0.0011045 \text{ in2}$$

That cross-sectional area corresponds to an 18-gauge wire.

Appendix H - PCTFE (polychlorotrifluoroethylene) Data Sheet

PCTFE IS WIDELY USED FOR THE FOLLOWING:

- Cryogenic and chemical processing components
- Seals and gaskets
- Aerospace valve seats, pump parts, impellers, diaphragms, and plugs
- Laboratory instruments
- Nuclear service/high radiation exposure
- Liquid oxygen and liquid nitrogen valve linings

PERFORMANCE CHARACTERISTICS:

- Dimensionally stable, rigid, and resistant to cold flow
- Shallow gas permeation and outgassing
- Near zero moisture absorption
- Excellent chemical resistance
- Useful temperature range: –400°F to 380°F
- Radiation resistance

Typical Properties

	UNITS	ASTM TEST	PCTFE
TENSILE STRENGTH	psi	D638	4,860 - 5,710
FLEXURAL MODULUS OF ELASTICITY	psi	D790	200,000 - 243,000
IZOD IMPACT (notched)	ft-lbs/in of notch	D256	2.5 - 3.5
HEAT DEFLECTION TEMPERATURE (66psi / 264psi)	°F	D648	259 / -

WATER ABSORPTION (Immersion 24 hours)	%	D570	0

Physical Properties

	UNITS	ASTM TEST	PCTFE
SPECIFIC GRAVITY	-	D792	2.11 - 2.17
WATER ABSORPTION (Immersion 24 hours)	%	D570	0

Mechanical Properties

	UNITS	ASTM TEST	PCTFE
TENSILE STRENGTH	psi	D638	4,860 - 5,710
TENSILE MODULUS OF ELASTICITY	psi	D638	-
TENSILE ELONGATION	%	D638	100 - 250
FLEXURAL STRENGTH	psi	D790	9,570 - 10,300
FLEXURAL MODULUS OF ELASTICITY	psi	D790	200,000 - 243,000

COMPRESSIVE STRENGTH	psi	D695	-
HARDNESS	scale as noted	D785, D2240	Shore D 90
IZOD IMPACT	ft-lbs/in	D256	2.5 - 3.5

Thermal Properties

	UNITS	ASTM TEST	PCTFE
COEFFICIENT OF LINEAR THERMAL EXPANSION	in/in/°F x 10^{-5}	D696	3.9
HEAT DEFLECTION TEMPERATURE (66psi / 264psi)	°F	D648	259 / -
MAX CONTINUOUS SERVICE TEMPERATURE IN AIR	°F	-	380

Electrical Properties

	UNITS	ASTM TEST	PCTFE
DIELECTRIC STRENGTH	V/mil	D194	500

Bibliography

Bardwell, T. (n.d.). *How Much Electricity Does A 3D Printer Use?* Retrieved from 3dsourced: https://www.3dsourced.com/guides/how-much-electricity-does-a-3d-printer-use/

Curbell Plastics. (n.d.). *PCTFE*. Retrieved from Curbell Plastics: https://www.curbellplastics.com/materials/plastics/pctfe/

Dwamena, M. (2023, February 14). *How Much Does a 3D Printer Weigh?* Retrieved from Printerly: https://3dprinterly.com/how-much-does-a-3d-printer-weigh-heavy-or-not/

Hill, A. M. (2020). *SMD Rideshare 101*. Washington, DC: NASA.

Manning, C. G. (2023, September 27). *Technology Readiness Levels*. Retrieved from NASA: https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/#:~:text=Technology%20Readiness%20Levels%20(TRL)%20are,based%20on%20the%20projects%20progress

Mecademic Industrial Robotics. (n.d.). *Meca500 Robotic Arm*. Retrieved from Mecademic: https://www.mecademic.com/meca500-industrial-robot-arm/

Micro Swiss. (n.d.). *Direct Drive for Creality CR-10*. Retrieved from Micro Swiss: https://store.micro-swiss.com/products/micro-swiss-direct-drive-extruder?variant=31316019773507

NASA. (n.d.). *Thermal Test Levels & Durations*. Retrieved from Llis: https://llis.nasa.gov/lesson/783

Peterson, Z. (2023, September 25). *Types of PCB Soldering and the Assembly Process*. Retrieved from Altium: https://resources.altium.com/p/types-pcb-soldering-and-assembly-process

Smith, P. (n.d.). *Working with Wire*. Retrieved from Sparkfun: https://learn.sparkfun.com/tutorials/working-with-wire/wire-thickness

Wooding, S. (2023, September 21). *Wire Size Calculator*. Retrieved from Omni Calculator: https://www.omnicalculator.com/physics/wire-size

Xometry. (2022, August 23). *4 Types of Metal 3D Printing Processes and Their Materials*. Retrieved from Xometry: https://www.xometry.com/resources/3d-printing/types-of-metal-3d-printing