

Cosmic C3: Orbital Manufacturing & Assembly

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Abstract

This project presents the conceptual design of a semi-autonomous multifunctional payload for orbital manufacturing and assembly, developed for the 2025–2026 COSMIC Capstone Challenge Track 1. The payload is intended to operate within Arkisys' Bosun's Locker and demonstrate a chain of three discrete manufacturing operations that together provide a meaningful in-space fabrication capability. The proposed system integrates polymer-based 3D printing, soldering, and embedded wire deposition to support the fabrication of structurally and electrically functional components in orbit.

The design was developed to satisfy the physical and operational constraints of the Bosun's Locker platform, including limitations in volume, mass, and power consumption, while also addressing the environmental challenges of microgravity and vacuum operation. The payload is designed to function semi-autonomously through limited remote commands such as start, pause, resume, and abort, while onboard systems manage tool switching, process execution, and sensor-based monitoring. Materials such as PEEK and ULTEM 9085 were considered due to their thermal stability and mechanical suitability for space-related applications.

Preliminary development included CAD modeling, subsystem integration, trade studies, and initial engineering analyses to evaluate structural layout, thermal considerations, and functional feasibility. The proposed concept demonstrates a potential pathway toward reducing dependence on Earth-based manufacturing by enabling on-orbit fabrication, repair, and assembly of spacecraft hardware. This work supports the long-term advancement of sustainable space infrastructure and autonomous orbital operations.

1. Problem Definition

1.1 Background

The development of autonomous in orbit manufacturing systems marks a critical advancement in modern space operations. Traditionally, spacecraft are fully assembled on Earth and launched as complete systems, which creates major limitations when components fail or require upgrades. Launching replacements is costly and inefficient, increasing mission risk and long-term waste. To overcome these constraints, this project aims to design an autonomous multifunctional payload compatible with Arkisys' Bosun's Locker platform, enabling on-orbit manufacturing and assembly through 3D printing, soldering, and wire embedding processes.

The payload must operate within the COSMIC Capstone Challenge Track 1 specifications, maintaining the dimensions of 462 x 462 x 924 mm, a maximum mass of 400 kg, and a power limit of 300 W continuous / 1000 W peak. It will operate to ensure safety and adaptability in microgravity. Materials such as PEEL and ULTEM 9085 were selected for their high thermal stability, mechanical strength, and resistance to space environments, making them suitable for producing space-grade parts.

The project addresses several pain points:

1. High launch and replacement costs from Earth-based manufacturing.
2. Limited repair capabilities once satellites are deployed.
3. Dependence on terrestrial production, leading to long lead times.
4. Integration challenges of multiple fabrication tools in microgravity.
5. Energy and space constraints that limit continuous operation.

Users need to include a compact, reliable payload capable of autonomous fabrication, real-time data collection, and minimal human oversight. The system must ensure precision and repeatability while safely switching between tools for multiple fabrication processes. It should efficiently manage power, maintain operational safety, and collect temperature, current, and motion data for monitoring.

By fulfilling these requirements, this design supports sustainable space manufacturing, reducing dependence on Earth, and advising the future of autonomous orbital construction and maintenance.

1.2 Stakeholders

The success of the autonomous in-orbit manufacturing payload depends on the collaboration of several key stakeholders who contribute to its design, operation, and long-term sustainability. Each group plays a crucial role in ensuring that the system operates effectively within the constraints of the COSMIC Capstone Challenge and supports the advancement of autonomous space manufacturing.

The primary users of the payload are the Arkisys and COSMIC Capstone mission teams, who will operate and test the system aboard the Bosun's Locker platform. Their goal is to validate the payload's ability to perform 3D printing, soldering, and wire embedding processes in microgravity. Satellite manufacturers and spacecraft operators also represent an important user group, as they will benefit from the system's capacity to produce and repair components directly in orbit. This capability reduces reliance on Earth-based production, decreases launch costs, and allows for rapid response to equipment failures or upgrades.

The maintainers include payload engineers, ground control teams, and Arkisys technicians. These stakeholders are responsible for monitoring system health, ensuring power efficiency, performing diagnostics, and updating software to maintain reliability during operations. They also ensure that the payload integrates safely with the Bosun's Locker platform, managing power, communication, and structural stability.

The broader community comprises research institutions, universities, and commercial space organizations that will utilize the mission data to further develop technologies for autonomous fabrication, robotics, and sustainable operations in orbit.

Finally, regulatory authorities such as NASA, the Federal Communications Commission (FCC), and the United Nations Office for Outer Space Affairs (UNOOSA) ensure that the system complies with safety, communication, and debris mitigation standards.

Together, these stakeholders form a collaborative network that enables the creation of reliable, autonomous, and sustainable manufacturing technologies for future space missions.

1.3 Design Objective

The primary objective of this project is to design and develop an autonomous multifunctional payload capable of performing in-orbit manufacturing and assembly operations on the Arkisys Bosun's Locker platform. The payload will integrate 3D printing, soldering, and wire embedding technologies to fabricate and repair components directly in microgravity. This system aims to reduce dependence on Earth-based manufacturing, minimize launch costs, and support long-term mission sustainability through autonomous and adaptable operations.

From a performance perspective, the payload must demonstrate precision, reliability, and repeatability in all fabrication processes. It should seamlessly switch between tools, manage power distribution efficiently, and maintain stability during motion. The system must operate within the COSMIC Capstone Challenge Track 1 specifications, respecting the limits of 462 x 462 x 924 mm, 400 kg maximum mass, and 300 W continuous power with 1000 W peak. Real-time data collection from temperature, current, and motion sensors will ensure continuous monitoring and control of manufacturing performance in orbit.

Safety is a fundamental goal, as the payload will function autonomously in a highly sensitive environment. The design must prevent overheating, electrical faults, and unintended tool movements, ensuring both system and platform integrity. Materials such as PEEL and ULTEM 9085 are selected for their thermal stability and mechanical strength, contributing to operational safety under extreme conditions.

Cost efficiency is achieved by reducing the need for replacement launches and enabling on-orbit fabrication, which minimizes material waste and transportation expenses.

Finally, sustainability is central to the mission's purpose. By supporting in-orbit repair, recycling, and adaptive manufacturing, the system contributes to long-term space infrastructure resilience and reduces environmental impact from frequent launches.

Overall, the design aims to establish a foundation for future autonomous orbital construction, ensuring efficient, safe, and sustainable operations in space.

2. Design Constraints and Requirements

2.1 Constraints

Physical Constraints:

- The payload must fit within 462 x 462 x 924mm, which defines the maximum allowable dimensions for Arkisys Bosun's Locker. The limitations demand compact modular design.
- The total mass can't exceed 400kg, such as the structure frame, electronics, and tooling modules. It ensures that the system remains compatible with the launching capabilities.

- The design must maintain a low and centered center of gravity in order to balance during the orbital operations and minimize rotational instability.

Functional Constraints:

- The payload must operate three distinct operations, such as 3D printing, soldering, and wire embedding.
- Must autonomously swap toolheads without any human intervention.
- Include sensor redundancy, using temperature, current and motion feedback to ensure reliability in a vacuum environment.

Environmental Constraints:

- Materials and components must operate between 40 to 80 Celsius.
- All materials should have a release of payload with few volatile substances when exposed to vacuum and temperature changes in space. This ensures gases or residues from building sensors, cameras, or other parts, making sure the system is reliable and clean.

2.2 Requirements and Acceptance Criteria

Requirement	Units	Target	Tolerance	Testing Method	Status
Payload mass < 400 kg	kg	400	+5	Structural mass analysis	planned
Power consumption <300 W continuous/ 1000 W peak	W	300/100	+10	Electrical power test	Planned
Operational Temperature range	C	-20 to + 60	+5	Thermal vacuum test	Planned
3D printing precision	mm	0.1	+0.05	Microgravity printing simulation	Planned
Tool switching time	s	10	+2	Functional timing test	Planned
Payload volume	mm	462x462x924	+10	CAD verification	Planned

3. Concept of Operations (CONOPS)

3.1 Mission Lifecycle

The proposed payload is designed to operate as a hosted orbital manufacturing system integrated within Arkisys’ Bosun’s Locker. The mission begins with the payload being fully assembled, secured, and

integrated into the Bosun's Locker prior to launch. During launch and ascent, the payload remains in a stowed and powered-safe configuration to protect all internal mechanisms and toolheads from vibration, shock, and structural loads.

Once the host platform reaches its designated orbit and completes initial spacecraft commissioning, the payload receives startup power and system initialization commands. At this stage, the onboard controller performs a health check of all major subsystems, including actuators, heaters, sensors, and tool exchange components. If all systems are verified to be within acceptable operating limits, the payload transitions into operational standby mode.

When commanded to begin a manufacturing cycle, the system executes a pre-programmed sequence of manufacturing operations with limited remote oversight. Sensor data, including temperature, current draw, and motion feedback, is continuously monitored throughout operation to verify safe and reliable performance. At the completion of each cycle, the payload either enters standby mode, repeats the process for additional test articles, or executes a safe shutdown depending on mission requirements.

3.2 Operational Sequence

The payload is designed to demonstrate a chain of discrete orbital manufacturing operations that together provide the capability of fabricating electrically integrated components in orbit. The operational sequence is described below:

Step 1: System Initialization

The payload receives a command from ground control or host platform software to begin operation. Internal sensors verify:

- toolhead position
- thermal readiness
- actuator availability
- material feed readiness
- power availability

If all startup conditions are satisfied, the system proceeds to fabrication mode.

Step 2: Material Preparation

The manufacturing platform prepares the build area and positions the required material feedstock for the first operation. Polymer filament or feed material is loaded into the print subsystem, while conductive wire and soldering materials remain secured in standby positions until needed.

Step 3: 3D Printing Operation

The payload begins the first discrete manufacturing operation by depositing polymer material to create the structural geometry of the target component. This stage forms the physical base of the manufactured part. Motion control along the print axes is coordinated through the onboard controller to maintain dimensional consistency and repeatability.

Step 4: Tool Exchange

After the printing operation is completed, the system autonomously transitions to the next toolhead using the internal tool exchange mechanism. The selected toolhead is aligned and verified using position and engagement sensors before the next operation begins.

Step 5: Wire Embedding Operation

The wire embedding subsystem places conductive wire into designated channels or pathways in the printed structure. This operation is intended to support the integration of electrical functionality directly into the manufactured component.

Step 6: Soldering Operation

Following wire placement, the soldering toolhead is deployed to create electrical junctions or secure embedded conductive paths. This step completes the electrically functional portion of the fabrication process.

Step 7: Data Collection and Process Monitoring

Throughout all manufacturing operations, onboard sensors continuously collect:

- toolhead temperature
- electrical current
- actuator movement
- operation timing
- system health data

This data is stored and relayed to the host system for review and validation of manufacturing performance.

Step 8: Completion and Safe State

Once the manufacturing cycle is complete, the payload retracts active tools, powers down thermal systems as required, and enters a safe standby mode. The payload remains available for future operation cycles or diagnostic commands.

3.3 Ground Interaction and Autonomy

The payload is designed for semi-autonomous operation, meaning that the system performs detailed manufacturing tasks independently once a high level command is received. Ground operators or host platform controllers are expected to issue only limited commands such as:

- Start
- Pause
- Resume
- Abort
- System Check
- Shutdown

This control philosophy reduces the need for continuous human intervention while preserving operational safety and mission flexibility. In the event of abnormal sensor readings, excessive thermal conditions, actuator failure, or tool misalignment, the payload is designed to stop the active sequence and enter a safe state until further commands are received.

4. Iterative Design Process and Trade Studies

The development of the multifunctional orbital manufacturing payload followed an iterative, evidence-based design process. Each design cycle included concept development, subsystem testing, evaluation against COSMIC Track 1 constraints, and refinement based on performance results. The following sections summarize the major iterations (v0, v1, v2, V3,V4), the changes implemented, the rationale behind each revision, and the test results that guided the next design phase.

Iteration	Date range	Change summary	What drove change	Test/Analysis Performed	Outcome
v0 (Initial Concept)	09/08 – 10/22	Basic frame layout, fixed tool positions, off-the-shelf print head and solder module	Need for baseline geometry and feasibility check	CAD fit check, mass estimation, power budget calculation	Fit within volume limits, but tool clearance issues identified; power draw unbalanced across modules
V1 (Refined Layout)	10/22 – 11/05	Introduced linear rail tool exchanger, reorganized internal structure, updated wiring paths	Tool interference in v0; need for autonomous switching and better cable management	Motion simulation, interference/clearance analysis, wiring harness routing test	Tool switching became feasible, improved spatial efficiency; however, increased mass and thermal hotspots observed

V2 (Optimized Prototype)	11/05 – 11/19	Reduced frame mass, redesigned toolhead mounts, added thermal shielding, optimized print pathing	Mass exceeded target; thermal loads exceeded predictions; need for more reliable autonomous operation	FEA structural test, thermal CFD study, tool change timing test	Met mass target, improved thermal safety, tool switching achieved in <10 s; ready for further testing in microgravity-analog environments
V3(Subsystem integration)	01/21 – 02-24	Completed design of the 3D printing, soldering, and wire embedding tool heads.	No tool head were previously made	Extrusion path and feed mechanism, motion path, interference and clearance analysis between tool bays and exchanger	Completed the major payload subsystems and improved mechanical compatibility between the tool exchange system and fabrication modules.
V4(Final Integrated Concept)	02/24 – 04/9	Completed System animation, finalized extrusion mechanism, and prepared payload architecture for final report	Final refinements focused on improving system clarity, operation flow, and confidence in subsystem interaction	Full operation sequence animation review, Final CAD packaging and fit confirmation, Final concept walkthrough against COSMIC requirements	Produced a finalized conceptual payload consisting of 3D printing, tool exchange, wire embedding, and soldering-related operations.

Trade-Off Decisions

Throughout the design process, the team weighed several critical trade-offs:

1. Mass vs. Structural Rigidity
 Reducing frame mass risked higher vibration during tool use
 Chosen solution: lightweight aluminum for primary structure + reinforced tool mounts
2. Thermal Protection vs. Power Efficiency
 Higher thermal shielding improves safety but increases power usage
 Chosen solution: passive aluminum heat sinks and insulation instead of active cooling
3. Autonomy vs. Mechanical Complexity
 Fully autonomous tool swapping requires additional actuators and sensors

Chosen solution: one linear rail with limited actuator count (lower power, simpler wiring)

4. Compactness vs. Accessibility

Tighter designs save volume but complicate internal repair/maintenance

Chosen solution: modular detachable panels and accessible rail-mounted tool bays

5. Engineering Analyses

For this part of the project, we mostly worked on the CAD models and some CFD checks to see how the payload design would perform. The main idea was to make sure the design fits the COSMIC Capstone Track 1 limits for mass, power, and size. We used Fusion 360 to create models for the frame and the main mechanisms, including the tool exchanger, soldering head, and the wire-embedding system. While modeling, we tried to keep everything compact and simple so it would fit inside the Arkisys Bosuns Locker and be something we could assemble without problems.

5.1 CAD Drawings

The 2D drawings were made from the Fusion 360 models to show the main sizes of the payload and each module. We used these drawings mostly to double-check that everything fits inside the Arkisys Bosuns Locker and that there is enough space between parts. They also helped us see how each subsystem sits inside the frame and how the assembly lined up during installation.

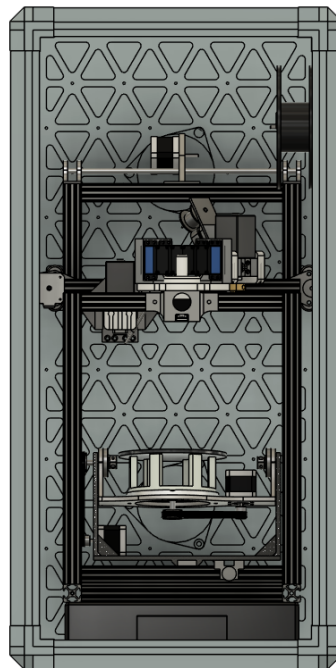


Figure 1.1. Assembly

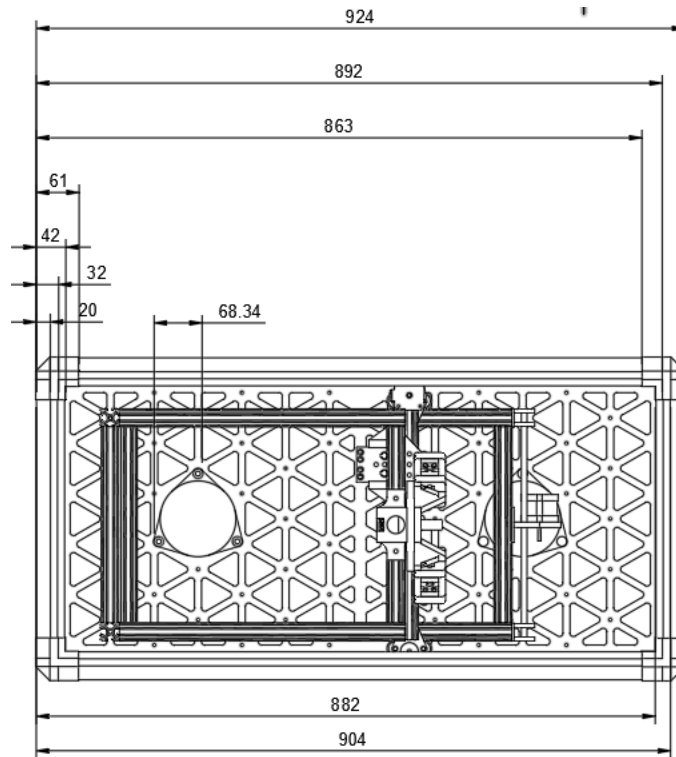


Figure 1.2. Assembly 2D Dimensions

This is the top view of the full payload. It shows the overall length, width, and spacing of the internal rails. This drawing was helpful for confirming that the whole structure stays within the required footprint.

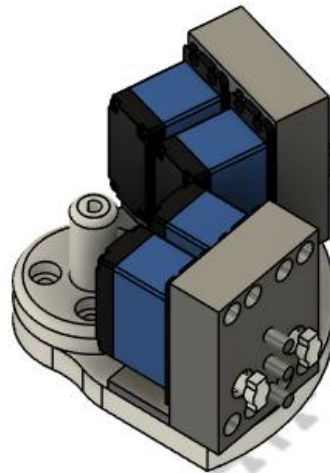


Figure 2. Rotary tool exchanger

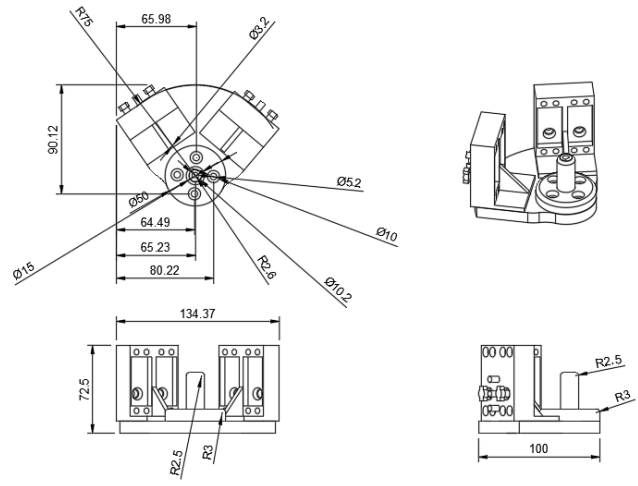


Figure 2.1. Rotary tool changer 2D Dimensions

Shows the rotary tool changer. The drawing includes the main angles and arm lengths, which we used to check that the arms can rotate without hitting any other components.

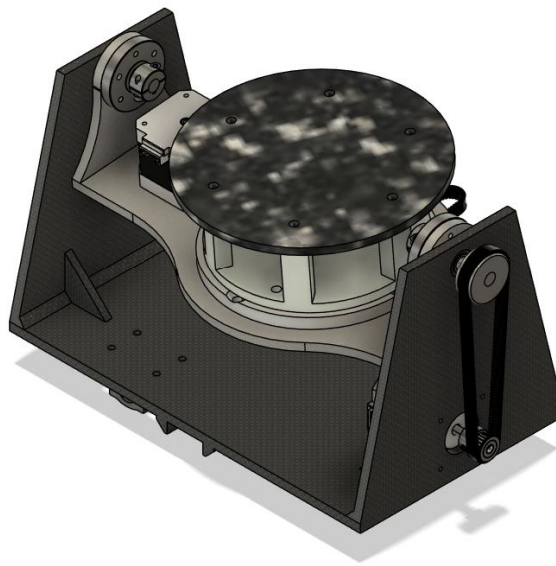


Figure 3. Multi-Axis Print Assembly

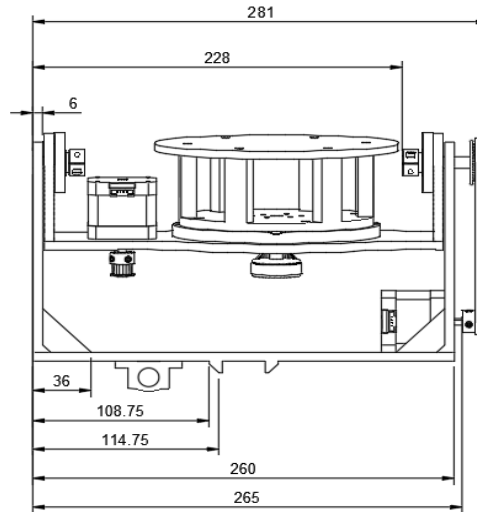


Figure 3.1. Multi Axis Print Assembly 2 Dimensions

It is the multi-axis print assembly. It shows the height of the platform, the spacing of the support, and the general layout. This helped us make sure the print module fits correctly and has room to move.

5.2 Structural Considerations

The structural design of the payload was developed to support all major subsystems while maintaining rigidity, alignment, and compatibility with the Bosun's Locker constraints. The internal frame must support the 3D printing module, soldering toolhead, wire-embedding mechanism, rotary tool exchanger, and electronics while minimizing deflection during operation.

Because the payload is intended for orbital deployment, the structure must also tolerate launch-related mechanical loads such as vibration, acceleration, and shock. Special attention was given to the mounting of the tool exchange system and fabrication modules, since small positional shifts could reduce print accuracy, tool alignment, or wire placement repeatability. To address this, the design uses a lightweight aluminum frame with reinforced mounting locations at high-load or high-precision interfaces.

The final structural configuration represents a trade-off between low mass and high stiffness. Reducing structural mass is desirable for launching compatibility, but excessive mass reduction may increase vibration and reduce manufacturing precision. For this reason, the design emphasizes a rigid primary frame with localized reinforcement near the toolheads, motion systems, and rotary switching mechanism.

5.3 Thermal Considerations

Thermal management is a critical aspect of the payload design because several subsystems generate concentrated heat during operation, particularly the extrusion module, soldering toolhead, motors, and control electronics. In the orbital environment, thermal control becomes more challenging because heat cannot be removed through natural convection as it would in Earth's atmosphere. As a result, localized heating and thermal accumulation must be carefully managed to prevent component degradation, loss of precision, or system failure.

To address these concerns, the payload incorporates passive thermal management strategies including aluminum heat sinks, thermal shielding, and insulation around high-temperature components. The extrusion and soldering modules were treated as primary thermal sources and were positioned to reduce heat transfer to nearby electronics, sensors, and structural interfaces. Thermal shielding was also added during later design iterations to reduce thermal concentration near the tool exchange area.

The design prioritizes passive cooling over active thermal control to reduce system complexity, lower power consumption, and improve reliability. This approach supports the semi-autonomous operation of the payload while helping maintain safe operating temperatures during extended manufacturing cycles.

5.4 Power Budget

The payload power budget was estimated to verify compatibility with the Arkisys Bosun’s Locker available power limits of 300 W sustained and 1000 W peak. Major contributors to power consumption include the extrusion heater, soldering module, wire-embedding mechanism, rotary tool exchanger motor, motion actuators, control electronics, and sensor systems. Since not all subsystems operate at the same time, the payload was designed around a staged operation sequence to reduce sustained power demand.

The highest expected power loads occur during active extrusion and soldering operations, while sensing, control, and monitoring functions require significantly less power. Tool exchange and motion systems are expected to operate intermittently rather than continuously. To remain compatible with the host platform, the payload is intended to operate one primary fabrication process at a time rather than running all toolheads simultaneously. This operational strategy reduces both electrical and thermal stress while improving system reliability.

Table 3. Power consumption under normal and maximum stress

Power Components	Max Power	General operating Power	Quantity	Total max	Total general
Laser Soldering	100W	65W	1	100W	65W
Stepper Motor	9.6W	2.4W	8	76.9W	19.2W
Servo Motor	1.5W	0.8W	4	6W	3.2W
Nozzle Heater	50W	30W	1	50W	30W
Print Hot Bed	300W	100W	1	300W	100W
TOTAL	461.1W	198.2W	15	532.8W	217.4W

Based on these preliminary estimates, the payload appears capable of operating within the Bosun’s Locker sustained power limit during normal operation while preserving margin for short-duration peak loads during startup, tool switching, or thermal ramp-up. Additional electrical validation would be recommended in future development stages.

5.5 Mass Budget

A preliminary mass budget was developed to estimate the total payload mass and verify compatibility with the Bosun’s Locker with maximum allowable payload mass of 400 kg. The system mass is distributed across the structural frame, fabrication toolheads, motion hardware, control electronics, sensors, and feedstock storage. Maintaining a low total mass was important not only for launch compatibility, but also for improving structural efficiency, reducing actuator demand, and simplifying subsystem integration.

The largest expected contributors to mass are the structural frame, motion system, and tool exchange assembly. As a result, design iterations focused on reducing unnecessary structural material while preserving stiffness and alignment. Lightweight materials and modular subsystem mounting were used to reduce total system mass without compromising manufacturability or mechanical performance.

Preliminary estimates indicate that the payload remains well below the maximum allowable mass, leaving margin for future refinement, added shielding, or expanded subsystem functionality.

5.6 Feasibility Assessment

Based on the current design development, subsystem integration, and preliminary engineering analyses, the proposed payload appears to be a feasible conceptual solution for the COSMIC Track 1 orbital manufacturing challenge. The system satisfies the core challenge requirements by demonstrating a chain of discrete operations including 3D printing, tool exchange, wire embedding, and soldering-related fabrication tasks within the dimensional and operational constraints of Arkisys’ Bosun’s Locker.

From a mechanical standpoint, the payload architecture supports compact packaging, subsystem accessibility, and realistic tool integration. Structurally, the frame and mounting approach appear capable of supporting the required fabrication modules while maintaining alignment and minimizing interference. Thermal and power considerations were addressed through passive heat management strategies and sequential subsystem operation, helping the design remain within practical operational limits. The preliminary mass budget also indicates a substantial margin below the host platform’s maximum payload mass.

Although the current design demonstrates strong conceptual feasibility, additional validation would be required before prototype or flight-level development. Future work should include more detailed structural and thermal simulation, vacuum compatibility assessment, motion repeatability testing, and validation of extrusion and tool-switching performance in microgravity-analog conditions. Overall, the proposed concept represents a credible and scalable starting point for future autonomous orbital manufacturing systems.

6. Design Standards & Codes

Standard / Code	Purpose / Relevance	Edition / Year
NASA-STD-6030	Defines additive manufacturing qualifications, material traceability, inspection requirements, test coupons, and documentation for spaceflight hardware.	Approved April 2021
NASA Material Guidelines (PEEK, ABS, ULTEM 9085, Stainless Steel)	Ensures materials meet low-outgassing, thermal stability, and structural reliability	NASA Publications 2014–2018

	required for microgravity and vacuum environments.	
ISO/ANSI Fastener Standards	Standardizes M3–M5 mechanical fasteners used in aerospace structures to ensure consistent mechanical integrity.	Latest ISO/ANSI Editions
Robotics & Motion System Standards	Governs design requirements for stepper motors, linear rails, actuators, and encoder-based position control.	Industry Practices (2020+)
Arkisys Payload Specification	Defines operational constraints including 300W sustained power, allowable payload mass, and locker volume limits for system integration.	Competition Requirements 2025
Aerospace Thermal Practices	Applies emissivity-based thermal modeling used to predict heat distribution in spacecraft components.	Thermal Engineering Standard Practice 2024

7. Project Management

7.1 Team Roles

- Ruben Espinoza – CAD, Final Presentation, Final PowerPoint
- Brian Gamboa – Simulations, CAD
- Juan Luna – CAD, Final Report, Final Presentation
- Estrella Martinez – Midterm Report, PowerPoint
- Francisco Miranda – 3D Printing, Midterm Report
- Ingrid Nunez – Midterm Report, PowerPoint
- Vanessa Preciado – ?
- Manuel Ruiz de Esparza – Simulations, CAD
- John Smith – Simulations, Animations, CAD, Final Presentation
- Mario Solis – Midterm Report, Midterm PowerPoint
- Jofiel Zapata – Simulations, Calculations, CAD, Midterm PowerPoint

7.2 Path to Preliminary Design Review (PDR)

The current payload design represents a conceptual and CAD-based solution for the COSMIC Track 1 orbital manufacturing challenge. To advance this concept toward a Preliminary Design Review (PDR), several key development steps would be required to improve subsystem maturity, validate performance, and reduce technical risk.

A primary focus of future work would be the refinement and validation of the rotary tool exchange system, which currently does not provide full clearance during tool rotation. Resolving this issue would

require redesign of tool spacing, adjustment of rotational geometry, and verification of reliable tool switching under repeated operation. This subsystem represents one of the most critical areas for improvement prior to PDR.

In addition to resolving known mechanical limitations, the next phase of development would include the creation of physical prototypes of key subsystems, particularly the extrusion mechanism, wire embedding system, and tool switching assembly. Prototype testing would allow for validation of motion repeatability, alignment accuracy, and fabrication performance under controlled conditions.

Further engineering development would also involve more detailed structural, thermal, and electrical analysis. This includes evaluating structural integrity under simulated launch loads, assessing thermal behavior of high-temperature components such as the extrusion and soldering modules, and refining the electrical architecture to ensure stable and efficient power distribution.

To support the payload’s semi-autonomous operation, additional work would be required to develop and test control algorithms, sensor integration, and command logic. This includes implementing feedback systems for monitoring temperature, current, and tool position, as well as validating reliable execution of the manufacturing sequence under limited remote command input.

Finally, preparation for PDR would require validation of the payload’s compatibility with orbital operating conditions, including vacuum exposure, thermal cycling, and long-duration operation. While full space qualification is beyond the scope of this project, preliminary testing in laboratory or simulated environments would significantly improve confidence in system performance.

Overall, advancing to a Preliminary Design Review would require transitioning the current concept from a design-focused solution to a tested and validated engineering system, with particular emphasis on resolving subsystem integration challenges and demonstrating reliable operation of the complete manufacturing workflow.

8. Bill of Materials (BOM)

Component	Category	Avg Cost (USD)
Aluminum Extrusion Frame	Structural	\$150.00
Mounting Brackets/Corners	Structural	\$25.00
Multi-Axis Print Bed Frame	Structural	\$40.00
Heat Plate Carriage	Structural	\$35.00
Stepper Motors	Actuation	\$20.00
Motor Holder & Mount	Actuation	\$10.00
Rotary Tool Exchanger	Actuation	\$60.00
Linear Guides/Rails	Actuation	\$35.00
Nozzle Mechanism	3D Printing	\$25.00
Bowden Tube Assembly	3D Printing	\$10.00
Hot end + Heater Block	3D Printing	\$35.00
Thermistor	3D Printing	\$8.00
Soldering Heating Module	Soldering	\$30.00
Soldering Mount Bracket	Soldering	\$10.00
Wire Deposition Hardware	Wire Embedding	\$25.00
Copper Wire Path Components	Wire Embedding	\$12.00

PEEK (per kg)	Materials	\$400.00
ULTEM 9085 (per kg)	Materials	\$300.00
ABS (per kg)	Materials	\$25.00
Stainless Steel (per kg)	Materials	\$60.00
M5 Screws (pack)	Fasteners	\$6.00
M3/M4 Screws (pack)	Fasteners	\$6.00
Heat-Set Inserts (pack)	Fasteners	\$12.00
Temperature Sensors	Electronics	\$8.00
Current Sensors	Electronics	\$15.00
Motion Encoders	Electronics	\$20.00
Control Board	Electronics	\$50.00
Power Distribution Board	Electronics	\$30.00
Conveyor Belt	Conveyor	\$35.00
Drive Rollers	Conveyor	\$15.00
Conveyor Motor	Conveyor	\$25.00
Insulating Sleeve	Thermal	\$8.00
Heat Sink Assembly	Thermal	\$15.00
Thermal Paste/Pads	Thermal	\$6.00
Total:		\$1036.00

9. Ethics

We designed the multifunctional payload with requirements such as reliability, safety, and sustainability in mind. For example, we chose low emission materials while adding sensors and built in fail-safe features to protect both operators and orbital assets. The system's semi-autonomous functions include manual override and abort to prevent uncontrolled operation in orbit. By supporting in-orbit manufacturing, our design helps satellites last longer and cuts down on waste. With this project we documented all the data, analyses, and design work and cited all external sources, standards, and research material.

10. Public Health, Social Impact, and Economic Analysis

Our project helps public health and safety by making satellites more reliable. These satellites are important for everyday life. With in-orbit manufacturing and repair, our payload lowers the chance of satellite failures that could affect disaster management and global monitoring.

The design focuses on safe autonomous operation, backup sensors, and careful tool use, helping prevent malfunctions and debris, and supporting long-term safety in orbit for both unmanned and future crewed missions. The technology that is being used supports sustainable space operations by extending satellite lifespan. Helping lower the cost for both commercial and government users. While also having the payload available to be used in future markets such as on-orbit assembly and satellite, making the space industry more open and fairer.

11. Results and Discussion

11.1 Summary of Key Findings

Through the development of this project, the team obtained important results that helped confirm that the design can operate within the limits of the COSMIC Capstone Challenge. First, we created the CAD models in Fusion 360, which allowed us to test the integration of all the modules. Thanks to these designs, we verified processes such as 3D printing and cable routing, ensuring that everything fits within the available space (462 x 462 x 924 mm) without affecting performance.

Preliminary analyses also showed that they can maintain printing precision even while in motion, as long as the linear guides remain stable. Additionally, we evaluated materials such as PEEK and ULTEM 9085 to determine whether they could withstand the required thermal and mechanical conditions. These evaluations helped confirm that both materials meet the necessary tolerance and strength requirements for the mission.

Another challenging part of the project was analyzing the thermal behavior of the system. In orbit, heat dissipation becomes much more complex, so monitoring current, temperature, and movement will be essential to avoid failures or overheating.

Overall, the results we obtained are viable for the system as a whole. The simulations and models we developed provide a solid foundation for the next phase of the project and help ensure that future designs can be improved and validated more efficiently.

11.2 Design Performance Relative to Requirements

The final payload design was evaluated against the primary technical requirements established by the COSMIC Track 1 challenge and the team's internal design goals. Based on the current conceptual design and preliminary analyses, the payload appears capable of satisfying several of the most critical system-level requirements, while also identifying areas that still require additional refinement.

From a dimensional standpoint, the CAD-integrated design remained within the allowable Bosun's Locker envelope, and the overall subsystem layout was refined to improve internal packaging, wiring organization, and component accessibility. From a functional standpoint, the design supports a meaningful chain of manufacturing operations, including 3D printing, tool exchange, wire embedding, and soldering-related fabrication tasks, which aligns with the challenge requirement of demonstrating a useful orbital manufacturing capability.

However, not all functional requirements have been fully resolved at the current stage of development. One of the most significant remaining issues is the rotary tool exchange mechanism, which does not yet achieve full clearance during tool rotation. While the mechanism concept has been developed and partially refined, additional redesign is still needed to improve rotational spacing, toolhead interference clearance, and switching reliability. This means that although the overall manufacturing sequence is conceptually valid, the tool transition subsystem has not yet reached full functional maturity.

The design also showed positive performance relative to estimated power and mass constraints. Preliminary mass estimates indicated that the payload remained well below the maximum allowable payload mass, while staged operation of the fabrication subsystems helped keep projected sustained power demand within practical operating limits. Thermal design refinements, including passive shielding and subsystem separation, also improved confidence in the payload's ability to manage heat-generating components.

Although the design has not yet been physically validated, the current level of integration and subsystem refinement suggests that the payload meets many of the conceptual design requirements

and provides a strong basis for future development. At the same time, unresolved issues such as rotary clearance and final tool-switching performance represent important next-step challenges that must be addressed before higher-fidelity prototyping or mission-level readiness.

11.3 Limitations

Despite the progress made during the design process, several limitations remain that should be acknowledged. The current payload exists primarily as a conceptual and CAD-based design, meaning that the system has not yet undergone full physical prototyping or hardware validation. As a result, several important performance characteristics remain unverified under real operating conditions.

One of the most significant current limitations is the rotary tool exchange system, which does not yet provide full clearance during tool rotation. Although the mechanism concept has been developed and partially refined, interference between tool positions remains an unresolved issue that affects full validation of the multi-tool manufacturing sequence. Additional redesign will be required to improve rotational spacing, toolhead packaging, and switching reliability before the system can demonstrate complete operational readiness.

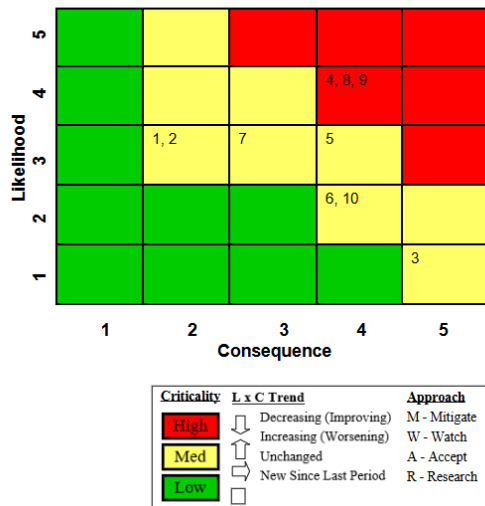
Another major limitation is the lack of experimental testing in a vacuum or microgravity-analog environment. Since the proposed payload is intended for orbital manufacturing, future validation would be needed to confirm extrusion behavior, tool switching reliability, thermal dissipation, and motion repeatability under space-like conditions. Similarly, the long-term effects of repeated operation on subsystem wear, alignment stability, and thermal cycling have not yet been physically evaluated.

In addition, the current engineering analyses are primarily preliminary and design-stage assessments, rather than full flight-level qualification studies. While the design demonstrates strong conceptual feasibility, additional work would be required to validate structural loads, refine electrical architecture, improve subsystem integration, and confirm overall robustness. These limitations are consistent with the scope of a senior design conceptual mission and provide a clear direction for future refinement and development.

11.4 Risk Assessment and Mitigation

The proposed payload introduces several technical and operational risks related to laser-based soldering, wire handling, thermal effects, and mechanical reliability within a compact enclosed system. A preliminary risk assessment was performed to identify key failure modes and define mitigation strategies based on their consequence, likelihood, and mission importance.

Top Risks



Rank	Trend	Risk ID	Approach	Risk Title
1	<input type="checkbox"/>	1	M	Solder Temperature High (300°C+)
2	<input type="checkbox"/>	2	M	Laser module is overheating
3	<input type="checkbox"/>	3	W	Laser Scattering
4	<input type="checkbox"/>	4	M	Laser Burning
5	<input type="checkbox"/>	5	A	Wire Stripping and Grip Loss
6	<input type="checkbox"/>	6	M	Optical Kickback
7	<input type="checkbox"/>	7	M	Thermal Creep in Feed Mechanism
8	<input type="checkbox"/>	8	M	Internal Gantry Contamination (Debris)
9	<input type="checkbox"/>	9	M	Solder Does Not Stick (Wetting Failure)
10	<input type="checkbox"/>	10	M	Mechanical Binding of the Sealed Locker

Figure 11.4. Risk Assessment Chart

Laser-related risks are significant due to reflection, scattering, and heat concentration, especially when interacting with metallic surfaces. These risks are mitigated through controlled enclosure, alignment verification, and thermal monitoring.

Manufacturing process risks include solder wetting failure and wire feed issues, which can affect bonding quality and system reliability. These are addressed through process control, debris containment, and subsystem testing.

Mechanical risks are primarily associated with debris contamination, thermal expansion, and subsystem alignment within the enclosed payload. In addition, the rotary tool exchange system currently lacks full clearance during rotation, representing an unresolved integration issue that must be addressed to ensure reliable operation. Overall, the identified risks are manageable at the conceptual design stage, but they highlight the need for further testing, refinement, and subsystem validation. Addressing these risks will be critical for advancing the design toward prototype development and Preliminary Design Review (PDR).

12. Conclusions

12.1 Final Conclusions

This project resulted in the conceptual design of a semi-autonomous orbital manufacturing payload for integration within Arkisys' Bosun's Locker as part of the COSMIC Track 1 challenge. The final design combined 3D printing, tool exchange, wire embedding, and soldering-related operations into a single payload intended to support the fabrication of functional components in orbit.

Through multiple design iterations, the payload was refined to improve subsystem integration, internal packaging, and overall feasibility. The final concept showed that a compact hosted payload can support a chained manufacturing process rather than a single isolated task, which is important for future orbital manufacturing systems. Overall, the project met the main challenge objective by demonstrating a realistic conceptual approach to in-space fabrication and assembly.

12.2 Mission Relevance

This project supports the long-term development of in-space servicing, assembly, and manufacturing (ISAM) by showing how a compact payload could perform multiple fabrication tasks in orbit. A system like this could help support future missions involving satellite repair, replacement part fabrication, orbital maintenance, and autonomous assembly.

By reducing dependence on Earth-based manufacturing and launch logistics, concepts like this could improve mission flexibility and help support more sustainable space operations in the future.

12.3 Future Work

Although the design shows strong conceptual promise, additional work would be needed before prototype or mission-level development. Future work should focus on:

- physical prototyping of the key mechanisms,
- validation of tool switching and extrusion performance,
- improved structural and thermal analysis,
- and testing in more realistic operating environments.

Overall, this project provides a strong starting point for future orbital manufacturing system development.

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