

AEROSPACE SENIOR DESIGN: ADVANCING AEROSPACE TECHNOLOGY

Conceptual Design of In-Space Orbital Reliable Printed Circuit Boards (ORCA)

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Mechanical Engineering
Minor in Aerospace Engineering



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Presentation Expert



PROJECT OUTLINE

- **EXECUTIVE SUMMARY**
- **MISSION CONCEPT REVIEW**
- **SYSTEM REQUIREMENT REVIEW**
- **CONCEPTUAL DESIGN REVIEW**
- **PRELIMINARY DESIGN REVIEW**
- **LESSONS LEARNED**
- **CONCLUDING REMARKS**

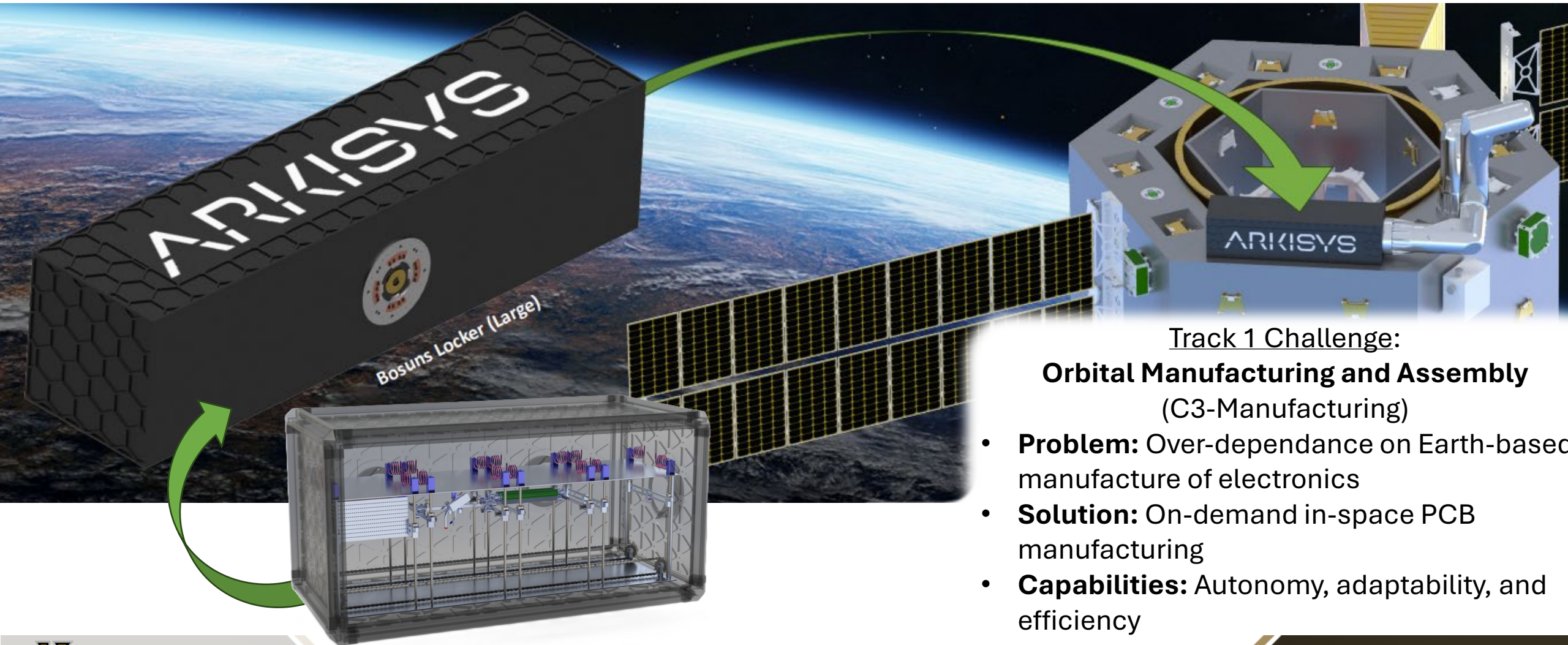


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EXECUTIVE SUMMARY



Track 1 Challenge:

Orbital Manufacturing and Assembly (C3-Manufacturing)

- **Problem:** Over-dependance on Earth-based manufacture of electronics
- **Solution:** On-demand in-space PCB manufacturing
- **Capabilities:** Autonomy, adaptability, and efficiency



PROJECT OUTLINE

- **EXECUTIVE SUMMARY**
- **MISSION CONCEPT REVIEW**
 - **MOTIVATION**
 - **PROBLEM DESCRIPTION**
 - **OBJECTIVES**
 - **PROJECT APPROACH**
 - **MANAGEMENT PLAN**
 - **PROJECT TIMELINE**
- SYSTEM REQUIREMENT REVIEW
- CONCEPTUAL DESIGN REVIEW
- PRELIMINARY DESIGN REVIEW
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MOTIVATION

- **Reduced dependence on Earth-based manufactured products**
- **On-demand manufacturing**
- **Customizable**
- **Time and cost efficiency**
- **Support for future in-space manufacturing**

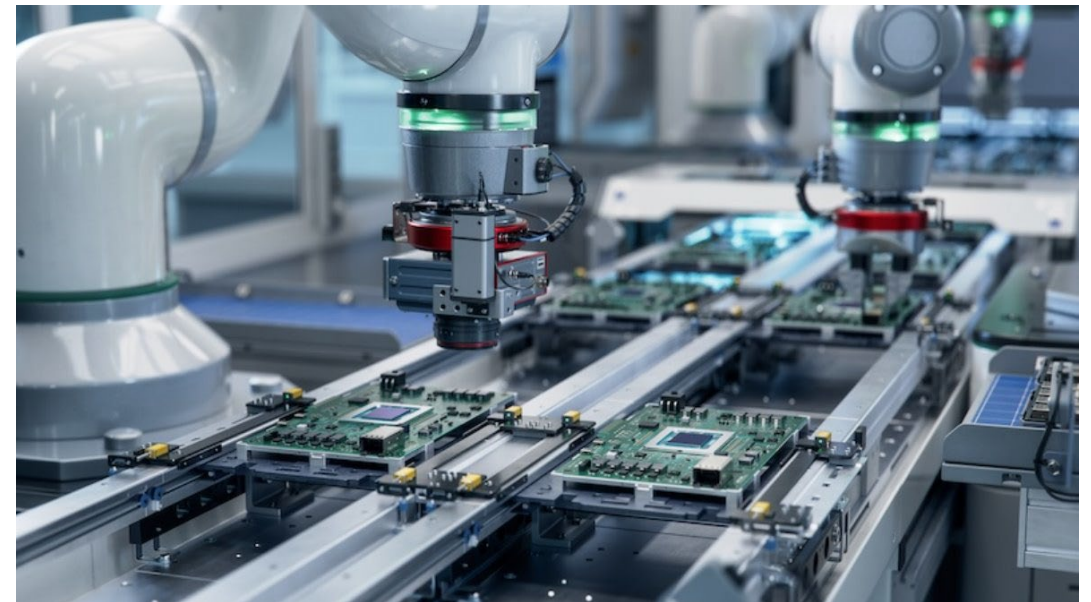




PROBLEM DESCRIPTION

A sustained presence outside Low-Earth Orbit cannot rely on Earth-based manufacturing for critical components, including PCB-based electronics.

Developing and demonstrating a process to manufacture PCBs in space is an important, currently absent, step to achieve long-term human exploration of space.





OBJECTIVES

Goal: Autonomously complete the first steps in the manufacturing of printed circuit boards within the confines of one Bosun's Locker.

Storage

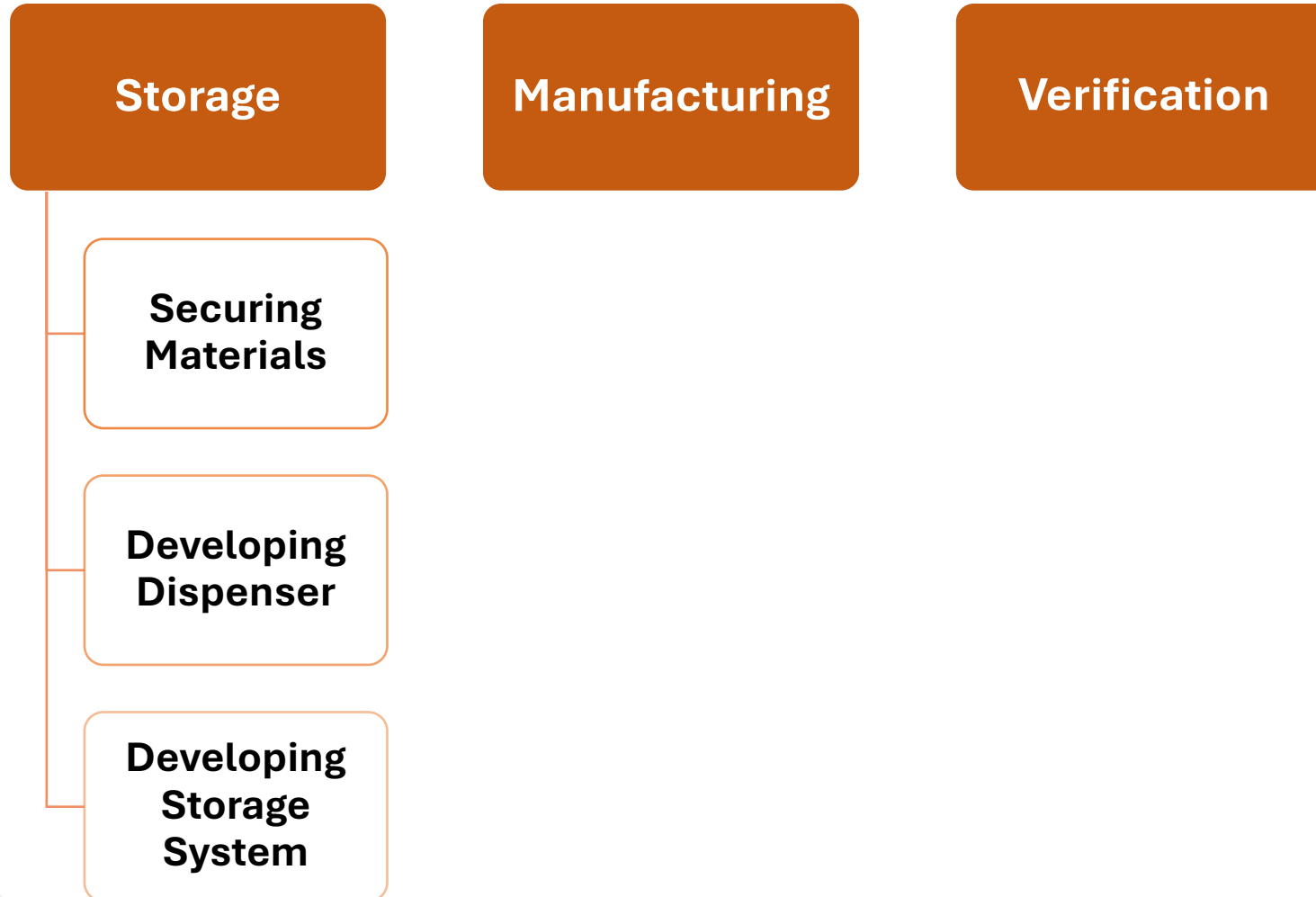
Manufacturing

Verification



OBJECTIVES

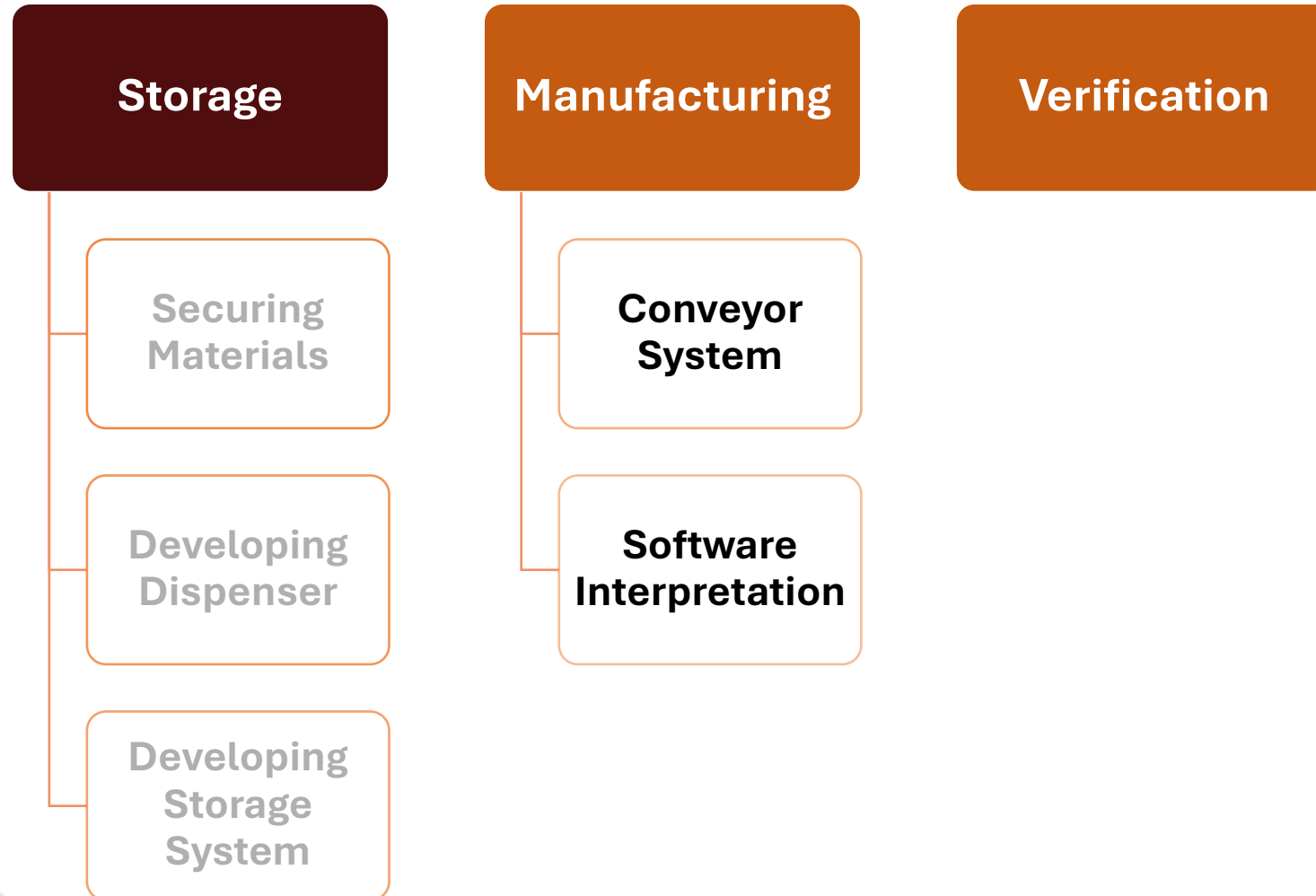
Goal: Autonomously complete the first steps in the manufacturing of printed circuit boards within the confines of one Bosun's Locker.





OBJECTIVES

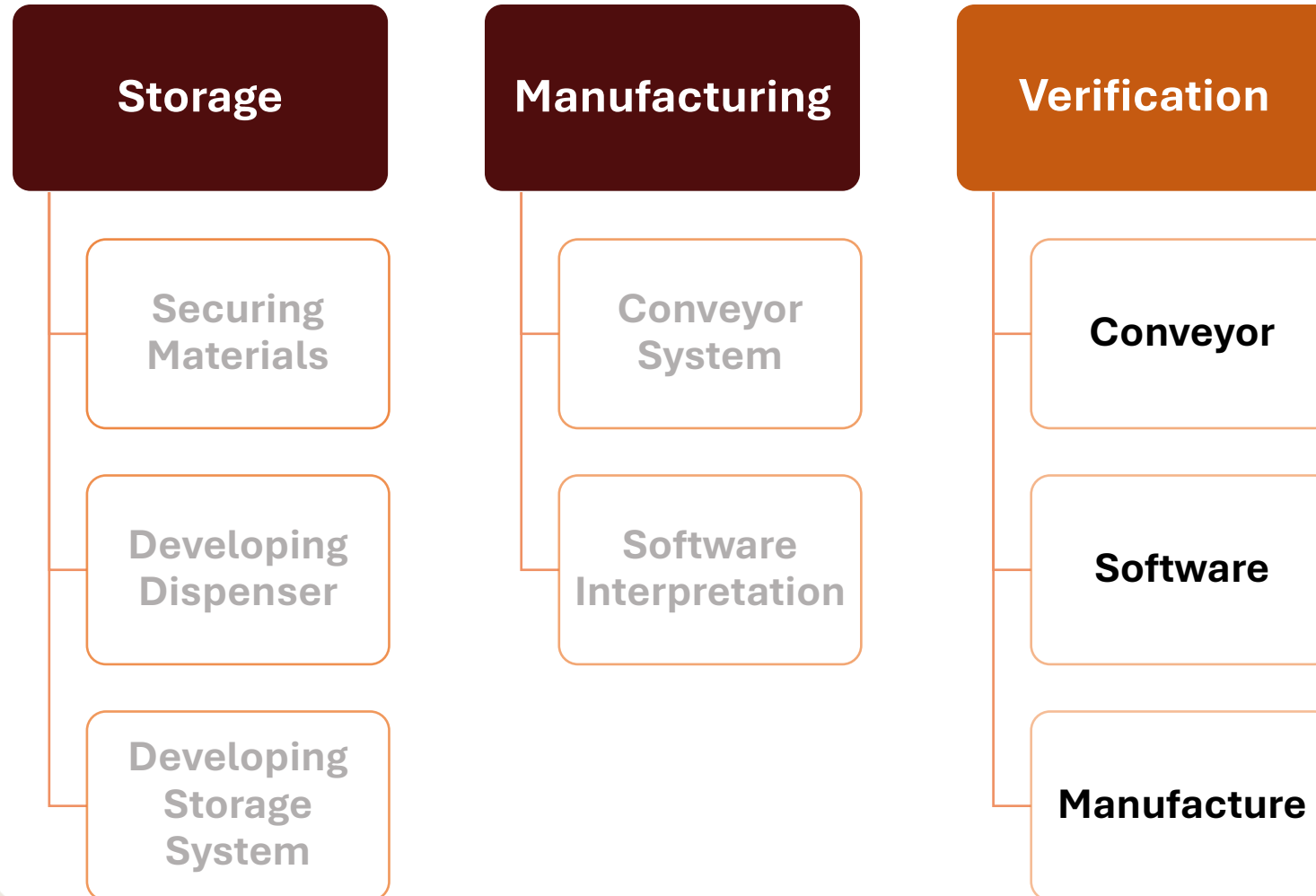
Goal: Autonomously complete the first steps in the manufacturing of printed circuit boards within the confines of one Bosun's Locker.





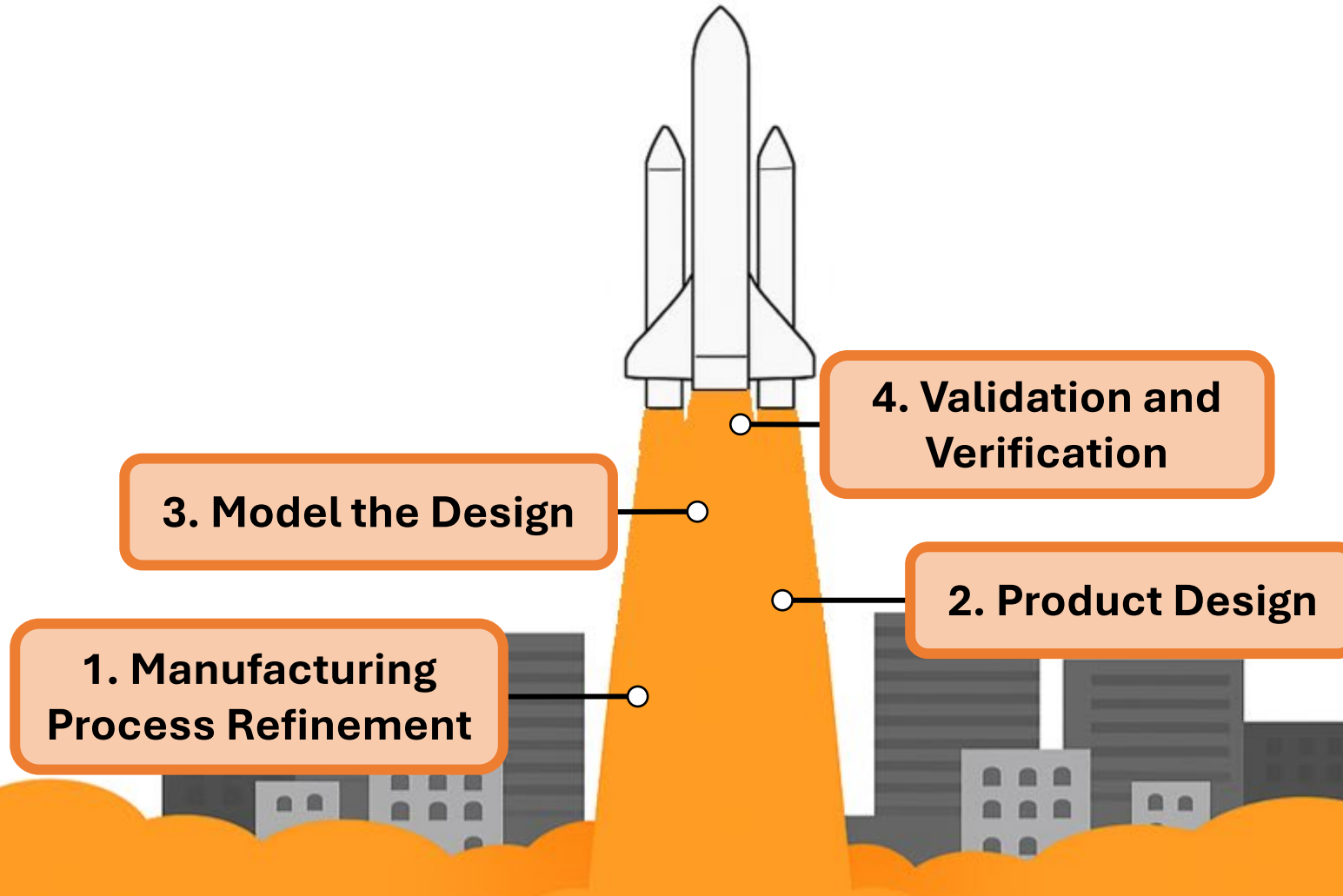
OBJECTIVES

Goal: Autonomously complete the first steps in the manufacturing of printed circuit boards within the confines of one Bosun's Locker.



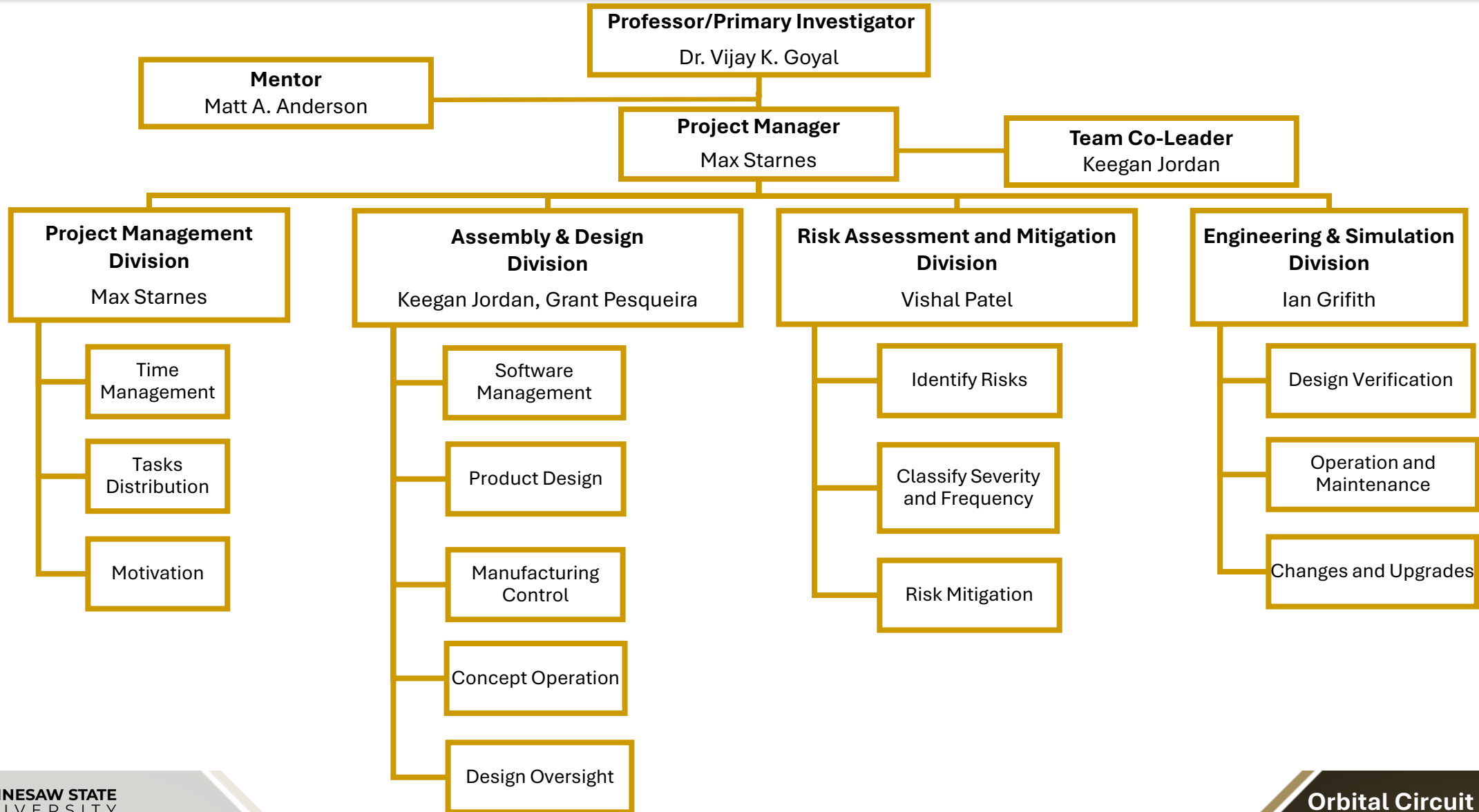


PROJECT APPROACH





MANAGEMENT PLAN



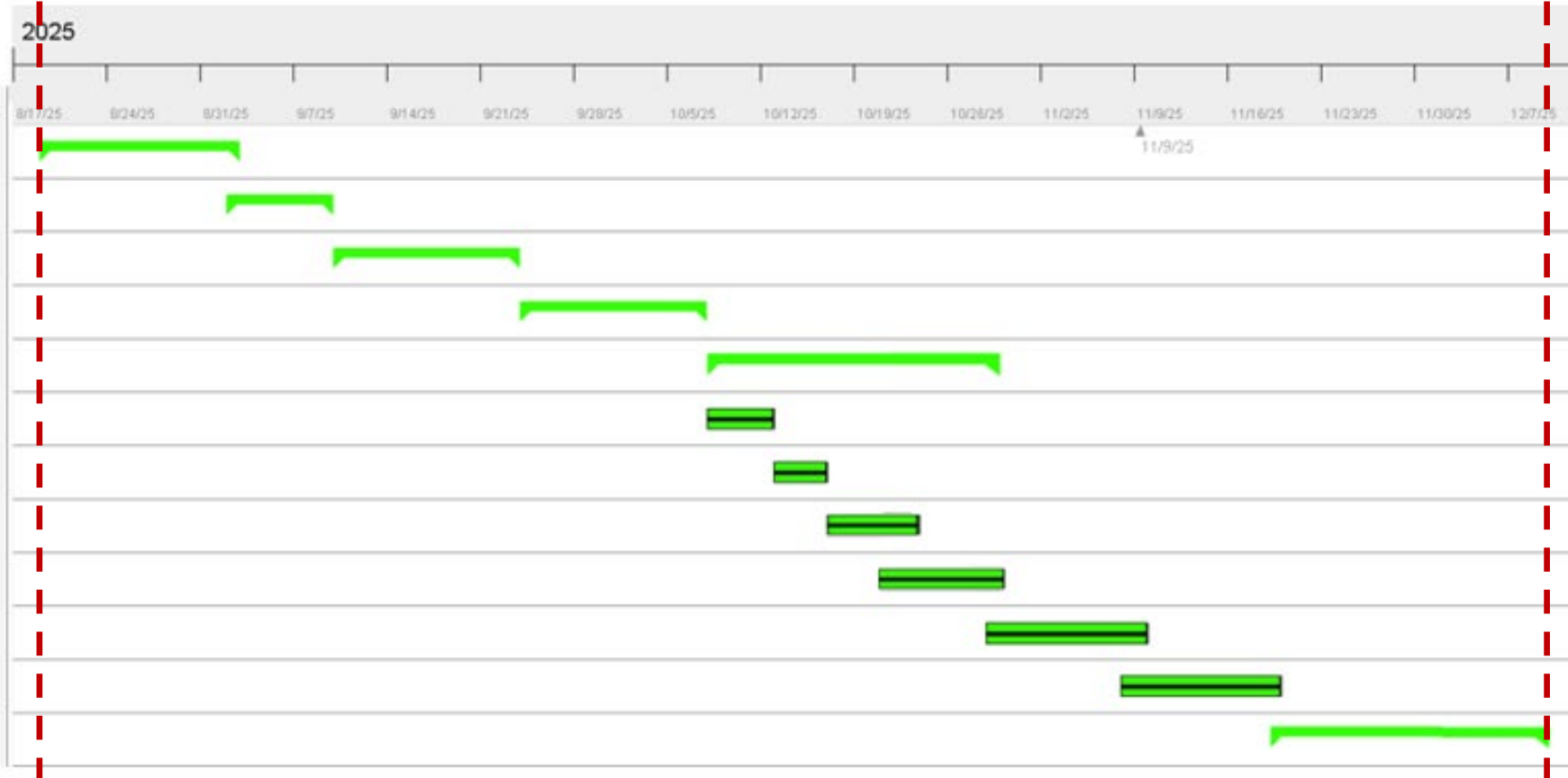


PROJECT TIMELINE

Aug 19

Dec 9

Name	Resources	Begin date	End date
> Mission Conce...		8/19/25	9/2/25
> System Requir...		9/2/25	9/9/25
> Conceptual De...		9/10/25	9/23/25
> In progress Re...		9/24/25	10/7/25
▼ In Progress Re...		10/8/25	10/29/25
Initial CAD D...	Keegan	10/8/25	10/12/25
Technology ...	Max,Grant	10/13/25	10/16/25
Trade Space...	All	10/17/25	10/22/25
Risk Assess...	Ian,Vishal	10/21/25	10/29/25
Preliminary De...	All	10/29/25	11/9/25
CAD Simulation	Keegan,Ian	11/8/25	11/19/25
> Deliverables		11/19/25	12/9/25





PROJECT OUTLINE

- **EXECUTIVE SUMMARY**
- **MISSION CONCEPT REVIEW**
- **SYSTEM REQUIREMENT REVIEW**
 - **SYSTEM REQUIREMENTS**
 - **FUNCTIONAL REQUIREMENTS**
 - **ENVIRONMENTAL REQUIREMENTS**
 - **MANUFACTURING REQUIREMENTS**
 - **DESIGN REQUIREMENTS**
 - **OPERATIONAL SUCCESS REQUIREMENTS**
 - **DATA HANDLING AND COMMS REQUIREMENTS**
- **CONCEPTUAL DESIGN REVIEW**
- **PRELIMINARY DESIGN REVIEW**
- **LESSONS LEARNED**
- **CONCLUDING REMARKS**



SYSTEM REQUIREMENTS

1. The system shall manufacture PCBs in orbit.

1A. System shall be able to manufacture 10 PCBs before being restocked.

1B. System shall be able to operate without human input beyond initialization of the system.

1C. System shall be able to process/interpret circuit diagrams, manufacture completed boards, and test functionality.

1D. System shall be able secure completed PCB assemblies.

2. The system shall collect any dust of from the manufacturing process.

2A. System shall collect any dust from the manufacturing process.

3. The System shall operate under the specified conditions of the Bosun's Locker

3A. System shall use between 5 and 28 V and less than 300 W for standard operation.

3B. System shall be no larger than 144,145 cm³ and have a center of gravity 17.5 cm from a BL-S/C Interface Panel (connection between satellite and locker) .



FUNCTIONAL REQUIREMENTS

1. The system shall store PCB blanks.

1A. System shall be able to secure up to 10 PCB blanks.

2. The system shall be capable of three or more discrete movements.

2A. The system shall move the PCB blank from the initial storage area to work area.

2B. The system will be able to preform necessary steps to assemble the PCB including:

2B-1. Etching circuitry onto the PCB.

2B-2. Applying solder mask.

2B-3. Creating connection points for electrical components.

3. The system shall move the complete PCB into storage.

3A. The system shall be able to store all 10 completed PCB boards.



ENVIRONMENTAL REQUIREMENTS

1. The system shall be able to operate in low Earth orbit.

1A. The system shall maintain low outgassing levels under vacuum conditions.

1B. The system shall withstand cosmic and solar radiation exposure without functional degradation.

1C. The system shall maintain electrical performance and structural integrity in microgravity environments.

2. The system shall be able to operate in extreme thermal environments.

2A. The system shall remain functional at a maximum operating temperature of 394 K.

2B. The system shall remain functional at a minimum operating temperature of 148.15 K.

2C. The system shall dissipate internally generated heat effectively to stay within component safety limits.



MANUFACTURING REQUIREMENTS

1. The system shall be able to withstand mechanical forces.

1A. System strength shall exceed 10 MPa.

1B. System strain shall be less than 50 $\mu\text{m}/\text{mm}$.

2. The system shall be adaptable.

2A. System shall contain 60% COTS components.

2B. System shall have three remotely adjustable DOF.



DESIGN REQUIREMENTS

1. The system shall be cost-effective.

1A. The system shall have a cost of less than twenty thousand dollars.

2. The system shall be able to fit into the dimensions of a Large Bosun's Locker.

2A. System shall fit into the useable payload area of 144,145 cm³.

3. The system shall be able to operate with the power supplied to the Bosun's locker.

3A. System shall be able to perform using a power passthrough of 300 W.

3B. System shall be able to perform between 5 and 28 V.

4. The system shall not launch debris into space.

4A. System shall release no solid, liquid, or gaseous debris into space.

5. The system shall have a long-service life.

5A. System shall have a service life of one-year.



DESIGN REQUIREMENTS (cont.)

6. The system shall be able to secure pre- and post-manufactured materials.

6A. System shall be able to store 10 PCB blanks.

6B. System shall be able to store 10 manufactured PCB assemblies.

6C. System shall be able to secure assemblies at each manufacturing step.

7. The system shall be accurate and repeatable.

7A. System shall maintain accuracy in reference to the technical drawings within 100 μm .

7B. System shall maintain consistent results.



OPERATIONAL SUCCESS REQUIREMENTS

1. System Performance

1A. The system must manufacture 1 PCB within 20 minutes.

2. Accuracy

2A. The system must generate accurate results according to technical drawings of the PCBs.

3. Reliability

3A. The system must maintain repeatable results.

4. Maintainability

4A. All system components must be designed for maintenance within a 4-hour maximum.

5. Modularity

5A. The system should be designed to work in conjunction with other systems on the Arkisys.



DATA HANDLING AND COMMS REQUIREMENTS

1. **The system should be capable of receiving 2 MB within five minutes of the command being sent.**
 - 1A. The system must not require more than one input from Earth to complete its processes.
2. **The systems controller should be capable of diagnosing and transmitting error information at a rate of 2 MB every five minutes.**
 - 2A. The system must be able to detect errors autonomously and build reports to transmit.



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- EXECUTIVE SUMMARY
- MISSION CONCEPT REVIEW
- SYSTEM REQUIREMENT REVIEW
- **CONCEPTUAL DESIGN REVIEW**
 - DESIGN CRITERIA
 - DECISION MATRIX
 - CONCEPTUAL DESIGNS
 - **SELECTED DESIGN**
- PRELIMINARY DESIGN REVIEW
- LESSONS LEARNED
- CONCLUDING REMARKS



DESIGN CRITERIA

Design Criteria	Description	Parameters	More or Less?
Simplicity	Quantity and complexity of components	N/A	Less
Autonomy	Quantity and complexity of human input required for operation	No. of Inputs: 2	Less
Size, Weight, and Power (SWaP)	Total volume, weight, and wattage consumed	Max Mass: 400 kg	Less
		Max Power: 300 W	Less
		Max Vol: 144,145 cm ³	Less
Price	Program cost (R&D, AI&T, Operations)	~20,000 USD	Less
Manufacturability	Prototype and PCB manufacturing time, tolerances, quality, process efficiency	N/A	Less
Durability	Resistance against mechanical strength	Strength: 10 MPa	More
		Strain: 50 μm/mm	Less
Adaptability	Quantity of COTS components and number of DOF accessible for remote manipulation	60% COTS No. of DOF: 3	More



DESIGN CRITERIA RANKING

Design Criteria	Simplicity	Autonomy	SWaP	Price	Manufacturability	Durability	Adaptability	Weight
Simplicity	---	0.5	1	1	0.5	0	0.5	17%
Autonomy	0.5	---	1	1	0.5	1	1	24%
SWaP	0	0	---	0.5	0	0	0	2%
Price	0	0	0.5	---	0.5	0.5	0	7%
Manufacturability	0.5	0.5	1	0.5	---	1	0.5	19%
Durability	1	0	1	0.5	0	---	0	12%
Adaptability	0.5	0	1	1	0.5	1	---	19%
								100%

0.0 – Not impactful

0.5 – Somewhat impactful

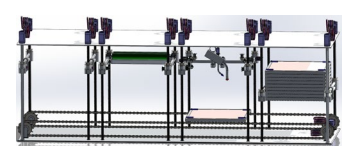
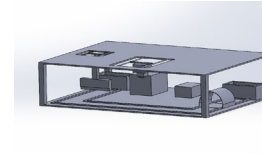
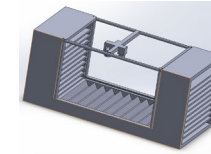
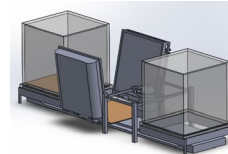
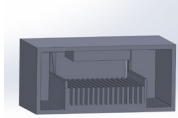
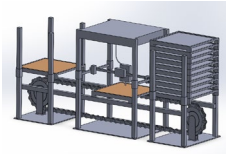
1.0 – Most impactful

$$\text{Weight} = \frac{\text{Criteria Score}}{\text{Total Score}}$$



DECISION MATRIX

Orbital Reliable Circuit Assembly



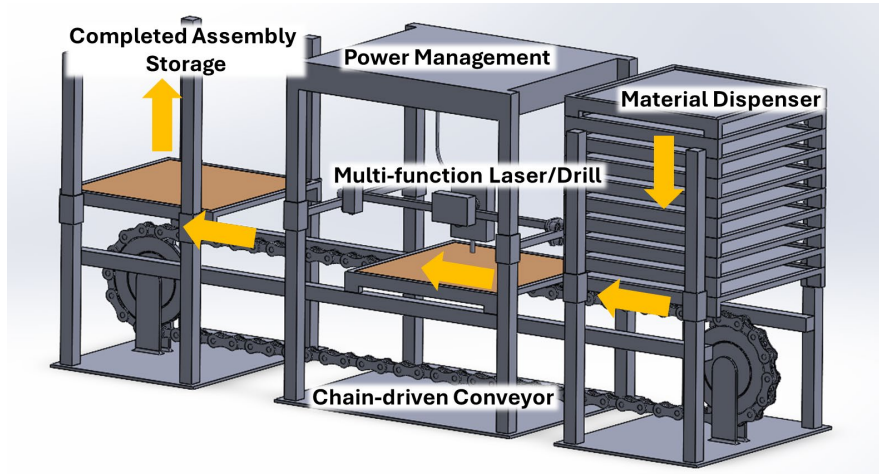
Metrics	Weight	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Simplicity	17%						
Autonomy	24%						
Size, Weight, and Power (SWaP)	2%						
Price	7%						
Manufacturability	19%						
Durability	12%						
Adaptability	19%						
Total	100%						

+3 = Significantly better than the requirement
 0 = Nonfactor
 -3 = Significantly worse than the requirement



CONCEPTUAL DESIGN 1 RANKING

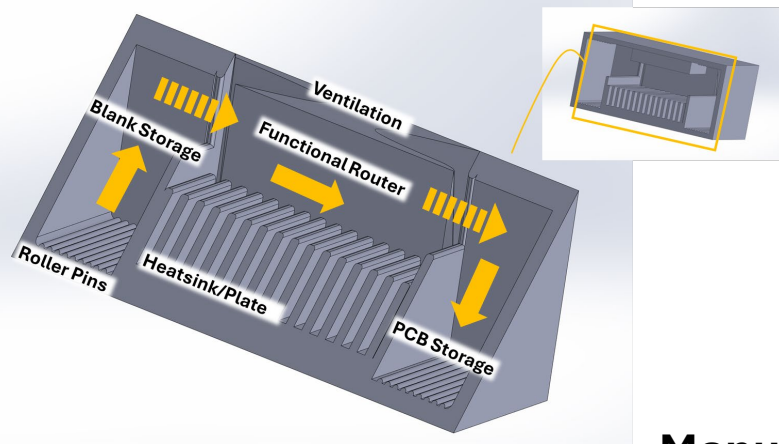
Criteria	Rank	Advantage	Disadvantage
Simplicity	+2	Minimal moving parts. Four moving component systems. 60-70 parts per unit.	Gantry system (magnets). Multi-step storage.
Autonomy	+2	Fully autonomous.	
SWaP	0	Fills available volume. Skeletonized design.	Chain takes up excessive space. High power draw.
Price	+2	Utilizes all COTS parts. Overall program cost of ~10,000 USD .	Many servos.
Manufacturability	+1	Simple construction, geometry, and COTS parts. Laser and integrated router enabling high procession. Run time of 12 hr .	Complex tool head.
Durability	-1		Skeletonized design with stress concentration points. Chain and sprocket meshing becomes difficult with large temperature swings.
Adaptability	+1	75% COTS Parts / 3 DOF	



+3 = BETTER
0 = NO FACTOR
-3 = WORSE



CONCEPTUAL DESIGN 2 RANKING

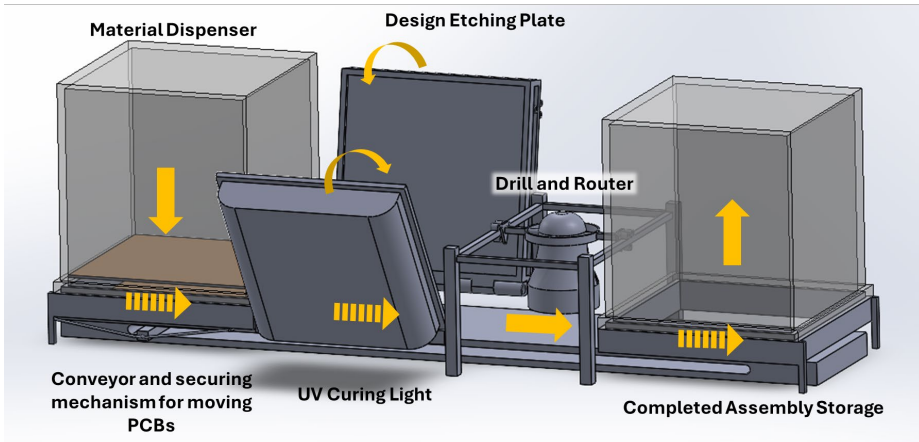


+3 = BETTER
 0 = NO FACTOR
 -3 = WORSE

Criteria	Rank	Advantage	Disadvantage
Simplicity	-2		Large number of small moving parts.
Autonomy	+1	Fully autonomous.	
SWaP	0	Fits within the volume.	
Price	+1	~15,000 USD development cost.	Small components requiring high precision increase manufacturing cost.
Manufacturability	+2	Integrated fan and mobile tool suite allow for tight tolerances. Improved heat dissipation.	Small parts require significant assembly.
Durability	+3	Robust unibody shell.	
Adaptability	0	65% COTS / 3 DOF	Large number of small custom parts.



CONCEPTUAL DESIGN 3 RANKING



Criteria	Rank	Advantage	Disadvantage
Simplicity	-1	Each part of the system has an isolated function.	High number of parts.
Autonomy	+1	Fully autonomous	
SWaP	+1	Uses less than 300 W . Lightweight design.	Does not efficiently utilize space.
Price	+2	~10,000 USD	
Manufacturability	0	Simple construction and geometry lead to ease of manufacturing.	Cannot etch copper plating or apply solder mask
Durability	-1		High number of parts lead to more POF. Minimal support structure.
Adaptability	-1	3 DOF	45% COTS

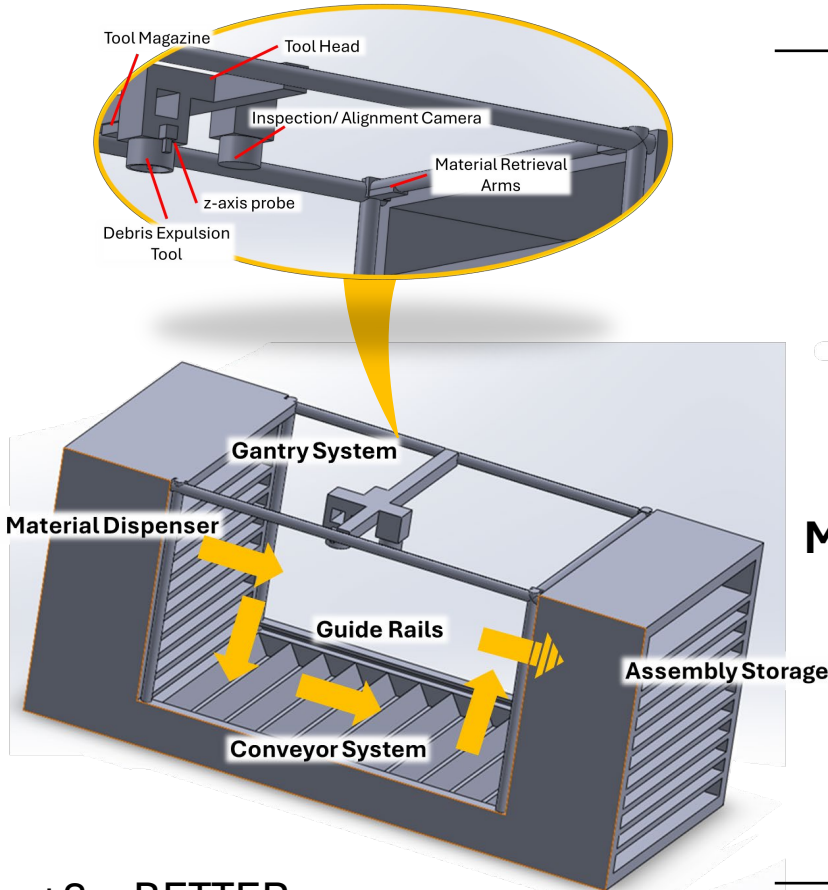
+3 = BETTER

0 = NO FACTOR

-3 = WORSE



CONCEPTUAL DESIGN 4 RANKING

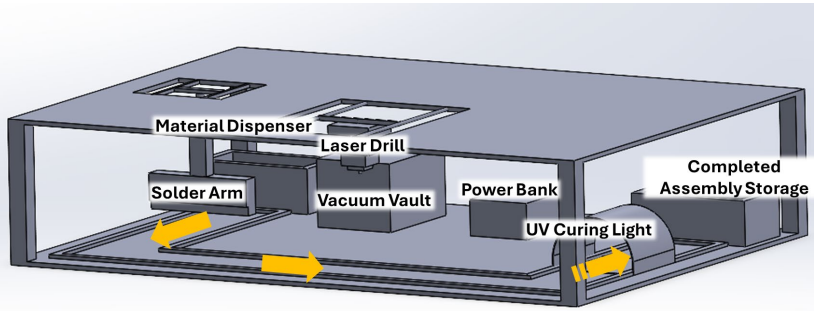


+3 = BETTER
 0 = NO FACTOR
 -3 = WORSE

Criteria	Rank	Advantage	Disadvantage
Simplicity	-2	Simple parts.	Many moving parts and subsystems needed for precision.
Autonomy	+2	Verifies design with onboard camera.	
SWaP	+1	Router uses less power than laser.	Utilizes space poorly.
Price	+2	~12,000 USD	
Manufacturability	-2		Only capable of dry routing PCBs. No resist. Complex gantry.
Durability	+2	Rigid frame and tube structure.	
Adaptability	+1	70% COTS / 3 DOF	



CONCEPTUAL DESIGN 5 RANKING



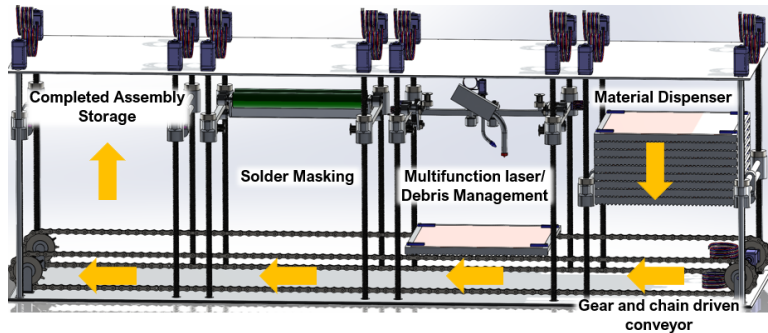
Criteria	Rank	Advantage	Disadvantage
Simplicity	+1	Minium moving parts, total of four moving component systems.	Hand placement storage.
Autonomy	-3		Semi-autonomous at the beginning and end.
SWaP	-1	Lack of excessive non-structural components.	All volume presented it not used effectively.
Price	0	~ 20,000 USD	Conveyor system.
Manufacturability	-2	UV solder mask and UV curing light. Vacuum system between solder arm and laser drill.	No heat resistance. Human interaction is inefficient.
Durability	-1		Wear and tear on solder arm and extensive heating.
Adaptability	-1	65% COTS	2 DOF

+3 = BETTER
 0 = NO FACTOR
 -3 = WORSE



CONCEPTUAL DESIGN 6 RANKING

Criteria	Rank	Advantage	Disadvantage
Simplicity	+1	Minimal number of moving parts. Gear driven system. Modular.	Six moving component systems.
Autonomy	+3	Fully autonomous once started. Verifies accuracy after manufacturing – conductivity.	
SWaP	+2	Design utilizes all available space in locker. Lack of excessive non-structural components.	Draws high power.
Price	+1	~20,000 USD. More complete PCB.	
Manufacturability	+3	Will be capable of manufacturing completed unit within 20 mins. Completes additional processes. High precision from separating process steps into modules.	
Durability	0	Robust structure capable of withstanding 10 MPa compression.	
Adaptability	+2	85% COTS / 3 DOF	



+3 = BETTER

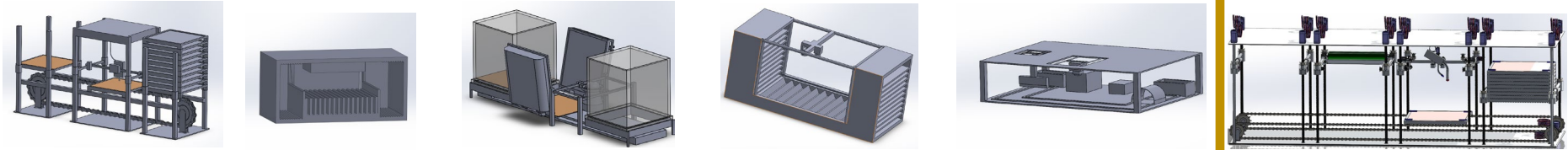
0 = NO FACTOR

-3 = WORSE



DECISION MATRIX

Orbital Reliable Circuit Assembly

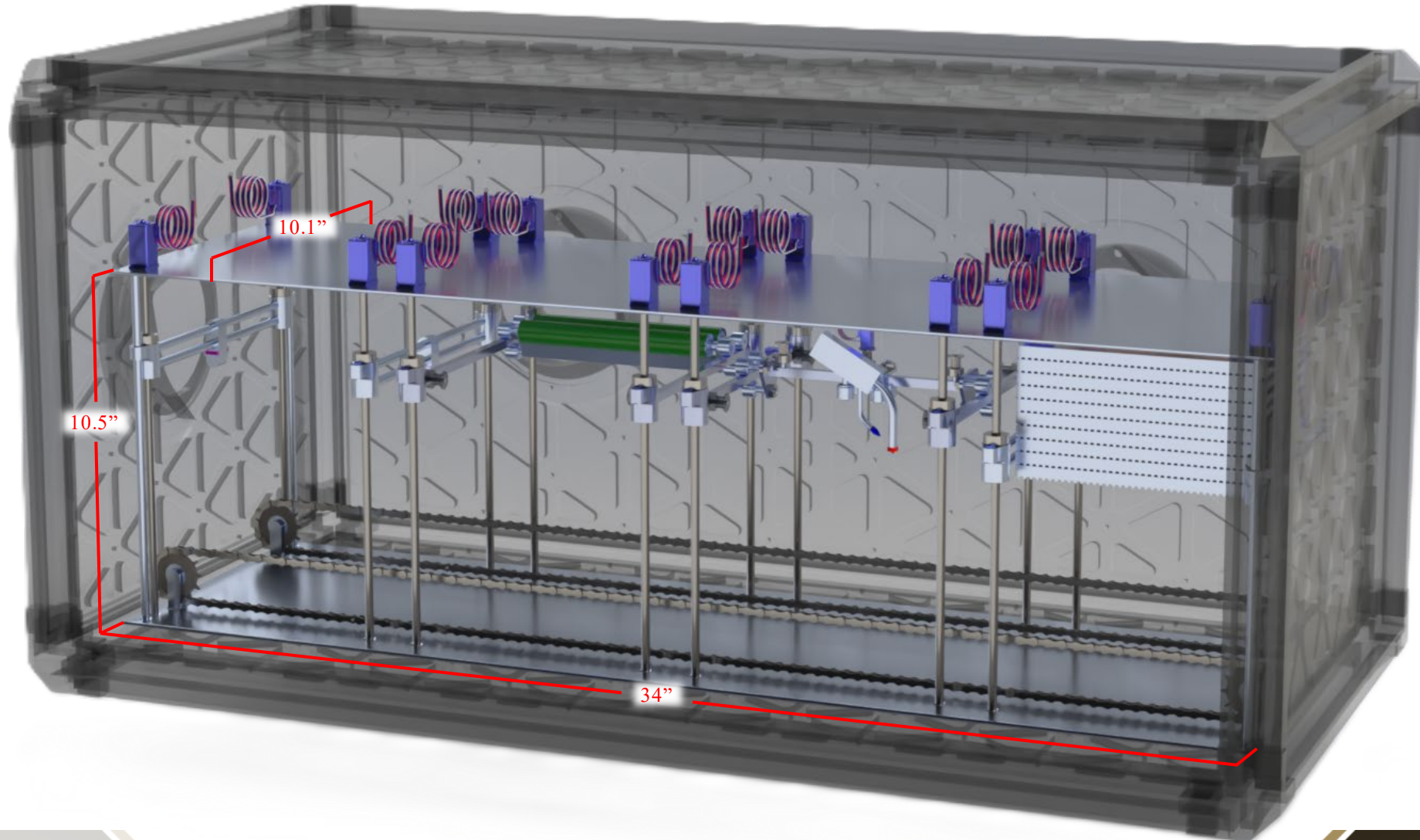


Metrics	Weight (%)	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6
Simplicity	17	+34	-34	-17	-34	+17	+17
Autonomy	24	+48	+24	+24	+48	-72	+72
Size, Weight, and Power (SWaP)	2	0	0	+2	+2	-2	+4
Price	7	+14	+7	+14	+14	0	+7
Manufacturability	19	+19	+38	0	-38	-38	+57
Durability	12	-12	+36	-12	+24	-12	0
Adaptability	19	+19	0	-19	+19	-19	+38
Total	100	+122	+71	-8	+35	-126	+195

Weight (%) × Ranking = Total



SELECTED DESIGN



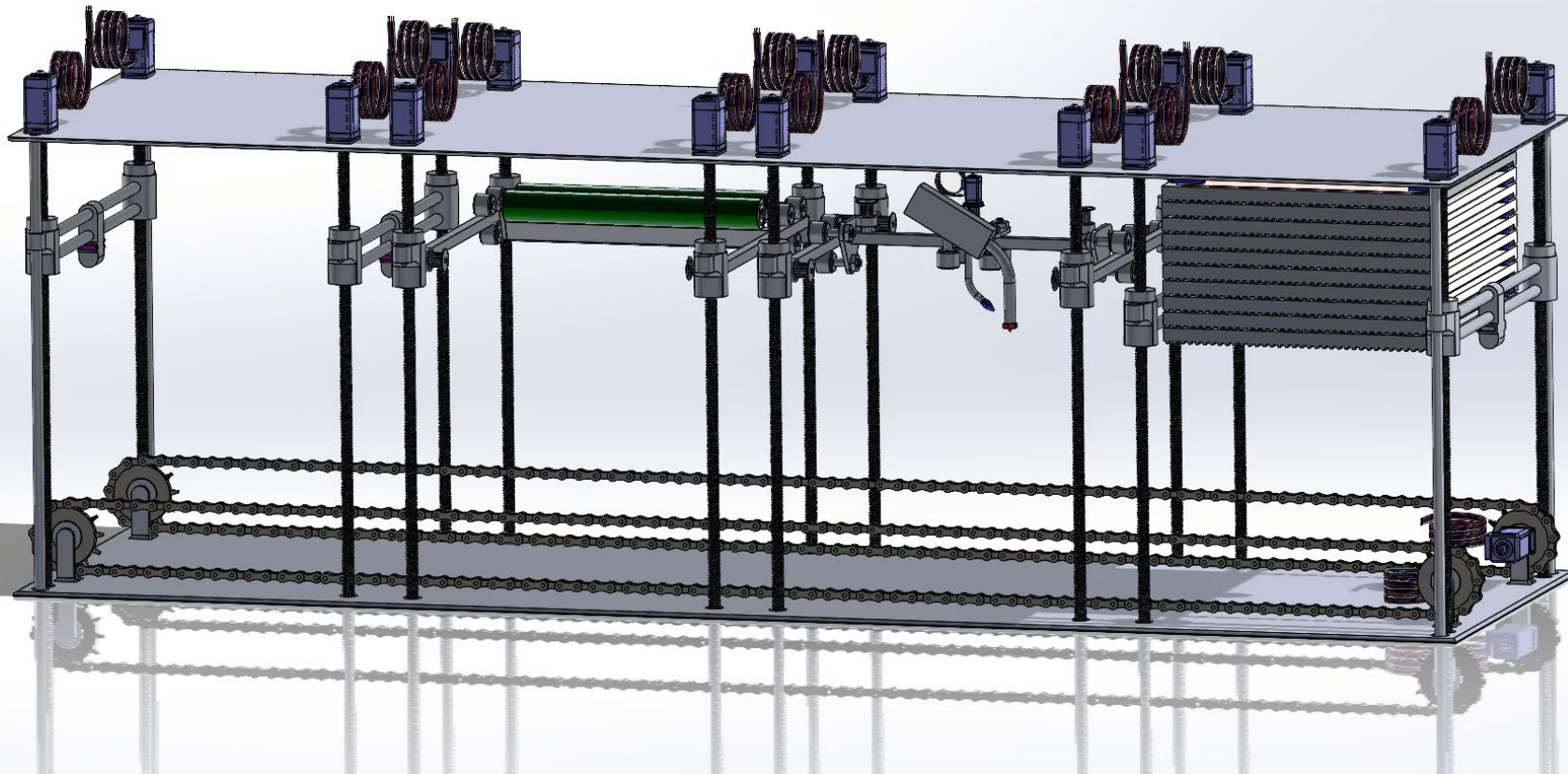


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- CONCEPTUAL DESIGN REVIEW
- PRELIMINARY DESIGN REVIEW
 - CONCEPT OF OPERATIONS
 - ENGINEERING DESIGN AND ANALYSIS
 - NASA TECHNOLOGY READINESS LEVEL
 - RISK ASSESMENT
- LESSONS LEARNED
- CONCLUDING REMARKS



CONCEPT OF OPERATIONS





ENGINEERING DESIGN AND ANALYSIS

- **COMPONENT 1: FRAME ASSEMBLY**
- **COMPONENT 2: POWERSCREW ASSEMBLY**
- **COMPONENT 3: CONVEYOR ASSEMBLY**
- **COMPONENT 4: PCB TRAY ASSEMBLY**
- **COMPONENT 5: DISPENSER AND STORAGE ASSEMBLY**
- **COMPONENT 6: LASER ETCHER AND EXPULSION ASSEMBLY**
- **COMPONENT 7: SOLDER MASKING ASSEMBLY**
- **MASS, POWER, COST ANALYSIS**



ENGINEERING DESIGN AND ANALYSIS

- **COMPONENT 1: FRAME ASSEMBLY**
- COMPONENT 2: POWERSCREW ASSEMBLY
- COMPONENT 3: CONVEYOR ASSEMBLY
- COMPONENT 4: PCB TRAY ASSEMBLY
- COMPONENT 5: DISPENSER AND STORAGE ASSEMBLY
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- COMPONENT 7: SOLDER MASKING ASSEMBLY
- MASS, POWER, COST ANALYSIS



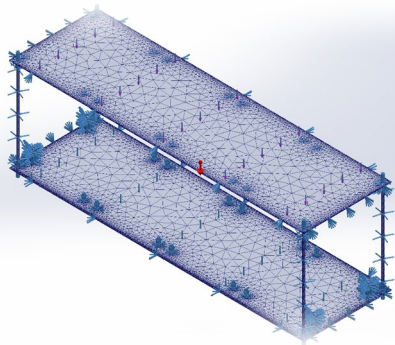
FRAME STATIC AND THERMAL LOAD ANALYSIS

Description:

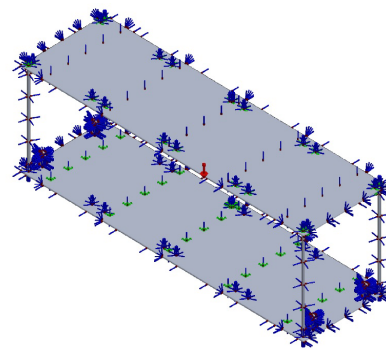
- Sturdy 6061- T6 Aluminum Frame for support structure
- Houses bearings to hold power screws
- Service-friendly layout for quick bearing replacement or lubrication access
- Thermal stability for consistent performance in variable operating temperatures

Assumptions (worst-case scenario):

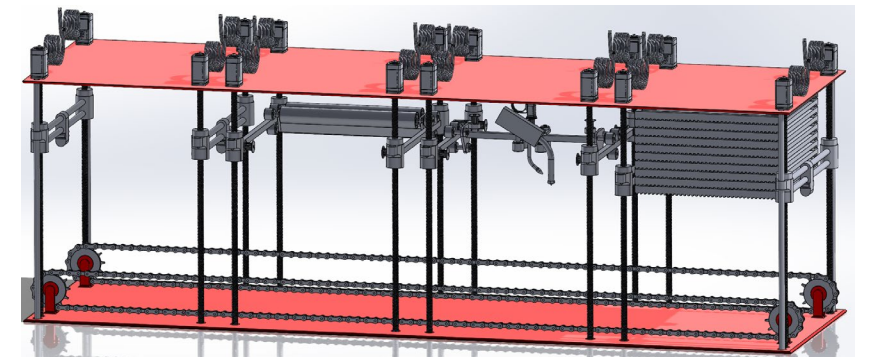
- Simulations based on Earth gravity.
- Static temperature set to full shadow conditions and direct sunlight conditions.
- Support poles are under load from the weight of the top panel.



Mesh Geometry



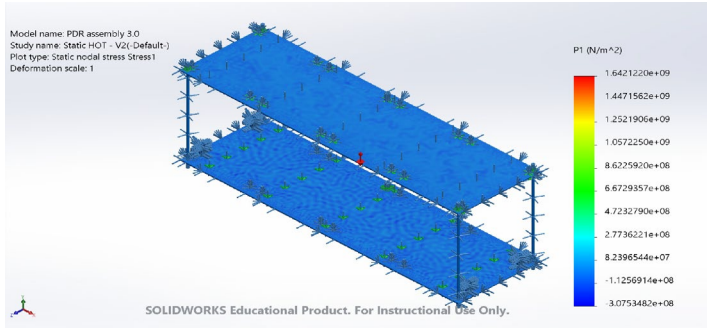
Displacement and Load



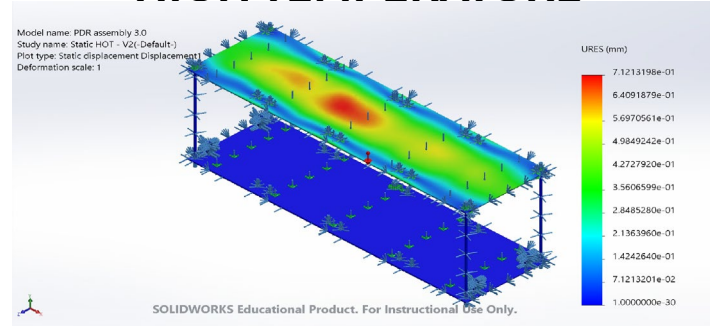


FRAME STATIC AND THERMAL LOAD ANALYSIS

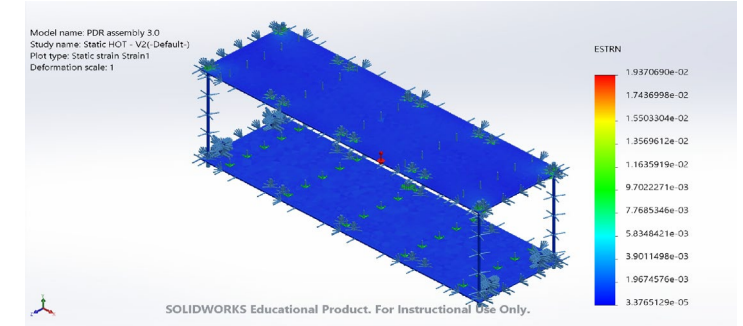
HIGH TEMPERATURE



$$\sigma_1 = 1.6 \text{ MPa}$$

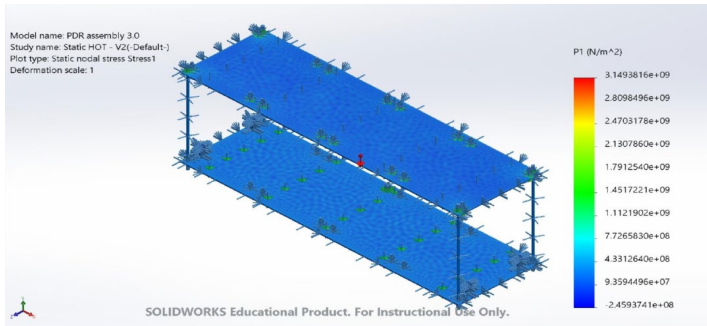


$$u_{eq} = 712 \mu\text{m}$$



$$\epsilon_{eq} = 19.3 \mu\text{m/mm}$$

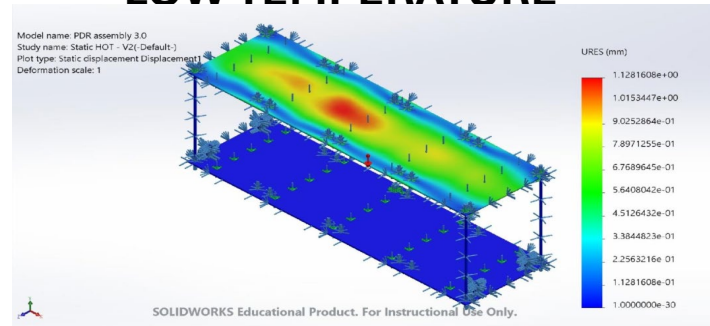
LOW TEMPERATURE



$$\sigma_1 = 3.1 \text{ MPa}$$

TARGET STRENGTH: 10 MPa

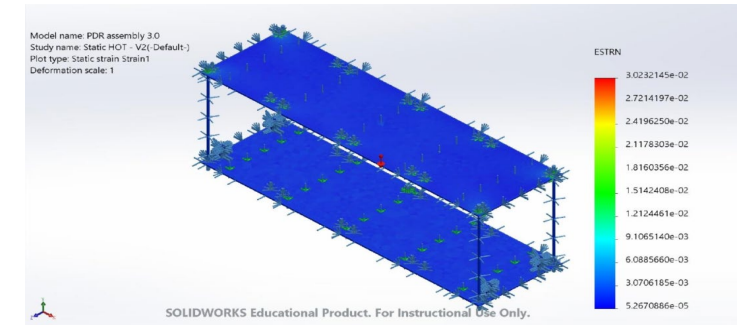
$$MS = \frac{F_{tu}}{\sigma_1} - 1 = +HIGH$$



$$u_{eq} = 1.13 \text{ mm}$$

TARGET DISPLACEMENT: 5 mm

-126% DIFFERENCE



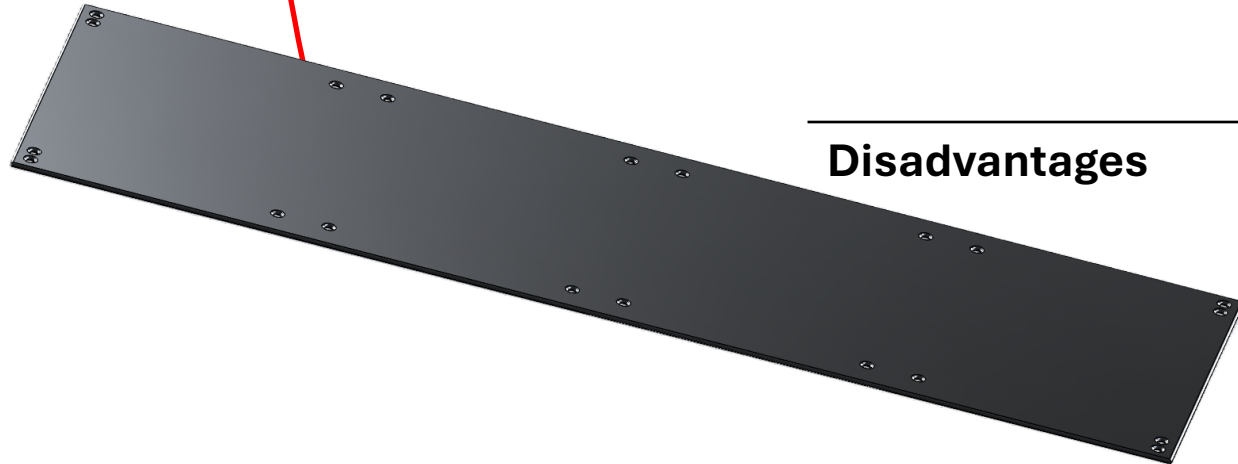
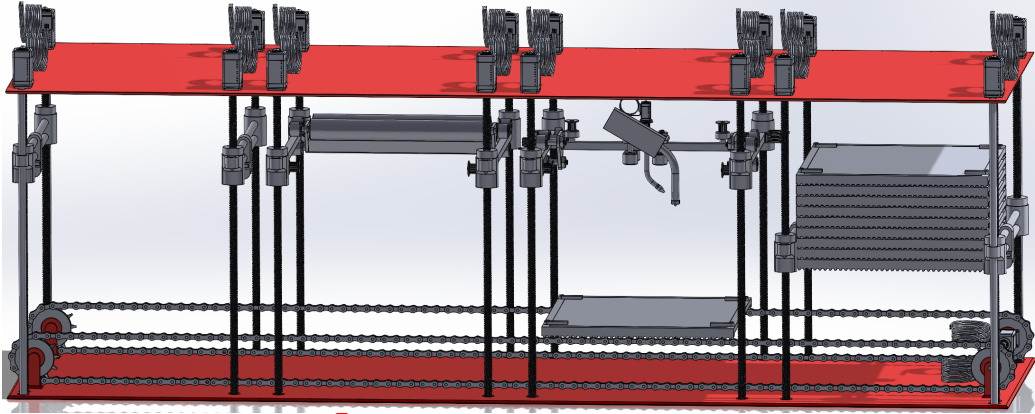
$$\epsilon_{eq} = 30.2 \mu\text{m/mm}$$

TARGET STRAIN: 50 $\mu\text{m/mm}$

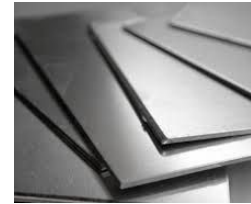
-49% DIFFERENCE



FRAME TRADE STUDY: SUPPORT BOARDS



304 Stainless Steel



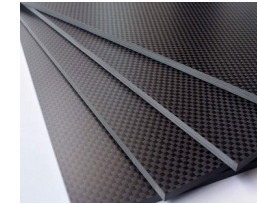
Advantages

1. High strength.
2. Thermal durability.
3. Inexpensive
4. Corrosion resistant

Disadvantages

1. High weight.
2. More difficult to machine

Carbon Fiber Reinforced Polymer



1. Low CTE.
2. High stiffness lightweight.
3. Corrosion Proof

1. Resin outgassing.
2. Delamination under bearing/shear stress.
3. Expensive.

Aluminum Alloy 6061-T6



1. Robust.
2. Easy to machine.
3. Handles 1g loads.
4. Inexpensive
5. Relatively lightweight

1. High CTE

Justification: Robust, lightweight, cheap, and most suitable for expected stress.



ENGINEERING DESIGN AND ANALYSIS

- **COMPONENT 1: FRAME ASSEMBLY**
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- **COMPONENT 3: CONVEYOR ASSEMBLY**
- COMPONENT 4: PCB TRAY ASSEMBLY
- COMPONENT 5: DISPENSER AND STORAGE ASSEMBLY
- COMPONENT 6: LASER ETCHER AND EXPULSION ASSEMBLY
- COMPONENT 7: SOLDER MASKING ASSEMBLY
- MASS, POWER, COST ANALYSIS



ENGINEERING DESIGN AND ANALYSIS

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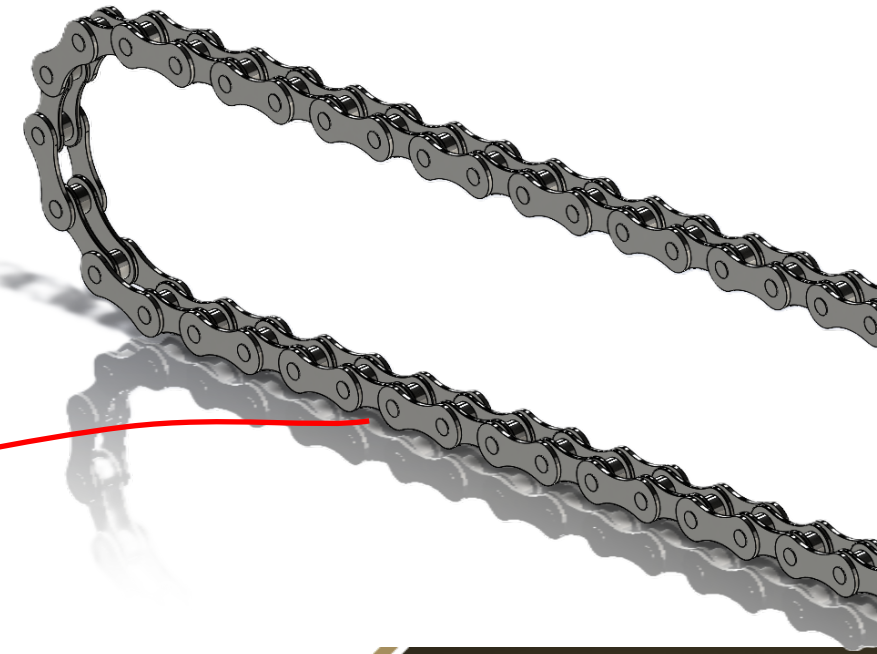
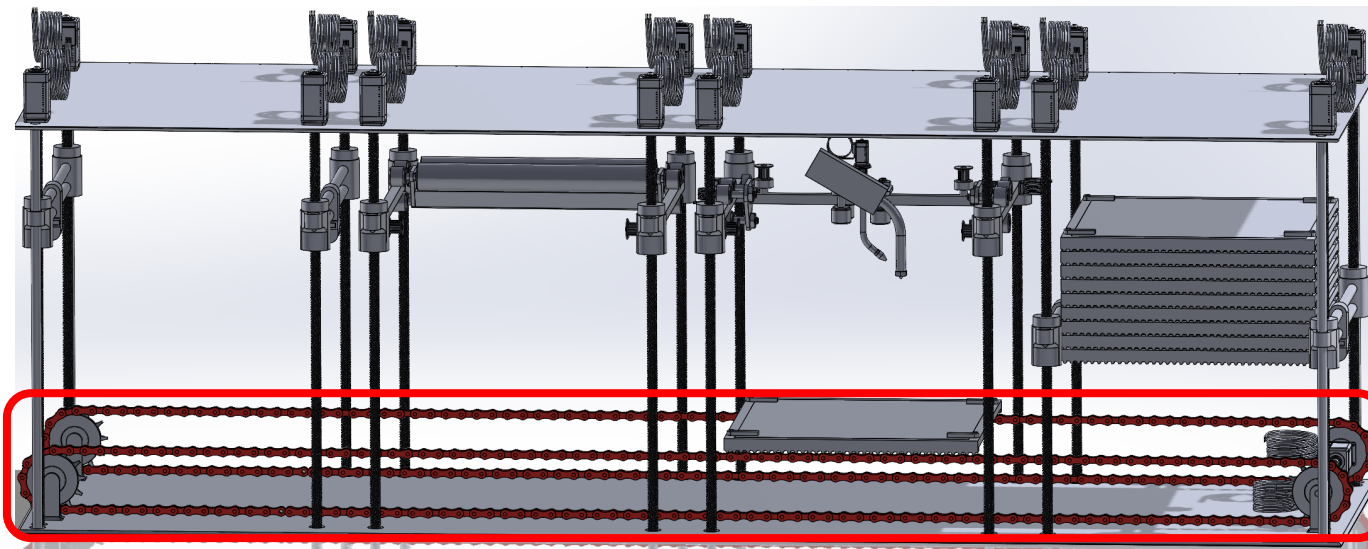
CONVEYOR CHAIN ANALYSIS

Description:

- Transfers the PCB tray between manufacturing stages with precise, repeatable motion.
- Operates through a sprocket-driven chain assembly powered by a larger stepper motor.
- Designed for high-vacuum conditions, using dry, wear-resistant materials with no lubrication.

Assumptions (worst-case scenario):

- Simulations based on Earth gravity
- Static temperature set to full shadow conditions and direct sunlight conditions.
- Chain under load of all 10 PCB trays load with copper blanks.





CONVEYOR CHAIN ANALYSIS

Key Design Inputs

Parameter	Value
Pitch p	9.525 mm
Sprocket Teeth	12
Pitch Radius r	18.4 mm
Chain Speed	19–57 mm/s
Pretension F_p	10–20 N
Force Δ	50 N

Chain Dimensions

Parameter	Value
Roller Dia d_1	6.35 mm
Inner Width b_1	5.72 mm
Pin Dia d_2	3.30 mm
Plate Thickness t	1.30 mm
Plate Height h_2	8.20 mm

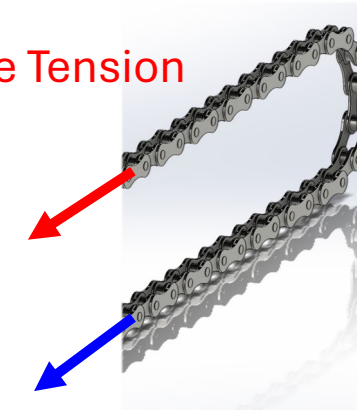
Torque and Tension Results

Parameter	Value
Standard	ISO 06B-1 (Metric #35)
Tight Side Tension T_1	60 N
Slack Side Tension T_2	10 N
Required Motor Torque	0.92 N-m

Tight and Slack Side Calculations

$$T_1 = F_p + \frac{\Delta}{2} = 60 \text{ N}$$
$$T_2 = F_p - \frac{\Delta}{2} = 10 \text{ N}$$

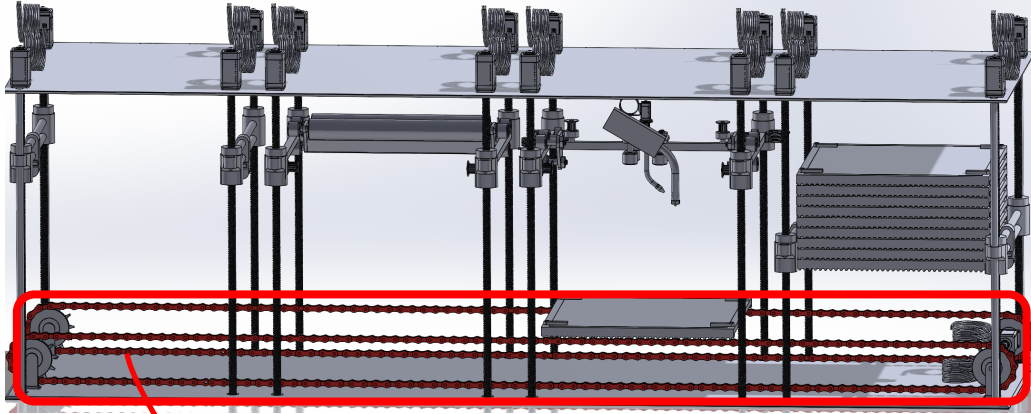
T_1 = Tight Side Tension



T_2 = Slack Side Tension



CONVEYOR TRADE STUDY: CHAIN



IWIS 06B-1 Elite Chain



BS Simplex Stainless Steel Roller Chain



Renold SD BS Simplex Roller Chain



Advantages

1. Premium performance, trusted for high-reliability systems.
2. Stainless and matched 9.525 mm pitch exactly.

1. Stainless, vacuum-compatible material
2. Good cost baseline

1. Precision brand chain, high manufacturing tolerances
2. Stainless material suitable for dry-film and vacuum

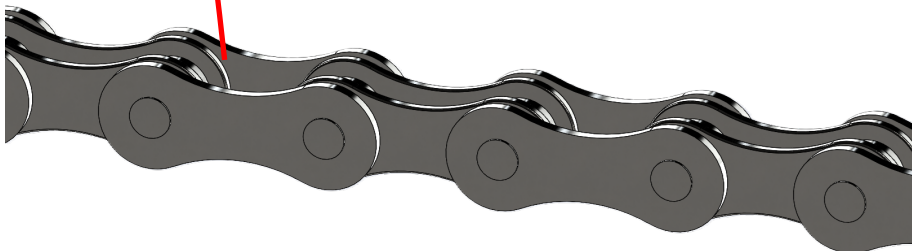
Disadvantages

1. Low cost VS. effect ratio.

Justification: High reliability and functionality out-weigh high price for this application.

1. Standard grade finish, might need further coating
2. Less premium brand, potentially higher risk of quality issue

1. Higher cost than baseline
2. Lead-time may be longer than standard stock





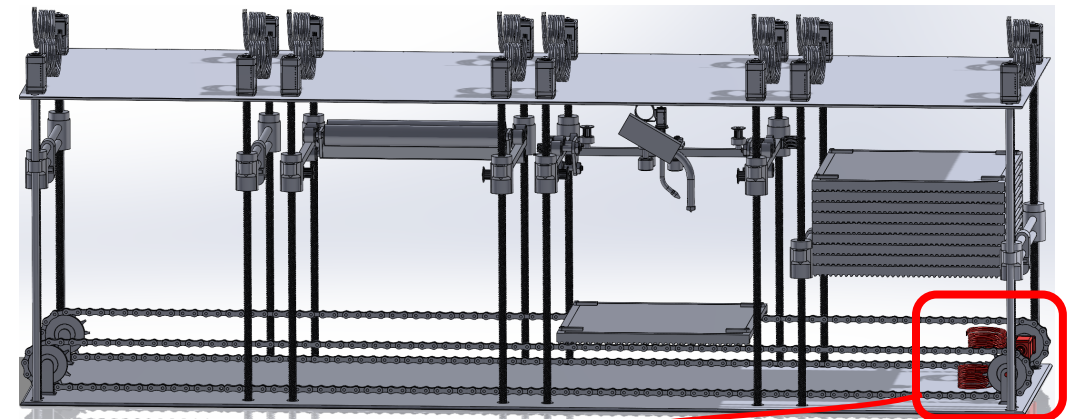
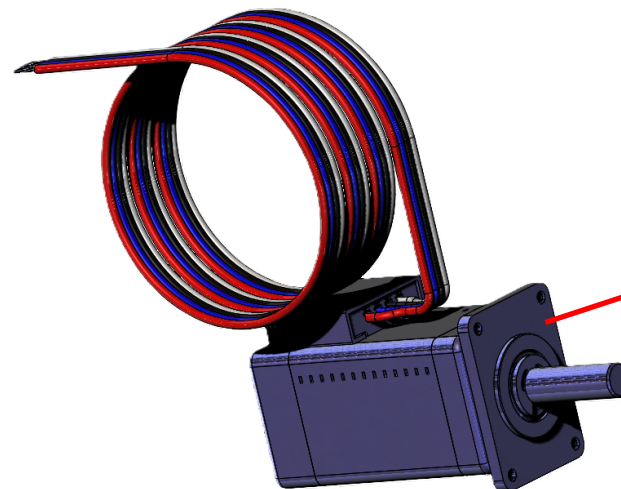
CONVEYOR STEPPER MOTOR ANALYSIS

Description:

- Provides the rotational power that drives the sprocket and chain assembly to move the PCB tray between stages with controlled speed and position
- Delivers sufficient torque margin to overcome chain tension and payload load while preventing slip or loss of step alignment
- Operates at low speed with smooth micro-stepping to ensure precise, repeatable motion suitable for in-vacuum manufacturing processes

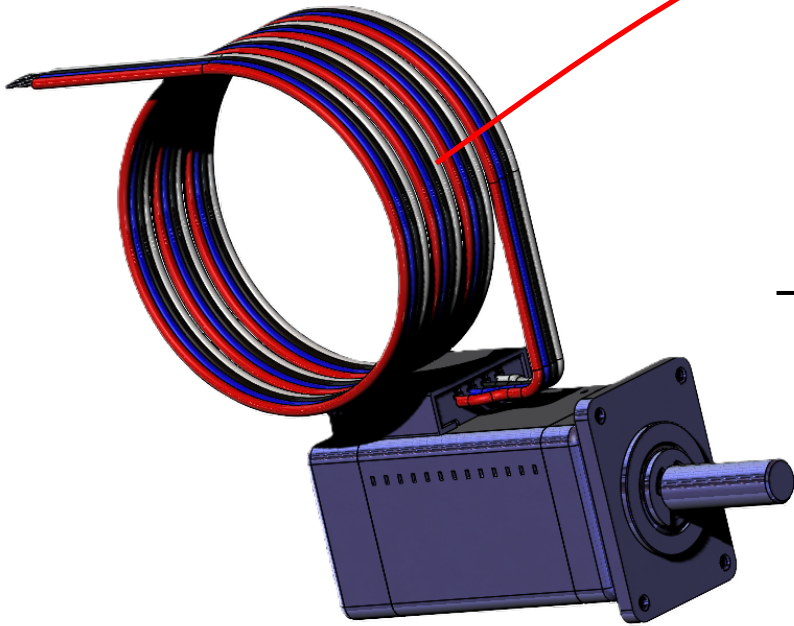
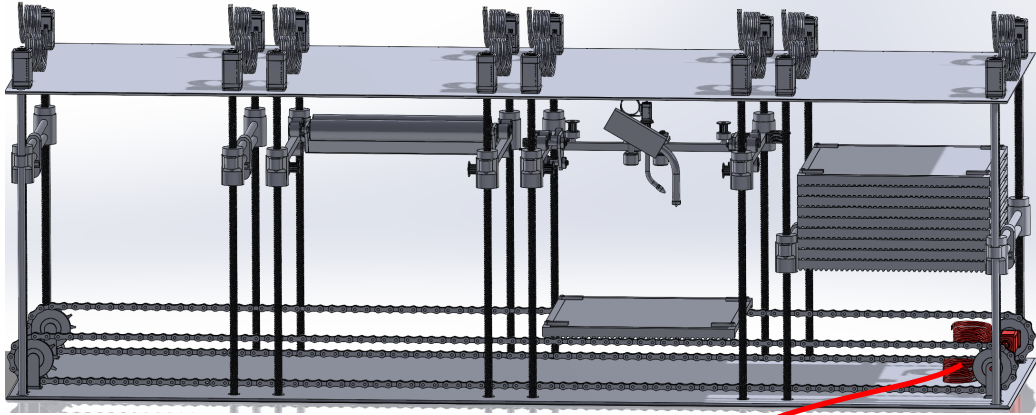
Assumptions (worst-case scenario):

- Simulations based on Earth gravity
- Static temperature set to full shadow conditions and direct sunlight





CONVEYOR TRADE STUDY: STEPPER MOTOR



Advantages

PhySPACE 52-2
NEMA-17



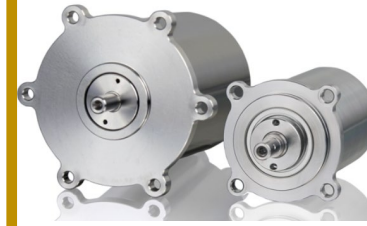
1. Higher output torque due to integrated gearbox
2. Smooth low-speed motion
3. Compact form factor

Disadvantages

1. Additional mass vs ungeared motor
2. Requires more careful stepper tuning

Justification: High reliability and precise motion

Phytron VSS 52
NEMA-23



1. High reliability, proven flight heritage
2. Wide thermal margin

1. High cost and lead time
2. Heavier than COTS equivalents
3. Less flexibility in driver compatibility

Oriental Motor PKP
NEMA-23



1. Strong holding torque
2. Compatible with range of encoders and drivers

1. Not space rated
2. Larger footprint
3. Needs careful thermal routing



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- COMPONENT 7: SOLDER MASKING ASSEMBLY
- MASS, POWER, COST ANALYSIS



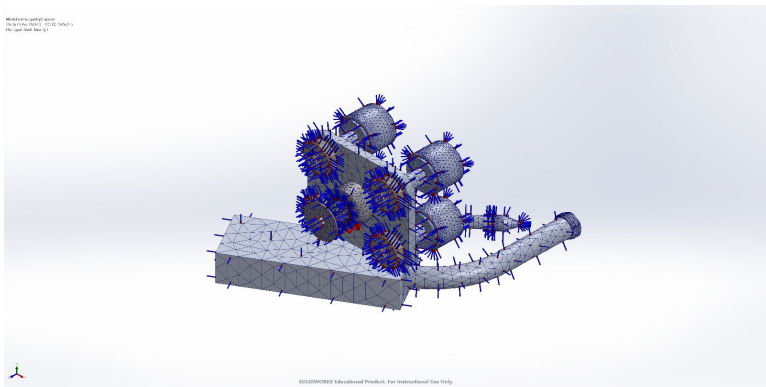
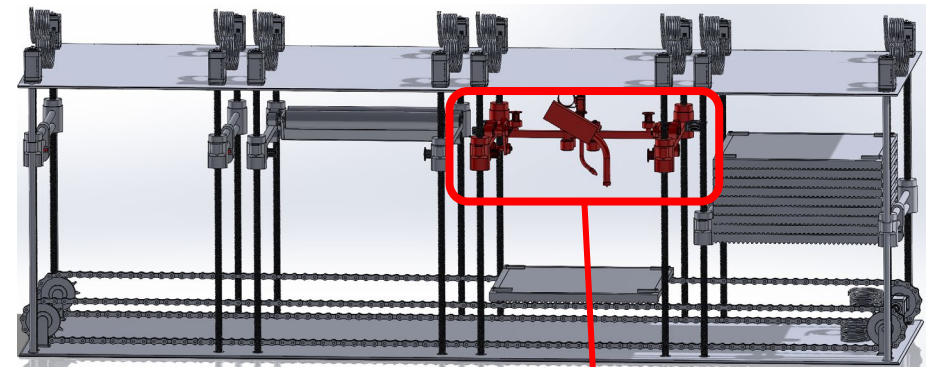
TOOL HEAD STATIC AND THERMAL LOAD ANALYSIS

Description:

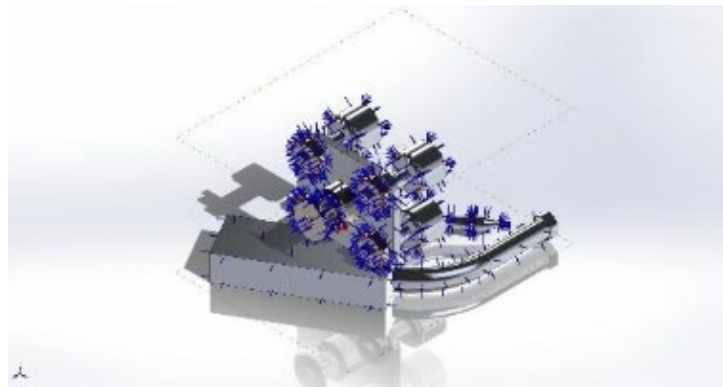
- 3 DOF controlled by stepper motors
- Laser etches design into copper PCB material and solder mask.
- Expulsion system uses an inert gas to expel any debris floating away from working area into collection zone.

Assumptions (worst-case scenario):

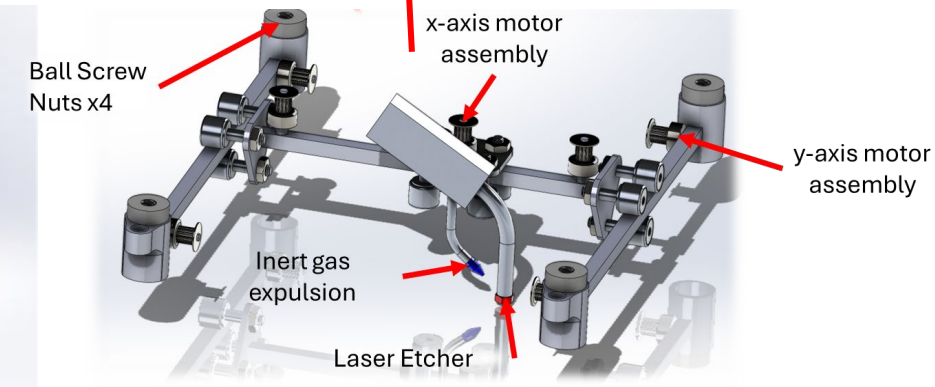
- Simulations based on Earth gravity
- Static temperature set to full shadow conditions and direct sunlight conditions.



Mesh Geometry



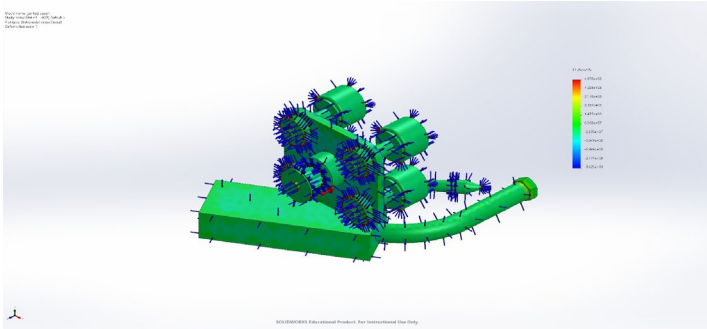
Displacement and Load



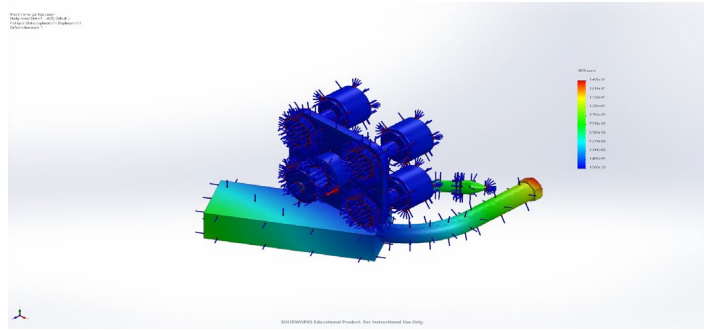


TOOL HEAD STATIC AND THERMAL LOAD ANALYSIS

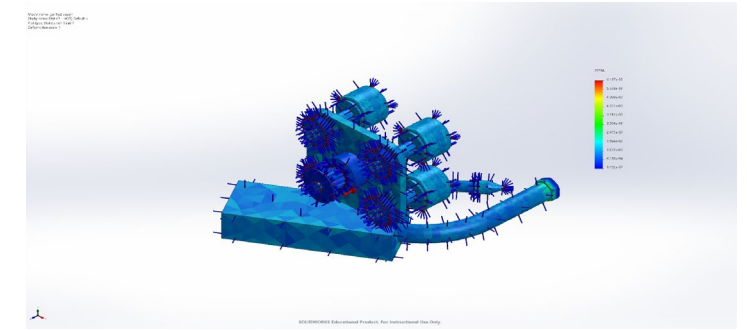
HIGH TEMPERATURE



$\sigma_1 = 0.488 \text{ MPa}$

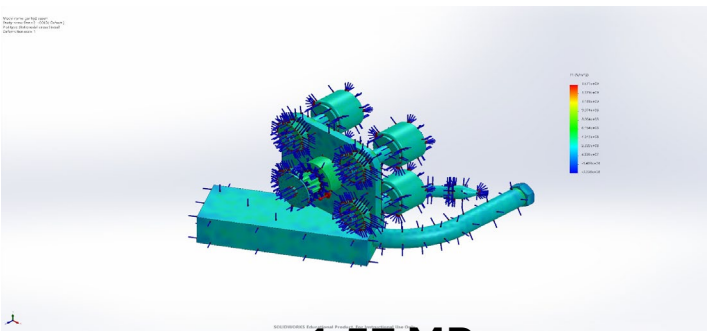


$u_{eq} = 146.0 \text{ } \mu\text{m}$

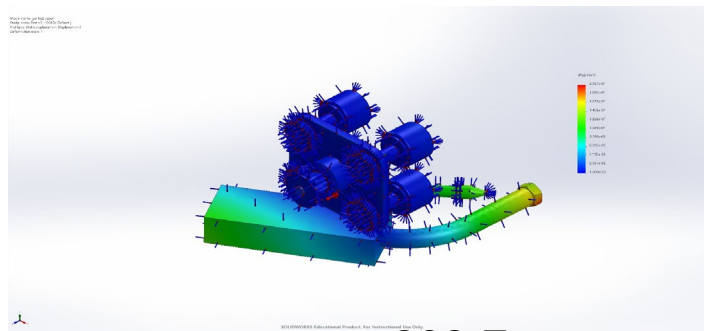


$\epsilon_{eq} = 6.2 \text{ } \mu\text{m/mm}$

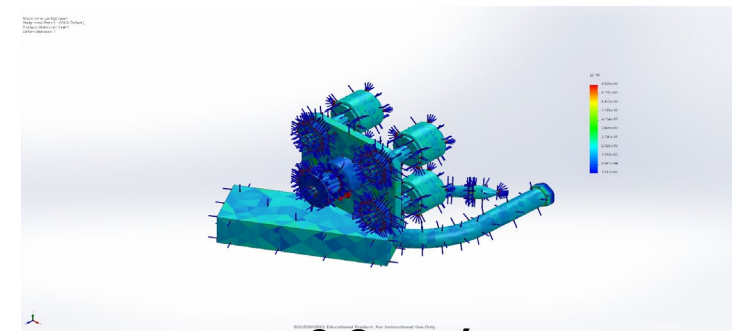
LOW TEMPERATURE



$\sigma_1 = 1.57 \text{ MPa}$



$u_{eq} = 209.7 \text{ } \mu\text{m}$



$\epsilon_{eq} = 6.8 \text{ } \mu\text{m/mm}$

TARGET STRENGTH: 10 MPa

$$MS = \frac{F_{tu}}{\sigma_1} - 1 = +HIGH$$

TARGET DISPLACEMENT: 1 mm

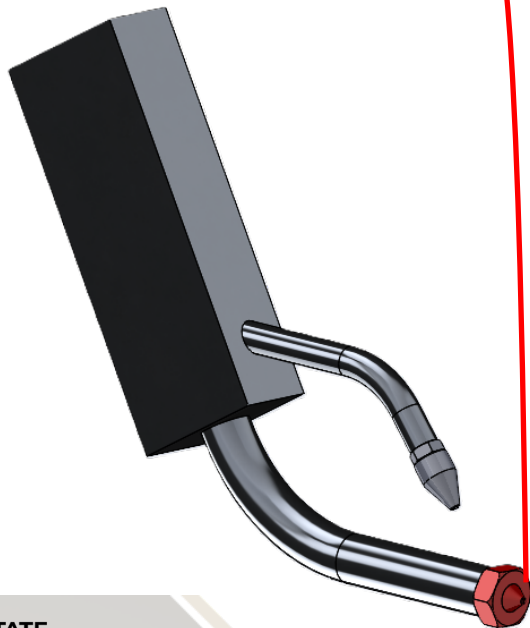
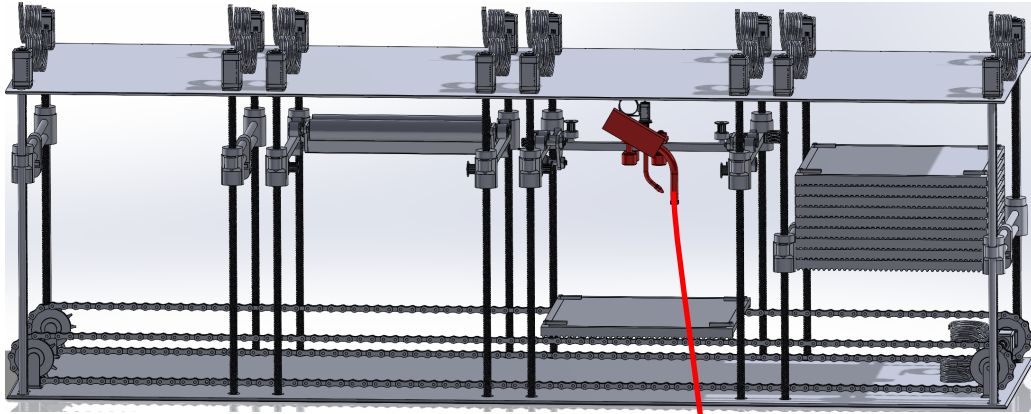
-131% DIFFERENCE

TARGET STRAIN: 10 $\mu\text{m/mm}$

-38% DIFFERENCE



TOOL HEAD TRADE STUDY: LASER



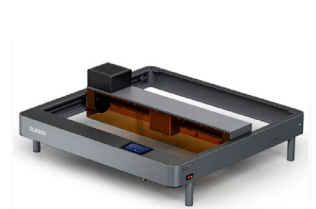
xTool F1 Ultra
20W



OMTech MOPA
20W



Elegoo Phecda
20W



Advantages

1. Highly accurate.
2. Capable laser for etching.

1. Moderately accurate.
2. Meets power requirement.

1. Cost effective.
2. Moderately accurate.
3. Meets power requirements

Disadvantages

1. Does not meet power requirements.
2. Expensive.

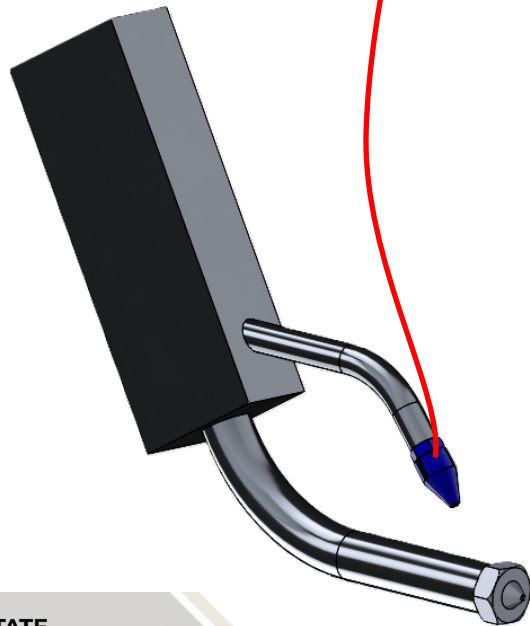
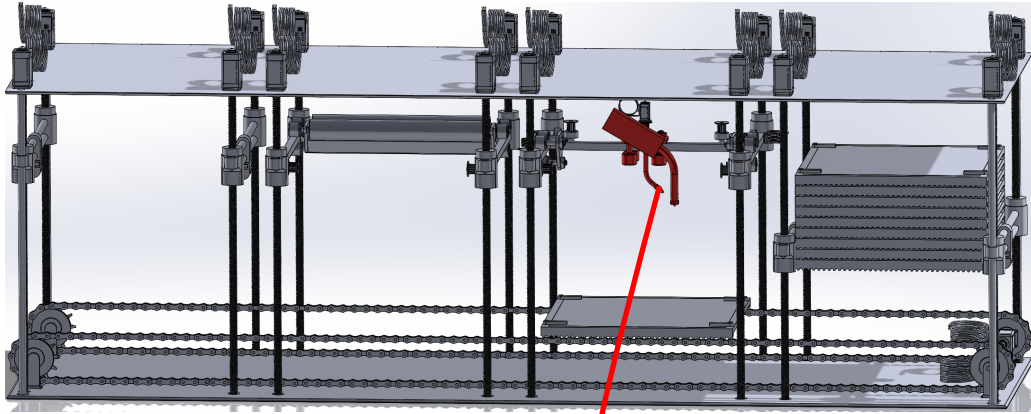
1. Heavy.

1. Heavy.
2. Less capable laser.

Justification: Meets power requirements and is the most cost-effective option.

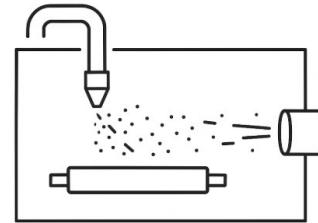


TOOL HEAD TRADE STUDY: DEBRIS EXPULSION



Advantages

Directed N₂ Purge



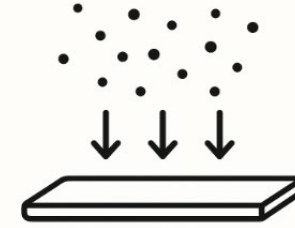
1. Only moving part is purge valve.
2. Minimal gas plumbing.
3. Simple construction.

Disadvantages

1. Wider gas jet, less direction.
2. High out-gassing

Justification: Most simplistic design.

Electrostatic Capture Grid

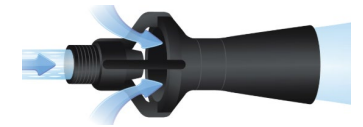


Capture pad

1. No gas usage.
2. Continuous passive capture.

1. Requires high voltage supply.
2. Requires significant shielding and insulation to reduce arcing risk.

Venturi Eductor and Capture Duct Purge



1. Better direction control of gas.
2. More efficient gas usage.

1. Requires most plumbing, additional weight and complexity.
2. Requires nozzle sizing.

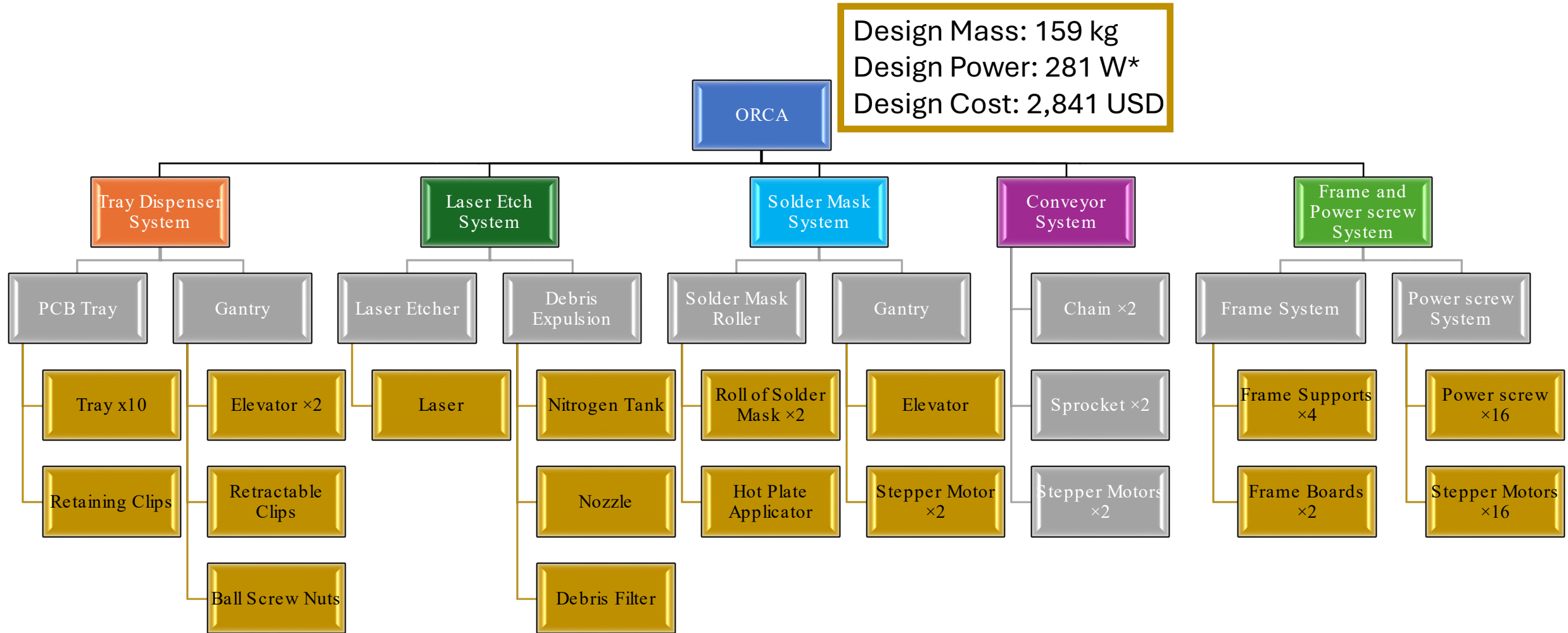


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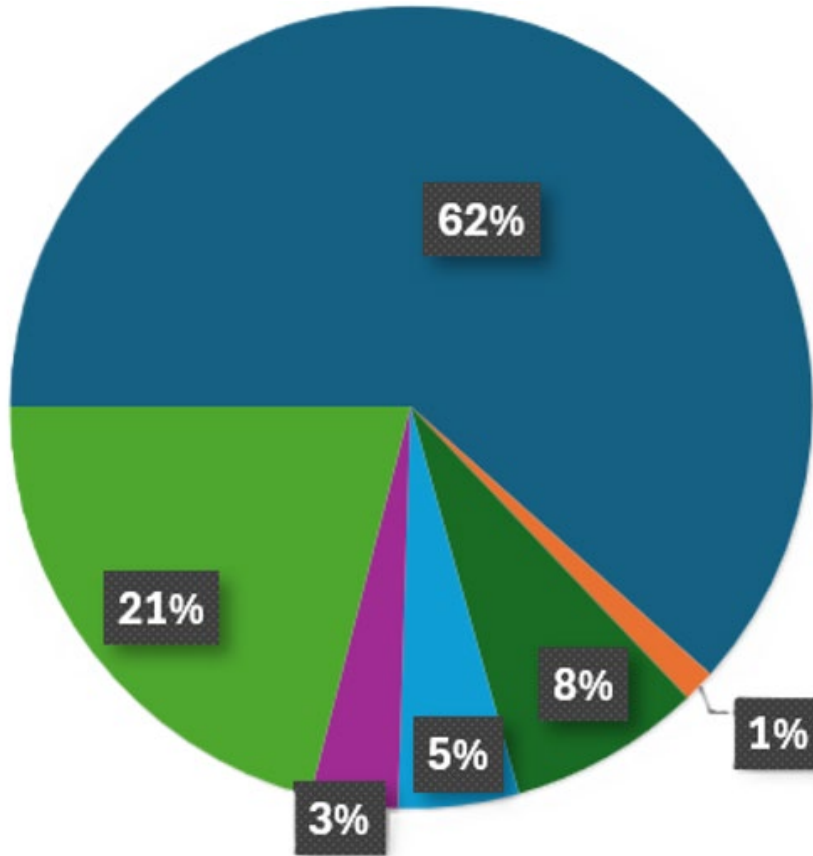


MASS, POWER, AND COST ANALYSIS





MASS ANALYSIS BREAKDOWN

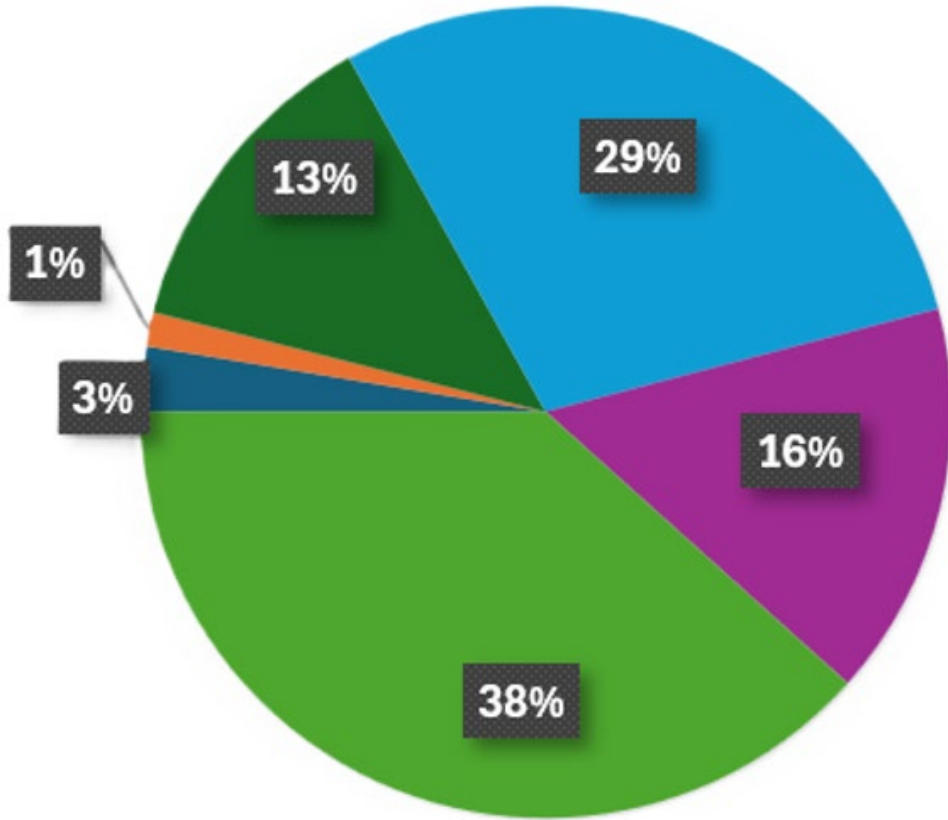


Actual Mass: 159 kg
Max Allowed Mass: 400 kg
60% of mass still available

Mass Analysis	Mass (kg)	Mass (%)
Remaining	246	62
Tray Dispense Assem	5	1
Laser Etch System	31	8
Solder Mask System	19	5
Conveyor System	14	3
Frame and Powerscrew System	84	21



POWER ANALYSIS BREAKDOWN



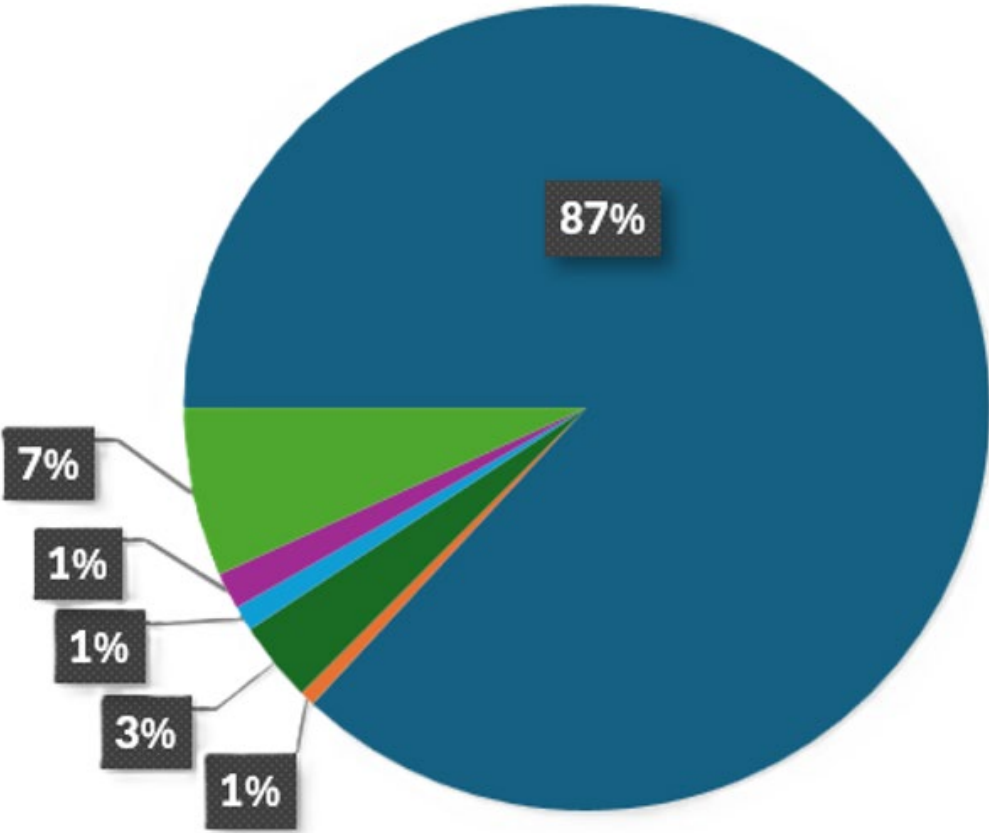
Actual Power: 281 W*
 Max Allowed Power: 300 W
 6% of power still available

Power Analysis	Usage (W)	Usage (%)
Remaining	19	6
Tray Dispense Assem	0	0
Laser Etch System	95	32
Solder Mask System	212	71
Conveyor System	115	38
Frame and Powerscrew System	281	94

*Wattage shown represents power used at one time, not the assembly's total consumption.



COST ANALYSIS BREAKDOWN



Actual Cost: 2,841 USD
 Max Allowed Cost: 20,000 USD
 86% of budget still available

Cost Analysis	Cost (USD)	Cost (%)
Remaining	17,713	87
Tray Dispense Assem	122	1
Laser Etch System	650	3
Solder Mask System	201	1
Conveyor System	297	1
Frame and Powerscrew System	1,358	7



NASA TECHNOLOGY READINESS LEVEL

OVERALL DESIGN:

ORCA Device | L3 |

SUBSYSTEMS:

PCB Tray and Retaining Clips | L2 |

Chain and Sprocket Assembly | L5 |

Stepper Motors and Drivers | L5 |

Gantry Positioning System | L4 |

Power Screw for Gantry Actuation | L5 |

Aluminum Frame | L6 |

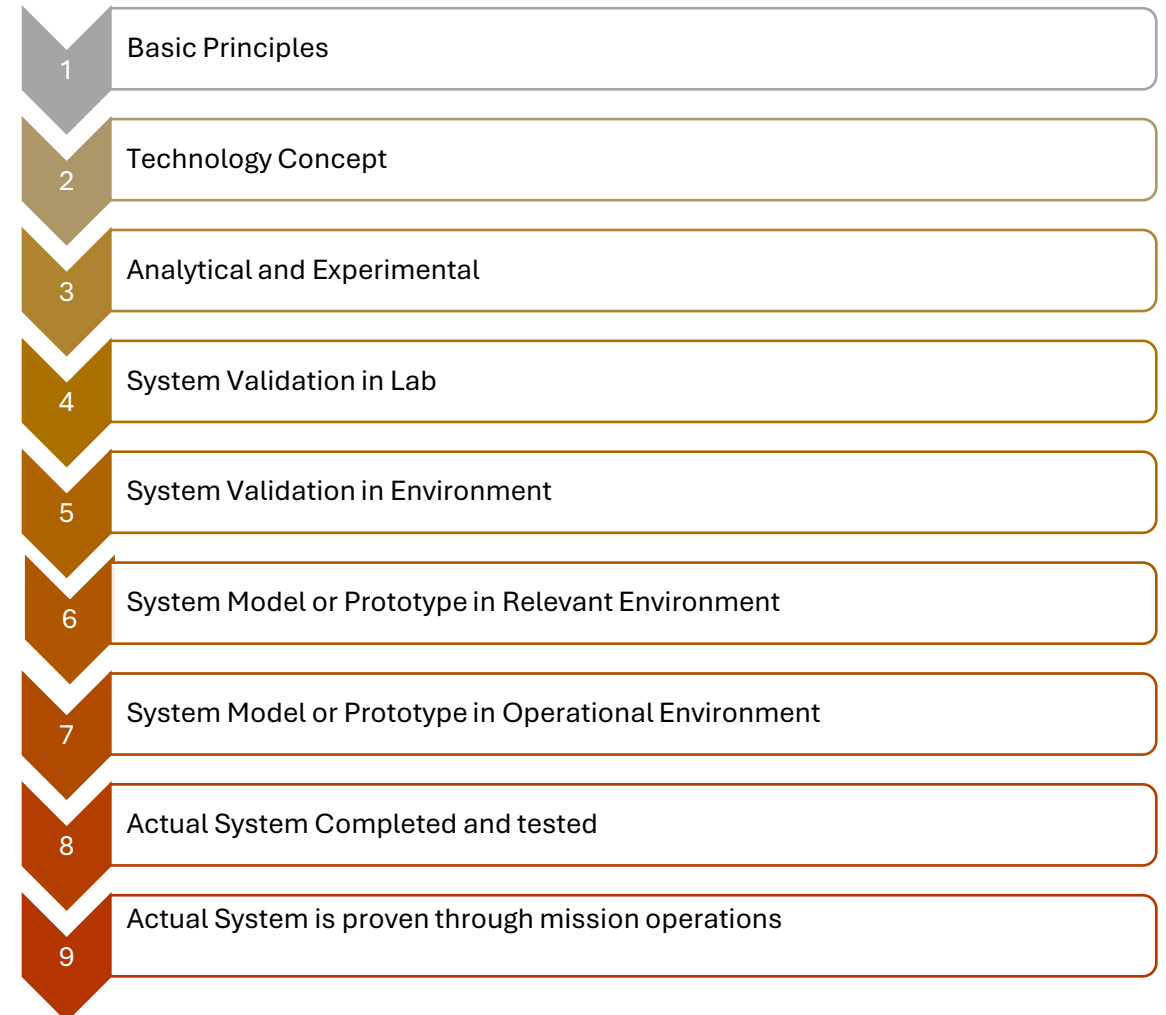
Solder Mask Applicator | L2 |

Laser Etcher Tool Head | L3 |

PCB Storage and Retrieval Dispenser | L4 |

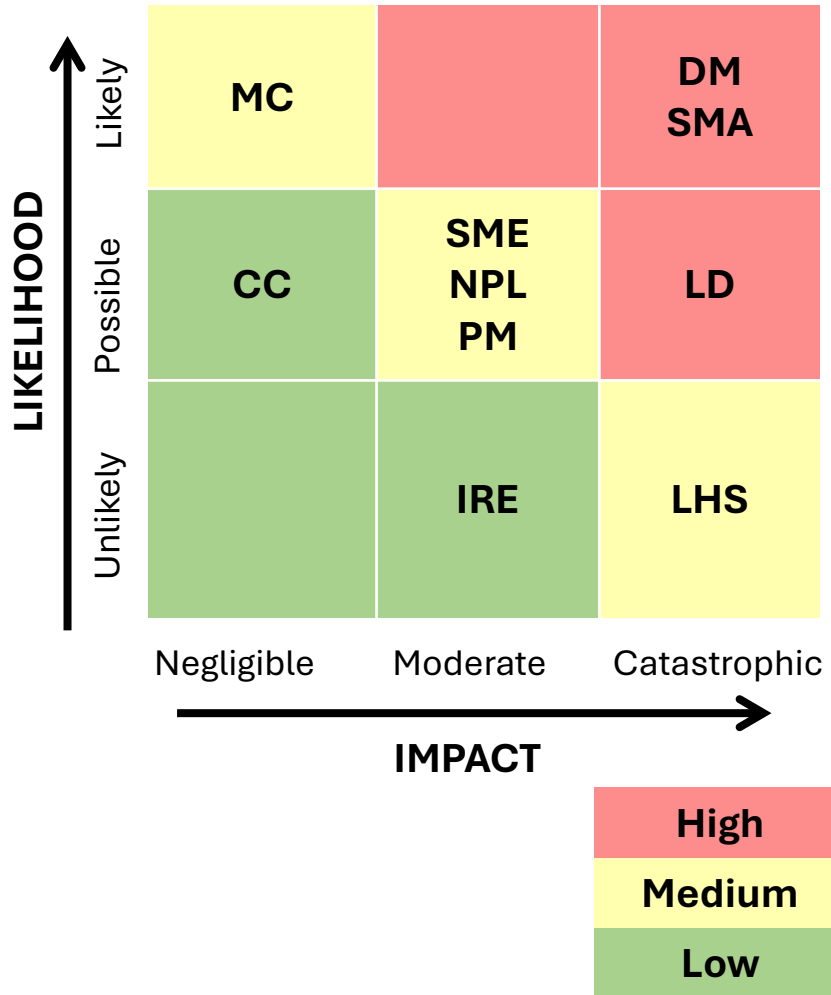
Debris Management and Nozzle System | L2 |

Motion Control and Sequencing Logic | L4 |





RISK ASSESSMENT



Criticality	Mitigation Approach	Risk Title	Abbreviation
High	Path Verification	Laser Beam Path Deviation	LD
High	Controlled Lamination	Solder Mask Adhesive Failure	SMA
High	Localized Purge	Debris Mismanagement	DM
Medium	Position Verification	PCB Tray Misalignment	PM
Medium	Alignment Control	Solder Mask Feed Error	SME
Medium	Thermal Management	Laser-Etching Hot-Spot	LHS
Medium	Pressure Sensor	Nitrogen Pressure Loss	NPL
Medium	Tension/Slip Monitoring	Mechanical Jam/Chain Slip	MC
Low	Tray Shielding	Conveyor Contamination	CC
Low	Software Startup Checks	Initialization/Reset Errors	IRE

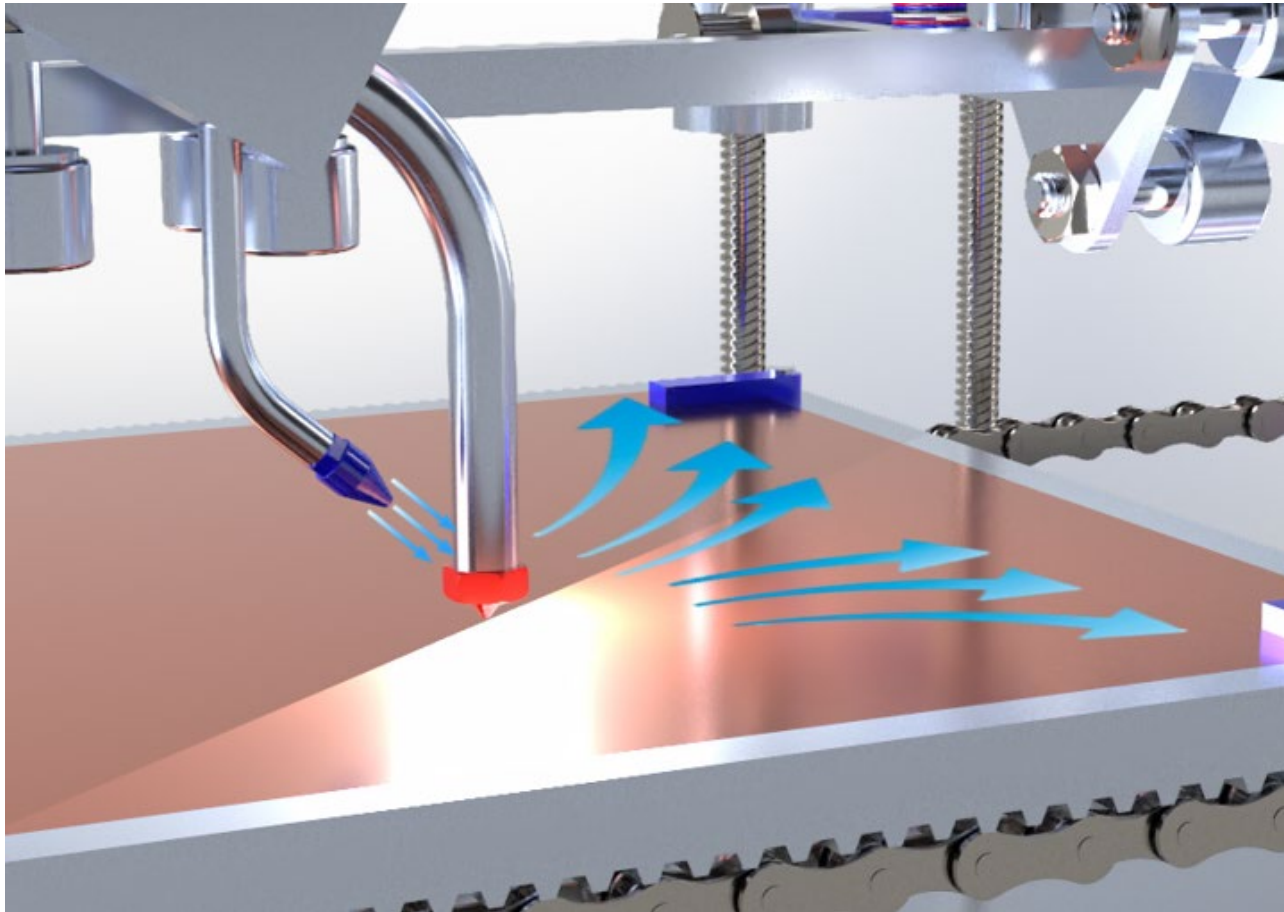


PROJECT OUTLINE

- **MISSION CONCEPT REVIEW**
- **SYSTEM REQUIREMENT REVIEW**
- **CONCEPTUAL DESIGN REVIEW**
- **PRELIMINARY DESIGN REVIEW**
- **LESSONS LEARNED**
 - **INNOVATIVE CONCEPTS**
 - **TECHNICAL GAP ASSESMENT**
 - **DESIGN CHALLENGES**
 - **SKILLS GAINED**
- **CONCLUSION**

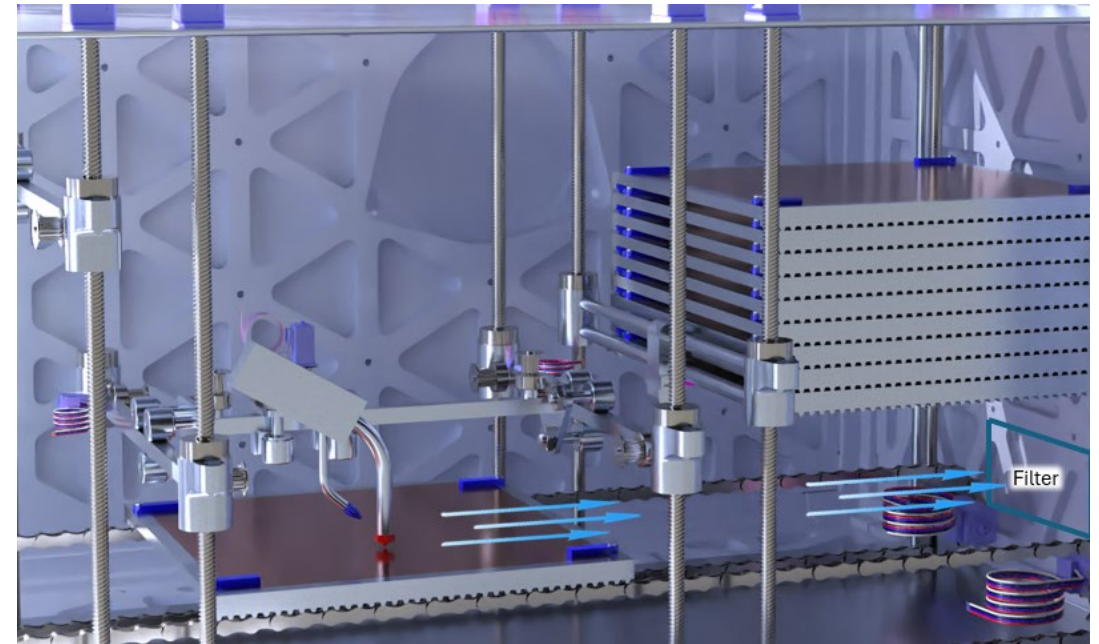


INNOVATIVE CONCEPTS



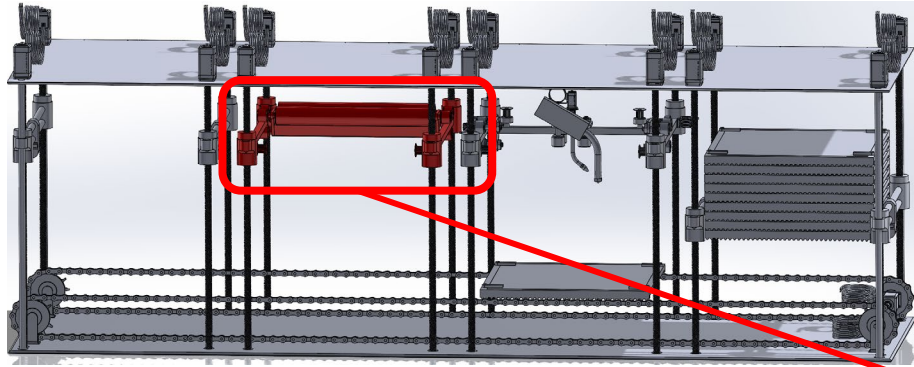
Debris Collection

Inert gas will be used to control where gasses and debris are expelled from the system to prevent interference with other components.



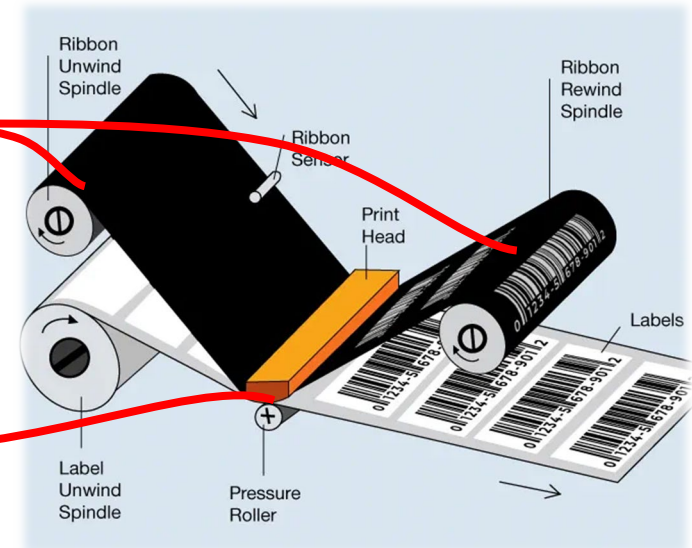
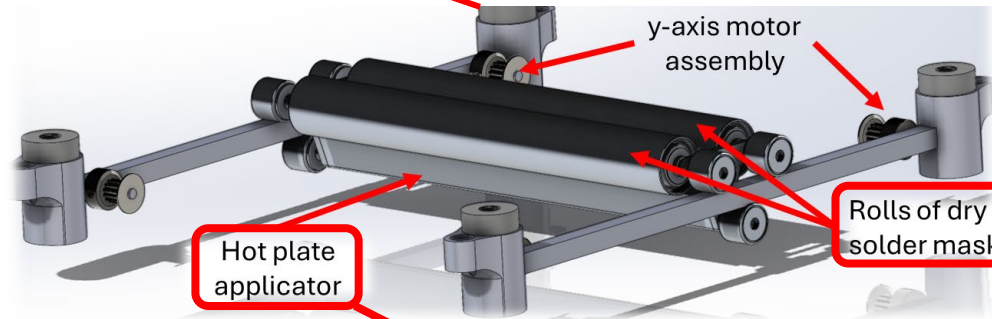


INNOVATIVE CONCEPTS



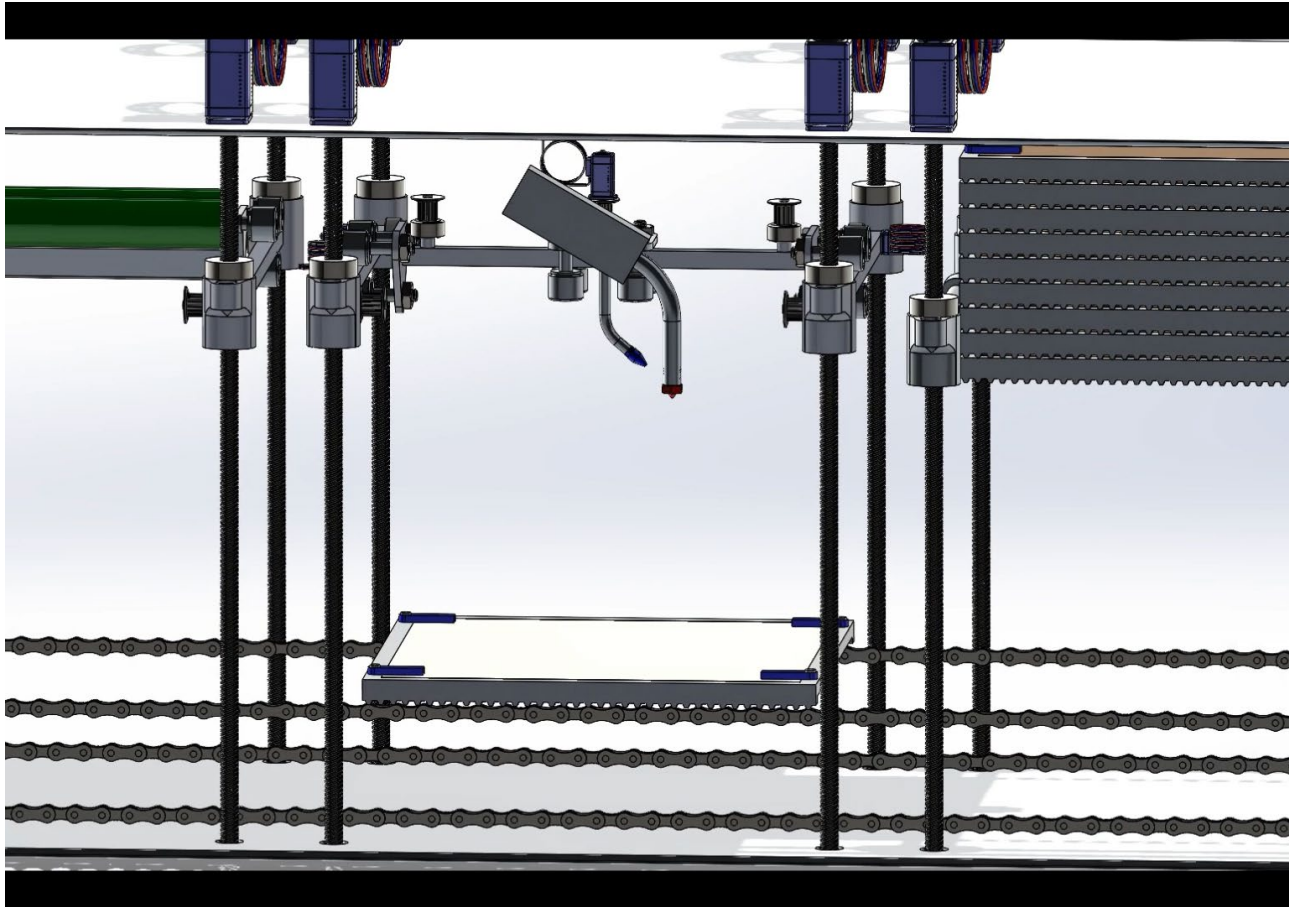
Thermal Printed Solder Mask

Combined technologies of dry solder masking and thermal printing to create a new process to apply a solder mask designed specifically for low-gravity environments.



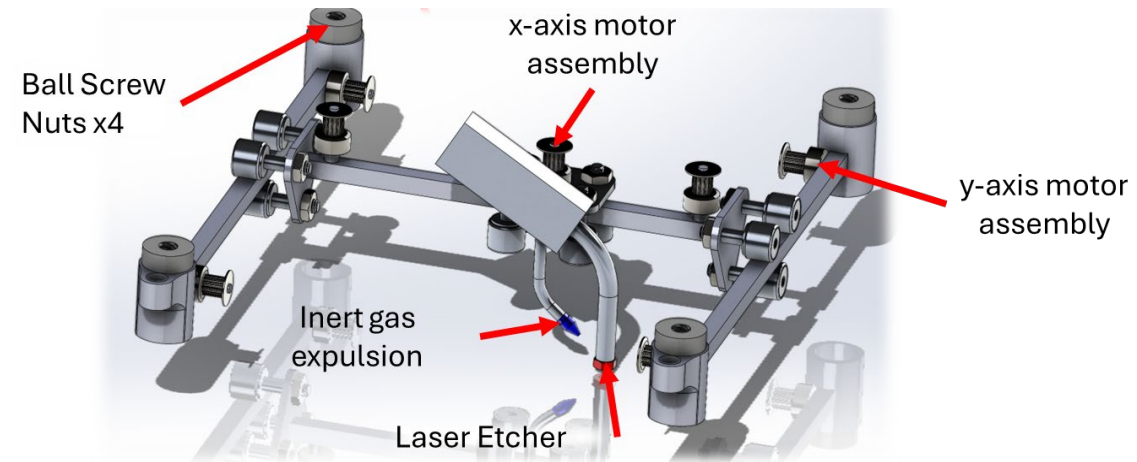


INNOVATIVE CONCEPTS



Laser Etched Traces

Pioneers a new method of PCB manufacturing in an untested operational environment.





TECHNICAL GAP ASSESMENT

1. To achieve the level of precision and accuracy needed for circuitry, there needs to be advancements in small laser etching technology, especially in vacuum environments.
2. Further research into debris expulsion or mitigation technology is necessary to ensure issues related to these factors do not impact ORCA's current setup.
3. Development of dedicated laser etch-able PCB blanks will need to be developed to prevent issues caused by current PCB technologies like excess off-gassing or warpage.



DESIGN CHALLENGES

1. Deciding which design path to follow delayed overall progress in the design.
2. Concerns over the extreme thermal conditions led to multiple revision changes.
3. Finding stepper motors that fit the profile outlined calculations and met the environmental requirements was difficult and required different iterations.
4. Debris expulsion and collection system.
5. Finding a solution on how to apply solder mask in low-Earth orbit.





SKILLS GAINED

1. Collaborative decision-making enabled the team to quickly break down problems into manageable parts.
2. Developed teamwork and conflict resolution skills.
3. Shifting the schedule to the left allowed us to effectively meet milestones.
4. Organizational practices helped to use resources and time efficiently.
5. The team gained experience in industry and government practices related to the storage and management of all digital documents, ensuring compliance with security policies.
6. Enhanced engineering skills: CAD animations, FEA, and heat transfer analysis.
7. Team gained soft and technical skills: PowerPoint, journal paper, and public speaking.



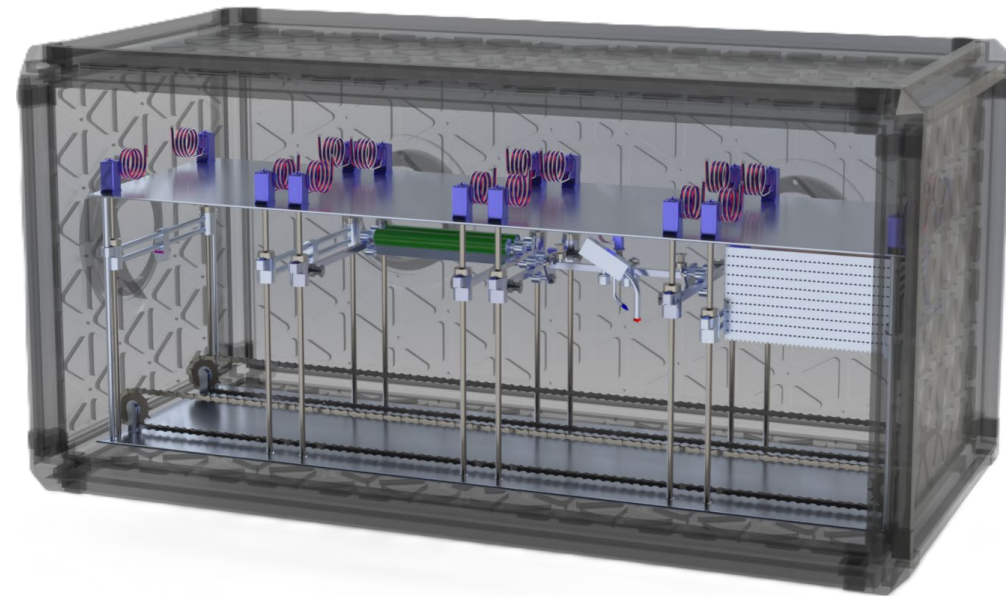
PROJECT OUTLINE

- **MISSION CONCEPT REVIEW**
- **SYSTEM REQUIREMENT REVIEW**
- **CONCEPTUAL DESIGN REVIEW**
- **PRELIMINARY DESIGN REVIEW**
- **LESSONS LEARNED**
- **CONCLUSION**
 - **FINAL REMARKS**
 - **KEY ACCOMPLISHMENTS**
 - **PROJECT IMPACT**
 - **CHALLENGES/RECOMMENDATIONS**
 - **SUGGESTED FUTURE WORK**



FINAL REMARKS

1. ORCA theoretically accomplishes the goal of manufacturing PCBs in orbit for use in multiple critical environments.
2. Deep Interstellar Solutions feels that the application for this technology have the capability to revolutionize the aerospace industry and hope that this research is valuable to the industry moving forward.
3. Currently, this concept has not been tested and is still in the beginning stages of design; however, it is with full faith in the work put forth that Deep Interstellar Solutions submits its findings.





KEY ACCOMPLISHMENTS

1. The development of an innovative, useful, and necessary concept to fulfill the challenge presented by COSMIC is Deep Interstellar Solutions proudest accomplishment.
2. DIS put forward a comprehensive multi-subsystem engineering and simulation effort that considered a wide range of criteria and possible issues.
3. DIS worked with engineers in industry to tailor our design using current cutting-edge technologies.
4. DIS accomplished its goal of maintaining 60% COT components.
5. DIS developed multiple conceptual changes to current technology to suit the needs of ORCA, including an inert gas debris management system, a zero-gravity solder mask film applicator, and a PCB storage and conveyor system.
6. Finally, DIS met or exceeded the design requirements of The COSMIC Challenge.



PROJECT IMPACT ON AEROSPACE INDUSTRY

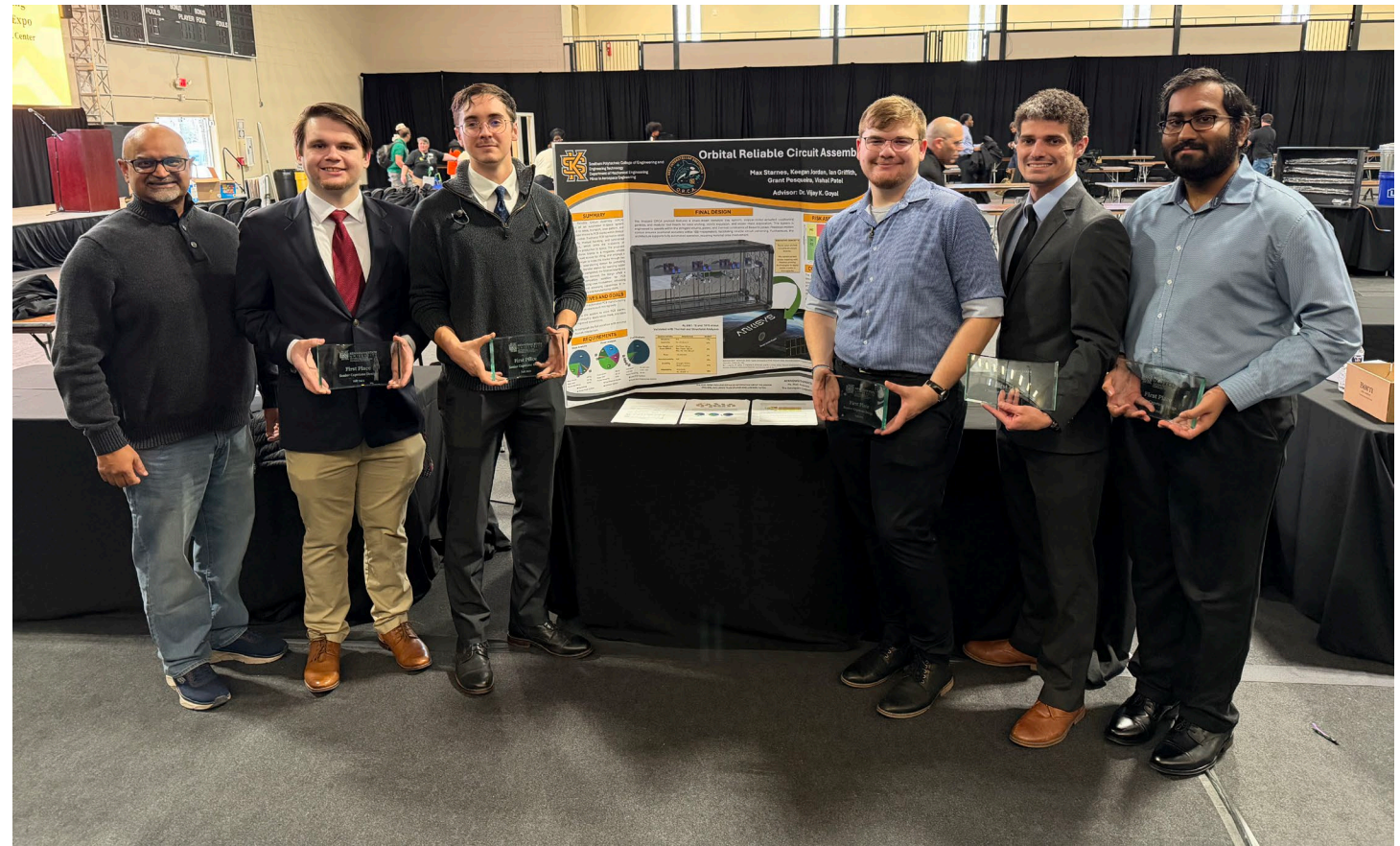
1. Reduces reliance on resupply missions for custom components.
2. Opens the door for in-space manufacturing of mission or case specific tools or equipment.
3. Bridges the gap that currently exists between Earth-based manufacturing and in-space manufacturing capabilities of electronic components.
4. Drastically increases the capabilities of a crew to accomplish mission objectives, be self-reliant, and innovate in their approach to issues that may arise.





PROJECT IMPACT ON STUDENTS

1. This concept sets the stage for future advancement in ISAM capabilities.
2. DIS became familiar with how aerospace innovations translate disproportionately into other areas of engineering.
3. This project has inspired many members of DIS to pursue careers in the aerospace field.
4. The C3 challenge showed DIS how critical ISAM is to future exploration of space.





CHALLENGES AND RECOMMENDATIONS

1. Thermal simulations were conducted using steady-state extremes instead of transient temperature cycles.
 - Recommend identifying adverse effects from rapid heating/cooling.
 - Recommend evaluating mechanical performance under true conditions.
2. Behavior between components was based on assumed optimal performance in microgravity.
 - Recommend evaluating true friction and torque behavior in a vacuum.



SUGGESTED FUTURE WORK

1. Fail-safes were conceptually implemented but not yet validated through testing.
 - Plan to implementing redundant sensors and real-time fault detection for PCB validation and safeguarding.
2. Concepts for circuitry testing were discussed, however, time constraints meant little development was done.
 - Investigate probing system to test contacts and circuitry.
3. Do further testing into laser capabilities and research into vacuum rated models.
4. Further validate and confirm specifications and simulation results.



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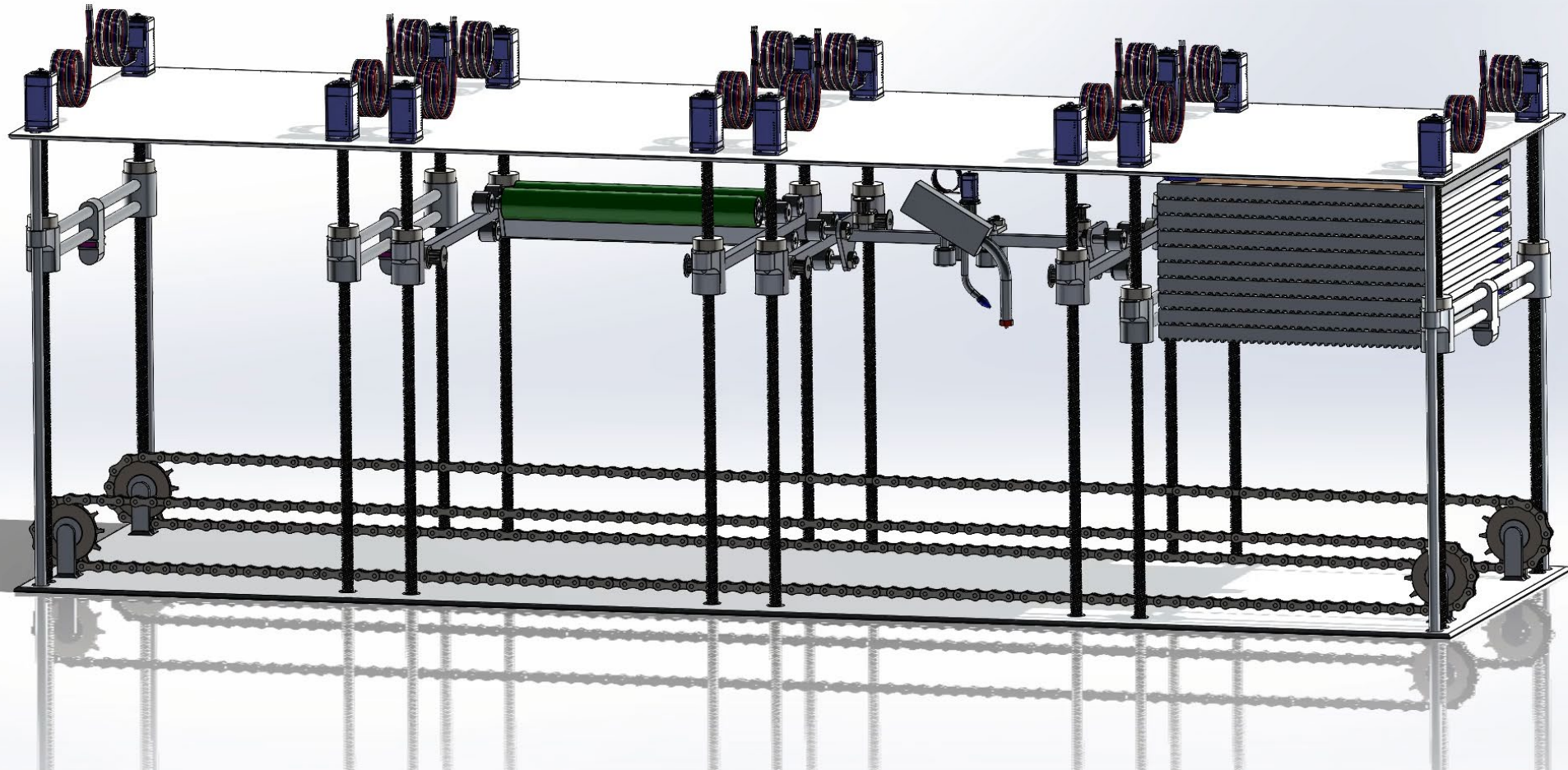


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QUESTIONS ?



BACK-UP SLIDES