Project Daedalus

Team H.A.D.E.S.

4/16/2025

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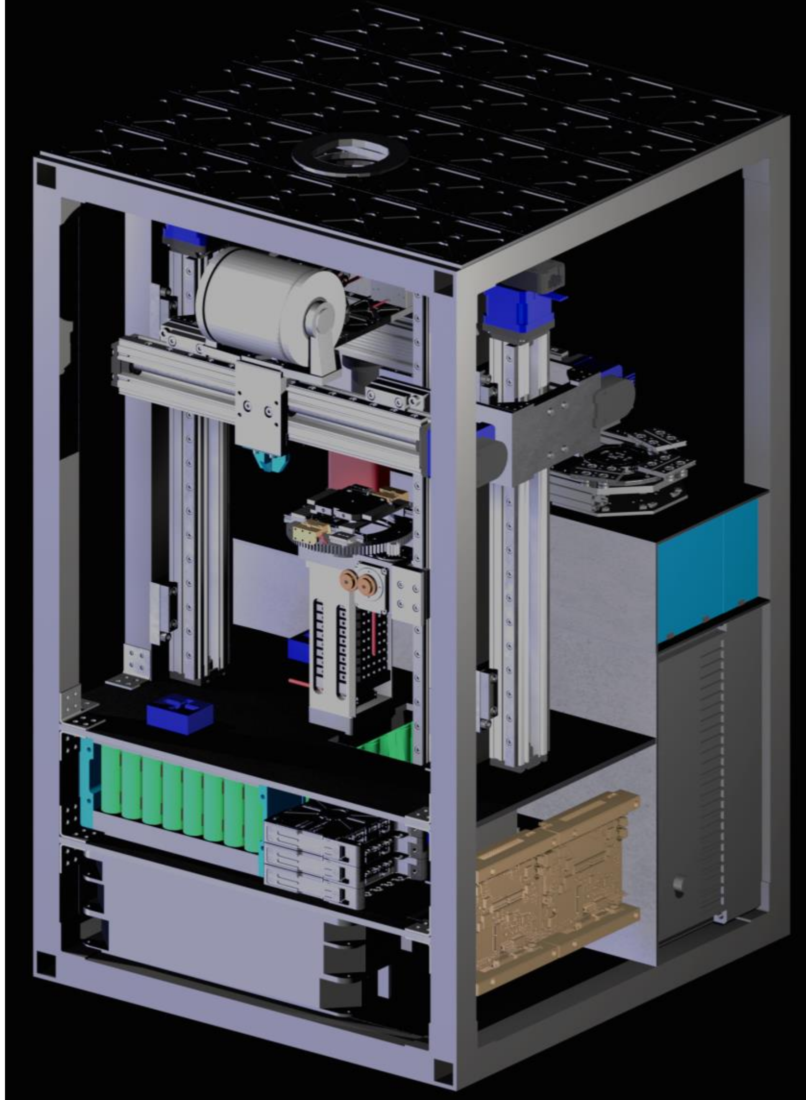
COSMIC
CONSORTIUM FOR SPACE MOBILITY AND ISAM CAPABILITIES

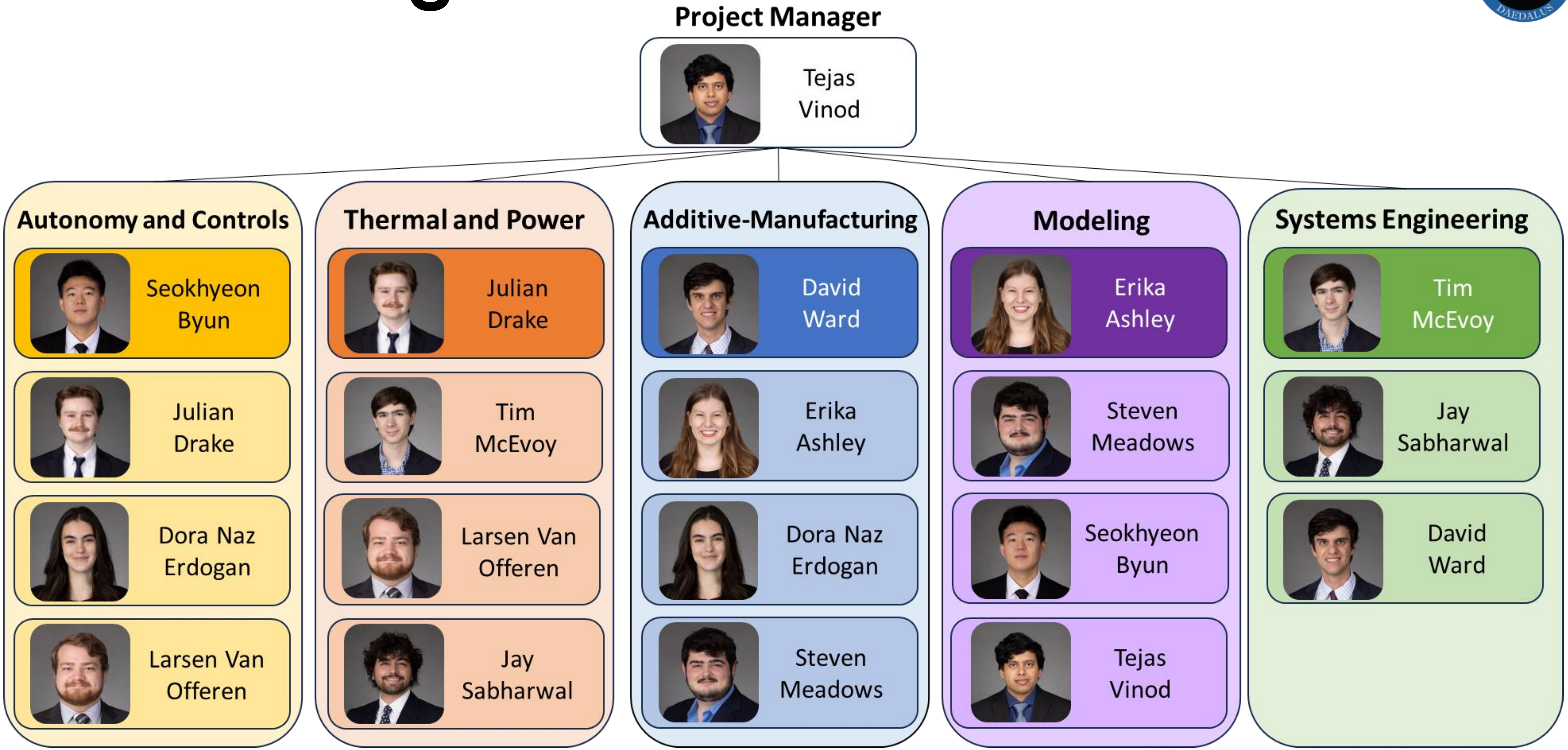
COLLEGE OF ENGINEERING
KEVIN T. CROFTON DEPARTMENT OF AEROSPACE AND OCEAN ENGINEERING
VIRGINIA TECH

Executive Summary

- Team H.A.D.E.S. has developed a system within the ISAM domain focusing on structural manufacturing and assembly
- This project will use Directed Acoustic Energy Deposition (DAED), a novel low-power additive manufacturing method, to fabricate aluminum structures in LEO and subsequently assemble them using a laser-based weld system
- The payload demonstrates integration of advanced manufacturing processes, novel assembly methods, and AI-powered defect detection, all within the restrictions of the Blue Canyon Technologies' (BCT) Venus-Class Bus



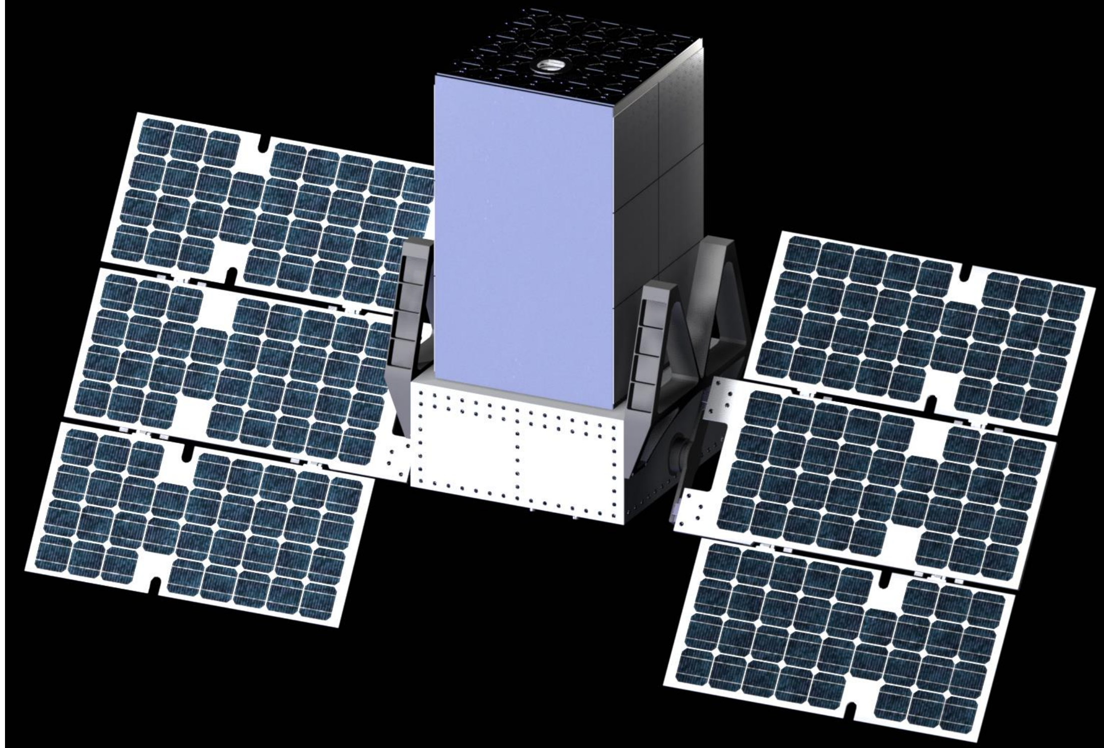
Team Organization Chart



BCT Venus-Class Bus

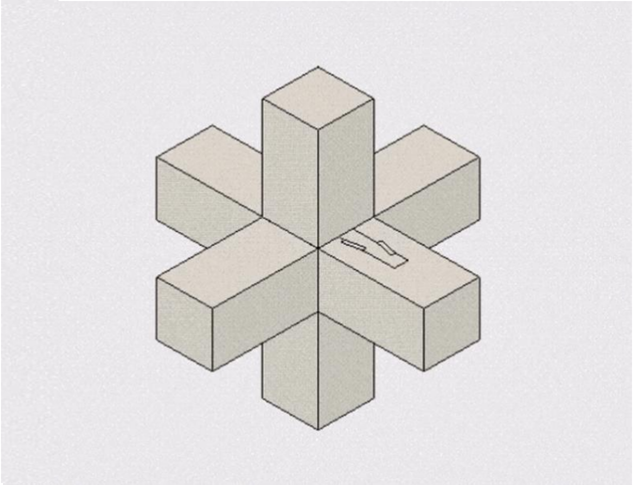
Specification	Value
Bus Class	ESPA Standard
Pointing Accuracy	±0.002°
Slew Rate	> 1.5°/s
Solar Array Power	444 W
Orbit Average Payload Power	**60 W**
Energy Storage	13.6 Ah
Payload Volume	17.0"x16.4"x27.0"
Orbit Lifetime	> 5 years in LEO
Bus Dry Mass (Without Payload)	64 kg
Max Payload Mass	**78 kg**
Science Data Downlink	S-Band (<2 Mbps)
Propellant Capacity	10 kg
Max delta V	50 m/s

[1,2]



Considered Concepts

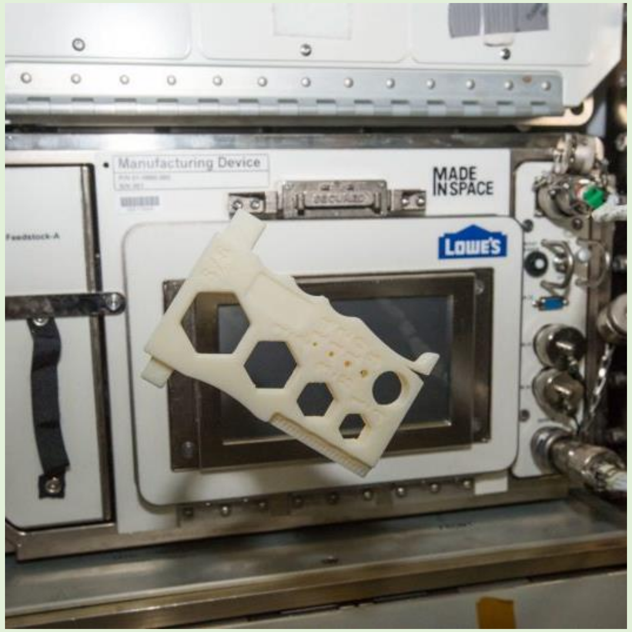
1. Reusing Earth's polymer waste for space 3D printing
2. Space coating for repair & atomic oxygen resistance hardening
3. Traditional East Asian architectural joint for space structures



Traditional East Asian joint method. Traditional East Asian joint assembly was considered for in-space structural assembly early in concept development. It was not pursued due to the precision required to join the pieces together [3,4].

Project Daedalus Final Selection

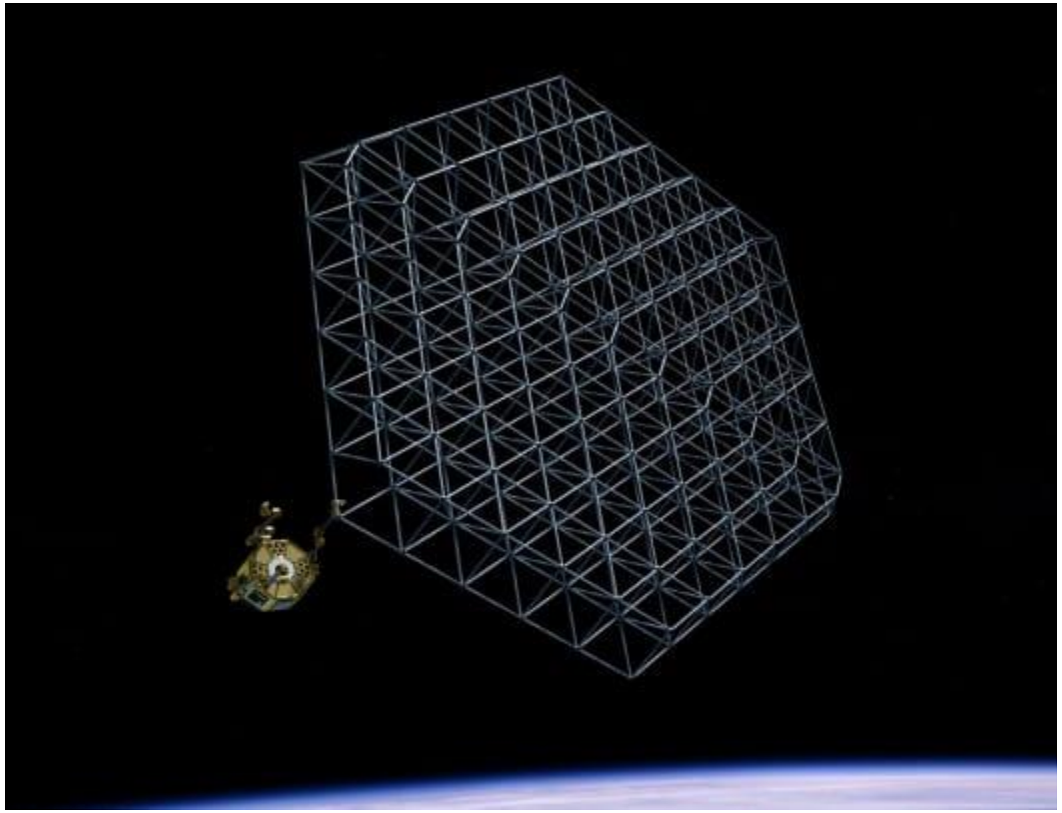
In-Space Additive Manufacturing



In-Space Additive Manufacturing Experiments. These test samples were manufactured on the ISS with the Made In Space polymer 3D printer (left) and the Airbus LDED additive manufacturing system (right) [5,6].

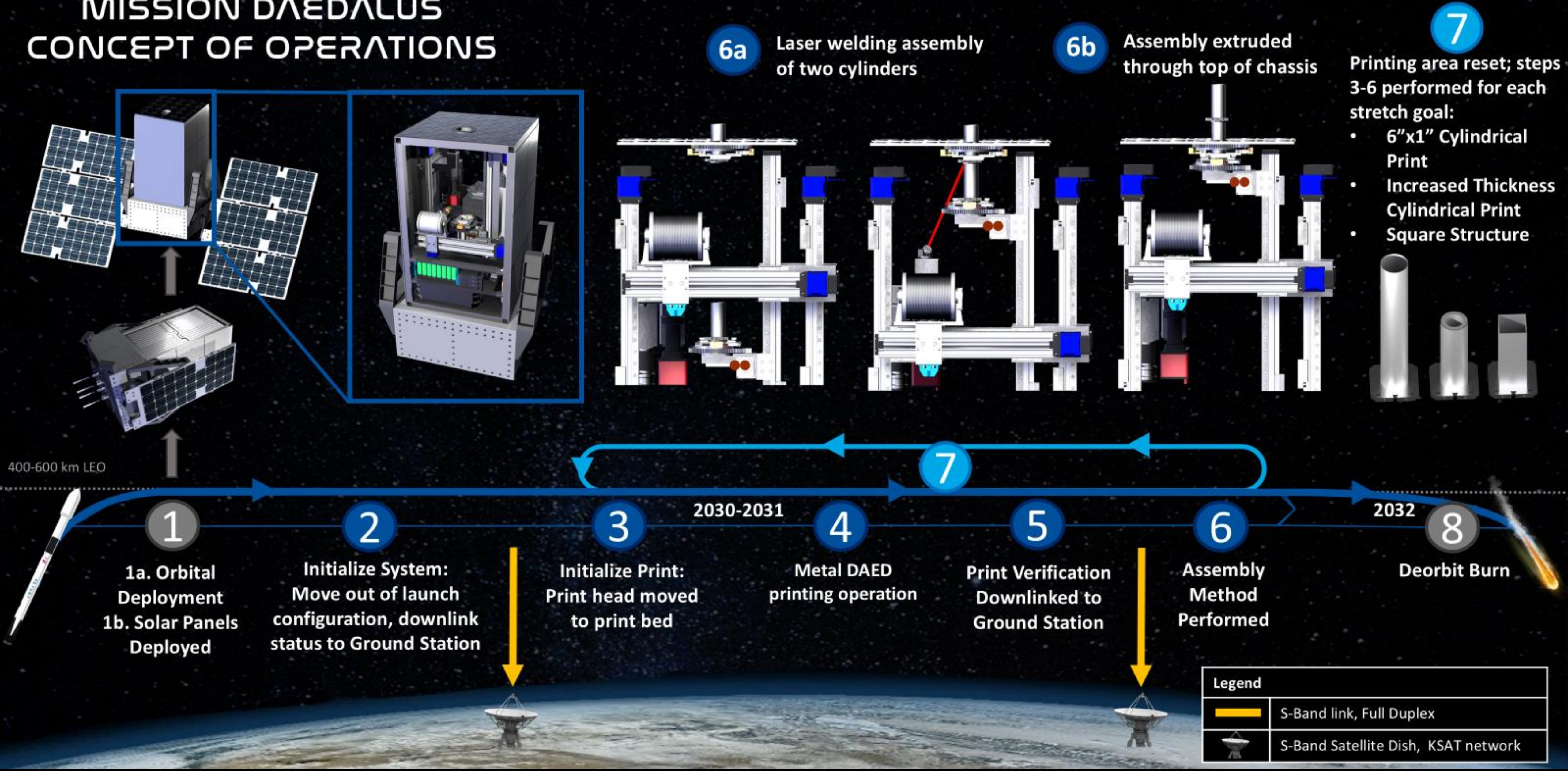
Impact

- The goal is to successfully print 3D printed cylindrical beams and prove the concept of assembly in space
- Structures optimized for space rather than launch
- Supports new or improved types of spacecraft
  - Enables on-demand part production
- Allows for more efficient repair of existing satellites
  - Spacecraft components can be replaced
  - Increases the satellite lifespan
- Prove new technologies in space



Concept of In-Space Structural Fabrication. Demonstrating the ability to fabricate and assemble structures in space would enable future missions to manufacture large structures without the restrictions launch puts on modern space vehicles. This concept art was developed by Made in Space [7].

MISSION DAEDALUS CONCEPT OF OPERATIONS



Additive Manufacturing

- Compared four AM technologies in a trade study
- Directed Acoustic Energy Deposition was found to be optimal for the mission

Material Extrusion
- Low power
- Good resolution
- Active on-orbit use

Laser Directed Energy Deposition
- High power
- Fast deposition
- Active on-orbit use

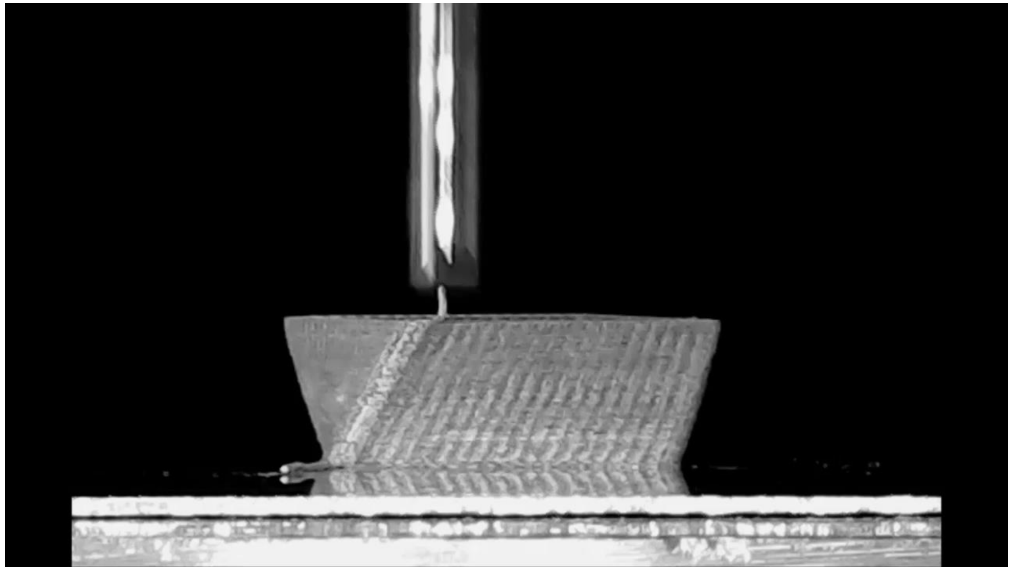
Electron Beam Directed Energy Deposition
- High power
- Fast deposition
- Radiation concerns

Directed Acoustic Energy Deposition
- Low power
- Highly experimental
- Not microgravity tested

	Power Required (W)	System Volume (m^3)	System Mass (kg)	Research Value		Sources
	Minimize			Maximize		
Weights	0.331	0.167	0.148	0.354	Results	
DAED	100 – 300	0.05	20	3	0.36	[8-16]
MEX	150 – 200	0.05	17	1	0.29	[8-12,17-20]
EDED	500 – 600	0.06	40	2	0.21	[8-12, 20-22]
LDED	750 – 900	0.06	40	1	0.14	[8-12, 22-24]

DAED Printing

- Experimental additive manufacturing technology
- Acoustically soften feedstock material during compression
- Deposit voxels layer by layer



DAED Additive Manufacturing. The DAED AM process is demonstrated in the video by the ASU School of Manufacturing, Systems and Networks to the left. Wire feedstock is deposited and compressed by a vibrating toolhead to form a voxel in the build area. The finished product of this print is shown to the right [15].

Deposition Parameters	
Shear amplitude	1.1 μm
Shear frequency	60 kHz
Compression time	0.03 s
Compression load	100 N
Realignment time	1.0 s
Wire diameter	0.35 mm
Voxel plane area	0.48 mm^2
Voxel height	0.12 mm
Wire feed rate	0.4 mm/s

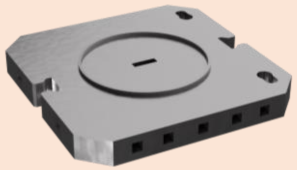
System Parameters	
Operating Power	100 W
Mass Estimate	10.8 kg
Build Volume	375 cm^2

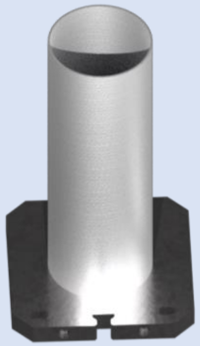
Mission Success Criteria

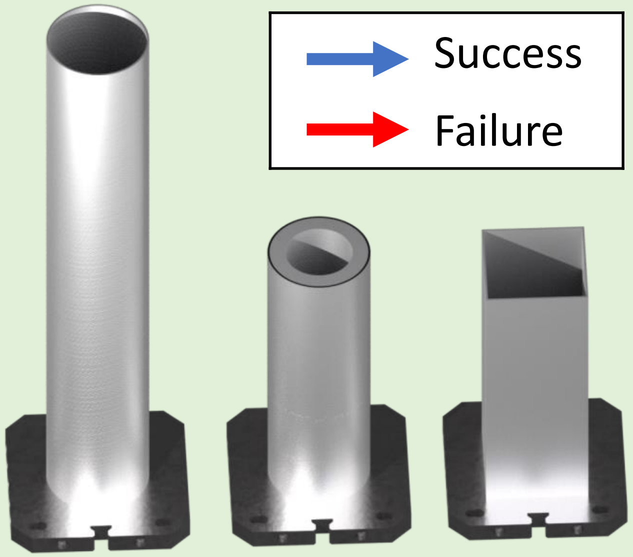
Initialization

Prefabricated Specimens

Minimum Success Condition	Optimal Success Condition	Stretch Goals
Deposit one voxel layer of a cylinder specimen	Print a 3 in. high cylinder specimen	Printing additional shapes/parameters
Laser weld two finished parts along circumference	Repeated assembly	Test weld strength



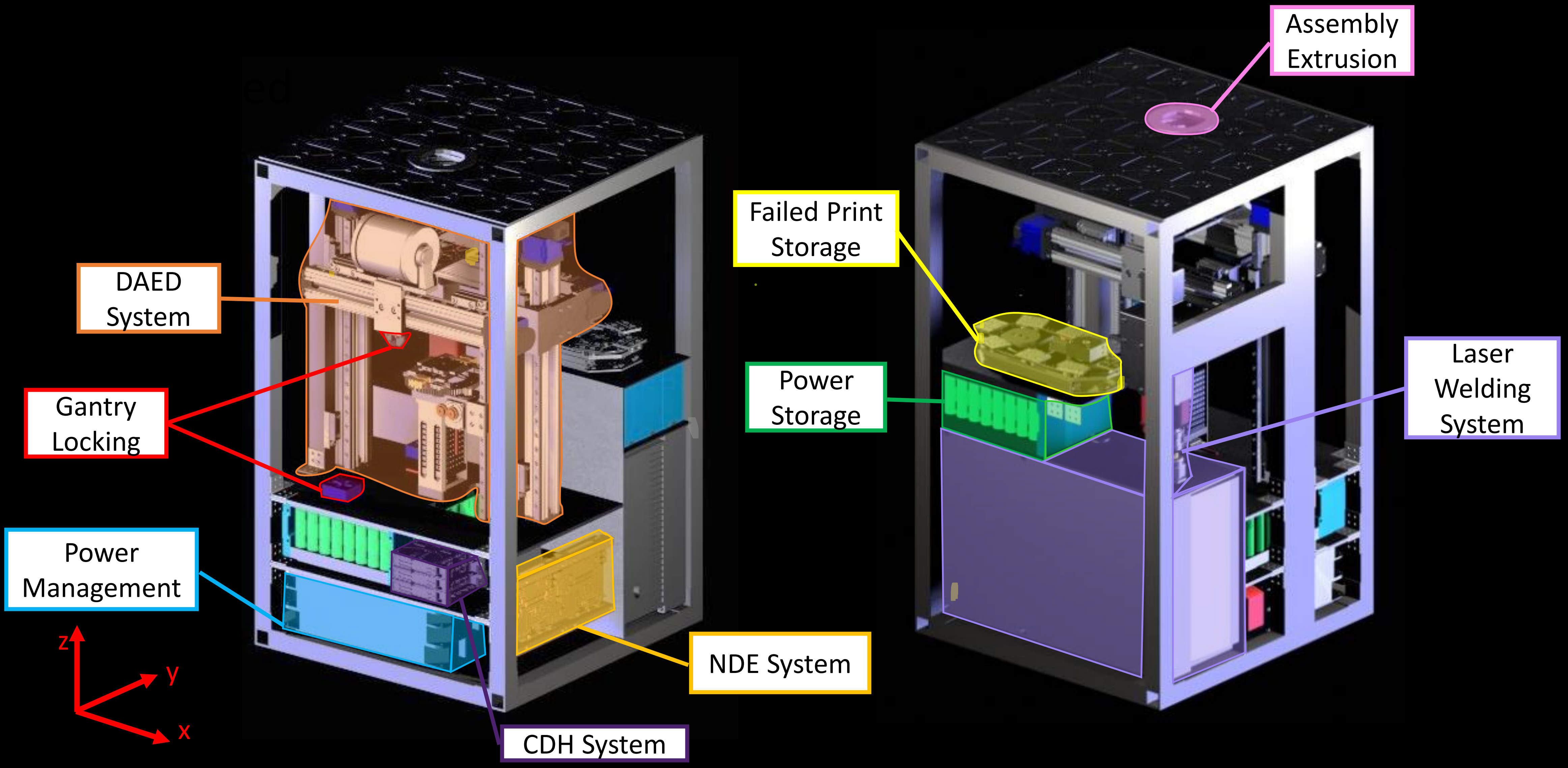




Success

Failure

Payload Overview

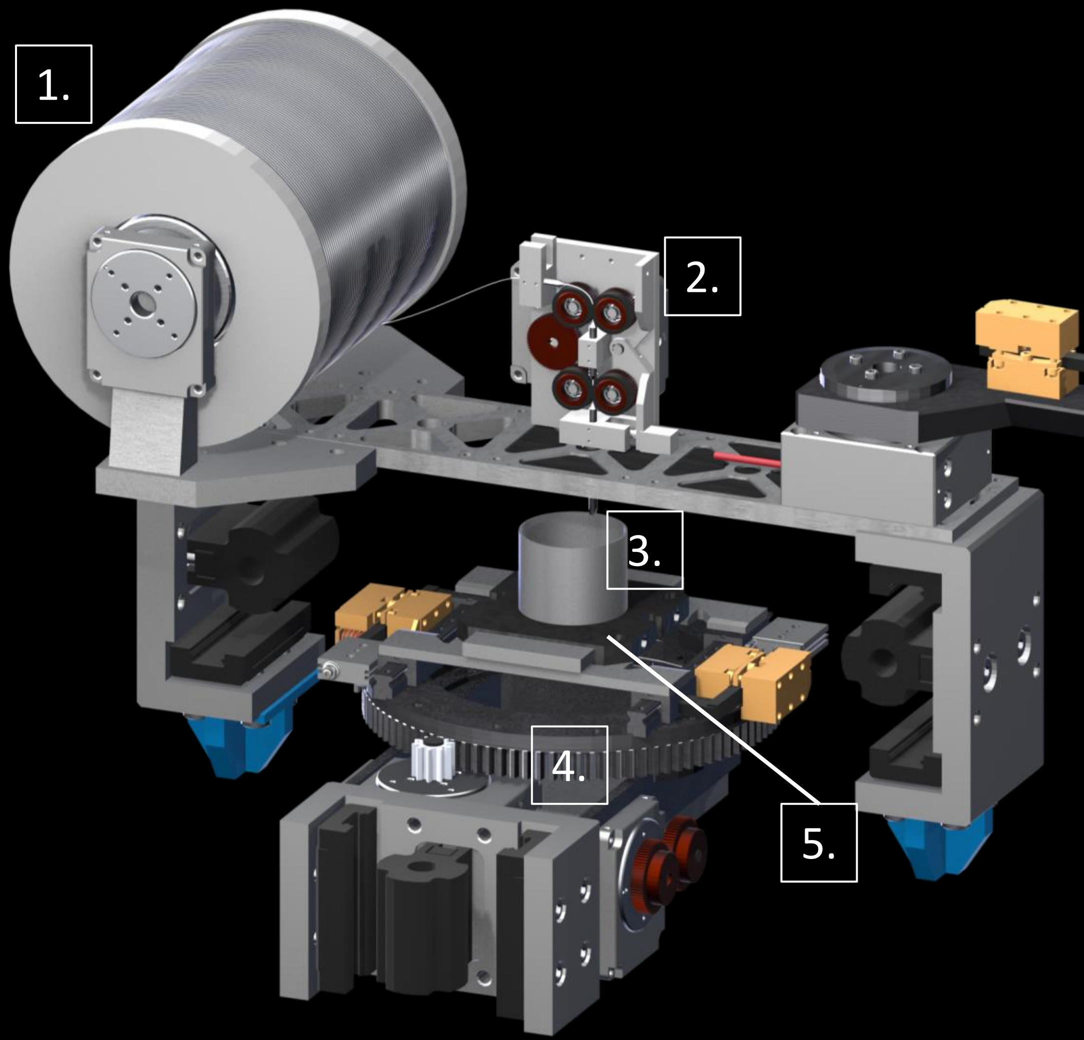


Key Components

1. Al 6061 feedstock spool
2. Wire Feeder
3. Deposition head
4. Rotational traversal system
5. Consumable substrates

Not Pictured

- Print graveyard
- Prefabricated samples to enable assembly should deposition fail



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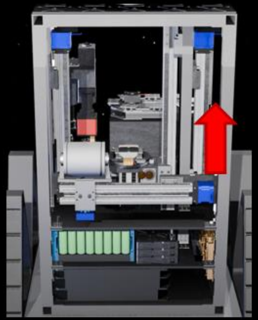
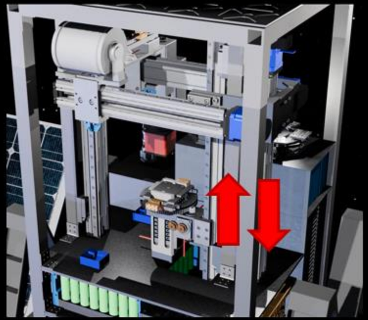
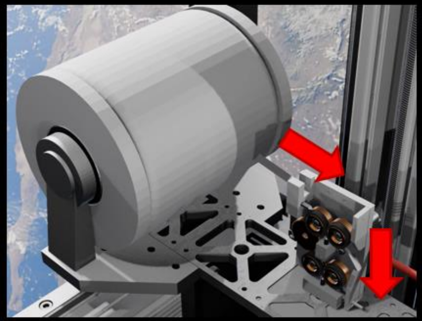
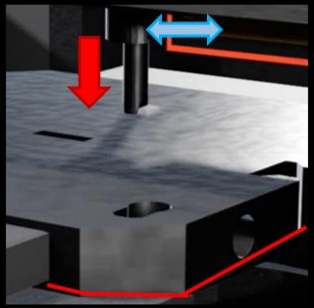


1b.





3a.



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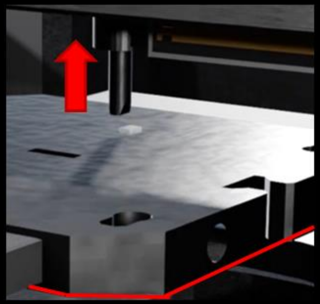
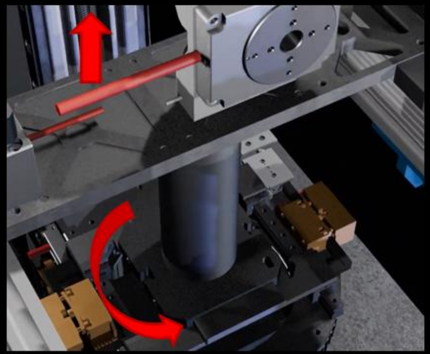


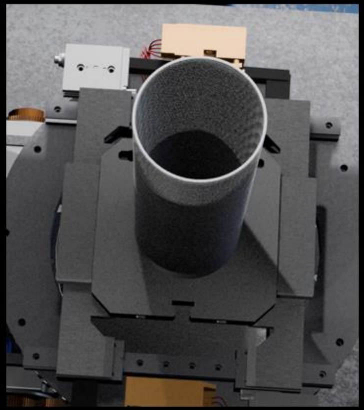


1 Initialize System
1a. Move from launch configuration.
1b. Subsystem checks performed; system diagnostics downlinked to ground station.

2 Filament Preparation
Filament is directed into feed tube for plasticization. Substrate is heated to 121° Celsius.

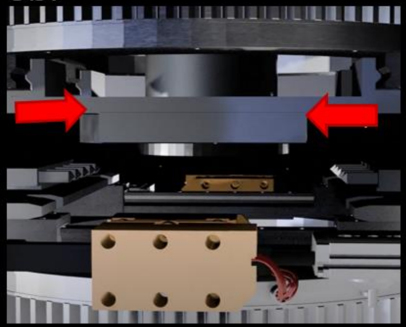
3 Place Filament
3a. Filament is plasticized by 60 kHz transducer. Voxel of filament is deposited and compressed
3b. Nozzle returns to initial position

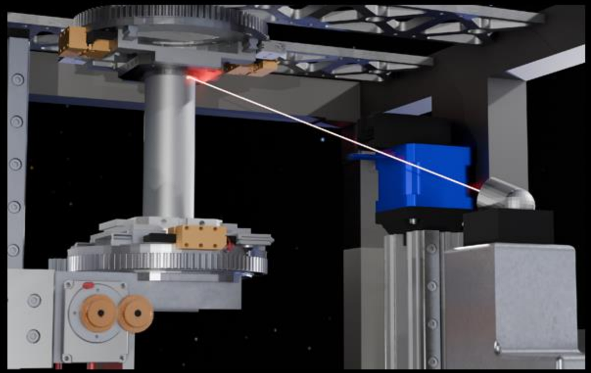
4 Spin Print Bed
Operations 3a and 3b are continued while the print bed spins for each layer of filament building a cylinder.

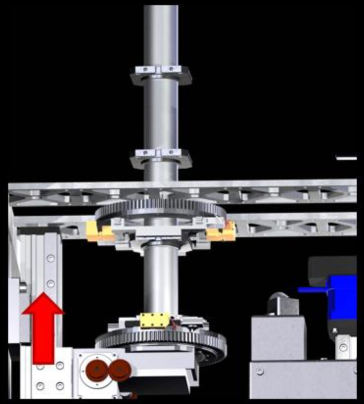


6a.

6b.







5 Finish Print
Print head is returned to original position. Print quality is analyzed and downlinked to ground station.

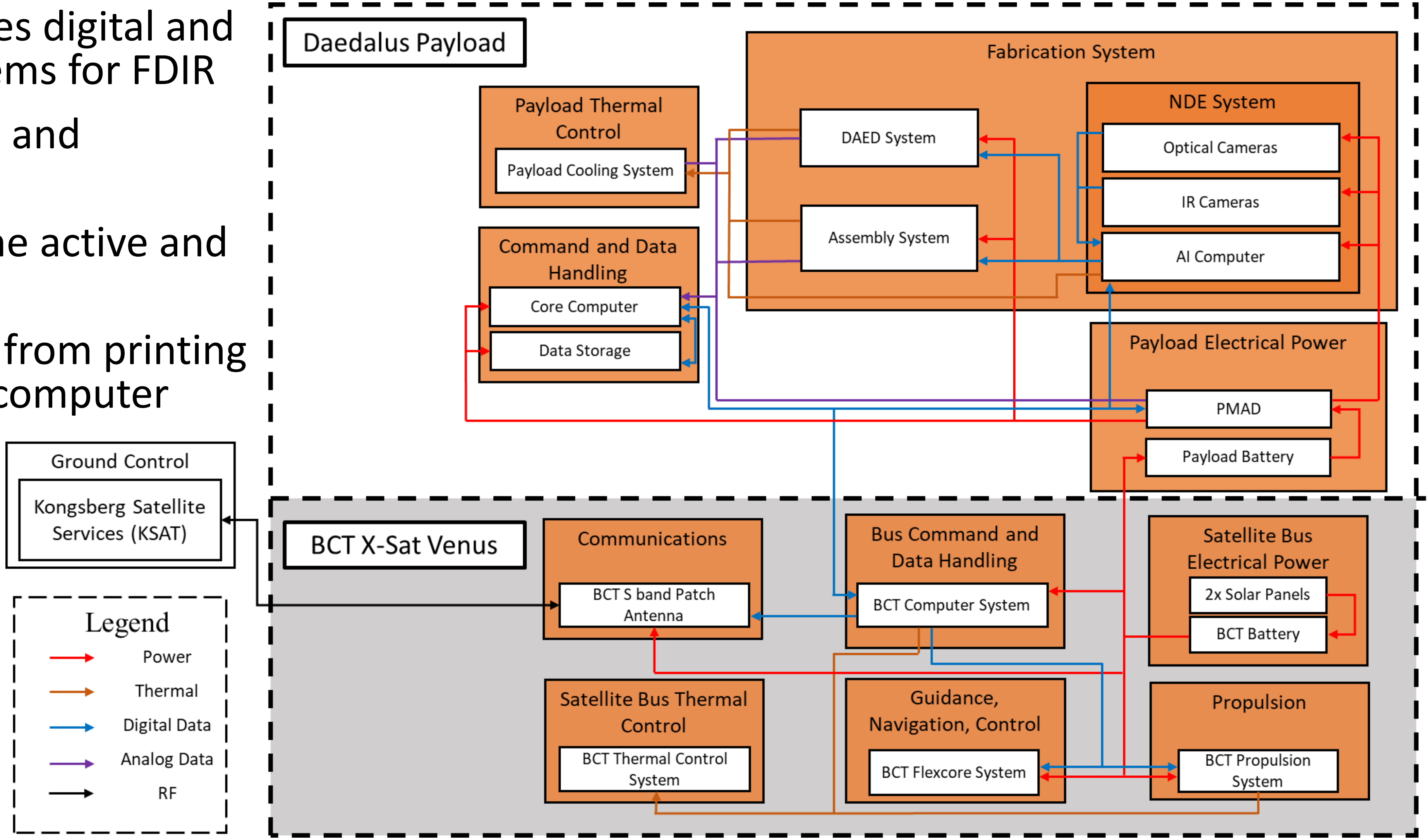
6 Initialize Print Assembly
6a. Finish print is maneuvered and
6b. secured to assembly position.
Operations 2-5 repeated for next print.

7 Laser Weld
Next print is maneuvered and secured to assembly position. Laser is powered to weld the seam between the prints.

8 Finish Assembly
Assembled prints are moved and secured upwards out of the chassis. Operations 2-7 repeated until mission criterion satisfied.

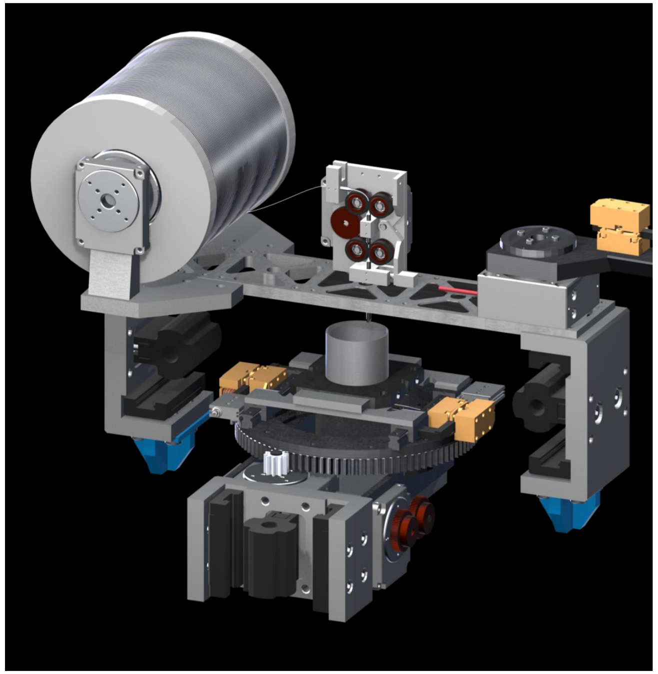
System Block Diagram

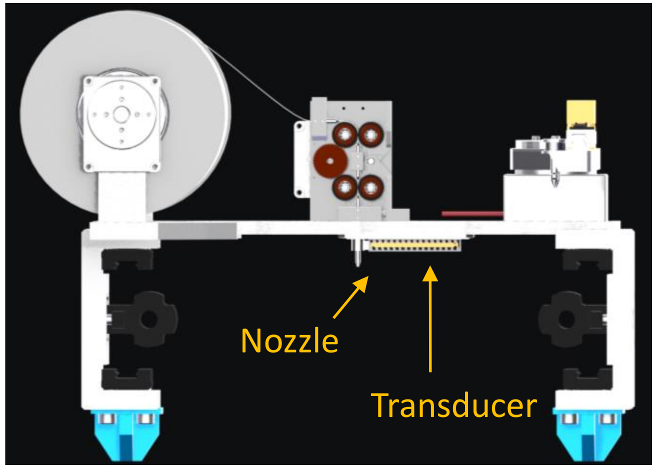
- The core computer receives digital and analog data from subsystems for FDIR
- PEP: Battery storage level and temperature data.
- PTC: Thermal data from the active and passive systems
- Fabrication: Thermal data from printing bed, laser chassis, and AI computer
- Ground will receive intermittent data packets and have command uplink capability for non-resolvable faults



Additive Manufacturing System

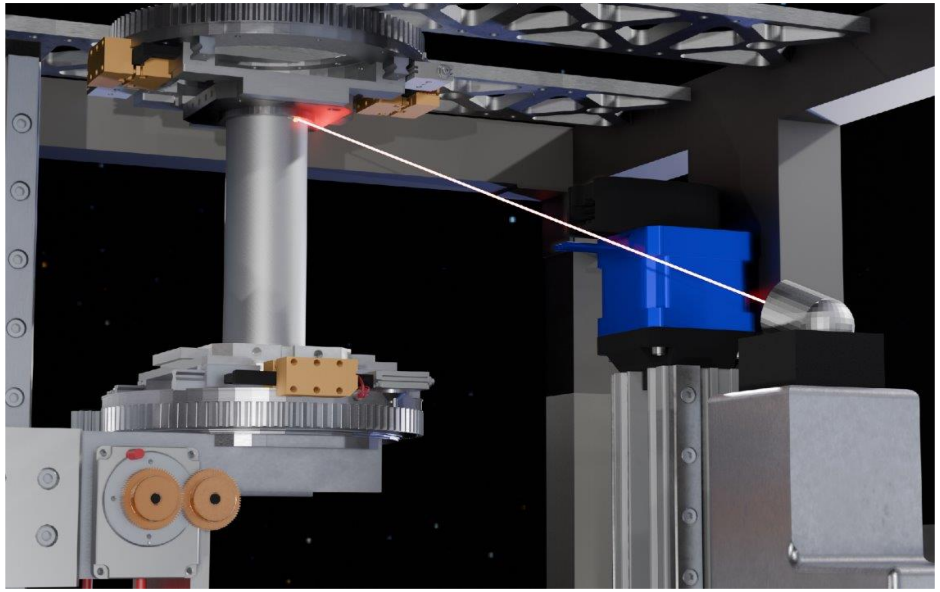
- Resistive heater embedded in substrate
- 28-gauge aluminum feedstock
  - Feedstock motor: Xeryon XRT-U-25 [26]
- P885.11 Piezoelectric Transducer at 60 kHz [25]
- 891 Wh (82% Battery) per inch printing
  - 5.17 hours of printing required
- Maximum print volume
  - 7.0”x2.0”x2.0”

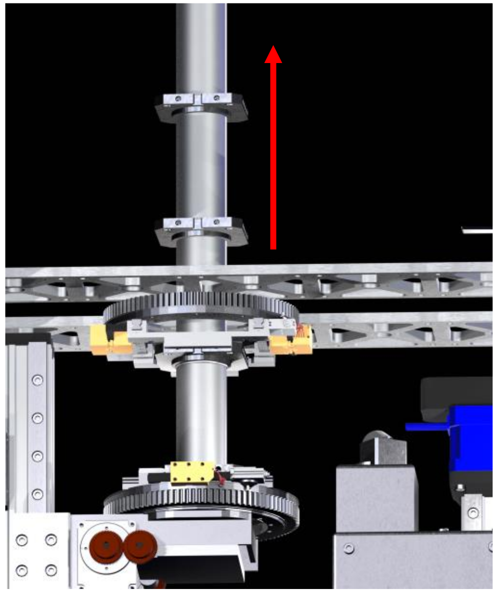




Assembly System

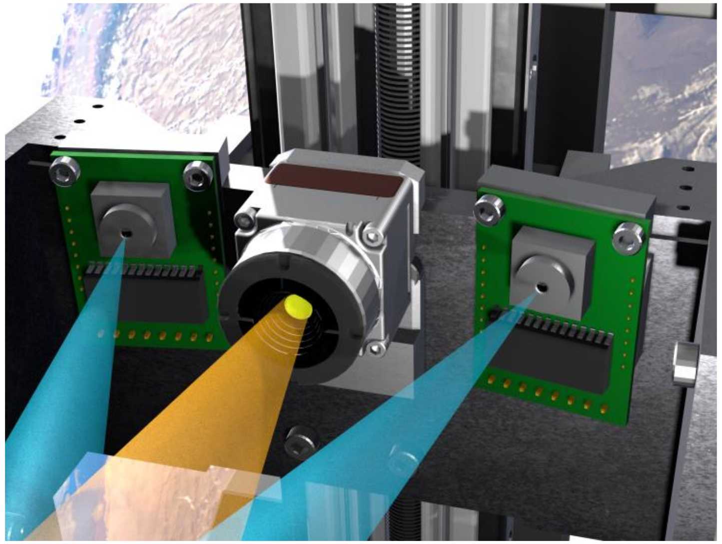
- Modified YLM-150/1500-QCW Fiber Laser [27]
  - 450 W average power
- LDW100 MINNI Robotic Wobble Head [28]
- 3.14” weld circumference
  - Weld time estimate: < 2 min
  - Energy for single weld: 99 Wh (~9% Battery)

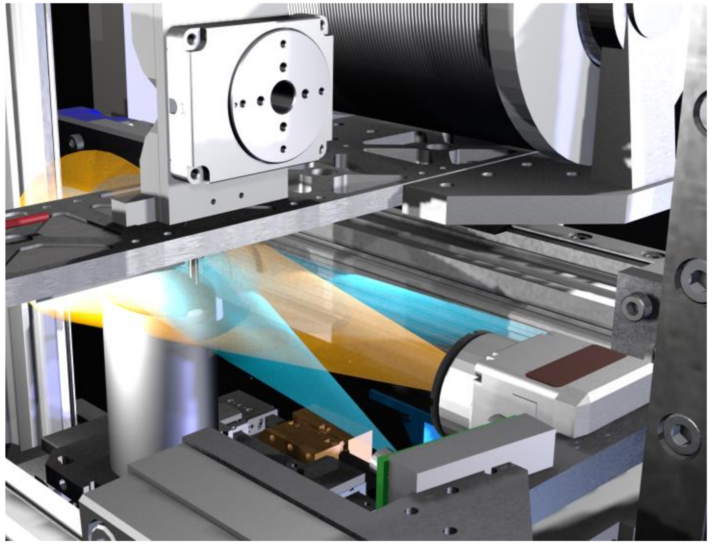


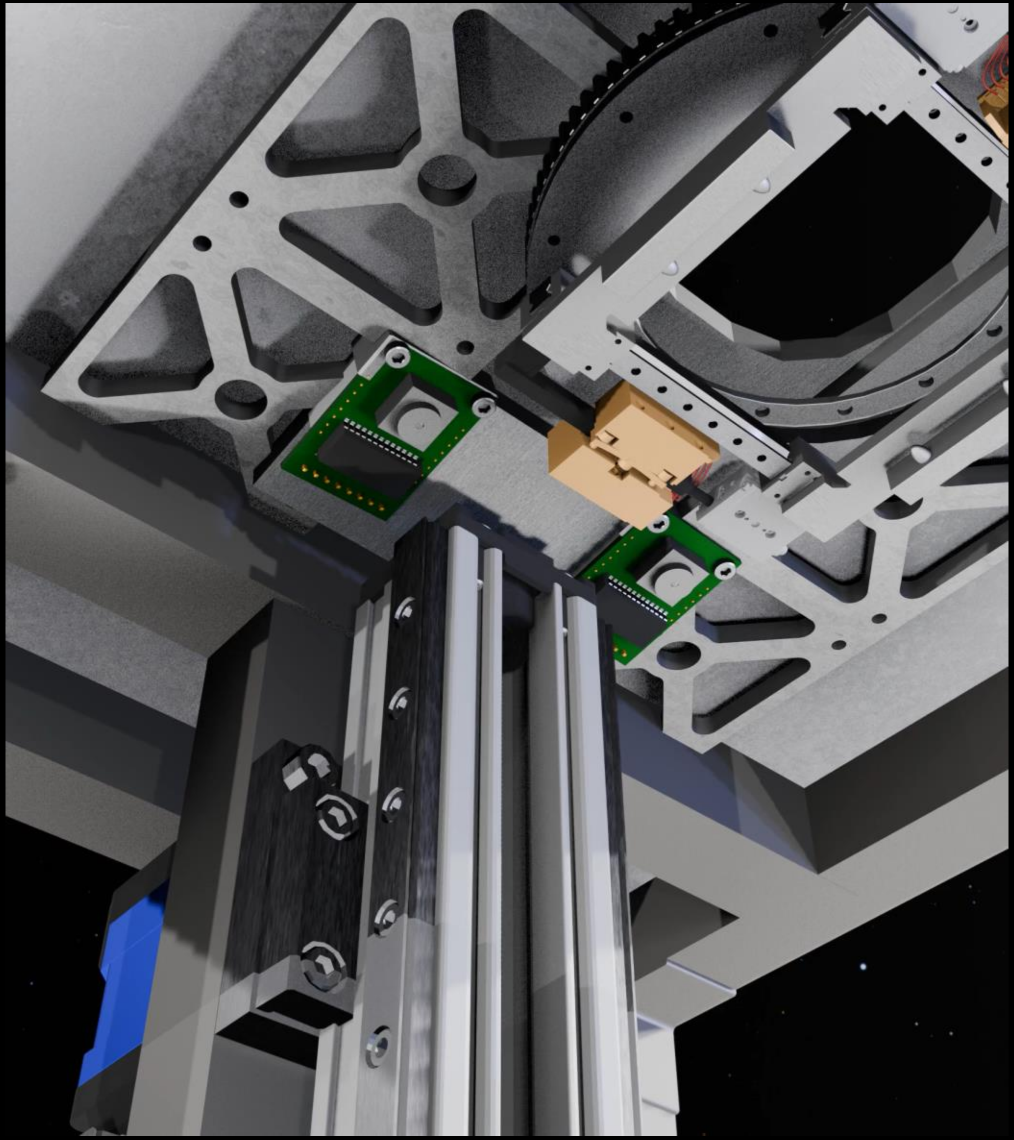


Non-Destructive Evaluation System

- Printing Monitoring:
  - Detects surface-level defects via transfer learning with (CNNs) using optical camera data [29]
- Assembly Monitoring:
  - Short-range inspection of thermal anomalies using IR camera [30]
- NVIDIA Jetson Xavier NX
  - AI computer, 21 TOPs, 16GB [31]
- Optical camera (Arducam IMX219)
  - 3280x2464 resolution, 1.0 W, MIPI compatible, 3” focal range [32]
- IR camera (FLIR Boson+)
  - 320x256 resolution, 0.3–0.5 mils wavelength, 0.5 W, optimized for 2”–8” range [33]

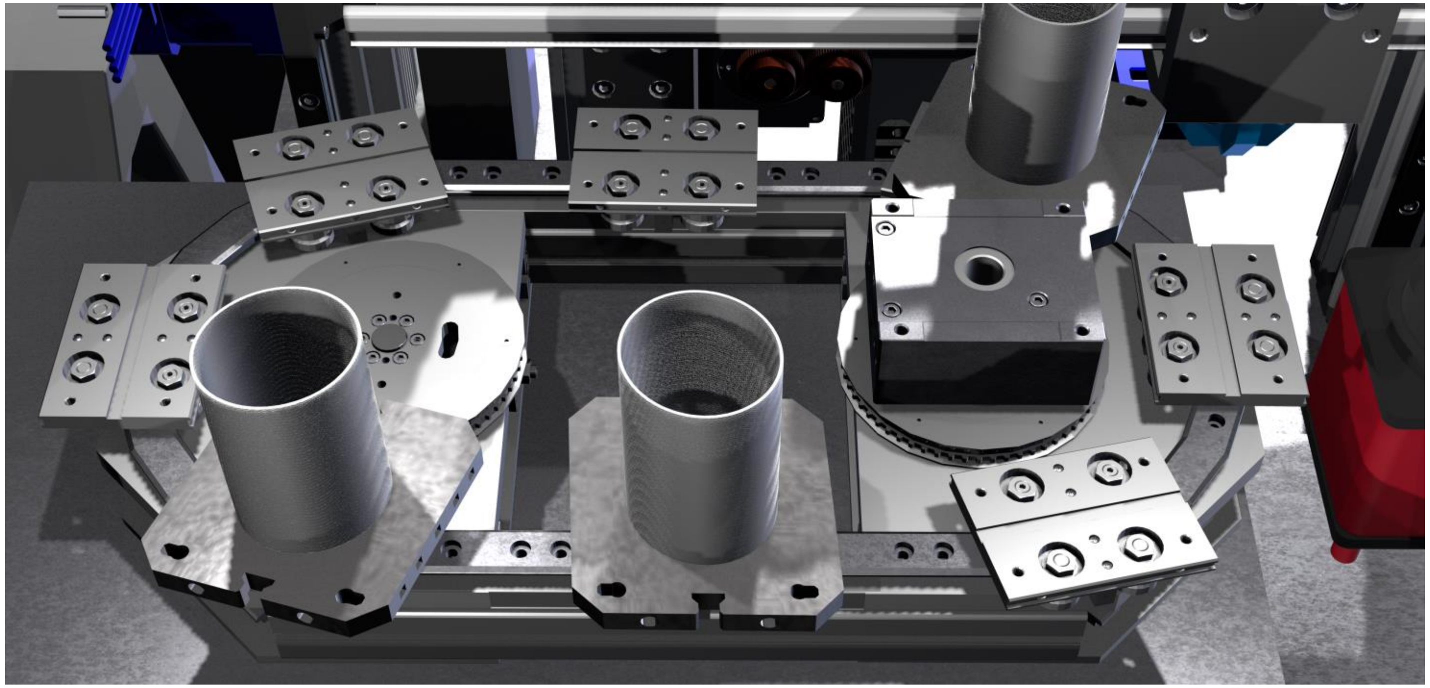


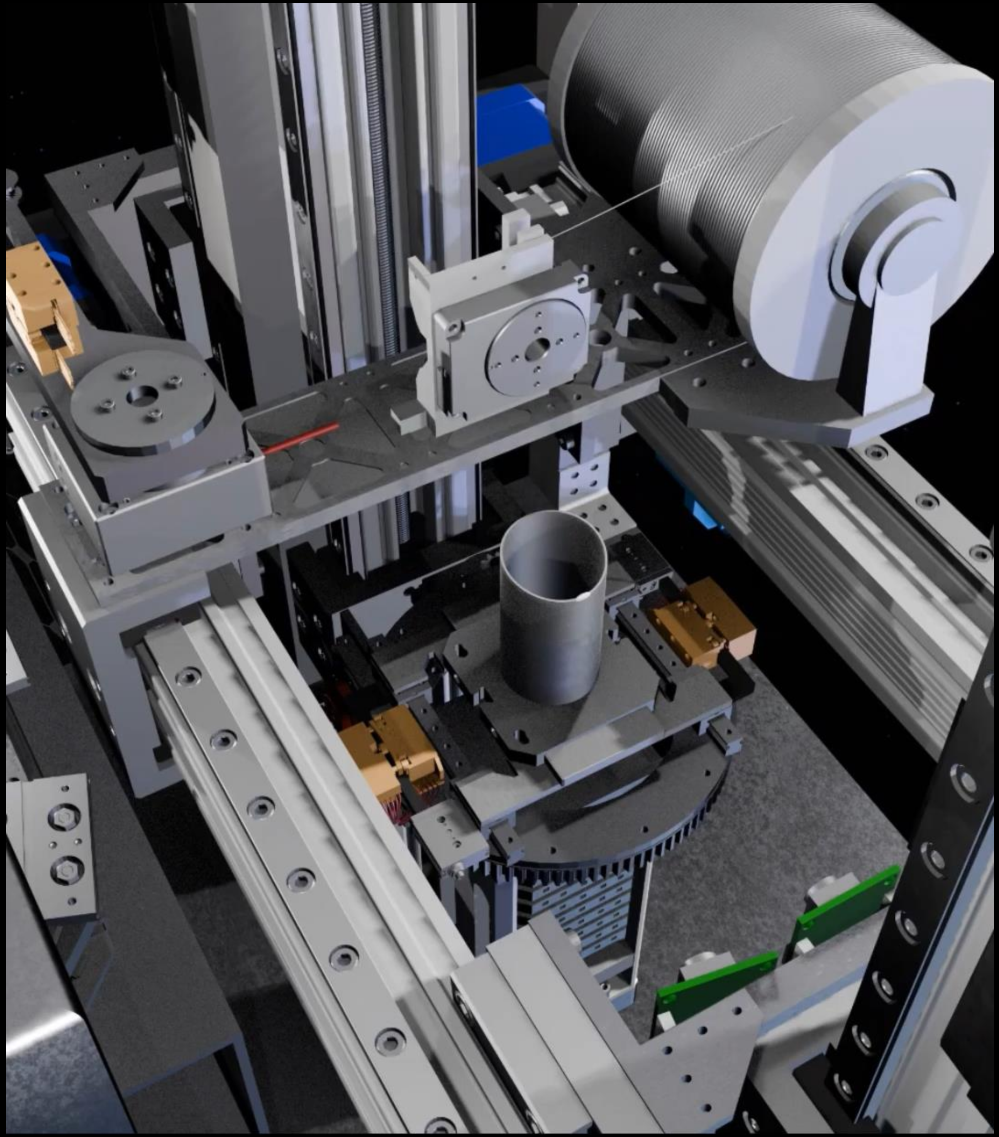




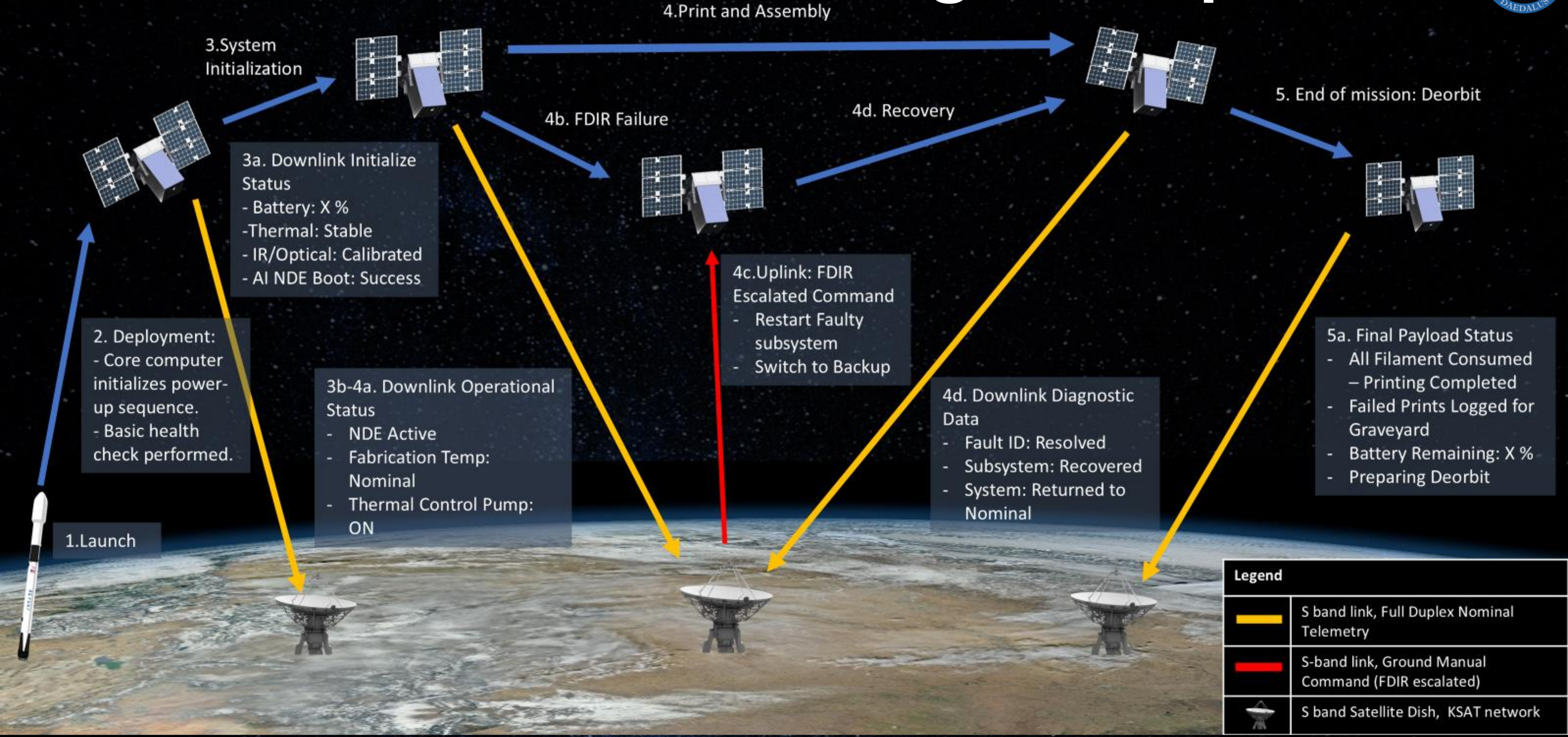
Failed Print System

- Based loosely on the Hepcomotion DTS Track System [34]
  - 8 storage slots
  - 2 slots pre-filled with prints
    - Allows for assembly to be proven if printing fails
  - Run by Xeryon XRT-A-30-X motor [35]





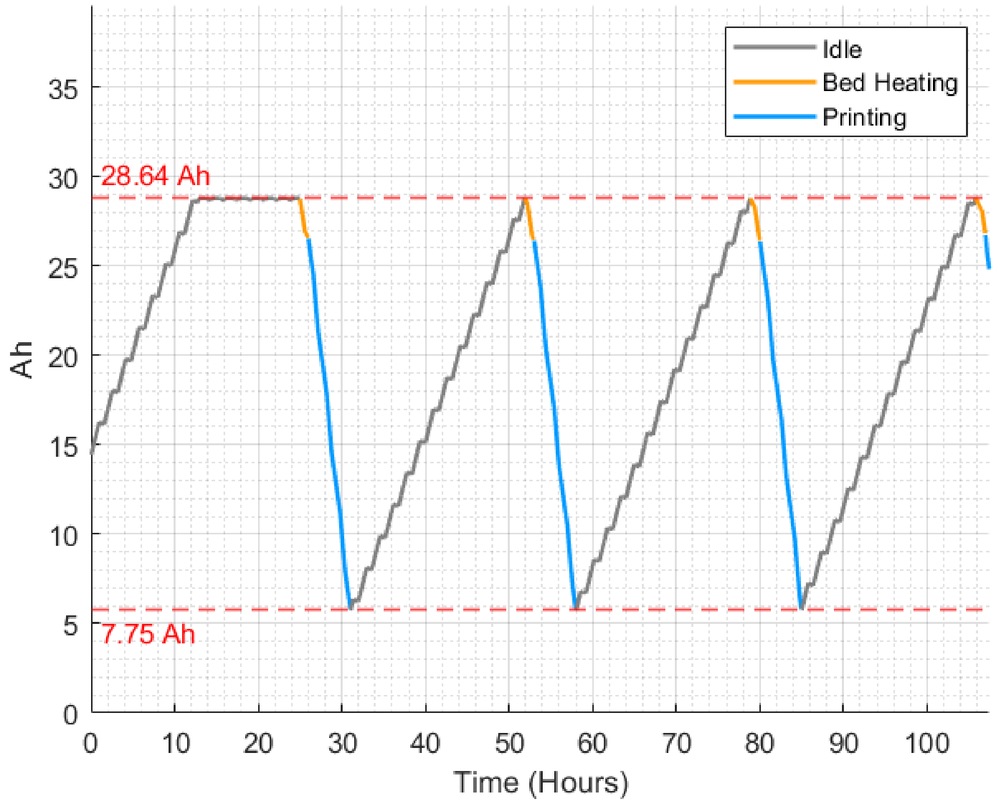
Command & Data Handling ConOps



Power Considerations

Power Draw by Power Mode

Subsystem	Idle (W)	Print Initialize (W)	Printing (W)	Assembly (W)
Assembly Bed	0	0	0	1
Avionics	4	13	50	27
Deposition Mechanism	0	74	32	0
Filament Handling	0	6	32	0
Health Monitoring	7	7	7	7
Laser System	0	0	0	810
Power Control	5	5	5	5
Rotating Bed	0	9	43	37
Thermal Control	4	4	4	4
Total	**20**	**117**	**172**	**891**

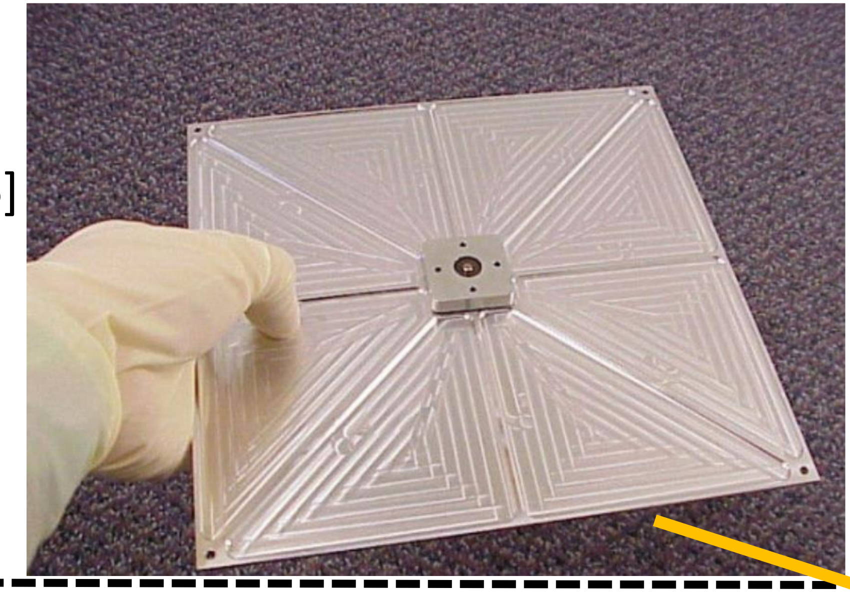


Predicted Power Timeline for a 3 Inch Print. The power draw of the fabrication subsystem during a print cycles between a charging phase up to 28.64 Ah (80%) battery storage followed by a discharge down to 7.75 Ah (20%) battery storage during voxel deposition. Ridges in the charge cycle are caused by eclipsing from the Earth. The time to print a 3” tall cylinder is estimated to be approximately 107 hours (70 orbits), with the first 24 hours allocated for idle charging.

Thermal Summary

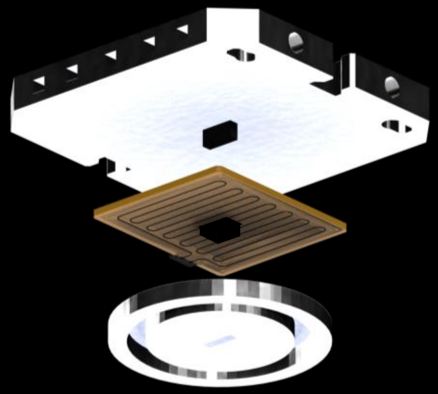
Passive Cooling System

- 12 Wall-mounted Sierra Space Miniature Satellite Energy Regulating Radiators (MiSER) [36]
- 8.5 x 8.5 inch dimension
- ~12 W dissipation per panel
- >100,000 cycle lifetime
- Heat pipes from components



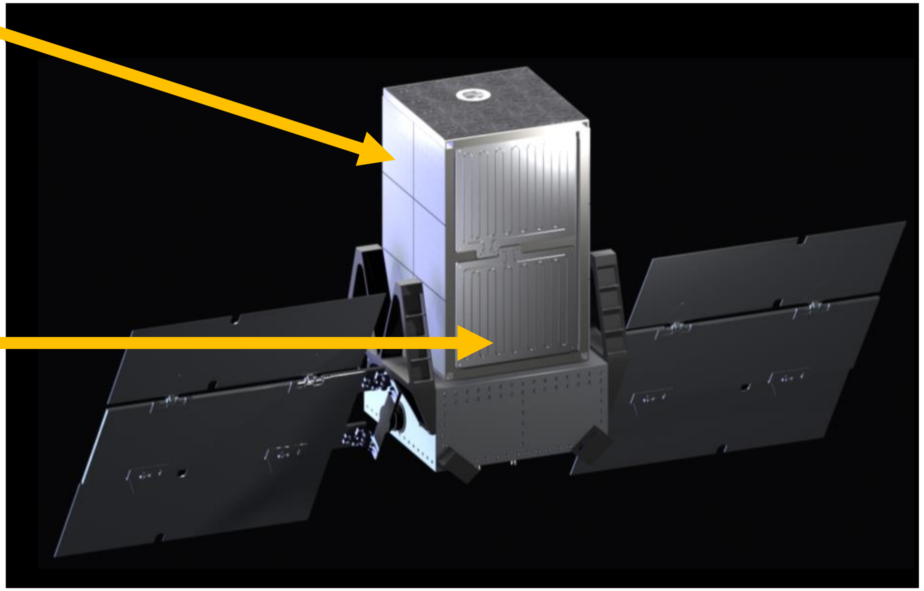
Substrate Internals

Print bed heats using internal patch heater to 121 degrees Celsius before a print



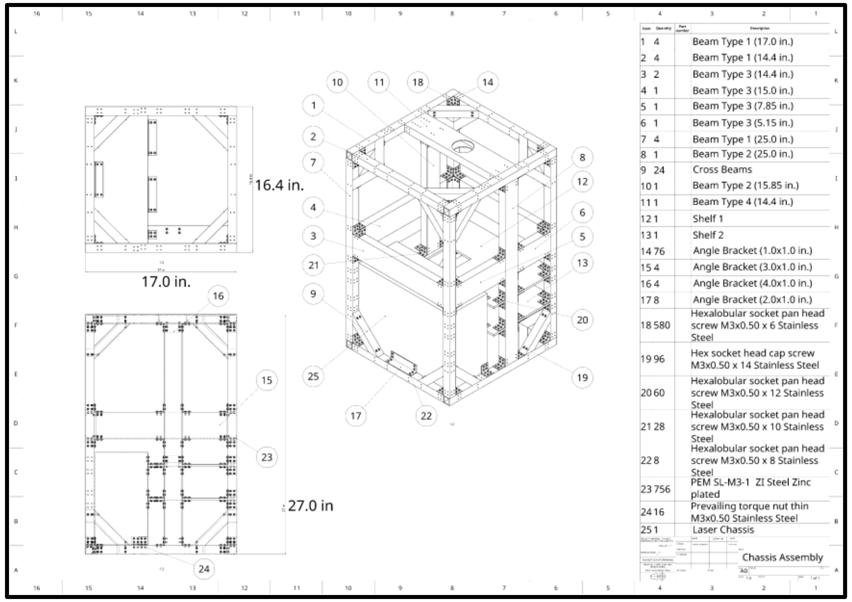
Active Cooling System

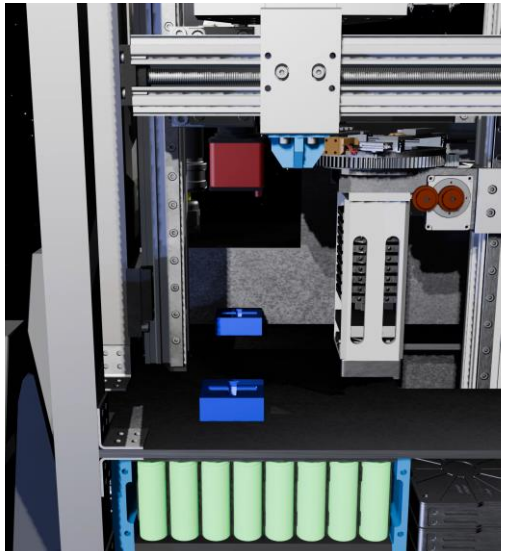
- Novec 7000 Engineering Fluid [37]
- TCS M510 micro-pump [38]
- Ultrasonic Additively Manufactured (UAM) radiator [39]
  - Embedded fluid paths
- Components requiring active cooling:
  - (x2) NVIDIA Jetson Xavier NX
  - Laser Chassis

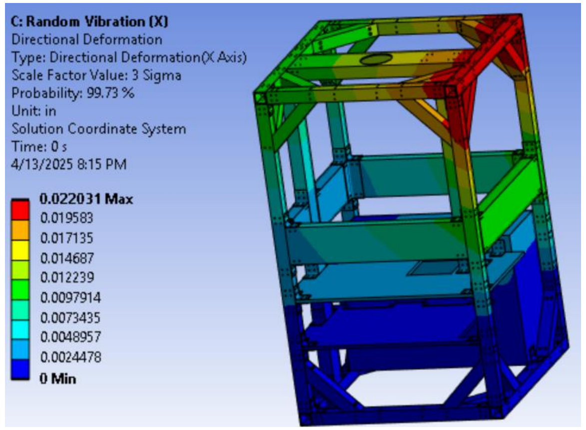


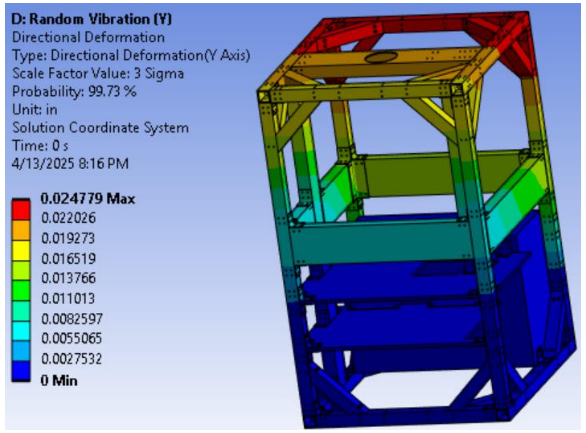
Launch Considerations

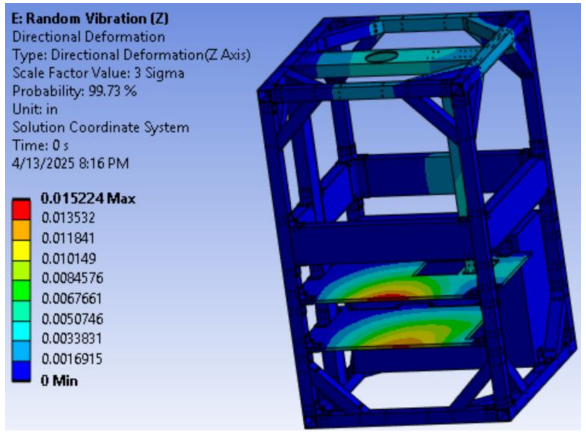
- SpaceX Bandwagon launch (full plate config) for $1.3M [40]
- The payload system structure was designed to be endure launch loads including vibration and acceleration loads.
- Our chassis structural stability analysis was conducted with Ansys Mechanical FEA (random vibe and acceleration G-loading), and G-loading results were verified using direct stiffness method hand calculations [41].











Cost Estimation

Overall Mission Cost Estimate [42]

	Non-Recurring ($K)	Recurring Production ($K)	Total Cost ($K)
Project Management	800	1,900	2,700
Safety/Mission Assurance	1,200	1,700	2,900
Science/ Technology	200	300	500
Payload	200	600	800
Flight Systems	3,200	8,300	11,500
Spacecraft Bus	20,000	0	20,000
Flight System I&T	800	2,300	3,100
Launch Vehicle	1,300	0	1,300
System Integration	400	1,100	1,500
Total Project Cost	**30,000**	**20,400**	**50,400**

Payload Material Cost Estimate (Per Unit)

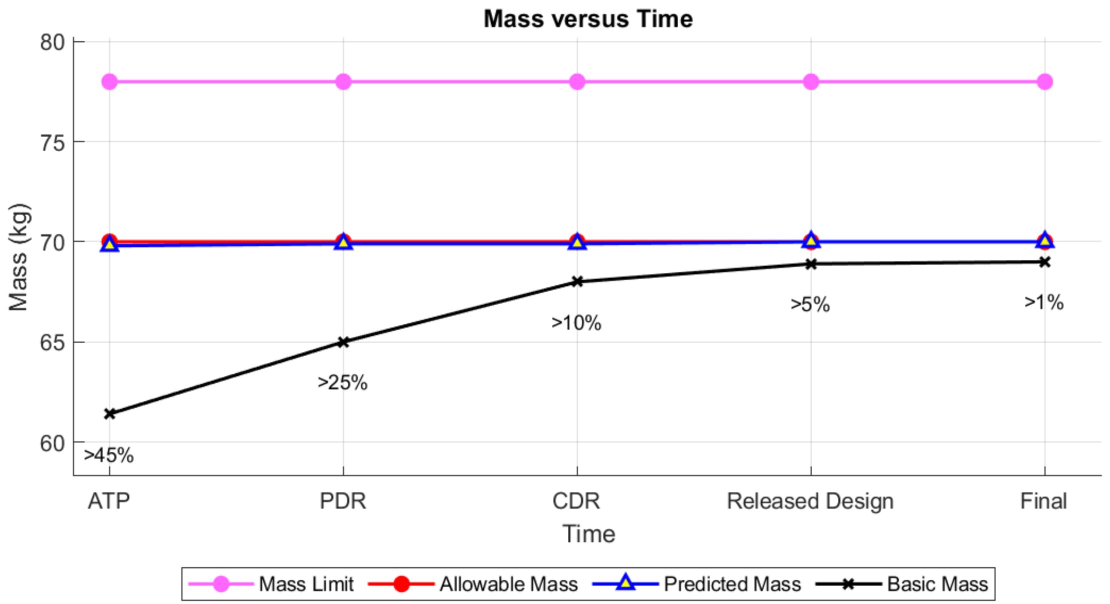
Subsystem	Basic Cost ($K)	GA (%)	Total Cost ($K)
Chassis	5.3	10	6.3
Deposition Mechanism	14.1	5-20	15.2
Filament Handling	0.6	15	0.7
Rotating Bed	12.3	5-20	13.0
Laser Assembly	16.0	5-30	19.1
Assembly Mechanism	6.5	5-25	6.9
Avionics	301.5	15	346.7
Health Monitoring	24.6	20	29.6
Substrate	8.5	10	9.3
Thermal Control System	100.5	15	115.6
Power Management	130.0	5-15	141.5
Electrical	7.5	45	10.9
Total Payload Cost	**627.4**		**715.0**

Mass Budget

Subsystem	Total Basic Mass (kg)	Growth Allowance (%)	Total System Mass (kg)
Chassis	14.7	10-30	16.9
Deposition Mechanism	4.4	5-20	8.5
Filament Handling	0.8	15	0.9
Rotating Bed	2.9	5-20	3.1
Laser Assembly	11.8	5-20	13.9
Assembly Mechanism	0.5	5-10	0.6
Avionics	0.4	15	1.0
Health Monitoring	0.6	20	2.3
Substrate	0.5	10	0.9
Thermal Control System	5.7	15	6.4
Power Management	3.7	15	11.6
Electrical	2.5	30	3.6
Total System Mass	**61.4**		**69.8**

	Value	Mass Margin
Allowable Mass - Proposal	70 kg	<1%
True Mass Limit - BCT	78 kg	10%

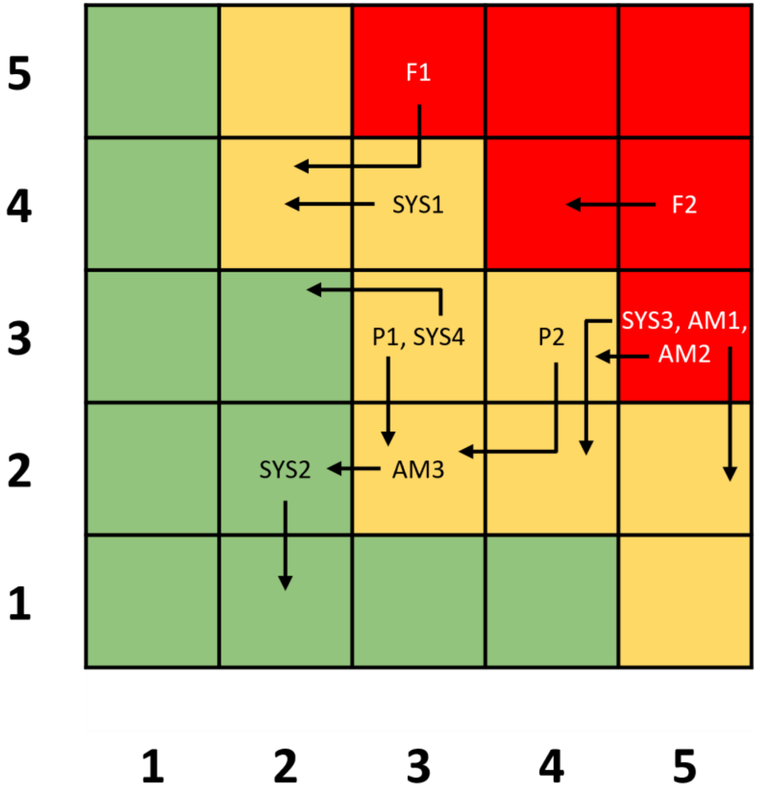
- Mass margin of 0.2 kg (<1%) of 70 kg total
- Under mass requirement



Predicted Mass Growth of Project Daedalus. The mass margin for Project Daedalus is <1% as indicated in the figure above. The allowable mass is 70 kg as specified in the C3 Packet [43]. The mass limit is 78 kg as specified by BCT documentation for the X-Sat Venus class bus [44].

Mission Risk Analysis

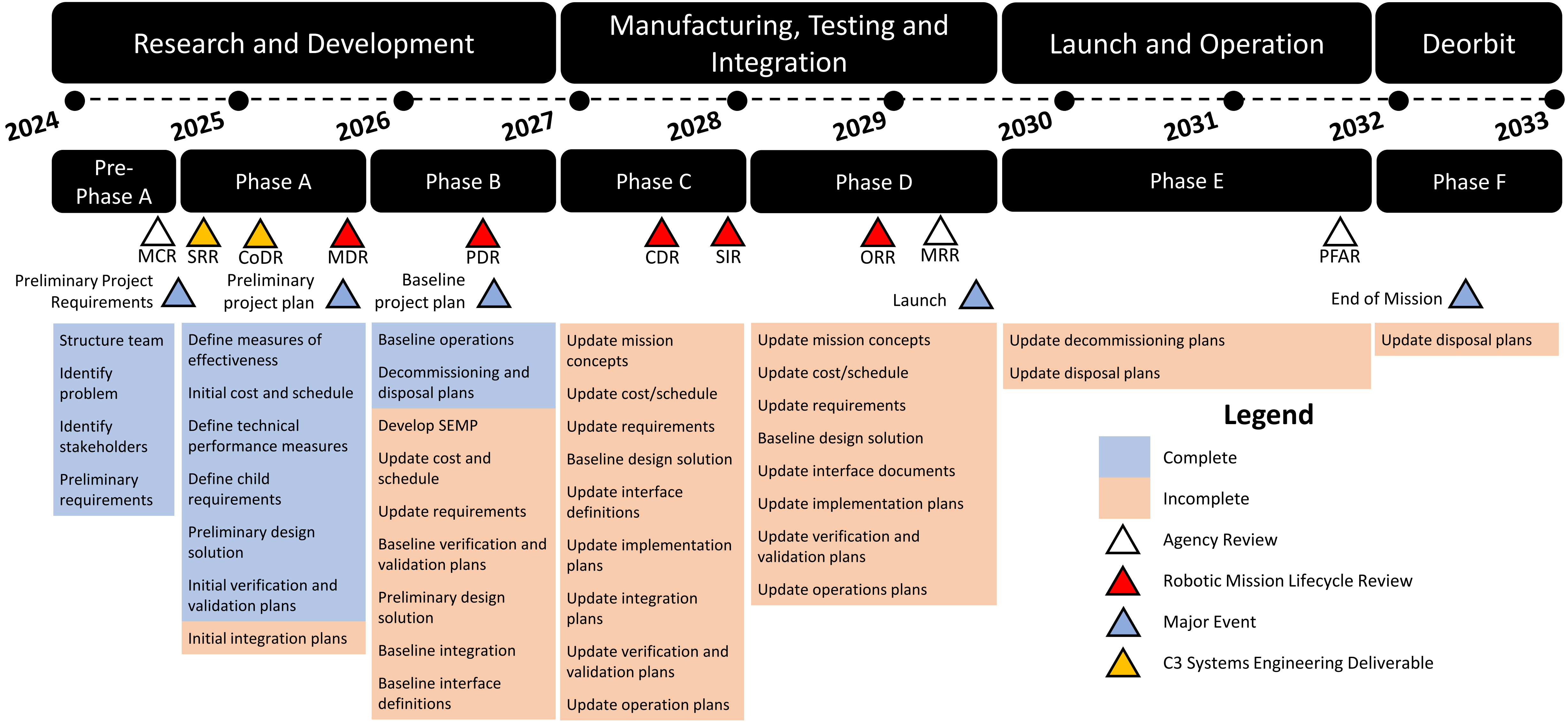
Likelihood of Failure
Very High 51-100% (5)
High 26-50% (4)
Medium 13-25% (3)
Low 6-12% (2)
Very Low 0-5% (1)



Consequence of Failure	
Catastrophic (5)	Total mission failure; failure to satisfy mission requirements.
Critical (4)	Failure to satisfy multiple mission requirements.
Moderate (3)	Failure to satisfy a mission requirement.
Minor (2)	Mission requirements are met. Disruption to mission timeline.
Negligible (1)	Minimal to no impact on mission outcome.

System Risks		Consequence	Mitigation Strategy
SYS1	ADCS Saturation	If the ADCS system is saturated from internal motion of the payload, the spacecraft may lose control of its attitude.	Perform spacecraft maneuvers to de-saturate the control system.
SYS2	System Overheat	If thermal energy is not dissipated from components with high thermal energy, critical components may overheat.	Switch operating states as needed to dissipate thermal energy.
SYS3	SEE Occurrence	If a single event effect occurs to the onboard AI or core payload computer system, the system may lose control.	Apply radiation shielding to the core and AI computer(s). Add redundant core and AI computer systems.
SYS4	Mass Overrun	If the mass of the satellite grows beyond expectation, the satellite may not meet its mass requirement.	Optimize structures or simplify systems.
Project Risks		**Consequence**	**Mitigation Strategy**
P1	Cost Overrun	If the system is not designed following good engineering practices, cost overruns may occur.	Perform consistent design reviews and updates to prevent cost overruns from critical design errors.
P2	Schedule Overrun	If the program is not managed correctly, schedule overruns may result in the failure to launch by the required deadline.	Consistent design reviews and updates to prevent schedule overrun. Plan mission timeline with buffer before required launch date.
Additive Manufacturing Risks		**Consequence**	**Mitigation Strategy**
AM1	Deposition System Damage	If the deposition head is damaged during specimen fabrication, the system may be unable to manufacture samples.	Reinforce deposition head to prevent potential breakage.
AM2	Feedstock Breakage	If the aluminum filament is damaged the system may be unable to deposit any material resulting in mission failure.	Utilize a pin roller system to control the speed of spooling into the deposition head; stop feed if necessary.
AM3	Deposition System Overheat	If the deposition head is damaged from overheating, the system may be unable to manufacture samples.	Actively monitor the temperature of the deposition head and halt operation as needed.
Fabrication Risks		**Consequence**	**Mitigation Strategy**
F1	Print Deformation	If specimens are deformed during fabrication, the system may be unable to assemble components together.	Monitor and actively correct deposition errors with an AI FDIR monitoring system. Remove failed prints to a containment unit.
F2	System Cold Welding	If system components cold weld together, parts of the fabrication system may be unable to function.	Adhere to ESA STM-279 standard for materials used in system to prevent cold welding.

Plan to PDR


Research and Development
Manufacturing, Testing and Integration
Launch and Operation
Deorbit
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
Pre-Phase A
Phase A
Phase B
Phase C
Phase D
Phase E
Phase F
MCR
SRR
CoDR
MDR
PDR
CDR
SIR
ORR
MRR
PFAR
Preliminary Project Requirements
Preliminary project plan
Baseline project plan
Launch
End of Mission
Structure team
Identify problem
Identify stakeholders
Preliminary requirements
Define measures of effectiveness
Initial cost and schedule
Define technical performance measures
Define child requirements
Preliminary design solution
Initial verification and validation plans
Initial integration plans
Baseline operations
Decommissioning and disposal plans
Develop SEMP
Update cost and schedule
Update requirements
Baseline verification and validation plans
Preliminary design solution
Baseline integration
Baseline interface definitions
Update mission concepts
Update cost/schedule
Update requirements
Baseline design solution
Update interface definitions
Update implementation plans
Update integration plans
Update verification and validation plans
Update operation plans
Update mission concepts
Update cost/schedule
Update requirements
Baseline design solution
Update interface documents
Update implementation plans
Update verification and validation plans
Update operations plans
Update decommissioning plans
Update disposal plans
Update disposal plans
Legend
Complete
Incomplete
Agency Review
Robotic Mission Lifecycle Review
Major Event
C3 Systems Engineering Deliverable

Manufacturing and Testing

- Environmental and vibration/structural testing
  - Vacuum, radiation and thermal test to ensure payload stability and the survival of off the shelf parts
  - Random vibration load to simulating launch, ensuring the survival of critical payload components.
  - Conducted at NASA Langley or similar test facility.
- Modify off-the-shelf parts for space applications
  - Testing
  - To ensure proper functionality, some modifications may be necessary.
- Optimize design for assembly
  - Relocate certain components and fasteners to make assembly easier.
- AI FDIR system
  - The model used for failure detection and recovery system needs to be trained and tested on a similar DAED additive manufacturing system to ensure effectiveness.

Technological Gaps

- DAED Additive Manufacturing System
  - Develop and evaluate feasibility of DAED system.
  - Determine thermal requirements of bed for print adhesion in microgravity.
  - Environmental testing to prove DAED process in a space environment.
- Software Optimization
  - FDIR and NDE logic must be refactored for resource-constrained onboard execution.
  - Core computer software must be designed for optimized memory allocation.
- System Integration
  - AI-based NDE must interface seamlessly with the FDIR decision process.
  - Requires validation of data exchange, priority logic, and fallback.

Biggest Challenges

- Narrowing the scope of our mission.
  - ISAM is a large field with over ten unique capabilities [45].
  - Choosing a capability to pursue was difficult.
- Working with the BCT X-Sat Venus Class bus.
  - Blue Canyon Technologies was not open about system information.
  - Using an existing satellite bus introduced confusion.
  - A theoretical bus with explicit limitations would reduce confusion.
  - The Apex Aries satellite bus provides more clear documentation and better performance at an almost identical size compared to the BCT X-Sat Venus [46].
- Balancing innovation and feasibility
  - The most innovative ideas often carry the most risk as well. We worked hard to keep a balance between innovation and feasibility with our project.

Project DAEDALUS

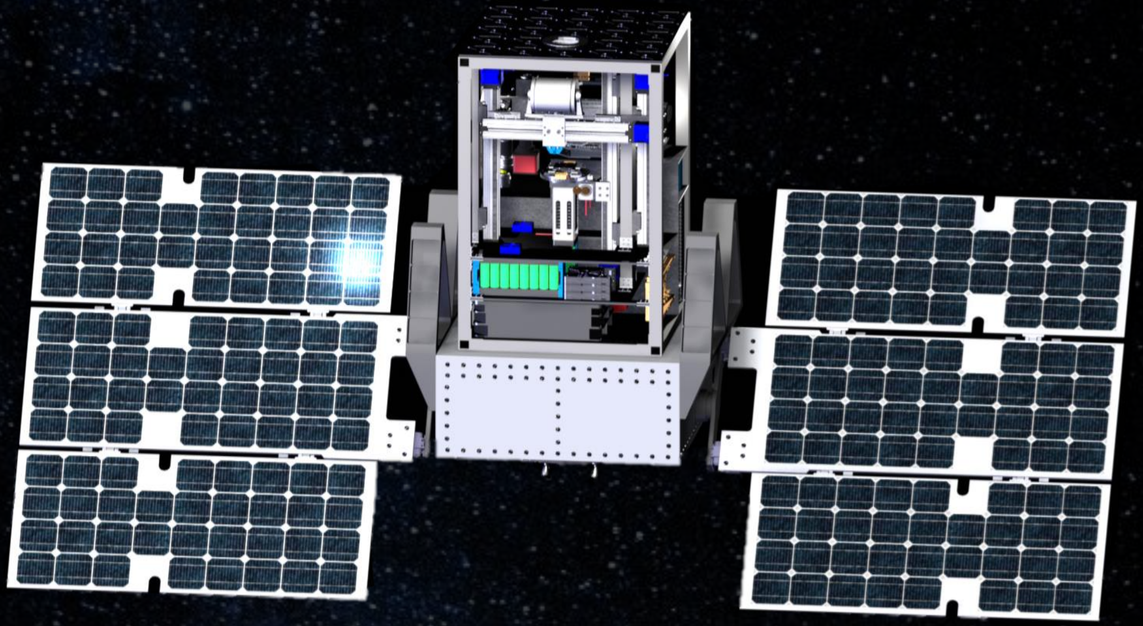
Estimated Mass:
68.0 kg

Mission Timeline: 2030-2032

SpaceX Bandwagon Launch
(45-degree inclination)

Payload Material
Cost: $715,000

Overall Mission Cost:
$50,400,000



Power Draw
- Idle: 20 W
- Print Initialize: 117 W
- Printing: 172 W
- Assembly: 891 W

Conclusion

- This mission plan provides a proof of concept of a potential method of repeatable structural manufacturing and assembly in a space environment
- The mission would be a breakthrough for autonomous ISAM capabilities
  - Showing potential of autonomous additive manufacturing
  - Testing of DAED as a low power and heat in-space additive manufacturing method
- Many considerations have been taken within the payload design to limit the impact of:
  - Temperature fluctuations in LEO
  - Vacuum
  - Microgravity
  - Satellite bus constraints
- With proper space rating of off the shelf parts and testing of terrestrial models, this mission can be assembled and launched before the end of the decade


Questions?

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Thank You

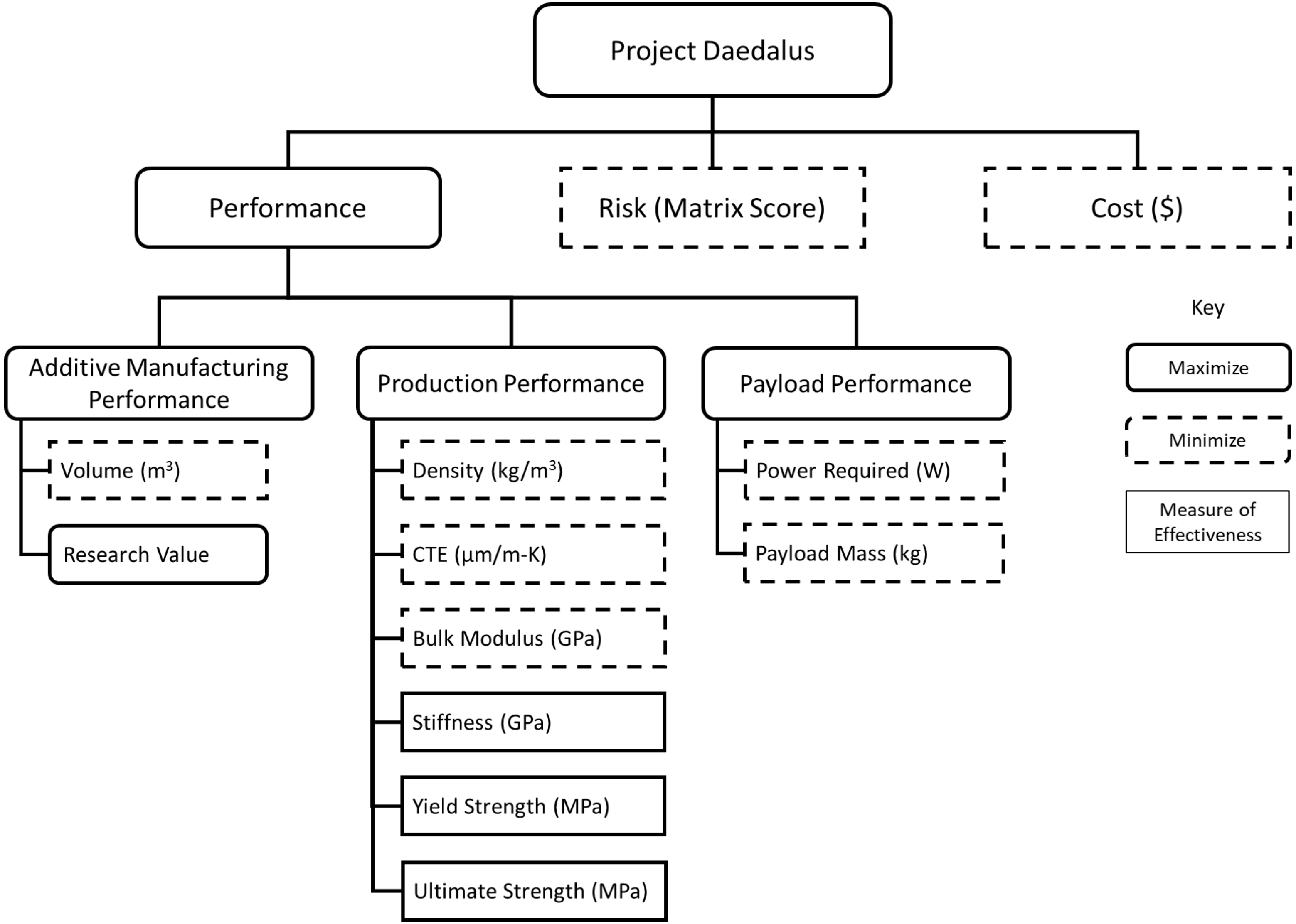
CONSORTIUM FOR SPACE MOBILITY AND ISAM CAPABILITIES

COLLEGE OF ENGINEERING
KEVIN T. CROFTON DEPARTMENT OF AEROSPACE AND OCEAN ENGINEERING
VIRGINIA TECH.

Backup Slides

Product / Mission Phase	Pre-Phase A	Phase A		Phase B	Phase C		Phase D		Phase E	Phase F
Document	MCR	SRR	MDR/SDR	PDR	CDR	SIR	ORR	FRR	DR	DRR
Stakeholder Identification	Baseline	Update	Update	Update						
Concept Definition	Baseline	Update	Update	Update	Update					
Measure of Effectiveness Definition	Approve	Approve								
Cost/Schedule	Initial	Initial	Update		Update	Update	Update	Update		
SEMP	Preliminary	Baseline	Baseline	Update	Update	Update				
Requirements	Preliminary	Baseline	Update	Update	Update					
Technical Performance Measures			Approve							
Architecture definition			Baseline							
Next level requirements			Baseline							
Required leading indicator trends			Initial	Update	Update	Update				
Design solution definition			Preliminary	Preliminary	Baseline	Update	Update			
Interface definitions			Preliminary	Baseline	Update	Update				
Implementation plans			Preliminary	Baseline	Update					
Integration plans			Preliminary	Baseline	Update	Update				
Verification/Validation plans	Approach		Preliminary	Baseline	Update	Update				
Operations plans				Baseline	Update	Update	Update			
Decommissioning plans				Preliminary	Preliminary	Preliminary	Update	Update	Update	
Disposal plans				Preliminary	Preliminary	Preliminary	Update	Update	Update	Update

Objective Hierarchy



AM System Criteria	
System Volume	0.167
System Research Value	0.354
System Power Requirement	0.331
System Mass	0.148

Feedstock Material Criteria	
Density	0.40
Coefficient of Thermal Expansion	0.05
Bulk Modulus	0.35
Stiffness	0.10
Yield Strength	0.10
Ultimate Strength	0.05

Material Trade Study

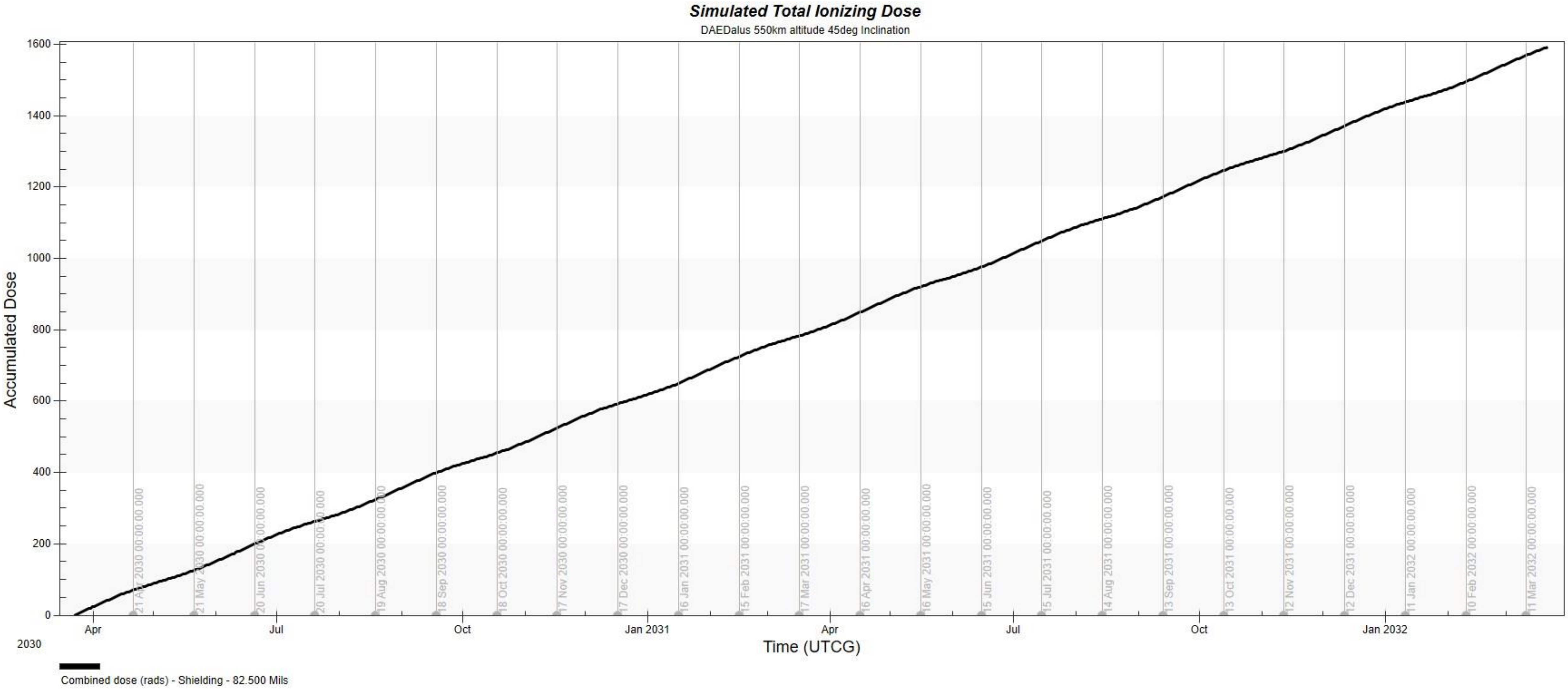
	Stiffness (GPa)	Yield Strength (MPa)	Ultimate Strength (MPa)	Bulk Modulus (GPa)	Density (kg/m³)	CTE (µm/m-K)	
	Maximize			Minimize			
Weights	0.05	0.10	0.05	0.35	0.40	0.05	Result
Al 6061	73	55	124	70	2700	21	0.218
Ti 6Al-4V	114	1100	895	97	4430	9	0.198
Inconel 718	193	1100	1375	205	8190	13	0.143
316L SS	180	205	515	134	7610	16	0.116
CuCrZr	114	200	300	130	8900	18	0.107

[47]

Transfer Learning with CNNs

- Memory of Each Models tested in historical research
  - VGG16: 528 MB
  - VGG19: 549
  - InceptionV3: 92 MB
  - ResNet50: 98 MB
  - EfficientNetB0: 29 MB
  - EfficientNetV2L: 479 MB
- But the size of pre-trained custom model really depends on how we build our model and design algorithms that's optimized for our system.
- NVIDIA Jetson Xavier NX:
  - 8 or 16 GB memory
  - 16GB eMMC 5.1 Storage
  - Up to 6 cameras (24 via virtual channels) 14 lanes MIPI CSI-2, D-PHY 1.2 (up to 30 Gbps)

Total Ionizing Dose



AI Computer Trade Study

AI Hardware	Power (W)	Dimension (mm)	Mass (kg)	Cost ($)	Performance (TOPs)	RHA (krad)	
	Minimize				Maximize		
Weights	0.35	0.1	0.2	0.01	0.3	0.04	Result
NVIDIA Jetson Xavier NX+shield	10 - 20	70 × 45	0.48	400	21	0.8-1.2	0.273
AMD Versal VEK280	50	240 x 186	0.54	7000	228	120	0.271
Nvidia Jetson Orin NX+shield	10 - 30	100 × 87	0.73	700	157	0.8-1.2	0.262
NVIDIA Jetson AGX Xavier+shield	10 - 40	70 × 45	0.63	1100	32	0.8-1.2	0.193

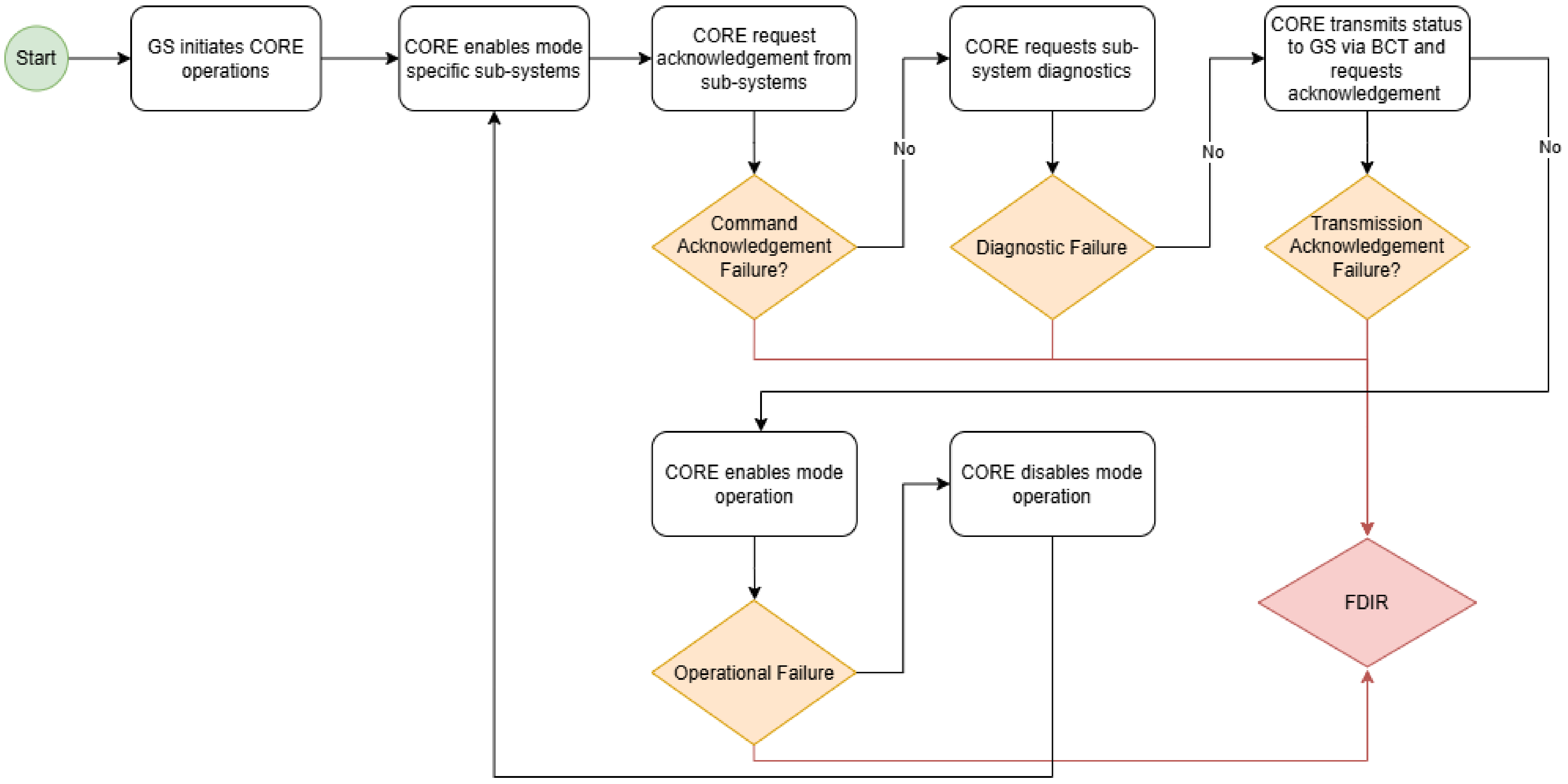
Fault Detection, Isolation, & Recovery

- All subsystems transmit telemetry and diagnostics to the core computer via the C&DH system.
  - Anomalies from Fabrication system are first detected by the AI computer using CNN-based NDE(Non-Destructive Evaluation) and analyzed.
  - Thermal, power and other subsystems send data directly to the core computer.
- The core computer autonomously performs:
  - Detection: Detect anomalies/faults or out-of-range values
  - Isolation: Isolate faulty subsystem and activates redundancy
  - Identification: Classifies fault severity (Level 0 - 4)
  - Reconfiguration: Issues recovery commands or switches to backup
- If unrecoverable, the core computer downlinks diagnostic data via the BCT antenna for ground intervention.

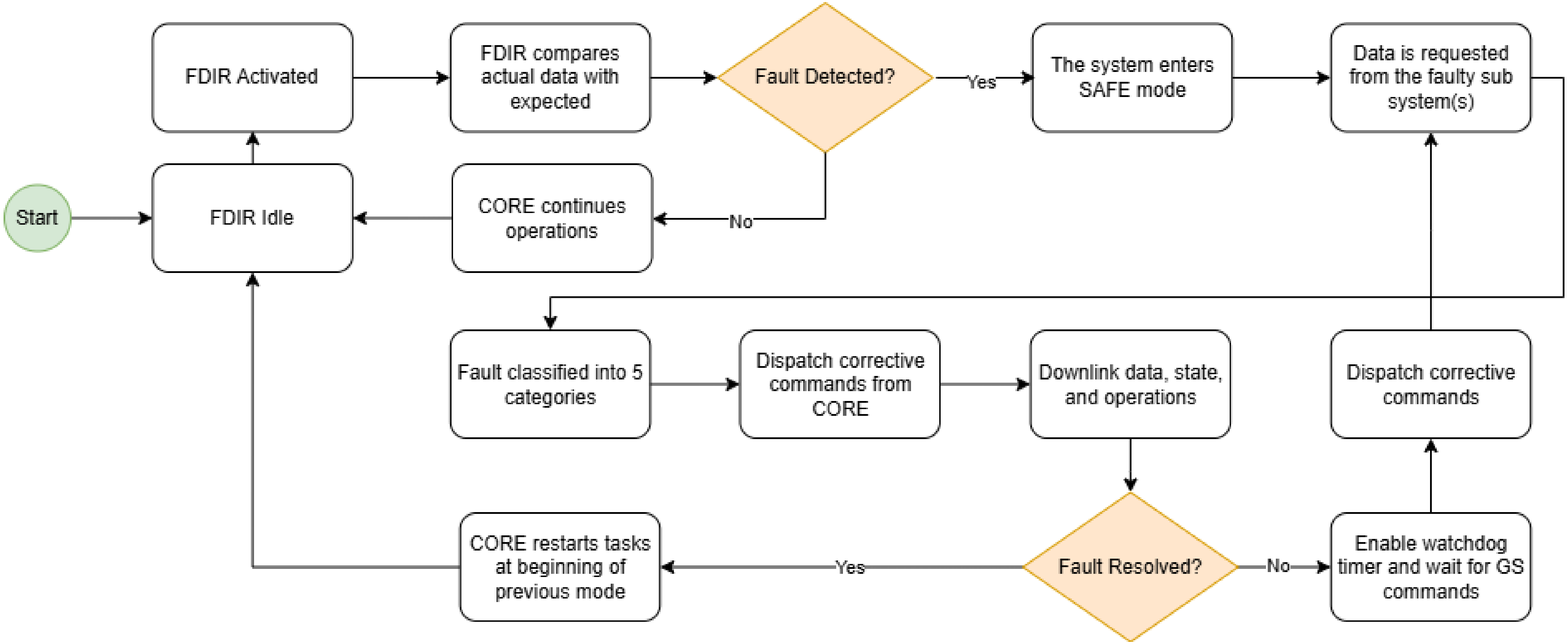
FDIR Detailed Classification

1. Fault Detection: Real-time monitoring of all telemetry streams for deviations, signal dropouts, or out-of-range values.
2. Fault Isolation: Identification of the affected subsystem, activation of safe mode, engagement of redundant components (if available), and request for additional diagnostics.
3. Fault Identification: Classification of the fault into severity levels:
   a) Level 0: Minor, single unexpected data point
   b) Level 1: Subsystem non-responsiveness
   c) Level 2: Multiple inconsistent or anomalous values
   d) Level 3: Failure within the FDIR handling process itself
   e) Level 4: Critical or cascading faults affecting system-level functionality
4. System Reconfiguration: Dispatch of corrective commands (e.g. reboot, reinitialize). If unsuccessful, the system shifts to backup hardware. Persistent unresolved faults result in a downlink of diagnostic data to ground operations for human intervention

CDH Flowchart



FDIR Flowchart



On Board Computer

Core Computer	Power (W)	Dimensions (mm)	Mass (kg)	Cost ($K)	Performance (MHz)	
	Minimize				Maximize	
Weight	0.25	0.3	0.15	0.05	0.25	Result
Sirius OBC LEON3FT	1.3	96 x 90 x 17	0.13	50	50	0.344
MA61C CubeSat	1.5	110 x 110 x 35	0.15	200	50	0.243
Argotec FERMI OBC	5	102 x 100 x 45	0.5	250	100	0.188
BAE Systems RAD6000	5	233 x 160 x 17	1.5	20	33	0.125

Deposition Mechanism Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Deposition Mechanism	DAED Piezoelectric Transducer	0.0	1	20	0.00	0.01
	DAED Nozzle	2.0	1	20	0.40	2.40
	Z Actuators	1.2	2	5	0.06	2.52
	Z Actuator Motor	0.6	2	5	0.03	1.26
	X Actuator	1.2	2	5	0.06	2.52
	X Actuator Motor	0.6	2	5	0.03	1.26
	X-Z Gantry Frame 1	0.4	1	10	0.04	0.44
	X-Z Gantry Frame 2	0.2	1	10	0.02	0.22
	Nozzle Gantry Frame	0.1	1	15	0.02	0.15
Total Subsystem Mass (kg)						10.8

Filament Handling Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Filament Handling	Filament Feedstock	0.3	1	15	0.04	0.29
	Filament Storage	0.5	1	15	0.08	0.58
Total Subsystem Mass (kg)						0.9

Rotating Bed Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Rotating Bed	Z Actuator	1.2	1	5	0.06	1.26
	Z Actuator Motor	1.3	1	5	0.07	1.37
	Rotational Motor	0.3	1	5	0.01	0.26
	Bed Frame	1.0	1	5	0.20	1.20
	Bed Slewing Ring	0.3	1	15	0.05	0.35
	Linear Actuator	0.003	4	5	0.00	0.01
Total Subsystem Mass (kg)						4.4

Laser Assembly Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Laser Assembly	Laser Chassis	8	1	30	3.00	13.0
	Laser Wobbler	1.3	1	5	0.07	1.37
Total Subsystem Mass (kg)						11.8

Assembly Mechanism Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Assembly Mechanism	Bed Frame	1.0	1	10	0.10	1.10
	Linear Actuators	0.0	2	5	0.00	0.01
Total Subsystem Mass (kg)						1.1

Avionics and Electrical Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Avionics	AI Computers	0.3	2	15	0.05	0.69
	C&DH Computers	0.1	3	15	0.02	0.35
Total Subsystem Mass (kg)						1.0

Health Monitoring Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Health Monitoring	Optical Camera	0.1 0.5 0.1 0.1 0.1 0.1	5 3 3 3 3 3	20 20 20 20 20 20	0.02 0.10 0.02 0.02 0.02 0.02	0.60 1.80 0.36 0.36 0.36 0.36
	IR Camera	0.5	3	20	0.10	1.80
	Watchdog Timer	0.1	3	20	0.02	0.36
	Vibration Sensor	0.1	3	20	0.02	0.36
	Temperature Sensor	0.1	3	20	0.02	0.36
	Power Sensor	0.1	3	20	0.02	0.36
Total Subsystem Mass (kg)						3.8

Substrate Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Substrate	Substrates	0.0	12	10	0.0	0.40
	Substrate Holder	0.2	1	10	0.02	0.22
	Substrate Holder Structure	0.3	1	10	0.03	0.33
Total Subsystem Mass (kg)						0.9

Thermal Control Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Thermal Control System	Insulation/Shielding	2.0	1	15	0.30	2.30
	Radiator Panels	5.0	1	15	1.50	5.75
	Active Fluid Loop	3.0	1	15	0.75	3.45
Total Subsystem Mass (kg)						11.5

Power Management Mass Budget

Subsystem	Component	Mass (kg)	Number Required	Growth Allowance (%)	Growth (kg)	Total Mass (kg)
Power Management	PMAD	2.5	1	15	0.38	2.88
	Batteries	1.2	8	5	0.06	10.08
Electrical	Wiring Harness	2.5	1	45	1.13	3.63
Total Subsystem Mass (kg)						16.6

Chassis Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Chassis	Frame	2.25	20	0.45	2.70
	Shielding	3.00	20	0.60	3.60
Total Subsystem Cost					6.30

Deposition Mechanism Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Deposition Mechanism	DAED Piezoelectric Transducer	0.75	20	0.15	0.90
	DAED Nozzle	1.35	20	0.27	1.62
	Z Actuators	6.00	5	0.30	6.30
	Z Actuator Motor	0.45	5	0.22	0.47
	X Actuator	4.00	5	0.20	4.20
	X Actuator Motor	0.30	5	0.02	0.32
	X-Z Gantry Frame 1	0.30	10	0.03	0.33
	X-Z Gantry Frame 2	0.30	10	0.03	0.33
	Nozzle Gantry Frame	0.60	15	0.09	0.69
	Filament Feedstock	0.05	15	0.00	0.05
	Filament Storage	0.60	15	0.09	0.69
Total Subsystem Cost					15.90

Rotating Bed Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Rotating Bed	Z Actuator	3.00	5	0.15	3.15
	Z Actuator Motor	0.23	5	0.01	0.24
	Rotational Motor	0.12	5	0.006	0.13
	Bed Frame	0.70	20	0.14	0.84
	Bed Slewing Ring	0.25	15	0.04	0.29
	Linear Actuator	8.00	5	0.40	8.40
Total Subsystem Cost					13.00

Laser Assembly Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Laser Assembly	Laser Chassis	15.00	20	3.00	18.00
	Laser Wobbler	1.00	5	0.05	1.05
Total Subsystem Cost					19.05

Assembly Mechanism Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Assembly Mechanism	Bed Frame	0.51	25	0.13	0.64
	Linear Actuators	6.00	5	0.30	6.30
Total Subsystem Cost					6.90

Avionics Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Avionics	AI Computers	1.50	15	0.23	1.73
	C&DH Computers	300.00	15	45.00	345.00
Total Subsystem Cost					346.70

Health Monitoring Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Health Monitoring	Optical Camera	1.00	20	0.20	1.20
	IR Camera	12.40	20	2.48	14.88
	Watchdog Timer	2.25	20	0.45	2.70
	Vibration Sensor	2.25	20	0.45	2.70
	Temperature Sensor	4.50	20	0.90	5.40
	Power Sensor	2.25	20	0.45	2.70
Total Subsystem Cost					29.60

Substrate Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Substrate	Substrates	7.2	10	0.72	7.92
	Substrate Holder	0.375	10	0.037	0.4125
	Substrate Holder Structure	0.9	10	0.09	0.99
Total Subsystem Cost					9.3

Thermal Control Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Thermal Control System	Insulation/Shielding	3.00	15	0.45	3.45
	Radiator Panels	60.00	15	9.00	69.00
	Active Fluid Loop	37.50	15	5.63	43.13
Total Subsystem Cost					115.60

Power Management Cost Budget

Subsystem	Component	Cost ($K)	Growth Allowance (%)	Growth ($K)	Total Cost ($K)
Power Management	PMAD	50.00	15	7.50	57.50
	Batteries	80.00	5	4.00	84.00
Electrical	Wiring Harness	7.50	45	3.38	10.88
Total Subsystem Cost					152.40

Assembly Mechanism Power Budget

Subsystem	Component	Part Number	Number Req	Volts	Amps	Power (W)	Duty Cycle (%)	Growth (%)	Total Power (W)	Total (KJ)
Assembly Mechanism	Laser chassis	YLM-QCW-MM	1	48.000	12.500	600.000	5.000	15.000	34.500	9.594
Assembly Mechanism	Linear Actuators	LEGS LT20	1	42.000	0.714	30.000	50.000	5.000	15.750	43.801
Assembly Mechanism	Laser Wobbler	LDW200 MINNI	1	24.000	0.417	10.000	10.000	20.000	1.200	0.667
Assembly Mechanism Total					13.631	640.000			51.450	54.063

Assembly Mechanism Power Budget

Avionics	AI Computers	Nvidia Jetson Orin NX	2	20.000	1.000	20.000	80.000	10.000	17.600	74.160	156.626
Avionics	C&DH Computers	SIRIUS LEON 3FT	3	16.000	0.081	1.300	100.000	10.000	1.430	92.700	23.861
Avionics	Radio Board Idle	RocketLab Frontier X	1	30.000	0.050	1.500	20.000	5.000	0.315	18.540	0.350
Avionics	Radio Board RX+TX	RocketLab Frontier X	1	30.000	0.400	12.000	80.000	5.000	10.080	74.160	44.852
Avionics Total					1.531	22.800			19.345		225.689

Our Questions