THE UNIVERSITY OF TEXAS AT EL PASO

Spacecraft 3D Concept Team

Deliverable #4

Agenda

- Team introduction
- Mission Overview
- Concept of Operations
- Requirements
- Requirement Flow down
- Requirement Verification and Validation (V&V)
- Trade Studies
- Design Concept
- Risk Assessment
- Integration and Test
- Proposed Future Work

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Team Introductions

Aerospace Engineering Team

Victor Bonilla

Lead Engineer

- Undergrad Research xx
- Special Projects LEAD SCS Rocket Team

Thomas Del Palacio

Thermal Lead

- Incoming GNC Engineer at L.M.
- Propulsion & Thermal Intern | NASA MSFC

Jorge Caraveo

Manufacture Lead

-Undergrad Research W.M. Keck Center
- SCS Rocket Team Avionics Sub- team Co-Captain

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Analysis Lead

- Structures LEAD SCS Rocket Team

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Team Introductions

Industrial and Systems Engineering Team

Montserrat Sandoval

System Engineer

- Manufacturing Engr. Intern Schneider Electric

Cesar Rodriguez

System Engineer

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Mission Overview

Design, analyze, and prototype an additively manufactured (AM) integrated structural cold plate for a LEO satellite avionics module. The subsystem that will integrate the bus (base plate) with the thermal management structure (cold plate), effectively making two separate structures into one body. Eliminating complex interfaces and joining techniques such as bolts or rivets.

Objective

Design an AM cold plate that reduces mass and part count, while maintaining thermal resistance and structural integrity comparative to a conventional cold plate + bracket architecture through launch loads and thermal stability over a 5–10-year LEO mission life.

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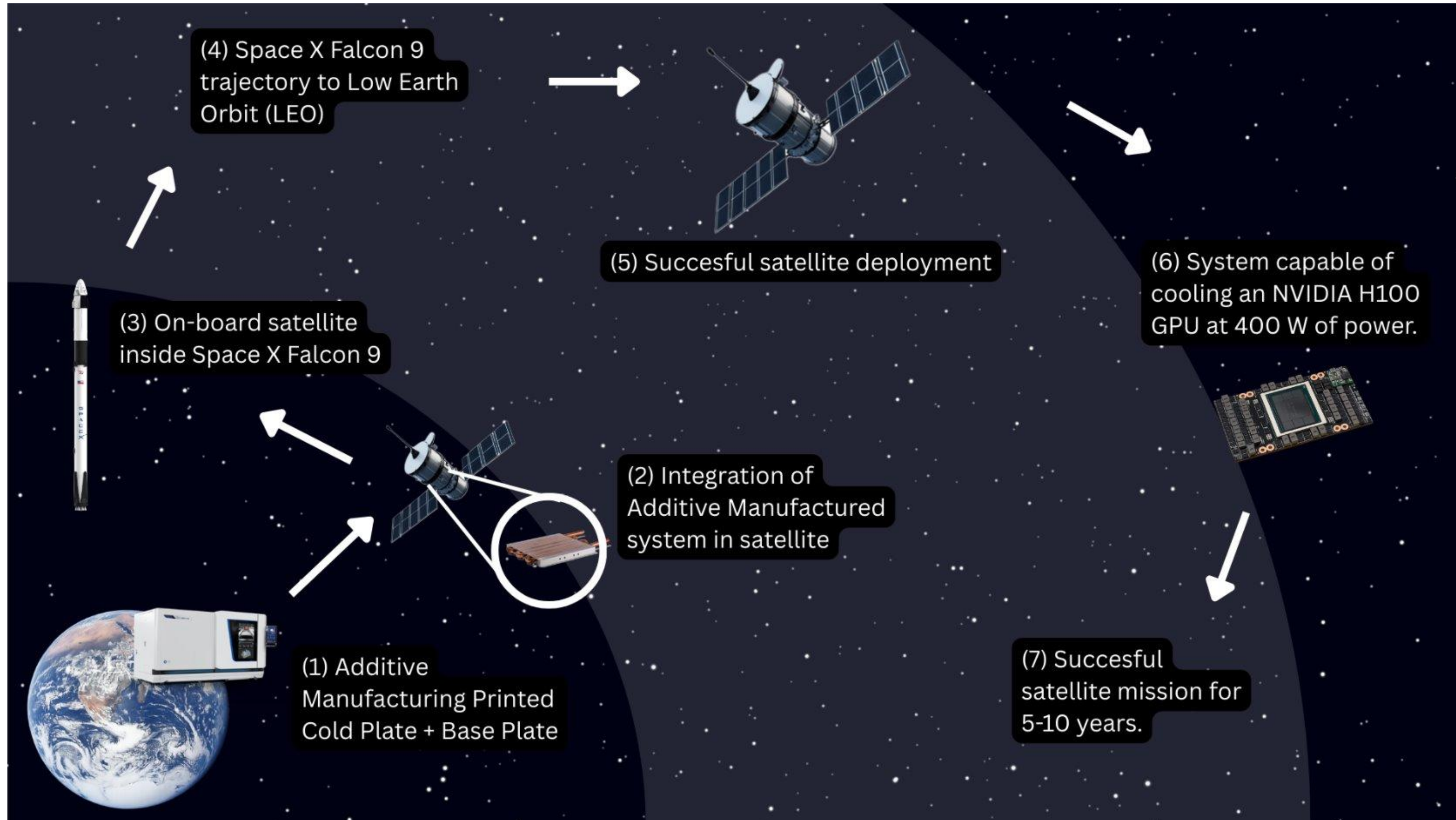
Concept of Operations



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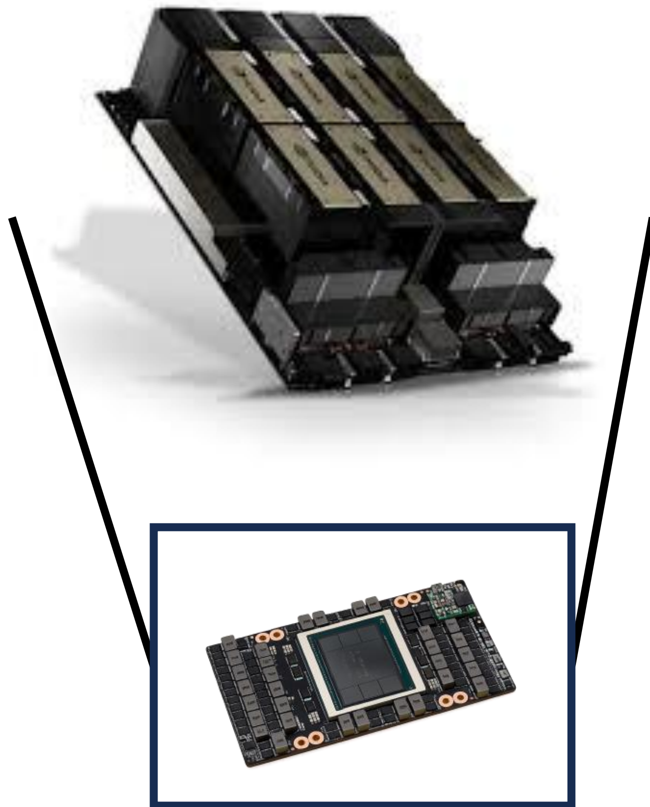
CONOPS

The sub-system is fabricated using additive manufacturing and integrated with spacecraft avionics. The spacecraft is launched aboard a Falcon 9, deployed into Low Earth Orbit, and enters nominal operations. Throughout the mission, the subsystem provides continuous thermal control and structural integrity.

The reason for selecting additive manufacturing over conventional machining is driven by system-level optimization objectives .By consolidating multiple components into a single topology-optimized structure, the subsystem reduces part count, interfaces, and potential failure points. This approach enables integration between structural and thermal designs, minimizing excess material, overall mass and lifecycle cost.

Thermal Challenge in High-Power LEO Electronics

Modern space electronics such as **AI accelerators (NVIDIA H100)** produce extremely high heat loads.



NVIDIA H100

In Vacuum Environments:

- No Convection
- Heat Rejection only Through **Radiation**

Thermal management becomes the **primary spacecraft design driver**.

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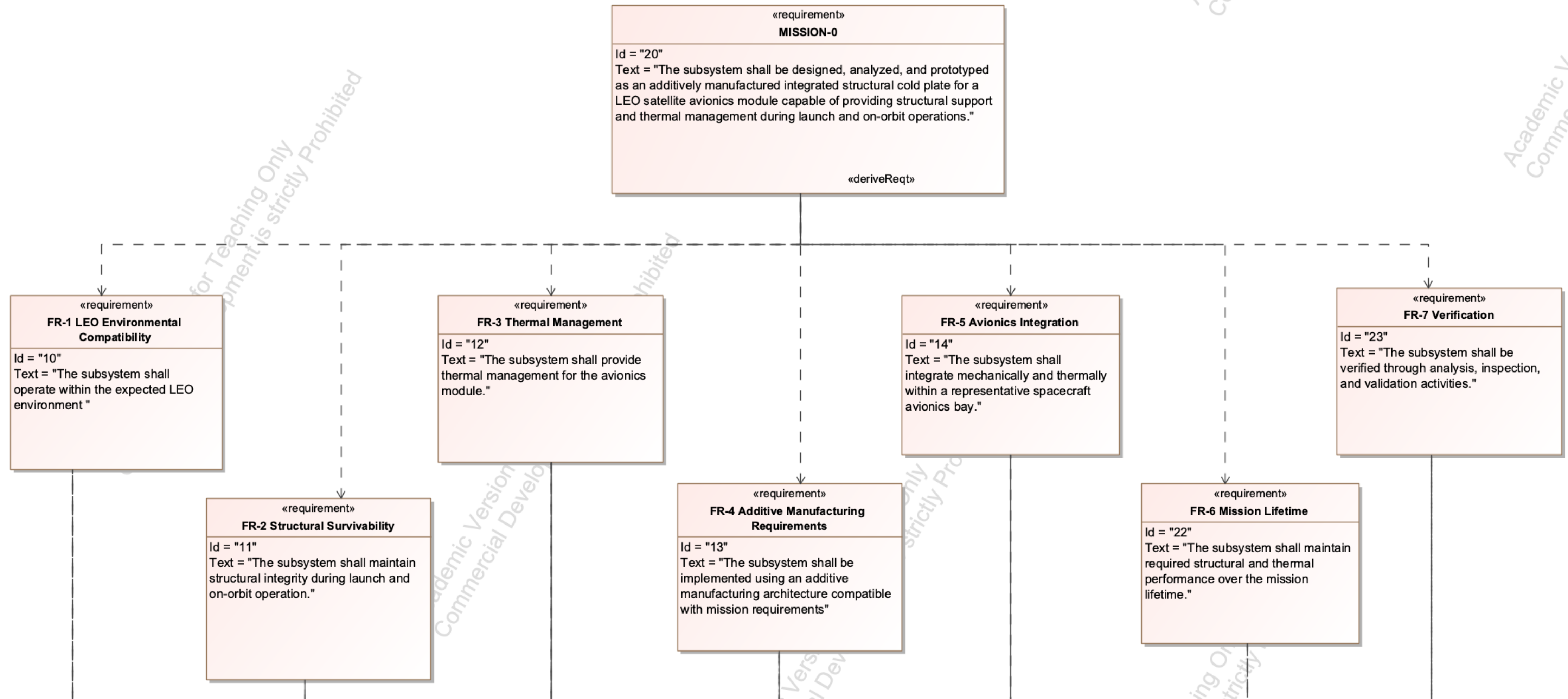
System Requirements Overview



Requirements Flow – Environment

SR-1 LEO Environmental

- **SR-1.1** The subsystem shall operate in the Low Earth Orbit spacecraft environment at orbital altitudes between 600 km and 1000 km.
- **SR-1.2** The subsystem shall tolerate orbital thermal cycling between −40 °C and 95 °C without degradation of structural integrity or thermal performance.
- **SR-1.3** The subsystem materials shall be compatible with the vacuum environment of space.
- **SR-1.4** The subsystem materials and surface finishes shall maintain performance when exposed to LEO environmental effects including atomic oxygen and radiation.

Requirements Flow – Structural

SR-2 Structural Support Requirements

- **SR-2.1** The subsystem shall provide structural support for spacecraft avionics hardware during launch and on-orbit operation.
- **SR-2.2** The subsystem shall maintain structural integrity under Falcon 9 launch environments.
    - **SR-2.2.1** The subsystem shall withstand Falcon 9 sine vibration loads per the SpaceX Falcon User's Guide (Section 4.3.2) without yielding or loss of function.
    - **SR-2.2.2** The subsystem shall withstand Falcon 9 random vibration loads at a qualification level of MPE + 3dB without structural failure.
    - **SR-2.2.3** The subsystem shall withstand the Falcon 9 acoustic environment with a Maximum Predicted Environment (MPE) of 133-135 dB without degradation.
    - **SR-2.2.4** The subsystem shall withstand Falcon 9 shock loads (Spacecraft Separation Shock) with a Peak Acceleration of 1,000 g at frequencies above 1,000 Hz.
- **SR-2.3** The subsystem shall support mounted avionics hardware and maintain structural integrity under launch static load conditions of 8.5 g (Axial) and 6.0 g (Lateral).
- **SR-2.4** The subsystem shall maintain avionics mounting alignment within ± 0.1 mm and ± 0.05° degrees through launch and operational environments.

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Requirements Flow – Thermal

SR-3 Thermal Management Requirements

- **SR-3.1** The subsystem shall dissipate a maximum avionics heat load of 400 W during on-orbit operations.
- **SR-3.2** The subsystem shall provide a conductive thermal path from avionics mounting interfaces to the heat rejection interface.
- **SR-3.3** The subsystem shall maintain total thermal resistance between avionics interfaces and the heat rejection interface ≤ 0.1 °C/W.
- **SR-3.4** The subsystem shall maintain avionics interface temperatures within −5 °C to 95 °C under steady-state operating conditions.
- **SR-3.5** The subsystem shall provide conductive interfaces capable of routing heat to designated secondary thermal sinks without degrading primary heat rejection performance.
- **SR-3.6** The subsystem shall provide a conductive interface compatible with the spacecraft radiator heat rejection system.
- **SR-3.7** The avionics mounting interface shall maintain surface flatness within 0.05μm
- -0.4μm Ra value to ensure adequate thermal contact with avionics components.
- **SR-3.8** The subsystem shall provide defined thermal interface surfaces compatible with approved thermal interface materials (TIMs).

Requirements Flow – Manufacturing

SR-4 Additive Manufacturing Requirements

- **SR-4.1** The subsystem shall be fabricated using additive manufacturing LPBF processes.
- **SR-4.2** The base plate and cold plate shall be fabricated as a single monolithic component using AlSi10Mg.
- **SR-4.3** The subsystem design shall reduce mechanical interfaces relative to conventional cold plate and bracket architectures.
- **SR-4.4** The subsystem shall maintain structural and thermal performance equal to or greater than a conventional baseline architecture.
- **SR-4.5** The subsystem shall undergo post-processing operations required to achieve interface flatness, positional tolerances, and surface finish requirements.

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Requirements Flow – Integration

SR-5 Avionics Integration Requirements

- **SR-5.1** The subsystem shall integrate mechanically and thermally within a representative spacecraft avionics bay.
- **SR-5.2** The subsystem shall provide standardized mechanical mounting interfaces compatible with spacecraft avionics hardware mounting practices.
- **SR-5.3** The subsystem shall provide defined thermal interface surfaces to support installation of approved thermal interface materials.
- **SR-5.4** The subsystem shall allow avionics installation and removal without structural modification of the primary component.

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Requirements Flow – Lifetime

SR-6 Mission Lifetime Requirements

- **SR-6.1** The subsystem shall maintain functionality over a 10-year mission life.
- **SR-6.2** The subsystem shall maintain structural stiffness and mounting integrity over the 10-year mission duration.
- **SR-6.3** The subsystem shall maintain thermal performance within ± 5% of beginning-of-life performance over the 10-year mission duration.

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Requirements Flow – Verification

SR-7 Verification Requirements

- **SR-7.1** The subsystem shall be verified through structural analysis representative of Falcon 9 launch conditions.
- **SR-7.2** The subsystem shall be verified through thermal analysis representative of LEO orbital conditions.
- **SR-7.3** Critical mechanical interfaces shall be verified through dimensional inspection and tolerance measurement.

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Requirements V&V

Req ID	Parent ID	Requirement Summary	Verification (Design/Specs)	Validation (Mission/Hardware)	V&V Method
TR-0	Mission	Prototype AM Cold Plate	Design review and FEA modeling of monolithic geometry.	Physical prototype assembly check and fit-check.	A, D
SR-1	A.1.2	LEO Environmental	Material outgassing analysis per ASTM E595.	Thermal cycling (-40°C to 95°C) in vacuum chamber.	A, T
SR-2	A.1.1	Structural Support	FEA margin of safety reports (1.25 FoS) per NASA-STD-5001B.	Static load testing of 3D-printed coupons to yield/failure.	A, T
SR-3	A.1.7	Thermal Management	CFD simulation of 400W load vs. 0.1 °C/W target.	Thermal Vacuum (TVAC) steady-state performance test.	A, T

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Requirements V&V

Req ID	Parent ID	Requirement Summary	Verification (Design/Specs)	Validation (Mission/Hardware)	V&V Method
SR-4	A.1.6	Additive Manufacturing	Build file validation and AlSi10Mg powder certification.	Archimedes density check (≥ 99.5%) and CMM inspection.	I, T
SR-5	A.1.5	Avionics Integration	CAD interference check and envelope volume analysis.	Physical tool-access and hardware installation demo.	A, D
SR-6	A.1.4	Mission Lifetime	Fatigue and radiation degradation analysis for 10-year life.	Modal frequency shift test post-environmental soak.	A
SR-7	A.1.1	Verification Methods	Cross-correlation of FEA/CFD models with coupon data.	Final sign-off of the Verification and Validation Report.	A, I

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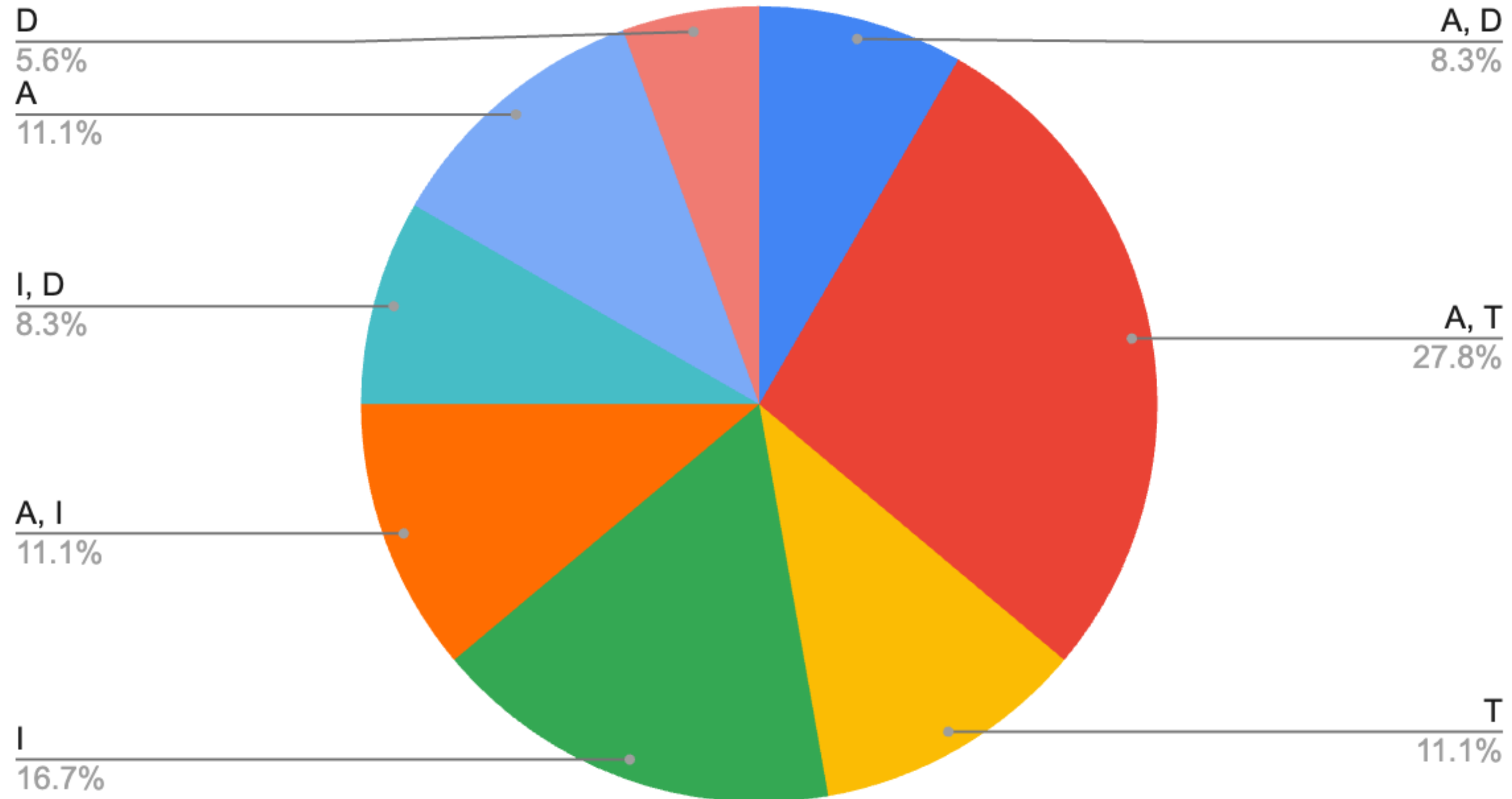
Requirements V&V



A – Analysis, T-Test, I-Inspection, D- Demonstration

Thermal Model Development (Thermal 1D Model)

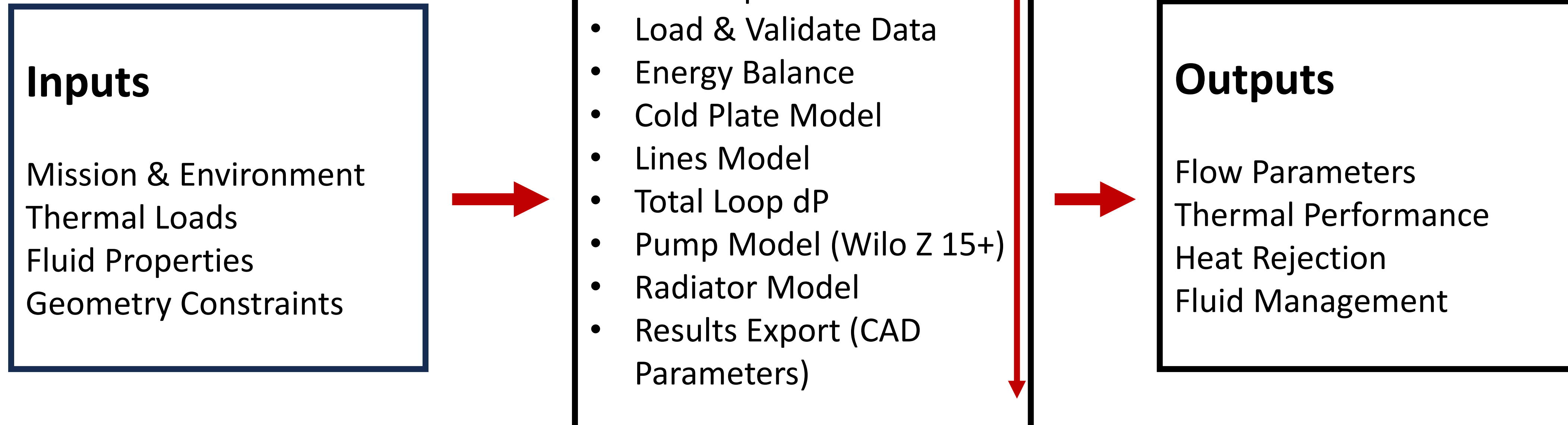
Steady-State Single-Phase Loop Architecture for Additively Manufactured Cold Plate Integration

Model Purpose

- Rapid Sizing Tool
- Enables Trade Studies
    - dT_Loop
    - Channel Geometry
    - Line Diameter
    - Fluid Selection

Design Philosophy

- Steady State Solver
- Physics-Based Correlations
- Ready for parametric optimization

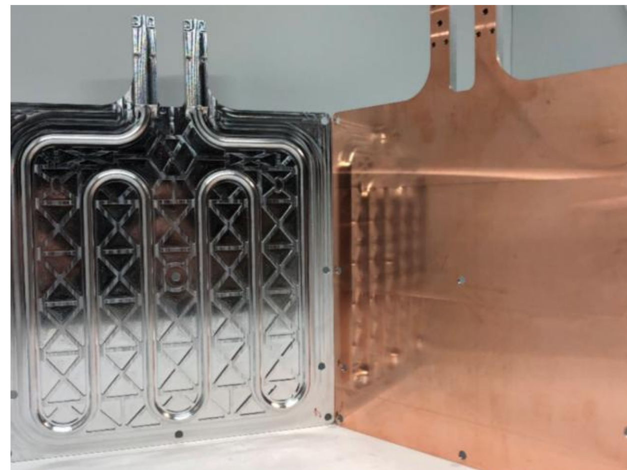


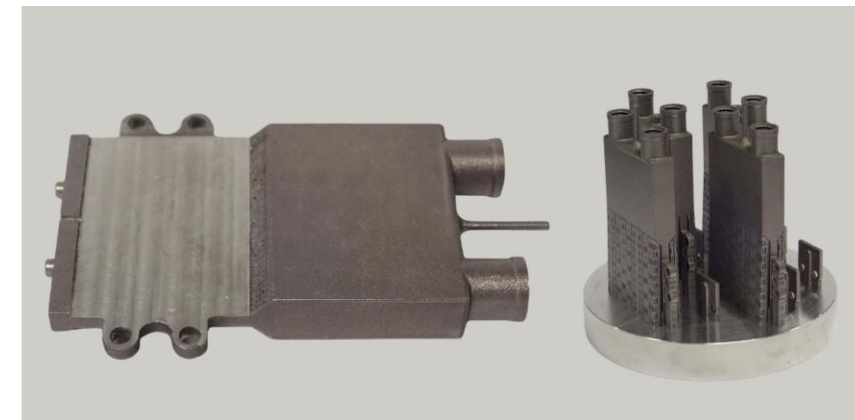
Trade Study – Cold Plate

Pros
- Reduced mass and Part Count
- Passive operation
- Flight-representative architecture
- Modular for different avionics loads
- Scalable for constellation production

Cons
- Two-phase loop integration complexity
- Interface contact resistance sensitivity
- AM surface finish concerns
- Qualification path for AM structural components

Traditional cold plate by Heyutech


Ultrasonic AM cold plate by Fabrisonic


AM cold plate by Centre suisse d'électronique et de microtechnique (CSEM)

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Thermal Architecture Trade Study

Multiple thermal architectures were evaluated

Passive conduction architecture

Advantages
Simple design

Disadvantages
Insufficient heat transport capability

Heat pipe architecture

Advantages
Passive operation

Disadvantages
Limited scalability for large heat loads

Two-phase loop architecture

Advantages
High transport capability

Disadvantages
Integration complexity

Single-phase pumped loop architecture

Advantages
Flexible design

Disadvantages
Added pump complexity, power consumption & plumbing complexity

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Trade Study – Heat Transport

1. Alternatives

Alternative	Description
A	Passive conduction
B	Two-phase loop
C	Heat pipe
D	Single-phase pumped loop

2. Selection Criteria

Sponsor Requirement	Selection Criteria	Measurement Method
System must dissipate required heat load	Thermal Transport Capability	Analytical calculation (W), simulation results, or experimental testing
System must operate reliably in-flight conditions	Reliability	Failure mode analysis (FMEA), heritage data, SME evaluation
System must be feasible to implement and test within project scope	Implementation Feasibility	Model maturity, ground test feasibility, manufacturability, schedule compatibility
System must be integrable with minimal risk	Integration Risk	Interface count, control complexity, plumbing complexity, system coupling
System should be simple and robust	Design Simplicity	Number of parts, moving components, and system architecture complexity

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Trade Study – Heat Transport

3. Weight Selection Criteria

Criteria	Weight	Justification
Thermal Transport Capability	0.25	Primary mission requirement, failure leads to system overheating
Reliability	0.20	No maintenance possible in flight → critical for mission success
Implementation Feasibility	0.25	Must be realistically modeled, built, and tested within project scope
Integration Risk	0.20	Captures uncertainty and potential failure during development
Design Simplicity	0.10	Simpler systems are more robust and easier to validate

Normalized Scoring

$$Higher\ Better\ S = \frac{x}{x_{max}}$$

$$Lower\ \ Better\ S = 1 - \frac{x - x_{min}}{x_{max} - x_{min}}$$

4. Criteria Scoring Scales & Evaluation

Criteria	Heat Capacity Basis	Heat Transport Capability (Pass/Fail)	Active Components	Major Subsystems	Major Interfaces	Major Components	Total Score
Weight		0.25	0.20	0.25	0.20	0.10	
A: Passive Conduction	Estimated Conduction Path	150 W	0	1	9	10	0.497
B: Two-Phase Loop	High-Capacity Option	800 W	3	6	5	6	0.414
C: Heat Pipe	Passive transport option	300 W	0	3	8	9	0.494
D: Single Phase Pumped Loop	$\dot{m}c_p\Delta T$	400 W	1	4	8	6	0.449

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Trade Study – Radiator Selection & Sizing

1. Alternatives

Alternative	Description
A	Body-mounted radiator only (limited spacecraft surface area)
B	Single deployable radiator
C	Hybrid: body-mounted + deployable radiator
D	Larger spacecraft with sufficient fixed radiator area

2. Selection Criteria

Sponsor Requirement	Selection Criteria	Measurement Method
System must dissipate required heat load	Thermal Transport Capability	Radiator area sizing (m^2), Stefan-Boltzmann analysis
System must fit within spacecraft constraints	Packaging Feasibility	Available surface area vs required area
System must must operate reliably in space	Reliability	Deployment mechanisms, heritage systems
System must be integrable with minimal risk	Integration Risk	Complexity of deployment and integration
System should be simple and robust	Design Simplicity	Number of moving parts and interfaces

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Trade Study – Radiator Selection & Sizing

3. Weight Selection Criteria

Criteria	Weight	Justification
Thermal Transport Capability	0.35	Primary mission driver (cannot overheat GPUs)
Packaging Feasibility	0.25	Must fit within spacecraft constraints
Reliability	0.20	Deployable's introduce failure modes
Integration Risk	0.10	Captures uncertainty in implementation
Design Simplicity	0.10	Simpler systems easier to validate

Normalized Scoring

$$Higher\ Better\ S = \frac{x}{x_{max}}$$

$$Lower\ \ Better\ S = 1 - \frac{x - x_{min}}{x_{max} - x_{min}}$$

4. Criteria Scoring Scales & Evaluation

Criteria	Available Radiator Area	Area Margin (Pass/Fail)	Area Occupied (Bus Face)	Deployment Mechanics	Major Interfaces	Major Components	Total Score
Weight		0.35	0.25	0.20	0.10	0.10	
A: Body Only	$0.063\ m^2$	6.9%	100%	0	2	1	0.672
B: Deployable	$0.95\ m^2$	103%	100%	1	4	3	0.661
C: Hybrid	$1.013\ m^2$	110%	200%	1	5	4	0.582
D: Larger Bus	$0.92\ m^2$	100%	1460%	0	3	1	0.718

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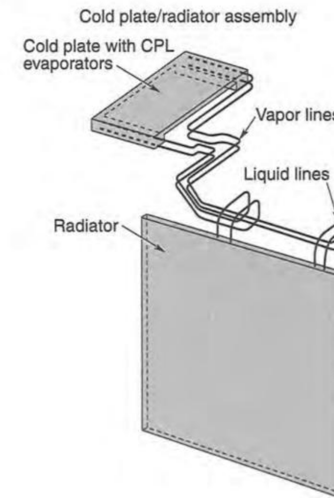
Trade Study - Radiator Architecture

Two radiator configurations were evaluated.

Body-mounted radiator

Advantages
Simple integration

Disadvantages
Limited available area

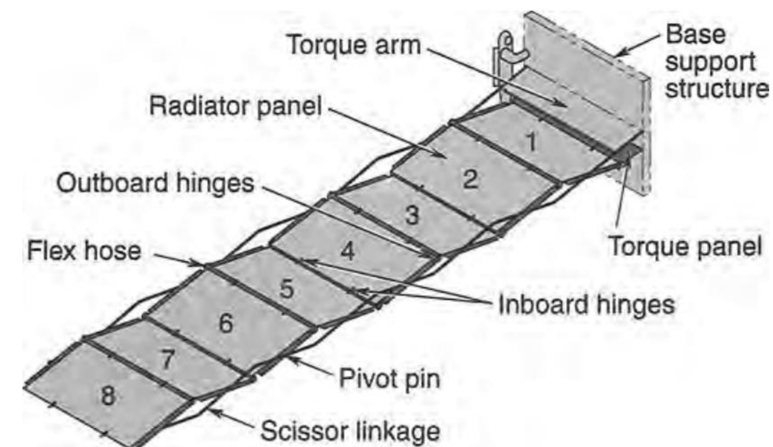


Body-Mounted Radiator Example

Deployable radiator

Advantages
Large heat rejection area &
Minimal spacecraft footprint

Disadvantages
Deployment mechanism required



Deployable Radiator Example

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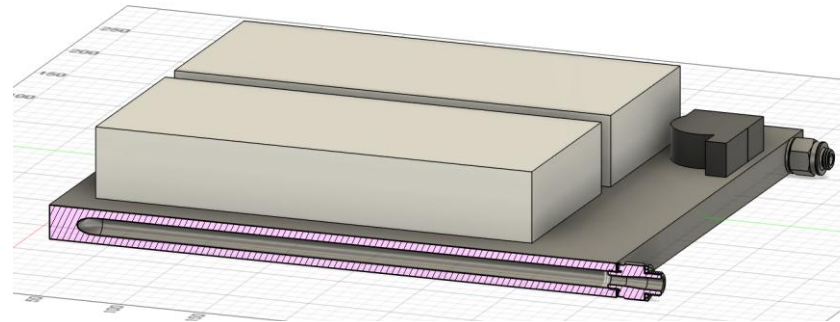
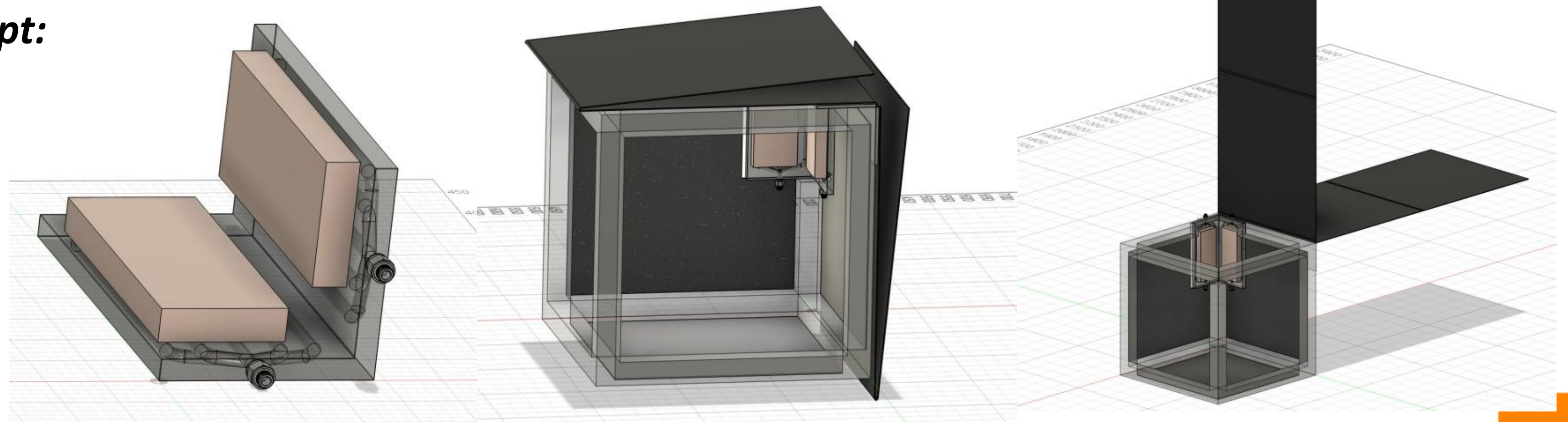
Design Concept

Initial concept:



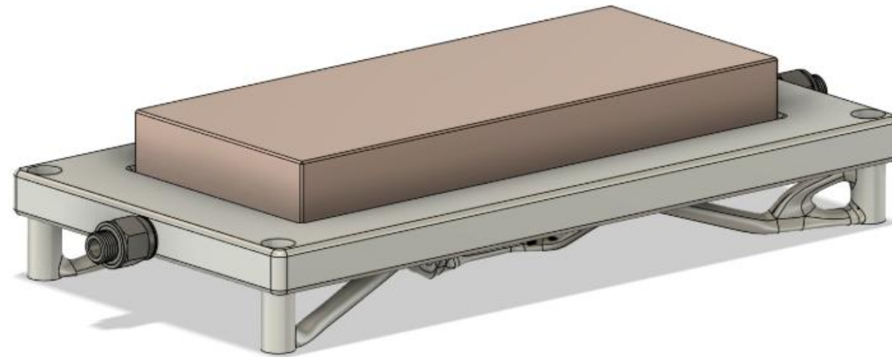
ESPA-Class Satellite

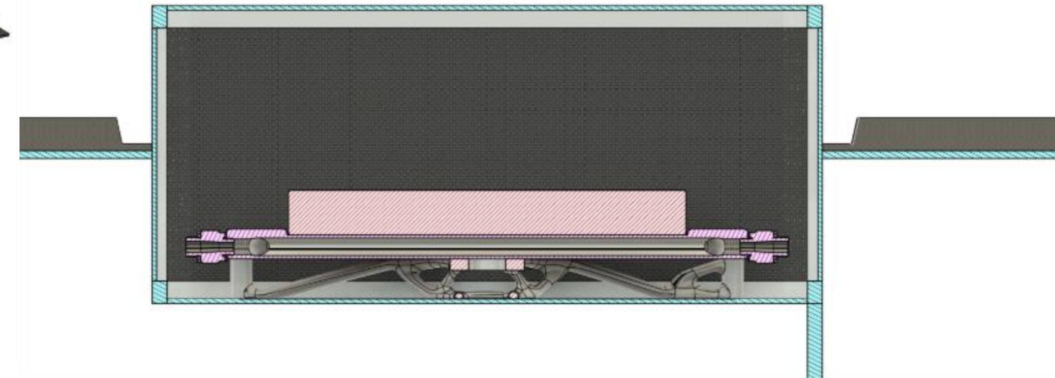
Revised concept:



Design Concept

Final concept:





- **Envelope**

  Bus: ~350 × 180 × 180 mm

  Cold plate depth: ~20 mm

- **Internal volume for avionics and subsystems**

  Gross Internal Volume ~ 0.0113 m^3

  Cold Plate Volume ~ 0.0017 m^3

  Remaining Volume ~ 0.0096 m^3

Net volume considering insulation Installed

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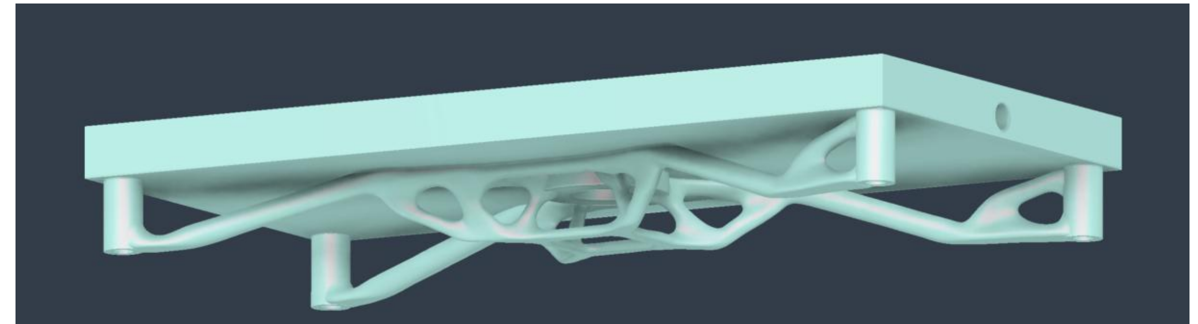
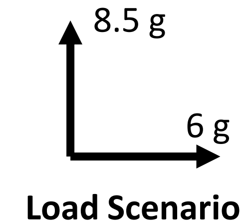
Design Concept



Attachment structure refined using load-path optimization

- Material removed where not required using generative design methodologies
- Forces heat flow through intended path by minimizing contact with bus
- Geometry directs load efficiently into bus interface under launch conditions
    - Non-conductive spacers between cold plate and bus
        - Reduce parasitic heat leakage

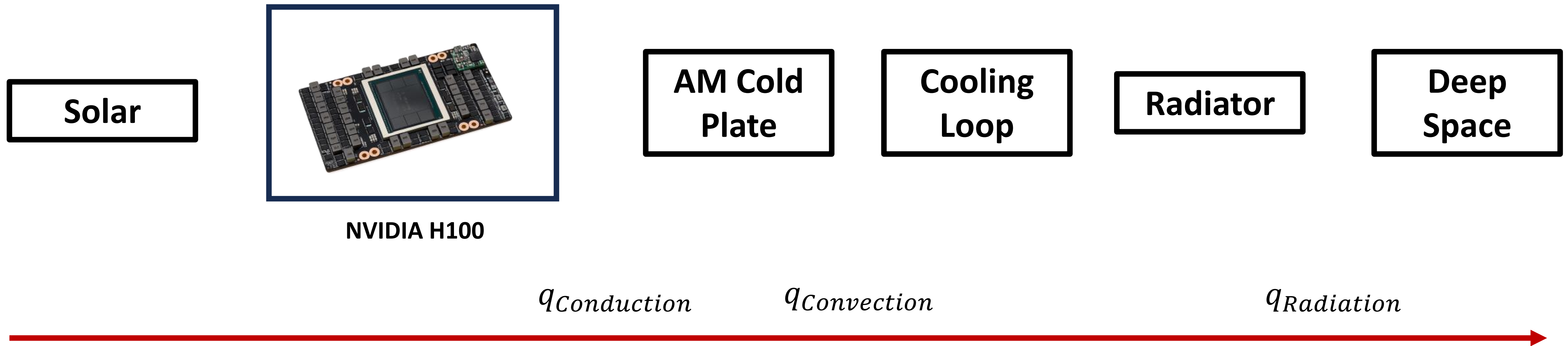


Load Scenario

Thermal isolation prevents the bus from acting as a heat sink

Heat Flow Architecture

$$P_{in} = Q_{reject}$$



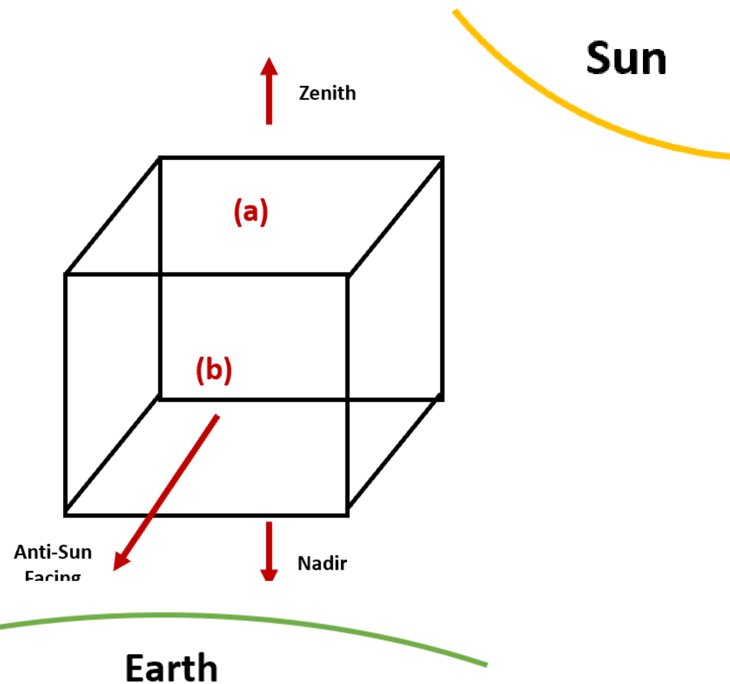
Heat Transport Path:

1. Conduction from GPU to cold plate
2. Fluid transport in cooling loop
3. Heat rejection through radiator radiation

Satellite Orientation Considerations

Radiator performance strongly depends on spacecraft orientation

Key objective:
Maximize the radiator view factor to deep space.

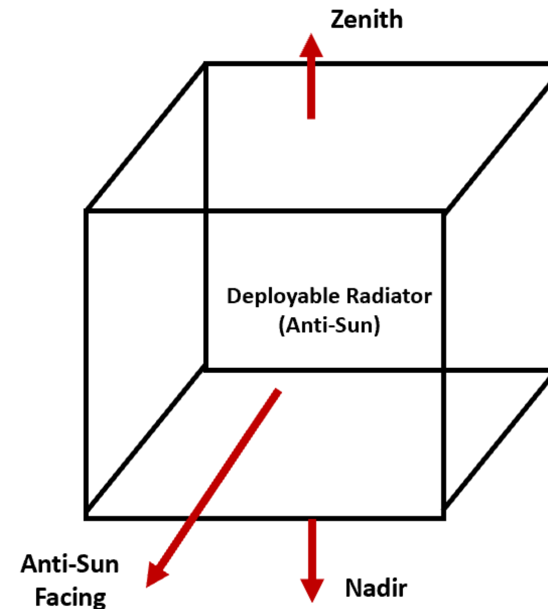


$$Q_{in} = Q_{out}$$

$$P_{in} = \varepsilon \sigma A F_{Space}\left(T_{Rad}^4 - T_{Sink}^4\right) - q_{solar} - q_{albedo} - q_{IR}$$

Deployable Radiator

- One GPU per cold plate
- ~400 W handled
- Rejection using deployable radiator



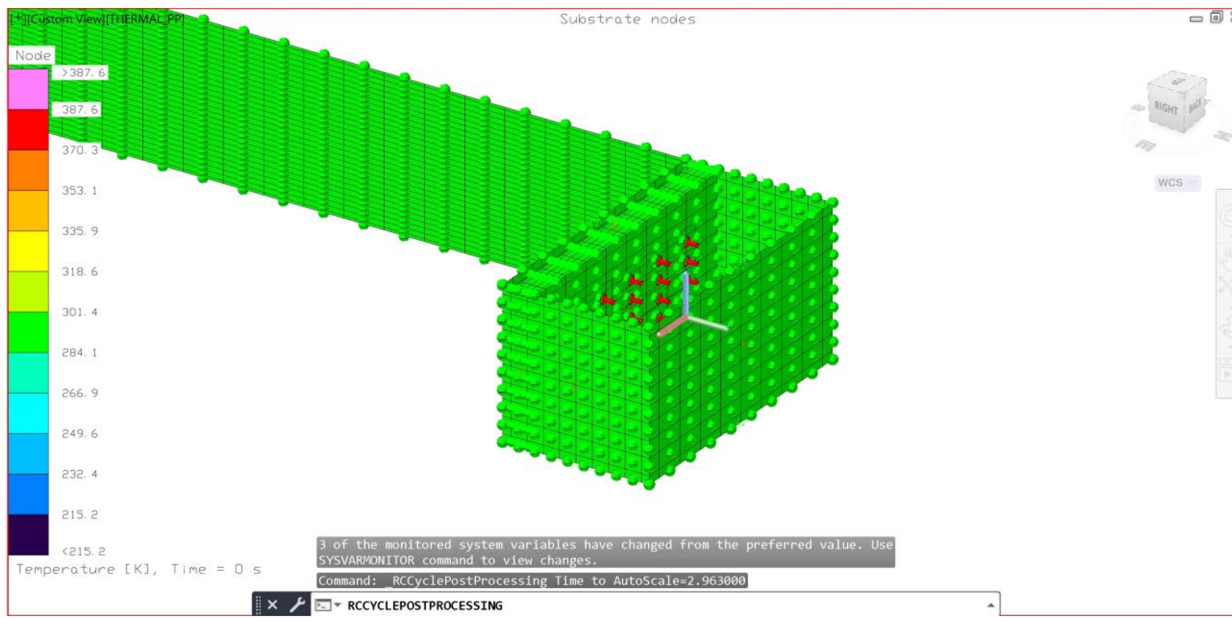
Consider Zenith Oriented

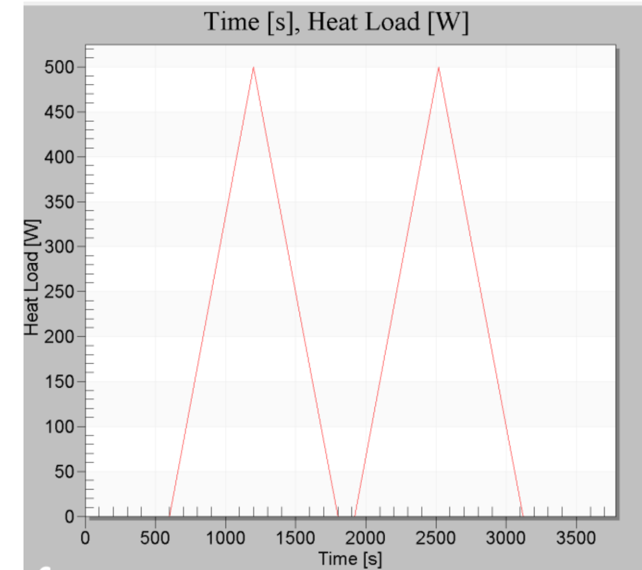
$$P_{in} = \varepsilon \sigma A\left(T_{Rad}^4 - T_{Sink}^4\right)$$

$$q_{solar}, q_{albedo}, q_{IR} \ll q_{rad}$$

Thermal Modeling Heat Load Case (400W) 1.25 SoF

- Transient simulation with time-dependent GPU heat load
- Peak load: 500 W (representative burst)
- Duty cycling implemented to maintain thermal limits
- Heat path validated: GPU -> Cold Plate -> Radiator -> Space





GPU Heat Load Profile (Time Dependent)

- Cyclic operation to simulate real compute workload
- Ramp-up and ramp-down implemented (non-instantaneous 500 W heat load)
- Periodic heating allows passive cooling phases.

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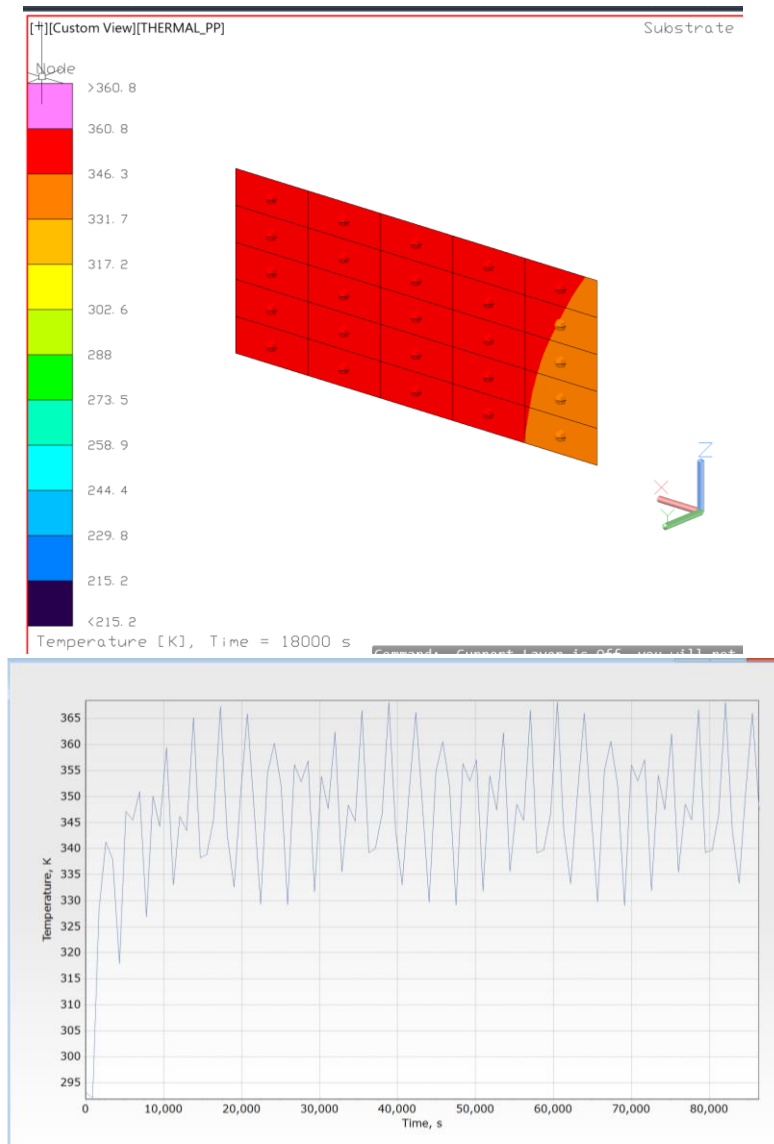
Thermal Modeling GPU Temperature Response (Transient)

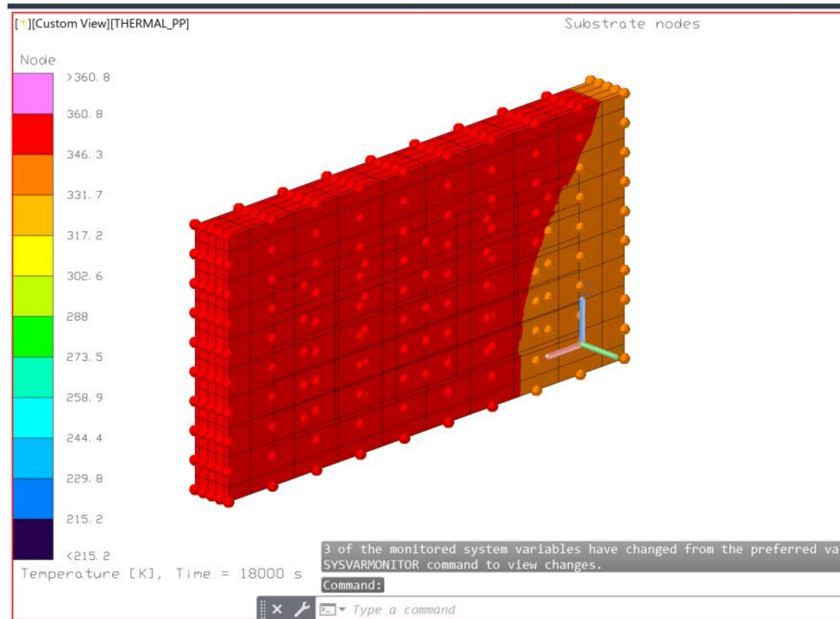


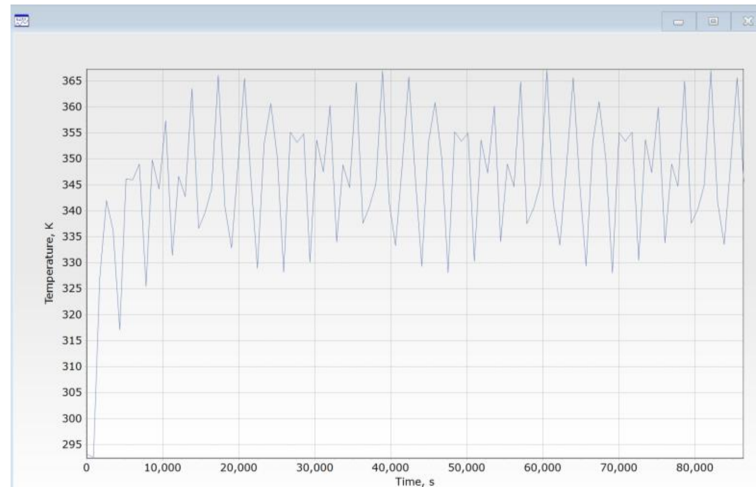
- Peak temperature: ~360–365 K
- Minimum temperature: ~310–320 K
- Temperature oscillates with duty cycle
- Stable cyclic behavior achieved

GPU operates within a controlled thermal band under cyclic loading

50 – 95 C

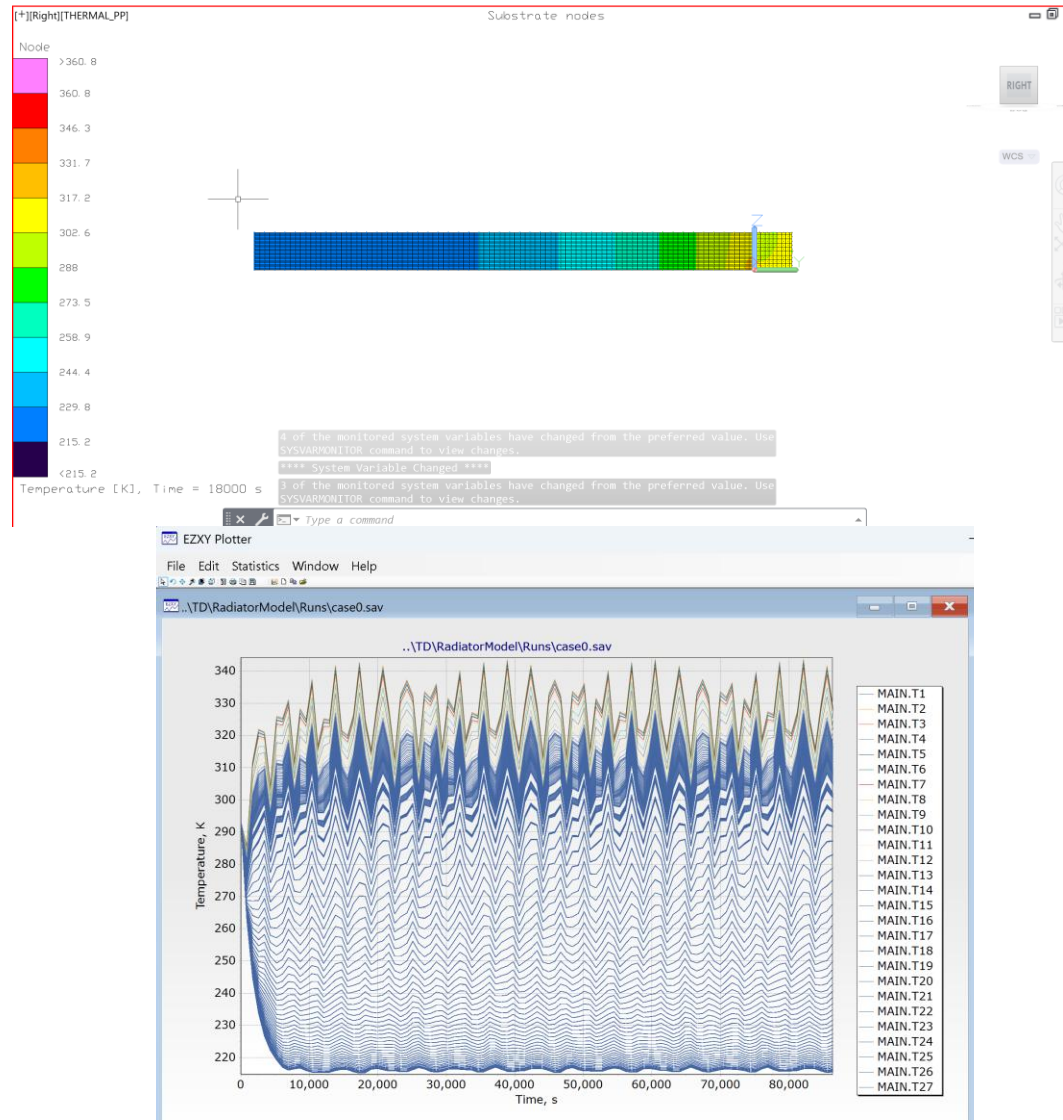
Thermal Modeling Cold Plate Thermal Performance





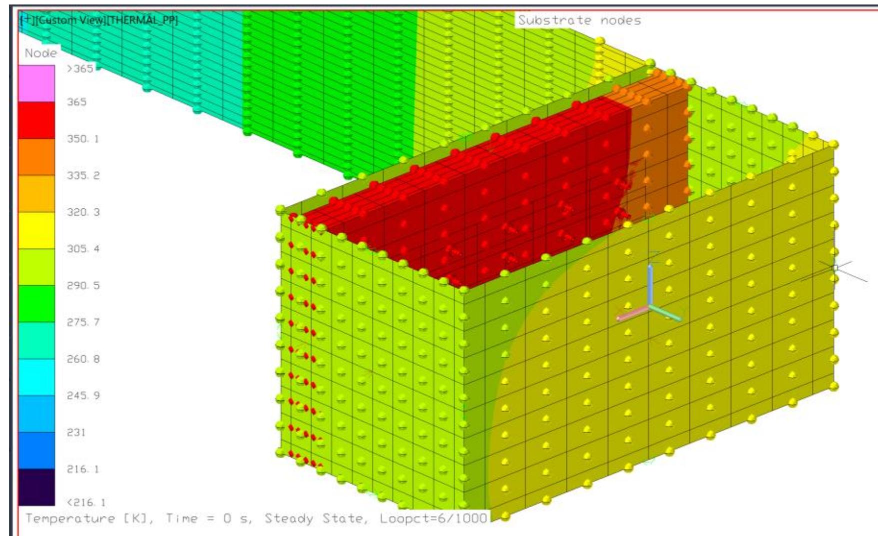
- Directly receives GPU heat load
- Acts as thermal buffer and spreader
- Smooths transient spikes before radiator rejection
- Maintains conductive heat path efficiency

Thermal Modeling Radiator Heat Rejection Performance

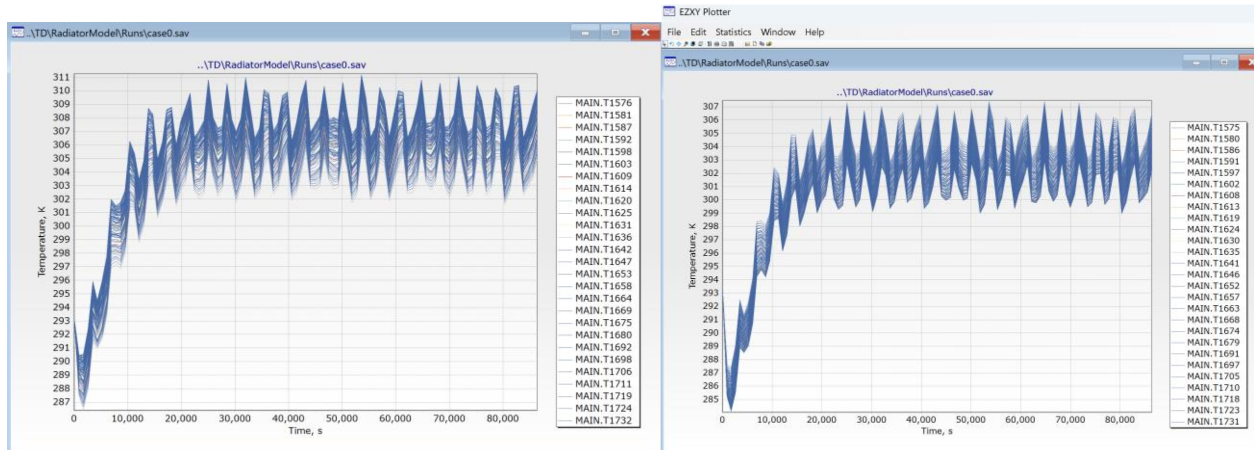


- Temperature gradient confirms directional heat flow
- Highest temps near cold plate interface
- Far radiator approaches space sink temperature
- Effective radiative heat rejection observed
- Supports continuous cyclic operation

Thermal Modeling Spacecraft Bus Thermal Stability



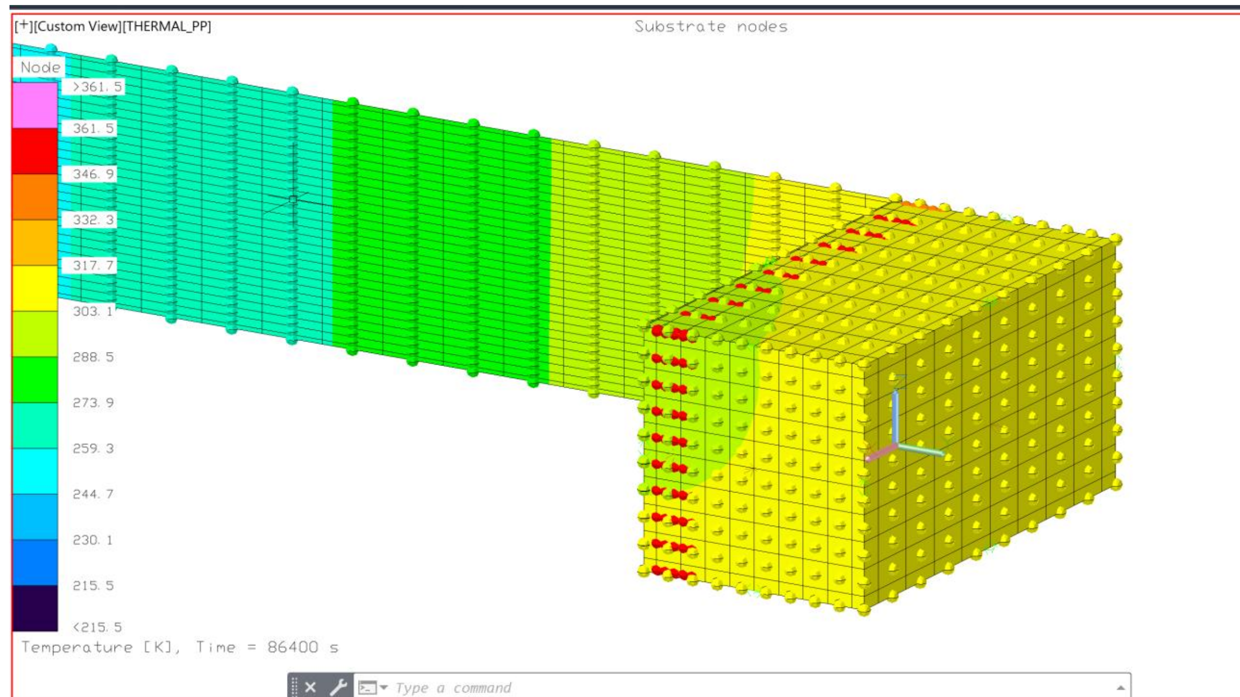
- Bus temperatures remain ~300–310 K
- Minimal thermal coupling from payload
- Thermal isolation between payload and structure is effective
- No overheating of structural elements observed
- High-power payload does not thermally destabilize the spacecraft bus



Sun Facing

Anti-Sun Facing

Thermal Modeling Thermal Control Strategy



- Active cooling via radiator
- Thermal spreading via cold plate
- Duty cycling of GPU load
- System optimized for LEO environment

Thermal System Validation

- Successfully modeled 400W GPU heat load
- Demonstrated stable transient operation
- Maintained temperatures within operational range
- Validated heat transfer path
- Meets requirement A.1.7 (Thermal)

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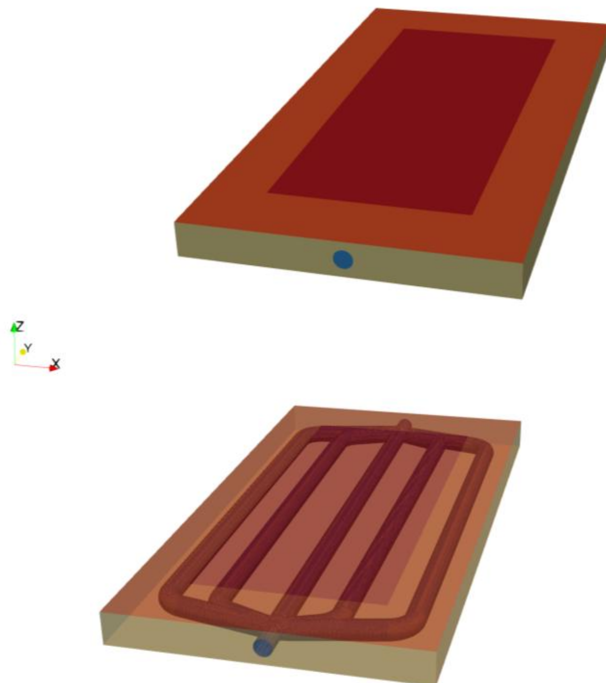
CFD Simulation - Multi Region Conjugate Heat Transfer

Simulation Setup – Boundary Conditions

- Red square on the left figure defines the area for the heat flux at 400W
- The interface between solid and fluid is a no-slip BC applied at the channel's walls
- A mass flow rate inlet is chosen and prescribed pressure at the outlet of 6.58 g/s
- Zero gradient BCs are used for every other patch
- The simulation was performed using OpenFOAM's solver chtMultiRegionSimpleFoam.

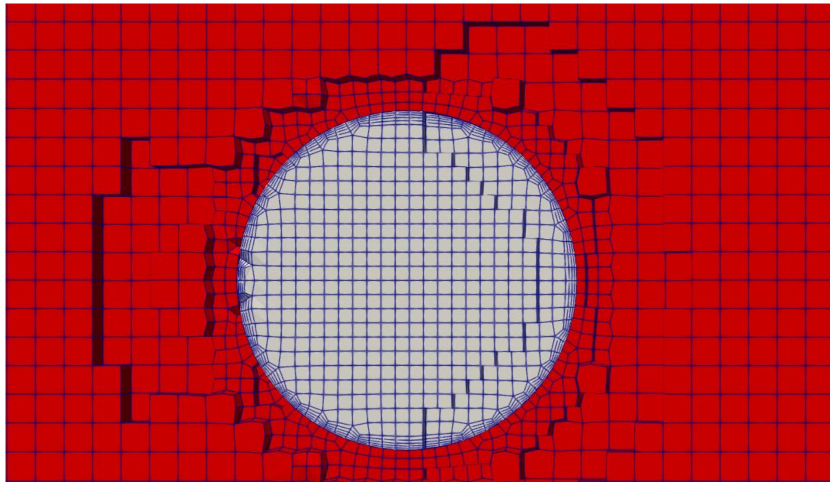


Property	Fluid (PGW-30)	Solid (AlSi10Mg)
Density	1035 $\frac{kg}{m^3}$	2670 $\frac{kg}{m^3}$
Thermal Conductivity	0.45 $\frac{W}{m*K}$	130 $\frac{W}{m*K}$
Specific Heat (Cp)	3800 $\frac{J}{kg*K}$	900 $\frac{J}{kg*K}$

CFD Simulation Multi Region Conjugate Heat Transfer

Simulation Setup – Computational Domain

- The computational domain consists of a ~7.5 M multi-region mesh
- Cell refinement and inflation layers is used near patch interface in an effort to produce a low y^+ first cell height for resolving of the thermal boundary layer and gradients

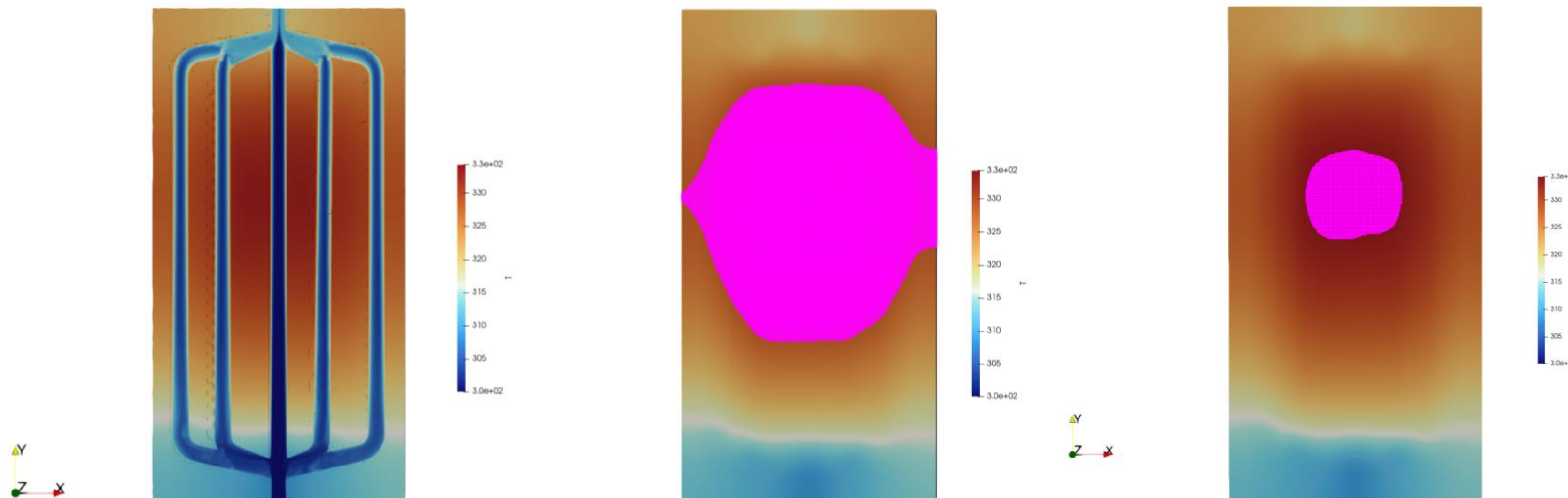


CFD Simulation Multi Region Conjugate Heat Transfer

Results – Temperature Analysis

- The left figure shows temperature distribution over the plate and channels (cross section)
- The middle figure shows hotspot with T > 55°C with maximum temperature reaching 60.9 °C
- The data from the results is manipulated to find the cells that produce a hotspot for the maximum temperature within a tolerance of $\pm$ 0.5 °C

- The right image illustrates the maximum average temperature of this region measures 60 °C
- With the known temperature at the inlet of 26.85 °C, the heat resistance is calculated, yielding a Heat Resistance value of 0.082 °C/W.



Risk Assessment Matrix

Likelihood		1 Very Low	2 Low	3 Medium	4 Medium/ High	5 Very High
Very High	5					
Medium/ High	4			R6		
Medium	3			R4	R2, R7, R8, R12	R1
Low	2			R10, R11, R13	R9, R14	R3, R5, R15
Very Low	1					
				Effect		

Color	Level
Red	High
Orange	Medium/ High
Light yellow	Medium
Green	Low

ID	Risk
R1	Radiator Undersizing
R2	Cold Plate Thermal Inefficiency
R3	Pump Failure
R4	Excessive Pressure Drop
R5	Coolant Leakage
R6	Thermal Model Inaccuracy
R7	Microgravity Flow Effects
R8	GPU Heat Load Underestimation
R9	Manufacturing Defects
R10	Structural Integration Issues
R11	Radiator Surface Degradation
R12	System Scaling Risk
R13	Pump Power Consumption
R14	Launch Vibration Damage
R15	Thermal Runaway

Risk Assessment Top risks and mitigation

ID	Risk	Likelihood	Impact	Score	Mitigation
R1	Radiation under sizing	3	5	15	Add radiator margin and hot case analysis
R2	Cold plate inefficiency	3	4	12	CFD Validation and channel optimization
R6	Thermal model inaccuracy	4	3	12	Validate model with multiple methods
R7	Microgravity flow effects	3	4	12	Use heritage cooling loop data
R8	Heat load underestimation	3	4	12	Add thermal margin
R12	System scaling risk	3	4	12	Modular cold plate design

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Integration and Test

Phase 1: Analysis (Pre-Prototype)			
Structural Finite Element Analysis (FEA)		Computational Fluid Dynamics (CFD) / Thermal FEA	
Activity: Perform Quasi-Static, Sine, and Random Vibration analysis, using the Falcon 9 flight data.	**Goal:** Determine if the AlSi10Mg wall thicknesses and internal lattices survive the 8.5 g load and 3-sigma vibration peaks without yielding.	**Activity:** Model the 400 W heat flux through the 3D printed geometry.	**Goal:** Confirm the 0.1 °C/W resistance. AM surfaces are rough; analysis must account for the actual contact area of AM AlSi10Mg.
Current Status: Completed			

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Integration and Test

Phase 2: Sub-scale Testing	
Material Characterization	
Activity: Tensile testing and Thermal Conductivity measurement of AM-specific AlSi10Mg samples.	**Goal:** Determine empirical material data to feed back into the FEA to account for the anisotropy and build-direction variability inherent in the LPBF manufacturing process.
Current Status: Pushed into future work due to internal issues at the W.M Keck Center. **Tentative Schedule:** Project for Fall 2026 Semester.	

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Integration and Test

Phase 3: Qualification Testing (The Prototype)			
Vibration & Shock Testing		Thermal Vacuum (TVAC) Cycling	
Activity: Subject the prototype to the Falcon 9 "Qualification" levels (keep it 3dB higher than flight levels).	**Goal:** Verify SR-1.2.1 through SR-1.2.4.	**Activity:** 8–12 cycles between −40 °C and 95 °C in a vacuum chamber ($\leq 1 \times 10^{-5}$Torr).	**Goal:** Verify SR-3.2 and check for delamination or micro-cracking in the AM structure.
Tentative Schedule: Project for Fall 2026 semester.			

Future Work

- **Architecture & Trade Studies**: Refine additive structural-thermal integration concept; conduct capillary transport trade study (CPL vs. heat pipe vs. hybrid); compare mass and part count across concepts.

- **Thermal & Structural Analysis**: Define heat loads and complete thermal model; establish structural load cases and margin assessment.

- **Integration & Manufacturability**: Characterize AM design constraints; validate heat pipe/loop integration concept; define post-processing and interface machining requirements.

- **Testing Strategy**: Develop TVAC test concept; define heater placement and thermocouple mapping; establish model-to-test correlation methodology.

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TBX Management

ID	Type	Description	Resolution Plan / Action
TBX-01	TBR	Inclusion of parasitic heat loads in thermal models.	Refine CFD and FEA models in Section 5.3 to account for heat leakage from avionics cabling.
TBX-02	TBC	Model Correlation Error Margin.	Establish an acceptable ± 10% error margin between simulation and experimental validation.
TBX-03	TBD	Material Procurement (50kg Powder).	Secure procurement of 50kg of AlSi10Mg powder to support full-scale prototype fabrication.
TBX-04	TBR	Keck Center Print Compatibility.	Finalize build-plate orientation and parameters to confirm LPBF printing at the W.M. Keck Center.
TBX-05	TBC	Post-Processing Finish Specification.	Coordinate with UTEP Machine Shop to verify fly-cutting steps for a 0.4 µm Ra surface finish.
TBX-06	TBD	Thermal Vacuum (TVAC) Test Profile.	Define ramp rates and soak times for TVAC testing to validate LEO orbital performance.

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Q&A