Mars Sample Recovery Helicopter Thermal System Design

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This document has been reviewed and determined not to contain export controlled technical data.

Update on Ingenuity Helicopter & Perseverance Rover

Spacecraft Status: Nominal as of Sol 844 on July 6, 2023

- **Ingenuity Helicopter Log:** https://mars.nasa.gov/technology/helicopter/#Flight-Log
- 52 flights, Distance Flown: 12,097 m, Total Flight Time: 5,632 secs, (94 min)
- Fastest Ground Speed: 6.5 m/s, Highest Altitude: 18 m

Perseverance Rover:

Odometry: 19606.0 meters

- **Samples:** 10 rock cores, 1 regolith sample, 2 witness tubes

- **Three Forks Cache:** 7 rock cores, 1 regolith sample, 1 atmospheric sample, 1 witness tube

- **Remaining Tubes:** 18 sample tubes, 2 witness tubes

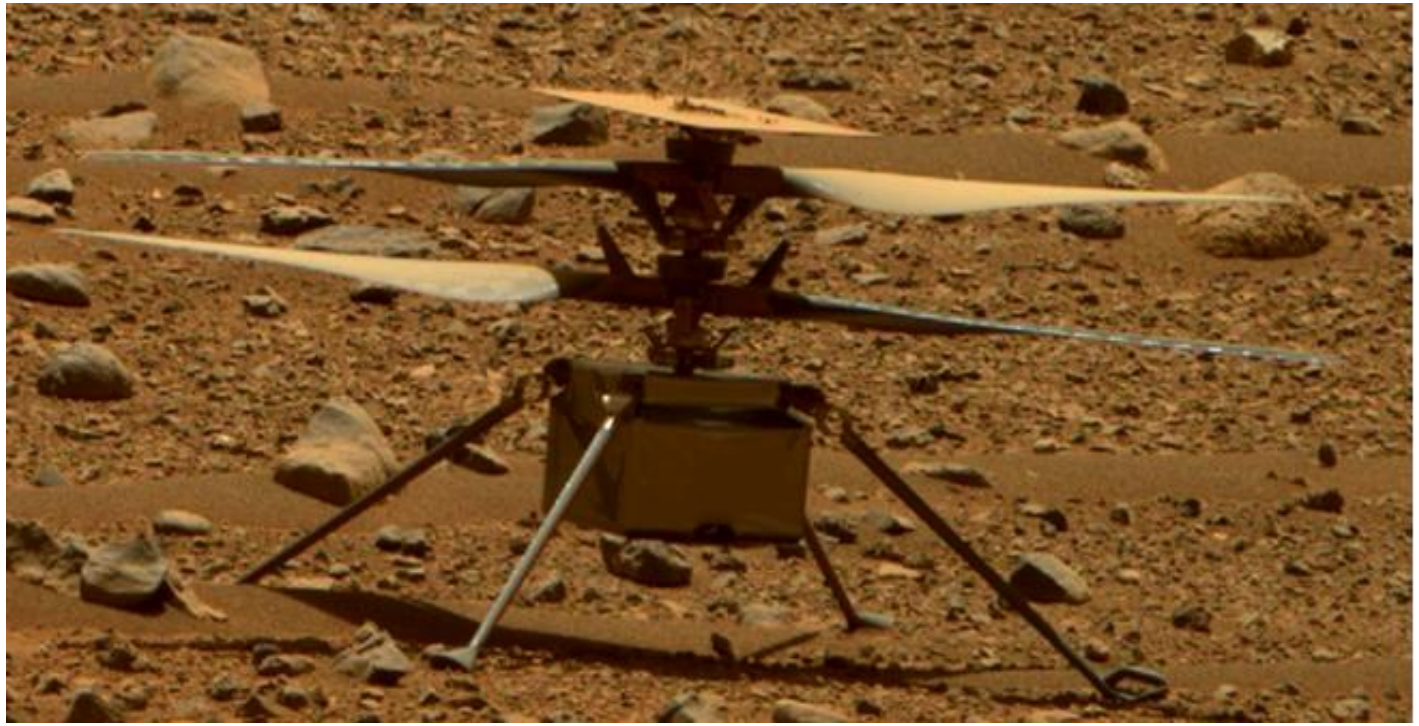
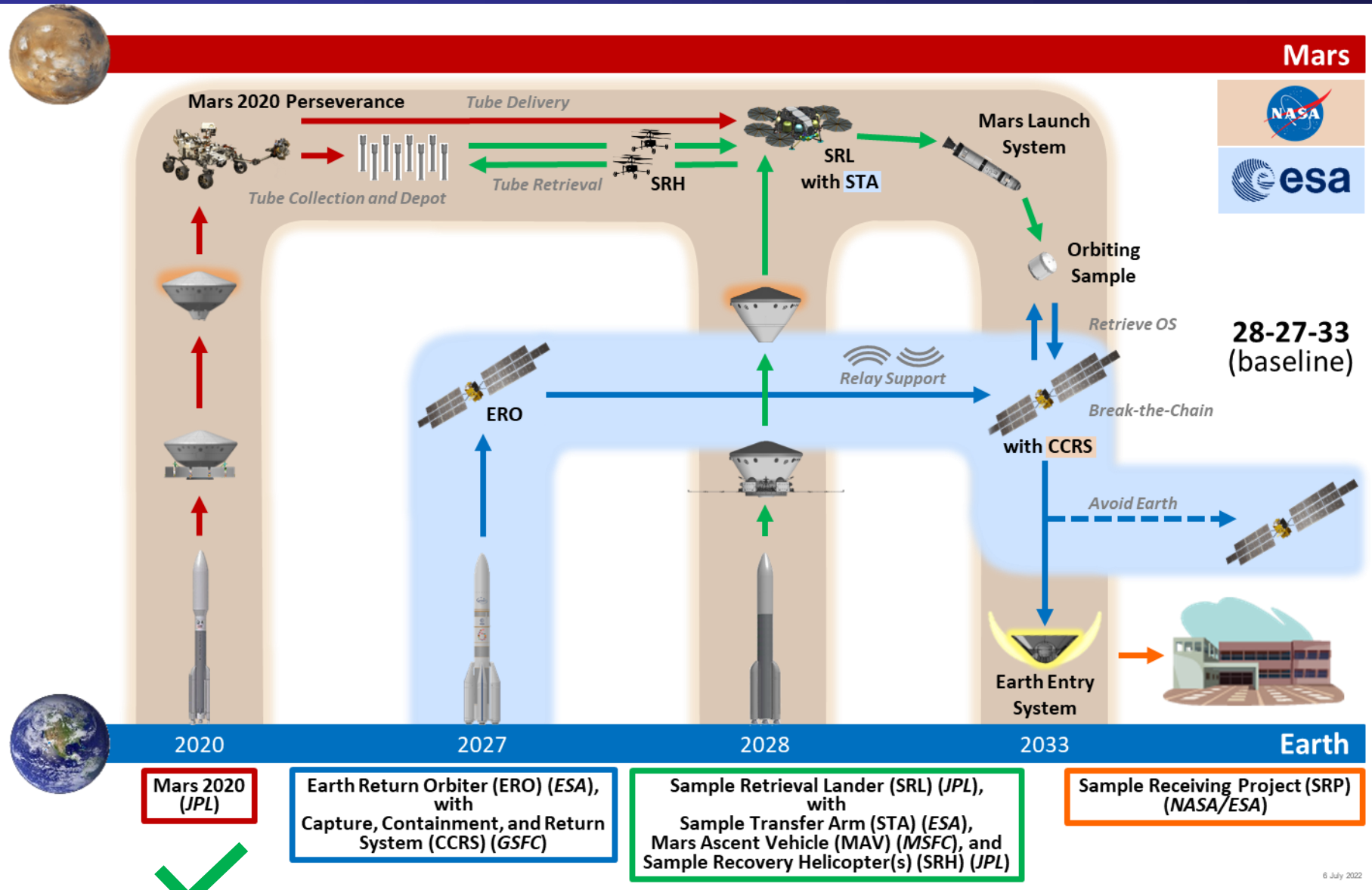


Image of Ingenuity captured on sol 776 by the Mastcam-Z team

Mars Sample Return (MSR) Planning Architecture



Sample Recovery Helicopter (SRH) Overview

- **2 Ingenuity-like rotorcraft with:**
  - **Ground mobility**
  - **Tube manipulator**
  - **Stereo vision**
  - **Inflight, absolute localization**
- **1 Base station and 2 antennas**

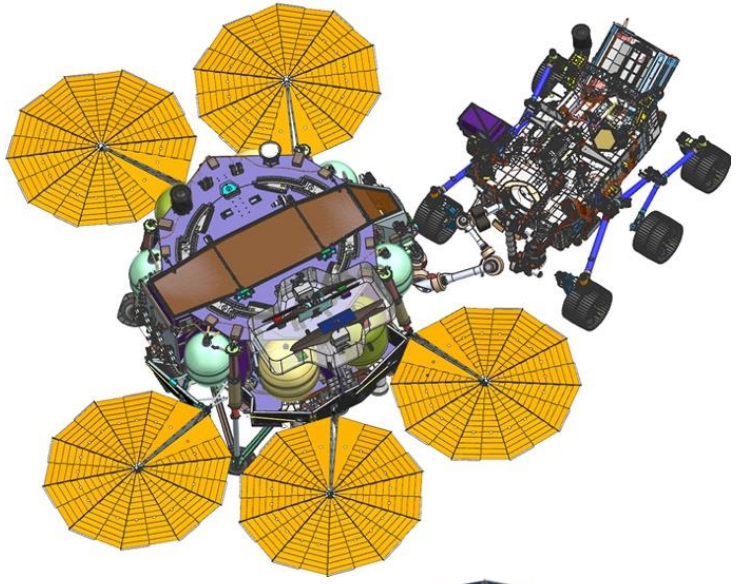
Parameter	Ingenuity	SRH
Rotor Diameter	1.21 m	1.4m
Mass, no payload	1.8 kg	~2.3 kg
Max payload	0 g	150 g
Max Flight Time	~3 mins	~3 min
Groundspeed	~5 m/s	~5 m/s
Max range per daily charge	~700m	~700m

Base Station

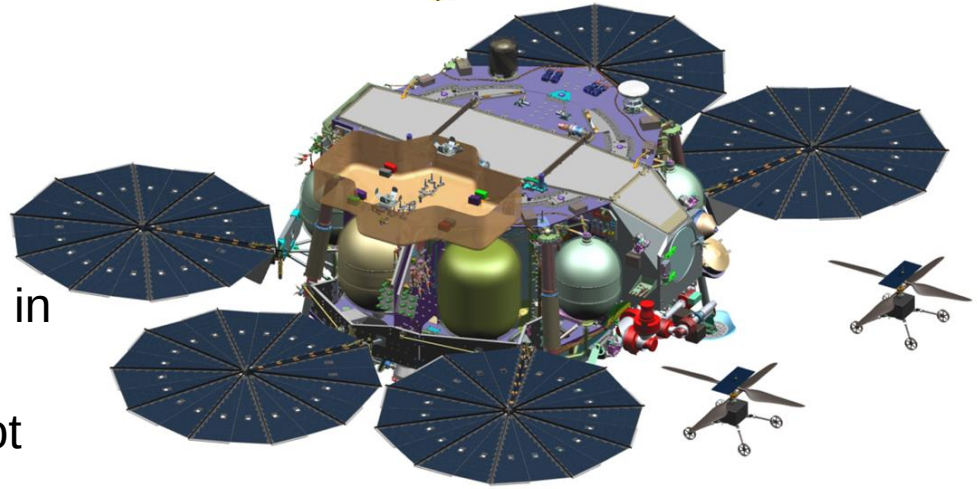
Helicopter with Sample Tube Manipulator and Drive Wheels

SRH is Backup to Perseverance

- **Scenario #1: Direct Delivery from Perseverance**
  - Perseverance is healthy ~9 months prior to SRL arrival at Mars.
  - Perseverance transfers tube to lander
  - In this scenario **SRH would not be used** for sample delivery
  - SRH may perform reconnaissance or conduct science operations.

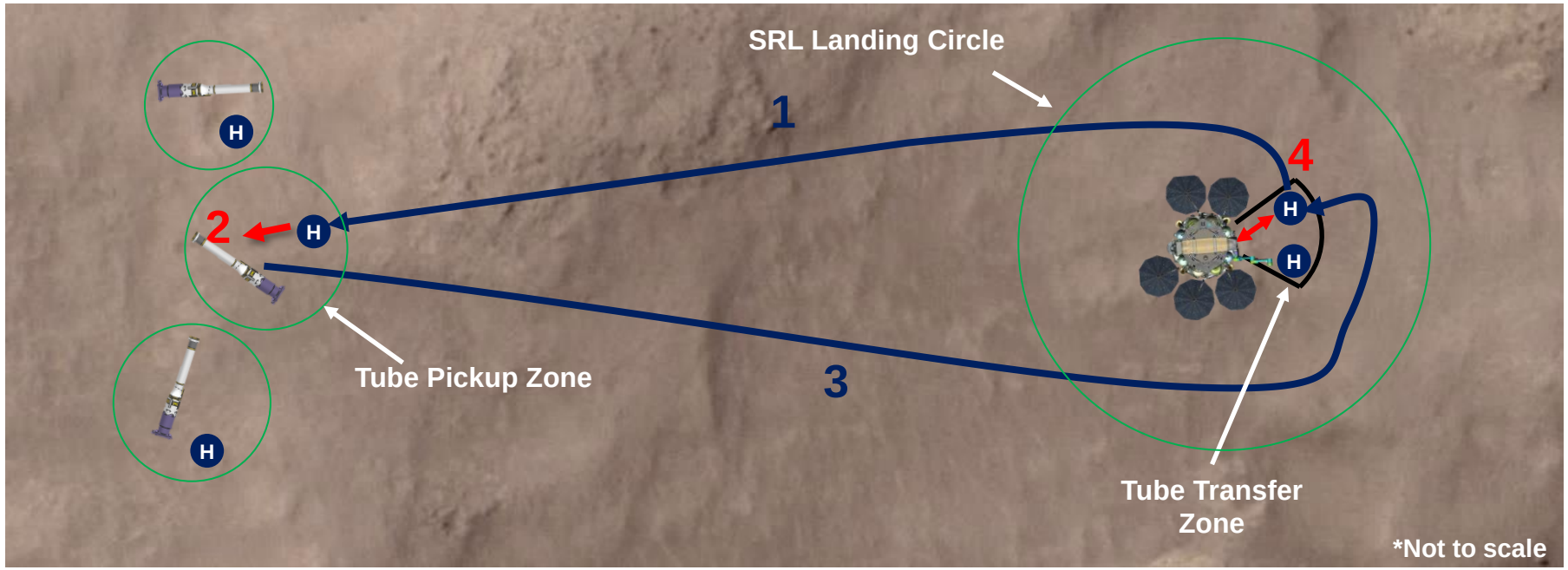


- **Scenario #2: If Perseverance experiences a failure → SRH delivery from a Sample Depot**
  - M2020 dropped a subset of sample tubes in a sample depot in January 2023
  - **SRH would be used** to retrieve sample tubes from the depot



Proposed Concept of Operations

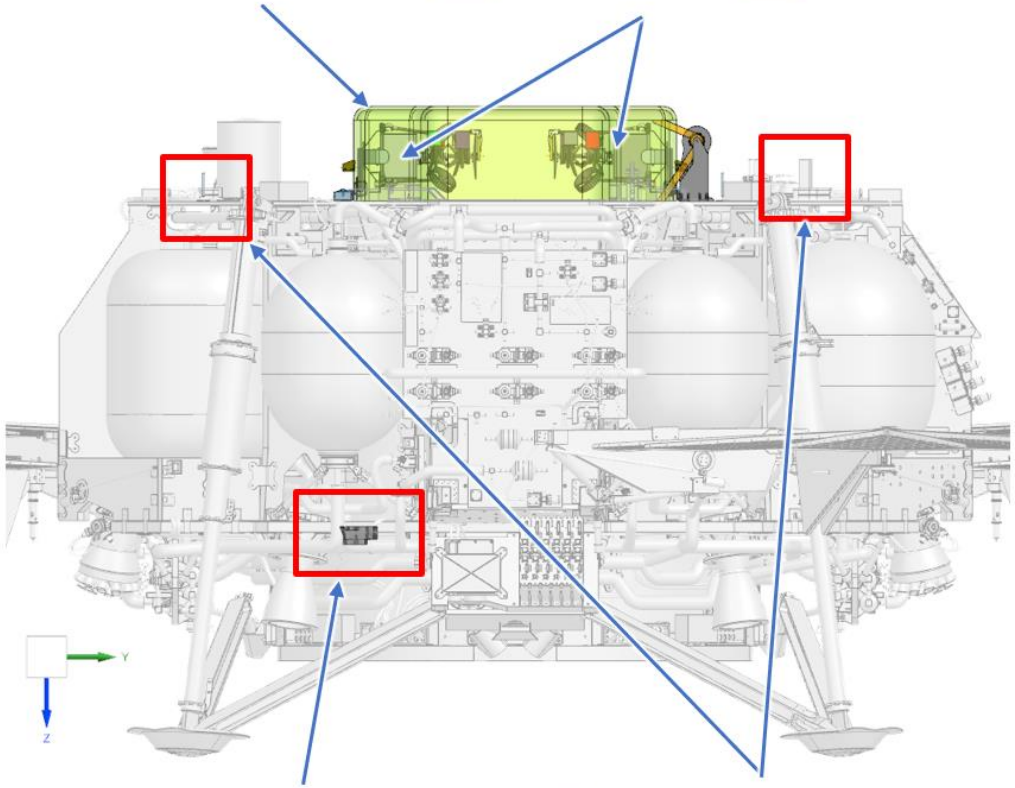
- SRH deploys and takes off from lander deck
- SRH performs commissioning and mapping flights
  1. ← SRH flies from the Lander to a small number of meters from the sample tube depot
  2. ← SRH drives to position, orients itself over a sample tube and picks up the tube
  3. → SRH flies back to a small number of meters from the front of the lander
  4. → SRH drives to position itself in the Lander's Sample Transfer Arm workspace and drops the tube



SRH Accommodation Locations

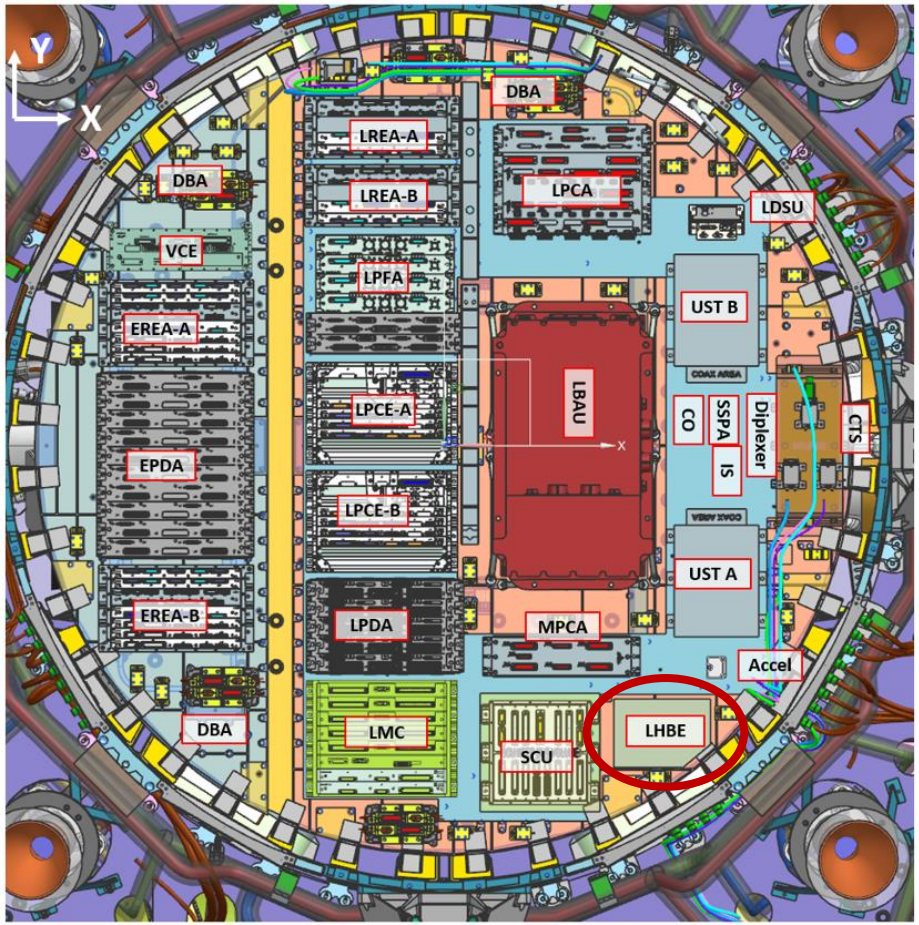
1 **LAIR Install**
(all HW accommodating the Helis)

2 **SRH Install**
2x Helis



3 **Internal Electronics SRH Install**
Heli Base Station Electronics on Warm LAMP (LHBE)

4 **External SRH Antenna Install**
2x Heli Base Station Antennas on Top Deck

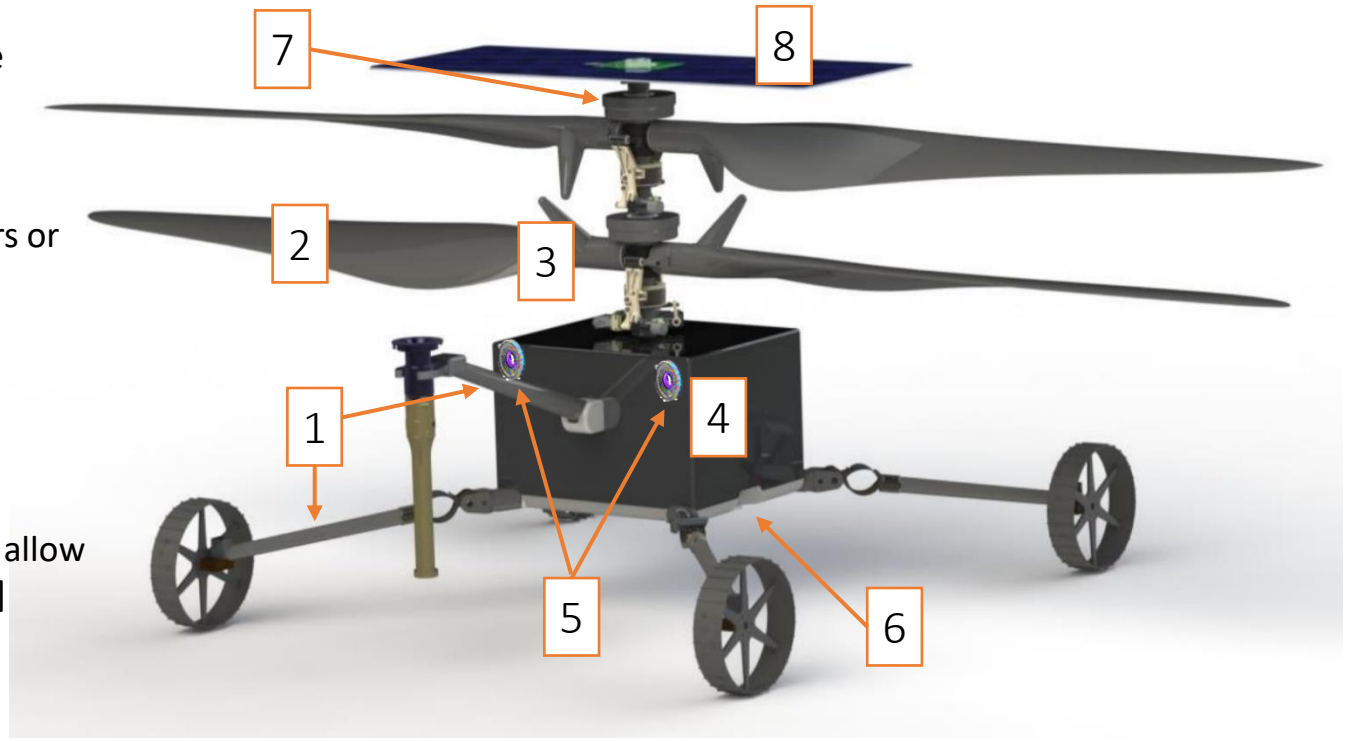


Lander Helicopter Base Station Electronics

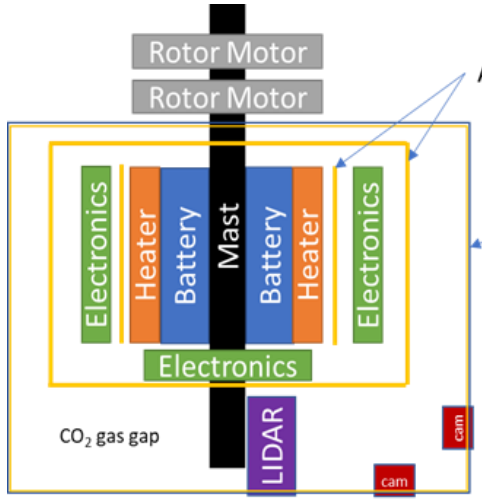
Heritage and changes with respect to Ingenuity

Changes for SRH:

- Add mobility and sample manipulation systems [1]
- Mass savings:
  - Updated rotor blade layup [2]
  - Lightened CW and blade attachment [3]
  - Removed unused mast wiring, IMU mount, and wire tie mount
- Use newer, higher-density, battery [4]
- Adding ~6 extra servo-motor control interface [4]
  - Power and PWM signals. Use switch to multiplex motors or extend FPGA. 80% utilization
- Add second RTE color camera for stereo vision [5]
  - Mobility hazard avoidance. 10cm baseline
  - Accommodated by new snapdragon
- Longer range altimeter [6]
  - WASP-200 LRF with 400m range
- Optionally add hall sensor for absolute rotor angle sensing to allow knowledge of blade configuration in close proximity to SRL [7]
- Increased motor stator thickness [7]
  - Longer flights
- Slightly larger solar panel [8]
- In-flight map-based localization, sub-meter landing accuracies



Ingenuity Thermal Block Diagram



T PRT

Heater

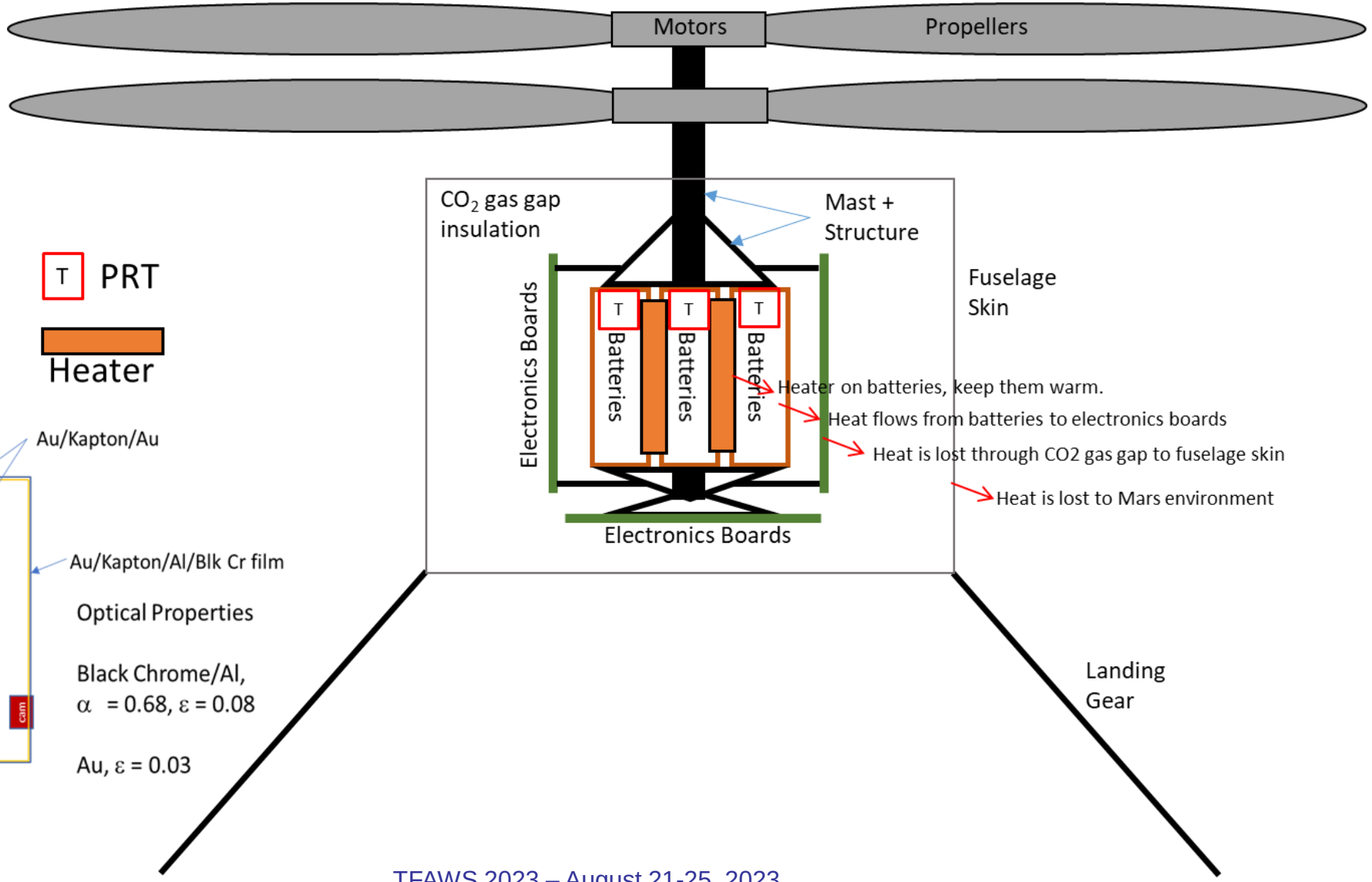
Au/Kapton/Au

Au/Kapton/Al/Blk Cr film

Optical Properties

Black Chrome/Al,
α = 0.68, ε = 0.08

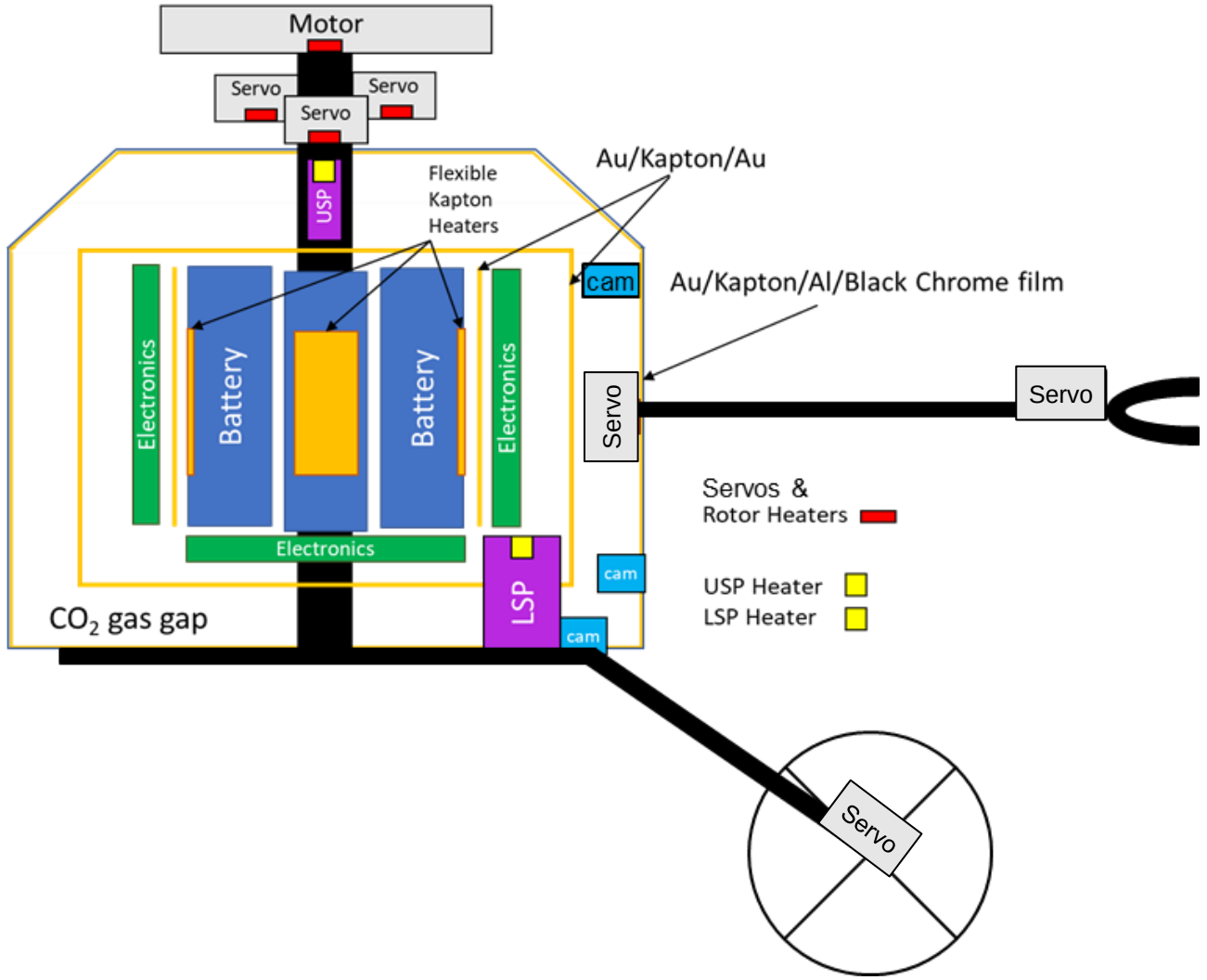
Au, ε = 0.03



SRH Thermal Block Diagram

SRH Thermal Design

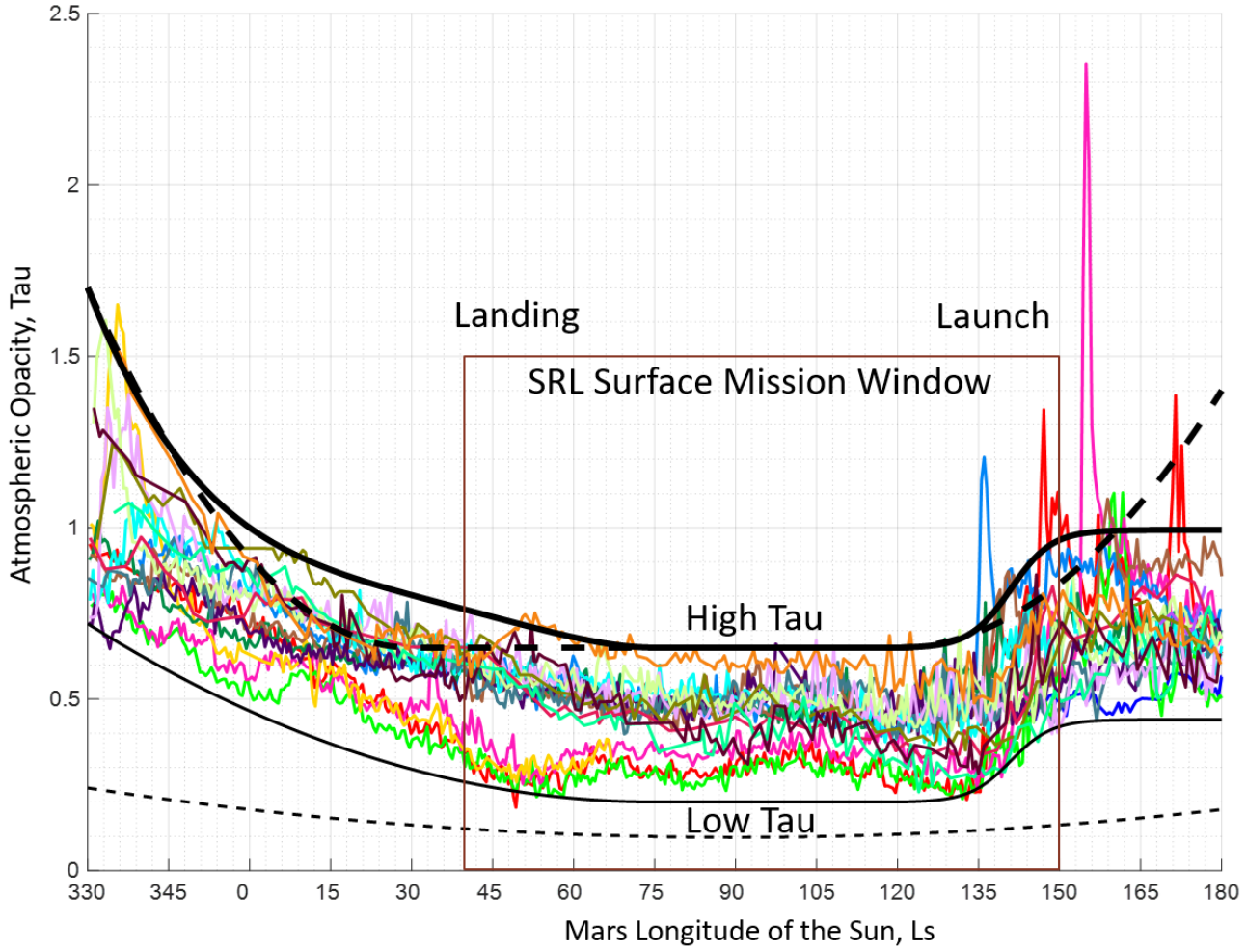
- Survival Heater on batteries keeps all components inside the fuselage within AFT during the night
- Warm up heaters on prop servos, prop motors, sensors for operations
- Gold coated Single Layer Insulation blankets to reduce radiation losses +CO_2 gas gaps to reduce conductive heat losses
- High α surface coating on fuselage to absorb environment heat and low ε to minimize heat loss



Mars Dust Environment

Mars environment is largely driven by the dust loading in the atmosphere

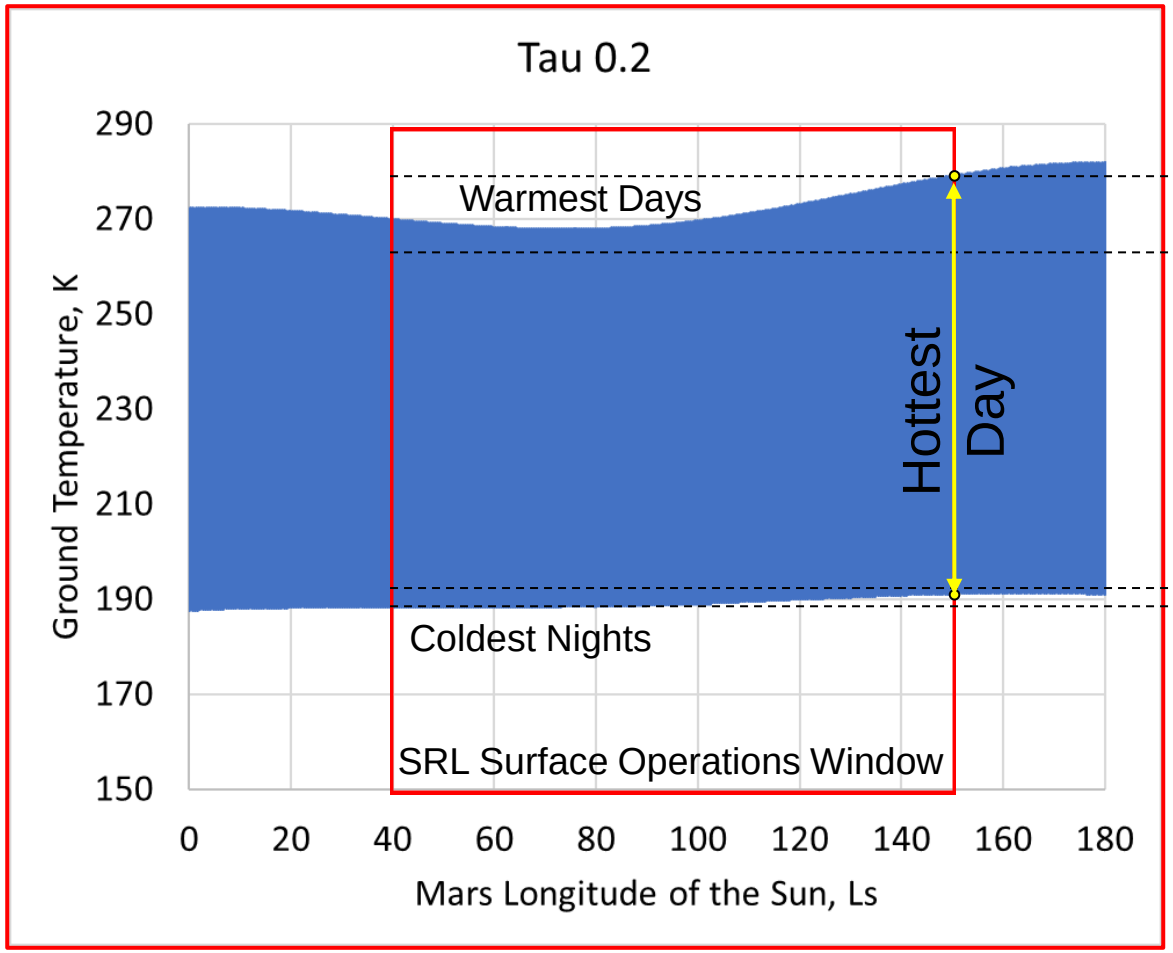
Optical depth from numerous Mars missions

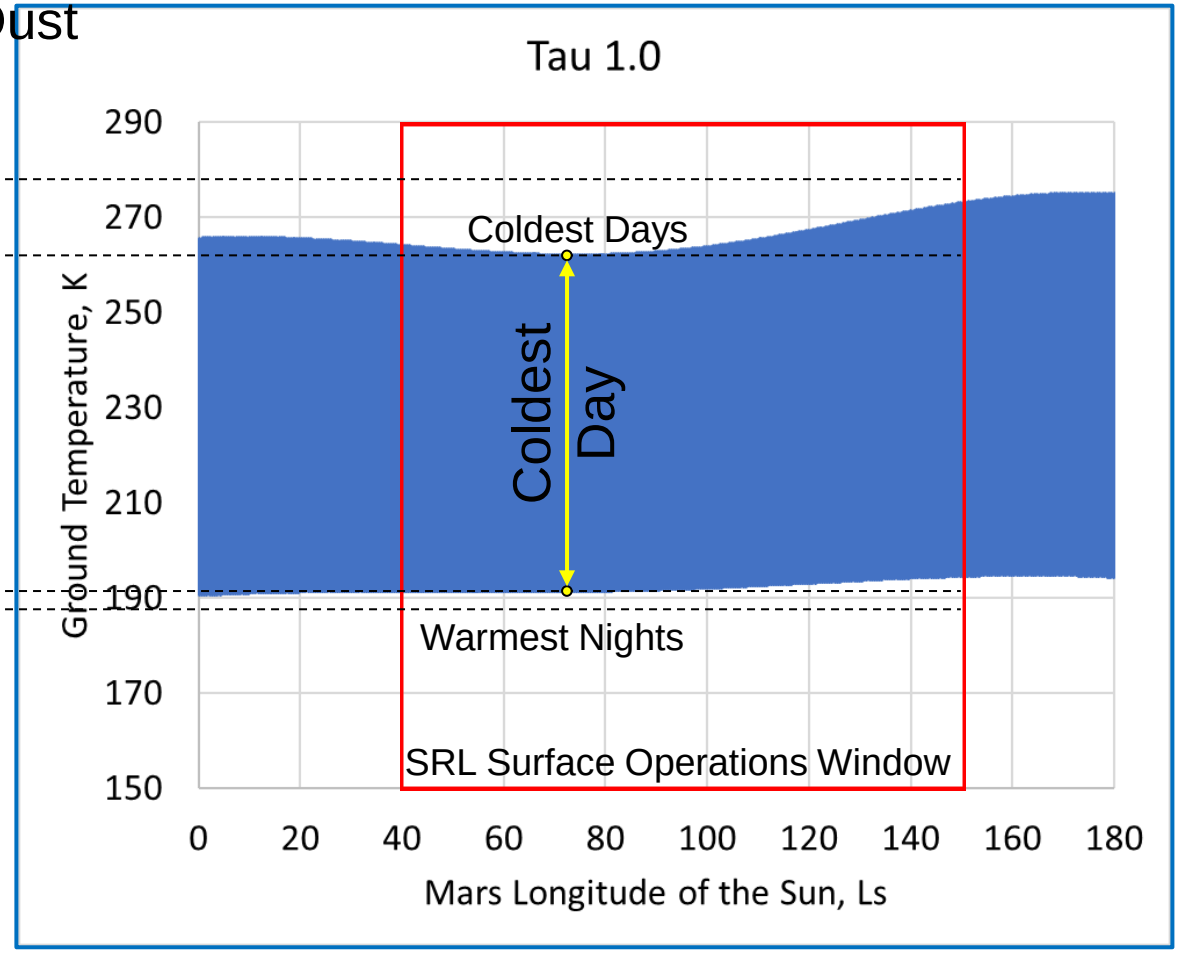


Hot and Cold Environment Case Identification

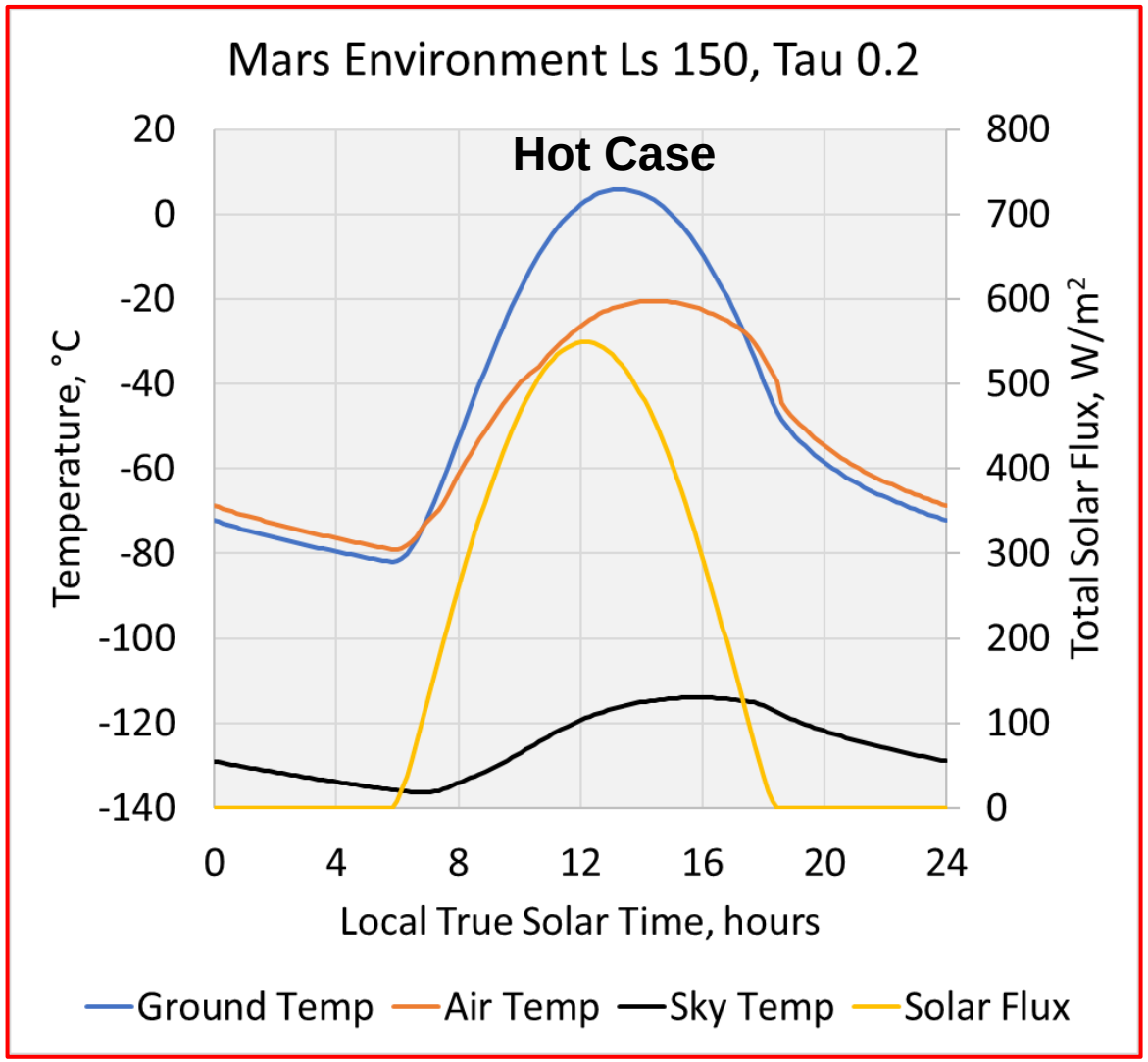
Ground temperature provides good proxy for overall environment

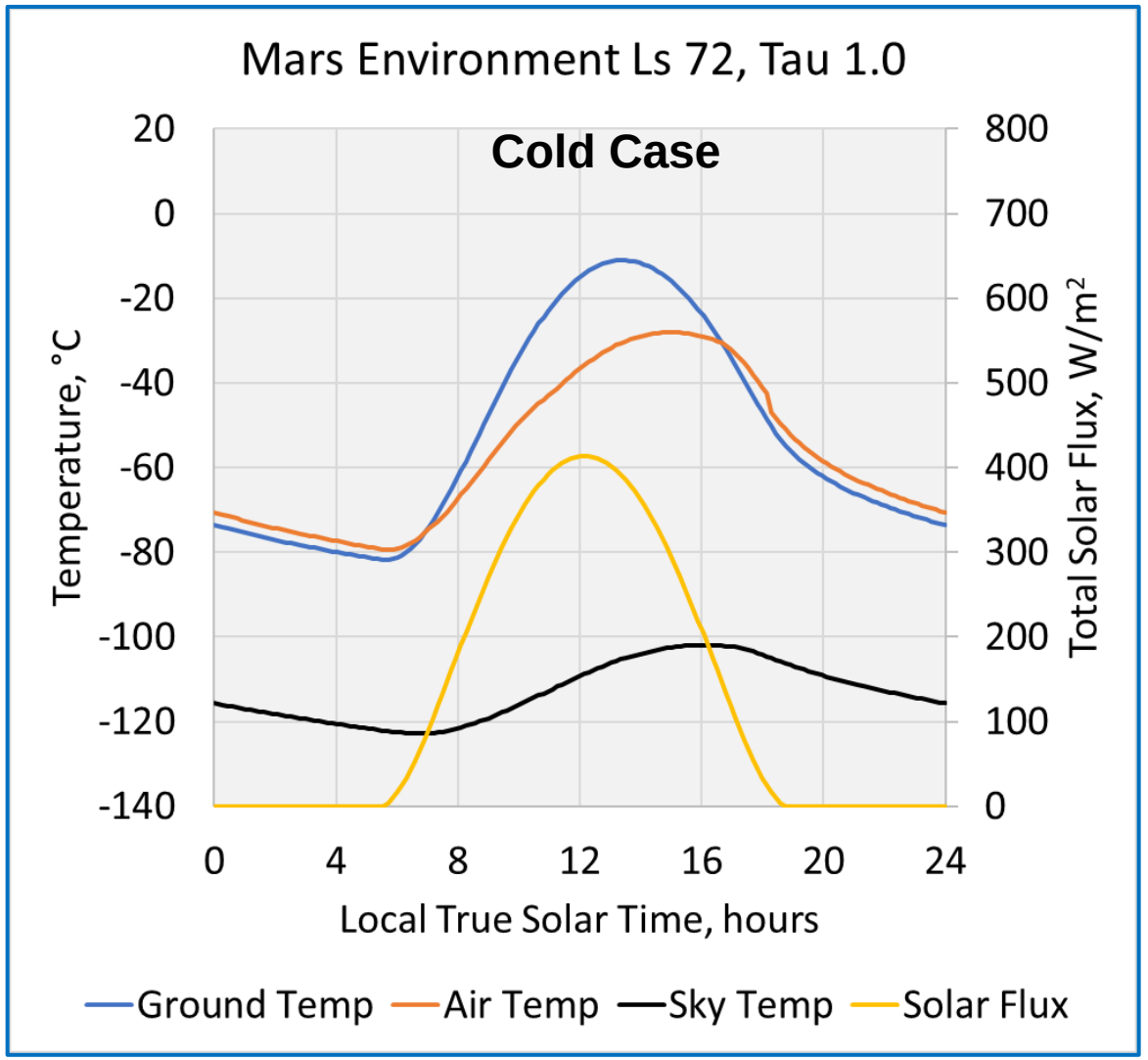
Low Dust (Tau) provides more diurnal temperature variation than High Dust





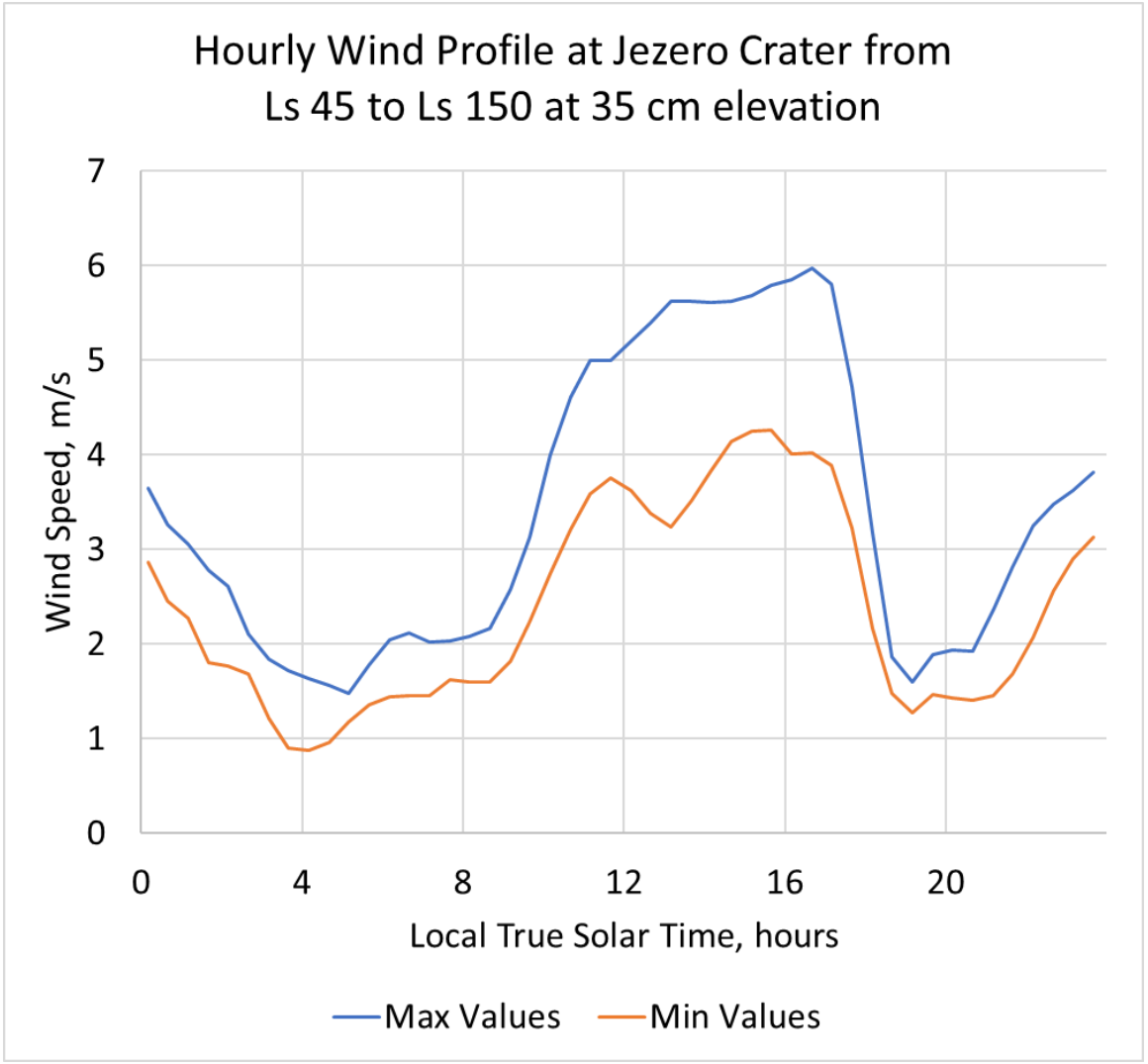
Mars Thermal Environment

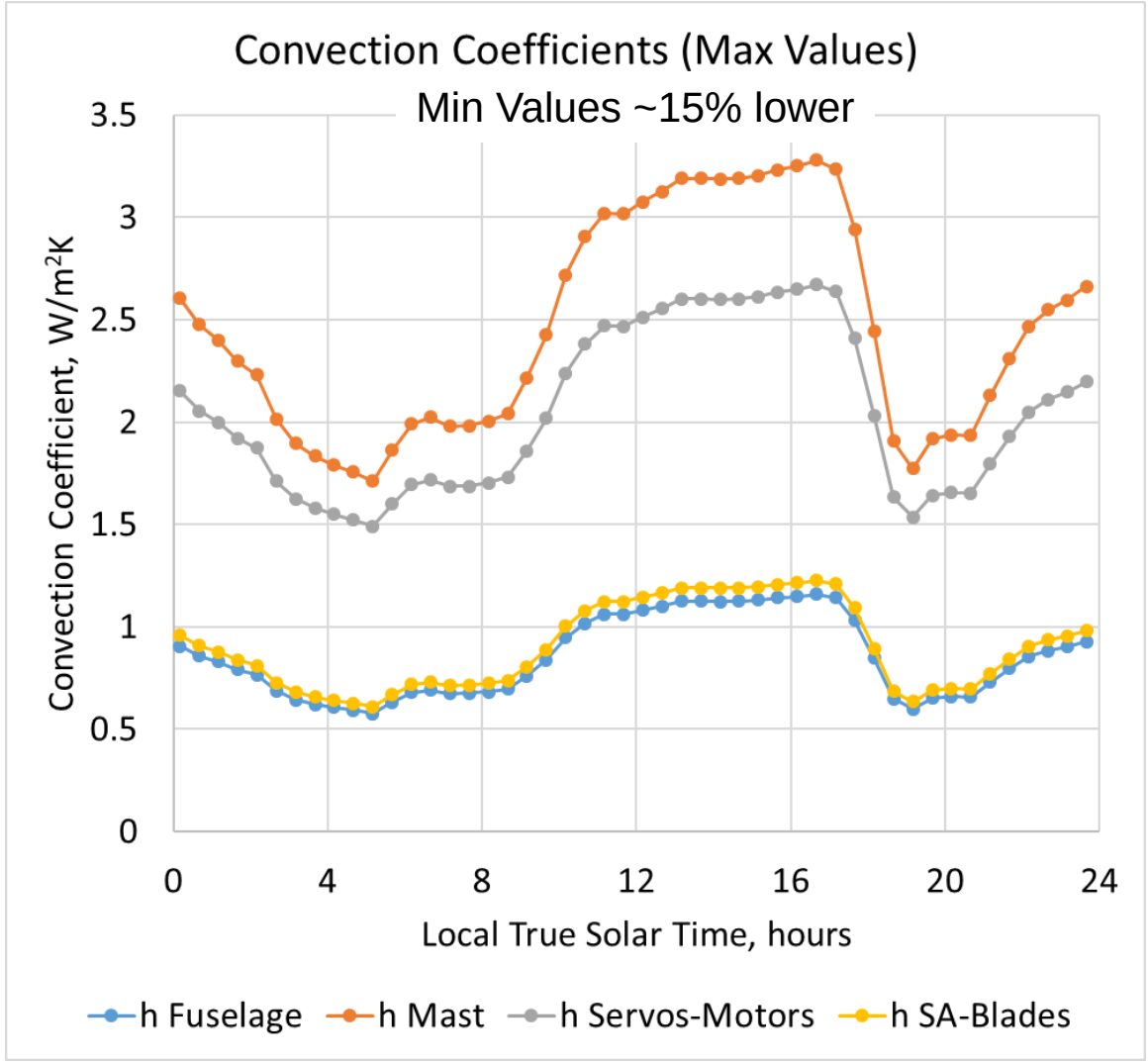




These are a subset of all environment cases to be run. Shown for illustration purposes only.

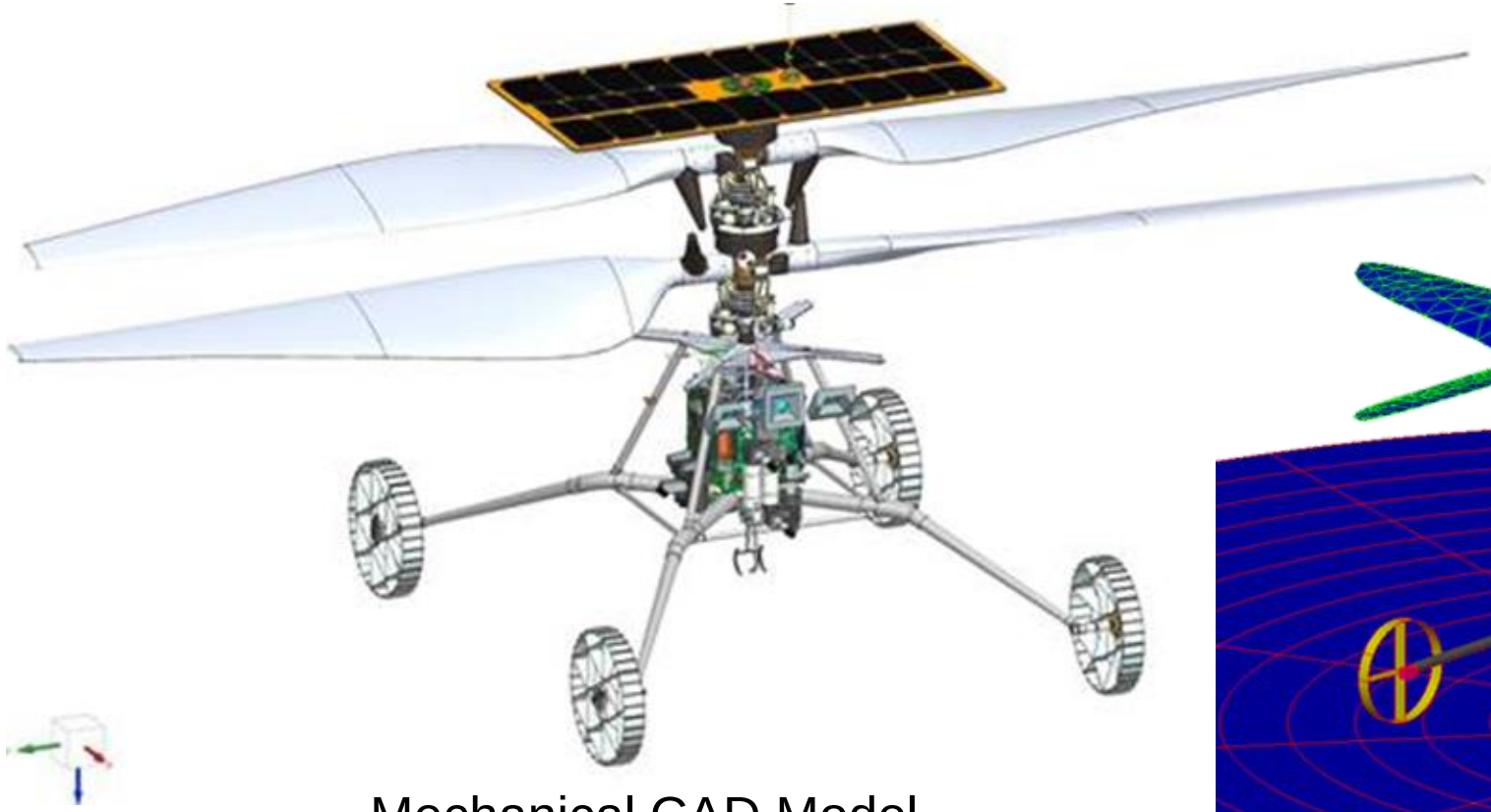
Jezero Crater Winds and Convection Coefficients



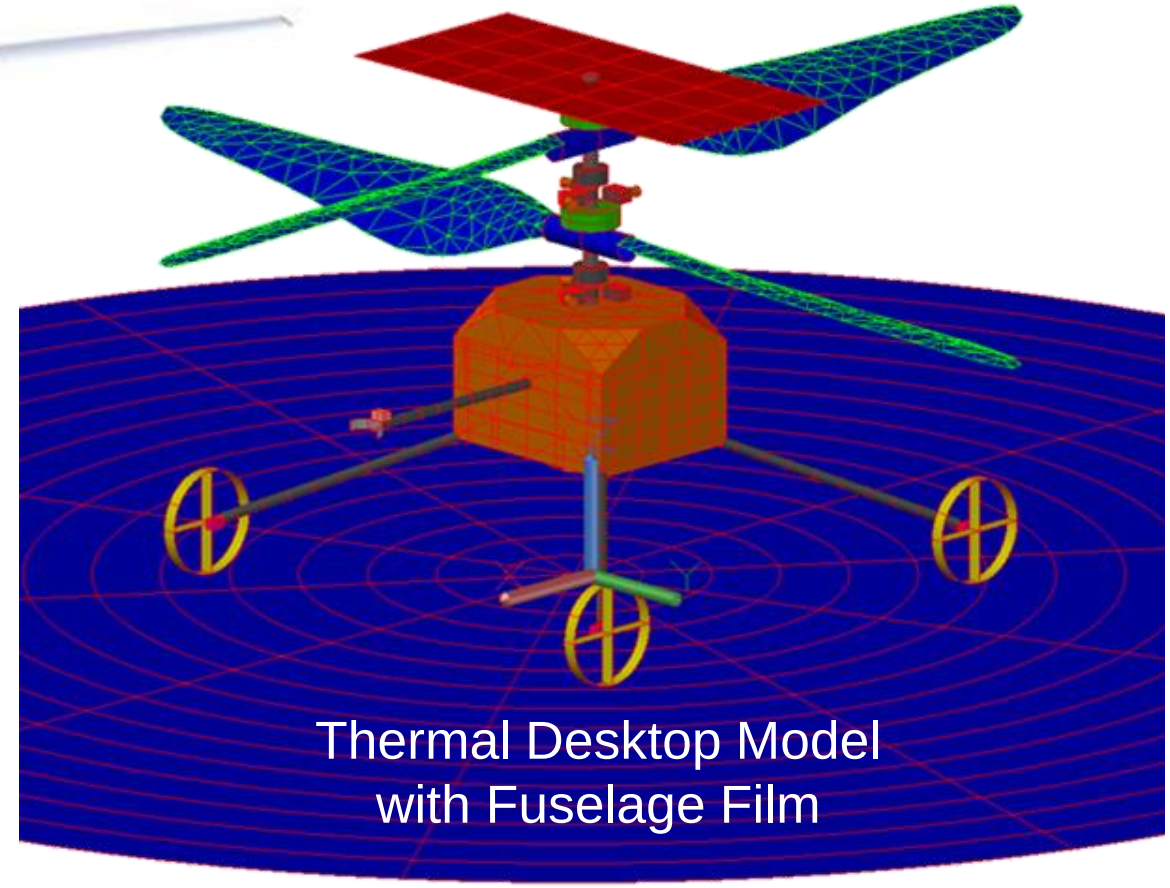


Instantaneous min wind speed is 0 m/s, this is the range of peak hourly wind speeds.

Thermal Model



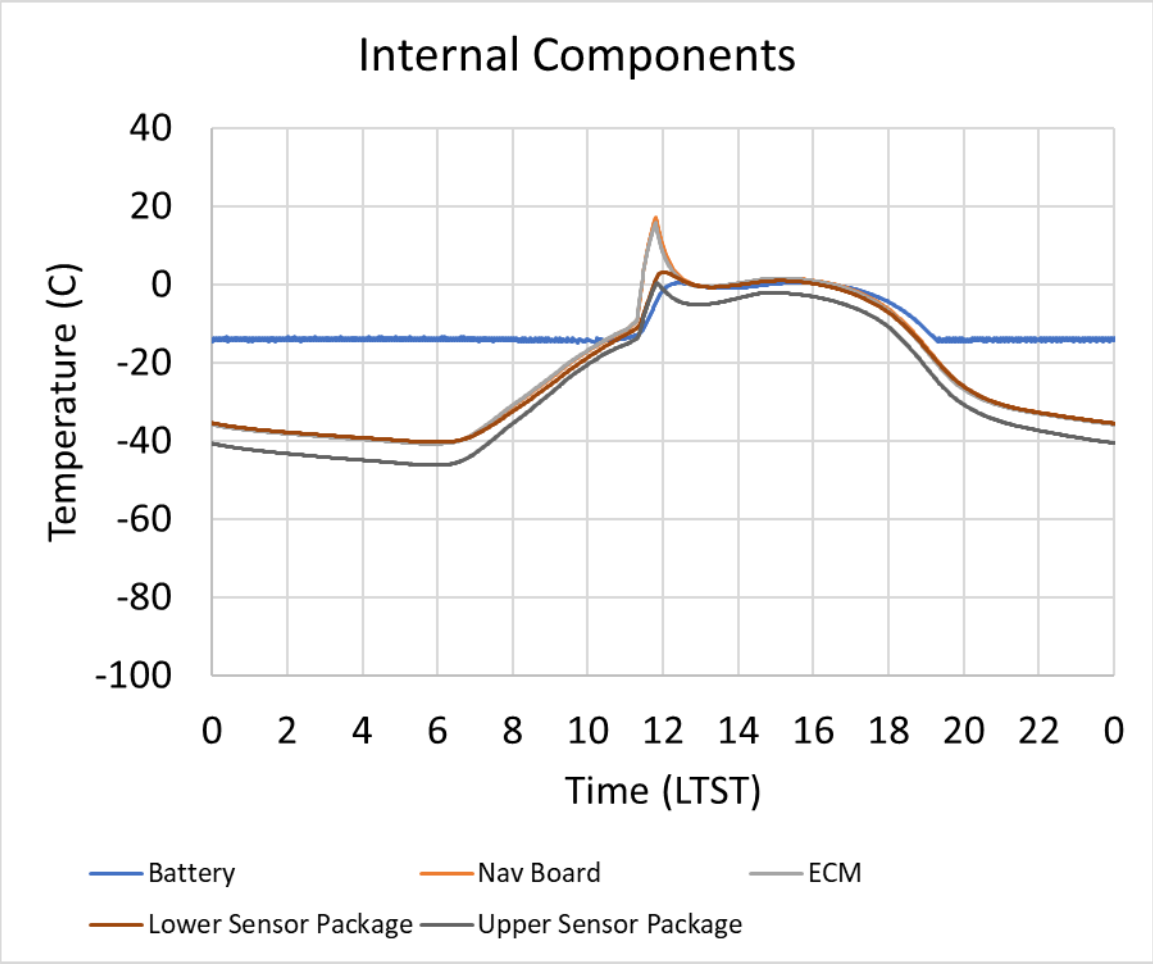
Mechanical CAD Model
without Fuselage Film

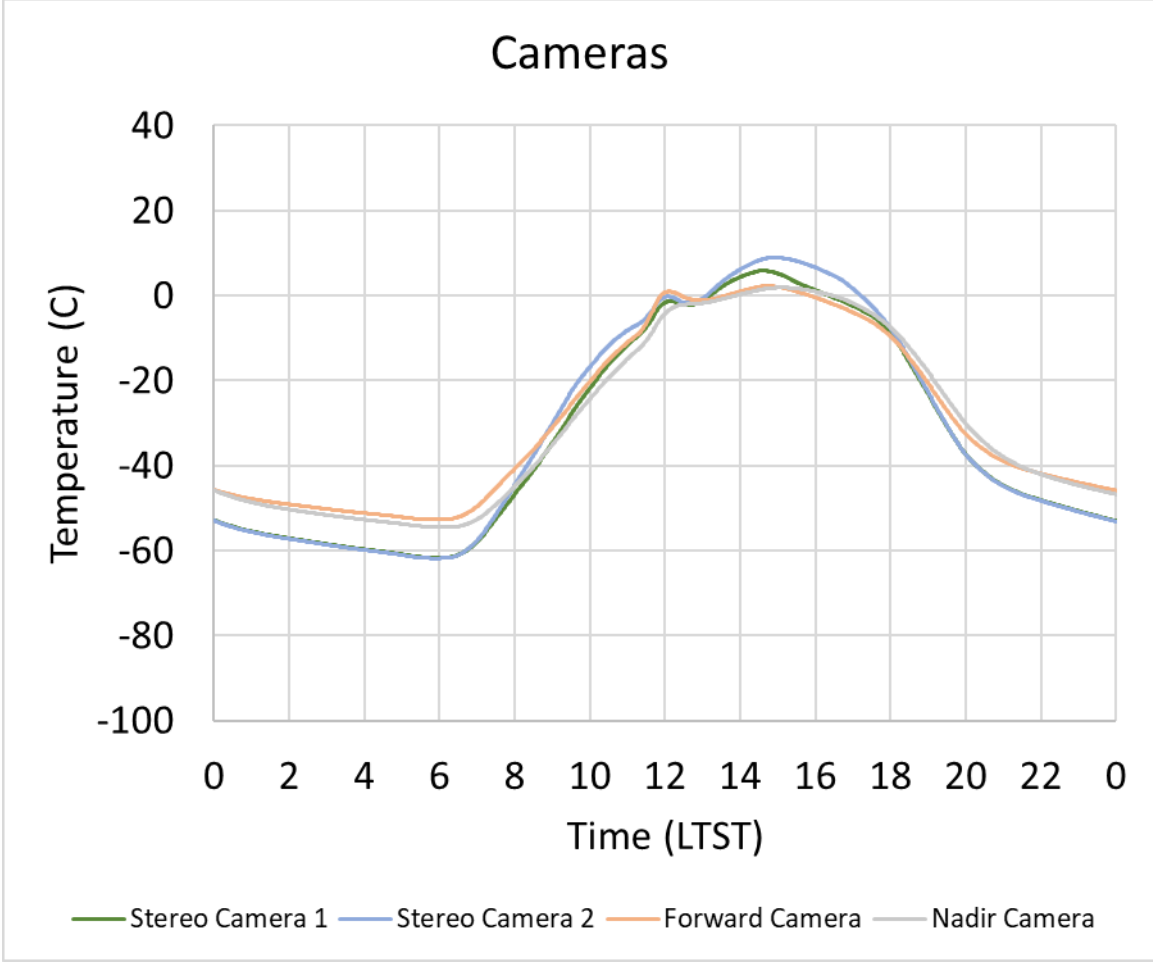


Thermal Desktop Model
with Fuselage Film

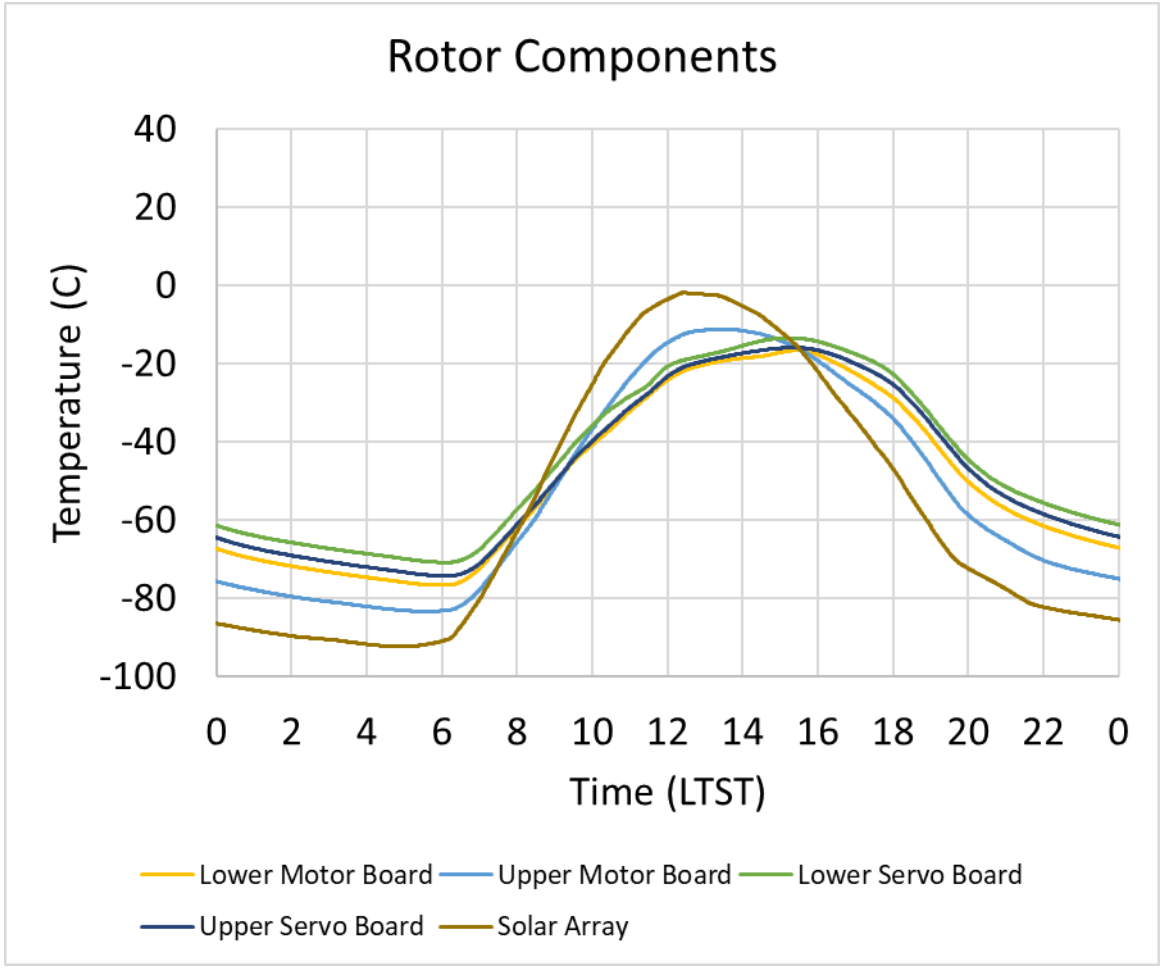
Analytical Results: Cold Case – Ls 72

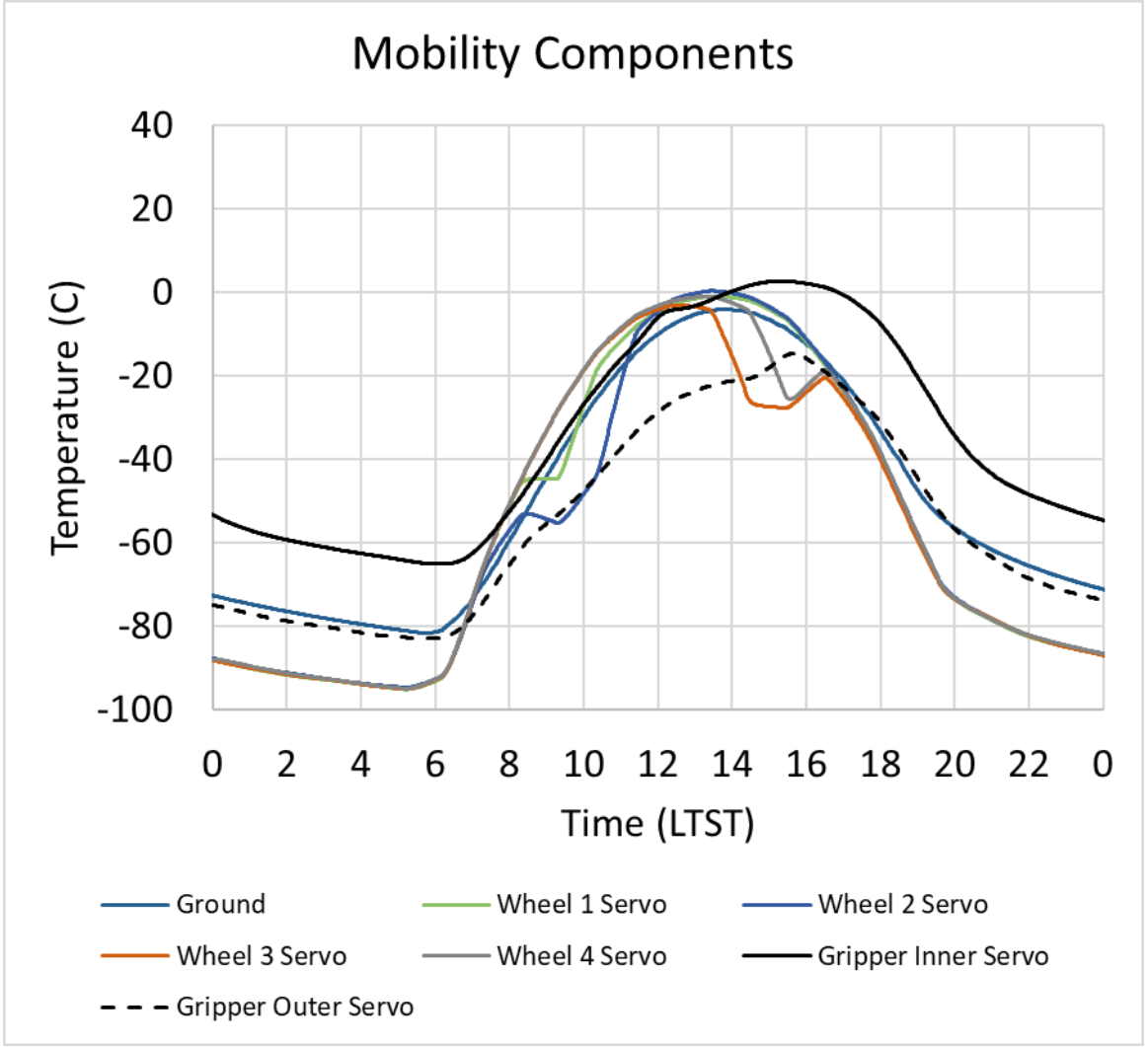
Battery Set Point: -15°C





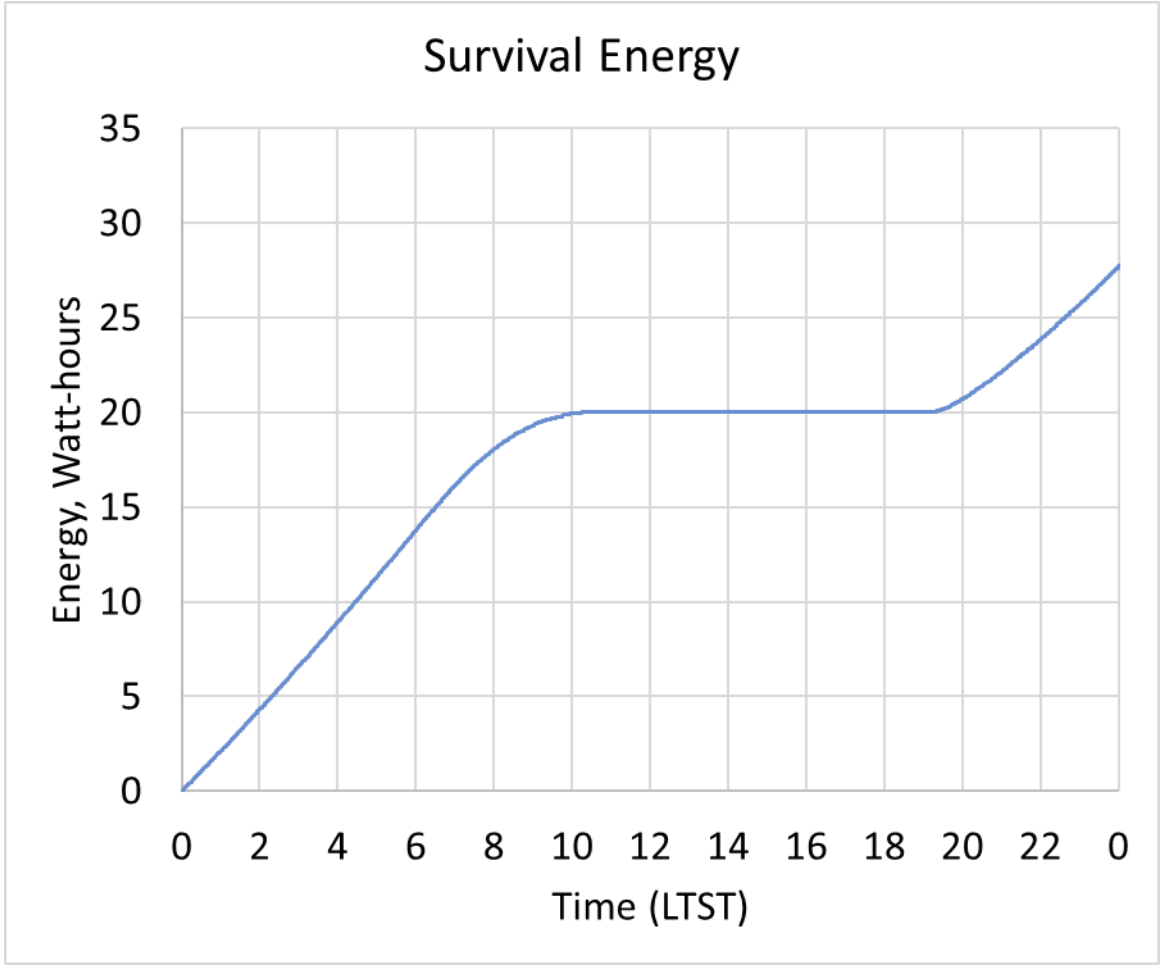
Analytical Results: Cold Case – Ls 72





Analytical Results: Cold Case – Ls 72

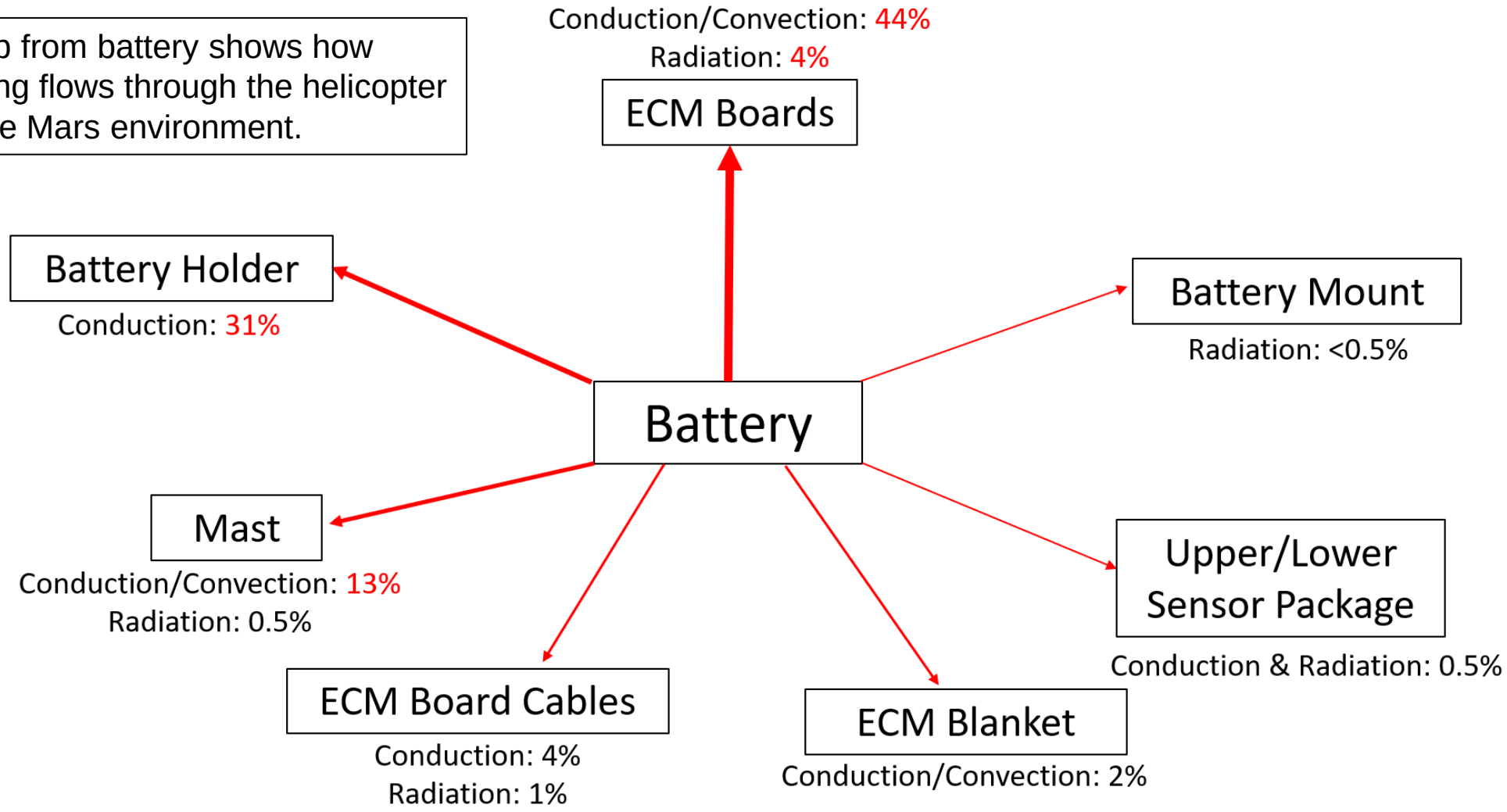
Survival Energy: 27 W-hr



Survival Energy meets allocation requirements from power systems.

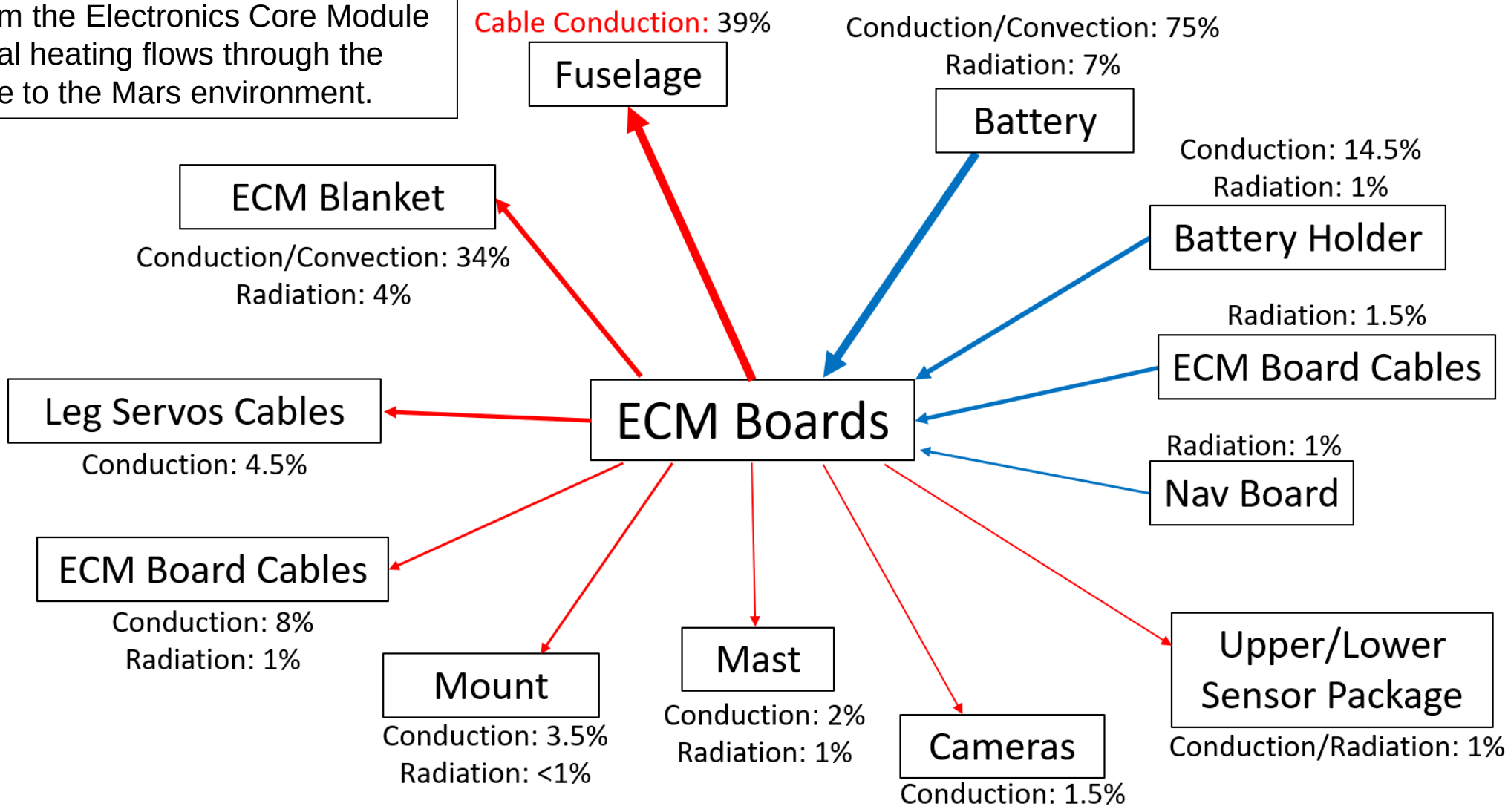
Battery Heat Flow Map

Heat flow map from battery shows how survival heating flows through the helicopter fuselage to the Mars environment.



Electronics Boards Heat Flow Map

Heat flow map from the Electronics Core Module shows how survival heating flows through the helicopter fuselage to the Mars environment.



Conclusions

- Sample Recovery Helicopter Thermal Model is starting to mature.
  - Thermal Model closely follows current Mechanical CAD configuration. Modified version of Ingenuity Thermal Model.
  - Numerous cases have been run: Hot Environment, Cold Environment, Prop Blades Parallel, Prop Blades Crossed, North-South Orientation, East-West Orientation, Flight Profiles, Non-flight Profiles.
- Numerous additional cases to be run
  - Cruise configuration
  - Stowed in the **L**ift-off **A**dapter with **I**nverted **R**etention (LAIR) configuration on Mars Surface
  - Deployed on top of lander configuration
  - Initial take-off configuration
  - Off-nominal cases: Shadow of lander, dust storms
- Survival Energy Predictions and Temperature Predictions are within requirements

Acknowledgements

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