46th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL SYSTEMS
ICES 2016

Thermal Stability Testing of Two-Phase Thermal Control Hardware for the Surface Water Ocean Topography Mission

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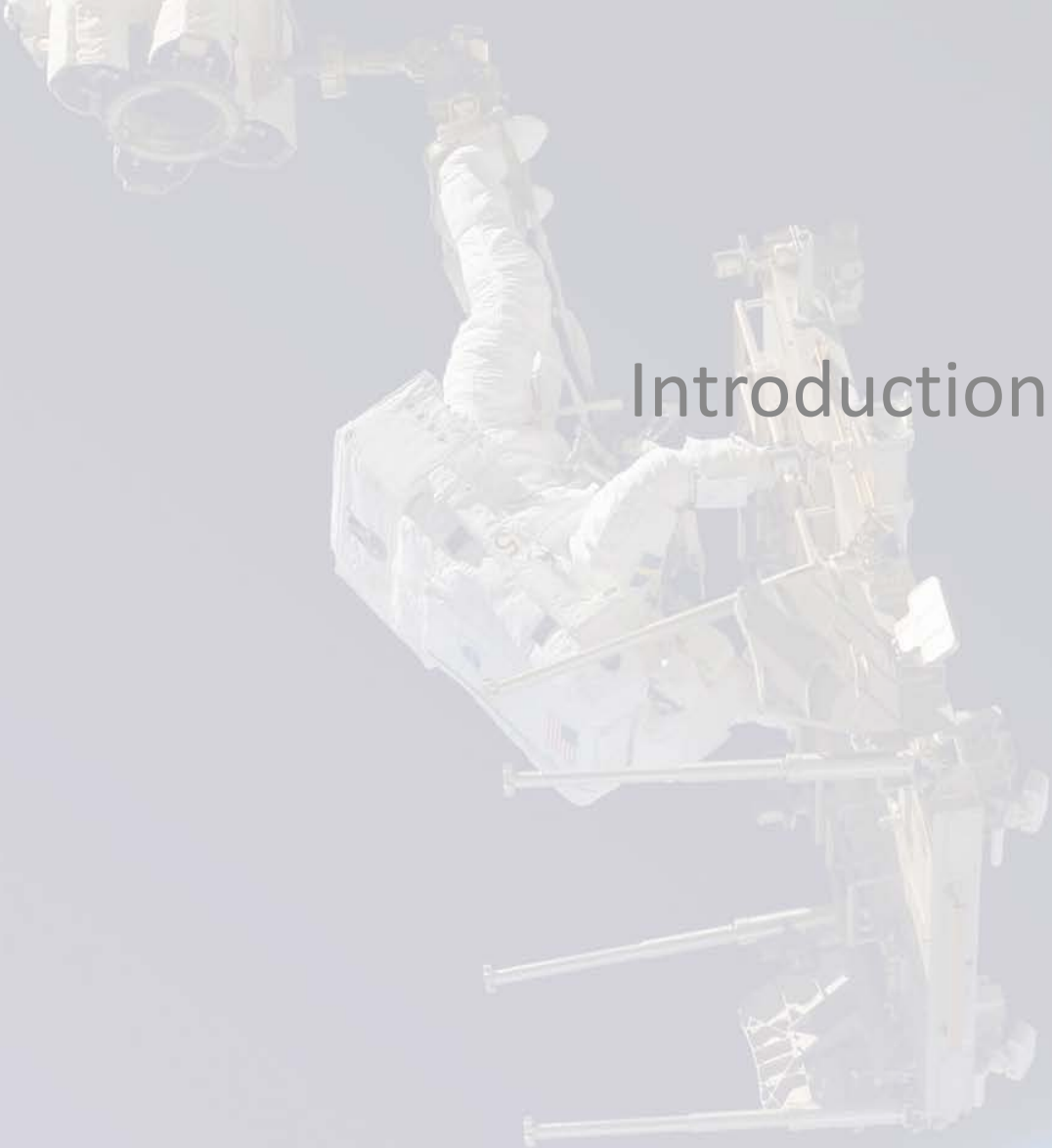
Overview

- Introduction
- KaRIn Thermal Design and Validation Approach
- Testbed
- Conclusions

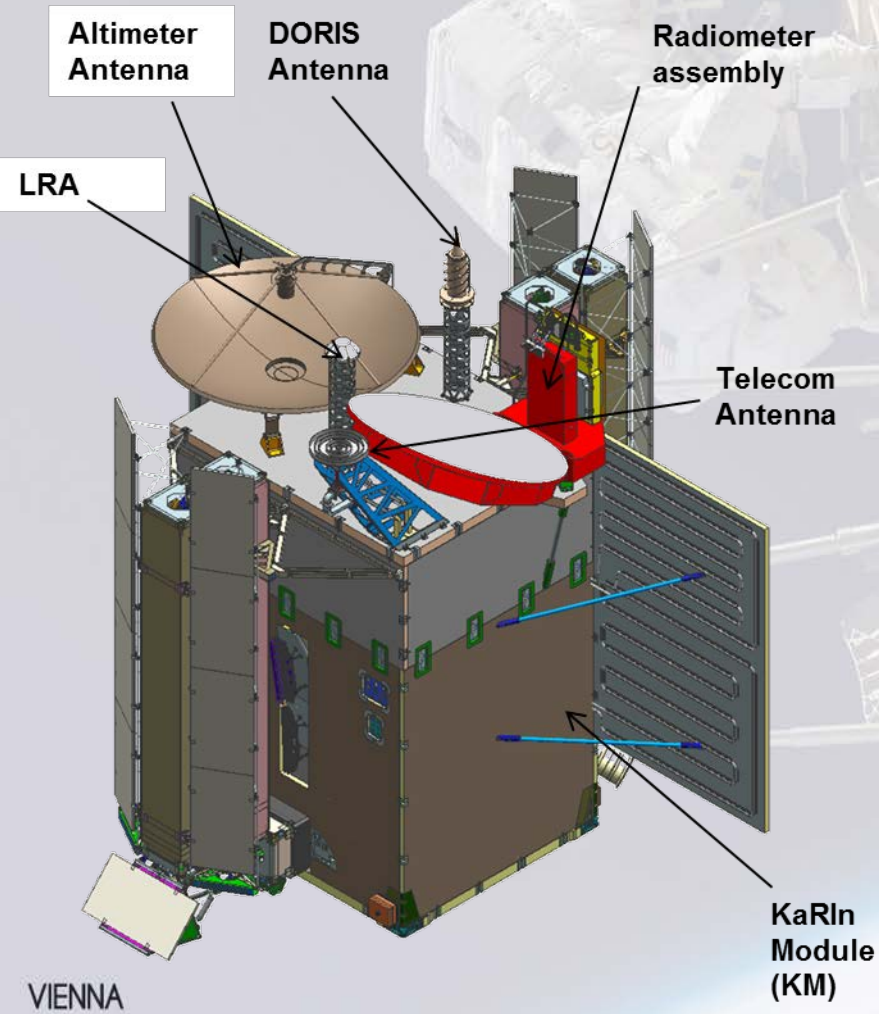


Introduction

Introduction

- The Surface Water Ocean Topography (SWOT) mission primary science goal is to measure ocean circulation and land hydrology to spatial resolutions between 15 and 200 km in order to aid climate modeling
  - Helps fill data gap between in-situ measurements and airborne/space based measurements to help oceanic climate studies
  - Data could be used to generate global assessment of surface water resources
- Suite of six science instrument payloads planned
  - Ka-band Radar Interferometer (KaRIn) is primary instrument
- Current baseline launch of 2020
  - Joint NASA/CNES program
  - Phase B (preliminary design) completed May 2016

Payload Overview



- Three year prime mission with an orbit altitude of 891 km, 77.6° inclination, 21 day repeat cycle (Beta angle = 0° to 90°)
  - Yaw flips to maintain primary radiator cold view (+Y side of s/c)
- Configuration
  - X-band Telecom (JPL)
    - For high rate downlink of P/L data
  - Ka-band Radar Interferometer (JPL + partners) - KaRIn
    - The primary instrument, to measure a swath of surface elevations
  - Nadir Altimeter (CNES) - NA
    - To measure absolute height, calibration at cross-overs, ionospheric delay
  - Cross-Track Advanced Microwave Radiometer (JPL) - AMR
    - To measure wet tropospheric delay
  - Instruments for Orbit Determination
    - GPSP (JPL)
    - DORIS (CNES)
    - Laser Reflector Array (JPL) - LRA

KaRIn Thermal Design and Validation Approach

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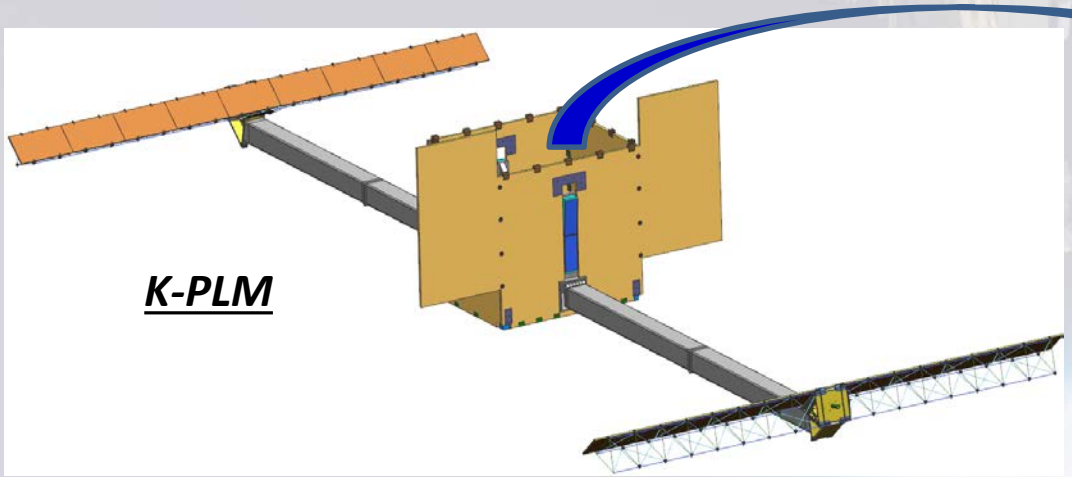
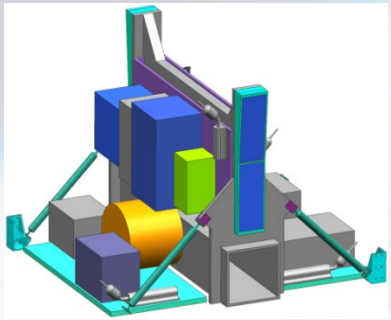
KaRIn Requirements

- To produce mission critical science, KaRIn has multiple thermal requirements that are challenging when coupled
  - Total electronics dissipation > 1kW
  - RF losses impose co-location requirements
    - Eliminates option to directly couple to radiator
  - Thermal drift in electronics affect measurement quality
    - Thermal stability requirement of <0.05 °C/min

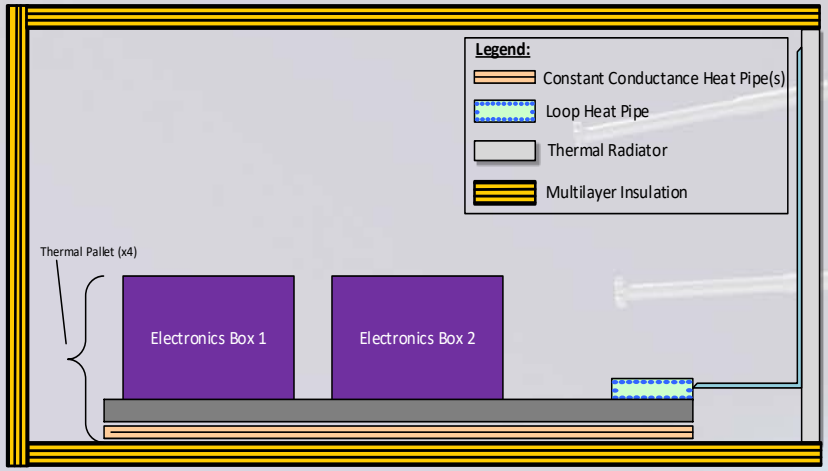


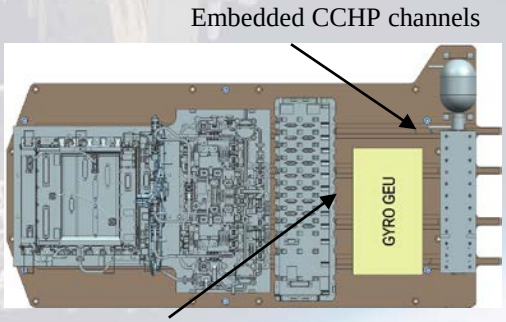
K-PLM Electronics

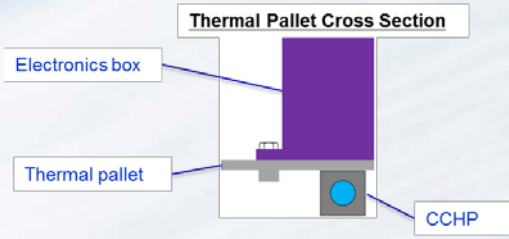


Thermal Architecture

- KaRIn electronics split into four zones with similar architecture
  - Electronics mounted to thermal pallets
    - Each pallet manages 100 W – 360 W; approximately 0.5 m^2 each
  - Thermal pallet design is hogged-out aluminum panel with embedded constant conductance heat pipes (CCHPs)
  - Heat transport from thermal pallets to radiators via loop heat pipes (LHPs)
    - One LHP per pallet







Thermal Architecture Requirements Compliance

- Total electronics dissipation > 1kW
  - Four zones allow for independent control of each zone as well as reduces the total dissipation any single zone must manage; LHPs can transport maximum zone requirement of 360W
- RF losses impose co-location requirements
  - LHPs allow zones to be co-located in a 3-D spatial package without need to directly couple to a radiator
- Thermal drift in electronics affect measurement quality (<0.05 °C/min)
  - Under certain operating conditions, oscillatory temperature performance has been observed

Thermal Architecture Validation Approach

- Requirements well defined such that radiator can be conservatively sized to minimize risk of instability due to vapor front moving into transport lines
- Thermal dissipation of electronics are stable by design (<0.051% variability)
- Varying heat sink (8°C/min max) main risk to thermal stability
  - System-level modeling showed that thermal mass was not sufficient
  - Concern that LHP hardware could exasperate stability problem with such large varying heat sinks

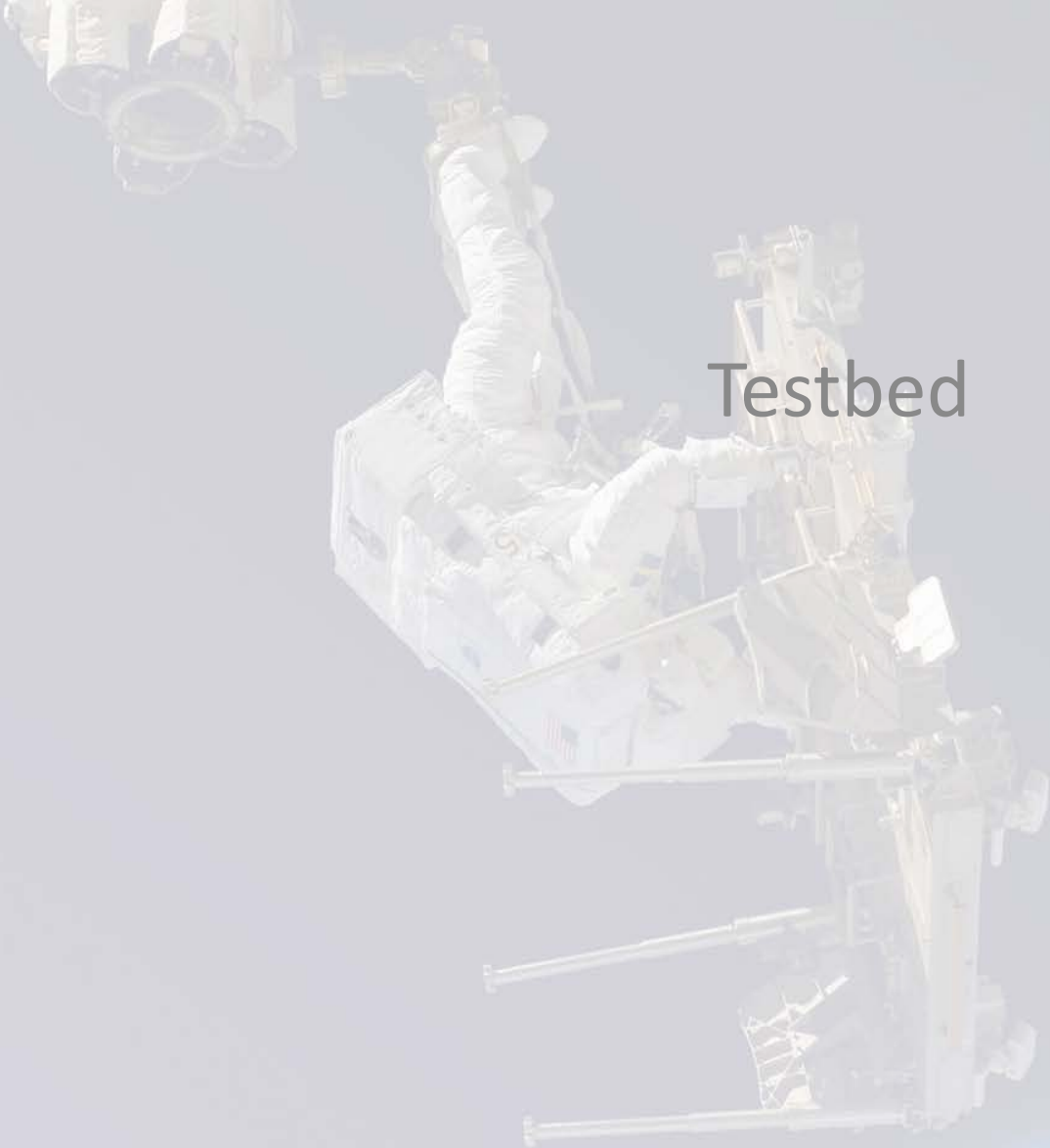
System-level Thermal Model Predictions

Pallet	Max Drift Rate [°C/min]	Violation Duration [min]
RFU	0.03	none
KDES	0.06	14
EIK	0.07	21
HVPS	0.03	none

Thermal Architecture Validation Approach

- Due to difficulty in modeling LHPs in detail and for transient conditions, primary design validation and requirement verification method through testing
- Testing campaign
  - Step 1, Discovery Phase: December 2012-June 2014
    - See ICES-2014-032 for summary
  - Step 2, Ambient Performance Testing: December 2012-August 2015
  - Step 3, Vacuum Performance Testing: Contingency, no planned execution to-date

Testbed



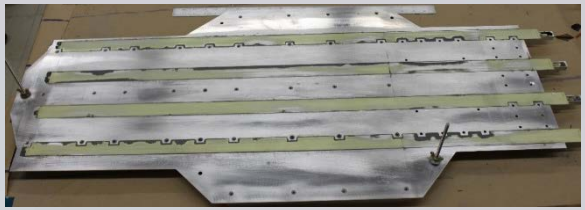
Testbed Design

- High fidelity testbed of end-to-end architecture desired to validate architecture
  - Flight-like thermal hardware, mass models, and heat loads/distributions per known specifications at the time of testbed development

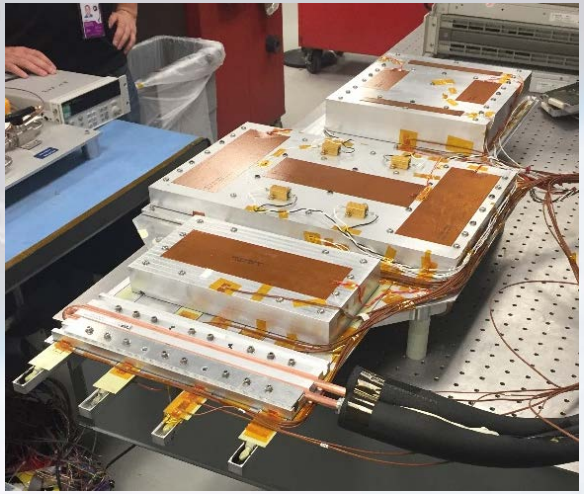
Testbed Design: Thermal Pallet

- Thermal pallet consists of hogged out aluminum structure with embedded CCHPs
- Mass models of electronics and approximate heat load distribution mounted with anticipated flight configuration

Thermal Pallet Post CCHP Integration



Fully Integrated and Instrumented Thermal Pallet



Testbed Design: LHP

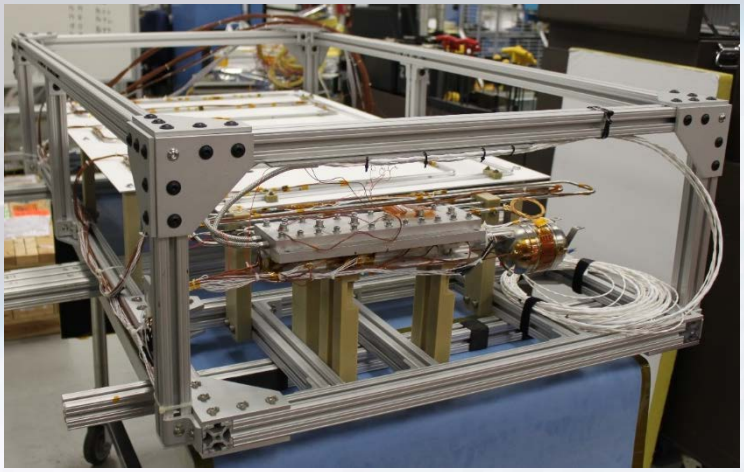
- Flight-like LHP procured
  - Design had lower heat transfer between the reservoir and liquid return than current state-of-the-art in attempt to provide dampening between condenser and evaporator to aid stability

Testbed LHP vs Flight Design Parameters

Design	Step 2 (Phase A)	Flight (Phase B)
Working Fluid	Propylene	Propylene
Max transport line length [m]	2	2.3
Max Cond Line Length [m]	6.9	17.9
Heat Transport Capacity Range [W]	150 to 350	211 to 370*
Thermal Conductance from Evap-to-Cond [W/°C]	30	40
Evap Operating Temperature [°C]	-10 to 40	-15 to 30

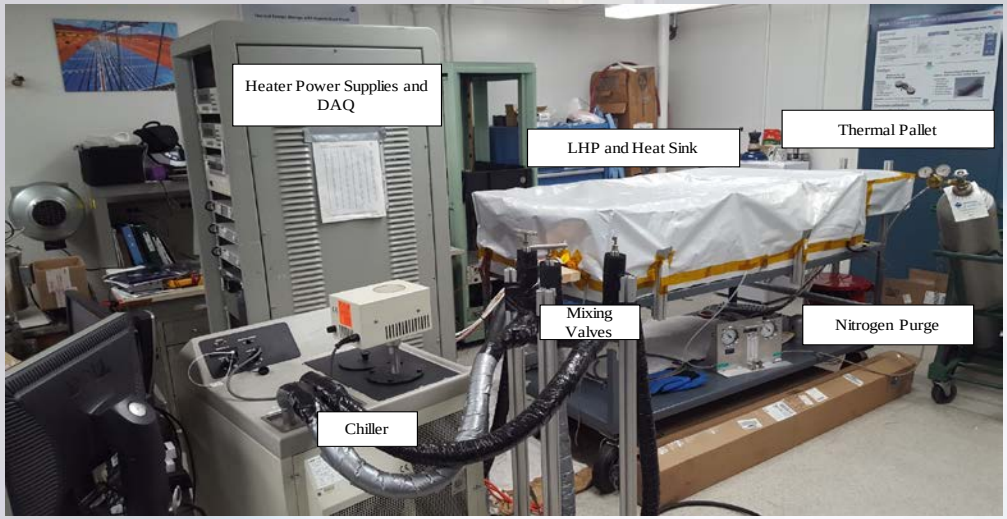
*combined range across all LHPs is 74W to 370W

LHP with Painted Radiator



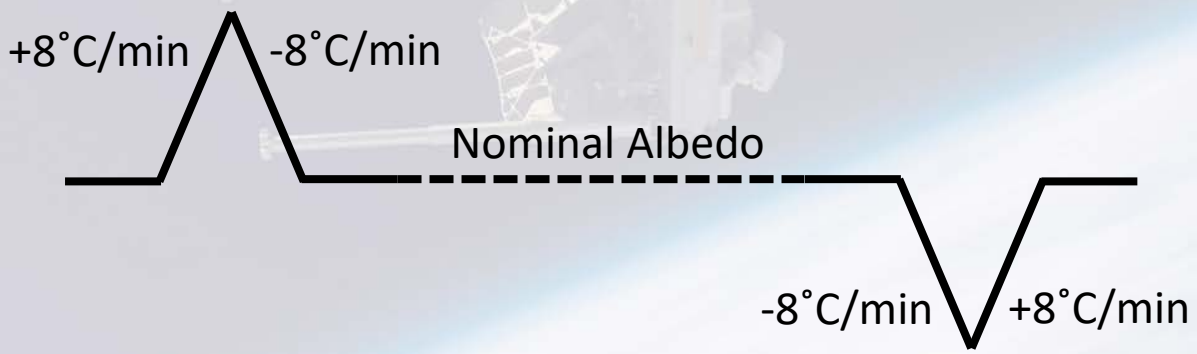
Testbed Design: Integrated Setup

- Thermal Pallet and LHP were mated and instrumented with 118 measurement points
  - Combination of PRTs and thermocouples
- Entire setup, including heat sink were encapsulated in a purge bag to reduce condensation



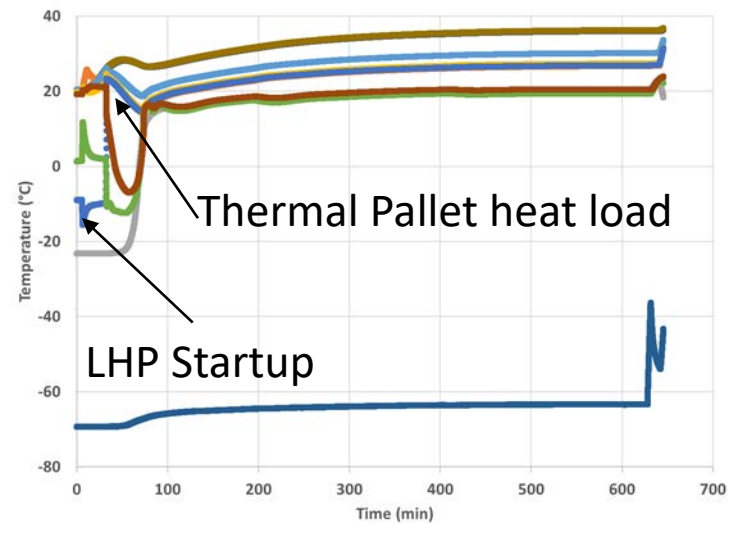
Testbed Capabilities

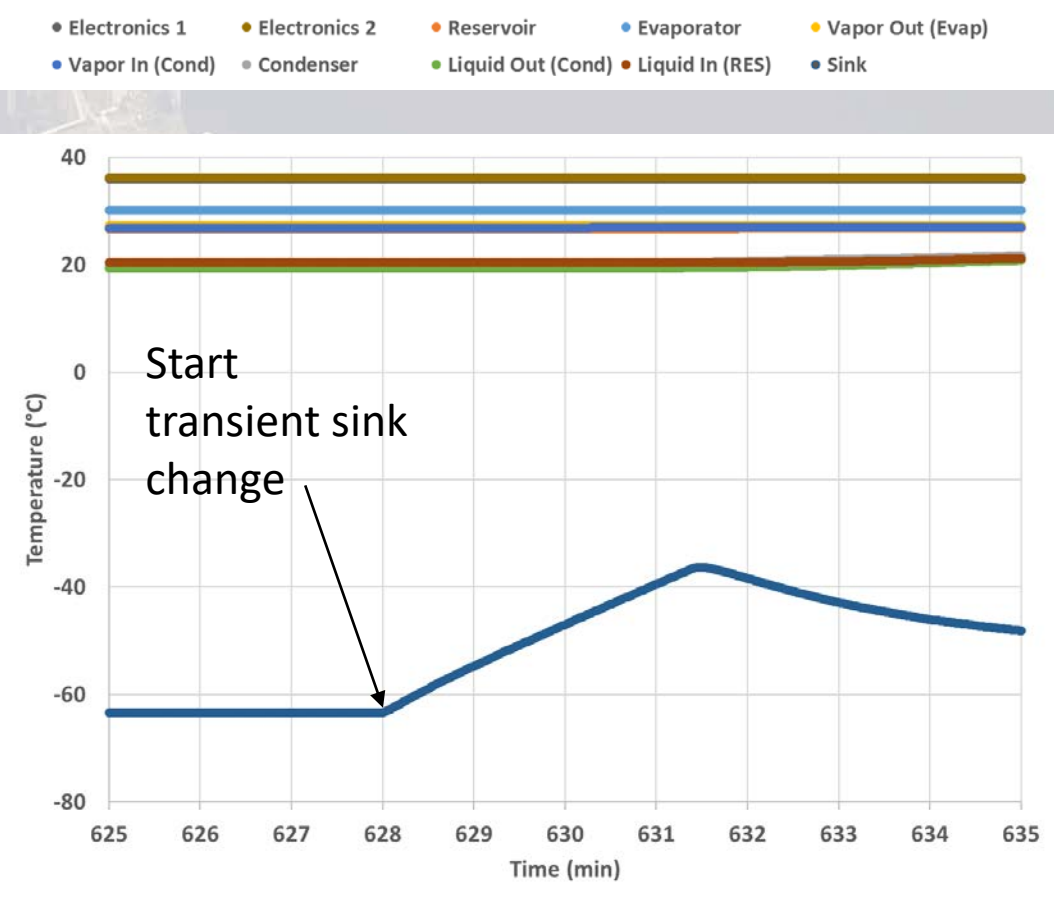
- Initial design intent was to enable testing of a worst-case sink temperature pulse; conservatively 8°C/min over 3 min period
- The setup maximum cold-to-hot transient rate capability is 10 K/min
  - Limitations of cooling system design prevents testing the hot-to-cold transient
  - Modification to testbed to accommodate hot-to cold transients under review for future testing



Stability Testing

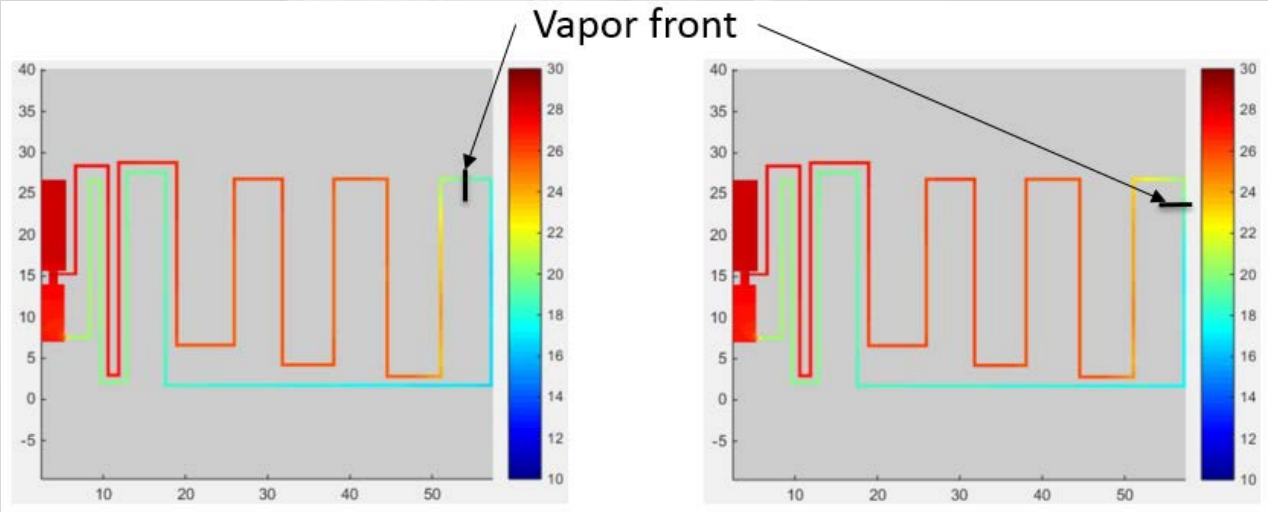
- Cool heat sink to minimum temperature
- Start-up LHP
- Turn off start-up heater
- Apply nominal heat load to Thermal Pallet
- Allow for steady-state of all temperatures
- Initiate sink temperature ramp rate and run for 3 min (target 8°C/min)
- Shut-down LHP





Vapor Front Visualization

- Data shows vapor front movement due to sink temperature change



All temperatures in °C

Stability Assessment

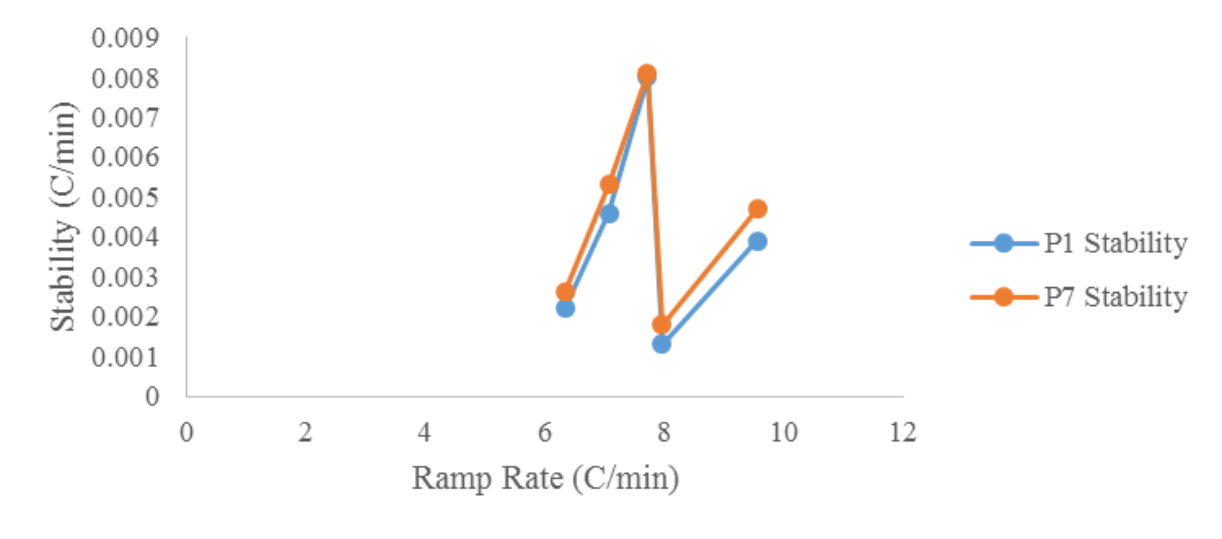
- Testing showed two findings
  - Testbed appears to respond almost an order of magnitude slower than current model predicts
    - Stability improvement is hypothesized to be due to thermal resistance between warmer return liquid (as shown by vapor front movement) and reservoir fluid attenuating overall impact of environmental energy change
    - Thermal capacitance of the reservoir mass also contributes to attenuation
  - Stability appears to improve at lower heat loads
    - Further testing required to correlate this due to large uncertainty
    - Could be due to smaller overall flow rate at lower power

Test Condition	Nominal Power	Low Power
Heat Sink Start [°C]	-71.25 ± 0.75	-71.25 ± 0.75
Pallet [W]	208	75
Steady-State Pre-Ramp [°C/min]	0.000 ± 0.001	0.000 ± 0.001
Heat Sink Ramp [°C/min]	7.84 ± 0.14	7.74 ± 0.14
Pallet Stability	0.008 ± 0.020	0.000 ± 0.020

Stability uncertainty due to partials of all error sources and data reduction

Repeatability

- Five separate tests performed with varying sink temperature pulses (maximum pulse 10°C/min for 7 min)
  - All within requirement shows that performance testing to date has margin



All values have uncertainty of ±0.02°C/min

Conclusions

Conclusions

- KaRIn thermal control system appears to be capable of meeting key and driving thermal requirements
  - Includes stability requirement of < 0.05°C/min
  - Further testing (sink change from hot-to-cold) recommended for full requirement verification
- LHP stability hypothesis (thermal coupling between return liquid and reservoir fluid) warrants further study to truly understand the attenuating benefits LHPs may provide to a thermal system
  - Can be leveraged in future system designs as well as LHP designs

Acknowledgements

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