GSFC · 2015

Thermal Control Design, Analysis, and Test for the Radiation Dosimetry Experiment (RaD-X)

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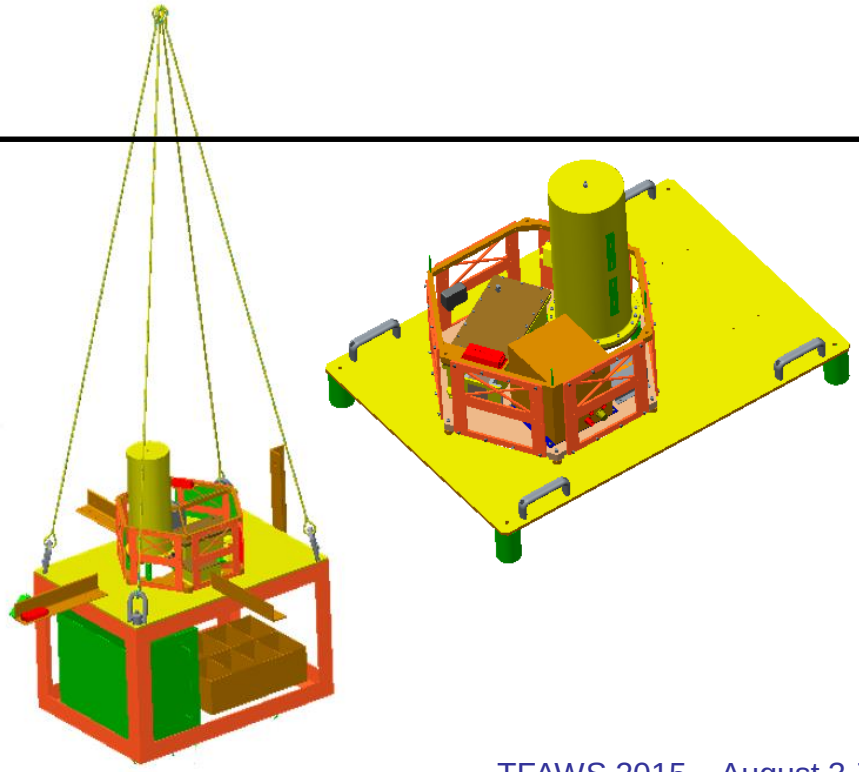
Agenda

- RaD-X Mission
- Subsystem Testing
- Full System Testing
- Correlation
- Lessons Learned

Radiation Dosimetry Experiment

Objectives

- HOPE training project
- Collect cosmic radiation measurements penetrating Earth's atmosphere
- Assess combination of COTS detectors prospect as a low-cost alternative to expensive industry standard



Execution

- 24 hour balloon flight
- 2 distinct altitude regions
- 4 science instruments

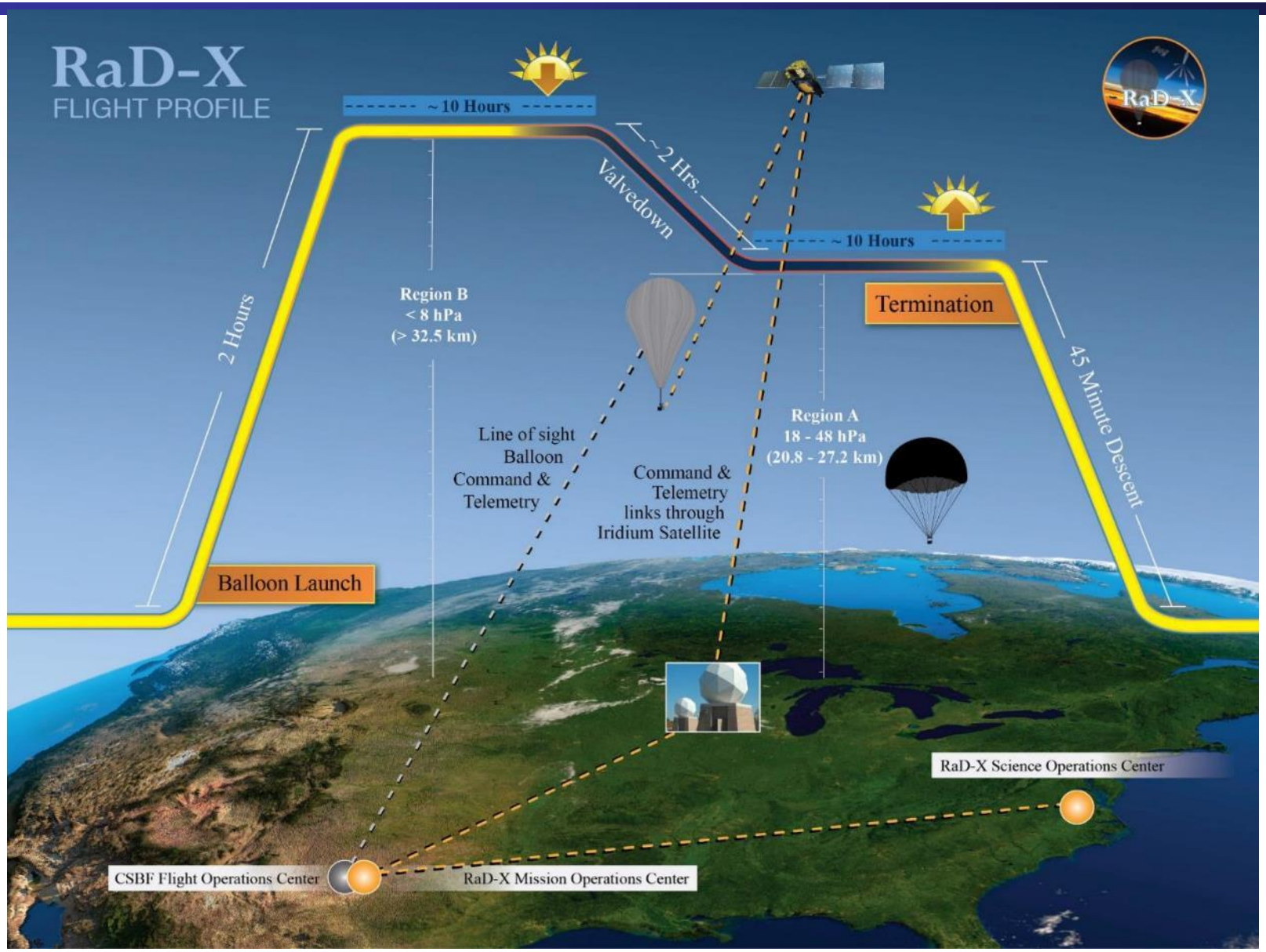
Science Requirements

- >4 hours of data in each region
- Measurements during sunrise and sunset

Major Milestones

- Kickoff: November 2013
- Pre-Ship Review: June 2015
- Flight: September 2015, Fort Sumner, NM

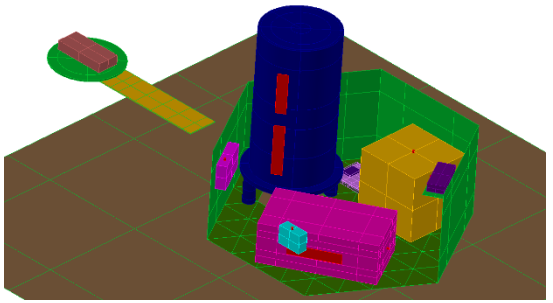
Flight Profile



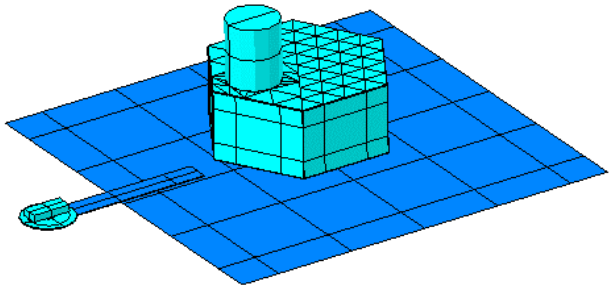
Thermal Model and Design

- Low-fidelity thermal model made using analysis software Thermal Desktop
- Thermal Environment
  - Software handles Earth spin and solar angles using Lat/Lon/Alt inputs
    - Solar Flux: function of altitude, launch location and date
    - Albedo: CERES data
    - Earth IR: CERES data
    - Sky IR: conservative estimates based on air temperature
  - Software calculates convection coefficients
    - Air Temperature: measurements from past flights out of Ft Sumner in September
    - Air Pressure: standard atmosphere model

- Passive and active thermal design
  - Insulating foam
  - White tape/paint on all exterior surfaces
  - Heaters sized for cold case



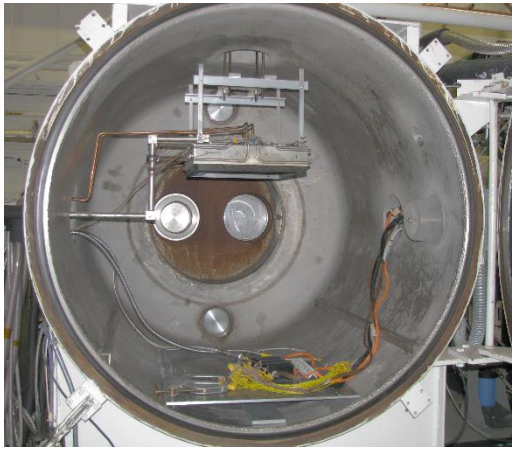
Red strips represent film heaters



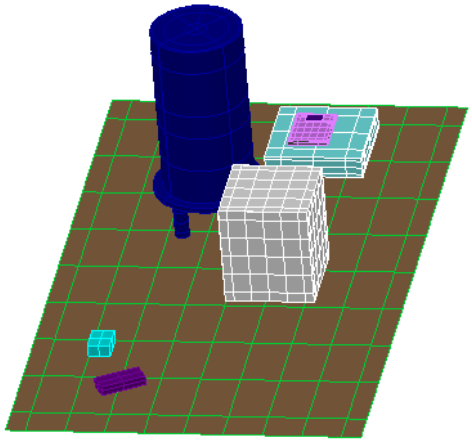
Lighter blue indicates insulating foam covers

Subsystem Test in Thermal Vacuum Chamber

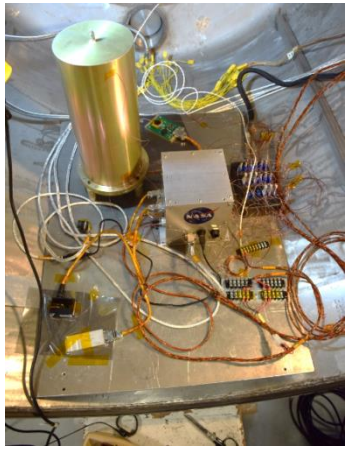
Test apparatus: 5'x5' thermal-vacuum chamber at LaRC



- Vacuum chamber
  - Air pressure control only
- Key Test Objective
  - Show that flight components work in relevant low-pressure environment
- Bonus Thermal Objectives:
  - Asses Thermal Desktop natural convection calculation at low air pressure
  - Verify power draw of instruments
  - Add fidelity to avionics box thermal model



Thermal model of test configuration

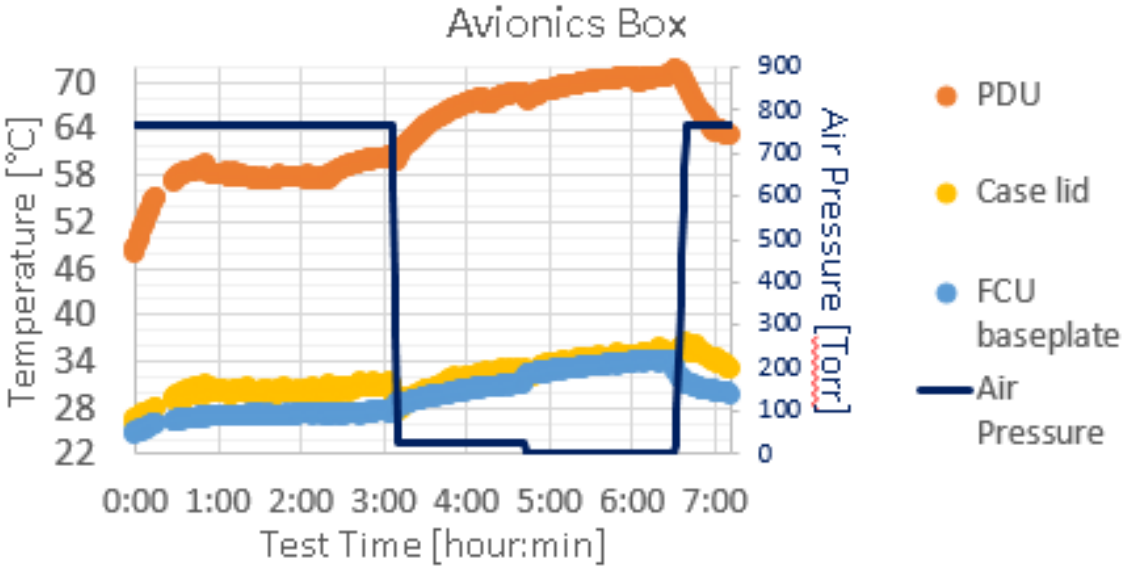


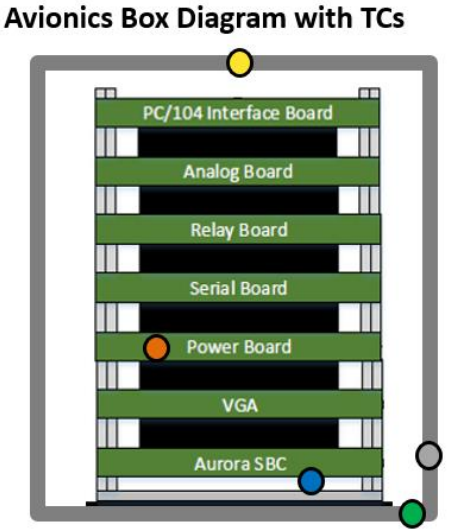
Hardware in the chamber with facility TCs

Air pressure profile

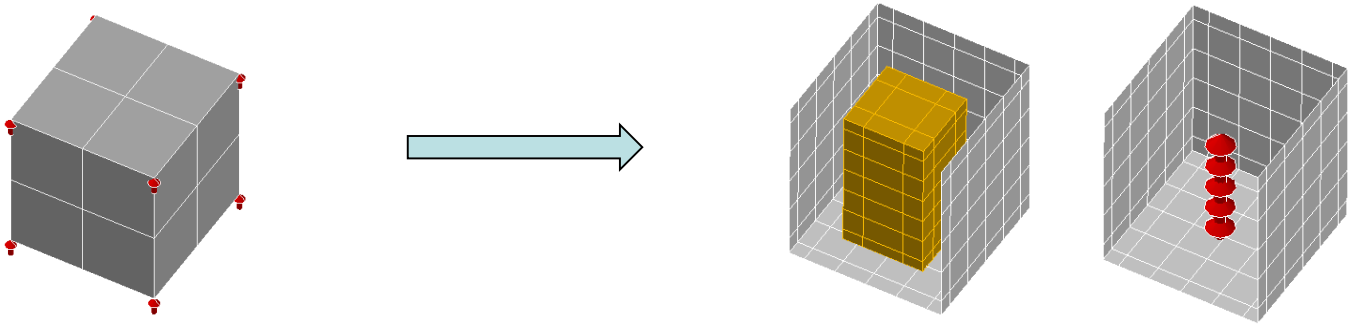
Subsystem Test Results (1/2)

- There were noticeable jumps in temperature when air pressure reduced



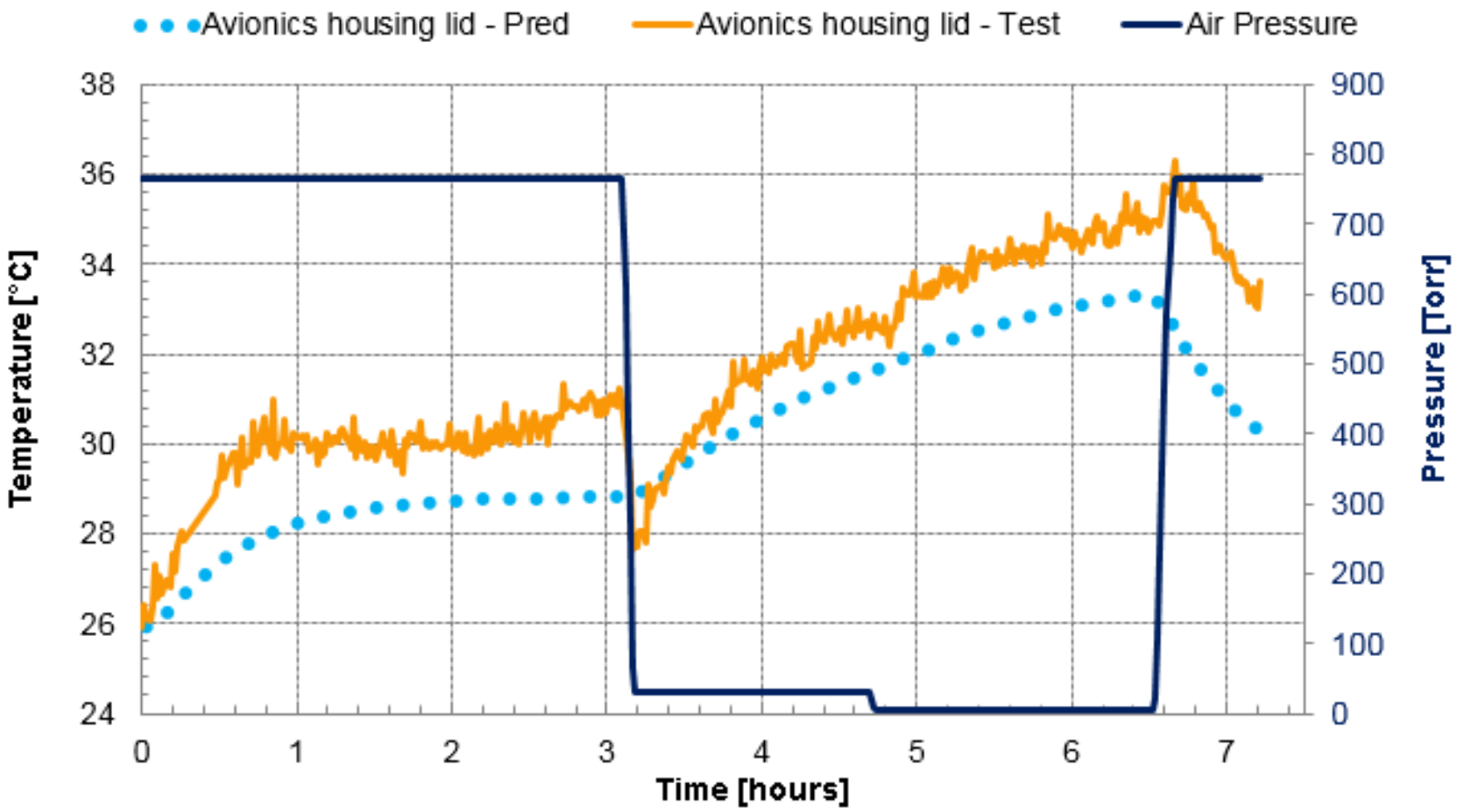


- Avionics box model masked the high temperature reached by the power board
  - Prompted adding fidelity to the geometric thermal model



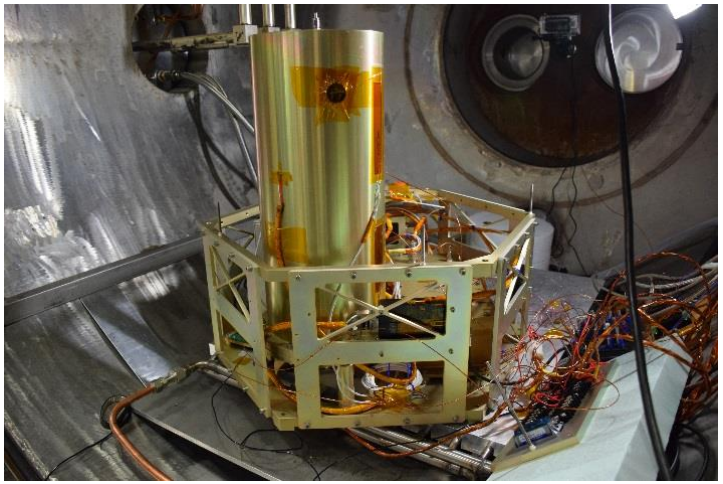
Subsystem Test Results (2/2)

- Able to conclude that Thermal Desktop computes low-pressure natural convection fairly well

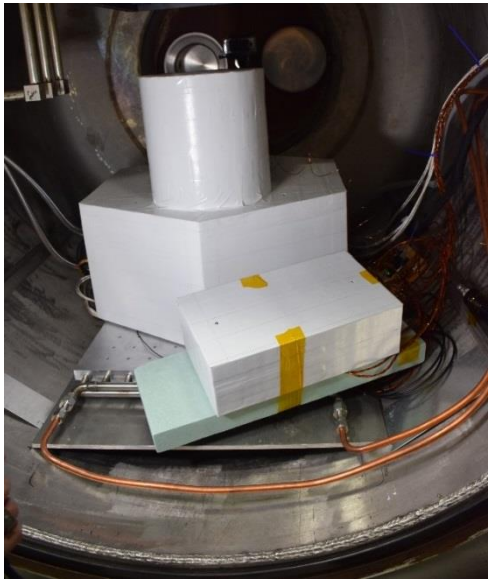


System Thermal-Altitude Test

- Test apparatus: same chamber with added auxiliary platen
  - Controllable auxiliary platen temperature (heaters and nitrogen)
  - No thermal shroud



Flight hardware wired with facility TCs and the flight TCs

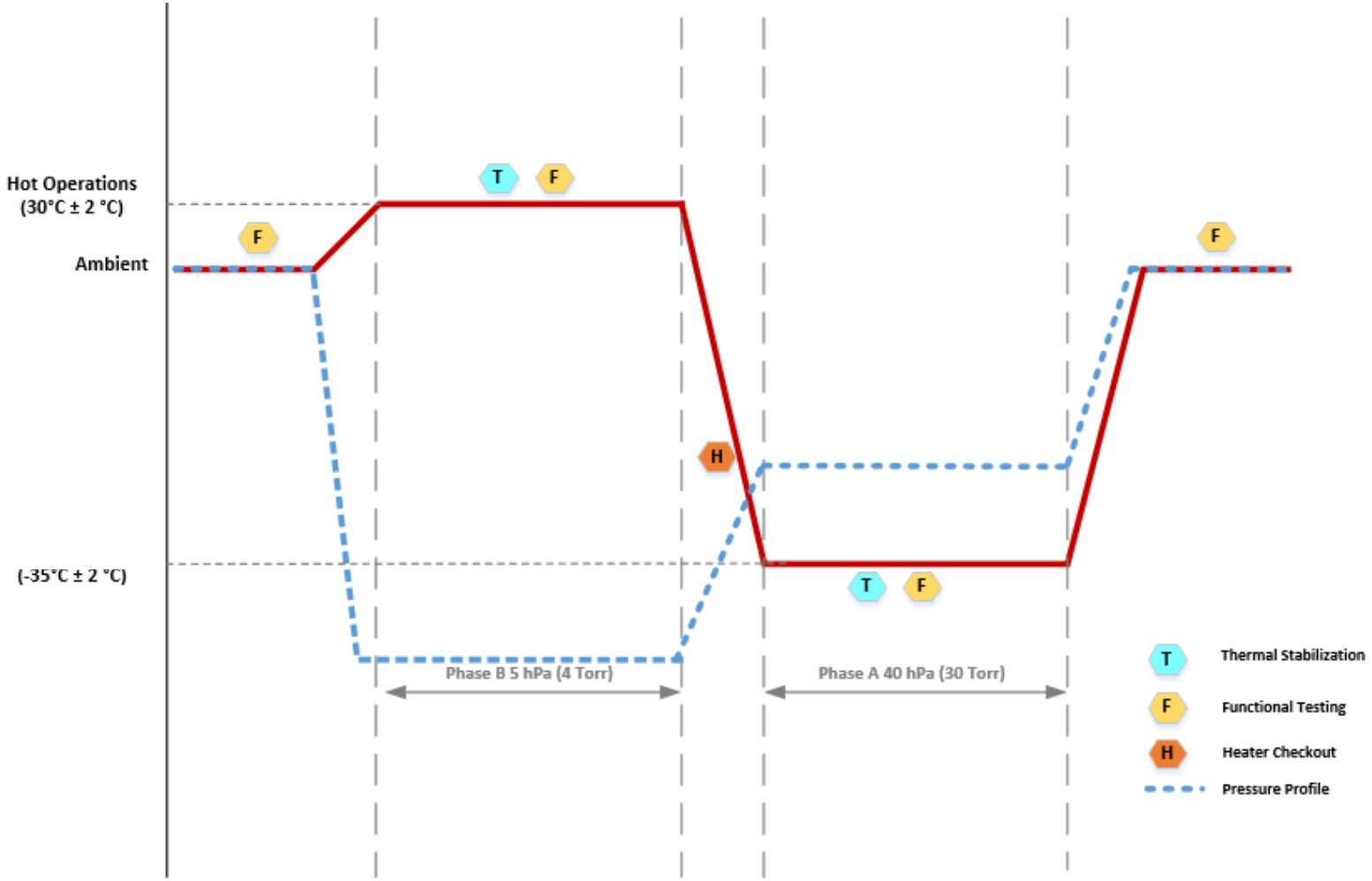


Flight foam covers

- Main Test Objectives
  - Show that flight hardware functions at predicted temperature extremes with added margin
  - Test the active thermal control system and health monitoring
- Thermal Objective
  - Collect temperature data and power data to validate the thermal model

Thermal-Altitude Test #1 Profile

- Change air pressure before changing platen temperature
- Single cycle: low-cost high-risk project without standard test requirements



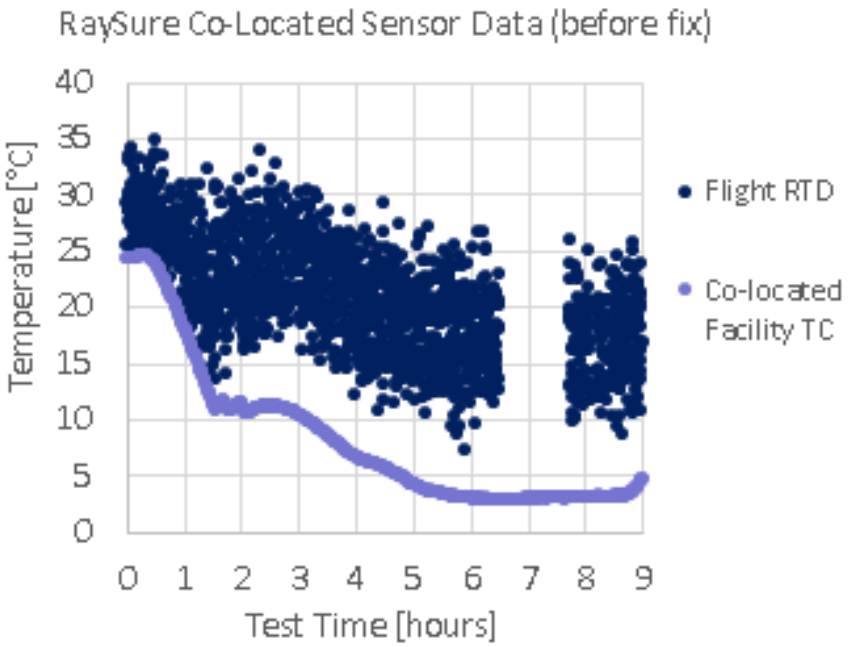
Thermal-Altitude Test #1 Results

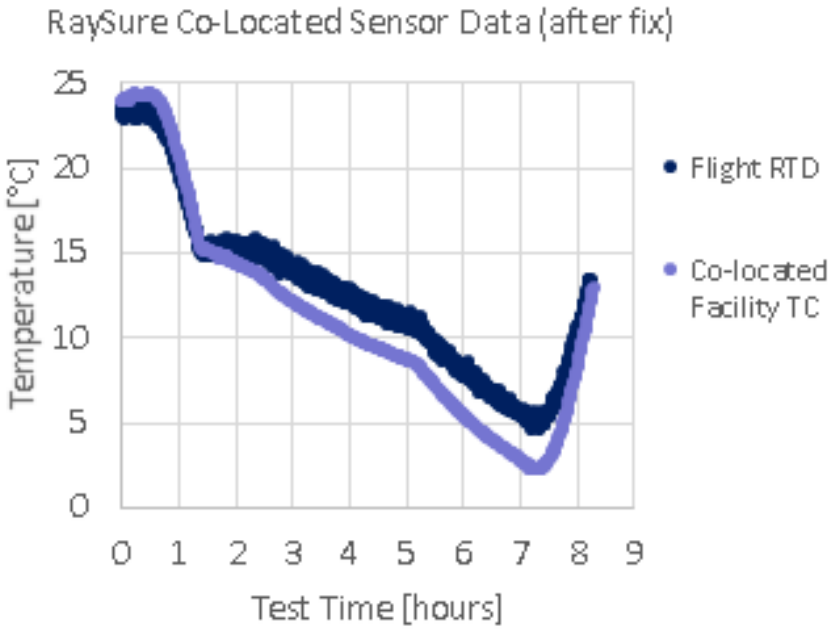
- Temperature targets were reached (hot and cold)
- 2 Thermal-Related Anomalies

1) Flight sensor noise and incorrect measurement (data for RaySure detector shown below)

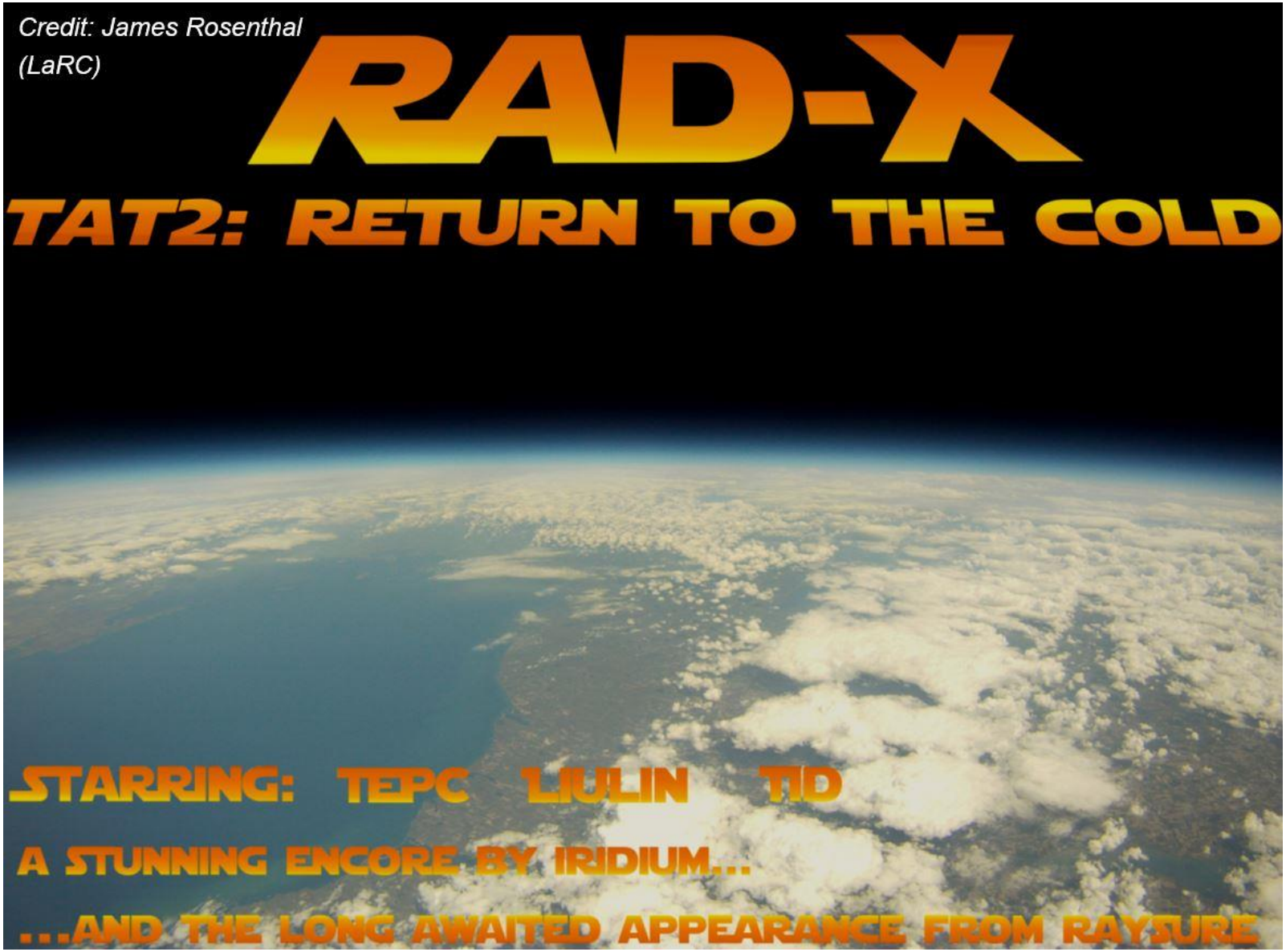
  - Root cause of noise traced to floating ground and long wires

2) Iridium modem had not been turned on for cold test point, and did not cold-start when attempted (off-nominal condition)



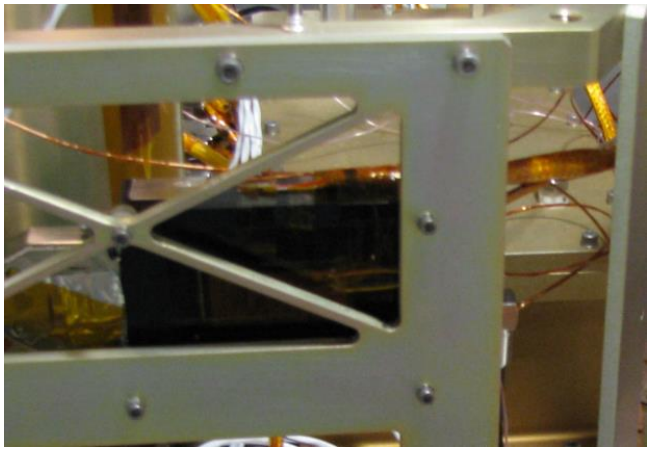


Thermal-Altitude Test #2

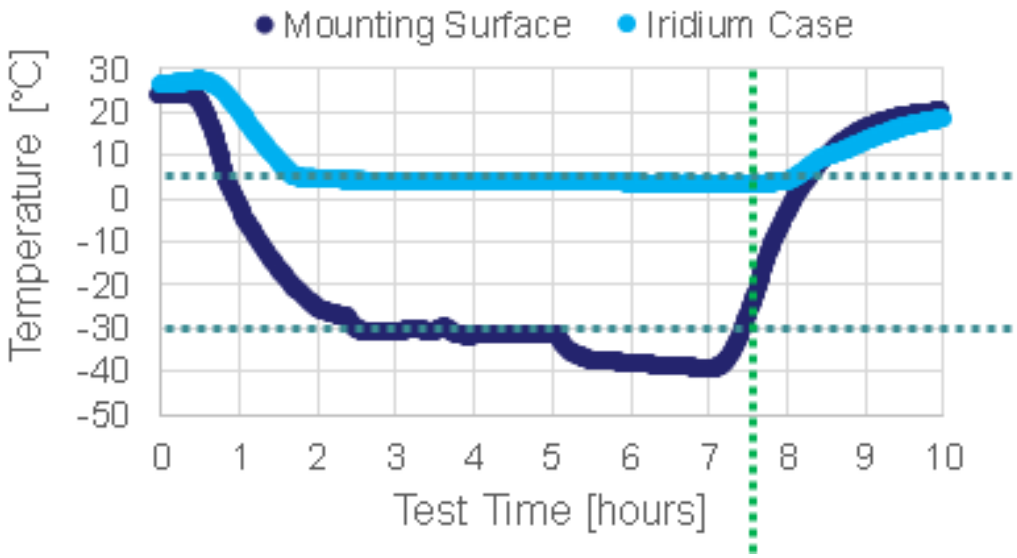


Thermal-Altitude Test #2

- Co-located all flight TCs with facility TCs
- Results
  - Reached same state as in previous test
  - Iridium functioned nominally
- Iridium Anomaly Root Cause



Iridium module mounted at 4 corners with film heater visible



Heater control setpoint 5°C

Cold Operation Limit on Data Sheet -30°C

Powered/Nominal

Unpowered

Powered & Unresponsive

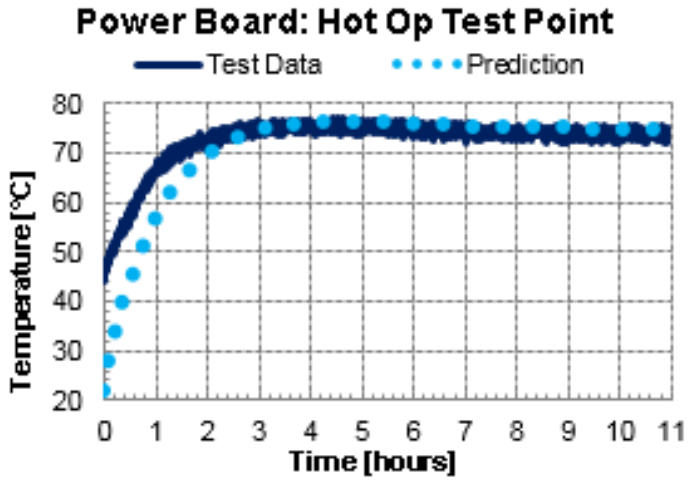
Model Correlation

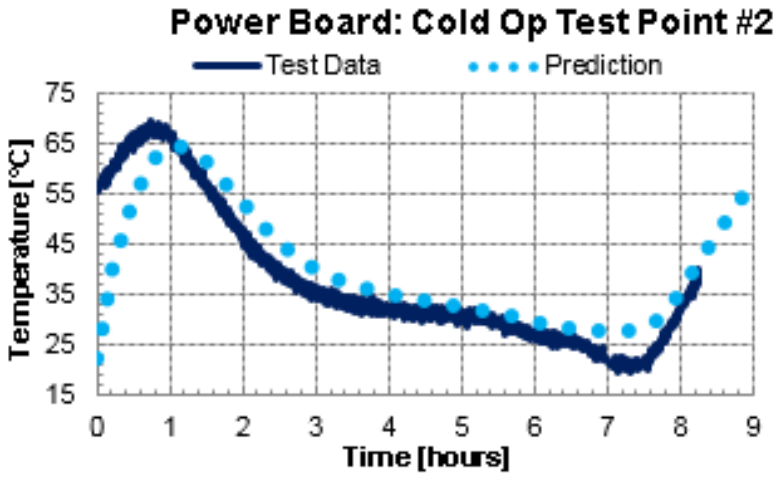
- Key Assumptions in Model
  - Chamber wall: isothermal
  - Chamber wall emissivity: uniform
  - Auxiliary platen temperature: isothermal
  - Air masses modelled using single node
  - No mass transfer between air nodes
    - Single nodes represent air masses inside chamber, payload, and avionics box

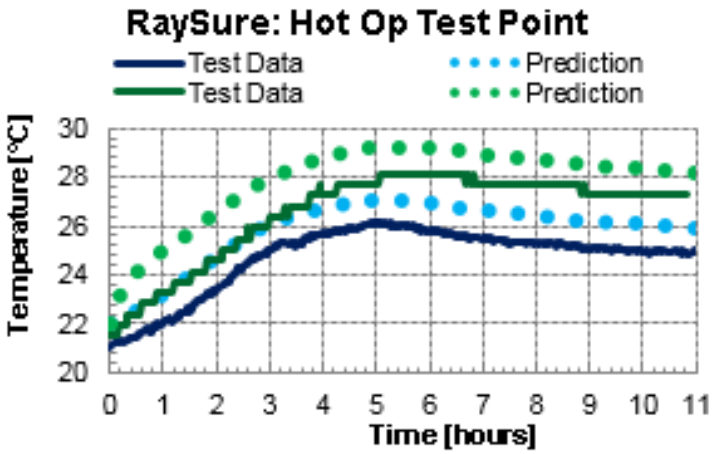
- Adjustable Parameters
  - Component masses
  - Thermal contact conductances
  - Measured power dissipation

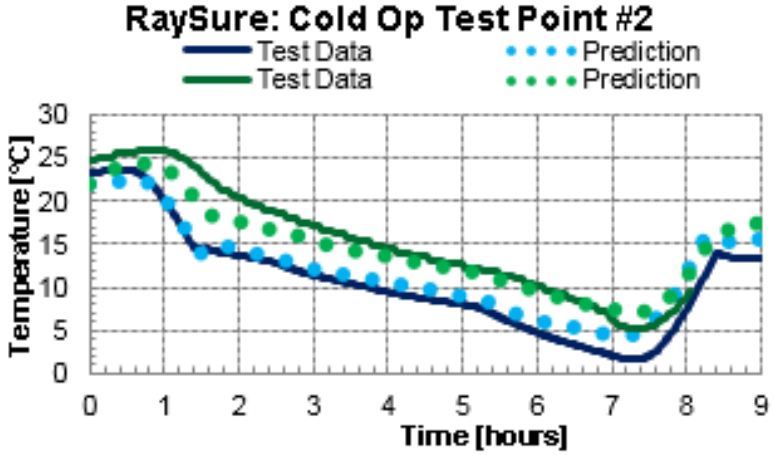
Model Correlation

- Correlating to low-fidelity thermal model
- Acceptable correlation was defined to be within 3°C of test data, ignoring initial condition transients



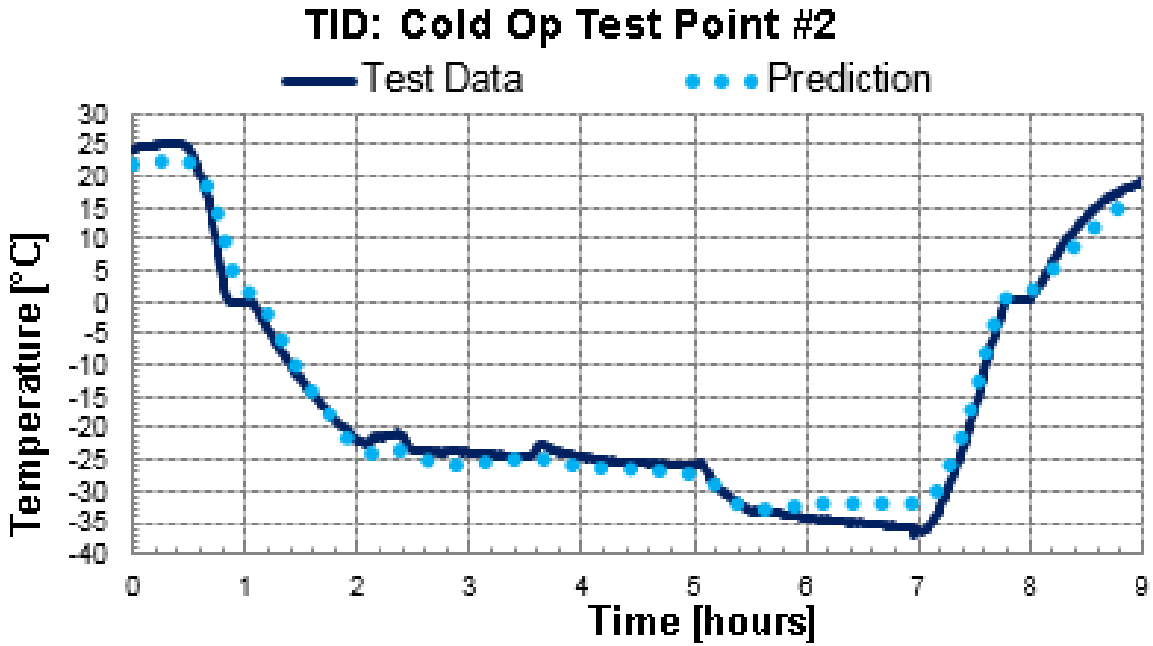


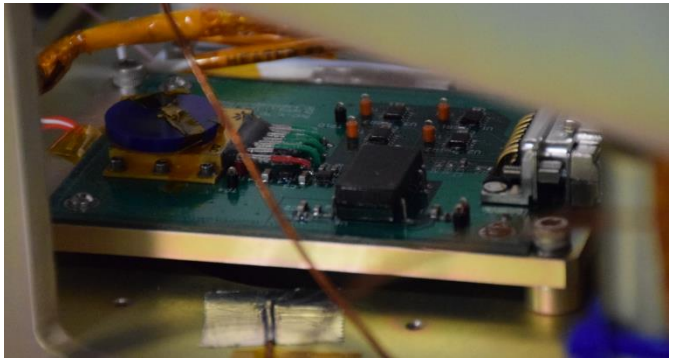




Model Correlation

- Outcome of Correlation
  - Most of the final model predictions agreed well with test data
  - Small, built-in-house components showed better agreement





TID detector board

- Results of Correlated Model
  - Worst-case flight predictions of several components became a few degrees warmer
  - All components predicted to stay within operational temperature limits
  - Increased confidence in system surviving mission

Lessons Learned

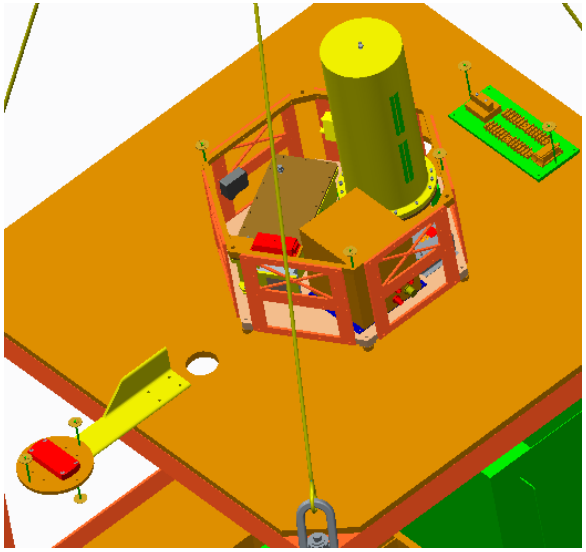
- Thermal Desktop does a good job with natural convection at low air pressure
- Co-locate flight temperature sensors with facility sensors during testing
- COTS datasheets don't always do a good job of specifying where Op/Storage Temperatures should be measured
- Air temperature gradients in test chamber vs simplified assumptions in thermal model
- HOPE program

Acknowledgements

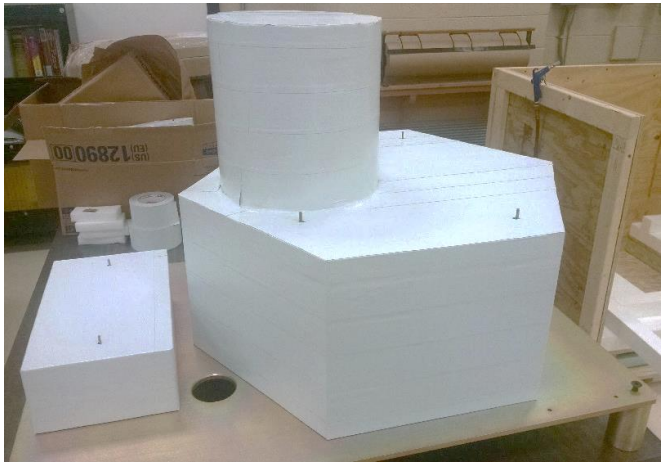
- Kevin Daugherty Project Manager, LaRC
- Amanda Cutright Chief Engineer, LaRC
- James Rosenthal Avionics Lead, LaRC
- Denisse Aranda Integration & Test Lead, LaRC
- Walt Bruce Thermal Engineer, LaRC
- Ruth Amundsen Thermal Engineer, LaRC

BACKUP

RaD-X Payload



RaD-X payload on gondola



RaD-X payload with foam covering

Similar gondola

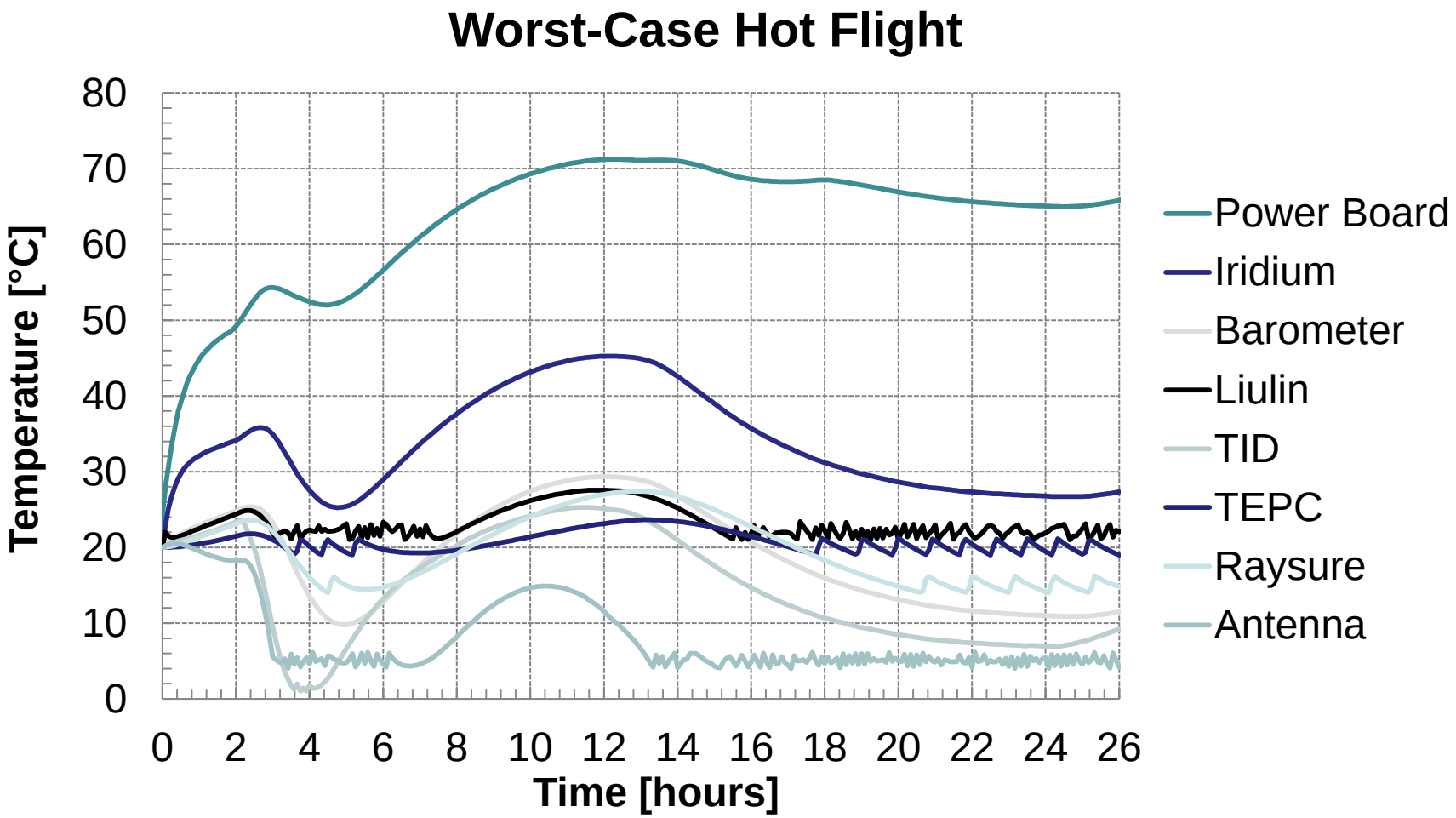
Thermal Requirements

- Operating, Non-Operating, and Data-Quality Limits

Component	Temperature Limits (°C)					
	Non-Operational Limit		Operational Limit		Data Quality Limit	
	Cold	Hot	Cold	Hot	Cold	Hot
TEPC	-40	50	-20	50	15	35
TID	-40	110	-30	70	-30	25
RaySure	-20	50	0	40	15	35
Liulin	-20	80	-20	50	15	35
Barometer	-55	90	-40	80	*N/A*	*N/A*
Antenna	-55	85	-50	85	*N/A*	*N/A*
Iridium Modem	-40	80	-30	70	*N/A*	*N/A*
Flight Computer Board	-55	125	-40	80	*N/A*	*N/A*
Analog and Serial I/O Boards	-55	125	-40	85	*N/A*	*N/A*
Power Board	-55	125	-40	100	*N/A*	*N/A*
Flash Memory Board	-55	125	-40	85	*N/A*	*N/A*
Digital Relay Board	-55	125	-40	85	*N/A*	*N/A*
Batteries	-50	70	-50	70	*N/A*	*N/A*
Battery Relay Plate	-50	60	-50	60	*N/A*	*N/A*

New Flight Predictions

- Results of Correlated Model
  - Flight predictions became a few degrees warmer in the hot case



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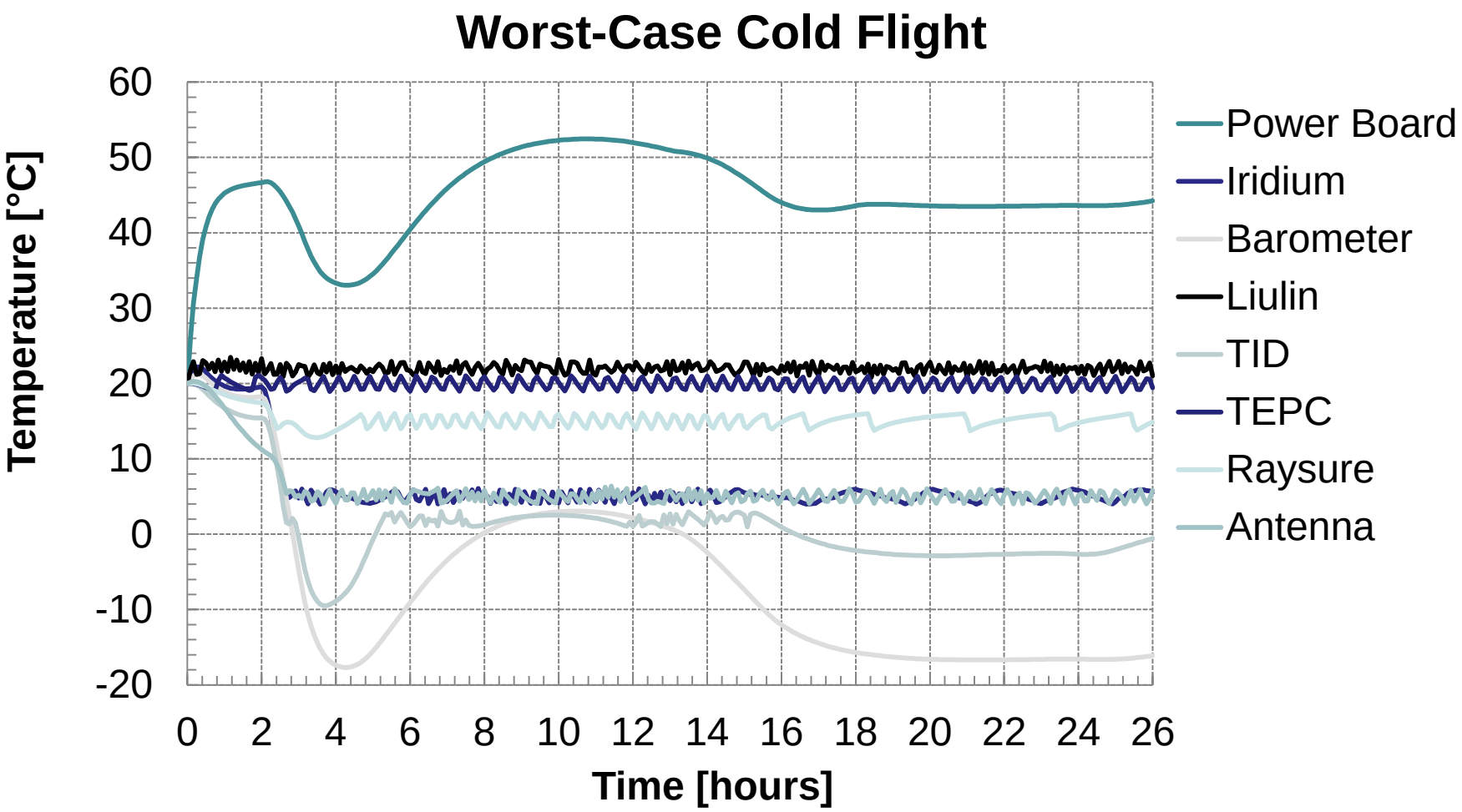
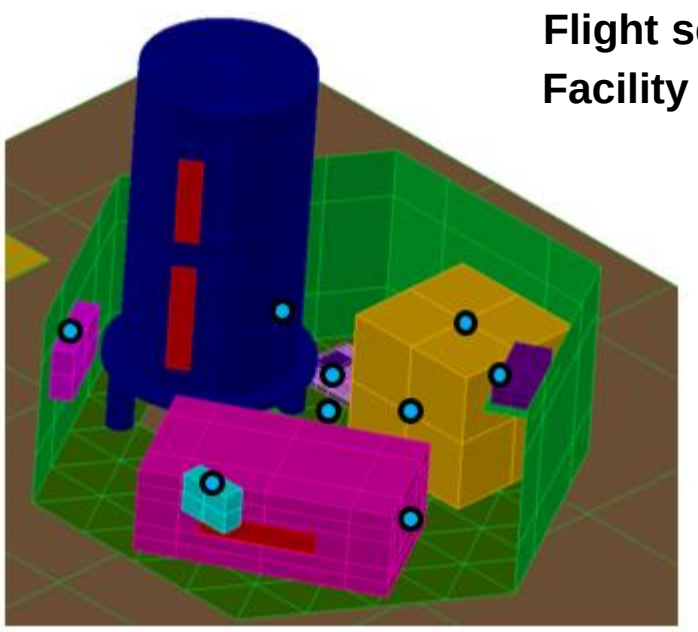


Thermal Test Instrumentation

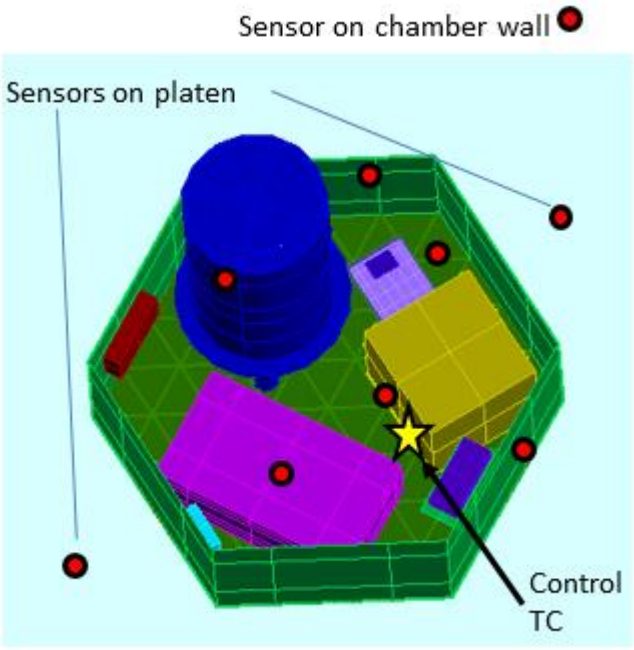
- Set facility sensors to get temperature distribution throughout the payload
- Co-located several facility sensors with (some) flight sensors



Flight sensor:

Facility sensor:

2 side walls and foam cover hidden



Top down view, foam cover hidden