Lessons Learned from SAGE III on ISS Thermal Vacuum Testing

Kaitlin A. K. Liles, Ruth M. Amundsen, and Warren T. Davis
NASA Langley Research Center

Presented By
Ruth M. Amundsen

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Agenda

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- Thermal Vacuum (TVAC) Test Descriptions
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  - Test Procedure Development
  - Thermocouple Placement and Installation
  - Hardware Interfaces
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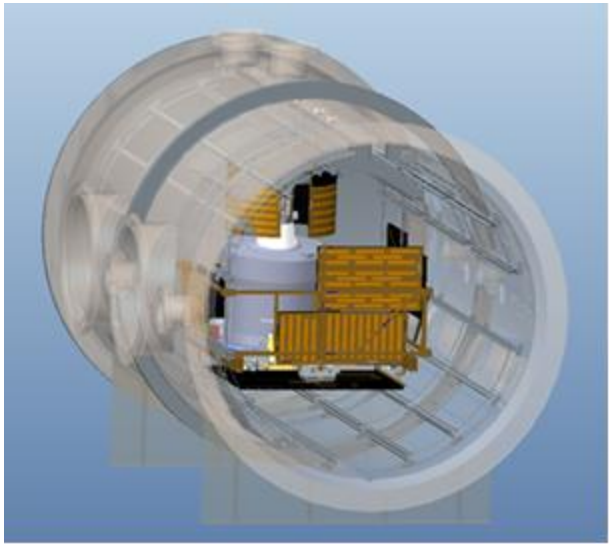
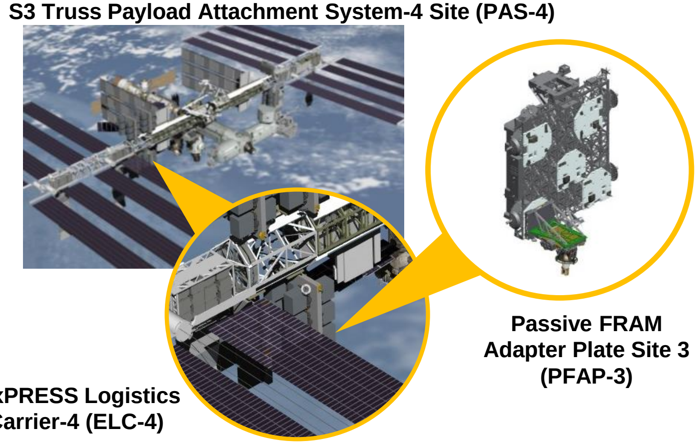
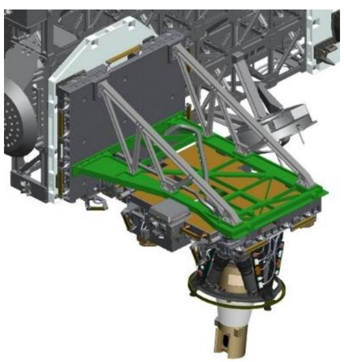
- Summary



SAGE III on ISS Background

- Stratospheric Aerosol and Gas Experiment
- Fifth in a series of instruments developed to monitor ozone, aerosols, and other trace gases in Earth's stratosphere and troposphere
- Partnership between NASA Langley Research Center (LaRC), Thales Alenia Space- Italy (TAS-I), and Ball Aerospace and Technologies Company (BATC)
- Launched to the International Space Station (ISS) via Space X Falcon 9 in February 2017
- Consists of two payloads – Instrument Payload (IP) and Nadir Viewing Platform (NVP)



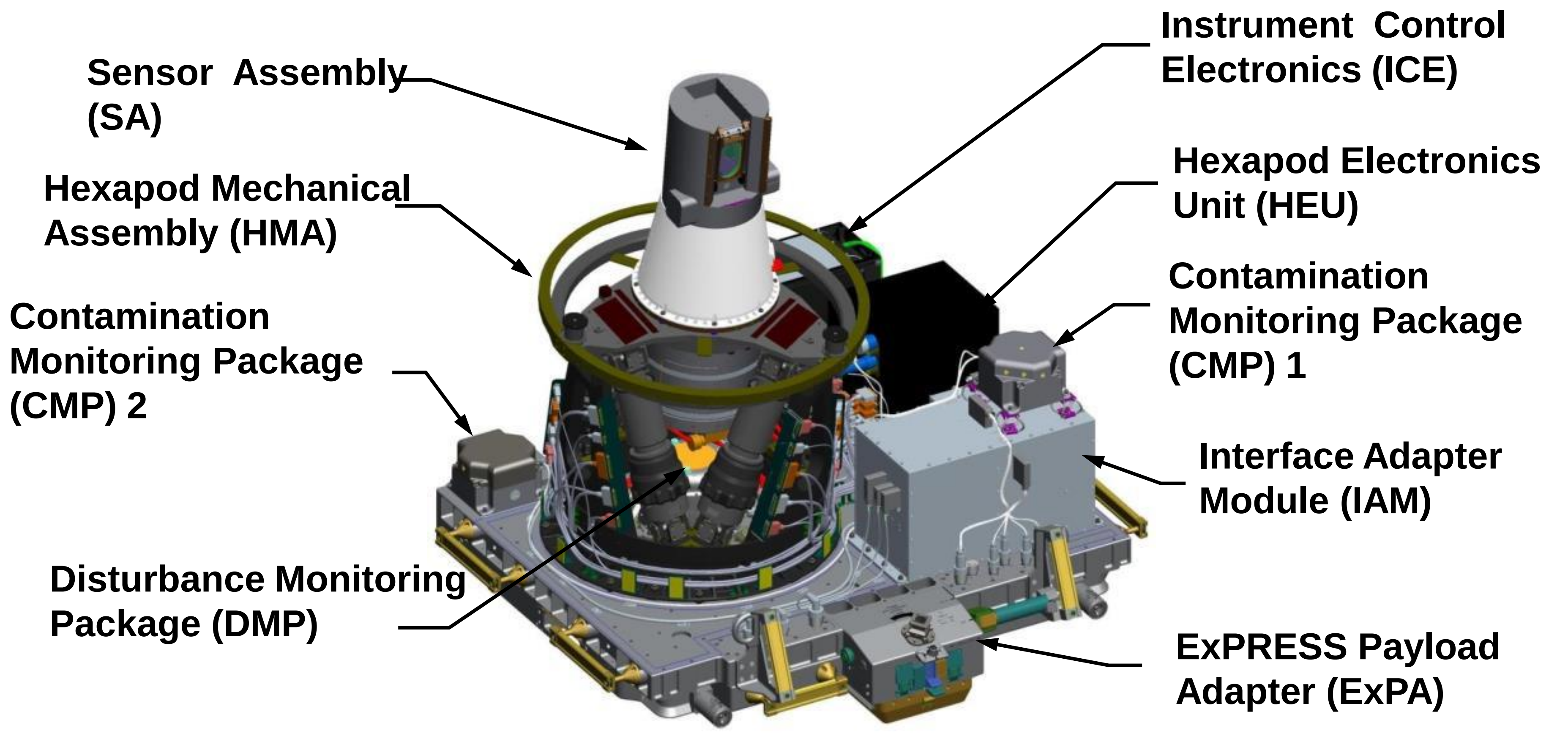


SAGE III On-Orbit Configuration

Payloads in Dragon Trunk (CRS-10)

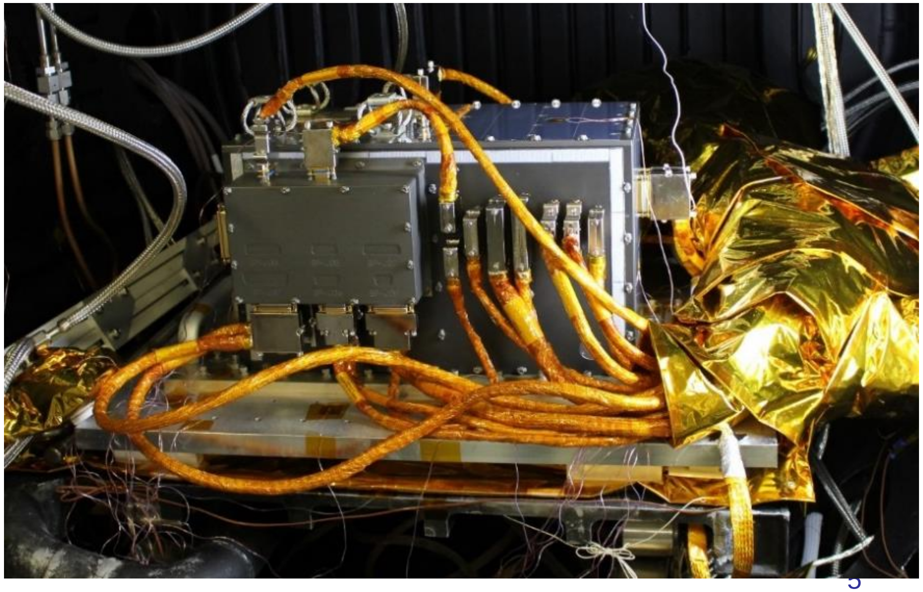
SAGE III In-Transit to ELC-4

Instrument Payload (IP)



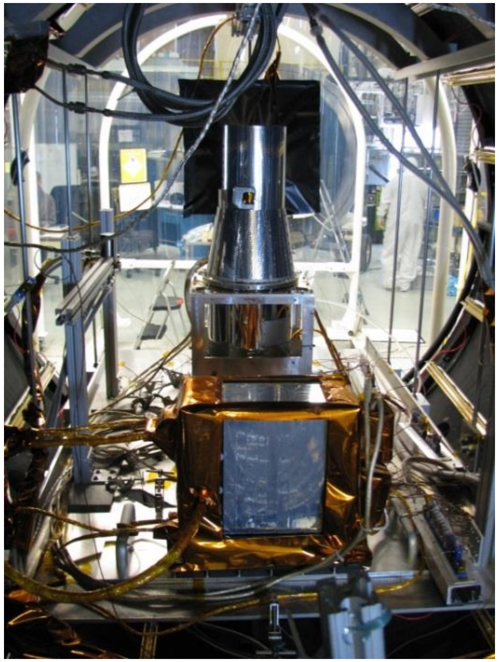
Interface Adapter Module (IAM) TVAC

- New build, flight computer and power distribution unit
- Tightly-coupled to chamber interface plate in flight-like configuration using thermal epoxy
- MLI on back, silver Teflon all other sides
- Operational and survival heaters controlled via mechanical thermostats



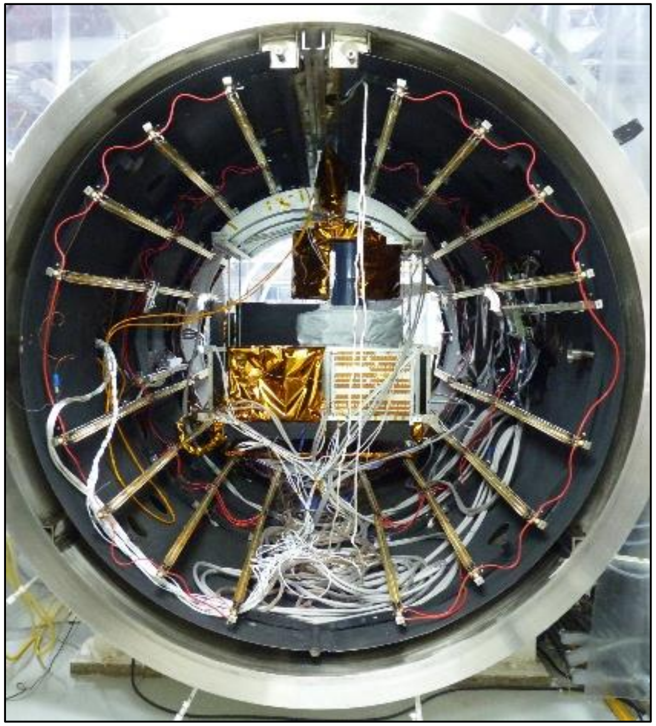
Instrument Assembly (IA) TVAC

- Consists of the Sensor Assembly (SA) and Instrument Control Electronics (ICE)
  - Hardware built in late 1990's
- Quartz lamps used for heating
- IA contains heaters, rotating azimuth motor, rotating scan mirror, thermo-electric cooler (TEC)
- Exterior surfaces mainly silver-Teflon
- Conductive interfaces designed to be flight-like



Instrument Payload (IP) TVAC

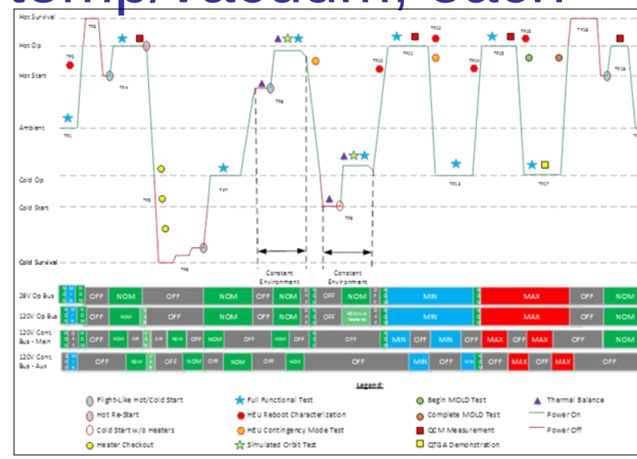
- Flight IP and custom heater plate system
- IP contains operational and survival heaters, multi-layer insulation (MLI), silver Teflon, and TECs



Test Profile

Project requirements heavily influence test profile definition; items to consider:

- Functional tests: door open, ambient temp/vacuum, each plateau, full voltage range
- Heater checkouts during first ramp
  - Verify current and turn on/off temps
- Hot and cold operational dwells; ≥4 payload-level cycles



- Survival dwells, hot and cold with and without heaters
  - Cold dwell without heaters for verification of thermal margin, cold dwell with heaters for verification of performance
- Thermal balance conditions, including hot/cold, powered/unpowered, heater-only, and transient
- Hot and cold re-starts; can be critical for identifying issues

Target Definition and Stability Criteria

- Temperature targets set based on thermal model predictions plus margin
  - Defined based on project requirements and/or discussion with project personnel
- Cold op margin can be achieved by analysis of margined environment rather than temperature target
- SAGE III approach:
  - Targets achieved to a tolerance of +/-2°C
  - Stability achieved when specified sensors (one per subsystem) are in target range and changing <2°C per hour
  - Balance achieved when all sensors change <0.1°C per hour for 6 hours

Test Procedure Development

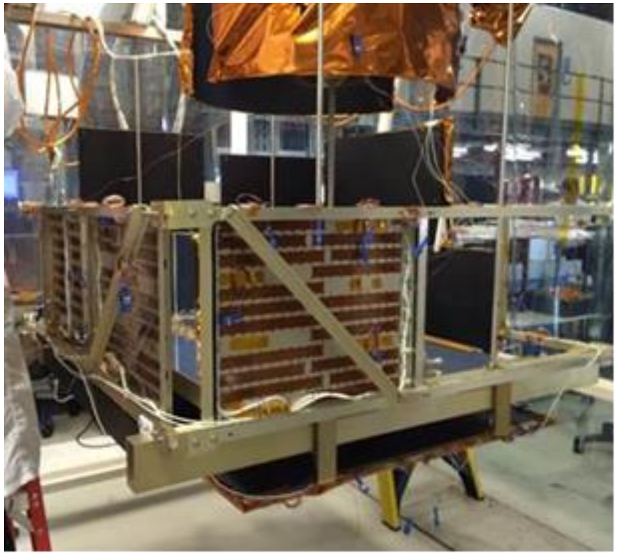
- Develop test plan well in advance of procedure development
- Conduct multiple table-top and email reviews, including project and facility personnel
- Leverage previous testing by adopting format and content from previous successful procedures
- Create separate procedures for hardware setup and removal; clearly define required personnel
- Conduct peer review at least 2 months prior to testing
- Use open-ended format for scenarios with uncertain sequencing (e.g. heater checkouts)
- Test Director responsible for procedure execution
  - Should be project personnel knowledgeable about payload to facilitate timely decisions

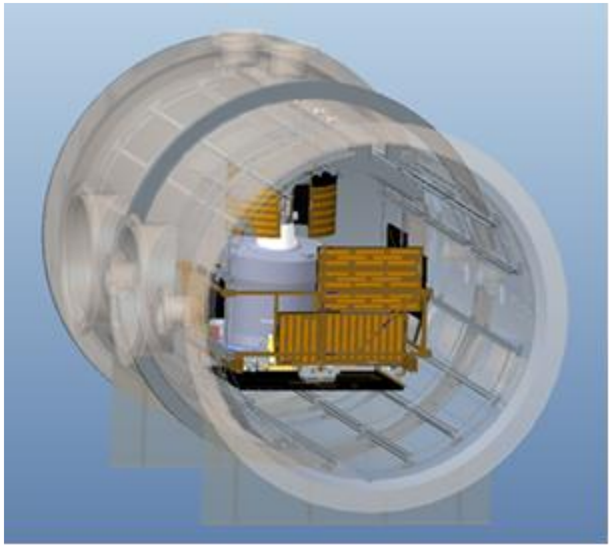
Thermocouple Placement and Installation

- Placement
  - Have backups for control TCs
  - Place TCs to verify model assumptions
  - Ensure each heater has nearby sensor to verify on/off
- Installation
  - Check TC extension wires to verify leads are properly connected
  - Use high conductivity tape to mount TCs to hardware
    - Kapton may be preferable for low mass and/or soft items
    - Minimize high-conductivity tape in high gradient areas
    - If taped area represents a significant percentage of total, consider over-taping with tape that matches hardware emissivity
  - Label TCs at bead and connector ends
  - Route wires such that path is as isothermal as possible
  - Perform touch tests through facility DAS at end of set up; check for noise
  - Photograph TCs, ensuring location is easily discernable

Hardware Interfaces

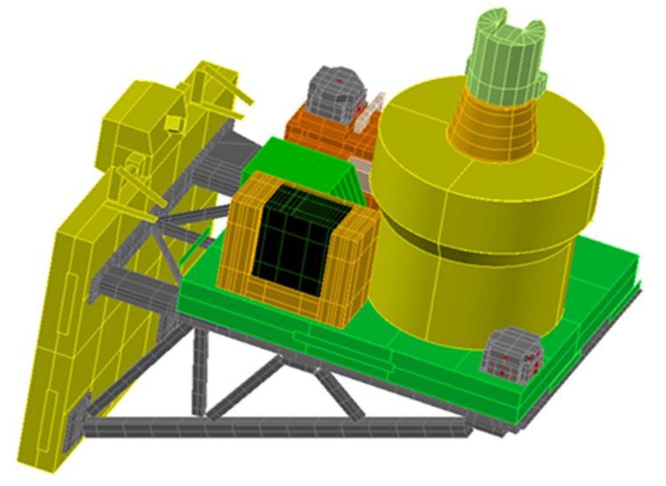
- Conductive and radiative interfaces should be as flight-like as possible
  - Surface finish
  - Fasteners
  - Standoffs
  - Torque values
- Thermal analyst reviews test configuration drawing to ensure test setup correct and model accurate





Model Correlation (1 of 2)

- Use of single model for flight and ground test scenarios greatly improves efficiency
  - SAGE model in Thermal Desktop (TD)
- Balance sequence with conditions focused on thermal behavior is effective for correlation
  - Unpowered correlation first
  - Transient for heater power-up
  - Transient to powered operation
  - Powered balance
  - Power-off for cool-down transient



- Proceed from simple to complex
- Correlate to both hot and cold
- Transient cases provide more accurate prediction of behavior, even for quasi-steady-state

Model Correlation (2 of 2)

- RMS error very effective single measure of model quality
- Correlation of TEC behavior can be complex
  - Required modification of TEC parameters due to degradation; test data when TEC data went out of the control range valuable
  - Run time reduced via mod of TEC power dissipation equation
- For MLI covering multiple plates at different temperatures, cannot use Insulation tab on TD surface
  - Model explicitly to get correct radiative transfer under MLI
- Solar output of quartz lamps can complicate correlation
  - Facility characterization test required to perform IA model correlation
- Chamber shroud had larger gradients than expected, should be well-instrumented
- Characterize new chamber equipment before payload testing

Schedule

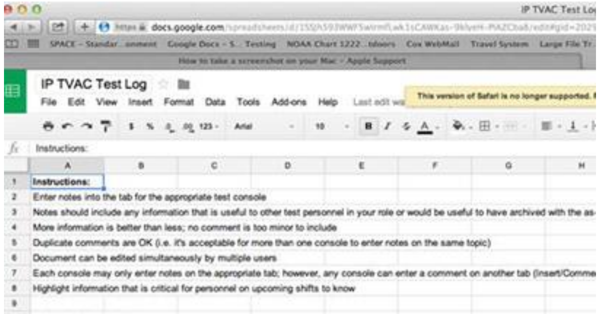
- Develop schedules early
  - Initial prior to System Requirements Review (SRR) and detailed prior to Critical Design Review (CDR)
- Include all test-related activities in schedule
  - Procedure development
  - Peer reviews
  - Test setup
  - Test, with predicted duration based on thermal model with margin
  - Post-test hardware removal
- Provide opportunity for stakeholder review and input
- Use probabilistic risk assessments to establish reserve and review after each major test
- Begin discussions related to GSE development very early in the planning process

Staffing

- Initiate staffing plans approximately 2 months prior to testing; finalize 2 weeks prior
- Use a collaborative tool (e.g. Google docs or Sharepoint) to maintain master schedule
  - If possible, use system that alerts users of updates
- Have backup personnel in place with pre-defined method of response for no-shows
- Post contact information online and in test area
- Schedule shifts with 30-minute overlap to aid transition
- Consider pros and cons of staggering shift start times for different groups
- For test setup shifts, include a lead and at least one person from each discipline for each test setup shift

Communication - General

- Daily status meetings and distribution of minutes is an effective way to share info and make decisions
- Common log with concurrent editing capability extremely valuable for sharing info and record-keeping; can include:
  - Tabs for each test role
  - Date, time, name, test point, type of comment, and notes
  - Test profile and time projections, updated during test
  - NCR log
  - Daily status summary
  - Operator guidelines
  - Test configuration / change log



- Consider 2-part Test Readiness Review (TRR); first for majority of information and second for final go/no-go
- Carefully define on-shift and lead roles prior to testing

Communication – Thermal Team

- Conduct pre-test briefing for all thermal engineers (TEs); led by lead TE and facility engineer
- Create a shared TE log, separate from common log, to provide thermal-specific information including:
  - Targets and predicted facility settings
  - Tracking of critical temperatures, with stability checks
  - Temperature sensor location graphics and limits
  - Watch list items
  - How-to information (displays, data retrievals, etc.)
- Create a template for comparing predictions to test data ahead of time

Summary

- SAGE III TVAC testing resulted in many lessons learned, both technical and logistical
- More detail on SAGE III design, analysis, and model correlation available:
  - ICES-2017-170
  - ICES-2017-171

Acknowledgements

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