

Passive Thermal Design approach for the Space Communications and Navigation (SCaN) Testbed Experiment on the International Space Station (ISS)

Radiator

Solar Array

TFAWS 2014

August 4-8, 2014 Cleveland, Ohio

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**SCaN Testbed aboard
International Space Station**

Truss





INTRODUCTION - PURPOSE



Introduction:

- The SCaN Testbed payload provides an on-orbit, adaptable, SDR/STRS-based facility to conduct a suite of experiments to advance the Software Defined Radio (SDR) Space Telecommunications Radio Systems (STRS) Standards, reduce risk (TRL advancement) for candidate Constellation space flight hardware/software, and demonstrate space communication links critical to future NASA exploration missions.
- The SCaN Testbed Project provides NASA, industry, other Government agencies, and academic partners the opportunity to develop field communications, navigation, and networking technologies in the laboratory and space environment based on reconfigurable, software defined radio platforms and the STRS Architecture.
- The SCaN Testbed payload is resident on the P3 Express Logistics Carrier (ELC) on the exterior truss of the International Space Station (ISS).

Purpose:

- This presentation summarizes the thermal design, analysis, and environmental thermal testing performed for the design and development of the Thermal Control System (TCS) of the SCaN Testbed space flight payload.
- This presentation provides thermal analysis and test results showing the thermal performance of the SCaN Testbed space flight payload throughout every stage of the mission starting with the JAXA HTV free orbit and on-orbit transfer, and ending with payload operations on the P3 ELC.



SCaN Testbed REQUIREMENTS



It was important that the requirements of the SCaN Testbed Thermal Control System (TCS) were defined early in the analysis/design cycle.

SCaN Testbed requirements included:

- Launch and Transfer Vehicle (JAXA HTV) requirements.
- International Space Station (ISS) requirements, such as:
 - On-orbit Extra Vehicular Robotics (EVR) HTV to P3 ELC transfer.
 - On-Orbit Survival during Planned 6-hr Power Outage
- Science requirements

Early meetings and with both ISS and JAXA thermal teams were necessary to establish a set of preliminary requirements for the SCaN Testbed TCS because at that time ISS and JAXA requirements were still in flux.

The SCaN Testbed TCS team took the initiative and met with the ISS and JAXA thermal teams and generated an Excel spreadsheet that included all ISS and JAXA thermal requirements based on all ISS and JAXA governing requirement documents. It was understood that several Preliminary Interface Revision Notices (PIRNs) were to follow that would change some of the requirements, but it was agreed that this way a preliminary set of requirements was put in place for the SCaN Testbed thermal team to start preliminary design and analysis of the SCaN Testbed TCS.

The SCaN Testbed TCS thermal team kept track of any requirement changes till they all became final.

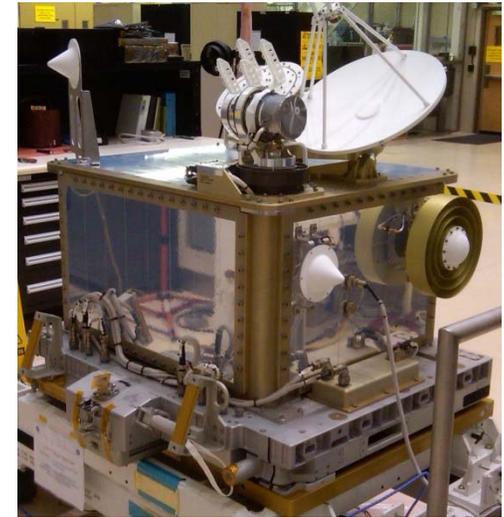


SCaN Testbed TCS DESIGN



The SCaN Testbed payload is passively controlled.

- Three of its five sides (Starboard, Zenith, and Ram) function as highly efficient radiators coated with 10 mil Silver Teflon. All heat generated by the SCaN Testbed electronics is radiated to space through these three (3) radiators.
- The Wake and Nadir sides (facing toward other ORUs on the ELC) are non-radiating surfaces and are covered with Multi Layered Insulation (MLI).
- During cold environments the SCaN Testbed avionics actively control the radiator temperatures with resistance heaters and power supplied by the operational ISS power feed (120VDC, 200W). Contingency power will be used to provide temperature control during periods when the ELC is not powered and during the HTV to ELC transfer. This is intended to keep the component temperatures above the minimum storage temperatures. The heaters are controlled with thermostatic electromechanical switches (Quad configuration, protection for both failed-on and failed-off cases)

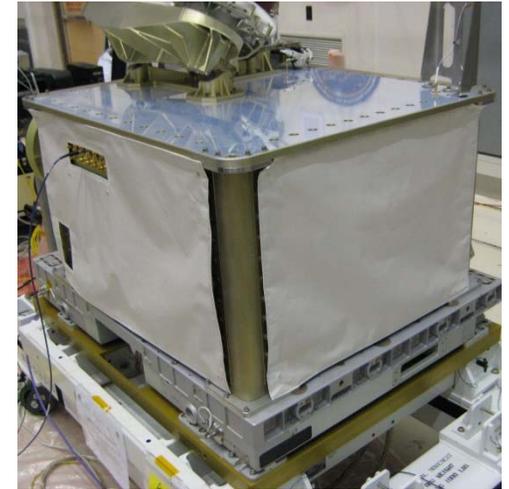




SCaN Testbed TCS DESIGN



- The total surface area of the three radiators (Starboard, Zenith, and Ram) is about $\sim 1.70 \text{ m}^2$, but only about 1.22 m^2 ($\sim 72\%$) of the radiators are covered with 10 mil Silver Teflon.
- This was driven by the requirement to survive on the P3 ELC during times when SCaN Testbed was not operating and using the ISS provided heater power, which was limited to about 200 watts. This requirement was key to the design of the SCaN Testbed TCS.
- The radiators were not sized to reject maximum operating power during worst case hot environments but instead they were sized to survive and maintain electronics above their survival temperatures during non-operational times, worst case cold environment, with the minimum ISS provided heater power ($\sim 200\text{w}$).
- The SCaN Testbed TCS was designed with guidance from MIL-STD-1540E.
 - The maximum test-to operating and non-operating temperature limits for all heat dissipating components were de-rated by 11°C for analysis uncertainty margin and 5°C for proto-qualification margin.
 - The minimum test-to operating and non-operating temperature limits were de-rated by 5°C for proto-qualification margin and a 25% margin on heater capacity was used in lieu of the 11°C for analysis uncertainty margin.

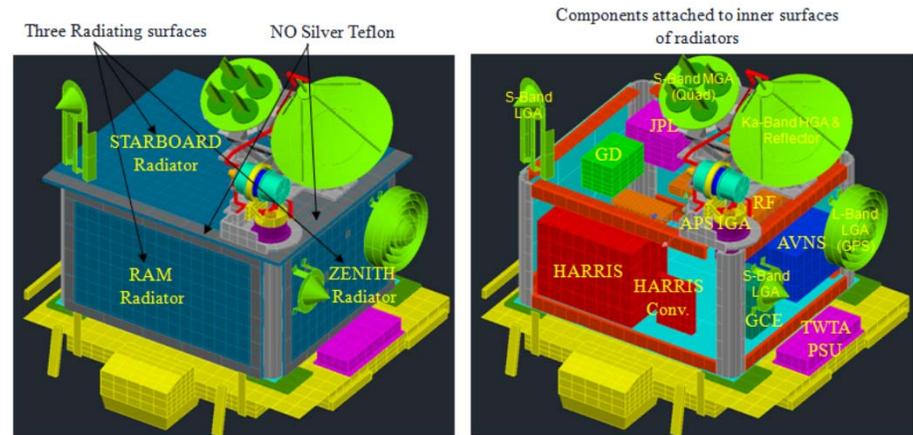




SCaN Testbed THERMAL ANALYSIS APPROACH



The Thermal Analysis approach was to develop an integrated Thermal Desktop model composed of the ISS model (provided by JSC), the HTV model (provided by JAXA), and the P3 ELC with the SCaN Testbed model that was generated by SCaN Testbed Thermal Team.



Key areas analyzed included:

- Minimum heater power required for worst case cold environment during non-operating conditions (Design driver).
- On-orbit operations (% of time operation) for the worst case hot environment.
- Survival during planned 6 hour power loss for worst case cold environment.
- HTV to P3 ELC transfer for worst case cold environment.

The SCaN Testbed on-orbit environment used for the Thermal Analysis was dictated by ISS and JAXA requirement documents, such as “SSP 57003” and “SSP 57003-ELC”



SCaN Testbed THERMAL ANALYSIS APPROACH



A simplified Thermal Desktop model was derived from the detailed model and used for the Orbital Heating Rates analysis.

A variety of combinations of the following parameters were analyzed to determine the worst case hot and cold orbital heating rates for the SCaN Testbed payload:

- Beta angles and Altitude with Roll, Pitch and Yaw combinations.
- Hot and Cold Solar & Earth Radiation, and Earth Albedo.
- Some of the cases were analyzed with and without other ORUs on P3 ELC, without seeing any substantial differences.
- Over 100 possible combinations were analyzed.

With the worst case hot and cold environments established the detailed Thermal Desktop model was used to predict SCaN Testbed component temperatures and minimum heater power requirements.

As discussed earlier, the minimum heater power available to the SCaN Testbed payload during ELC contingency scenarios is ~ 200 watts. In order to maintain the SCaN Testbed components above their survival limits with ~ 200 watts of heater power (including 25% margin) the efficiency of the 3 radiators had to be reduced. The total area of the 3 radiators is ~ 1.70 m². It was determined by analysis, and later validated by the TVAC test, that about 28% of the total radiator area, or 0.48 m², will not be covered with 10 mil Silver Teflon.



SCaN Testbed THERMAL ANALYSIS



The detailed Thermal Desktop model was used to predict SCaN Testbed component temperatures during:

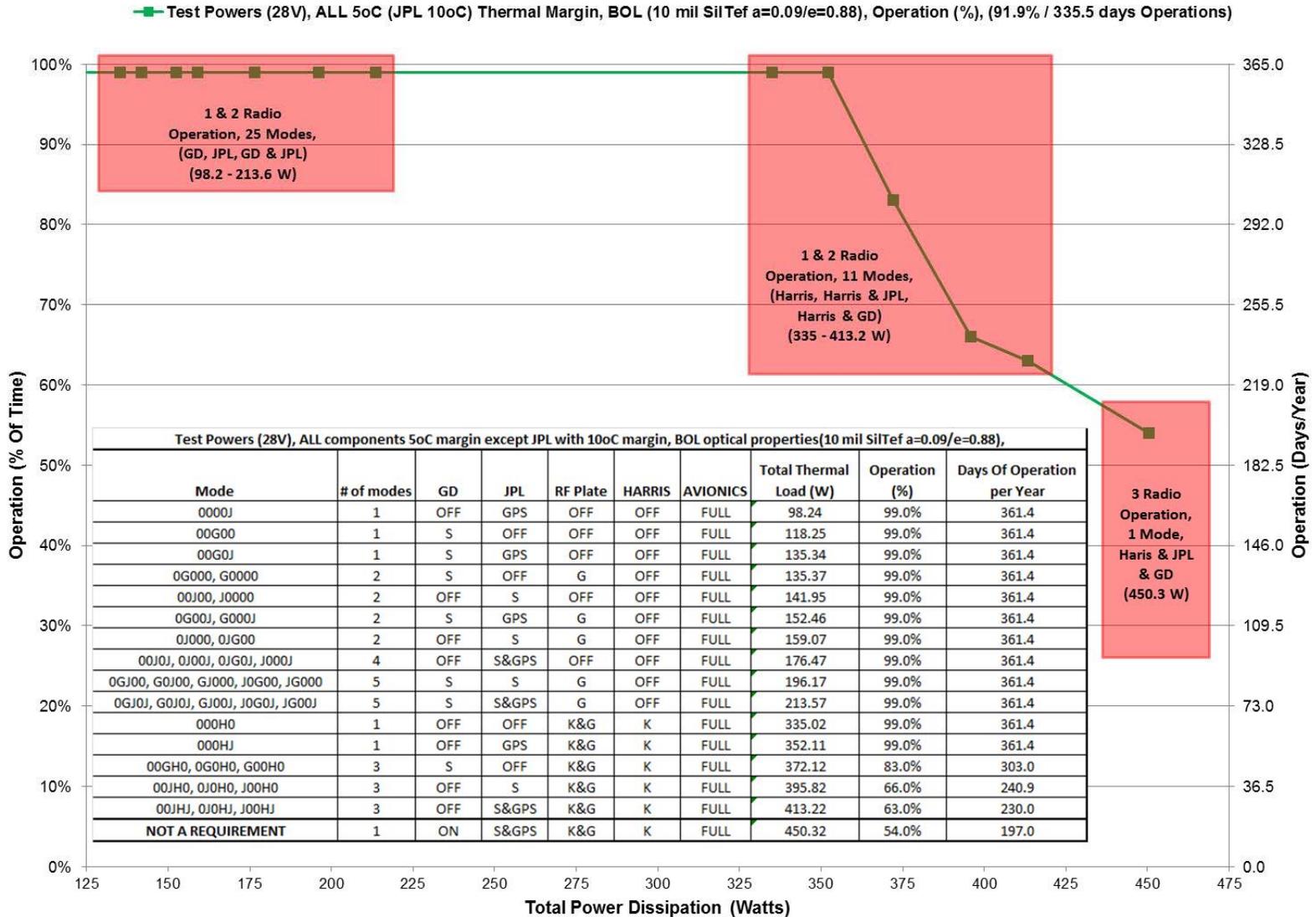
- On-Orbit HTV to P3 ELC Transfer
 - On-Orbit Survival during Planned 6-hr Power Outage
 - SCaN Testbed On-Orbit Operations
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- The SCaN Testbed radiators must reject all internal heat loads while maintaining all components at or below their maximum operating temperatures in the warmest environment.
 - Using the TVAC test validated Thermal Desktop model, analyses were performed for all 37 modes of operation over the full range of ISS Beta angles (-75° to $+75^{\circ}$).
 - Results show that with a 5°C margin incorporated for all components except JPL, and a 10°C incorporated for JPL, SCaN Testbed can operate close to 334 days per year (91.9% of the time) during the initial years assuming there is no contamination of the optical properties of the 10 mil Silver Teflon.



SCaN Testbed THERMAL ANALYSIS



CoNNeCT On-Orbit Operations





SCaN Testbed THERMAL Margins



Based on the results of the System TVAC test, it is recommended to use a 5°C margin for all components except JPL and 10°C (5°C + 5°C) margin for JPL (JPL requested the additional 5°C margin to account for their thermal analysis uncertainties)

The 5°C margin is incorporated to account for:

- The temperature difference between the mounting surface under the baseplate of each component and the approximate location of the Thermistor or RTD monitoring that component.
- The temperature sensor accuracy/error.
- The temperature drop across the thermal interface material between each component baseplate and the radiator surface.

Thermal analysis results (confirmed by TVAC test data) showed that the TOTAL offset of the temperature limits due to the above, varied between 1°C and 4°C for the different SCaN Testbed components.

Incorporating the margins, the SCaN Testbed can operate up to 334 days per year or 91.9% of the time.



SCaN Testbed TVAC TESTING



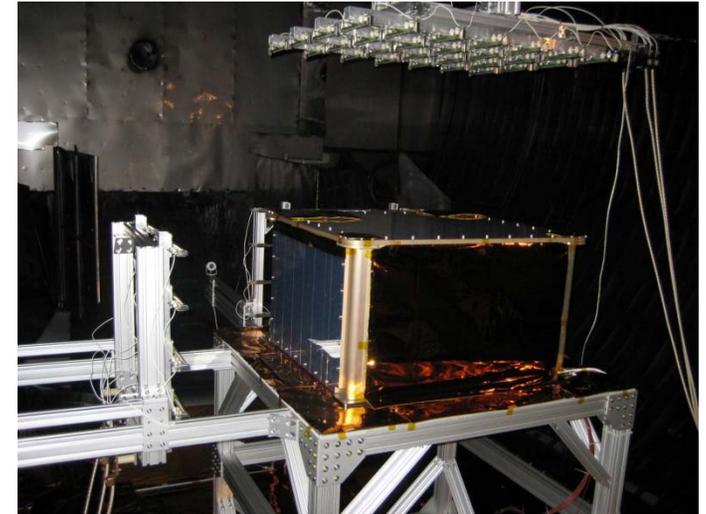
SCaN Testbed STA TVAC Testing

Early in the design phase, the SCaN Testbed thermal team decided to utilize the existing Structural Test Article (STA), which was built for structural testing, to perform a TVAC test and define the test setup necessary to simulate the on-orbit environment of the SCaN Testbed radiators.

The setup of these environments (hot and cold) required numerous changes to the arrangement and intensity of lamps being used to dial-in the correct thermal environment for each of the three radiators.

By using the Structural Test Article (STA) to define this test setup in advance, the project reduced the time needed for thermal vacuum cycling and performance verification of the Flight payload.

Additionally, by simulating the operational heat loads on the STA, the project obtained an early report on the performance of the thermal control system, specifically, the effectiveness of the radiators. This allowed more time for design adjustments if needed. For example, the most likely adjustment would be the percentage of radiator coverage with silver/teflon (Ag/FEP). The test data also provided some validation of the thermal model used to predict the on-orbit performance.



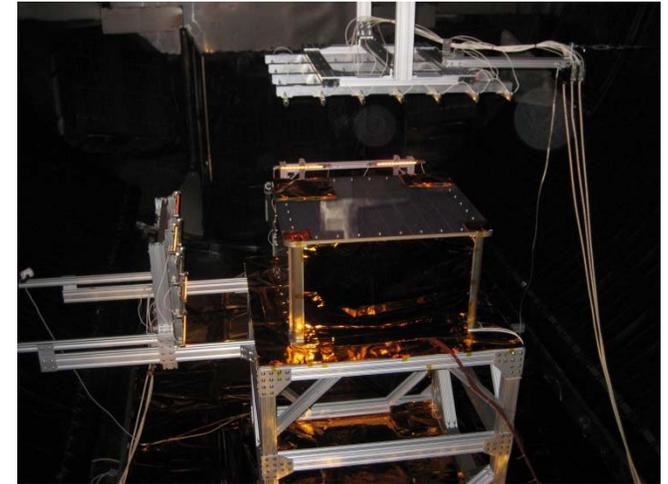


SCaN Testbed TVAC TESTING



IR Lamps Setup for Protoflight Testing

The VF6 facility is equipped with a LN2 cold wall that operates at 85K (-188°C). This is far below the environmental sink temperatures of the SCaN Testbed radiators. Therefore heat flux must be added to the radiators to achieve the designated sink thermal environment. IR lamps are commonly used for this purpose.



The heat flux values that the lamps are required to produce was calculated from the SCaN Testbed detailed Thermal Desktop model.

Given the Thermal Desktop generated target heat fluxes for the incident surfaces, a number of lamps, and a mathematical description of the lamp energy output, it was possible to find satisfactory lamp arrays and predict the intensity of the lamps required to produce the necessary fluxes.

The lamp intensity was varied (voltage regulation) to bring the radiator to temperatures predicted by the on-orbit SCaN Testbed thermal model. The starting lamp voltages were based on the STA TVAC test.

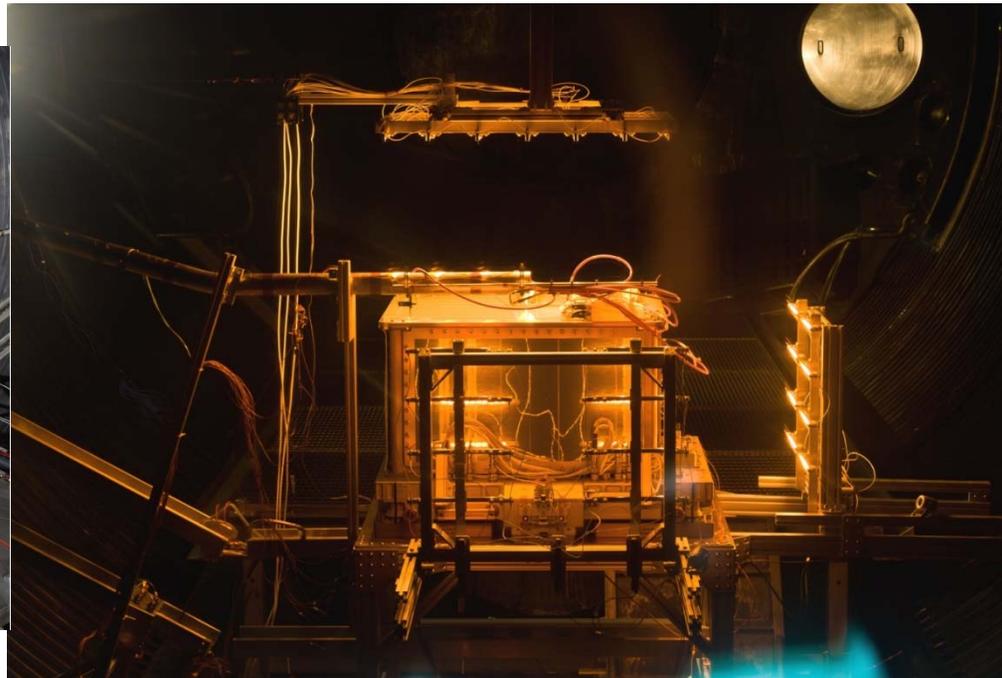


SCaN Testbed TVAC TESTING



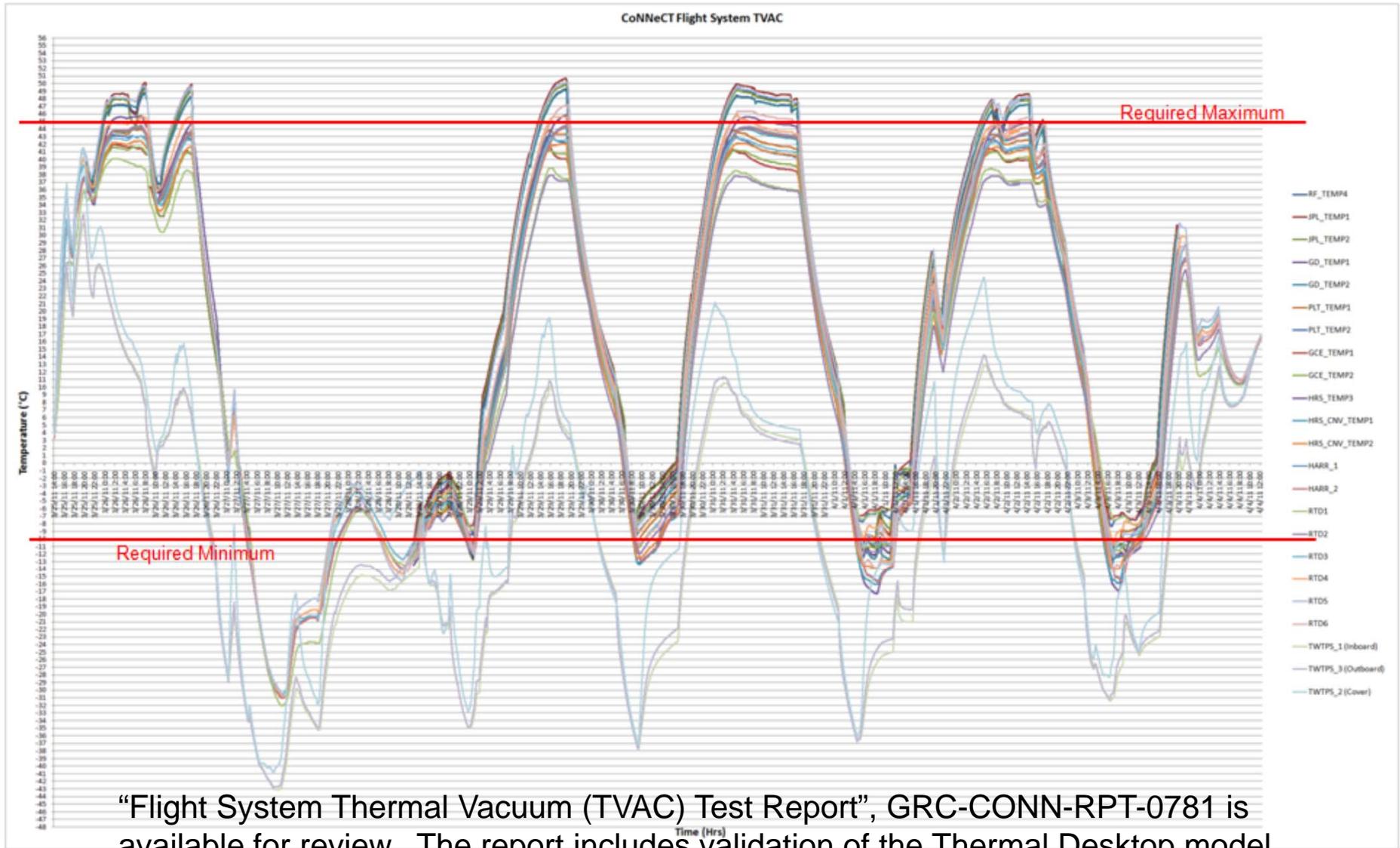
System TVAC Testing (3/25/2011 – 4/4/2011)

The SCaN Testbed Flight System was tested in Vacuum Facility #6 (VF6), in Building 301, at NASA GRC.





SCaN Testbed TVAC TESTING



“Flight System Thermal Vacuum (TVAC) Test Report”, GRC-CONN-RPT-0781 is available for review. The report includes validation of the Thermal Desktop model.



SCaN Testbed ON-ORBIT TRANSFER



The SCaN Testbed Payload was launched on-orbit aboard the JAXA HTV3 on Friday, August 20th, 2012.



The HTV3 docked with ISS Node 2 on Friday, August 27th, 2012. The SCaN Testbed Payload remained inside the HTV3 for about 10 days.



On Monday August 6, 2012, at 3:10 am the 1st part of the on-orbit EVR transfer from the HTV3 to the JEM EF started and was completed 5 hours and 7 minutes later, at 8:17 am, when heater power from JEM-EF to SCaN Testbed Payload was confirmed.

On Tuesday August 7, 2012, at 1:30 am the 2nd part of the on-orbit EVR transfer from the JEM EF to the P3 ELC started:

- 1:30 am: SSRMS with DEXTER takes hold of SCaN Testbed FRAM
- ...
- 7:25 am. The SCaN Testbed Payload is successfully installed and heater power from the P3 ELC to SCaN Testbed Payload is confirmed via telemetry received at GRC Control Room.





SCaN Testbed ON-ORBIT THERMAL MODEL VALIDATION



After the successful installation of the SCaN Testbed payload on the ISS P3 ELC, and for the following four months (August – November 2012) the SCaN Testbed Operations Team went through their detailed on-orbit check out of the payload. During this time, there were several combinations of radios operating with different Beta angles, and other parameters such as ISS altitude, attitude, etc. The SCaN Testbed thermal team reviewed the on-orbit telemetry data and worked with the SCaN Testbed operations team and gathered several on-orbit data “points” for several power configurations and Beta angles, to start the thermal model validation.

Six cases were chosen to be used for the on-orbit TD thermal model validation because they covered a wide range of parameter variation and SCaN Testbed total power dissipations.

The detailed SCaN Testbed Thermal Desktop thermal model was then used to predict temperatures for the six on-orbit cases. Predicted component temperatures were in excellent agreement (within 3 to 4°C) with the on-orbit temperatures.

NO further (after TVAC testing validation) TD thermal model modifications were necessary. The TD thermal model is therefore available to provide SCaN Testbed scientists a set of predicted temperatures that can be used in the future to estimate when a specific “mode” of operations can be performed and what the expected temperatures will be. Since there were no modifications to the TD thermal model, the Analysis Report and all the accompanying information that has been delivered to the team in the past is still adequate and there is no need for an update.