

Technical Capability Upgrades to the NASA Langley Research Center 8 ft. by 15 ft. Thermal Vacuum Chamber

Description and Characterization of the technical capabilities in preparation for space flight qualification testing

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ABSTRACT

The 8 ft. by 15 ft. thermal vacuum chamber (TVAC), housed in Building 1250 at the NASA Langley Research Center (LaRC), and managed by the Systems Integration and Test Branch within the Engineering Directorate, has undergone several significant modifications to increase testing capability, safety, and quality of measurements of articles under environmental test. Significant modifications include: a new nitrogen distribution manifold for supplying the shroud and other cold surfaces to liquid nitrogen temperatures; a new power supply and distribution system for accurately controlling a quartz IR lamp suite; a suite of contamination monitoring sensors for outgassing measurements and species identification; a new test article support system; signal and power feed-throughs; elimination of unnecessary penetrations; and a new data acquisition and control commanding system including safety interlocks. This paper will provide a general overview of the LaRC 8 ft. by 15 ft. TVAC chamber, an overview of the new technical capabilities, and will illustrate each upgrade in detail, in terms of mechanical design and predicted performance. Additionally, an overview of the scope of tests currently being performed in the chamber will be documented, and sensor plots from tests will be provided to show chamber temperature and pressure performance with actual flight hardware under test.

INTRODUCTION

Thermal vacuum chambers (TVAC) are a critical ground test assets used to test and qualify flight hardware, primarily to expose the test article to the space-like vacuum environment, coupled with the extreme hot and cold temperature conditions that can be seen on orbit. To create these conditions in the chamber, a series of specialized pumps are employed to create the vacuum, and then a number of various apparatuses are employed to create the temperature conditions, such as heater plates, shrouds, or fluid controlled conductive cold plates. Thermal vacuum testing is typically complicated, with special ground support equipment (GSE) used to operate the test article, which must pass power and signal feeds through the chamber wall. Additionally, TVAC testing requires an accompanying suite of specialized test equipment, either as an inherent part of the chamber infrastructure, or brought in specifically for a particular test. This accompanying equipment is used for various tasks, such as to monitor the pressure, sense and record temperatures, monitor the molecular species within the chamber, or specialized equipment used in the contamination control discipline. Finally, operational systems within a TVAC environment are highly reliant on specific conditions, so reliability of the operational systems and appropriate constraints must be employed to ensure the overall safety of the operators, the TVAC facility, and the article under test.

NASA Langley Research Center (LaRC) owns and operates a number of TVAC chambers, ranging in volume from $\sim 10 \text{ ft}^3$ to $\sim 750 \text{ ft}^3$, each with various pressure and temperature capabilities. The chamber used most extensively for qualification testing of LaRC's largest test articles, such as International Space Station FRAM based ELC payloads, is the 8 ft. by 15 ft. TVAC chamber (8x15). The 8x15 chamber is a horizontal cylinder that is 8 ft. in diameter, and 15 ft. long with a hemispherical door on one end, and a flat door on the other. Payloads can be inserted or removed from either end using the custom trolley and overhead rail system. The chamber can accommodate payload masses of approximately 1000lbs, but can vary based on GSE and test equipment requirements. The chamber contains three liquid nitrogen (LN2) cooled surfaces: a cylindrical shroud, and two circular plate shrouds on the front and back doors. These shrouds are used to create a cold background scene, with average temperatures of the shroud surfaces approximately -150°C . For heating test articles, the chamber houses a system of quartz infrared (IR) lamps, placed radially around the shroud, and divided into six zones. The IR lamp system is capable of producing approximately 30kW of heat. The pumping system of the chamber is capable of achieving pressures well below 5.0×10^{-6} Torr (mmHg). The moderate size of the chamber, along with the wide temperature capabilities, and relatively inexpensive operation costs, make the 8x15 an excellent asset for testing test articles $< 30 \text{ ft}^3$ (0.75 m^3) or less in volume, and less than 1000 lbm ($\sim 450 \text{ kg}$) in mass. Typical test articles include science instruments, avionics enclosures, and ISS FRAM based payloads. Additionally, the contamination free nature of the chamber makes it an ideal choice for testing sensitive payloads and optics. An overview of the 8x15 test facility is shown in Figure 1.



Figure 1 8x15 TVAC Chamber Test Facility

During preparations and facility readiness assessments to support several space flight projects, numerous deficiencies were noted in the operations, performance, and safety, of the 8x15 chamber that needed to be addressed. These items included, but were not limited to: no over/under temperature safety cutoffs; low reliability of primary temperature control system; lack of temperature performance on control surfaces; outdated controls; no safety interlocks of the primary

vacuum and temperature controls; lack of contamination control equipment; and chamber not rated for unattended operations.

Significant upgrades to the chamber between 2013 and 2015, in preparation for qualification test campaigns of the SAGE III subsystems include a new liquid nitrogen supply and exhaust system for maintain even temperatures of <150°C on the shroud surfaces; upgrade and relocation of the IR Quartz lamp heater system; a suite of contamination monitoring sensors for outgassing measurements and species identification; modern signal and power feed-throughs; new pressure gauges; and a new data acquisition and control commanding system including safety interlocks. The extensive upgrades and refurbishment efforts that the 8x15 underwent will be described in this paper.

Symbols and Acronyms

| | |
|-------|---|
| °C | Degrees Celsius |
| °F | Degrees Fahrenheit |
| 8x15 | 8 ft. by 15 ft. Thermal Vacuum Chamber |
| D-sub | D-Subminiature |
| ELC | ExPRESS Logistics Carrier |
| FRAM | Flight Releasable Attachment Mechanism |
| GN2 | Gaseous Nitrogen |
| GSE | Ground Support Equipment |
| ISS | International Space Station |
| Hg | Mercury |
| HMI | Human Machine Interface |
| LaRC | NASA Langley Research Center |
| LN2 | Liquid Nitrogen |
| NASA | National Aeronautics and Space Administration |
| PID | proportional-integral-derivative |
| QCM | Quartz Crystal Microbalance |
| TQCM | Thermoelectric Quartz Crystal Microbalance |
| TVAC | Thermal Vacuum Chamber |
| V | Volts |
| W | Watts |

8x15 Chamber Description and Instrumentation

The 8x15 chamber resides in Building 1250 at LaRC, and is operated by the Systems Integration and Test Branch, within the Engineering Directorate. The primary chamber specifications are described in Table 1.

Table 1 NASA LaRC 8x15 TVAC Specifications Summary

| Feature | Specification/Description |
|-----------------------------------|--|
| Size | 8 ft. x 15 ft. Cylindrical |
| Useful Volume | ~150 ft ³ |
| Pressure | <5.0x10 ⁻⁶ Torr |
| Temperature Range | -150°C to +150°C |
| Number of Thermocouples | 96 |
| Cooling/Heating Method | Radiative LN2 Shroud; Quartz IR Lamps |
| Auxiliary Temperature Controllers | Six w/ 2-channel output (ON/OFF or linear control) |
| Maximum Test Article Dimensions | 60 in. W x 50 60. L x 36 60 H |

Legacy Hardware

The following sections describe the instrumentation of the 8x15 chamber that was not included in the upgrade and refurbishment effort, but is included here for completeness to provide a complete facility description.

Vacuum Pumps

The 8x15 vacuum system consists of a pair of large mechanical roughing pumps, a shared resource that is part of the facility infrastructure, coupled with four cryogenic pumps, which are 10 in. in diameter. The cryogenic pumps are cooled by remote helium compressors. While this effort did not include new roughing pumps or cryogenic pumps, many upgrades were made in the controls to increase reliability, operation, and safety of the respective systems.

Vacuum Gauges

The chamber is equipped with an Inficon BGC-450 gauge. This gauge eliminates the need for multiple vacuum sensors (hot ion, Pirani, et al), to cover the entire range from ambient pressure to high vacuum.

Electrical Interfaces

The 8x15 chamber is equipped with an ample supply of electrical bulkhead feed-throughs to accommodate both signal and power needs. Six large 10 in. ports are dedicated to electrical interfaces and each port contains a series of either mil-circular or D-subminiature (D-sub) connectors. These connectors can be mixed and matched to meet a variety of test article needs.

8x15 Chamber Upgrades

The following sections describe the numerous upgrades that were incorporated to the 8x15 chamber between 2013 and 2015, in preparation for extensive thermal vacuum testing activities.

Heat Lamp System

The primary heating control of the 8x15 chamber is achieved through a network of quartz IR lamps, arranged radially around the chamber in six independent zones. Each lamp zone is capable of producing approximately 5000W of heat output. While the lamp system operated as designed, there were several safety and configuration needs that were required to be corrected. First, the lamp zones are each powered by a 120V linear power controller, with approximately 40A of current. These power controllers were located in a cabinet in close vicinity to personnel and other instrumentation controllers used by personnel. Therefore, it was imperative that the power controllers be packaged and located in a much safer location. To achieve this, a custom UL listed power supply box was procured and located in an area close to the chamber, but away from personnel during normal test operations. A series of safety interlocks were installed to ensure that the high power system would not operate when certain conditions existed, discussed further in this paper. The IR lamp array and power supply enclosures are shown in figures 2 and 3.

In addition to the relocation of the power supply system, the lamp system chamber bulkhead penetrations were completely rethought and redone. Prior to the upgrade, power was fed to the lamps through a series of twenty-four individual bulkhead conductors, arranged in a similar radial pattern around the chamber. Furthermore, prior chamber pressure performance data indicated that the chamber pressure would normally increase as temperature of the shroud would decrease, a direct inverse of what would be expected. It was later confirmed through RGA analysis and helium leak testing that the Teflon compression fittings used to secure the power feed-throughs would leak as a result of cold soaking. As a result of this discovery, it was decided to remove the twenty-four individual connectors, weld the bungs closed, and install a modern bulkhead feedthrough with multiple power conductors. This feature vastly simplified the power routing, reduced the web of wires around the chamber, resulting in both increases in safety and chamber operational reliability.

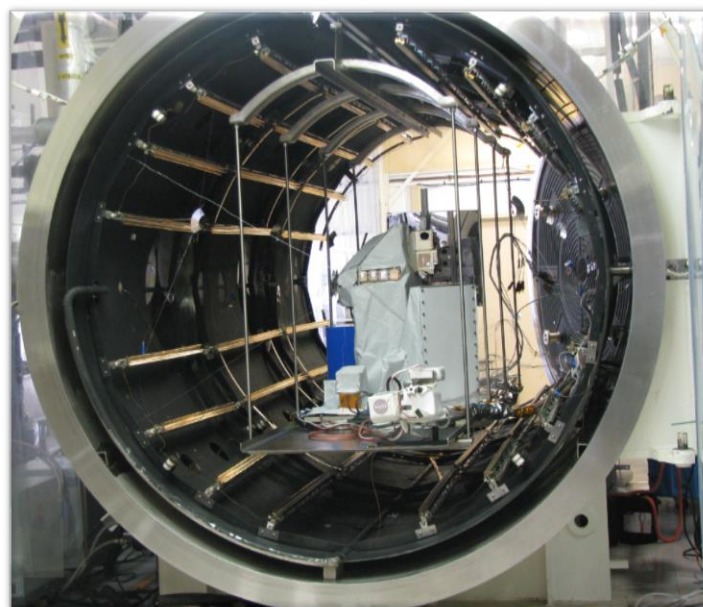


Figure 2 Quartz IR Lamp System of the 8x15 Chamber



Figure 3 Heat Lamp Power Supply Enclosure

Liquid Nitrogen Supply and Exhaust Systems

The 8x15 chamber is cooled using a series of three liquid nitrogen cooled plate-coil shrouds; a primary cylindrical shroud, and two plate shrouds on each door. In normal operations the shrouds are flooded with liquid nitrogen, resulting in a very even and cold background temperature. The LN2 is supplied from a 15,000 gallon LN2 storage Dewar, located just outside the building and with minimum pipe runs to the 8x15 chamber. Prior to the upgrade, the supply side of the shroud consisted of a complicated series of pipe runs and distribution legs, aging solenoids that were not rated for cryogenic use, and lacked the required safety features for pressure systems, such as relief valves and burst disk protection in every isolated section within the pipe network. Additionally, it was shown through test that the piping runs were inadequately sized to provide the volume of LN2 required to supply such a large system, so the shroud temperature performance was inadequate with large temperature gradients from the top to bottom the shroud systems. With the problems of the 8x15 LN2 supply identified, several significant modifications and upgrades were implemented. First, all the piping from the main supply valve was removed and the main supply line was extended and routed into custom designed and built manifold distribution box; a key component of the new supply system. This supply manifold box served as the primary LN2 distribution box that would control flow of LN2 to the three shrouds, as well as additional channels to supply LN2 to surfaces inside the chamber required nitrogen service, such as cold plates, scavenger plates, and other contamination control related systems. The distribution manifold was sized correctly for the required flow volumes, contained cryogenic rated solenoids, and was insulated to prevent icing and condensate build-up. The distribution lines on the downstream side of the manifold were routed and insulated in a manner to minimize pipe runs and provide clearance for personnel. The LN2 distribution manifold enclosure is shown in Figure 4.

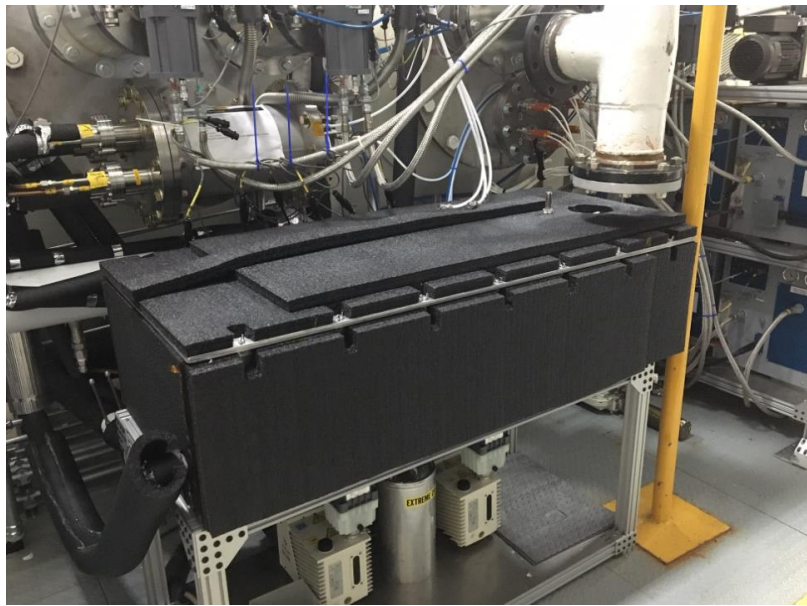


Figure 4 LN2 Supply Manifold Enclosure

For the exhaust side of the system, similar problems existed. The three shroud systems and other LN2 cooled devices, fed into a primary exhaust manifold and then routed to a large pipe that exited the building and ultimately exhausted through a vent stack on the roof of the building. The main problem with the previous exhaust system is that the operational practice of the shroud is to flood with LN2, therefore maintaining a very even cold temperature, top to bottom. This normal operational mode results in a large volume of the exhaust being liquid. Therefore, it was not uncommon for a column of liquid nitrogen to accumulate in the exhaust stack and ultimately spill over, creating an extremely unsafe condition. Additionally, it was discovered during the rebuild process that the main exhaust line had a significant crack, resulting in LN2 leaking down inside the laboratory during operations. To address these issues, first the primary exhaust pipe was replaced with a new stainless steel pipe and insulated properly to prevent icing and condensate. Next, the network of exhaust lines and pipes feeding the primary exhaust line were replaced, if necessary, and outfitted with new insulation. Finally, to address the flow of liquid exhaust, a vaporizer heat exchanger was installed outside the building and adjacent to the LN2 Dewar. All the LN2 exhaust from the 8x15 chamber is routed through this heat exchanger to convert the liquid to gas, and ultimately raise the temperature up to near ambient temperatures. The gas then flows harmlessly out of a vent stack.

Temperature control of the shrouds is achieved via a commercially available external proportional-integral-derivative (PID) temperature controller. Temperature set points and desired ramp rates for each shroud can be made manually at the controller, or via control software on an external PC (National Instruments LabView, for example). A temperature plot of several thermocouples evenly spaced across the shroud surface is shown in Figures 5. Results show very even temperatures at near LN2 temperatures.

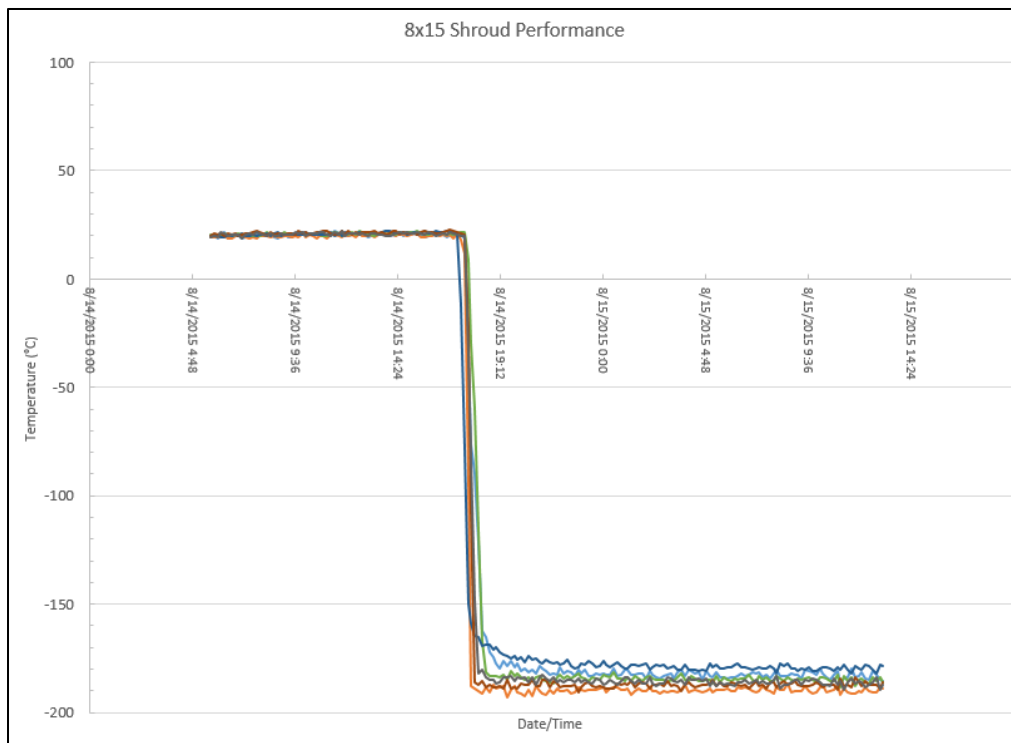


Figure 5 Shroud Performance

TVAC Control Systems

Overview and philosophy

Another key component of the 8x15 chamber upgrade and refurbishment effort was the redesign and implementation of the chamber control systems. The control system is comprised of the hardware (controllers, switches, relays, indicators, etc.) and software needed to operate the two primary systems of the TVAC chamber: the vacuum control system, and the temperature control system. Throughout the design phase of the refurbishment effort, special care was taken to ensure that the final design would be simple, reliable, safe, and low-maintenance, with an emphasis on having the capability for unattended operations. With this in mind, a general control system philosophy was implemented to both the vacuum and temperature controls that incorporated more hardware and less software. The driving factors to this approach included high reliability of available switches and relays, a hard-wired approach to safety interlocks, minimal software effort, and minimal maintenance and upkeep. While the chamber system does incorporate software, it is employed as a means of command and data handling only; no control algorithms for control surface temperatures, valve, or solenoid control is processed within the software. The primary function of the software is to: send commands to the external controllers, receive state, health, and status back from the controllers; collect and log data from the chamber data acquisition system. The primary advantage to this approach is that the risk of chamber failure in the event of a software crash is minimized or eliminated. In the current state of the upgraded chamber, the only risk to a software or computer crash is that chamber data will not be recorded; all systems are designed to 'stay the course' if the software fails, and the controller commands do not change until either the software is brought back online and commanded, or manually commanded at the controller interface. As a precaution, however, a system was designed and implemented at the control panel to monitor the hardware connectivity to the software interface. In the event of a software crash, an audible alarm is activated, and the user can take appropriate action. With this design philosophy

in place, it is believed that test articles could safely reside in the chamber at a hot or cold condition in an unattended mode, meaning no personnel are present at the chamber. This is particularly advantageous to saving costs during long-duration contamination bake outs that can last on the order of weeks for sensitive hardware. The vacuum and temperature control panels are shown in Figure 6 and 7.



Figure 6 8x15 Temperature Control Panel



Figure 7 8x15 Vacuum Control Panel

Vacuum Control System

The vacuum control system of the 8x15 chamber is designed to be operated from a series of mechanical switches and relays to operate the various pumps and gate valves. This includes the roughing pump gate valve, four cryogenic pump gate valves, and the nitrogen vent valves. During the design phase of the effort, it was chosen to incorporate a hardware approach to this system, as opposed to a software based Human Machine Interface (HMI.) Special care was taken in this system to evaluate and design a series of safety interlocks. The goal of the interlock design is to prevent accidental opening or closing of certain valves when a corresponding condition exists. For example, when the cryogenic pumps are operating and pumping the chamber to a high vacuum, the gate valve on the roughing line is not allowed to open because this would cause a rapid vent of the chamber and possibly back stream oil to the chamber, which could result in damaged test articles and equipment; this event could also cause damage to the cryogenic pumps. To achieve the desired interlocks, solid state relays were used to create a series of Boolean operators to match the designed interlock matrix. Extensive testing of the interlock design has shown it to operate as prescribed, increasing the overall safety of the system from an accidental operator error. As an added feature to the system, test jumpers were designed and implemented at the rear of the control

panel to override the interlock safeties; a useful tool when testing systems during non-test time, such as replacing valves and other maintenance tasks.

Temperature Control System

In addition to the primary control systems, the 8x15 chamber contains a suite of auxiliary temperature controlled systems. These items include: up to twelve independent heater surfaces, a contamination scavenger plate, a contamination cold finger, and two cryogenic cold plates for Quartz Crystal Microbalances (CQCM). The scavenger plate, cold finger, and CQCM cold plates are cooled with LN₂, and have no method to heat. Additionally, many tests require additional heated plates to achieve desired temperature scenes. These surfaces are typically heated with resistive heaters, and have no method to cool. The 8x15 has equipment for 12 heater zones to give test users ample options for locating independent localized heater plates around the test article. This wide range of heating and cooling needs for temperature control in the 8x15 chamber results in needing a robust method of control. In the design phase of the effort, it was chosen to use a commercially available PID temperature controller that could be commanded from the either the front panel of the unit, or remotely via a control software program. As in the vacuum system, external hardware control was desired over software control to promote reliability and simplicity. Additionally, a suite of spare identical temperature controllers is warranted to accommodate special test equipment as needed for test such as radiative heater plates or additional conductive platens. A ten-channel temperature controller suite is incorporated using identical controllers and interfaces to accommodate additional special test equipment.



Figure 8 8x15 Auxiliary Heater Control System and Power Supplies

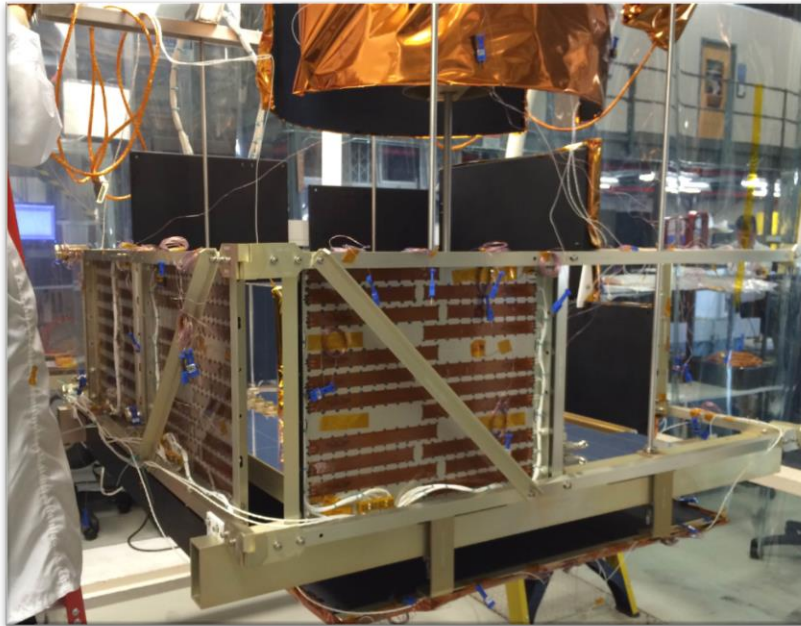


Figure 9 8x15 12-Channel Heater Plate System

Contamination Monitoring Suite

A suite of thermoelectric quartz crystal microbalance (TQCM) contamination sensors was procured for the 8x15 chamber to meet test requirements for future TVAC tests. Test hardware requirements are generated by the projects, based on the number of locations that are required during the outgassing certification phase of a TVAC test. Based on these requirements, the 8x15 chamber was upgraded to be capable of operating four sensors in the chamber simultaneously. To support the sensors and allow maximum flexibility in placement and pointing, truss structures or robust mounting brackets were built inside the chamber, along with custom mounting fixtures, that the TQCM sensors attach to. The mounting fixture with TQCMs connected is shown in Figure 10.

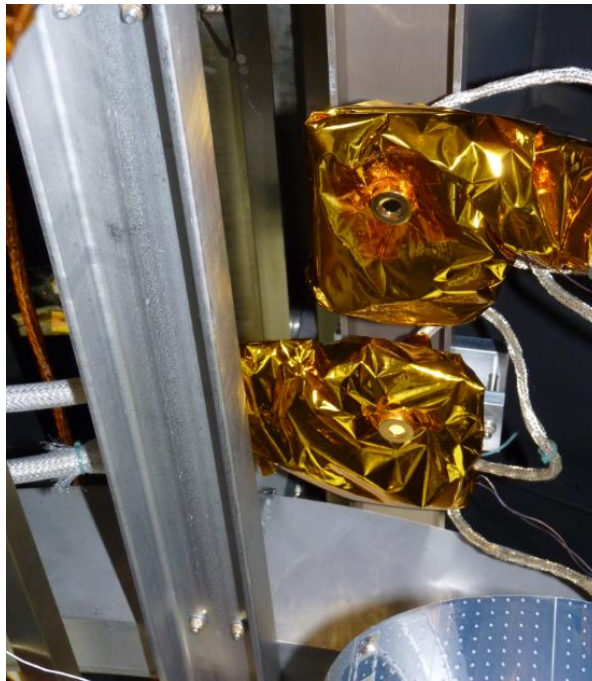


Figure 10 Internal Support Structure with QCM sensors mounted

In addition to purchasing and installing TQCM sensors, a significant number of chamber infrastructure additions must be considered in order to operate the sensors. First, each TQCM has an electrical harness that must connect through the chamber wall. Therefore, a special interface plate was procured to accommodate the four electrical feed-throughs for the corresponding TQCM sensors. Additionally, for TQCM sensors to operate correctly individual cold plates must be provided to mount the TQCM body to, and the cold plate must be actively cooled during test. This cooling can be achieved a number of ways, but for the 8x15 chamber, it was elected to cool the cold plates using cold nitrogen gas via small gas chiller units that take room temperature gaseous nitrogen from the facility supply, cool, and circulate through the cold plate, and then exhaust to the atmosphere outside the building. This method of cooling was chosen primarily to reduce risk of leaking potentially dangerous heat transfer fluid into the chamber in the event of a leak, especially during unattended operations. Also, the gas chillers purchased cool using thermoelectric cooling technology and have a high reliability in that the only moving part is the cooling fan. Pressure to push the gas through the cold plate is achieved from the facility nitrogen supply. As with the electrical bulkhead connectors, a special interface plate was procured to accommodate the four nitrogen gas feed-throughs at the chamber wall.

Conclusion

In conclusion, the NASA Langley 8 ft. by 15 ft. TVAC chamber was upgraded between 2013 and 2015. Significant modifications to the chamber included: new LN2 supply and exhaust system for circulating nitrogen through the chamber; an upgraded power supply system for operating the IR quartz lamp system; a suite of contamination monitoring sensors for outgassing measurements and species identification; signal and power feed-throughs; new pressure gauges; and a new data acquisition and control commanding system including safety interlocks. Additionally, the chamber modifications were upgraded in a manner to have a key capability of unattended operation. When all modifications were complete, the upgrade effort was concluded with a final acceptance test in which all systems, included safety systems, were functionally checked against design parameters, and performance of the chamber was characterized. This included verifying pressure performance,

operation of temperature controlled surfaces, and operation of the contamination monitoring and measurement system. This test was completed successfully and the chamber is presently fully operational. The overwhelming success of this effort has led to numerous successful thermal vacuum verification test efforts, and to date, the chamber continues to operate in reliable and user-friendly manner.