Technical Capability Upgrades to the NASA Langley Research Center 6 ft. by 6 ft. Thermal Vacuum Chamber

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

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ABSTRACT

The 6 ft. by 6 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 thermal conditioning unit for controlling shroud temperatures from -150°C to +150°C; two horizontal auxiliary cold plates for independent temperature control from -150°C to +200°C; 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. This presentation will provide a general overview of the LaRC 6 ft. by 6 ft. TVAC chamber, an overview of the new technical capabilities, and 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.

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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.

NASA Langley Research Center (LaRC) owns and operates a number of TVAC chambers, ranging in volume from ~10 ft^3 to ~750 ft^3, each with various pressure and temperature capabilities. The chamber used most extensively for current qualification testing, particularly for the Stratospheric Aerosol and Gas Experiment III on International Space Station (SAGE III on

ISS, or SAGE III), is the 6 ft. by 6 ft. TVAC chamber (6x6). The 6x6 chamber is a horizontal cylinder that is 6 ft. in diameter, and 6 ft. long with a hemispherical single door and end cap. The chamber contains a gas heated/cooled cylindrical shroud, circular plate shrouds on the back wall and front door, and finally, a large horizontal surface, referred to as the main platen, for mounting hardware. The shroud and main platen are coupled together and temperature controlled using a large nitrogen gas conditioner, capable of temperatures from -150°C (-238°F) and in excess of +150°C (302°F). The pumping system of the chamber is capable of achieving pressures well below 5.0x10-6 Torr (mmHg). The moderate size of the chamber, along with the wide temperature capabilities, and relatively inexpensive operation costs, make the 6x6 an excellent asset for testing test articles <30 ft^3 (0.75 m^3) or less in volume, and less than 250 lbm (~115 kg) in mass. Typical test articles include small science instruments and avionics enclosures. Additionally, the contamination free nature of the chamber makes it an ideal choice for testing sensitive payloads and optics. An overview of the 6x6 test facility is shown in Figure 1.

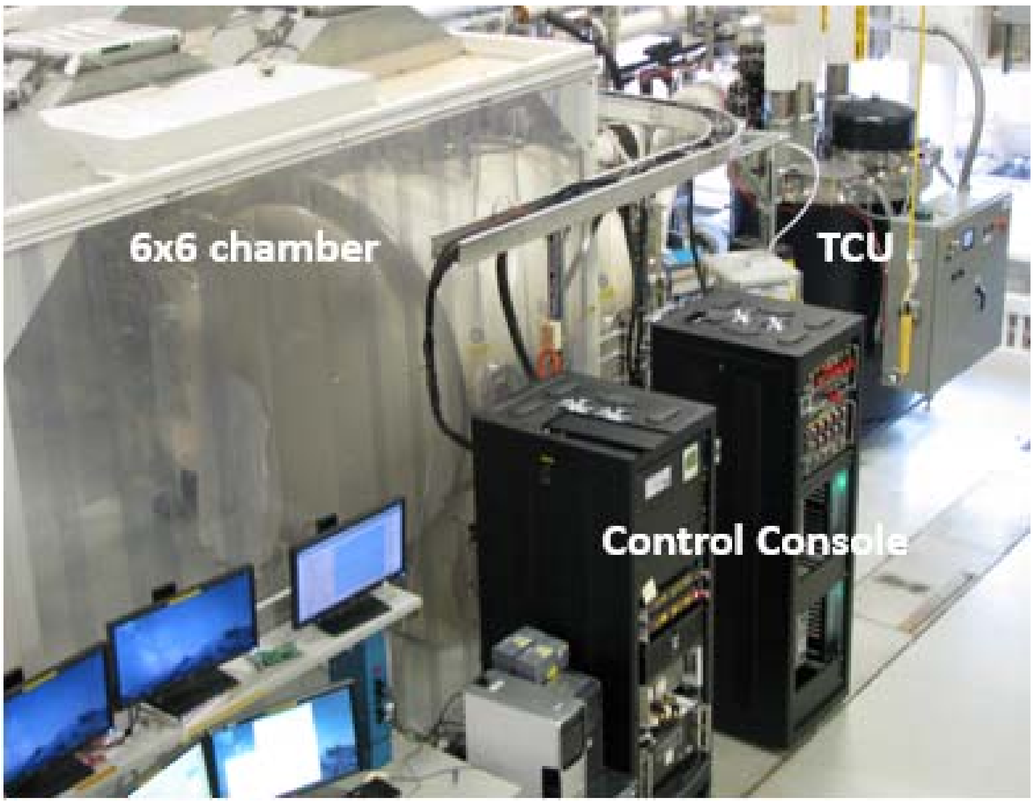

Figure 1 6x6 TVAC Chamber Test Facility

During preparations and facility readiness assessments to support the SAGE III on ISS Project, several deficiencies were noted in the operations, performance, and safety, of the 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 multiple conductive cold plates; 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 2012 and 2014, in preparation for qualification test campaigns of the SAGE III subsystems include a new nitrogen thermal conditioning unit for controlling shroud temperatures from -150°C to +150°C; two horizontal auxiliary cold plates for independent temperature control from -150°C to +200°C; 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. Additionally, as new systems are described, accompanying data will be presented to show pressure and temperature performance of the various control systems. The extensive upgrades and refurbishment efforts that the 6x6 underwent will be described in this paper.

Symbols and Acronyms

°C	Degrees Celsius
°F	Degrees Fahrenheit
6x6	6 ft. by 6 ft. Thermal Vacuum Chamber
D-sub	D-Subminiature
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
SAGE III	Stratospheric Aerosol and Gas Experiment III
TCU	Temperature Control Unit
TQCM	Thermoelectric Quartz Crystal Microbalance
TVAC	Thermal Vacuum Chamber
V	Volts
W	Watts

6x6 Chamber Description and Instrumentation

The 6x6 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 6x6 TVAC Specifications Summary

Feature	Specification/Description
Size	6 ft. x 6 ft. Cylindrical
Useful Volume	~36 ft^3
Pressure	<$5.0x10^{-6}$ Torr
Temperature Range	-150°C to +150°C
Number of Thermocouples	48
Cooling/Heating Method	Conductive Cold Plates, Radiative Shroud
Auxiliary Temperature Controllers	Six w/ 2-channel output (ON/OFF or linear control)
Maximum Test Article Dimensions	35 in. W x 50 in. L x 36 in. H
Mounting Bolt Pattern	¼”-20 on a 3 in. by 3 in. grid

Instrumentation

The following sections describe the instrumentation of the 6x6 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 6x6 vacuum system consists of a pair of large mechanical roughing pumps, a shared resource that is part of the facility infrastructure, coupled with two cryogenic pumps, which are 10 in. in diameter. The cryogenic pumps are cooled by a remote helium compressor.

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 6x6 chamber is equipped with an ample supply of electrical bulkhead feed-throughs to accommodate both signal and power needs. Three large 10 in. ports are dedicated to electrical interfaces and each port contains a series of D-subminiature (D-sub) connectors. These connectors can be mixed and matched to meet a variety of test article needs. The electrical interfaces are shown in Figure 2.

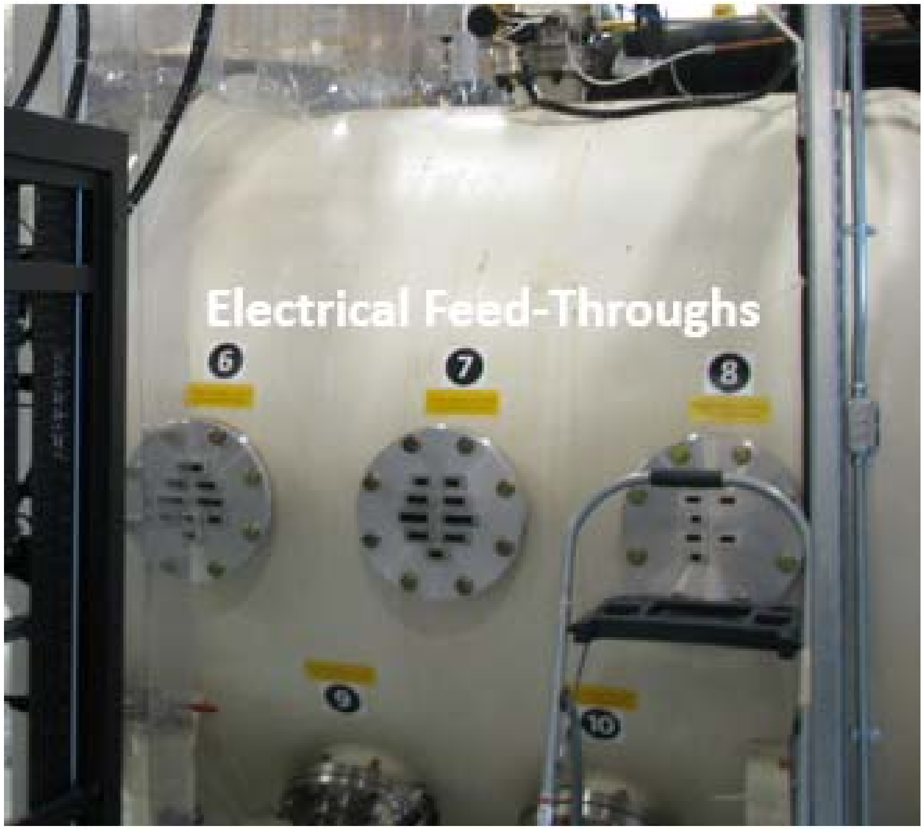

Figure 2 6x6 Chamber Showing Electrical Interface Plates with D-sub connectors

6x6 Chamber Upgrades

The following sections describe the numerous upgrades that were incorporated to the 6x6 chamber between 2012 and 2014, in preparation for extensive thermal vacuum testing activities on the SAGE III on ISS Project.

Temperature Control Unit

The temperature control of the chamber shroud and main platen is achieved by recirculating conditioned, high pressure gaseous nitrogen through the system. Prior to the upgrade, this system consisted of a piecemealed apparatus in which liquid nitrogen (LN2) was injected to an electric blower housing and a 10 kW inline heater on the supply pipe to the chamber was used to heat the gas to the temperature set-point. This gas would recirculate through the chamber, and control software running on an external PC would command the LN2 injection and heater settings to maintain steady temperature conditions. While this system worked with reasonable success, it did pose several key disadvantages. From a performance perspective, the blower did not circulate gas at a high enough flow rate, and large temperature gradients across the shroud were experienced. Additionally, the unit experienced a high rate of failure and repairs were needed on a regular basis, which increased downtime and operating costs of the chamber. However, most notably, from a safety perspective, the system did not have the ability to protect itself from a runaway hot or cold condition, which posed a safety risk in that a fire could manifest in the pipe insulation if temperatures were exceeded, a situation that was realized on at least one occasion.

During the refurbishment of the 6x6 chamber, a new Temperature Control Unit (TCU), shown in Figure 3, was procured. The TCU provides 300 CFM of conditioned nitrogen gas through the 6x6 shroud and main platen, and is capable of achieving chamber temperature between -150°C and +150°C. Additionally, the system is equipped with a sophisticated control system that monitors system parameters and safes the system in the event an anomaly is experienced, such as a loss of facility chilled water or nitrogen. Additionally, the system is protected from exceeding both user-defined hot and cold limits using separate, independent temperature monitors attached to independent temperature sensors. This feature is a key advantage to protecting test hardware from over testing or damage, and is one of the key components to obtaining certification for unattended operation. The even temperatures achieved with the use of the TCU are show in plot in Figure 4.

Figure 3 NASA Langley 6x6 TVAC Temperature Conditioning Unit

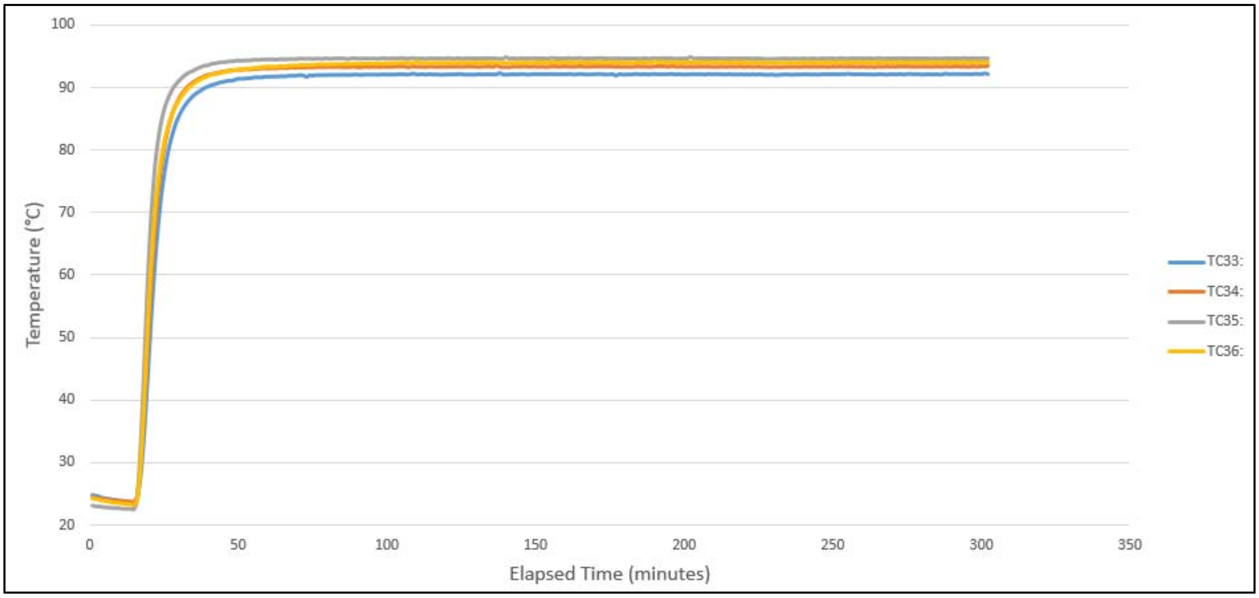

Figure 4 6x6 Shroud Temperature Performance of the 6x6 Chamber Shroud with TCU During a Hot Soak

Conductive Cold Plates

As mentioned previously, the SAGE III on ISS Project requires multiple independent temperature zones in order to test coupled subsystems at different predicted temperatures (i.e. a science instrument connected remotely to an avionics box, in which cold temperature predictions are different between the two.) The project requirements dictated that the chamber have a radiative hot or cold shroud, and two horizontal conductive surfaces with approximately 550 in^2 each of surface area. This requirement led engineers to design and procure two additional cold plates to be placed on top of the main platen. These cold plates were procured in the spring of 2014. The platens were designed and manufactured to maintain test article temperatures between -150°C and +200°C with an assumed maximum test article heat load of 400 W. The design maximum heating and cooling rates were specified to be between three and five degrees Celsius per minute, based on a parasitic heat load of 100 W. Steady-state temperature gradients across the cold plate acreage was specified as +/-5°C in either the cold or hot condition. To prevent conductive heat loss through the bottom of the cold plate to the chamber main platen, the mounting feet of the plates are made from Teflon, a material with low thermal conductivity. The two auxiliary cold plates are shown installed in the chamber in Figure 5.

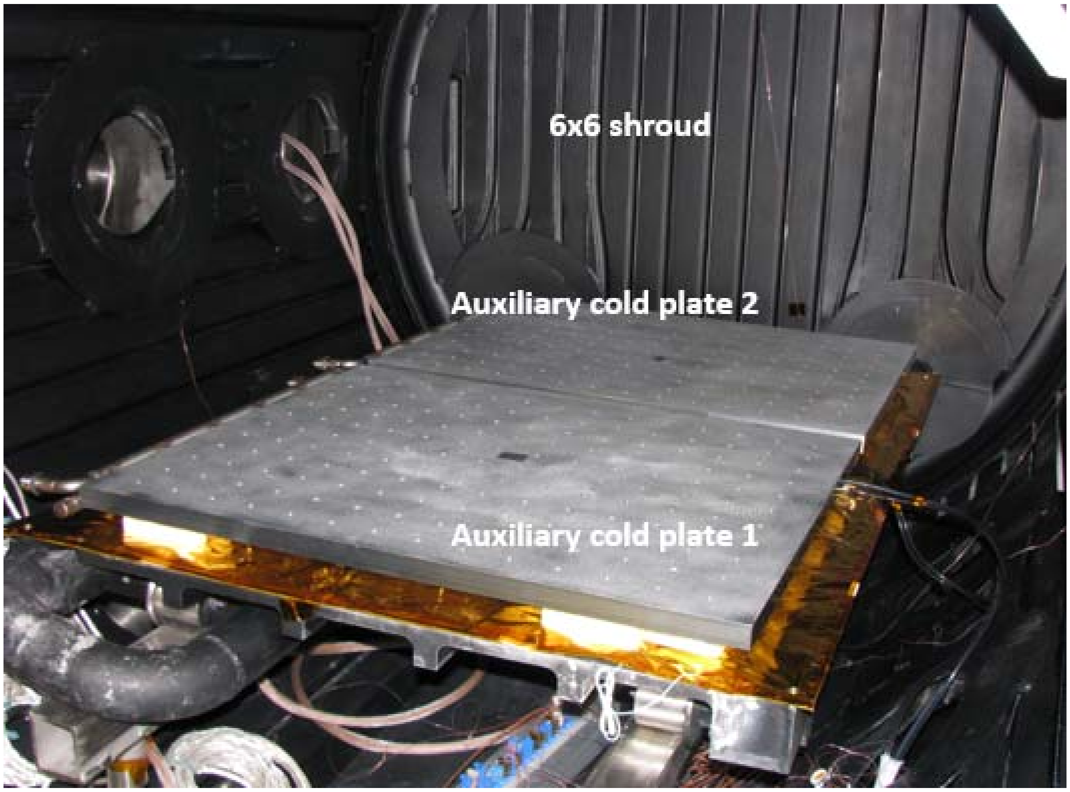

Figure 5 6x6 Auxiliary Cold Plates Installed in Chamber on Top of Main Platen

Cooling of the cold plates is achieved using liquid nitrogen, pumped in from a facility supply reservoir, and routed to the cold plate through six loops, press fit in to the aluminum body, in a cross flow fashion. With only the parasitic heat load of the chamber walls, the cold plates are capable of cooling to approximately -170°C at approximately 3°C/min.

For heating of the cold plates, eleven 20 in. long cartridge heaters are press fit in between, and parallel to, the cooling coils, providing a total heat output of approximately 3000 W at 120 V supply voltage. To power the heaters, external variable power supplies were procured and placed on dedicated 30 amp facility power circuits. The plate has been demonstrated to achieve 200°C at approximately 4°C/min.

Temperature control of the cold plates is achieved via a commercially available external proportional-integral-derivative (PID) temperature controller. Temperature set points and desired ramp rates for the cold plates can be made manually at the controller, or via control software on an external PC (National Instruments LabView, for example). Temperature plots of several thermocouples evenly spaced across the cold plate surface, showing both hot and cold temperature performance, are shown in Figures 6 and 7. Ramp rates between three and five degrees Celsius per minute are also shown in Figures 6 and 7, and the temperature gradient across the acreage meets the design specifications.

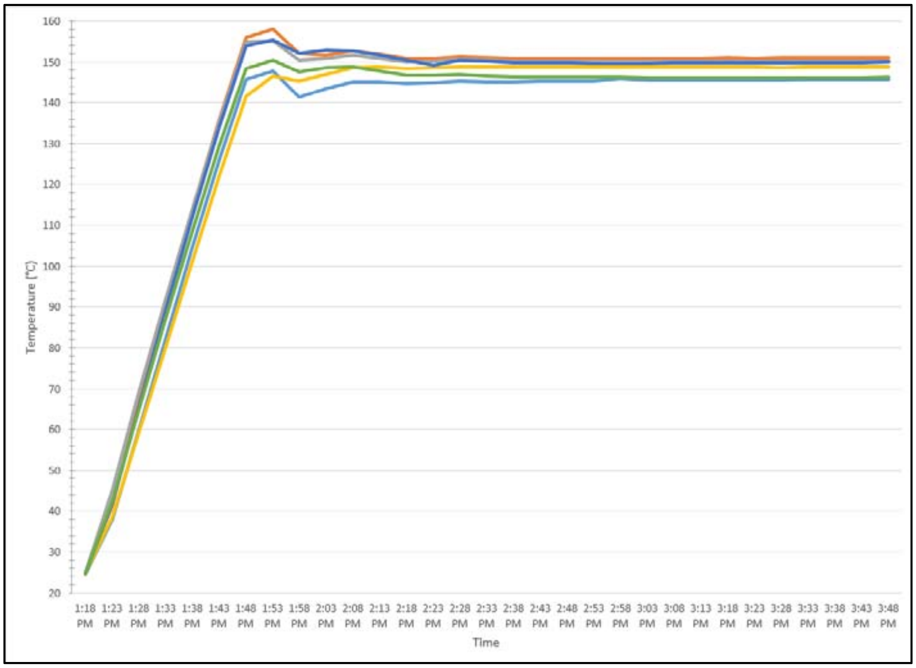

Figure 6 Auxiliary Cold Plate, Hot Performance

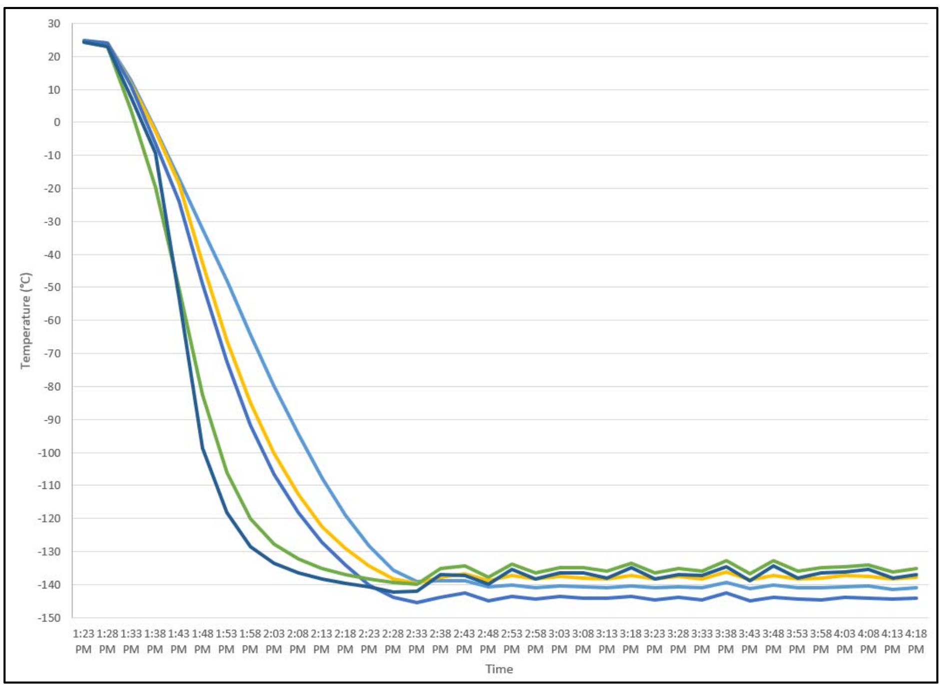

Figure 7 Auxiliary Cold Plate, Cold Performance

TVAC Control Systems

Overview and philosophy

Another key component of the 6x6 chamber upgrade and refurbishment effort was the redesign and implementation of the 6x6 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, 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 8.

Figure 8 6x6 Vacuum and Temperature Control Panels

Vacuum Control System

The vacuum control system of the 6x6 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, two 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 rouging 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 TCU unit, the 6x6 chamber contains a suite of additional temperature controlled systems. These items include: the two auxiliary platens described in the previous section, a contamination scavenger plate, and a contamination cold finger. The auxiliary platens are cooled by LN2 and heated with resistive cartridge heaters. The scavenger plate and cold finger 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 wide range of heating and cooling needs for temperature control in the 6x6 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, at 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. The ten temperature controllers and power supplies for the auxiliary cold plates is shown in Figure 9.

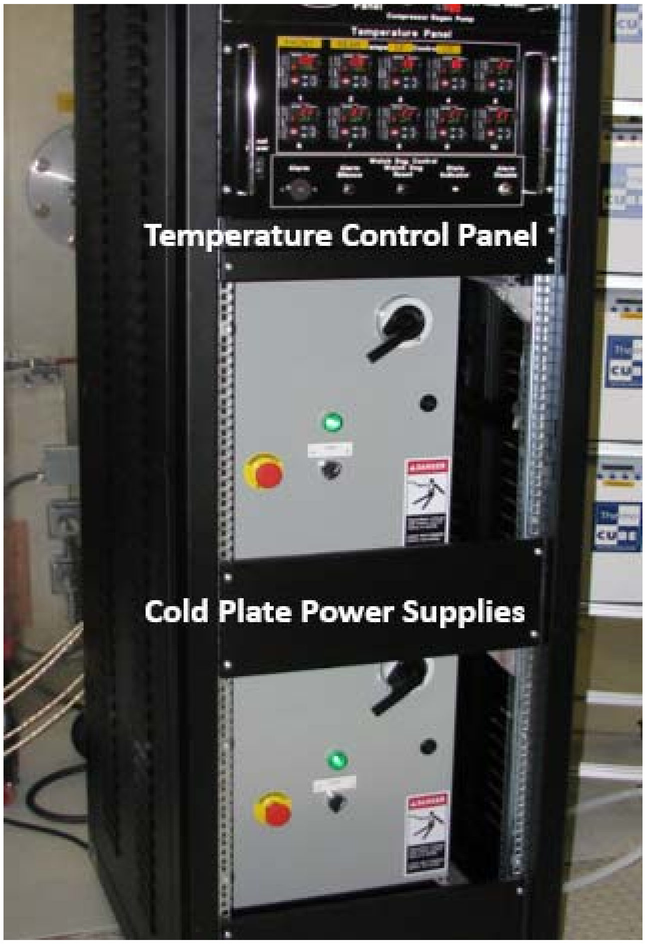

Figure 9 6x6 Temperature Control System with Auxiliary Cold Plate Power Supplies

Contamination Monitoring Suite

A suite of thermoelectric quartz crystal microbalance (TQCM) contamination sensors was procured for the 6x6 chamber to meet test requirements for the SAGE III on ISS Project. Test hardware requirements were generated by the project based on the number of locations that are required during the outgassing certification phase of a TVAC test. Based on these requirements, the 6x6 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, a truss structure was 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.

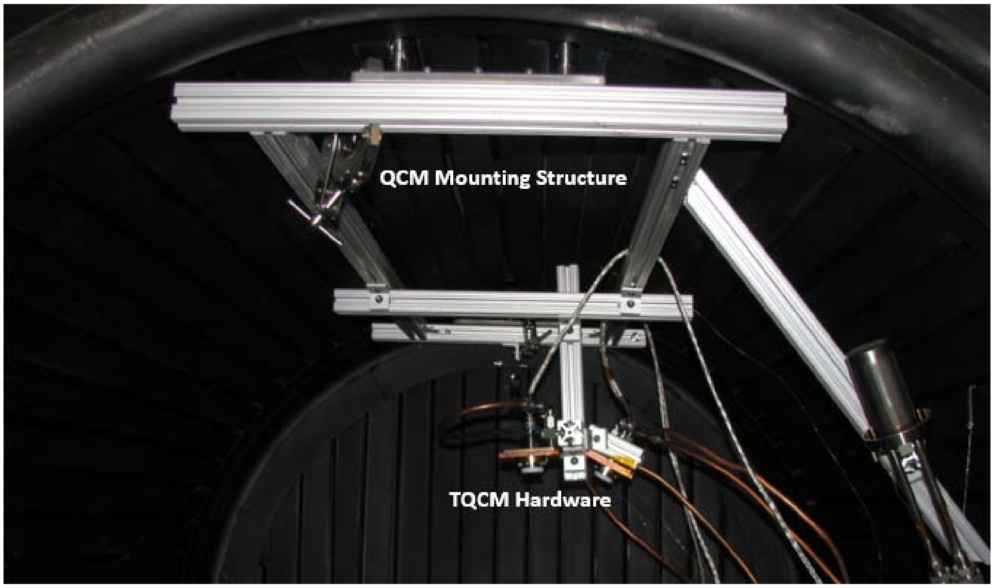

Figure 10 Internal Support Structure with QCM sensors mounted

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 6x6 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 6 ft. by ft. TVAC chamber was upgraded between 2012 and 2014. Significant modifications to the chamber included: a new nitrogen thermal conditioning unit for controlling shroud temperatures from -150°C to +150°C; two horizontal auxiliary cold plates for independent temperature control from -150°C to +200°C; 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 discussions on the upgrade and refurbishment of another thermal vacuum chamber at NASA LaRC, which is planning to commence in late 2014.