

Modernization of NASA Johnson Space Center’s Chamber A to support Cryogenic Vacuum Optical Testing of the James Webb Space Telescope (JWST)

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ABSTRACT

NASA is the mission lead for the James Webb Space Telescope (JWST), the next of the “Great Observatories”, scheduled for launch in 2021. NASA is directly responsible for the integration and test (I&T) program that culminated in an end-to-end cryo vacuum optical test of the flight telescope and instrument module in Chamber A at NASA Johnson Space Center. Historic Chamber A is the largest thermal vacuum chamber at Johnson Space Center and one of the largest space simulation chambers in the world. Chamber A has undergone a major modernization effort to support the deep cryogenic, vacuum and cleanliness requirements for testing the JWST. This paper describes the upgrades to the Chamber A facility: Thermal Shrouds, Helium Refrigeration, Liquid Nitrogen System, High Vacuum System, Clean Airflow System, and Utilities.

INTRODUCTION

The NASA Space Environment Simulation Laboratory (ESL) is home to National Historic Landmark Chambers A & B at Johnson Space Center. The ESL was designed, built, and used to conduct thermal-vacuum testing for all manned spacecraft of the Apollo-era.

Chamber A is the largest of the JSC test facilities at 65 ft outer diameter, 120 ft end-to-end height and 40 ft diameter payload door. When commissioned in 1965, Chamber A represented the state of the art in thermal vacuum testing. Features included eighteen diffusion pumps, LN2 cooled shrouds, 20K cryopanel, solar simulation, 180 deg rotating “lunar plane” floor, and human-rated systems. Chamber A earned its landmark status in testing the Apollo Command Service Module.

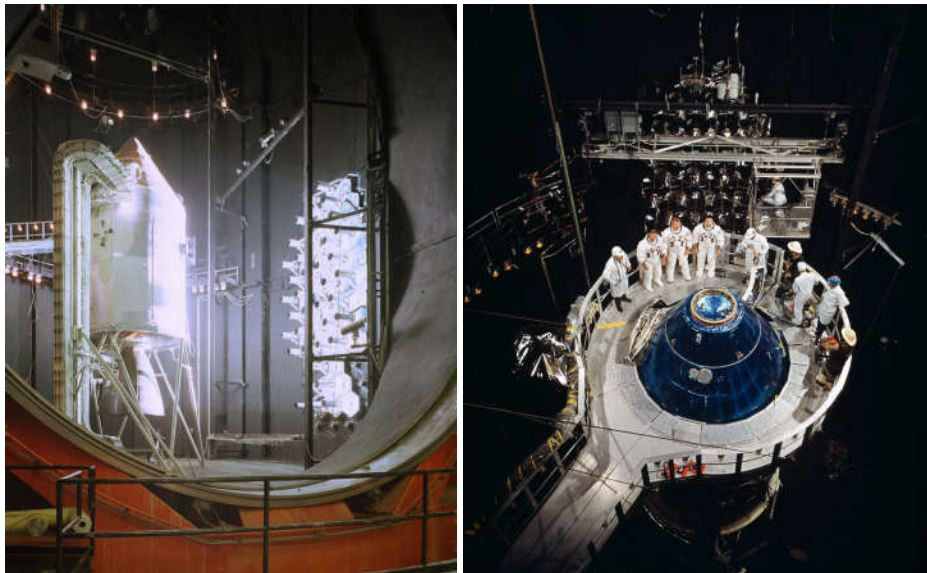


Figure 1. Apollo Service and Command testing in Chamber A

In 2006, Chamber A was selected to perform the end-to-end cryo vacuum optical test for the JWST Optical Telescope Element (OTE) and Integrated Science Instrument Module (ISIM) known as OTIS (=OTE+ISIM). NASA JSC initiated an extensive modernization project of SESL facility systems and Chamber A to meet the demanding test requirements for the JWST program.

This required a paradigm shift in priorities for facility operations. Chamber A was designed for short duration (weeks), manned low Earth orbit (LEO) environmental simulation testing for the Apollo program. JWST would require Chamber A to provide long duration (3+ months), simulated deep space (Sun-Earth Lagrange Point 2) environment for optical testing. NASA JSC examined SESL and Chamber A system by system for modernization with focus on system efficiency, long duration reliability, contamination control, vibration mitigation and achieving the colder environment. Modifications to the facility included the removal of solar simulation, installation of new LN2 shrouds in place of solar, conversion from a LN2 forced flow to LN2 thermo-siphon system, new Helium thermal shrouds and supporting 20K Helium Refrigeration system, a new clean High Vacuum system, a new clean Airflow system and modern controls.

THERMAL SHROUDS

Chamber A was built with 150 solar simulator nozzles extending along the full height of the north side of the cylinder. The top head of Chamber A included 43 solar simulator nozzles. All legacy Chamber A solar simulation capability was removed to be covered with new LN2 thermal shrouds in order to meet JWST thermal environment requirements. The solar ASA flange nozzles were either blanked off or repurposed for test data, telemetry and new cryogenic distribution interfaces. The rotating LN2 floor drive mechanism was removed and blanked off as it was a long-standing source of hydraulic oil contamination and leakage within the chamber.

External to Chamber A, solar infrastructure was demolished and replaced with platforms to access the penetrations. Internal to Chamber A, the new LN2 shrouds completed the shielding for the new internal 20K Helium thermal shrouds providing the deep space thermal environment for JWST.

The new Helium shrouds were sized to accommodate a fully deployed JWST Optical Telescope Element and its associated optical Ground Support Equipment (GSE) at proper focal lengths. This required Helium shroud dimensions of approximately 13.7 m (45 ft) in diameter by 19.8 m (65 ft) tall with a payload door 12 m (40 ft) high by 10.7 m (35 ft) wide. The Helium shrouds were designed to meet JWST program requirements for optical density (2-bounce), vacuum conductance, thermal environment, interfaces to GSE, and top-down air flow over the telescope.

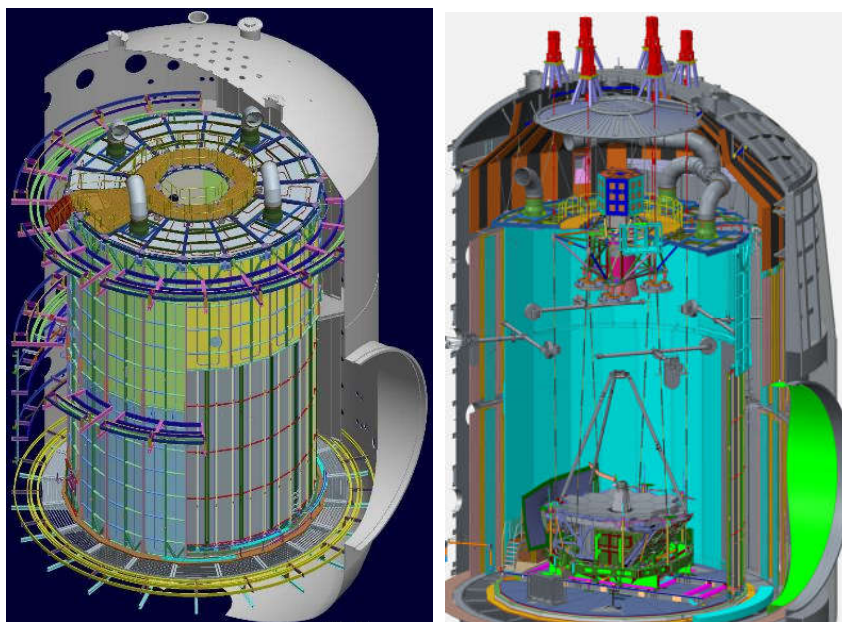


Figure 2: Chamber A Helium Shroud

Jacobs CLG developed the design of the Helium shrouds and oversaw the fabrication, assembly and installation at NASA JSC. The Helium shrouds were designed to meet program thermal requirements for steady-state temperature, uniformity and heat loads. The ceiling and cylindrical wall shrouds were suspended from the chamber top dome by 316L SS rods. The Helium floor was supported above the LN2 floor by G-10 isolating blocks. Lords “Z307” paint was selected as the high emissivity coating for interior surfaces due to its emissive properties at low temperature and durability for cleaning. Special shroud features include the barn style rolling doors and payload rails to allow full access through the chamber’s 40-ft door. Helium shroud instrumentation includes over 200 silicon diodes to read temperatures from 400K to 10K.

The Helium shrouds (ceiling, cylindrical walls, & floor) were fabricated in three shops across the country and integrated in Chamber A in modular sections. Special lifting fixtures were fabricated for shroud assembly inside Chamber A with the four 25-ton hoists accessible through ports in the top head of the chamber. Interior distribution piping required seven Helium shroud zones and eight GSE cooling zones each supplied by a cryogenic control valve from the Helium Refrigeration System. Cryogenic interfaces to GSE cooling were made with ConFlat flanges and VCR fittings inside Chamber A.

VACUUM SYSTEM

Chamber A was originally equipped with eighteen 35-inch diameter diffusion pumps each connected by 48-inch diameter hydraulically operated right-angle valves installed along the full height of the west side of the cylinder. The diffusion pumps were backed by a parallel set of blowers and mechanical pumps. JWST optical testing required the removal of the diffusion pump system and replacement with a clean high vacuum system to eliminate the source of pump oil contamination inside the Chamber.

The eighteen Chamber A diffusion pump nozzles were modified to accept a 48-inch ASA flange. Twelve 48-inch cryogenic adsorption pumps and gate valves were installed in rows of four on Chamber A 1st, 3rd and 5th levels. Six 14-inch turbo molecular pumps and gate valves were installed on 48-inch ASA adapter plates on Chamber A 2nd level. The new turbo molecular pumps utilized the original backing system with the addition of a LN2 baffle to mitigate the possibility of back streaming mechanical pump oil.

The cryo pumps are designed to achieve high vacuum (1e-6 Torr) for all Chamber modes of operation from ambient temperature testing through cooldown, steady-state, warm-up and bake-out. The cryo pumps crossover pressure is 2 mTorr for Chamber A.

The turbo molecular pumps are essential in achieving crossover to high vacuum and pumping non-condensable gases in particular Helium from the chamber. JWST pathfinder testing required the introduction of Helium gas into the chamber for Free-Molecular Heat Transfer (FMHT) in order to accelerate cooldown and warm-up of the test article. The turbo pumps were selected to remove the free-molecular Helium to return the chamber to high vacuum conditions within 4 hours.

The entire high vacuum system (cryo pumps, turbo pumps, backing system, instrumentation, utilities, & controls) was placed on facility emergency power to protect the JWST test article upon loss of facility power. Ultimately the facility roughing system as well was backed by emergency power generators to mitigate risk to JWST OTIS. This was necessary to rapidly re-establish high vacuum conditions inside the chamber upon loss of power or failure of the Helium Refrigerator resulting in an uncontrolled release of condensed gas off the Helium shrouds.

The Turbo molecular pumps proved essential in leak testing the chamber. A Helium mass-spectrometer leak detector was placed on the Turbo pump backing line throughout the chamber test series. Chamber A sensitivity measured approximately 15 for the leak detector at the Turbo pumps backing against a calibrated leak. Initial Chamber A leak rates were greater than 100 Torr-liters per second during functional testing. Through methodical leak testing and incremental improvement across the test series, the Chamber A leak rate including GSE was reduced to approximately 0.5 Torr-liters per second for JWST OTIS testing.

Major leaks addressed include the solar ASA flanges, 40-foot door, internal GSE / instrument air purges, Helium GSE cooling, and 36-inch butterfly vacuum valves. Of particular note, a second 3/4 inch o-ring was installed on the 40-foot door flange for intermediate pumping between the O-ring grooves.

CONTAMINATION CONTROL

The JWST program required the design, installation and certification of a ISO Class 7 (Fed. Std. Class 10,000) cleanroom in the JSC SESL for assembly, integration and testing the JWST OTIS. The JSC Cleanroom complex consists of the Main Cleanroom, attached Equipment Room and a detached Gowning Area. The Main Cleanroom is 64-ft by 70-ft inner dimensions with 56-ft cleanroom ceiling and physically attached to Chamber A around the 40-ft diameter door. The Cleanroom is designed as a closed recirculating airflow system providing a minimum of 40 air changes per hour. The Cleanroom was certified to meet ISO Class 7 and JWST program contamination requirements for airborne particle counts, positive pressure, temperature, relative humidity, airflow, total hydrocarbons, and fallout as listed in Table 1. Special features include a 25-ton capacity cleanroom bridge crane, large roll-up door (33-foot wide by 30-foot tall), ultra-smooth static dissipative epoxy coated floor, and an oil-free air compressor for air barging within the Cleanroom.

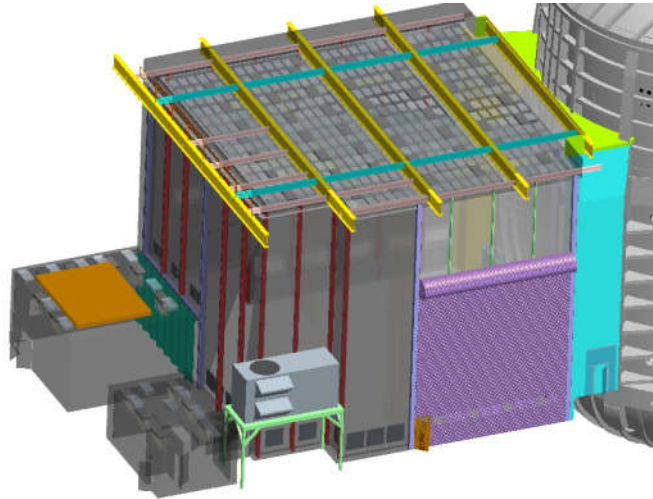


Figure 3: SESL Cleanroom

Facility Parameter	Requirement
Air Quality:	ISO Class 7
Max. Number of Particles > 0.5 μm	352,000
Max. Number of Particles > 5.0 μm	2,930
Positive Pressure	> 0.05" H ₂ O
Temperature	20 \pm 3 °C
Relative Humidity	30-50%
Air Flow	90 \pm 10 lfm
Total Hydrocarbons (Methane Equivalent)	15 ppm
Particulate Fallout	< 0.001 PAC/day
Molecular Accumulation	< 0.5 Å /day

Table 1: Operating Requirements for SESL Cleanroom and Chamber A

Chamber A required a clean Airflow management system to meet ISO Class 7 and JWST program contamination control requirements. The original Airflow management system was designed to provide chamber bottom-up air ventilation and sized to warm up the chamber upon emergency repressurization for manned cryo-vacuum testing. The original Airflow management system needed extensive refurbishment and modification to meet the JWST program requirements. The chamber recirculating blower was cleaned, coated, and balanced for clean service. A new variable-frequency drive (VFD) was installed on the blower to allow for a wide-range of air flow from 5,000 to 50,000 cfm. The Airflow Filter Coil box was replaced with a modern unit to provide cooling, particle filters, HEPA filters and carbon filters of recirculated Chamber air. The Makeup Air unit was replaced with a modern unit with heating,

dehumidification, particle filters, HEPA filters, carbon filters, humidification and fan capable of up to 25,000 cfm. Airflow system butterfly valves were replaced with SS valves. An exhaust fan was added for purging the chamber after repressurization with GN2. The large bore Airflow distribution piping was blasted clean, coated, and modified for top down air flow. Within the chamber, airflow ducting through the Helium ceiling supplies four diffusers to provide an air curtain over the JWST observatory.

Contamination control test equipment was installed in Chamber A to validate protection of all critical optical surfaces from contamination per JWST program requirements. Contamination was monitored with Cryogenic Quartz Crystal Microbalance (CQCMs) placed in locations that are representative of the JWST flight primary mirrors. The CQCMs measured the outgassing rates and molecular deposition real time and provide a total integrated mass collected over the entire test. Facility LN2 is supplied to the CQCM heat sink cold plates to measure outgassing rates during ambient temperature operations.

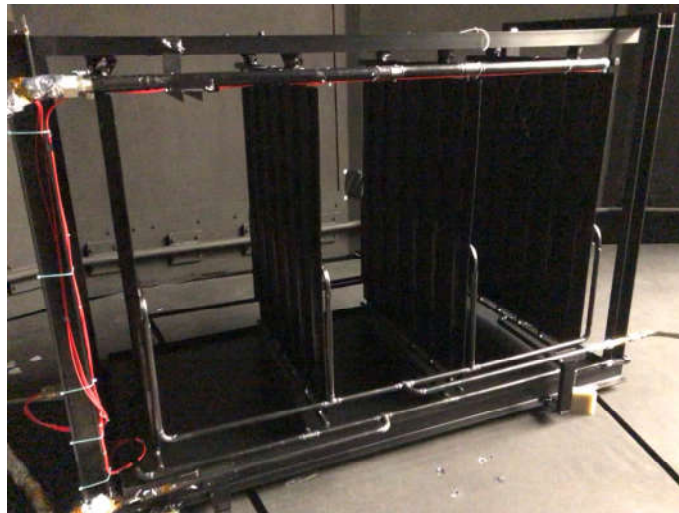


Figure 4: Interior Cryogenic Scavenger

Two Cryogenic Scavenger panels were installed within the Chamber A Helium Shroud volume to protect JWST from chamber off-gassing and contamination through all phases of testing. Each Scavenger (located north and south on Helium floor) has a surface area of 8 sq. meters and dual fluid circuits for liquid nitrogen (LN2) and cryogenic Helium. LN2 is supplied to the Scavenger from ambient vacuum down to a Helium shroud environment of 100K. Then the Scavenger LN2 circuits are drained, purged and backfilled with Helium as the chamber environment proceeds down to 20K. An individual Helium zone supplies both Scavenger panels to actively cool down to 20K with the Helium shroud. Two additional LN2 Scavenger panels were installed in between the LN2 shroud and Helium shroud volumes on 1st and 5th levels to mitigate contamination sources outside the Helium shroud.

LIQUID NITROGEN SYSTEM

The original SESL Liquid Nitrogen (LN2) System supplied both Chambers A and B. Its primary purpose was to cool the LN2 thermal shrouds to provide the 100K simulated LEO test environment. The original LN2 system was a forced flow system utilizing cryogenic transfer pumps to circulate up to 585 gpm LN2 at 120 psig through the thermal shrouds and ancillary equipment. The return flow was routed to a low pressure boil-off tank (BOT) for phase separation of nitrogen vapor to vent and liquid back to the pumps.

The original LN2 pumped system was considered too unreliable and unstable to meet the long duration test duration required by the JWST program. Initial project estimates to refurbish and upgrade the original LN2 system proved to be cost prohibitive. NASA JSC collaborated with Thomas Jefferson National Accelerator Facility (JLab) to perform a high level thermodynamic study of the original LN2 system and propose various options for system modernization. The study looked at technical performance, capital cost for implementation, project schedule, efficiency of operations, ease of maintenance, and risk (technical/programmatic). The result showed a significant advantage in conversion to a natural flow (thermo-siphon) process design over the original and upgraded forced flow systems. Advantages of the

thermo-siphon system include stability (nature-driven process), reliability (no rotating parts), reduced maintenance (fewer control valves and safety devices), lower capital cost (fewer components), lower shroud temperature, lower LN2 consumption, minimal electrical power (controls only) and greater efficiency.

After selection of the thermo-siphon approach, JLab provided NASA JSC with technical assistance in the process design, component selection, sub-system specifications, and system commissioning. Jacobs CLG was responsible for the field engineering, vacuum jacket and distribution piping design, contract management, system integration, installation and operations for NASA JSC.

A simplified schematic flow diagram of the LN2 system is presented in Figure 5. This system eliminates all limited-life rotating equipment and relies on natural circulation (i.e., the exploitation of gravity and fluid density change) to move the LN2 through the chamber thermal shrouds. It uses five identical 900 liter phase separator tanks located on top of Chamber A. Each phase separator tank is an independent thermo-siphon loop made up of a proportional size of LN2 shroud zones. Makeup LN2 is supplied for each loop by a control valve to maintain the liquid level in the phase separator tank. The system utilizes a refrigeration recovery coldbox to reduce the LN2 consumption during normal operations and provide sub-cooled LN2 for cooldown and makeup.

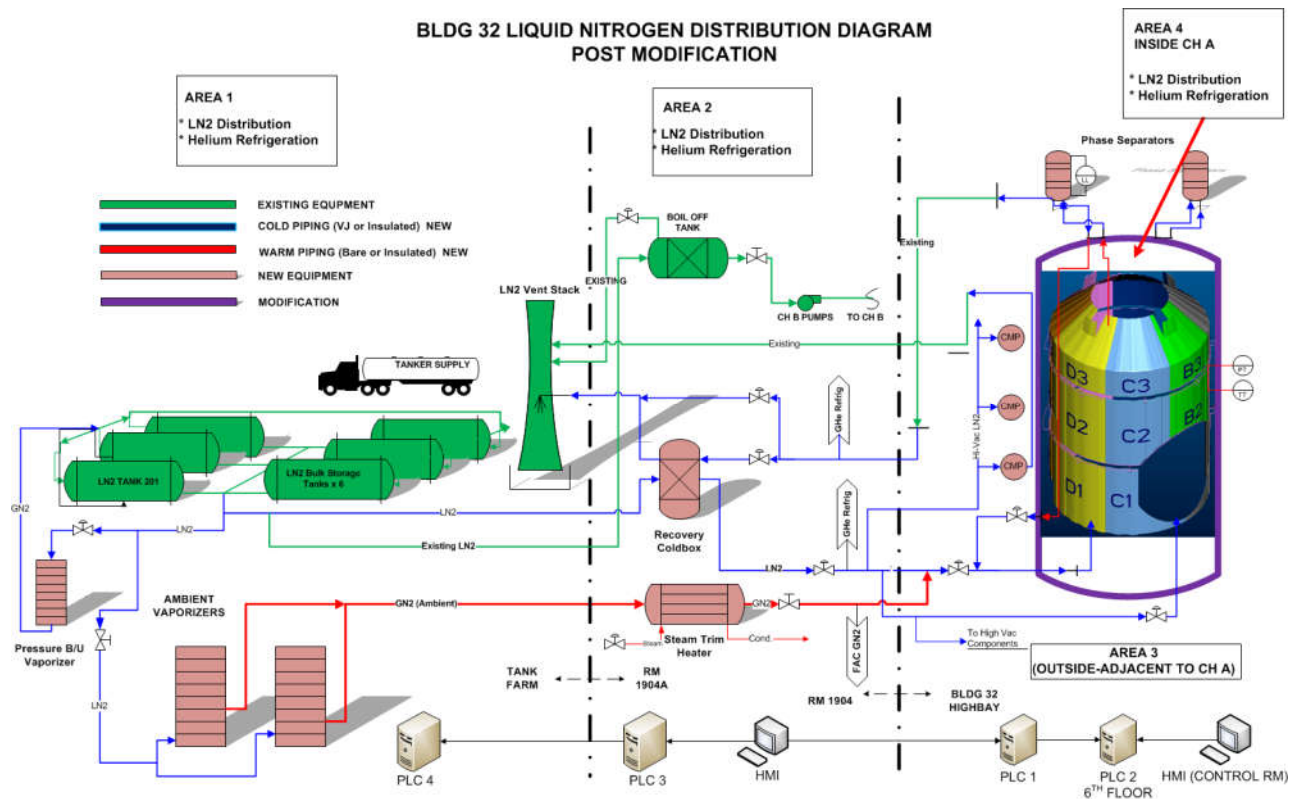


Figure 5: SESL LN2 System

In the LN2 storage area, a horizontal pressure build-up ambient vaporizer was installed to replace the original steam vaporizer for LN2 storage pressurization and facility GN2. Large vertical ambient air LN2 vaporizers were required to provide up to 1000 gm/sec gaseous Nitrogen at 300K for LN2 shroud warm-up and chamber repressurization. For chamber bake-out operating mode, a steam trim heater was added in line with the gaseous Nitrogen supply. New vacuum jacketed piping was installed to interface between the LN2 storage, new system equipment and Chamber A. Inside Chamber A, the existing LN2 piping was modified for bottom up LN2 zone flow to the Phase Separator Tanks to allow for natural circulation. These modifications resulted in the reduction of system cryogenic valves from over one hundred to less than thirty. The number of safety devices went from 45 relief valves and 45 rupture discs on the original system to five relief valves and three burst discs for the upgraded system.

The new LN2 system is capable of the following modes of operation required by JWST for Chamber A testing:

- a. Bake-out: Warm the 25 tons of LN2 thermal shrouds to $> 45^{\circ}\text{C}$ while the Helium shrouds are heated to $> 60^{\circ}\text{C}$. This assists drive off contaminants form the panel surfaces to meet the chamber cleanliness requirements to test critical JWST optics.
- b. Cool down: system to cool the LN2 shrouds to steady-state operating conditions at 80K within 16 hours.
- c. Steady-state: system to support long term 80K operations in a reliable, stable and efficient way.
- d. Drain: system to drain LN2 back to storage at end of test to minimize time for warm-up.
- e. Warm-up: system to warm the LN2 shrouds with gaseous Nitrogen to ambient temperature within 96 hours.
- f. Ancillary: provide independent LN2 supply to all test support equipment (Helium Coldboxes, Cryopumps, Coldtraps, Scavenger panels, CQCMs) throughout all chamber modes of operation.

Throughout the JWST test series, the LN2 thermo-siphon exceeded all of the design goals and predicted performance for the system. Table 2 summarizes the original, projected, and actual loads from Chamber A testing.

		Original Forced Flow (Option-0)	Projected Thermo-Siphon (Option-4A)	Test Results Thermo-Siphon (Option-4A)
Chamber heat transfer	[kW]	176	176	89
Supply transfer lines	[kW]	15	9	5
Return transfer lines	[kW]	15	2	2
LN2 valves	[kW]	5	1	1
LN2 connections	[kW]	1	1	1
LN2 pump	[kW]	37	0	0
Phase separator	[kW]	2	1	1
LN2 helium plant	[kW]	5	10	10
Other loads (cryo-pumps etc.)	[kW]	0	5	5
Pressurization	[kW]	0	5	3
Estimated loads	[kW]	256	210	117
Supply pressure	[bar]	5.07	5.07	5.07
Supply temperature	[K]	94.1	94.1	94.1
LN2 supply enthalpy	[J/g]	-86.6	-86.6	-86.6
Return pressure	[bar]	2.23	1.01	1.01
Return temperature	[K]	84.7	93.1	93.1
LN2 return enthalpy	[J/g]	81.7	94.5	94.5
Enthalpy difference	[J/g]	168.3	181.1	181.1
Required LN2 flow rate	[g/s]	1521	1159	646
LN2 supply density	[g/ℓ]	722.7	722.7	722.7
Required LN2 volume flow rate	[m ³ /day]	182	139	77
	[gal/day]	48,000	36,877	20,500
Savings compared to Option-0	[m ³ /day]	N/A	43	105
	[%]	N/A	24%	58%

Table 2: Estimated loads and LN2 required flow

The overall heat load on the chamber has been reduced significantly with the removal of the legacy solar simulators covered over by new LN2 shrouds and radiant barriers at the chamber walls. The Chamber A LN2 shrouds operate at a lower average environmental temperature of 87K in comparison to the original 100K. NASA JSC has realized significant cost savings in LN2 consumption, system capital cost, maintenance upkeep and operations manpower in implementing the LN2 thermo-siphon system.

HELIUM REFRIGERATION SYSTEM

Chamber A was originally outfitted with approximately 4800 sq. ft. of Helium panels shielded in between overlapping LN2 shroud panels from the chamber wall and interior solar simulation. The Helium panels served for cryopumping the chamber at 20K supplied by two 3.5kW Helium Refrigerators. This capability was maintained to support JWST testing. NASA JSC with JLab successfully refurbished and upgraded the process controls of the 3.5kW at 20K Helium Refrigerators in 2008 [4].

To provide the deep space test environment for JWST, a new 20K Helium Refrigeration System was required to supply the new internal Helium shrouds and GSE cooling zones. The key program requirements for the refrigerator included the ability to rapidly cooldown a large test article, handle a variable load, control temperature across the full operating range, and support an estimated steady state refrigeration load of 10kW at 20K with a thermal stability of 0.25K. The new Helium Refrigeration System was designed to support a variable load from 100kW at 100K to 12.5kW at 20K utilizing the “Ganni Cycle” Floating Pressure Process. The new distribution piping system allows the configuration of any combination of Compressor and Coldbox (new and existing) for the ultimate in system flexibility and redundancy. A block diagram is presented in Figure 6 of the integrated Helium Refrigeration Plant.

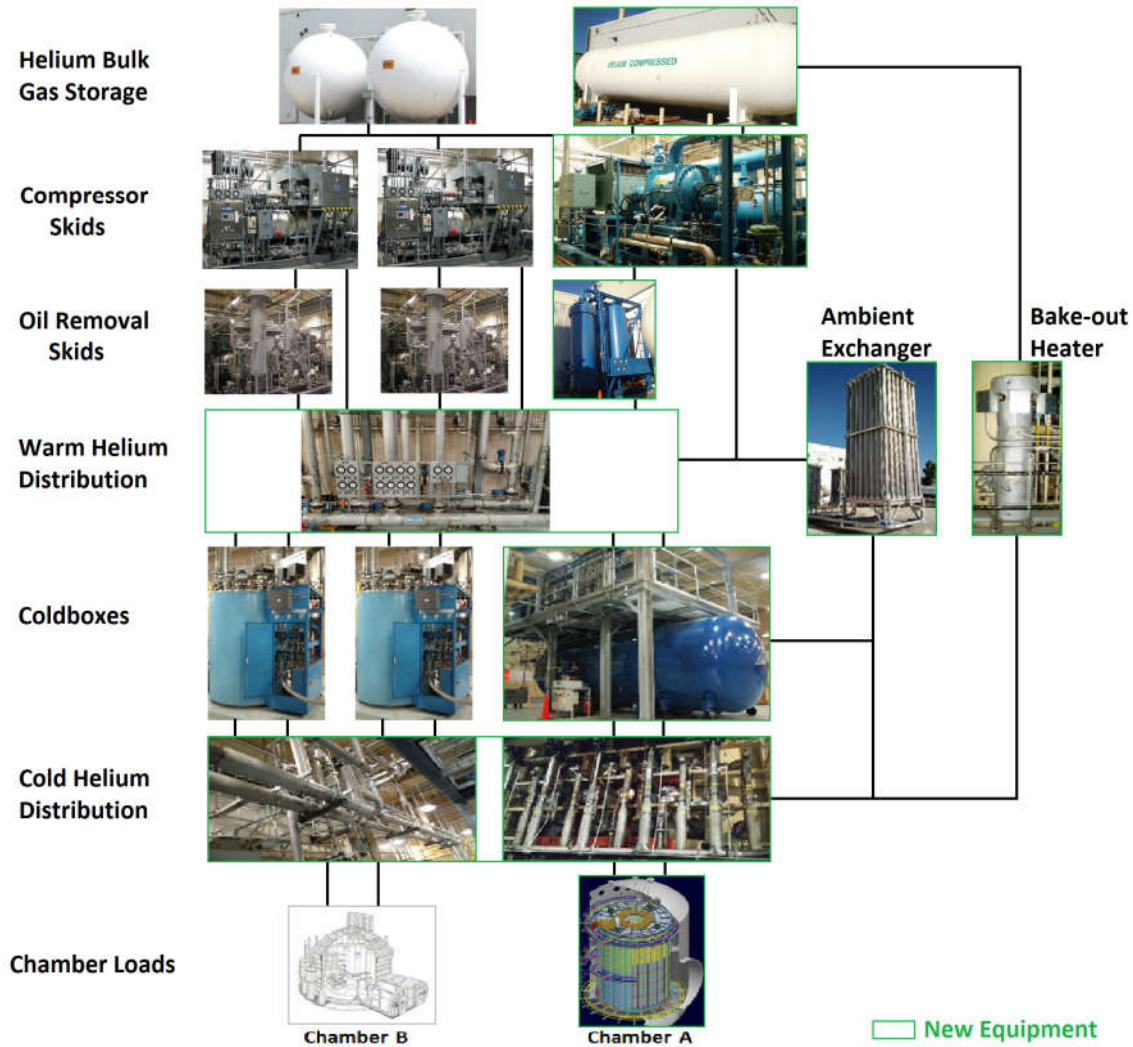


Figure 6: SESL Helium Refrigeration Plant

The Helium Refrigeration System was a collaborative effort between NASA JSC, Jefferson Lab, Jacobs CLG, and industry partners. JLab designed the process for the new refrigerator, selected all the major components to be used in the system and divided the system into sub-systems for competitive procurement. Instead of a turnkey approach, JLab developed the detailed specifications for each sub-system based on cost effective industrial practices. Jacobs CLG implemented the JLab design providing field engineering, sub-system procurements, system integration, construction oversight, and system operations at NASA JSC.

The Helium Refrigerator is composed of the following sub-systems: bulk Helium storage, Helium Compressor skid, Oil Removal System, Warm Distribution piping, Ambient Air Exchanger, Bake-out Heater, Helium Refrigeration Coldbox, and Vacuum Jacketed piping. A top level description of each sub-system is listed below:

- Bulk Storage: a 30,000-gallon cylindrical low-pressure ASME tank installed to provide helium storage capacity for the new Helium Refrigerator. It was made by Paragon Fabricators Inc. of La Marque, TX.
- Helium Compressor Skid: provides the Helium circulation to transfer heat from the load to the environment. The Compressor selected was a Howden oil-injected, single stage, rotary screw, positive displacement type rated for 2673 CFM at 3550 rpm. JLab developed the detailed Compressor Skid design drawings, controls philosophy, and specified the Howden compressor, oil cooler, and helium gas cooler heat exchangers, valves, and instrumentation. The Compressor Skid was fabricated by Salof Engineering of New Braunfels, TX.
- Oil Removal System: removes the remaining compressor lubrication oil and trace impurities from the Helium stream to the ppb level before entering the Coldbox. It was built by Riggins Co. of Hampton, VA per JLab detailed drawings.
- Bake-out Heater: rated at 40 kW for Chamber A main Helium shrouds bake-out and built by Riggins Co.
- Ambient Exchanger: designed to protect the Compressor suction from low or high temperature Helium return gas and balance the Coldbox during cooldown and warm-up. It was built by Cryoquip of Murrieta, CA.
- Warm Distribution Piping: consists of low and high pressure manifolds between Helium Refrigerators. Allows the configuration of any combination of Compressor and Coldbox for system redundancy.
- Gas Management Skid: Floating Pressure process control valves to add or remove gas charge from the system and Compressor bypass control valve to prevent sub-atmospheric suction condition.
- Cold Distribution Piping: consists of supply and return Vacuum Jacketed manifolds and isolation valves between Coldboxes. Allows any combination of Coldbox to supply the load (main Helium shrouds, original Cryopumping panels). Chart Industries provided the VJ piping in accordance with JLab detailed drawings.
- Helium Refrigeration Coldbox: JLab designed the custom Coldbox for 12.5kW at 20K refrigeration. The specification included the process design, sizing of Aluminum plate-fin heat exchangers, selection of valves, instrumentation, and controls. It was built by Linde Cryogenics of Tulsa, OK. Key features of the new Coldbox include: two parallel TED45 turbines to provide optimal refrigeration performance and redundancy; two parallel 80K charcoal adsorbers for helium purification, switch-over and regeneration through long duration testing; and large LN2 vessel, two parallel warm-end heat exchangers and load return valves at different temperature stages to ensure a large effective cooldown capacity.

The process control of the Helium Refrigeration System is based on the “Ganni Cycle” floating pressure approach, which is a constant pressure ratio process. Basically it allows the refrigeration system to automatically adjust its gas charge to match the load as it varies while maintaining high system efficiency. Commissioning of the new Helium Refrigerator showed essentially constant efficiency down to nearly one-third of the maximum 20K load.

Throughout the JWST test series, the Helium Refrigeration System met and exceeded all of the design goals and predicted performance for the system. The following is a list of required chamber modes of operation for the Helium Refrigeration System, the program goals and results achieved:

- Bake-out: the goal was to heat the Helium shrouds to an average of 330 ±5K. During testing, an average temperature of 333K was achieved with the potential for higher average temperature.
- Cool-down: the requirement for cooling the new Helium shrouds (50 metric tons of aluminum) to 20K within 48 hours. During cryo-proof testing, this was achieved in nearly 24 hours.
- Steady-state temperature: the requirement was to achieve a Helium shroud environment temperature of 20K. During functional testing, the refrigerator achieved a Helium shroud average of 14K.

- Temperature stability: the requirement was to maintain $\pm 0.25\text{K}$ stability at steady state for JWST thermal balance testing. Throughout testing, the refrigerator achieved cryo-stability of $\pm 0.05\text{K}$.
- Control Temperature Range: the test program required the Helium refrigerator to control the Helium shroud environmental temperature anywhere between 20 to 330K. Throughout the test series, the refrigerator demonstrated precise control of cooldown, warm-up at targeted rates and allowed for slow release of condensed air off the Helium shrouds.
- Heat Loads: the Helium Refrigerator measured chamber test loads of 4kW at 20K under high vacuum conditions up to 7.5kW at 20K with Helium backfill to $1\text{e-}3$ Torr for FMHT cooling of the test article.
- System Performance: the Helium Refrigerator demonstrated outstanding load range from 11.2 kW at 15K to 118 kW at 100K as shown in Figure 7.

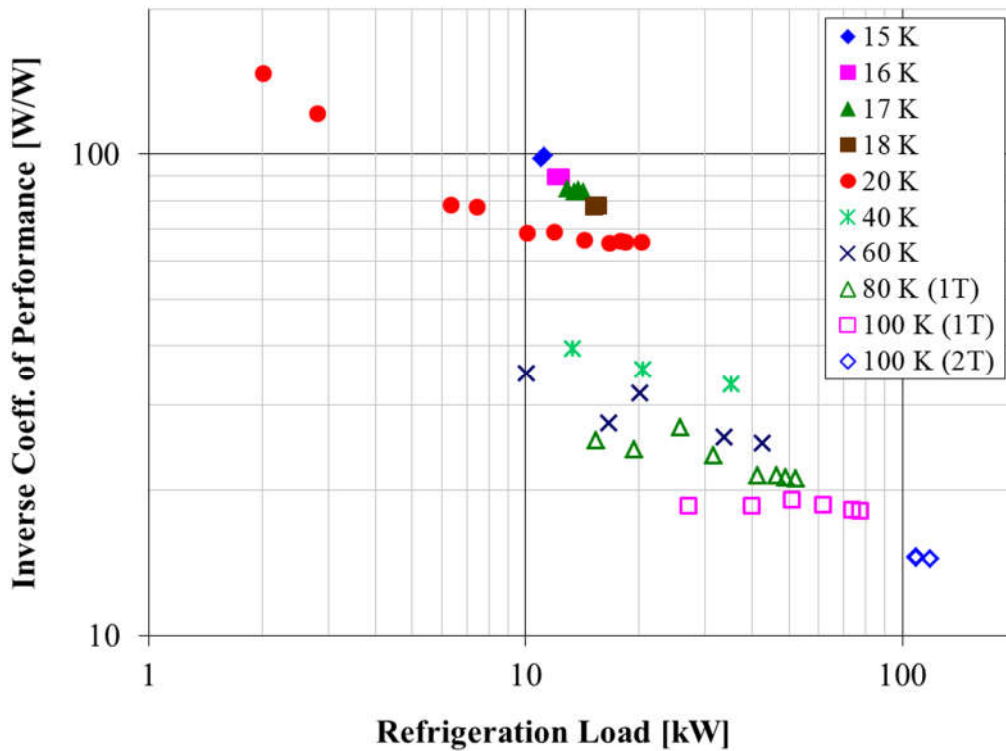


Figure 7: Helium Refrigerator Performance at various loads and load temperatures

SUMMARY

NASA JSC Chamber A earned its landmark status in the 1960s manned testing of the Apollo Service and Command Module in simulated Low Earth Orbit. With a major modernization effort, Chamber A continues to add to its historic legacy with the successful completion of the JWST test program. Chamber A remains a world-class facility now capable of ISO Class 7 test article integration and assembly for long duration, deep space environmental testing.

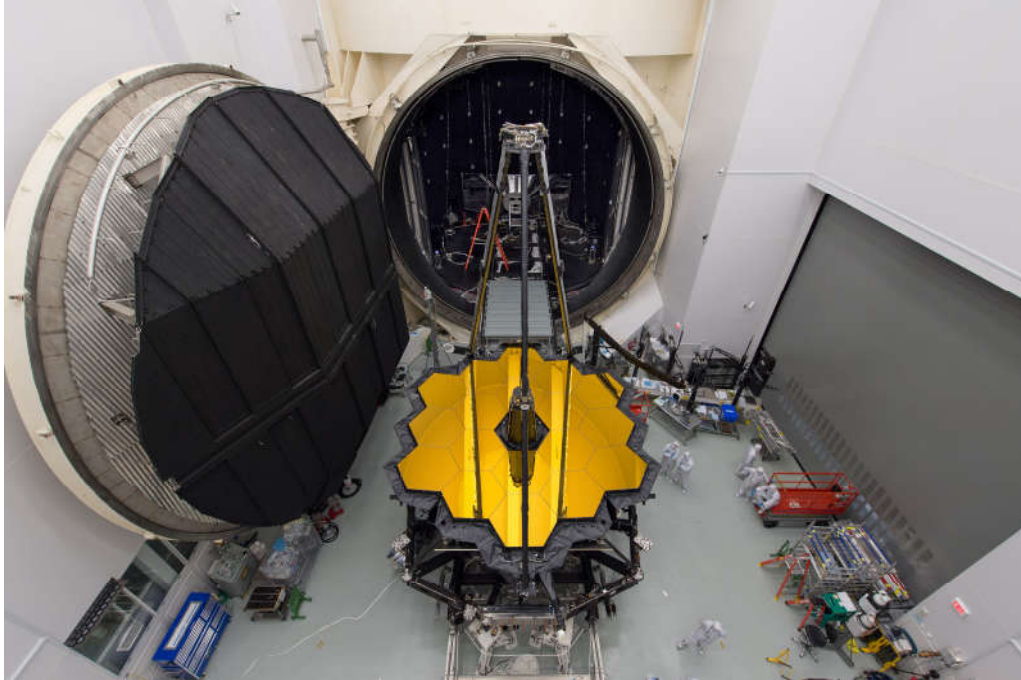


Figure 8: JWST OTIS at Chamber A

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