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

Sammy Garcia, Jonathan Homan, Michael Montz
NASA Johnson Space Center, Houston, Texas, 77058, USA

ABSTRACT

NASA is the mission lead for the James Webb Space Telescope (JWST), the next of the "Great Observatories", scheduled for launch in 2018. It is directly responsible for the integration and test (I&T) program that will culminate 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 steps performed in efforts to convert the existing the 60's era Liquid Nitrogen System from a forced flow (pumped) process to a natural circulation (thermo-siphon) process. In addition, the paper will describe the dramatic conservation of liquid nitrogen to support the long duration thermal vacuum testing. Lastly, describe the simplistic and effective control system which results in zero to minimal human inputs during steady state conditions.

INTRODUCTION

America's mission to land a man on the moon led engineers at NASA's Johnson Space Center to commission the Thermal Vacuum systems of Chamber A in 1962. The cryogenic and vacuum system technology of that era served their purpose successfully by providing the crucial space environment needed to qualify the Apollo command module for its role to ferry men and the lunar lander to the moon and back to earth. Chamber A has since then provided successful space simulations test for numerous NASA and Department of Defense space projects. The facility used piston driven compressor technology to achieve 20 K Helium for cryopumping. For high vacuum pumping the chamber used twelve 48" diffusion pumps guarded by 12 high vacuum angle valves. The environment was cryogenically conditioned by using pumped Liquid Nitrogen process and aluminum heat sink panels.

For the optical testing series of the James Webb Space Telescope our Thermal Vacuum systems for Chamber A had to change to meet the environmental, cleanliness and long duration test requirements. The preexisting LN2 system used a forced flow (pumped) semi recoverable process. The Liquid Nitrogen system operated on two primary and one backup LN2 pumps each capable of providing 10,410 l/min @ 109.7 m TDH [275 GPM @ 360FT TDH]. Piping used mechanical type insulation supplying LN2 to twenty nine zones each having supply and return valves, safety devices and control sensing devices for each zone. Five technicians were required to cool down and maintain the system operational with a two - three week operating limitation and maintained the environment at 100 K.

In comparison, the new system requires no rotating equipment, provides pressurized sub-cooled liquid Nitrogen to the chamber and support equipment at 80 Kelvin. The LN2 panel surface temperatures are maintained stable between 78K - 90 K. Consumption is between 78% to 118% less than previous configuration. Five key components and the modification of piping external and internal to the chamber are what make this new process a success. The system operates standalone which complements the long deep space thermal vacuum simulation temperatures and the long duration testing of JWST.

Apollo Program Configuration

The primary objective of the Liquid Nitrogen system was to simulate the temperature of space. The space environment temperatures had the capability of reaching -180 F. The means to get that environment to those temperatures were rigorous. The bulk storage tanks sit approximately 250 feet from the chamber. Approximately 457 meters [1500 feet] of pipe which was mechanically insulated 50 years ago was supplying LN2 to the chamber to the LN2 panel zones. Between the bulk storage vessels and the chamber was a phase separator (boil off tank) which is situated 7.62 meters [25 feet] above site elevation and ensured no cavitation in the centrifugal pumps. The LN2 was driven into the phase separator by means of a heat exchanger called the "Steam Trim Heater." The Steam Trim heater generated warm gaseous nitrogen by vaporizing liquid nitrogen using facility steam. The heat exchanger was exposed to two extreme fluids having a difference in temperatures of 362 K [625 F]. The warm gaseous nitrogen generated from the Steam Trim Heater pressurized and pushed LN2 from the bulk storage tanks to the phase separator (boil off tank). LN2 was delivered to the first level zones of the building by the use of the centrifugal pumps. LN2 was delivered to the inlet of the zones on the first floor zero meters [0' elevation], third floor 9.45 meter [31'] elevation, sixth floor 18.9 meters [62'] elevation and to the chamber lunar floor zone located -12.1 meters [40'] below the chamber floor elevation. The supply piping was mechanically insulated which was installed 50 years ago. Reflecting back the engineers of that era had the latest in technology and materials. The system performed and met the requirements it was intended for. Comparing to today's technology and equipment we can account for the cumulative heat loads that contributed to the 182-197 cubic meters [48,000- 52,000 gallon] per day usage.

JWST Program Configuration

The primary objective of the Liquid Nitrogen system today is to provide an 80 K heat shield for the newly installed 20 K environmental panels.

The new driver to flow liquid nitrogen to the facility is a pressure build-up vaporizer. The pressure build-up vaporizer pressurizes the bulk storage tanks which flow LN2 into the facility. The pressure build up vaporizer provides gaseous nitrogen at ambient temperatures unlike the previous steam trim heater which used steam which generated warm nitrogen for this part of the process which caused excess LN2 boil off.

A liquid nitrogen cold box sub cools the pressurized liquid nitrogen from the bulk storage tanks. The results is pressurized sub-cooled liquid nitrogen up to 6 ATM [75 psig] at 80 K. The liquid nitrogen cold box also recovers waste gaseous nitrogen from the thermal siphon process at steady state conditions.

A valve box manages the distribution of LN2 to the main chamber, three helium refrigerators and lastly the high vacuum cryopumps. Legacy mechanically insulated supply piping was completely removed and replaced by vacuum jacketed piping and valves. Legacy inlet and outlet valves (uninsulated) were demolished at all elevations. New valves were replaced with vacuum jacketed cryogenic valves.

Major efforts within the chamber focused on connecting zones to zones to provide and upwards vertical flow path of the LN2 from the zero elevation through the LN2 panels and allow the LN2 to collect in the phase separators at the 36.6 meters [120 feet] elevation. The LN2 panels zones were connected by means of fluid jumpers of 3" aluminum to stainless steel transition joints, double braided stainless steel flex hoses with an assortment of 76.2 mm [3" SCH 10] pipe fittings and piping. These zone to zone jumpers are located at the 9.45 meter [31 feet] and 18.9 meter [62 feet] elevations. Temperature and pressure sensing instruments were installed at each of these jumpers. The scaffolding efforts for this modification were in confined spaces and extremely difficult to access. Men, equipment and materials worked in these confined and cramped spaces to fit and weld the piping, tubing and route temperature instrument wiring to penetration plates. Two new zones were installed to cover the Apollo era sun simulator areas. Approximately 2800 welds were required within the chamber. Each weld was helium leak checked.

Major component placement required civil and structural engineering to design the structures and platforms. Piping flexibility analysis was performed on vacuum jacketed piping and piping within the chamber. A point cloud scan was performed of the facility and chamber and used to perform clash studies between exiting facility and proposed LN2 major components and piping.

Operation of the system is a one operator task for cool down to 80 K with a cryogenic engineer. At steady state the Chamber A LN2 thermo siphon system operates autonomously with hourly checks on the health of the process and system. The only interaction from personnel is the attending to the loading of the bulk storage tanks to maintain the supply LN2 into the process. There are six bulk storage tanks each having a capacity of 94,635 liters [25,000 gallons.] The daily liquid nitrogen usage during chamber steady state conditions with the 20 K helium panels and chamber vacuum pressure at 2 x 10 ^-7 Torr is and average of 51,103 liters [13,500 gallons.] A decrease in LN2 consumption of 128,704 [34,000 gallons] per day.

The decrease in consumption can be accounted to the change to vacuum jacketed distribution piping from mechanically insulated piping. The use of and LN2 sub-cooling cold box which provides LN2 which is 20-25 K lower than previous process. The stability of the LN2 fluid temperature and pressure provides much more stable performance at the chamber LN2 panels. The primary reason for the decrease in LN2 consumption is the thermo-siphon process which has zero liquid waste. LN2 fills the panel flow paths thru make up control valves from the zero elevation upwards thru the LN2 panels and exits the chamber and collects in the 908.5 liter [240 gallon] phase separators. There are five of these phase separators strategically located above the panel and chamber nozzle elevation. Equivalent heat loads from the chamber panels are divided into each phase separator. Each phase separator has a recirculation line which supplies LN2 to the zero elevation of the LN2 panels by using recirculation valves. The head pressure created by the LN2 volume in the phase separators and the column of LN2 in the recirculation lines produce 3.5 ATM which drives the LN2 when needed.

The recirculation driver of the thermo siphon process is the heat load influences from chamber onto the LN2 panels. The heat load boils the liquid nitrogen into gaseous nitrogen. The liquid displaces the nitrogen gas as the nitrogen gas rises to the phase separators. The change in density within the LN2 panel flow tubes is what drives the liquid nitrogen upwards towards to the phase separators. As the liquid rises in elevation the pressure drops from 3.5 ATM At the inlet of each zone to 1.12 ATM at each phase separators. The liquid in the phase separators is maintained by the makeup valves for each zone. A PLC monitors the liquid level and the makeup valves open when required to maintain the liquid level set point. As the pressure drops within the piping and flow tubes the LN2 temperature also drops yielding and average surface temperature of the LN2 panels between 87K - 90 K. The culmination of key components, vacuum jacketed piping, controls and the thermo siphon process has provided a stable, lower operating pressure and temperature with a daily usage that can sustain long deep space simulation thermal vacuum testing.