# Refurbishment of NASA's Johnson Space Center Liquid Nitrogen Bulk Storage Tanks in preparation for Thermal 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 2019. It 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. Chamber A utilizes Liquid Nitrogen as a thermal barrier between the 300 Kelvin vessel wall and the 20 Kelvin helium environmental conditioning shrouds. The 155,000 gallon capacity of the six vessels support long duration testing which support low and deep space simulations for today's testing.

This paper describe the challenges of refurbishing six liquid nitrogen bulk storage vessels that are 60 year old. The vessels were refurbished in place and focused primarily on the vacuum annulus. The challenges of vessel research, design engineering and project management will be discussed. The refurbishment of the vessels has extended the life of the vessels for another 35-50 years on the vacuum annulus integrity. The survivability of the bulk storage vessels was tested during the historic hurricane Harvey of 2017 during the 100 day JWST thermal-vacuum test.

## Acronyms

| | |
|---|---|
| ASME | American Society of Mechanical Engineers |
| LN2 | Liquid Nitrogen |
| NASA | National Air and Space Administration |
| NPT | National Pipe Thread |
| MAWP | Maximum Allowable Working Pressure |
| OTIS | Optical Telescope Element (OTE) plus ISIM |
| RMS | Root Mean Square |

### Introduction

With the creation of the Space Environmental Simulations Lab at the NASA's Johnson Space Center a multitude of support systems needed to be developed in the drive for NASA's Apollo program. The liquid nitrogen system would provide the cold nature of the simulated space environment. Four identical horizontal 28,000 gallon tanks were installed to meet this requirements. Each tank having common functionality when compared to today's cryogenic vessels. Some difference are the shear size and the use of robust materials compared to today's vessels. Another contrast is the vessels are pearlite filled compared to todays's superinsulation. Several years' later two additional tanks were requested by NASA and two Liquid Oxygen tanks were acquired from Francis E Warren U.S. Air Force Base, Wyoming. This addition increased the facilities capacity to 144,000 gallons. Each vessel is pearlite filled with a carbon steel shell. Each vessel has its own active vacuum pump with two pressure safety devices to protect the annulus from rupture in case of a catastrophic failure of the internal cryogenic vessel. Each vessel has two 8" relief valves to protect the internal vessel. This paper overviews the successful project which removed and replaced end of service life components on the annulus to increase the reliability and lengthen the life of the six cryogenic vessels.

| Vessel Name | ASME Serial # | Size (Gal) | Manufacturer | MAWP (PSIG) | Vac - Press microns * | Year Built |
|---|---|---|---|---|---|---|
| TK-LN2-101 | C-3793 | 28,000 | Horton Tank | 165 | 22 | 1958 |
| TK-LN2-102 | C-3787 | 28,000 | Horton Tank | 165 | 80 | 1958 |
| TK-LN2-103 | C-3796 | 28,000 | Horton Tank | 165 | 6 | 1958 |
| TK-LN2-104 | C-3786 | 28,000 | Horton Tank | 165 | 33 | 1958 |
| TK-LN2-201 | T-201-19 | 26,500 | LOX Equipment | 100 | 600 | 1960 |
| TK-LN2-202 | 59G0244-1 | 24,000 | Strutners-Wells | 165 | 16 | 1960 |

*Table 1*

(* With continuous vacuum pumping and full with LN2)

**We Have a Problem**

This storage facility serves as the onsite storage and distribution of all of the Liquid Nitrogen for the Johnson Space Center and also provide Liquid Nitrogen to the two Space Environmental Chambers in the building 32 complex. In 2015 with two years away from the JWST Flight OTIS test JSC had two tanks that were removed from service due to several problems with the annulus and the remaining tanks were indicating similar signs of vacuum component failure. In 2016 JSC performed the OTIS Thermal Pathfinder with only five vessel operating due to problems with the vacuum annulus on one vessel. All but one tank had signs of potential vacuum integrity loss. All of the cryogenic tanks had to be fully operational by the flight OTIS test so JSC developed a plan to identify what level of work needed to be done. At the end of the Chamber A testing in the fall of 2016 all six tanks underwent a helium leak check. Using a 40 ft. boom lift a leaks were identified at various components that were welded to the vessel. Two main areas were identified as the major leak sources 1) Annulus safety devices 2) Vacuum pump piping and valves.

Various companies were asked to recommend solutions to the vacuum leaks. Several company wanted to take the vessels to them and retrofit into a sealed vacuum system. This path that would have resulted in a 1.35 million dollar investment for these companies to refurbish all six vessels. JSC NASA would still have incurred a cost of disconnect, rigging and transport to their facility in the U.S. After a reassessing the cost and schedule it would have taken go the offsite repair route, a solution to perform the work on-site and phase the project over two years in anticipation of the OTIS Flight Test in the fall of 2018.

**Phase 1**

An assessment of each vacuum interface was done from a physical condition (i.e. Rust, Field repairable etc...) standpoint. A helium leak check map of each vessel was made. Based on vendor delivery and the vacuum piping configuration only two tanks could be fully retrofitted with both new stainless steel annulus safety devices and stainless steel piping to the vacuum pumps. The other four tanks also had all of the vacuum piping from the annulus to the vacuum pump replaced.

After a cost, schedule and technical assessment a plan was devised to have functional vessels one month prior to the next Chamber A test. Five of the vessels contents were transferred into one operational tank. The remaining operational tank provided LN2 to the JSC site consumers and also provided the warming nitrogen gas to the tanks to be repaired. The warm up time for the inner cryogenic tanks took 30 days to reach ambient temperature. The vacuum pumps continued to pump on the annulus. The oil in the vacuum pumps had to be monitored and changed a minimum of three times during the warm up period an indication of high moisture content within the annulus. A 35 PSIG nitrogen pad was kept on the cryogenic vessel at all times.

The design was completed by JSC. ASME B31.3 was the governing code for the piping. For this phase the design was completed to accommodate field welding. The existing piping was Sch 40 carbon steel piping with carbon steel valves and vacuum TC gauges not rated for outdoor or wetted areas. JSC performed all of the equipment disconnects and to safe all of the vessels. A low pressure nitrogen repress panel was used to repress the annulus and provided low pressure flow when the annulus was exposed to the atmosphere. All new piping is 304 S.S. Sch 10 seamless piping. Each interface between new and existing is a stainless steel to carbon steel weld. All welds were 100% dye penetrant checked. New 2” ASA flanged vacuum isolation valves were replaced. New 2” fail closed solenoid valves were installed between the vacuum pump and the annulus. The solenoid valves are vacuum rated and will fail close in case of a power loss. During this time a 500 year flood occurred in the Houston, Texas Area hampering our progress.

All of the piping and components were helium leak checked prior to final welding or flanging onto the vessel annulus. All welding shops were within a 50 mile radius of JSC. One company performed the shop welding and a separate company performed the field welding. All NPT fittings were sealed with epoxy sealant. Three thermocouple vacuum gauge tubes were installed on each vessel at different locations. Only one thermocouple vacuum gauge tubes is connected to the facility data acquisition system. The other two thermocouple vacuum gauge tubes are to check the health of the vacuum pump when isolated and the other is directly mounted on the end of the vessel head. Each thermocouple vacuum gauge tube can be isolated from the annulus or vacuum process for maintenance by a vacuum valve. Figure 1 is a typical installation of the vacuum tubes. JSC performed the post modification helium leak check. A three day minimum rate of rise was performed on each vessel. The results can be seen on Table 2. Finally a two part epoxy coat was applied to all affected areas where carbon steel to stainless steel welds were made. One vessel was brought on line and the tank that remained in operation during these modifications was warmed up. After a thirty day warm up this last vessel underwent the same modification.

*Figure 1, Typical Thermocouple Vacuum Tube Installation*

This stage of the project was an opportunity to perform exploratory engineering on a warm tank to prepare a design for the next phase of the project after the OTIS Thermal Pathfinder test in the Fall of 2016. A six inch pearlite fill flange from one of the tanks was removed to identify the port configuration, see Fig 2-3. The last time these flanges were open was fifty eight years prior to this year. Pearlite was still to the top of the port flange, a gasket with hardened sealant replaced a failed attempt of an O-ring on the blank flange, severely corroded carbon steel studs and finally an RMS on the flange which was unacceptable for vacuum service. Measurements were taken to formulate an engineering design in efforts to remove and replace all of the vacuum jacket safety devices on the pending four tanks.

*Figure 2, Pearlite Fill Flange Uncovered*

*Figure 3, Pearlite Fill Flange*

All of the carbon steel studs were removed and the welded flange on the vessels was machined in place to a 32 RMS and new 304 S.S. Studs were installed with a high nickel content anti seize compound. A new 304 S.S. blank flange was machined with an O-ring gland for vacuum service. A Viton O-ring was used with an application of Dow Corning vacuum grease. This exploratory engineering solidified the phase 2 plan in efforts to perform the final refurbishment of the vacuum annulus of the last four vessels.

*Figure 5, Field Machined Pearlite Fill Flange*

*Figure 4, New Pearlite Fill Flange Configuration*

Tank 201 was not able be pumped down below 250 micron and the rate of rise was not able to last one hour before reaching the Torr range. Two oil vacuum pumps were fouled in the process and it was determined that this tank would not be ready for the Chamber A OTIS Thermal Pathfinder test. A high water and oil content was found in the vacuum pump. During the Chamber A OTIS Thermal Pathfinder test our technicians manned the facility 24/7 for 52 days. During this time heating of the internal vessel was done with dry nitrogen to 300 F while pumping on the vacuum annulus thru an LN2 cold trap. The cold trap was removed and replaced every four to six hours depending on a local vacuum pressure reading at the cold trap. Vast quantities of water was removed from this vessel. Ultimately this vessel was resurrected to its old vacuum integrity of 46 microns at warm conditions.

**Phase 2**

After a successful Chamber A OTIS Thermal Pathfinder test, the tanks were emptied at the tail end of the chamber test. The LN2 was consumed during the chamber warm up with nitrogen in preparations to warm up the four vessels with the leaking annulus safety devices. With our engineering design in hand JSC went out for request for quotations to provide a service to design, fabricate, remove, replace existing vacuum annulus safety devices. There were several no bids and remaining quotations were in excess of project funding. After two months pursuing a turnkey RFQ to perform the scope of work. JSC shifted gears and managed every aspect of the project by late February 2017 in efforts to meet the flight OTIS Thermal Vacuum test in August 2017. Five separate statements of works were developed. The five statements of work comprised of scaffolding, mobile machining, shop fabrication\welding, field welding and procurement of the annulus safety devices and other piece parts required for the project. The project was completed by May 1$^{st}$ 2017 and the overall results after both phases can be illustrated in Figure 6. A photograph timeline summary of phase 2 is shown on Figure 7. All six tanks were placed back into service one month prior to test.

**Conclusion**

In summary the project was successful in several ways. A learning experience for our organization, improved reliability, and cost was a fraction compared to new vessels or if a contractor were to perform each phase of refurbishment. The price comparison for in shop repair did not meet fiscal schedule constraints. The six Liquid Nitrogen vessels longevity have been extended. With preventative maintenance it is foreseeable that these Liquid Nitrogen vessels can operate for the next three to five decades.

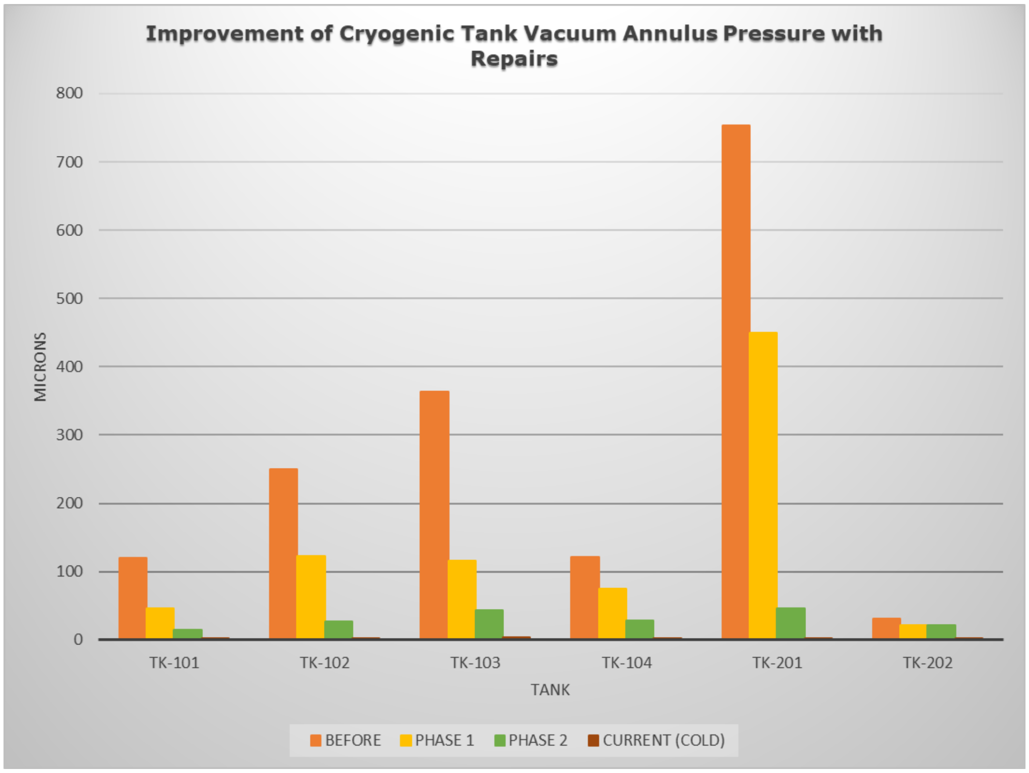


*Figure 6, Vacuum Comparison Chart*


*Figure 7, Phase 2 Project Photograh Summary*