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Using Mylar-Insulated Cryopumping Panels to Improve Vacuum Level During Warm Temperature Testing at JSC's Large Thermal Vacuum Facilities

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Introduction

The Johnson Space Center's Space Environment Simulation Lab (SESL) houses two specialized chambers. Chamber A, seen in *Figure 1*, is the world's largest purpose-built thermal vacuum chamber capable of creating deep space conditions. Chamber B, seen in *Figure 2*, is the largest thermal vacuum chamber designed for human-rated operations. Chambers A and B were built in 1964 to support testing of the Apollo vehicle and command module to train astronauts in a simulated space environment[1]. For the James Webb Space Telescope (JWST) thermal vacuum test in 2017, Chamber A was upgraded to simulate a deep space environment with temperatures as low as 11 Kelvin[2].

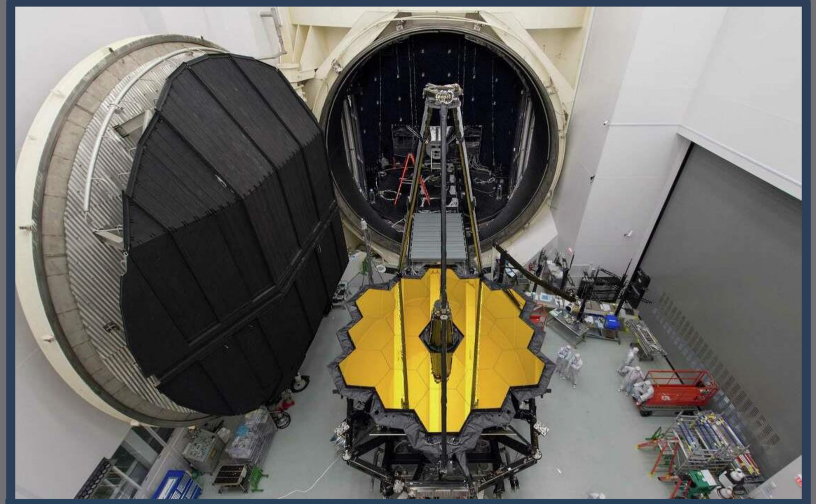

Figure 1: James Webb Space Telescope & Chamber A

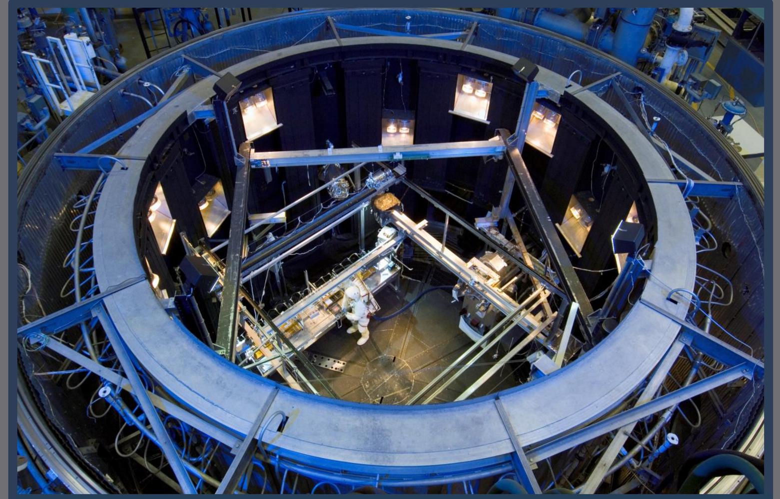

Figure 2: Top Down View of Chamber B

Helium Cryopumping Panel Background

A unique design feature of these chambers is the presence of gaseous helium cryopumping panels within the chamber's liquid nitrogen shroud. This shroud is used to bring the chamber to cryogenic temperatures while the cryopumping panels utilize their extensive surface area to trap gases, creating a high vacuum environment with pressures as low as $5*10^{-6}$ Torr.

In preparation for the JWST flight test, a series of functionals required Chamber A to operate at higher temperatures. Active cooling from the liquid nitrogen shroud was not necessary, since the cryopumping panels could still effectively mitigate contamination at these higher temperatures. During the main shroud warm-up, one of these cryopumping panels was covered with several layers of aluminized mylar. The mylar insulation was added to reduce heat transfer and thermally protect the zone from the warmed shroud. This strategy proved effective in improving efficiency and mitigating contamination, and became part of operations during JWST testing.

Proposed Insulation on Cryopumping Panels

Currently, Chamber B has requests from both commercial and NASA space suit tests to accurately generate thermal models at both high and low temperatures. High temperature tests would greatly benefit from simultaneous shroud warming and the high vacuum environment provided by the cryopumping panels. To enhance the efficiency of operations during these tests, it has been proposed that thermal insulation be added to Chamber B's cryopumping panels.

Building the Thermal Model of Chamber B

To begin this process, a feasibility study, requiring the analysis of a model of the chamber in Thermal Desktop, was conducted. Within Chamber B, there are four different LN_2 shroud zones (labeled as N2, M2, L2, and P2) and an LN_2 shroud covering the outer walls of the chamber (labeled as A) as seen in *Figure 3* below. In addition, there are fifteen cryopumping panels (labeled as B) located behind each inner LN_2 panel. It should be noted—neither the zones nor the inner and outer shrouds of the LN_2 panels can be controlled individually. Since there is no individual control of the LN_2 panels, the model assumed all of the helium cryopumping panels were insulated with mylar for the feasibility study. The surface emissivity of the shrouds and panels was needed for the model and was measured using an emissometer/reflectometer. The front of the LN_2 panels, which are coated in black paint, have a measured emissivity of 0.90, and the back of the LN_2 panels, with no paint, have a measured emissivity of 0.16. The helium cryopumping panels, which are uncoated, have an emissivity of 0.13.

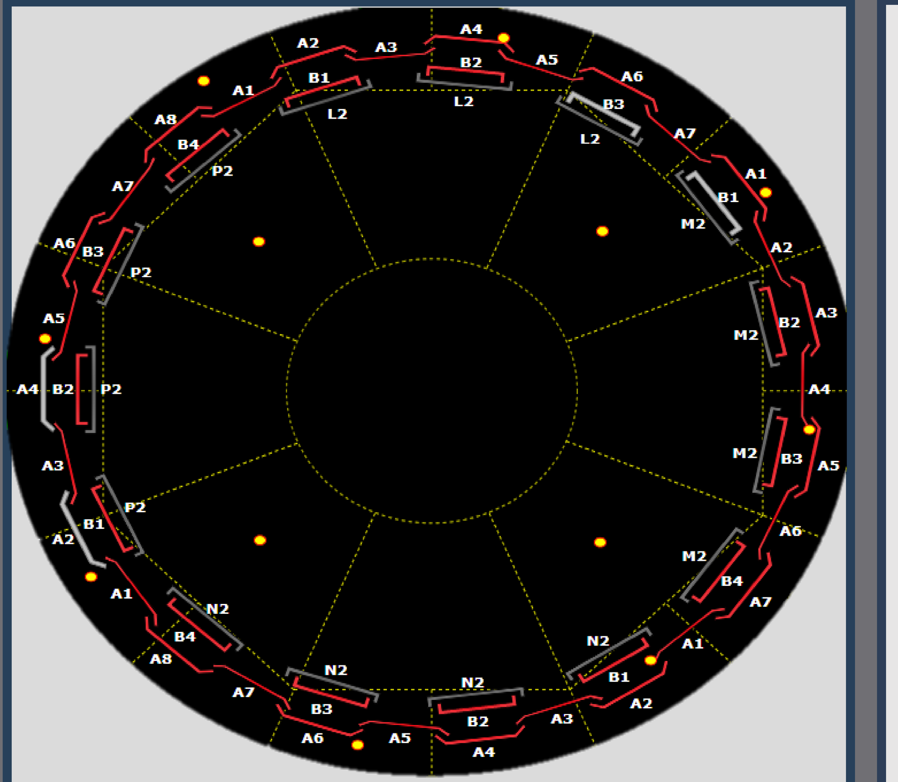

Figure 3: Representation of the LN_2 shrouds and Helium Panels on the Facility Data Screens

In March of 2023, a full thermal vacuum functional was run on Chamber B in preparation for future testing. This presented the opportunity to collect data regarding the temperature of the LN_2 zones and the helium cryopumping panels to feed into the analysis. The time that the cryopumping panels took to go from their initial (room temperature) steady state condition to their final cold steady state condition was used to make the Thermal Desktop model as accurate as possible. *Figure 4* above shows the helium cryopumping panel temperature, and *Figure 5* shows the LN_2 shroud temperature in Zone N of Chamber B throughout the functional.

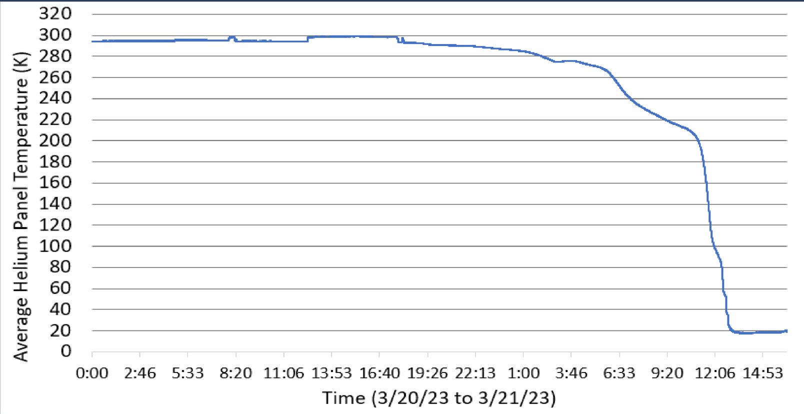

Figure 4: Helium Cryopumping Panel Temperature

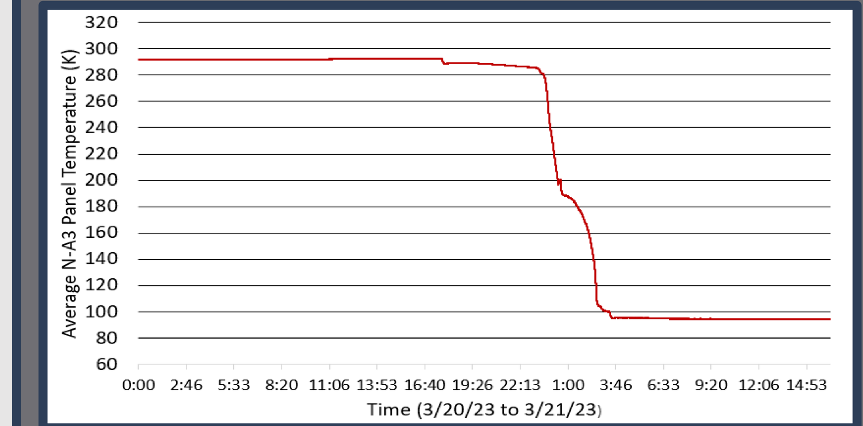

Figure 5: Zone N LN_2 Shroud Temperature

The first step of building the thermal model was to record the physical measurements of the cryopumping and shroud panels in Zone N of Chamber. These features were reconstructed in Creo Parametric 8 and imported into Thermal Desktop. This analysis used a three-dimensional model with a unit height as opposed to a two-dimensional model, in order to utilize the insulation feature of Thermal Desktop. The CAD was used as a skeleton for the creation of Thermal Desktop elements and included the specific locations of pipes. Convection nodes for helium and LN_2 were tied to the inside of these pipes and provided temperatures of 20K and 90K to the cryopumping panels and shrouds respectively, as shown in *Figure 6*.

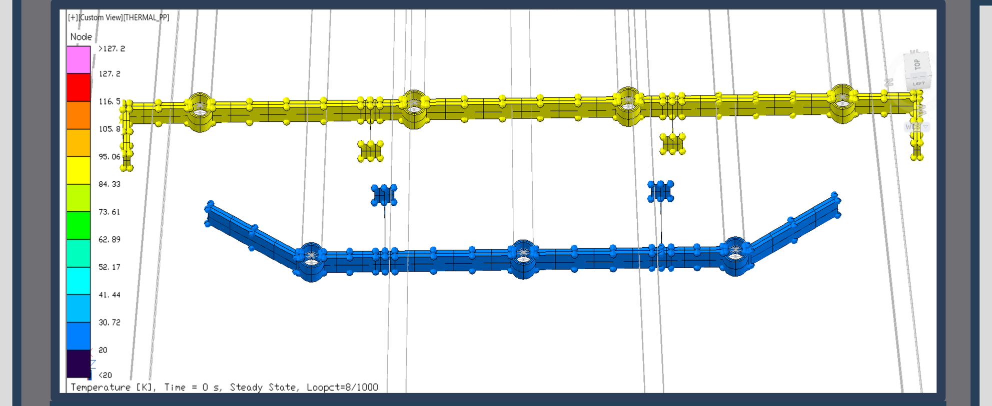

Figure 6: Thermal Model with Provided Temperatures of 20K and 90K to the Cryopumping Panels and Shrouds

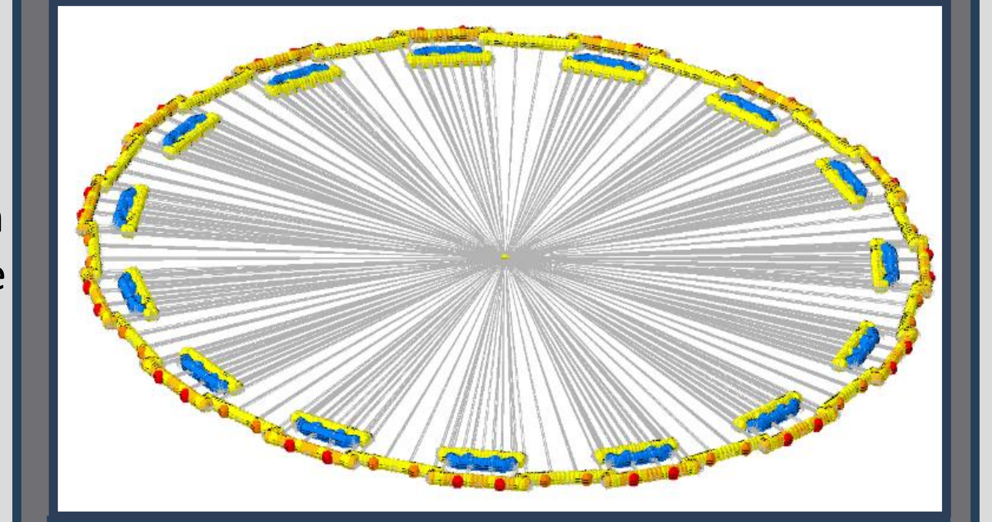

Figure 7: Final Result Thermal Model of Back Insulation Case

The thermophysical and optical properties of the Aluminum 1100-H14 panels and the black paint coating was added to the model, including the emissivity values gathered previously. The temperature of the floor underneath Chamber B was measured at 190K during testing and was used as the radiation temperature of the walls beyond the shroud. Two blackbody circles were created above and below the thermal elements in order to ensure no heat flux outside the unit height. Lastly, insulation was added to the model using the effective emittance (E-star) values of varied MLI (multi-layer insulation) layer[3]. The result of the model can be seen in *Figure 7*, displaying the temperature outputs for a test case with insulation.

Conclusion

Three insulation configurations of the cryopumping panel were analyzed. These cases modelled insulation on the front of the cryopumping panel, pointing towards the center of the chamber, on the back of the panel, and a final case with both sides insulated. These cases were run parametrically, with layers modelled from five to fifty, in increments of five. Additionally, a control case with no insulation was run. The heat flux of the cryopumping panels in each instance was recorded, and these values were compared to the heat flux of the control group, as a percentage.

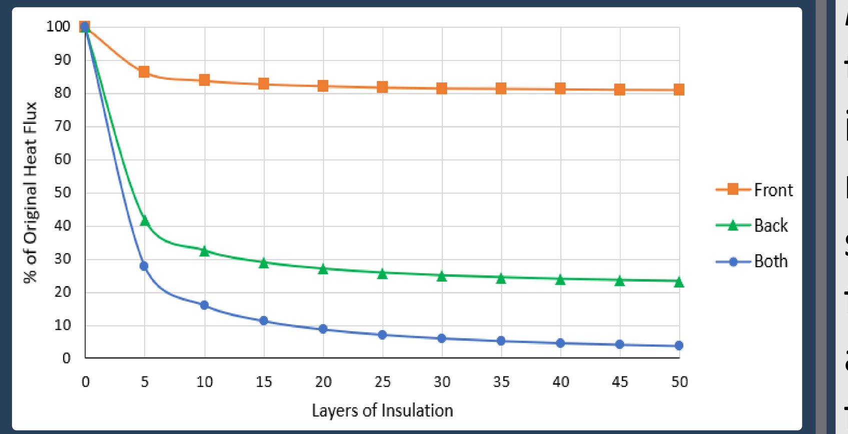

Figure 8: % of Heat Flux Per Layer of Insulation

Figure 8 displays the percentage of the original heat flux per layer insulation for all three cases. The results of these graphs all have similar large initial reductions of heat flux near the first five to ten layers, and then stabilize around 81% for the front case, 23% for the back case, and 3.5% for the case with both.

Future Work

Following this study, experimental validation is necessary. As seen from *Figure 8*, slight temperature differences in the thermal model can greatly impact the results. In July, a full thermal vacuum functional will be run on Chamber B, and multiple TCs will be attached to the chamber walls beyond the shroud and between the pipes flowing LN_2. This additional data will ground the thermal model with more accurate boundary conditions. Tests need to be conducted to validate the results of the thermal analysis and to assess the impact of adding 5 layers of MLI around the cryopumping panels. As part of this feasibility study, the reliability, integration aspects, and economic costs must also be considered.

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