Cryogenic Thermal Vacuum Testing with Remote Optical Metrology

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Flexure Engineering was awarded an SBIR to research and develop technology needed to build a thermal vacuum chamber made to take laser radar metrology through a window. The XATF test is proof of concept for this, and demonstrated the need for such a chamber.

XATF refers to two pieces of critical ground support equipment for NASA's JWST (James Webb Space Telescope) Integrated Science Instrument Module (ISIM), the ISIM Alignment Target Fixture (IATF) and the Master Alignment Target Fixture (MATF). These optical alignment assemblies require characterization while under cryogenic temperature.

A thermal vacuum chamber equipped with a shroud cooled with gaseous and liquid nitrogen was used. An inner shroud was cooled with liquid helium to approximately 30K. The XATF assemblies were kinematically mounted and oriented inside the inner shroud such that the optical targets were visible from outside an optical window on one of the chamber ports. Laser radar and theodolite mounted outside the window took measurements of various optical targets.

Two cold cycles were completed. A third cycle was aborted. Metrology was successfully taken. There were some problems with the helium system. The cryo pumps were turned off to reduce vibrations during metrology.

Many new technologies and testing methods must be developed for JWST and future programs that will require precision measurements. These technologies will be applicable to other cold temperature applications, such as lunar missions and superconductors. Remote metrology technologies can also be applicable to testing in harsh environments. Facilities with remote metrology capability will be valuable.

CRYOGENIC THERMAL VACUUM TESTING WITH REMOTE OPTICAL METROLOGY

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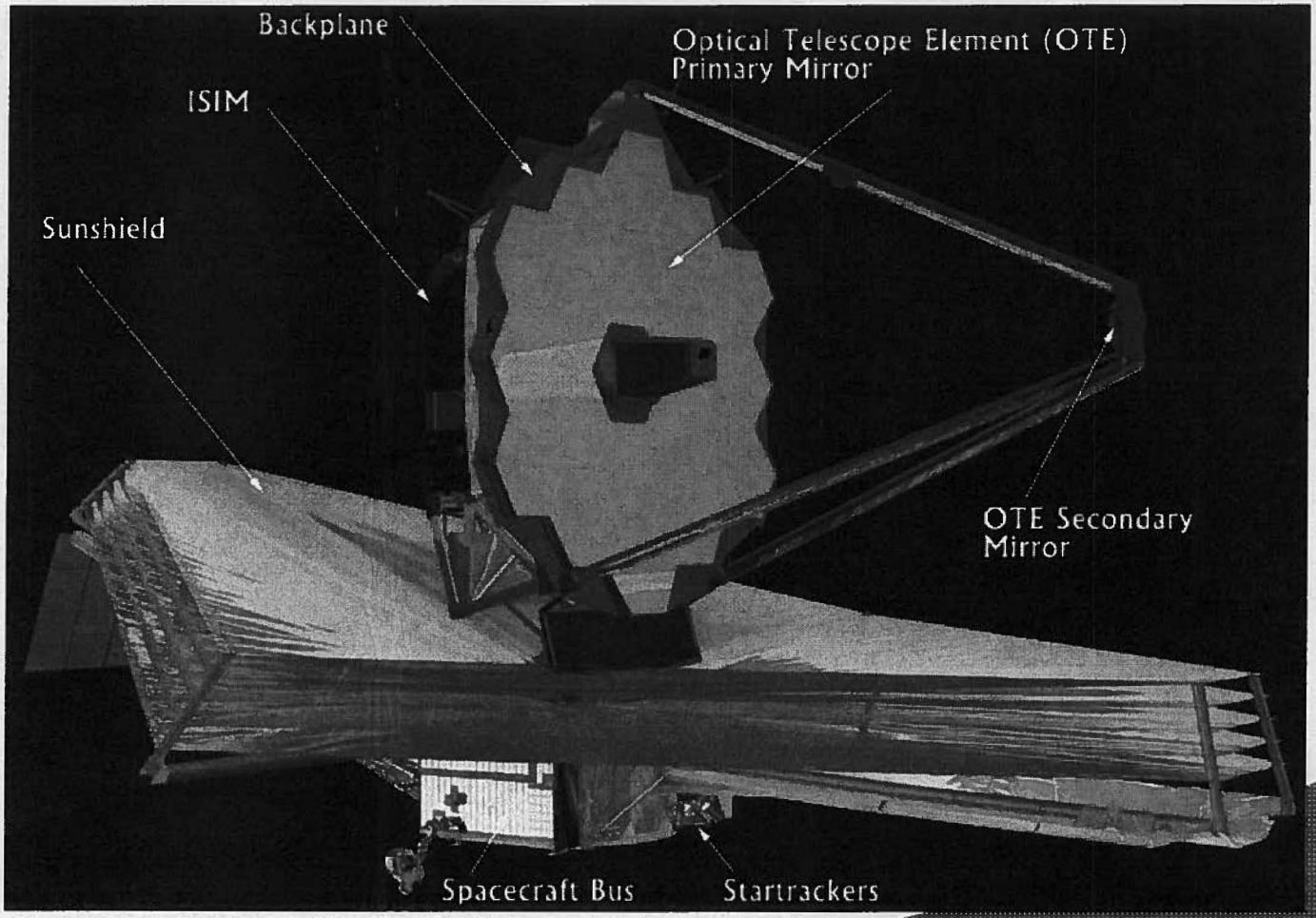
Overview

- Background
- Optical Metrology
- Reaching and Maintaining Cryogenic Temperature
- Contamination Control
- Vibration Control
- SBIR and Future Applications

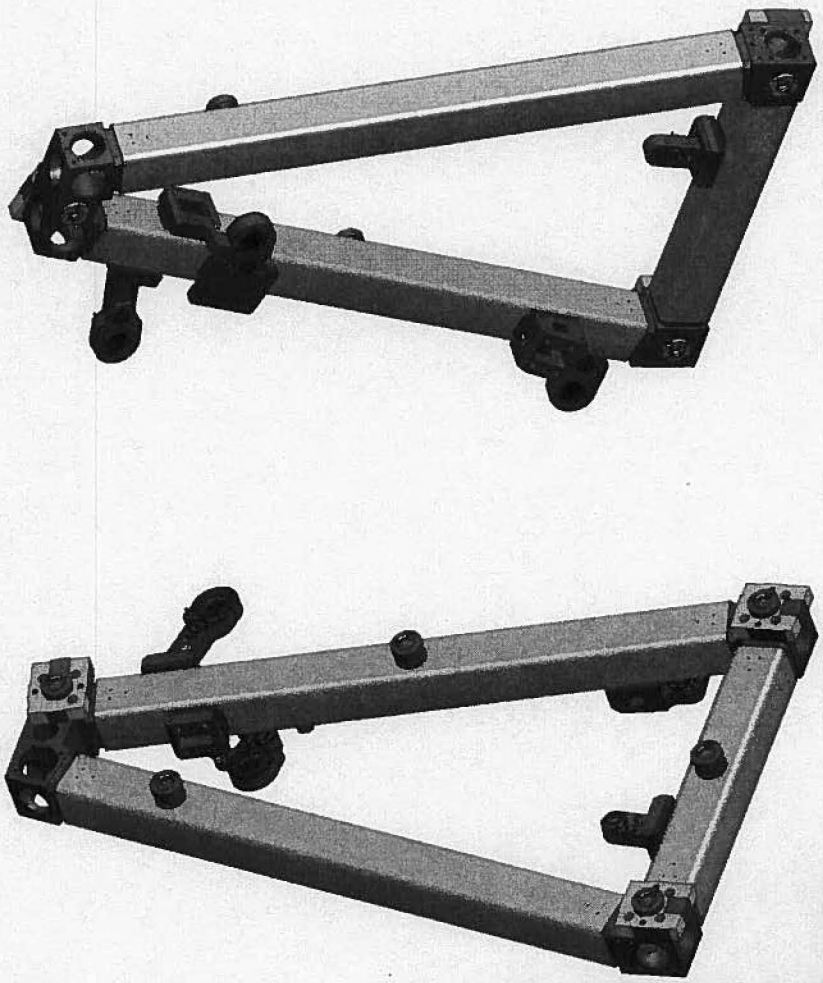
James Webb Space Telescope



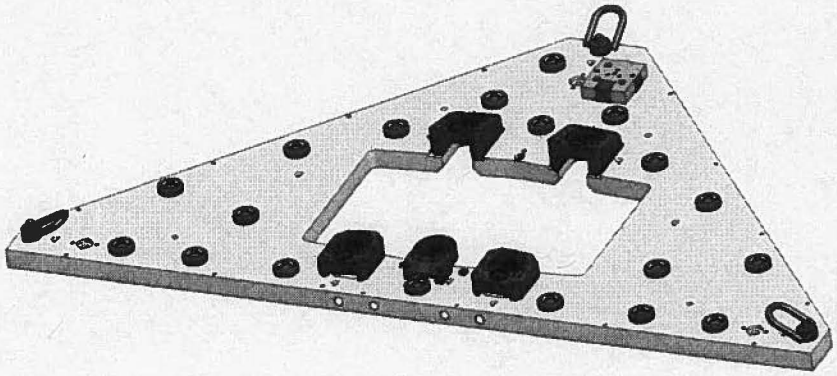
XATF

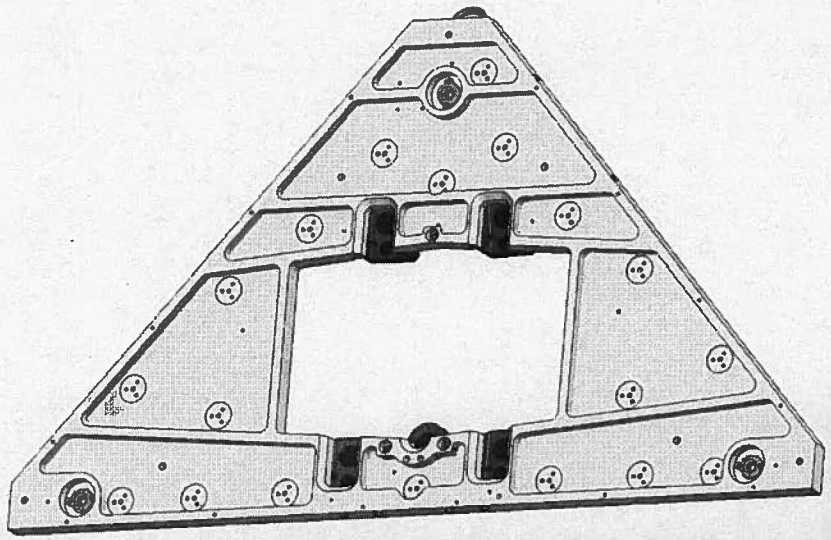
- XATF includes two assemblies.
  - ISIM Alignment Target Fixture (IATF)
  - Master Alignment Target Fixture (MATF)
- The fixtures contain optical targets that are used to align the JWST instruments.
- XATF is made primarily of invar and composite for low CTE.

IATF



MATF





XATF Test

- XATF must be optically characterized at ambient and cryogenic temperatures prior to integration with ISIM and testing.
- Laser radar and theodolite are used to take measurements of various targets to characterize the assemblies.
- A window made of fused silica and ground very parallel minimized effects on the laser radar and theodolite beams.

Laser Radar and Theodolite Mounted Outside Chamber Window

Laser Radar Targets

- Retro Reflectors
- Flat Mirrors
- LEDs
- Tooling Balls (in SMR nests)
- Holes
- Flat Surfaces

Optical Metrology

- Fixtures are kinematically mounted inside the thermal shrouds such that all targets are visible from the window.
- Metrology accuracy must be within microns, therefore stability is vital.
  - Vibrations can interfere with metrology.
  - Thermal stability must be less than one degree per hour.
  - Kinematic mounts do not induce moments.

XATF Setup

Thermal Requirements

- <1K/hr drift during metrology
- 10K/hr rate limit
- <50K thermal gradient on IATF (37K yellow limit)
- IATF average <50K, MATF average <35K to begin cold metrology

Thermal Shrouds

- Facility 238 is equipped with a Nitrogen shroud. Liquid Nitrogen (LN2) is used to reduce the thermal gradient.
- An inner shroud called "The Doghouse" is used to obtain cryogenic temperatures. The Doghouse lines can carry liquid Helium (LHe) or gaseous Nitrogen (GN2).

Thermal Setup

- Copper thermal straps conduct heat to the payload without inducing any moments.
- Heaters are applied to the Doghouse panels.
- XATF fixtures have a view of the Doghouse for radiative heat transfer.
- Gaseous Helium (GHe) is used while under vacuum for Free Molecular Heat Transfer (FMHT).

FMHT

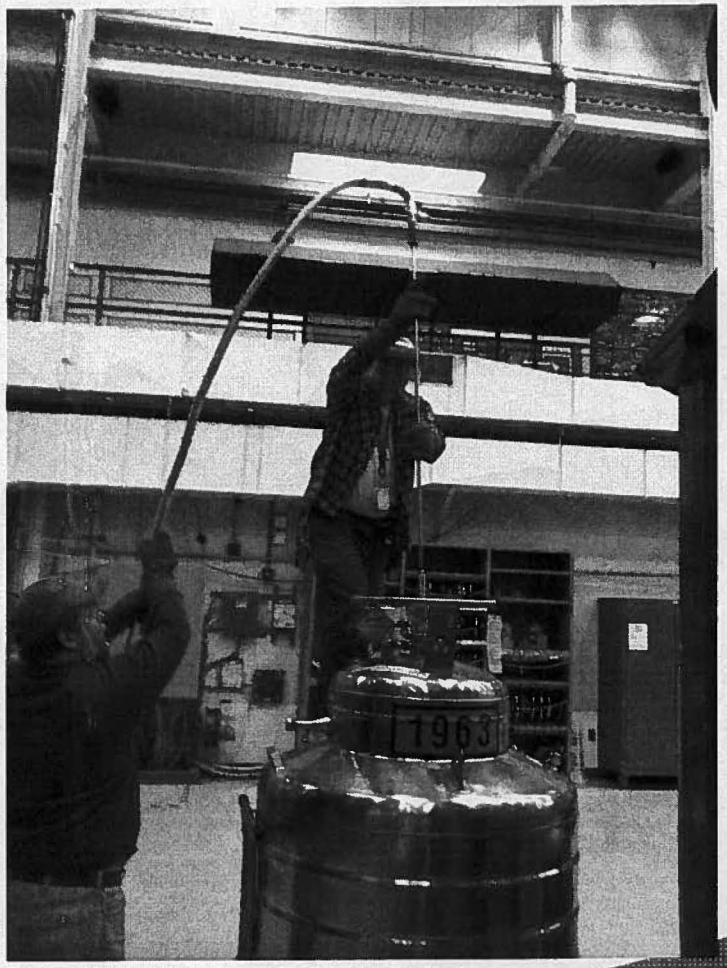
- Thermally couples payload to doghouse.
- Cryo pumps are turned off.
  - Reduce vibrations for metrology.
  - Prevent saturation with helium.
- Turbo pumps are on.
- GHe is injected into chamber.
  - Pressure increases to ~5×10^{-5} Torr.
  - Pressure quickly returns to ~2×10^{-7} Torr when GHe is turned off.

Helium System Issues

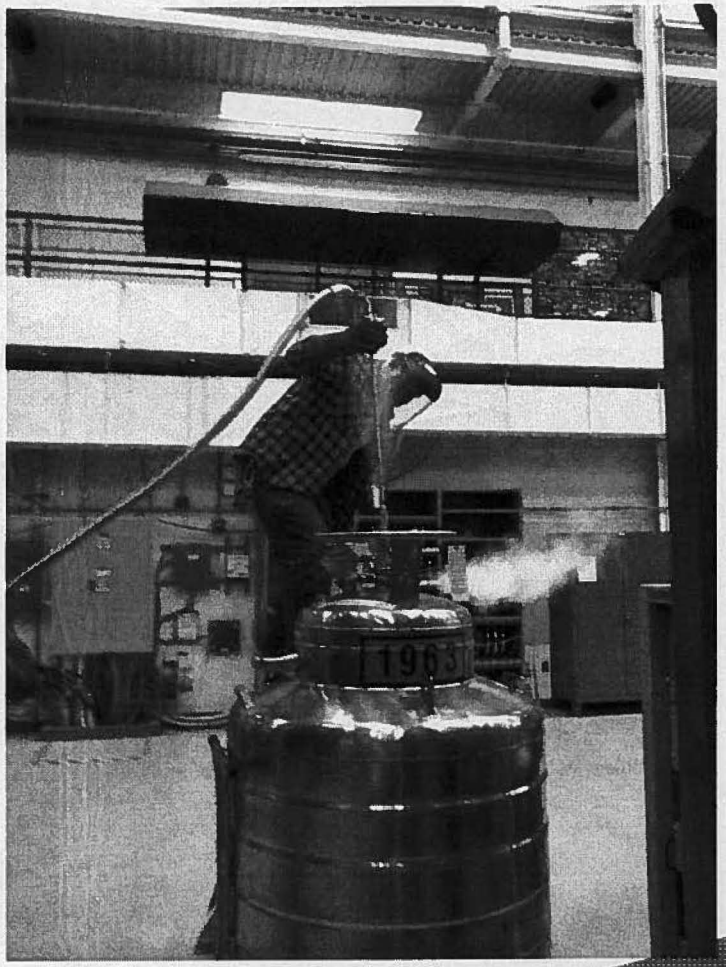
- Helium Flow Stability
- Gas Lock
- Ice Plugs
- Dewar Changeouts

Preventing Ice Plugs

Dewar Changeout



Dewar Changeout



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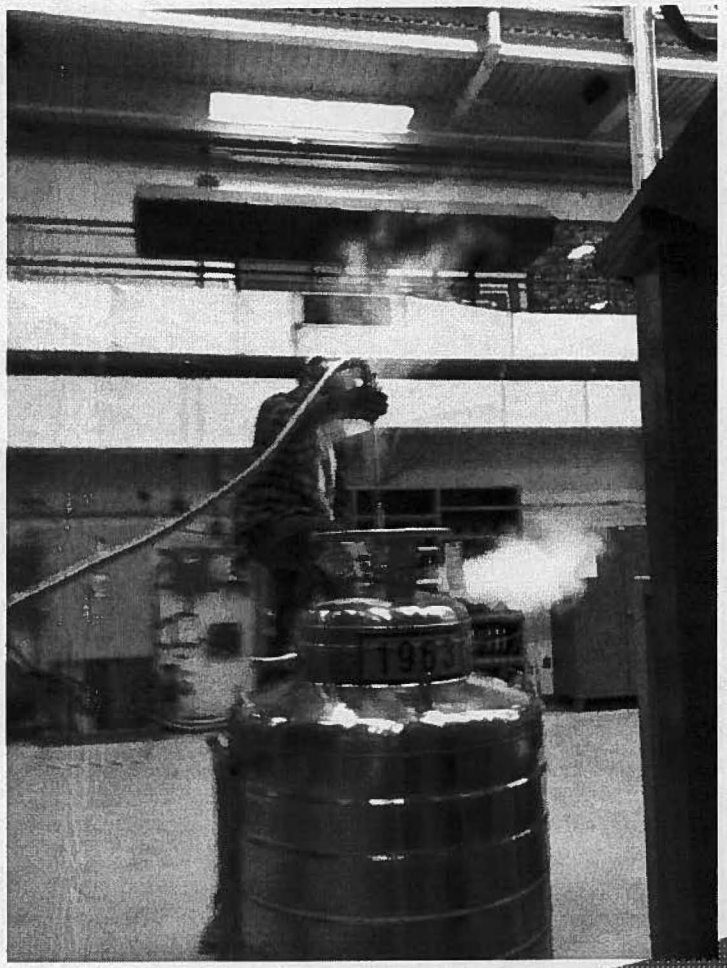

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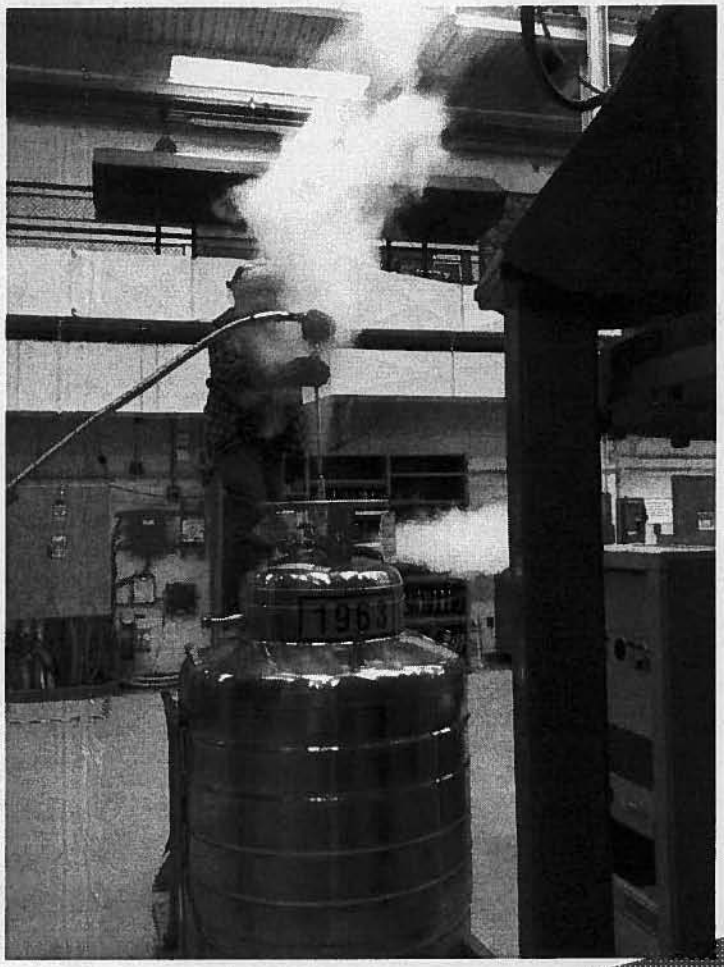
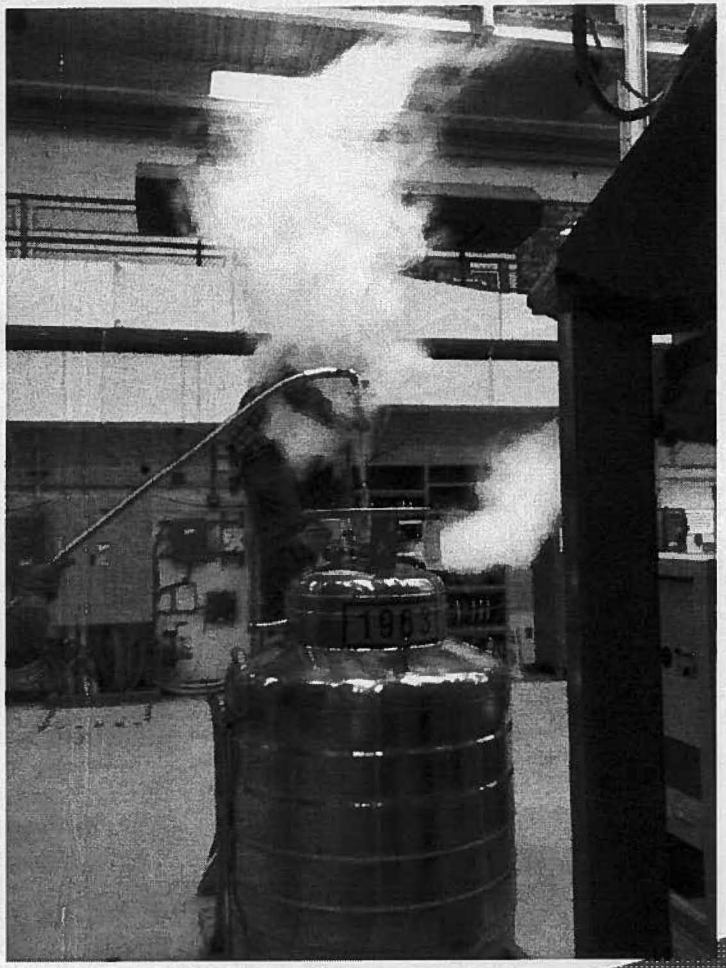
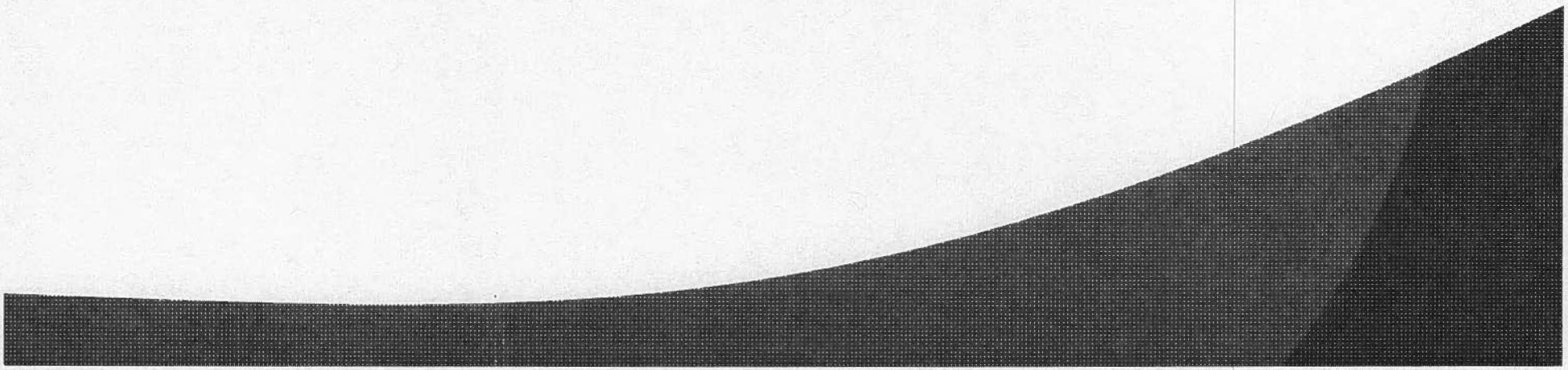


Dewar Changeout



Going Cold

- Small tweaks were required due to <10K/hr rate limits.
- Attempting to drive cold close to rate limit used up to 30 lbs/hr of Helium.



Stabilizing the Payload

- Chamber shroud in LN2 mode.
- Set FMHT (GHe injection) to ~5×10^{-5} Torr.
- Set LHe to 4-7 lbs/hr.
  - Difficult to adjust; best to let it stabilize and adjust heaters accordingly.
  - Rate drifts over time.
- Adjust heaters on bottom panel to compensate for LHe, about 25-150 W.
  - Minor adjustments needed as LHe rate drifts.

Going Warm

- Start with cryo pumps on to reduce contamination risk.
  - Regenerate pumps during breaks from metrology to reduce startup time.
- Small tweaks were required due to <10K/hr rate limits.
- GSE outside of doghouse took a long time to warm up and stabilize.
  - Apply heaters to outside GSE.

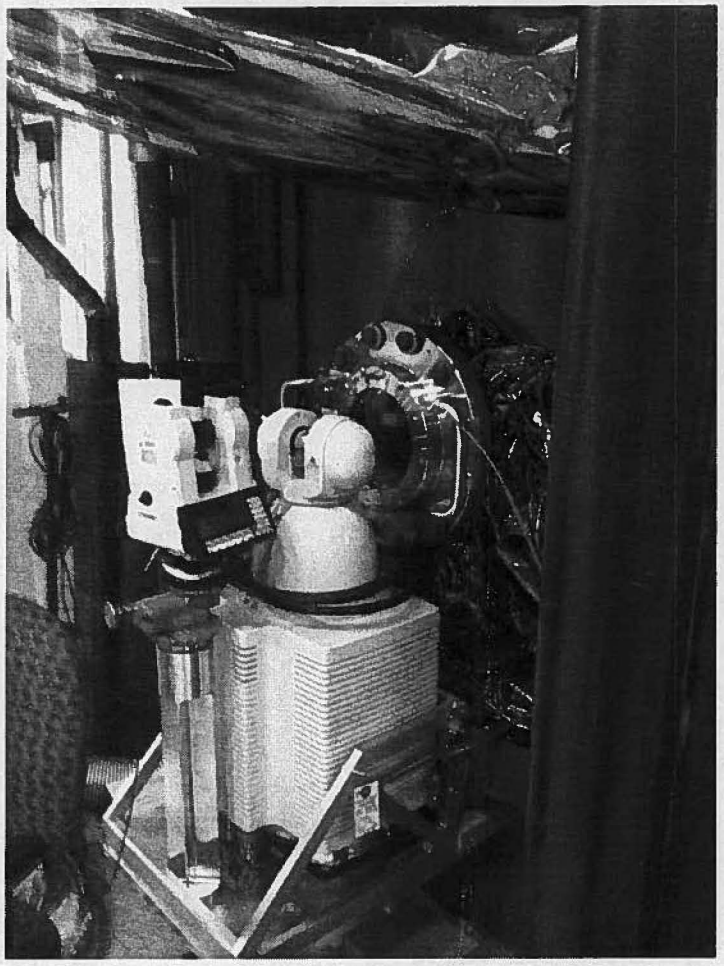
Contamination Control

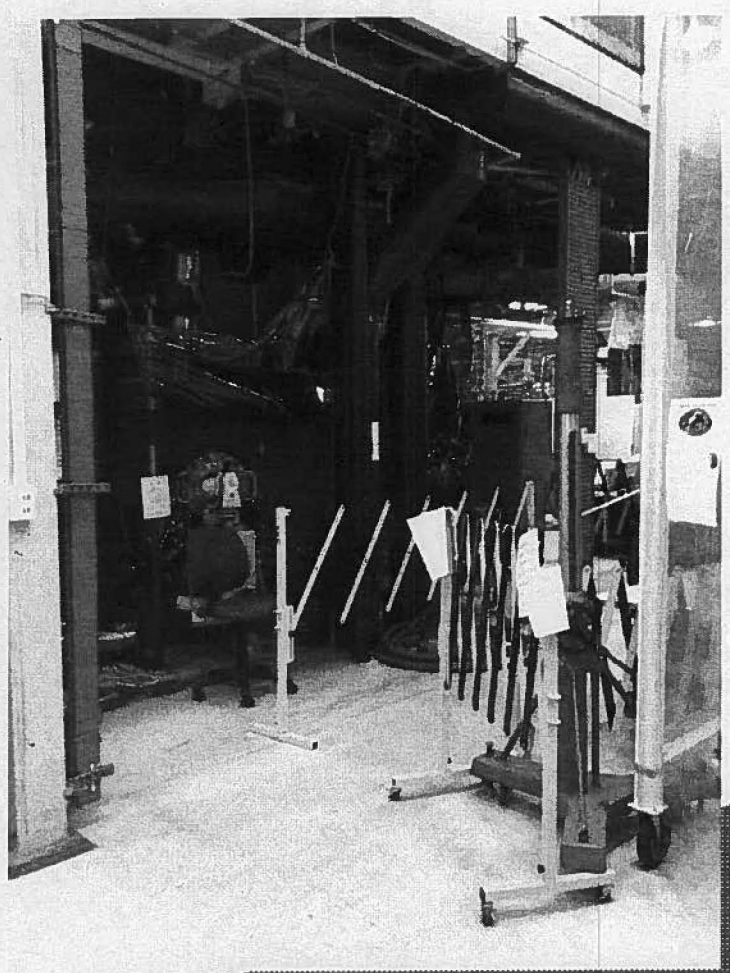
- When going warm, at approximately 30K Nitrogen outgases from the Doghouse.
  - Pressure Increase
  - Increased Risk of Contamination
- The payload should not be the coldest thing in the chamber.
  - Contaminants will redeposit on a colder surface.

Vibration Control

- Vibrations reduce accuracy of laser radar metrology.
- Cryo pumps on Facility 238 and surrounding chambers were turned off.
- It is possible that turbulent LN2 flow in shroud creates additional vibration.

Laser Radar Mounted to Chamber, Not Floor





SBIR

- Flexure Engineering was awarded an SBIR to research and develop a thermal vacuum chamber that is built to take remote metrology.
- The XATF test serves as proof of concept, and demonstrated the need for such a chamber.

Possible Improvements for Future Chambers

- Additional windows
- Helium Shroud with finely tuned helium control system
- Rotary shields or blinds to reduce thermal gradient
- Vibration reduction and/or isolation
- Ground/stabilize payload and laser radar
- Can be adapted for other sensors

Future Applications

- As space telescopes are developed to take more accurate measurements, more accurate testing will be required. Current facilities will be insufficient.
- Remote metrology technology can also be applied to environments that are hazardous to humans, such as machining beryllium.
- Improvements in cryogenic testing can benefit other space projects as well as superconductors.

QUESTIONS?