CRYOGENIC TELESCOPE TEST FACILITY

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ABSTRACT

An optical test Dewar has been constructed with the unique capability to test mirrors of diameters 1 m, $f \leq 6$, at temperatures from 300 to 5 K with a ZYGO Mark IV/V interferometer. The facility possesses extensive thermometry throughout for characterization of the test chamber thermal environment and Dewar performance. Optical access is controlled with cryogenically cooled shutters. The entire Dewar is vibration isolated by 40 dB where the fundamental resonances of the Dewar structure are highest. The facility has been brought on line for its first user, the Infrared Telescope Technology Testbed (ITTT) for the Space Infrared Telescope Facility (SIRTF) at JPL The design requirements for this facility and the resultant design and implementation experiences and challenges will be presented.

1 INTRODUCTION

In the astronomical community there is clearly the desire for large spaceborne optical systems. Due to NASA's need to produce smaller, lighter, lower cost spacecraft, there exists an effort to develop large lightweighted optics, In order to mitigate the risk of using these new lightweight technologies, it was necessary to build a facility to permit the testing of these systems. In keeping with NASA's desire to simplify and reduce the cost of flight operations, the Jet Propulsion Laboratory (JPL) undertook the task of a quick development, low cost facility for the optical interferometric testing of mirrors of diameters 1 m, $f \leq 6$, at temperatures from 300 to 5 K. The project was constrained by an allocation of one year in which to complete the design, fabrication, and optical qualification test, with funding commensurate with the allotted schedule. The system design performance was traded off against cost to minimize the resources necessary to develop the system yet still meet the requirements for cryogenic optical testing. The Dewar, instrumentation, vibration isolation and support equipment were all treated in the trade space. The facility requirements were that: the system environment be stable enough for $\lambda/40$ rms interferometric measurements with a helium neon laser interferometer, the Dewar permit disassembly for mounting the test apparatus, and that all surfaces in the test chamber reach 8K. Two goals of the facility were to reach equilibrium in no more than 72 hours and that cryogen hold time be at least 72 hours.

The approach was the use of a small, dedicated team with an industry partner (Janis Research Co., Inc.) for the Dewar fabrication, Specific expertise was procured on an as needed basis. Another part of the approach was to use, to the extent possible, hardware inherited from previous JPL projects.

GENERAL FEATURES

Dewar structure

The Dewar has a vertically oriented inner cylindrical test chamber with a diameter of 1.4 m and an internal eight of 2.3 m. The experiment mounting surfaces, the upper and lower surfaces of the chamber, are the exterior surfaces of two liquid helium tanks. The upper liquid helium tank maybe positioned at any height within the cylindrical wall of the test chamber to facilitate the testing of optics with various focal lengths. The cylindrical wall of the test chamber is conductively cooled by two 300 liter capacity tanks. All exterior helium cooled surfaces (tank walls and shroud) are covered with a single layer of aluminized mylar to raise the surface emissivity[1]. Surrounding the test chamber is an aluminum dome covered with a 10 layer multi-layer insulation (MLI) blanket made of layers of aluminized mylar with spacer material[2]. This dome is conductively cooled through a bolted contact joint with a3001iter capacity liquid nitrogen tank (which also hasa 10 layer MLI blanket) directly below the helium cooled test chamber. The outer vacuum shell of the Dewar is constructed of an aluminum dome that makes an O - Ring seal with a stainless lower shell

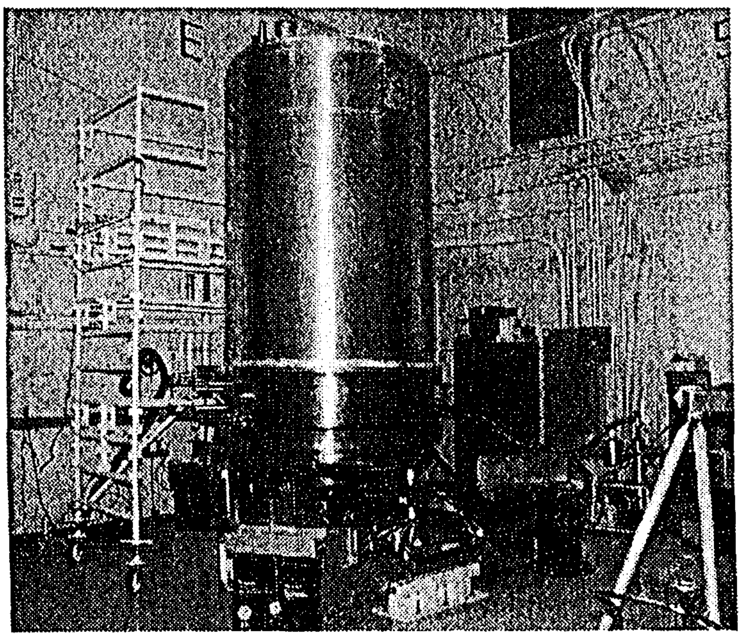


Figure. 1. SIRTF Telescope Test Facility (STTF)

surrounding the lower cryogen tanks. Structural and thermal separation between the outer vacuum shell, the nitrogen tank, and the lower helium tank is provided by titanium struts and a stainless tension/compression system necessary for earthquake safe operation of the facility *in* southern California. The entire Dewar is designed to withstand 1.0 g in the vertical and 0.5 g in the horizontal axis without serious hazard to human safety. Optical access is provided through a window at the bottom of the Dewar, with cryogenically cooled bathes and shutters in the apertures through the lower cryogen tanks. The Dewar was fabricated through a partnering arrangement with Janis Research Company, Inc.

Instrumentation

The facility possesses 61 resistance thermometers with multiplexed "quasi" 4- wire dc readout for characterization of the test chamber thermal environment and Dewar performance. All three cryogen tanks have resistive elements inside with multiplexed "quasi" 4- wire dc readout for detection of liquid nitrogen level. Both helium tanks have superconducting helium level sensors. The Dewar guard vacuum is monitored with two pairs of cold cathode and Pirani sensors. All instrumentation control and data acquisition is accomplished with a GPIB interfaced Pentium based personal computer. Graphical user interface software written with LabView permits real-time monitoring and analysis of facility parameters.

Cryogenic Optics

A two axis optical gimbal mechanism[3] for aligning 1 meter diameter telescope primaries and test flat mirrors at temperatures from 300 to 4.2 K was constructed for use in the STTF. This mechanism consists of an aluminum frame, pivoting on a monoball bearing, and driven in tip and tilt by tungsten di-sulfide lubricated lead screws with external room temperature drive motors. Flexures decouple the optical support frame from stresses generated by differential rates of cooling. A second set of flexures decouples the mirror mechanically and thermally from distortion in the gimbal mechanism. The mechanism provides arc-second resolution in either axis, while designed to limit the heat leak to less

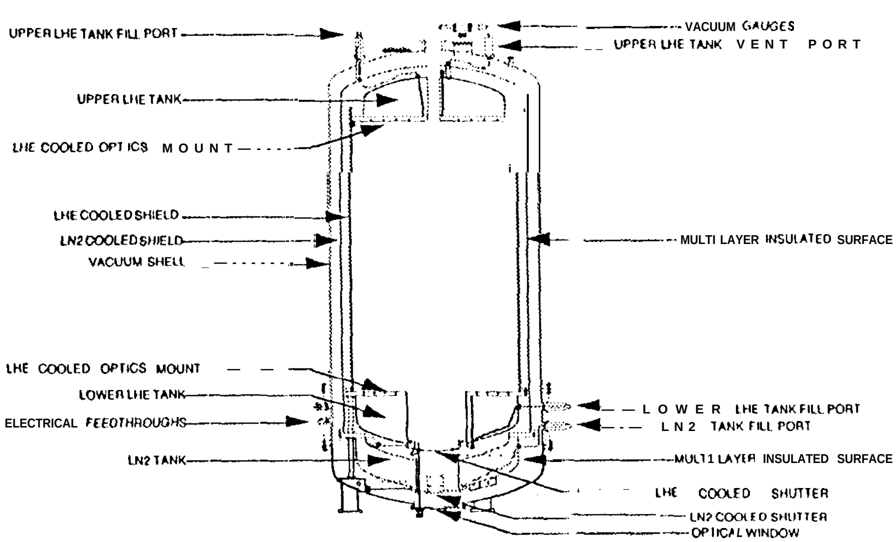


Figure. 2. STTF Dewar structure

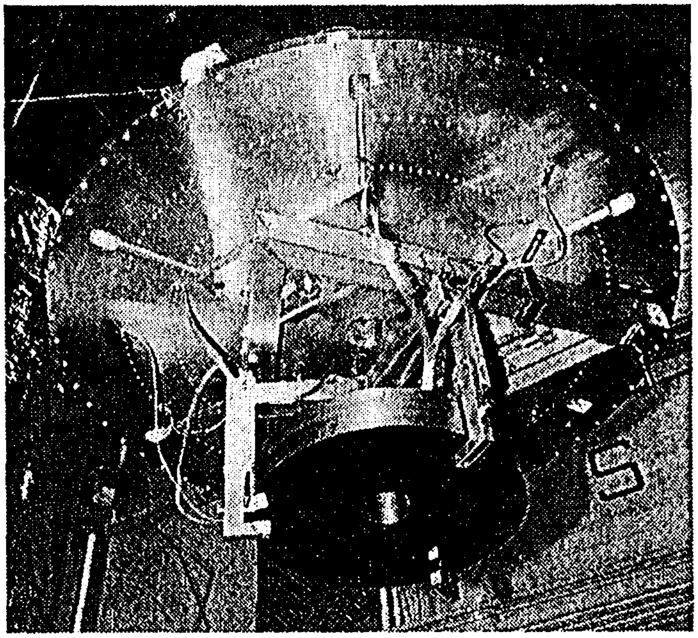


Figure 3. Upper helium tank with gimbal and 0.5 m beryllium mirror center of the figure

than 100 mW at 4.2 K. Linear variable differential transformers (LVDT's) were used at temperatures from 300 to 4.2 K as readout for the gimbal mechanism. The full system was qualified by obtaining λ/40 interferograms of a well-characterized beryllium mirror at room temperature, 77K and 6K. These tests proved to be successful and have been presented elsewhere.[4]

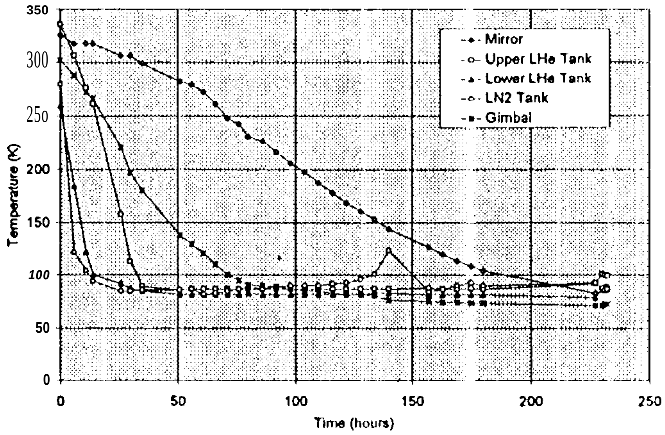
Facility Infrastructure

The Dewar was mounted on an existing triangular vibration isolation frame that was modified to provide additional strength to meet earthquake safety requirements and to provide additional stiffening to improve stability for optical measurements The vibration isolation frame was supported by three pairs of Newport I-2ooO pneumatic isolators that have been measured to give the entire facility up to 40 dB of isolation from vibrations in the floor from 5 to 20 Hz (the dominant vibration coupling to the Dewar is through acoustic coupling to the walls of the room).'

The attachment and optical alignment of the interferometer components is achieved on standard optical breadboards bolted to the vibration isolation frame, Accelerometer spectra indicate that the vibration isolation frame, the Dewar, and the optical component mounting surfaces respond as a single unit to external vibration.

CRYO-SERVICING AND SYSTEM PERFORMANCE

Two system tests have been performed. The first test was to qualify the facility for optical testing using a ZYGO Mark IV interferometer and a 0.5 m diameter beryllium mirror. The second test was performed after procedural and hardware improvements identified from the first test were implemented. The second test also utilized a new interferometer (ZYGO Mark V).



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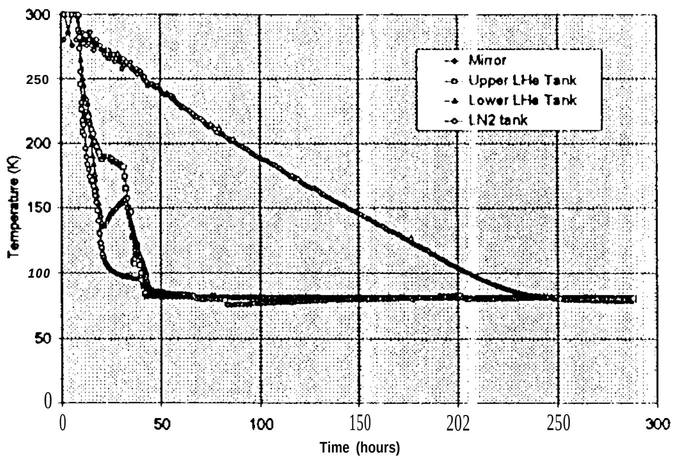


(b)

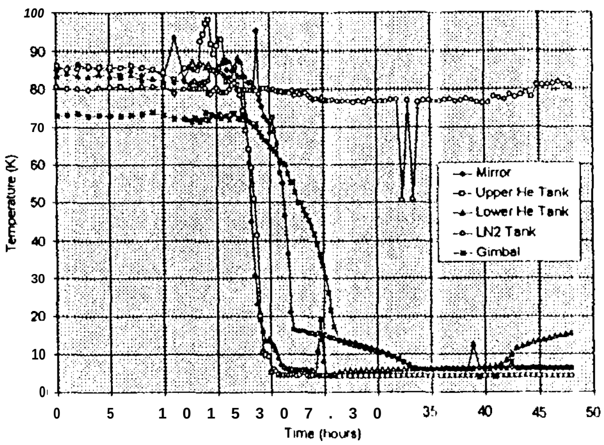
Figure 4. LN_2 cooldown data for (a) first test and (b) second test of the STTF.

Liquid nitrogen cool down

After achieving a guard vacuum of better than 10-4 Torr in the Dewar, the cool down begins with the introduction of liquid nitrogen into all three cryogen tanks simultaneously. Cool down is achieved by first cooling the tank walls adequately to accumulate liquid inside and till the tanks, with the conductively cooled surfaces then relaxing to equilibrium with a longer time constant. Results of the LN_2 cooldown are shown in Figure 4. Cooldown of the dewar itself took about 72 hours in the first test and 50 hours in the second test. However, the cooldown of the mirror took much longer, 225 hours in each test. The mirror was thermally attached to the upper tank by 6 copper braid straps bolted at 6 locations to the tank and 3 locations on the mirror. One improvement, that is evident in Figure 4, is that the upper tank thermal attachment to the LN_2 tank was made much more sound for test #2 based on the result of the first test. This is shown by the more uniform temperature distribution at times greater than 50 hours

Liquid helium cool down

To cool the test chamber below liquid nitrogen temperatures, any remaining liquid nitrogen is purged from both liquid helium tanks by over pressurizing the tanks with helium gas. Liquid helium is then transferred into both tanks simultaneously. Cool down was achieved by first cooling the tank walls adequately to accumulate liquid inside and fill the tanks, with the conductively cooled surfaces then quickly relaxing to equilibrium. Cool down to steady state took about 24 hours and required approximately 1200 liters of liquid helium when transferring at an average rate of 1 liter/minute into each tank. At steady state the guard vacuum was approximately 10^{-6} Torr in the Dewar Results similar to Figure 4 for the helium cooldowns of tests 1 and 2 are shown in Figure 5. Figure 6, shows most clearly the effect of the additional thermal strapping added between the upper tank and the helium shroud (twenty two 3.8 cm wide, 0.6 cm thick copper straps). This figure shows the axial temperature variations of that surface when at helium temperatures. In the first series of tests, there was up to SK variation along the surface. This improvement was critical to the facility as later tests are planned for the Space Infrared telescope Facility which have a



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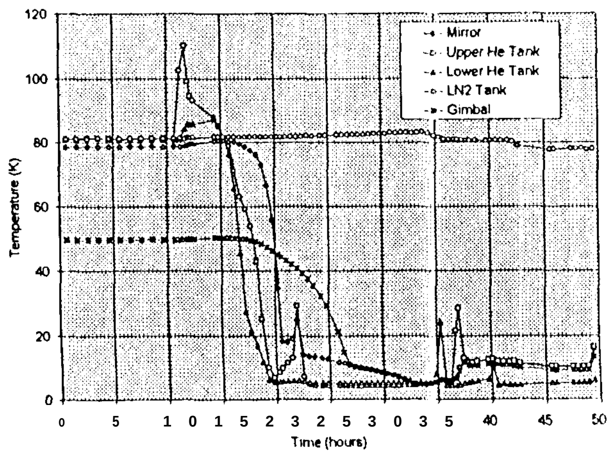


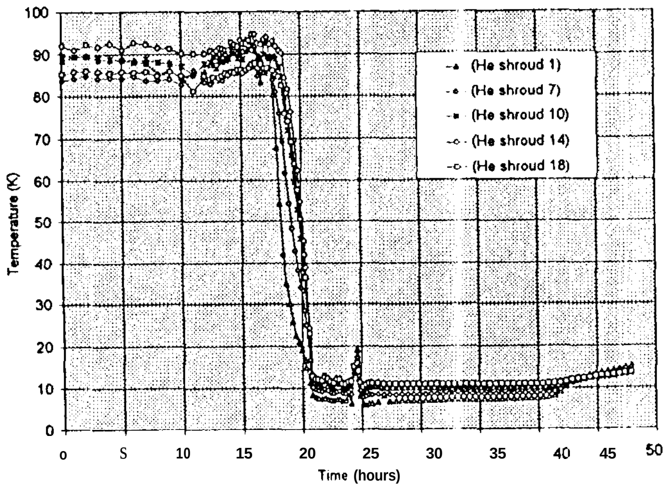
(b)

Figure 5. LHe cooldown for (a) first helium test and (b) second helium test.

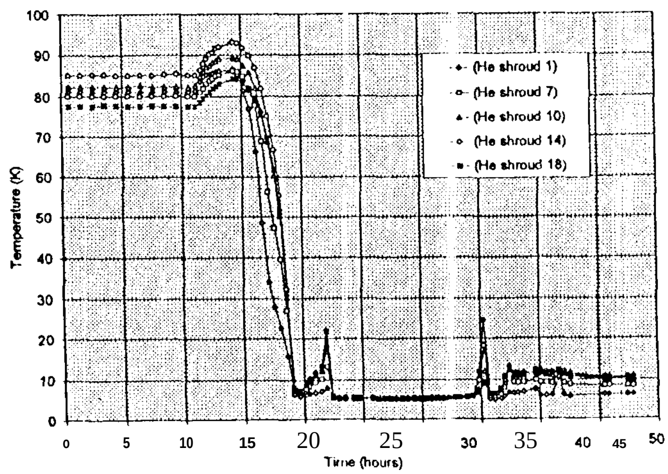
requirement that no helium cooled surface have a temperature greater than 6. SK. The excursions in temperature in Figure 6(b) at 35 hours are due to one of the helium tank (the upper tank) running out of helium.

Sternly **State Performance**

Steady state parasitic heat rate data for both tests of the test facility is presented in Table 1. The poor thermal connection between the upper helium tank and shroud in the first test is again evident in this data, particularly at helium temperature. Unfortunately, helium temperature data for the second test were not gotten due to a problem encountered late in the test. However, the load on the upper helium tank is evident even at nitrogen temperatures. We expect that the parasitic rate at helium temperatures would have roughly a 60-40 split, upper tank to lower tank of the total parasitic load (or slightly less) seen in the



(a)



(b)

Figure 6. Helium shroud axial temperature variation for (a) first test and (b) second test

first test. Although this performance is not particularly good from a cryogenics perspective, it does meet all of the requirements for optical testing, However because of the resource limitations of the project, thermal performance was forsaken for savings in cost and delivery schedule.

A thermal model of the system' indicates that the majority of the heat load is through radiative transport. If a thermal improvement were necessary, it could most likely be achieved by adding 5 to 10 more layers of well laid ML] between the outer shell of the system and the nitrogen shroud.

Table 1, Heat loads on helium and nitrogen tanks,

	First Test		Second Test	
	LN_2	LHe	LN_2	LHe
Upper He Tank	2.4 W	2.2 W	3.7 W	NA
Lower He Tank	2.8 W	9.7 W	2.5 W	NA
LN_2 Tank	99 W	57 W	78 W	NA

SUMMARY

Developed by the Jet Propulsion Laboratory's Low Temperature Science and Engineering Group, the SIRTF Telescope Test Facility (STTF) was completed, from conceptual design through construction and evaluation testing, in less than one year and within the allocated budget. Two system tests have been performed and the system has been fully qualified as meeting the performance criteria both cryogenically and optically. The facility has the unique capability to conduct interferometric tests of mirrors of diameters 1 m, f $\leq$ 6, at temperatures from 300 to 5 K. The facility includes instrumentation for characterization of the test chamber thermal environment and Dewar performance.

ACKNOWLEDGMENT

This work was performed by the Jet Propulsion Laboratory, California Institute of Technology under contract to NASA Special thanks to Dr. Dan Coulter of the Jet Propulsion Laboratory for his continued support during this development,

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