The SIRTF Telescope Test Facility

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ABSTRACT

In this paper we describe the key features of the SIRTF Telescope Test Facility developed at the Jet Propulsion Laboratory. Information on the cryogenic performance including details of the test cycle time and cryogen hold time will be included. Emphasis will be on the operation of the facility. Data will be presented on the cryogenic optical testing of the ultra-lightweight 85cm diameter beryllium primary mirror assembly for the Infrared Telescope Technology Testbed.

Key Words: Optics testing, cryogenic optics, SIRTF, telescope

1. INTRODUCTION

Early in 1994, the Jet Propulsion Laboratory (JPL) embarked on an effort to develop and demonstrate an ultra-lightweight cryogenic infrared telescope for the Space Infrared Tel escope Facility (SIRTF). This effort, which is part of the NASA Code X supported Telescope Technology Program, has three principal elements. The first is the design and development of the Infrared Telescope Technology Testbed (ITTT) which is a full scale technology demonstration of a SIRTF class telescope. The second is the development of the SIRTF Telescope Test Facility (STTF), a state-of-the-art, cryogenic optical test facility capable of supporting testing of the ITTT and the SIRTF flight telescope at liquid helium temperature. The final element is the design and development of a meter class silicon carbide Cryogenic Optical Test Flat (COTF) which will be installed in the STTF and enable autocollimati on testing of the ITTT telescope assembly. The design, development and initial checkout of the STTF has been reported in detail elsewhere[1,2]. This paper will focus on the initial operational phase of the facility- the testing of the ITTT primary mirror assembly (PMA).

2. THE INFRARED TELESCOPE TECHNOLOGY TESTBED

In June of 1994, JPL issued the Infrared Telescope Technology Testbed RFP inviting industry and academia to propose to design and build a prototype telescope meeting the needs of the SIRTF mission. The principal requirements levied on the proposers were that the ITTT should achieve diffraction limited performance at 6.5μm, at 5.5K with an 85cm clear aperture and a total mass of <50kg. The primary mirror and system focal ratios were specified as F/1.2 and F/12 respectively, Hughes Danbury Optical Systems (HDOS) was selected to build the ITTT based on their concept for a (nearly) all beryllium telescope. A schematic representation of the HDOS ITTT design is shown in

Figure 1. The telescope is fabricated from hot isostatic pressed I-70H (special) beryllium except for six titanium biped flexures and several pins used to mount the primary and secondary mirrors. The design is based on a single arch primary mirror attached to a lightweight bulkhead via three of the flexures. The secondary mirror is mounted in a similar fashion to the secondary mirror cell. The secondary mirror cell is attached to a lightweight metering tower which incorporates the primary and secondary cone baffles and three longitudinal struts into a single machined piece. Copper cooling straps are used to facilitate cooling of the ITTT in the test chamber. The secondary mirror cell is designed to accommodate a one degree of freedom focus mechanism but this element has not been incorporated into the current hardware. The total mass of the ITTT at completion is estimated to be approximately 30kg. HDOS has fabricated the primary mirror assembly (PMA) which includes the primary mirror, the bulkhead, the metering tower adapter tube, the primary mirror biped flexures and the cooling straps. A photograph of the ITTT PMA is shown in Figure 2. The large plate at the bottom of the assembly is an aluminum adapter plate attached to the bulkhead via three aluminum bipeds which interfaces to the STTF. The initial cryo-optical testing of the PMA has been completed and will be described in detail later in this paper. The PMA has been returned to HDOS for final figuring. The remaining pieces of the ITTT including the secondary mirror, the secondary mirror cell and the metering tower are still in fabrication and will be delivered to JPL later this year for integration with the PMA and final testing.

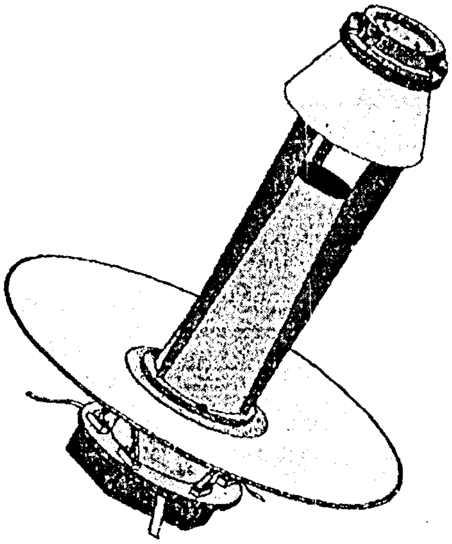

Figure 1. Schematic Diagram of The Infrared Telescope Technology Testbed

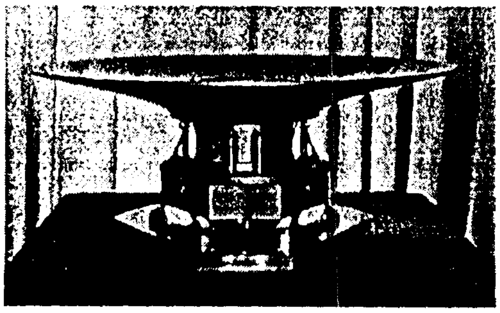

Figure 2. Infrared Telescope Technology Testbed Primary Mirror Assembly.

3. THE SIRTF TELESCOPE TEST FACILITY

As mentioned earlier, the details of the design and construction of the STTF are described elsewhere.[1,2] The facility was a joint development of JPL and Janis Research, Inc. A photograph of the facility is shown in Figure 3. Briefly, the facility consists of three concentric shells. The outer shell maintains vacuum, the intermediates shell is at liquid nitrogen temperature cooled by a single tank at the base, and the inner shell is at liquid helium temperature cooled by dual tanks at the top and bottom. These tanks also supply cryogen for cooling a vibration isolated precision gimbal mount and the experimental hardware which can be mounted either on the upper or lower tank. The upper tank is movable within the helium shroud thus accommodating optics of differing focal ratio. Each of the tanks has a cylindrical hole through its center to allow light to pass, The interior diameter of the helium shroud is 1.4m. In the testing of the PMA, it is mounted to the gimbal via three titanium flexures and the gimbal/PMA assembly is attached to the base of the upper tank with the mirror facing down. Copper straps to the tank baseplate provide cooling and platinum resistance thermometers provide a means to monitor temperature. Near the base, are two shutters, an inner one at helium temperature and outer one at nitrogen temperature. These are normally closed and can be easily and quickly opened prior to measurement,

The base of the vacuum shell has an optical window, below which is an instrument rack upon which rests a turning mirror, a null lens and the Zygo GPI phase shifting visible (0.633μm) interferometer. The entire assembly, tank and instrument rack is mounted on a large aluminum triangular frame which rests on three Newport pneumatic vibration isolation legs.

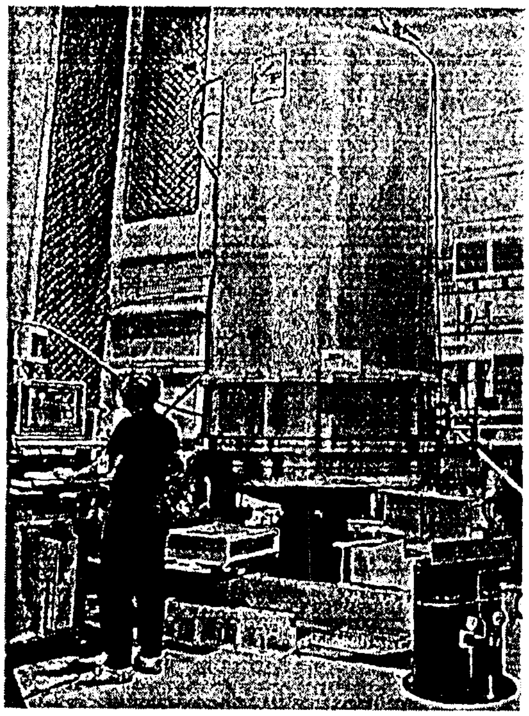

Figure 3. The SIRTF Telescope Test Facility

4. THE CRYOGENIC OPTICAL TEST FLAT

The COTF is a 90cm diameter reaction bonded silicon carbide optical test flat which Lockheed-Martin Missiles and Space is providing via a collaboration with the Vavilov State Optics Institute in St. Petersburg, Russia. The principal requirement is that the COTF maintain a surface flatness of ≤0.07μm at S. SK, The optic and its six point aluminum mount is currently in fabrication in Russia and is due to be delivered shortly for integration into the STTF. A picture of the back side of the COTF blank is shown in Figure 4.

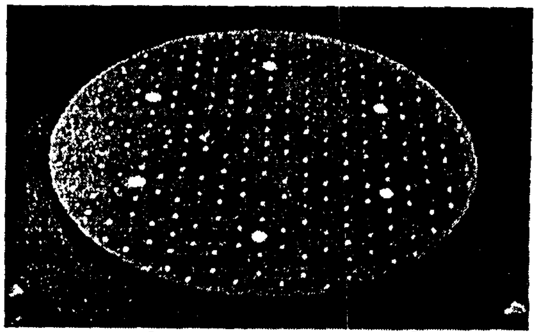

Figure 4. The Cryogenic Optical Test Flat blank in fabrication at Vavilov State Optics Institute in St. Petersburg, Russia.

When the COTF arrives, it will be mounted on the gimbal and attached to the upper helium tank, Once all the ITTT hardware is completed and delivered to JPL, the fully integrated ITTT will be mounted on the lower helium tank facing up. Autocollimation tests will then be performed to verify performance of the fully integrated telescope assembly.

5, CRYOGENIC OPTICAL TESTING OF THE ITTT PRIMARY MIRROR ASSEMBLY

The loading of the PMA into the STTF is accomplished by removing the vacuum shell, the nitrogen shroud and the upper helium tank assembly with an overhead bridge crane, The upper tank assembly is positioned on a work stand and the PMA adapter plate is mounted to the gimbal through the titanium flexures. Heat straps are then attached between the adapter plate and the base of the upper tank. Temperature sensors are applied to the PMA at various locations with silicone adhesive. The upper tank assembly is then carefully lifted into position inside the helium shroud. Large copper straps are positioned between the tank and the shroud. The nitrogen shroud and the vacuum shell are then replaced and secured with large bolts. This entire process is easily accomplished in one day.

The tank is then evacuated, normally overnight, baseline room temperature interferograms are recorded, and cooling is commenced. In the most recent tests, the time required to cool the PMA to 77K from room temperature (including fill time) is approximately 80 hours, Once the PMA has equilibrated at 77K, more interferograms are recorded. Cooling to liquid helium temperature requires approximately another 12 hours (including fill time). With the tanks full, the hold time is approximately 30 hours. In the most recent tests, the PMA temperature stabilized at 4.8K. Interferograms were recorded and the facility was allowed to warm up. The warm up time to room temperature is approximately 90 hours. An entire test cycle can be performed in approximately two weeks if everything goes smooth! y.

6. TEST RESULTS

The PMA was delivered to JPL by HDOS in July, 1995. The initial room temperature test results for the PMA (Figure 5A) showed an rms surface error of O. 192λ @ 0,633p-I. The peak-to-valley error was 1.56λ. The dominant error feature is a series of concentric zones which resulted from form grinding. The ridges are 1-2 waves in height and will be removed with small tool computer controlled polishing. Historically, large beryllium optics have shown “thermal hysteresis”, that is, they changed shape following cycling between room temperature and cryogenic temperature.[3] Over the past six months, the PMA has been cycled five times to 77K and three times to SK with no evidence of hysteresis. The most recent room temperature data is shown in Figure 5B. The rms surface error is O. 194λ and the peak-to-valley error is 1.36λ. We do not believe that the 0.2λ difference in the peak-to-valley error is significant.

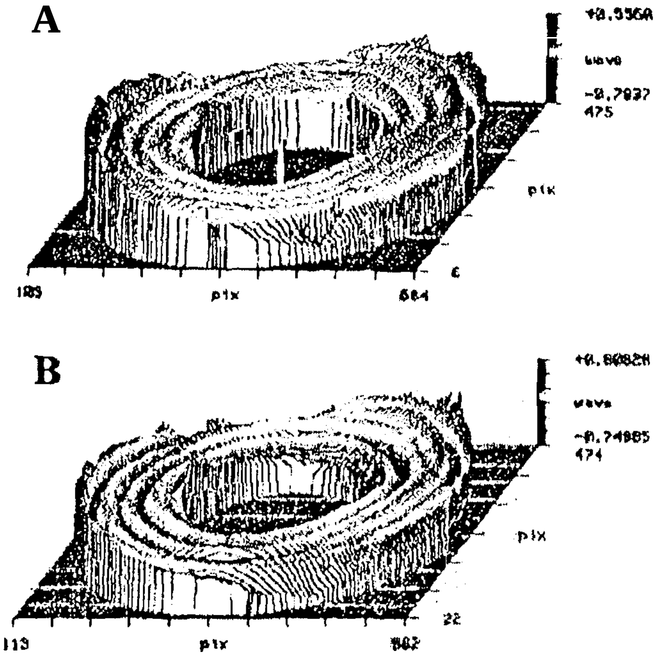

Figure 5. Interferometric data recorded on the ITTT Primary Mirror Assembly at 295K. The upper phase map (A) is as received and the lower one (B) is following 5 cycles to 77K and 3 cycles to 5K.

While the PMA showed no hysteresis, it did show a moderate cryogenic distortion. Typical interferometric data recorded at 77K and SK is shown in Figures 6 and 7 respectively. At 77k, the rms surface error was 0.580~ and the peak-to-valley error was 4.42λ. At 5K, the rms surface error was 0.588λ and the peak-to-valley error was 4.30λ. It is our conclusion that there is essentially no difference between the liquid nitrogen and liquid helium test data. Furthermore, the data was highly repeatable from cycle to cycle.

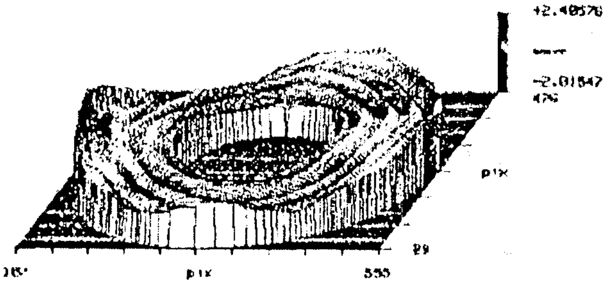

Figure 6. Interferometric data recorded on the ITTT Primary Mirror Assembly at 77K.

Following the initial discovery of the cryo-distortion, an investigation to determine its source ensued. First, the possibility of systematic errors in the test set-up was investigated. The PMA was rotated 120° and cryo-tested again. The cryo-distortion rotated with the hardware. Then, the null lens was rotated 180° with no effect. Secondly, the PMA was decoupled from the aluminum adapter plate and the aluminum biped flexures and cryo-tested suspended from a simple three point kinematic mount. Again, no change was observed. Following that, the primary mirror was removed from the PMA and itself cryo-tested using the same mounting scheme. The observed error in the primary mirror matched the error measured in the PMA thus indicating that the source of the cryo-distortion was in the mirror itself and not in the mounting hardware. Finally, the entire PMA was reassembled and measured once again to liquid helium temperature. The results were identical to those measured earlier,

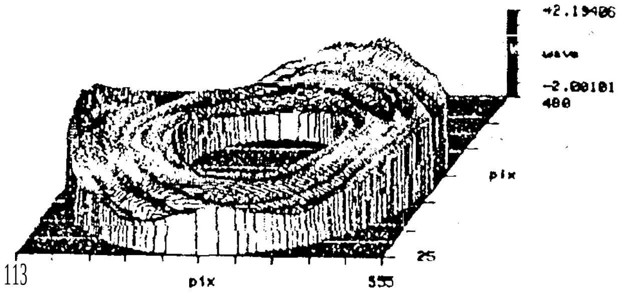

Figure 7. Interferometric data recorded on the ITTT Primary Mirror Assembly at SK

7. FUTURE PLANS

The PMA has been shipped back to HDOS for final figuring, The concentric zones will be removed and the mirror will be null figured (utilizing the most recent liquid helium test data) in such a manner so as to have the correct shape at 5K. This process will be accomplished with computer controlled polishing. As mentioned previously, the remaining pieces of the telescope assembly are currently in fabrication and will be completed soon. The telescope will then be assembled aligned and tested in the STTF. Following the cryo-optical testing, the ITTT will be vibration tested to levels relevant for the Delta 11 launch vehicle and subsequently retested optically to validate performance.

8. ACKNOWLEDGMENTS

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9. REFERENCES

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