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N70-29617

(ACCESSION NUMBER)	(THRU)
14	1
(PAGES)	(CODE)
CR-110349	14
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FACILITY FORM 602

JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

750-10

PHOTOHELIOGRAPH OPTICAL TESTING

August 12, 1968

C. J. Chocol

Approved by:

J. Denton Allen, Task Leader,
Photoheliograph Task

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

Prepared Under Contract No. NAS7-100
National Aeronautics & Space Administration

FOREWORD

This report covers work on one phase of the photoheliograph development task, NASA Code 945-84-00-01-00, for the period November 1967 through June 1968. The photoheliograph has been proposed to NASA for the Apollo telescope mount (ATM) by Caltech, with Professor Harold Zirin as the principal investigator and Dr. Robert Howard of Mt. Wilson and Palomar Observatories the co-investigator (see TM 33-369, November 1967). The objective of the investigation is to obtain high resolution cinematographs in white light near ultraviolet and narrow band hydrogen alpha. Because of the ATM program uncertainties, emphasis has been placed on areas of technology that are somewhat mission-independent, but the ATM spacecraft has been used to establish design constraints.

ABSTRACT

Optical performance of a nearly diffraction limited system for space environment depends upon the quality of the optical elements and the relationship in which they are mounted with respect to each other. Testing of such a system must incorporate equipment and techniques such that the quality can be distinguished from the alignment when subjected to a simulated space environment.

Optical testing on the Photoheliograph will provide quality measurements to $\lambda/40$ (1/40 of a wavelength of light at 5000 Å) and alignment sensitivity to ±0.001 inches translation and ±0.005° tilt. A space environment will be provided consisting of a vacuum at 1×10^{-4} torr and solar simulation at 133 watts/ft^2.

This paper covers the techniques and equipment to be used in testing the Photoheliograph.

CONTENTS

ILLUSTRATIONS

SUMMARY AND CONCLUSIONS

Several methods of adequately measuring the performance of the optical system were considered. A collimator system would require a focal length of over 5000 inches. Focault and Ronchi tests were evaluated but the obtainable accuracy of these tests proved insufficient. Also, reduction of the output of these two tests to a meaningful criteria relative to acceptance or rejection proved difficult. A Twyman-Green type interferometer was chosen because of its high accuracy (i. e. $\lambda/50$,) coupled with the ease with which it can be mounted to the test chamber and the direct reduction of its output to MTF and Strehl ratio for evaluation.

The instrument to be used is an Itek Laser Unequal Path Interferometer (LUPI). Used in conjunction with a 30-inch diameter flat, this instrument is capable of measuring the optical quality of the primary mirror of the Photoheliograph alone or of the entire optical system by autocollimation. Calibration of the interferometer and associated test optics will allow measurements that are accurate to within $\lambda/40$. Data reduction of the interferograms will be by computer program to yield the direct Modulation Transfer Function and subsequently the Strehl ratio.

The interferometer will be used in conjunction with a vacuum chamber. The configuration is shown in Fig. 1. The vacuum chamber will provide the vacuum environment 1×10^{-4} torr and solar simulation of 133 watts/ft^2 over a 30-inch diameter circular area. Isolation of the test chamber from local seismic disturbances is imperative for proper operation of the interferometer.

Application of the test program to the Photoheliograph will be to determine optical performance of the primary mirror in its cell and of the telescope in three modes. First in an aligned condition at nominal temperature with no solar flux. Second, in a space environment with solar flux both aligned and misaligned. And third, to evaluate and initialize the alignment system independent of environment.

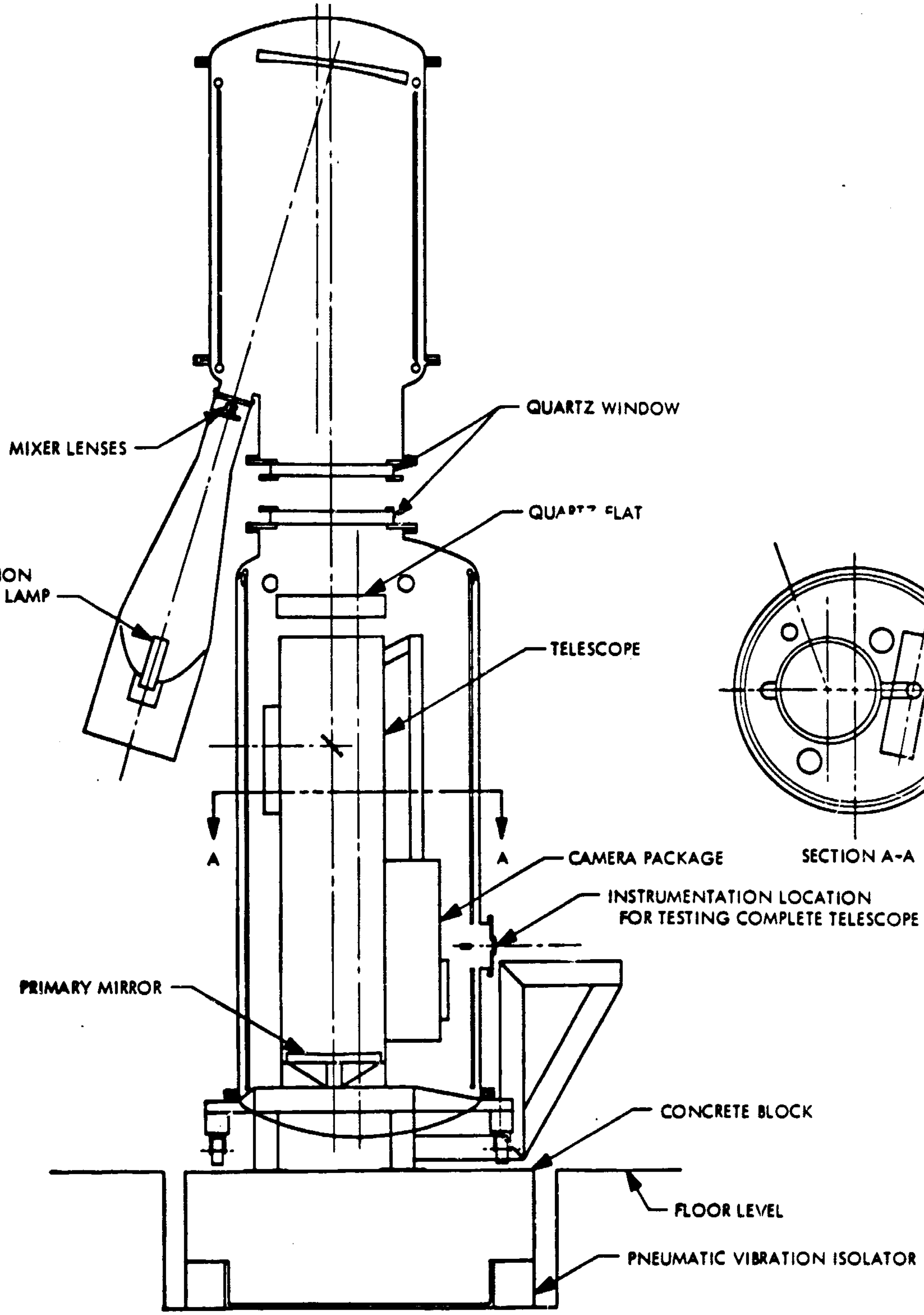

Figure 1. Photoheliograph Test Chamber

PHOTOHELIOGRAPH OPTICAL TESTING

INTRODUCTION

The objective in designing the Photoheliograph is to gain the high resolution achieved by placing an essentially diffraction-limited telescope above the earth's atmosphere. To adequately evaluate this instrument prior to launch, a comprehensive test program is required. The objectives of the test program are to evaluate the structural soundness of the Photoheliograph when subjected to a vibration environment approximating a launch and to determine the optical performance in a space environment with the diffraction limit as a goal. This report describes in detail the test program required to evaluate the optical performance.

TEST METHOD

The theoretical performance of the Gregorian telescope will be 0.19 arc-seconds of resolution (Strehl ratio = 1). Surface errors of the mirrors will degrade the performance, especially since there are four mirrors in the image forming portion of the telescope. However, two of these mirrors are small flats, and it is felt that the random surface errors of these flats can be held to perhaps a 1/100th wave thus opening up the tolerance on the random surface errors on the two curved mirrors (primary and secondary mirrors). The manufacturing tolerance systematic wavefront error of the optical system should be held to approximately 1/15th to 1/20th wave. Systematic thermal distortions of approximately 1/20th wave are anticipated which, combined with the manufacturing tolerance, should lead to approximately 1/10th wave performance. It appears possible through tight control on random and systematic surface errors to achieve a Strehl ratio in the order of 0.8 (a Strehl ratio of 0.8 is equivalent to the Rayleigh quarter-wave criteria). Measurement sensitivity must accordingly be in the range of 1/20th wave for accurate determination of optical performance.

To successfully evaluate the performance of the telescope, measurements of the wavefront errors of the system must be made to within 1/20th wave. The Rayleigh criteria of 1/4 wave optical path difference in the image (Strehl ratio = 0.8) is the expected operating point for the optical system. However, the accuracy of measurement is required to systematically evaluate each contributed error.

The performance will be evaluated then by Strehl ratio and the acceptable limit will be 0.8 or better. The Strehl ratio is also defined as the ratio of the volume under the three-dimensional MTF curve to the volume under the 3-dimensional MTF curve for an aberration free system (Ref. 1). The MTF will be the parameter by which the Strehl ratio is determined and the MTF will be computed from the measured optical path difference of the system. The PAGOS computer program (Program for the Analysis of General Optical Systems) and a program yet to be written will use the measured OPD to compute MTF using a technique described by H. H. Hopkins and J. L. Rayces (Ref. 2).

Characteristics of the telescope that will affect the optical performance as measured by the Strehl ratio are mechanical effects of thermal gradients, misalignment and defocusing.

The optical arrangement (see Fig. 2) for testing either the photoheliograph primary mirror or the entire telescope will be double pass. This means that optical path differences will be twice as large at the interferometer as compared to actual errors generated by the telescope when in use. The double pass system also causes surface deviations of the optical elements to appear four times as large at the interferometer such that a $\lambda/40$ surface error on a mirror will result in a $\lambda/10$ fringe error in the interferometer. Sensitivity of the interferometer single pass is $\lambda/2$ from one maxima to the adjacent maxima of the fringe pattern. A $\lambda/40$ surface error will be easily discernable as a $\lambda/10$ fringe error.

[1] Smith, W. J., Modern Optical Engineering (McGraw-Hill Book Co., New York) 1966, p. 311.

[2] Hopkins, H. H., "The Application of Frequency Response Techniques in Optics," Proc. of London Phys. Soc. Part 5, 79 (511), 889-919 (1962).

Hopkins, H. H., "Numerical Evaluation of the Frequency Response of Optical Systems," Proc. of the London Phys. Soc. Sec. B, 70, 1002-1005 (1957).

Rayces, J. L., "Theory of a Numerical Method for the Computation of Optical Transfer Curves Based on Diffraction," Perkin-Elmer Corp., Report No. 7277, Electro-Optical Division, Norwalk, Connecticut (Rev. July 1962).

OPTICAL-THERMAL-VACUUM TEST CHAMBER PHOTOHELIOGRAPH

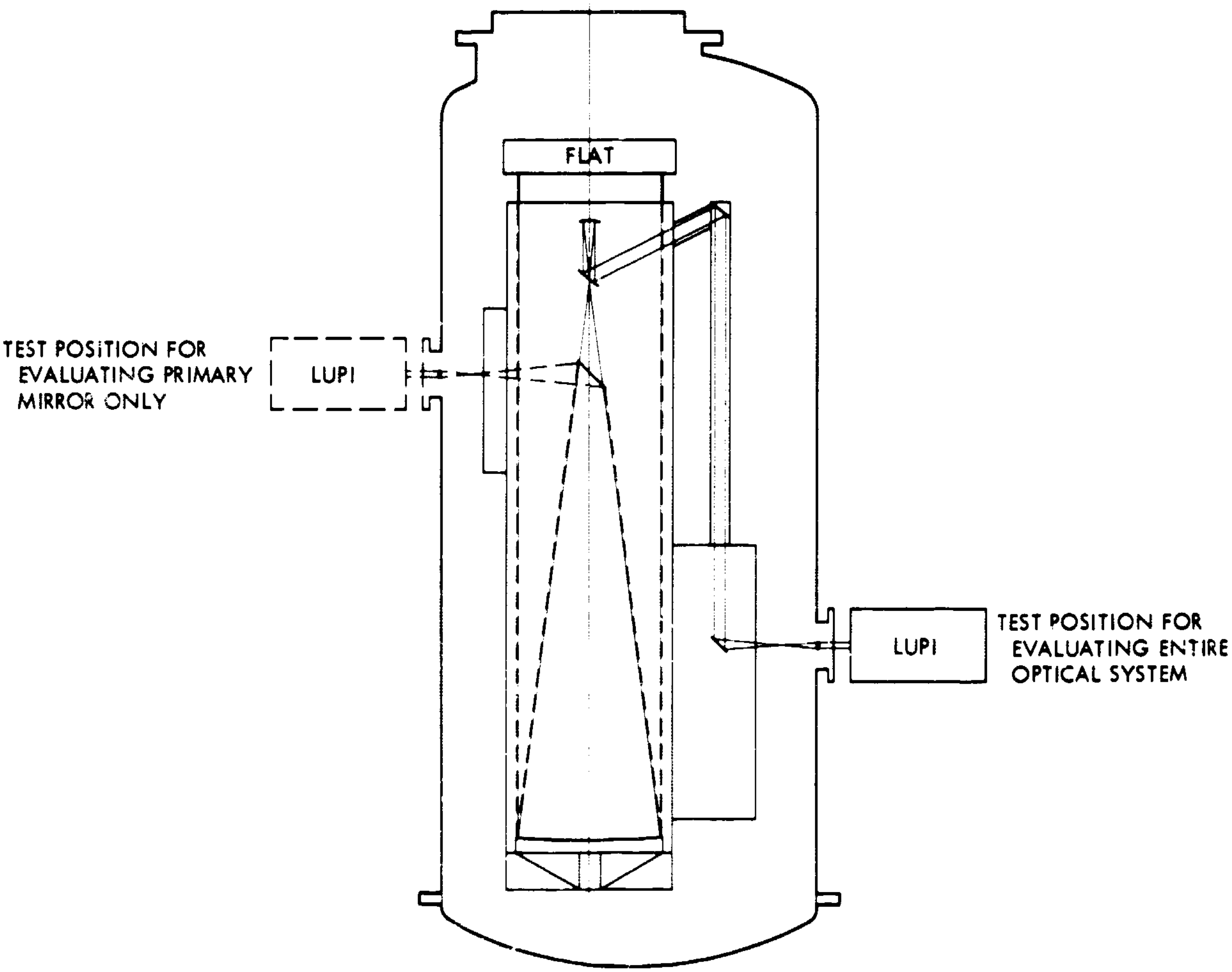

Figure 2. Optical-Thermal-Vacuum Test Chamber Photoheliograph

The interferometer is denoted as a Laser Unequal Path Interferometer or LUPI and will be called such for the remainder of the paper.

Calibration of the LUPI and the associated test optics will follow a schedule such that all systematic errors inherent to the test optics can be eliminated. First the LUPI will be evaluated using an internal calibration flat. An interferogram from this test can be used during data processing to remove errors from the data originating in the LUPI. A general schematic of the LUPI is shown in Fig. 3.

Similarly, the diverger lenses, which generate the diverging spherical wavefront, will be calibrated against the LUPI and a test sphere. The remaining test optics (i. e., autocollimating flat, diagonal flat, and folding flats) will all be calibrated using the LUPI, a test sphere and one of the diverging lenses. This type of test (for flat surfaces) is called a Ritchy test and is shown in Fig. 4. All systematic errors for each element will then be known and can be subtracted from the test data.

Complete analysis of the primary mirror may be accomplished using the LUPI in the arrangement shown in Fig. 2. This method will analyze a parabolic mirror at the focal point using an autocollimating flat. Changes in the optical performance will be correlated with thermal control of the mirror (under solar simulation) and mechanical mounting. The resultant primary mirror performance, in terms of MTF and Strehl ratio, can then be used as a base for complete system testing of the telescope.

An alternate method of analyzing the primary mirror has also been considered. This method would require the mirror to be figured to a sphere and testing would be done at the radius of curvature. This technique would not require the autocollimating flat, but the sensitivity will be halved as the system is only single pass.

Both of the above described test methods may be used on the mirror either in a vacuum or in normal atmosphere. Testing the mirror in a vacuum will allow complete analysis and include thermal deformation due to solar input, coolant fluid pressure study, thermal gradient due to coolant fluid, coolant fluid vibration study, and mechanical mounting. Tests that can be performed on the mirror while in normal atmosphere include coolant fluid pressure study,

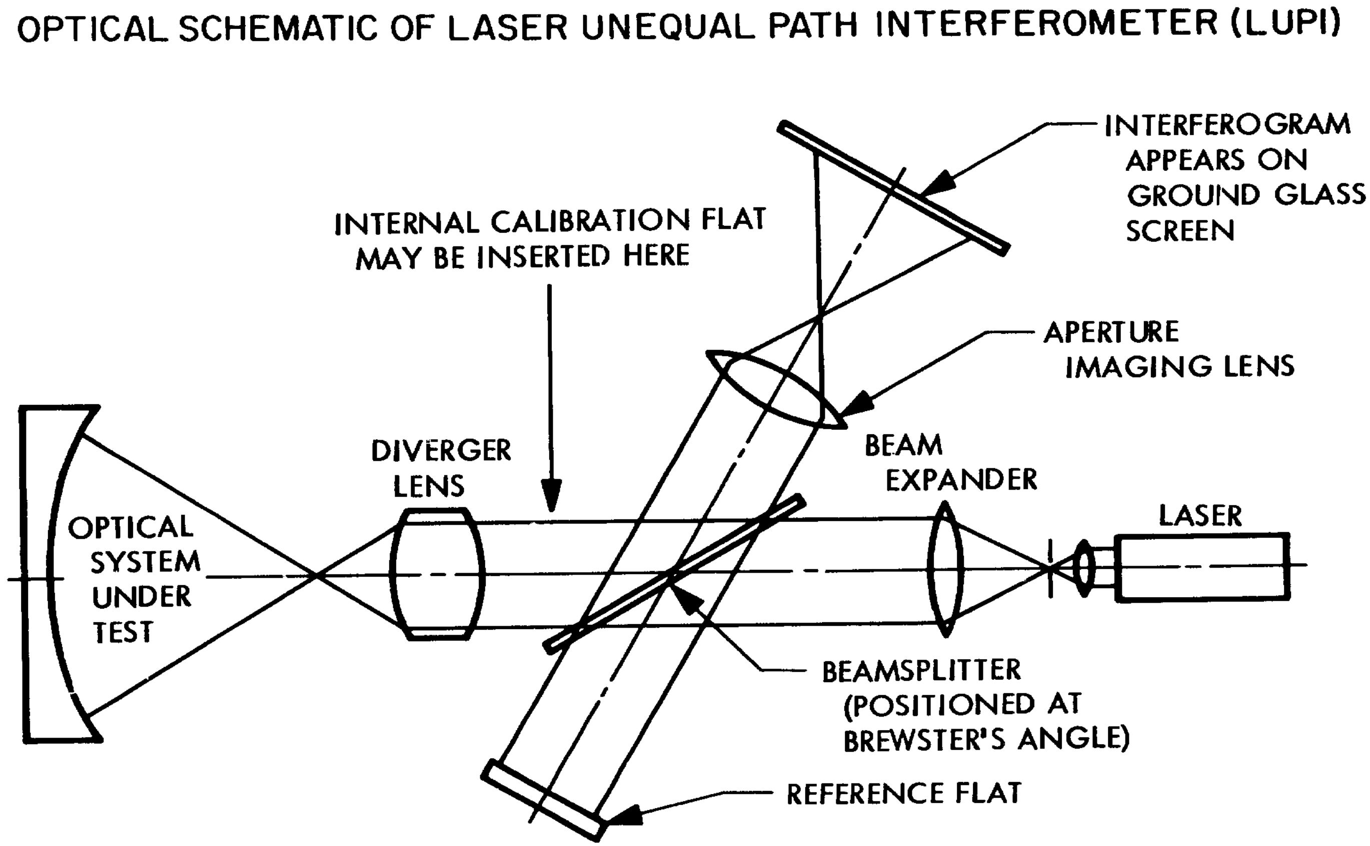

Figure 3. Optical Schematic of Laser Unequal Path Interferometer (LUPI)

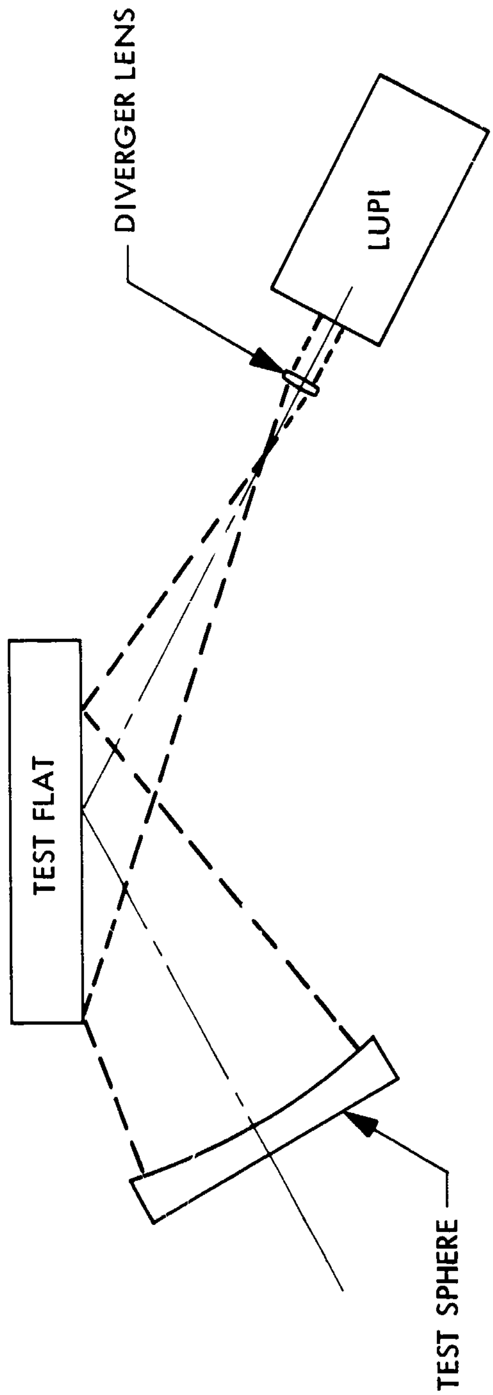

Figure 4. Ritchey Test A. rangement

coolant fluid vibration study, and mechanical mounting. Any test requiring thermal input cannot be performed in normal atmosphere due to the turbulance generated.

All the tests performed on the primary mirror will be repeated in the telescope system tests in addition to optical misalignment and defocusing. Interferograms taken for each test on the telescope system will determine experimentally the allowable limits of thermal gradients and their mechanical effects, optical misalignment and defocusing. A complete simulated mission with the telescope operating will be performed to determine the length of time required after entering full sunlight to become operational within the optical performance tolerances.

TEST FACILITY

The test facility is described in Document 750-9, Photoheliograph Thermal Vacuum Optical Test Chamber.

STATUS

The interferometer has been purchased and the test optics purchase order is in process. Modification to the Pagos computer program is under way to provide the Strehl ratio subroutine. A proposed schedule for the Photoheliograph testing is shown in Fig. 5.

2 YEAR

JET PROPULSION LABORATORY

APPROVAL RESPONSIBILITY J. D. Allen

ACHIEVEMENT RESPONSIBILITY C. J. Chocol

Figure 5. Proposed Optical Test Plan for Photoheliograph

CONTRACTOR

NO

LEVEL

ORIGINAL SCHEDULE APPROVAL ______ DATE

LAST SCHEDULE CHANGE ______ DATE NO INITIALS

STATUS AS OF July 26, 1968 DATE INITIALS

MILESTONES	1968 J	F	M	A	M	J	J	A	S	O	N	D	1969 J	F	M	A	M	J	J	A	S	O	N	D
1 Buy Interferometer			XXX	XXX	XXX	XXX	XOO	OOO	OOO	OOO														
2 Buy Test Optics					XXX	XXX	XOO	OOO	OOO	OOO														
3 Prepare Optical Test Plan						XXX	XOO	OOO	OOO															
4 Write Data Reduction Program						X	XOO	OOO	OOO	OOO														
5 Modify Computer Program							XO			OO	OOO													
6 Calibrate Interferometer											OOO	OOO												
7 Calibrate Test Optics												OOO	OOO											
8 Verify Data Reduction System												OO	OOO											
9 Calibrate Primary Mirror														OO	OOO									
10 Thermal-Vacuum Test (Primary Mirror)																OOO								
11 Recalibrate Primary Mirror																	OO							
12 Solar Flux Study (Primary Mirror)																	OO							
13 Coolant Pressure Study (Primary)																		OOO						
14 Coolant Vibration Study (Primary)																		OOO						
15 Recalibrate Primary Mirror																			OO					
16 Vibration-Shock Test Primary Mirror																			OO	OO				
17 Calibrate Optical System FVU																					OO			
18 Thermal-Solar-Vacuum Test FVU																						OOO		
19 Alignment System Analysis FVU																							OO	
20 Test Report																			OOO	OOO	OOO	OOO	OOO	OOO

NOTES

Activity Scheduled 00000

Activity Completed XXXXX

SCHEDULE NO