Range Commanders Council

OPTICAL SYSTEMS GROUP

DOCUMENT 457-93

TEST METHODS FOR ACCEPTANCE TESTING OF TELESCOPES

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KWAJALEIN MISSILE RANGE
YUMA PROVING GROUND
DUGWAY PROVING GROUND
ELECTRONIC PROVING GROUND

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NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
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TEST METHODS FOR ACCEPTANCE TESTING OF TELESCOPES

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RANGE COMMANDERS COUNCIL

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

TEST METHODS FOR ACCEPTANCE TESTING OF TELESCOPES

1.0 INTRODUCTION

1.1 Background. This telescope test methods guide is intended as a general guide to assist government agencies responsible for the procurement of long focal length optical systems. It was prepared in accordance with Optical Systems Group task OS-3.

This task, which was initiated in 1984, has suffered many delays because of unavoidable changes in task managers. In addition, the title has evolved from "Test Methods for Acceptance and Field Testing of Telescopes" to "Test Methods for Acceptance Testing of Telescopes." This change reflects the realization that it would be impractical to write a definitive guide for field testing considering the many variables involved in field operations, not the least of which is the atmosphere.

The test guide was prepared at White Sands Missile Range (WSMR), New Mexico, with input from technical personnel of the Optical Test Laboratory, Instrumentation Development Directorate. Neither funds nor manhours were available for travel to other government test facilities so it is inevitable that this draft guide is biased toward the procedures and test equipment used in the WSMR facility.

1.2 Purpose. This guide will provide government organizations who are responsible for the procurement of long focal-length optical systems (telescopes) with a general knowledge of what tests can, and generally should, be performed on these systems to ensure compliance with the required specifications. General test procedures are also included. Since test facilities and test equipment available vary considerably among organizations, it is impractical to write a "cookbook" type of guide to be followed rigorously by all. It is also true that some procured systems may possess special features not generally found in the normal imaging telescope system such as beam splitters, special filters, and reticles. Special tests of such features are outside the scope of this guide and must be considered on a case-by-case basis. In addition, this guide does not address testing of mid-to-far infrared optical systems incorporating refractive elements, which do not transmit visible light. The testing of such systems should be considered separately, because they usually require very specialized radiation sources and detectors.

1.3 Overview. The following paragraphs discuss tests of wavefront and resolution analysis, focal-length and flange-focal-distance measurements, optical mechanical parallelism, T-number, range calibration, and veiling glare. Environmental considerations are also discussed.

2.0 INITIAL INSPECTION

When the system arrives at the test facility, the first thing that should be done is to conduct a thorough initial inspection to look for any signs of shipping damage. Following that, specified mechanical features such as dimensions, weight, finish, sealing, pressurization, proper location and spacing of mounting holes, and desiccant holders should be checked. Screws, nuts, and bolts should be checked for tightness when they are accessible. If the system is to be used on a mobile mount, the presence of lockwashers or "locktite" should be determined. On systems with a secondary mirror, the rear of the secondary holder should be grasped, if accessible, and tested for rigidity. A flashlight with a bright beam should be used to inspect the optics for uniformity of coatings and the presence of chipped optical elements.

While all or most of this examination seems obvious, it is surprising how often it is overlooked in the excitement of taking delivery of a new telescope. Often flaws are found after the acceptance period has expired which could have been detected by a careful examination.

3.0 WAVEFRONT ANALYSIS

3.1 Interferometric Test. The development of the laser and the personal computer (PC) has made interferometric testing of telescope systems available to even small optical test facilities. The great advantage of such tests is the optical performance of a system can often be characterized by a single interferogram which can be quickly made, digitized, and reduced. Interferometers of various configurations are commercially available as are fringe analysis software packages that can be run on PC-compatible computers having 1Mb and a 20Mb Random-Access Memory (RAM) hard disk. An interferometer can be assembled in-house, although such a system usually will not have the alignment ease and user-friendly features of a commercially manufactured instrument.

Although various interferometer configurations are used, they all basically operate on the same principle. The beam from a stable continuous wave (cw) laser, usually a HeNe, although a CO_2 laser might be used in the testing of infrared (IR) systems, is divided into two parts by a beam splitter. One of the two resulting beams, the test beam, is diverged and directed to pass through the optical system under test. This beam is then, after proper sizing, recombined with the reference beam, the one that did not pass through the optical system being tested. The recombined beams are then projected onto film or into a video camera. The recombined beams form a pattern of light and dark lines or fringes in the image plane. This pattern is referred to as an interferogram and is caused by the constructive and destructive interference of the two beams. The fringes represent lines of constant optical path difference (OPD) between the test and the reference beams. The pattern produced by the test of a system without aberrations will appear as a series of straight, parallel, and equally spaced lines. The number of lines in the pattern is variable and may be controlled by adjustments to the interferometer. Fringes produced from tests of a system having aberrations will deviate from straightness at points where the surface deviates from an ideal optical surface. The amount of deviation represented by the width of a fringe depends on the test configuration. If the test beam passes once through the optical system under test (single pass) then the width of a fringe is equivalent to one wavelength of the light emitted by the interferometer's laser. If the test beam is reflected back through the optical system before re-entering the interferometer for recombination with the reference beam (double pass), then the fringe width is equivalent to 1/2 wave. Figure 1 shows a 150-inch focal-length lens system being tested using a Twymann-Green interferometer in the double-pass mode. The large mirror in front of the lens system is a high-quality flat and is being used to reflect the test beam back through the lens, after which it enters the interferometer and is recombined with the reference beam. In this case, a video camera and a hard copier are being used to record the interferogram.

While the setup procedure of the optical system under test will vary depending on the interferometer and configuration used, some general comments regarding precautions may be made. Care should be taken to place the test equipment in a vibration-free environment as much as possible. An air-supported table is ideal. If such a table is not available, consideration should be given to using a video camera equipped with a high-speed shutter to record the interferogram. The reference mirror used should be of higher quality than the system under test. The beam diverger used should be of sufficient speed to spread the test beam such that the entire aperture of the optics under test is covered. It, too, must be of a higher quality than the optics being tested. It is extremely important that the interferogram be in sharp focus if accurate test results are to be obtained. It is usually sufficient to adjust the interferometer to obtain an interferogram with 20 fringes; however, complex interferograms, those with tightly curving fringes, may require additional fringes for a good reduction.

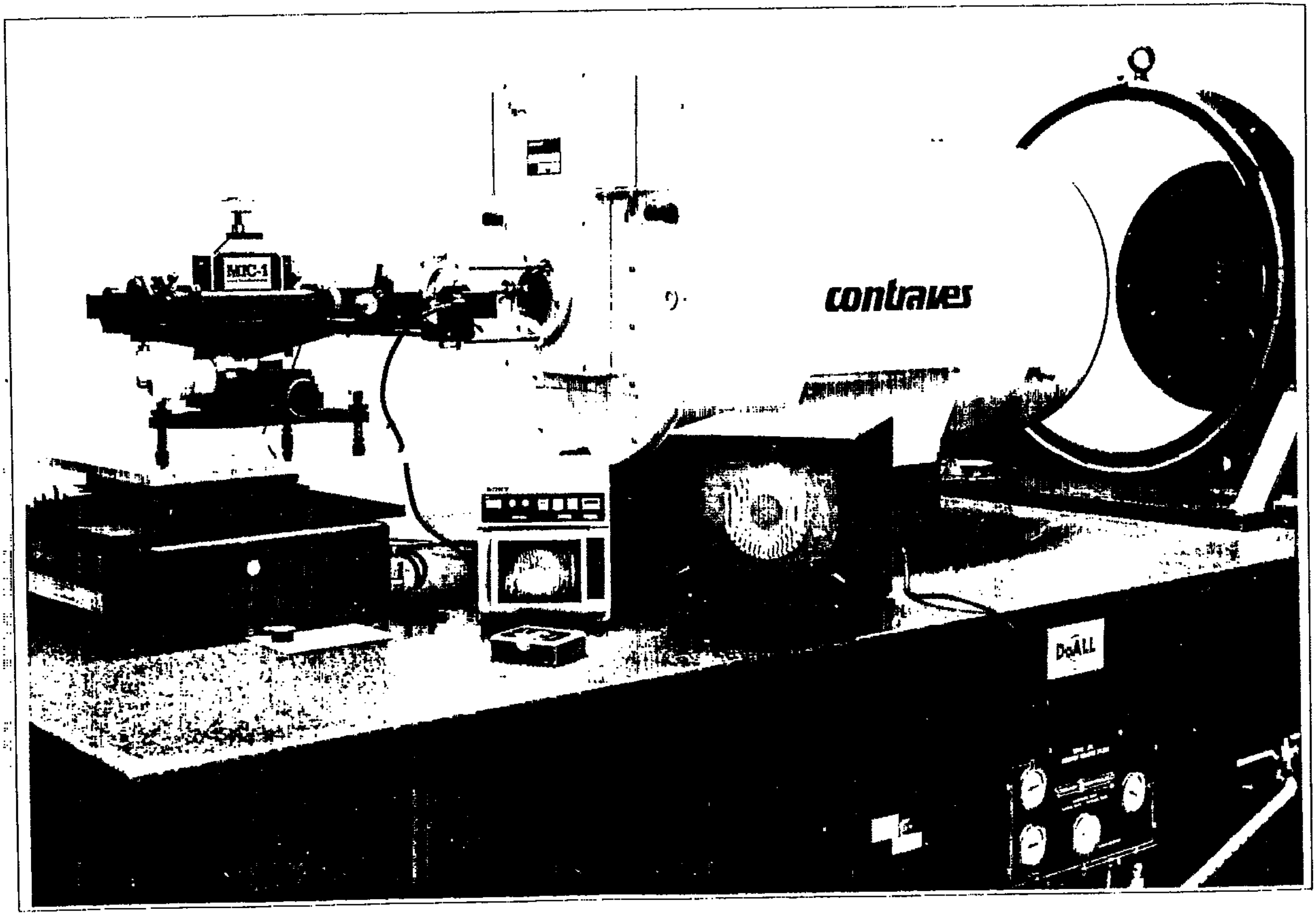
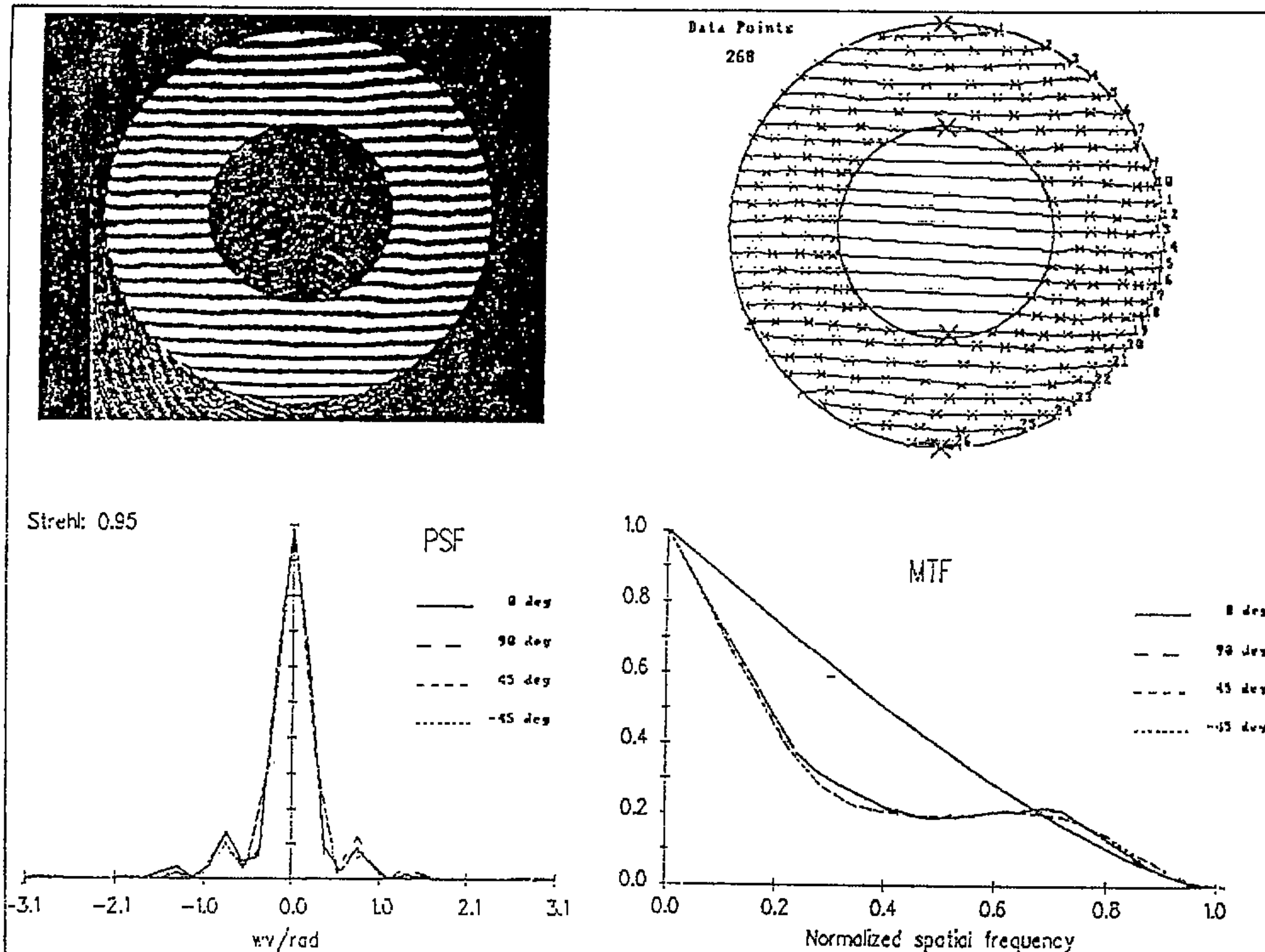


Figure 1. Interferometric test of 150-inch lens.

4

Before the interferogram can be reduced, it must be digitized. It is possible to digitize automatically if a video camera is used and the PC is equipped with a frame grabber. Most fringe analysis software contain this provision. However, most optical systems interferograms include noise caused by such things as dust, which must be edited out before the reduction can be made. This process can be very time-consuming. The more common digitization method is to use a graphics tablet to digitize the fringes. The larger the interferogram the better, but it should be at least 2 inches in diameter when using this method. A mouse is moved along each fringe, starting at one side of the interferogram, and points are selected by clicking a switch on the mouse. Usually 150 to 200 points are selected to be digitized, although a complex fringe pattern may require more. After digitization, the program will compute all the parameters of the wavefront. These parameters include point-spread function, modulation-transfer function, rms deviation from an ideal surface, and maximum peak-to-valley deviation. The parameters are presented in both tabular and graphical form. Figures 2 and 3 illustrate data taken in typical interferometric reductions. Starting at the top left corner of the figure and going clockwise is a photo of the fringe pattern, selected digitizated points, the modulation-transfer function plot, and the point-spread function plot.

3.2 Knife-Edge Test. If an interferometer is not available, useful though qualitative information concerning the wavefront can be gained by employing the knife-edge test. For this test, the optical system must be setup in a collimator having an aperture equal to or larger than the system to be tested, and a point source of light located at the collimator's focal point. A knife edge (a razor blade works quite well) mounted on an x-y stage is located precisely at the focal point of the system under test. The eye is placed behind the knife-edge as the knife-edge is slowly moved in to the imaged point. As the knife-edge cuts into the point image, a shadow pattern will appear. The pattern from a uniform wavefront will appear gray with no apparent structure. Hills, valleys, and ridges on the optical surfaces will appear as white and black areas or lines. It should be noted that a hill which may appear as a white area on one side of the image will appear as a dark area on the other side. The image may be recorded on a photograph or on a video. Figure 4 shows a knife-edge behind a 150-inch lens system. Figure 5 is a photograph of the knife-edge pattern which shows severe zoning in the system.



WISP [Ver. 3.21]   SN- 228   05-02-91
852-69AH   13:37:32 05-02-91

TERM	RMS FIT	COEFFICIENTS		OPD map	
TILT	0.039	-0.226	-6.430		
FOCUS	0.039	-0.226	-6.430	0.015	
SEIDEL	0.000	-0.235	-6.426	-0.034	0.031
		0.052	0.055	-0.027	0.048

	AMT	ANGLE
TILT	6.382	266.9
FOCUS	-0.272	
ASTIG	-0.121	-60.3
COMA	0.185	-25.8
SA3	0.285	

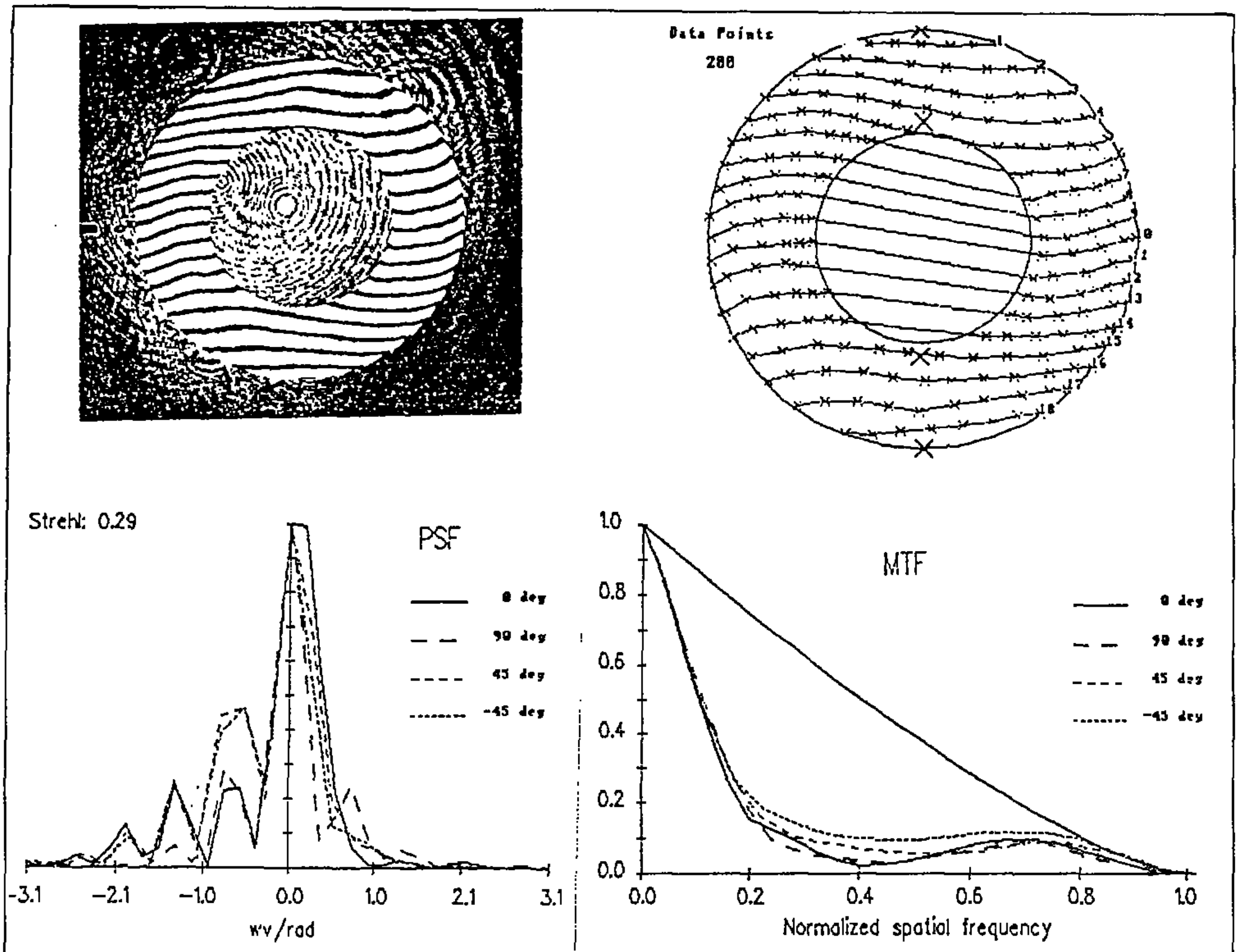
TERMS REMOVED: TILT FOCUS

x center	y center	x radius	Aspect
50.00	50.00	49.50	1.00

OPD map Statistics

DATA PTS	WEDGE	PEAK	VALLEY	P-V	RMS	STREHL RATIO
5780	0.50	0.116	-0.081	0.197 λ/5	0.037 λ/27	0.947

Figure 2. Wavefront data from "good quality" 50-inch lens.



TERM	RMS FIT	COEFFICIENTS		OPD map	
TILT	0.184	-0.245	-4.690		
FOCUS	0.184	-0.245	-4.690	-0.010	
SEIDEL	0.001	-0.303	-4.696	0.020	0.118
		-0.215	0.391	0.038	-0.036

	AMT	ANGLE
TILT	4.893	257.2
FOCUS	0.012	
ASTIG	0.490	-30.6
COMA	1.179	5.5
SA3	-0.217	

TERMS REMOVED: TILT FOCUS

x center	y center	x radius	Aspect
50.00	50.00	49.50	1.00

OPD map Statistics

DATA PTS	WEDGE	PEAK	VALLEY	P-V	RMS	STREHL RATIO
5780	0.50	0.508	-0.491	0.999	0.177	0.291

Figure 3. Wavefront data from 50-inch lens with coma.

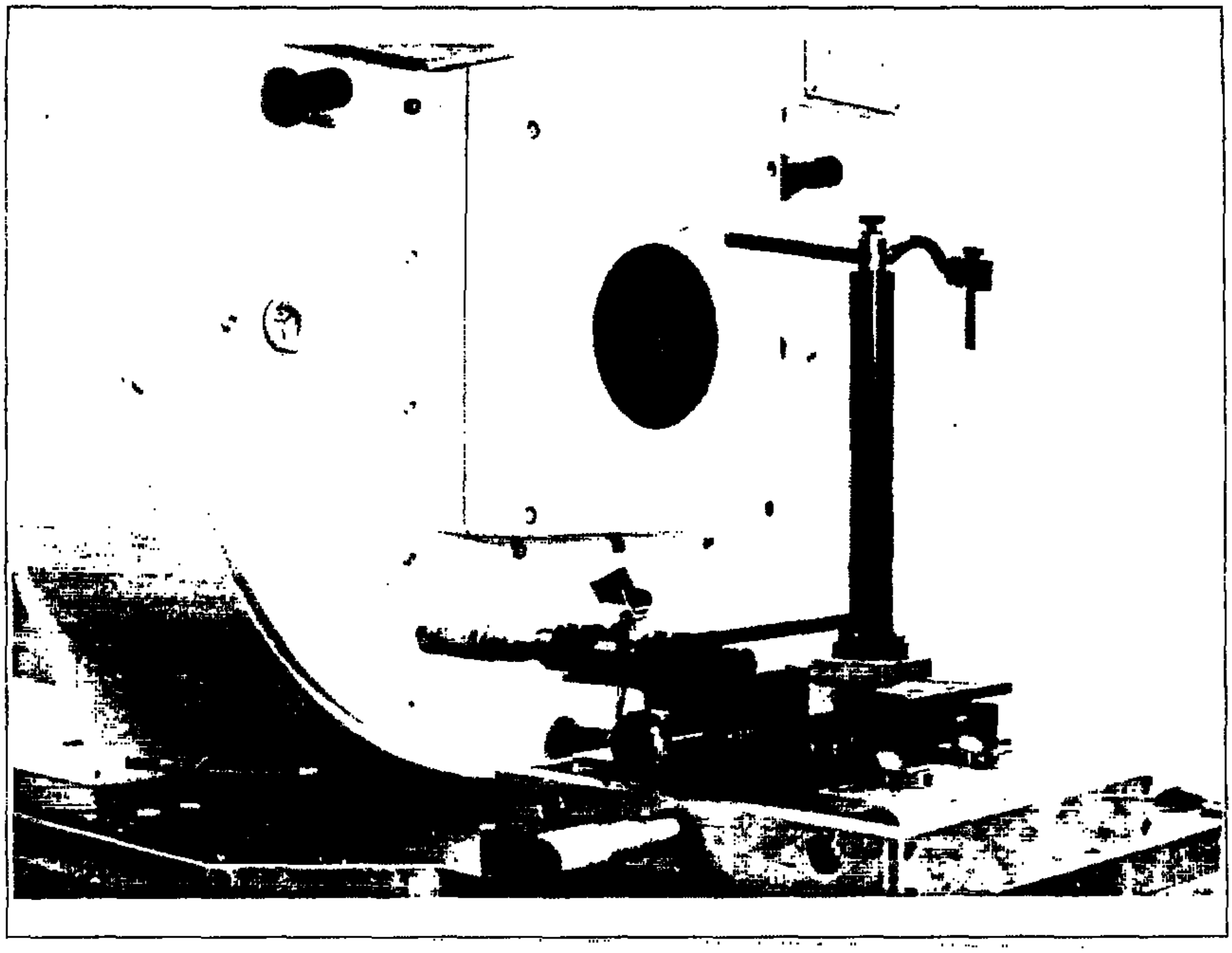


Figure 4. Knife edge behind 150-inch lens.

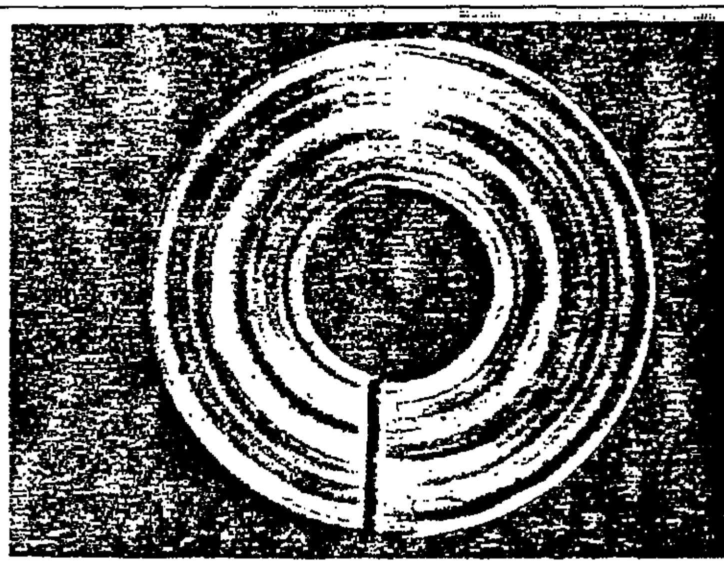


Figure 5. Knife-edge photo of lens exhibiting aberrations.

4.0 RESOLUTION ANALYSIS

The resolution of a system is a measure of its ability to image fine detail in a scene and is usually the specification of most importance for systems that are to be used to record photographic or video imagery. To measure resolution in the laboratory, the optical system must be setup in a collimator. An illuminated resolution target, usually a glass plate with an image of both vertical and horizontal bars of varying widths and spacing, is placed at the focus of the collimator and viewed or photographed through the system under test. The resolution of the system is then determined from the dimension of the smallest bar pattern corrected by the ratio of the focal length of the collimator to the focal length of the system.

4.1 Collimator. Because a long focal length system cannot be focused in the confines of a room, a collimator must be used in most tests. A collimator is a telescope used in reverse with an illuminated target located at its image plane. The target is placed precisely at the focal point so that light from the target is projected from the primary lens or mirror in a parallel bundle of rays which appears to be coming from infinity. While there are many configurations of collimators, the most common type used in the testing of large optical systems resembles a Newtonian telescope. The collimator uses a parabolic mirror and a flat diagonal mirror with a target off to one side, outside of the field of view. For the testing of telescope systems, the aperture of the collimator should be somewhat larger than the aperture of the system being tested and its focal length equal to or longer than that of the system under test. It is desirable that the collimator and the system being tested are both supported on the same surface, preferably one isolated from the rest of the building, to minimize vibration effects. Figure 6 shows a lens undergoing resolution testing in the 144-inch focal length, 24-inch collimator at the White Sands Missile Range (WSMR) Optical Test Facility. Both the lens and the collimator are supported on a 26-foot long concrete air-supported beam.

NOTE

The collimator target should be periodically "autocollimated" to ensure it is precisely at the collimator focal point for creditable test results.

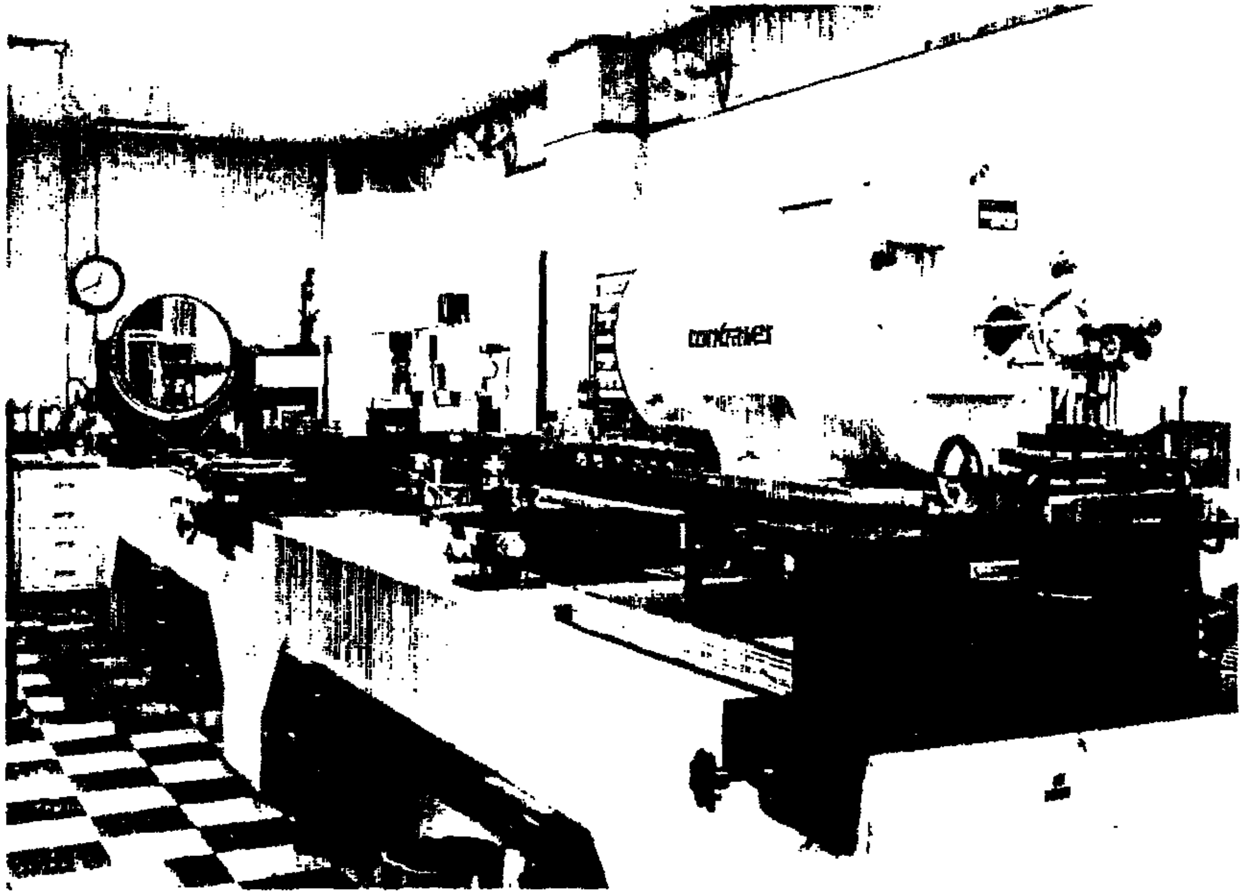


Figure 6. Testing lens in collimator.

4.2 Target. The resolution target used in most test labs is the standard Air Force target described in MIL-STD 150-A, *Photographic Lenses*, subparagraph 5.1.1.7. The targets are available from a number of commercial sources and come in various sizes, contrasts, and backings. A sample data sheet from one supplier can be found in appendix A. The target should be mounted with the emulsion side toward the collimator mirror. For visual measurement of the resolution, the target may be illuminated with a microscope lamp. For photographic measurements, a strobe lamp should be used to eliminate the possibility of shutter vibration degrading the measurement. Also, the high-speed exposure possible with the strobe reduces the effect of air turbulence. Figure 7 shows the collimator's target arrangement. In the photo, a lamp is being used to illuminate the target for visual measurements. For photographic measurements, the strobe mounted on an instrument stand is lowered to position it behind the target. The strobe is isolated from the rail holding the target to prevent vibrations when the strobe is fired.

4.3 Alignment. Before making resolution measurements on an optical system, the system must first be aligned in the collimator. Assuming that the collimator is properly aligned and autocollimated for infinity, the lens system should be mounted so that it is coaxial with the collimator. For this procedure, it is very useful to use an alignment fixture such as the one illustrated in figure 8. The fixture shown in figure 1 is securely fastened to the rear opening of a 150-inch lens. Adjustable standoffs support the frame of a glass reticle. The reticle lines and circles are sized to represent definite distances across the field of view with the pattern towards the front of the lens. The lens is moved until the image of the target appears at the center of the reticle. The microscope is then focused on the reticle and the standoffs are adjusted until the target is in focus. If off-axis measurements are to be made, it is essential that the x axis of the microscope be precisely aligned at 90° to the axis of the optical system. This alignment is checked by moving the microscope across the field, making sure the reticle remains in focus. When resolution measurements are made, the glass plate is removed from the alignment fixture. Off-axis measurements are made by moving the lens in an angle by the correct amount, and then by moving the microscope a compensating distance.

4.4 Photographic Measurements. The correct focus and exposure are very critical when photographing a resolution target. A 35-mm, 1/2-inch frame camera is used at the WSMR Optical Testing Laboratory. The camera is mounted on a micrometer controlled stage for focusing. The stage is mounted on a precision cross slide for off-axis positioning. For focusing, the camera back is opened and a glass with a finely etched reticle (or even lines

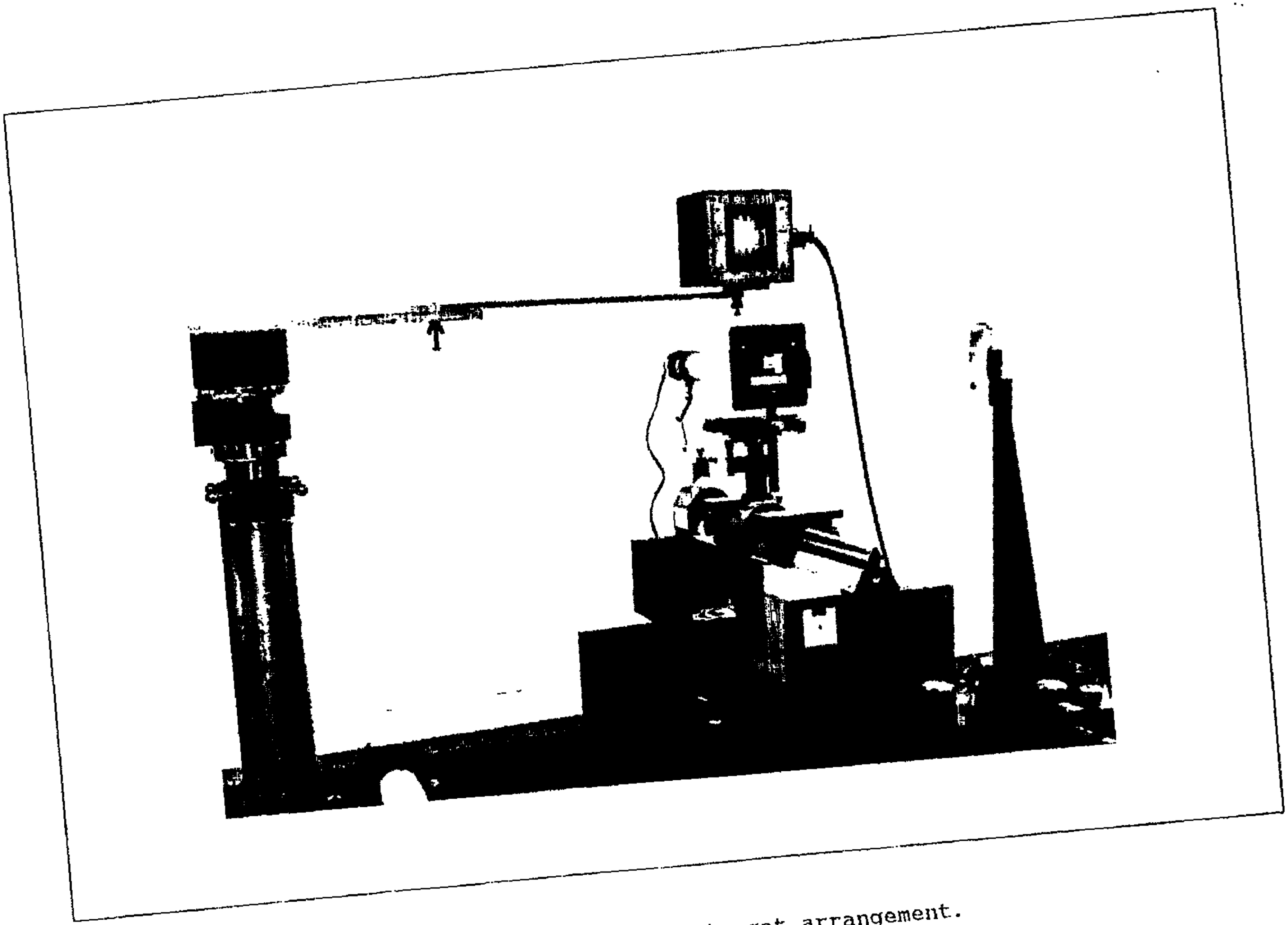


Figure 7. Collimator target arrangement.

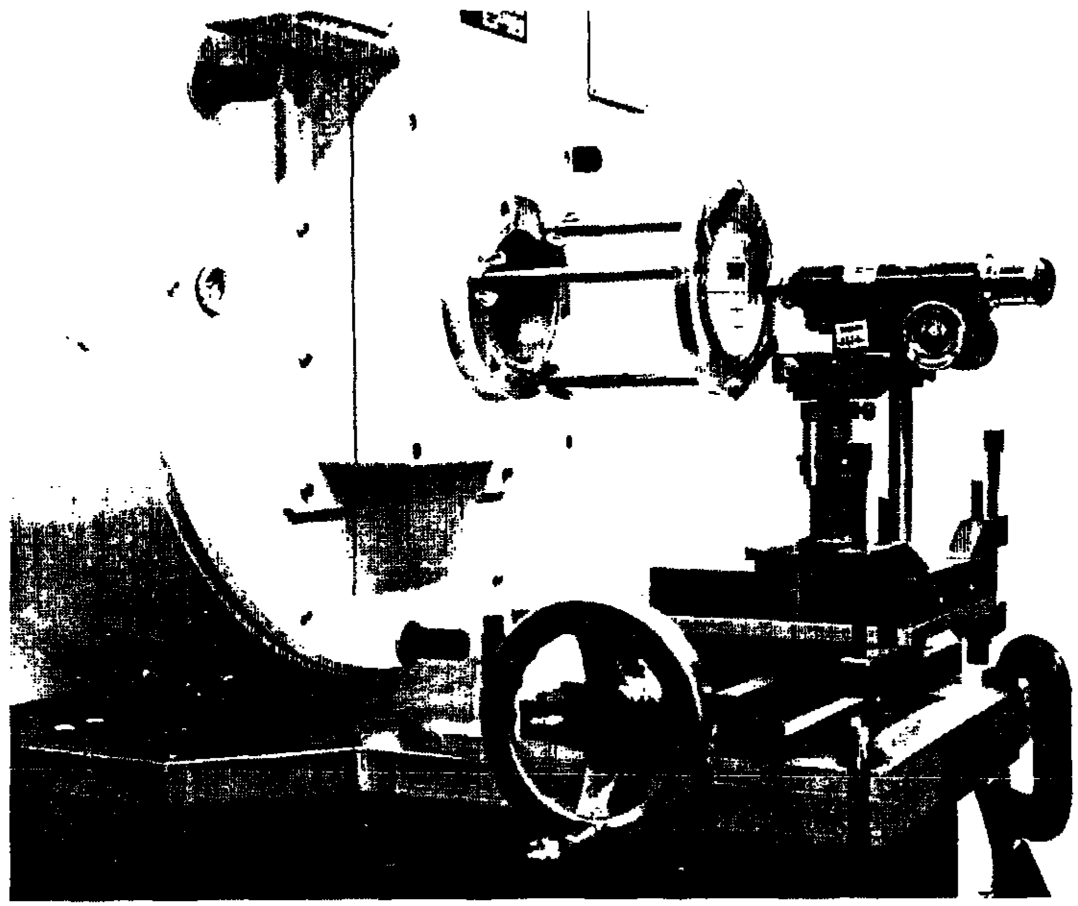


Figure 8. Rear of lens with alignment fixture attached.

drawn with a ball point pen) is taped to the film guides at the back of the camera with the etched surface in front. The focusing stage is constructed so that a microscope can be temporarily mounted behind the camera to observe the reticle. First the microscope is focused until the reticle is sharp. Then without refocusing the microscope, but still observing through the microscope, the micrometer is adjusted by moving the camera stage until the resolution target is sharp. Quite often, focus tests are made by noting the micrometer readings and making exposures at intervals through the apparent best visual focus. Again, if off-axis photos are to be taken, make sure the x axis of the camera is normal to the optic axis of the lens system under test. Figure 9 shows the camera setup for a photographic resolution test.

4.5 Film Handling. The exposure and subsequent development of the film have a great effect on the results obtained. The correct exposure must be determined through trial and error by either varying the strobe intensity or by using the filters. For resolution measurements, better results can be obtained by slightly underexposing the film. The most important thing to remember when developing the film is to be consistent. The chemicals used, temperature, method, and length of agitation, and even the type of tanks and reels should not vary from one test to the other. The method used with good results at the WSMR test facility is described next.

Linagraph Shellburst EKCO Type 2476 film is used for the tests. It is the same film used to record missile flights in black and white. The film is developed in D-19 to a gamma of 1.9. The film is loaded onto Nicor reels and developed for seven minutes at 75° F plus or minus .5°. It is agitated by a solenoid timer set for a 1-second burst of nitrogen bubbles every 10 seconds. The agitator is made from a locally fabricated stainless-steel reel holder, which has a hollow center post to allow the insertion of a 1/4-inch plastic tube to the bottom of the perforated film reel. Approximately 2 pounds of nitrogen pressure is used.

4.6 Determining Resolution. The maximum resolution of the optical system is determined by noting the group and element number of the smallest pattern of bars resolved on the target. Next, a value, in line pairs per millimeter, for this pattern is read from the chart supplied with the target by the vendor. This value must be multiplied by the ratio of the focal length of the collimator divided by the focal length of the optics being tested to obtain the final resolution.

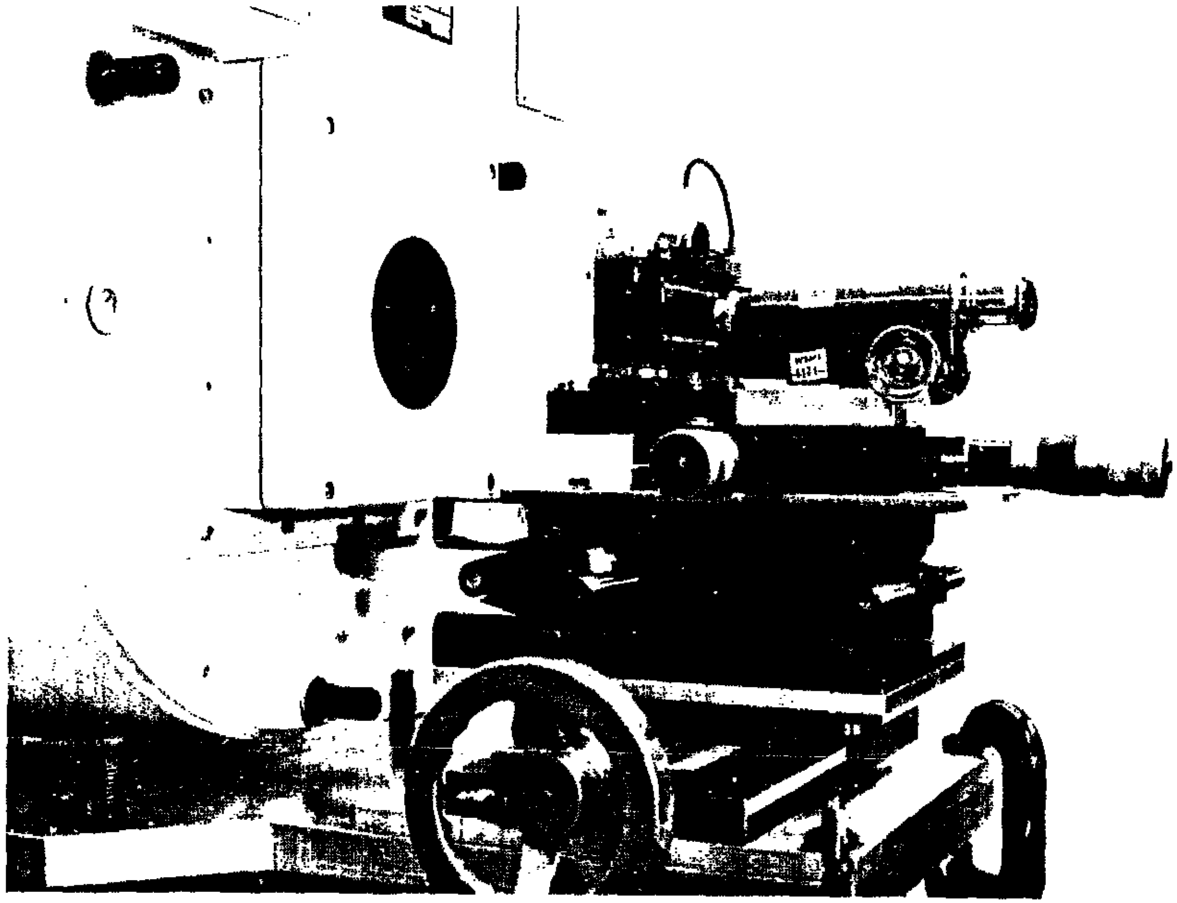


Figure 9. Setup for photographic resolution test.

5.0 FOCAL LENGTH MEASUREMENT

The focal length of the telescope is measured by its magnification while it is setup in the collimator used for the resolution measurements. With a micrometer resolution of 0.0001 inch, a precision measuring microscope is setup to image the target through the system, and the width of the large square block located at the top of the Air Force target is measured. The target is then removed from the collimator, and the width of the block on the target plate is measured using a machinist precision microscope to a precision of 0.0001 inch. The ratio of the image size to the object size multiplied by the focal length of the collimator is the focal length of the system.

The flange focal distance of the telescope is the distance between the back surface of the telescope and its focal point. It is important to know this distance accurately, so cameras or other detector packages can be positioned properly. The flange focal distance is easily measured using the alignment fixture illustrated in figure 8. The image of a target is focused on the reticle while the system is setup in the collimator. A depth mike is used to measure the distance between the back surface of the telescope and the back surface of the glass. The glass is then measured with a thickness gauge and subtracted from the measured value to give the flange focal distance.

6.0 OPTICAL/MECHANICAL PARALLELISM

In most applications, it is essential that the optical axis of a telescope be parallel with its mechanical axis or its mounting surface. It would be difficult to boresight a system to other optics on a tracking mount if the mounting surface of the system was not essentially parallel to the optic axis. This parallelism can be checked in the collimator. First, the axis of the collimator must be horizontal, which can be checked by autocollimation and observance of the reflected target image near the target. The flat must be set vertically. The telescope should be set in the collimated beam, so its axis is parallel to the axis of the collimator. The target image should then be centered in the field of view.

7.0 T-NUMBER

The T-number of an optical system is a dimensionless number representing the light-gathering power or "speed" of the system. Generally, the speed of short focal length simple optics is given by the F-number which is the ratio of the focal length divided by the lens diameter. In specifying a telescope system, the F-number can be misleading as a measure of the light-gathering potential of the system, because there are many air-optical interfaces; each contributes to light losses in the optics.

If the telescope uses a folded optical system such as a catadioptric, the light blockage, because of the secondary mirror and its support structure, may be considerable, although it would not be indicated by the F-number. The T-number is a function of both the F-number and light losses caused by obscurations, absorption, and air-optics interfaces.

The T-number may be determined in a number of ways. These methods are well described in subparagraph 5.1.2.10 of MIL-STD-150A. In general, the T-number is determined by placing a uniformly illuminated, diffuse screen in front of the lens to be tested and a small aperture at the focal point. A light detector, having a flat spectral response in the visible, is positioned behind the aperture and the detector's output voltage measured and recorded. The aperture and detector are then positioned behind a reference "lens." This reference lens may simply be an adjustable iris. The spacing between the reference lens and the aperture is adjusted, so the cone of rays entering the aperture is identical to that produced by the test lens. The iris is then adjusted, so the detector output is equal to that recorded from the test lens. The iris diameter is measured and the ratio of the iris diameter to the iris aperture spacing is the T-number of the lens. Care must be taken to make sure the diffuse screen is uniformly illuminated and the drift of the detector circuit is minimized.

A different method for T-number determination is used by the Optics Laboratory at WSMR in testing the catadioptric lens systems; lenses having the secondary mounted on the back of a corrector plate with no supporting structure. This method involves measuring the obscuration and clear aperture transmission directly. First, the diameters of the primary mirror and the secondary cell are measured. The clear aperture transmission is determined by directing a laser beam into the front of the telescope and aligning the beam such that it is focused in the image plane. The beam power is carefully measured before and after passage through the optics. The transmission is the power collected at the lens focus divided by the output power of the laser (at the laser wavelength). Care must be exercised to ensure all of the beam energy falls on the detector and that the power meter does not drift between measurements. Additionally, background lighting must be suppressed. At WSMR, the green line (513.4nm) from an Argon laser is used, because it is close to the maximum sensitivity of the film used in the recording cameras. The measured values (primary and secondary cell diameters plus transmission) are then used to calculate the T-number using the expression below:

$$\text{T-number} = \frac{f}{(T\ (D_1^2 - D_2^2))^{1/2}} \qquad (1)$$

where

D_1 = lens diameter,
D_2 = obscuration diameter,
T = transmission,
f = focal length.

8.0 RANGE CALIBRATION

Focus problems are the most common source of data loss when long focal length optics are employed on tracking missions. The normal practice is to mount the camera behind the lens in the field, so the image plane is approximately at the flange focal distance. Next, view the moon or other celestial body while fine focusing the system on infinity. The camera's boresight viewer or a video monitor is used to determine the best infinity focus. The camera positions for focus at closer ranges, if required, are arrived at by calculation. While this method is workable, it has many problems such as the unavailability of a suitable target because of clouds, the uncertainty of focus caused by atmospheric turbulence, and the difficulty in fine focusing on a moving target while moving a heavy camera on a mount at a steep vertical angle.

If the camera can be permanently mated to the optics, it is much more desirable to set the system for infinity focus using a collimator in the laboratory. In addition to the advantages of viewing a high-resolution target in a controlled atmosphere, the collimator can be adjusted to simulate ranges closer than infinity, the camera position for those ranges can be precisely measured, and the minimum focus range of the system can be easily determined. For those systems having a power switching or a zoom capability, tests with the collimator can determine any boresight shift during operation of such features if great care is taken to precisely align the optics to pass through the same straight line with the collimator. Systems having a motor-driven focus with position readout can be tested and calibrated by simulating various ranges by adjusting the collimator's target position. To simulate various ranges, the collimator is first set for infinity. A dial indicator is attached to the target, and it is moved a precise distance to simulate the desired range. The amount of offset from the infinity position can be calculated from the mirror equation

$$\frac{1}{S} - \frac{1}{S^I} = -\frac{1}{f} \qquad (2)$$

where

S = range,
S^1 = target position,
f = collimator focal length.

For all ranges less than infinity, the range used in the calculation must be reduced by the distance measured from the optics under test to the primary of the collimator. Figure 10 shows the large collimator at WSMR set up for range calibration.

In many cases, it is not feasible to permanently mount the camera to the lens for testing in the collimator, for example, when the lens and camera are to be mounted on the arms of a mobile tracking mount. To address similar issues, WSMR constructed a portable collimator assembled from a 92-inch cassegrainian lens having an aperture of 12 inches. This collimator, called the optical reference system, features an illuminated resolution target mounted on a longitudinal stage behind the lens. It can be used to simulate any target range from infinity to 500 yards. The assembly is mounted on a pan-and-tilt head and is used to calibrate the infinity positions of lenses while they are mounted on KTM tracking mounts. Many of the lenses used at WSMR are automatically kept in focus during a mission using range data to drive motorized focus elements in the lenses, which have digital position feedback. The optical reference system, used daily at WSMR, is more fully described in the next section. Figure 11 shows the reference system undergoing autocollimation. Figure 12 shows the system setup to calibrate the lenses on a KTM.

9.0 OPTICAL REFERENCE SYSTEM

The optical reference system comprises a target collimator through which a resolution target can be projected into lenses which may remain in place on tracking mounts for the purpose of setting correct focus on cameras. Ranges may be simulated with the collimator from infinity to 500 yards, and cameras may be set visually by the camera boresight scope. Film samples can be made to ensure that the focus is correct.

9.1 Assembly Description. The collimator lens is a Goerz with a nominal focal length of 92 inches. This lens has been recoated and carefully aligned to produce excellent image quality. The focus shelf at the rear is equipped with a longitudinal stage at the back focus position and contains the focusing microscope and a holder for inserting the target, reticle, and diffuser. Stage movement is controlled by a metric micrometer with 25 mm total travel. Readout for the micrometer is 0.01 mm.

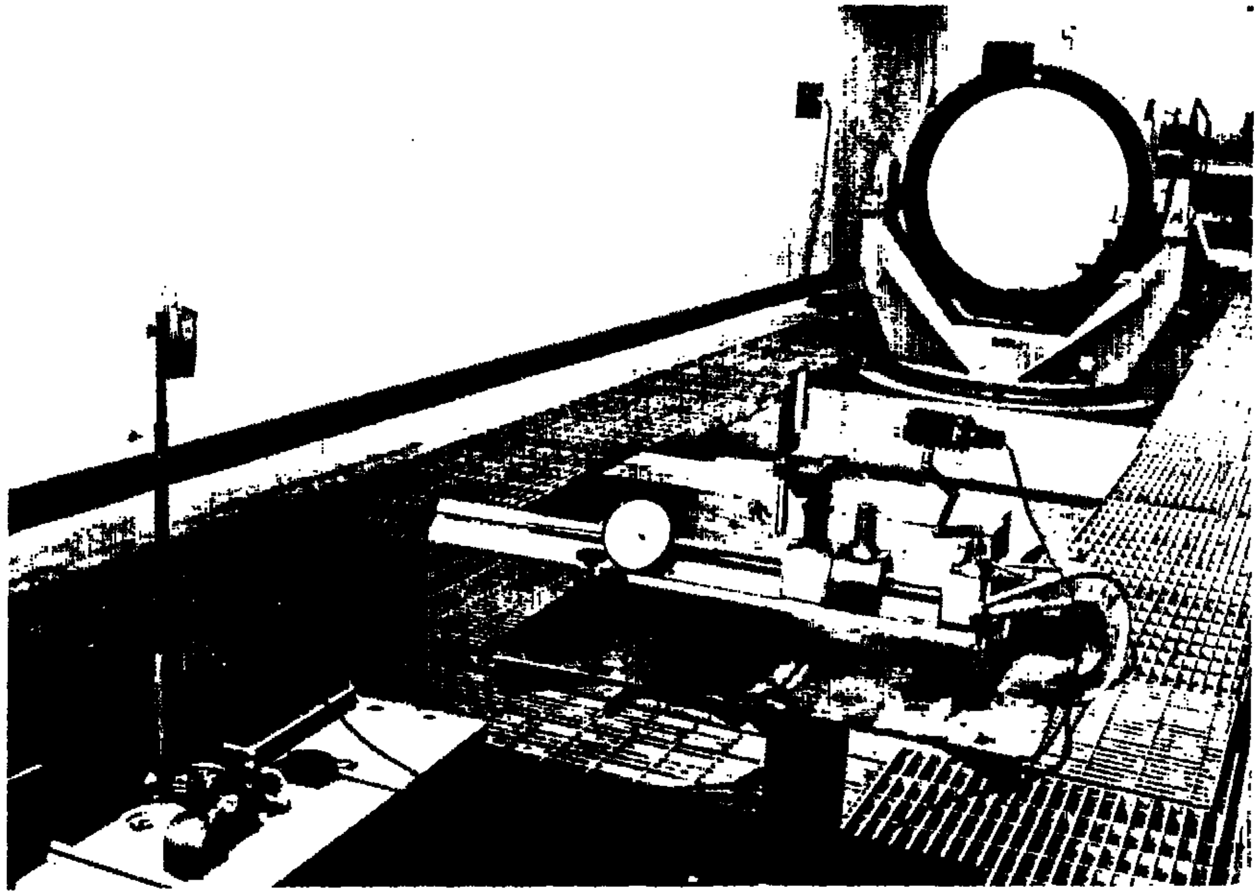


Figure 10. Collimator target setup for range calibration.

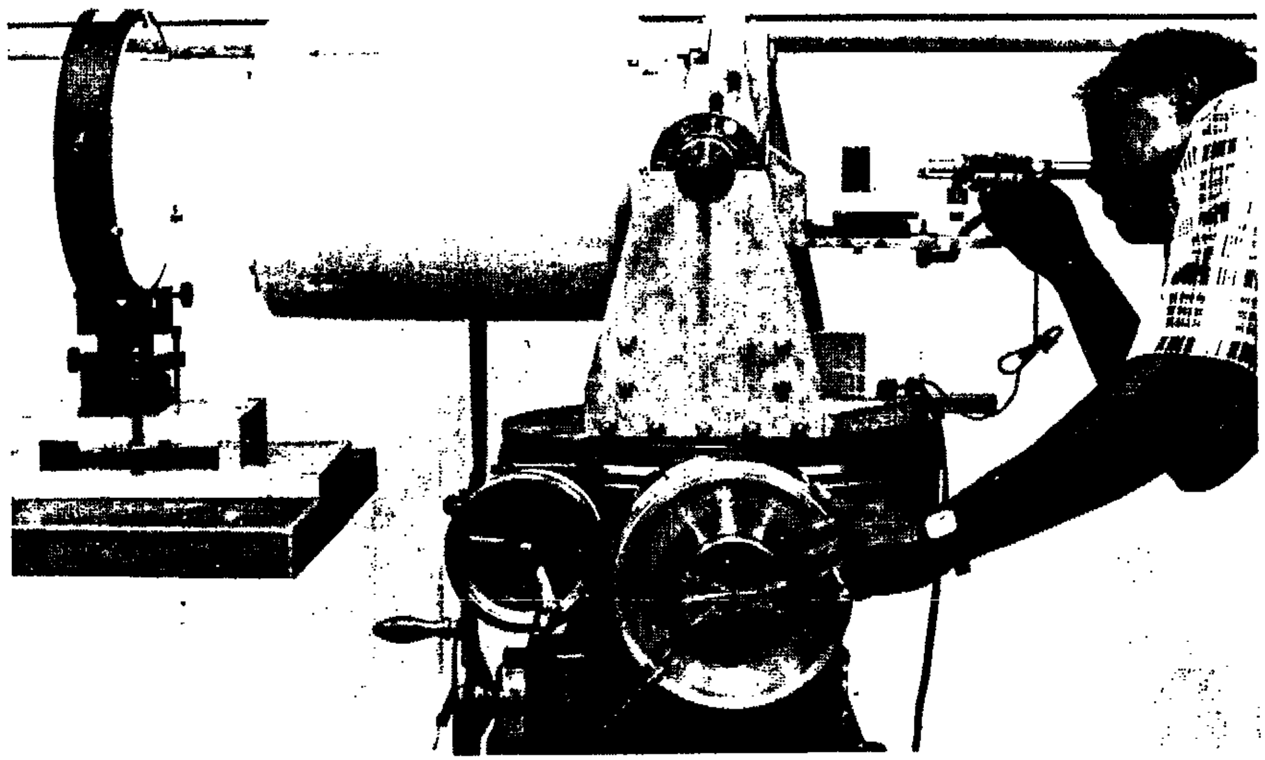


Figure 11. Autocollimation of mobile target.

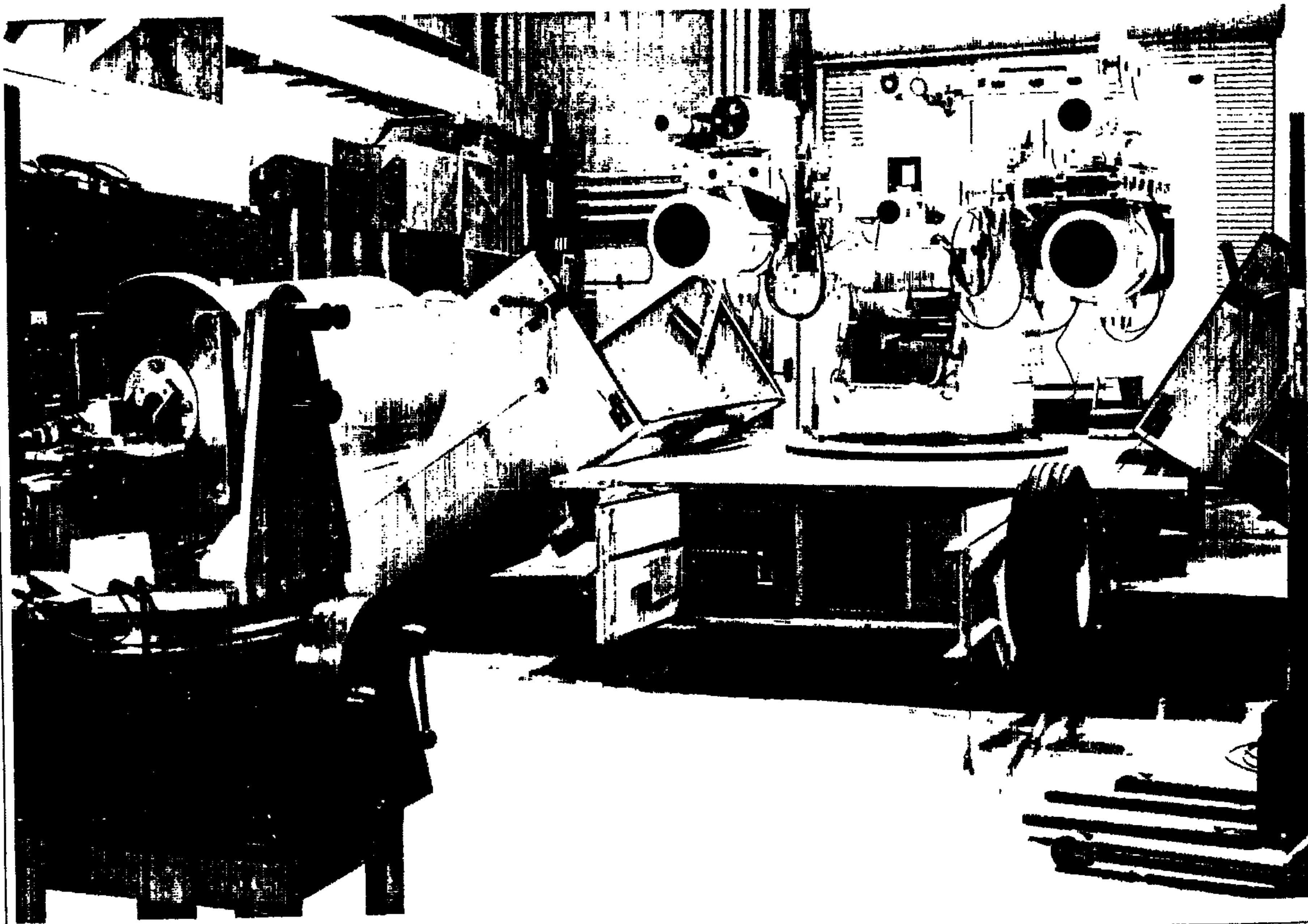


Figure 12. Mobile target being used to set up KTM lenses.

A microscope illuminator with a collimated light source is anchored to the right side of the focus shelf so that it may be positioned to project light through the resolution target or for autocollimation using the reticle. A 12-inch diameter flat mirror and cell is provided for autocollimation. Space and bolt holes allow the mirror cell to be bolted to the front of the collimator platform when in use. The target collimator assembly is supported by a pan-and-tilt head adapted to a K&E instrument stand.

9.2 Autocollimating. Autocollimation is necessary to establish the correct position for the target when the collimator lens is at infinity. When the target is projected into other lenses on tracking mounts, the lenses will see the target clearly while focused on infinity. This autocollimation should be done periodically especially if the collimator is moved, subjected to vibration or to severe temperature changes.

Autocollimation should not be attempted with the system mounted on the K&E stand for two reasons. First, the return image is very subject to vibration. On the stand it is almost impossible to get an accurate focus to position the target. Second, the system becomes very front heavy and somewhat unsafe. It is much better to remove the collimator assembly from the stand and place it on a solid table top, then bolt on the mirror cell. Even then, it may be necessary to put shims under the corners of the base plate to help dampen out vibration.

With the mirror cell bolted in front of the collimator lens, two people are required to align the mirror: one to position the mirror and the other to look into the rear of the lens with the microscope, target, and reticles removed. For a rough alignment, the mirror may be moved manually without the micrometers. As the mirror is moved back and forth, a flash of light will be seen as it passes the aligned position. When close to alignment, your eye will be reflected back through the center.

Replace the reticle in the front position of the holder (the reticle on the thickest glass is best for autocollimating). Then replace the microscope with the eyepiece and objective giving the widest field of view. Set the illuminator at the best position for autoreflection which is behind the reticle, beaming down at 45°, and as close as possible. Focus on the reticle with the microscope. Once the microscope is focused sharply on the reticle, it should not be refocused. Set the stage micrometer at a good starting position for the lens (approximately 23 mm). The return image should be visible and near focus when seen through the microscope. Focus the return image with the stage micrometer. Adjust the mirror cell micrometers so that the center of the reticle image is near the center of the reticle. Next, put the higher power eyepiece and objective in the microscope and refocus it on the reticle.

It will be necessary to make several readings. Keep practicing the readings until they are repeatable to within ±0.03 mm, then compute the average for about six readings. From readings made in the Optical Test Laboratory, the average was 23.21 mm. This figure will be used for calculating micrometer settings for simulating different ranges.

Both the resolution target and the reticles for autocollimation are cemented in the holders with the reference surfaces forward. The holders are manufactured so the shoulder of the recess where the target and reticles are mounted are of identical depth. This is the reference plane for flange focal distance of the collimator lens when focused on infinity. When simulating ranges closer than infinity, the target is moved forward toward the collimator lens.

9.3 <u>Calculating Target Micrometer Reading as a Function of Range</u>. Rearranging equation 2, it is possible to obtain

$$S^1 = \frac{fS}{f+S} \qquad (3)$$

where again,

S = range,
S^1 = image or target position,
f = focal length of the collimator lens (93.637 inches).

The range must be reduced by the distance between the target collimator and the lens which is being set; usually about 10 yards. This distance is especially important for the shorter ranges because of diverging rays.

$$S^1 = \frac{f[(S-10)36]}{f+[(S-10)36]}$$

for S^1 converted to inches.

<u>Example</u>: Range is 2000 yards.

$$S^1 = \frac{(93.637)[(2000-10)36]}{(93.637)+[(2000-10)36]} = \frac{6708154.680}{71733.637}$$

S^1 = 93.515 inches;

Target displacement = 93.637- 93.515 = 0.122 inch or 3.10 mm toward the lens.

Micrometer reading at infinity = 23.213 mm minus 3.10 = 20.11 mm which is the micrometer reading for 2000 yards.

Using the same equation, the following calculations were made:

Range	Micrometer setting
Infinity	23.21 mm
2000 yds	20.11 mm
825 yds	15.65 mm
525 yds	11.26 mm

9.4 Alignment. To align the collimator with a lens being set, first point the collimators toward each other. Remove the microscope and target, and look through the collimator lens with your eye centered. This method was found to be the best when using the prototype collimator at the Instrumentation Directorate (ID) at WSMR. With practice you will be able to get them in close alignment this way. It may require a few tries. Replace the resolution target in the front slot and the diffuser in the rear slot. Position the illuminator looking straight through the collimator in a position approximately 7 3/4 inches behind the resolution target. This position should be the best for taking photographs. Tests will be necessary to determine correct exposures for the photographs.

For lenses with automatic focusing, the focus is usually checked at infinity and the near range. For 50- and 100-inch Contraves lenses, the near range is 525 yards. For the 150-inch Contraves, the near range is 825 yards.

Photographs of the resolution target with the best exposure, development, and focus should produce negatives resolving at least 30 lines per millimeter on Linagraph Shellburst film. A microscope with about 30X magnification is needed to read the film. To calculate resolution, determine the smallest element distinguishable.

$$\text{Resolution} = \frac{\text{fl of collimator}}{\text{fl of lens being set}} \times \text{smallest resolution element}$$

10.0 VEILING GLARE

Veiling glare is caused by light which is scattered inside the telescope and reaches the image plane where it results in a reduction of image contrast. This scattered light may originate from oblique rays outside the field of view being reflected from internal structures, from scratches, or from other imperfections in optical elements. Proper baffel design and absorptive coatings are used to minimize scattered light, and careful optical fabrication techniques will eliminate scratches and other lens imperfections. All optical systems have some veiling glare, but in most systems, it is acceptable if it can be kept to less than 5 percent of the light forming the image.

Methods of measuring veiling glare are set forth in subparagraph 5.1.2.19 of MIL STD 150A and will not be repeated in detail here. In brief, at the WSMR Optical Facility, the telescope to be tested is set up in front of a collimator. The collimator's target consists of a piece of opal glass with a narrow opaque bar (made from black electrical tape) in the center. First, the aperture of the telescope is blocked and a photodetector, masked down to a small area, is scanned across the image plane. The detector's output voltage is recorded. (This output voltage is equivalent to obtaining a dark current reading). Next, the target is illuminated from behind to a level approximating the daytime sky. A large diffuse screen is placed in front of the telescope, having a hole equal to the telescope's aperture cut in it so that the target may be viewed, and is illuminated on the side of the screen facing the lens. The photodetector is again scanned across the image plane so that the scan line intercepts the image of the opaque bar, and the detector's output voltage is again recorded. The screen should be illuminated to the same level as the target. The reduction in contrast, because of the scattering of light from the screen inside the telescope, can be determined by comparing the size of the voltage dips, caused by scanning across the opaque spot, both with and without the screen being illuminated.

11.0 ENVIRONMENTAL CONSIDERATIONS

Long focal-length optical systems are seldom used in a controlled, benign environment; however, acceptance testing of these systems are almost always done under ideal laboratory conditions. Very few manufacturers have the facilities to test their product under the environmental conditions spelled out in the purchase description (PD), relying instead on the use of proper design techniques to ensure compliance with the specifications. This method does not always work out, and often it is long after the system has been delivered and accepted that failures under extreme environmental conditions occur. If it is essential that the system perform under specified conditions of vibration such as a system to be used on a mobile mount, it would be wise to require a vendor to demonstrate conservation of system alignment after subjecting it to vibrations similar to those in the field. Likewise, systems containing moving parts such as focus drives and filter wheels should be tested over the expected temperature extremes. This testing can be done by removing such subsystems and measuring performance in a small environmental chamber. It is unlikely that a vendor will have access to a chamber suitable to test the entire system including optical performance.

A method of testing large lenses, up to 150-inch focal length and 15-inches diameter, under extremes of temperature (-10 to +110° F) has been developed at WSMR. A temperature shroud, large enough to cover the lens, was constructed of sheet aluminum and lined with styrofoam. The shroud was built in two parts: a base and a cover. The base features an invar base to which the lens is clamped. After aligning the lens in the collimator and connecting cables from the lens, cables and thermocouple sensors are fed through the housing and the cover is installed. Hoses from commercially available environmental chambers are connected to the cover. Hot or cold air is blown through the shroud until the desired temperature is reached. A panel in the front of the cover can then be removed after first shutting off the air flow. The panel is replaced with another, bearing three optically thin pellicles. Resolution, focus shift, and boresight shift measurements can be made using either a video or film camera, viewing the target through the pellicle window. Operation of mechanical devices such as focus drives can, of course, also be tested. Figure 13 shows a 150-inch lens in the shroud with the front panel removed. Figure 14 shows the pellicle window in place.

12.0 PROCUREMENT CONSIDERATIONS

Since the purchase of long focal-length optical systems represents a considerable monetary investment, everything possible should be done to ensure a successful procurement. The first step in the procurement cycle is the definition of requirements. Sometimes a costly mistake is made at this point by over specifying the performance required. There is a large cost difference between a quarter-wave surface and one ground to a tenth wave. How and where the system is to be used should be considered. Specifying diffraction limited optics for a large aperture system to be used looking through atmospheric turbulence or specifying a tenth-wave system for use with a video camera with its limited resolution capability is a waste of money. If the requiring agency does not have personnel experienced in the use and specification of telescopes, the agency would do well to seek assistance from another source that does. If an agency uses an in-house contractor to handle the procurement, every effort should be made to ensure that the person assigned to the task possesses the necessary skills and experience. Another strong recommendation is that the Purchase Description (PD) require the contractor to perform an in-plant test of the system, with a government witness present, to demonstrate compliance with the PD prior to delivery.

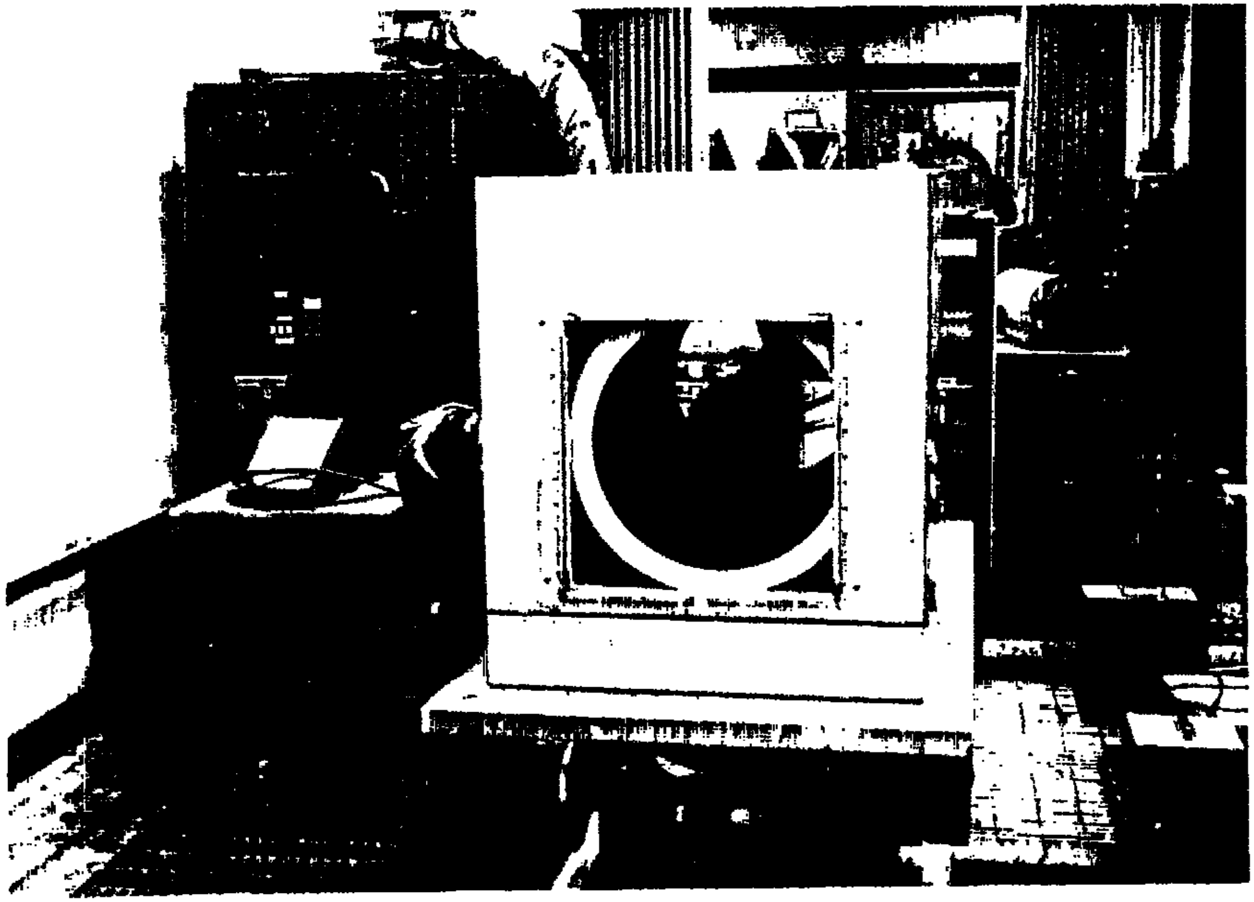


Figure 13. Temperature Chamber: Front cover removed.

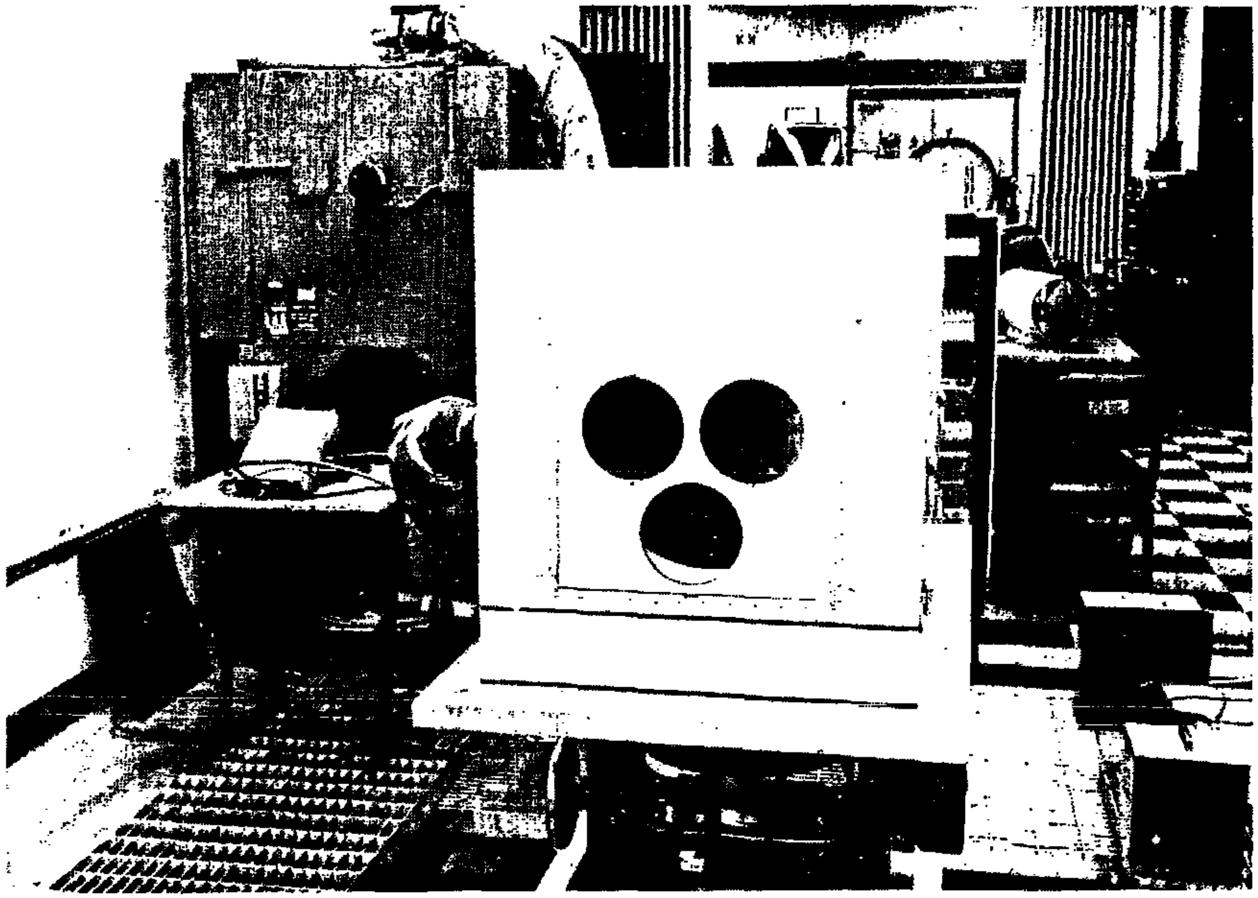


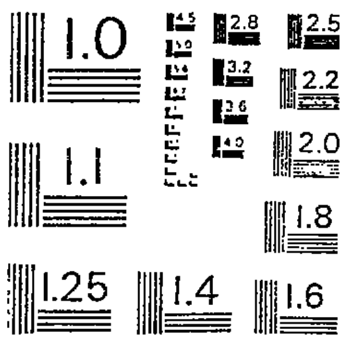
Figure 14. Temperature Chamber: Pellicle window in place.

The contractor should also be required to submit a test plan for government approval prior to the test. Such requirements are necessary when the procuring agency has no facilities for performing adequate tests. It is also an excellent policy even when the procuring agency has such capabilities, because it is much easier to reject or have the contractor bring into compliance a defective system before it is delivered. Although this requirement will add to the system cost, it will also ensure that the successful bidder has the facilities, test equipment, and "know-how" to perform the required work.

APPENDIX A

SAMPLE DATA SHEET

RESOLUTION TARGETS



NBS 1963A TARGET

STOCK #	Description	PRICE
70.6010	50.8 × 50.8 × 2.5mm	$ 50.57

CONVERSION

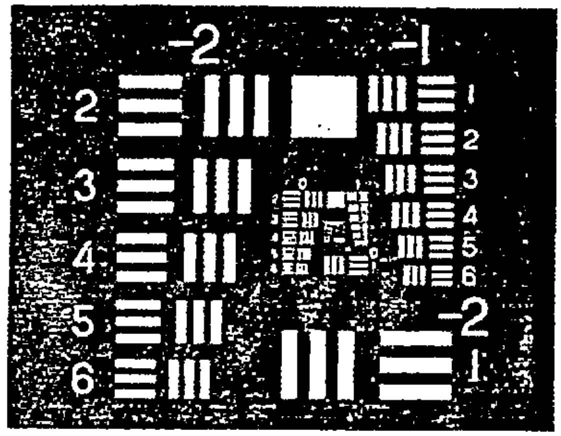
While most optical work is done in the metric system, the practice is not yet universal. We have shown a few conversion values for your convenience.

Lines/mm	Lines/in.	Lines/in.	Lines/mm
.25	6.35	10	.39
.5	12.7	25	.98
1.00	25.4	50	1.97
2.00	50.8	100	3.94
4.00	101.6	250	9.84
8.00	203.2	500	19.68
16.00	406.4	1000	39.37
32.00	812.8	2000	78.74
64.00	1625.6	3000	118.11
128.00	3251.2	5000	196.85

NOTE:

Additional technical help available on request. Please call or write for further assistance.

(818) 915-5707
(818) 915-5717



USAF 1951 TARGET

This is the standard "Air Force" target described in Military Standard 150-A paragraph 5.1.1.7.

An Element consists of two Patterns at right angles to each other. Each Pattern consists of three lines and two spaces of equal width and length five times the width.

The change in pattern size progresses geometrically as the sixth root of two or conversely the lines per millimeter count doubles with every sixth element, and these groups of six elements are referred to as a Group and assigned a group number which tells the power of 2 to which the first element in the group was raised to determine the number of lines per millimeter in that element. The zero group then has one cycle per millimeter.

The chart below enables the use of the target without computations.

	GROUP NUMBER									
Element No.	−2	−1	0	1	2	3	4	5	6	7
1	0.250	0.500	1.00	2.00	4.00	8.00	16.00	32.0	64.0	128.0
2	.280	.561	1.12	2.24	4.49	8.98	17.95	36.0	71.8	144.0
3	.315	.630	1.26	2.52	5.04	10.1	20.16	40.3	80.6	161.0
4	.353	.707	1.41	2.83	5.66	11.3	22.62	45.3	90.5	181.0
5	.397	.793	1.59	3.17	6.35	12.7	25.39	50.8	102.0	203.0
6	.445	.891	1.78	3.56	7.13	14.3	28.51	57.0	114.0	228.0

All Standard ROLYN Targets are high contrast containing 0 through 6 groups on a 50 × 50 × 1.5mm glass substrate. Others available on special order.

STOCK #	Description	PRICE
70.6030	Positive, chrome, 1.5mm thick	$79.55
70.6035	Negative, chrome, 1.5mm thick	79.55
70.6040	Positive, emulsion, 1.5mm thick	56.32
70.6045	Negative, emulsion, 1.5mm thick	56.32

1951 USAF HIGH CONTRAST RESOLUTION TARGET

F.L. Columinator/F.L. Lens = 144.4/? = magnification ratio

target lens view	target lines view	best group-element number	*VISUAL* average x ratio = lines/mm	best group-element number	*FILM* average x ratio = lines/mm
on axis	Horiz_	________	________	________	________
	Vert__	________	________	________	________
15mm left	Horiz_	________	________	________	________
	Vert__	________	________	________	________
15mm right	Horiz_	________	________	________	________
	Vert__	________	________	________	________
30mm right	Horiz_	________	________	________	________
	Vert__	________	________	________	________
30mm left	Horiz_	________	________	________	________
	Vert__	________	________	________	________

++

++

DATE______________________________________

LENS BRAND NAME___________________________

LENS FOCAL LENGTH_________________________

LENS SERIAL NUMBER________________________

LENS BARCODE NUMBER_______________________

____

____

++

++

EFFECTIVE FOCAL LENGTH

(this is large white square block as seen on resolution target)

|<—G—>| G = 2.25679 mm (.08885 in.)

Set up metric microscope behind lens with 10X objective and 10X eyepiece for 100X magnification.

Focus on large white square block of resolution target (between group 0 & 1 on 1951 USAF High Contrast Resolution Target)

Reference: Navy Photographers Mate 3 & 2, page 92,

Image-Object Relationship

$$\frac{I}{F} = \frac{G}{A}$$

where: I = image size

F = image focal distance

G = object size or area covered

A = lens to object distance

and: focal length of columinator = 3667.76mm (144.40 in.)

READINGS

1.______

2.______

3.______

4.______

5.______

(I)=Avg.

$$\frac{(I)}{(G)0.08885\text{in.}} \times \frac{(A)144.40\text{in.}}{1} = \frac{(F)}{1} \text{ inches}$$

$$\frac{(I)\_\_\_\_\_\_}{(G)2.25679\text{mm}} \times \frac{(A)3667.76\text{mm}}{1} = \frac{(F)}{25.4} = \frac{\_\_\_\_}{1} \text{ in.}$$

Note: May also measure large white block on negative during resolution test using Brown & Sharpe X & Y microscope and compute EFL using formula noted in this chart.

BEST FOCUS OF 1951 USAF TARGET - VISUAL

install fixture & reticle-focus 30mmL to 30mmR-remove fixture
install camera-lens on axis-center target in view finder
tape reticle to camera film plane & white card to lens back
install micscope-focus on reticle-DON'T refocus micscope
adjust Y micrometer to best focus of target on reticle
remove reticle - Y micrometer________ X micrometer________
150' lens - bracket best visual focus in .0015" steps
100' lens - bracket best visual focus in .0010" steps
50 ' lens - bracket best visual focus in .0005" steps

STROBE

50' lens on axis = 0.4 ND filter - knob setting #2
50' lens 30mm off axis = 0.3 ND filter - knob setting #2
100' lens on & off axis = no filter - knob setting #2
150' lens on & off axis = 0.2 ND filter - knob setting #3
distance. strobe/target = 1.5'

++

TARGET

50' & 100' lens = Kodak Wratten #2 (K2) filter (to reduce ultra violet light)

++

FILM

kodak linagraph starburst
develop__________minutes at __________degrees

++

neg #	group - element #		micrometer #	neg #	group - element #		micrometer #
	H	V			H	V	
1	____	____	______in.	19	____	____	______in.
2	____	____	______in.	20	____	____	______in.
3	____	____	______in.	21	____	____	______in.
space xxx	xxxxx		xxxxxxxxxx	space xxx	xxxxx		xxxxxxxxxx
4	____	____	______in.	22	____	____	______in.
5	____	____	______in.	23	____	____	______in.
6	____	____	______in.	24	____	____	______in.
space xxx	xxxxx		xxxxxxxxxx	space xxx	xxxxx		xxxxxxxxxx
7	____	____	______in.	25	____	____	______in.
8	____	____	______in.	26	____	____	______in.
9	____	____	______in.	27	____	____	______in.
space xxx	xxxxx		xxxxxxxxxx	space xxx	xxxxx		xxxxxxxxxx
10	____	____	______in.	28	____	____	______in.
11	____	____	______in.	29	____	____	______in.
12	____	____	______in.	30	____	____	______in.
space xxx	xxxxx		xxxxxxxxxx	space xxx	xxxxx		xxxxxxxxxx
13	____	____	______in.	31	____	____	______in.
14	____	____	______in.	32	____	____	______in.
15	____	____	______in.	33	____	____	______in.
space xxx	xxxxx		xxxxxxxxxx				
16	____	____	______in.|> \				
17	____	____	______in.|>>>> BEST VISUAL FOCUS <<<				
18	____	____	______in.|> /				
space xxx	xxxxx		xxxxxxxxxx				

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