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PREFLIGHT OPTICAL EVALUATION OF THE RIGHT-HAND HATCH WINDOWS OF GEMINI MISSIONS VII, VIII, IX, AND XII

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ABSTRACT

Preflight studies of the transmission, schlieren, and resolution qualities of the Gemini spacecraft G-VII, G-VIII, G-IX, and G-XII right-hand hatch windows were conducted. Transmission measurements were made for angles of incidence of 0°, 15°, 30°, and 45°. All windows were comparable in transmission qualities, and the schlieren studies indicated that all windows were excellent in optical quality. Relative resolution was tested by resolution-chart photography. The G-XII window proved superior in resolution.

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SUMMARY

Preflight studies of the transmission, schlieren, and resolution qualities of Gemini spacecraft G-VII, G-VIII, G-IX, and G-XII right-hand hatch windows were conducted to assist in the evaluation of experiments performed through the Gemini windows. The transmission measurements were made for angles of incidence of 0°, 15°, 30°, and 45°. All the windows had comparable transmission qualities, and the schlieren studies showed that all the windows were of excellent optical quality. Relative resolution through the windows was determined by photographing a resolution chart. The G-XII window proved to have the best resolution.

INTRODUCTION

The specifications for windows on the Gemini spacecraft include excellent optical quality in a 6-inch-diameter circle in the center of the right-hand hatch window. All optical experiments are performed through this 6-inch-diameter circle. Knowledge of these measured optical properties enables the principal experimenters to evaluate the results of their experiments accurately.

Although the optical properties have been uniquely defined for each pane of glass, it is impossible to predict the characteristics of an assembled window, since each window is coated with an antireflectance material and since the geometry of mounting the windows varies from spacecraft to spacecraft. Thus, the studies must be performed on the completely assembled window. The optical tests described in this report were conducted with the assembled window installed in the right-hand hatch of the G-VII, G-VIII, G-IX, and G-XII spacecraft.

The studies on the G-VII spacecraft window were conducted at St. Louis, Missouri. The studies for the G-VIII, G-IX, and G-XII spacecraft windows were made at the NASA Manned Spacecraft Center. This report presents the results of these studies.

SYMBOLS

I	incident voltage
I_{av}	average incident voltage
IN	incident noise
IN_{av}	average incident noise
i, m	summation indexes
P_{ET}	probable error in percent transmission
P_I	probable error in incident voltage
P_T	probable error in transmitted voltage
T	transmitted voltage
T_{av}	average transmitted voltage
TN	transmitted noise
TN_{av}	average transmitted noise
θ	angle of incidence
σ_I	standard deviation in incident voltage
σ_T	standard deviation in transmitted voltage

TEST PROCEDURE

Spectral Transmission Studies

The transmission of a window is defined as the ratio of the rad ant energy transmitted through the window to the radiant energy incident upon the window. The method used to determine the transmission is described in the following paragraphs and is illustrated in figures 1 and 2.

The transmission measurements are performed in a darkroom in which the light source is a heated tungsten lamp that has a continuous spectrum and a color temperature of approximately 2500° K. The energy from the lamp is focused upon the entrance slit of a grating monochromator. The grating diffracts the energy incident from the tungsten lamp and forms the spectrum. The desired portion of the spectrum, obtained by manually rotating the grating, is focused at the exit slit of the monochromator. (For the transmission study of the G-XII right-hand hatch window, two changes were made in the procedure. A prism monochromator was used in place of a grating monochromator, and a hydrogen lamp was used as the source of energy for wavelengths shorter than 450 millimicrons.)

The energy exiting from the monochromator is collimated by a monochromator exit slit placed at the focal point of an off-axis parabolic mirror. The parallel light is directed upon a photomultiplier, and the intensity of the light incident upon the photomultiplier is measured and recorded as millivolts of output. The reading obtained in the manner is the incident voltage I.

With the apparatus in the previously described configuration, the window is inserted between the collimator and the photomultiplier. The beam of energy is incident within a 6-inch-diameter circle in the center of the window. This procedure is necessary because the specifications for the Gemini windows require excellent optical quality only in a 6-inch-diameter circle in the center of the right-hand hatch window. The angle between a normal to the window and the incident ray is defined as the angle of incidence θ (fig. 1). A certain portion of the energy incident upon the window is transmitted and enters a photomultiplier. The intensity of the light entering the photomultiplier is recorded as millivolts of output. This reading is the transmitted voltage T. After I and T have been determined, the percent of transmission %T can be determined in its simplest form (neglecting noise) from

$$\%T = \frac{T}{I} 100 \tag{1}$$

The percent of transmission was obtained for wavelengths ranging from 350 to 1000 millimicrons in 25-millimicron steps for the G-VII and G-VIII window studies. The G-IX study covered the same spectral region, but the percent of transmission was obtained in 10-millimicron steps. For the G-XII window, the spectral range was extended down to 300 millimicrons in 10-millimicron steps. The transmission measurements were made for angles of incidence of 0°, 15°, 30°, and 45° for G-VII, G-VIII, and G-XII. No reading was obtained on the G-IX study for an angle of incidence of 30°.

Two series of noise readings are taken at each angle of incidence. One reading is taken of the incident noise IN, and the other reading is taken of the transmitted noise TN. To obtain the reading for IN, the exit slit is blocked, which permits the photomultiplier to read the background. The reading for TN is taken in the same manner, except the window is in front of the photomultiplier. Before the readings for I and T are taken, 12 readings are taken for IN and TN. Twenty-four readings are then taken for I at each wavelength setting over the desired spectral range. The window is inserted into the beam, and 24 readings are taken for T at each wavelength. When the procedure is completed, the exit slit of the collimator is again blocked, and 12 more readings are taken for IN and TN. Twelve readings are taken for IN and TN before readings are taken for I and T, and then 12 more readings are taken for

IN and TN in order to average the posible changes in noise levels occurring during the time needed to take the readings for I and T.

When the readings are completed, each set of 24 values for I, T, IN, and TN is averaged to obtain average incident voltage I_{av}, average transmitted voltage T_{av}, average incident noise IN_{av}, and average transmittance noise TN_{av}. As an example, the average incident voltage is computed from

$$I_{av} = \frac{\sum_{i=1}^{m} I_i}{m} \qquad (2)$$

where m = 24. After the averages are computed, %T is given by

$$\%T = \frac{T_{av} - TN_{av}}{I_{av} - IN_{av}} 100 \qquad (3)$$

Determination of the probable error in the percent of transmission begins with the standard deviation, defined as

$$\sigma_I = \left(\frac{\sum_{i=1}^{m} I_i^2 - mI_{av}^2}{m - 1}\right)^{1/2} \qquad \sigma_T = \left(\frac{\sum_{i=1}^{m} T_i^2 - mT_{av}^2}{m - 1}\right)^{1/2} \qquad (4)$$

where σ_I is the standard deviation of I, and σ_T is the standard deviation of T. The probable error in incident voltage P_I and the probable error in transmittal voltage P_T are then found by

$$P_I = 0.6745\sigma_I \qquad P_T = 0.6745\sigma_T \qquad (5)$$

The probable error in the percent of transmission P_{ET} can now be found from

$$P_{ET} = \left[\left(\frac{P_I}{I_{av}} 100\right)^2 + \left(\frac{P_T}{T_{av}} 100\right)^2\right]^{1/2} \qquad (6)$$

Another statistical factor, the reproducibility of the data, must be considered. Besides data fluctuations that result in the probable error, other factors limit the data reproducibility. The windows could not be moved about easily because they were in their hatches when the measurements were made. Thus, instead of the window being moved in and out of the light beam for each wavelength, a complete wavelength scan was performed with the window out of the beam, followed by another wavelength scan with the window in the beam. Time-dependent photomultiplier drift became a factor. Another factor affecting data reproducibility was the manual selection of the wavelength. Data reproducibility is estimated to be within ±4 percent for the G-VII, G-VIII, and G-IX studies and within ±2 percent for the G-XII study. The greater accuracy for the G-XII study is a result of the change in measuring systems.

Schlieren Studies

No schlieren studies were made on the G-VII right-hand hatch window. The apparatus used for the schlieren studies on the G-VIII, G-IX, and G-XII right-hand hatch windows is shown in figure 3. A point source of light is placed at the focal point of an off-axis parabolic mirror. This mirror has a 16-inch diameter and a 90-inch focal length. The mirror collimates the light from the source to an identical mirror that refocuses the light. A knife edge is placed at the focal point of the second mirror so that the knife edge partially interrupts the light to give the uniformly illuminated field shown in figure 4.

The window is inserted between the mirrors and perpendicular to the light beam. Any deviations in the parallel light beam appear in the schlierengraphs as variations in light intensity. The variations indicate irregular surface conditions, variations of the index of refraction, nonparallelism of the surfaces, and flaws in the window materials. Schlierengraphs of the G-VIII, G-IX, and G-XII windows are shown in figures 5, 6, and 7, respectively. The windows are as seen from outside the spacecraft.

Resolution Studies

Any resolution loss due to the windows must be evaluated in order to interpret optical experiments conducted through the window. To obtain the resolution losses, a resolution chart is photographed with the window in the camera field of view and again with the window out of the camera field of view. A National Bureau of Standards (NBS) resolution chart was photographed for G-VII, G-VIII, and G-IX. For G-XII, a United States Air Force (USAF) bar chart was photographed. A 1400-mm-focal-length telescope is used as a lens for the 35-mm camera.

The relative resolution is defined as the ratio of the resolution of the system without the window to the resolution of the system with the window, without refocusing of the telescope. The telescope system remained perpendicular to the center of the window to simulate the manner in which optical experiments were mounted in the spacecraft. The camera-telescope system had a fixed aperture, and the chart was placed as far as possible from the window. The relative resolution was obtained by microscopic examination of the original negatives. Photographs made from these negatives are included in this report as figures 8 to 11.

RESULTS

Transmission Studies

The results of the transmission studies are illustrated in figure 12. The percent of transmission is plotted against the wavelength for each of four angles of incidence for the G-VII, G-VIII, G-IX, and G-XII right-hand hatch windows.

When the transmission plateaus are compared, the right-hand hatch window of G-XII appears to have the best transmission characteristics; however, all the windows are of comparable quality.

The probable error was found from equation (6) to be approximately ± 0.5 percent in the G-VII, G-VIII, and G-IX window studies. In the G-XII window study, the average probable error was found to be approximately ± 0.2 percent.

Schlieren Studies

The results of the schlieren tests are best noted by comparing figures 5 to 7 (the schlierengraphs of the right-hand hatch windows of G-VIII, G-IX, and G-XII with figure 4 the schlierengraph without a window in the light path). These comparisons indicate that each window has excellent schlieren qualities.

Resolution Studies

Figures 8 to 11 are the photographs of the resolution charts. Figures 8(a), 9(a), 10(a), and 11(a) are the charts photographed without a window in the optical path. Figures 8(b), 9(b), 10(b), and 11(b) are the charts photographed through the window. The following table gives the number of lines resolved in each negative and therefore the relative resolution loss due to the window.

Window	Resolution, lines/mm			Resolution loss, percent	
	Without window	With window		Horizontal	Vertical
		Horizontal	Vertical		
G-VII	80	68	40	15	50
G-VIII	80	56	56	30	30
G-IX	80	56	56	30	30
G-XII	35.4	31.2	31.2	12	12

In interpreting the percent of resolution loss due to the window, it is readily apparent that the G-XII window caused the least resolution loss. The results of the G-XII study indicate the presence of astigmatism in the window. Postflight examination of the windows after they have been removed from the hatch will include an interferometric study for information regarding the astigmatism.

CONCLUDING REMARKS

Spectral transmission measurements, schlieren studies, and resolution measurements performed on the G-VII, G-VIII, G-IX, and G-XII right-hand hatch windows show the windows to be of high optical quality. The resolution studies indicate a slight astigmatism in the G-VII window. All the windows were comparable in transmission and schlieren characteristics.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, August 21, 1969
923-50-10-06-72

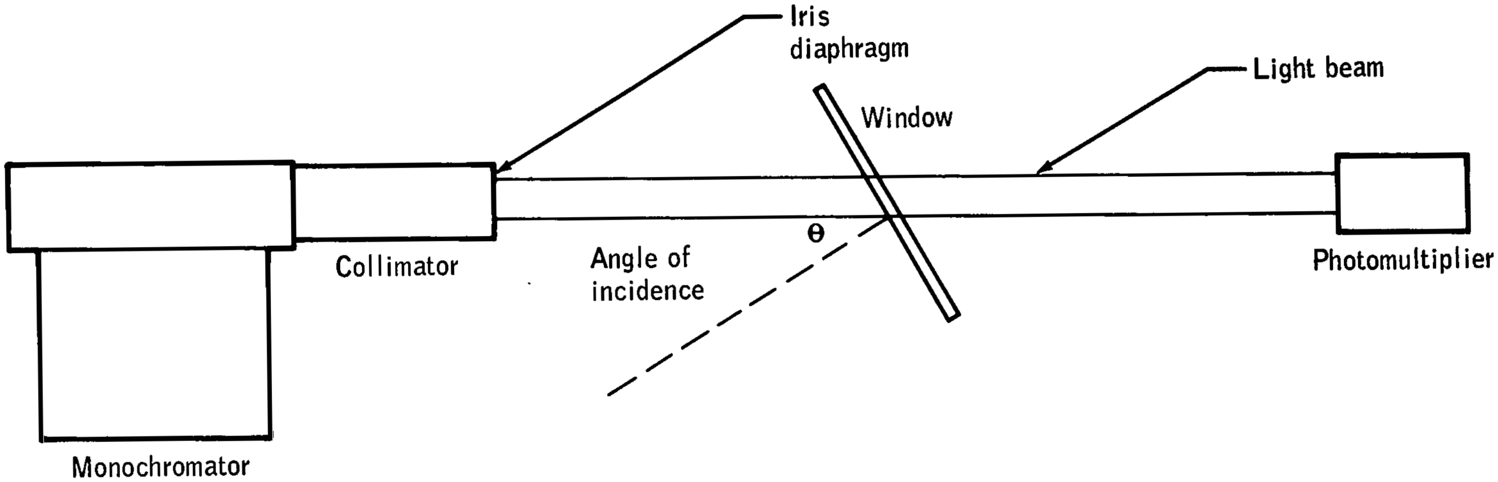


Figure 1. - Schematic of transmission-measuring system.

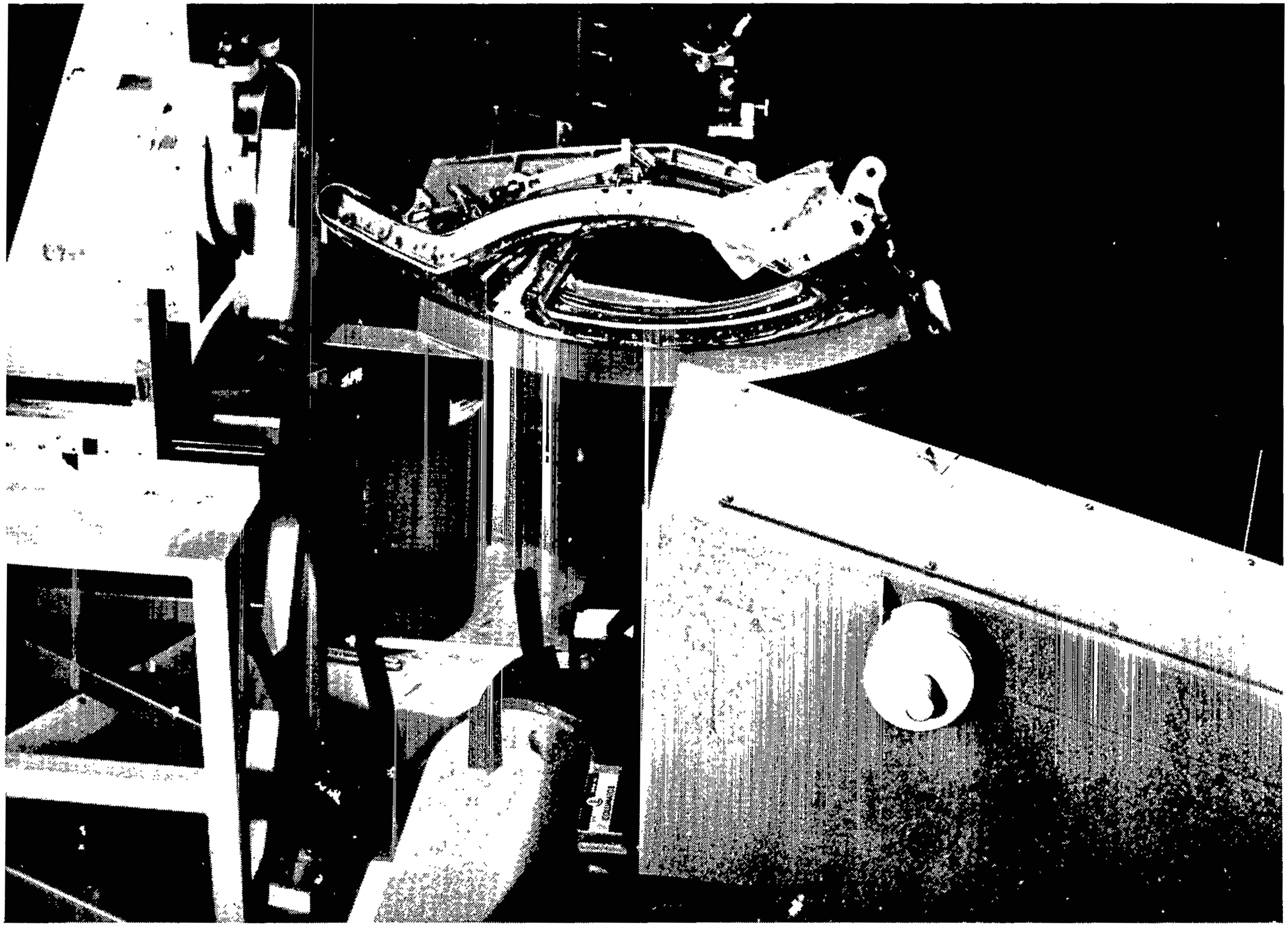


Figure 2. - Transmission-measuring system.

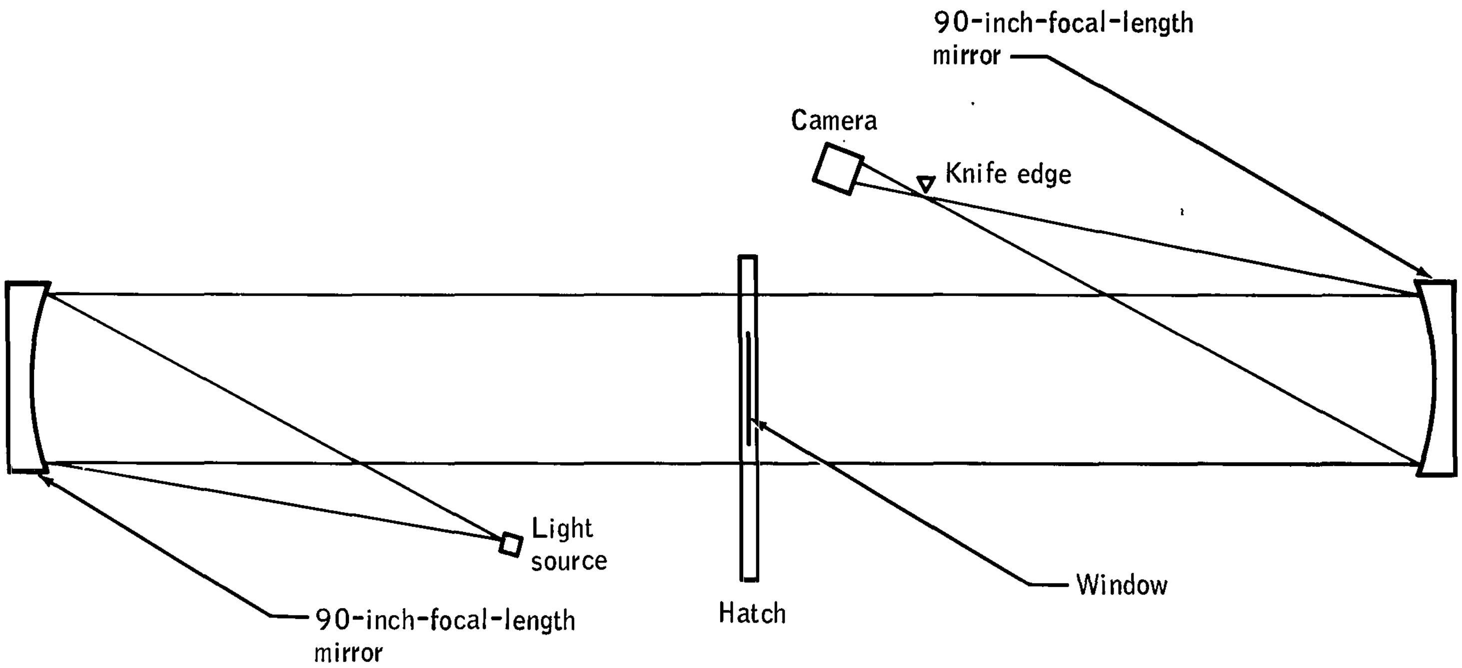


Figure 3. - Schematic of schlieren-measuring system.

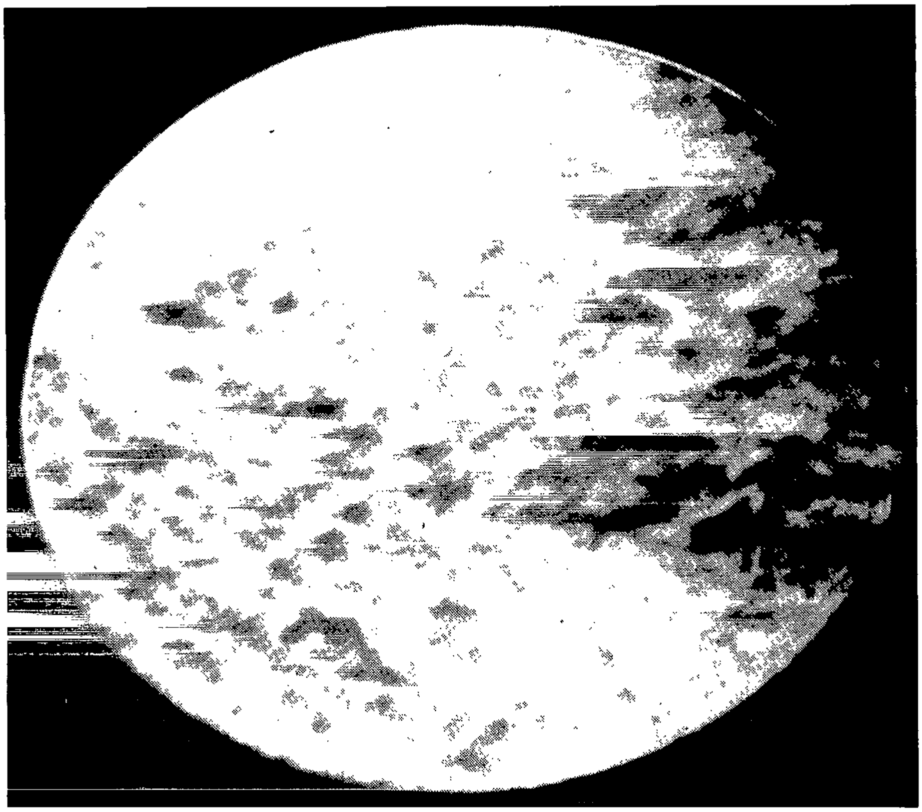


Figure 4. - Schlierengraph without window.

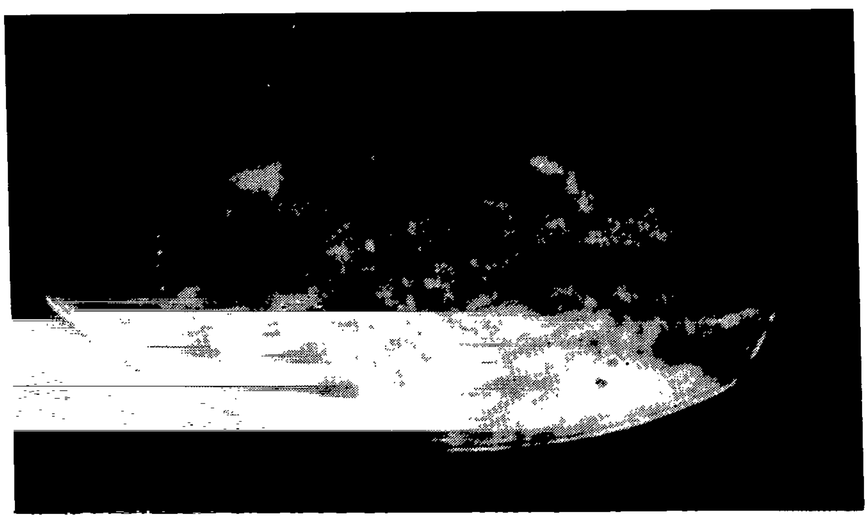


Figure 5. - Schlierengraph with G-VIII window.

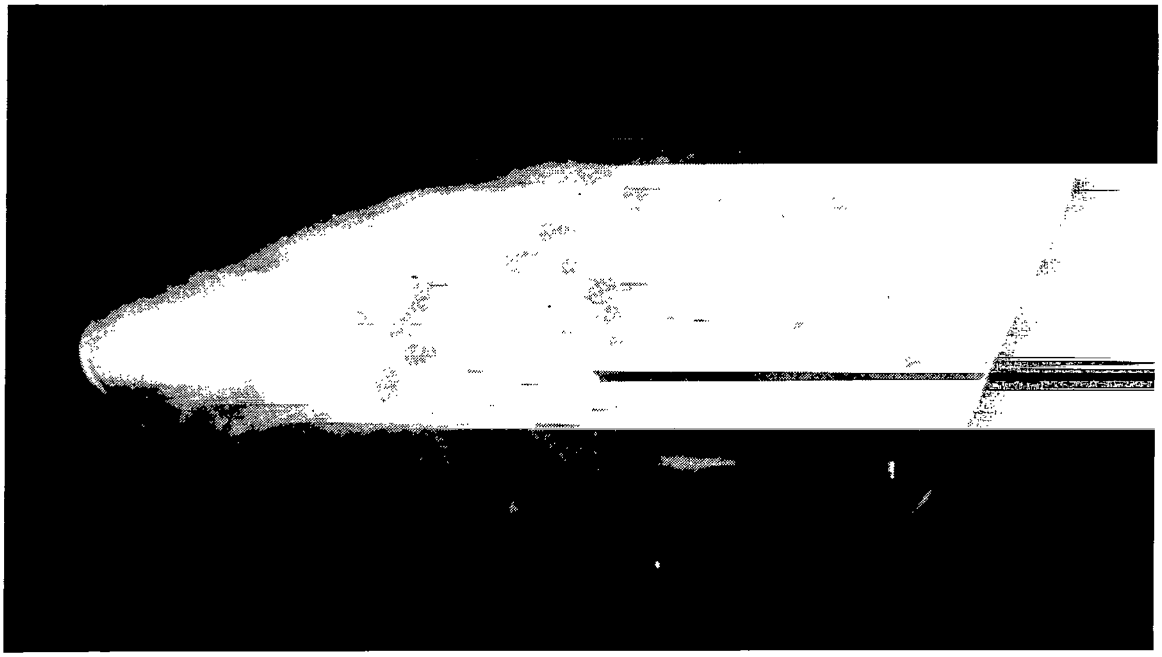


Figure 6. - Schlierengraph with G-IX window.

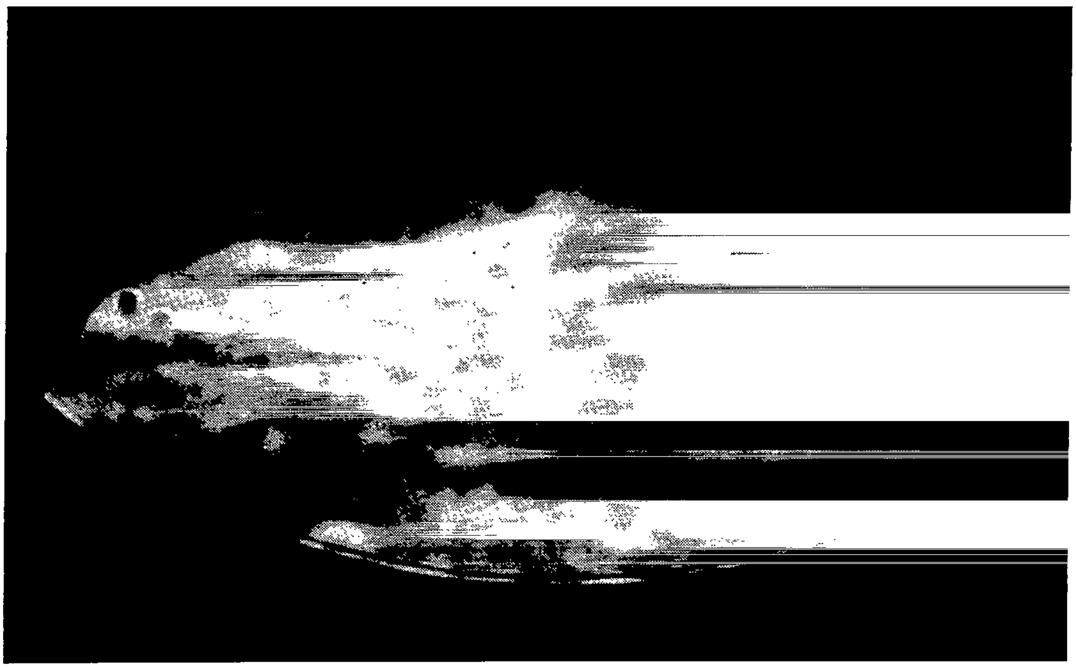
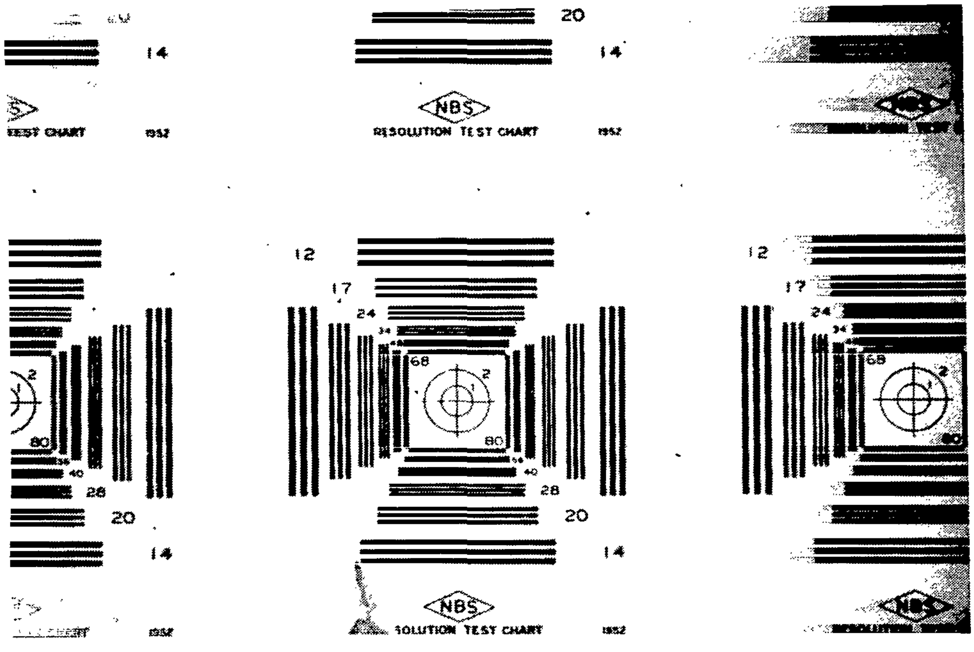
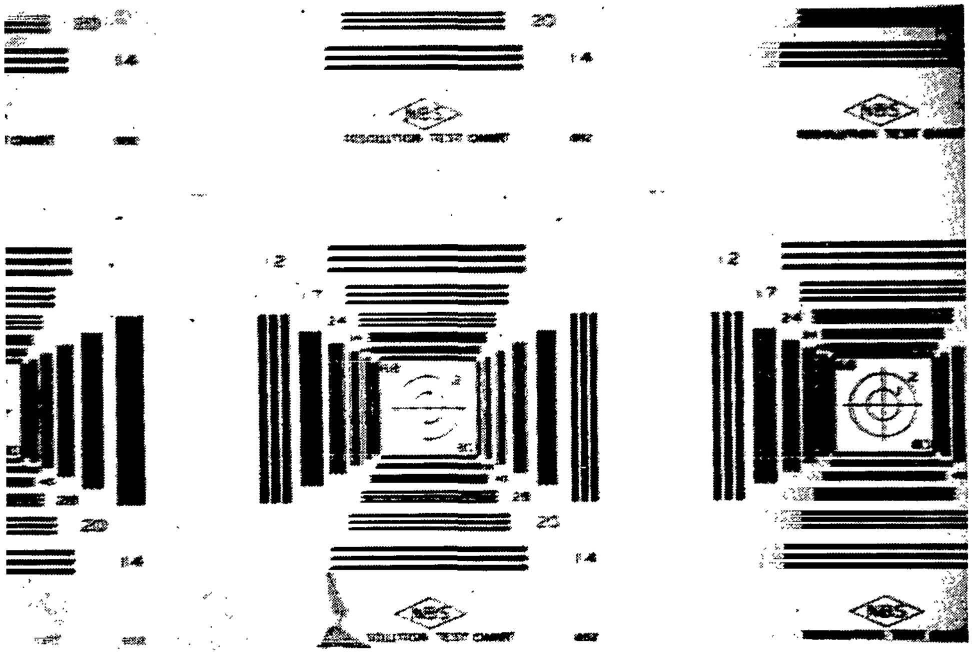


Figure 7. - Schlierengraph with G-XII window.

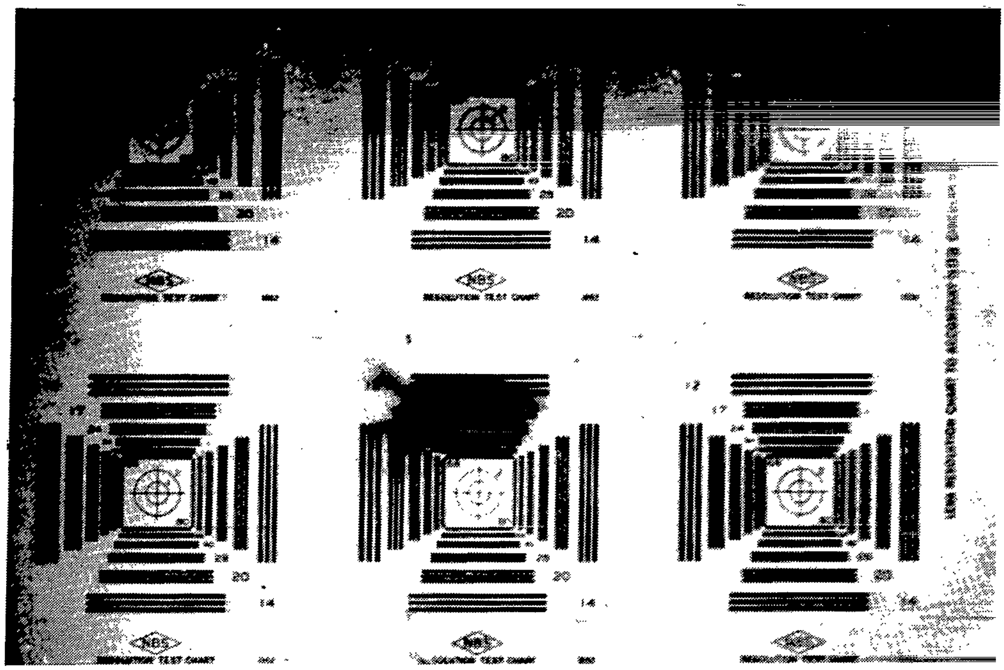


(a) Without G-VII window.

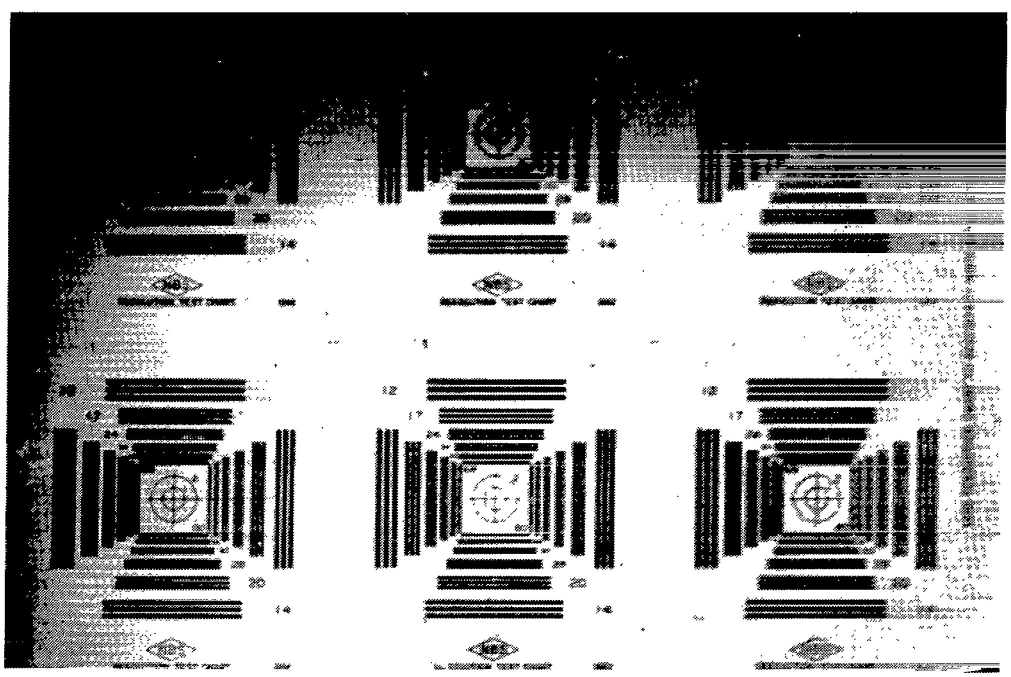


(b) With G-VII window.

Figure 8. - Photograph of NBS resolution chart with 1400-mm-focal-length telescope and camera (with and without G-VII window).

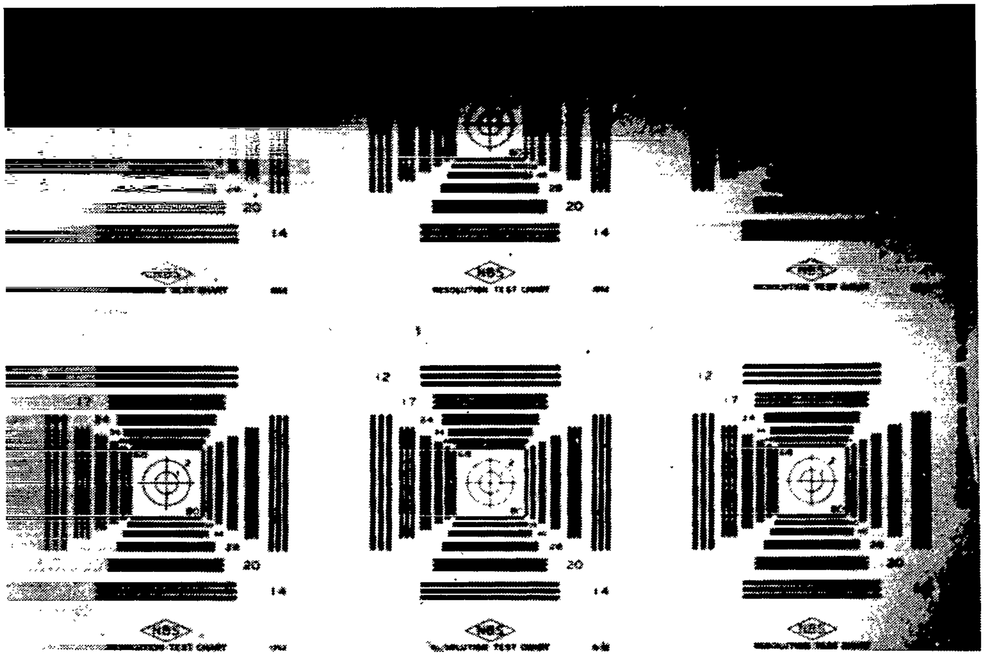


(a) Without G-VIII window.

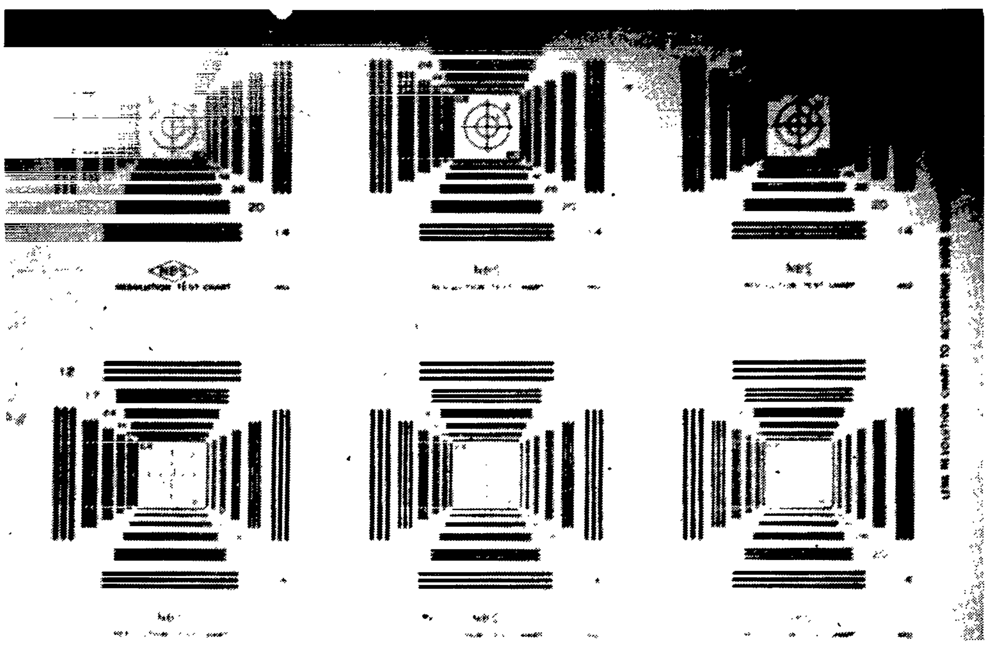


(b) With G-VIII window.

Figure 9. - Photograph of NBS resolution chart with 1400-mm-focal-length telescope and camera (with and without G-VIII window).

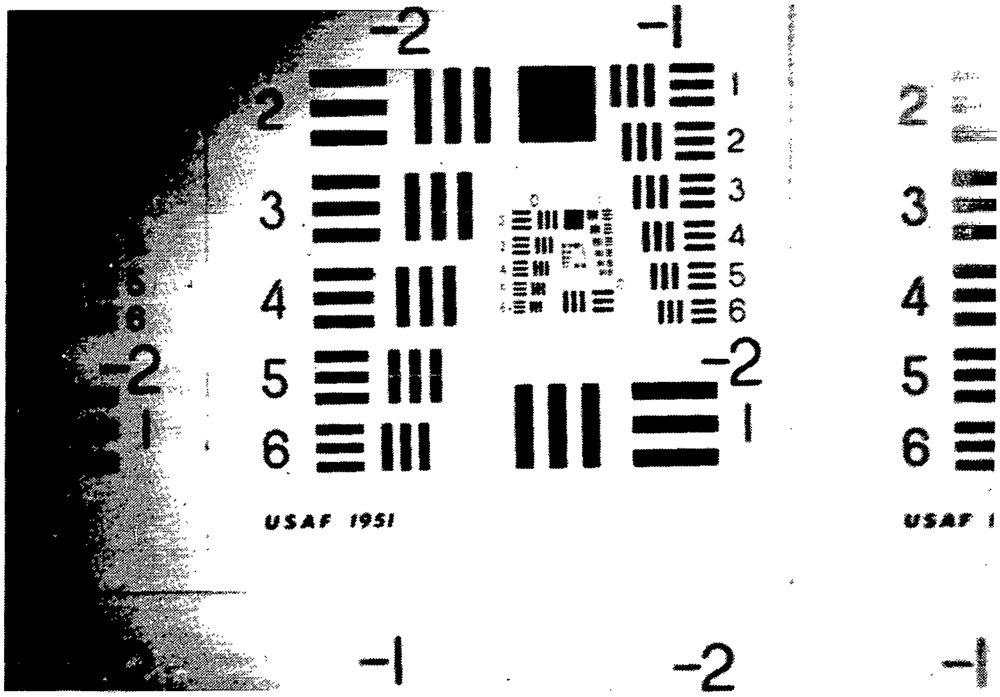


(a) Without G-IX window.

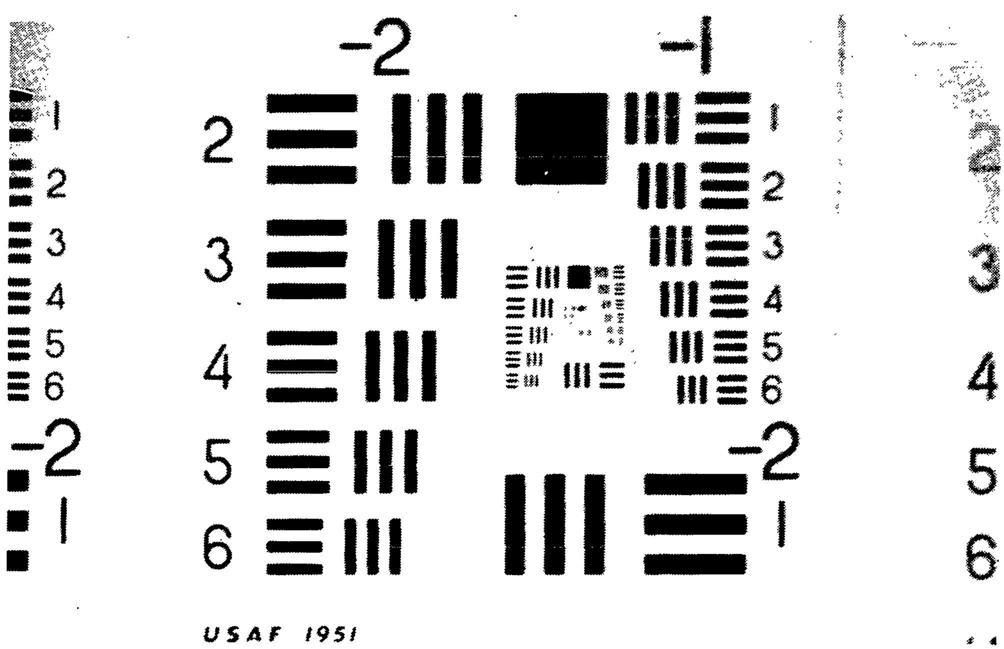


(b) With G-IX window.

Figure 10. - Photograph of NBS resolutions chart with 1400-mm-focal-length telescope and camera (with and without G-IX window).

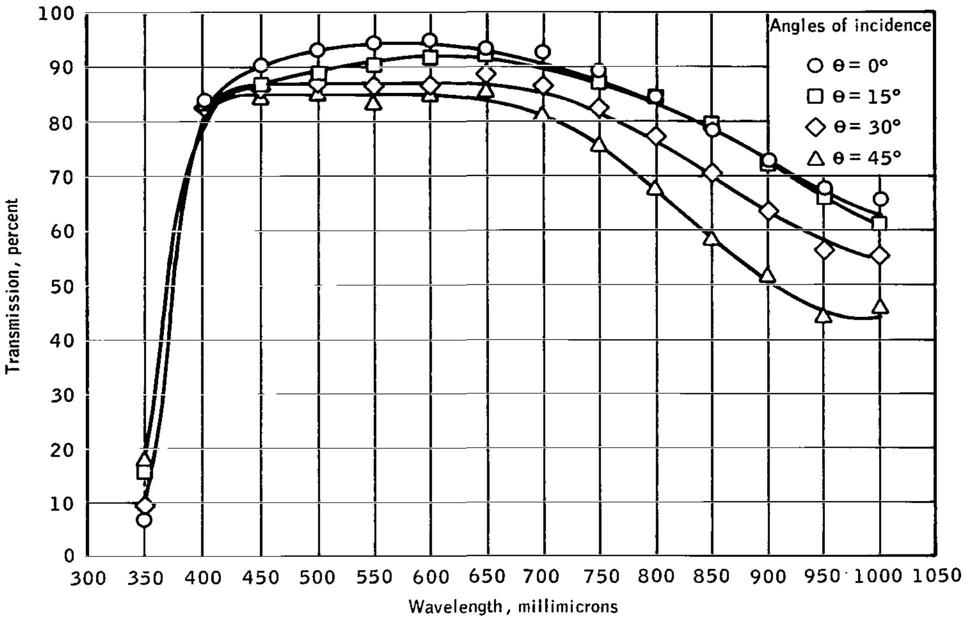


(a) Without G-XII window.

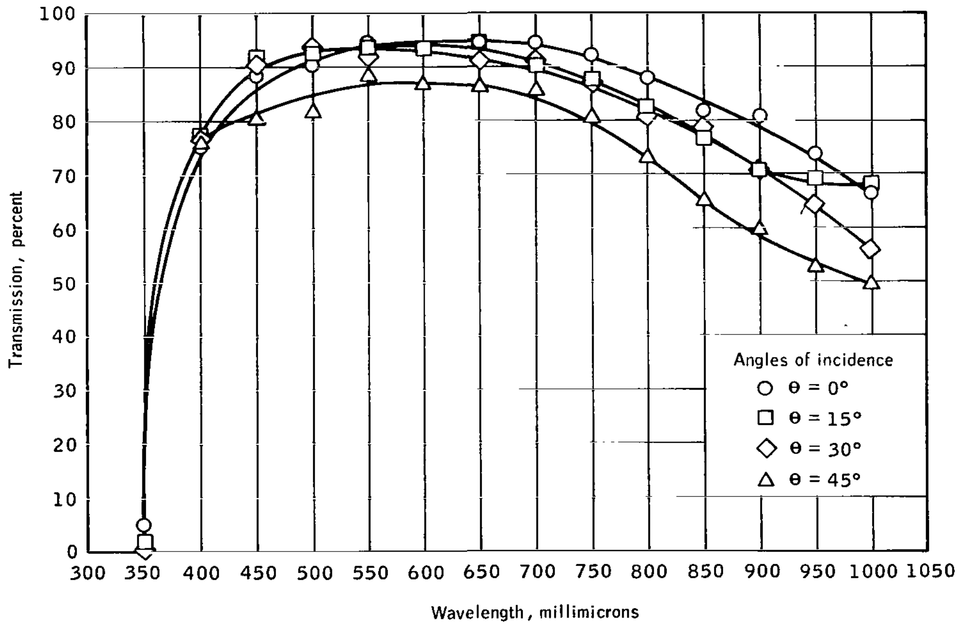


(b) With G-XII window.

Figure 11. - Photograph of USAF bar chart with 1400-mm-focal-length telescope and camera (with and without G-XII window).

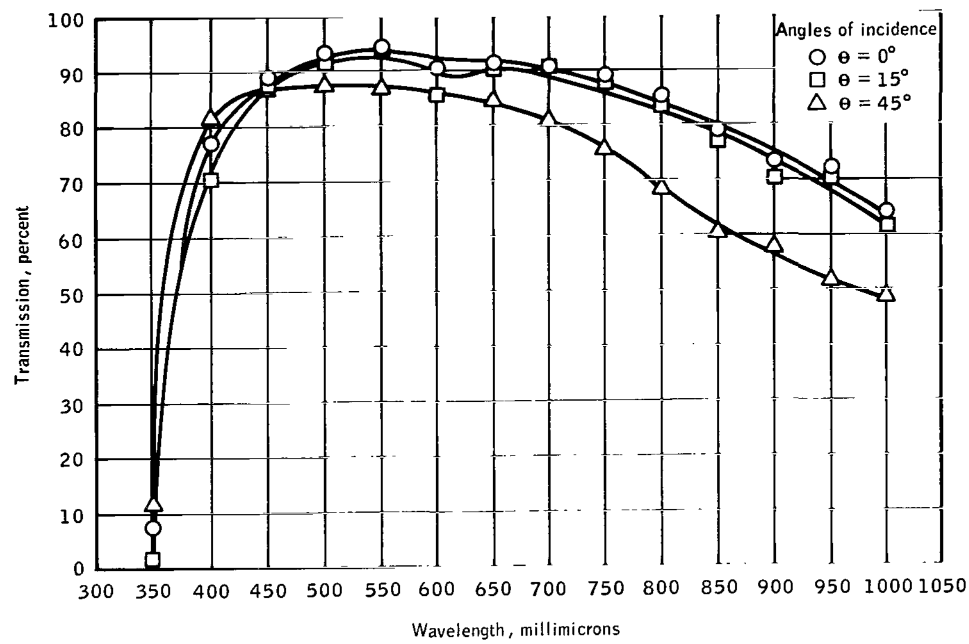


(a) For G-VII window.

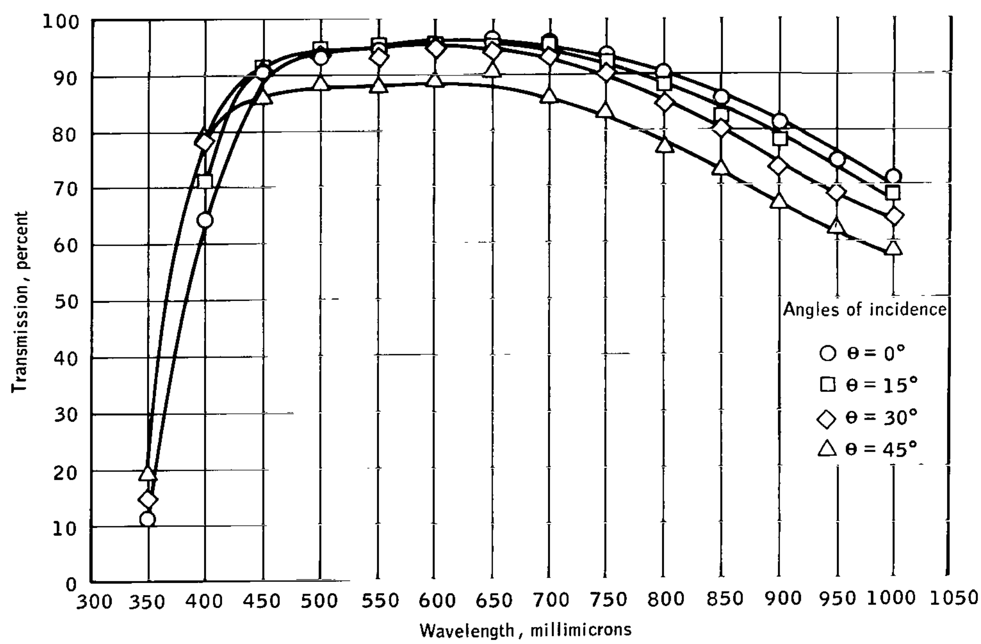


(b) For G-VIII window.

Figure 12. - Curve showing percent of transmission compared with wavelength.



(c) For G-IX window.



(d) For G-XII window.

Figure 12. - Concluded.

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