Journal of the
Society of Motion Picture
and Television Engineers

VOLUME 67 • NUMBER 4 • APRIL 1958

Symposium on Optical Instrumentation for Missile Testing

During the decade in which the Society has had an organized interest in the applications and development of high-speed photography, missile programs have been extended far beyond anything foreseen at the time the Committee on High-Speed Photography was first appointed. The demands of the Age of Space have brought about a greatly expanded concept of photography and its relation to military science, though photography is only a part of the mechanism of detecting and recording the visible and infrared spectrum perceived by optical instruments in this field.

Many problems encountered in this field are related to the sciences of astronomy and meteorology. The first papers of the group describe the atmospheric problem, basic theoretical approaches and prospective results of present programs. Other papers describe specific operations and equipment. Finally, we have the group discussion in which diverse specialists have sought one another's help. A very important part of the process of obtaining final film records is that of film processing. It is hoped that this phase as well as others will be given careful attention in future meetings of the Society.—*Sidney M. Lipton*, Program Topic Chairman.

Atmospheric Optics

By H. C. SCHEPLER

The factors affecting the visibility and photographability of distant objects through the atmosphere are described. The manner in which each factor deteriorates the visual or photographic image is explained in detail. Means are suggested for reducing the effect of these factors to a minimum in the photography of airborne test targets.

TWO MAIN PROBLEMS in photographing airborne targets are: (1) how to obtain an airborne target image from which the angular position of the target with respect to the camera can be determined; and (2) how to obtain the attitude (roll, pitch and yaw) of the airborne target with respect to the camera location.

In tracking and photographing an airborne target, the photographer is primarily concerned with resolution and contrast in the film image of the airborne target with respect to its background. In most instances, the background is the sky. If the problem includes tracking the airborne target throughout all or a portion of its trajectory, the background will vary considerably with the elevation of the camera and the relationship between the airborne target and the camera with respect to the position of the sun. Thus, the atmosphere is the major limiting factor in obtaining the desired photograph.

Certain aspects of the problem concern receptors. Receptors fall into three categories: (1) visual — where the eye observes the distant airborne target through a telescope; (2) photographic — where a camera records the image of an airborne target; and (3) infrared — where an infrared receiver detects the airborne target.

These receptors are affected in varying degrees by the various image-deteriorating factors in the atmosphere. These factors operate on the working material which is the contrast at the airborne target between it and its background.

Atmospheric Refraction

We are familiar with the bending of light as it passes, for example, from air into glass. This is due to a difference in density of the air and the glass. Air itself is a media of variable density depending on the elevation above the earth, temperature, pressure and local air currents. Therefore, when light from an airborne object to the camera passes through air of variable density, a displacement occurs of the target image on the film due to the bending of the light. This results in an error in the angular position of the target with respect to

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(This paper was received on April 15, 1957.)

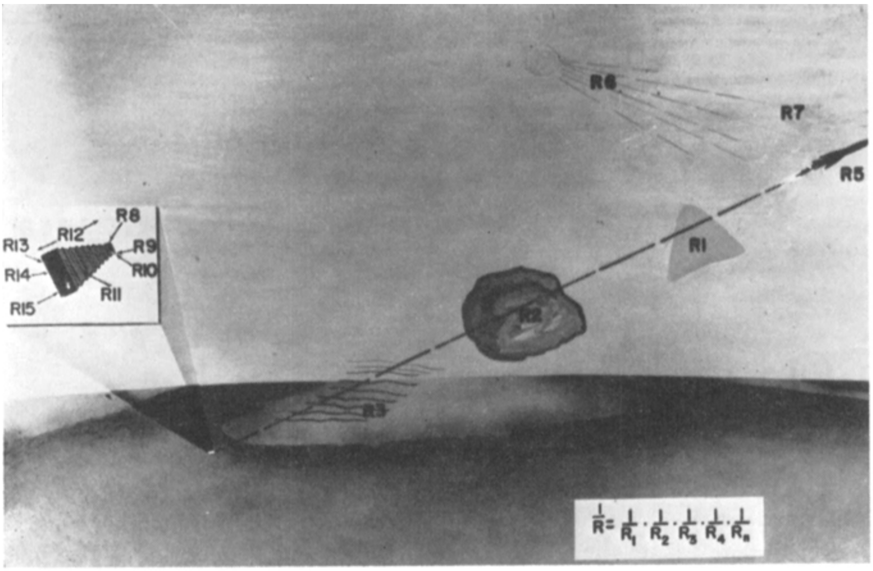

Fig. 1. Factors affecting photographic image.

the camera. Only partial correction can be made for this error by using standard atmospheric refraction tables.

Haze

Small particles of water vapor, dust and other atmospheric impurities within a rather broad range of particle size will reflect, refract and absorb rays of light from the target which would normally enter the camera lens to form a photographic image of the target. Many extraneous rays from areas other than the target that are similarly reflected and refracted by these particles will enter the camera lens. Both of these occurrences reduce the contrast of the target image on the film with respect to its background image. The amount and the nature of such deterioration depend upon the types of particles, number of particles and particle sizes in the atmosphere between the target and the camera.

Another condition brought about by these particles is a loss of contrast due to the predominance of certain wavelengths of light entering the camera lens. Certain particles absorb and refract certain wavelengths more than others. A good analogy of this is the predominance of the color of red in the setting sun.

Shimmer

The appearance of a distant object viewed over a black-top road or a sandy beach in the heat of the summer sun shows a variable irregularity. This effect is a distant relative of atmospheric refraction in that it is caused by numerous air currents and bundles of air with varying densities and hence varying indices of refraction rising from the hot areas below. This condition further reduces contrast on the film due to the redirection of the light rays passing through such turbulent media.

Recent studies show that the greatest deterioration to the image on the film is due to the media or air near the camera. We can therefore somewhat reduce this deterioration by careful selection of camera location. The planting of green vegetation around the camera location for a radius of about a quarter of a mile can reduce shimmer effects considerably.

The seriousness of image deterioration on the film can best be appreciated by observing that all of the factors mentioned, plus many others, operate on the image simultaneously when photographing a distant airborne object.

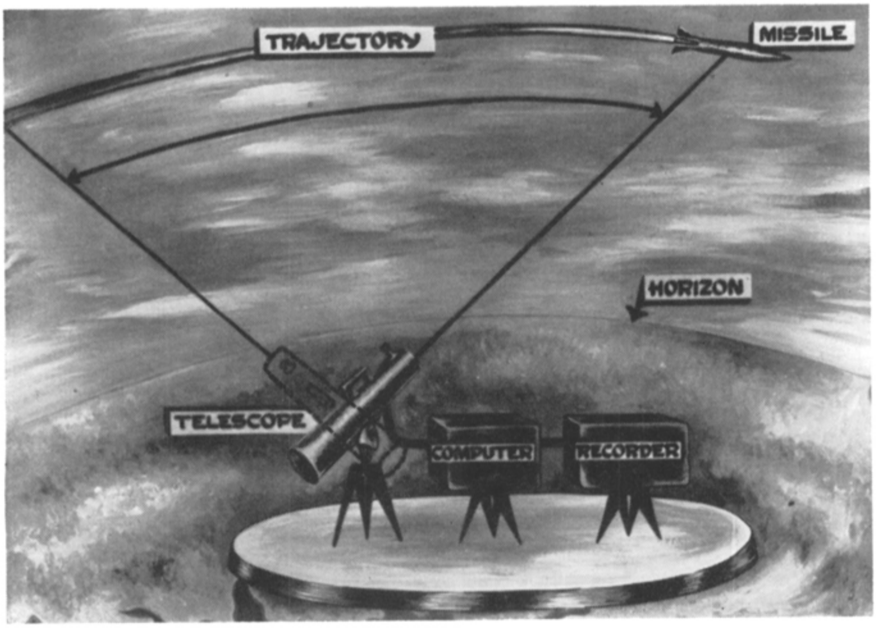

Fig. 2. Measurement of atmospheric visibility.

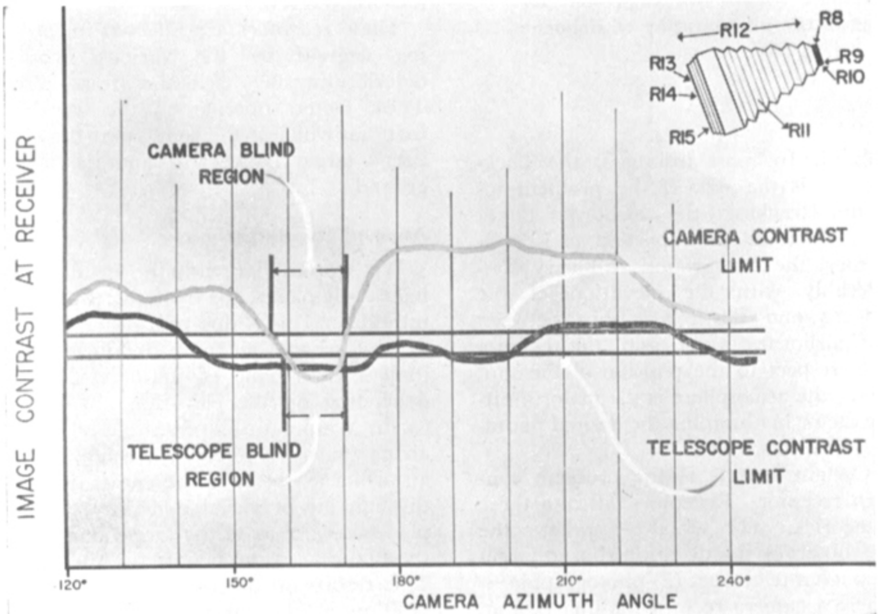

Fig. 3. Atmospheric visibility limitations.

In Fig. 1 the relationship is:

$$\frac{1}{R} = \frac{1}{R_1} \cdot \frac{1}{R_2} \cdot \frac{1}{R_3} \cdot \frac{1}{R_4} \cdot \frac{1}{R_n}$$

where R = the overall image deterioration,
R_1 = image deterioration due to atmospheric refraction,
R_2 = image deterioration due to haze,
R_3 = image deterioration due to shimmer, and
R_n = image deterioration due to causes other than the atmosphere.

Items contained in R_n are:

R_5 = color of airborne target,
R_6 = illumination of target,
R_7 = color of sky background,
R_8 = lens aberrations,
R_9 = lens distortion,
R_{10} = contrast factor of lens,
R_{11} = contrast factor of camera box,
R_{12} = focus of camera,
R_{13} = type of film,
R_{14} = film processing, and
R_{15} = film reading.

How instrumentation may make this accomplishment possible in the near future is indicated in Fig. 2. The anticipated missile or airborne target trajectory is scanned with a telescopic device that records the "contrast factor" for the anticipated trajectory. Two sample recordings are shown in Fig. 3. Also shown are the contrast limit of a camera and its sighting telescope. No signal is photographed or viewed below these respective lines. Blind regions for this particular camera and telescope are thus established; thus the practicality of running a mission under the prevailing atmospheric conditions is determined.

At such time that this instrumentation is constructed and found to be reliable, the time, effort and money now spent in obtaining test data on airborne targets will be considerably reduced. This instrumentation will also provide data sufficient to determine the physical limitations of camera lenses, that is, the physical lens sizes above which reliable and consistent photographic results cannot be obtained. With this information, instruments usable for a much higher percentage of time under adverse atmospheric conditions can be procured.

The various operating test ranges in the country are greatly concerned with these problems and have given them considerable study. Each range is concerned with analyzing the problem with the hope of finding some means of reducing the image deterioration effects of any one or all of these factors.

A related problem is that of prediction. If atmospheric conditions can be predicted in advance, considerable improvement in photographic results can be expected by the proper selection of photographic materials and equipment and of time for performing missions where photographic data are to be procured. At the present time methods of determining the nature of the atmosphere and of predicting the atmosphere in the near future are quite inadequate; however, there are good possibilities for constructing suitable instrumentation for accomplishing these purposes. It appears feasible to devise an instrument to measure the contrast of a target with respect to its background from the camera position. Knowing the color and luminance of the airborne target, the target contrast at the target can be determined with respect to its background. The contrast factor of the camera to be used can be measured. From these factors, the detectability of an airborne target can be determined by the eye, by film or by other means.

Discussion

S. M. Lipton (*Session Chairman*): Have there been any tests conducted at your installation, which would indicate the maximum diameter of optics which would give you good detail? This seems to be a paramount question for many.

Mr. Schepler: There have been many tests of this type, but I think this has been answered fairly well by the comments of Dr. Duntley and Mr. Martz, in that a 6-in. diameter lens is a good practical limit. This is as much information as we have on this problem. There are tests, of course, being continued on this subject and we undoubtedly will, as we go along, get additional information on it.

E. P. Martz, Jr. (*Air Force Missile Development Center, N. M.*): It may be interesting to note that since about 1890 there have been a large number of tests run by astronomers on this question of lens aperture and focal length, particularly aperture, as they affect astronomical seeing — shimmer-blur, haze — optical haze, whatever you want to call it. The same atmospheric refractive blurring has been studied, particularly at Lowell Observatory, and at other observatories. In general, where you want fine detail (such as, let's say — if I can use those nasty words — "*canals*" of Mars), or fine detail on the moon, or fine detail on the planets, an aperture of around 20 in. is an optimum. Above that, for night-time use, you normally run into too much atmospheric turbulence and you lose any gain of resolving power. Of course, this is the question Mr. Keene raised: where is the optimum gain? The loss of image quality and size of the image on the film begin to deteriorate compared to the increase in light or the increase in resolution you get from a larger lens.

Mr. Schepler: Around 20 in. for the astronomical problem is the case; 20 in. at *f*/15 is about what is normally operated. This might be taken as a guide for the missile work. There are, of course, large missile telescopic cameras under way, which other people could speak about if you wanted to go into this.