

Application of the "Slit-Aperture" Camera for Observation and Data Acquisition in Projectile Studies

PAPER I-3

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The "slit-aperture" camera was first constructed by making two modifications to a standard Fastax high-speed camera. The first modification was to remove the rotating prism which served as the shutter and the second was to insert a mask having a narrow aperture or slit in front of the film plane. The slit was oriented so that the long dimension extended across the width of the film and the narrow dimension or width of the slit was in the line of film travel.

This camera has been utilized to secure: (1) large-size qualitative photographs of high-velocity projectiles; (2) angular attitude of projectiles in flight; (3) velocity data of projectiles having a minimum length of 2 ft using one camera; (4) rate of spin or the rotation about the longitudinal axis of a projectile; (5) deceleration of the base of a projectile during "crush-up" of the fuse after impacting a nonyielding target; and (6) acceleration of a projectile during the early phase of firing.

IN THE LAST fifteen years a tremendous growth has occurred in the need for, and the application of, photographic instrumentation, a relatively new and versatile method of providing data for the engineer working on research and development programs.

The great progress in military accomplishments has produced an ever-increasing demand for new instrumentation and techniques. The need always exists not only for more and better data, but also for a shorter time lapse between testing and the availability of final data and for other elements that combine to provide answers to pertinent problems.

During the late 1940's the demands of projectile testing changed considerably owing to the higher velocities of projectiles. The high-speed rotating-prism camera of the Fastax type was no longer satisfactory for all purposes; therefore radically different methods were desired.

During late 1948 the following idea was suggested. A detailed photograph of a projectile could be recorded if a film was moved in the same direction as the image movement, and if the two movements were synchronized so that there was little or no relative motion. Furthermore, if a high film velocity could be obtained, it would be feasible to photograph ultra-high-velocity projectiles and still secure a large image of high quality. Additional study indicated that this procedure would be feasible if the period of synchronization of the moving film and image could be held to less than 1 msec. If the period of synchronization could be further shortened, a greater difference between image and film movement could be tolerated and an acceptable record could still be produced.

Tests to prove this idea were carried out on experimental equipment and the first results were satisfactory. A 35mm Fastax camera was modified to eliminate the prism and shutter effect; and in addition a very narrow rectangular aperture was placed close to the film plane. The length of the aperture or slit extended across the width of the film, and the narrow dimension or width of

the slit was in the line of film travel. Later experiments dictated that this slit width should not be fixed but should be capable of being varied in width as much as several hundredths of an inch. This modified camera was mounted on its side so that the film travel could be in the direction of the image motion.

At the Aberdeen Proving Ground the "slit-aperture" or "smear" camera has been applied to many types of test programs to provide observational photographs and to acquire data. A few of the applications and techniques are described in the hope that other persons may realize the versatility of the slit-aperture camera and perhaps benefit from our experience.

Observational Photographs

The prime reason for the development of the slit-aperture or smear camera was for the study of component separation, and of the condition of a fired projectile due to the forces exerted upon it during the tremendous acceleration in the tube.

Qualitative or observational photographs are obtained by placing the camera to one side of the line of fire with the optic axis normal to the expected trajectory. The object distance is selected so that the object-image ratio is 40 to 1. The camera is oriented to permit the film to travel in the same direction as the image of the projectile, with the long dimension of the slit perpendicular to the trajectory. The slit width in line with the film travel is usually set at 0.030 in. (This is the optimum size as determined experimentally.) By careful adjustment of the voltage to the camera motors it is possible to synchronize the velocity of the film motion with the image motion at the slit. Thus, the slit aperture controls the exposure time and also precisely determines the object position along the trajectory. The exposure time, per image point, is approximately 25 μ sec, but this will vary depending upon the slit width and film velocity.

The image of a projectile which achieved only 80% of the expected velocity was elongated by approximately 20%, and the quality was such that the elongation would not be noticed if one were not aware of the length-diameter ratio.

Presented on October 21, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by Stanley M. Keen, Instrumentation Laboratory, Development and Proof Services, Aberdeen Proving Ground, Md.

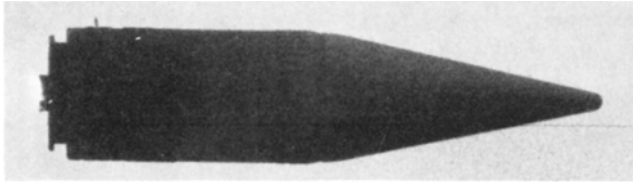


Fig. 1. Silhouette photograph of projectile, with sky as background, to show general appearance.

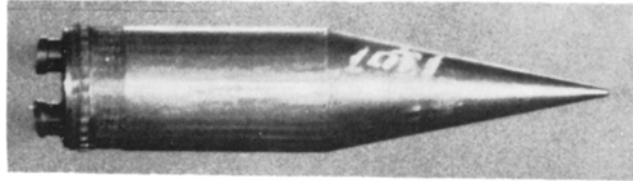


Fig. 2. Front illumination of projectile by photoflash lamps to obtain detailed photograph.

Silhouette photographs, utilizing the sky as background, often suffice for the needs of a particular test program. See Fig. 1. When detailed photographs are required, photoflash lamps are used for front illumination. See Fig. 2.

Photographs of projectiles in flight, obtained by this method, are of such high quality that minute details such as finely cut threads on the projectile are readily discernible. See Fig. 3. This type of photography has been incorporated into the test requirements of approximately 90% of the camera-instrumented firings conducted at the Proving Ground.

Angular Attitude

Measurement of attitude, which is the angle between the longitudinal axis of the projectile and the expected trajectory or gun elevation, can provide valuable data when new projectile designs are being tested.

Several slit-aperture cameras, placed at selected locations along the trajectory and operated in the manner used in securing observational photographs, can provide these data. The elevation of the gun or launcher is indicated by a stationary reference line — a taut wire or cord — placed within the field of view of the camera. To prevent the bow shock wave of the projectile from disturbing and distorting the reference line during the exposure time, the line is placed approximately three feet off the trajectory on the side away from the camera. Figure 4 shows a projectile and reference line.

Projectile Velocity

A slit-aperture camera equipped to record timing markers may be utilized to provide projectile velocity data. The camera is placed and operated in the manner used in securing observational photographs. Although synchronization of the film and image velocity is desired, the data are valid even when the film velocity is not equal to the velocity of the image. The projectile travels its own length (which is measured and recorded prior to the firing) in the time the film moves the length of the image of the projectile. The film, with a high-quality image of the projectile and time markers, is thus a record from which the velocity can be computed. Other things being equal, the accuracy of velocity measurement is greater with long projectiles.

Two slit-aperture cameras placed a measured distance apart and each recording the common time markers also

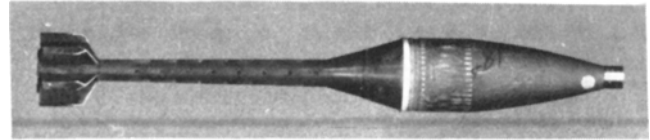


Fig. 3. Fine details of projectile in flight secured by photoflash lamp illumination.

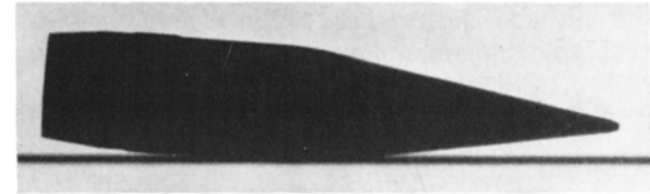


Fig. 4. Reference line used with projectile in measurement of attitude.

provide an even more accurate system for determining object velocity.

Spin Rate

The rate of spin, i.e., the rate of rotation of a projectile about its longitudinal axis, has been determined by the use of two slit-aperture cameras equipped to record common timing markers. The cameras are oriented as when securing observational photographs and are separated by a distance less than that traveled by the projectile during one complete revolution. Increased accuracy is obtained by the use of a third camera which is positioned downrange from the second camera at a distance approximately ten times greater than that between the first and second cameras. The rotation between the first and second cameras is used to determine the number of complete revolutions between the first and third cameras.

To aid in determining the rotational velocity of a projectile, a black-and-white helical pattern is painted on the projectile. With the pattern applied to a cylindrical section of the projectile, the developed pattern is rectangular in form, the diagonal being the helix. Alternatively, the pattern could be said to consist of two right triangles, one of which is painted white and the other black. The hypotenuse of either triangle will form the helix. The distance represented by the height of the triangle will represent one revolution. It is necessary to present the base and apex positions to the camera regardless of the projectile orientation. Since the base of the triangle will circle the projectile, it is only necessary to add an indication for the height of the apex. This is accomplished by painting a narrow white band around the projectile at the apex or positioning the apex where a major change in diameter of the projectile is located.

The painting of the helix about the cylindrical section of the projectile body is not always satisfactory because the gases escaping past the rotating band of the projectile occasionally erase or wash out the pattern. When gas washing is expected, the helix is applied to the ogive, which is the forward sloping section of the projectile. In this case the developed pattern is not a rectangle. In order to maintain high accuracy, the painted pattern is not extended to the vertex but is terminated where the diameter is at least one-half inch. The projection of the slant height of the frustum of the ogive will represent one revolution of the projectile. The helix is formed by a

smooth curve, representing proportional parts of one revolution, extending from one end of the pattern to the other.

Illumination of the projectile is supplied by two photoflash lamps which are initiated at a time to permit peak illumination to be attained when the projectile passes before the camera.

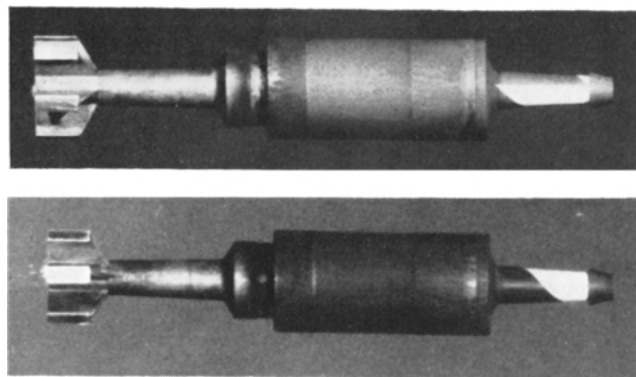
Each camera produces a record which contains common timing markers and the image of the projectile. Figures 5 and 6 show two stages of the rotation of a projectile. To determine the rotational velocity in revolutions per second, the following image measurements are made along the longitudinal axis of the projectile: from triangle base to helix and from triangle base to the white band representing the apex. The ratio of these distances is proportional to the ratio of the rotational angle to 360° . Thus, each camera provides the rotational angle at that position. The difference between the rotational angle at camera No. 1 and camera No. 2 is extrapolated to determine the number of complete revolutions between camera No. 1 and camera No. 3. The flight time is also determined from the common timing markers recorded by all cameras.

Deceleration Data

The design of a base-located and base-detonating fuse for use with a projectile impacting upon a nonyielding target often requires knowledge of the deceleration of the base and the time from the impact to a specified deceleration. A slit-aperture camera producing a true smear photographic record is used to provide these data. A typical record is shown in Fig. 7. In a slit-aperture camera producing a smear record the image moves at right angles to the film travel or in the direction of the film width. The line representing the projectile nose will enter from one side of the film and proceed across the film and the line representing the base will follow a similar course.

To provide a photographic record from which data of high accuracy may be obtained, several field setup conditions must be considered. Measurements made of the image travel distance are more accurate if: (1) the area of camera coverage is held to a minimum, thereby producing a large image of the projectile length and a camera distance is selected that permits a horizontal field of view 4 in. greater than the length of the projectile at the target; and (2) the zero time or time of first impact is indicated by the intersection of two lines, the one moving line representing the nose of the projectile and the stationary line representing the face of the target and the camera is positioned in such a manner that any point on the face of the target, visible through the camera optical system, coincides with the image of the near edge of the target. If the camera does not see directly across the face of the target, the near edge or the far edge will appear to represent the face, and thereby cause an error in the estimate of the impact time. It is not necessary to record the total thickness of the target as only the front surface is of interest; therefore only a 2-in. section is shown.

The base of the projectile is represented by a line separating two areas, one of maximum exposure and the other unexposed. The deceleration of the base of the projectile is indicated by a change in slope of this line. This line should be as sharp in definition as possible — a



Figs. 5 (above) and 6 (below). Two stages in the rotation of a projectile about its longitudinal axis.

width as small as 0.001 in. is desirable. Taking into consideration the duration of action, desired image size, film velocity and a projectile velocity of approximately 2700 ft/sec, an effective exposure time of $\frac{1}{2}$ μ sec is indicated. A film velocity of 150 ft/sec or 1.8 in./msec, and a high-intensity, very-narrow-strip light source which produces an image height of 0.001 in. at the focal plane, provide the effective exposure time of $\frac{1}{2}$ μ sec. To provide this narrow light source, a tinned wire 0.025 in. in diameter is mounted taut on a black background and illuminated by four No. 22 photoflash lamps. The lamps are placed at a distance of 6 to 8 in. from the wire and are shielded from the lens.

This unit (background, wire and lamps) is placed on the far side of the trajectory so that the black background area is visible to the film through the slit aperture, with the image of the tinned-wire light source extending across the width of the film parallel to the trajectory. The wire light source is adjusted so that the camera slit aperture, trajectory and wire light source are in the same plane. Since the maximum exposure is derived from the tinned-wire light source, and the black background excludes all other light, it is not necessary to alter the slit aperture in the camera from the usual 0.030 in. To aid in the data reduction, black stripes $\frac{1}{8}$ in. wide are painted at two positions on the wire light source. The distance between the two black stripes, and the distance from the wire light source to the film plane, and from the expected trajectory to the film plane, are measured and recorded prior to firing.

In operation the photoflash bulbs are initiated by a projectile sensing device or sequence timer, thus illuminating the wire and causing the vertically moving film to be exposed across its width with the exception of the two small areas masked by the narrow black stripes. During a portion of this period of illumination the projectile passes between the illuminated wire and the camera, thereby causing an unexposed area on the film. A typical test used a 10-in. lens with the camera placed at a distance of 20 ft from the target.

The camera is oriented in a manner to permit the film motion to be in the vertical plane, whereas the projectile image will travel in the horizontal plane. Although the projectiles may contain no explosive, the possibility of damage to the camera by flying metal from the projectile at impact makes it necessary to place the camera behind armor plate for protection. A high-quality front-surfaced mirror is utilized to "see around" the armor-plate barricade.

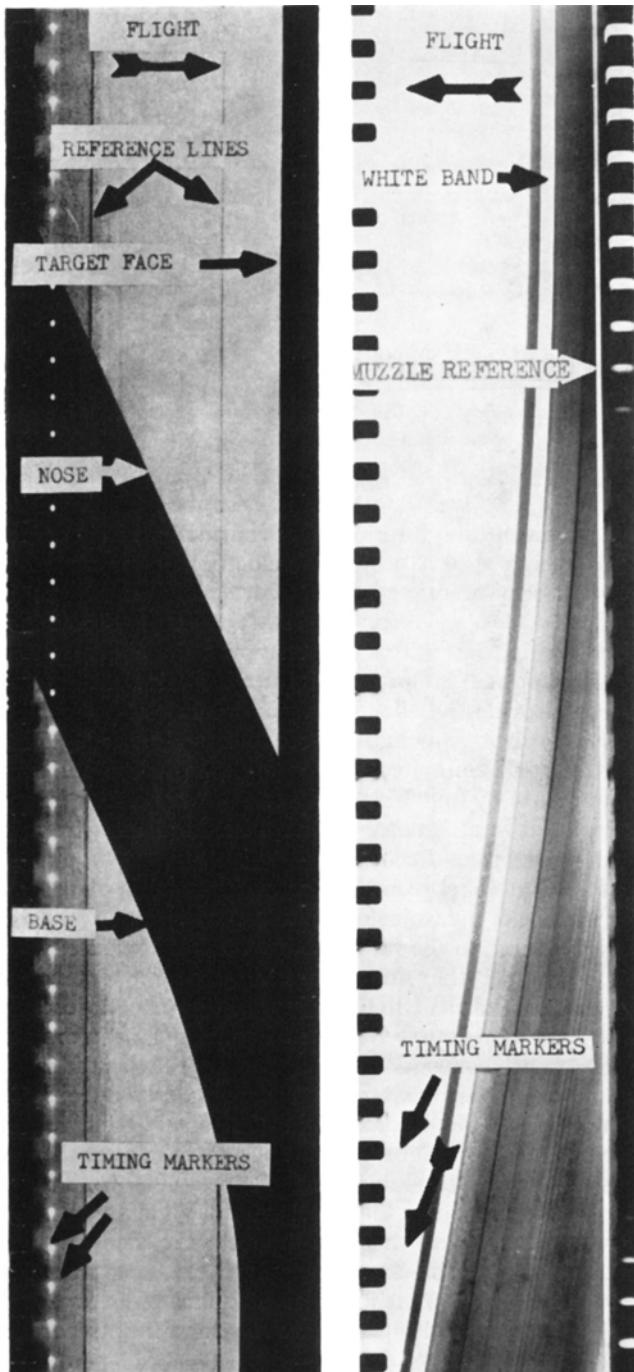


Fig. 7. Deceleration data recorded in smear photograph with slit-aperture camera.

Fig. 8. Time-displacement record obtained in application of slit-aperture camera to provide acceleration data.

It may not be possible to record the zero time of all firings because all projectiles may not follow a trajectory which permits the longitudinal axis to be in line with the camera and tinned wire. For several of the records which do not show zero time it is possible to establish the zero time to an accuracy of a few microseconds by observing the obscuration of the tinned wire by the metallic dust which is produced upon impact.

Acceleration Data

During a recent test the maximum acceleration of a fired missile was being obtained by means of accelerometers installed in the missile, and also from time-pressure records from electronic gages installed through the wall of the firing chamber. A large number of missiles were to be fired and only a few accelerometers were on hand, therefore it would have been necessary to recover the fired missile in order to obtain the accelerometer for re-use in another missile. To expedite the program, the slit-aperture camera was put into operation as a third method; and the data obtained corresponded well with those of the other two methods. Thereafter the slit-aperture camera and chamber pressure gages were used to provide the data.

The missiles are painted a dark color, and a white band of known width is painted circumferentially on the body. This band serves two purposes: first, it provides two locations on the missile to which film measurement may be made; and second, it provides a scale factor by which the image measurements may be converted to object measurements. A white band is painted around the muzzle end of the weapon within the field of view of the camera and is utilized as the stationary reference from which measurements of the missile image travel are made.

The camera is placed with the optic axis normal to the trajectory, with the missile and the first 5 ft of missile travel within the field of view. The camera is oriented in a manner to permit the trajectory to extend across the width of the film. The longitudinal axis of the missile is in the center of the small dimension of the slit aperture. A record of this type, Fig. 8, is a time-displacement record from which travel distances are measured at selected time intervals, and the velocity and acceleration are computed.

Conclusion

The techniques described for using the slit-aperture camera to provide such data as angular attitude, velocity, spin rate, deceleration and acceleration are some of the important applications at Aberdeen but are by no means all the uses of this valuable instrument. The various applications which have been made of this type of camera provide us with knowledge of its versatility and understanding of its capabilities.