Photographic Instrumentation at the Air Proving Ground Center

By H. C. SCHEPLER

Precise spatial position of airborne test objects such as rockets, bombs and missiles is recorded photographically on the Air Force Armament Center test ranges. The instrumentation employed, the use of triangulation in determining spatial position and the accuracies obtained are discussed.

It is the responsibility of the Air Force Armament Center to determine engineering performance characteristics of various types of armament. Answers are required for such questions as: Why do certain mechanical linkages exhibit malfunction during armament release from aircraft? What is the precise acceleration curve and the trajectory of a rocket from firing to burnout? What are the causes for failure in bomb release mechanisms? The answers to these and similar questions are found only through photography. (Missiles, bombs, rockets and other projectiles will hereinafter be referred to as airborne targets, or targets.)

Perhaps the most important and also the most difficult problem in airborne armament testing is to determine the precise position in space of an airborne target. Spatial position is determined most precisely by triangulation methods from photographs taken simultaneously and at known times by two or more cameras from established geographic positions. This provides three basic requirements for determining accurately the spatial position of airborne targets: (1) several cameras located in a coordinate system, (2) means for establishing angular position from camera to target, and (3) means for recording the time that each photograph was taken.

Use of Cinetheodolites

Instrumentation used to track airborne targets had its beginnings about 1940 with the development of Askania cinetheodolites in Germany. These were first used to test V-I and V-II missiles at Peenemunde. Since then cinetheodolites have been used in many countries for testing guided missiles and other airborne targets. The Air Force Armament Center uses Askania cinetheodolites procured from Germany and Contraves cinetheodolites procured from Switzerland for such test work.

Spatial position of a target at a given instant of time is obtained with cinetheodolites by triangulation from at least two photographs taken simultaneously by cameras with a rather large base line distance between them. This base line may be one mile or several miles long, depending upon the particular problem at hand. A minimum of three cinetheodolites is used to photograph the target simultaneously since measurements from three films in most cases provide highest efficiency in terms of accuracy vs. data reduction time consumed.

Tracking is usually accomplished by having one operator control the azimuth position and another the elevation position of the camera by visual observation of the target through two appropriately aligned telescopes. Both operators keep the target in the field of view of their sighting telescopes and hence in the field of view of the camera by rotating the instrument about its vertical and horizontal axes while tracking the target. Azimuth and elevation scale readings and film frame number are photographed by flash illumination onto each film frame taken of the moving target. When the cinetheodolite is prepared for operation the azimuth and elevation scales are oriented with respect to a fixed coordinate system. Fiducial marks are recorded on each film frame as a fixed reference to determine the optical orientation axis of the cinetheodolite. Photographic data are recorded double-frame size on 35mm film taken at sequential rates up to 30 frames per second.

In data analysis the distances from the reference fiducial marks to the target image are measured on the processed film. Knowing the focal length of the lens the image off-axis position (tracking error) is converted to an angular value and integrated with the scale recordings of the cinetheodolite to give the true angular position of the target from that particular camera location at a known instant of time. Target spatial position is then determined in data analysis from this camera film frame and film frames taken at the same time by other cinetheodolites.

Time pulses sent out to all instruments from a central timing system synchronize all flashlamps and trigger the camera shutters and film advance mechanisms.

Shutter Speeds

It is important that the shutter speed be fast enough to "stop" image motion during maximum acceleration and tracking rates. The Contraves cinetheodolite shutter speed is $\frac{1}{120}$ sec at 30 frames/sec. The maximum acceleration of the instrument is 60°/sec/sec and the maximum velocity is 30°/sec. The Contraves is provided with a rate servo aided tracking system and the maximum tracking error encountered for maximum velocity is about 1 mil.

Cinetheodolites usually require long-focal-length lenses and fast film. The Contraves has a photographic lens system of 1500mm effective focal length and commonly employs Shellburst Panchromatic film with an ASA speed of 200. The overall accuracy of the Contraves approaches one part in 18,000. This is considerably better than accuracies obtained to date with similar systems in operation on the Air Force Armament Center ranges.

A high-speed photographic application similar to the one just described is employed in the testing of rockets. Spatial positions of rockets through and slightly after burnout are determined on a rocket test range. Airborne rockets are ground tested by accelerating them up an inclined track to normal aircraft velocity. A sled carrying the rocket is driven up the track by high thrust rocket motors. The track is 500 ft long and has a 5° incline. The rocket is fired as the sled reaches the end of the track. For a typical firing, the velocity of the sled at launch is 1000 ft/sec and the rocket velocity at burnout is 3200 ft/sec.

Camera Installations

Fixed cameras are used for the rocket tests and are located so as to photograph the rocket from the rear and from the side as it leaves the sled. The camera found best suited to these applications is the CZR-1 (Bowen) acceleration camera (Fig. 1) manufactured by Mitchell Camera Corp. The CZR-1 is not a tracking camera and it is designed for the specialized purpose of obtaining film recordings of the trajectories of rockets, missiles and other projectiles. The data from the film record are used to calculate the velocity, acceleration, fin opening, spin, dispersion, burn-out time and other ballistic characteristics of the test item during launching and the early portion of the flight.

Seven of these cameras, spaced at 450 ft intervals, are located along each side of the rocket trajectory or flight line at 1000 ft from the flight line. Four more CZR-1 cameras are located along each side of the flight line at greater spacings

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and at greater distances from the flight line than those previously mentioned.

The theoretical trajectory of the rocket is computed from static test data which provide adequate information for positioning and orienting the CZR-1 cameras so that the rocket trajectory will fall successively in their fields of view. When setting up a camera, it can be rotated about azimuth, elevation and roll axes in order that the rocket images will fall in the long direction of the film frame after the rocket is fired.

In this application of the CZR-1 camera the frame rate is 30 frames/sec on a film frame size 0.9 in. high by 5 in. wide at a frame exposure time of 1/10,000 sec. Time in minutes and seconds down to 0.0001 sec is photographed onto each film frame from a binary coded time display appearing as a dot raster on a cathode-ray tube. This complete time readout is presented every 100 μsec and is gated to the frame speed.

The CZR-1 camera takes a long and narrow film frame size at frame rates up to 180 frames/sec. A standard 100 ft roll of film $5\frac{1}{2}$ in. wide is driven past a rectangular aperture that establishes the film frame size. The shutter is a series of 6 slots in a rotating drum that passes between the moving film and the rectangular field aperture. The frame rate can be set at 30, 60, 90 or 180 frames/sec by the proper selection of the number and sequence of shutter slots left open. Any of the shutter slots may be closed by means of shutter slides. Whenever the frame rate is changed, an appropriately dimensioned aperture slide or frame must be inserted in the rectangular camera aperture to change the vertical dimension of the individual photograph. The aperture insert with the largest opening is used with the lowest frame-per-second rate.

The shutter drum is driven directly by its own synchronous drive motor. Shutter rotational speed and film transport speed are maintained at a constant rate with film transport being accomplished by a separate motor drive through a series of reduction gears and specially designed clutches. These clutches perform two functions: the maintenance of a constant predetermined tension on the film through the take-up spool and prevention of film transport until the film transport drive motor has attained its full operating speed. Thus during camera operation the film moves in the direction across the narrow part of the film frame. The film is actually moving during exposure but the high shutter speed used does not materially reduce resolution in the direction of film movement. The direction of target travel is imaged onto the film at right angles to the direction of film movement in the camera. Thus the resolution of the target image in its direction of travel is not impaired by film movement during exposure.

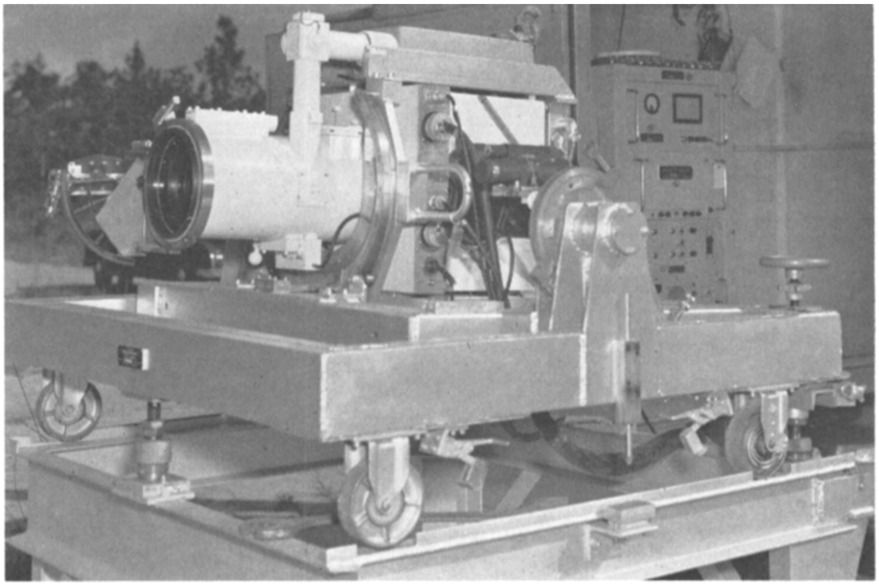

Fig. 1. CZR-1 (Bowen) acceleration camera used for obtaining film recordings of trajectories.

The CZR-1 camera is adaptable to and well suited for multiple-camera test operations. Arbitrary selection of any one camera as the "master" is possible for purposes of "phasing in" the shutter drums of the other cameras usually designated as slave cameras. Each camera has a self-contained strobe unit. An integral pulse or "pip" generator is connected in a manner which feeds the synchronizing or phasing pip signal from the master camera to the strobe units of the slave cameras. Adjustment of the shutter drum phasing control on each slave camera as required, insures shutter drum synchronization for all cameras in the system. Additional camera features provide a timing mark on the edge of the film which is used in precision determination of interframe time intervals, film footage and temperature indicators and a reference mark projector which places three reference marks in the form of crosses across the film width. These marks provide a means to determine film distortion caused by processing and also serve as reference points for all measurements. The CZR-1 optical system is shown in Fig. 2.

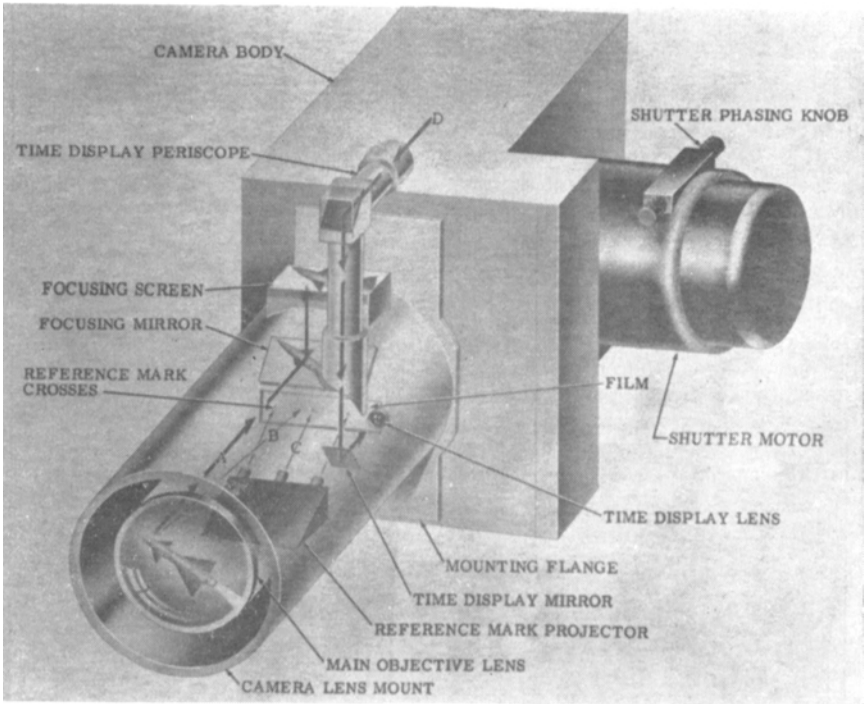

Fig. 2. CZR-1 optical system. A, B, C and D define the reference mark and timing systems.

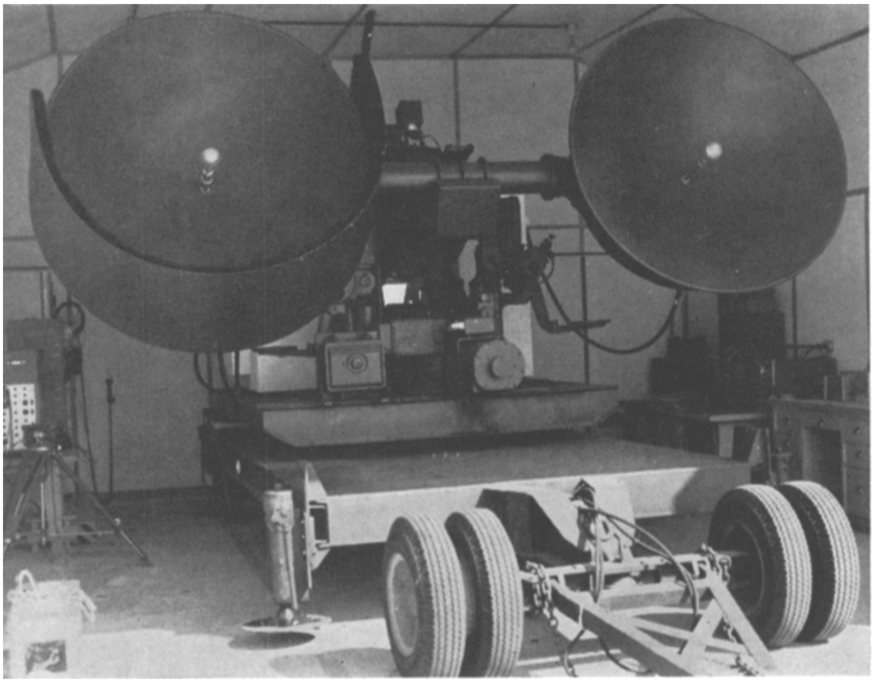

Fig. 3. Doppler Velocimeter.

Located beside the end of the track are three high-speed Mitchell cameras with lens focal lengths of 1 in., 6 in. and 15 in. which photograph the rocket from the rear at 128 frames/sec. Time in code is put onto these Mitchell photographs with neon lamps. Another high-speed Mitchell camera, located directly in front of the track so that the rocket and sled pass over the camera, records how far off side the rocket goes in its trajectory. Rocket spatial position and trajectory are determined at successive instants of time from these Mitchell and CZR-1 cameras. Rocket firing time is recorded on a 16mm ground event camera which has continuous moving film at 20 in./sec. Real time is also recorded on this camera so that rocket firing time can be established on the Mitchell and CZR-1 camera films. Other 16mm and 35mm Fastax cameras are used at 5000 frames/sec to observe the sled while going up the track.

Doppler Velocimeter

The Mitchell and CZR-1 cameras provide photographic data on the accelerations and velocities of the rocket with high accuracy. However considerable film must be read and measured to make these determinations. A less accurate auxiliary system is therefore used to make a much faster determination of these characteristics. The instrument used in this auxiliary system is the Doppler Velocimeter (Fig. 3) which is located directly behind the track. From this instrument a radio wave of known frequency is beamed at the rocket. The return reflected wave combined with the wave sent out is recorded as a Doppler wave which, when associated with time, provides the velocity of the rocket. The Doppler signal and a time code are recorded on magnetic tape. The tape is run through a dual beam oscilloscope which is photographed by a Fastax camera with its rotating prism removed. The result is the Doppler wave and the timing code recorded side by side on the film. The velocity of the rocket at any instant of time is determined by counting the number of Doppler waves per unit time as determined from the time code.

Discussion

A. M. Erickson (*U.S. Naval Ordnance Laboratory, White Oak, Md.*): How do you calibrate one of these cinetheodolite machines to get an answer that corresponds exactly with the actual conditions in the field?

Mr. Schepler: We use both laboratory and field calibration methods for our cinetheodolites. In the laboratory we make complete checks of the optical system. We check distortion of the lens, obtain the distortion curve, determine that the optical axis of the lens is symmetrical with the symmetry of the distortion curve and make measurements of the lens aberrations. In the field we run evaluation tests with target boards surveyed in to first-order survey and we make measurements on the film frame to determine the aberrations for field conditions.

Another problem we are pioneering in at the Armament Center is the accurate calibration of the instrument scales. These are marked on a glass disk to ½ and can be read to about 6 sec of arc by means of a scale divider arrangement. We have used various methods for calibrating the scales. We are about to receive delivery of an angle-measuring interferometer with which we will be able to measure an angle to an accuracy of hundredths of a second. This will give us something to spare in checking the angular calibration of these scales.

Lincoln L. Endelman (*Convair Astronautics, Cocoa Beach, Fla.*): What is the focal length of the lenses used in the Askania; how does the operation of the Askania compare with that of the other type of theodolite; and approximately how many stations does it take to give you a good three-station solution?

Mr. Schepler: The Askania lenses originally obtained from Germany after the War were 24 in. or 60 cm in focal length. There are also a few 30-cm focal-length lenses in this country, but our demands for taking photographs at greater ranges are such that the 30-cm lens, to my knowledge, has never been used in this country. Many of our ranges have built, or have had built, longer-focal-length lenses for the Askania. Holloman Air Development Center has built lenses with a focal length of 84 in. For some applications, lenses up to 120-in. focal length have been used. However, these lenses are quite unwieldy because it is difficult to balance the instrument so that you get smooth tracking, particularly in elevation. The Perkin-Elmer Corp. has built some 48-in. and 60-in. focal-length lenses for Patrick AFB, and some long-focal-length Ransom lenses are used at Holloman and at other ranges.

In contrast, the Contraves cinetheodolite has a five-foot focal length lens that is not interchangeable. We are presently interested in having this optical system redesigned to a longer focal length.

We have found that the accuracy of the Contraves cinetheodolite is better than that of the Askania. The Askania is generally considered to give an accuracy of ± 20 sec of arc. There is not good agreement on this figure among various ranges. Experience with the Contraves indicates an angular accuracy of about ± 10 sec of arc.

We seem to get the most for our money in terms of data reduction by using a three-station solution. From the point of view of data reduction time required, it is usually impractical to reduce data from more than three cameras. You do gain a very small amount by using more than three, and successively less improvement as you reduce data from more cameras. So data from three cameras are, I believe, rather generally used at the various ranges. There have been special tests run at NOTS using eleven cameras for an eleven-station solution for particularly close calibration work.