High-Speed Camera Facilities at the University of California, Lawrence Radiation Laboratory

PAPER L–3

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The high-speed camera facilities at the University of California Ernest O. Lawrence Radiation Laboratory include five firing sites using framing cameras with framing rates up to 3.3 million/sec, Kerr cell cameras of 0.005 μsec exposure time, and smear cameras with writing rates up to 15mm/μsec. These cameras are coordinated with other techniques for simultaneous recording. Techniques have been developed for using two discontinuously writing cameras simultaneously. High explosive light sources are used; and electronic light sources have been developed that allow photography in color at 1.2 million frames/sec. Termination of the record is done with a simple mirror cutoff which takes only 3 μsec to go from open to closed.

The camera arrangements and auxiliary equipment have been designed for maximum flexibility and fail-safe operation. The safety of personnel is very carefully considered. Annoyance of nearby residents has been minimized.
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THE Lawrence Radiation Laboratory at Livermore, Calif., has extensive high-speed camera facilities for high explosive research. No nuclear explosions could be conducted at Livermore or at our high explosive test facility at Site 300. This site is 7 miles west from Tracy, a city of about 10,000 population. To avoid any possible annoyance to this population, we allow no more than 300 microbars of over-pressure at any sonic focal point. Three weather samplings are taken each day, a calculation involving wind velocity and temperature distribution is made, and the explosive limits required to keep maximum sound below the 300 microbars are set up.

Safety of personnel is always a primary consideration at the site. An important aspect of safety is the supervised access between the various firing sites. When people wish to enter the firing area, a guard has them sign a list and receive a numbered badge. Upon request of a bunker for permission to fire, the number of badges outstanding is counted. From each bunker the number of people at that position is counted and when the totals add up to equal the number of people known to be in the area, only then is the bunker allowed to proceed with the firing. Control power is kept off the detonator unit until these totals coincide.

Our installations are large: for example, Bunker 312, which is 125 ft long and 50 ft wide, has a machine-shop trailer, photographic laboratory and electronics maintenance laboratory.

A linear accelerator is also housed at Bunker 312. It delivers 40 ma at 11 million electron volts. The electron beam is pointed through the wall, converted into x-rays on the far side and allowed to shine on the experiment outside. This is the primary facility at this bunker.

Figure 1 illustrates the firing table. The gamma ray beam comes out through the armor plate in the center of the building. This bunker has some high-speed cameras. For this particular experiment no linear accelerator was used. The mirror stands indicate the position of the underground portholes through which the shot is observed by the high-speed cameras. One method used to provide nearly identical optical paths by the use of a folding mirror is shown at the far left in the figure, where the light rays that come under one mirror are relayed into another mirror. The optical ports beneath the mirrors consist of $1\frac{1}{4}$-in. glass, 5 in. in diameter; beneath these are the cameras. The use of mirrors for turning the rays of light also allows for our fast capping mechanism, a mirror cutoff which will be described in a later figure. The camera room beneath the firing table is shown in Fig. 2. The cameras mounted at the time of this photograph were, in the right foreground, a Beckman & Whitley Model 189, a synchronized framing camera; in the background, a Los Alamos designed framing camera with essentially continuous writing capability; and in the left foreground, a Los Alamos designed rotating-mirror smear camera. The Lawrence Radiation Laboratory calls this smear camera Model 508; it uses a telephoto lens behind the rotating mirror. All cameras can rotate about the optical axis to allow for better alignment of the experiment in the frame

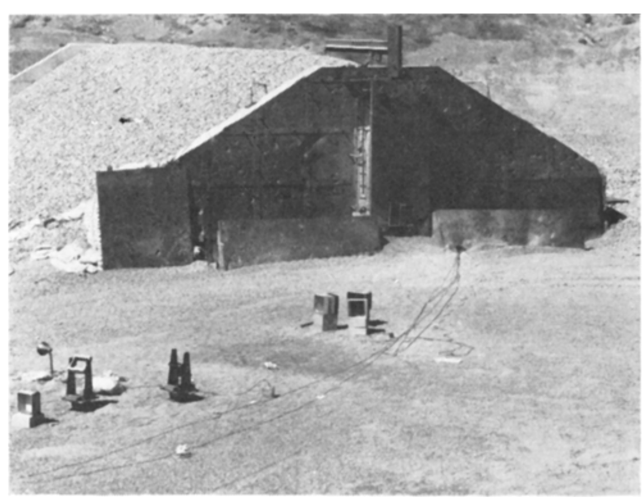

Fig. 1. Firing table at Bunker 312 with mirror stands over portholes above optics room underground.

Presented on October 21, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by David C. Oakley, Lawrence Radiation Laboratory, University of California, Livermore, Calif.

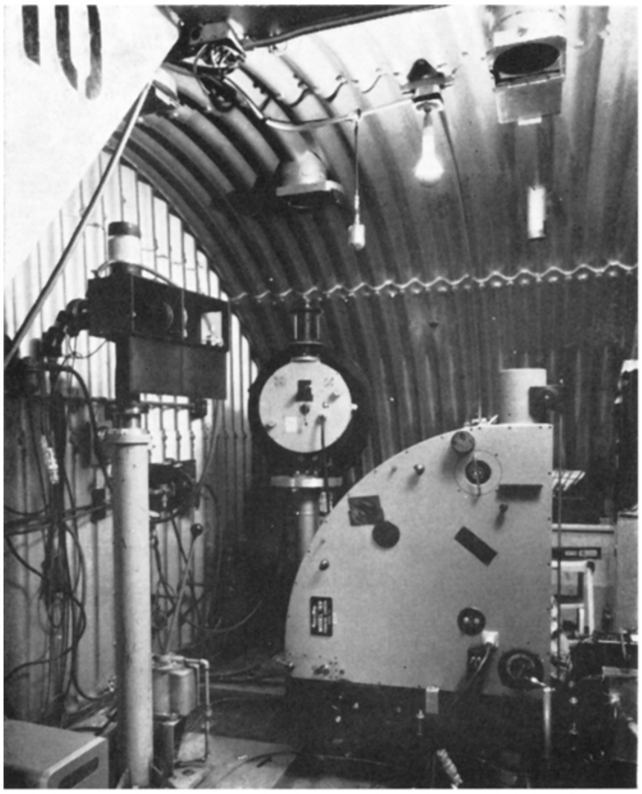

Fig. 2. Bunker 312 camera room with, left to right, Model 508 streaking camera and Models 6 and 189 framing cameras.

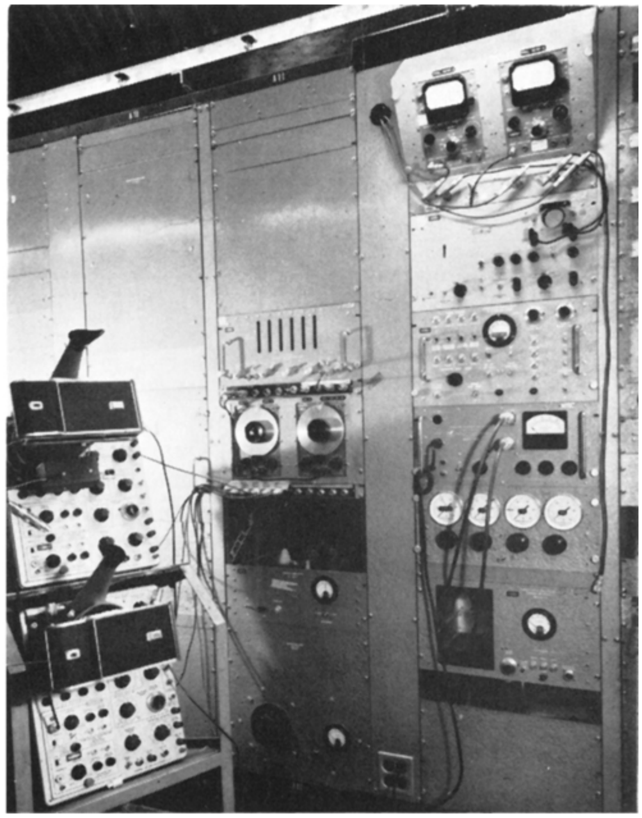

Fig. 3. Electronic controls for Bunker 312 high-speed cameras. Left to right: timing monitor oscilloscopes; audio oscillators for the Lissajous figure; and frequency meters, Lissajous oscilloscope, camera selection controls and air pressure controls.

available. Notice, at the top of the room, the shutters which are used to darken the room for loading the film. All of our 35mm film is loaded in individual cassettes; we do not use 100-ft rolls of film. It is our practice to focus on the film plane of each camera, and therefore the microscope focusing attachment that is standard on Beckman & Whitley cameras is not used in our models.

These cameras are controlled from the bunker, and Fig. 3 shows the electronic control rack for Bunker 312. On the left, the oscilloscopes are used for timing during the shot to verify that the delays operate as desired. In the middle panel is a 1-mc counter which is used to measure the frequency of one of the mirrors. Two oscillators are just below the counter; these are used as secondary standards when beating the rotating-mirror frequency to obtain a Lissajous figure. At the top of the righthand rack are two frequency meters which are used to monitor two cameras when both are used at once. Next panel down is the Lissajous oscilloscope for precise rotor-frequency observation, and the next panel is the camera selector panel which allows selection of any of the three cameras. This panel also includes the fire button which allows the next synchronizer pulse from the selected camera to fire the shot. A little below midway are four dials indicating the air pressure sent to the camera rotors; these dials indicate the pressure that is sent up to the camera room and at that point a pressure-matching regulator valve controls the actual pressure to the camera.

At this particular bunker, in addition to the linear accelerator, Lawrence Radiation Laboratory has an extensive electronic diagnostic facility. Figure 4 shows the array of raster oscilloscopes, 4-gun oscilloscopes and diagnostic oscilloscopes used with many experiments which can be operated in conjunction with the high-speed photography equipment. Notice that the recording cameras use 4 by 5-in. glass plates which were chosen because of ease of handling.

The main optics facility at present is Bunker 302 which is approximately 100 ft square. Small portable bunkerettes are also used. These contain electronic power supplies for our flash x-ray tubes and electronic light sources. In the middle of the firing table is the pit box which provides protection for the connections of 110-v a-c power, various gases, vacuum lines, connections for the pin leads and other diagnostic apparatus. As described for Bunker 312, mirrors are used to deflect light down through the camera ports to the cameras which are housed below ground level.

Figure 5 shows the camera room at Bunker 302 with the selection of cameras that may be used. The hydraulic lifts put the cameras as high as possible toward the portholes and their rotation allows precise alignment in the field of view, regardless of folding the light path from several mirrors. This particular experiment used two Model 189 cameras. These are not continuous writing. They have a duty cycle of 1 in 4 for a double-sided rotating mirror. By proper choice of the two rotor speeds one can guarantee that they will both be within acceptable limits sometime during a 20-msec period. For example, if both cameras are allowed to fire within 0 to 3 μsec after a reference point on each, then setting one camera at 3,000 rps and the other at 2,953 rps guarantees a coincidence within 20 msec. Slower rotor speeds require longer allowable periods. Some other cameras can be seen in this room; in the left foreground

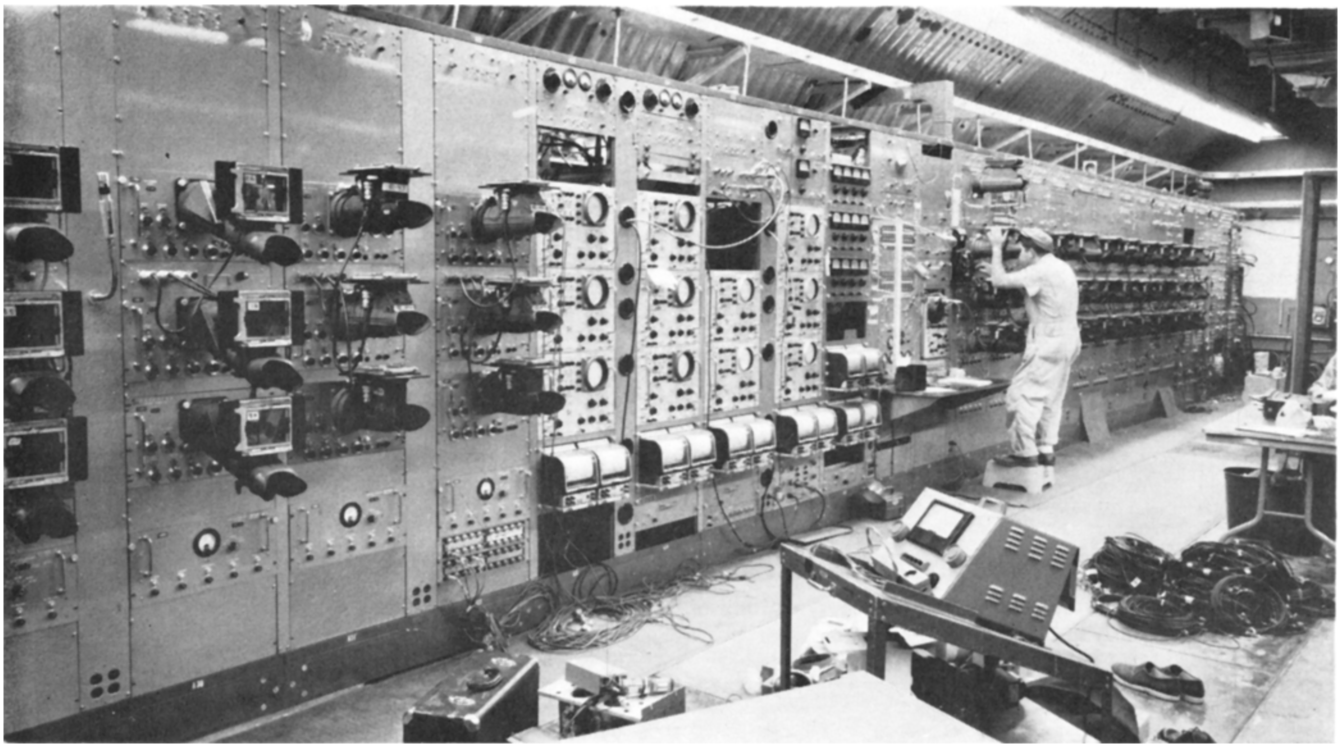

Fig. 4. Oscilloscope diagnostic section of Bunker 312.

is the Model 754, a Lawrence Radiation Laboratory design, a smear camera with a 3.2 mm/μsec writing speed using a 4 by 10-in. curved film for recording and incorporating a 2:1 magnification ratio from the slit to the film plane. This camera has an aperture of approximately $f/14$. On the floor in the foreground is a smear camera designed by the Los Alamos Scientific Laboratory; it uses an octagonal rotor and obtains a writing speed of 15 mm/μsec. In the background is another example of the Los Alamos continuous-access framing camera, the Model 6.

The control console necessary to operate three cameras at once is shown in Fig. 6. This console has successfully fired experiments which required three synchronized cameras. The waiting period to get a coincidence among the three was of the order of $\frac{1}{2}$ sec. In order to have completely equivalent circuits, there are three oscillators, three frequency meters and three Lissajous oscilloscopes.

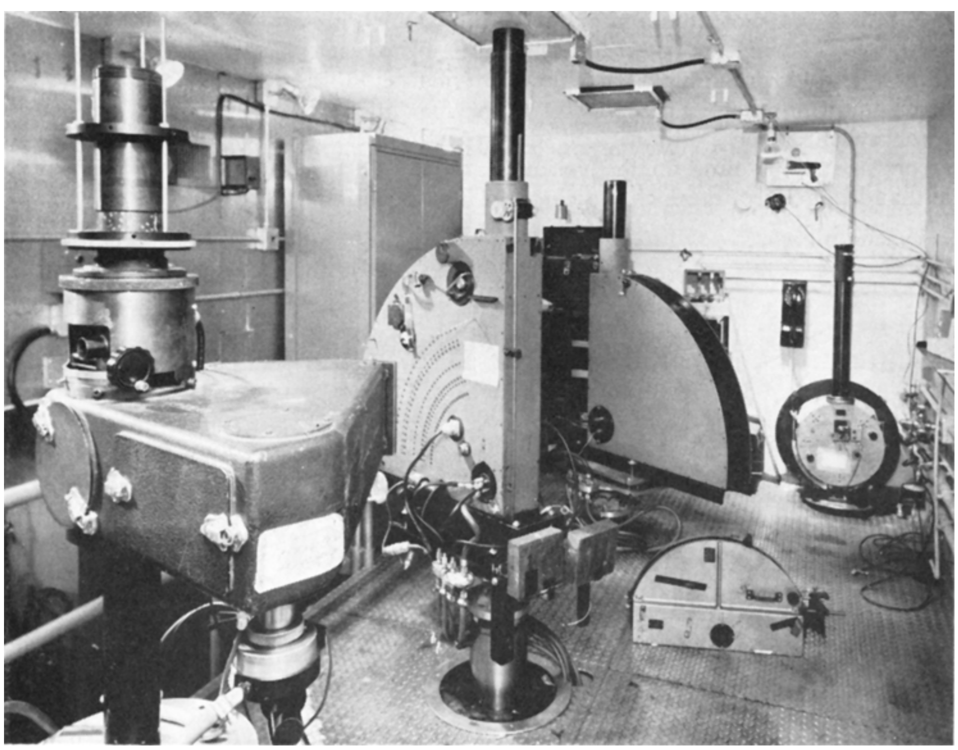

Fig. 5. Camera room at Bunker 302. The cameras are, left to right, Model 754 streak camera, two Model 189 framing cameras, Model 100 streak camera and Model 6 framing camera.

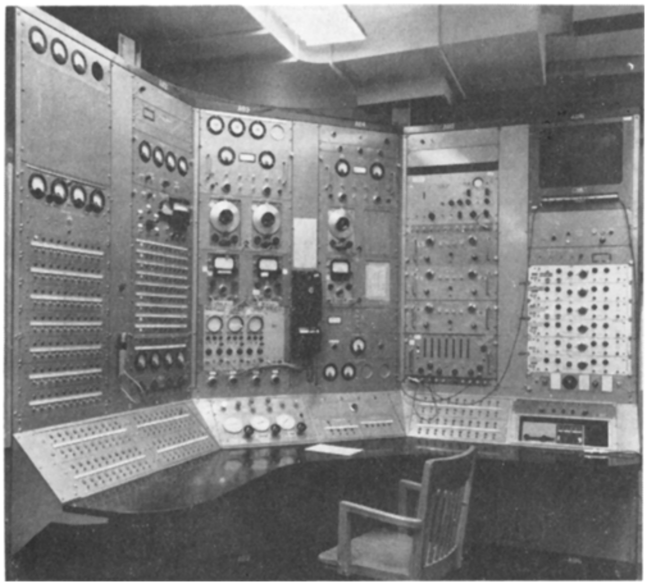

Fig. 6. Control console used to operate three synchronized cameras simultaneously in Bunker 302.

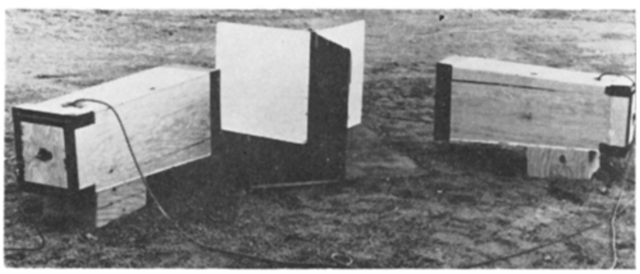

Fig. 7. Two standard argon flash bombs. Each is 3 ft long, 12 by 16 in. at the large end and 9 in. square at the small end.

Not seen in this figure are three 1-mc counters for rotor frequency or period. On the righthand two racks are delay units for putting in desired delays between detonation pulses and shot time and six delay units which are used for delaying the synchronizer pulses from each camera and for providing a variable width of acceptable error in firing time. These delays allow for different rotor synchronizer positions and different acceptable errors in starting time on the various cameras. At the lefthand panel are interlock indicators. There is a sign-

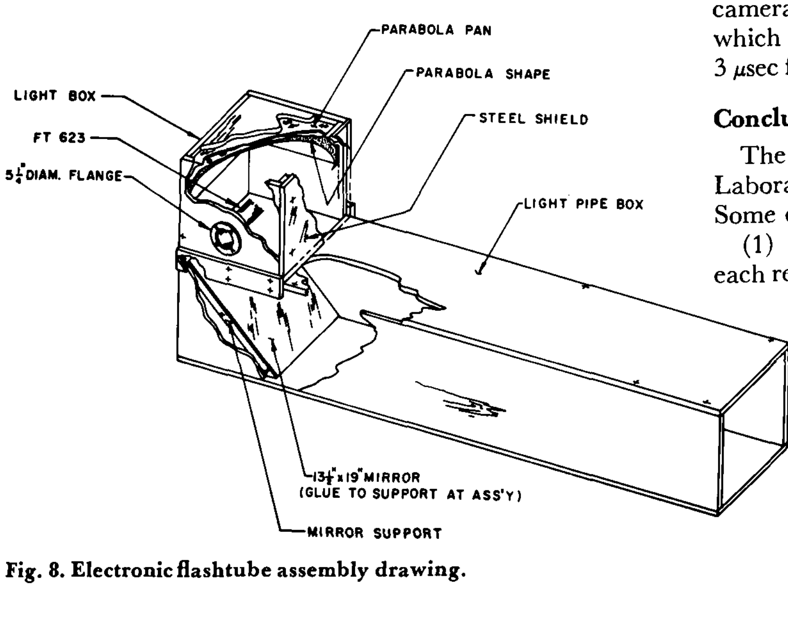

Fig. 8. Electronic flashtube assembly drawing.

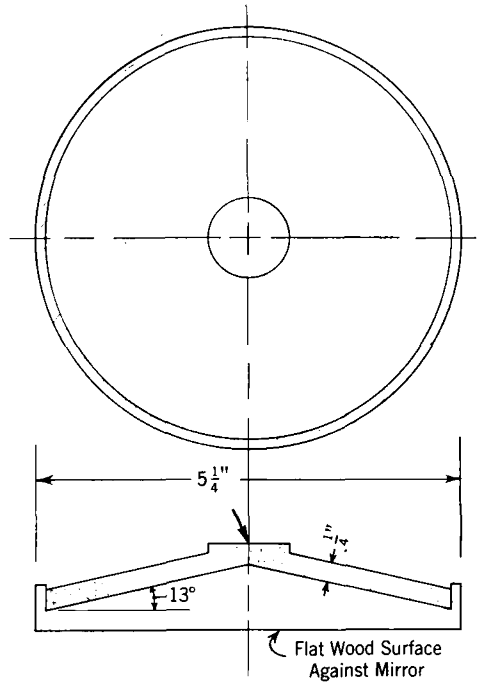

Fig. 9. Mirror breaking lens made of a cone of wood backed by ¼ in. of Composition C-3 explosive.

out board which keeps track of the number of personnel in the bunker at all times.

Our standard light source is an argon flash bomb using 13 lb of high explosive and a 10-min flow of argon at approximately 10 lb. Figure 7 illustrates two of the typical sources.

Some work has been done on the use of electronic flash for high-speed photography. Figure 8 illustrates the Lawrence Research Laboratory setup using FT-623's, reflectors and aluminized Mylar light pipes. Use of condensers of 100 μf at 10 kv gives sufficient light to use the Model 189 with color film. For example, color check experiments were made on the Model 189 at 1,000 rps with the small stops. This light source has been estimated at 4 billion lumens peak, with a usable light pulse duration of 70 μsec.

The standard method of fast capping is to explode a small charge behind the mirror on the firing table and prevent the light from being reflected into the camera. Figure 9 illustrates our small wooden "lens" which permits us an 18-μsec reaction time and then 3 μsec from full-open to full-closed shuttering action.

Conclusion

The University of California Lawrence Radiation Laboratory has an extensive high-speed camera facility. Some of the distinguishing features of this facility are:

(1) As many as three cameras are used simultaneously, each requiring synchronization.

(2) Cameras have been mounted on rotating mounts with their axes vertical to allow most economical alignment of the image.

(3) Electronic flashtubes have been adapted to high-speed photography.

(4) An explosively broken mirror does the fast capping operation.

(5) High-speed photography simultaneously accompanies many other types of measurement.