NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

PHOTOGRAPHIC METHODS OF RECORDING BEHAVIOR OF STEEL DIAPHRAGMS UNDER EXPLOSIVE LOAD

~~CONFIDENTIAL~~ 30

August 1942

Report R-66

PERSONNEL

The apparatus described was developed by Professor Harold E. Edgerton, of the Massachusetts Institute of Technology, who was assisted in its use for these tests by Mr. F.B. Kaye, Principal Photographer, of the David Taylor Model Basin Staff. The smear methods were developed by Dr. D. Bancroft and Dr. B.L. Miller. Lt. D. Campbell, USNR, has been in charge of this work at the David Taylor Model Basin.

PHOTOGRAPHIC METHODS OF RECORDING BEHAVIOR
OF STEEL DIAPHRAGMS UNDER EXPLOSIVE LOAD

INTRODUCTION

Recent developments at the David Taylor Model Basin in the investigation of the behavior of thin circular diaphragms loaded by explosions in water have included a number of experimental photographic techniques.

A general description of the micro-flash (single flash) and of the high-speed motion picture cameras, their associated equipment and general method of operation has been included in prior official correspondence (2).* Information relative to their procurement at the time of writing, August, 1942, was given in Reference (3). Copies of both these references have been forwarded to England.

The use of the micro-flash single exposure camera for photographing gas bubbles and other objects under water during the explosion experiments of 1941 is explained, with diagrams, in Reference (1). The method of setting up the motion

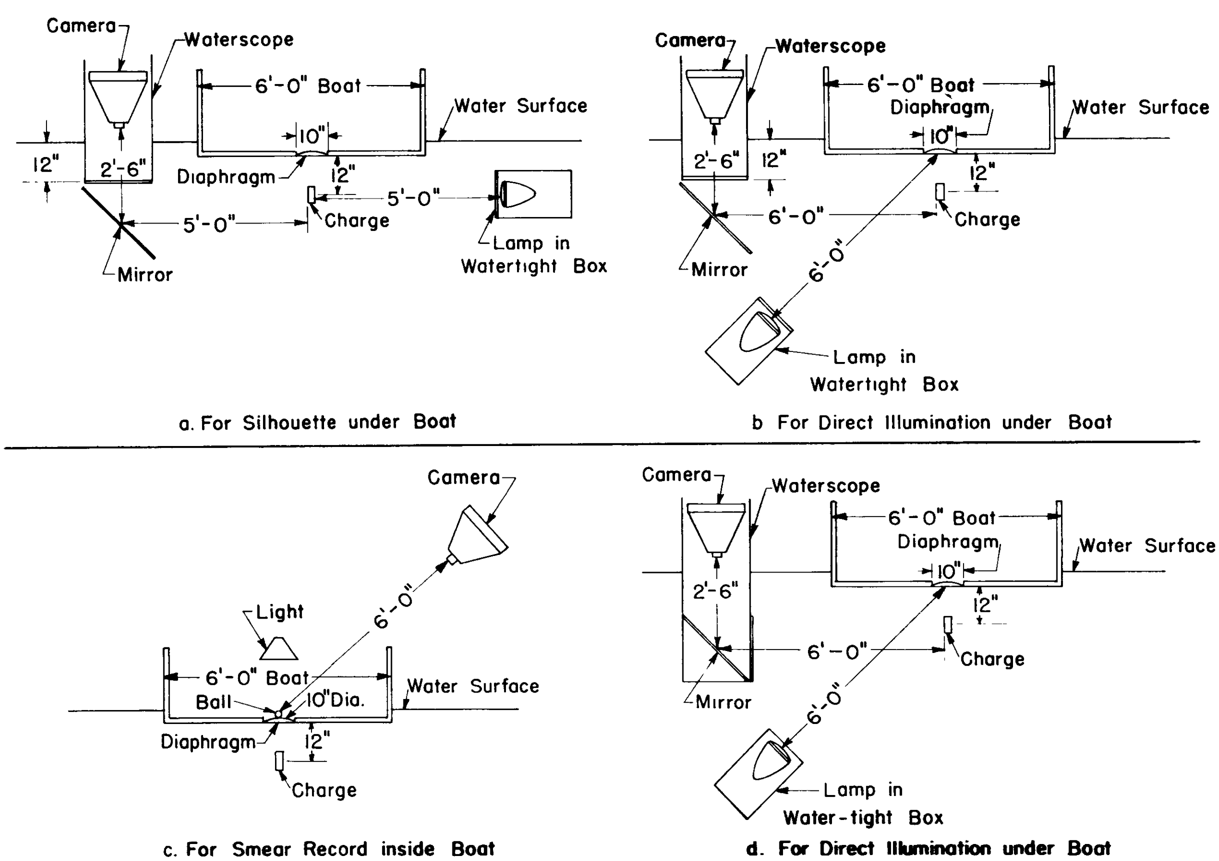

Figure 1 - Experimental Photographic Arrangements in Underwater Diaphragm Tests

* Numbers in parentheses indicate references on page 6 of this report.

picture cameras, the illuminating lamps and auxiliary devices for the explosion work of 1942 is described in this report for the benefit of those who may wish to undertake similar experiments.

ARRANGEMENT OF ELEMENTS

The diaphragms have been placed with respect to the explosion in two typical assemblies. The first of these is shown in Figure 1, a, b, c, and d. A heavily constructed wood boat with an outer steel sheathing 6 feet square, floats at a draft of about 6 inches. The diaphragm to be tested is secured to heavy clamping rings in the center of the bottom and the charge is placed on the axis of the diaphragm at a suitable distance below. Three different dispositions of photographic apparatus have been used as shown in Figure 1, a, b, and c; a fourth is proposed for future work as in d.

A separate series of diaphragms has been tested under the conditions shown in Figure 2. The diaphragm forms the bottom of a cylindrical steel tank 36 inches in diameter and filled with water. The explosion, as before, occurs at a point on the axis of the diaphragm. Observations in this case are confined to the air side of the diaphragm which, with this arrangement, is underneath the tank.

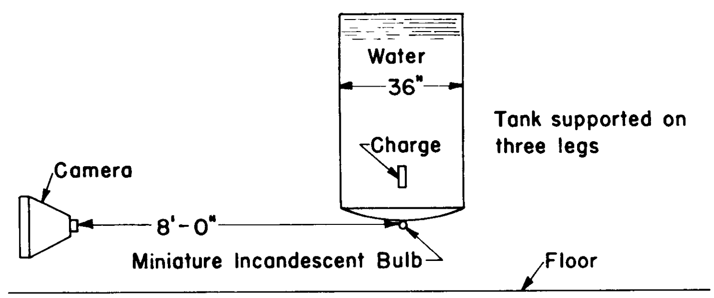

Figure 2 - Experimental Photographic Arrangements to Obtain Smear Record of Tank Bottom in Air

Improvements in underwater photography during the past year have resulted in reducing the light path under water by placing the flashing lamp (2) in a watertight box and by using a "waterscope" to eliminate the air-water surface.

The proposed modification of Figure 1, d places the mirror inside the waterscope and still further reduces the length of the light path in the water. In previous experiments the mirror was of polished plate glass, silvered, mounted in a wood frame and suspended at the proper position. No attempt was made to protect it from the water.

In both the lamp box and the waterscope the window is made of lucite* about ten inches in diameter and one-half inch thick. With the small charges used, no difficulty has been experienced with breakage of the windows. However, the optical qualities of lucite leave something to be desired, and in some instances poor definition has been traced to this source. Details of the watertight box and of the water-

* An acrylic resin plastic material; also known under the trade names of PLEXI-GLASS, ACRYLOID, and CRYSTALITE.

scope are shown on TMB drawings A-5172, A-5173, and A-5231, A-5232, A-5133, respectively.*

It is believed that, with the information as to operation in Reference (2) and as to arrangement in Figure 1, the apparatus can be set up and satisfactory records obtained. It goes without saying, of course, that the water must be clear to a superlative degree to enable good photographs to be taken.

SMEAR PHOTOGRAPHY

A special technique for following the motion of the diaphragm from the air side, Figure 1, c, and Figure 2, has been developed; it is referred to as "Smear Photography." The record consists of one or more traces like those made by a chronograph on a continuously moving paper or film.

In the simplest form of this method, a lens is so arranged as to project an image of an illuminated point on a moving film. The film lies in a plane parallel to the line of motion to be observed, while the motion of the film is in that plane at right angles to the direction of motion of the point. If either of these conditions is not satisfied, an appropriate correction can be developed by the principles of solid geometry and introduced. However, to develop the correction requires an assumption in advance as to the motion of the point to be observed, so that an error in this assumption will reflect itself in the correction. Thus the method in its simple form is not applicable to complicated three-dimensional motion, but only to motion in a known or assumed straight line.

CAMERA AND FILM

A motion picture camera or its equivalent can be used for this work if the framing mechanism is disconnected or removed so that the movement of the film through the camera is steady and continuous. If desired, the film can be attached to the periphery of a rotating drum. In either case the shutter remains open and the film moves continuously while it is being exposed.

The film speeds must be adjusted to produce negatives with the required contrast and with a time scale sufficiently large to record all the motions clearly.

Timing on the film may be accomplished by using the 60-cycle spark mentioned in Reference (2) or by any other suitable means.

When records of motion of more than one light source are being obtained, the camera must be tilted so that the line of images lies at an angle to the direction of motion of the film; in other words, the images must be offset as in Figures 4 and 5 so that the traces from adjacent lights do not cross or interfere with each other. This tilting for the arrangement shown in Figure 2 is about 20 degrees; it involves about a 6 per cent reduction in the recorded amplitudes of motion of the light sources.

---

*Prints of these plans will be furnished upon request to those desiring to duplicate this equipment.

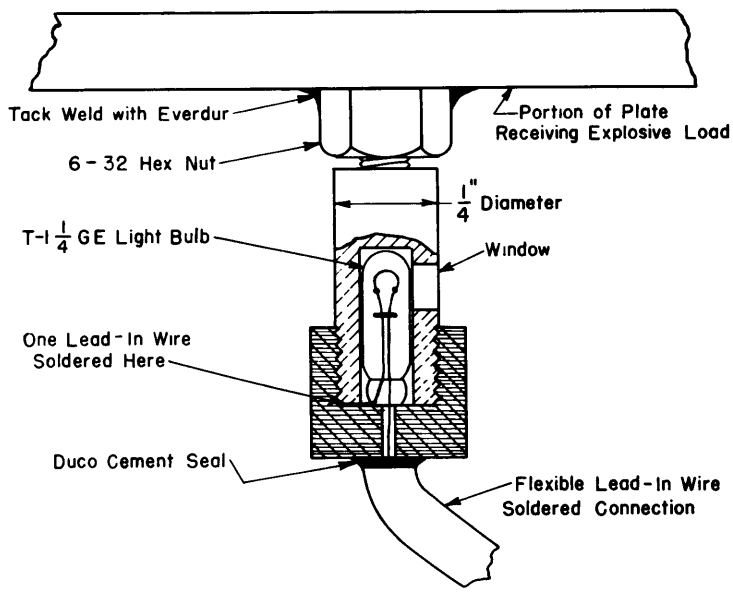

Figure 3 - Assembly of Light Source for Records of Explosive Displacement in Air

In general the point to be observed must be brightly illuminated, while the entire background remains dark. Two effective means of accomplishing this have been used.

SELF-LUMINOUS LIGHT SOURCE

In the first of these, miniature incandescent lamps are attached to the diaphragm, Figure 3. Since these lights are mounted on a diaphragm subjected to explosive load, it is necessary to have a bulb that can withstand severe shock. The lighter the bulb and its elements, the smaller the acceleration forces acting on them; for this reason a very small bulb is used.

After experiments with bulbs of various types a General Electric Mazda Type T-1 1/4, 3-volt, 0.19-ampere bulb was found fairly suitable. This bulb is cemented with Duco cement in a brass cylinder 1/4 inch in diameter and 9/16 inch long, in the side of which is a window 1/8 inch in diameter; see Figure 3. The top of the cylinder is sealed off by a bakelite cap through which passes one bulb lead-in wire. The other wire is grounded to the brass case within the bakelite cap. From the bottom of the brass cylinder extends a threaded stud 1/4 inch long which screws into nuts welded on the diaphragm to be studied. 6-32 nuts have been used but 8-32 nuts are advisable in cases of severe loading.

The lights are attached to the diaphragm in a horizontal row at intervals of 3 to 6 inches. Ordinarily from 4 to 8 bulbs are thus spaced over the plate. Under explosion within the tank the diaphragm moves vertically downward, carrying the light sources with it. The resulting negative films are measured under a dual-travel microscope to 0.001 inch, affording a time resolution of ± 10 microseconds and a full-scale displacement accuracy to ± 0.05 inch. Figure 4 is an enlarged print of a record thus obtained.

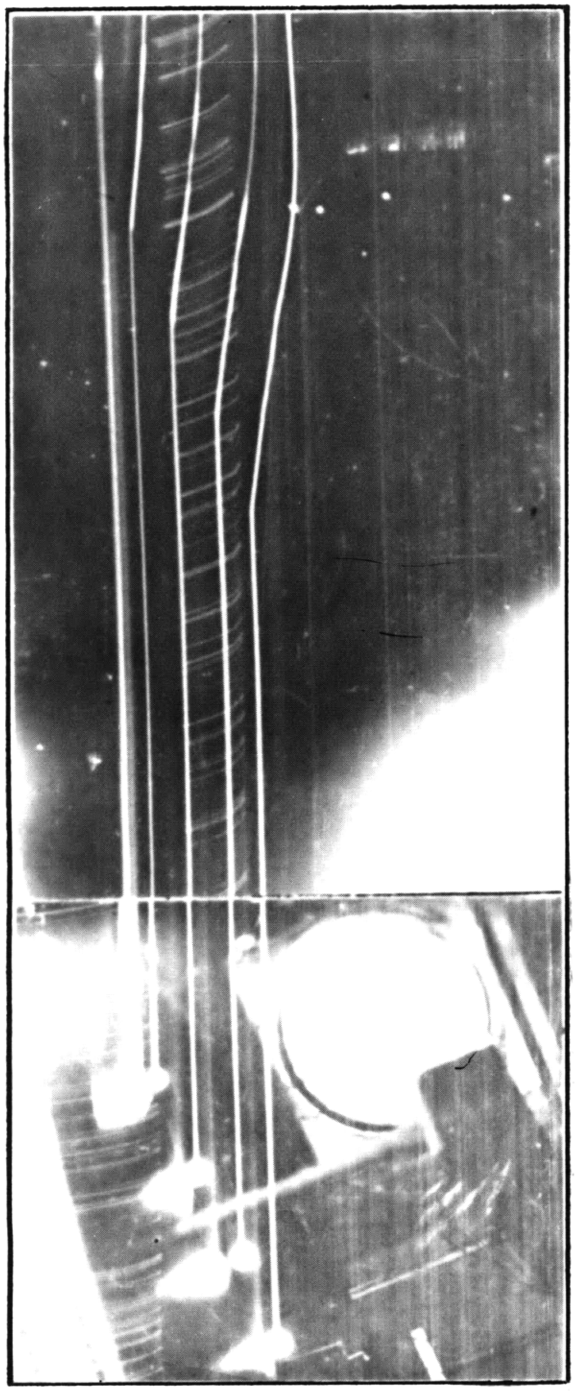

Figure 4 - Traces of Light Bulbs

This record shows the motion of points on a steel diaphragm 1/8 inch thick and 36 inches in diameter and protected by a 2-inch thickness of wood, due to the explosion of 1 ounce of tetryl 12 inches distant, in the tank, Figure 2. The lowest bulb in the photograph is at the center of the diaphragm, the uppermost is on the clamping ring at the edge.

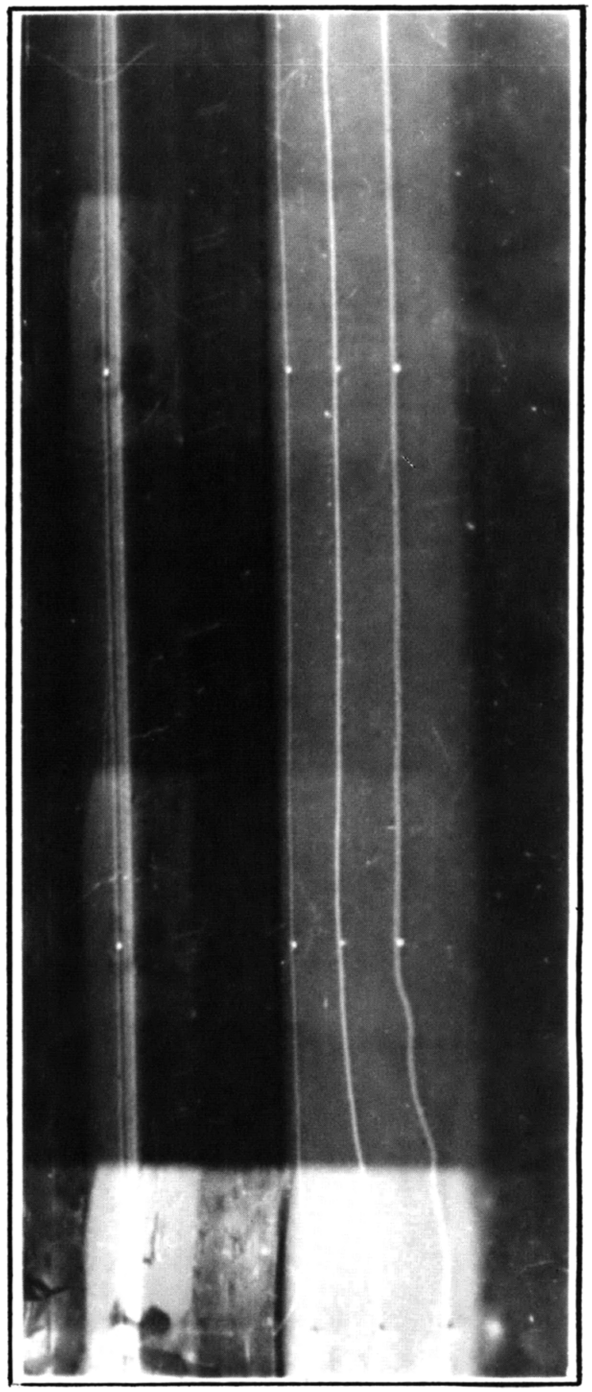

Figure 5 - Traces of Steel Bearing Balls

An instantaneous "smear photograph" was made at the moment of detonation of the charge. The record shows the motion of three points on a steel diaphragm of 25-cm diameter, when mounted in a boat as shown in Figure 1 and attacked by a 25-gram charge of tetryl at a distance of 50 cm.

ILLUMINATED STEEL SPHERE

The second device consists of a small, highly polished sphere in the form of a 3/16-inch bearing ball, suitably mounted on the object and brightly illuminated from above. A virtual image of a bright light is formed within the sphere, thus providing a sharp point of high luminosity for photographic purposes.

The ball is illuminated by a single 250-watt photo-flood lamp mounted within a foot of the bearing ball, and provided with a suitable reflector. With this illumination, a film speed of 1 cm per millisecond or 10 meters per second produces an excellent trace with an aperture of f5.6. It appears likely that more intense illumination could be provided by a carbon arc, but for present purposes the arrangement described suffices. A sample record is reproduced in Figure 5.

Reducing the size of the luminous object, i.e., the virtual image within the bearing ball, while maintaining the luminosity constant, has the net effect of reducing the exposure at any point on the trace, for the image projected on the film will thereby be reduced in size, and the time of exposure for any particular sensitive grain will thus be reduced. Thus as the photo-flood lamp is moved closer to the bearing ball, the density of the trace is improved, although the definition is somewhat impaired.

The trace on the film can be measured, with the exercise of care, to within about 0.001 cm. Since mechanical vibration in the camera can easily produce random fluctuations of this order of magnitude, this represents a practical limit on the precision attainable.

As was the case with the self-luminous light sources, the path of several luminous points on the same object can be recorded simultaneously.

A further development, which has not been attempted because of its inherent complexity, is the use of two cameras to provide stereoscopic viewing of the object.

REFERENCES

(1) "A Photographic Study of Small-Scale Underwater Explosions," TMB CONFIDENTIAL Test Report, August 1941.

(2) CONFIDENTIAL TMB letter C-S85-2, 7 August 1942, to Coordinator of Research and Development, Navy Department.

(3) CONFIDENTIAL TMB letter C-S85-2, 17 August 1942, to Coordinator of Research and Development, Navy Department.