Underwater High-Speed Photography

PAPER I—4

By JOHN V. PFLAUM

Experiments conducted by the U.S. Navy Electronics Laboratory required high-speed motion-picture photography of pneumatic and spark sound producing devices from 100- to 300-ft water depths. Film speeds of 1500 to 3000 frames/sec were necessary to observe and evaluate equipment performance. Two Eastman high-speed cameras and light sources were enclosed in special underwater cases designed to withstand pressures equal to a 700-ft water depth.

The use of SCUBA divers for servicing the equipment was not feasible due to the operating depths, therefore, both the devices undergoing tests and the photographic equipment were mounted on a semiportable rig to be lowered into the water after having been properly aligned on the surface. Cable lengths, voltage drops, synchronizing camera and event, and field processing all posed problems to be overcome. Usable data were obtained on both Eastman Tri-X and Super Anscochrome.

IN CONNECTION with the evaluation of some experimental novel sound sources of both pneumatic and spark-gap type, Navy Electronics Laboratory (NEL) engineers had a need for more information than could be gathered from oscilloscopes, sound recorders and other available instruments. It was necessary for them actually to *see* what occurred when the tubing, spheres or spark gaps exploded and produced sound under water. High-speed photography seemed to be the answer to this need.

At that time the Laboratory had two medium-sized tanks, but both were unsuitable for the experimental purpose. The tank that was needed had to be small, strong enough to withstand a force produced by the explosion of several pounds of TNT, and equipped with ports and windows for lighting and photography. Accordingly, a discarded ready-service ammunition box from a Navy ship was adapted for the experiments by adding lighting ports, camera windows, and brackets to hold the devices being tested (Fig. 1).

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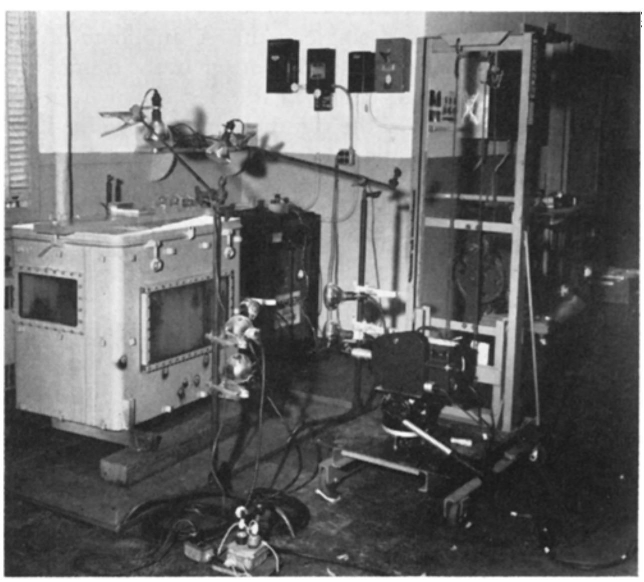

Fig. 1. Small laboratory test tank for high-speed photography of pneumatic and electrical spark sound sources showing camera windows, camera and lights. The second camera has been removed to show end window and tank construction.

The tank was painted flat white on the inside. Openings were made to fit a prearranged lighting plan. Two windows with 4:3 aspect ratio openings, one in front and one on the end, allowed for two camera positions 90° from each other. Two cameras were used on all tests. As a result, the engineer was provided with two views of each operation. If one camera failed, the other still provided a photographic record.

The tank was about 4 ft long, 2½ ft wide, and 4 ft high. It held approximately 250 gal of water. All lighting and photography were done from the outside, through 1-in. Plexiglas.

Some 50 to 60 tests were conducted with this tank before an explosion blew out the bottom. Results were good. Operation was simple, and the tests were made rapidly. The experiments made with this tank led to the design of the portable, adjustable, high-speed photographic rig (as it was called) which is described in this paper.

Test Site

It was decided to use the NEL Calibration Facility at Lake Pend Oreille, Idaho, to test the experimental sound sources down to depths of 500 ft, which was one-half the depth of the water at the facility. Tests were planned to commence at 50 ft and work down. Such depths, and a mean water temperature of about 45 F, made use of the laboratory's SCUBA divers inadvisable.

Fig. 2. U. S. Navy Electronics Laboratory calibration barge at Lake Pend Oreille, Bayview, Idaho, showing extension dock used to drape power and control cables into water. Small float in foreground holds transformers for boosting shore power to barge.

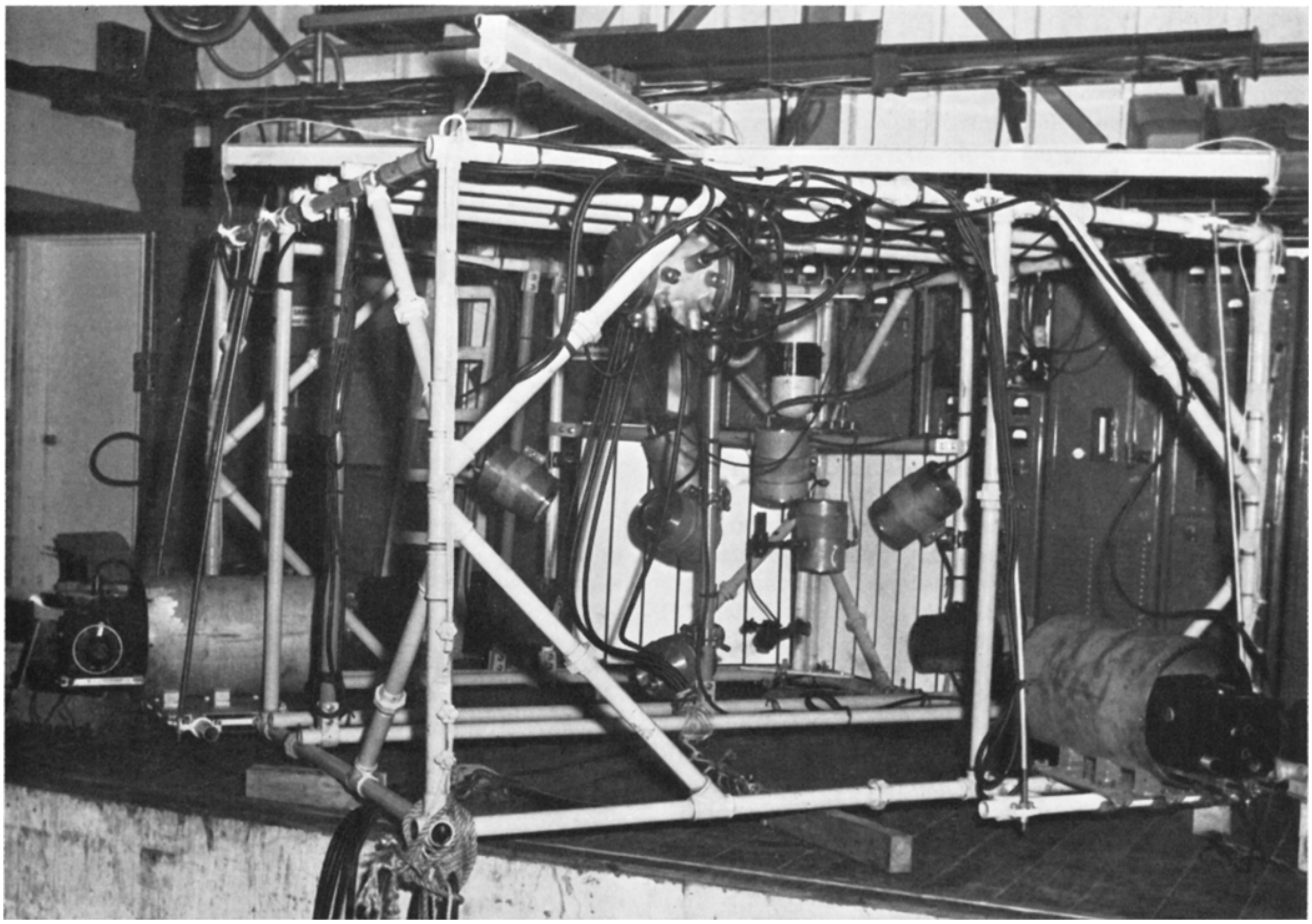

Fig. 3. Underwater high-speed photographic rig on deck alongside well in barge showing frame, cameras and cases, light and cables attached to frame.

The Calibration Facility barge (Fig. 2) was suitable for the work as it had a well cut inside with large doors to the outside, but could be protected from all sides if necessary. It also had a bridge crane over the well, a machine shop, ample cable drums, a hydrophone calibration station, a photo lab, a long dock from which cables could be draped. The ride to shore and living quarters was conveniently short.

Apparatus

A simple apparatus in the form of a large frame was designed to hold the two cameras in their deep-water cases, eight underwater lamp cases, two calibration grids, hydrophone, junction box, power supply for the spark gaps and air supply and valve for the pneumatic devices. This large frame was constructed from $1\frac{1}{2}$-in. standard galvanized pipe with movable horizontal and vertical braces for support. The use of standard pipe and fittings had the advantage that any necessary modifications could be made easily in the field.

Places were provided in the frame to attach lights, cables, junction boxes and numerous auxiliary devices (Fig. 3). All ends and sections of the frame were left open to free flooding, thereby making the density of the frame as close to that of water as possible, and cutting down the buoyancy. Actually, the buoyancy of the rig proved to be just negative enough for it to sink slowly and evenly.

Extra lengths of vertical and horizontal bracing were made up in the shops and the rig was predrilled before leaving for the field. This saved much time, and all the additional braces were used. Supplies of spare pipe T's, unions, L's, etc., were shipped to the field site but were not used.

Two sets of $\frac{1}{2}$-in. wire rope slings or four-legged stays were manufactured, one for the top and one for the bottom of the frame. Additional wire cable was run down the corner posts to support the weight of the assembly. At the top of this set of stays was a large steel ring with a swivel. A wire from the bridge crane carried the entire load from a single point. A duplicate of this wire device was attached to the bottom of the frame, and the power cables and control cable led down from the surface to the corner of the rig, then on down to the large steel ring and up to the junction box. It should be said at this point that, although there were four 500-ft lengths of extra flexible welding cable and one six-conductor control cable in the water, no tangling or twisting was experienced. The cables were about 8 ft apart when they left the surface and they ended up in a cluster of five, 500 ft away, at the photographic rig. The cable drape needed no additional attention once placed in the water in this manner. It was not pulled up onto the barge until after all the testing was over, which took about five weeks. It is believed that the weight at the corner helped considerably to keep the wires straight, even though the lake does have a strong current running toward its mouth.

Simple outrigger-supports in two corners served for both camera mounting platform and for up-and-down alignment. These supports extended out from the main frame and were held from the top rail by $\frac{1}{2}$-in. stainless-steel round rods threaded on both ends. Two open-end wrenches were the only tools necessary to make adjustments. Side-to-side or left-to-right alignment was made by loosening three 2-in. stainless-steel straps under the camera cases and sliding the cases until the cameras were lined up. The cameras' own viewing tubes were used in both cases, without modification.

The two underwater camera cases for the Eastman Type III High-Speed Cameras were rolled and welded cylinders made from $\frac{1}{2}$-in. stainless-steel plate, with outside dimensions of $22\frac{1}{2}$ in. in length and $14\frac{3}{4}$ in. in diameter. With the end plates, they weighed about 160 lb. Due to the effort and cost, it was decided to make the cases long enough to accommodate the three lenses available for this camera — the 152mm, 75mm and the 25mm — which were used for all of these tests. Drawer-pull type slides supported the camera inside the case and spring-loaded pilot pins automatically positioned the camera for the lens used.

The camera port window was made of Lucite, 1-in. thick and 4 in. in diameter. It was set on two "O" rings backed up with an opening $2\frac{1}{2}$ in. in diameter and made of $\frac{1}{2}$-in. stainless steel. This was the only opening in the $1\frac{1}{2}$-in. stainless-steel front plate. The rear plate also was of $1\frac{1}{2}$-in. stainless steel. It had two openings with Joy-type glands welded on the outside. The end plates had "O" ring seats around their outside diameter and were secured into the ends of the case by eight $\frac{1}{2}$-in. by $\frac{1}{4}$-in. stainless-steel screws set 45° apart around the case. This placement of the "O" rings was considered best because of the massiveness of the end plates. The front end plate has never been removed since it was put on; the rear end plate is removed every time the camera is serviced, but no leaks have been experienced.

It should be noted that the "O" rings and grooves were thoroughly cleaned and greased each time the plate was removed. In addition to the two packing glands, there were two handles on the rear plate for handling the case or the rear cover plate. All Joy-type cable plugs and connections were molded at the laboratory during construction; they are not interchangeable because special molds were made for the glands used in this project.

The eight underwater lights (Fig. 4) were in watertight cases similar to the camera cases but more easily constructed due to their smaller size. Outside dimensions of the lamp cases were $7\frac{3}{8}$ in. in diameter and $9\frac{5}{16}$ in. in length. They were made from $\frac{1}{4}$-in. stainless-steel tubing. The lamp cases were designed around the popular General Electric PH750R spot lamp which is well known as a standard lamp for high-speed photography. A front plate $1\frac{1}{2}$ in. thick holding a Lucite window $5\frac{3}{4}$ in. in diameter and also $1\frac{1}{2}$ in. thick, and a rear cover $\frac{7}{8}$ in. thick with a single packing gland for the power cable, completed the case.

The same method for placement of the "O" ring and seating screws was used for the lamp cases as for the camera cases. To dissipate the heat, eight copper springs were formed to the contour of the lamp on the inside of the case. They also acted to take up any shock during shipping and prevent lamp breakage during the testing. Burning the lamps for more than 15 sec at a time, however, caused some damage to the Lucite windows. This damage was in the form of small black-rimmed pock marks, but seemed not to interfere with the general overall spread of illumination.

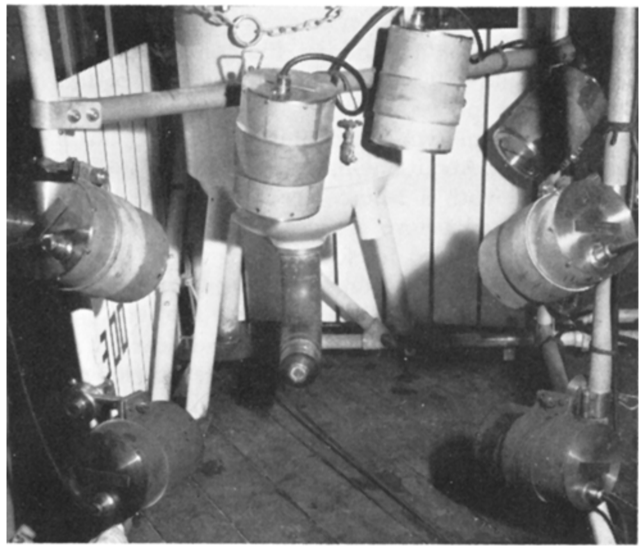

Fig 4. Circular spark gap with cluster of underwater lights for illuminating event. Wide-angle view from a point near the camera position. Visual calibration grids in background.

Ordinary porcelain lamp sockets were mounted on a clip inside the rear cover plate to hold the 750-w lamp. A special two-way swivel clamp was designed that is similar to those used on a "century" stand, well known in the motion-picture industry. This two-way clamp was attached to the lamp body with a heavy stainless-steel strap, and to the pipe frame with a split clamp, allowing it to be placed anywhere on the frame and to swing in any direction. All the lamps were located around the test device in two squares with the lamps not over 24 in. from the subject. All lamps pointed in a downward direction, except one which acted as front fill light. This general downward direction gave a greater return than if the lamps were aimed directly at the subject, as is the practice in air. The closer the lamps could be placed to the device being tested, and still remain outside the field of view, the better was the quality of the photography.

Synchronizing the experimental event and the photography was a joint effort of the project engineers and the photographer. It was not a simple task, especially with the pneumatic devices. The air flask was on the rig with the cameras and lights, and an electrically operated valve opened to allow air to fill the sphere, but shut off immediately after the explosion so as not to cause excess bubble activity. With the aid of a hydrophone and surface amplifier, and with a small amount of practice, the crew learned to lead with the camera at the shallower depths, start the camera and the inflation process at the same time at the medium depths, or to lead with the inflation device at the greater depths.

Timing the camera run was not difficult with the aid of the hydrophone. In water the cameras could be heard to start and gain speed, and the device heard to go off. After a few runs even the different tones of the two cameras could be distinguished, and one could tell if both cameras completed their runs before bringing the rig to the surface.

In synchronizing the spark-gap events, use was made of the internal program trigger microswitch with added holding relays to assure a positive start pulse. In the spark-gap photography approximately 60% of the film was used to assure that camera speed was in the useful speed range for data gathering. Picture/sec rate averaged out at around 2000 for the pneumatic devices and over 2800 for the spark-gap events. Tri-X negative was used for the black-and-white film and Super Anscochrome for the color film. About one-half of the Tri-X was developed in the field with a Micro Record Unit, and the films were evaluated before a succeeding photographic run. The schedule called for four photographic dives a day with other work going on in between. Recordings were made on both film and tape. In-the-field evaluation of the film was made with the aid of a Recordak reader. D-76 with Kodalk added was used as developer in the field, as it closely approximated that used in the laboratory. Thirty per cent additional developing time was added in the Micro Record Tank Set, but only 10% in the continuous processing machine at the laboratory.

Conclusions

The crew in the field considered the machine compact and workable. By mounting all components on a single hoist much time was saved, and only a single assembly period was necessary. The device was shipped in two halves, minus the heavy cases, in an overland furniture van. Setup time at the field station was two days for four men. This time included moving the device by boat from the lake shore to the barge.

The addition of four more lamps would make color photography more feasible and allow for some stopping down of the camera lens. For future tests of this type, closed-circuit television should be included so as to be able to monitor the nonphotographic events and make more effective use of the audio from the hydrophone for visual synchronization of the high-speed cameras. About an hour of preliminary work was required for a 3-sec shot.

The techniques learned in this work are now being applied to another tank, with hopes of providing scientists with better high-speed data in the future.

All photographs are official photographs of the U.S. Navy.