Unusual Applications of Optical Instrumentation at NOTS

PAPER L—2

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The Naval Ordnance Test Station has expanded its programs of weapon development to include new areas of investigation such as determining satellite orbital elements, testing components on supersonic research tracks, obtaining data on underwater missile launchings, analyzing sea animal propulsion, determining the cause of malfunctions on rocket motor static-test stands and studying hydroballistic phenomena in model tanks. These new programs have called for unusual applications of optical instrumentation techniques and equipment, which in turn have depended greatly upon advances in the art of high-speed camera techniques, some of which have been developed at this Station.

THE U.S. NAVAL ORDNANCE TEST STATION is unique in that it combines the functions of research, development and test of weapons and weapon systems within one organization. The measurement requirements of weapon testing are increasing in complexity in almost direct proportion to the increase in complexity of modern weapons. To keep abreast of data-measurement requirements, this Station is pursuing a planned program of research, development, modification and improvement of the instrumentation used to obtain and interpret test data. This paper discusses some of the optical instrumentation and techniques thus evolved, especially in the area of unusual applications.

Determining Satellite Orbital Elements

An unusual use of the cinetheodolite (Fig. 1) is for tracking and acquiring data on man-made satellites. For this purpose the Station employs the well-known Askania cinetheodolite, with a modified shutter. The shutter was modified by installing a pin on the shutter solenoid so as to engage the shutter in its open position and hold it there until released. By this means, controlled exposures of 1/25 to 1/2 sec, depending upon expected brightness of the satellite, can be obtained. Exposures as short as 1/200 sec are used on unusually bright satellites, such as Echo.

The timing control unit for the satellite-tracking cinetheodolite (Fig. 2) consists of an intervalometer which counts down the output from a crystal-controlled frequency standard to the desired operating rate of the instrument. The camera pulse is synchronized to WWV by adding pulses in the countdown circuit until an oscilloscope shows the flashlamp pulse to be coincident with the 1000-cycle burst from WWV, marking the start of the second. The signal from WWV and the one monitoring the instrument shutter operation are recorded side by side by a two-channel pen recorder. This permits correlation of the instrument operation throughout a tracking run to the nearest second. Overall timing accuracy is usually within 2 msec.

All satellites visible to the naked eye have been tracked and photographed successfully on Eastman Tri-X film. Some of the dimmer satellites have been photographed by means of "smooth tracking," as with astronomical telescopes, whereby a long time is allowed for each exposure.

Two-man tracking is used. Telescope magnifications are 12×, which diminishes the need for accuracy in predictions, and 20×, which makes easier the tracking of dimmer satellites. The advantages of using cinetheodolites for satellite tracking lie in the utilization of existing equipment, the reasonable portability, the ease of setting up in a remote location, and the ability to obtain data on large segments of the satellite's trajectory. This last advantage was demonstrated in the tracking of the 1958 Delta II (Sputnik III instrument package) for 13 min, with usable records obtained throughout 10 min of the period. This was approximately 9% of the total 104-min orbit.

The standard deviation of the data obtained with this instrumentation was found to vary from 30 to 60 sec of arc. This variation was a function of the conditions existing at the time the observation was made: the brightness of the satellite, tracking error, etc. The standard deviation in time was 2 msec.

Supersonic Testing of Components on Research Tracks

NOTS has five research tracks for various types of testing. One of these, SNORT (Supersonic Naval Ordnance Research Track), provides a high degree of versatility in the supersonic captive flight testing of rockets, guided missiles, jet aircraft, airborne launchers, and related ordnance components. Optical instrumentation—including sled-borne instruments, tracking mounts, and precision-oriented mounts such as the CZR-1 ribbon-frame camera—plays an important role in collecting track test data.

An unusual application of sled-borne instrumentation is the testing for Project "Catshell." In these tests a shell is fired from a 155mm howitzer and caught by a high-velocity track sled without damage to the shell. The varied optical instrumentation employed in these tests included two sled-borne high-speed cameras which record the behavior of the shell as it enters the catch box

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Presented on October 19, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by David F. Keyes, Carl Koiner, Wesley Lambert, George G. Silberberg (who read the paper) and Darwin Tiemann, U.S. Naval Ordnance Test Station, China Lake, Calif.

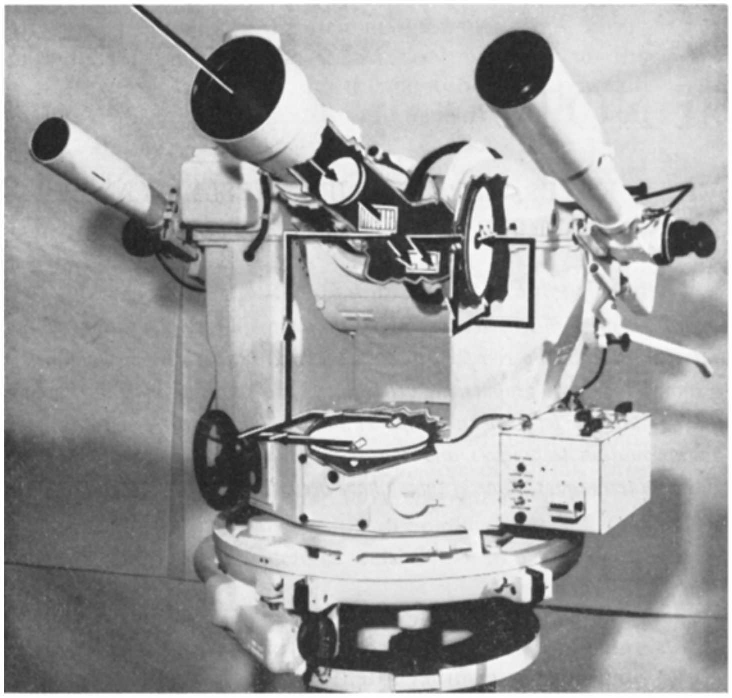

Fig. 1. Mk 5 cinetheodolite showing optical train.

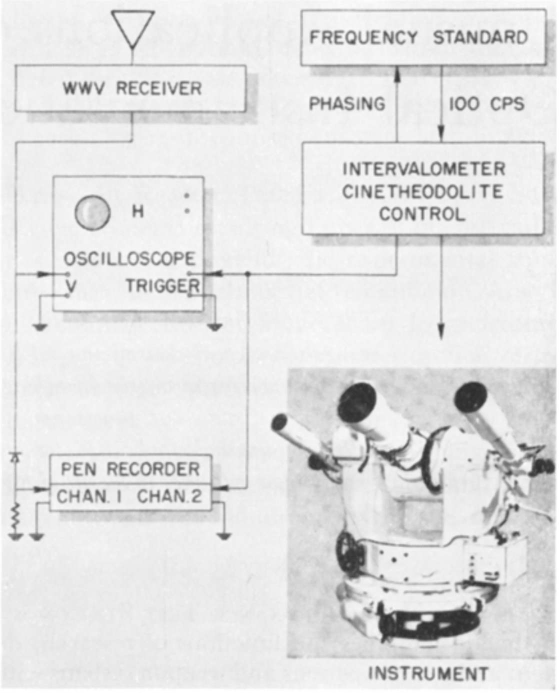

Fig. 2. Block diagram of timing control for satellite-tracking cinetheodolite.

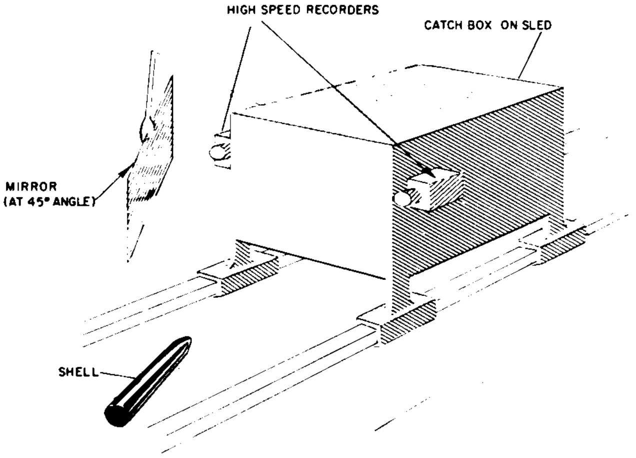

Fig. 3. Sled-borne high-speed camera setup.

(Fig. 3). The resulting photographs (Fig. 4) present the seldom-seen view of a shell traveling at its terminal velocity.

Seat ejection tests on SNORT also present unusual requirements. One of the most useful tools for photographically recording this type of test is the M-45 tracking camera mount. As many as eight mounts have been employed, depending on the complexity of the particular seat ejection. A typical test is that of the A3J two-seat aircraft, which requires two mounts for tracking, and one for each ejection to obtain, photographs such as that shown in Fig. 5. Each M-45 can support up to three cameras (Fig. 6). One of these is usually a full-frame 35mm camera, with a 48-in. effective-focal-length Thompson lens, running at 500 frames/sec with color film. On the opposite arm of the mount there is a 70mm camera, with a 75-in. lens, running at 60 frames/sec and using black-and-white film. A third camera, with a 10-in. lens, running at 400 frames/sec uses 16mm color film. The problems of tracking rates, heat waves, and change of focus for the long-focal-length lenses all affect the quality of the image. The operator has to guess when the seat will eject in order to keep the action properly framed. Mounts placed 2000 ft. to the side of the track produce the best image quality, but so short a distance presents a very difficult tracking problem.

Obtaining Data on Underwater Missile Launchings

The use of optical instrumentation for gathering data under water has required some unusual techniques and modifications to existing high-speed cameras. Since the field is relatively new, on-the-shelf hardware was not available; therefore, new underwater housings, lenses and accessory equipment had to be developed. NOTS undertook this development in support of the San Clemente Island sea range, where many programs are being conducted. One of these is the underwater launching phase of the Polaris missile in which as many as twelve underwater cameras are simultaneously used to record the underwater action (Fig. 7).

Sea water is a poor medium for photography since the scattering of light, attenuation of certain parts of the

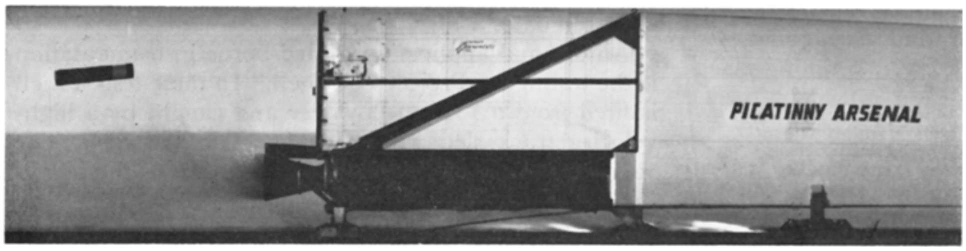

Fig. 4. Shell about to be caught.

spectrum, and the presence of suspended particles in the water degrade the image to the point where the camera is not usually able to photograph objects more than a few feet away. Fortunately the water at San Clemente Island is exceptionally clear and usable images have been recorded at distances up to 50 ft at operating depths.

Four 35mm Mitchell cameras with 18.5mm lenses, running at 120 frames/sec and using color film, are installed in underwater housings attached to towers standing on the ocean floor to record the entire underwater launching action. Each housing is fitted with a lens which corrects for the index of refraction of sea water and for some of the color characteristics of the water as well. Each camera has a special synchronous motor that allows phasing of all the shutters in order to permit simultaneous exposures in all four cameras.

Six Milliken cameras, in housings, are located around the perimeter of the launcher to record cavitation and other details of the missile performance as it leaves the launcher. The Milliken cameras employ a 5mm lens, operate at 400 frames/sec and use black-and-white film. A Fairchild camera, with an 8mm lens, running at 1000 frames/sec, and using black-and-white film, enables the recording of "first motion" of the missile in the tube.

No artificial lighting is used, hence some means of measuring the light value at the working depth is required. An underwater photometer developed by NOTS is used to measure horizontal and vertical light in the vicinity. This information is sent by means of an FM signal to a Sanborn recorder, and the signals are converted into ASA readings in order that light values may be recorded throughout the day. Camera settings are made on the basis of previous settings found to have been optimum. No adjustments of the cameras can be made once they are lowered into the water; but with the aid of the light readings, compensation can later be made in the film processing to correct for most of the deficiencies in lighting.

To record the behavior of the missile after it leaves the water several types of optical instruments are employed. High-speed 35mm cameras with long-focal-length lenses are used to record the ignition of the missile. Some of the

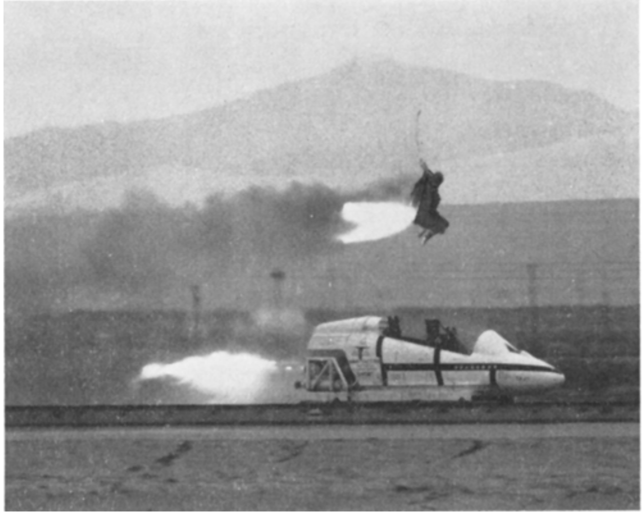

Fig. 5. Frame from M-45 70mm film of seat ejection run.

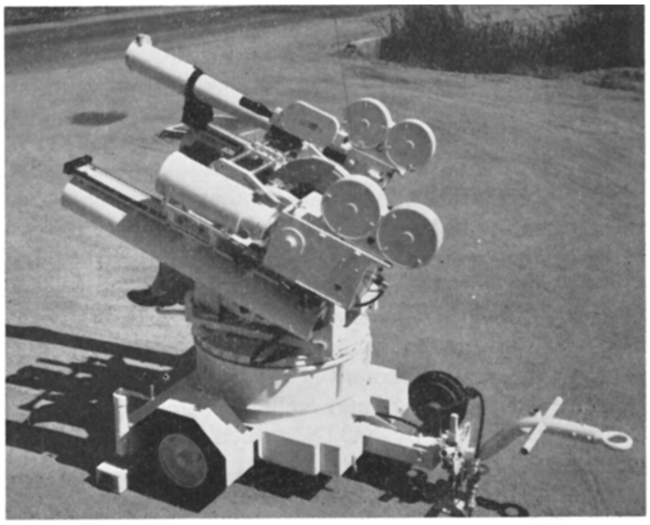

Fig. 6. M-45 tracking camera mount with 70mm, 35mm and 16mm high-speed cameras attached.

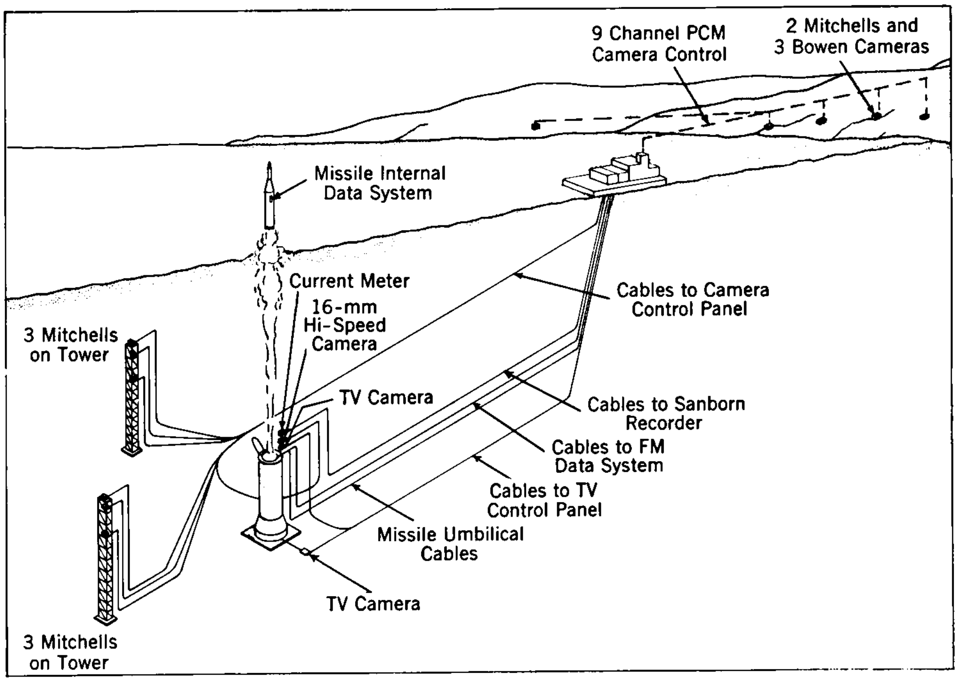

Fig. 7. Pop-up instrumentation system.

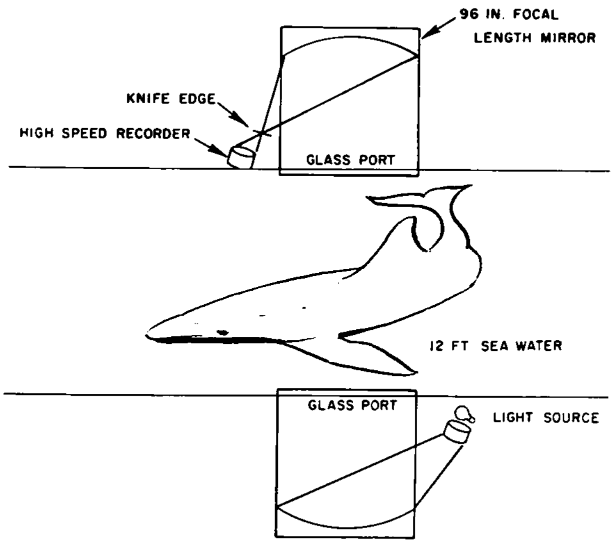

Fig. 8. Schlieren system for porpoise boundary layer studies.

cameras are on land-based tracking mounts, and others, on barges close to the point of emergence. Land-based cinetheodolites, Bowen cameras, and Mitchell cameras are also utilized.

Sea-Animal Propulsion Studies

Among the multitude of undersea enigmas is the method by which fish propel themselves through the water so efficiently. NOTS scientists working in the development of underwater ordnance have a special interest in fish propulsion. They would like to apply the secret of quiet, low-friction movement of bodies through the water to their various underwater vehicles. One recent test program conducted by NOTS studied the performance of a porpoise under controlled conditions. Optical instrumentation was used to obtain the following data; drag coefficients, maximum power expended, top speed, extent of the laminar boundary layer, flow pattern around the porpoise while swimming and gliding, and the relation of physiological phenomena to hydrodynamic characteristics.

The tests were conducted in a tank 300 ft long, 12 ft wide and 6 ft deep, filled with sea water. Again, the problem of photographing through sea water presented many difficulties that had to be overcome by unique methods. One of these methods, used to record the boundary layer of the porpoise, involved a modified schlieren system (Fig. 8). A mercury arc lamp was used as the light source, and two 96-in.-focal-length, 12-in.-diameter mirrors were used to produce the underwater collimated light beam. A 16mm high-speed camera running at 400 frames/sec was used to record the images. As the porpoise swam by, variations in temperature between its body and the water were recorded on the film as different contrast densities and colors. Laminar flow and turbulence could thus be recorded.

To record maximum power expended, top speeds and drag coefficients, an array of twelve high-speed 35mm Mitchell cameras was placed along the tank at surveyed positions. Each Mitchell camera covered a known section in the tank so that position and time could be determined. All of the cameras were correlated with a binary-coded time base. The first two cameras were aimed through the water at a 20-ft grid to determine the acceleration of the porpoise at the beginning of each run.

Fluorescent lights, submerged in the water on the opposite side of the tank from the cameras, were used as reference markers for each camera (Fig. 9). When the porpoise's nose went by these lights, time and position

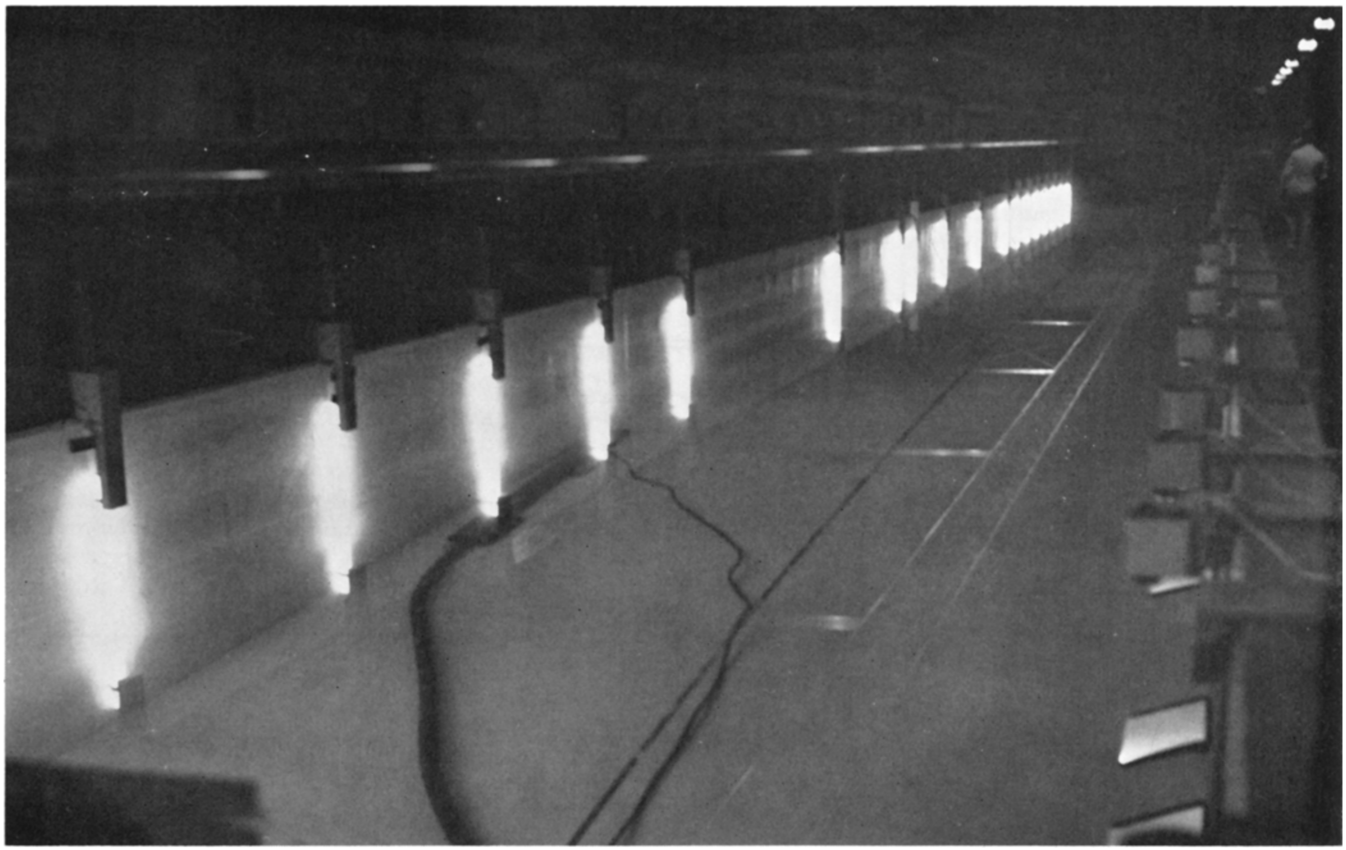

Fig. 9. Camera reference markers used in porpoise studies.

were recorded. The twelve stations produced data over a 240-ft section.

To record the flow pattern around the porpoise while it was swimming, two techniques were used. The first was an open-shutter technique with a large-format camera. Small particles suspended in the water were illuminated by means of back lighting. When the porpoise swam through these particles their movement was recorded as a trace on the film, delineating the flow pattern (Fig. 10).

Another method of producing a flow pattern utilized a high-speed 35mm Mitchell camera with a strobe light synchronized with each exposure. This produced a series of exposures showing the exact position of each particle throughout the run.

Another fish-propulsion study was conducted by NOTS at the University of Washington in Seattle. Salmon and trout were used for these tests, and methods similar to those described above were used to record boundary layers, flow patterns and drag coefficients. The fact that these fish are smaller than porpoises and are at home in fresh water greatly reduced the photographic problems.

A 35mm Mitchell camera running at 120 frames/sec was used to record the flow pattern. A unique lighting system was used, employing a series of lights, the beams of which were projected on a thin strip of mirror and then reflected from another mirror into the test section. Styrofoam beads were dropped into the test section and floated in such a manner as to produce a grid in the horizontal plane. As the fish swam through the test section, only a band of light along the side of the fish was visible. The sensitive horizontal discontinuity formed by the beads in the water made it possible to capture the flow patterns with the camera.

A schlieren system, similar to the one used for the porpoise studies, was used to study boundary-layer conditions. The light source was a 25-w zirconium arc lamp; and a 35mm Photo Sonics camera, running at 500 frames/sec, was used to record the images. Instead of a knife edge, two filters (Wratten Nos. 9 and 47) were placed at the focal point of the mirrors. This arrangement resulted in greater sensitivity than that obtainable with a knife edge, and produced very satisfactory results on color film.

Rocket-Motor Test Stand Studies

The Naval Ordnance Test Station operates rocket test stand facilities capable of statically testing rockets with thrusts up to 1 million lb.

Detailed studies of the flame structure and the exhaust of rocket motors are frequently requested. Although the nature of the flame itself makes photographic investigation within the flame area extremely difficult, the standoff area (the area between the nozzle of the rocket and the flame) presents an ideal location for study. In a unique method of investigating this area, a high-speed camera running at 8,000 frames/sec is located at the same height as the rocket on the test stand (Fig. 11). Directly in line, but on the opposite side, is located a Fresnel lens with a projection lamp behind it to provide light. The lighting is concentrated in the stand-off area so as to produce an even illumination of high intensity. Any substance coming through the area appears in silhouette and is easily discernible. A 20-μsec exposure at $f/22$ on Tri-X film yields excellent contrast.

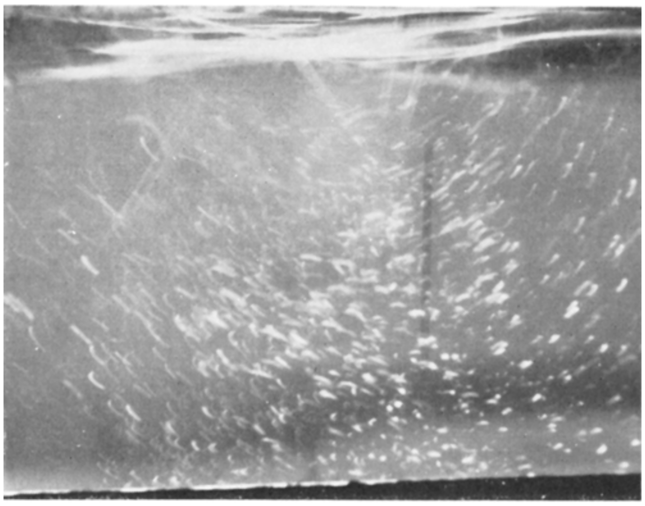

Fig. 10. Particle trace resulting from porpoise swimming action.

Research and development of propellants plays another large role at NOTS. One particular kind of experiment requires a detailed study of the exact behavior of propellant burning as a high-pressure wave passes over it (Fig. 12). To study this photographically, a 16mm Fastax camera running at 8000 frames/sec is used. A 1:1 image-to-object ratio is achieved by utilizing a reimaging lens system. A flashbulb backlights the burning sample, enabling discernment through the flame for study of the effects of the high-pressure wave when it passes over the grain. Since the wave is travelling at nearly 6000 ft/sec, and the total action lasts only 3 msec, a 0.002-in. slit is placed in the camera aperture to achieve the necessary stopping action.

Model Tank Studies

One of the new facilities at NOTS is the variable atmosphere tank now in operation at the hydroballistic

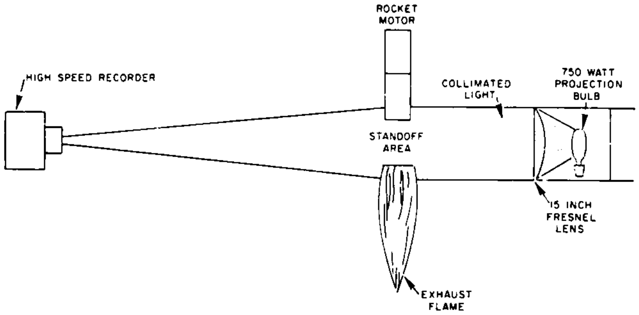

Fig. 11. Rocket-exhaust study setup.

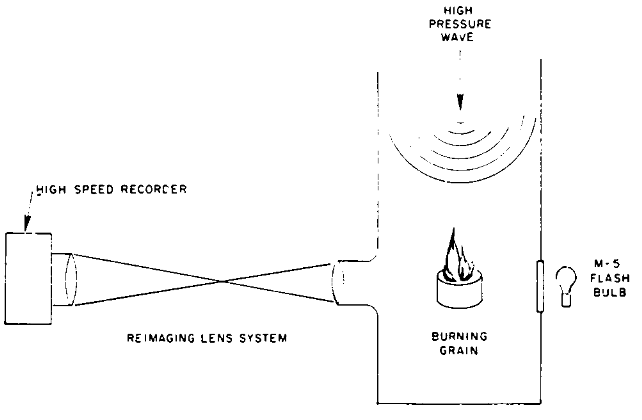

Fig. 12. Propellant-grain study setup.

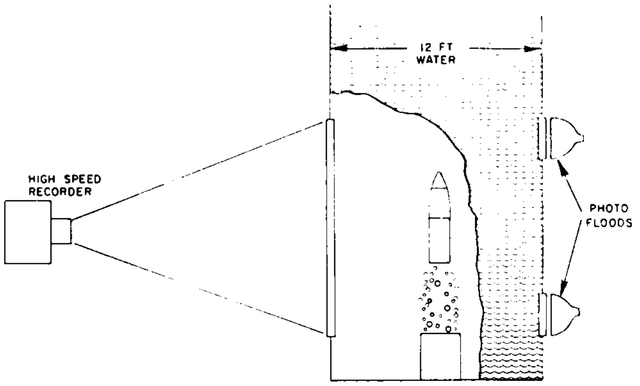

Fig. 13. Cavitation study setup in variable atmospheric tank.

laboratory in Pasadena. This 38-ft-tall tank is presently being used to study 1/5-scale models of the Polaris missile. High-speed cameras are used to gather data on the firings. For studying bubble growth and cavitation (Fig. 13), a special 42mm lens has been adapted to the 35mm Photo Sonics camera. To do this, the prism assembly had to be shaved off because of the short back focus. This particular lens-camera combination has proved ideal for covering the launching phase of these missiles (Fig. 14).

Concluding Remarks

As we have seen, optical instrumentation at NOTS is extensive, and covers an extremely wide field. Along with the programs mentioned here there are many others, including guided missiles, rockets, aircraft, hyperballistics and hydrodynamics. Overall, the high-speed camera is one of the most useful tools available for gathering data by photographic means at NOTS.

Acknowledgment: The photographs for this paper are Official United States Navy Photographs.

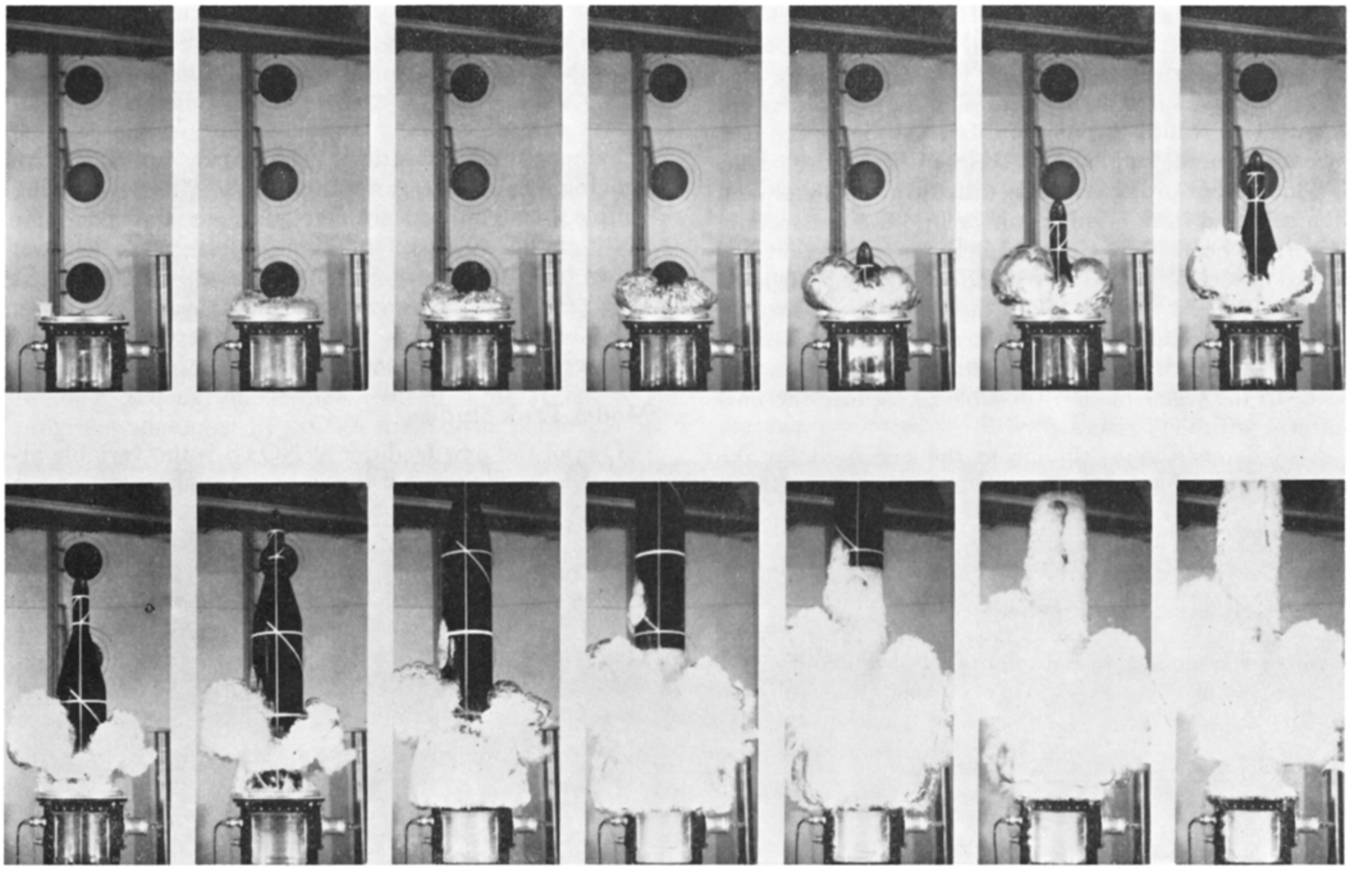

Fig. 14. High-speed photographs of one-fifth scale Polaris model.