HYDRO SHOCK EXPERIMENT

Final Report

Contract N00014-69-C-0238

By Edwin Miller and Vincent J. Cushing

Prepared for

OFFICE OF NAVAL RESEARCH
Washington, D. C. 20360

January 1970

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ABSTRACT

A number of small scaled explosions have been carried out in the ONR Shock Hydrodynamic Facility operated by the Engineering-Physics Company. The source of the explosion is an exploding wire, energized by rapid discharge from an electrical capacitor. The explosions are nuclear-like in that there are substantially no combustion products. In order to approximate a point-source explosion, the exploding wire consisted of #40 nichrome wire with lengths ranging from 2.3 mm to 4.5 mm. Burst points ranged from a depth of 63.5 mm beneath the water surface to an altitude of 100 mm.

Bubble growth and progress of shock fronts in the air and in the water were followed through a schlieren optical system by means of very high speed photography. Pressure-time information, in the water only, was provided by piezoelectric gages. Surface waves were followed by means of high speed photography.

Data reduction is being carried out by A. R. Kriebel at the URS Corporation under Contract N0014-67-0451. Preliminary results are available in URS Report No. 679-6 dated April, 1970, and entitled "Hydrodynamic Data from Exploding Wires."

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In accordance with Contract N00014-69-C-0238, a series of experiments was conducted at the ONR/EPCO Shock Hydrodynamic Facility. The purpose of these experiments was to take data relative to physical activity in the proximity of explosions occurring about surface-zero.

Through the use of high speed photography, (circular) schlierin recordings were made on 35 mm film to follow shockwave progression, both in water and in air; steam bubble oscillation; bulk cavitation formation; and water surface motion.* Additionally, observation of explosively generated water waves was performed by a 16 mm movie camera operating at a 12.07 millisecond framing rate. The camera, a Bolex H-16 unit, was set for operation at a nominal 64 frames per second. It was, however, calibrated at this setting using a General Radio Strobotac shining directly on the shutter with the lens removed. This calibration indicated the actual operating speed to be 82.83 frames per second, or 12.07 milliseconds per frame. Several replications of the calibration procedure show this value to be valid to an accuracy of ± 1%. Shockwave pressures were monitored by oscilloscope and photographic recordings were made as the trace progressed in time along the face of the CRT.

Three sets of records are available: 35 mm film strips, 16 mm rolls, and oscillograms. A tabulation is also provided showing the identifying symbol for each explosion and the complementary data records obtained. Of the 42

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*The camera used for this work was a Dynafax Model 326, Serial No. 183.

experiments listed, 25 are defined as being complete, these being those experiments producing a trio of useful data records. A complete set, then, consists of:

1 - 35 mm strip;

1 - sequence of a 16 mm roll; and

1 - oscillogram.

The 35 mm strips are identified by the code number as used in the Table and have been cut into four strips, each of which bears the code number suffixed by the lower case letters a-d. Succeeding frames on these strips are 14.5 frames apart and in alternate rows, i.e., frames 1, 3, 5, etc., are in one row, and frames 2, 4, 6, etc. in the second row. The dot appearing at the lower part of each 35 mm frame is 1/4 inch in diameter. The circular image is 9-1/2 inches in overall diameter.

The 16 mm rolls are marked #1 through #7. The leader of each roll has this number recorded on it, as well as the sequence of events filmed. Each event is referred to by the height or depth at which the wire was exploded.

In the field of view of each 16 mm frame is a wave gage board which is scaled with 0.005 inch wide horizontal lines separated vertically by 0.01 inch. A reflection of a mounting screw on the wave gage board appears on the water surface and may also be used to quantitatively determine wave motion. A framing rate of 82.83 frames/second was used.

Two sensor arrangements were used in obtaining data. Runs 0131691 to 0303691 utilized Atlantic Research LC 10 series pressure transducers fixed at two arbitrary radial distances from the exploding wire fixture. Number 40 nichrome wire solder fastened to two brass rods on the vertically mounted high voltage probe was used. In the 35 mm photos, the wire end is facing downward.

Runs 0304691 to 0217691 utilized three Atlantic Research Corporation LC series pressure transducers in a vertical array radially located approximately 6 inches from center of explosion. Gage designations, vertical distances below the water surface, and sensitivities are:

LC-10-2	1 inch	0.311V/psi
LC-10-1	6 inches	0.325V/psi
LC-5M	21 inches	0.018V/psi

On those oscillograms displaying the output of the LC-5M, a pulse will be noted to appear at the beginning of the trace. This pulse is due to the high energy capacitor discharge trigger pulse and may be used to determine zero-time more accurately.

The experimental set-up is shown in figure 1.

The original pressure records, Dynafax photographs, and 16 mm Bolex film have been transmitted to URS Research, 155 Bovet Road, San Mateo, California, under separate cover. Table I lists all records available and gives identifying data for each.

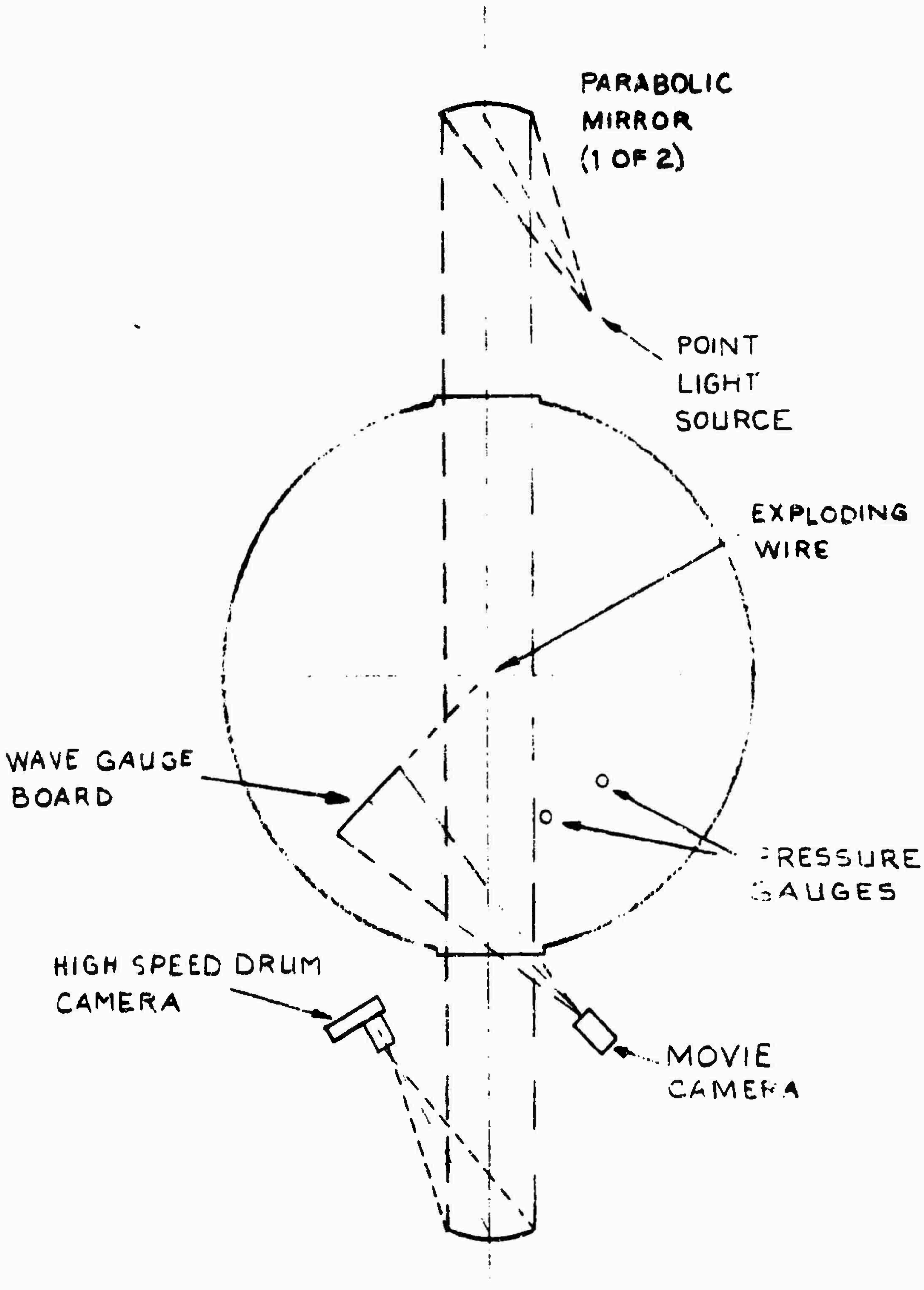

Figure 1. Experimental Configuration.

SHOCK HYDRODYNAMIC FACILITY RECORDS

No.	Distance + Ht. - Depth	Wire Length	Wire Resistance	35 mm	Pressure Record	16 mm Film Roll	Sequence	Complete	35 mm Frame Separation in μsec	
0131691* (a b c d)	-2.5 in.	3.2 mm	0.77 Ω	No	Yes	#1	1		40.1	
0131692	-2 in.	3.3 mm	0.815 Ω	Yes	Yes	#1	2		40.1	late shutter
0131693	-1½ in.	3.4 mm	0.92 Ω	Yes	Yes	#1	3		40.1	late shutter
0131694	-1 in.	3.5 mm	0.98 Ω	Yes	Yes	#1	4		40.1	
0203691	-1½ in.	3.7 mm	1.01 Ω	Yes	Yes	#1	5		40.1	early shot
0206691	-1½ in.	3.0 mm	0.94 Ω	Yes	Yes	#2	1	*	40.1	
0206693	-2 in.	2.6 mm	0.72 Ω	No	Yes	#2	2		--	self fire
0207691	-2 in.	2.6 mm	0.72 Ω	Yes	Yes	#2	3	*	40.4	use -1.97 (-5 cm) 0306691
0211691	-1½ in.	4.5 mm	0.95 Ω	Yes	Yes	#2	4	*	40.4	
0212691	-1 in.	4.0 mm	0.83 Ω	Yes	Yes	#2	5	*	40.4	
0218691	-1 in.	4.0 mm	0.80 Ω	No	No	#3	1		40.7	
0218692	0 in.	3.0 mm	0.80 Ω	Yes	Yes	#3	2	*	40.7	
0218693	-0.04 in.	2.4 mm	0.69 Ω	Yes	Yes	#3	3	*	40.5	
0219691	-0.05 in.	3.5 mm	0.8 Ω	Yes	Yes	#3	4	*	40.6	
0219692	-0.06 in.	3.5 mm	0.8 Ω	No	Yes	#3	5		40.5	capping shutter failed to open
0224691	-0.06 in.	3.0 mm	0.84 Ω	Yes	Yes	#4	1	*	40.5	
0225691	-0.09 in.	2.8 mm	0.78 Ω	Yes	Yes	--	-		40.8	16 mm camera not actuated

*a = month c = year
b = day d = shot number

SHOCK HYDRODYNAMIC FACILITY RECORDS

No.	Distance + Ht. - Depth	Wire Length	Wire Resistance	35 mm	Pressure Record	16 mm Film Roll	Sequence	Complete	35 mm Frame Separation in μsec	
0227691	-0.09 in.	4.5 mm	1.18 Ω	Yes	Yes	#4	2	*	40.5	
0228691	-0.09 in.	2.5 mm	0.86 Ω	Yes	Yes	#4	3	*	40.7	
0228692	-0.1 in.	3.5 mm	0.96 Ω	Yes	Yes	#4	4	*	40.5	
0303691	0	4.5 mm	1.17 Ω	Yes	Yes	#4	5	*	40.5	
0304691	-3.44 in. (8.75 cm)	2.5 mm	0.84 Ω	Yes	Yes	#5	1	*	40.6	
0305691	-1.97 in. (5 cm)	4 mm	0.99 Ω	Yes	Yes	--	-		40.5	16 mm camera not actuated
0305692	-1.97 in. (5 cm)	3.8 mm	1.08 Ω	Yes	No	#5	2		40.5	oscilloscope triggered early
0306691	-1.97 in. (5 cm)	2.7 mm	0.8 Ω	Yes	Yes	#5	3	*	40.5	
0307691	-0.788 in. (2 cm)	2.3 mm	0.72 Ω	Yes	Yes	#5	4	*	40.6	
0307692	-0.394 in. (1 cm)	2.8 mm	0.[illegible]1 Ω	Yes	Yes	#5	5	*	40.5	
0310691	-0.295 in. (0.75 cm)	3.6 mm	1.12 Ω	Yes	Yes	#6	1	*	40.5	
0310692	-0.197 in. (0.5 cm)	3.3 mm	1.04 Ω	Yes	Yes	#6	2	*	40.6	
0311691	-0.0984 in. (0.25 cm)	3 mm	0.96 Ω	Yes	Yes	#6	3	*	40.6	
0311692	-3.94 in. (10 cm)	3 mm	0.95 Ω	Yes	Yes	#6	4	*	40.5	
0312691	0	3.3 mm	0.97 Ω	Yes	Yes	#6	5	*	40.7	
0312692	+0.197 in. (0.5 cm)	3.9 mm	1.04 Ω	Yes	Yes	#7	1	*	40.6	
0313691	+0.394 in. (1 cm)	2.8 mm	0.9 Ω	Yes	No	#7	2		40.6	Polaroid camera failed to develop film

SHOCK HYDRODYNAMIC FACILITY RECORDS

No.	Distance + Ht. - Depth	Wire Length	Wire Resistance	35 mm	Pressure Record	16 mm Film Roll	Sequence	Complete	35 mm Frame Separation in μsec
0313692	+0.394 in. (1 cm)	4.1 mm	1.19 Ω	Yes	Yes	#7	3	*	40.7
0313693	+0.787 in. (2 cm)	4 mm	1.11 Ω	Yes	Yes	#7	4	*	40.8
0313694	+1.576 in. (4 cm)	3.8 mm	1.03 Ω	Yes	Yes	#7	5	*	40.8
0314691	+2.36 in. (6 cm)	3.0 mm	0.74 Ω	Yes	Yes	No			40.4
0314692	+3.148 in. (8 cm)	3.2 mm	0.80 Ω	Yes	Yes	No			50.1
0314693	+3.94 in. (10 cm)	4.0 mm	0.935 Ω	Yes	Yes	No			48.0
0317691	-2 in.	--	0.9 Ω	Yes	Yes	No			40.7

capacitor voltage: 15 kilovolts

capacitance: 15 mfd.

APPENDIX A

SHOCK HYDRODYNAMIC LABORATORY FACILITY

SHOCK HYDRODYNAMIC LABORATORY FACILITY

I. INTRODU__ION

A facility for the investigation of underwater explosions on a laboratory scale has been designed and constructed. Its principal application has been to investigate the phenomena of bulk cavitation and the effects of underwater explosions on ships and structures. Although the system was designed to investigate explosion phenomena, it would be equally well suited for the investigation of sound absorbers and radiators. The facility consists of a cylindrical tank approximately 6 feet in diameter and 6 feet high equipped with portholes through which the underwater explosions may be observed by means of a Schlieren optical system employing both single frame and high speed photographic techniques. Simultaneously, pressure gages monitor the progress of shockwaves and these outputs are recorded with oscilloscopes using Polaroid cameras. In order to produce thermal, non-chemical, explosions an exploding bridge wire system has been installed. A system for timing and coordinating the sequence of events is also included. The hydrodynamic test facility is shown in Figure 1.

Figure 2 is an example of the type of photographs which can be obtained with the Schlieren optical system. In this photograph, one can see the surface of the water, which appears as a dark horizontal line across the upper part of the porthole. The exploding wire bridge is visible at the bottom of the porthole. Along the upper left edge (shown at an angle of about 30°) is a compliant surface simulating a ship's hull. The round dot just above the surface of the water is a marker on the optical glass porthole to be used as a reference point. The shock front from the exploding wire can be seen near the surface of the water at the upper right hand of the porthole. Reflected rarefaction waves can be seen propagating down from the water surface and away from the compliant model. In the neighborhood of the exploding wire, a steam globe can also be seen. This photograph is an unretouched reproduction of the original 4 x 5 Polaroid color print.

II. HYDRODYNAMIC TEST VESSEL

The hydrodynamic test vessel consists of a near-cylindrical tank 6 feet in diameter and 6 feet high, as shown in Figure 1. The tank has 9 portholes, two of which are 12 inches in diameter and equipped with optical flat glass windows. Five of the portholes are 6 inches in diameter and are equipped with plexiglass windows through which instrumentation cables are fed. The remaining portholes are used in conjunction with a device for positioning the exploding wire fixture from the exterior of the tank. A 24-inch manhole with cover is provided at the top of the tank for access. The interior of the tank is coated with an anechoic lining so that the explosions in the tank simulate a free field test condition. The entire tank can be sealed off and fully evacuated or alternatively pressurized to 54 psi. The plumbing system is provided with a filter through which

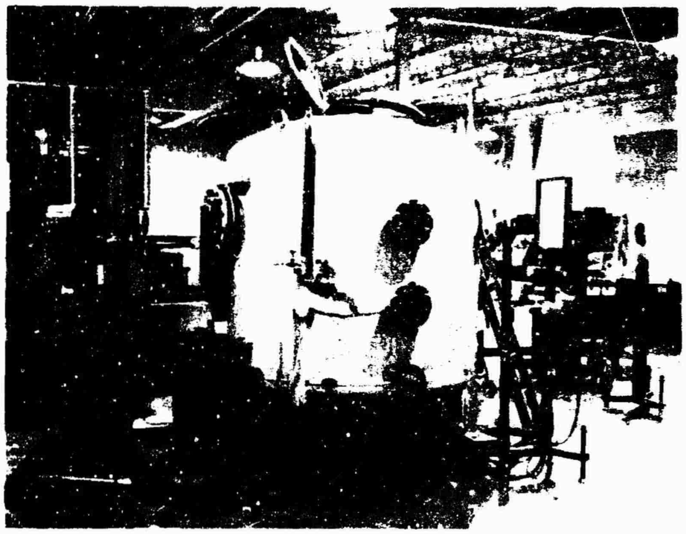

Figure 1. Shock hydrodynamic laboratory facility showing test chamber and Schlieren optical system.

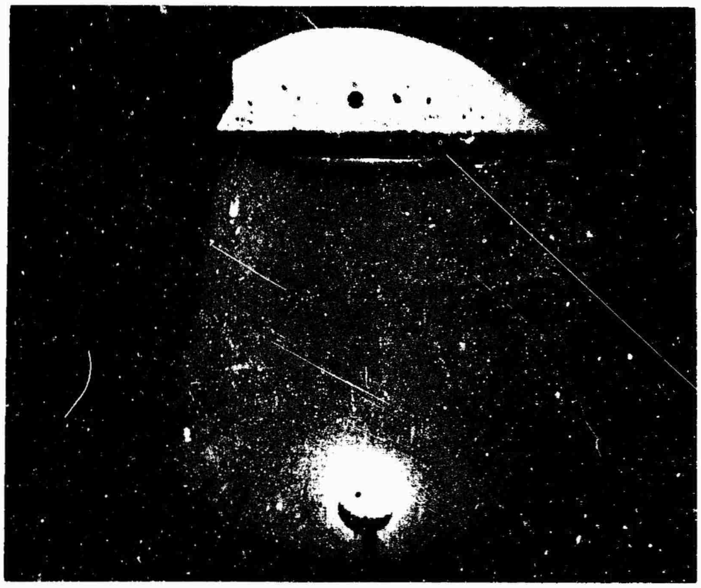

Figure 2. Photograph of an underwater explosion showing shock front and rarefaction front from a water-air and water compliant surface interface. Steam bubble from explosion is visible at bottom center.

water can be continuously circulated to maintain its optical qualities.

III. ENERGY DISCHARGE SYSTEM

An exploding wire fixture is mounted in the tank connected via coaxial cable to a 20 kilovolt, 15 microfarad, 5 nanohenry capacitor. The ringing frequency of the electrical system is about 2 megacycles, and because of the rapid energy dump, the shape of the pressure-versus-time disturbance in the water generated by the explosion is determined primarily by characteristics of the water. A high voltage switch initiates the explosion. Either mechanical or electronic triggering can be used. The switch discharges over a range from 2000 volts or 30 joules up to 20 kilovolts or 3000 joules. Should the need arise, additional energy storage capacitors are available in the laboratory to increase the energy of the system to 9500 joules. A typical exploding bridge wire used in the investigation of bulk cavitation from underwater explosions is an AWG #40 nichrome wire two millimeters in length; it very closely approximates a point source explosion for most applications. The exploding wire fixture can be moved across the diameter of the vessel from the exterior of the tank, thereby providing a means for changing the location of the explosion in the tank relative to the position of the transducers and models.

IV. SCHLIEREN SYSTEM

A 10-inch Schlieren system is incorporated in this facility and makes use of the 12-inch optical flat portholes which are on diametrically opposite sides of the tank. The Schlieren system consists of two parabolic first surface mirrors of 80-inch focal length. Each mirror is correct to within one-quarter wave length of mercury light. Three types of point light sources are available: 1) a steady point light source using a high pressure mercury arc lamp; 2) a millisecond xenon flash lamp source; and 3) a 1 microsecond air gap spark light source. The mercury lamp is used where phenomena of a relatively slow nature are to be studied, or for purposes of positioning models and transducers. The xenon lamp is most useful with high speed cinephotography where a sequence of events takes place over a period of 1 millisecond or less. The air gap spark is most useful where extremely high speed events are to be monitored with the ultra high resolution provided by single frame fixed film photography. The cameras available with the Schlieren system consist of a single frame 4 x 5 camera and a high speed drum camera capable of taking a total of 224 frames per event at a shutter speed of 1 microsecond with a frame separation of 40 microseconds. The camera can also be run at lower framing rates with consequently lower shutter speeds and longer frame separations.

V. SEQUENCING EVENTS

In order to establish a sequence of events in an experiment and to correlate oscilloscope and photographic records, a number of timing circuits are required. All units can be actuated with electrical pulses. A digital time delay generator is available which allows one to delay an input pulse from a tenth of a microsecond to one second in increments of one tenth microsecond. A time delay generator is available on the spark light source and on the electronic explosion triggering circuit. Time delay units are also available in the Tektronix 545 oscilloscope and Tektronix 549 storage oscilloscope. A 1 megacycle timer counter is used for accurately establishing framing rates on the drum camera.

VI. PRESSURE TRANSDUCERS

Three pressure transducers of the piezoelectric type are in use in the hydrodynamic test vessel. These transducers are mounted on positioners and can be located at any point on the interior of the vessel. Two Atlantic Research Type LC-10 hydrophones are available having a sensitivity of 2300 micromicrocoulombs per psi with an open circuit voltage sensitivity of 0.3 volts per psi. The transucer has a useful pressure range of 0 to 2000 psi. The LC-10 is cylindrical in shape, having a diameter of 0.38 inches x 1.13 inches in length. Two of these gages are available in the system. An Atlantic Research Type LC-5M gage is also available. This gage has a sensitivity of 11.3 micromicrocoulombs per psi and a voltage sensitivity of 0.018 volts per psi open circuit. The LC-5M has a useful pressure range of 0 to 50 psi and the gage is cylindrical in shape, having a diameter of 0.1 inch and a length of 0.5 inch.

VII. SCREENED ROOM

All of the instrumentation in the test facility is enclosed in a room covered with copper screening so as to protect it from the electromagnetic radiation which results when the capacitor bank is discharged across the exploding wire bridge. The screened room is 10 feet long, 6 feet wide, and 8½ feet high.

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