The velocity (and therefore the pressure) of the shock wave at the air surface was varied either by varying *h* or the detonation pressure of the shock-generator charge.

Figure 2 presents a typical streak camera trace showing the attenuating shock wave, the release wave, and the free surface "wave." Note that in this case conditions were such that the free surface velocity was constant over a relatively long distance, thus assuring its accurate evaluation. Both the shock and the free surface velocities were obtained from the slopes of the traces at the interface through application of the proper magnification factor and camera writing speed.

While some shock-parameter determinations for Lucite were made in the same manner as those for water, i.e., by simultaneous measurements of shock velocity at the free surface and the free surface velocity, for convenience most measurements for Lucite were made by observing the transmission from Lucite into water, measuring the final velocity of the shock in Lucite and the initial velocity of the shock in water by means of a streak camera (utilizing a silhouette back-light bomb to render the shocks visible), and applying the Goranson shock transmission equations to calculate the shock pressure in Lucite immediately inside the Lucite-water interface. The two methods gave consistent results. The strength of the shock in Lucite at the Lucite-water interface was varied by varying the thickness of Lucite between the charge and the water using a constant shock generator system. The diameter of the Lucite was in all cases sufficiently large to shield the detonation products from the region where the motion of the shock wave was observed.

(b) Detonation Pressure Determinations

Figure 3 illustrates the application of the aquarium technique for measuring the initial velocity of the shock (and pressure) in water transmitted directly from the detonating explosive. As in the previous cases the assembly was aligned such that the streak camera observations were made along the charge axis, the height and tilt of the assembly being such that the bottom face of the charge in this case was coincident with (and parallel) to the optical axis of the camera. The streak camera viewed the charge upward through a periscope in which the line of sight was reflected to a horizontal direction by a front surface mirror. The camera was mounted on a turntable and three supporting casters, permitting rotation of the camera about its optic axis. Thus the slit view of the camera could conveniently be adjusted to either the horizontal or vertical direction or to any position between them simply by rotation of the turntable, thus easily permitting proper alignment.

The cast charges were detonated with the bare end immersed in the aquarium. In cases where there existed the possibility of absorption of water or solution of some of the charge components the charges were sprayed with Krylon for waterproofing. Charges made up from granular or loose material were vibrator-packed in thin-walled (approximately 0.16 cm thick) cardboard tubes and waterproofed with a 3-mil thick sheet of Polyethylene.

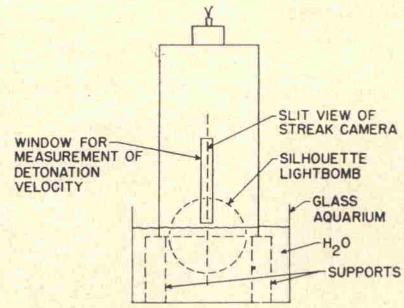

FIG. 3. Aquarium assembly for measurement of velocity along the axis (and pressure) of the transmitted shock in water from a detonation wave.

The explosives included in this study were pelleted TNT of standard Tyler mesh sizes $-4+6$, $-6+8$ and $-8+10$; granular $-48+65$ mesh TNT; cast 65/35 baratol; cast 50/50 amatol; granular 50/50 AN/TNT; granular RDX; granular RDX-salt; HBX−1; and a classified explosive X. Results obtained in this investigation for 50/50 cast pentolite, composition B, TNT, and tetryl were summarized previously.[13] Similar measurements have been made by Bauer and Cook[14] for commercial "blasting agents", including 94/6 ammonium nitrate/fuel oil, and the "slurry" explosives.[15] The blasting agents are of interest because their reaction zones are among the longest possible in detonating explosives since they remain nonideal even in very large diameter charges.

Except for a study with composition B and the classified explosive X where charge length was varied to observe transient effects of pressure against charge length, the charges were at least four charge diameters in length insuring a constant velocity and steady detonation head before the detonation front reached the end of the charge. In the case of the pelleted TNT, charge diameter was varied from the critical diameter to a diameter sufficiently large for the detonation to be ideal, thus covering the entire nonideal region. An ideal explosive is defined as one which detonates at its theoretical maximum or hydrodynamic velocity, i.e., $D=D^*$, and a nonideal one has a lower velocity, $D<D^*$ (reference 16, Chapter 3).

RESULTS

(a) Shock Parameter Determinations

In Fig. 4 are plotted the experimental results for water with pressure as the ordinate and shock velocity as the abscissa. Figure 5 presents a similar plot in which the low pressure part of the curve of Fig. 4 has been

[14] A. Bauer and M. A. Cook, Can. Min. and Met. Bulletin, January 1961; Trans. Can. Inst. Mining Met. **61**, 62 (1961).
[15] M. A. Cook and H. E. Farnam, U. S. Patent No. 2,930,685, March 29, 1960.
[16] M. A. Cook, *The Science of High Explosives* (Reinhold Publishing Corporation, New York, 1958).

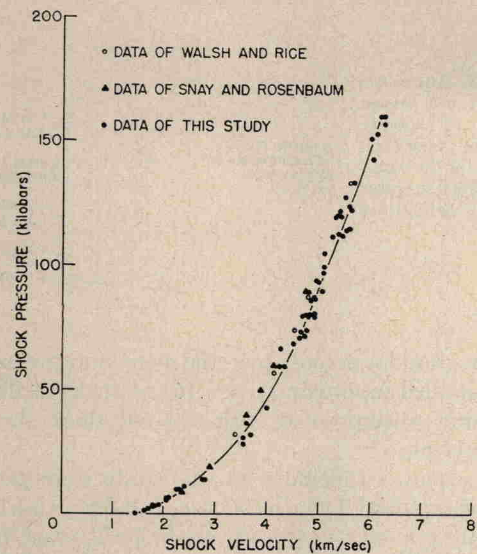

FIG. 4. Experimental shock velocity vs pressure data for water.

expanded to a larger scale. On both figures the smooth curve through the points represents an approximate best fit as "drawn by eye" to the data. Velocity-pressure values from this curve of best fit are given in Table I. Results of Snay and Rosenbaum,[8] and Rice and Walsh[11] also are plotted in Fig. 4 for comparison. Note that Snay and Rosenbaum's results agree with the results of the present study at pressures up to about 10 kbars, and from thence there is a tendency for their data to show greater compressibility. The results of Rice and Walsh fall about midway between those of Snay and Rosenbaum and this study. The differences in compression between the results of Rice and Walsh, which should be more comprehensive than Snay and Rosenbaum's data, and the data of this study were 3.2% for a shock velocity in water of 3.5 km/sec and 2.8% for a shock velocity of 5.5 km/sec, corresponding to pressures to 31 and 125 kbars, respectively. The disagreement in measured pressures at these two velocities amounted to 9.7% at the lower velocity and 4.2% at the higher one.

The agreement between the shock parameter data for water obtained by Rice and Walsh and the data of this investigation is reasonably good. One may conclude therefore that the Rankine–Hugoniot curves for water are now known with sufficient accuracy that water may reliably be used as the transmission medium for the measurement of pressures in shock and detonation waves. The agreement also demonstrates the general reliability of the aquarium technique.

The essential shock-parameter results for Lucite are portrayed graphically in Fig. 6. No differentiation was made as to which of the two methods mentioned above was used to obtain a given $p(V)$ point in this case because the results of the two methods were indistinguishable within the limits of experimental error. The smoothed results representing the most reliable values are given in Table II. The curve of Fig. 6 was not extended to the sonic velocity because there is some uncertainty in available values of the sonic velocity for Lucite.

TABLE I. Smoothed shock parameter results for water (20°±5°C).

Shock velocity (m/sec)	Shock pressure (kilobars)	Shock velocity (m/sec)	Shock pressure (kilobars)
1450	Sonic	3450	30.0
1620	1.0	3820	40.0
1740	2.0	4120	50.0
1840	3.0	4350	60.0
1940	4.0	4570	70.0
2020	5.0	4780	80.0
2100	6.0	4980	90.0
2170	7.0	5170	100.0
2240	8.0	5350	110.0
2310	9.0	5530	120.0
2380	10.0	5700	130.0
2680	15.0	5870	140.0
2980	20.0	6040	150.0
		6200	160.0

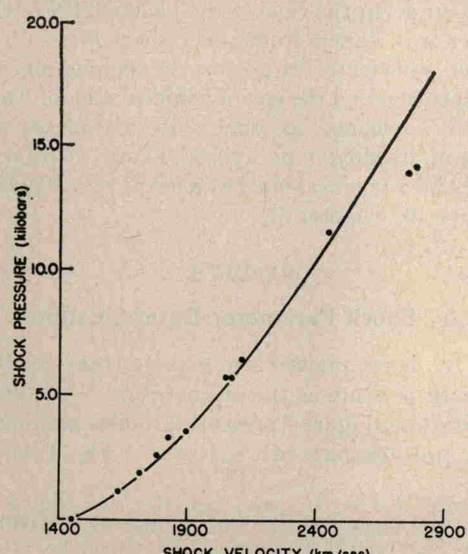

FIG. 5. Experimental shock velocity vs pressure data for water (low pressures).

(b) Detonation Pressure Measurements

Results obtained for ideal explosives (i.e., where $D=D^*$) in which the charge length was maintained at approximately four diameters to assure that the detonation wave was steady are listed in Table III. All the charges in this case may be considered to be effectively unconfined, the cast charges being bare and the loose charges being contained in only 0.16-cm-thick pasteboard tubing. In Table III are listed the type explosive, the charge density, the charge diameter, the measured detonation velocity, the initial pressure of the shock front in water p_t as determined from the measured initial shock velocity V_t in the water and the calibration