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EXPLOSIVE PERFORMANCE

SANL 712-004

J. K. Rigdon

July, August, September 1969

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This project is for experimentally determining the detonation pressure, etc., of explosives.

ABSTRACT

The detonation pressure of several sizes of PBX 9404 charges was determined using the aquarium technique. Pressure data (from the larger shots) were generally in good agreement with the quoted values for PBX 9404 in these geometries. The small unconfined charge pressure values were consistently about 6% below the accepted 375 kbar value. Experimental shock velocity and computed pressure data are reported.

DISCUSSION

We have been evaluating a method commonly referred to as the "aquarium technique"^{1,2} to measure the peak output pressure of PBX 9404. The relative simplicity and low cost of the aquarium test make it appealing as an alternate method of acquiring pressure data to supplement that generated by other methods, e.g., the LRL magnesium plate³, and the detonation electric effect.

When a strong shock propagates in water through which a light source is viewed by a streak camera, a continuous space-time history of the shock's progress can be recorded as the transmissivity of the water is greatly reduced at the shock front. Taking advantage of the hydrodynamic and translucent properties of the water in this manner permits a quantitative measurement of the initial transmitted shock velocity from which the initial shock strength can be computed.

The aquarium technique has been used for many years; however, the overall precision of the pressure data was typically considered to be no better than about $\pm 10\%$. Methods of treating the R-t data to best determine "jump-off" velocities, and the variations in water Hugoniot equations-of-state have given rise to the impression that the technique is largely an approximate method. We have evaluated the technique using what is considered to be the best equation-of-state for water⁴ and by applying a variety of analysis and data reduction schemes. Several aquarium shot experiments (beginning with PBX 9404, whose detonation pressure has been thoroughly examined) were planned and completed. The experiments were designed to measure the detonation

¹M. A. Cook, R. T. Keyes, & W. O. Ursenbach, *J. Appl. Phys.* 33, 3413 (1962).

²N. L. Coleburn, *NOLTR* 64-58 (1964).

³J. C. Cast, H. C. Hornig, J. W. Kury, *UCLRL Report No. 50645*, (1969).

⁴M. H. Rice & J. M. Walsh, *J. Chem. Phys.* 26 824, (1957).

pressure of several sizes of right circular cylinder charges carefully fabricated in diameters of 0.5, 1.5, and 3.0 inches with lengths of 0.5, 1.0, 2.0, 4.0, and 4.5 inches.

Commercial glass-walled aquariums (8 x 8 x 14 inches) were used. Each was equipped with a bridgewire alignment and condenser lens support fixture fabricated from Plexiglas. Backlighting was accomplished with bridgewires exploded in an atmosphere of liquid TF Freon. (The Freon has the effect of concentrating the EBW light as well as extending the useful life of the light source.) In some cases where both framing camera and streak camera coverage were desired, the aquariums were equipped with two backlighting systems such as is shown in Fig. 1. All shots, except the 0.5-inch diameter, were fired using plane wave lenses to maximize the "one-dimensionality" and to avoid overdriving the test charge. (Baratol PWL's were used; output pressure $\sim$ 140 kbars.)

The shadowgraphic or backlighted streak records were generally of very good quality. A sketch of the experimental setup as arranged on the test site firing pad is shown in Fig. 2. Records representative of those obtained in the series are shown in Fig. 3.

Analysis of the camera records, which were of approximately 1:1 magnification, was accomplished using a Grant comparator reading the time (t) value for successive 25 μ increments in the space direction, for a total of 2 millimeters. The process was then repeated in 250 μ increments for the entire trace or usually about 35 to 40 mm.

Fig. 1
Typical Aquarium Test Fixture

Fig. 2

Fig. 3

Two Typical Aquarium Shot Streak Camera Records

Fig. 3A shows two opposing 1/2-inch dia. PBX 9404 charges

Fig. 3B shows one 3-inch dia. PBX 9404 charges

Writing rate 5.0 mm/ μ sec

Problems were encountered in determining the initial transmitted shock velocity on some of the records which exhibited a "double trace" effect. This was attributed to improper alignment, i.e., non-perpendicularity of the charge axis to the camera axis. It appears that in such circumstances the camera views a moving "surface" instead of a true profile of the plane shock wave. Analysis of either the "first" or "second" visible trace will lead to anomalous results and therefore the shot is of little value for determining jump-off velocity by the usual method.

A small CW gas laser alignment technique and a parallel light source method appeared to have merit in aligning the test HE; however, neither completely eliminated the problem. The problem is also increased with diameter of charge. Tilt in the PWL's could cause similar effects, however, in testing several randomly selected P-40 PWL's, a degree of tilt large enough to perturb the experiments was not detected.

Treatment of the R-t data was approached several ways. First, an attempt was made to use 1 through 10th degree polynomial regression fits to the entire trace. In so doing, the first derivative of the best fit, $R = f(t)$ equation, could be evaluated at $t = 0$ to determine U_{s_t} , or the initial transmitted shock velocity. This approach was discarded since there appeared to be no clear and definite basis on which to select the "best fit."

Photographic enlargements ($\sim 40X$) of the streak camera negative were made in order to graphically determine the slope of the initial portion of the trace. Although the pressure values determined in this manner appeared to be in good agreement.

with the quoted detonation pressure, the results were somewhat sensitive to the experience of the analyst.

The third approach, and the most used, was to do a linear least-square fit to about the first 2 mm of R-t data. This method works particularly well on large shots where the attenuation rate of the shock in the water is low.

Since some small charges were included in the series, a better method of treating them was also required since rapid attenuation (trace curvature) occurs with these shots. Two models involving exponential and arc-tangent functions were tested. They were of the general form:

$$R = A_1 + A_2 t + A_3 e^{A_4 t}$$

$$R = A_3 t + 4A_1 A_2 \tan^{-1} (t/2A_1)$$

where the A's are constants determined by the computer after force-fitting the curve to three data points (first, middle, and last) followed by subsequent refinement through successive iterations until convergence to particular values is attained.

Each of these models fit some of the data sets very well, but would not fit all of them. Since the arc-tangent model must pass through the origin, a curve fitted to a normalized R-t data set that does not exactly intersect (0,0) would not yield the best results. In those cases, the other model was usually the better fit.

The results presented were finally determined, however, by linear best fits to 2 mm; until further work could be done on the alternate approaches.

Once the best value for the transmitted shock velocity U_t , is determined, it is combined with the Hogoniot equation-of-state for water to compute the associated particle velocity, U_{P_t} . The Rice-Walsh water equation-of-state, $(U_s - 1.483 = 25.306 \log_{10} (1 + U_p / 5.190))$, was used; however, the given form was simplified to a quadratic equation by a least-squares fit to their (Rice-Walsh) U_s , U_p , data. The resulting equation was:

$$U_p = -.607 + .372U_s + .0283U_s^2$$

The measured shock velocity and computed particle velocity are then entered into the usual conservation relation,

$$P_t \sim 10 \rho_o U_{S_t} U_{P_t},$$

to compute the transmitted pressure.

where: P_t = transmitted pressure (kbars)
 U_{S_t} = initial transmitted shock velocity (mm/ μ sec)
 U_{P_t} = initial transmitted particle velocity (mm/ μ sec)
 ρ_o = initial water density (g/cc)

The shock conditions in the water were then used, in conjunction with the impedance mismatch equation, to compute the incident or HE detonation pressure. The impedance equation used was of the form,

$$P_{CJ} = P_t \left[\frac{\rho_{o_t} U_{S_t} + \rho_{HE}^D}{2\rho_{o_t} U_{S_t}} \right]$$

where:

P_{CJ} = detonation pressure of the test HE (kbar)

ρ_{HE} = initial density of the explosive (g/cc)

D = test HE detonation velocity (mm/ μ sec) (computed from

$$D = 3.6 + 2.176 \rho \text{ for PBX 9404})$$

The results of the PBX 9404 series of experiments are given in Table I. The small diameter charges appear to yield an average pressure of 354 kbars, roughly 6% below the 375 kbar obtained from magnesium plate free surface velocity measurements by LRL and at Pantex. This is probably due to the divergence and edge losses that occur. The 1.5-inch and 3.0-inch diameter shots yielded average pressures of about 368 kbars and are in closer agreement—2%—with the quoted 375 kbars, and very close to the 365 kbars reported by LASL,⁵ using aluminum plate free surface velocity measurement and similar (slightly larger) geometry. All of the values quoted, with the exception of one shot (0.5-inch diameter 1-inch long) were calculated from the linear fit to one or two millimeters of trace motion.

⁵C. L. Mader, LA-3837-M5, (1968).

Table I

Aquarium Test Data

*(D = Detonation Velocity Computed from $D = 3.6 \rho + 2.76$)

<u>Shot No.</u>	<u>Charge Size</u> <u>Dia. (in)</u>	<u>Length (in)</u>	<u>Density (g/cc)</u>	<u>D*</u> <u>(mm/μsec)</u>	<u>U_t</u> <u>(mm/μsec)</u>	<u>P_t</u> <u>(kbars)</u>	<u>P_{CJ}</u> <u>(kbars)</u>	<u>P_{CJ}</u> <u>Average</u>
109-5-27-1**	0.5	1.0	1.8487	8.831	6.69	211	362	
109-10-7-1	0.5	1.0	1.8487	8.831	6.56	200	349	
109-5-27-2	0.5	2.0	1.8483	8.831	6.47	193	340	353
109-10-6-1A	0.5	4.0	1.8492	8.831	6.65	207	358	
109-10-6-1B	0.5	4.0	1.8492	8.831	6.63	206	357	
109-4-9-2	1.5	1.0	1.8485	8.831	6.73	214	365	
109-4-10-1	1.5	2.0	1.8439	8.814	6.80	220	374	368
109-4-9-1	1.5	4.0	1.8440	8.814	6.80	214	363	
109-5-5-2	1.5	4.0	1.8444	8.816	6.76	216	368	
109-8-5-2	3.0	0.5	1.8455	8.820	6.83	222	376	
217-7-21-1	3.0	0.5	1.8447	8.817	6.89	227	381	
109-10-17-1	3.0	1.0	1.8439	8.814	6.71	212	363	
109-10-17-2	3.0	1.0	1.8432	8.814	6.61	204	353	
109-9-12-1	3.0	2.0	1.8410	8.804	6.67	209	359	367
109-10-3-1	3.0	2.0	1.8446	8.817	6.71	212	363	
109-8-5-1	3.0	4.5	1.8442	8.815	6.81	226	376	
219-7-21-2	3.0	4.5	1.8442	8.815	6.75	216	368	

**Data fit by graphical approach.

COMMENTS, CONCLUSIONS, AND RESULTS

The half-inch diameter shots are apparently affected by lateral rarefactions, edge effects or divergence to the extent that the output pressure is somewhat low. The larger 1.5 and 3.0-inch diameter shots generally do yield detonation pressures in good agreement with other data: within 2% of the LRL method, and in very good agreement with LASL's method.

A more repeatable system should be devised to eliminate the problems associated with alignment of the larger shots. The two or three millimeters of linear velocity exhibited by the large shots make final data reduction considerably more straightforward; however, the various curve fit routines tested appeared very promising and indicate that there is probably some optimum technique for treating most R-t aquarium data.

The data do not show pressure change as a function of charge length, in the geometries tested.

There may be considerable additional information to be gained from analysis and comparison of the shock attenuation further into the water on the aquarium tests. Examination of this data is currently being done.

It is believed that further refinement of experimental and analytical techniques can significantly reduce the scatter in aquarium technique data.