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AN AQUARIUM TEST AS AN EXPLOSIVE PERFORMANCE MEASURE

by

G. McIntosh

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Approved by/approuvé par

P. Twardawa
A/Director/Directeur

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Date

ABSTRACT

An aquarium test was implemented to measure the performance of explosive formulations. This test consists of detonating a bare cylinder of explosive in a water bath and recording the radial positions (perpendicular to the axis of the cylinder) of the shock wave in the water and water-explosive interface as a function of time at a given distance along the cylinder. At later times (several microseconds after the detonation front has passed), the shock radii generated by three different explosives, Composition B, CX-84A and CHM, are compared. A larger radius is interpreted as resulting from a more powerful explosive. The conclusion is that Composition B is more powerful than CX-84A which in turn is more powerful than CHM. Computer simulations using the computer programs WONDY V and DYNA2D were also performed to support this conclusion.

RÉSUMÉ

On a implanté un test d'aquarium pour mesurer la performance d'un explosif. Ce test consiste à exploser un cylindre d'explosif nu dans un bain d'eau et à enregistrer les positions (perpendiculaires à l'axe du cylindre) de l'onde de choc dans l'eau et de l'interface entre l'eau et l'explosif en fonction du temps à une distance donnée le long du cylindre. Les rayons de choc générés par les trois explosifs (Composition B, CX-84A et CHM) sont comparés plusieurs microsecondes après le passage de l'onde de détonation. On considère que plus le rayon est grand, plus l'explosif est puissant. Selon ce critère, on conclut que l'explosif Composition B est plus puissant que CX-84A et que l'explosif CX-84A est plus puissant que CHM. Des simulations par ordinateur utilisant les programmes WONDY V et DYNA2D confirment cette conclusion.

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EXECUTIVE SUMMARY

The Canadian Department of National Defence should replace the explosives it currently uses with ones which are less sensitive to accidental ignition but which are just as powerful for operational purposes. Plastic-bonded explosives are being studied for this purpose.

To say that an explosive is as powerful, many tests must be done. One way the performance of an explosive can be measured is by studying its effects on a surrounding medium, such as a metal casing or, as in the present case, water. The sudden expansion of the detonation product gases accelerates and (in the case of a solid) shatters the surrounding medium. This effect is the basis of all practical uses of explosives. Thus, the acceleration caused by an explosion can be used as a measure of how useful (powerful) a given explosive will be. The aquarium test gives some idea of the relative performances of Composition B and two DREV-developed plastic-bonded explosives, CX-84A (RDX-based) and CHM (an early HMX-based formulation), and by measuring the acceleration of the water around a detonating explosive. This work found that CX-84A and CHM are less powerful which agrees with previous results found using other methods. This means that the Canadian Forces may have to accept a (small) reduction in performance for a (large) reduction in sensitivity if it decides to use these present explosives. In the meantime, the present test is still simpler and faster to carry out than the other methods, thereby enabling rapid feedback to the formulators and ultimately, to a quicker introduction of improved explosives into the CF inventory.

The results of this work will be shared with other NATO and TTCP countries through NIMIC and various WAGs and KTAs.

LIST OF SYMBOLS

a	parameter for linear shock Hugoniot relation
A	JWL equation of state parameter
b	parameter for linear shock Hugoniot relation
B	JWL equation of state parameter
D	detonation velocity
E	JWL equation of state internal energy
P, p	pressure
r,r	radius
$R_{1,2}$	JWL equation of state parameters
t,t	time
u, U	velocity (may be subscripted)
V	JWL equation of state specific Volume
v	volume or velocity (according to context)
z	distance along cylinder axis
ρ	density (may be subscripted)
$\omega_{1,2}$	parameters for JWL equation of state

Subscripts

i	time step
o	at original (ambient) conditions
p	particle
s	shock

This list is not exhaustive but includes most of the symbols used in this document.

1.0 INTRODUCTION

As new insensitive explosives are formulated, it it important to characterize them in terms of performance and sensitivity. These are two distinct types of tests, both important since the long term goal is to create new explosives which are less sensitive to accidental ignition yet (hopefully) with little or no sacrifice of performance. For preliminary screening, it is highly desirable to have methods which provide rapid yet accurate feedback to the formulators. The present report describes a performance test called the aquarium test which, in addition to being rapid to perform and accurate, is also inexpensive to carry out.

The work described in this report was performed at DREV between May 1992 and July 1993 under PSC 21A03, Detonation Processes.

2.0 BACKGROUND AND METHODOLOGY

Explosives must be characterized in terms of performance, but what is meant exactly by "performance"? Quite simply, performance is the ability of an explosive to do work on its surroundings. Work for an explosive can be defined as $\int p\, dv$ (p is pressure, v is volume) and can manifest itself as the velocity imparted to the material around the explosive. Most useful military explosives are used to fracture and accelerate metal (shell casings, etc.). The ideal test would study the velocity history of a metal around a detonating explosive and this is indeed done in certain tests such as the copper cylinder test. However, that test requires a precisely machined (i.e. expensive) copper cylinder. In the aquarium test, the surrounding medium is a liquid (usually water). Water is, of course, transparent and this is a distinct advantage for it allows the measurement of two velocities – the velocity of the accelerated water (particle velocity) and the velocity of a shock generated in the water.

Once these two velocities are measured, they can be used for comparisons between explosives. A simple comparison of velocities will give some idea of the relative performance (for the same size and geometry of explosives). A higher velocity will naturally be interpreted as a result of a better performance.

2.1 Experiments

The experimental results were obtained as follows. A cylinder of explosive (2 inches in diameter for Composition B, 1.75 inches for CX-84A and CHM and 6 inches long) was mounted horizontally in 1/4"-thick plexiglas aquarium cube 8" x 8" x 8". The center of each cylinder was 5" from the bottom of the aquarium and at the horizontal midpoint of the cube's side. The cylinder was held in place by RTV silicone glue and an O-ring. The cylinder projected 6" perpendicularly into the water from the wall and its end was supported by a plexiglas support. The aquarium was filled with pure water so that the water covered the explosive to at least 1 inch depth. The cylinder was ignited by a RP-83 detonator, a tetryl booster (5/8" diameter, 11/16" long), a RDX/wax booster (1.25" diameter, 5/8" long) and a plane wave generator (2" diameter). The slit of the streak camera was imaged perpendicular to the axis of the cylinder halfway along the bottom and covered a distance of 4" of which 3/8" (for CX-84A and CHM) or 1/2" (for Composition B) was on the explosive. The streak speed was generally 4 mm/μs with a 100 μm slit. The aquarium was backlit by an argon flash bomb. The experimental setup is shown in Figure 1. Two tests were performed for Composition B, four for CX-84A and five for an early CHM mixture (mixture numbers CHM-082 and CHM-084-T). The streak records were digitized using an optical comparator and entered into a computer for further analysis.

Different diameters were used for Composition B and the plastic-bonded explosives (PBX) because they were cast in different sizes, the Composition B as a 2.25" cylinder and the PBXs as 2.00" cylinders. These diameters were machined down to 2.00" and 1.75", respectively.

2.2 Simulations

Explosives can be characterized by what is known as an equation of state (EOS) which is basically the relationship between the volume of the explosive gases and the pressure in this volume. One form which is particularly useful for explosives is the Jones-Wilkins-Lee (JWL) equation of state which is

$$P = A(1 - \frac{\omega_1}{R_1 V})e^{-R_1 V} + B(1 - \frac{\omega_1}{R_2 V})e^{-R_2 V} + \frac{\omega_1 E}{V}$$

where P is the pressure, A, B, ω_1, R_1 and R_2 are parameters for each explosive, V is the volume relative to the initial volume and E is the internal energy of the gases. The pa-

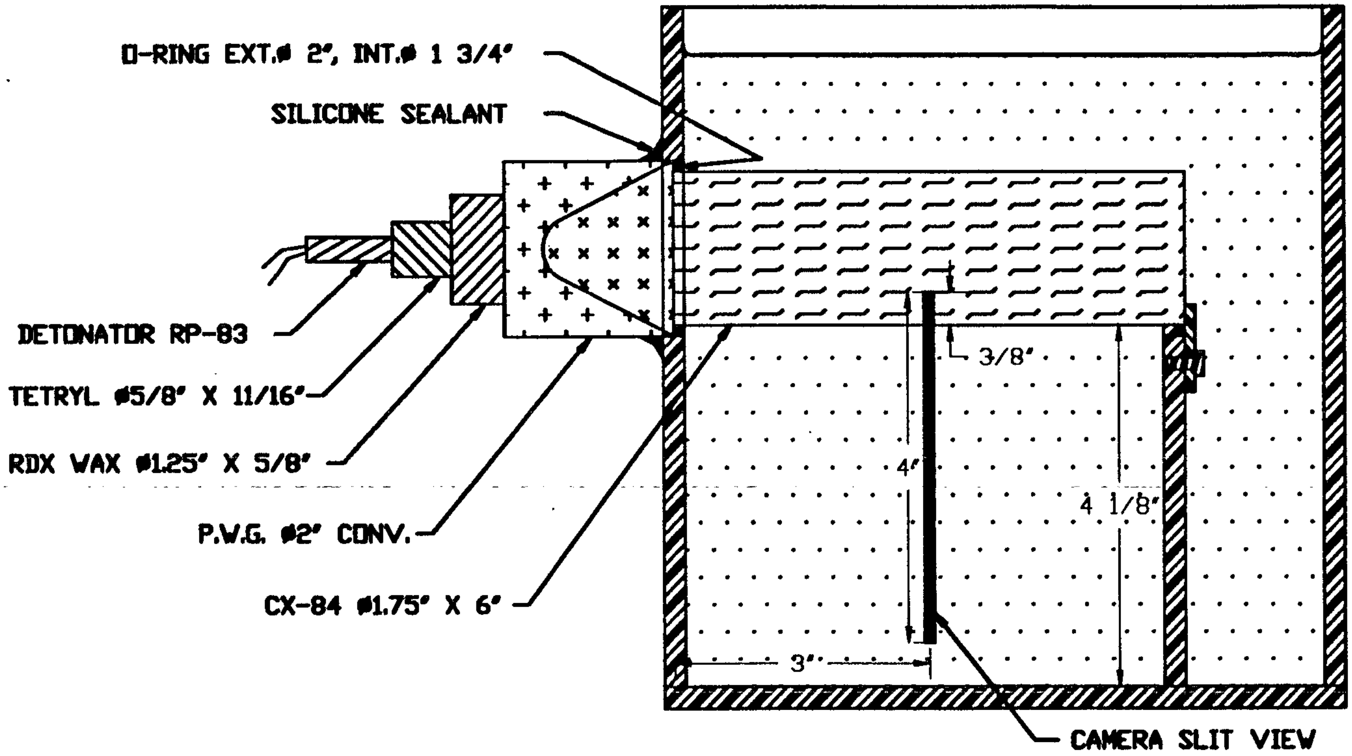

FIGURE 1 – Experimental setup for aquarium test in CX-84A and CHM

rameters are found by simulating the copper cylinder test (solving the equations of motion numerically) and varying the parameters until good agreement is reached between the simulated and experimental positions of the outer cylinder wall versus time records. With the parameters found, other simulations can be performed and compared to experiments to confirm the validity of the parameters under different conditions. This is what is done for the aquarium test.

Simulations can be performed in one, two or three dimensions. For situations with cylindrical symmetry, two dimensions (r,z) are sufficient and if the cylinder is sufficiently long (many diameters long) one dimension (r) is enough.

For one-dimensional simulations, a computer program called WONDY (Ref. 1) was used. The simulation was set up as follows. First, cylindrical symmetry was chosen. For CX-84A, a 2.2225 cm radius cylinder was divided in 32 radial cells with initial and final zone thicknesses of 0.0808 cm and was surrounded by a 1 m thick annulus of water divided into 100 zones with initial and final zone thicknesses of 0.0148 cm. The simulation was started with a detonation (simple Chapman-Jouget burn) at the center of the explosive and was run until the shock wave in the water reached the outer boundary. The explosive was modelled with the JWL equation of state with a detonation velocity of 7940 m/s, a density of 1550 kg/m^3 and the A, B, ω_1, R_1 and R_2 of 550 GPa, 3.492 GPa, 0.31, 4.31 and 0.75, respectively. For Composition B, the zoning was the same except that the radius was 2.54 cm. The JWL parameters were detonation velocity 7980 m/s and density of 1717 kg/m^3

with A, B, ω_1, R_1 and R_2 of 524.2 GPa, 7.678 GPa, 0.25, 4.20 and 1.10, respectively. For both simulations, the water was modelled as a fluid with a Grüneisen equation of state, with a linear Hugoniot relation between the shock velocity U_s and the particle velocity u_p. This means a density of 1000 kg/m^3 and a Hugoniot relation of $U_s = 1480 + 1.5u_p$ (m/s). No simulations were performed for CHM as the JWL parameters have not been measured for this explosive.

A two-dimensional simulation was performed for only CX-84A. The computer program DYNA2D (Ref. 2) was used. The cylinder of explosive was 6 inches long and 1.75 inches in diameter and was divided evenly into 30 radial sections and 100 axial sections, for a total of 3000 elements. A water jacket of radius 10 cm surrounded this cylinder (flush with the cylinder at both ends) and was divided into 60 radial sections and 100 axial sections, for a total of 6000 elements. The detonation was started simultaneously across the diameter at the bottom of the cylinder of explosive. The simulation was run until the detonation reached the top of the explosive cylinder. The explosive was modelled using a Chapman-Jouget burn (material 8 of DYNA2D) with a detonation velocity D of 7940 m/s , a density ρ of 1550 kg/m^3 and a detonation pressure P_{CJ} of 24.7 GPa. The JWL parameters (for EOS 2 of DYNA2D) were the same as for the one-dimensional case and an initial energy density E_o of 6.34 GPa. The water was modelled as a hydrodynamic fluid (material 9 of DYNA2D) with a density of 1000 kg/m^3 with a Grüneisen equation of state (EOS 4 of DYNA2D) with the Hugoniot relation of $U_s = 1483 + 2.0u_p$ (m/s).

The results of interest from both one- and two- dimensional simulations were the water-explosive interface position and the position of the shock wave in the water as functions of time. These can be compared directly with the experimental results.

3.0 RESULTS AND DISCUSSION

The results and their interpretation will now be discussed. In Figure 2, a typical streak camera record for CX-84A is reproduced. Two things can be immediately noted. First, the shock wave in water is clear and sharp. Second, the water-detonation products interface (necessary for particle velocity measurements) is irregular and not continuous. This interface also appears to start at a diameter larger than the initial diameter of the cylinder and at a time after the shock wave in the water has been generated, a non-physical situation. The explanation for this is quite simple. The shock wave in the water disturbs the passage of light near its leading edge, effectively blocking the light. This effect is most pronounced near the cylinder. Thus, water-explosive interface is not seen behind the shock wave near the beginning. Once the shock wave has expanded, the interface becomes visible. There are three regions seen: the undisturbed water in front of the shock wave; the shocked water between the shock front and the interface; and the cylinder region. Within the cylinder region, the reaction products are highly agitated and turbulent and thus the interface between the water and the gases is not sharp i.e. irregular as observed. This should be kept in mind as any mention of "interface" in subsequent sections is actually referring to this complicated interface region. The water shock and interface positions as digitized are plotted in Figures 3 and 4 where the radius change (radius at time t less the initial radius) for 4 CX-84A, 2 Composition B, and 5 CHM tests are overlaid. Both figures use the same time scale. Figure 3 show quite clearly the reproducibility of the results, fulfilling one of the criteria for a good test of performance. One can also see there is a clear difference between the explosives. Composition B gives rise to the fastest shock in water and this implies that it has the best performance of the three tested explosives.

The relative ranking of explosive performance seems to be "test dependent" as summarized in Table I. The simplest method to use is to rank them according to an estimated detonation pressure, $0.25\rho D^2$. This yields the order CX-84A (24.3 GPa), Composition B (26.7 GPa) and CHM (27.2 GPa). However, the details of how the energy (or pressure) is released (time scale, etc.) are important for determining how useful an explosive is. Using the ballistic capacity test (see Ref. 3), the 3 explosives are ranked (in increasing order of specific kinetic energy transfer) CX-84A, CHM and Composition B. The cylinder test (see Ref. 4) shows that CX-84A (or rather an earlier related formulation) is 13% less powerful than Composition B, based upon the cylinder wall velocity squared at a radial expansion of 19 mm. (Cylinder tests have not yet been performed for CHM.) The present aquarium test gives the order CHM, CX-84A and Composition B in terms of shock radius after 15 μs. The conclusion to draw evidently is that the PBXs have certainly worse performances than Composition B but that it is more difficult to choose between the PBXs.

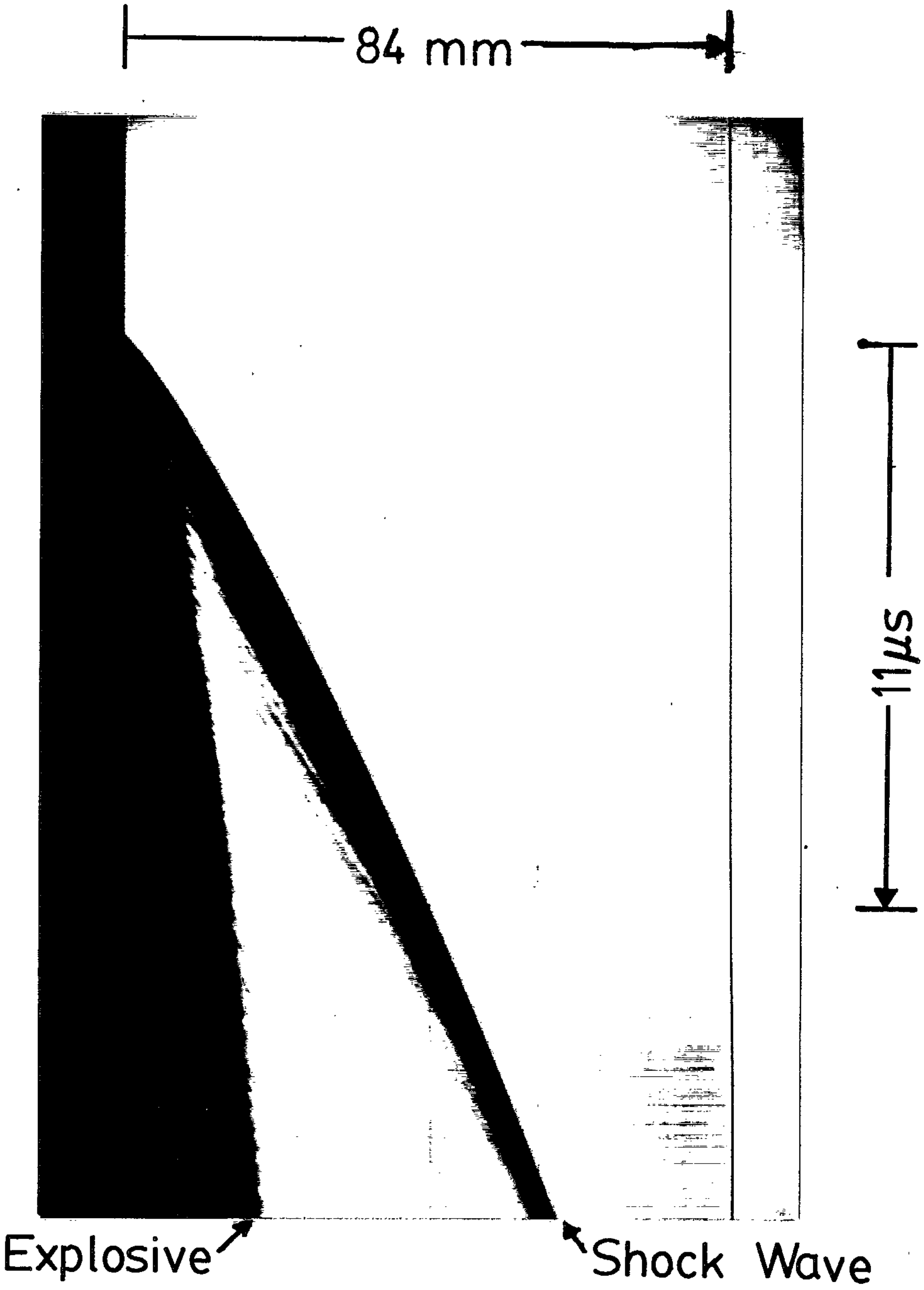

FIGURE 2 – Typical streak record for a CX-84A test

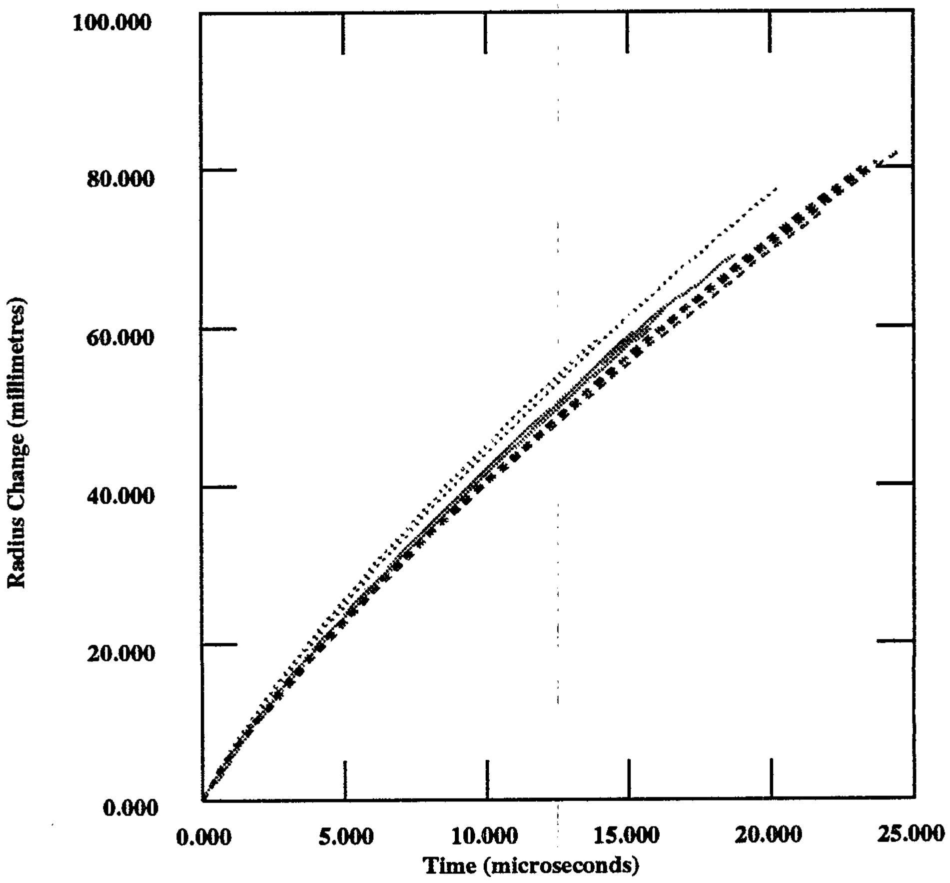

FIGURE 3 – Water shock radius versus time for Composition B (dotted), CX-84A (solid) and CHM (dashed)

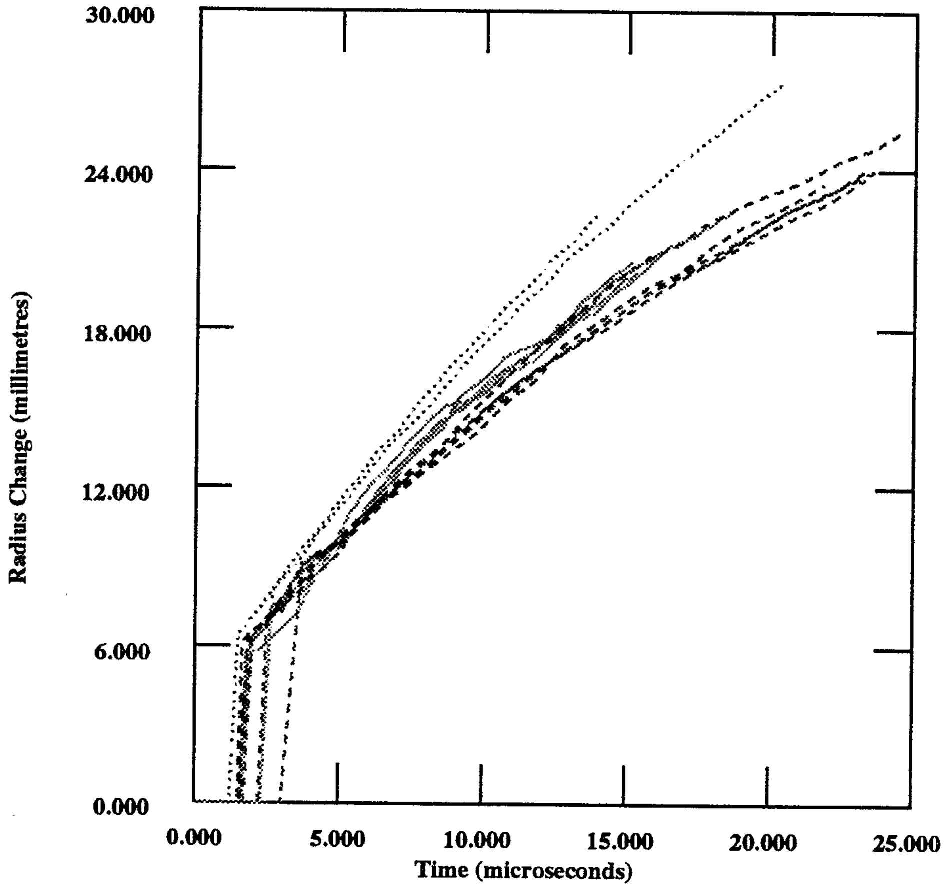

FIGURE 4 – Water-explosive interface radius versus time for Composition B (dotted), CX-84A (solid) and CHM (dashed)

TABLE I

Comparison of performance test results

Explosive	$0.25\rho D^2$	Ballistic Cap.	Cylinder	Aquarium
Comp B	26.7 GPa	1230 J/g	2.514 $(km/s)^2$	62 mm
CX-84A	24.3 GPa	1076 J/g	2.169 $(km/s)^2$	59 mm
CHM	27.2 GPa	1114 J/g	N/A	57 mm

The radius-time curves naturally contain the velocity record of the expanding shock wave. Numerically, this is found by differentiating the record by a simple finite difference method

$$v_i = \frac{r_{i+1} - r_{i-1}}{t_{i+1} - t_{i-1}}$$

where equal increments of time are desirable but not necessary. The results of this are shown in Figure 5. The irregularities in velocity are due to digitizing errors. At t=0, the water shock expands at about 6.4 mm/μs in the case of Composition B and at about 5.8 mm/μs for CX-84A. The shock pressure in the water is given by

$$P = \rho_o \frac{U_s - a}{b} U_s$$

where the shock Hugoniot for the water of density ρ_o is $U_s = a + bu_p$ where U_s is the shock speed and u_p is the particle velocity behind the shock front and a and b are constants. Using a ρ_o of 1000 kg/m^3, an a of 1483 m/s and a b of 2.0, we find the initial shock pressures are 16 MPa for Composition B and 13 MPa for CX-84A.

In principle, if the equation of state is known for the detonation products, and the surrounding medium is characterized vis-à-vis shock waves, it is possible to simulate the

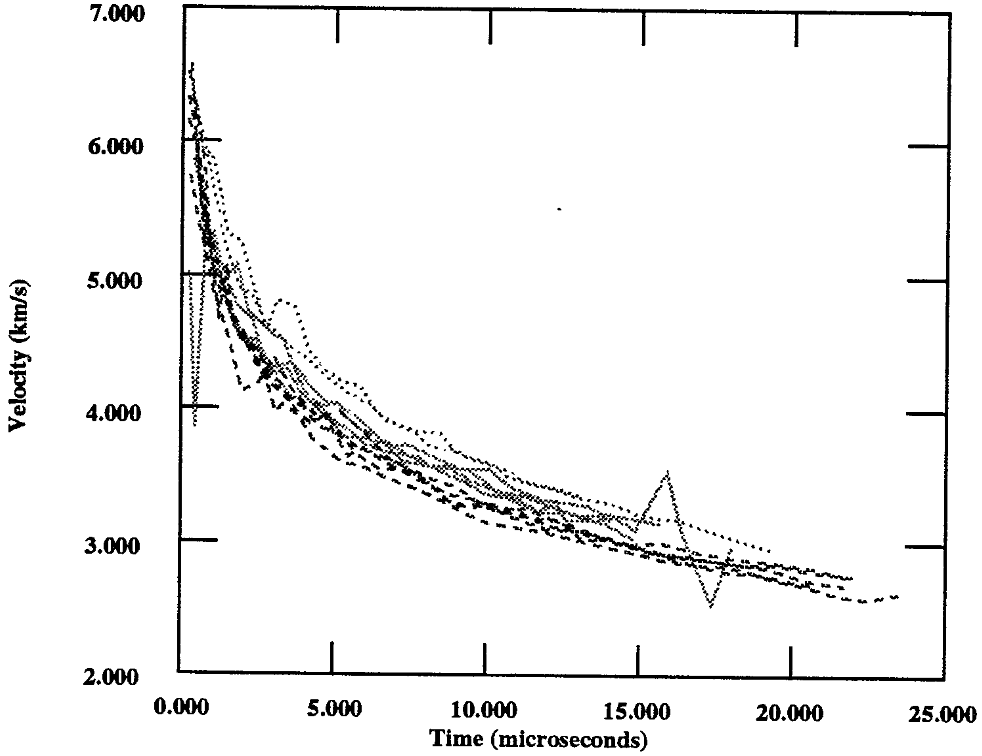

FIGURE 5 – Experimental shock velocities versus time for Composition B (dotted), CX-84A (solid) and CHM (dashed)

expanding cylinder. Since an equation of state is available for the detonation products and since water has been so characterized, simulations can be (and were) performed.

The results of the one-dimensional simulation will be discussed first. In Figure 6, the radius-time curves for Composition B and CX-84A are displayed. The difference between them is similar to the difference observed experimentally. However, on closer examination, we find that the computer underestimates the radius at a given time. For example, at 10 μs, the experimentally observed radii are 46 mm for Composition B and 43 mm for CX-84A. In the simulation, for the same time, we find the radii are 42 mm for Composition B and 38 mm for CX-84A. At 15 μs, we find experimentally 62 mm (Composition B) and 59 mm (CX-84A). Compare those radii with 57 mm (Composition B) and 51 mm (CX-84A) from the simulations.

The two-dimensional simulation will now be discussed where only CX-84A was simulated. The pressure contours in the water are shown quite clearly in Figure 7 at 19 μs after the ignition of the explosive. The detonation front started at z=0 and has moved to the left approximately 15 cm. The time scale indicates the time behind the detonation front given a steady detonation velocity. At 10 μs, the shock radius is 38 mm which is less than the experimental result of 43 mm. The two-dimensional calculation seems to give the same results as the one-dimensional calculation, at least at early times. Later, the two-dimensional influence is evident. Both radii start to decrease due to the rarefaction waves due to the expansion of the right boundary propagating into the reaction products.

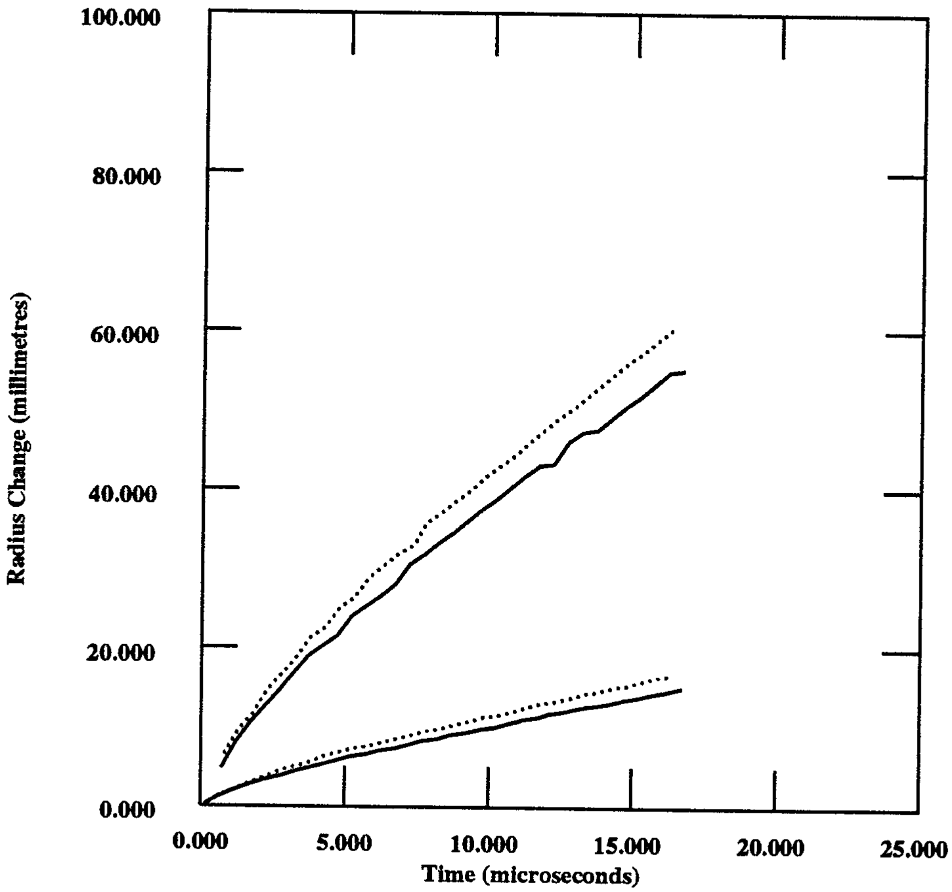

FIGURE 6 – WONDY one-dimensional simulation. Radii versus time for Composition B (dotted) and CX-84A (solid). The upper two curves are for the shock wave position, the lower two for the interface position.

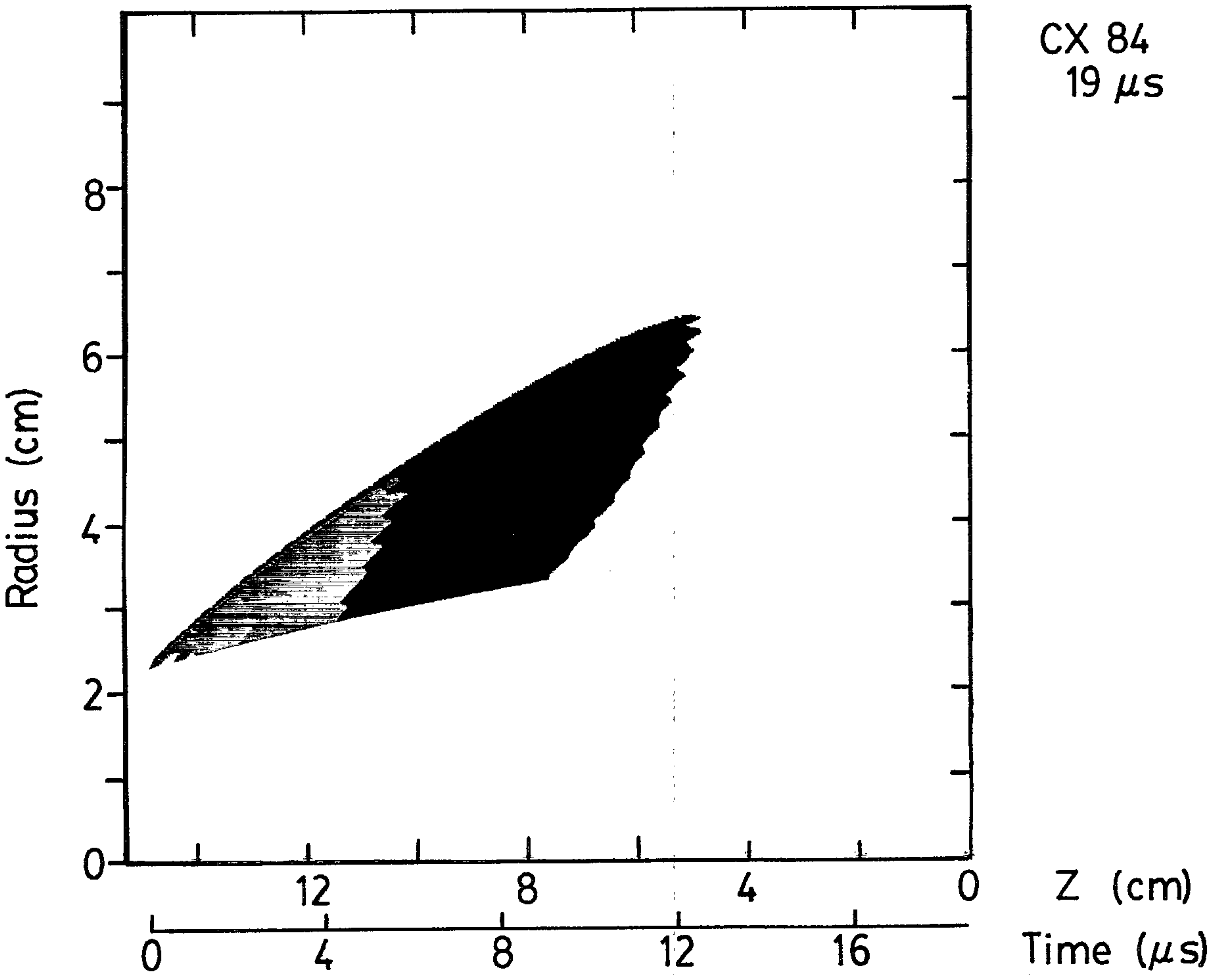

FIGURE 7 – DYNA2D two-dimensional simulation. Pressure contours in the water 19 microseconds after detonation for CX-84A

The differences between the experimental results and computer simulations in both one and two dimensions can be due to a number of factors. For example, there is an uncertainty in the Hugoniot (a, b coefficients) of water. In principle, this Hugoniot is unique and can be measured. In the literature, several different Hugoniots exist. For example, in Mader (Ref. 5), one can find a,b pairs of (1504, 1.786) (p.157), (2264, 1.325) (p.165) and (1483, 2.0) (p.280)! The discrepancies do affect the final results on the scale of the differences observed between the experiment and simulations but the relative behaviour of the simulations is not greatly affected by these changes in the Hugoniot.

There could also be errors in the JWL coefficients. It is known (see Ref. 5) that an aquarium test can confirm an EOS but cannot uniquely determine one. This means that if the JWL coefficients are wrong, a simulation of the aquarium test will not be accurate. In other words, a given set of JWL coefficients can be rejected as false solely on the basis of the aquarium test. The converse is not, unfortunately, true: the results of an aquarium experiment cannot be used to find the true JWL coefficients. In other words, a given set of JWL coefficients cannot be accepted as true solely on the basis of the aquarium test. Because the simulations do not accurately reproduce the experimental results, the JWL coefficients may not be correct although they are certainly not far wrong as the results of Composition B relative to CX-84A are reproduced.

Finally, a third reason, especially in the two-dimensional case, is that the detonation front in the simulations is planar whereas experimentally the detonation front starts planar but due to a finite reaction zone size, becomes curved as it propagates up the cylinder. This is quite probably the real reason the simulations do not match the experiments. Two dimensional simulations are planned in which a better detonation model is used in place of the simple burn model.

4.0 CONCLUSIONS

The observation of an expanding cylinder of explosive and shock wave generated in water by the detonation does give accurate and reproducible results for detonation performance. CX-84A was shown to be less powerful than Composition B, confirming a conclusion found some time ago. A surprising result is that the new CHM explosive was also found to be less powerful than both CX-84A and Composition B. Simulations using the previously determined JWL coefficients can reproduce the relative and to a large extent the absolute radius-time history of the expansion. The test is thus a good way to check the JWL coefficients, thereby gaining confidence in their accuracy and usefulness.

5.0 ACKNOWLEDGEMENTS

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6.0 REFERENCES

1. Kipp, M.E., and Lawrence, R.J., "WONDY V - A One-Dimensional Finite-Difference Wave Propagation Code", Sandia National Laboratories Report SAND81-0930, June 1982, UNCLASSIFIED
2. Hallquist, J.O., "DYNA2D - An Explicit Two-Dimensional Hydrodynamic Finite Element Code with Interactive Rezoning and Graphical Display", Lawrence Livermore National Laboratory Report UCID-18756, Rev. 3, March 1988, UNCLASSIFIED.
3. Farinaccio, R., Demers, C. and Beaupré, J., "Ballistic Capacity of Two Plastic Bonded Explosives", DREV Memorandum 3121/92, November 1992, UNCLASSIFIED
4. Pasman, H.J., Walker, G.R. and Matte, Y., "Castable Composite Explosives: Evaluation of Output by the Standard Cylinder Test", DREV Report R-4094/78, May 1978, UNCLASSIFIED
5. Mader C.L., "Numerical Modeling of Detonation", University of California Press, Berkeley, California, 1979.

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An aquarium test was implemented to measure the performance of explosive formulations. This test consists of detonating a bare cylinder of explosive in a water bath and recording the radial positions (perpendicular to the axis of the cylinder) of the shock wave in the water and water-explosive interface as a function of time at a given distance along the cylinder. At late times (several microseconds after the detonation front has passed), the shock radii generated by three different explosives, Composition B, CX-84A and CHM, are compared. A larger radius is interpreted as resulting from a more powerful explosive. The conclusion is that Composition B is more powerful than CX-84A which in turn is more powerful than CHM. Computer simulations using the computer programs WONDY V and DYNA2D were also performed to support this conclusion.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technical terms or short phrases that characterize a document and could be helpful in cataloguing it. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

EXPLOSIVE
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SHOCK WAVE
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