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The Effect of Detonation Curvature on Cylindrical Wall Motion

David F. Aldis, William Quirk, and R. Don Breithaupt

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Introduction

In the large scale analysis of explosive response, discrepancies have been found between the results predicted by a computer models using various sets of equation of state parameters derived from different experiments. In this report, we will present recent progress toward determining possible reasons for the differences.

The system that we have modeled in this study is the cylinder test. Numerous researchers have used this test to study the work potential of detonating explosives for the transverse expansion of metals (Lee, et al. 1968). One of the original purposes for the development of the test was for the determination of equations of state for detonation products of explosives. The method that is used to determine the parameters for these empirical equations of state, is to iteratively simulate the detonating explosive expansion using a two dimensional hydrodynamic code, adjust the parameters, and repeat until a 'best fit' to the experimental results is obtained. We will, in this present report, explore a small part of this problem. We will concentrate on the effect of the material that is used in the wall of the cylinder, the effect of detonation front curvature, and how the curvature might influence the cylindrical wall expansion.

The influence of cylinder radius on detonation velocity has been well documented (ie., Fickett and Davis, 1979). The effect occurs with explosives that have relatively large reaction zones. Two reasons that have been given for this effect. First, as the side wall expands energy is lost from the reaction zone to the side wall. Secondly, if the rarefaction coming in from the side causes the sonic plane to catch up and pass the

complete-conversion plane, then some energy liberated behind the sonic plane will not contribute to supporting the detonation.

Another, related feature of a detonating cylinder of high explosive that has a large reaction zone is that the detonation front is not flat, ie. perpendicular to the axis of the cylinder. An illustration of this effect is shown in Figure 1. In this figure, the high speed camera record of a detonation exiting a cylinder explosive is presented. The horizontal axis proportional to the radial position of the detonation front and the vertical distance is proportional to the time of arrival of the shock-detonation front at the exit plane of the cylinder. The curvature of the LX-17 is much larger than either PBX-9404 or LX-10.

Figure 1. Experimental Curvature of LX-17 in Cu Cylinder

Attempts have been made to use the large scale effect of charge diameter on detonation velocity to mimic the smaller scale curvature of a detonating explosive. This is done by using the large scale relationship between detonation velocity and charge diameter (or curvature) and a front tracking hydrodynamic code (ie., Buckiet, 1989). This approach is reasonable for relatively simple geometries but will not likely be able to simulate more complicated ones. Shock-reflected shock interaction environments would, for example, not be accurately simulated.

Numerical Approach

The specific computer code that was used in this study is the two dimensional hydrocode Vector-Hemp (VH). VH is a finite difference model of the equations of mass, momentum, and energy that has been perfected for use in the simulation of material response to shocks, explosive detonations, and extremely high pressure, large scale deformations. It is implemented for use on the CRAY computers at Lawrence Livermore National Laboratory.

The equation of state used in this study is the Jones, Wilke, and Lee (JWL) equation (Kury, et al., 1965). The equation is given below as Equation 1. The form of this equation is relatively simple considering the complexity of the phenomena for which it is used to simulate.

$$P_e = A_e e^{R_{1,e} V_e} + B_e e^{R_{2,e} V_e} + \frac{C_{p,e} \omega_e}{V_e} \quad (1)$$

The set of equation of state parameters evaluated in this study are shown in Table 1. EOS-1, was determined by Tarver and Halquist (1981) and Tarver, et al. (1985) by simulating a large number of experiments with various length scales, shock pressures, and pressure durations.

Table 1. Equation of State Parameters

Parameter	EOS-1
A_r	778.1
$R_{1,r}$	11.3
B_r	-0.05031
$R_{2,r}$	1.13
C_r	2.487×10^{-5}
ω_r	0.8938
A_p	5.31396
$R_{1,p}$	4.1
B_p	0.0270309
$R_{2,p}$	1.1
C_p	1×10^{-5}
ω_p	0.046
$r h o$	1.9
e_0	0.069
T_0	298.0

Two explosive burn models have been used in this study. The more sophisticated is the Tarver reactive flow model (Tarver, et al., 1985). This model is a rate dependent model of explosive decomposition. The rate law used in this model is given in Equation 2. In this model it is assumed that the explosive reactant decomposes irreversibly in to an explosive product. The variable, f , is the extent of reaction of the decomposition process. As can be seen in Equation 1, the decomposition rate is assumed to be dependent on the local extent of reaction, density, and local pressure. The set of reactive flow parameters used in the simulations presented in this report and are given in Table 2.

$$\frac{\partial F}{\partial t} = I(1 - F)^b \left(\frac{\rho}{\rho_o} - 1 - a \right)^x + G_1(1 - F)^c F^d P^y + G_2(1 - F)^e F^g P^z \quad (2)$$

where:

$$P_r = A_r e^{R1_r V_r} + B_r e^{R2_r V_r} + \frac{C_r \omega_r}{V_r} \quad (3)$$

$$P_p = A_p e^{R1_p V_p} + B_p e^{R2_p V_p} + \frac{C_p \omega_p}{V_p} \quad (4)$$

$$V = (1 - F)V_r + (F)V_p \quad (5)$$

Table 2. Reactive Flow Parameters

Parameter	EOS-1
a	0.22
$cappa$	$1.0x^{10}$
chi	1.0
$fmzig$	0.5
x	7.0
I	$4x10^6$
b	0.667
G_1	0.6
y	1.0
d	0.111
c	0.667
$fmxgr$	0.5
G_2	400.0
z	3.0
g	1.0
e	0.333

The less sophisticated explosive burn model is the programed burn model. In this model the detonation speed is given as a parameter. The reactant explosive, at some point in space, is assumed to detonate when the detonation arrives at that point. The distance from the initiator detonation point to any point in the explosive and the detonation velocity are then used to predict the local time of detonation. Normally only the product equation of state is then required to predict the pressure as a function of the local density and local specific internal energy.

The primary advantage to the programed burn model is its simplicity and that a larger zone size can be used. A disadvantage is that internal flow complexity such as rarefactions and shock-reflected shock environments can only be simulated by arbitrarily adjusting the program burn parameters to fit the desired experimental results or by similarly arbitrarily adjusting the equation of state parameters to mimic internal complex dynamics.

Experimental Results

Over the years significant effort has been expended in obtaining equation of state parameters for explosives with a great deal of success (ie. Dobratz, et al. 1985).

The materials used in the cylinder tests referenced in this report consisted of a 2 in diameter cylinder of LX-17 originally contained in either a copper or tantalum cylindrical case with an OD of 2.2 in. The explosive was detonated with a plane wave charge at one end. The wall motion was monitored during a separate experiment using Fabry-Perot velocimetry.

The measurement of the curvature of the detonating cylinder of explosive is made by recording the flash of an air gap at the end of the cylinder with a streak camera. The horizontal position corresponds to the radial position and the vertical position corresponds to the time of arrival of the shock at the end of the cylinder. Because the response was made for two perpendicular lines across the entire diameter of the cylinder, four sets of responses of time delay versus radial position are obtained. These responses can be seen in Figure 1. The primary experimental result is the maximum delay in the arrival time between the center and side. A reasonably rough measurement is obtained because of the difficulty in determining the edge of the cylinder. A difference in the measurements of approximately 10 % exists.

Numerical Results

The amount and type of data that can be obtained from an experimental measurement of detonating explosive is significantly less than that which can be modeled. In the cylinder test, the velocity of the side wall expansion versus both time and position is the primary experimental result. The predicted position of the expanding cylinder wall can be seen in Figure 2. The numerical results that will be presented here will be restricted to those which can be directly measured.

Figure 3. Expanded View of the Modeled Results for EOS-1 for LX-17, Cu Walled Cylinder Test.

In Figure 4, the experimental and predicted wall velocities are shown for a simulation of a cylinder test in which copper was used for the wall material. The corrections to the signal from the Fabry Perot velocimetry are made in the analysis for the angle of the expanding wall with the laser beam used by the velocimetry, and air density changes caused by the air shock from the moving wall. The modeled results were obtained using VH with the reactive flow burn model, the EOS-1 equation of state, and a Gruneisen equation of state for the copper.

Figure 4. Experimental and Model Results for EOS-1 for LX-17, Cu Walled Cylinder Test.

The agreement between the experimental and modeled results is very good over the time period measured. The ringing in the copper cylinder is modeled correctly, both in amplitude and frequency. The over all acceleration is also accurately modeled.

In Figure 5 experimental and predicted wall velocities are presented for the same explosive as for Figure 4, however the wall material was tantalum rather than copper. The appropriate Gruneisen equation of state was used for the Tantalum. In this prediction no strength model was used. It should be noted that the density of Tantalum is approximately $16.6 \frac{gm}{cm^3}$ and that of copper is approximately $8.6 \frac{gm}{cm^3}$.

Figure 5. Experimental and Predicted Results for EOS-1 for LX-17, Ta Walled Cylinder Test.

The agreement between the predicted and experimental results is not as good as that presented in Figure 4. For early times the agreement is not too bad but then the curves diverge. The predicted wall velocity is less than that measured at the end of the time period measured. The resultant energy imparted to the cylinder is therefore less than measured.

A possible reason for the difference in the results for tantalum is the material strength. In all of the calculations in this study the strength of the wall material was assumed to be small and not included. The EOS-1 calculation for the tantalum cylinder was repeated with a complete Steinberg Guinan material strength model. The results are shown in Figure 6. The effect of the strength appears to be small.

Figure 6. Experimental and Predicted Results for EOS-1 for LX-17, Ta Walled Cylinder Test with Steinberg Guinan Strength Model.

Conclusions

When the Tarver reactive flow model and the equation of state EOS-1 are used in VH, the Cu wall expansion velocity is very close to the experimental result for the time period measured. However, if the cylinder test is repeated with a denser wall, such as Ta, the fit is good at early times but not as good at later times. The net result is that the final effective energy release as determined by the final velocity of the Ta cylinder wall is low.

In the simulation of the cylinder test, the effect of the reaction zone does not appear to be critical. However, in experiments in which the degree of expansion is more severe, the possibility of the sonic plane passing the plane of complete conversion is greater. When material is left unconsumed behind the sonic plane it can not reinforce the detonation and the detonation strength will be reduced. The reactive flow model would be need to predict this behavior.

Suggestions for Further Work

The uniqueness, the numerically stability, and the sensitivity of equation of state parameters found, using an iterative fitting approach, should be evaluated. In addition, the method used to determine the 'best fit' should be carefully defined, described, and evaluated.

Only a single test has been performed using the tantalum wall cylinder. Additional tests are needed to allow one to use the results with any degree of assurance. In addition, no detonation front curvature measurements were made during the tantalum wall cylinder test. If the loss of energy from the reaction zone is more severe during a copper wall cylinder test than a tantalum wall cylinder test then the curvature should also be greater. When the tantalum test is performed, the curvature should also be measured.

References

Bukiet, B. 'The Effect of Curvature on Detonation Speed', SIAM J. Applied Math, 49(5), pp. 1433-1446, 1989.

Dobratz, B. M. and Crawford, P. C. 'LLNL Explosives Handbook Properties of Chemical Explosives and Explosive Simulants'. Lawrence Livermore National Laboratory Report UCRL-52997, Change 2, Livermore, California, 1985.

Fickett, W. and Davis, W. C. 'Detonation', University of California Press, Berkely, California, 1979.

Halquist, J. 'User's Manual for DYNA2D - An Explicit Two-dimensional Hydrodynamic Finite Element Code with Interactive Rezoning and Graphical Display'. Lawrence Livermore National Laboratory Report Draft, UCID-18756, Rev. 3, Livermore, California, 1988.

Kury, J. W., Hornig, H. C., Lee, E. L., McDonnell, J. L., Ornellas, D. L. Finger, M., Strange, F. M. and Wilkins, M. L. 'Metal Acceleration by chemical explosives, In the Fourth Symposium (International) on Detonation, pp. 3-13. Washington, D. C.: Office of Naval Research-Department of the Navy (ARC-126), 1965.

Lee, E. L., Hornig, H. C., and Kury, J. W. 'Adiabatic Expansion of High Explosive Detonation Products'. Lawrence Radiation Report UCRL-50422, 1968.

Tarver, C. M., Halquist, J. O., Erickson, L. M. 'Modeling Short Pulse Duration Shock Initiation of Solid Explosives', In the Eighth Symposium (International) on Detonation, Naval Surface Weapons Center NSWC MP-82334, Annapolis, MD, pp. 951-961, 1985.

Tarver, C. M. and Hallquist, J. 'Modeling Two-Dimensional Shock Initiation and Detonation Wave Phenomena in PBX-9404 and LX-17', In the Seventh Symposium (International) on Detonation, Naval Surface Weapons Center NSWC MP-82334, Annapolis, MD, pp. 488-497, 1981.

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