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TITLE **HIGH EXPLOSIVE SYSTEMS FOR EQUATION-OF-STATE STUDIES**

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HIGH EXPLOSIVE SYSTEMS FOR EQUATION-OF-STATE STUDIES

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Experimental and calculational studies were made to specify a suite of explosive-impactor systems to be used in high pressure equation-of-state (EOS) measurements. Thin stainless steel (SS) was used as the driver or impactor. The investigation included some systems where the high explosive (HE) driving the plate to be used as the impactor was preshocked by another thicker SS plate. The effect of lateral confinement, either by HE or iron rings constituted part of the study. The effect of separating the HE and driver was also studied. The velocity range encompassed was from less than 4 km/s to over 9 km/s, which was observed in a two-stage experiment.

1. INTRODUCTION

By using plane-wave explosive lenses and a combination of various explosives and metal plates it is possible to generate any desired shock pressure within the working range. During the last 30 years it was customary (except when establishing a primary standard) to obtain shock-wave EOS data by putting samples on a plate whose EOS was known (the standard) and using the impedance-match technique devised by Walsh to deduce the appropriate shock-wave parameters. With such a system the state of the driver was of little importance if it did not break up and all measurements were properly centered. However, during the last few years we have been making Hugoniot measurements by impacting the samples under investigation directly, the same way that the standards were impacted. The primary reason for doing this is to eliminate any uncertainties in calculating reflected shock or release states in the holder plate needed for calculating the standard-sample interface pressure states. The errors introduced because of uncertainties in the Grüneisen parameter are eliminated as well as those caused by our ignorance of the effect of the elastic-plastic behavior of the standard in shock reflection or release. Moreover, rarefaction-wave velocities are being determined from direct impact experiments, and it behooves us to have a suite of HE impact systems available for those measurements.

Direct impact EOS measurements require that the density of the driver be known in the impact area and how much shock heating has been incurred while accelerating the impactor to collision velocity. Previously these things needed to be known only while establishing the EOS of the standard. 6061-Al and 304-SS will be the new standards. They are uniform in composition so the first requirement was easily met. The problems associated with shock heating are somewhat more difficult, and they will be discussed more completely later. Since most of the shock heating occurs during the initial shocking of the impactor if it is placed in contact with the HE, we have tried to mitigate their shock strength by including large air spaces or low impedance materials between the HE and the metal plate. For the air spaces to be effective the driver plate must be relatively thin so they can begin to move before higher pressure waves develop in them.

It appears that the impactor should be of the order of 1 mm to meet these requirements, and also to be thick enough so that shock

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transit times can be measured on materials of reasonable thickness. Thin drivers and long runs also keep them as free as possible from pressure pulses at the time of impact. Part of this study has been devoted to finding HE systems that best maintain the flatness needed for good plane-wave experiments. It was also necessary to determine plate velocity-distance curves for a reasonable assessment of the problem.

We have investigated the use of what we call the double free run (DFR) system. Here an HE driver system (first stage) is used to overdrive, and to maintain pressure in the HE of a second smaller diameter system. Some work done here circa 1960 showed that some increase in veocity was possible. Because the number of combinations for doing this are really quite large, computer studies were used to chose the systems to be evaluated.

All phases of the program have been investigated by calculations and by experiments. One aspect that the calculations cannot address is whether the metal plates break up, and if they do, when? Results of smear camera experiments were used to establish criteria for that.

. THE DIAGNOSTICS

The performance of the systems was evaluated by monitoring impactor-plate arrival and velocity at different levels with a multiple flash-ap analyzer (MFA), viewed by a sweeping image amera. The MFA consists of a Plexiglas holder ar on which several relatively thin Plexiglas trips have been attached along the edges with ouble stick tape leaving a small gap in the entral area for some gas, which emits light hen closed by the shock. Three or more layers f Plexiglas were used so that shock strength ould be determined as a function of run.

. CALCULATIONS

All calculations were made using a two dimenional Eulerian hydrodynamic code with HE detonation and propagation governed by a JWL EOS. The effects of confinement and related edge effects were studied using the full 2-D capabilities of the code. Plane-wave calculations were also made to study the effects of HE gap and plate thickness on plate velocities. In the experiments plane-wave HE lenses were used. Since it is a major task to calculate the detonation of the lens, all calculations were made with the primary HE only. The effect of the lens must be added when comparing the calculated and experimental results. It was assumed that all dimensions scale (velocities are invariant), and that there were no time-dependent effects. The problem of plate break-up was not addressed. Spaces between the plates and HE in the experiments were filled with hydrogen and treated as voids in the calculations.

4. TWO-DIMENSIONAL EFFECTS

One of the goals of this program was to maximize the useful area for a given plane-wave initiator. One way to do this is to just use a larger diameter HE. In doing this the actual area completely free from side affects remains the same but the severity of the deleterious effects, e.g., lagging edges or bow, can be minimized somewhat. However, if the total mass of HE is limited, using confinement may be better. We have not studied that aspect and have only compared the effect of partial confinement with no confinement. A method available to control driver-plate acceleration and velocity is by separating the char from the plate by a gap. HE gases expand in a one dimensional fashion when they flow across the gap since they are essentially at zero pressure during that time. However, when they reach the plate pressures build up and the explosive products will now expand laterally if not confined. To minimize the loss in pressure because of this we have used systems similar to that in Fig. 1 where the two systems are compared.

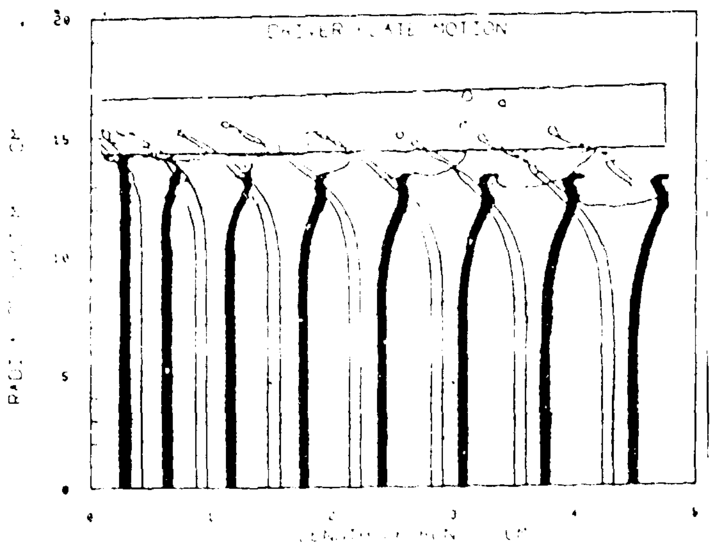

FIGURE 1. A set of calculated plate profiles showing the effect on the edges of confining the driver plate (the solid areas) with a similar but slightly different unconfined system (the open areas). In both calculations the lens and HE were unconfined, but in one the driver plate was held in a piece of iron pipe with an inside diameter smaller than the charge (the long rectangle at top of figure). The salient feature is that the HE-detonation wave causes the ring to expand inward a bit and directs the expanding gases in the cavity in such a fashion that the plate actually develops a lead in the outer regions instead of the lag at the edge in the unconfined system. Such systems would appear to be almost ideal in that if they were optimized long free runs could be used to reach maximum plate velocities. This effect has been verified experimentally.

5. SEPARATING THE HE AND THE DRIVER

This problem has been addressed primarily by 1-D calculations; complete experimental verification has not yet been done. Varying the separation between the HE and driver provides another way to control the velocity of the impactors and becomes most effective when thin HE is used. The Taylor wave causes tension waves in the driver plate if they are placed in contact with the HE. By spacing the HE away from the plate these are minimized. A somewhat surprising result (Fig. 2) was that the driver velocities had a maximum when a rather small separation was used. The cause of this is not understood nor has it been monitored experimentally at this time. The results of one set of calculations are summarized in Fig. 2. One effect that the separation is believed to have is to eliminate the large gradients associated with the reaction zone of the explosives, a feature not present in the calculations. Gradients are also present because of the Taylor wave, and they can have serious effects during the acceleration of the drivers especially when the HE is thin. Calculated velocity profiles demonstrate this. The fact that thin plates can be accelerated without being torn up when using some separation attests to the usefulness of separating the HE and impactor.

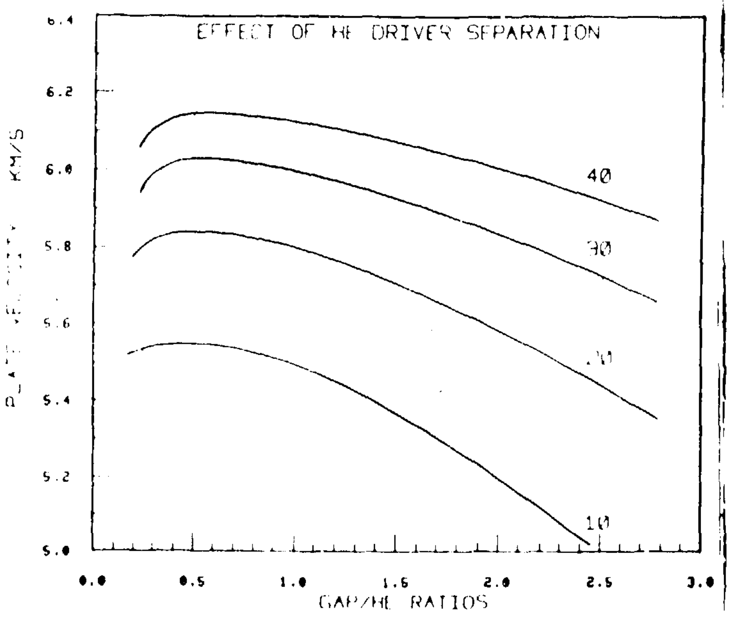

FIGURE 2. Calculated driver velocity vs. gap size. Here and elsewhere we have used the dimensionless ratios of the gap size, HE thickness, and length of run to the driver thickness, to describe the system. These three parameters fully characterize the results of the calculations. Since a 1-mm-thick driver is typical, these ratios are also representative of actual size (in mm) of many systems. The curves are for four run/driver ratios.

6. TWO-STAGE SYSTEMS

The concept of staging is not new. The idea is to use a rather massive plate (piston) moving with a velocity of from 4- to 6-km/s to accelerate a much thinner plate to somewhat higher velocities via some staging fluid. We used plates of HMX based, Plastic Bonded Explosive (9501)

5- to 15-mm thick as the intermediate material. In the calculations a SS piston moving at some prescribed velocity impacts the explosive and the reaction begins. Energy is released as the shock wave passes through the explosive. Calculations indicate that the ratios of some of the components used in these systems are critical. When the secondary HE was too thick relative to the piston, large tension waves developed in the driver, which caused velocity profiles with large gradients. These gradients would most likely destroy its usefulness. In the systems where the pressure pulses appeared flat in the driver, very large tension waves were present in the piston, but they caused no bad effects on the driver. When the HE was thin, the initial pressure pulses appeared to be quite large, so this may cause considerable shock heating. Results of four calculated systems are shown in Fig. 3, and some results of five experiments are given in Table I.

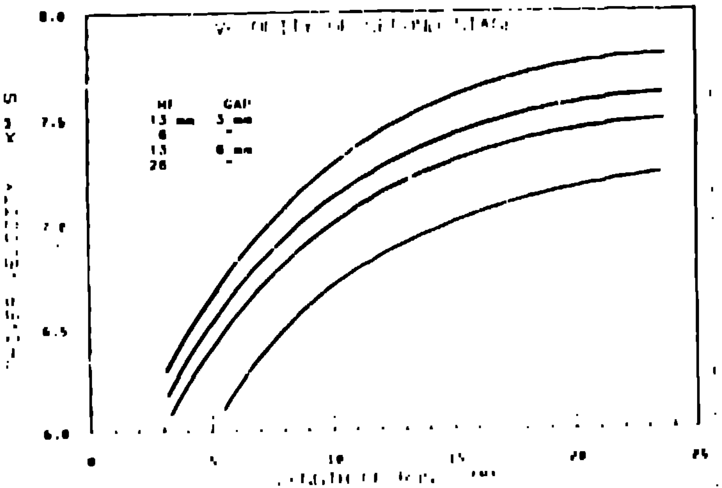

FIGURE 3. Calculated Velocities of 0.9-mm second stage driver for various seconda HE systems impacted by a 4.8-mm SS piston mov g at 4.5 km/s. The thicknesses of the HE and gaps are indicated in the table to the left of the curves. It appears that, as expected, the gap decreases the calculated velocities. It must also be concluded that for the 3-mm gap the top system is probably near optimum for the piston used.

TABLE 1. Results From Two Stage Experiments.

LENS	9501	GAP	SS	RUN	9501	GAP	SS	RUN	VEL
200	150	6.4	4.8	38	6.0	3.2	.89	13	7.3
200	150	6.4	3.1	38	6.0	3.2	.89	19	7.5
200	150	6.4	3.1	38	6.0	3.2	.71	16	8.1
300	250	12.7	6.4	64	12.7	6.4	.89	22	8.3
300	250	12.7	4.8	64	9.0	6.4	.71	19	9.2

The velocities of the second stage (under VEL) are km/s. All dimensions are in mm. The impactors were all intact for the runs indicated. There were indications that an additional few mm's of run might cause some break up.

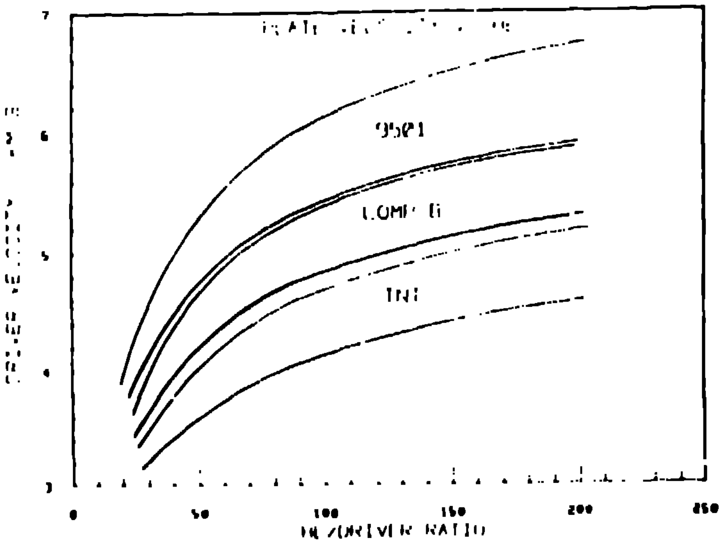

FIGURE 4. Calculated driver velocity vs. HE thickness for 9501, composition B (CB) and TNT. The top of each band represents a run/driver thickness ratio of 50, and the bottom a ratio of 10. At thickness ratios of 20 there is still substantial plate acceleration and ratios of 30 or more are recommended. The same HE driver separation was used in all calculations.

7. SUMMARY AND CONCLUSIONS

Some results of this study that can be used for designing single stage experiments are summarized in Fig. 4. By using standard materials almost any driver velocity can be obtained between 3 and 9 km/s. The use of some separation between the HE and driver is recommended. The actual amount is not critical unless the HE is very thin. Increasing the separation is preferable to reducing the length of run to decrease impact velocity. The results in Table I can be used as a guide for reaching pressures in a symmetrical SS collision that are in excess of 400 GPa.