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COMPARISONS BETWEEN FAST SHOCK TUBE CALCULATIONS AND TESTS

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Tests have been done to diagnose various aspects of the behavior of the shocked foam in the core of the fast shock tube. Calculations and test results of shock behavior in the foam are in good agreement. However, calculations with different foam equations of state differ in some details. Precursor shocks at the foam/HE interface were observed in some tests; a modified assembly procedure eliminated this problem. Calculations of shape and velocity of plates in direct contact with the foam are in relatively good agreement. Expansion of shocked foam down a barrel is complicated by perturbations from the barrel inlet and from deformed regions of the barrel. In one test, a 2.5-cm diameter by 2-mm thick stainless steel plate was accelerated to 0.78 cm/μs and remained planar for a 55-cm run through air.

1. INTRODUCTION

The Fast Shock Tube (FST) is a cylindrically convergent high-explosive (HE) system for driving a flat, axial shock in a polystyrene foam core inside the HE. The system is described by Meier and Kerrisk.[1] (A discussion of a related system is given by Menikoff and Lackner.[2]) The shocked foam, which acts like a gas, is used as a driver for gas-flow and plate-acceleration tests. This paper describes comparisons between results from FST tests and hydrocode calculations. The two-dimensional calculations were done using various Eulerian hydrocodes such as MESA 2D.[3] The comparisons are being used as a test of the ability of the codes to model the conditions in the FST.

The conditions in the foam core of the FST are controlled by the size and type of HE and the diameter, length, and density of the foam.[1] The detonation velocity of the HE (0.88 cm/μs) sets the axial shock velocity in the foam core. In the system tested, the foam is shocked to ~0.3 Mbar with a particle velocity of ~0.6 cm/μs. Driving pressures on plates of 0.3 to 1 Mbar are obtained by varying plate material and standoff distance between the end of the foam and the plate.

2. TESTING

The objective of the FST tests was to provide data on 1) the shape of the shock in the foam core, 2) expansion of the shocked foam (gas) down a barrel, and 3) acceleration of plates with the shocked foam.

Figure 1 shows sketches of two test arrangements placed at the end of the FST. The motion of plates placed directly over the HE and foam core (Fig. 1a) have been tracked with radiographs, electrical pins, or a VISAR. Flasher assemblies have also been placed directly on the end of the FST. These tests provide data about the shock in the foam at the end of the FST. Radiographs of the shock near the end of the FST have also been taken. An arrangement allowing gas expansion down a barrel and acceleration of a plate is shown in Fig. 1b. In these tests, early plate motion has been measured with point and line VISARs and later motion with radiographs.

3. SHOCK IN THE FOAM CORE

A number of equations of state (EOS) have been used to model the foam in the core of the FST. None predicts all aspects of the observed behavior of the 0.5-g/cm^3 density polystyrene. However, two EOSs, an ideal gas with $\gamma = 5/3$ and a SESAME[4] polystyrene EOS (7592) bracket the behavior sufficiently well for most design calculations.

The calculated position of the shock in the foam relative to the HE detonation wave varies with the foam EOS; it is about 3 mm ahead of the detonation front using the SESAME EOS but nearly aligned with the detonation front using the ideal gas. The

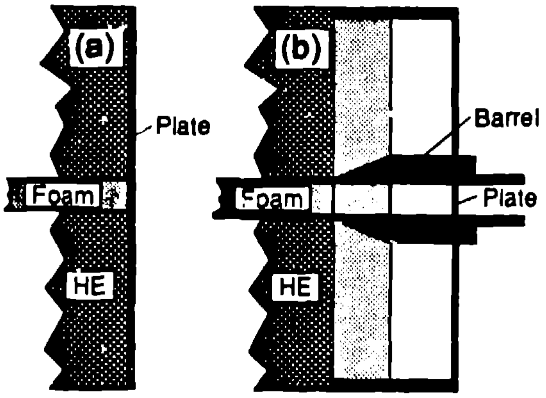

FIGURE 1
Sketches of two FST arrangements used for tests.

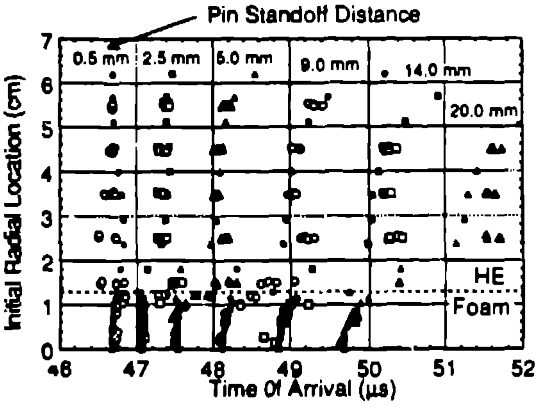

FIGURE 2
Observed (open points) and calculated (solid points) time-of-arrival data for a 3.5-mm thick titanium plate at various standoff distances from the end of the FST The testing arrangement of Fig. 1a was used.

observed (radiographs and flasher assemblies) position is between that predicted by hydrocode calculations using these two EOSs, but closer to that calculated using the ideal gas.

The shape of the shock in the foam core near the end of the FST has been observed with radiographs and with a flasher assembly The shock, running axially in the core at about the HE detonation velocity, is flat and fills the area of the foam core.[1] This behavior was also observed in tests in which azimuthal asymmetries in the HE detonation front were seen. These observations are in good agreement with hydrocode results, which indicate that a flat shock is stable in the core in spite of some asymmetries in the driving conditions.

In one test, 191 electrical pins at 6 standoff distances (0.5 to 20 mm) from the face of a 3.5-mm thick titanium plate on the end of the FST (Fig. 1a) were used to measure time of arrival (TOA) of the plate. The pins were spaced radially and azimuthally around the plate. Figure 2 shows a comparison of the observed and calculated (SESAME foam EOS) TOA data. The initial motion of the plate is flat. However, the driving conditions over the HE are less than over the foam, leading to relief waves that bow the plate at later time. The calculated TOA data are in good agreement with the observations.

The observed TOA of the HE detonation wave near the HE/foam interface (Fig. 2) shows considerably more scatter than farther out radially. This problem has been traced to precursor shocks in the gap between the HE and foam. A modified assembly procedure in which a stainless steel tube with 0.5-mm wall was located at the interface allowed an interference fit between the foam and tube, and a glue-joint between the tube and HE; this appears to eliminate the precursor shocks.

4. GAS FLOW DOWN A BARREL

Flow of the shocked foam down the 2.54-cm diameter barrel has been diagnosed by monitoring the early motion of a plate in the barrel (see Fig. 1b). A line-imaging VISAR, which records velocity across a diameter of the plate, has been particularly useful for this analysis. Figure 3 shows a plot of early plate velocity (initial motion was at 50.2 μs) as a function of radial location at four times. The VISAR data show that the edges of the plate are moving faster initially (first two times) but the calculations show the center is moving faster. At 50.9 μs the observed and calculated velocities are in good agreement, but at 51.2 μs they differ again.

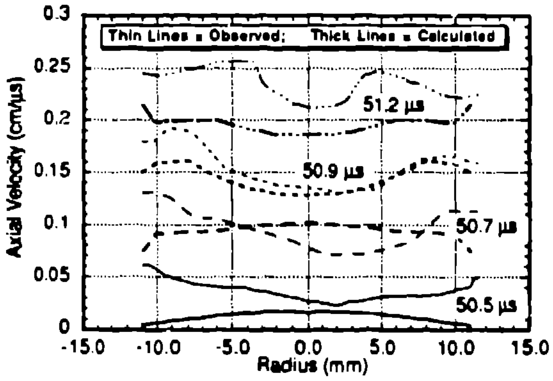

FIGURE 3
Observed and calculated axial velocity along a diameter of the plate at four times. Initial plate motion was at 50.2 µs.

Both VISAR data and calculations show various flow perturbations occurring as acceleration proceeds. Observation and calculation agree qualitatively but show quantitative disagreement on the size and timing of the perturbations. Figure 4 shows an interface plot of the barrel and plate region of an FST about 5 µs after start of plate motion; velocity vectors showing direction and magnitude of material velocity are superimposed on the upper half of the interface plot. The high velocities and pressures developed during gas expansion and plate acceleration lead to significant barrel deformation. The deformed regions of the barrel perturb the expanding gas flow. This interaction presents a difficult calculational problem that is still being addressed.

5. PLATE ACCELERATION

The previous tests were designed to diagnose FST behavior, not to fly a plate. In one test, a 2.54-cm diameter by 2-mm thick stainless steel plate in a barrel (see Fig. 1b) was accelerated to 0.78 cm/µs, allowed to fly for 55 cm, and impact a witness plate. Radiographs of the plate near the exit of the FST barrel along with the shape of the crater in

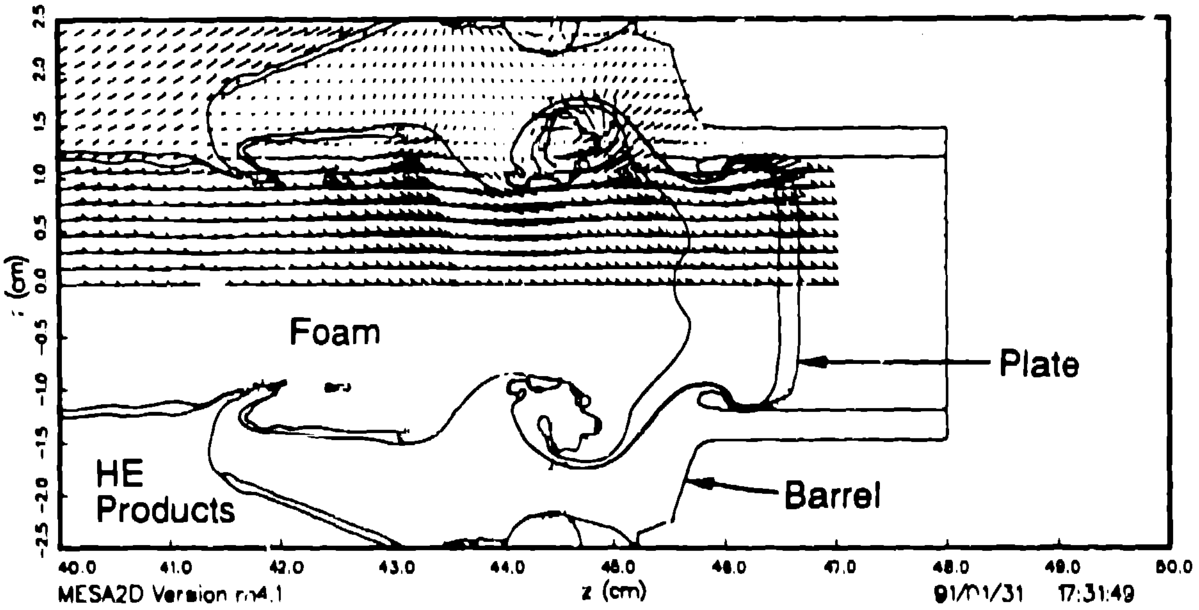

FIGURE 4
Interface plot of the barrel and plate region of the FST (from a Fig. 1b test) about 5 µs after start of motion of the plate. The velocity vectors represent the direction and magnitude of material velocity in every third computational cell. The maximum velocity indicated is 0.82 cm/µs.

the witness plate show that the plate left the barrel and flew without tumbling. A radiograph of the plate about 5 μs after it left the barrel shows that the plate is relatively flat, with some bowing forward in the center. The calculated plate shape is qualitatively similar. Figure 5 shows observed average velocities compared with calculated velocities. Results from the two foam EOSs bracket the observed results.

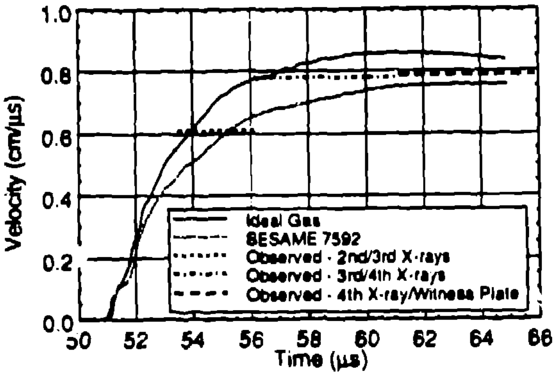

FIGURE 5
Observed and calculated velocities of a 2.54-cm diameter by 2-mm thick stainless steel plate during acceleration to 0.78 cm/μs. The testing arrangement of Fig. 1b was used

6. DISCUSSION

Calculations that model FST tests show good agreement with some aspects of FST behavior but only qualitative agreement with other aspects. The active interaction of testing and modeling has been very beneficial in developing an understanding of the physics underlying FST behavior.

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