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Analysis of a High-Explosive Shock-Tube Experiment*

H. David Glenn and Barbara K. Crowley

Lawrence Radiation Laboratory, University of California, Livermore, California 94550

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A shock-tube experiment was performed with 5.5 kg of high explosives to generate and to drive an air shock down a steel pipe 7.8-cm i.d. and $\sim$25-m length. Fiber optics and pressure transducers were installed at specific locations to record optical and pressure time of arrival of the air shock and pressure histories in the pipe. The initial $\sim$Mach 30 air shock attenuated to $\sim$Mach 6 at the end of the pipe. A numerical simulation of this experiment was performed. This paper presents the experimental arrangement and results, and briefly describes the numerical models used. The calculation results are compared with the data. During the interval of approximately 8 msec required for the shock to travel the length of the 25-m pipe, the calculations indicated that the predominant factors in attenuating the time of arrival of the shock were heat transfer and friction, respectively.

I. INTRODUCTION

A variety of high-explosive (HE) shock tubes are used[1–5] to study high-energy shock propagation and its effects. Most shock tubes are designed in one of two categories discussed in the following paragraphs.

The first category includes those shock tubes designed to remain as permanent structures.[1,2] In these tubes, the driver section is usually designed with a small portion of its volume filled initially with HE. The effective driver pressure for shock propagation in these tubes is generally an order-of-magnitude below the detonation pressure, and shock velocities are considerably below detonation velocities.

The second category includes those tubes designed with the HE outside the driver section, and these are not permanent structures. When the HE burns, a driver plate moves[4,5] or the walls of the driver section collapse[3] to act as a piston on the gas existing in the driver section. Such designs can produce shock velocities two to five times the detonation velocities of the HE. However, a significant high-pressure region which could sustain these velocities does not generally exist behind these shocks.

A middle region [i.e., 0.1–1.0-cm/μsec shock velocities, 0.1–1.0-kb shock pressures, high-pressure (1–3 kb) retention (>100 μsec) in the driver section, etc.] exists between the above two categories.

A HE experiment was designed and conducted to study shock propagation in a long steel exit pipe ($\sim$25 m, 7.8 cm i.d.) containing the driven gas, atmospheric air. The present design has the advantages of (1) being able to impart enough energy to the driven gas of atmospheric air to generate shocks of 1.0 cm/μsec, (2) retaining high pressures in the HE driver section, (3) having a length-to-diameter ratio of >300, and (4) being a simple geometry which is readily adaptable to numerical simulation with existing time-dependent finite-difference codes. An accurate numerical simulation provides a calculational reproduction of the complete temporal and spatial history of the flow variables.[6]

This paper presents the data from the above experiment. The numerical models and calculations are presented, and the agreement between experimental data and calculations is shown. This paper demonstrates that experiments combined with numerical simulation can provide considerable information not obtainable by either purely experimental or analytical approaches.

II. EXPERIMENTAL ARRANGEMENT

The shock-tube assembly and associated diagnostic instrumentation are depicted schematically in Fig. 1. A detonator and a plane-wave lens were used to initiate uniform burn in a 60-cm straight cylindrical section

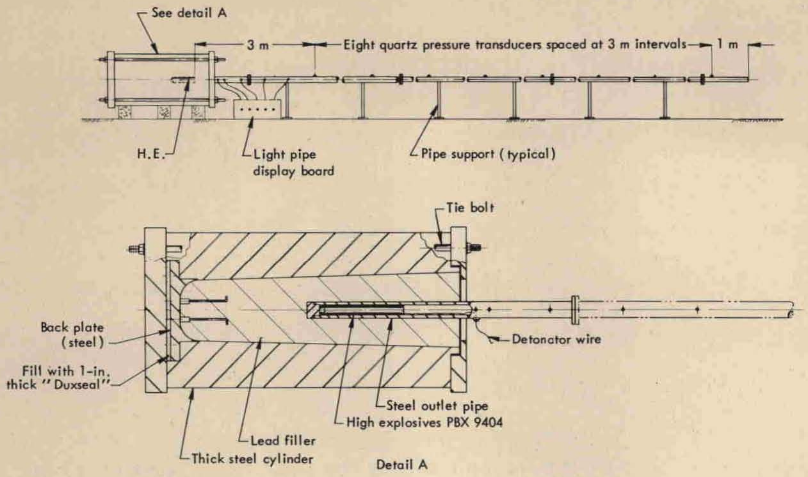

FIG. 1. HE shock-tube assembly and diagnostic coverage.

of HE (5.5-kg nitromethane PBX 9404 with a detonation velocity of $\sim$8.8 mm/μsec). When the burn reached the end of the HE ($\sim$80 μsec), an air shock was initiated in the outlet pipe. The propagation of the air shock was monitored by optical and electronic diagnostics at regular intervals along the outlet pipe.

The detonated HE section $\sim$7.8 cm diam and 60 cm long is the driver gas. High pressures in the driver section were retained by surrounding the HE with a high-density material (i.e., lead) and a thick steel cylinder.

The outer steel cylinder which enclosed the lead had a sufficiently high yield strength to restrain radial motion of the outer boundary of the lead cylinder. No direct radial path existed for the escape of HE gases. Motion of the lead in the axial direction was restrained by steel end plates secured by long 5-cm-o.d. steel rods (see Fig. 1). To detect and to record any physical motion or possible venting, front and rear portions of the HE housing were monitored by high-speed framing cameras.

Four light pipes[7] (fiber optics) were positioned at 60-cm intervals along the outlet pipe and a fifth (at 70 cm) was fitted with an aluminum reflector to view the front surface of the HE. The initiation and time of arrival (TOA) of the air shock for the first 2.4 m was determined with the above five light pipes. The light pipes were recessed in the steel wall about 3 mm and viewed the base through a 1-mm aperture in the wall. The light pipes were brought radially out of the outlet pipe and tied into a small display board. The luminosity associated with the shock front was transmitted via the light pipes to the display board which was scanned for approximately 500 μsec with a streaking camera. The light-pipe measurements provide an accurate means[5,8] of obtaining the shock arrival over the first several meters.

Eight standard Kistler quartz pressure gages were

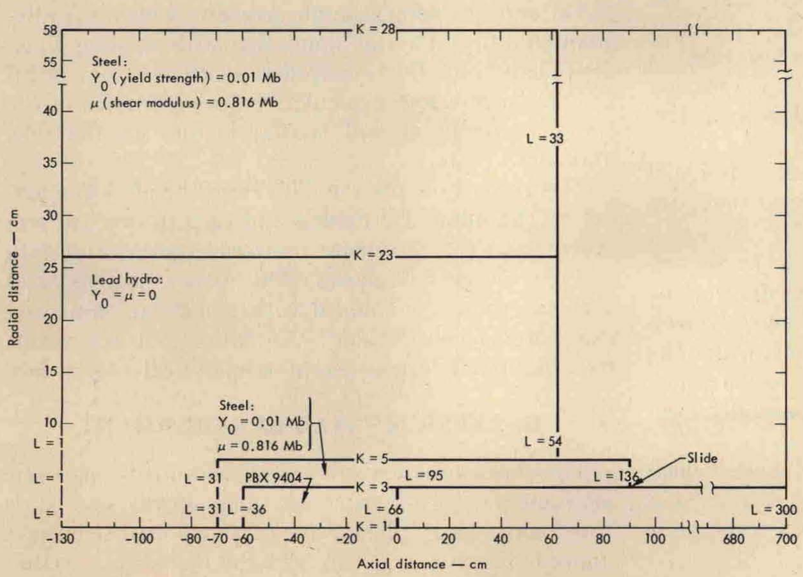

FIG. 2. Model used in HEMP numerical simulation of shock-tube assembly shown in Fig. 1. Horizontal (L) and vertical (K) zoning, yield strengths, and shear moduli assumed for different material regions are identified.