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Recent Experiments on Heterogeneous Detonation Waves

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Introduction

THIS Note presents some recent results of an ongoing study of the blast wave initiation and propagation of cylindrical heterogeneous detonation waves. Particular aspects of interest in this study are the details of and the initiator energy required for the initiation of detonation, the characteristics of the wave propagation, the influence of physical and chemical properties of the fuel, and wave propagation through a cloud which is nonuniform in fuel-oxidizer ratio.

The experimental facility employed is essentially the same as that described earlier[1,2] so that only a cursory description will be given here. The sectored shock tube, shown in Fig. 1, is designed to model a sector of a cylindrical combustible cloud. The angle of the sector is 20 deg, the "height" of the cloud (distance between the side walls) is 5.2 cm, and the radius is about 140 cm. The fuel drops are dispersed throughout the gaseous oxidizer by flowing the liquid fuel through as many as 322 needles and pulsing this flow at about the Rayleigh frequency. With the current size of needles in use, the resultant uniform drop size is about 400 μm. The cylindrical blast wave is formed by firing a blasting cap (Dupont E-106) and a measured amount of condensed explosive (Dupont Detasheet C). The propagation of the wave in the radial direction is monitored by 14 time-of-arrival pressure switches. This position-time data can then be converted to velocity vs radius information.

The chamber was operated with 42 rows with seven needles (0.02 cm i.d.) per row. For the oxygen case, the fuel flow was maintained constant and the air replaced by oxygen. As a consequence, the mixture ratio was quite lean in the oxygen studies. The theoretical Chapman-Jouguet detonation velocities, as calculated by the Gordon-McBride program[3] where the fuels were assumed to be in the gaseous phase but the enthalpy of formation used was that of the liquid, were 1810 and 1876 m/s for kerosene in air and oxygen, respectively, or 1850 and 1812 m/s for 75/25 kerosene + NPN in air and oxygen, respectively.

Experimental Results

A series of experiments was conducted whereby strong blast waves, generated by various amounts of condensed explosives, propagated into sprays of kerosene droplets in air and in oxygen. In the case of sprays in air, detonation waves were not attained and the blast waves in the sprays attenuated even faster than blast waves in air alone (no droplets). In the case of sprays in oxygen, detonations were attained even for the lowest initiation energy used.

Figure 2 represents results for various run conditions for a constant initiation energy level. As can be seen, the blast wave in air (no fuel) is somewhat faster than the reacting blast wave (no detonation) in kerosene and air, which, in turn, is only slightly faster than a blast wave propagating in kerosene spray in nitrogen (not shown on Fig. 2). These results indicate the attenuating effect of the droplets on the blast wave. The blast wave in a spray of kerosene in oxygen decays to a constant velocity of 1600 m/s, indicating that detonation has been attained but at a lower velocity than theoretical (1876 m/s).

Some further experimental results in kerosene-oxygen for different energy levels are shown in Fig. 3. It can be noted that the higher energy levels produce stronger blast waves which

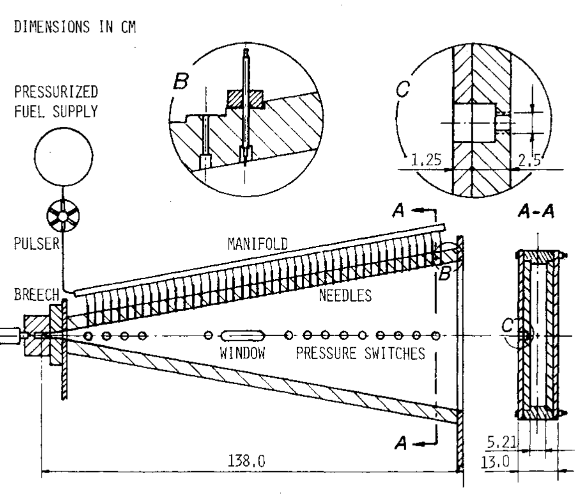

Fig. 1 Schematic of detonation chamber.

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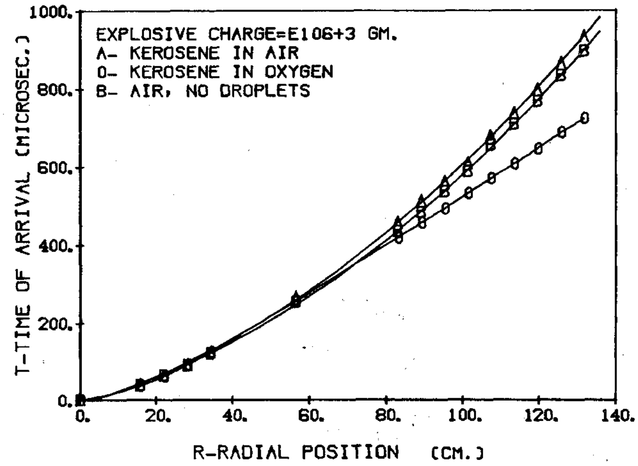

Fig. 2 Blast and detonation waves.

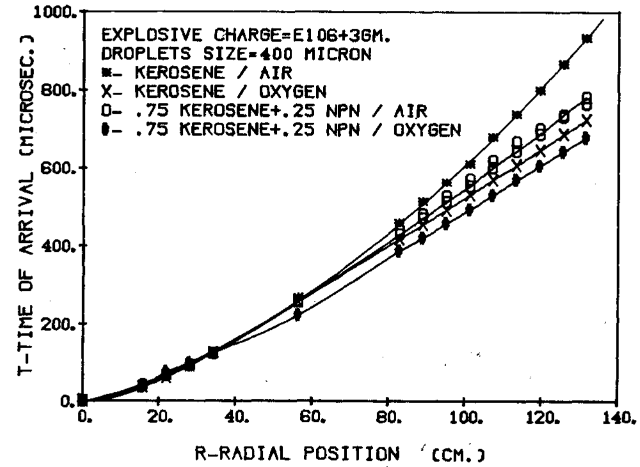

Fig. 4 Effect of the addition of NPN as sensitizer.

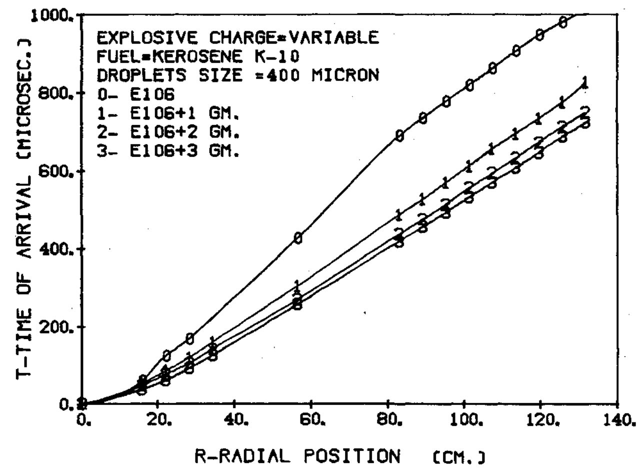

Fig. 3 Detonations of kerosene sprays in oxygen.

decay to a constant velocity, presumably the detonation velocity. Curves 2 and 3 show almost the same velocity of 1560 and 1595 m/s, respectively. Curve 1 reaches a slightly lower velocity of 1450 m/s. In the case of the blasting cap alone, initial decay of the blast wave can be observed but fast acceleration to detonation occurs in the second half of the chamber, and the final velocity seems to be about the same as for the larger charges (1475 m/s). It seems obvious that at larger distances all of those detonation waves will attain the same velocity. The measured velocities in all the runs were 15-22% lower than the theoretical value for an equivalent premixed all gaseous mixture. The lower detonation velocities are attributed in part to heat and drag losses to the walls of the chamber and in part to the incomplete combustion of the liquid droplets.

Further experiments were conducted wherein the kerosene was sensitized by the addition of 25% (by volume) of normal propyl nitrate (NPN). The results are shown in Fig. 4 wherein the energy level was the same for every run. Two curves for the nonsensitized case, shown earlier, are included for comparison. Two separate runs are shown for sensitized kerosene-air. In one case the smooth curve shown indicates constant velocity, or detonation. However, the indicated velocity, 1350 m/s, is low and there is some doubt that detonation occurs. The open circles for the other run, not connected by a curve, are above the curve except at about 115 cm a rapid acceleration of the wave is indicated. It is concluded that this kerosene-NPN-air mixture is close to detonation for this energy level and that higher initiator energies would produce detonation. Finally, the sensitized kerosene-oxygen mixture is seen to accelerate more rapidly to detonation conditions than in the unsensitized case. The observed velocity of 1660 m/s is again somewhat lower than the theoretical one (1812 m/s) and slightly higher than the nonsensitized case.

Acknowledgment

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Axisymmetric Transonic Flow Past Slender Bodies by an Integral Equation Method

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Introduction

THE transonic small perturbation equation for inviscid flow past thin airfoils and slender bodies can be transformed into an integral equation for perturbation potential by the application of Green's theorem.[1,2] The integral equation

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