JOURNAL OF PROPULSION AND POWER
Vol. 19, No. 4, July–August 2003

Detonation Initiation by Controlled Triggering of Electric Discharges

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It has been proved experimentally that the use of a sequence of relatively weak igniters with properly tuned triggering times allows one to initiate detonation in premixed propane–oxygen-enriched air and propane–air mixtures at distances as short as 0.6–0.7 m in a 2-in.- (51-mm-) diam tube at normal initial conditions. Simple one-dimensional calculations have been used to get better insight into the mechanism of detonation onset. The proposed technique of detonation initiation presents a promising approach for pulse detonation engine applications.

Introduction

ONE of the most challenging problems encountered in the development of pulse detonation engines (PDEs) is detonation initiation in fuel–air mixtures at distances that are feasible for propulsion applications. As is well known, detonation occurs via a transient stage of strong coupling between the shock wave and the shock-induced reaction in the explosive medium.

This paper deals with a promising technique for detonation initiation that is based on the necessity of the strong coupling between a shock wave and energy deposition. Fundamentally, it does not matter how the energy is deposited into the postshock flow: spontaneously, due to shock-induced chemical reactions, or by means of inducing chemical reactions with an external energy source. In the former approach, due to the high activation energy of exothermic chemical reactions in fuel–air mixtures, shock waves of high amplitudes and proper durations are required to ensure the coupling. Such shock waves can be obtained by means of exploding high-explosive charges with a mass exceeding 20–30 g. The latter approach implies the use of an external energy source to induce artificially exothermic reactions closely behind a relatively weak shock wave to stimulate the strong coupling. Clearly, in this case the external energy source should be distributed rather than concentrated and should provide pulse or continuous coupling of energy deposition with a propagating shock wave.

Originally, the idea of using external sources to drive a detonation came from Zel'dovich and Kompaneetz.[1] They have shown theoretically that motion of an ignition source in a compressible reactive mixture at the characteristic detonation velocity would result in formation of a self-sustaining detonation in a long run. To model the moving ignition source, Zel'dovich and et al.[2,3] considered the nonuniformly preconditioned reactive mixture, implying that the initial gradient of autoignition delay time will produce a similar effect. As a matter of fact, it has been proved computationally that temperature and composition nonuniformities in the reactive mixture preconditioned to auto ignition may result in spontaneous onset of detonation. Thibault et al.[4] reported their one-dimensional numerical study of the situation when the external energy source traveled at a constant velocity in an inert compressible medium. It has been proved that the strength of the shock wave arising in the medium depends on the energy source velocity and attains a maximum value when this velocity approaches the characteristic detonation velocity based on the specific energy (per unit mass of gas) deposited by the source, that is, substantiated the original idea of Zel'dovich and Kompaneetz computationally. Later, Yoshikawa et al.[5] extended the analysis to take into account coupling between the moving energy source and the shock wave. Lee and Moen[6] have suggested the concept of shock wave amplification by coherent energy release and applied it to explain qualitatively the experimental findings in photochemical initiation of detonation (Lee et al.[7]), detonation initiation by injecting hot turbulent jets into explosive mixture (Knystautas et al.[8]), and explosion in the explosion phenomenon during deflagration-to-detonation transition (DDT) (Oppenheim[9]). Shepherd and Lee[10] and Khokhlov et al.,[11] among others, further generaled the issue. So far, there has been no direct experimental substantiation of the ideas and mechanisms discussed.

The objective of this paper is to describe experimental studies of the possibility to accelerate a weak shock wave efficiently by in-phase triggering of distributed external energy sources (electric discharges) in the course of shock wave propagation along the tube filled with a nonreactive or reactive mixture. The research discussed herein has been partly summarized in Ref. 12. The results of simple one-dimensional simulations are included to better understand the accompanying phenomena.

Experimental Setup and Procedure

Figure 1 shows the experimental setup. A detonation tube (Fig. 2) is 2 in. (51 mm) in inner diameter and 1.5 m long with closed ends. The tube comprises a booster section 1.0 m long and a test section 0.5 m long connected by means of a flange. The booster section is equipped with 11 lateral ports for electrical igniters and 1 port for the aft igniter, 10 pressure transducers, and the opening for feeding a test mixture. The lateral ports for igniters are flush mounted to the tube at an angle of 45 deg as shown in Figs. 1 and 2. In cross section 1 (CS1), there are two ports for lateral igniters positioned opposite to each other. The axial distance between successive lateral igniters is 100 mm. The axial distance between the aft igniter and the igniters in CS1 is 26 mm. The test section is equipped with ports for pressure transducers and ionization probes and the opening for evacuating the tube. The distance between successive ports for the pressure transducers is 100 mm.

Three types of igniters were applied allowing one to produce electric discharges of various duration and intensity (Fig. 3). Igniters of

Received 23 October 2002; revision received 24 March 2003; accepted for publication 3 April 2003.

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