Nonclassical detonation and deflagration transmissions into half-limited space

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1 Introduction

Point explosion by different energy sources (high explosive materials, laser radiation, high-voltage discharge, etc.) and detonation transmission from the smaller-diameter various cross-sections tube are usually considered as standard means of detonation initiation in the half-limited space. Theoretical and empirical correlations, in particular, for direct detonation initiations and transmissions are proposed in the literature for estimation of the critical energy of direct initiation [e.g., 1-6] and conditions for successful transmission events [7-12].

The mentioned initiation means require the using of high-energy initiation source or already formed nonmarginal detonation with a cell size at least one order of magnitude smaller than the diameter of initiating tube. At the same time, for a number of applications the significant reducing of critical energies, tube diameter and mixture sensitivities are required for improving the overall effectiveness of system. One of the probable scenario is the onset of detonation in volume is a consequence of the deflagration to detonation transition (DDT) event in the vicinity of output from smaller tube to the volume.

The objective of this work was to elucidate the effectiveness of transmission of shock wave – deflagration for detonation initiation in a half-limited space.

2 Experimental setup

Experiments were carried out in a 2.76 m driver tube of 30 mm inner diameter attached to a stainless steel detonation vessel (test volume) of 142 mm inner diameter and 0.4 m long (figure 1). Such geometry provided the area expansion ratio $D^2/d^2 = 22.4$ where D is the diameter of the vessel and d is the inner diameter of the driver tube. A stoichiometric propane-oxygen mixture with 25 % of nitrogen dilution at wide range of initial pressures used as a test gas. A 50-cm long end section of the driver tube was equipped with 20 ionization probes for reaction flow velocity measurements. The probes were situated in four lines along the tube axis. The distance between each probe was 90 mm or three tube diameter. Five pressure transducers were located at the same cross sections (figure 1) with ion probes and simultaneously controlled an intensity of a leading shock wave. This setup allowed determining the following important parameters of emerging shock wave – reaction front complex:

- Velocity of the reaction and shock fronts;
- Spatial shape of reaction front;
- Length of the detachment zone between leading shock and reaction fronts.

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For detection of resultant transmission scenario, a test volume was equipped with two pressure transducers and ion probes located at a distance of 125 mm from the exit plane of the driver tube; the distance between them was 100 mm (figure 1).

For optical transmission observations, the plastic transparent window was mounted into the exit flange of test volume. A “Dicam pro” high-speed CCD camera was used to visualize transmission & initiation processes. Visualization was done with using doubled narrowband monochromatic filter at wavelength of 430.4 ± 1.3 nm that corresponded to the luminosity of CH radicals.

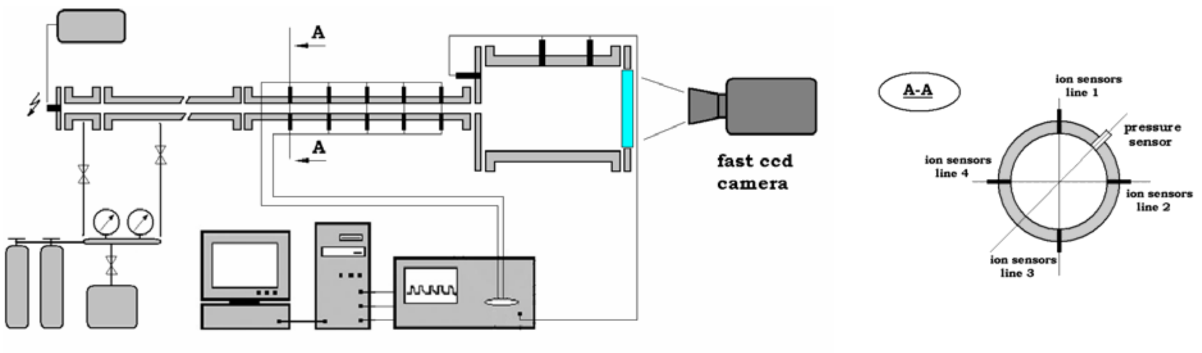

Figure 1. Experimental setup.

3 Results & discussion

Several transmission scenarios depending on the initial conditions and initiation regimes in the driver tube were observed in our experiments. There are the transmissions of a shock wave followed by accelerating deflagration or detonation, detonation and overdriven detonation transmissions.

Figure 2 and 3 presents momentary short-exposure photos and corresponding X-t diagrams and velocities of shock and reaction fronts in driver tube directly before the transmission into detonation vessel. Figures 2a and 2b show transmissions of overdriven detonations at velocities 2650 m/s (fig. 2a) and 2570 m/s (fig. 2b). For these initial conditions C-J velocity was near 2180 m/s. Time of a single exposure was 100 ns, and delay time between two frames was 10 µs.

Figures 3a and 3b demonstrate transmissions of shock wave followed by accelerating deflagrations at velocities 1250-1300 m/s. The exposure was 200 ns, and delay time between two frames was 10 µs.

For all described above experiments detonation initiation in main vessel was successful. The initial pressures ranged from 0.26 to 0.28 MPa. As it is seen from X-t diagrams, for transmissions of shock wave/reaction front complex the distance between leading shock front and following reaction front was up to 56 mm or almost 2 tube diameter (56 mm – fig. 3a and 44 mm – fig. 3b). It was shown that the shape of reaction front was not plane and had the form of “tongue”, which was extended along the tube axis and oscillated in the transverse directions. The mean “tongue” length was nearly equal to the tube diameter (32 mm – fig. 3a and 16 mm – fig. 3b). It should be mentioned that for some experiments the “tongue” length of several (3 - 4) tube diameters have been registered

The direct CJ detonation transmissions tests showed that for studied stoichiometric propane-oxygen mixture with 25 % of nitrogen dilution the critical initial pressure required for successful detonation re-ignition in the main detonation vessel was equal to 0.88 MPa.

4 Conclusions

It was found that the transmission of a nonstationary complex of a shock wave followed by deflagration into a semi-confined area could essentially facilitate the following detonation re-ignition and reduce the sensitivity and requirement for driver tube mixtures. The transmission of such a complex (also as transmission of overdriven detonation) could produce the successful detonation initiation in a large volume, at least, three times lower initial pressure than for the classical direct detonation transmission case.

Visualization and explanation of the different non-classical transmission scenarios will be presented.

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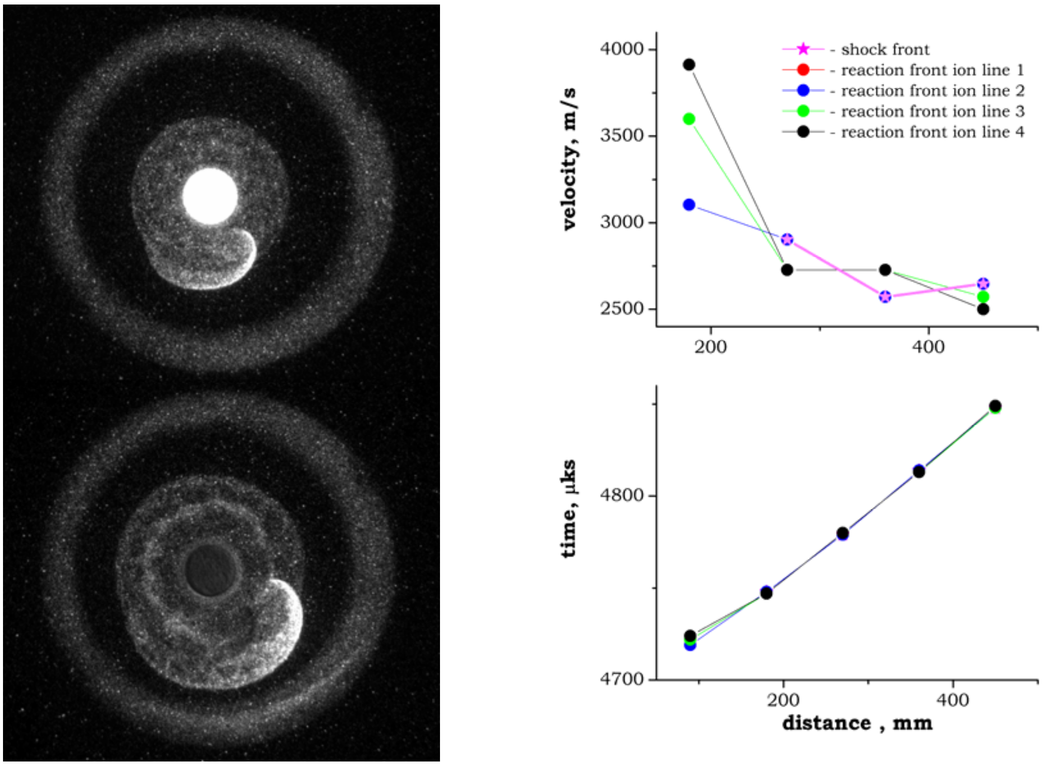
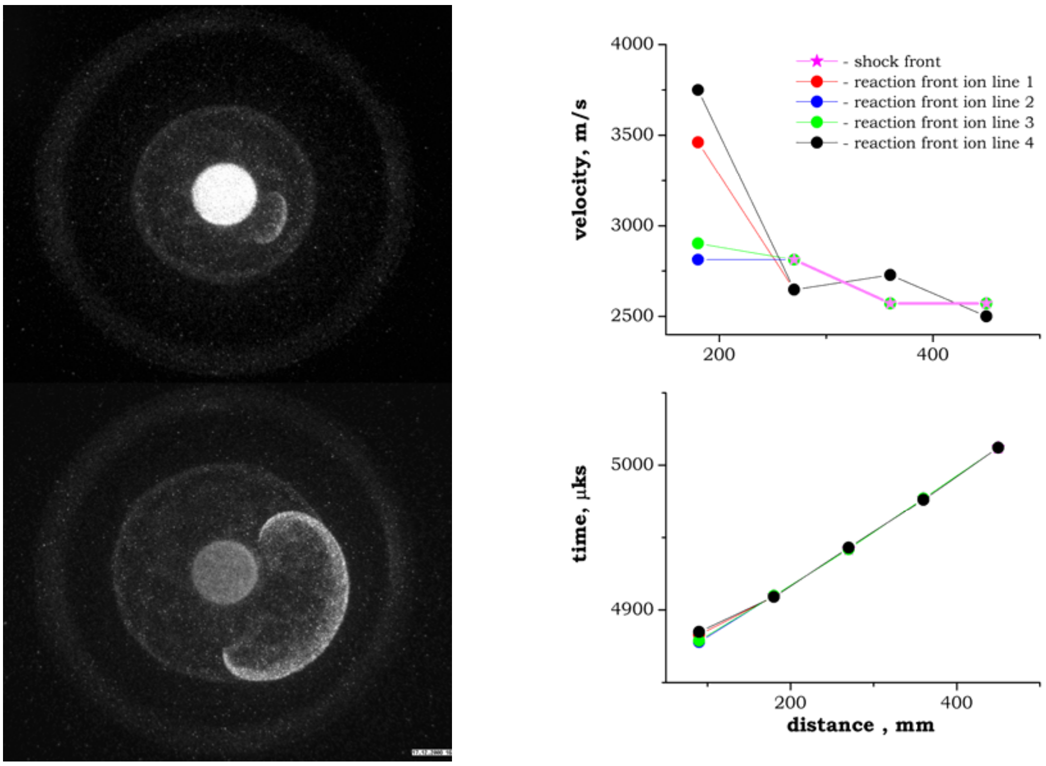
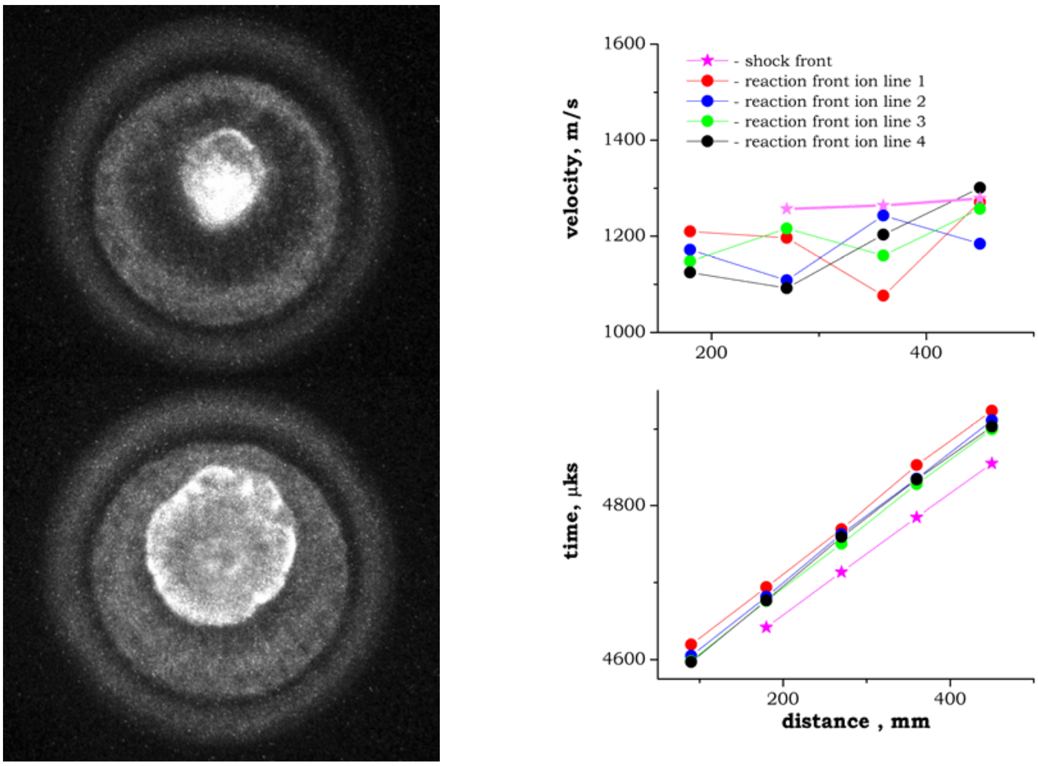


A)

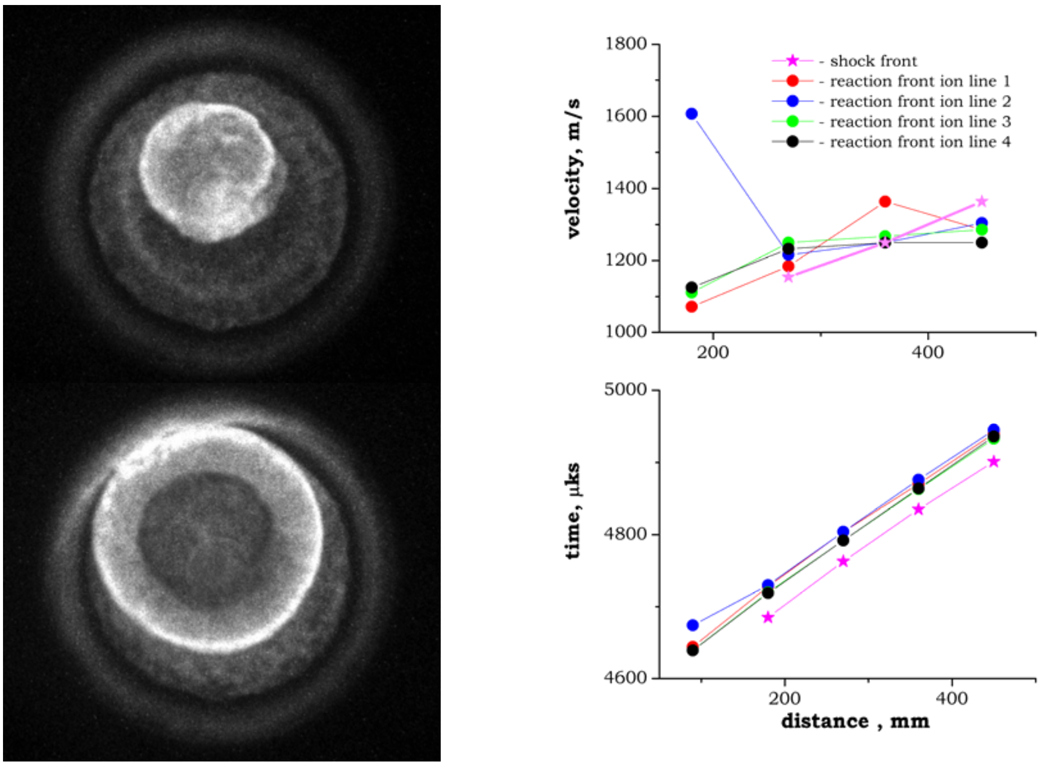


B)

Figure 2. Transmission of overdriven detonation. Momentary short-exposure photos and corresponding X-t diagrams and velocities of shock and reaction fronts in driver tube directly before the transmission.



A)



B)

Figure 3. Transmission of shock front / reaction complex. Momentary short-exposure photos and corresponding X-t diagrams and velocities of shock and reaction fronts in driver tube directly before the transmission.