SHOCK WAVE INITIATION OF PULSATING DETONATION IN A CHANNEL PARTIALLY FILLED WITH ALUMINUM PARTICLE GAS SUSPENSION

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1. FORMULATION OF THE PROBLEM

The paper focuses on numerical investigation of two-dimensional detonation flow in a channel filled on a part of width with aluminum particle gas suspension. Specific features of shock wave propagation over the cloud of incombustible particles and detonation initiation with supported shock wave action of large amplitude were considered in [1-2]. It was obtained that the propagation of the combined wave (consisting in the shock wave in gas and the detonation wave in the cloud) has a periodic character due to the transversal wave passing and multiple reflection from the channel walls. The present study concerns two cases. The first case is weak supported initiating shock wave which propagation velocity is less than the Chapman-Jouguet velocity in the mixture. The objective is to analyze the character of detonation initiation and the combined shock/detonation wave propagation. The other case is an action of a real shock wave accompanied by adjacent rarefaction wave. Here the purpose is to reveal the influence of the cloud width on detonation initiation and to examine the resultant detonation regime.

We consider a plane channel filled with gas and on a part of width occupied with a cloud of aluminum particles dispersed in oxygen. The semi-infinite cloud is situated adjoining the bottom channel wall and initially has a rectangular shape. The planar shock wave moving from left to right and entering the cloud is considered as initiating factor of detonation. The problem formulation is similar to one presented in [1-2]. Two types of the incident shock waves are in consideration: supported shock wave ($M_0=4$), and attenuated shock wave of sufficient amplitude and energy to initiate the detonation.

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The mathematical model of detonation in aluminum particle oxygen suspension verified by experimental data on detonation velocity and other characteristics was developed and analyzed in [3]. The numerical technique was tested on problems of plane detonation wave propagation and applied to calculations of one-dimensional detonation initiation in the cloud [4]. It includes a TVD-scheme for gas and the MacCormack scheme for the particle phase. The calculations were performed for particles of 5 μm in size and initial relative mass concentration 0.55 (that corresponds to 1.357 kg/m^3). The CJ velocity in the mixture is 1.56 km/s. The channel width is 10 cm, the cloud width D varies from 2 to 8 cm. The results of computations are presented in (x,y) plane, where x and y are evaluated in meters.

2. SUPPORTED INCIDENT SHOCK WAVE (M_0 =4)

The propagation velocity of the shock wave in gas at M_0 =4 is 1.38 km/s that is less than the detonation velocity in the cloud of particles. In one-dimensional formulation the supported incident shock wave entering the cloud excites an overdriven detonation. The present calculations show that the front propagation and the detonation flow in the channel have sufficiently non-stationary character with certain periodicity. The averaged in time propagation velocity in the cloud of 2 cm in width is about 1.5 km/s being rather less than the normal detonation velocity (1.56 km/s). The process does not decay in clouds of 2 cm width or wider at least to 1.5 ms that is confirmed in Fig. 1, which presents the pressure profiles on the bottom wall (y=0).

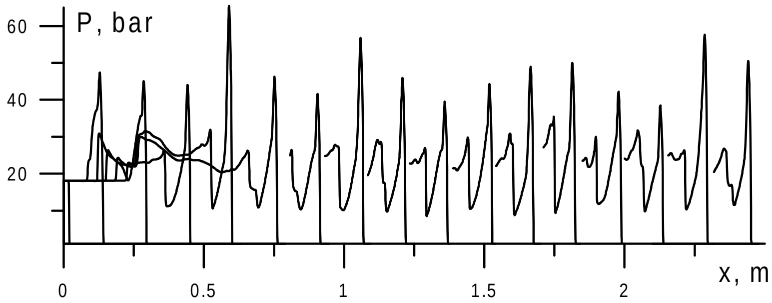

Figure 1. Detonation formation at supported incident SW; M_0=4, D=4 cm, Δt=0.1 ms.

The detonation flow is characterized with vortex structures that causes an instability of the surface of the cloud of unburnt particles in the detonation products. It is seen in Figs. 2 where an instantaneous gas temperature shaded relieves (parameter surfaces alight from the left) (*D*=2 cm) and particle density shadow images (*D*=4 cm) are plotted with some time steps. A certain periodicity of the front shape and flow structure is obvious.

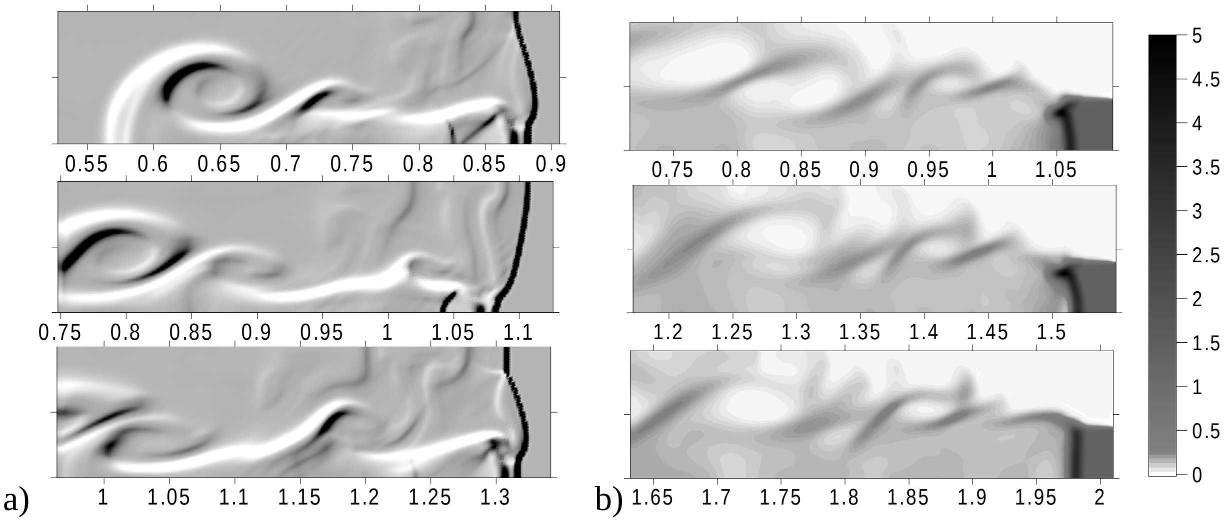

Figure 2. Flow fluctuations at the combined shock/detonation wave propagation (the supported incident SW, M_0=4; a) gas temperature; b) particle density.

The governing factor of non-stationary pulsating character is the transversal wave passing and reflections from the channel walls as in the case of strong supported incident SW [1-2]. This specific feature is similar to the cellular detonations, although here the detonation-like structure in the cloud is supported with the shock wave in gas.

2. REAL INCIDENT SHOCK WAVES

If the incident shock wave is attenuated with an adjacent rarefaction wave the detonation formation depends on its amplitude and reserved energy (the one-dimensional initiation criteria are presented in [4]). The cloud width is an additional factor of detonation formation in two-dimensional case. In thin clouds the detonation-like structure forms but then disintegrates to the leading shock and lagging combustion front due to lateral weakening. In sufficiently wide clouds the detonation structure forms and propagates along the channel joining and supporting the shock wave in gas. The flow structure is shown in Fig. 3 where gas pressure and particle density instantaneous pictures are plotted with 0.2 ms. The front shape and the flow behavior are characterized with fluctuations and the periodicity is obvious from comparing the upper and the bottom plots of Fig. 3. The averaged value of the propagation velocity is about 1.55 km/s being slightly less than the CJ velocity (1.56 km/s). The possibility of two-dimensional detonations with propagation velocity smaller than the CJ one was also obtained for cylindrical tube partly filled with a monofuel mixture in [5].

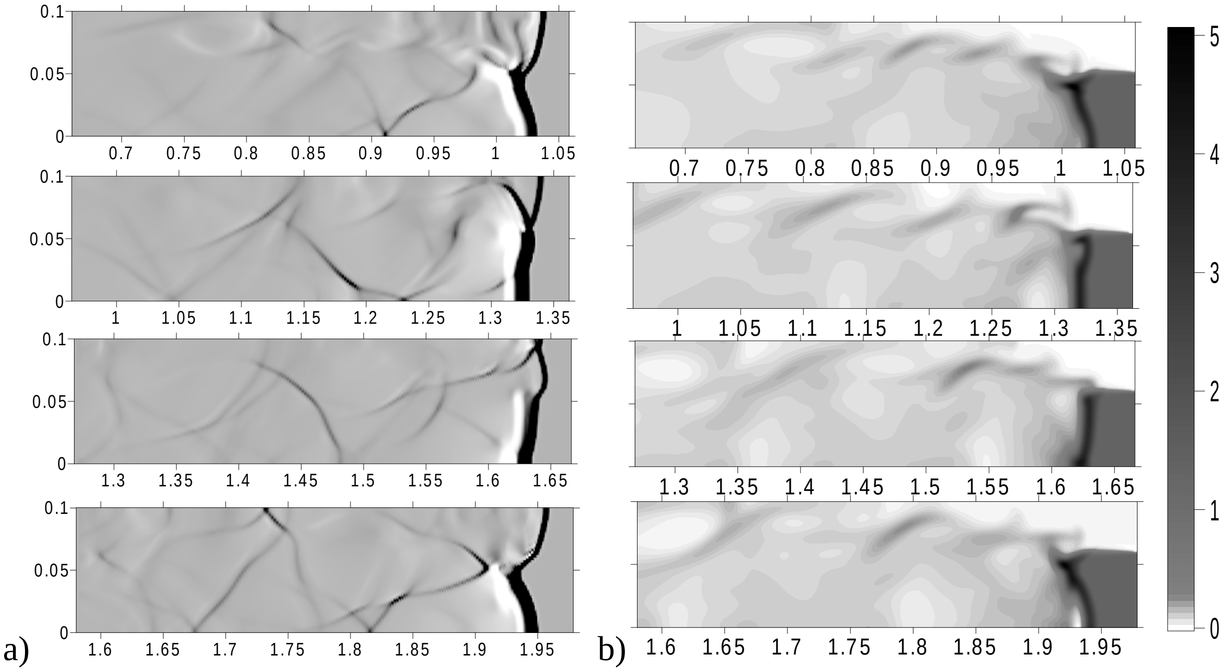

Figure 3. Flow structure behind the combined shock/detonation wave, M_0=5, D=6 cm; a) gas pressure (shaded relieves); b) particle density (shadow images).

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