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Detonation waves in the channels containing obstacles

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Abstract

The numerical investigation of detonation propagation in the plane encumbered channels filled by stoichiometrical hydrogen-air mixture under normal conditions has been carried out. The formation of cellular detonation in the plane channel and influence of rigid wall (barrier) placed in the channel to the propagation detonation has been studied. The behaviour of the cellular detonation in the case of sudden widening of the channel cross section has been considered too. The critical parameters for detonation propagation, restoration and destruction have been determined.

Examination of initiation and propagation of detonation is one of fundamental branch of the gas dynamics. Detail information about features of these processes is very important for solving the problems connecting both with prevention of detonation regimes of combustion to increase the blast safety and with applications of detonation to technological processes. In the present research the numerical investigation of detonation propagation in the plane encumbered channels filled by stoichiometrical hydrogen-air mixture under normal conditions is carried out. Detonation is initiated by the electrical discharge of narrow layer form near the closed end of the channel. It is supposed the electrical energy is transformed instantaneously into internal energy of gas mixture.

The system of equations describing plane two-dimensional flows of non-viscous gas mixture is as follows:

$$\frac{\partial \rho}{\partial t}+\frac{\partial (u\rho)}{\partial x}+\frac{\partial (v\rho)}{\partial y}=0$$

$$\frac{\partial (\rho u)}{\partial t}+\frac{\partial (\rho u^2+p)}{\partial x}+\frac{\partial (\rho uv)}{\partial y}=0$$

$$\frac{\partial (\rho v)}{\partial t}+\frac{\partial (\rho vu)}{\partial x}+\frac{\partial (\rho v^2+p)}{\partial y}=0$$

$$\frac{\partial(\rho(u^2+v^2)/2+\rho h-p)}{\partial t}+\frac{\partial(u(\rho(u^2+v^2)/2+\rho h)}{\partial x}+\frac{\partial(v(\rho(u^2+v^2)/2+\rho h))}{\partial y}=0$$

$$\frac{\partial (\rho n_i)}{\partial t}+\frac{\partial (u\rho n_i)}{\partial x}+\frac{\partial (v\rho n_i)}{\partial y}=\rho\omega_i,$$

where x and y are the Cartesian coordinates; u and v are the corresponding components of velocity; t is time; ρ, p and h are density, pressure and enthalpy, respectively; n_i is the molar concentration of the i th component of mixture; ω_i is the rate of formation/depletion of the i th component.
The equations of state for the hydrogen-air mixture have the usual form

$$p=\frac{\rho R_0 T}{\mu},\qquad h=\sum n_i h_i(T),\qquad \mu^{-1}=\sum n_i,\qquad i=1,2,\ldots 8.$$

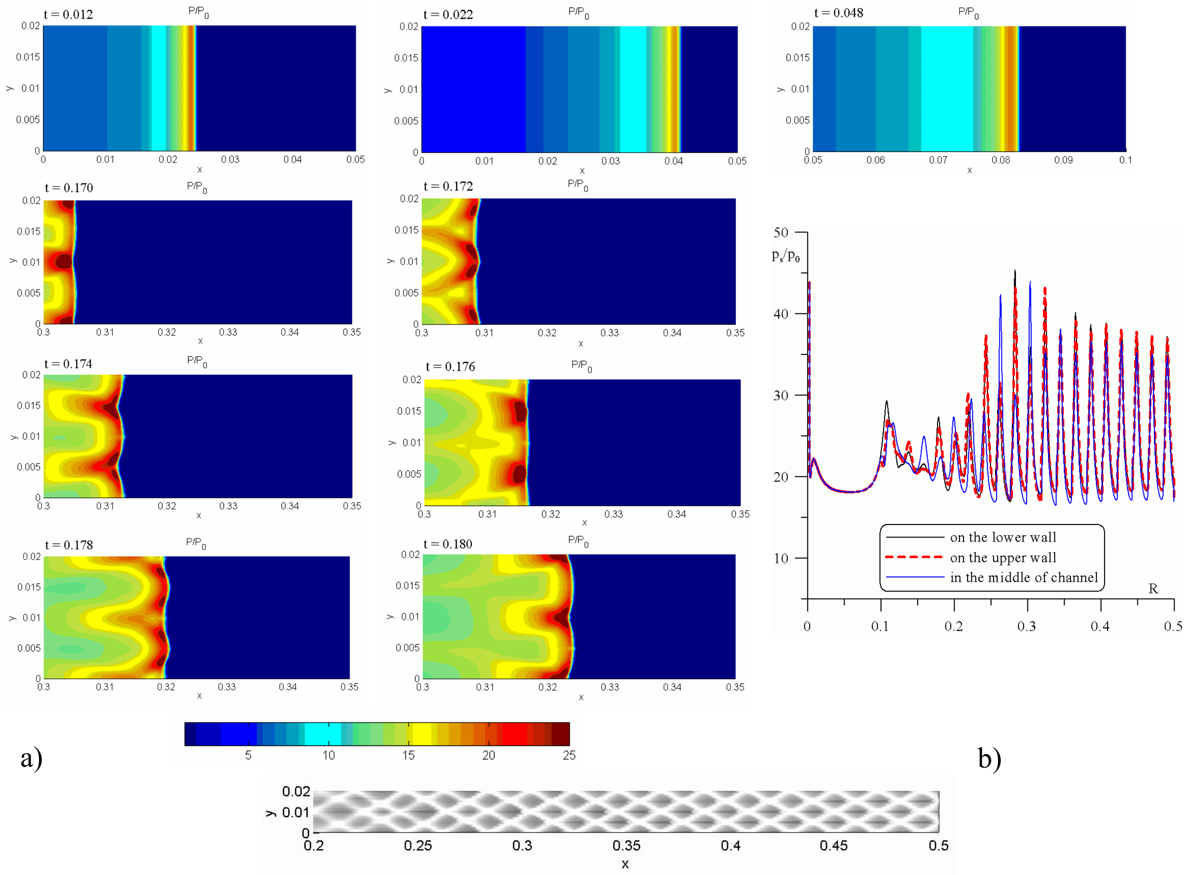
Here T is the temperature, R_0 is the universal gas constant. The values of the partial enthalpies $h_i(T)$ are borrowed from [1].

The set of gas dynamic equations jointly with the set of chemical kinetic equations [2], which takes into consideration principal features of chemical interaction of hydrogen with oxygen, was solved by a finite-difference method based on the Godunov's scheme [3].

Numerical Results

The propagation of formed detonation wave in the plane channel with parallel walls was examined. It has been established that the plane detonation front is curved with time due to instability of the combustion zone and the cellular detonation structure is formed (figure 1).

Let us note the number of detonation cells is determined by the channel width under others conditions being equal (figure 2). This fact is made agree with the experimental research [4].

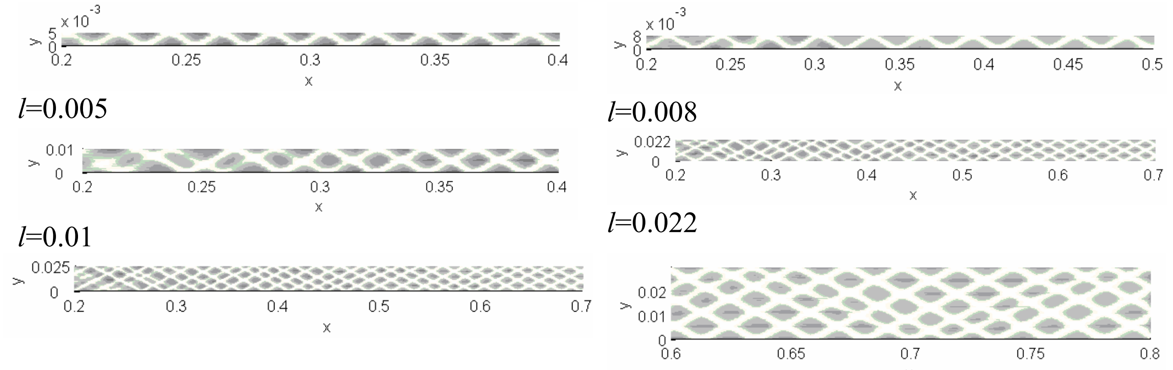


a)

b)

c)

Figure 1. Formation of cellular detonation in the plane channel: time variation of pressure fild (a), the pressure dependencies from the wave coordinate at the some points of front (b) and the trajectories of triple points (c)



l=0.005

l=0.008

l=0.01

l=0.022

l=0.025

l=0.03

Figure 2. Formation of cellular detonation in the plane channels of different width

The propagation of detonation wave in the channel with undestroyable rigid wall (barrier) that is placed across channel on the distance L from the closed end of channel has been investigated under consideration that the wall height l_w is smaller than width channel l (figure 3).

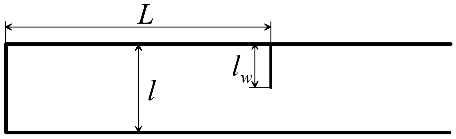
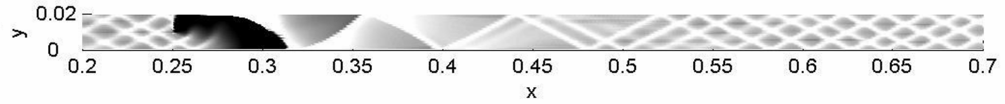
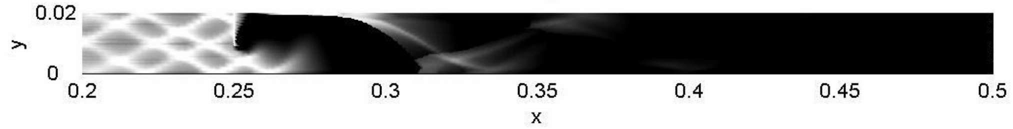


Figure 3. The scheme of channel with transversal rigid wall

The detonation regime of combustion is restored after the interaction with the barrier under conditions that the barrier height l_w does not exceed some critical value that depends on the channel width. Let us note that in the case of conservation of detonation after the passing of barrier the cellular detonation structure is restored only after some time (figures 4, 5).

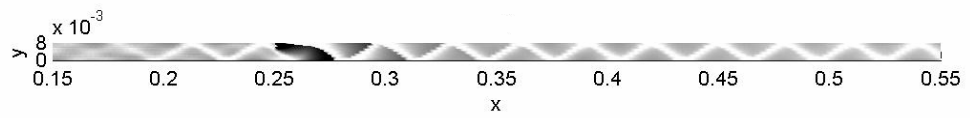


a) l_w=0.01

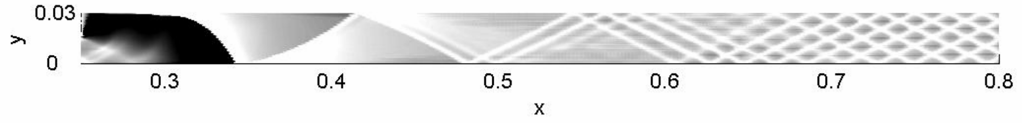


b) l_w=0.012

Figure 4. Conservation (a) and destruction (b) of detonation in the cannel with undestroyable transversal rigid wall in the case l=0.02 and L=0.25



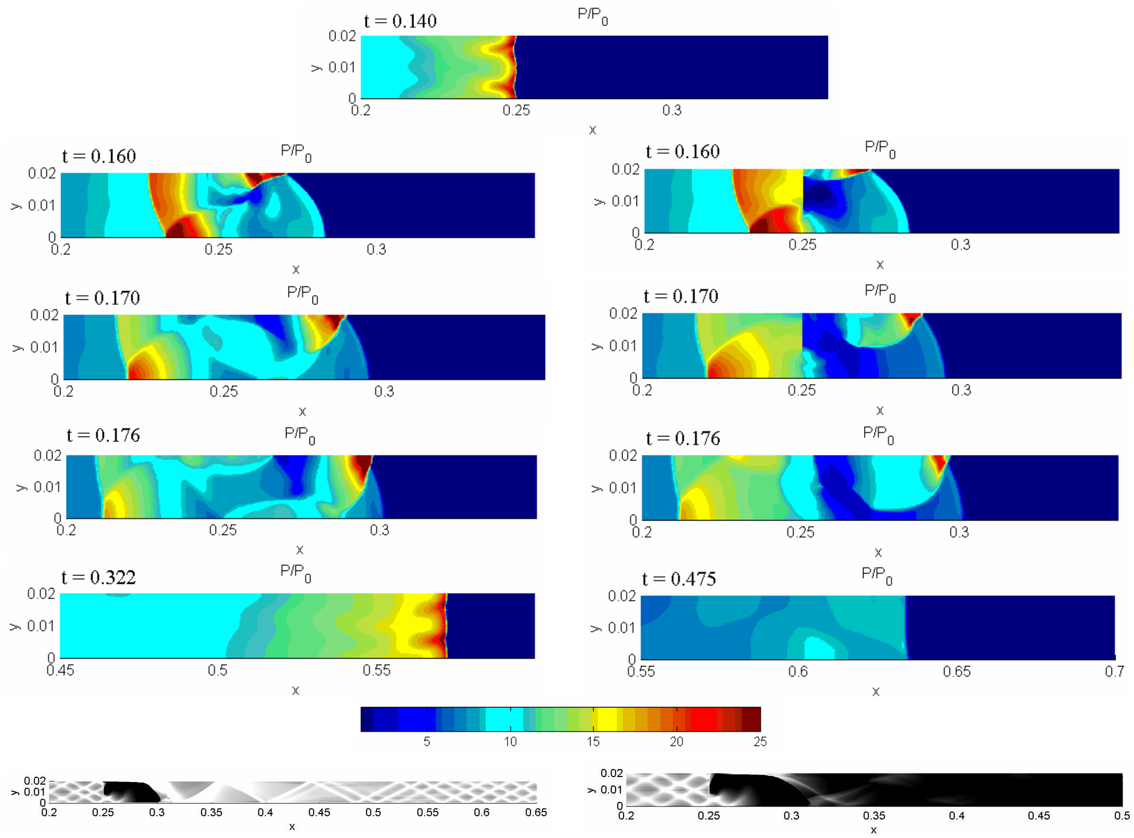
a) l=0.008, l_w=0.03



b) l=0.03, l_w=0.015

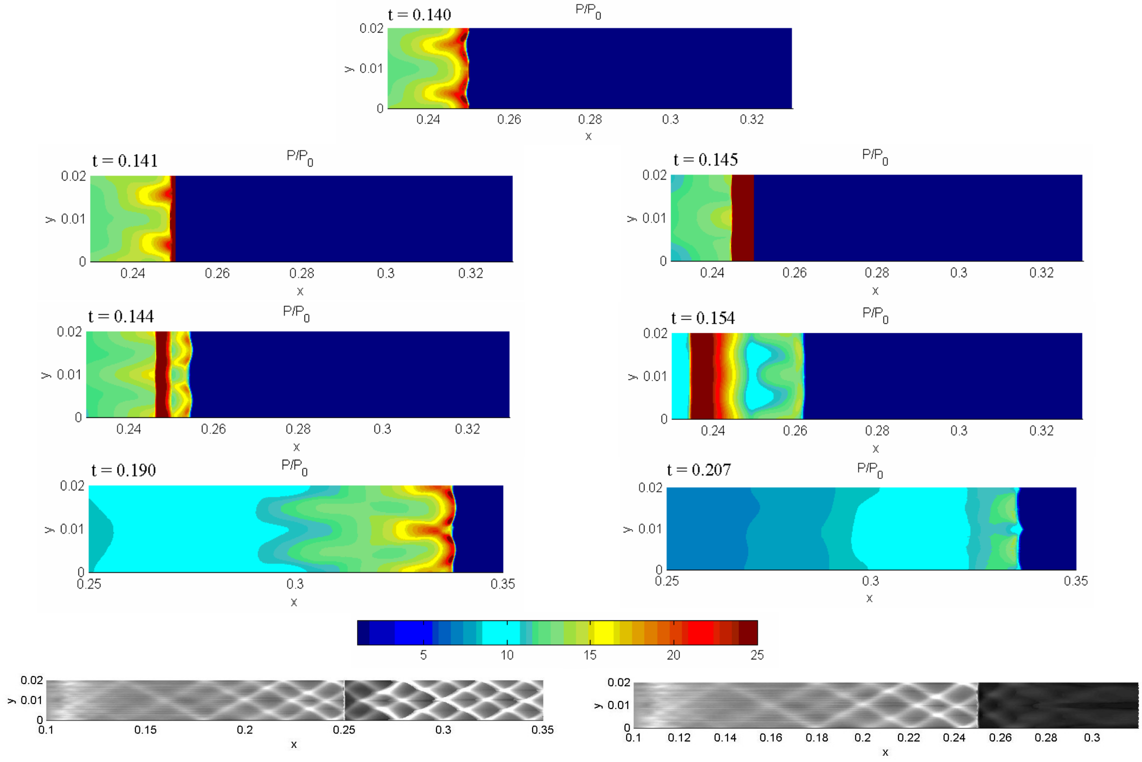
Figure 5. Restoration of cellure detonation structure after the passing of barrier for L=0.25 and some values of channel width l

In the case of destroyable rigid wall (barrier) of height l_w (l_w is smaller than channel width, see figure 3) the influence of wall existence time t_w on the conservation of detonation regime in the channel was analysed. Here t_w is the time after interaction of leading shock front with transversal wall. It has been obtained that in the case of destroyable barrier with height being greater than critical one the detonation is conserved under condition the time of barrier existence t_w does not exceed some critical value. For example, if the transversal rigid wall of height l_w=0.012 placed in the channel of width l=0.02 is destroyed after the time t_w=0.01 then the detonation is conserved. But if transversal wall is destroyed only after the time t_w =0.03 the detonation is failed in channel (figure 6).



a) t_w=0.01 b) t_w=0.03

Figure 6. Pressure fields for selected time moments and the trajectories of triple points in the cases of conservation (a) and destruction (b) of detonation in the cannel with destroyable transversal rigid wall under l=0.02, L=0.25 and l_w=0.012



a) t_w=0.001 b) t_w=0.005

Figure 7. Pressure fields for selected time moments and the trajectories of triple points in the cases of conservation (a) and destruction (b) of detonation in the cannel with destroyable transversal rigid wall with height that is equal to width of the channel

Thereupon it is interesting to consider the propagation of detonation in the channel with destroyable transversal rigid wall of height l_w that is equal to width of the channel l. In this case the detonation is conserved if the time of barrier existence t_w does not exceed some critical value. Let us note that in the case when detonation wave is conserved the cell detonation structure is restored immediately after destruction of the barrier (see figure 7).

The behaviour of the cellular detonation in the case of sudden widening of the channel cross section was studied. The scheme of channel is presented on the figure 8.

It has been established that in the case when channel width l is smaller than the critical channel width for the detonation transition into the unconfined space the detonation wave transits into the wide part of channel without failure if the widening h does not exceed some critical value (see figure 9).

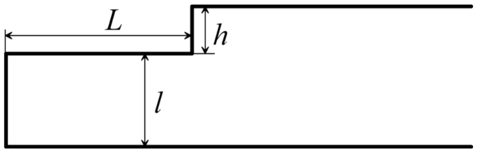
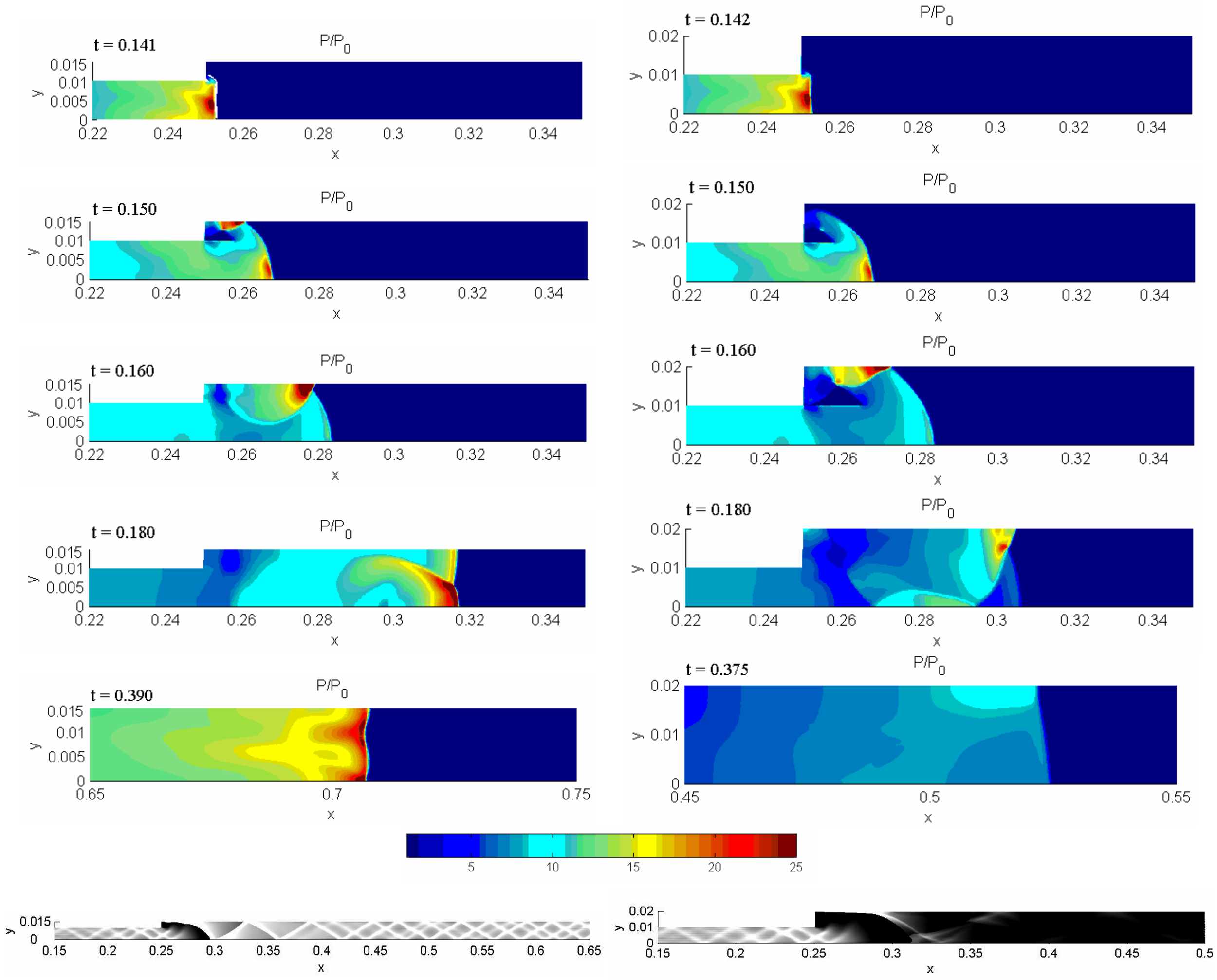


Figure 8. The scheme of sudden widening channel



a) h=0.005 b) h=0.01

Figure 9. Pressure fields for selected time moments and the trajectories of triple points for different value of the channel widening h in the case l=0.01 and L=0.25

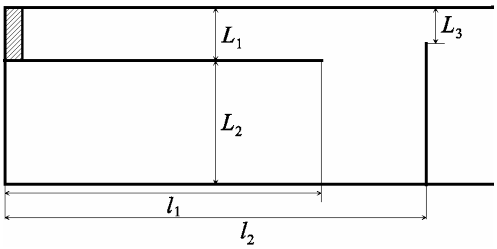
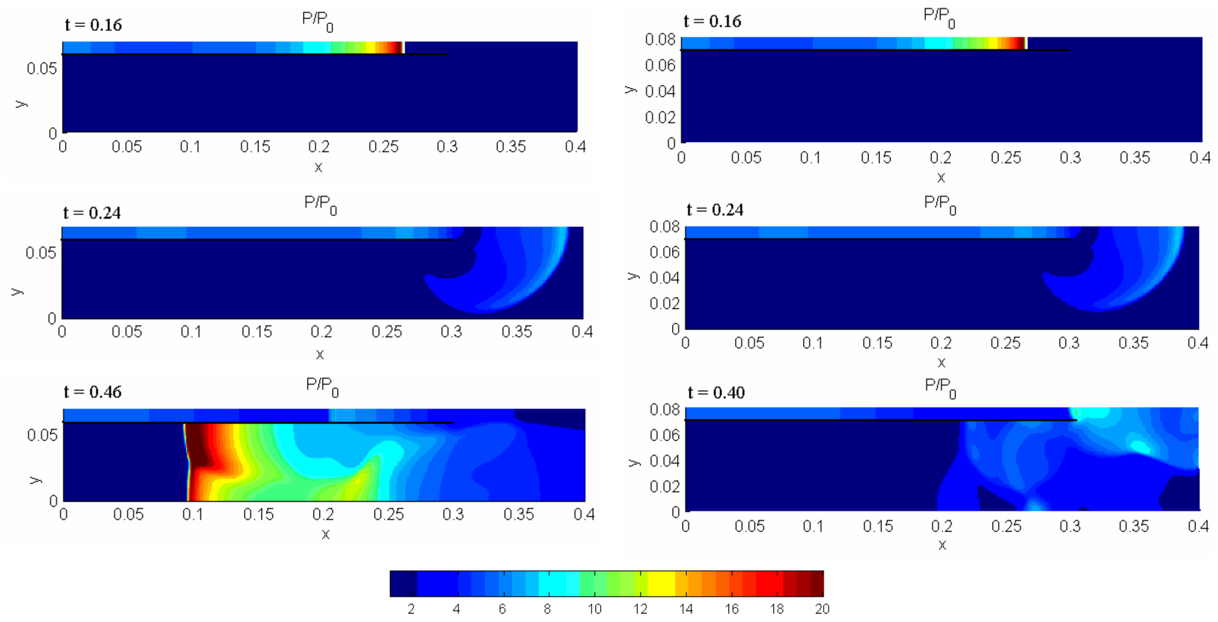


Figure 10. The schematic pattern of channel with partitions

The numerical calculations of detonation wave propagation in the plane channel containing the partition (that is parallel to channel walls) of length l_1, which is placed near the closed end of channel on the distance L_1 from the upper wall was carried out too. It was supposed that additional rigid wall with slot of width L_3, which is perpendicular to the channel walls, is situated in the channel at the distance l_2 ($l_2 > l_1$) from the closed channel end. The detonation is initiated by the energy input in the layer near the closed end of channel part of width L_1. The scheme of the channel with partitions is presented on the figure 10.

When the slot is absent (L_3 =0.0) it has been established that if the width of narrow part of channel is smaller than the critical channel width for the detonation transition into the unconfined space, then the detonation wave (“back” detonation) is formed in the part of channel of width L_2 under condition the last is not greater than some critical value (figure 11).

For the value L_2 that is smaller than critical one, the influence of the slot width L_3 on the formation of “back” detonation has been examined. It has been obtained that the detonation wave is formed too in the part of channel of width L_2 if the slot width L_3 is not greater than some critical value (figure 12).



a) L_2=0.06 b) L_2=0.07

Figure 11. Pressure fields for selected time moments for different value L_2 for L_1=0.01 l_1=0.3 and l_2=0.4

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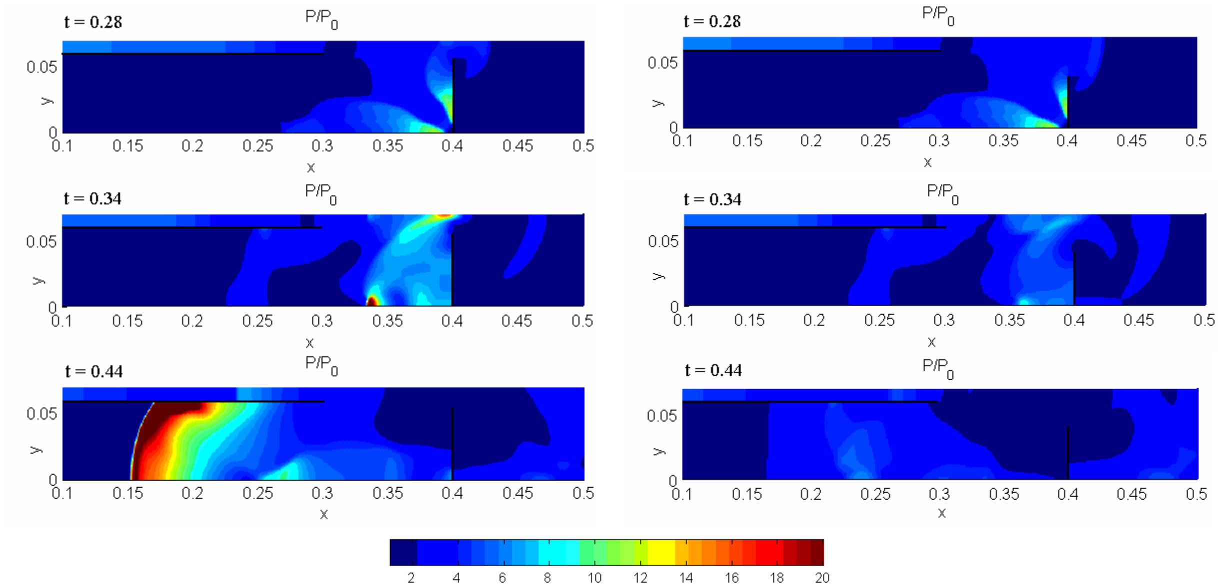

a) L_3=0.015 b) L_3=0.03

Figure 12. Pressure fields for selected time moments for some value of slot width L_3 for L_2=0.06, L_1=0.01, l_1=0.3 and l_2=0.4

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