# **Initiation of Detonation in the Supersonic Gas Flow**

Vladimir A. Levin<sup>1</sup>, Vladimir V. Markov<sup>2</sup>, Tatiana A. Zhuravskaya<sup>3</sup>, Sergei F. Osinkin<sup>3</sup>

<sup>1</sup>Institute for Automation and Control Processes, Far Eastern Branch of the Russian Academy of Sciences, 690041 Vladivostok, Russia

> <sup>2</sup>V.A. Steklov Mathematical Institute, Russian Academy of Sciences, 119991 Moscow, Russia

<sup>3</sup>Institute of Mechanics, M.V. Lomonosov Moscow State University, 119192 Moscow, Russia

#### 1 Introduction

The interest to the detonation examination visibly rises at last time. It's connected with a prospect to use detonation in pulsed reactive devices and generators of powerful pressure impulses. One of the main objects of realized investigations is the determination of critical detonation initiation energy and the analysis of energy decrease methods.

In the present research the numerical investigation of detonation initiation by the electrical discharge in stoichiometric hydrogen-air mixture under normal conditions moving with supersonic velocity in the plane channel of constant width l is carried out.

### 2 Mathematical problem state

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

2

 $\sim$ 

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

where x and y are the Cartesian coordinates; u and v are the corresponding components of velocity; t is time;  $\rho$ , p and h are density, pressure and enthalpy, respectively;  $n_i$  is the molar concentration of the i th component of mixture;  $\omega_i$  is the rate of formation/depletion of the *i* th component.

The kinetic model developed by Maas and Warnatz is used for account of the hydrogen oxidation [1,2]:

Correspondence to : levin@imec.msu.ru; levin@iacp.dvo.ru

$O_2+H \leftrightarrow OH+O$ ,	$O+O+M \leftrightarrow O_2+M$ ,	$HO_2+OH \leftrightarrow H_2O+O_2,$
$O+H_2 \leftrightarrow OH+H$ ,	$H+O_2+M \leftrightarrow HO_2+M$ ,	$OH+OH+M \leftrightarrow H_2O_2+M$ ,
$H_2+OH \leftrightarrow H_2O+H$ ,	$HO_2+H \leftrightarrow OH+OH$ ,	$H_2O_2+H \leftrightarrow H_2+HO_2,$
$OH+OH \leftrightarrow H_2O+O$ ,	$HO_2+H \leftrightarrow H_2+O_2$ ,	$H_2O_2+H \leftrightarrow H_2O+OH$ ,
$H+H+M \leftrightarrow H_2+M$ ,	$HO_2+H \leftrightarrow H_2O+O_2$	$H_2O_2+O \leftrightarrow OH+HO_2$ ,
H+OH+M ↔ $H_2O+M$ ,	$HO_2+O \leftrightarrow OH+O_2$ ,	$H_2O_2+OH \leftrightarrow H_2O+HO_2$ ,
	$HO_2+HO_2 \rightarrow H_2O_2+O_2$	

where M denotes a third particle.

The equations of state for the hydrogen-air mixture have the usual form

$$p = \rho R_0 T \sum n_i, \ h = \sum n_i h_i(T), \ i = 1, 2, \dots 9.$$

Here T is the temperature,  $R_0$  is the universal gas constant. The values of the partial enthalpies  $h_i(T)$  are borrowed from [3].

The set of gas dynamic equations jointly with the set of chemical reaction rate equations, which takes into account principal features of chemical interaction of hydrogen with oxygen, was solved by a finite-difference method based on the Godunov's scheme [4]. The size of computational grid mesh has been chosen by the optimal way for minimization of calculation time and for the guarantee of sufficient precision of numerical solution.

### **3** Numerical results

First of all the detonation initiation by the instantaneous discharge of narrow layer form of thickness h = 0.48 (here and later all linear dimensions are divisible by the mean transversal size of detonation cell) with the uniform energy-input distribution has been examined. In this case initially the plane detonation fronts propagating in opposite directions from discharge are curved with time and the cellular detonation structure is formed (fig.1). This fact is conformed to results of early realized examination of detonation initiation in the plane channel filled with the stoichiometric hydrogen-air mixture at rest [5] with use less detailed kinetic model. Let us note that in the case of channel, which is represented on the fig.1, only one detonation cell is formed across the channel.



Fig.1 Trajectories of triple points in the case of detonation initiation by instantaneous discharge with uniform energy-input distribution for the flow with Mach number M = 2

With the purpose of critical energy decrease the detonation initiation by the instantaneous discharge of the same configuration with nonuniform energy-input distribution was studied. It was supposed, the dependence of energy input density on transversal coordinate *y* is exponential one:

$$E_V(y) = A_0 \exp\left(-\frac{(y-y_0)^2}{r_0^2}\right),$$

were  $y_0 = \frac{l}{2}$ ,  $r_0 = \frac{h}{2}$ . The constant  $A_0$  is defined by the expression

$$E_0 = h A_0 \int_0^l \exp\left(-\frac{(y-y_0)^2}{r_0^2}\right) dy,$$

here  $E_0$  is the discharge energy.

21st ICDERS – July 23-27, 2007 - Poitiers



**Fig.2** Trajectories of triple points in the cases of detonation failing (a) and of detonation initiation (b) for instantaneous discharge with nonuniform energy-input distribution for the flow with Mach number M = 2

In this case the spatial heterogeneity of energy deposition leads to the decrease of critical energy of detonation initiation due to reflection of strong transversal waves which are formed at energy input from channel walls. It has been established detonation is formed when  $E_0$  equals  $0.87 E_*$ , where  $E_*$  is critical initiation energy by the instantaneous discharge of narrow layer form with the uniform energy-input distribution (fig.2). Let us note the detected decrease of detonation initiation energy due to use of discharge with nonuniform energy-input distribution takes place in the case of gas mixture at rest too, because the energy input is instantaneous. It's interesting to remark that in the case of detonation cell (due to the chosen heterogeneity of energy-input distribution) isn't modified with time and wave is propagated in stability regime. This is connected with the width of the channel under consideration (see. fig.1).

In the case of discharge with nonuniform energy-input distribution the influence of input time  $\tau$  ( $\tau >0$ ) on detonation formation was studied. The discharges with constant rate of energy input were considered. It has been established the critical energy of detonation initiation does not increase for discharge with short duration of energy input ( $\tau < \tau_0$ , where  $\tau_0$  is some value), see fig.3. However for  $\tau > \tau_0$  the critical energy increases with increase of discharge duration. So, in the case  $\tau = 1$ mks the critical energy exceeds 0.87  $E_*$  and it's more than  $E_*$  for  $\tau = 1.5$  mks. Let us note that in the case when discharge energy is smaller than critical one the flow with downstream detonation wave and without upstream one is possible, see fig.4.

The flow velocity (Mach number) influence on the initiation of detonation under others conditions being equal has been examined too.

At last the possibility of detonation wave stabilisation in the supersonic gas mixture flow was studied too. It has been established the upstream detonation is stabilised under condition that flow velocity is equal to velocity of self-sustained detonation wave under given conditions.



d)  $\tau = 1.0$  mks

**Fig.3** Trajectories of triple points in the case of discharge with nonuniform energy-input distribution and constant rate of energy deposition for flow with Mach number M = 2 and some values of time discharge  $\tau$ 



b) M = 2,  $\tau = 0.5$  mks,  $E_0 = 0.73$   $E_*$ 

Fig.4 Formation of flow with downstream detonation wave and without upstream one in the case of subcritical energy input

## 4 Acknowledgments

This work has been supported by the Russian Foundation for Basic Research (Grants 05-01-00004 and 05-08-33391), by the President Grant for Support of Leading Science Schools of Russian Federation (No. NSh-6791.2006.1).

#### References

- Maas U, Warnatz J (1988). Ignition Processes in Hydrogen-Oxygen Mixtures. Combustion and Flame. 74: 53
- [2] Singh S et al. (2001). Viscous detonation in H2-O2-Ar using intrinsic low-dimensional manifolds and wavelet adaptive multilevel representation. Combustion Theory and Modelling. 5, 2: 163
- [3] Glushko VP ed. (1978). Thermodynamic properties of individual substances. Moscow, Nauka
- [4] Godunov SK et al. (1976). Numerical solution of multidimensional problems in gas dynamics. Moscow: Nauka
- [5] Levin VA et al. (2005). Nonlinear wave processes that occur during the initiation and propagation of gaseous detonation. Proc. V.A. Steklov Inst. Math. 251:200