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# One Approach to the Experimental Study of Hydrodynamic Instabilities: Creation of a Gas-Gas Interface Using The Dynamic Technique\*

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The shock tube investigations of hydrodynamic instability evolution are very commonly used [1]–[7]. In these experiments the gases at the interface to be studied are separated by a thin film [1]–[7] or by a sliding plate retarded (with a time delay  $t_{del}$ ) before the shock arrival to the interface [3], [4], [7]. In the first case the flow may be affected by the film with small, but finite strength; in the second case a laminar diffusion zone forms (with  $t_{del} \sim 1$ s the zone characteristic width is a few cm).

The method is described below to study 3D perturbations and turbulent mixing zone development at the interface between the products of gaseous explosive mixture (GEM) and inert (non-explosive) gas initially separated by a thin film. This method allows to avoid the disadvantages mentioned above.

The method relies upon the following simplified scheme of the 1-D flow (Figure 1). Here domain I contains a GEM (for example, acetylene-oxygen mixture) and domain II contains inert (non-explosive) gas (air, helium, hydrogen etc.). The two gases have the atmospheric pressure ( $P_0 = 1$  atm). A rigid wall is located at  $R_2$ . The gases are initially separated by a thin film at  $R_1$ . This scheme can be applied to any type of 1D flow: plane, cylindrical or spherical (in the plane case the system center can be represented by the rigid wall).

After the detonation is initiated at  $R = 0$ , the diverging detonation wave ( $t_0 < t < t_1$ ) will propagate from the system center. After this wave arrives to the gas interface, a shock wave will propagate to the inert gas and the interface will be accelerated in jump manner and then moves with deceleration ( $t_1 < t < t_2$ ), that is the acceleration is directed to the center from the inert gas (IG) (with density  $\rho_{IG}$ ) to the explosion

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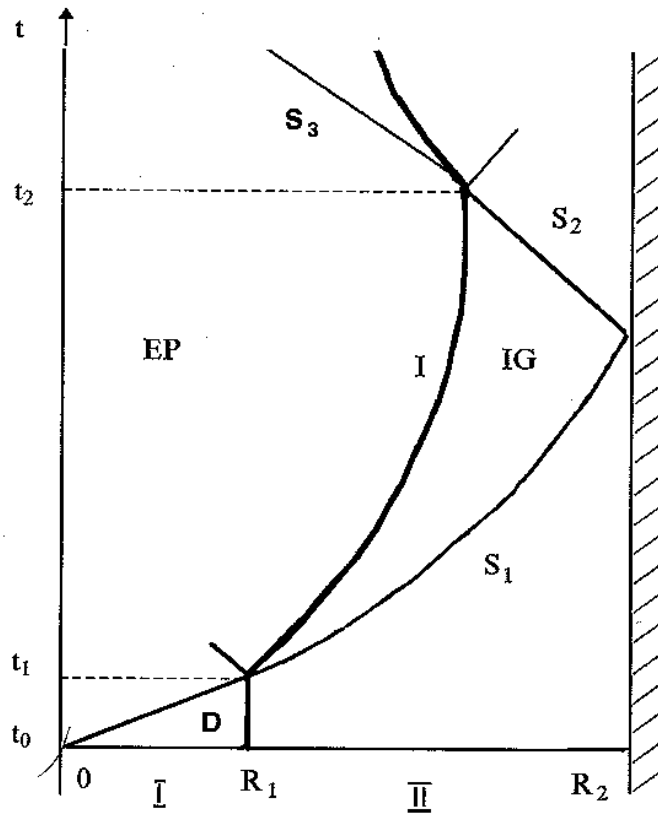


Figure 1: Simplified  $R-t$  diagram of flow after gas explosive mixture (GEM) detonation. Region  $I$  — GEM, region  $II$  — inert (non-explosive) gas (IG).  $D$  — detonation wave trajectory.  $S_1$ ,  $S_2$ ,  $S_3$  — shock waves.  $I$  — interface between explosion products (EP) and inert gas (IG). In region  $t_1 < t < t_2$ , interface moves with deceleration (direction of acceleration from IG to EP); in this case, the (interface is stable if  $\rho_{EP} < \rho_{IG}$ ).

products (EP) (with density  $\rho_{EP}$ ). After the shock wave arrives to the outer boundary ( $R_2$ ) it is reflected by the rigid wall and moves to the center.

After the wave arrives to the interface ( $t = t_2$ ), the latter will be accelerated to the center and then moves with deceleration, that is the acceleration will be directed from the explosion products to the inert gas. Further the interface will oscillate each time the wave crosses it. Depending on  $R_2/R_1$  and  $\rho_{IG}/\rho_{EP}$ , various flow modes will occur. Let us consider this in the general form:

a)  $R_2 \gg R_1; \rho_{EP} < \rho_{IG}$

In this case the expansion limit of the GEM explosion products is restricted by the internal energy of explosion products. As the practices show, when GEM is used in the form of stoichiometric mixture of acetylene and oxygen, the expansion of explosion products is  $V_{\max}/V_0 \sim 10$  times, that is on cylindrical case the interface radius must increase by about 3 times till it stops and by about 2 times in spherical case.

At this point the plane case is experimentally verified for this mode. Figure 2 presents the flow pattern. The experiment was carried out on a rectangular cross-section channel  $12 \times 4 \text{ cm}^2$  with transparent material walls (the test section of the shock tube [1], [2]). At the channel end an organic glass wall was installed. The channel was divided by a thin film ( $0.5 \mu\text{m}$ ) into two sections: the first was 2 cm and the second was more than 1 m long. The closed volume of the first section was filled with GEM - stoichiometric mixture containing acetylene and oxygen ( $\rho_0 = 1.38 \text{ g/l}$ ), the second section contained air ( $\rho_0 = 1.205 \text{ g/l}$ ). The GEM was detonated in three points uniformly spaced over the rigid wall. After the initial jump acceleration of the interface by the detonation wave, the acceleration changes the sign and decreases progressively in amplitude tending to zero. In this case the acceleration is directed from the heavy gas to light one and the interface will be stable; the perturbation attenuates with time. The initial interface perturbation stabilizes rather rapidly and by the maximum expansion of the explosion products ( $t \sim 2 \text{ ms}$ ) the perturbation amplitude does not exceed 5-10 mm. By this time the explosion products expand by  $\sim 10$  times. The film initially separating the gases decomposes and vaporizes under the high temperature of GEM explosion products. The mixing of gases at the interface will be due only to molecular diffusion with the rate  $\sim \sqrt{Dt}$  where  $D$  is the gas diffusion coefficient. The estimates show that in this case the diffusion zone width will be about 3 mm after 1ms. It should be noted that in any case the molecular diffusion ( $\sim \sqrt{Dt}$ ) rather than turbulent mixing ( $\sim gt^2$ ) must dominate at the unstable interface between two gases for the constant acceleration and relatively low times.

That is in the case described the geometry pattern of [2] is reproduced for a short time where the light gas is represented by the explosion products. This approach will allow to reproduce the experiments on turbulent mixing from [2] without film. The timing for the dynamic generation of the interface and stationary shock wave arrival formed in the shock tube channel can be accomplished with relatively simple and known

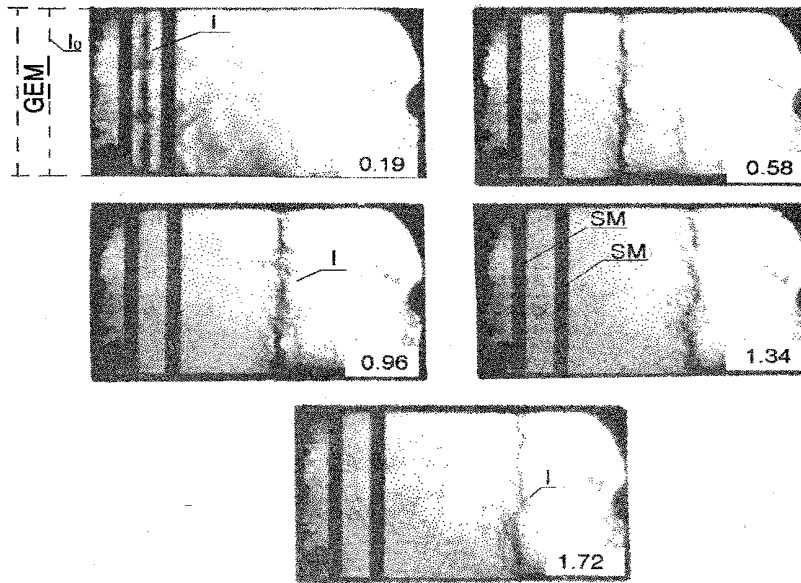


Figure 2: Interface creation by dynamics technique. The explosion products (EP) expansion from gaseous explosive mixture ( $C_2H_2 + 2.5O_2$ ) to air. GEM was initiated simultaneously in three points, uniformly placed on rigid wall plate.  $I_0$ — GEM – air initial interface position; I –interface EP– air, SM — construction elements out of channel. Time (in ms) is counted off moment of detonation initiation.

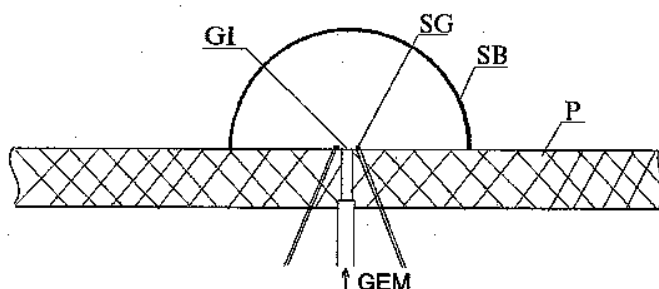


Figure 3: The soap bubble SB (filled with GEM) is blown down through the hole GI in the plane plate P, the GEM is initiated by a spark in the gap SG.

methods.

b)  $R_2 \gg R_1$ ;  $\rho_{EP} > \rho_{IG}$

In this case from the very beginning the interface of explosion products will be unstable, it demonstrates the evolution of initial perturbation and turbulent mixing. Since the density of explosion products decreases permanently, the Atwood number  $A = (\rho_{EP} - \rho_{IG})/(\rho_{EP} + \rho_{IG})$  also decreases, determining the instability evolution rate. For  $\rho_{GEM}/\rho_{IG} < 10$  also (stoichiometric acetylene-oxygen mixture) the Atwood number may reduce to  $O$  and even change the sign; in the latter case the interface converts to stable state. According, the evolution of perturbations and turbulent mixing will stop.

In the plane case of mode (b) the initial 3D perturbations can be specified by positioning the detonation initiation points. This allows, to some extent, to control the spectrum and amplitude of initial perturbations. Cases (a) and (b) can be experimentally studied in spherical geometry using for example, of variant of method for the measuring of burning rate of spherical flame front in GEM [8] (Figure 3). Here the hemispherical soap bubble forms at the plane surface. The inner volume of the bubble is filled with GEM with the detonation being initiated at the bubble center.

In the case where the rigid wall at  $R_2$  is relatively near from  $R_1$  (for example, at  $R_2 \sim 1.5 R_{st}$ , where  $R_{st}$  is the interface expansion stop radius) the situation changes c)  $\rho_{EP} < \rho_{IG}$

In this case at  $t_1 < t < t_2$  the interface is stable and unstable at  $t > t_2$  in the interface collapse phase.

In this situation one can study the evolution of instabilities at gas-gas interface accelerated by the converging spherical shock wave.

d)  $\rho_{EP} > \rho_{IG}$

In this case the interface will be unstable in the expansion phase ( $t_1 < t < t_2$ ); after the arrival of the shock wave reflected from the rigid wall  $t > t_2$  the interface becomes

stable.

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