Role of the flow characteristics in the flame acceleration

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The influence of the turbulence on DDT was investigated last one-half century in many papers. In [1] the role of instabilities in promoting turbulence and thus flame acceleration resulting in DDT was investigated. The transition that occurs via the formation gradients produced by a combination of turbulent mixing and local quenching of the flame was postulated. In [2] it forced a fully expanded Mach 2 circular jet using open rectangular and semicircular cavities mounted adjacent to the jet exit plane (Fig.1-left). The ensuing complex vortex interaction results in improved large- and small-scale mixing. The efficiency of external acoustic excitation of a high subsonic jet was demonstrated in [3] (Fig.1-wright).

In [4] the aim of the investigation was to observe the mixing enhancement due to different injectors. A comparison of the deflagration-to-detonation transition through reactants injected from different nozzles was investigated (fig.2). The detonation experiments were carried out in an 83 mm diameter by 660 mm long detonation tube. Different injectors were mounted in turn: supersonic nozzles, whistler ones. The fuel and oxidizer were injected separately in tube axis direction through injectors presented in fig.2. The supersonic nozzle (Fig. 2a) produces a Mach 2 flow. The whistler nozzle (Fig. 2b) producing strong acoustic disturbances like in [2] (fig.1-left, fig.2b) consists of a nozzle and resonator (annular cavity). Visualization

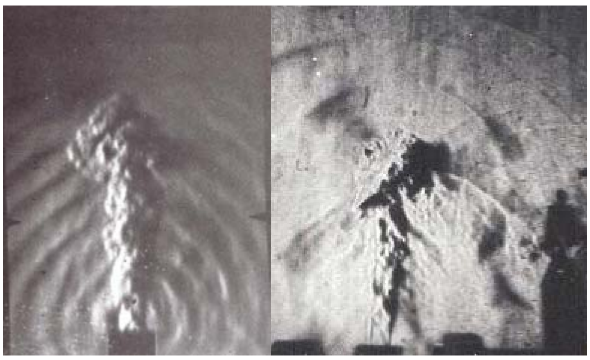
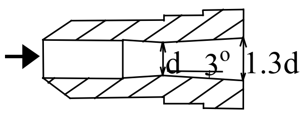
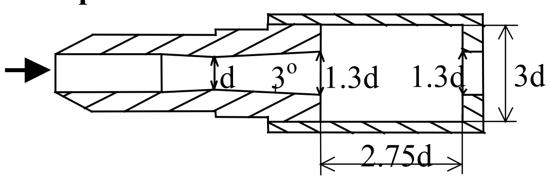


Fig.1 left- supersonic nozzle performance with cavity resonator, Wright- supersonic flow disturbed by sonic generator performance

experiments were carried out to visualize flow from the injectors using air as the working fluid. These experiments were simplified compared to subsequent detonation experiments in that only the flow from a single injector was visualized. The initial pressure P_0 and incident shock Mach number M_0 defined the test conditions. The mass flux through the injectors was adjusted to be equal to that calculated for the subsequent detonation experiments. Thus, the incident shock Mach number was set to obtain the same mass fluxes. The equipment consisted of a square-section shock tube connected to a vacuum chamber that was equipped with optical windows. At the end of the shock tube, different injectors were mounted in turn. These injectors had the same critical area s_o = 28 mm^2. The test flow was visualized by the IAB-451 schlieren system. The schlieren images show the evolution of the flow process at intervals of 5–10 μs with an exposure of 1 μs. To obtain 72 images in one experiment, a high-speed optical-mechanical device VSK-5, with a frame size of 16 × 22 mm^2 was used.



a. Supersonic nozzle.



b. Whistler nozzle.

Fig.2 Sketch of injectors. All dimensions are presented in terms of the diameter of critical area

The aim of the research is to investigate the media conditions that are initial ones for detonation experiments to find the general relationship between flame acceleration and ones. The numerical simulation of the injected supersonic jets was run. The steady solver [5] was analogue to second order Godunov method in space. It was developed in unsteady one and can be applied to the 2-D flat, axisymmetrical and 3-D flows. The grid generator allow interactive real-time multi block grid with arbitrary topology construction. Besides these tools give wide opportunities for grid adaptation to flow features and for speedup of solution process. In this research the flow characteristics and acoustic fields are compared to experimental ones.

The code validation of injected flow is presented in Fig.3. The calculated density and temperature distributions of injected flow (left up and below consequently) and density field highlighted by schieren visualization technique (left) are compared under the same initial conditions. The contact surface and acoustic field in numerical simulation and experimental picture are in agreement good enough to each other. The velocity, pressure, temperature of the jet and acoustic field around are initial media conditions where flame front is initiated and propagates. The numerical simulation jet parameters are investigated. The role of the flow parameters is determined.

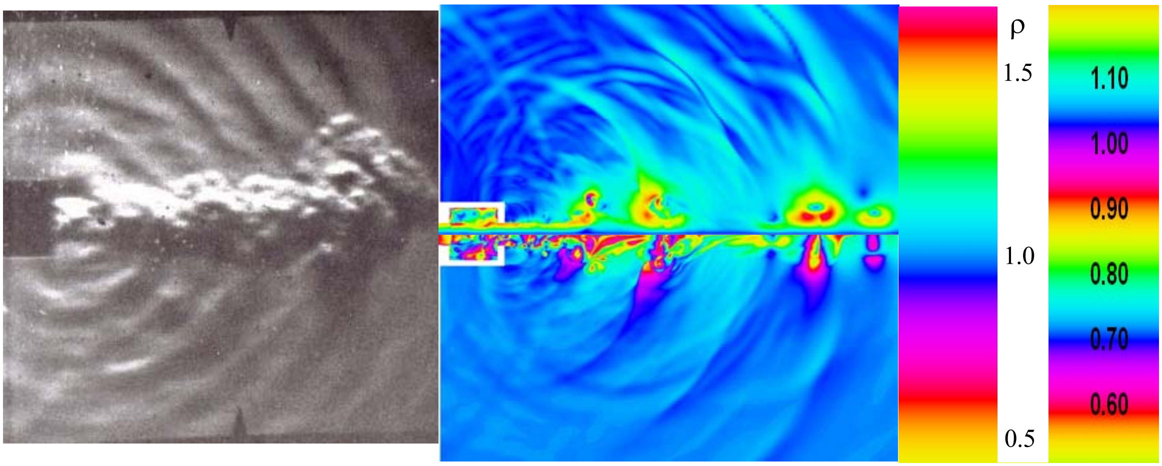


Fig.3 left -experimental schlieren picture of injected gas through whistler nozzle, wright up - density distribution, below- temperature distribution by the numerical simulation under the same initial conditions. Density ρ=1 and temperature T=1 in scales are corresponding to ambient ones

Numerical simulation methods and code validation

In this research the relationship between flow characteristics and flame front acceleration in rocket mode are investigated. The numerical simulation of the injected supersonic jets was run. are compared to experimental ones (fig.3).

The 3-D numerical simulation was done in parallelepiped domain (fig.4). The oxygen and hydrogen were injected from parallel axisymmetrical supersonic nozzles of Mach number 2. The flow parameters were determined in the exit nozzle section. The distance between nozzle axes was 2.5 nozzle exit diameters ($2.5d_e$). Since in experimental investigations the number of nozzles can be more than two therefore the periodic conditions were used on the top and bottom boundaries of simulation region (dashed lines) and symmetry (mirror) on the left and right ones (view A, solid lines). The length, width and high sizes of calculated domain were $20d_e$, $2.5d_e$ and $5d_e$ correspondingly. Godunov type flow condition was applied to the exit boundary of calculated domain on right side. The mirror conditions were used on the left side except exit nozzle areas. The unsteady flow was simulated up to the quasi-steady solution. Hydrogen and oxygen were taken into account separately in simulated equations to determine the mixing characteristics.

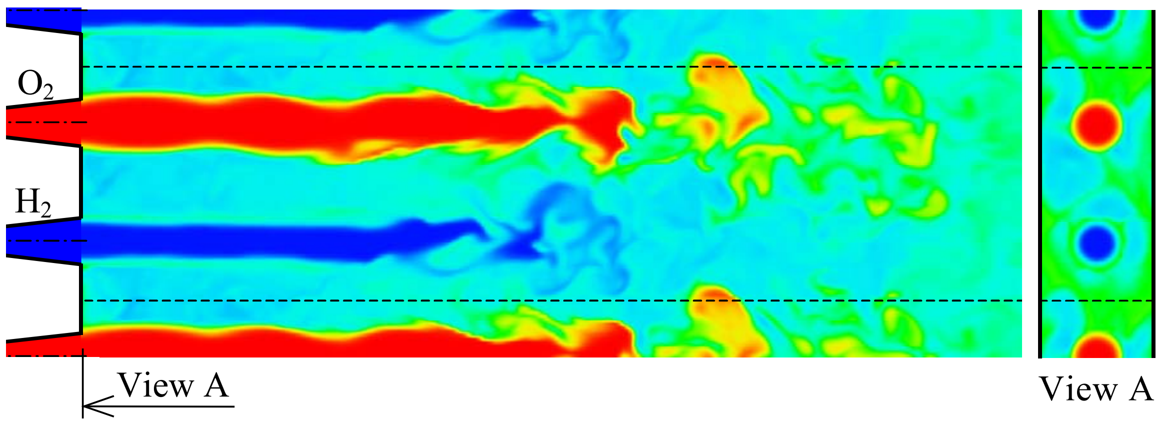


Fig.4 The value of mixing in simulated domain of quasi-steady regime

Results

The mixing characteristics in few cross sections are presented in fig.5. To avoid the infinitive values of equivalent ratios the value $\frac{\rho_{O_2}}{k\rho_{H_2}+\rho_{O_2}}$ describes mixture, where $k=\left.\frac{\rho_{O_2}}{\rho_{H_2}}\right|_{ER=1}$; 1 belongs to pure O_2, 0 belongs to pure H_2. For ER=1 introduced value equals ½. The contact surfaces of jets

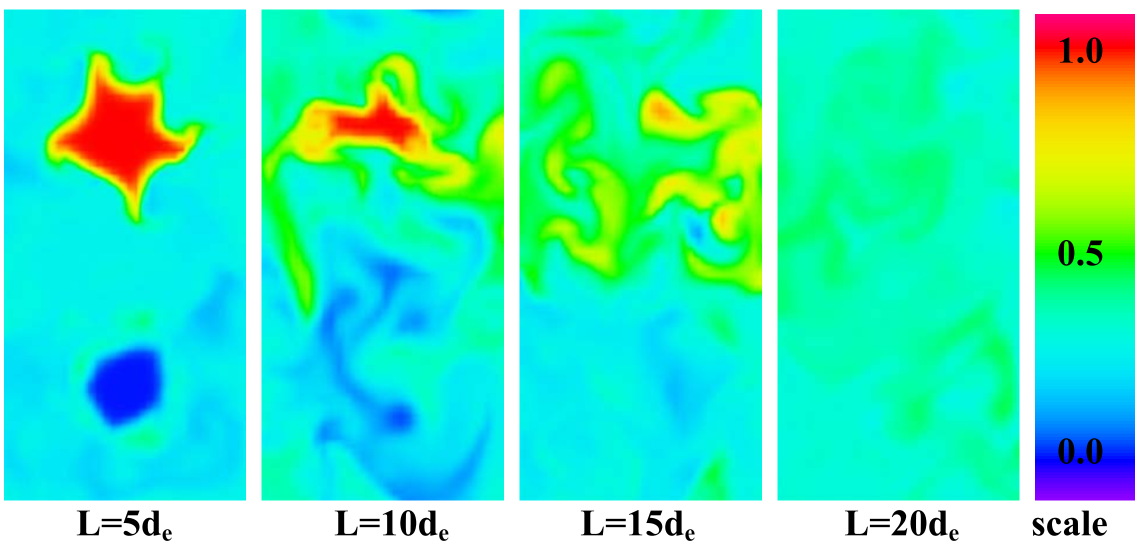


Fig.5 The value of mixing in 4 cross sections from nozzle exits

were determined clearly at the first $5d_e$ from exit nozzle section. The jets became turbulent with disturbed shear layers farther in propagation jet direction. The turbulent intensive mixing origin appears through $10d_e$. In [4] the mixture was ignited closely to $10d_e$ section.

Conclusions

Thus the mixing characteristics were good enough for all types of nozzle due to much smaller nozzle exit diameter than combustion chamber one in spite of other processes influencing on mixing aren't taken into account. It means that other flow characteristics influence on the flame acceleration and detonation formation along the detonation tube farther section where the mixture was ignited. In future the correlations between reactant flow characteristics and flame front acceleration should be investigated and compared for 2 injector types described above.

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