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NUMERICAL SIMULATION OF HYDROGENE IGNITION IN CHANNELS AT SUPERSONIC SPEEDS

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The work deals with a numerical study of hydrogen/air mixture ignition in supersonic combustion chambers. Supersonic combustion has been of interest for many years in order to support future hypersonic flights. It is rather difficult to get the ignition and stable combustion at supersonic speeds [1, 2]. The flow has a short residence time in the supersonic combustion chamber that is of the order of only a few milliseconds.

A simple geometry to generate a flameholding region in supersonic flow is a backward facing step (BFS) that generates a primary recirculation region in which mixture finds the necessary residence time. Another opportunity for flame stabilization gives a cavity that also organizes low-speed high-temperature recirculation zone. As a flameholder, both configurations exploit so called Trapped Vortex (TP) concept based on the expectations that the low velocity recirculation zone could serves as a continuous source of ignition. A recirculation region extends the residence time and serves as a reservoir of hot pool of radicals that sustains the flame in the combustor and so acts as a supplier of radicals helping to propagate combustion into the main supersonic flow. It is supposed that self–ignition of fuel occurs in the recirculation zone and then the flame front spreads all over the channel.

In the experiments by Goldfeld et al [3] performed at the hot-shot facility IT-302 the mechanism of the “two-stage” evolution of fuel combustion was described. It was shown that fuel ignition occurred not in the recirculation region behind BFS but far downstream the flameholder. After the self–ignition, the flame front moves upstream. If the flame reaches the recirculation zone behind the BFS, the intensive combustion occurs over all the combustor. In a case of low static pressure and static temperature, the flame did not reach the flame holder, and the regime of local combustion was realized.

The goal of the present work is to investigate numerically the process of the ignition in the plane channel with abrupt expansion (BFS or cavity) presenting a model combustion chamber. The computations were performed at supersonic speeds under the conditions typical for short duration facility where the experiments [3] had been done. One of the features of the flow in such facilities is so-called “cold-wall” conditions because due to short run time, the adiabatic temperature at the wall could be reached.

The numerical simulation was carried out by means of ANSYS Fluent [4] software on the basis of the full Reynolds averaged Navier-Stokes equations using two-equation k−ω SST turbulence model. The AUSM flux vector splitting scheme of third order is used for convective term approximation and an implicit temporal approximation is used for time integration. At the entrance of calculation area, the Mach number, static pressure and temperature were set. On the channel walls no-slip velocity, adiabatic and “cold wall” temperature (Tw=300÷1000 K) conditions were prescribed. For hydrogen combustion modeling a detailed kinetics with 38 reactions of 8 species (H_2, O_2, H_2O, OH, H, O, HO_2, H_2O_2) was implemented [5]. Previous computations by the authors [6] have demonstrated the ability of this kinetics to describe the ignition delay time in a wide range of flow temperatures.

At the first step, the computations of premixed hydrogen and air combustion were performed for channels with BFS. It was shown that ignition and flame propagation processes depended significantly on the flow stagnation parameters and the temperature conditions on the walls. The mixture first ignited in the local separation zones organized on the channel walls due to shock wave actions and after that the flame spread upstream and occupied the entire base region At low static temperatures in the channel, only the local combustion was observed. If the condition of a cold wall was taken into consideration, the ignition zone shifted downstream the recirculation zone or ignition did not occur at all. The influence of step configuration on the structure of supersonic reacting flows in the channel was investigated experimentally and numerically under adiabatic and cold wall conditions.

At the next step, 2D and 3D computations were carried out for non-premixed air and H_2 mixtures. The mixing process for the H_2 jets supplied into the channel before the expansion was simulated. The perculiarities of ignition process were studied numerically for various channel configarations, ignition schemes, stagnation parameters and fuel-to-air ratios.

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