Influence of input methods on jet mixing in a four-vortex chamber

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Abstract. In this work, a numerical study of aerodynamics and interaction of vortex structures is carried out depending on the organization of the injection of jets in the chamber. For unsteady calculation of aerodynamics, the URANS approach based on the k-omega SST turbulence model was used. The calculation results show the conditions for the formation of a stable four-vortex structure. The options are also identified in which a significant restructuring of the flow structure occurs.

1. Introduction

For a number of practical applications, increasing the efficiency of mixing liquids and gases in vortex devices (chemical reactors, gas cleaning systems, combustion chambers, etc.), it is necessary to be able to control the process of mixing jets that form a swirl of the flow with the environment. To solve this practical problem, it is necessary to investigate the characteristics of vortex structures and the parameters of their interaction.

The mechanisms of formation and interaction of vortices in technological apparatuses are insufficiently studied [1] and, therefore, there are not always rational methods of their control, and this, in turn, does not allow to optimize the modes of the apparatus as a whole.

2. Problem statement and research methods

Using the software package "Fluent", using the example of a four-vortex combustion chamber [2], a numerical study of aerodynamics and interaction of vortex structures was carried out, depending on the organization of the injection of the jets. The figure (figure 1) shows the arrangement of the jets for the investigated chamber.
Figure 1. Scheme of a chamber with a four-vortex aerodynamic scheme.

For unsteady calculation of aerodynamics, the URANS approach based on the k-omega SST turbulence model was used.

The calculation results were verified against detailed data on the flow structure [3] obtained on the experimental model of the four-vortex combustion chamber of the IT SB RAS.

3. Results and discussion

Figure 2 shows the calculated velocity field in the second tier of burners for the basic version of the combustion chamber. It can be seen that a flow is formed in the chamber in the form of four conjugate vortices. On the whole, the flow is unsteady with significant pulsation of the jets. However, the averaged flow pattern is symmetric and has double symmetry with respect to the central sections of the chamber. Two jets coming out of the side walls merge, then the interaction of counter jets in the center of the chamber takes place. The streams unfold in the direction of the frontal and rear walls and then moving along them are ejected into the root of the side streams. Additional nozzles on the front and rear walls intensify the formed vortices.

Figure 2. The flow pattern in the section along the second tier of burners for the basic version.

To analyze the effect of the mutual arrangement of the nozzles and the change in the flow rate of the supplied agent into the side and front nozzles, variant calculations were performed.

An increase in the flow rate through the side nozzles leads to an intensification of the flow swirl (figure 3a). An increase in the flow rate through the nozzles on the front and rear walls changes the structure of the flow, reducing the intensity of the central vortices and leading to the formation of elongated vortices in the corners of the chamber (figure 3b).
Figure 3. Flow patterns in the section along the second tier of burners:
a) option with increased flow through the side nozzles;
b) option with increased flow through front and rear nozzles.

The stability of the four-vortex structure is investigated depending on the shutdown of jets individual nozzles or tiers of nozzles. With the complete shutdown of the second or third tiers of the side nozzles, symmetrical stable vortex structures are still formed in the center of the combustion chamber (figure 4a). When the third tier of the front and rear nozzles is turned off, asymmetry appears in the vortex structures (figure 4b) and the characteristic flow velocity in the section above the nozzles is lower than in other versions.

Figure 4. Flow patterns in modes with nozzles turned off:
a) Section along the third tier of nozzles. Disabled side nozzles on the second tier.
b) The flow over the third tier of nozzles. The front and rear nozzles of the third tier are disabled.
With a decrease in the distance between the side nozzles, without changing the gas flow rate relative to the basic version, we also obtain a four-vortex structure. But in this variant, large vortices begin to form in the corners of the combustion chamber, which is not very good for a number of technologies, in particular, for combustion chambers, such zones can lead to the separation of ash particles on the surface (figure 5a).

With an increase in the distance between the side nozzles, the axial symmetry of the flow is violated (figure 5b), the jets are displaced and the four vortex structure of the flow in the chamber is not realized.

Figure 5. Flow patterns in the section along the second tier of burners:
   a) option with a reduced distance between the side nozzles;
   b) option with an increased distance between the side nozzles.

4. Conclusion
The calculation results showed that a stable four-vortex flow structure is formed in the investigated chamber in a wide range of changes in design and operating parameters. The options are also identified in which a significant restructuring of the flow structure occurs.

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