Dynamics of Combustion Products Flow in Ring Nozzle with Semienclosed Cavity

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1 Introduction

The search for the new promising nozzle devices, capable of competing with the traditional Laval nozzles, utilized in the jet engines, is examined at present as one of the promising trends on the way of an improvement in their size-mass and specific characteristics. Flat slit and annular nozzles are in this respect of significant interest. In comparison with the Laval nozzles they have smaller length and possess the important property of adaptation to the ambient conditions with a change in the flight altitude. At the present time some of them found application in the missile construction and aviations with the design of promising flight vehicles.

The paper is devoted to a study of the flow of the combustion products in the semienclosed cavity, which enter it with the speed of sound through the annular nozzle. In the cavity its afterburning occurs, and products of combustion elapse with supersonic speed through the exit nozzle into the surrounding space. Thus, the semienclosed cavity is simultaneously combustion chamber and drive unit.

As a number of experiments showed, there is both a stationary and high-frequency pulsating flow conditions in the device in question. This device, in the essence, is annular nozzle with the deflector of in the form semienclosed cavity, since with the outflow of gas from the annular slot in the direction to the axis of symmetry the central vortex zone, which is formed in the cavity, gives the same effect as central body in the bolt nozzles.

In the paper are represented the results of the comprehensive experimental-design study of the thrust characteristics of the model of end device of the jet engine, which works on the products of the equilibrium combustion of the acetylene of air mixtures, that make it possible to conduct the verification of mathematical models through the results of the comparison of experimental data with the calculated. The calculations of flow taking into account viscosity were performed with the use of a computer complex, which includes the programs of the numerical integration of Navie-Stokes equations for different models of gaseous medium. Flow in the inviscid approximation was described by the system of equations of Euler, augmented by the equations of chemical kinetics. Experiments on the testing of model in wind tunnel of end devices were executed in the laboratory pulse aerodynamic installation.

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2 Numerical end experimental researches

In the calculations was used the gas-phase model of the combustion of acetylene in air, which includes 10 chemical constituents: N2, O, O2, H, H2, OH, H2O, CO, CO2, C2[N]2, which participate in 6 chemical reactions of dissociation and in 13 exchange reactions. The schematic of experimental installation, which was investigated numerically, is represented in Fig. 1.

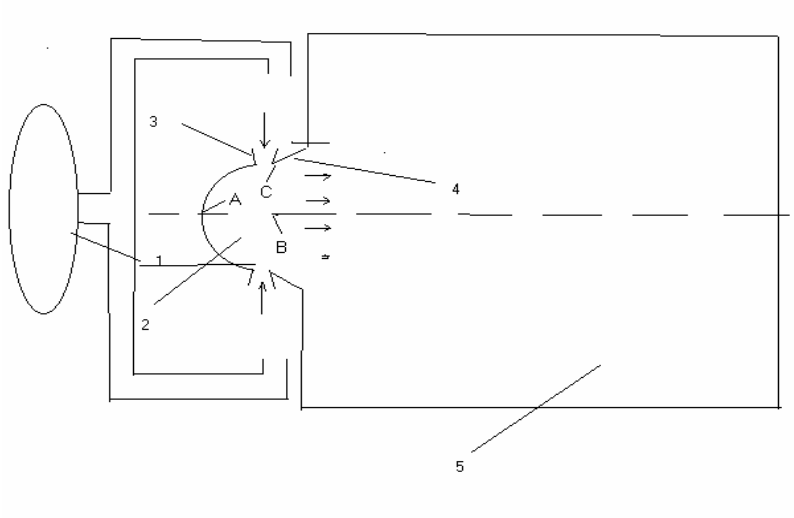

Figure 1. Schematic of the experimental installation: 1 - the reactor, 2 - the semienclosed cavity, 3- inlet annular nozzle, 4- outlet nozzle, 5 - receiver for the combustion products, A, B, C - the points of the control of the flow parameters with the numerical simulation.

It is assumed that the stoichiometric mixture of acetylene with air under the initial values of pressure - P_0, temperature - T_0=300K and molar concentrations of components - X_0 burns in the reactor at a constant volume. As a result what are formed the reaction products with the stagnation parameters Pt, Tt, Xt, which enter along the feeder into the annular nozzle and elapse with the sonic speed into the semienclosed cavity, and then they emerge into the receiver, filled with at rest under the values of the thermodynamic parameters Pe=0.01 atm, Te = 300K assigned at the initial moment of time. The motion of gas in the subsonic feeder was determined from the formulas of one-dimensional gas dynamics under the assumption "of icing" of chemical composition. The semienclosed cavity was spherical segment with a height of 22 mm and a diameter of d = 66.4 mm. The height of the critical section of annular nozzle composed h = of 4.4 mm. Four versions for the different values of the stagnation pressure Pt = 4.81, 9.77, 14.78 and 19.83 atm were counted. The values of total trust D and of specific impulse I were calculated using the distribution of pressure p_w received in calculations along a surface of the thrust module:

$$D = 2\pi \int_0^{s_n} (p_w - p_e) \mid x \mid n_y ds; I = D / gG.$$

Here x - distance to the axis of the symmetry, n_y - the projection of the unit vector of normal to the surface on the direction of the axis of symmetry, s - the distance along the outline of module, measured from the point A (see Fig. 1), s_n - distance to the edge of annular nozzle, G - the total gas flow through the nozzle, g - acceleration due to gravity.

Experimental studies were conducted on the pulse aerodynamic installation of the model of the nozzle device

of original construction, which made it possible to measure the pressures at several points on the surface of thrust wall and also in the feeder near the critical section. The typical operating time of the realization of quasi-stationary flow under the conditions for experiments was about 50 ms. For measuring the pressures in flow area were used both high-frequency piezoelectric and special strain gauges, which are characterized with stability of zero and constancy of calibration with a change in the temperature of the medium being investigated. In the course of the experiment thrust was simultaneously recorded by the strain gauge of force. Signals from the sensors were written by high-speed digital electron oscillographs of the type HP -54624a and in parallel by a digital multichannel amplifier of the type MGCplus. For the calibration of sensors the method of dynamic calibration under the conditions, maximally approximating operating conditions with the tests of the model in question, was used. The collection of those measured in the course of the experiment of the flow parameters in the subsonic and in the supersonic zones of flow made it possible by single-valued means to conduct their comparison with the computed values of the corresponding values.

3 Main results

The complete picture of the dynamics of flow in the cavity from the moment of the beginning of the inflow into it of annular jet to shaping of the resulting state of flow is numerically obtained. The analysis of the development of process made it possible to isolate its two stages, which are distinguished qualitatively and by the quantitative values of the flow parameters. Initial stage is characterized by short time and strong fluctuations of the characteristics of flow. The amplitude of fluctuations decreases in the course of time. With the use of an inviscid model for describing the flow of the products of the combustion of the fuel mixtures examined is established the resulting regime with the periodic oscillations of the relatively small amplitude of all flow parameters. At the account of viscous effects the stationary mode with close to nonviscous model of calculation in parameters is realized. In this case the time of establishment depends on the parameters of the problem and changes in the limits of 0.5 1.0 ms, and fluctuations are most intensive after starting and gradually they attenuate in the course of time. Most intensive fluctuations of pressure P(A) (see Fig. 2) are observed in the ground region on the wall of cavity (Fig. 1, point A). In Fig. 3 are shown particle trajectories, and in Fig. 4 - 5 the dependences of thrust and pressure in the ground region at point A on the stagnation pressure Pt (continuous lines), and the corresponding values, measured in the experiments (small crosses), after the establishment of steady state. The satisfactory agreement of the tendency of the behavior of specified values is observed.

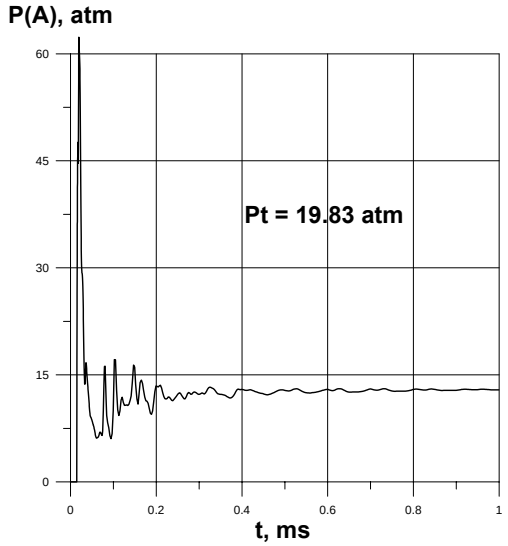

Figure 2.

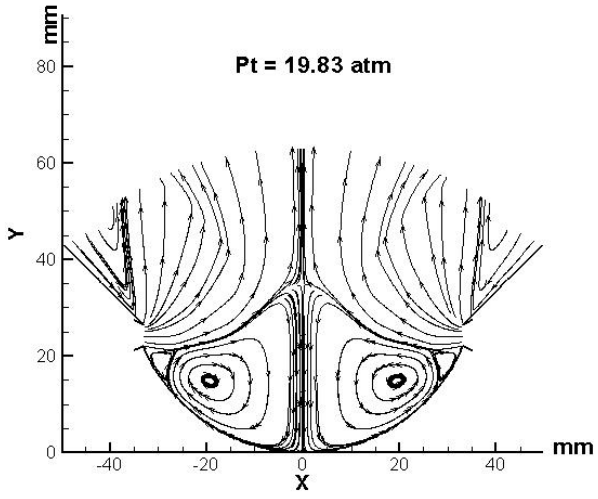

Figure 3.

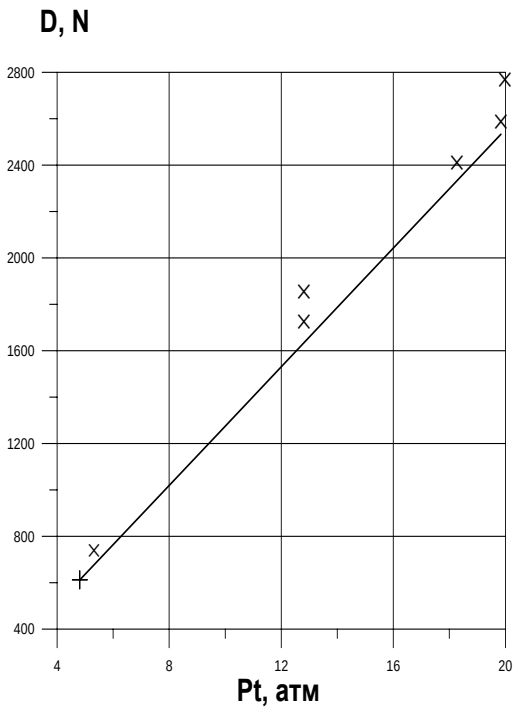

Figure 4.

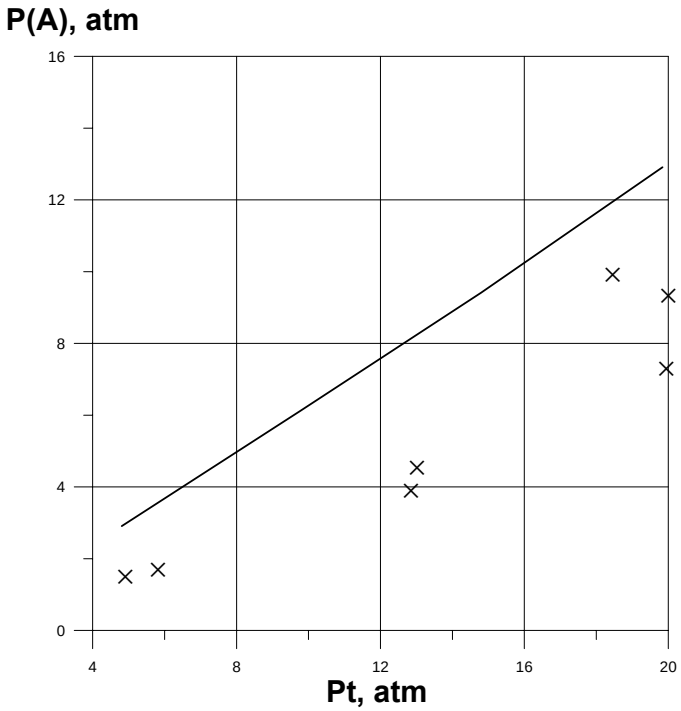

Figure 5.

4 Conclusions

The comparison of the results, obtained with the use of different models of gaseous medium with the data of experiments on the measurement of the pressure on the thrust wall and of thrust, made it possible to verify the design models of flow, to explain the degree of the influence of the calculation of the viscosity of gas on the calculated parameters, and also it suffices to reliably predict the expected values of the thrust, developed by nozzle device.

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