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NUMERICAL AND EXPERIMENTAL INVESTIGATION OF NON-STATIONARY PROCESSES IN SUPERSONIC GAS EJECTOR

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Abstract

The supersonic gas ejector, as gas dynamic appliance, has been applied a long time because of simplicity and reliability. However, for the ejector performance prediction with given parameters, that is, working gas pressure and the nozzle shape, it is necessary to rise modeling accuracy for ejector gas flow properties.
The represented work purpose is to compare one-dimensional modeling and numerical results with experimental data. The ejector with a conic nozzle has been designed and tested.

1 Introduction

The supersonic gas ejector (vacuum pump) is a device which a long time is used as gas-dynamic appliance and which is investigated in detail [1-5]. However, for adequate simulation of ejector performances, in particular, ejector overall characteristic and minimum level of vacuum pressure for known nozzle chamber parameters of working gas and the known nozzle shape, it is necessary to raise the simulation accuracy for ejector gas flow.

For the ejector providing peak pressure ratio, there is a start problem and stationary operating regime keeping. Instability of ejector operating regime is especially appreciable near breakdown pressure level. About this level pressure ratio is maximal. However, minimal pressure decrease in the nozzle chamber near the breakdown point destroys gas flow and decreases the pressure differentiation between the nozzle exit section and the vacuum chamber instantly. Design of the ejector creating vacuum chamber minimal pressure, it is possible to present as several stages.

The preliminary sizes of gas-dynamic channel characteristic sections (the mixing chamber diameter near the nozzle exit section, diffuser throat diameter, outlet diffuser diameter), ejector start pressure and nozzle operating pressure are determined by the one-dimensional theory [3]. The one-dimensional theory does not estimate the channel restriction-expansion corners and the channel linear sizes. There are recommendations of a choice for linear sizes and restriction-expansion corners based on experimental data. The channel length and restriction-expansion corners are selected, using numerical simulation of non-viscous gas flow. This simulation allows to specify ejector section diameters. The minimal ejector length and simplicity of ejector design are solution criteria.

The computed sizes and the ejector performances are specified finally using the viscous gas model. In the article the mentioned problem is solved by software package FlowVision [6].

The represented work purposes are the analysis of one-dimensional theory capacities for ejector diameter and starting pressure definition and present experimental data of non-stationary processes in supersonic gas ejector [7].

2 The Computational Simulation

Working regime for ejector includes two stages:
1 stage: Ejector regime. Starting ejector with ambient pressure equaled 1 bar and pumping out air from vacuum chamber.
2 stage: Wind tunnel. There is minimal pressure within vacuum chamber.

Ejector and wind tunnel have exit restriction-expansion section, so-called «the second throat». The ejector theory [3,4] explains the second throat necessity as follows. At first pressure increases up to maximal level during motor prechamber starting process. Maximal pressure allows to obtain required Mach numbers at nozzle outlet. If pressure within motor prechamber is reduced up to some minimal value then probability of penetration for air perturbation into ejector grows. There is balance for forces which fixes shock location and gas flow structure (shock-train) in ejector diffuser for correctly designed channel (a choice of the second throat).

Gas flow begins moving from nozzle outlet to ejector outlet high pressure (relatively ambient atmosphere) at fast increase of pressure within nozzle prechamber (Fig.1). It causes general movement for gas in direction from ejector. Therefore, for more ejector light-load start, the second throat should be maximal, but without flow separation (without inverse flow zones). Most simply to consider the constant diameter ejector (tube) in this case.

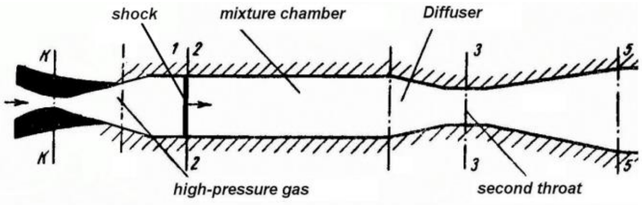


Fig.1. Ejector core elements and start shock.

After ejector starting the channel pressure goes down and penetration probability for air into ejector grows. It causes increasing of pressure in ejector. To exclude the phenomenon of growth for pressure in ejector, it is necessary to narrow the channel till minimally allowable size. Therefore 2nd throat ejector appears as an element of design. At minimal size of the 2nd throat the ejector will provide minimal pressure in vacuum chamber if pressure within nozzle prechamber will be minimally allowable, and its level will be less, than starting pressure. This phenomenon is ejector pressure hysteresis. The hysteresis takes place for ejector system at pressure decrease in nozzle prechamber. This phenomenon should be used for resources economy to provide vacuum chamber minimal level.

The ejector with a conic nozzle has been designed and tested. Working gas - nitrogen, was brought from gas bottles system. Stagnation temperature T_0=300 K . The following channel parameters are received: the nozzle throat diameter 6 mm; nozzle outlet Mach number 3.31, ejector mixture chamber diameter at the nozzle exit section was limited by condensation temperature of nitrogen and equaled 20 mm; minimal second throat is 16.4 mm; minimal starting pressure is 8.14 bar; average ejector inlet Mach number 4.035 (near nozzle outlet); average pressure about the nozzle exit section is 0.063 bar. Average temperature of flow at the nozzle exit section is 70.5 K. (Condensation temperature for nitrogen is T=72 K. This temperature corresponds to a point with pressure p=0.51 bar on a nitrogen saturation curve. Therefore condensation is minimal.)

The one-dimensional theory predicted the minimal starting pressure 8.18 bar (absolute) and underpressure 0.051 bar in the vacuum chamber.

Ejector is considered as classical ejector. Optimal ejector operating regime is achieved [3], if the compression shock is close on its parameters to intensive shock after 2nd throat and is located in expanding diffuser. In this case it is possible to use experimental recommendations of various authors concerning a diffuser expansion corner. The expansion corner of diffuser wall should not exceed 6^0. We shall use diffuser having two sections with corners 1^0 and 2.5^0. All linear dimensions for ejector are determined by 2D non-viscous gas model and are confirmed by viscous gas one (Fig.2).

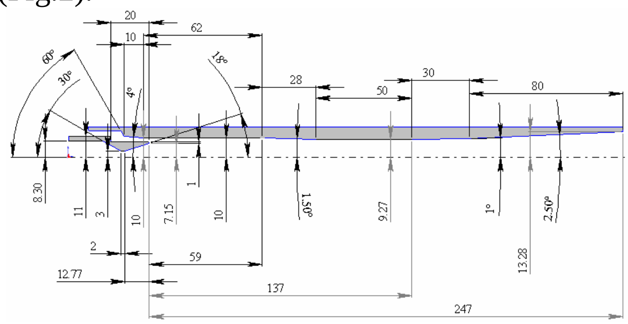
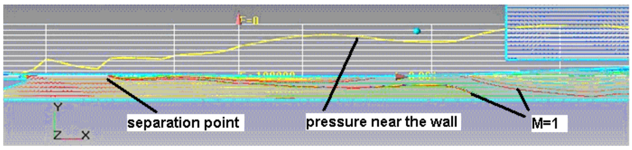
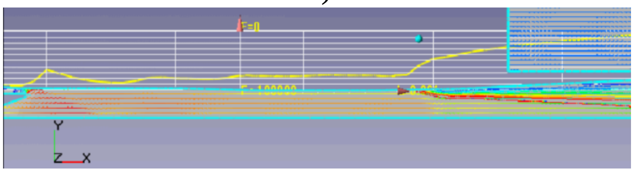


Fig.2. Designed ejector.

Ejector flow from start to stop was simulated by FlowVision at stepless increase of pressure and constant temperature in the nozzle prechamber. Numerical simulations have shown: designing result is channel with regular system of oblique shocks. The ejector provides pressure in vacuum chamber <0.07 bar at pressure 11 bar in nozzle prechamber. Two various turbulence models (*k-ε* and Spalart-Allmaras) have shown: separation point location varies, but parameters of a flow at nozzle exit section and pressure in the vacuum chamber do not change. When we use *k-ε* model the separation point is oscillate (extreme positions are shown on Fig.3-a, oscillation period is 0.0096 s). When we use Spalart-Allmaras model the separation point is stationary, are shown on Fig.3-b.



a)



b)

Fig.3. Numerical simulation. Pressure scale is changed from -100000 Pa to 0 Pa.

3 Experiments

Pressure sensors were located as shown on Fig.4. Sensor numerical order corresponds to alphabetical order. Sensors data along ejector wall are shown on Fig.5.

The minimal starting pressure was 9.055 bar (maximum 9.5 bar for another tests) and underpressure 0.057 in the vacuum chamber bar have been fixed in experiment. Vacuum chamber pressure against total (stagnation) pressure are shown on Fig.6 for some tests. Comparison predicted and experimental data has shown, that the one-dimensional theory allows to estimate low boundary of starting pressure.

The main experimental oscillation periods was obtained from pressure sensor data (example, see Fig.7). The low-frequency oscillations period change from 0.41 s to 1.66 s. The amplitude is changed very appreciably. The amplitude variation is corresponded to numerical data, but frequency is not.

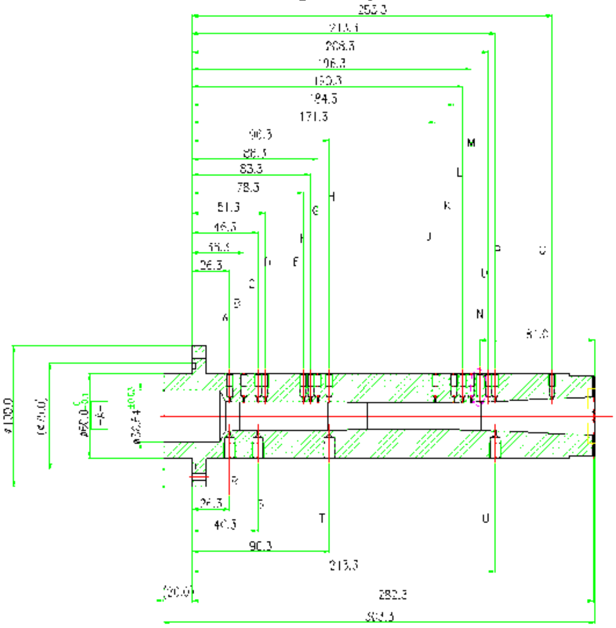


Fig.4. Experimental channel with sensor locations

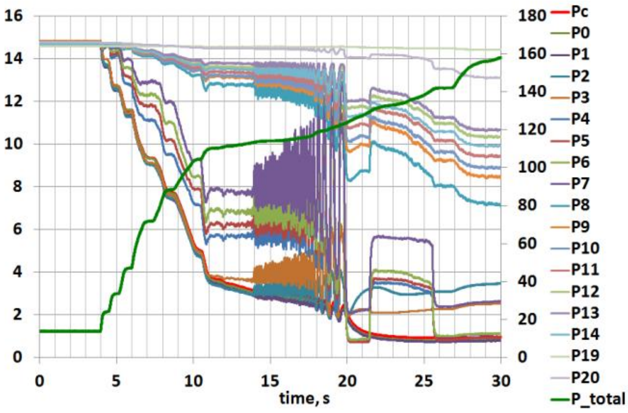
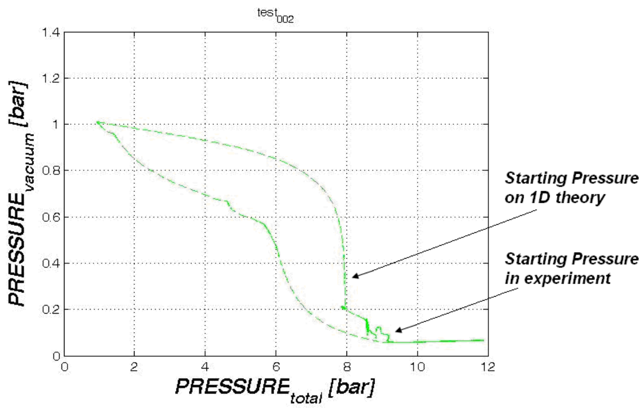
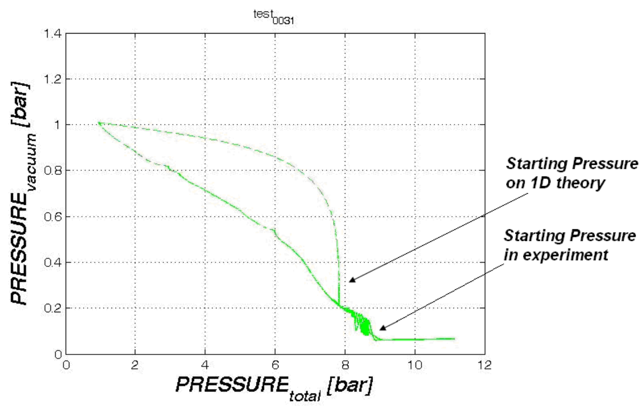


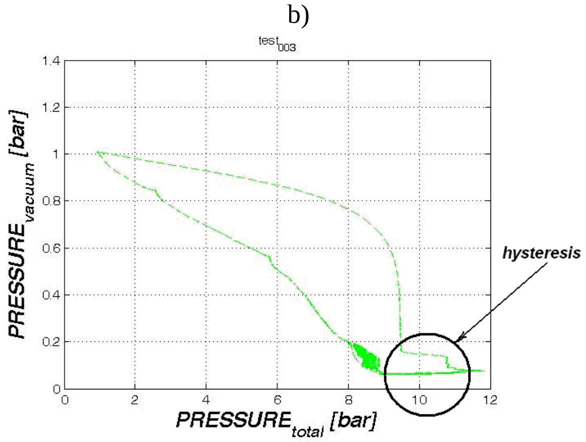
Fig.5. Sensors data along ejector wall (P – left scale, Torr) and in nozzle prechamber (Ptotal – right scale, Torr). From start to stop.



a)



b)



c)

Fig.6. Vacuum chamber pressure against total pressure (the file name is specified in the figure title).

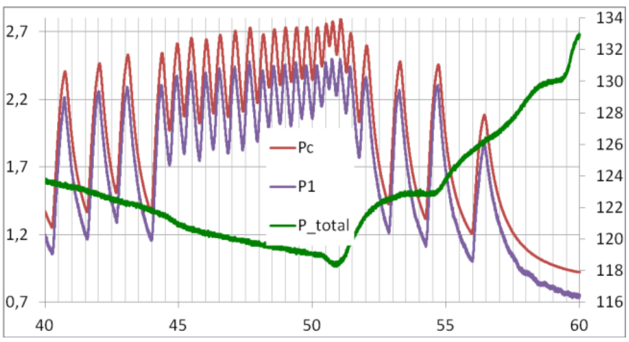


Fig.7. Sensors data in vacuum chamber (Pc – left scale, Torr), near nozzle outlet (P1 – left scale, Torr) and in nozzle prechamber (Ptotal – right scale, Torr). Unstable rigime

4 Conclusions

The designed channel provides predicted pressure in vacuum chamber at more high starting pressure, than starting pressure received on 1D theory, but smaller, than at 2D numerical experiment.

Optimum pressure in nozzle prechamber corresponds to low-noise ejector operating regime, thus, noise level can be as criterion of search for optimal regime (minimal pressure in vacuum chamber).

Numerical simulations have shown, that ejector starting pressure can be both more, and less than an experimental level of pressure, depending on a calculation grid, model of turbulence and evolution of calculation process.

2D (and 3D) numerical simulation allows to estimate a probable pressure fluctuation level on transitive operating regimes of an ejector, and also to specify prospective distribution for flow parameters, in particular, gas flow temperature along a wall of the channel. Also 2D (and 3D) numerical simulation allows to specify the additional information about gas flow, providing more adequate gas-dynamic and thermal designing.

The cause of large frequency difference between experiment and simulation is inadequacy of the turbulence model evidently. Selection or generation appropriate turbulence model for good determination of separation point (and it oscillation) – subsequent interesting research issue.

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