# Experimental study of flow around axisymmetric bodies in supersonic flow in case of a local injection into the boundary layer

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**Abstract.** A technique of experimental determination of the parameters and structure of supersonic air flow around of axisymmetric bodies form in the range of Mach numbers M = (2 ÷ 5) are presented. The results of the investigation of the interaction a supersonic stream flowing around of an axisymmetric model with gas jet which inject into the boundary layer are given.

## 1 Introduction

Determination of aerodynamic characteristics of bodies in the range of Mach numbers M = (2 ÷ 5) is important for designing aircrafts of various purposes. In this connection the necessity of solving a number of scientific and technical problems arises. This paper presents the technique and results of experimental studies of supersonic flow around an axisymmetric (conical) model in the presence of symmetric and asymmetric gas injection into the boundary layer.

## 2 Description of the aerodynamic installation and a technique of conducting experimental researches

Experimental researches were carried out on an aerodynamic installation [1, 2]. The range of realized modes of operation of the installation: the Mach number M = (2 ÷ 7), the braking pressure at the nozzle exit section of the diffuser, forming the supersonic flow, $P_0$ = (0.15 ÷ 0.3) MPa at static pressure $P$ = (0.03 ÷ 0.07) MPa, the braking temperature of the incoming air flow $T_0$ = (17.5 ÷ 250) °C. Scheme of modernized aerodynamic installation is presented in Fig. 1. The installation consists of the following basic elements: frame, basic valve, 8 cylinders with hand valves, splitter, diffuser, business end, nozzle, forehearth, electrical heater, power source. Before the experiment, the working gas is in 8 cylinders 4 with a total volume of 320 $dm^3$ at a pressure of up to 15.0 MPa. To start the installation, the basic valve is switched on from the control console and the working gas from the cylinders enters the electrical heater and the forehearth.

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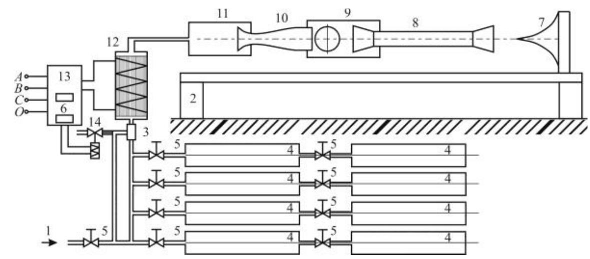



**Fig. 1.** Scheme of a model aerodynamic installation: 1 – air supply; 2 – frame; 3 – the basic valve; 4 – cylinders with compressed air; 5 – hand valves; 6 – the control panel; 7 – splitter; 8 – diffuser; 9 – working part; 10 – profiled nozzles; 11 – forehearth; 12 – electric heater; 13 – power supply 20 kW; 14 – control valve.

To measure the direct stresses (pressures) on the surface of the test body, holes (diameter 0.25 mm) are made. Drainage holes on the surface of the model were connected to a micromanometer using air-ducts. Each hole in the complex with the air-duct is a receiver (drainage receiver) of static pressure on the surface of the streamlined model. The peculiarity of drainage tests is that defining to their results only that component of the total aerodynamic force, which that is caused by pressure. The frictional forces in this case cannot be measured. The run duration of the aerodynamic installation is (1.0 ÷ 3.0) s. The preheating of the working gas is realized with using a pebble heater. To create a supersonic flow was used axisymmetric profiled nozzles. The installation is provided with registration system of pressure, of temperature, with a system of visualization and with three-component aerodynamic (tensometric) balance. The model aerodynamic unit is equipped with equipment for visualization the processes of gas flow of the studied bodies by the Tepler method with a parallel beam of rays. In Fig. 2 the photography and scheme of the shadow device are given.

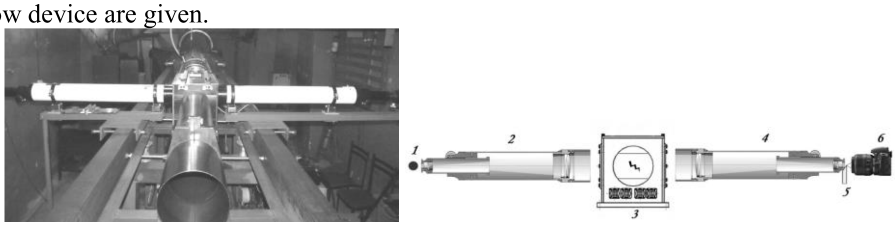
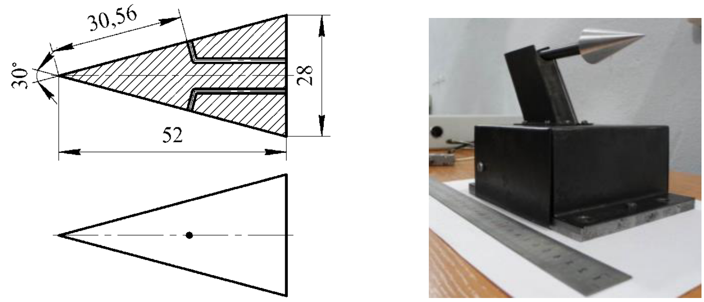



**Fig. 2.** Photo and diagram of the shadow device: 1 – point light source; 2, 4 – telescope "Tal-100SR"; 3 – working part; 5 – Foucault knife; 6 – video recorder (DVR).

With the help of the Foucault knife, the intensity of the light flux is regulated. The beam enters the lens of the DVR 6, where you can see the image of the body being examined. As a DVR, the high-speed video camera "Phantom v711" is used. The use of a high-speed video camera makes it possible to examine in more detail the picture of the flow around the model by gas, and also allows to correlate the obtained video frames with the readings of sensors, since the initiation of video shooting. The start of the measuring system and the opening of the electromagnetic air valve takes place at a time from one source of the signal.

## 3 Results of experimental studies

Cone models (Fig. 3) (axial symmetry) with the channels for measuring the pressure on the surface were under tests. Half-angle is 15 °. Drainage holes of the cannels were made in the fixed points of the surface in vertical plane. Shadow method jointly with high-speed videotaping were used during performing-drain and weight tests.




a) b)

**Fig. 3.** Scheme (a) and general view (b) of cone model.

Airflow data and force to have an effect on profiling surface by the stream were measured to calculate the model drag coefficient. The results of processing of experimental data of model weight tests for every Mach number are listed in the table 1. The comparison of obtained drag coefficient values with the values [3, 4] are presented in Fig.4.

**Table 1.** The results of processing of experimental data.

| Mach number | $C_x$ | $\overline{C}_x$ | $\Delta C_x$ | δ, % |
|---|---|---|---|---|
| 2 | 0.4651 | 0.4680 ± 0.0036 | 0.0153 | 3.27 |
| | 0.4750 | | | |
| | 0.4637 | | | |
| 3 | 0.326 | 0.3244 ± 0.0014 | 0.0060 | 1.85 |
| | 0.325 | | | |
| | 0.322 | | | |
| 4 | 0.2833 | 0.2830 ± 0.0003 | 0.0014 | 0.51 |
| | 0.2823 | | | |
| | 0.2833 | | | |
| 5 | 0.1877 | 0.1808 ± 0.0038 | 0.0161 | 8.93 |
| | 0.1748 | | | |
| | 0.1798 | | | |

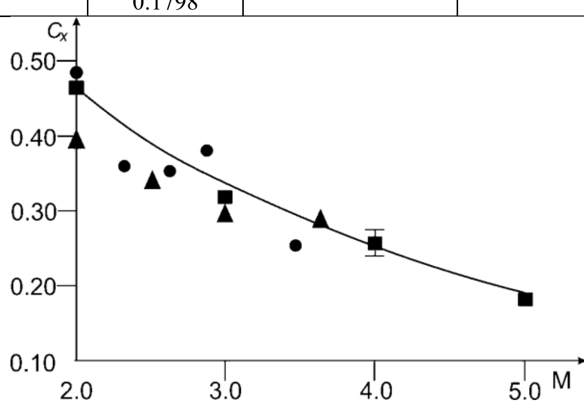
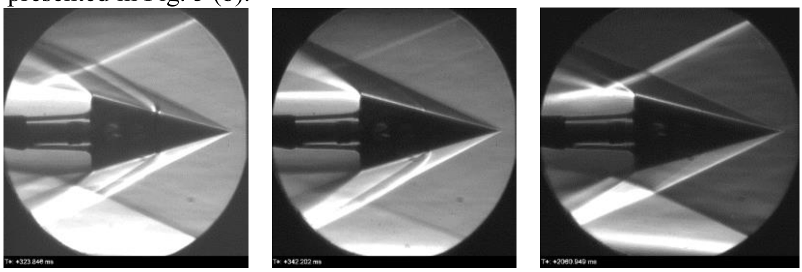



**Fig. 4.** Coefficient of the drag force for a cone: ■ – results of the experiments; ● – data [3]; ▲ – data [4].

Comparison of the results obtained with the findings of other authors showed their satisfactory agreement. In the range of the Mach numbers M = (2 ÷ 4) the maximum difference between the data of the authors [3] is ~ 8 %, between the data of the authors [4] is ~ 15 %. One of frames of high-speed videotape of supersonic air flow around cone (M = 3) with the organization of a local gas injection into boundary layer through two holes (nozzle-point) located at the top and bottom symmetrically about the model axis, is given in Fig. 5 (a).Conditions of blowing formation with a constant speed of M = 1 are diameter of a drainage hole – 0.25 mm, pressure in channels through which injection of air flow to boundary layer is organized, – (0.5 ÷ 1) MPa. One of video-frames of supersonic air flow around cone (M = 3) at non-symmetrical local injection out through hole in the bottom of model is presented in Fig. 5 (b).



a b c

**Fig. 5.** Video-frames of supersonic air flow around cone with injection out through two symmetrically located holes (a), out through one hole in the in the bottom of model (b), and without injection (c), M = 3.

## Conclusions

The results of experiments when flow around the cone without gas injection in the range of Mach numbers [2] were used as a control-test in experimental studies. The comparison of flow structure when flow around cone with symmetric gas injection and without it showed qualitative change of interaction of supersonic air stream with the cone surface (formation of Mach cone). In presence of injection the angle of Mach cone changes due to interaction between shock wave and injected air flow. It was observed that angles between Mach cone and surface of the model are different when flow around cone with the non-symmetric and with symmetric gas injection. Asymmetric Mach cone is formed when the non-symmetric gas injection. Thus qualitative analysis of the flow structure visualization results when flow around cone with gas injection and without it shows significant impact of injection to the boundary layer dynamics and Mach cone formation, and, consequently, to the change of the dynamic force on the body surface.

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