MATEC Web of Conferences **92**, 01056 (2017) DOI: 10.1051/matecconf/20179201056
Thermophysical Basis of Energy Technologies - 2016

An experimental study of flow over flat and axisymmetric bodies

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Abstract. The technique and results of an experimental study of the flow structure and critical parameters of the flow over flat and axisymmetric bodies in a range of the Mach numbers (M = 2 ÷ 5) are presented.

1 Introduction

Nowadays, there has been a tendency to increasing in speeds of aircraft to hypersonic ones. Hence, a problem of development of body frame geometries, optimized for large Mach numbers of incoming flow is becoming urgent. The technique and results of experimental studies of a supersonic air flow over flat (a wedge) and axisymmetric (a cone) models are given in this paper.

2 A technique of conducting experimental studies

Experimental studies were conducted in the aerodynamic unit [1]. The main function of the aerodynamic unit is creating a short-term supersonic flow of gas for carrying out aerodynamic and aerophysical testing. The range of its realized modes of behavior is the following: the Mach numbers M = (2 ÷ 7), the pressure in the stagnation chamber P_f = (1.5 ÷ 8) MPa, the braking pressure at the nozzle section P_0= (0.15 ÷ 0.3) MPa, the static pressure P = (0.03 ÷ 0.07) MPa, the braking temperature of the running air flow T_0 = (17.5 ÷ 250) °C. The operating time of the aerodynamic unit reaches (1.0 ÷ 3.0) s. For the operating time of t_k = 3 s, the values of parameters of the realized modes remain constant during $t_c \approx 2$ s. While testing the models in the aerodynamic unit, there is an opportunity to vary the temperature up to ~ 400 K and the wind velocity in the range of M =(2 ÷ 7). Preliminary heating of the working gas is realized by utilizing a pebble heater. To create a supersonic flow, the axisymmetric bell-shaped nozzles were used. For obtaining the maximum volume of experimental data on critical parameters and the structure of the air flow in the course of testing the models the aerodynamic unit is supplied with a pressure recording system, a visualization system and a three-component aerodynamic (tensometric) balance.

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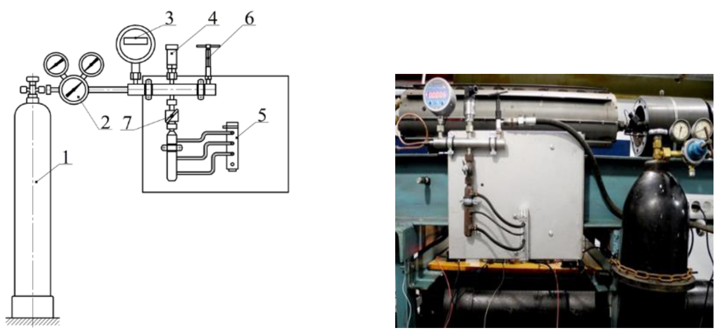
The definition of the pressure fields is based on application of a pneumometric method which consists in measuring the total, static flow pressures and the pressure in the stagnation chamber. In the wind-tunnel experimental chamber for measurement of the total and static flow pressure the Pitot-Prandtl tube was installed. Registration of measurement results was carried out by means of TDM2-A strain gage sensors. The sensor allows to measure pressure up to 0.5 MPa. Strain gage sensors are grouped in blocks. Each block contains five receivers. In the stagnation chamber, the pressure was measured by means of the sensor DM 5007A – DI U2. The sensor allows to measure pressure up to 10 MPa.

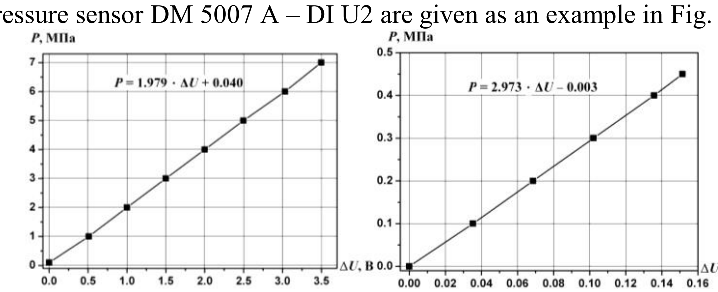
In carrying out the tests in the aerodynamic unit, pressure sensors are exposed to short-term pulse impacts. This leads to mechanical deformation of the sensors and, therefore, can lead to inadmissible error measurements. Because of this, there is a need for graduation of the sensors before each series of experiments. To ensure necessary accuracy of measurements, the calibration stand was developed and built up. The scheme (a) and external view (b) of the calibration stand are provided in Fig. 1.



a) b)

Fig. 1. A scheme (a) and a photo (b) of the calibration stand for pressure sensors: 1 – a cylinder with compressed air, 2 – a reducer, 3 – the digital manometer, 4 – the pressure sensor DM 5007 A – DI U2, 5 – the block of strain gage sensors; 6 – the pressure release valve; 7 – the regulating valve.

A distinctive feature of the developed stand is the possibility to graduate pressure sensors of both types used in the aerodynamic tests. Technically, it is implemented by means of the regulating valve 7. The graduation of the TDM2-A pressure sensor (Fig. 2, a) and the pressure sensor DM 5007 A – DI U2 are given as an example in Fig. 2 (Fig. 2, b).



a) b)

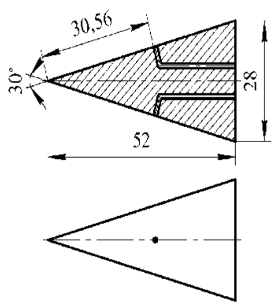
Fig. 2. Calibration dependences for TDM2-A (a) and DM 5007 A – DI U2 (b) sensors.

The average relative error of graduation for the TDM2-A pressure sensor amounts to 0.2%, for the pressure sensor DM 5007 A – DI U2 – 0.15%. The visualization system is intended to provide high-quality observations of the airflow over a model. Visualization of the processes which accompany a gas flow in a wind-tunnel experimental chamber is based on application of the schlieren method in a parallel beam. The complex of devices realizing visualization consists of a shadow device and a video recorder. The shadow device includes a pointlight, two transmitters and receivers installed coaxially relative to the wind-tunnel experimental chamber and a Foucault knife. Telescopes of Tal-100SR are used as the transmitters and receivers, the high-speed video camera "Phantom 711" is used as the video recorder.

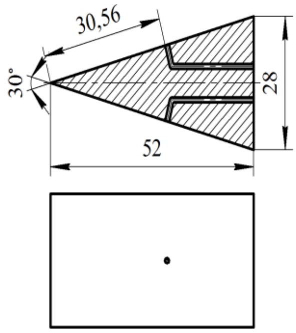
In the experiments to determine the drag coefficient of the bodies at a supersonic flow-past the three-component aerodynamic (tensometric) balance was used. The balance allows measuring the drag force, the lift force and the disturbing moment.

3 An experimental study of supersonic flow over symmetric models

On the basis of the presented technique an experimental study of critical parameters and the flow structure for symmetric models was conducted. The models are made in the form of a cone (axial symmetry) and a wedge (plane symmetry) [2] with diversion channels for pressure measurement upon surfaces. The corner of semi-solution made is 15 º. Drainage slots of diversion channels were carried out in the characteristic fixed points on a surface in the vertical plane. The schemes of arrangement of drainage slots and the photo of the models are provided in Fig. 3.



a)



b)

Fig. 3. Schemes and photos of the models in the form of a cone (a) and a wedge (b).

To measure pressure in the experiments (the drainage tests), the models were fixed by means of a holder on the support allowing to vary the pitch angle.

To determine the drag coefficient (the weight tests), the models were installed on the tensometric balance and then placed into the wind-tunnel experimental chamber (Fig. 4).

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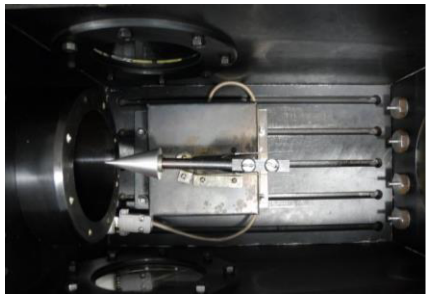
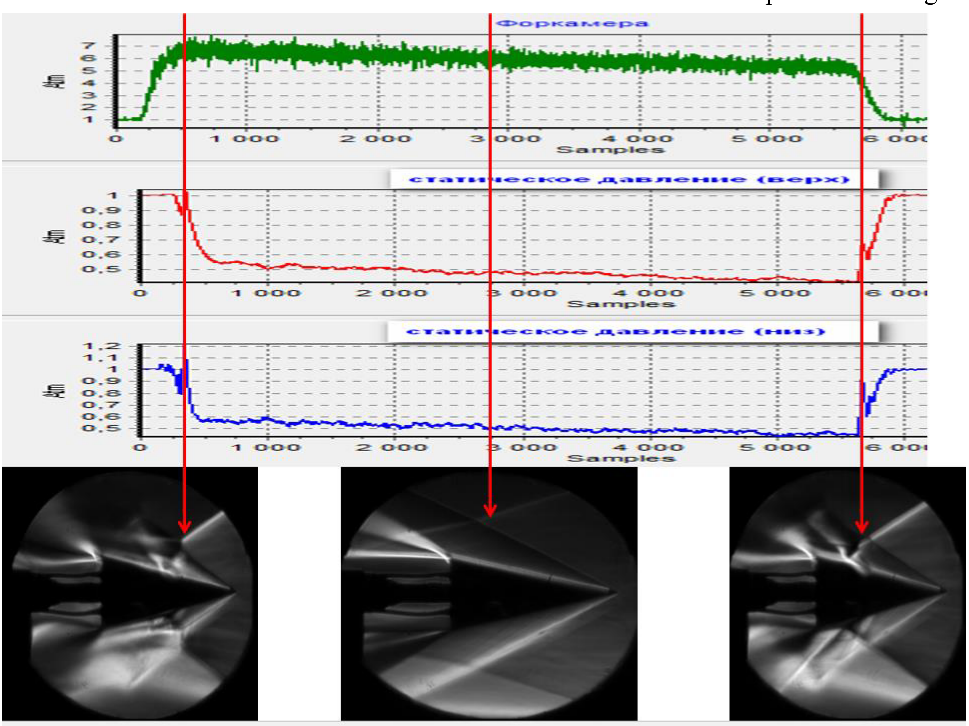


Fig. 4. The model in the form of a cone installed on the tensometric balance in the wind-tunnel experimental chamber.

4 Analysis of the results of the experimental studies

The amplitude-frequency characteristics in the antechamber and in two drainage slot, and visualisation frames of the air flow structure around a cone at M = 3 are presented in Fig.5.



a) b) c)

Fig. 5. Amplitude-frequency characteristics in the antechamber and in two drainage slots and visualisation frames of the air flow structure around a cone, M = 3.

These frames of visualisation describe three significant moments of flow around the model by a supersonic airflow.

The first significant moment is the onset of forming the Mach rhombus (Fig. 5, a). At the same time the shock wave passes through the drainage slots. At this moment there is a pressure jump which is fixed on the oscillograms.

The second image (Fig.5, b) features the stationary flow – the pressure in the antechamber and on the surface of the model is almost constant. At the same time the formed Mach rhombus is well visible on the video footage.

The third picture (Fig. 5, c) shows the moment of "collapse" of the Mach rhombus. At this time the pressure in the antechamber sharply falls, the shock wave again passes through the drainage slots. The signals are registered on the oscillograms as peaks.

The results of the drainage tests of the flow around a wedge and a cone in the range of the Mach numbers M = (2 ÷ 5) are shown in Fig.6, the pitch angle is equal to zero [2].

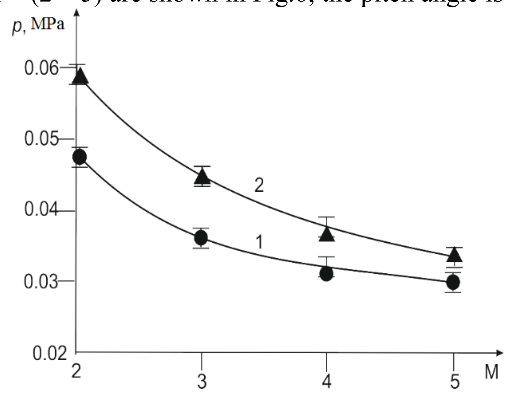


Fig. 6. Static pressure upon surfaces of the models: 1 – a cone; 2 – a wedge.

Analysis of the results obtained showed the difference in values of the static pressure upon the wedge and cone surfaces. The noted effect is explained by the fact that the flow over a cone in the considered speed range has a spatial nature. It promotes smooth change in direction of the gas flow in comparison with the flow over a wedge [2, 3]. At the same time it should be noted that the difference in values of the static pressure the flow over flat and axisymmetric models decreases with increasing the Mach number of the incoming flow.

The drag force and pressure in the antechamber were measured during the weight tests. The aerodynamic coefficient of the drag force C_x was defined by the results of the measurement. Fig. 7 shows the comparison between the obtained values of C_x for the cone and the data from [4, 5].

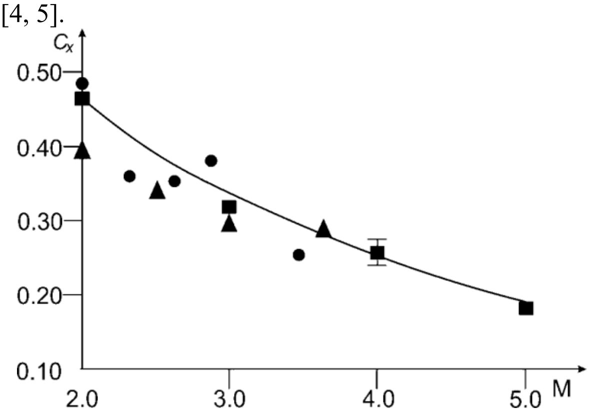


Fig. 7. Coefficient of the drag force for a cone: ■ – results of the experiments; ● – data [4]; ▲ – data [5].

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 [4] is ~ 8%, between the data of the authors [5] is ~ 15%.

5 Conclusion

An experimental study of supersonic flow over models in the wide range of the Mach numbers has been conducted. The comparison of experimental results with the data of other authors is given and their satisfactory agreement is shown. The analysis of the experimental study results showed that in mathematical modeling of gas-dynamic processes in propulsion systems in the range of M = (2 ÷ 5) it is necessary to consider the spatial nature of the flow over bodies.

Acknowledgements

This research carried out in 2015 was supported by «The Tomsk State University Academic D.I. Mendeleev Fund Program», grant № 8.2.46.2015.

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