Experimental studies of wedge models

L B Ruleva and S I Solodovnikov
Ishlinsky Institute for Problems in Mechanics RAS, Vernadsky prospekt 101(1), Moscow, 119526, Russia
E-mail: ruleva@ipmnet.ru

Abstract. The functionality of the more complete validation of the developed CDF is being expanded for "Hypersonic aerodynamic shock tube" laboratory facilities. Models of triple semi-wedge with sharp edge and blunt edges were tested. The regions of the high pressure close to the blunted edge of the model are revealed. In the upper model, the greatest pressure was detected on the front face and in the middle region of the flat channel. The experimental graphs of the pressure distribution on the upper and lower surfaces of the model are compared with numerical simulations at limited distances from the nozzle section.

1. Introduction
The aerothermodynamics of the input groups of air intakes of high-speed aircraft is studied by numerical modeling using the author's calculation codes [1]. The numerical simulation is compared with the known data of flight experiments [2]. For operational validation of numerical simulation, a laboratory setup is used [3]. The "Hypersonic Shock Wind Tunnel" (HAST) is a multi-mode, short-acting installation. HAST is shown in figure 1.

![Figure 1. HAST scheme.](image-url)
Calculation and experimental work [4] to improve the characteristics of the plant increased the time of quasi-steady flow in a shock tube and the nozzle, which is suitable for validation. The test tasks for adjusting the HAST to the required conditions for experimental studies of models in the gas flow are formulated by calculations in [5,6]. The influence of the initial pressure in the driven tube on the flow near the end of the driven tube at a constant initial pressure in the driver tube is studied.

The accuracy of the measurement processes in the HAST is ensured by high-frequency pressure certification sensors, a low-inertia valve, as well as other equipment for implementing the direct measurement method. The combination of the experimental conditions in the shock tube and the conditions in the receiver determines the gas dynamic parameters of the gas incident on the test model.

2. Models of triple semi-wedge with sharp and blunt edges
Variants of models for the study of air intakes are wedge-shaped. They contain the upper single or double half-wedges in combination with a sharp or blunted lower edge. The experimental models were supplemented with a triple semi-wedge with a sharp edge, the shadow flow patterns of which are shown in figure 2.

![Figure 2. A triple semi-wedge with a sharp edge and a side wall in the flow. M=7.](image1)

To measure the flow parameters in the channel formed by a triple semi-wedge with a blunted lower edge models were made, in which pressure sensors were embedded, as shown in figure 3.

![Figure 3. A triple semi-wedge with a blunted edge in front of the nozzle and the shadow picture.](image2)
In the experiments, the mutual orientation between the models and the shift of the lower model from the nozzle cutoff were changed. Shock-wave structures that occur in the channel formed by the upper model and the blunted edge, when flowing around a high-speed flow, were visualized using a high-speed video camera. The flow field behind the conical nozzle sections, both in the deviation from the nozzle axis and at different distances from the nozzle section before the validation experiments was studied. The technique of partial discharge of the boundary layer at the discretion from the nozzle [7] in a high-vacuum environment of the aerodynamic block (receiver) is applied. The pressure in the receiver in the experiments was $10^{-6}$ atmospheres.

3. Experiments in HAST
The shlieren-frame of shock-wave structures near the model of triple semi-wedge with blunt edges in development is shown in figure 4.

![Figure 4. Shlieren-frame of shock-wave structures of a triple semi-wedge with a blunted lower edge in development. M=7.](image)

At the beginning of the process, the flow structure is quasi-stationary. Then it is replaced by non-stationary configurations. The Mach disk is visible. When comparing the flows in figure 2 and figure 4, it can be seen the most intense pressure regions are manifested in the design of a triple semi-wedge model with a blunted leading edge.

The duration times of the fragments (figure 4) are different. Frame by figure 4a) is lasted about $1.5 \pm 4$ ms that correspond to a quasi-stationary state, the so-called "shelf" on the pressure graph of sensors located on the upper model or on the lower edge. For different modes of set pressures in the impact part of the HAST and different pressures at the nozzle inlet, the time of the quasi-stationary state will be different.

The graphics of the pressure sensors on the models and in the shock part of the HAST corresponding shlieren-frame of shock-wave structures to figure 4 are shown in figure 5.
Figure 5. Graphs of pressure sensors (from top to bottom): 1 - 100 mm before entering the nozzle; 2, 3, 4 - on the lower edge of the 1st, 2nd and 3rd sensor from the edge; 5 = 1; 6, 7, 8 - on the upper model of the 1st, 2nd and 3rd sensor from the edge. M = 7.

The pressure graphs of the sensors in the models were compared with the corresponding time video frames of shadow images of the visualization of shock wave structures formed in the channel between the models. In the experiments, the pressure graphs of the sensors in the shock part of the installation, as well as in the aerodynamic block on the upper (figure 6) and lower (figure 7) parts of the model were obtained.

Figure 6. Pressure distribution in the upper models. M=7.
The graphs were obtained at the 36 atm pressure in the driver tube and at different pressures in the driven tube: 0.5; 0.1 and 0.001 atm, as shown in figure 8 in color.

The regions of the greatest pressure close to the blunted edge of the model are revealed. In the upper model, the high pressure was detected on the front face and in the middle region of the flat channel. The first pressure sensor of lower model is detected in 2 cm from blunted edge, as shown in figure 7. The calculated variants of the upper models are shown in figure 8.

The pressure sensors were placed in 7, 5÷14 cm distances from the front faces of the model in figure 8. The pressure graphs have the same trends in figure 6 and in figure 8 at these distances from the front faces of the model. The graphs in figure 8, indicated by the numbers 1...5, correspond to different positions of the lower model relative to the upper model.

4. About heat flow measurement

The upper triple semi-wedge model was studied experimentally on the surface heating by the luminescent temperature converters method in HAST [8] and on the installation of the method developers. The advantage of the luminescent temperature converters method is that it covers the entire surface of the model. However, the experimental method includes the complex calculation part.
Further studies were aimed to test the method of direct measurements [9] with certified low-inertia heat flow sensors. Heating of the surface of the upper model in the flow was measured as St = 0.002÷0.012.

Conclusion
The study of the parameters that characterize the distinctive features of shock-wave processes in wedge models showed the following. The concentration of areas of increased pressure and temperature is observed more in the wedge models of the triple angle than in the two-wedge models at the same mutual distances and flow rates. The blunt edge influenced more dynamic process then a sharp edge. Further studies of the wedge models will be aimed to increase the number of sensors on the surfaces after the introduction of blocks of analog-to-digital converters and hermetic drives prepared for experiments. Normalized graphs of the distribution of individual pressure regions on the upper and lower surfaces of the model were compared with numerical simulations, which showed satisfactory agreement.

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