MODELLING OF THE FLOW AROUND A HIGH-ALTITUDE ION CONCENTRATION PICKUP

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The results are presented for a study of the flow structure in the supersonic flow of air around a cylindrical body with an open and a blocked inner channel under the conditions of altitudes of 54-67 km. The studies were conducted on a low-density wind tunnel using the electron beam method of measurements.

In the study of the electrical properties of the upper layers of the atmosphere pickups consisting of a condenser made in the form of a hollow body of rotation are used to measure the concentration of ions [1, 2].

As the pickup is moved in the atmosphere the ions entering the inner cavity of the pickup along with the air are filtered by an electric field. To determine the ion concentration one must know the flow rate of the air passing through the pickup. In the upper layers of the atmosphere where flow around the pickup is essentially viscous the determination of the flow rate of gas through the pickup presents considerable difficulty. The flow rate is decreased because of forcing back by a thin boundary layer in the interior of the pickup channel. In the case of supersonic flow of air around the pickup the picture is complicated by the presence of a bow shock wave, possibly detached. Correct determination of the flow rate requires the conducting of detailed calibrations of the pickup under conditions close to those under which the pickup is used.

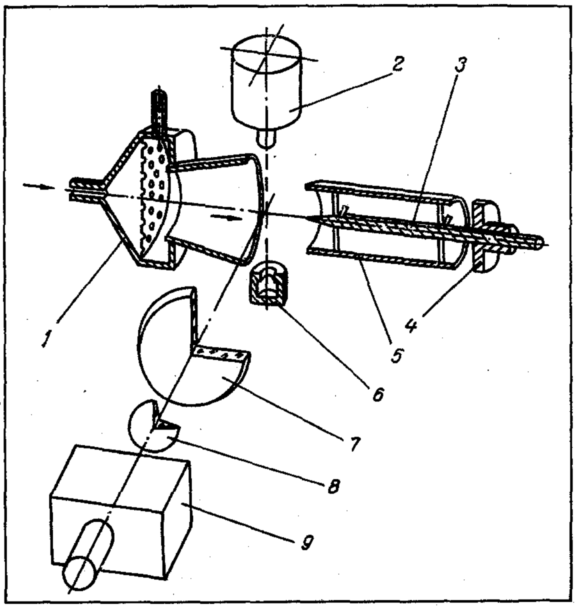

Fig. 1. Diagram of working section.

The purpose of the present work consists in an experimental estimate of the ratio between the true flow rate through the pickup and the flow rate calculated from the flight velocity and the area of the entrance cross section for a specific pickup and a specific mode of flight.

Method and Techniques of Experiments. The structure of the viscous flow of a supersonic stream around a specific body is characterized by the Mach and Reynolds numbers. A special lengthy selection of wind tunnel nozzles is required for the modelling of the variation in Mach number and altitude of actual flight under ground conditions.

A single conical nozzle with a mouth diameter of 150 mm, semiaperture angle of 10°, and geometrical Mach number of 2 was used in our experiments. Variation in the flow rate through the nozzle made it possible to vary the Reynolds number for the pickup with small deviations in the Mach number from the values which occur under actual flight conditions.

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TABLE 1. Flow Parameters and Modes of Nozzle Operation

Mode	1	2	3	4
p_0, mm Hg	0,169	0,108	0,071	0,037
T_0, °K	302	299	300	301
T_∞, °K	181	193	187	240
M_∞	1,83	1,66	1,73	1,13
$\rho_\infty \cdot 10^4$, kg/m³	6,35	4,32	2,73	1,41
H, km	54,7	58,1	62,1	67,2
Re_∞	1280	790	520	180
Kn_∞	0,018	0,024	0,038	0,04

A diagram of the experimental section is given in Fig. 1. The supersonic nozzle 1 is mounted within the vacuum chamber of the wind tunnel in such a way that an electron beam passing from the electron gun 2 to the collector 6 crossed the stream from the nozzle in a perpendicular direction through the axis. The pickup for which the flow is being studied is mounted movably in the stream beyond the nozzle. The construction of the nozzle consists of the hollow cylinder 5 which is 60 mm in diameter and 250 mm long with a central body 3 which is 15 mm in diameter. A plug 4, which closes the inner channel of the pickup when necessary, is mounted movably on the pickup holder. The region of space in front of the pickup being studied was scanned by displacement of the pickup relative to the electron beam.

The radiation excited by the electron beam in the gas is focussed by the lens 8 through the vacuum chamber illuminator 7 onto the entrance slit of the monochromator 9 which is equipped with a photomultiplier. The density and rotational temperature of the air can be determined from a spectral analysis of the radiation. A similar method is described in [3, 4]. To record the intensity of illumination, which reflects the air density, the monochromator was tuned to the edge of the (0, 0) band of the first negative system of N_2^+ at 3914 Å. The R-wing of this band was used to determine the rotational temperature. The localization of the measurements is determined by the diameter of the electron beam (≈2 mm) and the height of the observing zone (not more than 12 mm).

The pressure and temperature in the nozzle forechamber were taken as the stagnation parameters of the stream. The pressure was measured by a U-shaped manometer and the temperature by a thermocouple.

The parameters of the stream impinging on the pickup were measured in the following way. First the rotational temperature of the nitrogen of the air was measured with the pickup placed far from the nozzle. Then the Mach number and density were calculated from the stagnation parameters on the assumption that the measured temperature and the air temperature are equal and the expansion in the core of the stream is isentropic. The modelled flight altitude was determined from the density using the standard atmosphere of [5].

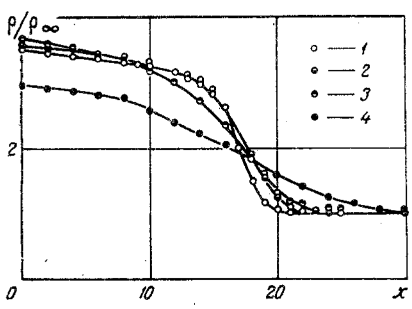

Fig. 2

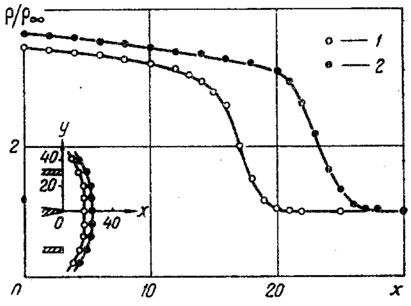

Fig. 3

Fig. 2. Axial density profiles in front of pickup in modelling of different altitudes. Curves 1, 2, 3, and 4 correspond to the modes of Table 1 (x, mm).

Fig. 3. Comparison of axial density profiles and shape of shock wave for pickup with open (curve 1) and closed (curve 2) inner channel. Mode 1. (x, mm).

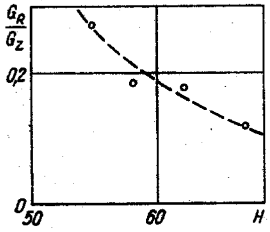

Fig. 4. Dependence of G_R/G_Z on the modelled flight altitude (H, km).

The axial density profiles were recorded with the pickup approaching the nozzle until the electron beam touched the edge of the pickup. Density profiles parallel to the axis at different distances from it were taken with the shifting of the point of observation along the electron beam.

Experimental Results. The gas-dynamic tests of the pickup were conducted in four modes of nozzle operation. The flow parameters are given in Table 1. The Re_∞ and Kn_∞ numbers were determined from the diameter of the pickup. Their range of variation indicates that the mode of streamline flow lies in the transitional region from continuous flow to free-molecular flow. The strong influence of viscous effects should be anticipated.

The results of measurements of the axial density profiles are presented in Fig. 2. The presence of a shock wave in front of the pickup is observed in all the modes. The thickness of the shock front is comparable with the pickup diameter. "Blurring" of the shock front is observed with an increase in altitude.

The difference in the flow structure for flow around an open and a closed pickup is illustrated in Fig. 3. An increase occurs in the separation of the bow shock front when the pass-through section of the pickup is shut off.

The magnitude of the separation of the bow shock wave from the body is an indicator of the hydraulic resistance of the pickup for the impinging gas. The results of an estimate of the ratio of the actual flow rate G_R through the pickup to the flow rate G_Z of the current running in the tube are presented in Fig. 4.

In the calculation of G_R/G_Z it was assumed that there is a proportional relation between the separation of the wave and the difference between the calculated and actual flow of air through the pickup ($\Delta \sim G_Z - G_R$). The point with the maximum density gradient was taken as the position of the shock wave. Thus, $G_R/G_Z = 1-\Delta/\Delta_1$, where Δ and Δ_1 are the magnitudes of the separation of the shock wave from the open pickup and from the same pickup with a closed inner channel.

It should be mentioned that the estimate of G_R/G_Z by this method has an approximate nature and can be used only as an illustration of the deviation of the true flow rate of air through the pickup from the rate calculated from the current impinging on the tube.

In conclusion it must be noted that the modelling and imitation of the flow around ion concentration pickups used to study the electrical properties of the upper layers of the atmosphere can be conducted on a low-density wind tunnel.

The shock wave generated in the flight of pickups of this configuration in the altitude range of 54-67 km is an isolated consequence of the large hydraulic viscous losses in the interior of the channel.

The actual flow rate through the pickup differs from the flow rate calculated from the pickup diameter and the velocity of the impinging stream by 3-10 times at altitudes of 54-67 km.

NOTATION

p	is the pressure;
T	is the temperature;
M, Re, Kn	are the Mach, Reynolds, and Knudsen numbers, respectively;
H	is the altitude;
ρ	is the density;
G	is the mass flow rate;
x	is the distance from edge of pickup;
Δ	is the separation of shock wave.

Subscripts

$0, \infty$ denote the parameters of the stagnant and undisturbed flow;
Z denotes the calculated value;
R denotes the actual value;
1 denotes the value with closed pickup channel.

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