STUDY OF THE INTERACTION OF A PLANAR SHOCK WAVE WITH A BLUNT BODY PLACED IN A SUPERSONIC FLOW

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UDC 533.6.011.72

We present experimental results relating to the interaction of a planar shock wave with a blunt body placed in a supersonic flow. We study the motion of the shock wave reflected from the surface of the body. We also ascertain the motion of the contact surfaces and the rarefaction wave after the interaction.

We consider the incidence of a planar shock wave on a blunt body immersed in a supersonic flow. A theoretical analysis of this problem involves great mathematical difficulties owing to the nonlinear nature of the phenomena. A calculation of the interaction of the incident shock wave with the head of the wave in front of a sphere in the vicinity of the axis of symmetry (one-dimensional approximation) was given in [1]. In [2] this problem is treated by a numerical method in which values of the pressure at the critical point of the sphere are given after incidence with the shock wave.

We investigated the motion of the shock waves and the contact surface which arises subsequent to interaction of the waves. The experiments were carried out in a two-diaphragm shock tube of rectangular cross section measuring 40×61 mm^2. A model consisting of a blunt body of given shape was placed in the working section of the tube. The experimental arrangement and the principles involved in its operation were described earlier in [3]. The gas flows behind the first and second incident shock waves can, for all practical purposes, be regarded as homogeneous. The Mach number of the flow passing the model, namely, M_1, was in the range 1.25-1.60. The Mach numbers of the wave incident on the body, M_2, were in the range 1.10-1.70. We used nitrogen as the working gas and hydrogen and helium as the propelling gas. To record the process we used a ZhFR photorecorder and shadowgraph instrumentation.

In Fig. 1 we present the time–distance diagram for wave interactions following the incidence of a shock wave on a cylinder with a flat nose immersed in a supersonic flow.

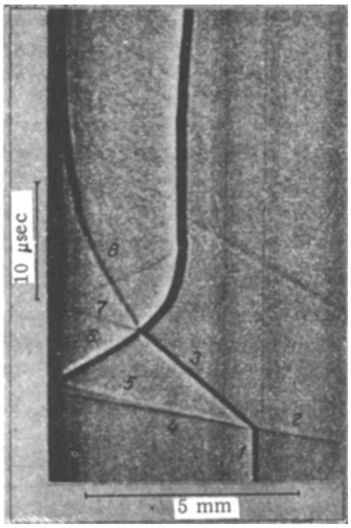

Fig. 1. Time–distance diagram of wave interactions on the axis of symmetry: 1) initially refracted shock wave ahead of the body; 2) incident wave; 3) heat wave after interaction; 4) impinging shock wave outside the layer of compressed gas in front of the body; 5) transient wave; 6) reflected wave from the body surface; 7) rarefaction wave; 8) contact surface.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 21, No. 3, pp. 419-422, September, 1971. Original article submitted April 28, 1971.

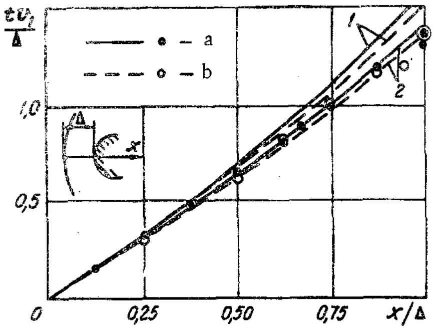

Fig. 2. Motion of transient wave (see Fig. 1, curve 5) in relation to motion of incident wave (2) at the axis of symmetry: $M_1 = 1.50$; $M_2 = 1.70$; a) cylinder with flat nose; b) cylinder with spherical nose.

The motion of the transient wave is shown in Fig. 2. The plotted points refer to experimental data. Curve 1 corresponds to a wave of infinitely small amplitude. Its motion was determined numerically from the known flow velocity distribution and the velocity of sound at the axis of symmetry. Corresponding values were taken from the tables in [4]. In addition, calculations were carried out on the assumption that the Mach number of the transient wave stays constant after interacting with the head of the shock wave in front of the body. The calculated results agree well with the experimental results (see curve 2 in Fig. 2).

In Fig. 3a we present the position and velocity of the shock wave reflected from the body on the axis of symmetry for a cylinder with a flat nose, and in Fig. 3b the same for a cylinder with a spherical nose.

In Fig. 4 we have plotted the speed of the contact surface formed from the interaction of the shock wave reflected from the surface of the body with the shock wave in front of the body. As is evident from Fig. 4, in the case of the flat-nosed cylinder the velocity of the contact surface near the body changes almost linearly with change in distance from the body. Up to the point of interaction with the rarefaction wave the velocity of the contact surface depends weakly on the distance from the body.

From Fig. 3 we can determine the interval of time subsequent to which the reflected shock wave becomes motionless with respect to the body. The magnitude of this interval characterizes the transition to stationary flow. The contact surface (see Fig. 1, curve 8) reaches the critical point of the body after a

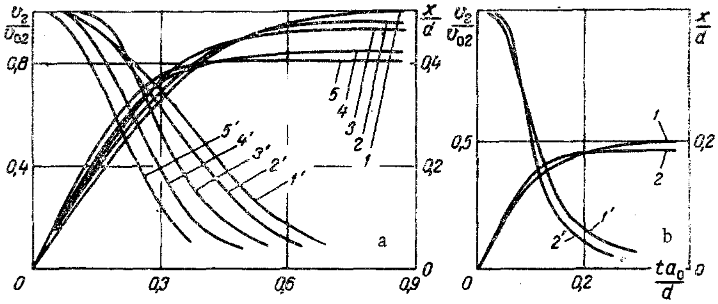

Fig. 3. Position (1-5) and velocity (1'-5') of the shock wave reflected from the body versus the time. $M_2 = 1.40$; a) cylinder with flat nose: 1, 1') $M_1 = 1.25$; 2, 2') $M_1 = 1.30$; 3, 3') $M_1 = 1.40$; 4, 4') $M_1 = 1.45$; 5, 5') $M_1 = 1.50$; b) cylinder with spherical nose; 1, 1') $M_1 = 1.50$; 2, 2') $M_1 = 1.55$.

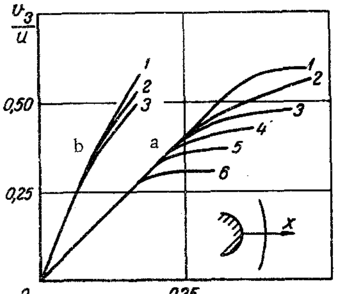

Fig. 4. Velocity of contact surface (see curve 8 in Fig. 1) at the axis of symmetry in relation to the velocity of the gas directly behind the wave (curve 6 in Fig. 1) for a stationary flow: a) cylinder with flat nose; 1) $M_1 = 1.45$; $M_2 = 1.10$; 2) $M_1 = 1.25$; $M_2 = 1.40$; 3) $M_1 = 1.40$; $M_2 = 1.40$; 4) $M_1 = 1.50$; $M_2 = 1.40$; 5) $M_1 = 1.45$; $M_2 = 1.50$; 6) $M_1 = 1.45$; $M_2 = 1.60$); b) cylinder with spherical nose; 1) $M_1 = 1.60$; $M_2 = 1.20$; 2) $M_1 = 1.50$; $M_2 = 1.40$; 3) $M_1 = 1.55$; $M_2 = 1.50$.

much longer time interval. At the contact surface the density undergoes a discontinuity. Therefore the density in the flow close to the body must assume values corresponding to the stationary flow subsequent to the instant that the reflected wave becomes motionless relative to the body.

NOTATION

M_1 is the Mach number of a flow around body before second shock wave;
M_2 is the Mach number of a shock wave falling onto a body;
x is the distance from body surface;
d is the diameter of body;
Δ is the distance between head wave and surface of body;
t is the time;
a_0 is the initial sound velocity in working gas;
v_1 is the velocity of incident shock wave;
v_2 is the velocity of reflected shock wave;
v_{02} is the value of v_2 at initial moment;
v_3 is the velocity of contact surface;
u is the predicted flow velocity directly behind the wave in steady-state flow. The velocity values correspond to the laboratory coordinate system.

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