PECULIARITIES OF THE INTERACTION OF ADIABATIC JETS WITH INCLINED BARRIERS

A. A. Stolyarov

UDC 533.6:534-13:53.01

A new effect, arising in the interaction of adiabatic jets with inclined barriers, is discovered, consisting in the fact that near the barrier the jet divides into cooled and heated streams with stagnation temperatures significantly lower and higher than the stagnation temperature of the oncoming jet.

Despite the fact that a considerable number of reports have been devoted to the study of the interaction of jets with barriers (in view of the importance of this field of aerodynamics), the question of the actual distribution of stagnation temperatures in established adiabatic streams near inclined barriers had remained unnoticed earlier. The fact that near an inclined barrier an adiabatic jet divides into parts with stagnation temperatures significantly higher and lower than the stagnation temperature of the oncoming jet was first reported briefly in [1].

A diagram of the experimental model is presented in Fig. 1. A Laval nozzle with an exit cross section 25 mm in diameter and a rated Mach number of 3.25 was used to create an axisymmetric jet of dry air. The true Mach number, estimated from the distribution of static pressure along the nozzle, lay in the range of 0.95-2.04. In this case the available pressure drop at the nozzle was $\pi = p_0/p = 2.88$-14.7. The air jet escaping from the nozzle *a* flowed over an inclined plane barrier b of stainless steel, on which five KhK thermocouples were located which were connected to an EPP-09M3 automatic potentiometer with continuous chart recording. The thermocouple readings were recorded every 5 sec. The center 0 of the barrier, inclined at a 40° angle to the jet axis, stood 92 mm away from the nozzle cut. The stagnation temperature t_0 and the total pressure p_0 of the air at the nozzle inlet and the pressure p at its outlet were measured. The counterpressure in the exhaust system was created with interchangeable plugs having calibrated openings for the discharge of air into the atmosphere. The air flow rate, measured with a standard diaphragm, lay in the range of $m = 0.09$-0.25 kg/sec.

Depending on the modes of operation of the nozzle, the following distributions of the stagnation temperatures t_i of dry air at an inclined plane barrier, presented in Table 1, were obtained. As is seen, a significant difference in the temperatures at the barrier, reaching 24.5°C, is detected in the experiments, there being

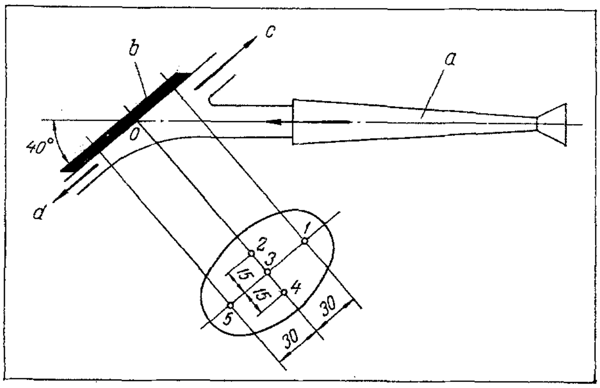

Fig. 1. Diagram of jet flow over an inclined barrier: a) Laval nozzle; b) inclined barrier; c) cooled stream; d) heated stream.

All-Union Scientific-Research Institute for Natural Gases, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol.34, No.2, pp. 288-291, February, 1978. Original article submitted December 20, 1977.

TABLE 1. Distribution of Stagnation Temperatures at the Surface of an Inclined Flat Barrier over Which an Adiabatic Axisymmetric Air Jet Blows (t, °C)

p_0, bar	15	15	15	6	6	6
t_0	1	1,5	1,5	0	0	3
π	14,7	10,8	3,12	6,03	5,6	2,88
Point number	t_i					
1	—8,5	—11	3	—4	8	5,5
2	—3	—2	—1	2	1,5	3
3	8	5,5	0	7	6	3,5
4	1	1,5	0	4	3	3,5
5	13,5	13,5	4	13	10,5	6

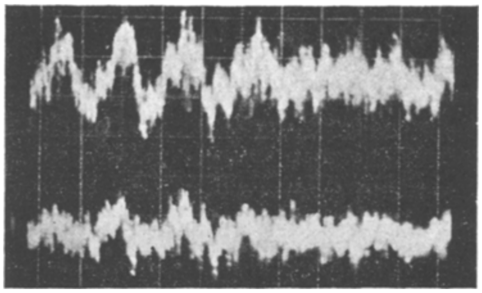

Fig. 2. Typical oscillogram of self-oscillations of an axisymmetric air jet flowing onto an inclined plane barrier: upper beam) pickup mounted at point 5; lower beam) pickup mounted at point 3; sweep calibration 0.002 sec/cm; $p_0 = 15$ bar; $\pi = 14.7$

points with temperatures both exceeding t_0 and less than t_0. The difference between the readings of the thermocouples mounted at points 2 and 4 is due to the placement of the exhaust system to one side of the nozzle, distorting the symmetry of the flow of the cooled and heated streams relative to points 2 and 4. In moving toward the exhaust window the cooled stream is again partly mixed with the heated stream in the lower part of the barrier, as a result of which the air temperature at point 4 proves to be somewhat higher than that at point 2 in all modes, as seen from Table 1. A decrease in p_0 from 15 to 6 bar leads to an increase in the temperature of the cooled air stream. For example, with a change in π from 10.8 to 6.03 the temperature of the cooled stream rises from -11 to -4°C, with the temperature of the heated stream hardly changing. The absolute magnitude of the effect becomes less with an increase in p.

It is impossible to explain the discovered phenomenon by the presence of a throttle effect, since this effect comprises 1.5-2.5°C in the investigated region of air pressures and temperatures. And it cannot be explained by heating as a result of heat exchange with the surrounding medium, since it could not exceed 1-2°C under the most unfavorable conditions. We note that with variation in p_0 the temperatures t_i at the barrier also vary rapidly, which shows the absence of any external heat-transfer effects.

In order to clarify the physical nature of the discovered phenomenon we mounted TsTS-19 piezoelectric pickups, whose receiver openings with a diameter of 5 mm were protected by steel foil 0.1 mm thick, at points 1, 3, and 5 of the inclined barrier where thermocouples were located before. The signals were read out on the dual-beam cathode of an S1-17 oscillograph, one channel of which was constantly connected with the pickup at point 3 while the second was alternately connected with the pickups at points 1 and 5. The modes indicated in Table 1 were repeated in these experiments.

Aperiodic self-oscillating processes with variable amplitudes and frequencies, recorded by each of the three pickups, were detected. The intensity of the self-oscillations increased with an increase in p_0 while it decreased with an increase in p, and at large counterpressures all the non-steady-state processes, and with them the effect of temperature redistribution at the barrier, practically disappeared for any p_0. As seen from

TABLE 2. Relative Distribution of Stagnation Temperatures at the Surface of an Inclined Plane Barrier over Which Adiabatic Two-Phase Axisymmetric Jets Flow (t, °C)

Jet	Air + diethylene glycol solution		Air + water		Air + diethylene glycol solution		Air + water	
p_0, bar	15	6	15	6	15	6	15	6
t_0	2	2	—1	—3	1	0	—4	—4
t^0	21	20	18	18,5	20	20	19	19
π	10,7	5,6	9,9	5,6	2,72	2,7	2,55	2,44
n	0,224	0,229	0,135	0,199	0,0995	0,15	0,151	0,192
Point number	t_i							
1	6,5	5,5	0	0,5	5	4,5	0,5	0,8
2	—5	—3	0	0,5	1	1,5	0,5	0,5
3	—13	—2	0	0,5	1,7	2	0,5	0,5
4	—7	—1,5	0	0,5	1,2	2	0,5	0,5
5	7,5	6	0	0,5	6	5	0,5	1

the typical oscillograms presented in Fig. 2, the signals of the two pickups are synchronous while the amplitudes vary in inverse proportion to the frequencies: high-amplitude signals are low-frequency while low-amplitude signals are high-frequency (the upper beam is pickup 5).

Analogous non-steady-state processes were also observed in work on two-phase mixtures of air with an aqueous solution of diethylene glycol and with water. It is interesting to note that in tests with two-phase mixtures there was secondary energy separation, consisting in the fact that the nonfreezing liquid, initially cooled uniformly in the Laval nozzle, acquires considerably unequal temperatures at different points near the inclined barrier.

The distribution of temperatures t_i at a plane barrier in work on two-phase mixtures is given in Table 2. The liquid flow rate, measured volumetrically, lay in the range of $m^0 = 0.0126$–0.054 kg/sec. Because of the separation of liquid particles near the barrier the distribution of temperatures t_i for two-phase mixtures does not coincide with that for dry air. More uniform distribution of the temperatures t_i over the surface than in work on nonfreezing solutions of diethylene glycol is observed for water in the case of its partial freezing at the exit from the nozzle and at the barrier. In tests where the water does not freeze there is also a marked redistribution of temperatures at the barrier.

NOTATION

p_0	is the total air pressure at nozzle inlet;
p	is the static air pressure at nozzle exit;
$\pi = p_0/p$	is the pressure drop at nozzle;
t_0	is the stagnation temperature of air at nozzle inlet;
t_i	is the stagnation temperature of air at i-th point of barrier surface;
t^0	is the liquid temperature at nozzle inlet;
m	is the mass flow rate of air;
m^0	is the mass flow rate of liquid;
$n = m^0/m$	is the relative flow rate of liquid.

LITERATURE CITED

1. A. A. Stolyarov, "Energy-separation properties of two-phase flows," Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No.6 (1976).