INVESTIGATION OF THE APPARENT MASS OF A
SUPERSONIC JET ESCAPING FROM A NOZZLE
INTO OFF-DESIGN MODES

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Results are presented of an experimental investigation of the dependence of the apparent mass on the number $M_a$ at the nozzle exit, on the off-design factor $n$, and the distance $x$ from the nozzle exit.

The apparent mass is the difference between the discharge at some section of the jet and the discharge through the nozzle. Direct measurement of the discharge in the cross section of a supersonic off-design jet is associated with known difficulties. The measurement of the apparent mass of an off-design supersonic jet is reduced herein to the measurement of the air discharge in a pipeline, which significantly raises the measurement accuracy. The investigation is conducted by two different methods, and this permitted a rise in the confidence of the results.

The experimental setup whose diagram is pictured in Fig. 1 was used for conducting the experiments by the first method.

The apparatus consists of the receiver A and the chamber B. The pressure $P_0$ in the receiver 2 ahead of the nozzle 14 is built up by using the valve 1 to which air is supplied with a pressure of 200 kg/cm². The pressure $P_0$ is measured by the manometer 4 to ±0.2 kg/cm² accuracy. The model housing 13 is mounted in the nozzle. An extension 10, on which a diaphragm 11 is fastened with an appropriate seal, is mounted on the down-flow endface of the model. The working length of the model $L$ is changed by using the extension, i.e., the jet length $x$ under investigation. To assure uniform delivery of the air drained to the jet, the whole space of the chamber is separated into two cavities by the cylindrical perforated wall 9 with a large quantity of fine orifices. The dissector 8 serves this same purpose by hindering the formation of a directed jet from the pipeline 7 into the chamber. The chamber is connected to the receiver by means of the pipeline 7 in which the stopcock 3 to regulate the air discharge is set, and by means of the measuring

Fig. 1. Diagram of experimental set-up No. 1.
plate 6 to measure the discharge through it. The pressure drop at the plate was measured by the differential manometer 12 and the pressure ahead of the plate by the manometer 5, with a ±0.02 kg/cm² measurement accuracy. The pressure in the chamber $P_c$ was measured by an alcohol manometer 16, and the pressure drop along the chamber which indicates the presence of accompanying flow, by the differential manometer 15. The choice of the orifice size in the diaphragm was subject to specific conditions, which will be examined below.

The method of conducting the experiment was the following.

As is known, as a jet propagates in a chamber, rarefaction forms there due to the ejection properties of the jet. In unit time the jet entrains a quantity of mass from the chamber which equals the apparent mass in the length $L$. By opening the stopcock 3 air in a quantity equal to that which has been entrained by the jet can be delivered into the chamber through the pipeline 7. In this case the pressure in the chamber should evidently be atmospheric, and therefore, an accompanying or counter flow should not exist since $\Delta P = P_N - P_c = 0$. The air discharge measured at this instant through the measuring plate 6 will equal the apparent mass of the jet in the length $\bar{x} = L$ being propagated in the medium at rest. The measurement of the axial drop in the space between the jet and the perforated wall, performed by the differential alcohol manometer 15, is a gage of the presence of an axial stream along the jet.

The experiments to determine the apparent mass were conducted in this order. A pressure $P_0$ corresponding to the number $M_a$ and the off-design factor $n$ which was determined by means of the relationship

$$P_0 = \frac{n P_N}{n(M_a)}$$

was built up ahead of the nozzle.

Furthermore, air was delivered to the chamber through the pipeline 7 until the rarefaction $H$ in the chamber was zero. At this time the discharge through the pipeline 7 was measured. By using the extension, the dependence

$$q = \frac{Q_{app}}{Q_a} = f(M_a, n, \bar{x})$$

could be obtained in the nozzle.

The size of the holes in the diaphragm $d_B$ was selected in conformity with data in [2] in such a way that when the stopcock 3 was closed the rarefaction $H$ in the chamber was not greater than 0.01 kg/cm², which afforded the possibility of assuring high accuracy in measuring $H$.

The accuracy of measuring the apparent mass in the method considered is determined mainly by the accuracy of measuring the pressure in front of the measuring plate and the pressure drop on it, which is evidently sufficiently high.

Measurements of the apparent mass on the apparatus whose diagram is shown in Fig. 2 were carried out as checks. Here, the nozzle mounted at the end of a long pipe was placed in a diffuser. Because of turbulent exchange with the surrounding medium in a length $\bar{x}$ the air jet annexes a definite quantity of air and, hence, a rarefaction is produced in the annular channel between the pipe and the diffuser, which is the reason for air from the surrounding space flowing into the channel through the smooth entrance. The air discharge in the channel depends on the efficiency of the turbulent exchange on the section $\bar{x}$, particularly on the number $M_a$, but the quantitative aspect of this dependence is not generally evident. The fact is that the whole air discharge flowing through the annular channel can provisionally be separated into two parts. One part is the quantity of air which annexes the section of the jet of length $\bar{x}$, and the other produces an external accompanying stream flowing in the annular gap between the diffuser wall and the outer boundary of the jet. The problem is to extract the apparent mass of the jet from the total quantity of air flowing through the annular gap. It was solved thus.