# ON THE POSITION OF THE CENTRAL COMPRESSION SHOCK IN AN UNDEREXPANDED SONIC JET ISSUING FROM A SLOT NOZZLE

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One of the most important characteristics of the geometric structure of an underexpanded jet, the distance between the nozzle exit and the central compression shock (CCS), is the Mach disc in the axisymmetric case.

While the geometric structure of underexpanded axisymmetric [1] and plane jets [2] has been studied in a sufficiently large range of changes in the degree of off-design, investigations devoted to the process of underexpanded jets issuing from finite width slots have been performed for only several nozzles [3].

Results are presented in [3] for an experimental study of the CCS location in underexpanded jets issuing from slot nozzles with the relative elongations (ratio between the nozzle length $\ell$ and its width h) a = 6 and 15, and it is shown that the CCS location is not subject to plane and axisymmetric jet regularities, where an axisymmetric nozzle with diameter equal to the slot nozzle width was chosen for comparison, i.e., with a gas discharge known to be less.

In this paper, the CCS location in the fundamental plane [3] of underexpanded sonic jets issuing from slot nozzles with a between 1.66 and 55.5 is investigated experimentally for changes in the degree of jet off-design n (the ratio between the pressure at the nozzle exit and the pressure in the surrounding medium) from 1 to 110.

The diagram of the experimental set-up is displayed in Fig. 1. A vacuum chamber 1 of 0.8 $m^3$ volume and with optical portholes was placed in the working arm of an IZK-454 Mach–Zender interferometer 2 equipped with a laser light source 3 to obtain qualitative interference patterns for any magnitude of the pressure in the chamber. The underexpanded jet was formed by the nozzle apparatus 4 by using the diaphragmed unit 5 which assured triggering the nozzle in the time $10^{-2}$ sec.

The interference pattern was photographed by the SKS-1M high-speed movie camera, 6. The gas pressure at the nozzle exit and in the chamber (outside the jet) was recorded by the sensors 7 and 8 of MDDF type and inscribed on a K12-22 loop oscilloscope 9.

The chamber was evacuated to a pressure of ∿10 Pa by the VN-2 vacuum pump 10 prior to the start of the experiment. The interferometer was adjusted to a band of infinite width to visualize the compression shocks. After the loop oscilloscope had been triggered and the movie camera had been accelerated to the requisite velocity, the diaphragmed unit was supplied with a command and the process of gas emergence from the atmosphere into the vacuum chamber through the slot nozzle started after the diaphragm ruptured.

TABLE 1

| No. of point in Fig. 3 | Nozzle size | a | $d_{eq}$, mm |
|---|---|---|---|
| 1 | 2,7×150 | 55,5 | 22,7 |
| 2 | 4×75 | 18,7 | 19,5 |
| 3 | 6×36 | 6 | 16,5 |
| 4 | 6×24 | 4 | 13,5 |
| 5 | 8×24 | 3 | 15,6 |
| 6 | 12×24 | 2 | 19,2 |
| 7 | 15×24,8 | 1,66 | 21,8 |

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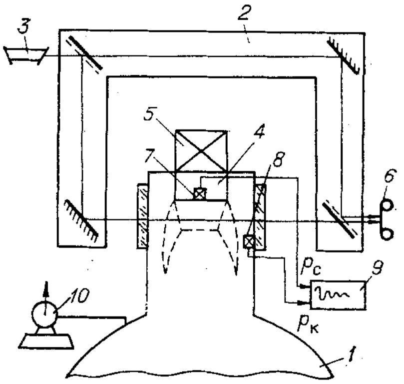


Fig. 1

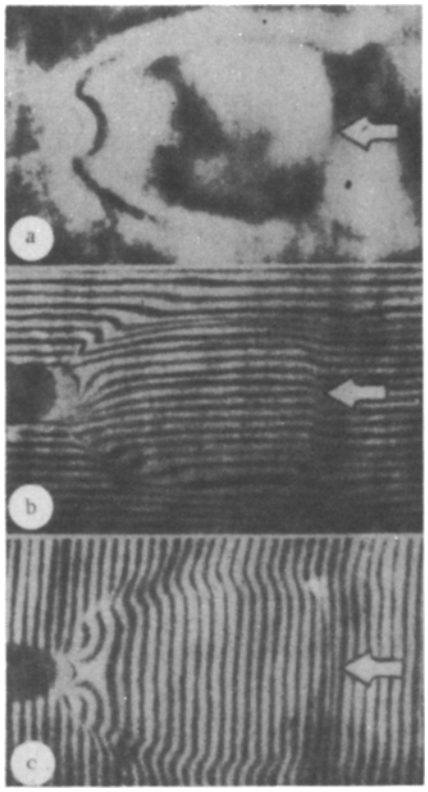


Fig. 2

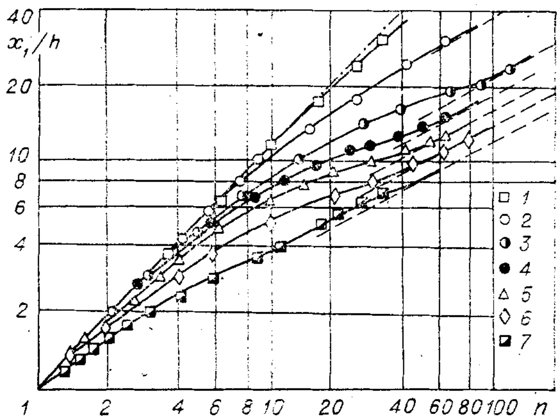


Fig. 3

The pressure $p_c$ at the nozzle exit remained constant, equal to the critical value of the atmospheric pressure throughout the existence of the underexpanded jet in the chamber; the pressure $p_k$ in the chamber grew from the initial pressure to $p_k = p_c$ as it filled. Therefore, the degree of jet off-design $n = p_c/p_k$ diminished from $5 \cdot 10^3$ to 1 as the chamber filled up, after which the jet became a design jet. The magnitude of the working field of the interferometer 200 mm diameter imposes a constraint on the maximum degree of off-design for which the CCS would be incident in the field.

Typical interferograms, taken in fringes of infinite (a) and finite (b) width, are presented in Fig. 2. A plotting bond was inserted in the working field before the start of the experiments and was photographed by the movie camera to determine the longitudinal and lateral scales of the jet image on the movie film. The movie camera and loop oscilloscope had timing markers; consequently, the degree of jet off-design was determined uniquely for each frame in frame-by-frame processing of the interferograms.

The results of measuring the distance between the nozzle exit and the CCS $x_1/h$ as a function of the degree of jet off-design are displayed in Fig. 3 for different nozzles. The nozzle characteristics are presented in the table. The dash-dot line $x_1/h = 0.7\ \gamma n$ ($\gamma$ is the adiabatic index which equals 1.4 for air) corresponds to the CCS location in a flat jet [2] issuing from a slot of the same width; the dashes indicate the CCS location in an axisymmetric jet issuing from a nozzle with the equivalent diameter $d_{eq} = 2h\sqrt{a/\pi}$ which is determined from the equality of the slot and axisymmetric nozzle areas.

The results obtained are approximated well by the formula

$$\frac{x_1}{h} = \frac{n}{e^{2n-a}+1} + \frac{1,65\sqrt{an/\pi}}{e^{2(14a-n)}+1} + e^{2n-a}\left[e^{2(14a-n)}\right]\left[n\left(\frac{1,03}{a} - \frac{1,54}{a^2} - 0,109\right) + \right.$$
$$\left. + \frac{1}{n}(0,516a - 0,693a^2 - 1,54) - \frac{2,73}{a} + 1,07\right],$$

found by known regression analysis methods.

As is seen from the graphs presented, for degrees of off-design less than half the magnitude of the relative nozzle elongation, the CCS location in a jet issuing from a slot nozzle is subjected to plane jet regularities (for $a \geq 2$).

For degrees of off-design $\sim 14a$ (and apparently for large values), the location of the CCS in a jet issuing from the slot nozzle agrees with its location in a jet issuing from an axisymmetric nozzle with the same gas discharge.

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