# ON THE LAW OF CENTRAL SHOCK DISPLACEMENT FOR AN UNDERSATURATED JET AFFECTED BY AN OBSTACLE

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A generalized dependence of the dimensionless position of the central shock on the dimensionless position of an obstacle relative to the nozzle exit is obtained. The dependence is obtained for $M_a = 1.0$-$2.0$ and uncalculability $n = 2.2$-$6.7$ of the jet.

On the basis of experimental data (Toepler photographs of a jet with an obstacle) results of an analysis of the influence of an obstacle placed at the beginning of the so-called second, or within the limits of the first "barrel" [1], on the wave configuration of the first barrel of an undersaturated supersonic jet are examined. As is known, the wave configuration of the first barrel of an undersaturated supersonic jet are examined. As is known, the wave configuration of the first "barrel" of a free undersaturated jet with nonregular reflection consists of suspended 1, central (Mach disk) 2, and reflected 3 shocks (Fig. 1). The reflected and central shocks are a result of disintegration of the hanging shock at a certain point. For a sufficiently remote location of the obstacle in the jet it exerts no influence on the wave structure of the first barrel. If the obstacle approaches the nozzle, then starting with a certain location $x_*$ it starts to influence the wave configuration. This influence is expressed as a displacement of the point of disintegration along the hanging shock.

If $x_1$ denotes the running position of the central shock relative to the nozzle, then a definite dependence $x_1 = f(x_2)$ evidently exists for each unrated jet and given obstacle, where $x_2$ is the spacing between the obstacle and the jet $x_2 < x_*$. It should be noted that there is a zone of instability in the wave structure of the first barrel in a definite part of the range of variation of $x_2$ for each uncalculability. But this zone does not include the whole range $x_2 < x_*$.

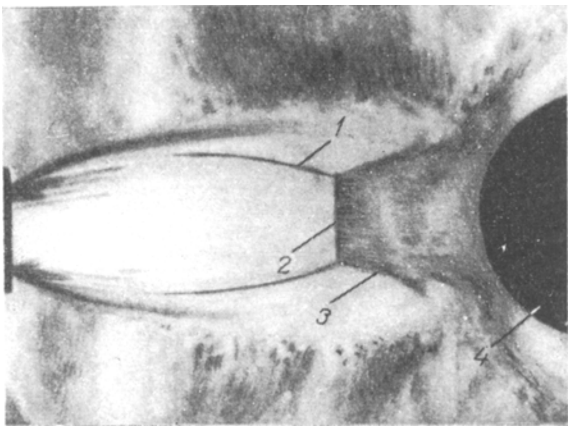


Fig. 1. Shock wave structure in a supersonic jet flowing around an obstacle: 1) hanging shock; 2) central shock; 3) reflected shock; 4) obstacle.

Processing the data of a large number of instantaneous Toepler photographs of a jet with an immersed obstacle indicated the existence of a self-similar dependence in the zone of central shock displacement under the effect of the perturbing obstacle. It turns out that a single dependence on the dimensionless distance of the obstacle $X_2 = x_2/x_*$ exists for the dimensionless distance of the shock $X_1 = x_1/x_0$, where $x_0$ is the distance between the central shock and the nozzle in the unperturbed jet. Some experimental points are presented in Fig. 2. It should be mentioned that all the above is valid for Mach numbers on the nozzle exit in the range $M_a = 1.0$-$2.0$. The range of uncalculabilities investigated is $2.2 < n < 6.7$.

The dependence $X_1 = f(X_2)$ was approximated by the quadratic parabola

$$X_1 = a_0 + a_1 X_2 + a_2 X_2^2 \tag{1}$$

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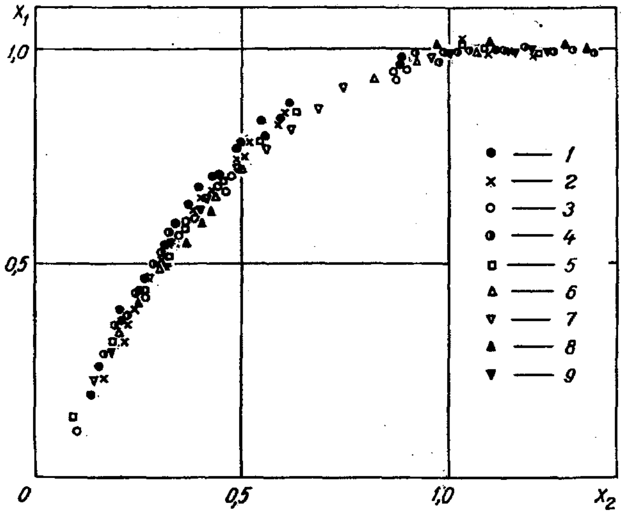


Fig. 2. Single generalized dependence of the dimensionless position of the central shock on the dimensionless position of the obstacle:

| Notation | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| $M_a$ | 1,0 | 1,0 | 1,5 | 1,5 | 2 | 2 | 2 | 2 | 2 |
| $n$ | 4,60 | 3,58 | 2,24 | 4,22 | 3,96 | 6,68 | 6,31 | 2,97 | 3,96 |
| $d_n$ | 40 | 40 | 40 | 20 | 20 | 20 | 20 | 20 | 20 |
| Obstacle | Plane ⌀43,5 | Plane ⌀43,5 | Plane ⌀43,5 | Plane ⌀43,5 | Sphere ⌀30 | ∞ Plane | ∞ Plane | Plane ⌀43,5 | Plane ⌀43,5 |

and the following values for the coefficients of the approximating polynomial were obtained:

$$a_0 = -0.057;\ a_1 = 2.13;\ a_2 = -1.082$$

as a result of processing 250 experimental points by least squares on an electronic digital computer.

The running coordinates of the mutual location of the central shock and the obstacle were found in dimensional units by using the single dependence found:

$$x_1 = X_1 x_0;\ x_2 = X_2 x_*.$$

The position of the central shock in a free jet $x_0$ is determined from any of the known approximating dependences, by the empirical formula of Adamson and Nicholls [2], say:

$$x_0 = 0.69 M_a \sqrt{kn},$$

where $k = c_p/c_V$.

To determine the critical position of the obstacle $x_*$, it is sufficient to have just one confident test position of the central shock $x_1$ for a known position of the obstacle $x_2$ because of the lack of a generalized dependence of $x_*$ on the governing parameters of the jet. This permits entrance into the universal dependence (1) for the value found for the dimensionless position of the central shock $X_1 = x_1/x_0$, and finding the dimensionless position of the obstacle $X_2$ for the found $X_1$, and the critical position of the obstacle $x_* = x_2/X_2$ thereby, for a given degree of uncalculability of the escape.

## NOTATION

$M_a$ is the Mach number at the nozzle exit;
$n$ is the uncalculability of the jet;
$x_0$ is the position of the central shock in a free supersonic jet relative to the nozzle exit;
$x_1$ is the position of the central shock relative to the nozzle exit;
$x_2$ is the position of the obstacle relative to the nozzle exit;
$x_*$ is the critical position of the obstacle relative to the nozzle exit;

$X_1$ is the dimensionless position of the central shock;
$X_2$ is the dimensionless position of the obstacle.

## LITERATURE CITED

1. I. P. Ginzburg, Aerogasdynamics [in Russian], Vysshaya Shkola, Moscow (1966).
2. Adamson and Nicholls, J. Aerospace Sci., 26, 16-24 (1959).