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TRANSLATION

RESISTANCE CRISIS OF THE DIFFUSER

By

A. I. Lashkov

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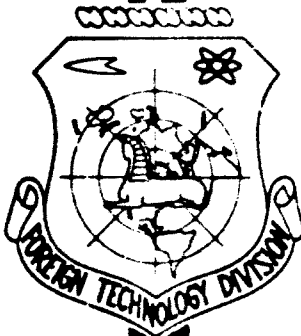
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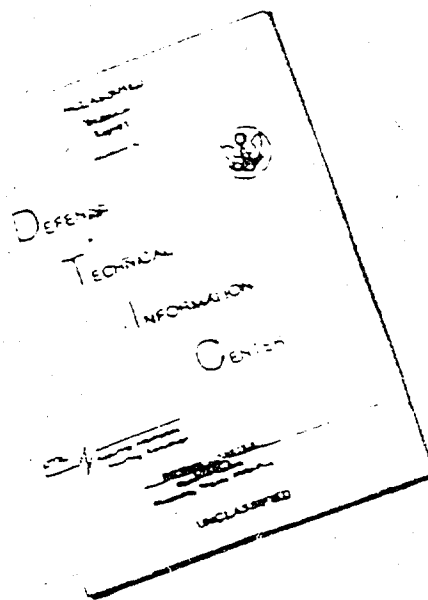


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RESISTANCE CRISIS OF THE DIFFUSER

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RESISTANCE CRISIS OF THE DIFFUSER

A. I. Lashkov

The losses of mechanical energy in diffusers with great angles of opening is very considerable and substantially depends on the Reynolds number. The peculiar character of this dependence up to now has not been explained from the angle of the physical nature of the phenomena involved in the flow of viscous liquids or gas in a diffuser.

In conical diffusers with great angles of the opening, $\alpha \geq 16^\circ$, which have in the input a nozzle with smooth configuration of the internal contour,

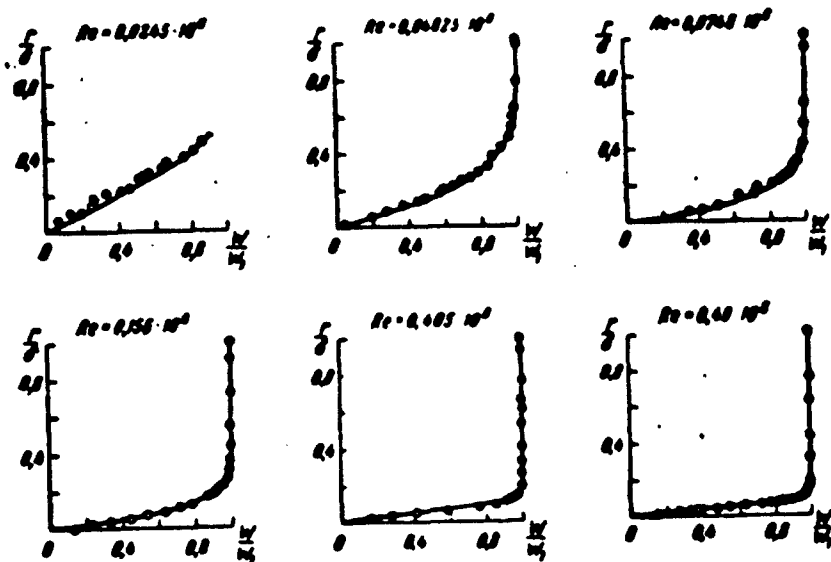


Fig. 1

the dependence of the resistance on the Reynolds number stands out in very plain relief. This is explained by the more pronounced structural changes in the flow which show up in the sharp change in the sign of the gradient

of pressure at the moment of transition of the flow from the narrowing part of

the channel into the expanding part.

The negative gradient of the pressure with the acceleration of the flow in the narrowing part of the nozzle facilitates the prolonged existence of the laminar flow. By experimentation [1] it was shown that in the absence of disturbing factors the laminar flow in the narrowing part of the nozzle is preserved up to $Re = 10^6$, the thickness of the boundary layer reaches considerable magnitude, and the profile of the velocities at the input into the diffuser differs from the smooth one. With the increase in the Re number the profile of the velocities is deformed, tending towards the even one (Fig. 1, $Re > 0.4 \cdot 10^6$).

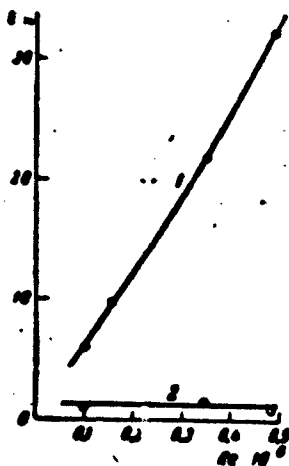


Fig. 2

At the same time the turbulation of the boundary layer increases, which is illustrated by the dependence of the number $\xi = \frac{\eta}{\omega}$ on Re (Fig. 2). This dependence is obtained by measuring the pulsation velocities of the flow, u , by the thermoanemometer set up at the input into the diffuser ($\alpha = 24^\circ$ in the boundary layer, curve 1) and in the prechamber ahead of the nozzle and the diffuser (curve 2).

The subsequent expansion of the flow in the diffuser facilitates still further turbulation, increase in the positive gradient of pressure, the retardation of the particles of the boundary layer in the region, and finally a break in the flow. The changes in the structure of the flow occurring at the input into the diffuser and in it itself, to a very substantial extent are reflected on its energy characteristics.

This fact is illustrated more conveniently by using as such a characteristic the coefficient of the hydraulic resistance of the diffuser:

$$\zeta = \frac{P_0 - P}{\rho \omega^2 / 2}$$

where P_0 is the pressure of the retardation ahead of the nozzle, P is the

pressure at the exit from the diffuser (in our case the atmospheric pressure), and $\rho w^2/2$ is the dynamic pressure at the input into the diffuser.

Actually, if one follows up on the dependence $\zeta = f(Re)$ for the diffuser $\alpha = 35^\circ$, with the ratio of the area of the final section to the initial one $m = 3$ (Fig. 3), then one can note that with $Re < 0.1 \cdot 10^6$ ζ has the greatest value; at some critical Re number the coefficient of hydraulic resistance begins to drop sharply, reaching the minimum value. From here on with the increase in Re for the diffuser with a diameter having an initial section of

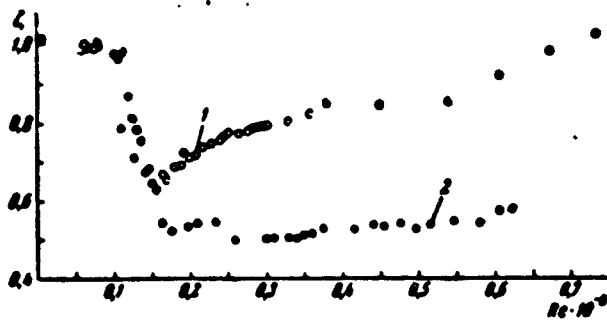


Fig. 3

$d = 208$ (curve 2) ζ practically does not change; with $d = 40$ mm (curve 1) ζ substantially increases.

If now we compare the dependence $\zeta = f(Re)$ for the diffuser (Fig. 3) and

$C_x = f(Re)$ (Fig. 4) [2]

for the cylinder, then it is possible to note an

identical character in the flow of these curves,

which corresponds to the change in the state in the

boundary layer and a shift in the point of the break in the flow.

This qualitatively identical character of the de-

pendences $\zeta = f(Re)$ and

$C_x = f(Re)$ point to a

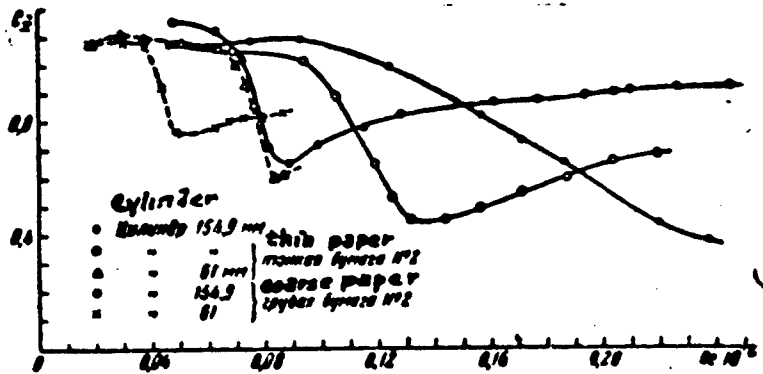


Fig. 4

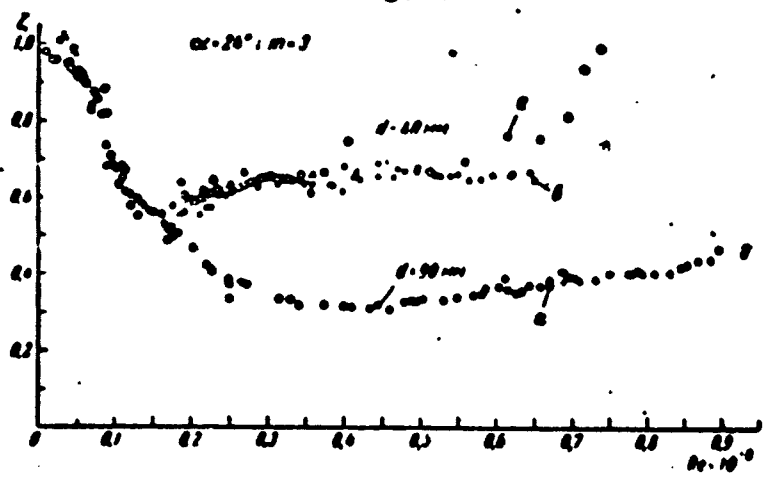


Fig. 5

profound analogy in the structural changes in the flow, which shows up with the increase in the Re number with the flow in a diffuser and the flow around a sphere, cylinder, etc.

In a similar way as occurs in a flow around a cylinder (sphere, etc.), in the diffuser the transition from the laminar flow to the turbulent one occurs also in the area of the change of sign in the pressure gradient. The zone of the break-off in the diffuser, Bam-Zelikovich [3] pointed out in his work, also is located in this area.

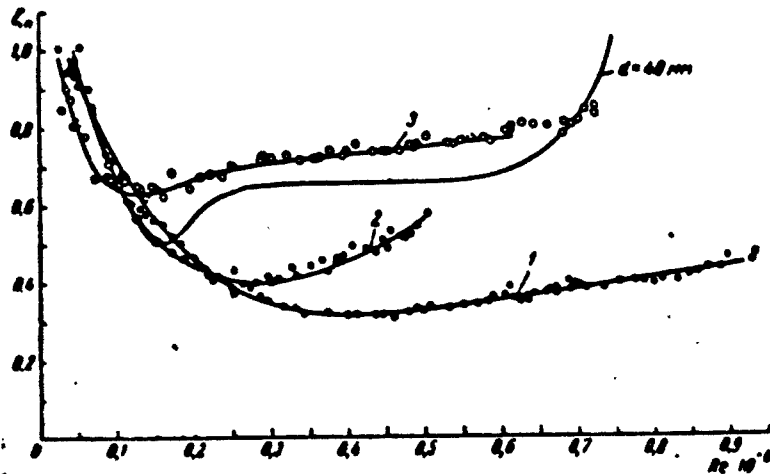


Fig. 6

The current in the midst of the flow with the formation close to the zone of the break-off of a turbulent mixing attracts behind it the boundary layer, and the point of the break-off is shifted somewhat down along

the flow. The coefficient of resistance falls sharply (Figs. 3, 5). The presence of a minimum on the curve $\zeta = f(Re)$ explains the shifting of the break-off into the narrower section of the diffuser.

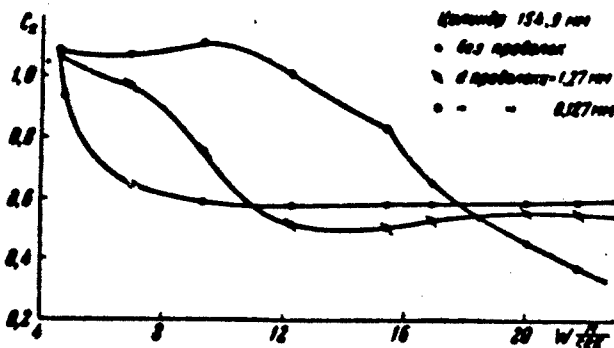


Fig. 7

Wording in graph: cylinder, without, wires, diameter, of wire

The analogy of physical phenomena accompanying the flow around a sphere, cylinder, etc., and the flow in a diffuser is also well confirmed by a repetition of Prandtl's experiment.

The following experiment was set up. Into a diffuser with diameter of

entrance of $d = 90$ mm (Fig. 6) and an angle of the opening of $\alpha = 24^\circ$, $m = 3$ (curve 1), there were set up two turbulators, the first in the form of a strip of paper of the thickness of 0.7 mm (curve 2) glued at a distance of 5 mm from the input section of the diffuser inside of the nozzle, the second in the form of a ring of wire of the thickness $\delta = 1.5$ mm (curve 3). As is seen from Fig. 6 with $Re = 0.075 \cdot 10^6$, the resistance of the diffuser with the turbulence-producing ring $\zeta = 0.7$, while without the wire $\zeta = 0.85$. Analogously for the cylinder the size C_x (Fig. 7) changed approximately with the same Re number from $C_x = 1.0$ without turbulator to $C_x = 0.69$ [2]. The putting on of the ring of the wired $\delta = 1.5$ mm makes an effect similar to that obtained in the flow around a cylinder with a turbulator (Fig. 7). The shifting of the curve 3 to the right relative to the curve 1 is explained (Fig. 6) by the occurrence of the phenomenon of crisis of resistance in the diffuser with the setting up in it of a turbulence-producing wire ring.

Another factor which aids to clear up the physical picture of the flow in a diffuser is the roughness of its walls.

Just as for cylinders of different diameters with different roughness of the surface (Fig. 4), the effect of the relative roughness is very clearly illustrated by a comparison of the dependences $\zeta = f(Re)$ for the diffusers with $\alpha = \text{const}$ and $d = \text{Var}$ (Fig. 3-6). As is seen in these graphs, as a result of the increase in the relative roughness the crisis of resistance sets earlier in the diffuser with the lesser diameter of the input section. Both in the case of the setup of the turbulence-producing ring in the opening into the diffuser and increase in the relative roughness with little values of Re , the thickness of the boundary layer exceeds the thickness of the turbulator or protuberances of roughness, and therefore the latter do not have a substantial effect on the structure of the flow. With the increase in the Re number the thickness of the boundary layer becomes commensurable with the height of the protuberances or the thickness of the turbulator. Afterwards there occurs

the turbulent break-off. The resistance drops sharply. With further increase in the Re number the protuberances of roughness become centers of local break-off, and the point of turbulent break-off is shifted opposite to the flow; in this situation the coefficient of resistance increases. Thus the increase in the relative roughness of about the doubling of it from 0.09% up to 0.2% corresponds to just such an increase in the coefficient of resistance ζ (Fig. 6).

For the diffuser with a great angle of opening the relative roughness of the input nozzle shows up in its resistance more substantially than the relative roughness of the walls of the diffuser. And if one were to compare two diffusers with great angles of opening not taking into account this circumstance under conditions of equality of all the criteria of similarity there could occur a very substantial error in the computations of the boundary resistance (Figs. 3, 6). In this way the relative roughness of the walls of the diffuser proves to be an indispensable criterion of similarity in the case $\alpha \geq 16^\circ$.

Conclusions

1. The character of the change in the dependence of the resistance of the diffusers with great angles of opening on the Re number is brought about by the same principles as for the bodies around which flow is difficult (dependence $C_d = f(Re)$ for the cylinder, sphere, etc.).

2. In the diffuser with a great angle of opening ($\alpha \geq 16^\circ$) there is possible the realization of a system of flow which is characterized by a crisis of resistance.

3. The relative roughness of the walls in the region of the input flow for the diffuser with great angles of opening proves to be an unavoidable criterion of similarity.

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