# THE MECHANISM BY WHICH THE ENTRY CONDITIONS AFFECT DIFFUSER DRAG

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A new explanation is provided for the mechanism by means of which the length of the straight-line segment positioned between a smooth collector and a diffuser affects the characteristics of the latter.

The effect of the entry conditions on the magnitude of diffuser drag, in particular, the effect of the relative length $l_1/D_1$ of the straightline segment in front of the diffuser, has been established long ago [1-6]. However, all of the research devoted to this problem was incomplete. On the other hand, our results from more extensive research enables us to determine the true nature of the effect exerted by the straightline segment on the magnitude of the drag and on the structure of the flow in the diffusers. The results indicate that when such segments are present the effect results both as a consequence of a change in the thickness of the boundary layer at the inlet to the diffuser (a change in the momentum thickness) and in the velocity profile as a whole, as well as a consequence of the flow regime in this layer, i.e., the turbulization of that layer. This effect is evidenced in various ways, depending on whether or not the given diffuser is entirely "free of separation" ($\alpha < 6°$), partially ($6° \leq \alpha \leq 14°$), or one with total "separation" ($\alpha > 14°$).

When a conical diffuser with some arbitrary angle of divergence is set up immediately behind a smooth collector, a laminar flow regime – such as exists in the straightline initial segment – is maintained in the boundary layer of the initial diffuser segment, to specific but rather high values of the Reynolds numbers. As the Re numbers rise to a certain limit, we find that there is a somewhat greater drop in the resistance factor of the "separation-free" diffuser, as well as in the resistance factor of the "partial separation" diffuser; the drop is greater than in the case of a turbulent flow regime in the boundary layer.

The location of the straightline segment between the smooth collector and the diffuser enhances the turbulization of the boundary layer before the flow reaches the diffuser, even when the Re numbers are comparatively small for the overall flow. This is one of the factors responsible for the increase in the resistance of the diffuser when $l_1/D_1 > 0$, in comparison with its resistance when $l_1/D_1 = 0$. As demonstrated by our experiments (Fig. 1), the greatest increase in the resistance of the diffuser over the entire range of Re numbers takes place even when the straightline segment is elongated only slightly ($l_1/D_1 \leq 5$). When $l_1/D_1 + 10\text{-}12$, the greatest values of the diffuser resistance factor $\zeta_d$ is attained, and with a further increase in $l_1/D_1$ the value of $\zeta_d$ diminishes slightly.

We can explain all of the foregoing by the fact that the greatest increase in the thickness of the boundary layer and the deformation of the entire velocity profile, as well as the increased turbulence of the flow in the initial segment of the straightline tube installed behind the smooth collector, occur precisely in the first segment (the segment in which the laminar flow makes its transition through the buffer region into turbulent flow).

Both factors – the thickening of the boundary layer and the turbulization of the flow at the inlet to "separation-free" diffusers – act in entirely opposite directions. The former reduces the friction losses in the diffuser, since it leads to a reduction in the transverse velocity gradient near the diffuser walls. The latter increases these losses, since it makes the coefficient of turbulent viscosity larger. It is obvious that when inlet segments with a length up to $l_1/D_1 = 10\text{-}12$ are installed, it is the second factor that is stabilized

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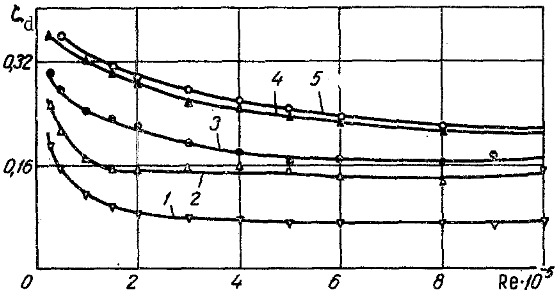


Fig. 1

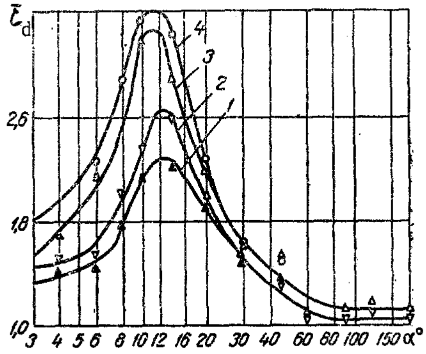


Fig. 2

Fig. 1. Resistance factor $\zeta_d$ of a conical diffuser as a function of the Re number for $\alpha = 10°$, $n = 4$ and: 1) $l_1/D_1 = 0$; 2) 2; 3) 5; 4) 20; 5) 10.

Fig. 2. Correction factors for the inlet conditions $\zeta_d = \zeta_{dl_1\ 0}/\zeta_{dl_1=0}$ as a function of the divergence angle of the conical diffuser when: 1) $l_1/D_1 = 2$; 2) 5; 3) 20; 4) 10.

whereas the effect of the first factor continues to increase slightly, which in the final analysis results in a slight drop in the magnitude of $\zeta_d$ with a continued increase in $l_1/D_1$.

Our experiments have demonstrated that the effect of the parameter $l_1/D_1$ initially increases with an increase in the expansion angle $\alpha$ of the diffuser. When $\alpha = 10$-$14°$, this effect is at its greatest. With a further increase in $\alpha$, the effect is again reduced, until we have $\alpha \geq 60°$ at which point it is virtually nonexistent (Fig. 2).

This can be explained in the following manner; the thickening of the boundary layer at the diffuser inlet simultaneously with the drop in friction losses leads to the earlier appearance of instability in the wall layer of the diffuser and to periodic separation of individual vortices (because of the positive pressure gradient along the flow), and this in turn leads to an increase in the overall resistance of the diffuser. The described phenomenon is intensified with an increase in the expansion angle $\alpha$, so long as the flow is not entirely separated from the walls. As demonstrated by experiment, such flow separation occurs when $l_1/D_1 > 10$ and $n = 4$, even in diffusers with $\alpha = 6°$. When $\alpha = 8°$ and $n \geq 4$ separation occurs when $l_1/D_1 \geq 5$. For $\alpha = 10°$ and particularly for $\alpha = 14°$ and $l_1/D_1 > 5$ separation is found to occur in those segments corresponding to $n = 4$. In this case, in diffusers with $\alpha = 14°$ the separation zone becomes quite extensive.

For this reason the effect of $l_1/D_1$ when $\alpha = 10$-$14°$ is at its greatest.

In diffusers with total flow separation ($\alpha > 14°$) the effect of the Reynolds number on the change in the resistance factor is different in nature from the case in which $\alpha < 14°$. As has been demonstrated earlier by one of the authors [4], for larger angles of diffuser expansion (separation angles), as well as for the case of flow through bent channels [2], the effect of the $R_e$ numbers on the resistance is associated with displacement of the initial point of boundary-layer separation along the diffuser. Therefore, turbulization of the flow in that region of the Re numbers in which the separation is laminar (achieved in this case by setting up a straightline segment in front of the diffuser) leads to the reattachment of the separation boundary layer, with the boundary layer separating once again, farther downstream. However, this does not reduce the separation zone and correspondingly lowers the resistance of the diffusers. With larger Re numbers the thickness of the boundary layer ("elongation of the velocity profile") in the straightline segment in front of the diffuser leads to an earlier (nearer the inlet) turbulent separation of the flow and, consequently, it raises the resistance of the diffuser. At the same time, with larger separation anges of expansion the difference in resistance between the cases in which $l_1/D_1 > 0$ and $l_1/D_1 = 0$ now turns out to be smaller. In this case it diminishes with an increase in $\alpha$, since for an even greater intensification of separation it is not enough to have that relatively weak deformation of the velocity profile which is caused by the initial segment of the straightline tube.

The unique thing about our results is the fact that the diffuser experiments were begun with the installation of the diffusers directly behind a smooth collector, which reduces conditions in which a laminar boundary layer is formed in the initial diffuser segment over a wide range of Re numbers.

However, in the theoretical research with which we are familar [5, 6] the flow is always completely turbulent at the diffuser inlet. For this reason, the values of the resistance factors of "separation-free" diffusers for $l_1/D_1 = 0$ must be lower in our experiments than those derived theoretically.

To the best of our knowledge, however, we have been the first to suggest the fact that a laminar boundary layer exerts influence on diffuser drag.

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