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THE DEVELOPMENT OF THREE DIMENSIONALITY IN THE NEAR AND IN THE FAR WAKE DUE TO CHANGES OF THE BOUNDARY CONDITIONS

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The laminar wake is investigated for its dependence of its boundary conditions. You get deviations from the nominal two dimensional case with pressure and velocity measurements and with flow visualization. In our investigation we use the latter two. The boundary conditions have considerable influence on the separation mechanismen, the spread of the circulation and the frequency in the vicinity of these boundaries, and futhermore you find this influnce again in the far wake. In this short report we show that secondary eddies are formed up to 100 cylinder diameters (d) in the wake dew to the end plate diameter DU.

Our set-up consists of a cylinder perpendicular to the flow and as boundary condition an end plate is chosen. The cylinder is 60-150d in length (L) and placed in a flow of low turbulence level, the experiments were carried out in the laminar windtunnel of the MPI für Strömungsforschung. x is pointing in the flow direction, z along the cylinder span and y is normal to both of them. Two regions with different shedding frequencies are found along the cylinder axis. In the vicinity near the end plate, which we hereafter denote as the influenced region, the shedding frequency f_2 is found to be $10 - 15\%$ less than along the remaining part of the cylinder, where the regular Strouhal frequency f_{Sr} is observed.

A is the distance where the frequency jumps from f_2 to f_{Sr}, see Gerich and Eckelmann (1982).

We start with the hypothesis that the influence on the shedding mechanism is caused by the two circulations involved in the process, namely Γ_f orininating from the horseshoe vortex, and Γ_k originating from the Karman vortex street. An estimation of the circulation of the horseshoe vortex is given by Gerich (1985) with $\Gamma_f = \lambda\, U_\infty$, λ is half the end plate diameter in the direction of the oncominng flow. The circulation of the Karman vortices is given by Berger (1964) with

$$\frac{\Gamma_k}{\nu} = 0.394 \frac{Re^2}{0.22 Re - 7.4}.$$

We postulate that the end effect occurs, if $\Gamma_f = \Gamma_k$. As a simple relationship in dimensionless form we get

$$\frac{\lambda}{d} = 0.394 \frac{Re}{0.22 Re - 7.4}. \qquad (1)$$

For $Re = 150$ we get $\frac{\lambda}{d} = 2.3$. With a set of end plates this relation is tested in steps of 1d. We obtain a real minimum end plate at $\frac{\lambda}{d} = 2$ (figure 1).

The broken line refers to (1). The measured data show the Reynolds numbers, at which the end effect occurs first, here detected with the onset of the second frequency f_2.

In our next example $\frac{\lambda}{d} = 10$ is great enough to produce an end effect and is visualized in figure 2. The distance of the smoke plane is 0.5d from the end plate and we view it from top. In front of the bluff body the smoke layer is very thin

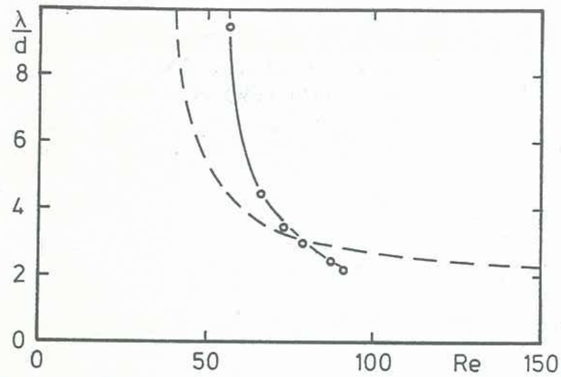

Figure 1 Relative circular length as a function of the Reynolds number in the case $\Gamma_k = \Gamma_f$. - - - - (1), o measured when f_2 appears in the wake.

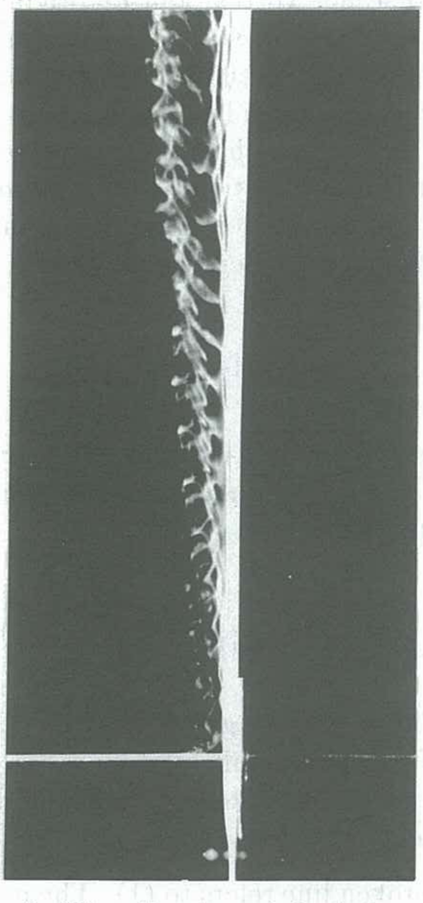

Figure 2 Visualization of the influenced region showing a tornado like structure originating from the wall at x/d=2.5.

and undisturbed. Behind the body the wake increases under an angle of 10°. At $x/d = 2.5$ there is a vortex tube coming from the wall which stretches itself perpendicular to the flow. This tornado like structure originates from a saddlepoint on the end plate and extents 5d in z direction. This observation leads immediately to the conclusion that a third component is present here. The next step undertaken is to find the extension of the three dimensionality quantitativly. It raises the question how far is the influence perpendicular to the flow and is it corresponding to the pictures. We measure velocity profiles with a hot wire, it is positioned in the middle of the wake and travels parallel to the cylinder axis, figure 3.

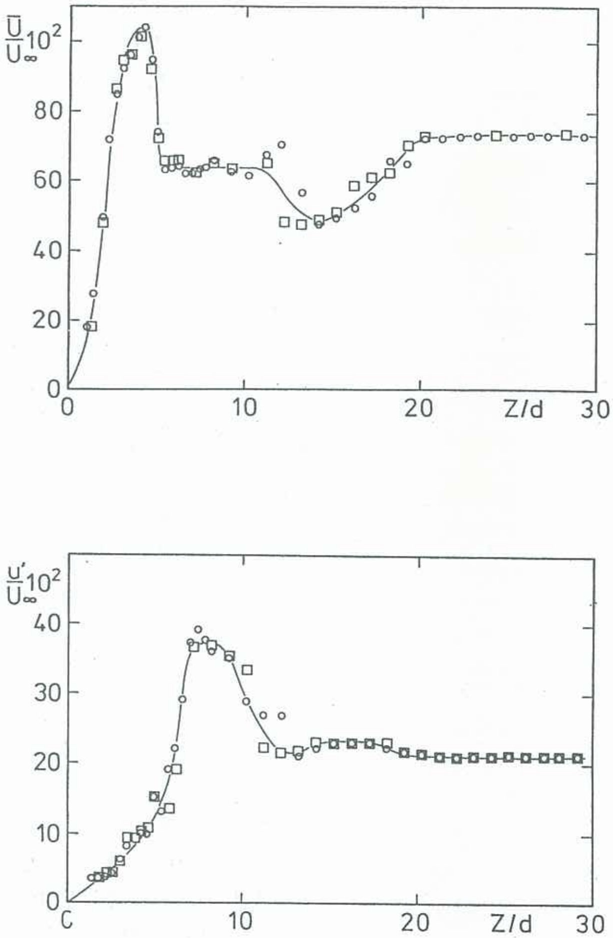

Figure 3 Velocity and RMS profile in z-direction with one end plate. $y/d = 0$, all datas are from the wake centerline. $Re = 136$, $x/d = 10$.

In the upper profile the mean velocity is given in percentage of the free stream velocity. For great distances from the end plate $20 < z/d < 30$ the data does not change. This part of the axis could be called two dimensional. The extremes of the velocity lay at $z/d = 14$ and $z/d = 4$. This is also the extension of the tornado like structure in figure 2. Furthermore we find two plateaus for the mean velocity at 64% and 74% of the free stream velocity. In the vicinity of the end plate the velocity is 10% less compared to the non influenced rest of the cylinder. This deviation is directly comparable to the difference of the shedding frequencies measured in each part here $f_{Sr} = 59Hz$ and $f_2 = 53Hz$ change. The RMS profile reflects similiar facts, two dimensionality lays at $20 < z/d < 30$ and the maximum fluctuation point is given at $z/d = 9$, which is exactly the point where in former observations the wake is divided in two parts or the frequency jumps from f_{Sr} to f_2.

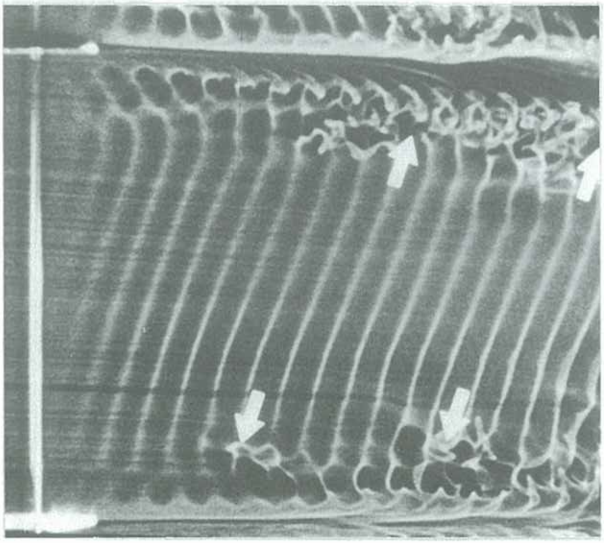

Figure 4 Developement of the far wake with two end plates. From the movie V 2531 IWF. Showing the black holes or the secondary periodically eddies with a periodicity of $\Delta f = f_{Sr} - f_2 = 6Hz$. $Re = 125$, $L/d = 80$, $f_{Sr} = 53Hz$, $f_2 =$

The next two pictures show the influence of the end plates on the far wake. Figure 4 shows the far wake from the cylinder to 100d in x-direction.

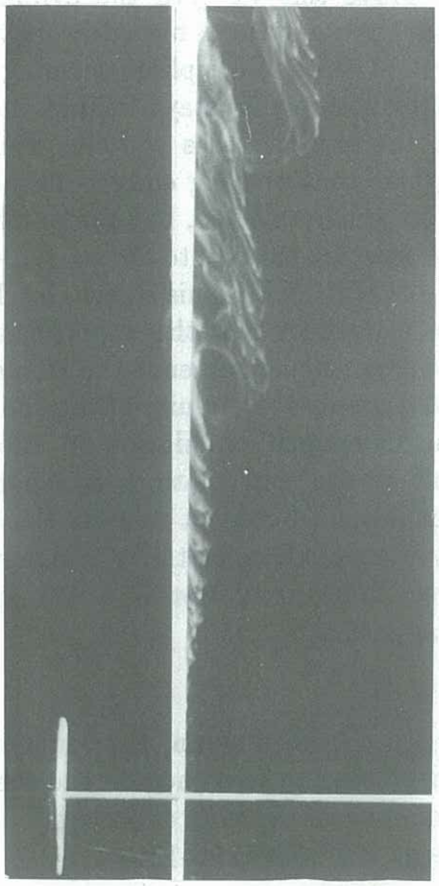

Figure 5 Same experiment as in figure 3 but cylinder turned 90°. A Bronto eddy type has moved out of the plane of line vortices and contains in itself six smaller eddies originating from the influenced region and following the law $\Delta_f = f_{sr} - f_2$. $Re = 125$, $L/d = 60$, smoke plane at $z/d = 6, f_{sr} = 53Hz$, $f_2 = 47Hz$.

The white arrows indicate black holes and white "noses", the first at 35d, which are formed regularly. The black holes are formed periodically at the upper and lower edge, hence the lower row is out of phase 180° with the upper row. This indicates that these vortex systems are not independent from each other. The black holes indicate that smoke material is moving out of the smoke plane and moves in front of the line vortices.

To prove this we turn the cylinder 90° and observe that a big eddy moves out $5cm$ of the smoke plane forming a big white nose which stays behind the flow. On the original fotos you can clearly recognize that one big eddy is formed out of six smaller eddies, but the number six corresponds eaxctly to $\Delta f = f_{Sr} - f_2 = 53 - 47Hz = 6Hz$ This shows clearly that the end effect and the superposition of two frequencies influence the whole wake and not only the vicinity of the end plate. The developed circulation in the front part of the end plate is so enormous, that it can't be swept away in the ordenary constellation of the Karman vortex street. The circulation Γ_f is transported away in Δf.

Literatur

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