Pressure and Vortex Shedding Patterns Around a Low Aspect Ratio Cylinder in a Sheared Flow at Transcritical Reynolds Numbers[1]

P. K. Stansby.[2] The main result of this paper is that the cellular wake structure of a circular cylinder of aspect ratio 9⅓ in a shear flow is similar at subcritical and transcritical Reynolds numbers. Reference is made to the experiments made by the writer (reference [14]), published in references [5 and 6]. This work emphasises the influence of end effects in uniform as well as shear flows and, for the former, end plate dimensions were optimised to remove end effects and so make the flow as two-dimensional as possible. The considerable spanwise variation of base pressure or the completely misleading uniform base pressure which can occur without end plates has also been reported in reference [15].

Certain complex three-dimensional end effects are thus virtually eliminated by suitable end plates although it became apparent from the shear flow work that they produce extra stabilising effects. These are discussed below. Rooney and Peltzer use very small end plates which will probably leave marked end effects in uniform flow (according to our experience). A more direct comparison between the influence of shear at subcritical and transcritical Reynolds numbers would perhaps have been made with larger end plates and we are pleased to note their proposed use for further studies.

The following misinterpretations should be noted. In the Introduction the statement that ". . . . the number and length of cells were insensitive to variations in shear and aspect ratio . . . . " is mistakenly accredited to reference [5] and is obviously incorrect. Reference [6] is later reported to have said that " . . . . for most cases only two end cells were produced . . . . " This was reported for an aspect ratio of 8; at the higher aspect ratio investigated, 16, cells other than the end cells occur. (Note that values up to 32 were investigated in reference [5].)

This latter point is vital to the actual application under consideration where the aspect ratio is around 100. The end cells are a special case and unlike the cells inbetween. They are stabilised by end plates as they are forced to approach the end plates normally. For aspect ratios of 8 or 9 end cells cover virtually all the span. At a value of 16 cells occur in between which may be fixed in position or moving and are of uncertain length, these properties being dependent upon all the incident flow parameters, including end plate dimensions. For OTECs with aspect ratios of around 100 these cells will occur over most of the span. (In our experiments the end cell at the high velocity end was usually about 5 diameters long and the end cell at the low velocity end about 3 diameters long.)

Reference is now made to the Conclusions, "following investigation 1.," where shear is to be varied to determine its influence on the two-cell structure. Figure 12 in reference [5] shows how the shear parameter β influences the end cells (at subcritical Reynolds numbers) and it appears that the two end cells approach in frequency as $\beta \rightarrow 0$. In uniform flow it seems likely that there will be two end cells of the same frequency. The observation in Conclusion 1, that it was impossible to determine a correlation between shear and cell length, was made because only end cells were present (dependent upon the ends rather than shear).

Conclusion 4 states that fluctuating pressures in uniform flow were significantly lower than in shear flow. The former are, however, very much influenced by the degree of three-dimensionality of the flow. The well-correlated shedding in nearly two-dimensional flow produces higher fluctuating pressures than less coherent wakes. In these experiments three-dimensionality will result from the very small end plates. The conclusion that shear increases fluctuating pressures is thus qualified. There are two conflicting effects here: shear will decorrelate vortex shedding causing a less coherent wake and reduce fluctuating pressures, while at the same time the unsteady behaviour of the streamwise vorticity from the incident shear flow will produce additional fluctuating pressures. At this point it is pertinent to mention that 'real' incident flows have a turbulence intensity of around 10 percent further complicating matters.

Since a good deal has been said about the stabilising influence of the ends, it is appropriate to mention a further stabilising influence described in the Introduction. Cylinder vibration can produce "locking-on" in shear flows as well as uniform flows (reference [6]). In shear flow the locked-on cell is stable in position and frequency and appears to stabilise unlocked-on cells above and below. In uniform flow varying the cylinder frequency n_c produces a range of values of n_c/n_{sc} (n_{so} being the shedding frequency from a fixed cylinder) for locking-on, dependent on vibration amplitude. In shear flow this variation can be produced along the span with a fixed n_c since n_{so} varies along the span and the range for locking-on is similar. However, the flow is in other ways rather different and a quasi-two-dimensional prediction for shear flows could well give misleading predictions of flow-induced vibrations. This is because the phase between lift and cylinder displacement is crucial to the latter. The phase varies along the span in shear flow but clearly not in a way which corresponds to the variation with n_c/n_{so} in uniform flow. For example, a jump of around 180° occurs in the middle of the locked-on range in uniform flow whilst a continuous spanwise variation occurs in shear flow (inferred from reference [6]). The ideas inherent in the formula in reference [6] for the spanwise extent of locking-on will have to be extended to accommodate phase variations for reliable predictions of flow-induced vibrations. (It does not even follow that, because forced cylinder oscillation produces locking-on in shear flow, flow-induced vibrations will also occur, although it is of course likely.)

It is suggested that prediction methods should be established at subcritical Reynolds numbers with high aspect ratio cylinders (greater than at least 30) in the controlled environment of the laboratory. Tests at these Reynolds numbers should be made with turbulent shear flows with realistic length scales and intensities. Once the method has been established, it should be calibrated by spot checks at transcritical Reynolds numbers through full or half scale experiments. (If this is the only way that very high aspect ratios may also be achieved.) The spanwise distribution of the unsteady force is the vital measurement.

Additional References

14. Stansby, P. K., "Vortex Wakes of Cylinders Oscillating in Uniform and Sheared Flows," Ph.D. dissertation, University of Cambridge, 1974.

15. Stansby, P. K., "The Effects of End Plates on the Base Pressure Coefficient of a Circular Cylinder," *Aeronautical Journal,* Vol. 78, 1974, p.36.

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[1] By D. M. Rooney and R. D. Peltzer, published in the March, 1981 issue of the JOURNAL OF FLUIDS ENGINEERING, Vol. 103, No. 1, pp. 88-96

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Authors' Closure

The authors welcome Dr. Stansby's comments and criticisms of their paper. A few closing comments will now be made.

Our apparent misinterpretation of the results in reference [5] was an unfortunate misprint, for which the authors are grateful to Dr. Stansby for pointing out. The statement should have ended "for an aspect ratio $L/D = 8$" instead of "and aspect ratio."

We are acutely aware of the limitations imposed by small aspect ratio cylinders, but saw no alternative which would permit an admittedly incomplete investigation of transcritical shedding patterns. The significant finding that transcritical flow patterns closely parallel subcritical flow patterns (even granted that only two forced end cells were observed) remains valid. To attribute the division of the shedding frequencies into a cellular pattern solely to the endplate effect would require further demonstration. Our tests clearly indicated a single spanwise shedding frequency at $\mathrm{St} = 0.165$ in subcritical uniform flow and at $\mathrm{St} = 0.215$ in transcritical uniform flow. No measurements were made near the center of the span to determine whether the shedding occurred in phase on both sides of the cylinder. Yet the evidence adduced by Dr. Stansby to infer that as β approaches zero, two end cells of the same frequency persist (as opposed to a single cell) does not seem compelling. If that were the case, the cell lengths should become equal as the limit is reached. However, Fig. 12 in reference [5] shows no change in the relative cell lengths of 5D and 3D with decreasing β. The implication is that there is either a discontinuity for very low values of β, when one spanwise cell suddenly appears (our contention), or the gradual transition to two cells of length 4D occurs at values of β smaller than examined in any investigation yet undertaken. In any case, the data on endplate cells versus shear flow cells remains inconclusive.

Subsequent tests employing the optimum endplate design for cylinders with an aspect ratio of 17 have been reported by the authors [16] and should help resolve some of the remaining questions about the relationship between roughness, shear parameter, and vortex shedding cell lengths for subcritical and critical Reynolds number flows. In addition, the authors have now examined results of tests on cylinders with aspect ratios of 27 and 48 in sheared flow and have determined that the strong cellular structure so evident at aspect ratios of 16 to 20 appears to break down, at least for subcritical flows in the range $2 \times 10^4 \leq \mathrm{Re} \leq 1 \times 10^5$, for a given value of the shear parameter. Corroborating evidence for this phenomenon can be seen in similar tests performed elsewhere [(17)].

Additional References

16 Peltzer, R. D., and Rooney, D. M., "The Effect of Upstream Shear and Surface Roughness on the Vortex Shedding Patterns and Pressure Distributions Around a Circular Cylinder in Transitional Re Flows," VPI & SU Report VPI-Aero-110, Apr. 1980.

17 Peterka, J. A., Cermak, J. E., and Woo, H. G. C., "Experiments on the Behavior of Cables in a Linear Shear Flow," Colorado State University Progress Report, 19 May, 1980.

A Theoretical Model for the Transverse Impingement of Free Jets at Low Reynolds Number[1]

S. B. Friedman.[2] An engineering research should have, as a minimum, the objective of either explaining the underlying cause of some physical effect, or providing a model by which design can be reasonably performed.

The subject paper falls into the first of the above categories. The phenomena of the "backward-bending" jet is complex and, as well demonstrated in this paper, can be attributed to many causes. If there is any weakness in the conclusions it is that the relative importance of the various causes is not considered or discussed.

In the original work by Dr. Martin and myself, a very simple and workable design model was established, which accounted for better than 90 percent of the previously unexplained variation. A quick analysis and comparison of our work and this one shows little significant improvement in the predictive value using the newer model.

In conclusion, this work should be a valuable addition to the literature, considering both its content and methodology.

Authors' Closure

We would like to acknowledge the comments of Dr. Friedman and his interest in this research; a continuation of his initial experimental work.

The purpose of the theoretical study was to develop a more detailed understanding of the mechanism describing the phenomena of the "backward-bending" jet. That greater insight was achieved and greatly compliments the original intuitive modelling proposed by Dr. Friedman. It is therefore very satisfactory that the original empirical relationships can still be used effectively for design.

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[1] By R. Winton and H. R. Martin, published in the December, 1980, issue of the JOURNAL OF FLUIDS ENGINEERING, Vol. 102, No. 4, pp. 510-518.

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