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INSTABILITIES IN UNIFORM FLOW PAST A ROTATING CYLINDER

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Introduction

A stabilized finite element method is utilized to investigate the flow past a spinning circular cylinder in a uniform stream. The Reynolds number based on the cylinder diameter and free-stream speed of the flow is 200. The non-dimensional rotation rate, α, (ratio of the surface speed and free-stream speed) is varied between 0 and 5. There are two regions of instabilities for the 2D flow. Regular 'karman vortex shedding' is observed for $0 \leq \alpha < 1.91$. The flow is stable for $\alpha > 1.91$. However, the flow becomes unstable again for $4.37 < \alpha < 4.75$. In the second region of instability, only one sided vortex shedding takes place. To ascertain the instability of flow as a function of α a linear global, non-parallel stability analysis of the two-dimensional steady-state flow is conducted. 3D computations for $\alpha = 5$ bring out the effect of end-conditions and aspect ratio of the cylinder. It is found that although the flow for $\alpha = 5$ is stable to 2D disturbances, centrifugal instabilities exist along the entire span in a three-dimensional set-up. In addition, a "no-slip" sidewall can result in separation of flow near the cylinder ends. Both these effects lead to a loss in lift and increase in drag.

1 Results and Discussions

Flow past a rotating cylinder has been studied by various researhers in the past (see, for example, [1, 2, 3]). In the present work, several issues that are still unresolved have been addressed. For $0 \leq \alpha \leq 1.9$ von-karman street is seen in the wake behind the cylinder. For non-zero α the vortex street is deflected away from the center line. The wake becomes narrower and the Strouhal number for vortex shedding decreases with increase in rotation rate. Vortex shedding ceases beyond $\alpha \sim 1.9$. However, it takes quite long for the flow to develop to the final solution following an impulsive start. It is for this reason that some researchers, in the past [3], concluded from their simulations that the flow at $\alpha = 3.25$ is associated with vortex shedding. The present results show that the flow achieves a steady-state for $\alpha = 3.25$. At high rotation rates it is seen that the lift for purely two-dimensional flows can be very large. The values of the lift coefficient obtained in the present work exceed the maximum limit based on the arguments of Prandtl.

The vorticity distribution around the cylinder goes through certain interesting changes with increase in α. For high α the vorticity generated on the cylinder surface is dragged along with it. The positive and negative vorticity appear as tightly wound spirals. The flow remains stable for $1.91 \leq \alpha \leq 4.36$ but looses its stability, again, for $\alpha \sim 4.37$. For this rotation rate, unlike the shedding for lower α, the cylinder sheds vortices of counter-clockwise sense only from its lower surface. Vortex shedding continues for higher spin rates and the flow becomes stable, yet again, for $\alpha > 4.8$. The results are verified by carrying out a global, linear, non-paralel stability analysis. It is observed that the stability of the flow is related to the diffusion of vorticity to regions of slow moving fluid.

Two steady-state solutions are seen for $\alpha = 4.8$ and $\alpha = 4.9$. One of them is unstable while the other is stable. The stable solution is quite similar to the one for $\alpha = 5$. The unstable solution bears resemblance with the steady-state solution for $\alpha = 4.7$ which, is itself, unstable.

Computations for three-dimensional flows show that the aspect ratio of the cylinder and its end-conditions (spanwise length/diameter) play an important role in determining the amount of lift generated by the rotating cylinder. A no-slip side-wall (no end-plates) result in flow separation. In addition, the entire span is associated with centrifugal instabilities. Both these effects contribute to loss of lift and increased drag as compared to a purely two-dimensional flow.

The present work has significant implication on the flow control strategies that utilize rotating cylinder elements. It would be undesirable to use $\alpha < 2$ and $4.3 < \alpha < 4.8$ because the flow is unstable. For other spin rates even though vortex shedding does not occur, one can expect centrifugal instabilities along the entire span of the rotating cylinder. In addition, the end-effects are expected to be important for low-aspect ratio cylinders.

References

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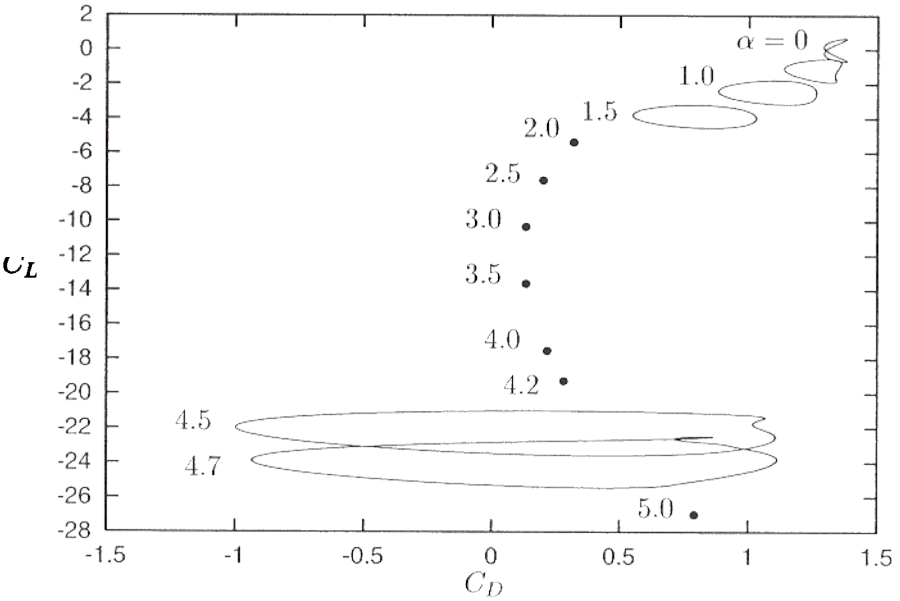

Figure Re = 200 flow past a rotating cylinder: phase diagrams of C_L with C_D for various α.