Ph.D. Defense

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A Refined Potential Theory for the Incompressible Unsteady Subcritical-Reynolds number Flows on Canonical Bluff Bodies

On

Tuesday, May 5 at 2:00 p.m.
Bluejeans : ***https://bluejeans.com/487890767***

Abstract:

Classical potential theory falls short of reconciling the actions of fluid viscosity and frictional forces in an actual flow with the theoretical analysis of such a flow. As such, it is unable to predict the important phenomenon of flow separation that leads, in part, to the pressure drag experienced by the body in an actual flow. However, analytical solutions that theories provide offer huge advantages over numerical and experimental solutions in the understanding of fluid flows and in design. These are in terms of cost and time consumption.

Therefore, a refinement of Classical potential theory of the flow over a circular cylinder was carried out to bridge this gap. It was achieved by introducing a viscous sink-source-vortex sheet on the surface of the cylinder. These singularities are modeled as concentric at every location. The vortices are modeled as Burgers vortices, and analytic expressions for their strengths and those of the sinks/sources are obtained from the classical theory. These are employed to obtain a Reynolds-number-and-time-dependent stream function that captures important qualitative features of the flow. A viscous potential function that satisfies the governing equations is then derived. It is obtained by defining the viscous stream function on a principal axis of the flow about which the vorticity vector is identically zero. Strategies have also been developed to account for the finite extent of the cylinder, to introduce dynamic unsteadiness, to predict separation/reattachment/transition, to obtain forces, and to apply the solution to an arbitrary geometry with a focus on spheres and spheroids.

The refined potential theory was verified against experimental and numerical data on the cylinder in an incompressible crossflow at $Re_\infty = 3{,}900$. Its drag prediction is within the error bound of measured data. The prediction of other quantities is also within acceptable ranges. Its prediction of the force coefficients over the range $25 \le Re_\infty \le 350{,}000$ was validated against experimental data on the cylinder in crossflow. There is a good agreement in the trend with slight disparity in magnitude that is in favor of safety for design purposes. The energy spectra of the wake velocity display the Kolmogorov's Five-Thirds law of homogeneous isotropic turbulence. This verifies and validates the unsteadiness in refined potential theory as turbulent in nature.

Committee:

- Professor Marilyn J. Smith – School of Aerospace Engineering (advisor)
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