

Modeling the unsteady wake of an impulsively started circular cylinder using refined potential flow theory

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Cylindrical structures find usage in many engineering applications including tethered oil drums and engine canisters slung beneath helicopters in flight. The motion of air around such circular cylindrical structures and the helicopter presents interesting phenomena including flow separation, wakes and turbulence. The physics of these are enshrined in the continuity equation and the Navier-Stokes equations. Therefore, their studies are not only important in mathematics and physics, but they are also required for efficient helicopter operations. In practice, reduced-order models of these operations that take in aerodynamics models of the tethered loads are utilized for stability analysis, flight certification and pilot training because of the prohibitive cost of experimentation and computational analyses of these configurations. However, there is a dearth of realistic analytical models of finite cylinder flows because of the Navier-Stokes problem. Classical potential flow theory provides an avenue to develop such models, but the extant gaps in its predictions significantly preclude its usage for engineering applications. Attempting to bridge these gaps, this article introduces refined potential flow theory in which the governing equations and boundary conditions are satisfied. Viscous effects, fluctuations of the mean flow and three-dimensional effects are also incorporated. For characterization, refined potential flow theory is employed on an incompressible flow over an impulsively started circular cylinder for Reynolds numbers and non-dimensional times in the range $30 < Re < 10^4$ and $0.2 \leq T \leq 77,047$ respectively. There is an excellent prediction of 0.209 for the Strouhal number at $Re = 3,900$. At this transitional Reynolds number, the harmonics of the Strouhal frequency are also captured, and the characteristic irregular fluctuations at sub-Strouhal frequencies are discernible in the velocity spectra. As the flow becomes more turbulent, these become more pronounced at $Re = 9,500$ when the predicted Strouhal number is within 10% of experimental result. In the fully developed stage, spectra analyses of the wake velocity components at some downstream locations also display Kolmogorov's Five-Thirds law of homogeneous isotropic turbulence. The present model can thus aid the development of reduced-order models of helicopter operations that feature tethered cylindrical loads.

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