Computation of Axial and Near-Axial Flow Over a Long Circular Cylinder

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Doctor of Philosophy

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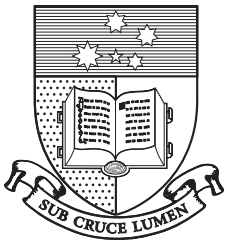

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Abstract

A direct numerical simulation study has been conducted to examine the flow that develops on long circular cylinders that are aligned, or nearly aligned, with the free-stream. Results are presented for turbulent boundary layers and vortex-shedding yawed flow. Although flows of these types occur in a range of engineering applications, they remain relatively unexplored compared with flat-plate flow.

The numerical scheme employed for solution of the governing Navier-Stokes equations is similar to that used in some previously published simulations, but here rather different boundary conditions are adopted. At the outer edge of the cylindrical computational domain, the imposed boundary conditions confine the vorticity field within a finite radius while allowing the continuous velocity field to converge to the free-stream velocity at large distances from the cylinder.

Axial flows are considered with radius Reynolds numbers in the range 311 to 20800, ratios of boundary layer thickness to cylinder radius in the range 0.15 to 27.5, and boundary layer thicknesses of between 160 and 800 viscous units (ν/u_τ). The mean-flow and turbulence statistics for axisymmetric boundary layers are found to differ significantly from flat-plate results when the boundary layer is strongly curved, that is when the boundary layer is thick in relation to the cylinder radius. The effects of curvature are mainly observed in the outer flow except when the cylinder radius in viscous units is small. Particular attention is given to the assessment of similarity scaling relations for the mean velocity profile, velocity fluctuation statistics and temporal wall-pressure spectra.

Structural features of axisymmetric turbulence are examined by inspection of instantaneous flow fields, correlation functions and conditionally-averaged flow structures. In very thick boundary layers on thin cylinders, the simulations reveal evidence of large-scale fluid motion across the cylinder, although the mechanisms of turbulence generation do not appear to be significantly different from those in flat-plate flow.

Simulations of turbulence in near-axial flow over cylinders are considered with radius Reynolds numbers up to 674 and yaw angles up to 0.5 degrees. No previous

flow simulations of this kind are reported in the literature. The mean-flow and turbulence statistics are found to depart rapidly from axisymmetry as the yaw angle increases. The quality of the calculated results suggests that the computational procedure is suitable for use in a more comprehensive investigation of near-axial flow over cylinders.

For cylinders inclined at sufficiently large yaw angles to the free-stream, turbulent boundary layer flow gives way to oblique vortex-shedding from the cylinder. Simulated flow fields corresponding to a radius Reynolds number of 311 and a yaw angle of 3 degrees are examined to reveal the three-dimensional structure of the flow. The results suggest that the oscillating flow fields in the cylinder wake have the character of a wave travelling in the axial direction at the same speed as the axial component of the free-stream.

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The computational resources used for the project have been provided by several organisations. In the early stages of the project, I learnt the fundamentals of parallel programming on the CM-5 supercomputer operated by the South Australian Centre for Parallel Computing (SACPC). A substantial grant of processing time, some 45000 CPU-hours in total, has been provided by the Australian Partnership for Advanced Computing (APAC) through the Merit Allocation Scheme. The bulk of the results presented in this thesis have been generated using several CPU-decades of processing time on supercomputers operated by the South Australian Partnership for Advanced Computing (SAPAC). Special thanks go to the system administrators, Grant Ward and Patrick Fitzhenry, whose friendly and dedicated assistance helped me to get work done with the minimum of delay. I would also like to thank Dr. Francis Vaughan, who has given support and advice on computational aspects of the current project since the days of the CM-5.

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Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

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