Flow Dynamics and Thermal Behavior Around a Cylinder Positioned Between Two End Walls

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INTRODUCTION: This study investigates the flow dynamics and thermal characteristics around a circular cylinder placed within a parallel-walled internal channel at Reynolds Number 5900. The configuration serves as a simplified model for understanding complex flow interactions and heat transfer mechanisms in constrained geometries. By examining the effects of turbulence on flow separation, vortex shedding, and local heat transfer rates, this work provides insight into the fundamental physics governing internal cooling flows. As an extension, the study considers an array of cylinders arranged within the channel, mimicking cylindrical pin-fins typically integrated into the trailing edge of turbine blades for enhanced cooling performance. This configuration enables a detailed analysis of the heat transfer behavior and aerodynamic interactions among multiple elements, contributing to the optimization of internal cooling strategies in gas turbine applications.

PROBLEM SETUP: All simulations are performed using the high-fidelity, open-source code **Incompact3d**, which is based on Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES) methodologies. Incompact3d is known for its high parallel efficiency and scalability, capable of handling billions of mesh points and running on up to millions of cores. The following table summarizes key computational parameters used in the current simulations:

Grid Size	Nodes	Processors	Computation Time
34 Million	20	960	68 Hrs
42 Million	20	960	74 Hrs
69 Million	35	1680	94 Hrs

Results:

Figure 1 shows a 3D visualization of vortex shedding, illustrating alternating negative and positive vortices that eventually lead to the formation of a Kármán vortex. Kármán vortices are shed from the cylinder but rapidly lose coherence and break down into smaller three-dimensional eddies, so a stable Kármán vortex street does not persist.

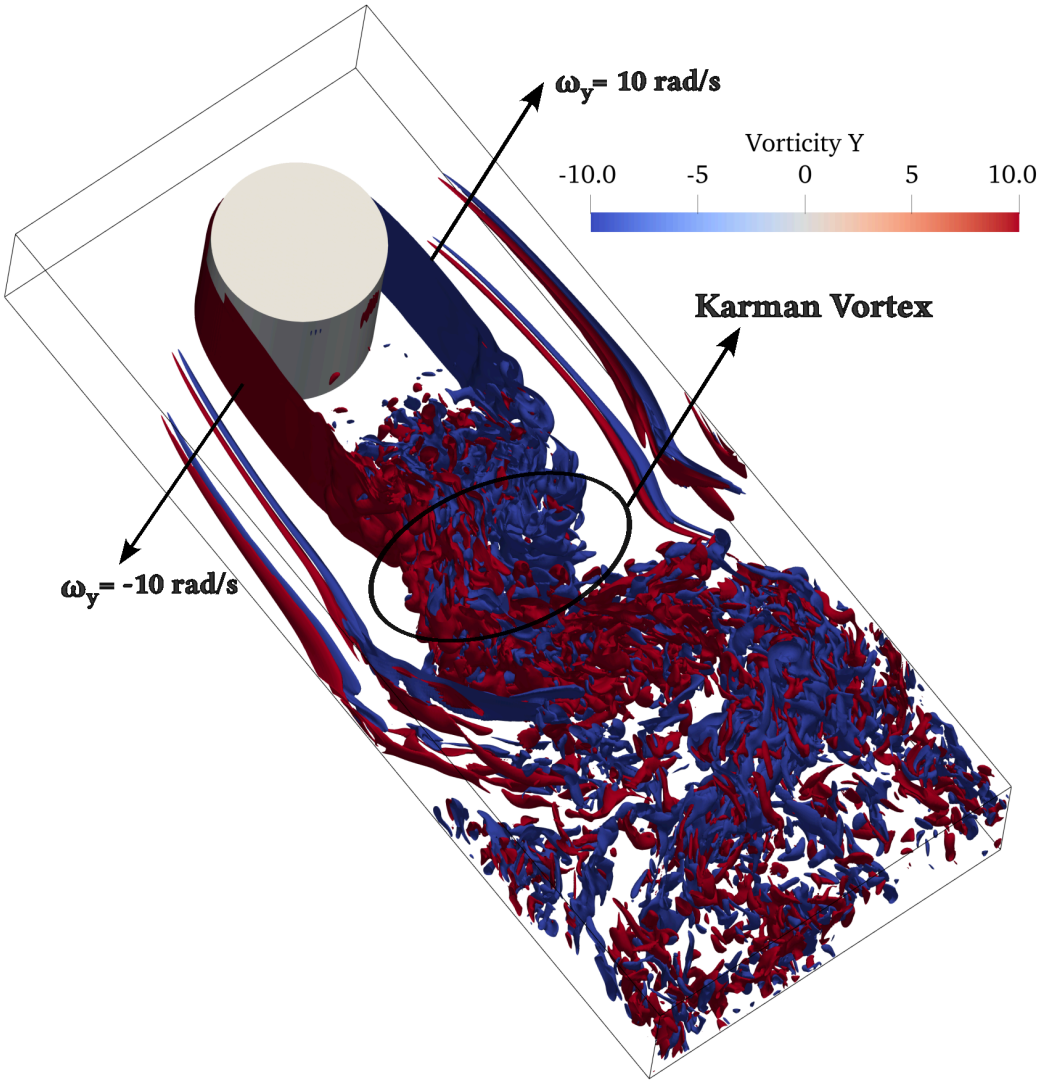

Figure 1: Iso-surfaces of instantaneous vorticity contour for flow around a cylinder.

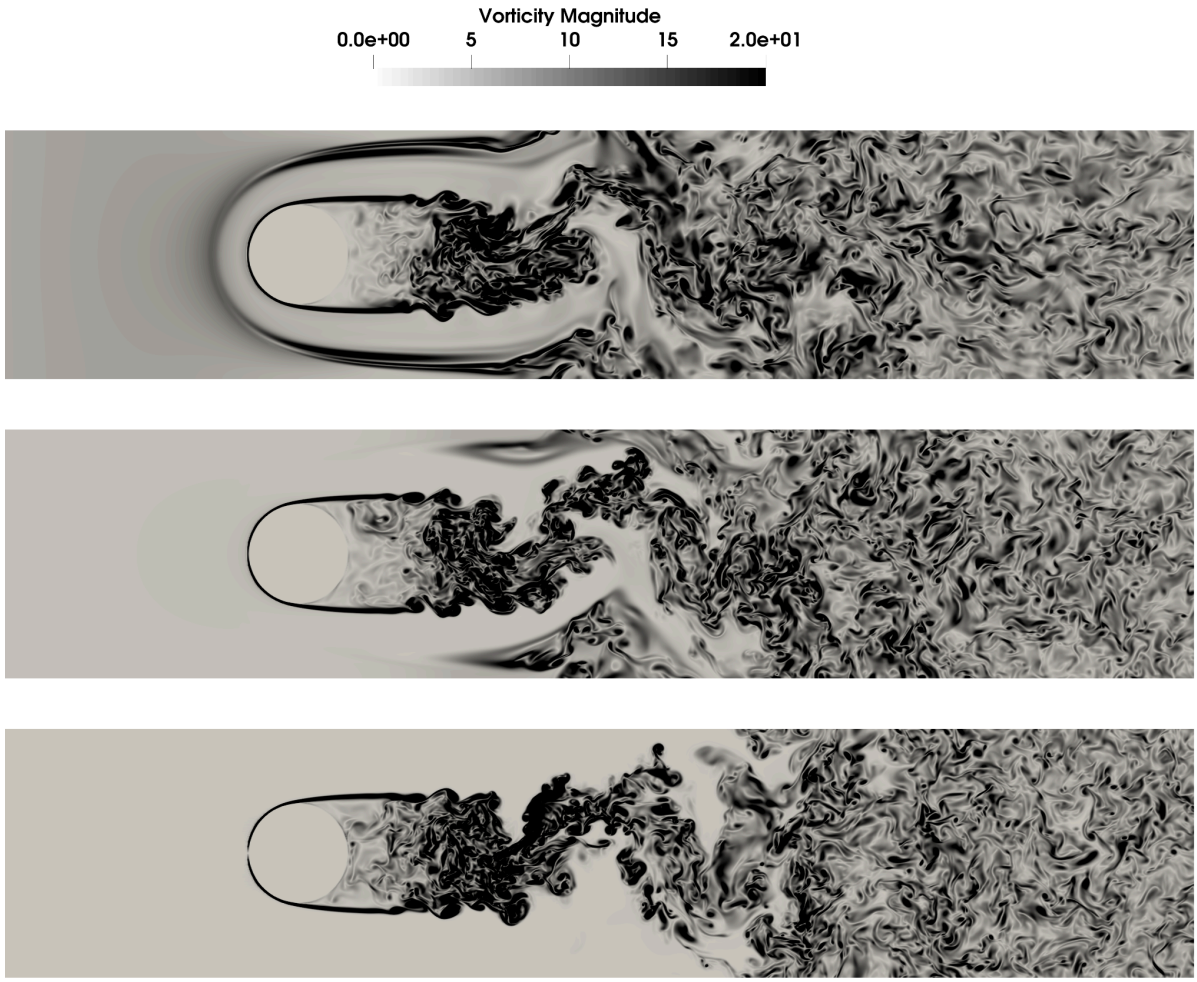

Figure 2: Instantaneous contours of vorticity magnitude at three different wall-normal locations from the bottom wall to the mid-plane, corresponding to y/D=0.1, y/D=0.25, and y/D=0.5, for the flow around a cylinder.

The three vorticity snapshots in Figure 2 illustrate how the wake structure behind a wall-mounted bluff body evolves from the near-wall region to the channel center. Near the wall (y/D = 0.1), the flow is strongly influenced by wall confinement, forming a distinct horseshoe vortex around the obstacle base and producing a narrow, organized wake with suppressed three-dimensional motion. At the mid-height plane (y/D = 0.25), the wake becomes more asymmetric and transitional as the shear layers from both sides of the obstacle roll up and interact, generating complex vortical structures through vortex stretching and tilting. Toward the channel center (y/D = 0.5), the flow is fully three-dimensional and turbulent, with the coherent shedding largely broken down into smaller eddies and chaotic motion.

References:

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