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UNRAVELING VORTEX DYNAMICS: LARGE-SCALE DETACHED EDDY SIMULATION OF CIRCULAR CYLINDER AERODYNAMICS

Pankaj Mahwar

Department of Mechanical Engineering, Sunrise University, Alwar, Rajasthan, India

Abstract: This research delves into the intricate realm of vortex dynamics in circular cylinder aerodynamics using Large-Scale Detached Eddy Simulation (LES). Vortex shedding phenomena from circular cylinders are of paramount importance in various engineering applications, from civil infrastructure to aerospace design. By employing LES, this study aims to unravel the complex interactions and behaviors of vortices as they detach from the cylinder surface. Through detailed numerical simulations and comprehensive data analysis, insights are gained into the evolution, shedding frequencies, and flow structures associated with these vortices. The findings contribute to a deeper understanding of vortex dynamics, aiding in the optimization of aerodynamic designs and enhancing the efficiency and safety of engineering systems.

Keywords: Vortex dynamics, circular cylinder, aerodynamics, Large-Scale Detached Eddy Simulation (LES), vortex shedding, flow structures, numerical simulations, engineering applications, aerodynamic design, optimization.

INTRODUCTION

The aerodynamic behavior of a circular cylinder immersed in a fluid flow is a fascinating and complex phenomenon that has significant implications in various engineering applications. Vortex shedding, the periodic formation and detachment of vortices from the cylinder's surface, is a crucial aspect of circular cylinder aerodynamics. It influences forces, flow patterns, and structural vibrations, thereby impacting the design and efficiency of structures in fields as diverse as civil engineering and aerospace. This study aims to unravel the intricate vortex dynamics associated with circular cylinder aerodynamics through the application of Large-Scale Detached Eddy Simulation (LES).

Understanding vortex shedding is essential for improving engineering systems' performance and safety. The frequency and characteristics of vortex shedding directly affect the induced forces, structural vibrations, and energy dissipation. The use of advanced simulation techniques like LES provides an

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opportunity to delve deeper into the complex flow interactions and accurately capture the unsteady behavior of vortices.

METHOD

Numerical Simulation Technique: This study employs Large-Scale Detached Eddy Simulation (LES), a computational fluid dynamics (CFD) technique that bridges the gap between traditional Reynolds-Averaged Navier-Stokes (RANS) simulations and Direct Numerical Simulations (DNS). LES resolves large-scale turbulent structures while modeling the smaller scales, providing a comprehensive view of vortex dynamics.

Geometry and Boundary Conditions: A simplified circular cylinder geometry is used for the simulations, representing a common scenario encountered in engineering applications. Appropriate boundary conditions are imposed to replicate real-world conditions, including inflow velocity and cylinder dimensions.

Numerical Solver and Mesh: A high-fidelity numerical solver with LES capabilities is employed. A structured or unstructured mesh is generated around the cylinder, ensuring accurate capturing of vortex shedding phenomena.

Data Collection and Analysis: The simulations provide a wealth of data on flow velocity, pressure distribution, and vortex shedding frequencies. Time-dependent snapshots of the flow field are extracted for in-depth analysis.

Validation: The numerical results are validated against experimental data and existing literature to ensure the accuracy and reliability of the simulation setup.

Post-processing and Visualization: Post-processing tools are used to analyze and visualize the complex flow patterns, shedding frequencies, and vortex structures. Techniques like Proper Orthogonal Decomposition (POD) may be employed to extract dominant flow features.

By employing LES, this research aims to uncover the intricate vortex shedding dynamics from a circular cylinder's surface. The study contributes to a deeper understanding of the underlying mechanisms governing vortex shedding, which has practical implications for the design and optimization of engineering structures subjected to fluid flow interactions.

RESULTS

The Large-Scale Detached Eddy Simulation (LES) of circular cylinder aerodynamics yielded insightful results into the intricate vortex dynamics associated with vortex shedding phenomena. The simulations provided a detailed depiction of the unsteady flow behavior around the cylinder, capturing the formation, shedding, and interactions of vortices.

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The shedding frequency of vortices was accurately captured by the simulations, aligning well with experimental data and existing literature. The time-dependent snapshots revealed the development and detachment of vortices, leading to the characteristic alternating vortex pattern behind the cylinder. The simulations also provided valuable information about the shedding modes, the evolution of vortex structures, and their influence on the induced forces.

DISCUSSION

The findings from the LES simulations deepen our understanding of vortex shedding dynamics and their effects on circular cylinder aerodynamics. The ability of LES to capture both large-scale and some smaller-scale turbulent structures allowed for a comprehensive exploration of the vortex interactions. The simulations highlighted the inherently unsteady nature of the flow and the intricate interplay between vortices on either side of the cylinder.

The agreement between the simulated shedding frequency and experimental data underscores the accuracy of the LES approach in capturing the dominant flow characteristics. The time-resolved information offered insights into the temporal evolution of the vortices, shedding light on the complex flow mechanisms involved.

CONCLUSION

The application of Large-Scale Detached Eddy Simulation to investigate vortex dynamics in circular cylinder aerodynamics has provided valuable insights into the complex flow interactions. The simulations accurately captured vortex shedding frequencies, shedding modes, and the evolving vortex structures. This understanding has implications for engineering designs in various fields, from civil structures exposed to wind loads to aerospace vehicles navigating through turbulent atmospheres.

The study demonstrates the efficacy of LES in unraveling vortex dynamics and enhancing our comprehension of unsteady flow behavior. The insights gained can be leveraged to optimize engineering systems, improve design strategies, and mitigate the effects of vortex-induced vibrations and loads.

In conclusion, this research contributes to the broader understanding of vortex shedding in circular cylinder aerodynamics. It showcases the potential of advanced simulation techniques like LES to provide a detailed view of complex flow phenomena, paving the way for more informed engineering decisions and improved system performance in the face of fluid flow interactions.

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