DNS of a Fully Developed Turbulent Flow over Confined Wavy Channel

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Abstract

Fluid flowing over a smooth boundary of a channel creates turbulence if the velocity is large enough. The relationship of the Reynolds shear stress to the structure of turbulence is the basic mechanism interested. Less attention has been given to flow over rough or structured surface. Turbulent flow over a wavy surface displays characteristics that are not found in flow over a flat surface. The mean and statistical quantities of a fully developed turbulent flow in a channel with a sinusoidal bottom wall (with wavelength λ) and a flat top wall have been a interesting research topic for a long time. A number of studies of flow over a period train of solid waves have been carries out based on both laboratory experiment and numerical simulation. A principal finding of these work is that the flow is characterized by an outer flow and by an inner flow extending a distance from the mean level of the surface. The mechanism of turbulence production in the inner region is fundamentally different from flow over a flat surface. Turbulence production in the inner region for turbulent flow over a flat plat is related to the formation of streamwise vortices in the wall region. In the turbulent channel flow with lower sinusoidal wall, however, turbulence production is mainly associated with a shear layer that separates from the back of the wave. Turbulence generation and sustainment by flow oriented vortices such as found for flat walls appears to be unimportant in a channel with wavy wall. This important, but poorly understood flow configuration is a focus of numerous studies because of its applicability as a reference flow for complex flows. Early numerical and analytical studies of flow over wavy surface considered waves of infinitesimal amplitude. Several researchers used Laser Doppler Velocimetry (LDV) to measure the velocity field to study the influence of wave steepness on the flow pattern. Particle image velocity (PIV) has been used to examine the spatial variation of the velocity in different planes of the flow through a water channel. Balasubramanian et al. solved the time-averaged Navier-Stokes equations using spectral method for laminar and turbulent flow over large amplitude waves. They explored both k-ε model and an algebraic model. The main uncertainty in the numerical results lies in the closure models for the Reynolds stresses. Extensive measurements of the Reynolds stresses are obtained by Hudson. The experiments done by Kuzan and Thorsness are at lower Reynolds numbers. In the last twenty years, direst numerical simulation (DNS) has become a valuable method in providing a theoretical understanding of turbulent flows. In DNS, the Reynolds stresses are not modeled. The velocity field is simulated by solving the Navier-Stokes equations directly. DNS is used to study turbulent flows at low or moderate Reynolds numbers because the spatial resolution required increases as the Reynolds number increases. This is a constrain. In this paper the results of direct numerical simulation of the flow over a wavy wall are presented. Two-dimensional Navier-Stokes equations are solved using WENO scheme which is an essentially non-oscillatory scheme with high resolution for multi-dimentional hyperbolic system of conservation laws. A structured surface, which consists of a train of sinusoidal waves with different height to length ratio (2a/) at values of 0.05 and 0.10 were used as the bottom wall of a rectangular channel with a half-height, h, of 25mm, and a width of 200mm. The evolution in space and time of fluid particles in this flow configuration are examined. Turbulence intensities, Reynolds stresses, turbulent energy production, instantaneous and mean flow field, and the pressure distribution of the turbulent channel flow with a wavy wall are calculated and investigated. A physical understanding of the structure of turbulent field would be greatly enhanced if information about the spatial variation of Reynolds stress is available. The purpose of this research is to obtain systematic structural information about the turbulent flow field. Features of the turbulence structure are discussed.

Keyword：Turbulent Channel Flow, wavy wall, Direct Numerical Simulation(DNS), WENO Scheme