DIRECT NUMERICAL SIMULATION OF TURBULENT FLOW AND HEAT TRANSPORT IN A TIGHTLY-SPACED ROD BUNDLE

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Direct Numerical Simulation (DNS) is increasingly used for generating reference databases, which are crucial for validating lower-order turbulence models. This allows more pragmatic Computational Fluid Dynamics (CFD) approaches, such as RANS and LES, to be improved through new correlations and refinements, enhancing their reliability in capturing turbulent flow and heat transfer phenomena.

In this study, DNS of fully developed flow and heat transfer is conducted for a bare rod bundle with a low pitch-to-diameter ratio using the highly scalable spectral element code Nek5000. The simulation is performed at a Reynolds number (Re_h) of 9800, based on bulk velocity and hydraulic diameter, under both iso-temperature and iso-flux thermal boundary conditions, with Prandtl numbers of 0.025, 1.0, and 2.0.

Flow anisotropy is analyzed through distributions of normal and Reynolds stresses and the Lumley invariant map. It is observed that turbulence in the subchannel region exhibits characteristics typical of wall-bounded turbulent flows, whereas in the narrow gap, turbulence is suppressed except in the streamwise direction due to flow pulsations.

Temperature statistics under both thermal boundary conditions highlight the influence of the Prandtl number on mean and fluctuating quantities. The behavior of temperature statistics with iso-temperature wall boundary conditions, which has not been previously reported in the literature, differs between the interstitial subchannel and the narrow gap between rods. The distribution of the turbulent heat flux is also examined, showing enhanced streamwise components compared to the subchannel.

Further analysis of flow pulsations in the narrow gap is performed using frequency analysis, revealing a low Reynolds number effect on these pulsations, in contrast to mean flow statistics.

DNS reference database will be made available on request.

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