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OpenFOAM Based Simulation of High Reynolds Number Separated Flows Using Bridging Method of Turbulence

Authors : Sagar Saroha, Sawan S. Sinha, Sunil Lakshmipathy

Abstract : Reynolds averaged Navier-Stokes (RANS) model is the popular computational tool for prediction of turbulent flows. Being computationally less expensive as compared to direct numerical simulation (DNS), RANS has received wide acceptance in industry and research community as well. However, for high Reynolds number flows, the traditional RANS approach based on the Boussinesq hypothesis is incapacitated to capture all the essential flow characteristics, and thus, its performance is restricted in high Reynolds number flows of practical interest. RANS performance turns out to be inadequate in regimes like flow over curved surfaces, flows with rapid changes in the mean strain rate, duct flows involving secondary streamlines and three-dimensional separated flows. In the recent decade, partially averaged Navier-Stokes (PANS) methodology has gained acceptability among seamless bridging methods of turbulence- placed between DNS and RANS. PANS methodology, being a scale resolving bridging method, is inherently more suitable than RANS for simulating turbulent flows. The superior ability of PANS method has been demonstrated for some cases like swirling flows, high-speed mixing environment, and high Reynolds number turbulent flows. In our work, we intend to evaluate PANS in case of separated turbulent flows past bluff bodies -which is of broad aerodynamic research and industrial application. PANS equations, being derived from base RANS, continue to inherit the inadequacies from the parent RANS model based on linear eddy-viscosity model (LEVM) closure. To enhance PANS' capabilities for simulating separated flows, the shortcomings of the LEVM closure need to be addressed. Inabilities of the LEVMs have inspired the development of non-linear eddy viscosity models (NLEVM). To explore the potential improvement in PANS performance, in our study we evaluate the PANS behavior in conjugation with NLEVM. Our work can be categorized into three significant steps: (i) Extraction of PANS version of NLEVM from RANS model, (ii) testing the model in the homogeneous turbulence environment and (iii) application and evaluation of the model in the canonical case of separated non-homogeneous flow field (flow past prismatic bodies and bodies of revolution at high Reynolds number). PANS version of NLEVM shall be derived and implemented in OpenFOAM -an open source solver. Homogeneous flows evaluation will comprise the study of the influence of the PANS' filter-width control parameter on the turbulent stresses; the homogeneous analysis performed over typical velocity fields and asymptotic analysis of Reynolds stress tensor. Non-homogeneous flow case will include the study of mean integrated quantities and various instantaneous flow field features including wake structures. Performance of PANS + NLEVM shall be compared against the LEVM based PANS and LEVM based RANS. This assessment will contribute to significant improvement of the predictive ability of the computational fluid dynamics (CFD) tools in massively separated turbulent flows past bluff bodies.

Keywords : bridging methods of turbulence, high Re-CFD, non-linear PANS, separated turbulent flows
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