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QUANTIFYING UNCERTAINTIES IN DIRECT NUMERICAL SIMULATIONS OF A TURBULENT CHANNEL FLOW

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Direct numerical simulation (DNS) provides unrivalled levels of detail and accuracy about turbulent flows. These high-fidelity simulations are often used to analyse flow physics, develop theory, and validate lower-fidelity models. However, like all numerical methods, DNS is subject to uncertainties arising from the numerical scheme and input parameters (e.g. mesh resolution). While uncertainty quantification (UQ) techniques are being employed more and more to provide a systematic analysis of uncertainty for lower-fidelity models, their application to DNS is still relatively rare. Therefore, to assess the robustness of DNS with respect to the input parameters, and enable appropriate analysis and interpretation of results, there is a need to apply these techniques more frequently to DNS studies. Following from this, the main aim of this work is to assess the sensitivity of DNS to the user-defined numerical parameters for a canonical wall-bounded turbulent channel flow at low Reynolds number ($Re_\tau = 180$), via stochastic collocation. The uncertain input parameters are the spatial resolution in each dimension, the time step interval, and the total simulation time for collecting statistics. Gaussian quadrature rules are combined via tensor products to sample the defined input distributions, resulting in 3,125 separate DNSs. To facilitate the non-intrusive forward UQ analysis, the open-source EasyVVUQ package [1] is used to provide integrated capability for sampling, pre-processing, execution, and post-processing of the computational campaign. To compute the DNS, Xcompact3D [2] – a highly scalable open-source framework based on high-order compact finite differences and a spectral Poisson solver – is used as a black-box solver. The output quantities of interest (QOIs) are the cross-channel first (mean and fluctuating velocities) and second-order (turbulent kinetic energy and Reynolds stresses) statistics after averaging both in time and in both homogeneous directions. The analysis focusses on the cross-channel statistical moments (mean and variance) of the QOIs with respect to the uncertain input parameters, as well as a global sensitivity analysis to obtain the Sobol indices for the QOIs along the cross-channel coordinate. This analysis enables an assessment of the robustness and sensitivity of DNS to the user-defined numerical parameters for wall-bounded turbulent flows and provides an indication of recommended ranges for defining the values of these parameters.

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