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DNS of turbulent flow with uniform heat flux in a pipe

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In this work we present results of direct numerical simulations (DNS) of the flow in a circular pipe at moderate Reynolds numbers, where a uniform heat flux is imposed on the walls. The simulations are performed by varying the Reynolds number (Re) and the Prandtl number (Pr), which allows studying the statistics of the turbulent variables in all observed cases. We compare the non-dimensional heat transfer coefficient Nu (Nusselt number) with the experimental correlations producing very accurate results.

INTRODUCTION

The turbulent numerical simulation of the flow in a circular pipe is one of the most widely studied problems in Fluid Mechanics, since it is a problem that presents a direct application to the determination of the global properties of the flow to obtain results applicable to the flow in pipes, and also presents a transition to turbulence in the form of a subcritical bifurcation in a Reynolds number band from 2000 to 3000. From $Re = 3000$ onwards the flow can be considered to be fully turbulent. The study of the thermal problem as presented in this paper is something that has received less attention in the literature, partly because axially periodic numerical codes cannot represent the coupled problem using the Boussinesq approximation. Recently, Straub et al. [1] have approached this problem in a decoupled way, looking at the effect of using different boundary conditions to model the heat flow in the walls. Within the uncoupled problems, there are works that study the turbulence generated in this type of flow for a fixed Reynolds number ($Re = 5000$), varying the type of fluid (varying the Prandtl number) [2].

RESULTS

We present a systematic and detailed study on how the temperature distribution and thermal statistics in a uniformly heated pipe are affected by changes in the Reynolds and Prandtl numbers. To that avail, we have implemented a highly optimized pseudospectral code to perform direct numerical simulations of the governing equations. The new code has been validated against previous DNS results in the literature (see figure that compares the temperature distribution plotted in viscous units against that in the reference [3]). Simulations have been performed for Reynolds numbers ranging from 3000 to 12500 and Pr between 0.025 and 2 and the evolution of the mean temperature, heat transfer coefficient (i.e. the Nusselt number, Nu) and second order statistics (e.g. variance of the temperature or turbulent diffusivities) have been obtained. It is found that the thermal structures become larger as the Pr number decreases, so that larger fluctuations in the statistical quantities are observed. The optimal pipe length and spatial resolution needed for the statistics to converge are also determined.

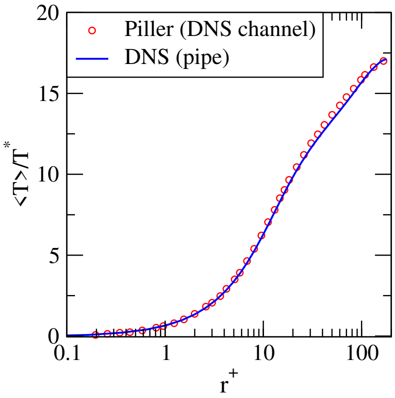

FIG. 1. Comparison of the mean temperature profile (normalized in viscous units) between DNS of pipe flow (current study) and channel flow [3] for $Re_\tau = 180$.

CONCLUSIONS

Direct numerical simulations of uniformly heated turbulent pipe flow for Reynolds numbers between 3000 and 12500 and Prandtl numbers 0.025 and 2 are presented. The influence of varying these parameters in the heat transfer coefficient, Nu, as well as in other thermal statistics, is examined in detail.

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