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Turbulence in the rotating-disk boundary layer investigated through direct numerical simulations

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Abstract

Direct numerical simulations (DNS) are reported for the turbulent rotating-disk boundary layer for the first time. Two turbulent simulations are presented with overlapping small and large Reynolds numbers, where the largest corresponds to a momentum-loss Reynolds number of almost 2000. Simulation data are compared with experimental data from the same flow case reported by Imayama et al. (*Eur. J. Mech. B/Fluids*, vol. 48, 2014, pp. 245–253), and also a comparison is made with a numerical simulation of a two-dimensional turbulent boundary layer (2DTBL) over a flat plate reported by Schlatter and Örlü (*J. Fluid Mech.*, vol. 659, 2010, pp. 116–126). The agreement of the turbulent statistics between experiments and simulations is in general very good, as well as the findings of a missing wake region and a lower shape factor compared to the 2DTBL. The simulations also show rms-levels in the inner region similar to the 2DTBL. The simulations validate Imayama *et al.*'s results showing that the rotating-disk turbulent boundary layer in the near-wall region contains shorter streamwise (azimuthal) wavelengths than the 2DTBL, probably due to the outward inclination of the low-speed streaks. Moreover, all velocity components are available from the simulations, and hence the local flow angle, Reynolds stresses and all terms in the turbulent kinetic energy equation are also discussed. However there are in general no large differences compared to the 2DTBL, hence the three-dimensional effects seem to have only a small influence on the turbulence.

Keywords: near-wall turbulence, rotation, turbulence statistics

1. Introduction

This paper investigates the turbulent rotating-disk boundary layer, which arises over a disk rotating in otherwise quiescent fluid. In contrast to a flat-plate boundary layer, the boundary layer on the rotating disk is three-dimensional. The flow is dragged along with the rotating disk, but it also has a radial outward component, the so-called crossflow component, and to fulfil mass conservation, fluid is drawn towards the disk from the non-rotating fluid outside the boundary layer. If the boundary layer is laminar, a similarity solution exists as shown in 1921 by von Kármán. For the laminar rotating-disk flow, a convenient measure of the Reynolds number is the nondimensional radius, defined as

$$R = r^* \sqrt{\frac{\Omega^*}{\nu}} = r, \qquad (1)$$