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Development of a turbulent boundary layer in a rotating square cross-section channel with relatively high local rotation parameter

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Abstract

The development of turbulent boundary layer in a rotating square cross-section straight channel were experimentally measured using hot wire in a new rotating facility. Measurements were conducted at four streamwise stations to study the development of turbulent boundary layer along the stream wise. The governing parameters of the boundary layer are local Reynolds number $u_\tau\delta/\nu$ and local rotation parameter $\Omega\nu/u_\tau^2$ (u_τ is the friction velocity, δ is the thickness of boundary layer, ν is the kinematic viscosity coefficient and Ω is the angular velocity of the channel, which is defined to be positive near the trailing side wall and negative near the leading side wall). The measurements are performed in the range of $199 \le u_\tau\delta/\nu \le 367$ and $-0.0135 \le \Omega\nu/u_\tau^2 \le 0.0054$ (these values correspond to $\bar{u}D/\nu$=19000 and $0 \le |\Omega|D/\bar{u} \le 0.362$, here, $\bar{u}$ means the cross-section averaged streamwise velocity, and D means the hydraulic diameter of the channel). Due to the relatively high local rotation parameter $|\Omega|\nu/u_\tau^2$ on the leading side (up to 0.0135), some new phenomena were discovered, such as the critical rotation number phenomenon revealed in the variations of wall friction coefficient (the critical rotation number ranges from 0.145 to 0.362), the so-called relaminarization process near the leading side wall. Moreover, in high local rotation parameter cases, the lower limit of the Coriolis force influenced region is too close to the wall to be recognized with the traditional method, hence a new method to evaluate the influence of Coriolis force was proposed in the present work.

Introduction

To improve the thermal efficiency of a modern gas turbine engine, the turbine blade has to be operated in the environment with extremely high temperature (>1900K). This extremely high temperature is far beyond the working temperature even melting point of the turbine blade materials. To resolve this conflict, lots of cooling techniques are applied to protect the turbine blade. As one of the most classical and prevalently used cooling techniques, sophisticated turbine blade internal cooling techniques, such as serpentine passage in the middle section of a turbine blade, have been developed over the past two decades which are reviewed by Han et al. [1-3].

Heat transfer and flow fields are coupled together and affect each other. Most of previous researches focused on the heat transfer phenomenon. However, the knowledge about the flow behavior under rotating conditions is scarce, as it is more difficult to be measured under the rotating condition. Due to the lack of knowledge