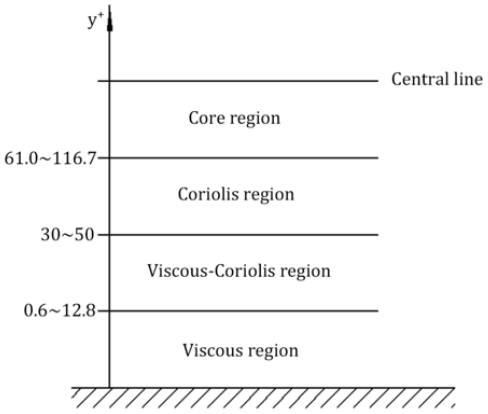
Flow and heat transfer in rotating channels

Deeply investigations on the flow and heat transfer in a rotating duct are of great practical value to improve the internal cooling of the aero-engine turbine blade. Since the 1960s, investigators had started to investigate the flow and heat transfer in rotating channels. However, most of the investigations are focusing on the heat transfer data, not many on the detail flow in rotating channels. This is because it is a difficult task to measure the velocity under rotating conditions. Yet, the velocity data in rotating channels is more useful than heat transfer data for designing the rotating turbine blades.

In order to understand the detail flow in rotating channels, Associate Professor Haiwang Li from the School of Energy and Power Engineering at Beihang University designed and established a new rotating facility which is able to measure the flow and heat transfer in a rotating channel. Moreover, the applications of a serial of techniques like hot wire and PIV on the rotating facility were validated.

The experimental method was used to study the flow in a rotating duct. And, the characteristics of primary flow and secondary flow in the entrance section of a rotating smooth straight channel were selected as the research object. The investigations were focused on the following aspects: the layered structure in turbulent boundary layer, the relaminazation phenomenon in turbulent boundary layer, the rotation correction of the turbulent boundary layer wall-function law, the motion law of secondary flow and the interaction between secondary flow and primary flow, and the separate flow near the leading side in a rotating channel.

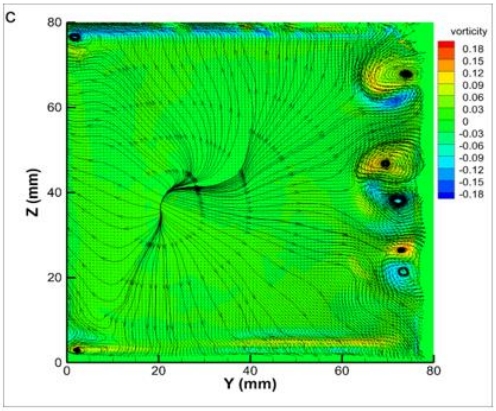


Stratification of boundary layer in rotating channels

After the experimental studies on the above five aspects, a serial of important conclusions that have never been published in the open literature are summarized as follow. On the layered structure in turbulent boundary layer, the author proposed theoretically that the slope of $\sqrt{\langle uu\rangle/U_\tau^2}$ in the linear layer can be used to determine the penetrate depth of the Coriolis force when the influence of the Coriolis force is penetrated into the linear layer, and this proposal was proved experimentally.

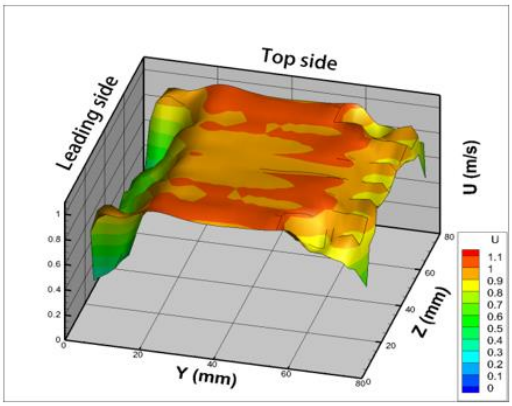
On the relaminarization phenomenon in turbulent boundary layer, for the first time, the entire relaminarization process of the leading side boundary layer was captured experimentally. In addition, the attenuation of $\langle uv\rangle$ was found to precede the attenuation of $\langle uu\rangle$ and $\langle vv\rangle$ in the relaminarization process. On the rotation

correction of the turbulent boundary layer wall-function law, the rotation correction formula of 1/κ in the Coriolis layer was given when the influence of relaminarization can be neglected. Moreover, the characteristics of the turbulent mixing length function were given, and this function has to be adopted in the rotation correction of the Van Direst formula.



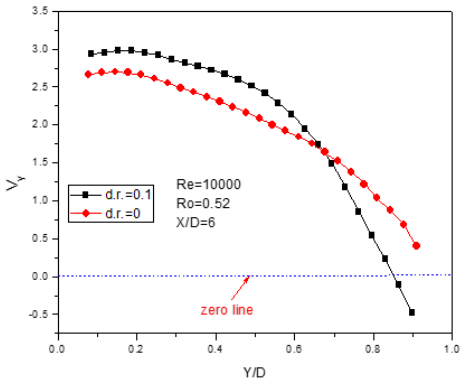
Second flow in rotating channels

On the motion law of secondary flow, the merge of the vortex pairs near the trailing side wall was found to have relationship with the variation of the vortices in the leading side corner region. On the interaction between secondary flow and primary flow, the vortex pairs near the trailing side wall were found to be able to induce a serial of pits in the 3D-reconstruction primary flow field. Besides that, in order to explain the contradiction between the secondary flow and the primary flow near the leading side wall, a hypothesis was introduced, and this hypothesis can provide an explanation different from previous studies to the critical rotation number phenomenon.

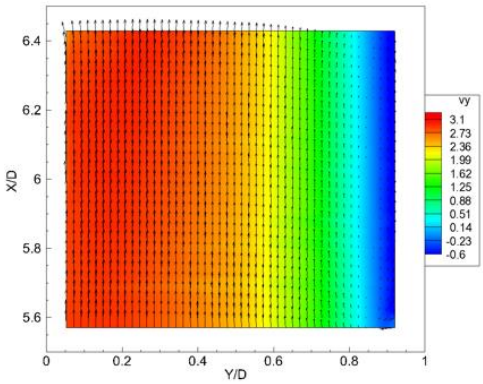


3-D distribution of detail flow in rotating channels

On the motion of separate flow on the leading side in rotating channels, Li found and conformed that, near the leading surface, under the Coriolis force and buoyancy force, there are separate flow happened, which will enhance the heat transfer at that position. This founding is important for engine turbine blade designers to understand the detail flow mechanism in the rotating blade channels.



Comparison of velocity along stream-wise direction in rotating channels



Velocity along stream-wise direction in rotating channels under buoyancy force

The above results were published in International Journal of Heat and Mass Transfer.

Reference

[1] Heat Transfer Investigation in a Rotating U-turn smooth channel with irregular cross-section, International Journal of Heat and Mass Transfer, 96 (2016) 267-277.

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