

TURBULENT FLOW IN ROTATING RIBBED CHANNEL WITH CORIOLIS FORCES AND CENTRIPETAL BUOYANCY

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1 Background

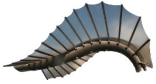
In turbomachinery, one of the applications in which rotational effects are most relevant is the coolant flows in the internal cavities of rotating turbine blades. The flow in internal cooling channels in stator blades is already complex due to the intricate shape of the passages and the presence of turbulence promoters such as ribs. In rotor blades Coriolis forces affect the stability of the shear layers and induce secondary flows. Moreover, because of the thermal boundary layers along the hot channel surfaces, the centrifugal acceleration induces radial buoyancy in the vicinity of the walls. The latter turns the typical forced convection regime in a mixed convection regime. In most past experimental studies concerned with rotating channel flows, point-wise velocimetry techniques are used (e.g. [1]), which cannot identify coherent instantaneous flow structures and velocity gradients. Few studies in literature present full field data in rotating channels using PIV, but typically the imaging system is attached to the fixed frame [2]. The relative velocity inside the channel is obtained by subtracting the peripheral velocity from the measured absolute velocity, resulting in low temporal and spatial resolution and in large uncertainties, especially at high rotation rates. Due to the lack of detailed experimental data, often numerical models need to be validated against more accurate simulations for validation, namely LES and DNS. The latter are anyway extremely expensive, if not unaffordable, due to the complexity of the cooling geometries.

2 Present experimental approach

The present contribution addresses the effect of Coriolis and buoyancy forces in a rotating channel with one ribbed wall, reproducing a turbine blade cooling channel. Two-dimensional PIV measurements are performed in a rotating facility where both the test section and the measurement chain rotate on a turntable up to 130 rpm [3]. The Reynolds number value based on the bulk velocity (2.8 m/s) and the hydraulic diameter (79 mm) is $1,5 \cdot 10^4$. A rotation number value equal to 0.35 is achieved both in clockwise and counter-clockwise sense. The ribbed wall, machined out of copper, is heated to a uniform temperature of about 100°C by means of electrical resistances powered by an on-board PDI controller. This allows obtaining a buoyancy number equal to 0.3. As the flow is outward the buoyancy is centripetal. In-plane velocity fields are measured along the channel symmetry plane by means of a 25 W continuous laser diode and a high-speed CMOS camera. Both ensemble-averaged and time-resolved measurements are performed. In the latter case the realizations are acquired at 3.3 kHz, allowing to resolve the resolution of the fine temporal flow scales. To the authors' best knowledge, these are the first time-resolved PIV measurements in a channel flow under rotational buoyancy.

2.1 Results

Figure 1 displays the mean streamlines for the non-rotating and rotating cases. With respect to the non-rotating case (fig.1a), the anti-cyclonic rotation (fig.1b) leads to the augmentation of free shear entrainment, which produces a stronger streamline curvature, and hence an earlier reattachment. The opposite holds for cyclonic rotation (fig.1c). Adding the effect of buoyancy forces in the cyclonic rotating case (1d) produces an even larger recirculation spanning the whole inter-rib area, which enhances mixing and transport. Figure 2 depicts the spatio-temporal travelling of the spanwise vortices shed by the rib in different rotating conditions. The vortical structures are identified by regions exceeding a positive threshold of swirling strength. Vortices which have a significant extension in the space-time domain satisfy the requirement of temporal coherence, which cannot generally be imposed analyzing instantaneous realizations. With anti-cyclonic rotation (fig.2a) higher convective velocities and fewer counter-clockwise rotating vortices are found with respect to cyclonic rotation (fig.2b). Furthermore the spanwise rollers are blurred by the destabilizing effect of anti-cyclonic rotation. In cyclonic rotation with centripetal buoyancy (fig.2c) the vortical structures are even neater, and counter-clockwise rotating vortices are fewer. It is argued that this is due to the buoyant flow streaming backward (negative X-direction), which interacts with the free shear flow past the rib: both streams create a pattern which is little affected by curvature, reminiscent of a mixing layer. The present data illustrate the great potential of the chosen



approach for exploring unsteady turbulent flows in rotating frames, both for complex configurations and for fundamental studies.

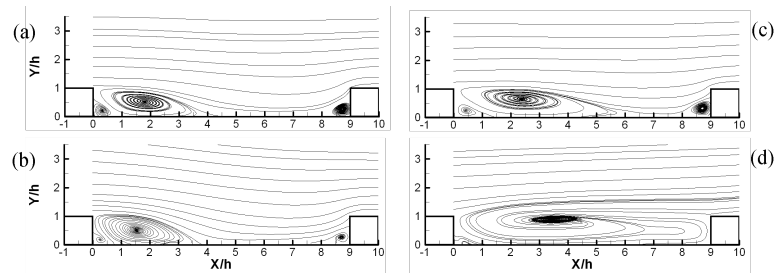


Figure 1: Mean streamlines. Flow from left to right.

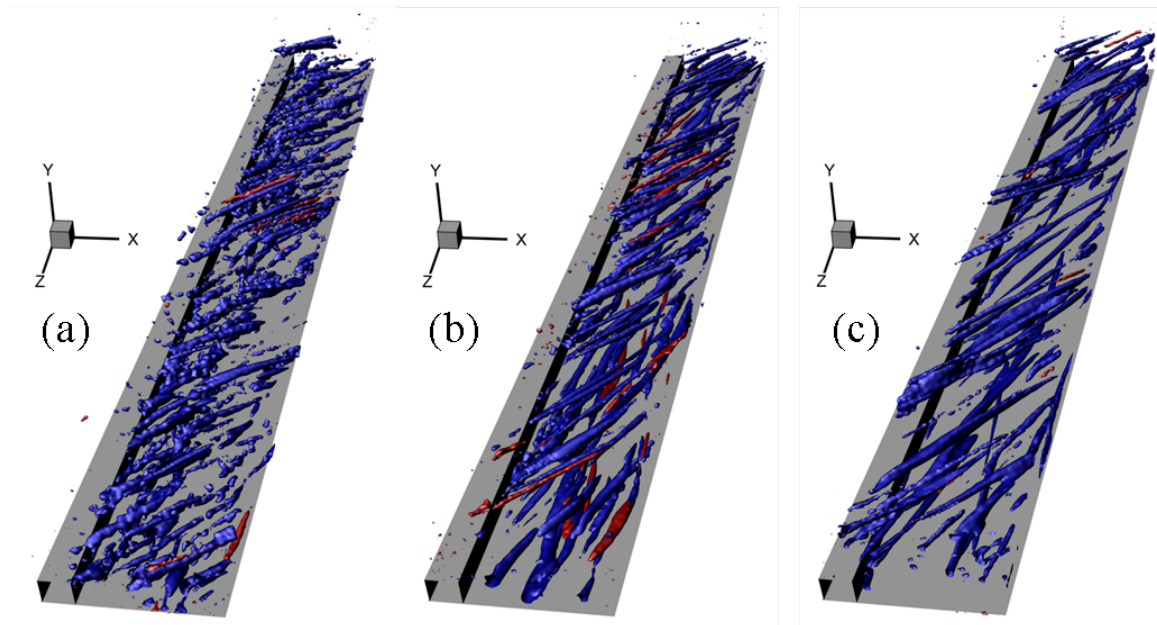


Figure 2: Iso-contours of signed swirling strength in the space-time domain. Flow in the positive X-direction. Time advances in negative Z-direction. Blue (red) indicates vortices which rotate clockwise (counter-clockwise) in the X-Y plane.

References

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- [3] A. Di Sante, R. Theunissen, R.A. Van den Braembussche, A new facility for time resolved PIV measurements in rotating channels. *Exp. Fluids* **44**, 179–188 (2008).