P.I.V. Flow Characterization Inside a Large-Scale U-Shaped Smooth and Ribbed Rotating Channel

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1. Introduction

A research program has been initiated at ONERA with the aim to improve methodology for turbine blade cooling design and tuning by using validated CFD codes. The approach has consisted in designing and manufacturing a specific large-scale U-Rotating cooling channel model in order to setup an experimental database for those types of flows with rotation. The first objective is to validate models and CFD codes in order to generate a reliable numerical tool capable of predicting steady performances of cooling for various configurations (Reynolds and Rotation numbers, centrifugal/centripetal branchs, walls heating temperature, with/without ribs, ribs geometries…). The second objective is to provide a better understanding of the aerodynamic and thermal phenomena at play during internal cooling of turbine blades by forced convection.

This paper describes the rig and the large-scale U-shaped channel designed and tested.

Recent experimental results obtained by using the Particle Image Velocimetry (P.I.V.) technique in this facility named BATHIRE (Test Bench for AeroTHermal flows Investigations in a Rotating Environment) are exposed.

2. Description of experimental facility

The BATHIRE facility, which follows another smaller-scale rig named MERCI [1] (rig for studying cooling by internal convection), was specifically designed for the use of modern optical diagnostic tools, such as PIV (Figure 1) for measuring the flow velocity fields. The turbine blade cooling channel model is attached to a support arm which contains two passages for air flow inlet and outlet, and rotates in a vertical plane inside an enclosure (non represented on Figure 1). The test channel and its support arm are balanced thanks to a counterweight arm located at the opposite diameter. The set is attached to a rotation shaft. This shaft is driven through a belt by a variable-speed electric motor, allowing a maximum rotating speed of 1,000 rpm in clockwise ($\Omega>0$) and counter-clockwise ($\Omega<0$) directions.

The test channel (Figure 2) is an evolutive section (square and rectangular) U-shaped channel with two branches, where hydraulic diameter is more or less constant and equal to a value within DH=50 mm. For the configuration presented here, the flow enters by the right square section branch of the test model. At the periphery, both branches are linked through a 180° U-curved bend with a constant height. The test channel design allows the optional installation of ribs on internal walls.

The study presented in this paper focuses on the case of smooth and ribbed internal walls.

3. Results

In order to characterize the effect of rotation (due to the centrifugal and Coriolis forces) on the flow structure, the mean velocity field inside this channel was explored. Results presented for the Smooth Channel (Figure 3) were obtained for a Reynolds number of 25000, and a

Rotation number of 0.33 (rotation speed equal to 50 rad/s). One wall of the channel was heated and its surface temperature was 333 K. The whole volume of the model could be explored thanks to a translation stage system which moved the laser light sheet and camera horizontally and vertically. The time duration between two consecutive laser flashes was set to 10 µs in rotation in order to meet the following compromises: measurable velocity range (minimum/ maximum displacement of particle images), spatial resolution of around 1 mm, spatial overlap of the two laser sheets during the rotation. The averaged velocity field (Figure 3) was reconstructed from 73 measurement planes. Due to the large model dimensions, six vertical planes (X direction) were needed for each section (Z direction) investigated. The reattachment point downstream from the bend for the centripetal channel was observed to appear more rapidly in the rotating case compared to the static case. Recent results presented for the Ribbed Channel (Figure 4a) were obtained for same operating conditions and analyzed also in comparison with Smooth Channel previous results [2] in Static (Figure 4b) and rotating (Figure 4c) cases.

Experimental results have been confronted with computational results for the smooth channel and have been useful to choose turbulence and wall laws models adapted to those types of flows.

4. Conclusions

The knowledge of flow and heat transfer characteristics inside internal cooling channels is required to optimize the geometry while increasing thermal efficiency. PIV measurements were performed in the centrifugal and centripetal branches of smooth and ribbed channels. Main conclusions issued from this experimental study are the followings: in the centrifugal branch, the effect of rotation is identified by velocity vectors deflected toward the pressure side; in the centripetal branch, the effect of rotation is identified by velocity vectors deflected toward the suction side. The use of the PIV technique (for flow fields measurements) associated with Infrared thermometry (for thermal measurements) will provide a useful database for validation of CFD codes.

References

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[2] P.I.V. Flow Characterization Inside a Large-Scale U-Shaped Rotating Channel, A. Ristori, Y. Servouze, M. Barat, F. Soulignac, 7th International Symposium on Particle Image Velocimetry , PIV 2007, Roma, Italy, September 11-14, 2007.

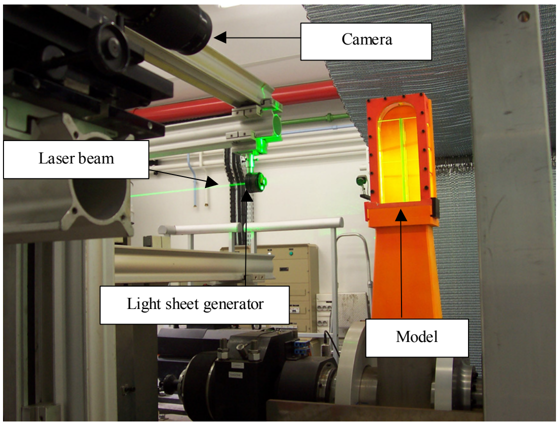

Figure 1: PIV arrangement setup around test rig.

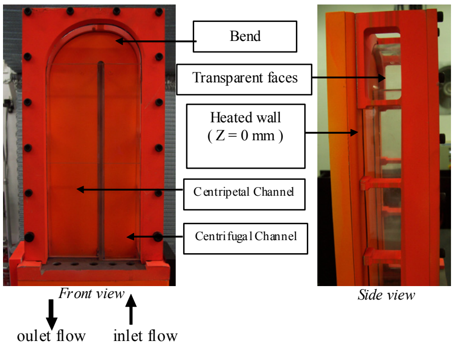

Figure 2: Photographs of the test channel.

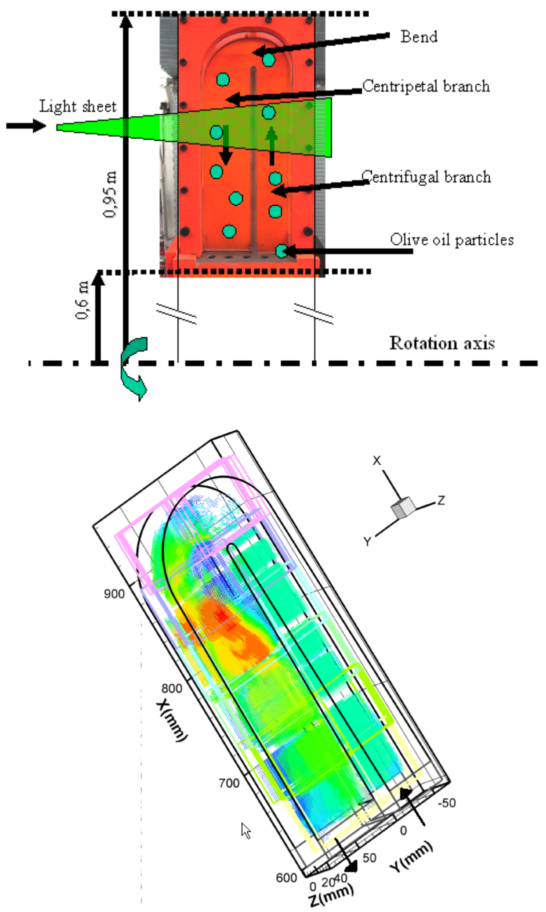

Figure 3: Model description (Smooth Channel) and velocity field results obtained from PIV measurement (Re=25000 - Ro=0.33 - Tw=333 K.

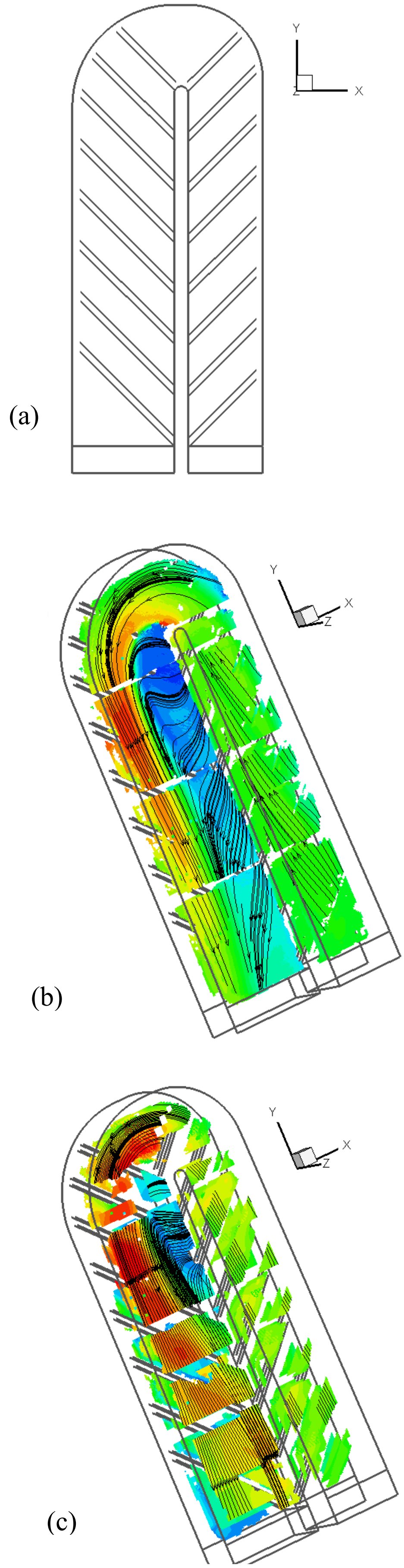

Figure 4: Model description of the Ribbed Channel (a) and velocity field results obtained from PIV measurements: Static case (b), rotating case (c).