INFLUENCE OF THE TIP GAP SIZE ON THE DEVELOPMENT OF THE TIP-LEAKAGE VORTEX USING LARGE EDDY SIMULATIONS

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Abstract In hydraulic turbines, the tip-leakage vortex is responsible for flow instabilities and for promoting erosion due to cavitation. To better understand the flow in the tip region, LES computations are carried out to compute the flow around a NACA0009 blade including the gap between the tip and the wall. The influence of the gap size is investigated by computing two gap widths.
The validation of the results is performed by comparisons with experimental data. The simulations are also used to investigate the flow in the tip gap region. Depending on the gap width, the vortex flow topology differs from one case to the other. At large gap widths, the tip-leakage vortex merges with the tip-separation vortex. On the contrary, at small gap widths, the tip-leakage vortex move upward and no tip-separation vortex is clearly identified. Part of these observations are validated by comparisons with experimental visualizations of the cavitating tip-leakage vortex.

Keywords: LES, Tip-leakage vortex, Tip gap width.

INTRODUCTION

The confined tip-leakage vortex was investigated experimentally in the case of air compressor flows [7], water axial pumps [5] or Kaplan turbines [8]. Numerical simulations were performed using Reynolds-Average Navier Stokes (RANS) approach [4], Reynolds Stress Models (RSM) [1] and Large Eddy Simulation (LES) [9]. Experiments are not able to provide a large overview of the flow in the tip gap region due to the small width (less than few millimetres). Therefore, numerical simulations can be a useful tool to better understand the development of the tip-leakage vortex and the influence of the gap width on the vortex development. RANS computations are able to capture the mean flow topology of the tip-leakage vortex, nevertheless the instantaneous flow field is far to be captured accurately. LES computations are able to capture the instantaneous features of the flow, which allows an investigation of the flow topology in the gap region. In the present work, LES are carried out to compute the flow around a NACA0009 blade for two gap widths [2]. First, the numerical results downstream the blade are compared with the experimental data [3]. Then, the flow in the gap region is investigated and compared between the two gap widths.

CASE STUDY

A truncated NACA0009 blade is mounted in a rectangular channel with an incidence of 10 degrees. The gap τ between the blade and the wall is set to $\tau/c = 0.02$ and $\tau/c = 0.1$ with $c = 0.1\,m$, the chord length of the blade.
The LES simulations are performed using the Yales2 solver [6]. The sub-grid scales are modelled using an eddy viscosity approach ν_{SGS} computed using the localized dynamic Smagorinsky model. In order to reduce the mesh size, a non-equilibrium wall law is used that takes into account the pressure gradient.
The computational domain is a square channel $0.15 \times 0.15\ m^2$ that extends two chords upstream the leading edge and five chords downstream the trailing edge. Two meshes are build, one for each case. For the small gap $\tau/c = 0.02$, the number of elements is closed to 300 millions, whereas for the second gap $\tau/c = 0.1$, the number of elements is closed to 200 millions. The inlet velocity is provided from a RANS simulation performed on an extended domain. At the outlet, a pressure condition is set.

MAIN RESULTS

Experimental measurements are performed in three cross-planes located downstream the trailing edge and are used to assess the simulations. The velocity field and the position of the vortex core are compared. The axial components u is displayed on figure 1 for the gap $\tau/c = 0.1$. A good agreement between the experiment and the simulation is observed both in velocity magnitude and topology.
Focusing on the flow in the gap region, the influence of the gap width is brought out. The Q-criterion, computed both with the instantaneous and the mean velocity, put in evidence the vortex structures (see figure 2). For the gap $\tau/c = 0.02$, the tip-leakage vortex develops from the leading edge on the suction side and moves upward quickly. No tip-separation

vortices develop in the gap. On the contrary, for the gap $\tau/c = 0.1$, a tip-separation vortex forms in the gap before moving to the suction side and to merge with the tip-leakage vortex, which does not move upward.

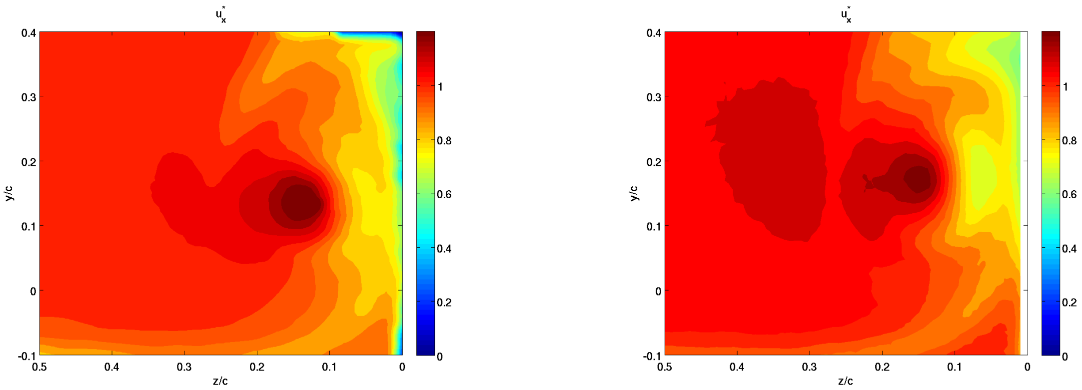

Figure 1. Axial velocity component u in a cross-plane downstream the blade for $\tau/c = 0.1$. Experiment (left), LES computation (right).

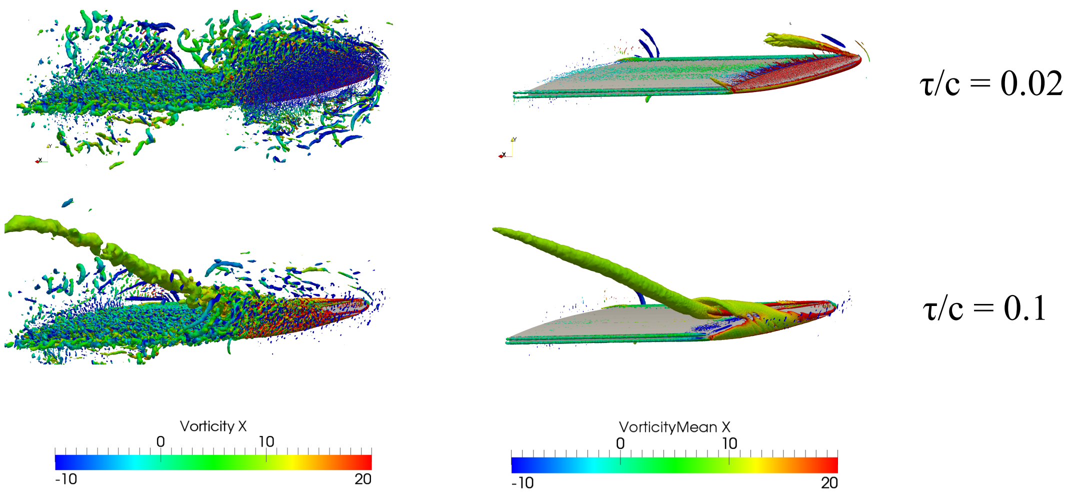

Figure 2. Q-criterion computed using the instantaneous velocity (left) and the mean velocity (right). LES computations.

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