LARGE EDDY SIMULATION OF TIP LEAKAGE FLOW IN A LINEAR TURBINE CASCADE

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Abstract. The tip leakage flow and its interactions with secondary flows over T106 low pressure turbine blade are investigated by large eddy simulation using OpenFOAM. Preliminary results indicate the formation of complex vortical structures close to the tip casing wall. The interaction of the tip leakage and the secondary vortical structures result in local adverse pressure gradient and trigger local separations on the blade suction surface. Besides, horseshoe vortices form due to the blockage of the upstream flow near the tip casing wall. The final paper will present the detailed analysis of tip leakage flow along with comparisons with other numerical studies. Furthermore, the study will be extended to examine inlet flow effect on tip leakage flow and the interaction amongst tip leakage and secondary flows.

1 INTRODUCTION

Aerodynamic losses in turbines are amongst the most crucial problems in modern turbomachineries [1]. Engineering tools play a vital role to probe the nature of complex flow physics in turbines, thus to preclude inevitable losses such as the tip leakage. Accordingly, considerable progress in the development of CFD applications into turbomachineries have been achieved for last decades. There are several CFD approaches to study turbine flows today. It is an obligatory task to choose compatible CFD approach for the problem necessities. RANS deals with the mean flow features such that turbulent flow properties can not be obtained. DNS requires a quite detailed domain with numerous amount of grid points, which makes it computationally expensive. Thereby, LES could take place to investigate flow problems in turbines. Its dominating ability on studying turbine flows has been shown [2]. LES outputs reliable informations on flow physics, which are in good agreement with both DNS and experimental results [3, 4]. Particular flow problems such as the effect of clearance height [5], viscous losses [6] in tip leakage aerodynamics were studied with the help of LES.

In the present study, tip leakage flow over an LPT blade is investigated by LES to contribute further understanding of the complex tip leakage flow mechanism. Flow features such as blockage of upstream flow near casing wall is investigated. Flow interactions causing local APGs on the suction surface near the tip clearance is studied. In the final paper, inlet flow effect on the tip leakage aerodynamics will be examined. Capabilities of LES on tip leakage flow containing complex turbulent flow structures will be sought alongside. Results will be compared with DNS and experimental results.

2 NUMERICAL METHODOLOGY

Figure 1(a) illustrates the computational domain for the simulations in the present study. Figure 1(b) shows the grid map of the preliminary case having 15 million grid points. Full structured hexahedral mesh is maintained in the computational domain. Rotational LPT blade having an unshrouded tip is settled on an infinitely long linear cascade as studied by Bindon and Morphis [7]. Therefore, cyclic boundary conditions are defined along pitch-wise direction. The no-slip boundary condition is specified at the blade surface and the tip end wall. Symmetry boundary condition is assigned at the hub end wall. Uniform velocity field is given at the domain inlet for the preliminary study. Based on the axial chord length, inlet velocity and the kinematic viscosity, Reynolds number is $8x10^4$. The incompressible LES solver utilizing the PISO algorithm is used in OpenFOAM with Smagorinsky model.

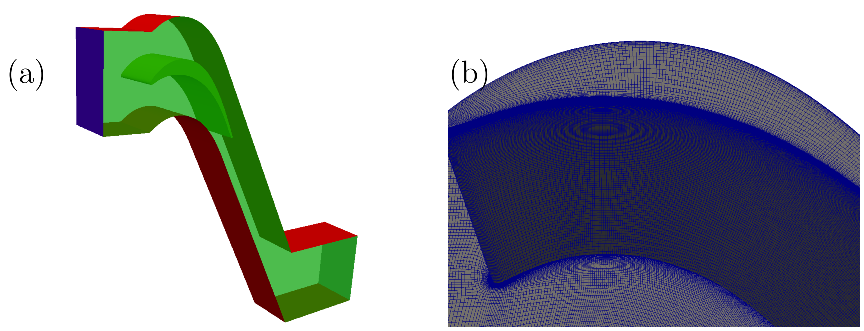

Figure 1: Computational domain (a) with periodic surfaces (red), tip end wall (green), inlet (blue) and close view to the grid map around the blade surface (b).

3 PRELIMINARY RESULTS AND FUTURE WORK

The preliminary statistical results for different cross-sections are compared with DNS and experimental results [8] in Figure 2(a). Time-averaged mean pressure coefficient agrees well for the pressure side of the blade and for $x/C_{ax} < 0.6$ at the suction side. LES results for the suction side of the blade deviates beyond the $x/C_{ax} \simeq 0.8$ due to the compressibility and the inlet turbulence effect [8]. The energy density spectrum obtained from a probe located in the wake region is shown in Figure 2(b). The spectrum follows the Kolmogorov's -5/3 law for approximately one decade. This is considered reasonable for LES.

Figure 3(a) shows the streamlines released from the blockage horseshoe vortices and the leakage streamlines of the adjacent blade. The incoming flow near the casing wall is blocked and directed to a different path from the main passage flow. For example,

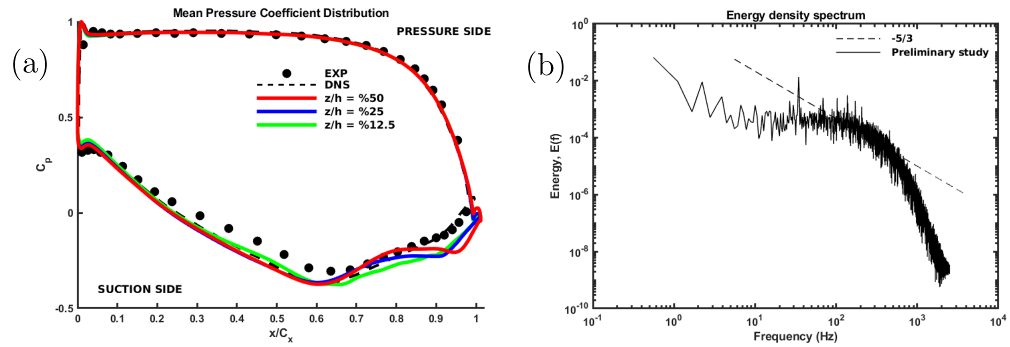

Figure 2: Time-averaged mean pressure coefficient at three cross-sections compared with DNS and experimental results (a) [8], energy density spectrum (b).

the streamlines belonging to group 1 slow down across the leading edge of the blade, roll and form horseshoe vortices off the leading edge. Those streamlines mix up with the tip leakage flow of the same blade in the suction side zone further downstream. The streamlines of the group 4 decelerate across the region near the leading edge, form the other leg of horseshoe vortices. Then, they develop through the neighborhood region of the adjacent blade. That turning flow rolls and mixes up with the leakage flow and streamlines belonging to the group 1 of the neighbor blade at the suction side. On the other hand, the streamlines belonging to the group 2 and 3 advances along the blade pressure side. Then, such streamlines either leak from the tip clearance (group 2) due to the suction effect or simply bypass the tip gap (group 3). Three-dimensional coherent structures and streamlines are also shown in Figure 3(b).

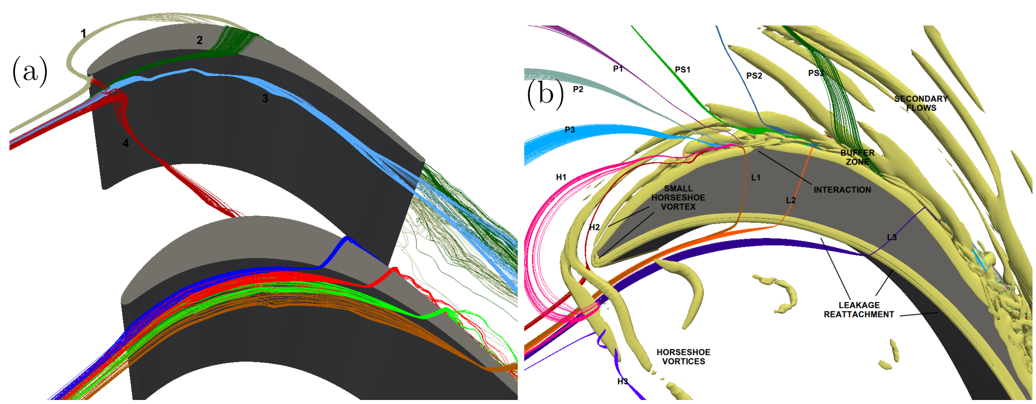

Figure 3: Visualization of blockage of the upstream flow (a) and coherent structures with relevant streamlines (b).

Three dimensional coherent structures based on Q-criterion along with the related streamlines are shown in Figure 3(b). Apart from the horseshoe vortices due to the upstream blockage, a small horseshoe vortex also forms attaching to the blade tip corner. The leakage flow near the leading edge forces and blows away the pressure side leg of such vortex. As a result, that leg of horseshoe vortex is decomposed and barely seen from the isosurfaces. The suction side leg of the small horseshoe vortex is entrained along the blade suction surface and grows in size. It is pushed downward where the leakage and the secondary flow near casing wall come across each other. That zone is called interaction area and shown in Figure 3(b). The interaction among the leakage and the secondary flows is very high such that flow quickly becomes turbulent further downstream. Such interaction vortices lead inevitable losses on blade performance since they cause local APGs on the blade suction surface. Moreover, such local APGs partly result in local separations on the suction surface close to the tip.

In the final paper, inlet flow effect will be studied to view the impact of the inlet condition on the leakage. More information about interaction mechanisms causing local APG and blockage of upstream flow will be provided thereby. Compatibility of LES on tip leakage flow will also be reported.

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