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ADVANCED AERO-THERMAL INVESTIGATION OF HIGH PRESSURE TURBINE TIP FLOWS

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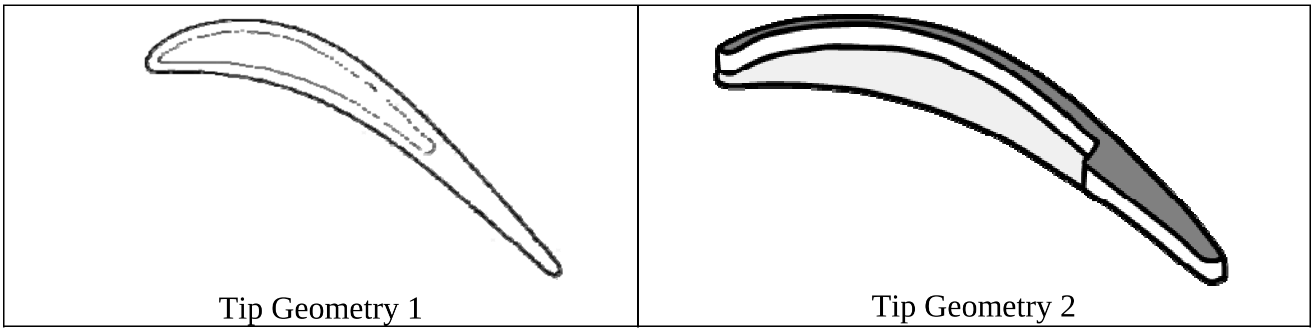
SUMMARY

The present contribution gives an overview of the numerical work performed at the Von Kármán Institute in the framework of the European research program AITEB-2, concerning the numerical investigation of tip gap flows in linear turbomachinery cascades, representative of high pressure turbine rotor blade geometries. The primary goal of the project is the computation of two distinct blade tip geometries (TG1 and TG2 hereinafter) in 3d, including the entire internal cooling setup inside the blade, and validation of the results versus the experimental campaign of Hofer et al. [2009]. The final article describes details of the mesh and aerodynamic results of the computations in case of high Reynolds, low and high Mach numbers (M=0.8-1.1, Re=900000), with and without cooling.

INTRODUCTION

In high pressure gas-turbine stages a source of significant losses is the leakage flow in the gap between the tip of the unshrouded rotor and the casing, called tip clearance. Adequately designed tip geometry – including the use of squealer etc. – is supposed to lower the mass flow through the tip-gap and thus the losses in its region. On the other hand, the inlet temperature, which in modern high pressure turbines exceeds the melting point of the blade material, can cause serious damage, especially on the tip of the rotor blade, where cooling is difficult. The numerical investigation of such a configuration helps to understand the features of the flow-field and aid the future design of blade tip geometries.



Tip Geometry 1

Tip Geometry 2

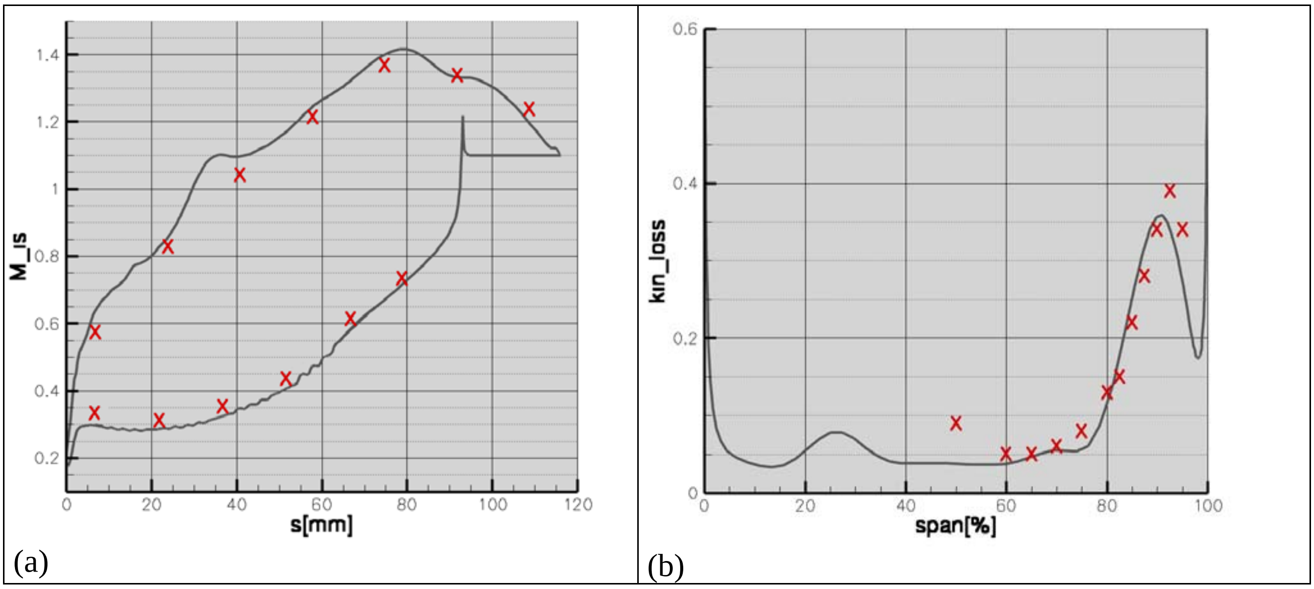
Figure 1. Abstract pictures of TG1 and TG2

METHODOLOGY AND RESULTS

The numerical campaign is a part of an ongoing project at the Von Kármán Institute (Key and Arts [2004]), concerning the thorough investigation of tip leakage flows. The current study focuses on the industrial approach to the aero-thermal investigation of the tip-leakage flow phenomena. The project is conducted within the framework of AITEB2, which is a European consortium dedicated to the aero-thermal investigation of turbine endwalls and blades. The geometries to be studied (see Figure 1) include the simple groove geometry (TG1), and the open groove geometry (TG2). The tests were performed under two different flow conditions: high Reynolds number (900000), low and high Mach number (0.8-1.1).

The test geometries also include sixteen film cooling holes on the pressure side of the blade and four dust holes at the blade tip, exiting at the bottom of the grooves. These holes are supplied with coolant through a common plenum inside the blade. There are four different coolant mass flow cases to be investigated including a non-cooling case. Since the cooling and dust holes are connected via the plenum, which is unblocked even in the no-cooling case, some bypass mass-flow is present in case of zero coolant supply, which causes blockage effects in the tip gap.

The results presented in the paper were obtained from 3d Navier-Stokes computations using the parallel finite volume solver elsA (developed by ONERA), on block structured grids. The authors benefited from the capability of the software of handling overlapping blocks of grids and masking. These features were applied at meeting points of small (internal) and large (external) scale flows, i.e. at cooling and dust hole in- and outlets. The equations were solved using a RANS approach invoking the k-omega Wilcox turbulence model with SST correction. The inlet boundary conditions (total pressure and temperature profiles) were obtained from former experimental investigations. Turbulence intensity was taken to be 0.8% at the inlet, outside the boundary layer for the aerodynamic simulations (measured values) and 3.7% for the thermodynamic ones. The boundary layer was supposed to be fully turbulent, with a thickness of 16% of the channel height at the inlet. The grid refinement was chosen such that wall y+ ~ 1 were realized in the entire domain.



(a)

(b)

Figure 2. Isentropic Mach number at 96.77% of the span (a) and kinetic loss coefficient downstream the blade in case of Re=900 000 and M_{out}=1.1

Results of the simulations will be presented in terms of pressure distribution and heat transfer coefficient in the tip region at 96.77% of the span (see Figure 2.a), on the inner and outer side of the squealer rim, on the bottom of the groove and on the endwall. Assessment of the losses will be performed downstream of the blade (see Figure 2.b). To explain the features captured by the abovementioned method, advanced flow visualization techniques will be invoked, and compared to experimental flow visualization.

CONCLUSION

The current study concentrates on the aerodynamic aspects of tip leakage flows, the effect of cooling, and outlet Mach numbers on distinct tip geometries. A full thermodynamic investigation exceeds the limits of the present contribution, but preliminary results will be presented and validated with measurements.

REFERENCES

Hofer, T.; Legrand, M.; Pons, L.; Arts, T. [1983], Aerodynamic Investigation of the Leakage Flow for a Blade with a Squealer Tip at Transonic Conditions, *8th European Turbomachinery Conference 2009, 23-27 March 2009, Graz, Austria.*

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