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INFLUENCE OF INTERNAL CYCLONE FLOW ON ADIABATIC FILM COOLING EFFECTIVENESS

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Due to the ever rising demand for high specific thrust and thermal efficiency, turbine inlet temperatures have reached values well above the melting temperature of currently available turbine blade materials. In order to guarantee sufficient component life, sophisticated blade cooling systems have been developed during the previous two decades. In general these cooling systems are supplied with compressor air, which is first passing through an internal blade passage system and then ejected through numerous film cooling holes in the wall of the stator aerofoil. The film cooling holes are designed such that the ejected air builds a cooling film downstream of the hole exit which shall protect the surface against the hot gas of the turbine annulus. The first stator of a High Pressure Turbine is the component which requires the highest amount of cooling air because it is located right at the exit of the combustion chamber and therefore has to cope with the highest gas temperatures, especially with the non-uniformity of the gas temperature distribution. A cooling mass flow of 6 – 10% relative to the turbine inlet mass flow is quite normal for the inlet stator aerofoil. Most of this air will be guided to the leading edge and trailing edge region of the stator. These are the areas with the highest heat load, mainly due to the peak heat transfer coefficients in these areas.

The cooling mass flow for blade cooling is lost for the cycle. So an increase of the internal heat transfer leads to the possibility to save coolant, which now can take part in the cycle. An improvement of the internal cooling method is desirable. In the past a lot of methods to increase the internal heat transfer were developed, so there are ribbed channels, pin fins or the impingement cooling for example. A new method for this is the so called cyclone cooling. Cyclone cooling means that a swirl is impressed to the coolant.

By developing those highly efficient internal cooling methods, the quality and effectiveness of film cooling could be reduced unintentionally by flow phenomena inside the blade, which would lead to a dramatic reduction in durability. Especially highly complex swirl flows, which appear using the internal cyclone cooling method, and the related disturbed inflow into the film cooling holes, may carry several effects onto the film cooling effectiveness on the blades surface.

A high number of experimental studies were carried out in the last three decades concerning film cooling and its improval. A variation of geometries, mass flow ratios, density ratios and other flow parameters were analyzed. Most of those studies were made using a plenum as film cooling air supply, sometimes even with a flow straightener [e.g. Sinha, Bogard, Crawford, 1991 or Lutum and Johnson 1999] to create a uniform inflow to the cooling holes. In recent years, studies began to deal with the influence of a more “engine like” internal flow on film cooling effectiveness. Burd and Simon [1997], Hale, Plesniak and Ramadhyani [2000] and others used a narrow plenum to feed the cooling holes and Wilfert and Wolff [2000] even used bumps and internal vortex generators to improve the film cooling effectiveness.

This paper will compare experimental results of the adiabatic film cooling effectiveness on the surface of an enlarged simplified turbine blade model with one single row of eight cylindrical film cooling holes, using different internal airflows in the leading edge cooling channel. On one hand, a standard internal cross flow with a sharp edged inflow is used and on the other hand, an internal cyclone cooling airflow is applied. The swirl is generated by two tangential slots on one side of the swirl tube (Fig 1).
Winter [preliminary, 2009] takes mass transfer measurements inside such a swirl tube on a rotational test rig to discover the effect of rotation on cyclone cooling. To be comparable with these experiments, as many geometric and flow related parameters as possible are kept similar here (e.g. the geometric swirl number of 3.53).

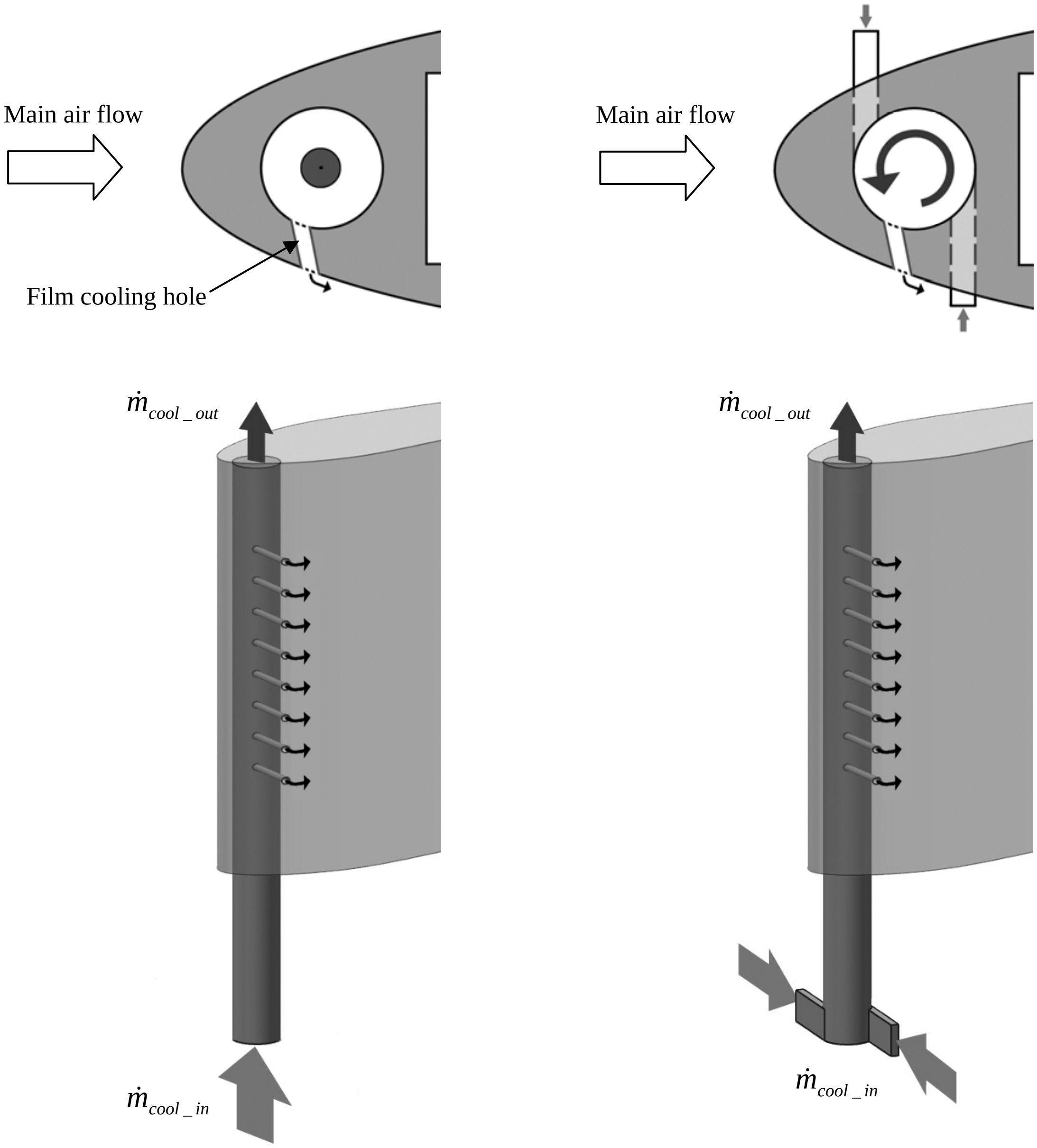

Figure 1. Cross section and side view of the two compared configurations of the coolant air flow inside the blade model (without swirl on the left side and with “positive swirl” on the right side)

The mass flow parameters are varied as follows: Blowing ratio M = 0.6 … 1.2 in steps of 0.2, and the film cooling discharge FCD = 20% and 50%. The definitions of these parameters are:

$$M = \frac{\rho_{cool} \cdot u_{cool}}{\rho_\infty \cdot u_\infty} \tag{1}$$

$$FCD = \frac{\dot{m}_{cool\_in} - \dot{m}_{cool\_out}}{\dot{m}_{cool\_in}} \tag{2}$$

whereas the subscript “cool” describes the coolant air flow.

The experiments were conducted in a subsonic open circuit windtunnel with a straight measurement section in suction mode (Fig 2). To measure the adiabatic film cooling effectiveness, the ammonia-diazo technique with online calibration, developed by Friedrichs, Hodson and Dawes [1996] was used. Therefore the temperatures of the main and coolant air flow were kept the same (density ratio = 1).

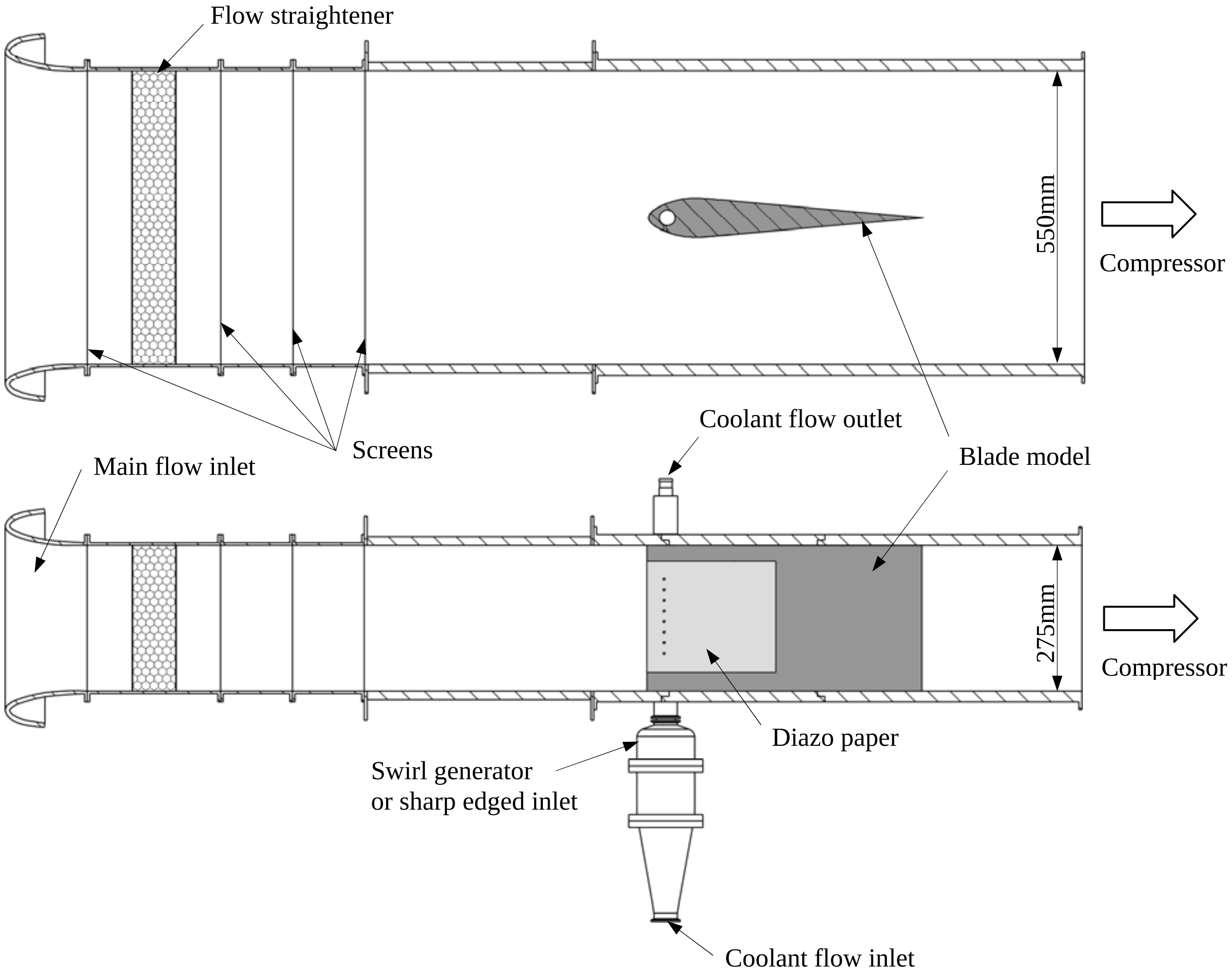

Figure 2. Cross section and side view of the test rig

The film cooling effectiveness η_{aw} will be shown and discussed by comparing the two configurations. As a short preview, the different cooling behaviors of one cooling hole are shown in Fig. 3.

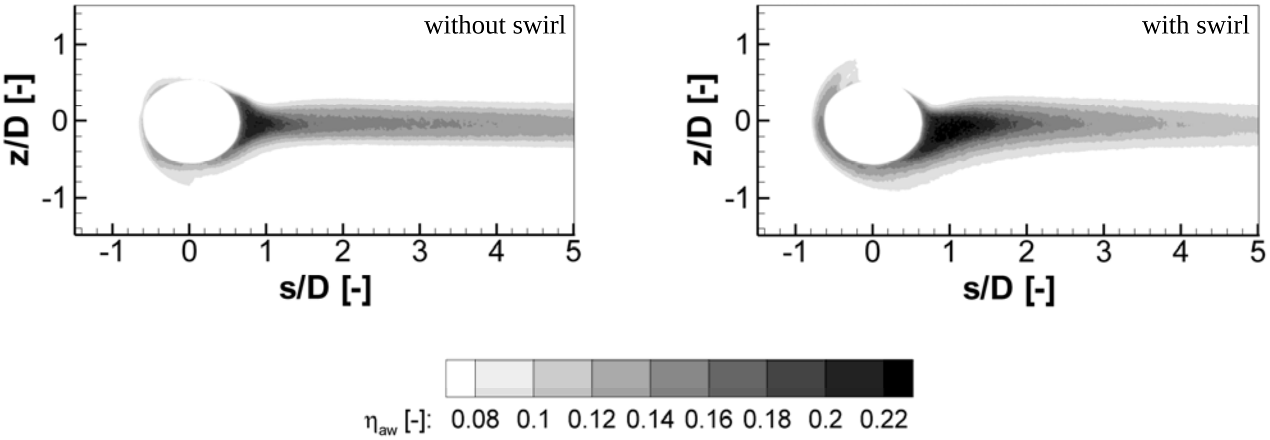

Figure 3. Comparison of the cooling behavior of an exemplary hole between the two configurations at M=0.8, FKA=20%

References

Burd S.W. and Simon T.W. [1997], The influence of coolant supply geometry on film coolant exit flow and surface adiabatic effectiveness, *ASME Paper 97-GT-25*

Friedrichs S., Hodson H.P. and Dawes W.N. [1996], Distribution of film cooling effevtiveness on a turbine endwall measured using the Ammonia and Diazo Technique, *ASME Journal of Turbomachinery*, Vol 118, pp.613 - 621

Hale C. A., Plesniak M.W and Ramadhyani S. [2000], Film Cooling Effectiveness for short Film Cooling Holes Fed by a Narrow Plenum, *ASME Journal of Turbomachinery*, Vol. 122, pp. 553 - 557

Lutum E. and Johnson B.V. [1999], Influence of Hole Length-to-Diameter Ratio on Film Cooling With Cylindrical Holes, *ASME Journal of Turbomachinery*, Vol 121, pp.209 - 216

Sina A.K., Bogard D.G. and Crawford M.E. [1991], Film-Cooling Effectiveness Downstream of a Single Row of Holes With Variable Density Ratio, *ASME Journal of Turbomachinery*, Vol. 113, pp. 442-449

Wilfert G. and Wolff S. [2000], Influence of Internal Flow on Film Cooling Effectiveness, *ASME Journal of Turbomachinery*, Vol. 122, pp. 327 - 333

Winter N. [preliminary, 2009], Effect of Rotation to the cyclone cooling method – mass transfer measurements, *Int. Symp. On Heat Transfer in Gas Turbine Systems*, Antalya 2009