# EFFECT OF REYNOLDS NUMBER, TURBULENCE LEVEL AND PERIODIC WAKE FLOW ON HEAT TRANSFER ON LOW PRESSURE TURBINE BLADES.

Dmitry Suslov, Achmed Schulz, Sigmar Wittig
Institut für Thermische Strömungsmaschinen
Universität Karlsruhe, 72168 Karlsruhe Germany

## INTRODUCTION

Increasing turbine inlet temperatures require a detailed investigation of heat transfer phenomena in convectively cooled low pressure turbines. Convective heat transfer is described by the local heat transfer coefficient and the associated boundary layer along the blade's surface. The boundary layer development depends on various flow parameters predominantly the Reynolds number, pressure gradient, and turbulence level, which vary both locally and with time. A tremendous impact on heat transfer is attributed to periodical fluctuations caused by moving blade wakes. The wakes are transported by the flow downstream through the next row of airfoils. Accurate computation of this complex unsteady flow is still difficult, although considerable progress was achieved in numerical modelling through recent years. Especially the treatment of near wall regions requires further efforts. Since detailed experimental data on local heat transfer coefficients of low pressure turbine airfoils is not available in the open literature, the present study aims on the generation of a database for developing new models and correlations describing the time averaged heat transfer under fluctuating flow conditions.

## EXPERIMENTAL TEST FACILITY AND MEASUREMENT SYSTEM

Experimental tests were conducted in a linear cascade (three blades) under subsonic flow conditions. Cascade inflow Mach numbers up to 0.4 and Reynolds numbers up to 700000 were investigated. The flow medium is preheated air with temperatures from 333 K to 383 K. The pressure/velocity distribution of the blades shows a typical aftloaded behaviour with an extended region of accelerated flow on the suction surface. To establish periodic flow

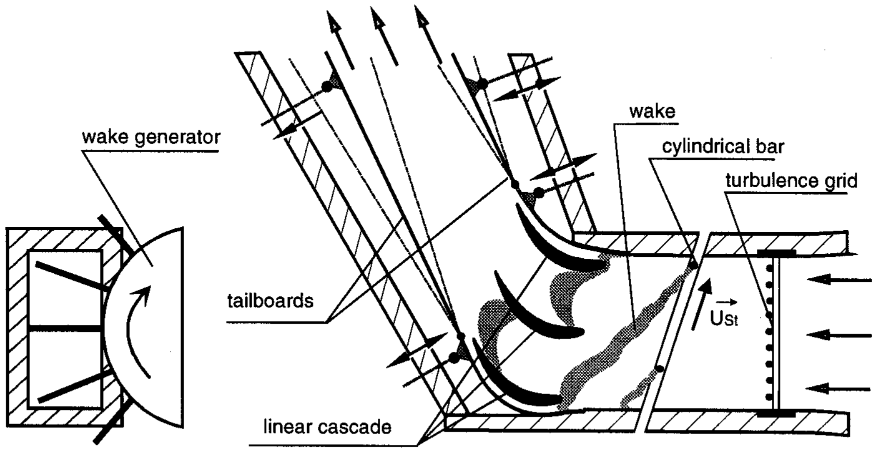


Fig. 1. Schematic of test rig

conditions with three blades only, the cascade is bounded with flexible sidewalls and tailboards. Figure 1 shows a schematic of the test section. For simulating turbine like wake conditions, a rotating disk with cylindrical spokes passing the cascade inflow was used as wake generator. In varying the number of bars along the circumference of the disk and the rotational speed, a wide range of Strouhal numbers could be realised. The superposition of elevated background turbulence and wake induced turbulence was investigated by inserting turbulence grids into the cascade inflow duct. The background turbulence level was in the range of 2% to 8% with corresponding length scales from 7 mm to 4.5 mm. The inner blade of the cascade was instrumented for heat transfer measurements. The method for determining time averaged heat transfer coefficients is based on surface temperature measurements and a heat flux calculation using finite elements. To introduce heat flux, the blade is convectively cooled by water through 11 cylindrical cooling holes. The surface temperature, necessary as boundary condition for the finite element code, is measured by 48 thermocouples of 0.25mm diameter embedded into small grooves in the surface. The flow and turbulence parameters downstream of the wake generator were measured with a hot wire system.

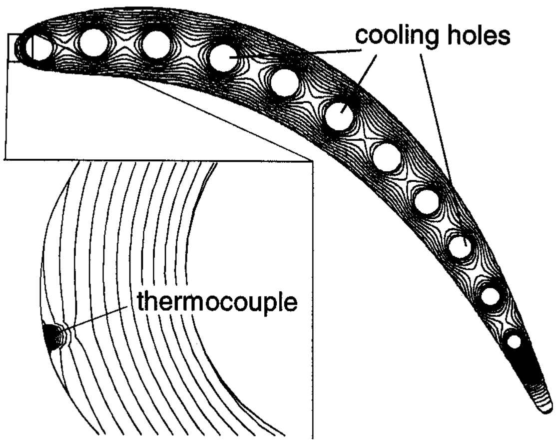


Fig 2. Temperature field in the test blade's cross section (FE- calculation)

## RESULTS

### Steady flow results

In the present study the effects of Reynolds number and turbulence level on the boundary layer development of the LP turbine blade were investigated. The dominating effects on heat transfer at this particular profile can be summarised as follows:

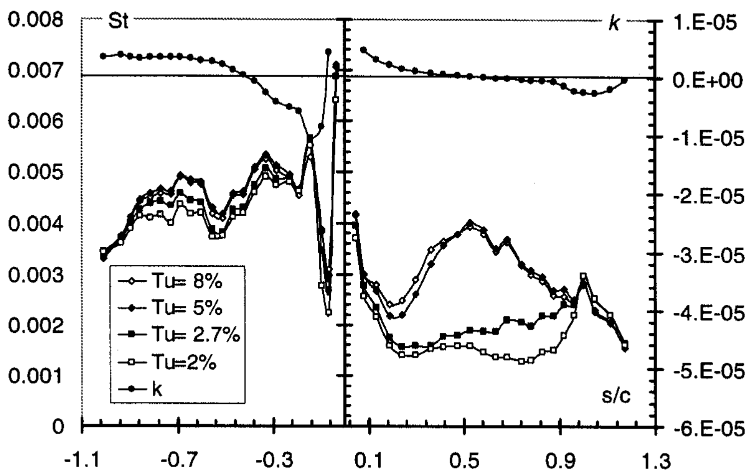


Fig. 3. Stanton number and acceleration parameter for $Re_1$=250000 and different turbulence levels.

- At low Reynolds numbers, increasing turbulence leads to the formation of a „pseudolaminar" boundary layer on surface areas with positive acceleration parameters.
- Increasing Reynolds number and turbulence level leads to an upstream shift of the onset of transition and to a reduction in transition length on the suction surface.
- The laminar-turbulent transition increases the stability of the boundary layer and hence prevents flow separation in an area with negative acceleration near the trailing edge.

**Unsteady flow results**

Wakes are characterised by their high turbulence intensity, which in general exceedingly surpasses the background turbulence. Since the affecting time of the passing wake is higher than the reaction time of the boundary layer, position and development of the laminar-turbulent transition is highly influenced by the wake flow. In this part of the study the effect of the Strouhal number on the local heat transfer on the LP turbine blade is investigated. Figure 4 shows distributions of heat transfer coefficients for different Strouhal numbers. For reasons of comparison a heat transfer distribution at 8% background turbulence is shown as well.

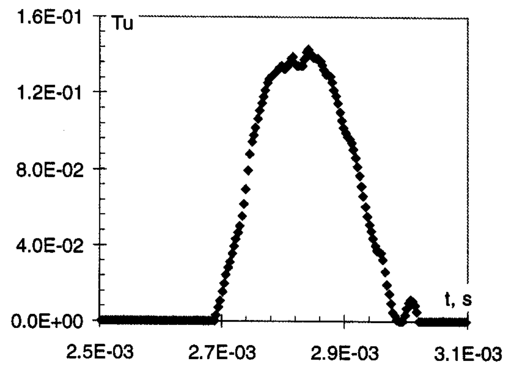


Fig. 4. Turbulence distribution in the wake

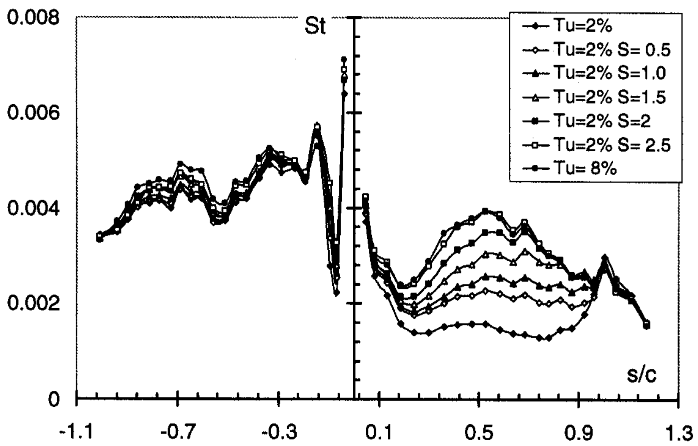


Fig. 5. Stanton number for $Re_1$=250000 and different Strouhal numbers.

**REFERENCES**


1. Dyban, E., Epick, E., Thermal/Mass transport and Hydrodynamics of Turbulent Flows, Kiev, 1985 (in Russian)
2. Mayle, R.E., Dullenkopf K., A Theory for Wake-Induced Transition, ASME Journal of Turbomachinery, Vol. 112, pp. 188-195, 1990.
3. Mayle, R.E., The Role of Laminar-Turbulent Transition in Gas Turbine Engines, ASME Journal of Turbomachinery, Vol. 113, pp. 509- 532, 1991.
4. Dullenkopf, K. Schulz A., Wittig, S., The Effect of Incident Wake Conditions on the Mean Heat Transfer an Airfoil, ASME Journal of Turbomachinery, Vol. 113, pp. 412-418, 1991.