LAMINAR TO TURBULENT TRANSITION IN LOW PRESSURE TURBINES

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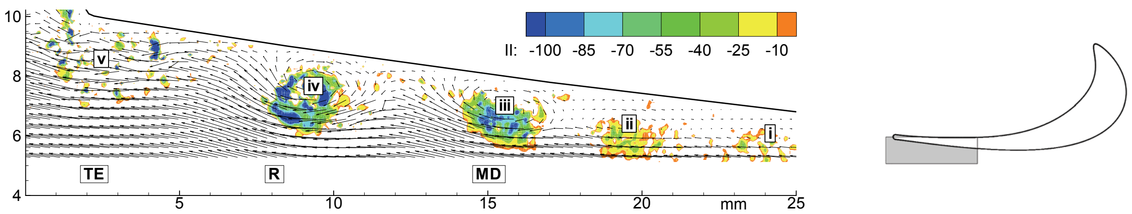
After accomplishing an extensive experimental and numerical research regarding aerodynamic performance of two low pressure turbine (LPT) airfoils at high speed (HS) conditions, the investigation of laminar to turbulent transition in LPT, carried out in Turbomachinery and Propulsion Department, proceeded further with additional measurements performed on a low speed (LS) version of the HS blade.

Reasoning behind the move towards the LS investigation was partly motivated by an intended use of advanced measurement techniques as particle image (PIV) and hot-wire anemometry (HW) susceptible to more detailed measurements, and in part by possibility of a relevant, direct and unique comparison with the previously obtained results of the HS investigation. This was an important notion, since bulk of the research in the field has been realized at LS conditions. The LS version of the highly loaded HS blade was at first designed by preserving an identical fully turbulent pressure distribution along the airfoil. The proposed redesign procedure consisted of two interconnected iterative loops – one involving an inviscid inverse design code and the other a Navier-Stokes code with a nested geometry adjustment procedure.

The measurement campaign was performed in the VKI's open-loop, linear cascade, LS wind tunnel - C1. It was initiated by detailed measurements of an upstream flow field, considering its crucial importance for separated flow transition. The inlet boundary conditions were characterized by means of flow angle and some relevant turbulence characteristics as its intensity, scales, decay rate of turbulence kinetic energy (TKE), etc. Subsequently, the overall mid-span aerodynamic performance of the LS blade was measured within a range of Reynolds numbers in terms of pressure distribution, exit kinetic energy losses and flow angles and compared with the HS results. A particularly good agreement was achieved for the pressure distributions at low Reynolds numbers (below 100,000) in between HS and LS results. The evolution of the losses suggested, however, somewhat higher rate of increase towards the lower Reynolds numbers for the LS case due to larger vortical structures generated in the separated region.

A profound insight into a mechanism of laminar to turbulent transition was gained by the PIV technique in terms of time-averaged and instantaneous flow fields, carried out for a steady inlet flow conditions and a low level of inlet turbulence intensity (0.5 %). A roll-up of a disturbed separated shear layer (inviscid Kelvin-Helmholtz mechanism), with subsequently generated large scale vortical structures and their eventual breakdown, was clearly identified as a predominant transition path resulting in a flow reattachment due to a turbulent boundary layer forming further downstream (figure). Additional measurements performed by a single HW probe were used to extend the information into frequency domain by evaluating a state of the transitional boundary layer in terms of power density spectra at several stream-wise and wall normal locations.



Large scale vortical structures formed and convected in the separated flow region at the rear part of the blade suction side. Contour plot of the second invariant of velocity tensor $II = (\partial u_i/\partial x_j)\cdot(\partial u_j/\partial x_i)$ superimposed on the instantaneous velocity field. $Re_{2,is}$ = 60,000, LS PIV measurements. Blade chord is 62.18 mm

Furthermore, the gathered data were used in comparison with the HS simulations obtained by a time-averaged RANS code (k-w turbulence model with Langtry-Menter transition model). A surprisingly good agreement in between some integral parameters of the boundary layer was again found mainly at low Reynolds numbers, despite the fact that the numerical code was not originally designed for a case of massive separation and tends to predict somewhat longer separated region. The results of the performed investigation suggest that described behavior is associated to a higher rate of production and dissipation of TKE for HS conditions, while the semi-empirical transition model was based entirely on LS data set. Moreover, the recently measured LS data indicate considerably lower level of the transition onset momentum-thickness Reynolds number with respect to the values used in the model. Above findings are being recently proved by additional LS numerical simulations.