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PREDICTION OF WAKE-INDUCED TRANSITION ON TURBINE BLADE WITH INTERMITTENCY TRANSPORT MODEL

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ABSTRACT

The proper prediction of the transition is a most challenging and most important problem in the design process of turbomachinery stages. The variety of possible transition mechanisms in turbomachinery flows makes it difficult to propose the general strategy for numerical simulation. Coupling with intermittency γ seems to be the best way to take into account the physical mechanism of transitional flow.

The paper presents the results of validation of γ-Re_θ model proposed by Menter at al [1], which was extended by in-house correlations on onset location and transition length. The tests performed were based on experimental data of a turbine blade profile, which is a stator vane of the high-pressure part of the TK–200 steam turbine, investigated at Czestochowa University of Technology [2]. The experiment was performed on a linear turbine blade cascade with upstream wake generator in the form of the wheel equipped with cylindrical bars. For the analysed test case (N3-60-0.4) inlet freestream turbulence levels 0.4% and 4 mm bars were applied.

The model proposed by Menter at al [1] is based on the SST turbulence model and two transport equations. The first one is an intermittency transport equation used to trigger the transition process. The second equation for transport of momentum thickness Reynolds number $Re_{\theta t}$ was implemented in order to avoid non-local operations introduced by experimental correlations. In those formulations the most important are two parameters i.e. F_{onset}, which triggers the intermittency production at the beginning of the transition and the F_{length}, which controls the length of the transition zone. Correlations describing the start F_{onset} and the length F_{length} of the transition were developed and proposed as a function of Reynolds number determined in the wall vicinity $\tilde{R}e_{\theta t\,max}$. F_{onset} is a function of vorticity Reynolds number and critical Reynolds number $F_{onset} = f\left(Re_V, Re_{\theta c}\right)$. $Re_{\theta c}$ is related with value of $\tilde{R}e_{\theta t\,max}$ by the following function:

$$if\ \tilde{R}e_{\theta t\,max} > 525 \quad Re_{\theta c} = -6.09\cdot 10^{-10}\,\tilde{R}e_{\theta t\,max}^{\;3} + 2.05\cdot 10^{-6}\,\tilde{R}e_{\theta t\,max}^{\;2} - 0.0023\,\tilde{R}e_{\theta t\,max} + 1.165$$

$$else\ Re_{\theta c} = 4.15\cdot 10^{-9}\,\tilde{R}e_{\theta t\,max}^{\;3} - 4.85\cdot 10^{-6}\,\tilde{R}e_{\theta t\,max}^{\;2} + 7.493\cdot 10^{-4}\,\tilde{R}e_{\theta t\,max} + 0.77$$

On the other hand F_{length} is defined as:

$$for\ \widetilde{Re}_{\theta\, max} > 100 \quad F_{length} = MAX\left(0.274 + 0.0039\, Re_{\theta\, max} - 2.13\cdot 10^{-5}\, Re_{\theta\, max}{}^{2} + +3.65\cdot 10^{-8}\, Re_{\theta\, max}{}^{3}, 1.75\right)$$

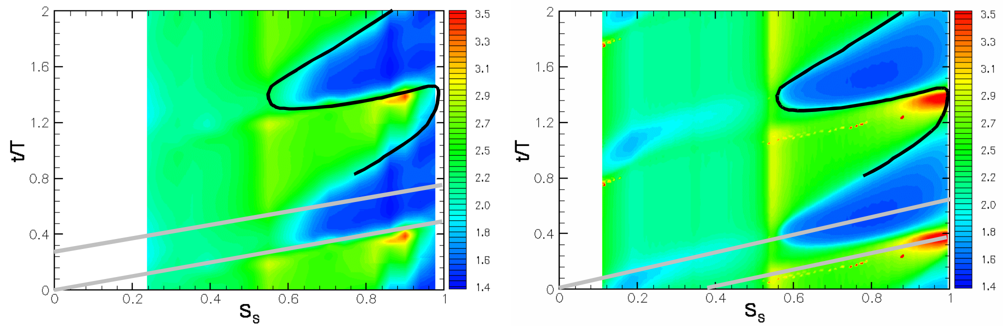

Figure 1. s-t diagrams of shape factor over the suction side for N3-60-0.4; experiment (left); computations (right)

Fig. 1 presents the comparison of the numerical results with experiment. The two white lines show the location of the wake based on local boundary edge velocity. The additional black line indicates the edge of turbulent region induced by the wake. The start of the transition under the wake was found to be almost identical. There are some differences in the extent of the separation zone (red area) in between the wakes. The quantitative comparison of the results are given in Fig. 2, which presents the time evolution of the shape factor at the relative position S = 0.65 on the suction side. For comparison the results obtained with Lodefier & Dick (L&D) and PUIM models [3] are also given. One can notice that the character of all curves is similar, not only for contour forms but also for the level of shape factor under the wake and in between the wakes. It confirms that proposed formulas for the transition onset and transition length appear to be sufficiently precise and enable accurate prediction of boundary layer development for various inflow conditions. The quality of the prediction is at least comparable if not better than other intermittency based models.

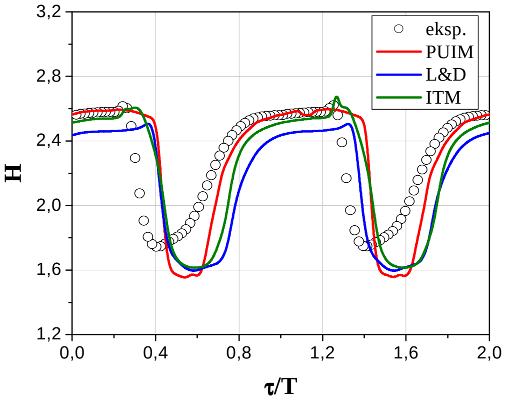

Figure 2. Time traces of shape factor at the location S_S=0.65 for N3-60-0.4

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