8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

VALIDATION OF A DYNAMIC INTERMITTENCY MODEL FOR WAKE-INDUCED TRANSITION ON TURBINE BLADES

K. Lodefier[1], S. Kubacki[1,2], R. Zarzycki[2], W. Elsner[2] and [*]E. Dick[1]

[1]Department of Flow, Heat and Combustion Mechanics, Ghent University, Sint-Pietersnieuwstraat 41, 9000, Belgium
erik.dick@ugent.be
http://www.floheacom.ugent.be

[2]Institute of Thermal Machinery, Czestochowa University of Technology, Al. Armii Krajowej 21, 42-200 Czestochowa, Poland
welsner@imc.pcz.czest.pl
http://imc.pcz.czest.pl

Key Words: *Transition model, Bypass transition, Turbine blades.*

ABSTRACT

RANS calculations are performed of wake-induced transition in the boundary layer flow of the steam turbine stator blade N3-60. A dynamic intermittency model is used. Four different configurations are computed and compared with experiments: two levels of free-stream turbulence intensity, 0.4% and 3%, combined with two diameters of the wake generator bars, 4 mm and 6 mm. The transition is mainly of bypass type, but for 0.4% free-stream turbulence intensity, between wakes, separation transition and natural transition occur. It is shown that the experiments can be simulated with good accuracy if the wake parameters at the inlet of the domain are carefully prescribed.

The turbulence model is the SST *k-ω* model of Menter et al. (2003), with the time scale bound of Medic and Durbin (2002). The transition model is the two-equation model of Lodefier and Dick [1]. A turbulence weighting factor τ is used as multiplier of the turbulent viscosity in the Navier-Stokes equations. The weighting factor is also introduced in the turbulence model to suppress turbulence production prior to transition.

The turbulence weighting factor τ ($\tau = \gamma + \zeta$) is the sum of the 'near-wall' intermittency factor γ and the 'free-stream' intermittency factor ζ. Both factors are modelled by a dynamic equation, but have strongly different time scales. The diffusion of free-stream intermittency into the boundary layer is a slow, quasi-steady, process. The near-wall intermittency due to vortex breakdown has a fast build-up.

$$\frac{\partial(\rho\gamma)}{\partial t}+\frac{\partial(\rho U_i\gamma)}{\partial x_i}=2\beta(1-\gamma)\sqrt{-\ln(1-\gamma)}\rho\frac{\left[U_\infty F_s+(U-U_\infty)(2-F_s)\right]}{\max\left[F_s,1.0\right]}+\frac{\partial}{\partial x_i}\left[\mu\frac{\partial\gamma}{\partial x_i}\right];$$

$$\frac{\partial(\rho\zeta)}{\partial t}+\frac{\partial(\rho U_i\zeta)}{\partial x_i}=-C_3\mu_\zeta\frac{U}{U_\infty^2}\frac{\partial U}{\partial n}\frac{\partial\zeta}{\partial n}+\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_\zeta}{\sigma_\zeta}\right)\frac{\partial\zeta}{\partial x_i}\right]$$

Empirical criteria are used to start transition by activating the starting function F_s from zero to one or two in the source term of the near-wall intermittency equation.

To model steady transition, F_s is switched from 0 to 1. The source term in the near-wall intermittency equation has been calibrated for steady flows. For wake-induced transition, F_s is set to 2 at start, then falls to 1 during the wake passage and finally becomes 0 after wake passage. With F_s =2, the source term is large. In this way, the sudden start of transition due to wake-impact is modelled.

The experiments were done at TU Czestochowa by Zarzycki and Elsner [2] in an open cascade wind tunnel with a wake generator. This generator is a wheel of pitch diameter 1950 mm with cylindrical bars rotating in a plane perpendicular to the flow direction. The wheel has a section of 4 mm bars, a section of 6 mm bars and a free-space section which is used for no-wake measurements. The bars are spaced by 204 mm on the pitch circle. The blade profile N3-60 is a stator vane of the high-pressure part of the TK–200 steam turbine. With a movable grid upstream of the cascade, the free-stream turbulence intensity is controlled. With grid, *Tu* = 3%. Without grid, *Tu* = 0.4%.

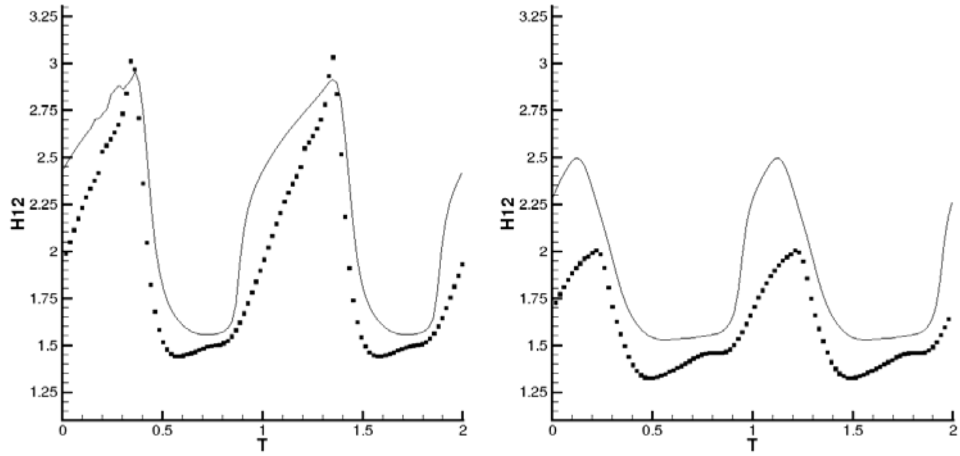

Figure 1. Comparison between experimental (dots) and computed (line) shape factor for S = 0.85. Left: Tu=0.4%, d=4mm; Right: Tu=3%, d=6mm.

Figure 1 shows the evolution of the shape factor at the relative position *S* = 0.85 on the suction side for two cases. The major difference between low and high background turbulence intensity flows occurs between the wakes where bypass transition disappears and the flow becomes laminar. For low intensity, due to the adverse pressure gradient, the shape factor reaches slightly separated values. Without wakes, a steady separation bubble occurs close to the trailing edge, with turbulent reattachment. With wakes and the effect of calming, the separation is much reduced. For high background turbulence intensity, the flow between the wakes becomes laminar but does not separate. The low levels of shape factor under wake impact are very well predicted.

REFERENCES

[1] K. Lodefier and E.Dick, “Modelling of unsteady transition in low-pressure turbine blade flows with two dynamic intermittency equations” *Flow, Turbulence and Combustion*, Vol 76, pp 103-132 ,(2006).

[2] R. Zarzycki and W.Elsner, “ The effect of wake parameters on the transitional boundary layer on turbine blade”. *IMechE Part A, J. Power and Energy*, Vol 219, pp. 471-480, (2005).