EXTENSION OF ITM MODEL TO ACCOUNT FOR WALL ROUGHNESS

Witold Elsner, Piotr Warzecha
Technical University of Czestochowa, Czestochowa, Poland

Introduction

Surface roughness has a strong influence on the efficiency, heat transfer and so on the machine maintenance cost. The experimental study on rough turbine blades (Boyle & Strip, 2008) reveal that the roughness due to aerodynamic erosion could decrease the efficiency of up to several points. It is known that the roughness could increase skin friction in the turbulent boundary layer as well as shift of laminar-turbulent transition upstream the flow. The accurate and reliable prediction of the effect of surface roughness on fluid flow and heat transfer are of great interest of designers.

Modeling of the flow on a rough surface should consist of the correct computation of the laminar, turbulent and transitional boundary layer. However, as shown by Stripf et al. (2008), the roughness influence on the laminar momentum boundary layer is negligible. Therefore the major tasks are modeling of turbulent boundary layer and transition process.

Modeling approach

Among the most popular recently methods to model boundary layer transition one could distinguish methods based on intermittency parameter γ, where the most representative is γ-$Re_{\theta t}$ model proposed by Menter et al. (2004).The model is based on the SST turbulence model and two transport equations. The first one is the intermittency transport equation used to trigger the transition process. The second transport equation for momentum thickness Reynolds number $Re_{\theta t}$ was implemented in order to avoid non-local operations introduced by experimental correlations. In the recent period the modification of Menter's model has been proposed by Piotrowski at al. (2008). It was done by development of two in-house correlations on onset location and transition length, which are confidential in the original model. The model proposed was named Intermittency Transport Model (ITM). In the frame of current work it was decided to further extend this model to have a possibility to calculate rough surface boundary layer. To predict the behaviour of turbulent boundary layer over the rough surface the modification of wall boundary condition for ω and modification for turbulent viscosity calculation proposed by Hellstein & Laine (1997) have been introduced. Modelling of transition process is possible by combination of $Re_{\theta t}$ transport equation with the onset correlation recently proposed by Stripf at al. (2008). The correlation accounts for the effects of roughness height and density as well as turbulence intensity and wall curvature.

Discussion of the results

The validation given in the paper concerns a flat plate flow with zero (Halzer, 1974) and non-zero pressure gradient (Colleman at al., 1977). In both cases the roughness was obtained of copper balls with a diameter of d_0 = 1.27 mm brazed together in a most dense configuration. The equivalent sand roughness needed to model the flow was k_s=0.62·d_0=0.79 mm. The inlet turbulence intensity was equal Tu=0.4% while inflow velocity was set to be equal U_∞=27, 42, 58 m/s for zero pressure gradient and 26 m/s for non-zero pressure gradient case. In the accelerated cases, the velocity distributions were designed to give equilibrium rough wall boundary layers, i.e. the friction coefficients assumed to be constant in the accelerated regions. The results have been verified against experimental data as well as the data obtained by Stripf at al. (2008) with a DEM-TLV model.

Fig. 1 shows skin friction coefficients for U_∞=27, 42 m/s, where additionally, results obtained according to Mills & Hang (1983) correlation are given. It is seen that ITM model predict the experimental data with high accuracy. It gives slightly lower values in comparison with DEM-TLV model and Mills & Hang (1983) correlation for the higher velocity case. Fig. 2 shows skin friction coefficients for accelerated cases. Due to limitation of the paper velocity profiles have been omitted. In both cases the variation of experimental data has been reproduced. ITM slightly underestimate skin friction coefficient, while DEM-TLV model gives too high values.

Acknowledgement The research was supported by the research grant No. PBZ-MEiN-4/2/2006.

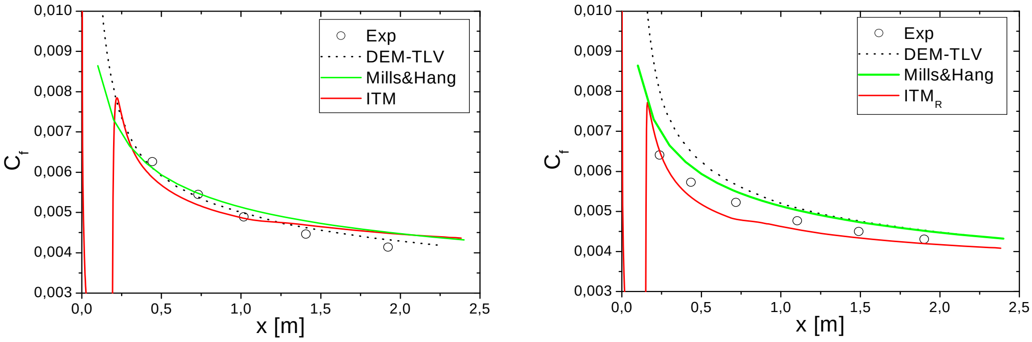

Fig. 1. Skin friction coefficient for zero-pressure gradient U_∞=27 m/s (left), 42 m/s (right)

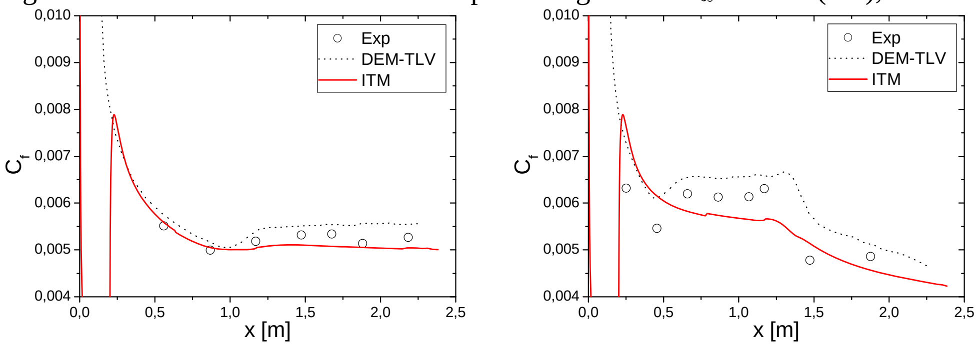

Fig. 2. Skin friction coefficient for non zero-pressure gradients flows

Bibliography

Boyle R., Strip M., 2008, *Simplified Approach to Predicting Rough Surface Transition*, ASME paper GT2008-51543.

Stripf M., Schulz A., Bauer H.-J., Wittig S., (2008), *Extended models for transitional rough wall boundary layers with heat transfer – part II: model validation and benchmarking*, ASME Paper GT2008-50495

Menter F.R., Langtry R.B., Likki S.R., Suzen Y.B., Huang P.G., Völker S., 2006, *A correlation – based transition model using local variables P.I – Model formation*, J. Turbomachinery, vol. 128, pp. 413-422

Piotrowski W., Elsner W., Drobniak S., 2008, *Transition Prediction On Turbine Blade Profile With Intermittency Transport Equation*, ASME paper GT2008-50796

Hellsten A., Laine S., 1997, *Extension of the k-ω SST turbulence model for flows over rough walls*, AIAA Journal, 97-3577

Halzer J.M., 1974, *The Turbulent Boundary Layer on a Rough, Porous Plate: Experimental Heat transfer with Uniform Blowing*. Dep.of Mech.Eng. Stanford University, report HMT-18

Coleman H.W., Moffat R.J., Kays W.M., (1977), *The accelerated fully rough turbulent boundary layer*, J. Fluid Mech., Vol. 82, part 3, pp. 507-528