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

A Transport Intermittency Model for Supersonic/Hypersonic Boundary Layer Transition

***S. Fu[1] and L. Wang[2]**

[1] School of Aerospace Engineering
Tsinghua University, Beijing 100084, China
fs-dem@tsinghua.edu.cn

[2] School of Aerospace Engineering
Tsinghua University, Beijing 100084, China
wangliang99@mails.tsinghua.edu.cn

Key Words: *Transition, Turbulence Model, Intermittency Factor.*

ABSTRACT

Modelling of flow transition has always been a research focal point in turbulence study. Currently, the RANS approach is still the main tool in the transition/turbulence modelling in engineering application. Since it is proved that turbulence model without making use of the intermittency are often extremely unreliable in the prediction of transition [1], there appear many correlation-based transition models involving the intermittency factor. However, these models include non-local formulations which are not easily compatible with modern CFD methods. The models based on local variables are thus much preferred for the application purpose. A successful example is the work of Menter et al. [2], which is now implemented in a commercial software package.

However, the existing local-variable-based models are not validated for the transition in supersonic flows or for the cross-flow transition. One reason is that these models rely on heavy load of numerical validation rather than the fundamental physical phenomena responsible for actual transition process, e.g. the flow instability mode can be rather different in supersonic boundary layers than that in incompressible or subsonic flows. The purpose of this investigation is to develop an improved flow transition model applicable to supersonic as well as three-dimensional flows.

Thus, a transition model based on k-ω-γ transport equations is proposed here. The model converts to the standard SST model [3] in the fully turbulent region. The fluctuating kinetic energy k includes the non-turbulent, as well as turbulent parts. The intermittency factor, γ, is set to play as a weight number between the non-turbulent and the turbulent components of stress in P_k and P_ω, i.e. the production terms of equations for k and ω. This approach focuses on the determination of effective viscosity of non-turbulent fluctuations, μ_{nt}, as derived from the linear stability theory (LST).

Both the LST and experimental observations give that at low Mach number the so-called ‘first-mode’ disturbance is the primary cause of instability while the effect of ‘second-mode’ disturbances becomes prominent at high Mach number flows. This mode variation, related to the effect of compressibility, is accommodated inherently in the present model through the local relative Mach number, i.e. $M_{rel} = (U - c_r) / a$, where U stands for the local mean velocity related to wall, a is the local sound speed, and c_r represents the phase velocity, as the same value, of all Mack-mode disturbances. μ_{nt} is

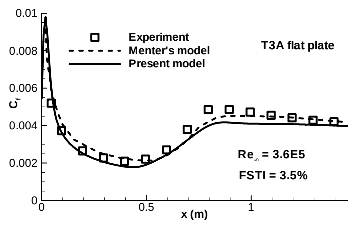
determined by the timescale of the first-mode fluctuations at $M_{rel}^2 \le 1$ while both of the first-mode and second-mode ones at $M_{rel}^2 > 1$.

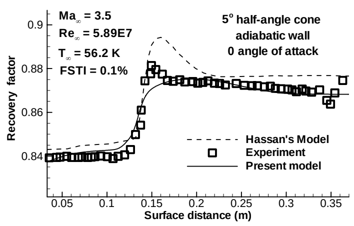
According to the experimental correlations and theoretical analysis, the formulations of μ_{nt} would involve non-local variables, such as the boundary layer thickness, which is calculated from integrals through the boundary layer. To avoid this practice, this study defines a length scale normal to wall of mean flow as $d\ ^2\Omega/\ (2\ Eu)^{0.5}$, where d is the distance to wall, Ω is the absolute value of mean vorticity, and E_u stands for the kinetic energy of mean flow.

Moreover, a new transport equation for intermittency factor is developed. Its particular feature is that a function in the source term, closely related to the flow physics, is set to trigger the onset of transition.

The present model proposal is calibrated and validated with three sets of experimental data involving incompressible flow over a flat plate, supersonic flow past a straight cone and hypersonic flow over a flared cone at zero angle of attack. The skin frictions for T3A flat-plate test case (http://cfd.me.umist.ac.uk/ercoftac/) is shown in Fig.1. It is seen that the flow transition profile are well captured with Menter's model [2] and the present model. Fig.2 and Fig.3 compare the measured and computed recovery factor and wall temperature distributions for cones in high-speed flows, respectively. The present model gives accurate transition onsets but misses peak values. For latter case, Hassan's model [4] gives too low temperature level though the onset location seems not bad.

In conclusion, a new *k-ω-γ* transition/turbulence model considering the modes of instability is proposed and validated in this work. It is based on local variables and is able to trigger the onset of transition automatically with the function in the source term of *γ* equation. The present model has been successfully applied to simulate the natural, as well as the bypass transitions.





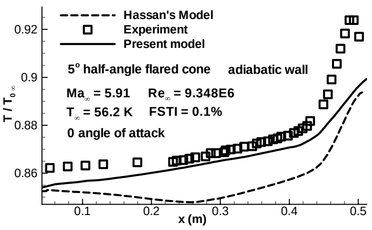


Figure 1: Skin friction (C_f) for the T3A test case. FSTI represents the free-stream turbulence intensity .	Figure 2: Comparison of computed and measured recovery factor.	Figure 3: Comparison of computed and measured wall temperature distribution.

REFERENCES

[1] A. M. Savill, "One-point closures applied to transition", In: Hallbäck M, *et al*. *Turbulence and Transition Modeling*. Kluwer, 1996.

[2] F. R. Menter, R. B. Langtry and S.Volker, "Transition modelling for general purpose CFD codes", *Flow Turbulence and Combustion*, Vol.**77**, pp. 277~303, (2006).

[3] F. R. Menter, "Two-equation eddy-viscosity turbulence models for engineering applications," *AIAA J.*, Vol.**32**, 1598~1605, (1994).

[4] R. D. McDaniel, R. P. Nance and H. A. Hassan, "Transition onset prediction for high-speed flow", *J. Spacecraft and Rockets.* Vol.**37**, pp. 304~312, (2000).