# Investigation of Correlation-based Transition Model coupled with Spalart-Allmaras turbulence model

Ke Zhao*, Zhenghong Gao* ,Jiangtao Huang*
* *National key laboratory of aerodynamic design and research, School of Aeronautics, Northwestern Polytechnical University, Xi'an, 710072, China*

*Summary* In this paper the $\gamma-\overline{\mathrm{Re}_{\theta t}}$ transition model is investigated and the transport equations are modified and a transition model integrated with the one equation S-A turbulence model is built. The model is validated by numerical simulation of transition flow around NLF0416 airfoil, MD30P-30N multi-element airfoil and DLR –F5 wing and comparison the result with the wind tunnel data. It is shown that the $\gamma-\overline{\mathrm{Re}_{\theta t}}-SA$ transition model in this paper can well simulate the natural transition and separation induced transition of different configurations, and the prediction precision of velocity and pressure distribution is improved. The aerodynamic forces are also well predicted than the one equation S-A turbulence model.

## Introduction

Laminar-turbulent transition of boundary layers has important effect on the friction drag of the aircraft, the separation position of the flow, transonic shock wave position and hypersonic aero thermal issue. Langtry and Menter [1] [2] have developed a local correlation-based transition model, called the $\gamma-\overline{\mathrm{Re}_{\theta t}}$ model coupled with SST k-ω turbulent model in 2004, which satisfies most of the requirements for a transition model that is fully compatible with a conventional CFD solver. Since the Spalart-Allmaras turbulence model is computationally less expensive compared to the SST k-w model, and is known for reliable prediction of external flow problems. In this paper and a new form of transition model based on S-A turbulence model is constructed by modify some basic variables and parameters of transport equations of γ and $\overline{\mathrm{Re}_{\theta t}}$ , a series of standard model is used to validate the model.

## Construction of $\gamma-\overline{\mathrm{Re}_{\theta t}}-SA$ transition model

The $\gamma-\overline{\mathrm{Re}_{\theta t}}$ transition model uses the concept of intermittency, in order to trigger transition locally, by controlling the production of turbulent kinetic energy. The transport equation for the intermittency γ developed by Langtry reads：

$$\frac{\partial\rho\gamma}{\partial t}+\frac{\partial\rho\gamma u_i}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial\gamma}{\partial x_i}\right]+P_\gamma-D_\gamma$$

The transport equation for the transition momentum-thickness Reynolds number reads:

$$\frac{\partial\rho\overline{\mathrm{Re}_{\theta t}}}{\partial t}+\frac{\partial\rho\overline{\mathrm{Re}_{\theta t}}u_i}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\sigma_{\theta t}(\mu+\mu_t)\frac{\partial\overline{\mathrm{Re}_{\theta t}}}{\partial x_i}\right]+P_{\theta t}$$

To couple with the S-A model some basic variables and parameters of transport equations of γ and $\overline{\mathrm{Re}_{\theta t}}$ is modified appropriately, the solution of the transport equation for the intermittency γ is used to control the production and destruction terms of S-A equation:

$$\frac{\partial\hat{\nu}}{\partial t}+u_j\frac{\partial\hat{\nu}}{\partial x_j}=\tilde{P}_V+\tilde{D}_V-\frac{C_{b2}}{\sigma}\hat{\nu}\frac{\partial^2\hat{\nu}}{\partial x_j^2}+\frac{1}{\sigma}\frac{\partial}{\partial x_j}\left[\left(\nu+(1+C_{b2})\hat{\nu}\right)\frac{\partial\hat{\nu}}{\partial x_j}\right]$$

$$\tilde{P}_V=\gamma_{eff}\cdot P_V \qquad \tilde{D}_V=\max(\min(\gamma,\beta),1.0)\cdot D_V \qquad \beta=0.5$$

The basic program in this paper is a structured, finite-volume, compressible, Reynolds-averaged Navier-Stokes solver developed in our research group. The $\gamma-\overline{\mathrm{Re}_{\theta t}}$ transition model equations is solved by coupling with the original code.

## Results and discussion

Transition flow around NLF0416 airfoil [3] is numerically simulated, computationally predicted drag polar for the airfoil is compared to the experimental values in Fig. 1. The transition position compared to the experiment data is shown in fig 2.The flow around McDonnell Douglas 30P-30N flap configuration [4] is also investigated, the skin friction coefficient results are shown in Fig. 3. The velocity distribution of different inspect station are shown in Fig. 4. At last a three dimensional case DLR F-5 geometry [5] is studied. The predicted pressure distribution of two wing sections is shown in Fig. 5.The experimental flow visualization is shown in Fig.10 (right). A diagram of the flowfield around the wing is constructed and can be seen in Fig.10 (right). From the measurements, the boundary layer is laminar until about 60% chord where a shock causes the laminar boundary layer to separate and reattach as a turbulent boundary layer. The contours of skin friction and the surface streamlines predicted by the transition model are shown in Fig.10 (left), while the one predicted by the SA model is shown in Fig.10 (middle).

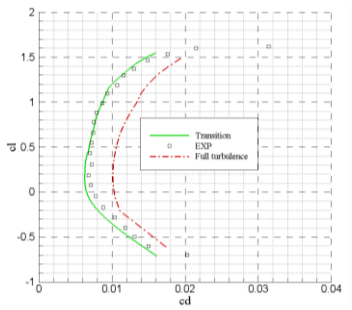


Figure 1 Comparison of drag polar

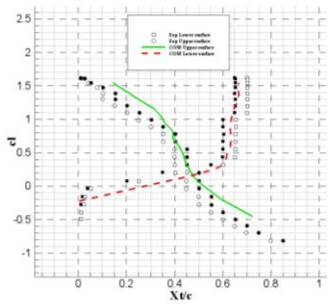


Figure 2 Predicted transition locations

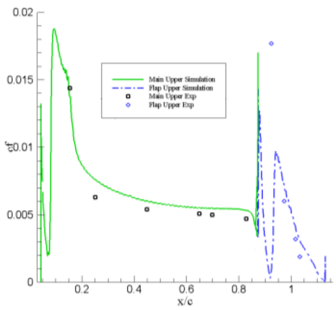


Figure3 Skin friction on the upper surface

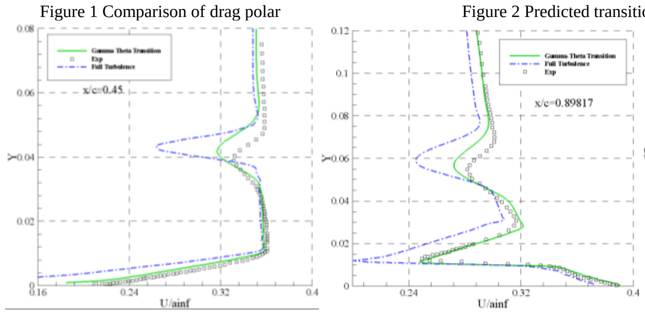


Figure 4 velocity distribution of different inspect station

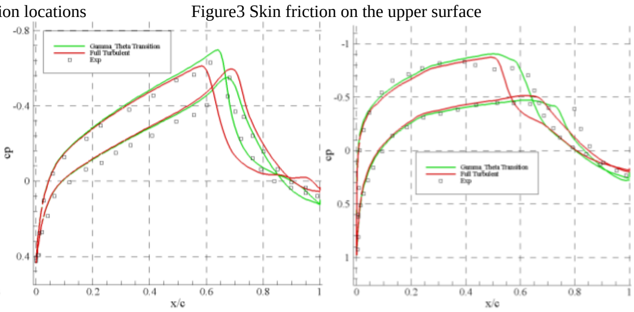


Figure 5 predicted pressure distribution of four wing sections

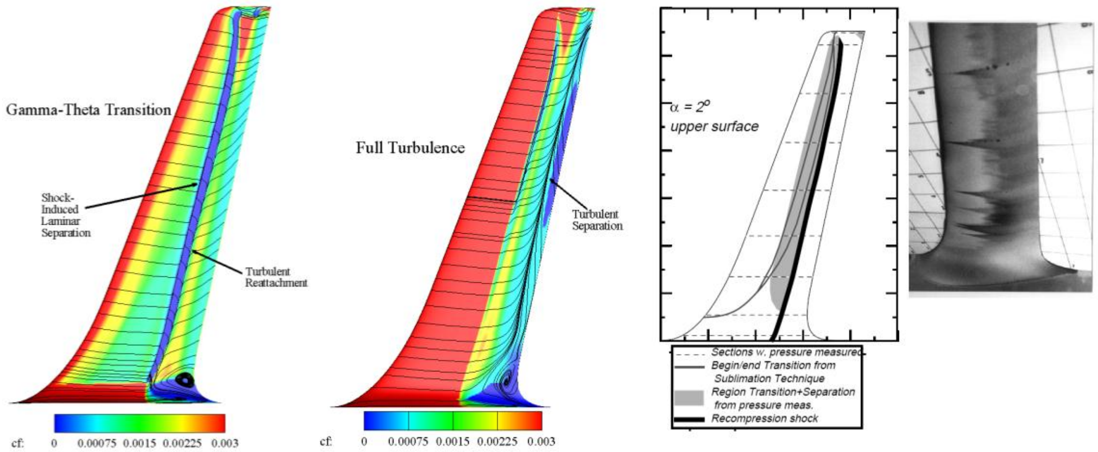


Figure 6 Contour plot of skin friction (Cf) and surface streamlines predicted by the transition model (left) and full turbulence model (middle), experimental diagram of the flow field and experimental flow visualization of the surface shear on the DLR-F5 wing (right)

## CONCLUSIONS

In the present work, the $\gamma-\overline{\mathrm{Re}_{\theta t}}$ transition model is investigate, and a new form of transition model based on SA turbulence model is constructed by modify some basic variables and parameters of transport equations of γ and $\overline{\mathrm{Re}_{\theta t}}$. The numerical simulations of transition flow around NLF0416, MD30P-30N multi-element airfoil and DLR –F5 wing are carried out and the results are compared with the wind tunnel data. It is shown that the $\gamma-\overline{\mathrm{Re}_{\theta t}}-SA$ transition model in this paper can well simulate the natural transition and separation induced transition of different configuration

## References


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