DEVELOPMENT OF THE $\gamma - \mathrm{Re}_{\theta t}$ TRANSIITON MODEL FOR HIGH SPEED FLOWS

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Summary The objective of the paper is to further the understanding of the transition to turbulence mechanism at high speeds. The main focus is on the transition happens in high-speed flow that caused by back pressure and separation. The $\gamma - \mathrm{Re}_{\theta t}$ transition model suggested by Langtry and Menter is used as the baseline model. Regarding the modification and development, a shock correction and a modification of the separation function were proposed. In particular, the shock correction is used to damp the artificially rapid increase of turbulent kinetic energy when shock waves exist. The modification of the separation fuction γ_{sep} is to implement the effect of pressure gradients into the modelling of transition process in a separation bubble. Numerical simulation of a double ramp case showed that the modified model predicts the transition process as well as the size of the separation bubble correctly.

INTRODUCTION

There are many available RANS transition models currently. We selected Langtry-Menter transition model [1,2](based on Menter's SST model) as our baseline model because of its following advantages: 1) The Menter SST model is well validated for complex flowfields and is extensively used in high-speed applications. 2) Langtry and Menter predict the transition by adding two more transport equations, γ (intermittency) and $\mathrm{Re}_{\theta t}$ (transitional Reynolds number based on momentum thickness), which is physically reasonable for most transition cases. 3) Langtry-Menter model is a well-published transition model. A series of detailed papers [3–7]devoted to this model have been published.

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Shock correction for the Menter SST model

A known drawback of Menter SST model in application of high-speed flows is that the turbulence intensity increases artificially rapidly when shock wave exists, see Fig.1. This artificial increasing of turbulence kinetic energy will definitely make the SST-based transition model invalid for high-speed flows, since turbulence kinetic energy is the most important and direct factor that caused transition.
By using the DNS data [8], a shock indicator for SST model is designed and implemented. The main function of this indicator is to judge the shock location and adjust the turbulence kinetic energy behind the shock into a reliable level. Fig.2 shows the comparison of the turbulence kinetic energy levels behind a shock, with and without shock indicator. It is observed that the indicator successfully recovers the turbulence kinetic energy into a correct level.

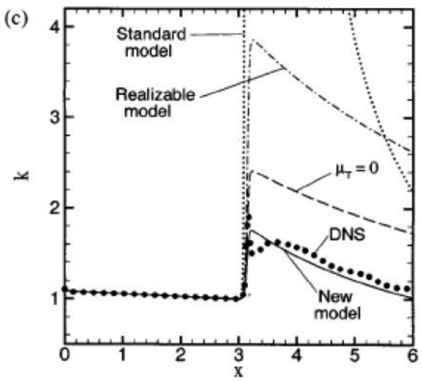

Fig. 1 Turbulence kinetic energy increasing behind a shock wave [8]

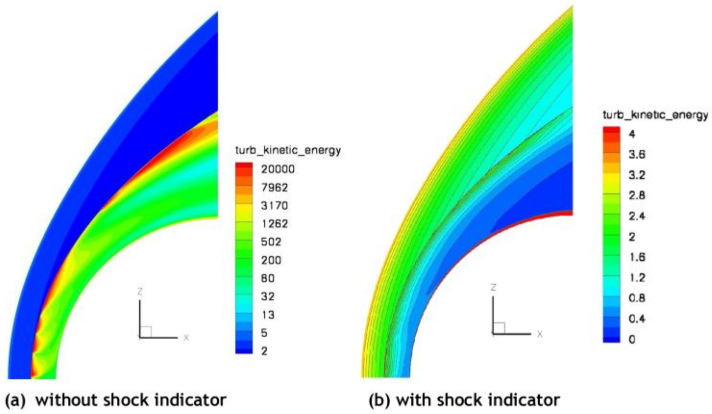

Fig. 2 Comparison of the turbulence kinetic energy levels behind a shock, with and without shock indicator

Correction of the separation function γ_{sep} with pressure gradients

Langtry and Menter verified their model's ability in simulating separation by the T3C4 test case, which is a subsonic flat plate case with mild back pressure. They implemented a parameter called γ_{sep} to improve the prediction of separated flow transition.

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$$\gamma_{sep} = \min(s_1 \max[0, (\frac{\mathrm{Re}_v}{3.235\,\mathrm{Re}_{\theta c}}) - 1] F_{reattach}, 2) F_{\theta t} \qquad (1)$$

The basic idea of γ_{sep} is to allow the effective intermittency to be above 1.0. In this way, the transition model achieved a good agreement in C_f distribution with the experimental result of the T3C4 case.

However, it is not evident whether such "effective intermittency" is necessary in hypersonic separated flow transition and to which level this value should be if necessary. Fig.3 shows the hypersonic double ramp case tested in this study. Fig.4 implies that original $\gamma - \mathrm{Re}_{\theta t}$ transition models (with Langtry or Krause's [9] fuctions) predict a relatively early transition, which results in a rapid increase of Stanton number when compared with the experimental data. This rapid increase could be caused by the overpredicted "effective intermittency". Therefore, the γ_{sep} parameter is firstly removed to test the performance of the model. The pink dash lines in Fig.3 show that when $\gamma_{sep} = 0$ ($\gamma_{eff} = \gamma$), the transition model obtains a similar level of Stanton number to the laminar model, especially in the reattachment zone. Two issues arises with respect to this outcome: 1) the "effective intermittency" is important to hypersonic separated flow transition as well; 2) the transition process can be better predicted by assigning a more physical "effective intermittency". The physical "effective intermittency" should be smaller than the value calculated by eq.(1), since the flow converges towards fully turbulent when eq.(1) is adopted.

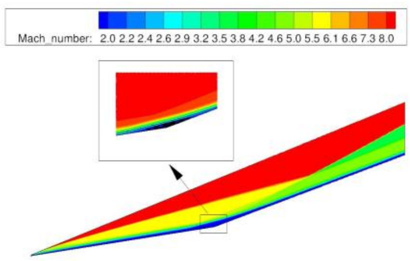

Fig. 3 Hypersonic double ramp test case

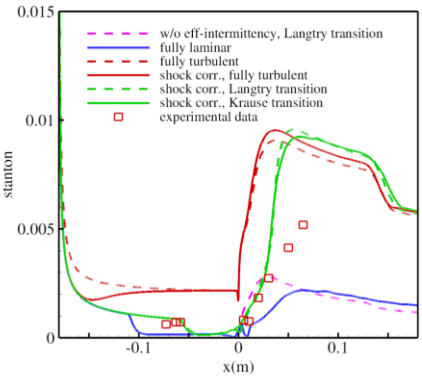

Fig. 4 Langtry transition model without γ_{eff}

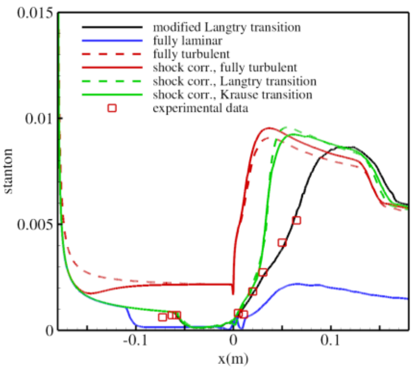

Fig. 5 Langtry transition model based on Eq.(2)

The effect of pressure gradient is involved to improve the physical meaning of "effective intermittency". The basic idea is to force the "effective intermittency" only works in the region of reattachment. Based on the experimental data of the double ramp case, eq.(1) is modified as follows, λ_θ ($|\lambda_\theta| < 0.1$) is the parameter of pressure gradient which has been calculated in the model.

$$\gamma_{sep} = \min(10 s_1 (0.1 - |\lambda_\theta|) \max[0, (\frac{\mathrm{Re}_v}{3.235\,\mathrm{Re}_{\theta c}}) - 1] F_{reattach}, 2) F_{\theta t} \qquad (2)$$

Fig. 5 shows the Stanton number prediction achieved by the current modification, which agrees well with the experimental data.

CONCLUDING REMARKS

More detailed experimental data will be much helpful to further validate the current Langtry-Menter transition model in TAU code. And this is what we plan to do in next steps, once experimental data is available.

There are lots of different reasons that could trigger transition, the work in this project mainly focuses on the transition happens in high-speed flow that caused by back pressure and separation. For other types of transition, the RANS transition model still needs to be studied and further developed

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