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NUMERCAL SIMULATION OF FLOWS USING A BLENDED IDDES AND CORRELATION BASED TRANSITION MODEL

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Summary. Numerical simulations of laminar-turbulent transitional flows involving massive separation are conducted by blending IDDES and a correlation-based transition model.

1 INTRODUCTION

Reynolds averaged Navier-Stokes equations (RANS) are widely solved in engineering fluid flow problems, because the RANS model provides satisfactory results at reasonable computational costs. However, the accuracy of RANS naturally degrades in massively separated flow regions. Because of this difficulty, hybrid RANS/LES has been suggested such that more accurate solutions can be obtained with moderate number of grid points, compared to RANS simulations. Detached eddy simulation (DES) [1] is one of the hybrid RANS/LES methods that adopt RANS in the near wall region while LES is applied in the separated flow region. Recently, improved delayed detached dddy simulation (IDDES) [2] was also proposed by adding the wall modeled large eddy simulation (WMLES).

The hybrid RANS/LES inherently assumed fully turbulent flows, and thus the model does not properly predict flow transition. A correlation based transition model, known as the $\gamma-\mathrm{Re}_{\theta t}$ transition model [3], was developed for predicting flow transition with local operations. To further consider transition induced by cross flows, Choi and Kwon [4] suggested the $\gamma-\mathrm{Re}_{\theta t}-CF^{+}$ transition model by modifing the transition onset function of the $\gamma-\mathrm{Re}_{\theta t}$ transition model.

In the present study, IDDES was blended with the $\gamma-\mathrm{Re}_{\theta t}-CF^{+}$ transition model for predicting separated flows involving laminar-turbulent transion, including the effect of cross flows. For this purpose, a new blending function was introducedused in IDDES for handling the WMLES calculations. To validate the blending model, numerical simulations were preformed for flows around a circular cylinder and a spheroid. The results were compared with experiment.

2 NUMERICAL METHOD

2.1 Governing equations

Compressible/incompressible Navier-Stokes equations were used as the governing equations. The governing equations were discretized by using a vertex-centered scheme with median-dual finite volumes based on unstructured meshes. The convective fluxes and the viscous fluxes were calculated by utilizing Roe's flux difference splitting scheme and the central differencing, respectively. Dual time stepping was used for unsteady time-accurate flow simulations. METIS and MPI libraries were adopted for parallel computations.

2.2 Hybrid RANS/LES model

In the present study, the IDDES model based on the $k-\omega\, SST$ model was adopted [2]. This hybrid RANS/LES model was coupled with a $\gamma-\mathrm{Re}_{\theta t}-CF^{+}$ laminar-turbulent transition model [4], which considers cross flow transition, in addition to the baseline $\gamma-\mathrm{Re}_{\theta t}$ model [3].

2.3 Blending function

Many blending functions have been suggested to couple the hybrid RANS/LES with the $\gamma-\mathrm{Re}_{\theta t}$ transition model. However, most of them were for DES or DDES as the blending model. Thus, the entire boundary layer is calculated by the $\gamma-\mathrm{Re}_{\theta t}$ transition model, and WMLES region in IDDES is excluded when those blending functions are used. Among the blending functions, one that can be used for IDDES was suggested by You and Kwon [5]. In the present study, for the blending of IDDES with the $\gamma-\mathrm{Re}_{\theta t}-CF^{+}$ transition model, eddy viscosity ratio values of 30 and 40 were used for the domain decomposition of the blending function [6].

3 RESULTS AND DISCUSSION

3.1 Circular cylinder

To validate the blending model without cross flows, calculations were conducted for a flow around a circular cylinder at a Reynolds number 140,000. At this Reynolds number, laminar flow separation occurs. The turbulent intensity was set to 0.1%. The spanwise direction of computational domain was set to 3.14D. Since the flow approaches perpendicuar to the cylinder, the $\gamma-\mathrm{Re}_{\theta t}-CF^{+}$ transition model recovers to the baseline $\gamma-\mathrm{Re}_{\theta t}$ transition model.

The computational mesh consists of 3,000,005 nodes and 13,001,266 cells. To capture the boundary layer, 40 prism layers were packed on the solid wall with a stretching ratio of 1.15. The initial layer thickness has a y+ value of 0.5.

In Fig. 1, the time-averaged surface pressure coefficient distributions of the three different turbulence models are compared with the experiment [7]. For the $\gamma-\mathrm{Re}_{\theta t}$ transition model, the wake region of the circular cylinder was calculated by usinf the URANS model, and thus the suction pressure in the rear surface of the cylinder was overpredicted. The IDDES adopts LES in the wake, but fully turbulent assumption causes the difference with the experiment. The present blending model shows good agreement with the experiment by simultaneously considering the flow transition and the LES calculation in the wake region.

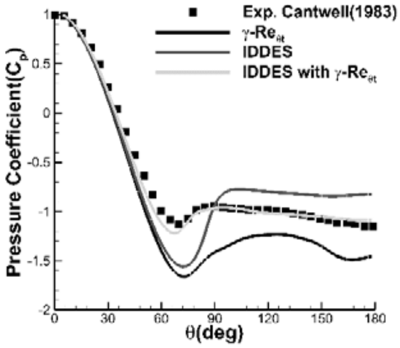


Fig. 1. Time-averaged surface pressure coefficient distributions

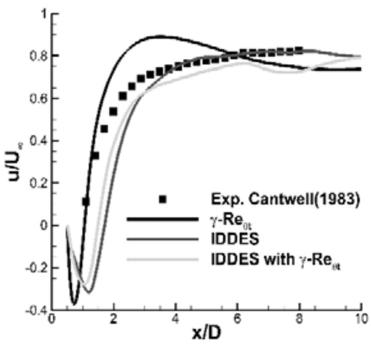


Fig. 2. Time-averaged streamwise velocity distributions

The streamwise velocity distributions in circular cylinder wake are compared in Fig. 2. Since the $\gamma - \mathrm{Re}_{\theta t}$ transition model is based on RANS, and thus the wake region is not well predicted without closely following the experimental results. On the other hand, the present blending model simulating LES in the wake region compares better with the experiment.

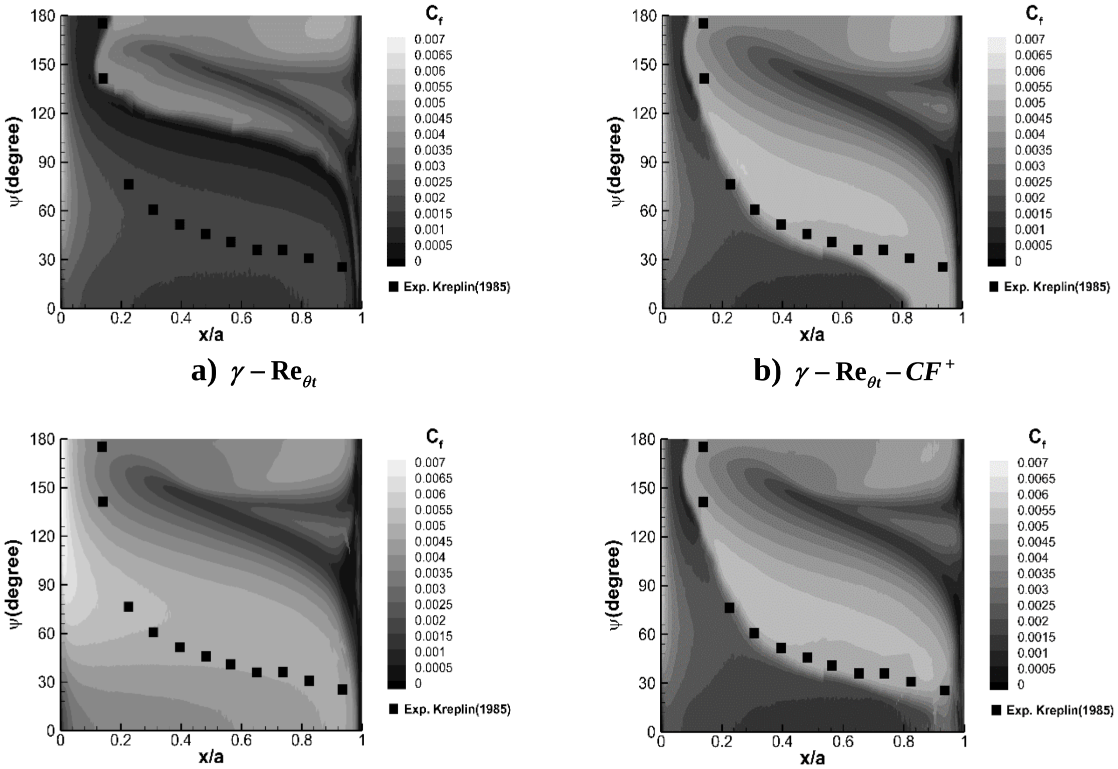
3.2 Prolate spheroid

Next, numerical simulations were conducted for flows around a prolate spheroid at an angle of attack 20 degrees and at a Reynolds number of 6.54×10^6 [8]. The turbulence intensity was set to 0.4%. The computational mesh consists of 2,586,419 nodes and 7,992,800 cells. To capture the boundary layer, 30 prism layers with a stretching ratio of 1.2 were packed on the solid surface. The initial layer thickness has y+ value of one.

In Fig. 3, the skin friction coefficient contours are compared with the measured transition location. It is shown that the $\gamma - \mathrm{Re}_{\theta t}$ transition model does not handle cross flow transition, and thus overpredicts the laminar region. Meanhile, the two models that consider cross flow transition show good agreements with the experiment. The IDDES coupled with the $\gamma - \mathrm{Re}_{\theta t} - CF^+$ transition model shows the most accurate results compared with the experiment.

4 CONCLUSIONS

The IDDES model was blended with the $\gamma - \mathrm{Re}_{\theta t} - CF^+$ transition model to capture separated flows accompanying flow transition both in streamwise and crossflow directions. For this purpose, a new blending function was introduced to preserve the wall modeled large eddy simulation region of IDDES. It was found that the blended model developed in the present study is accurate and is reliable for the prediction of separated flows involving laminar-turbulent transition.



a) $\gamma - \mathbf{Re}_{\theta t}$ b) $\gamma - \mathbf{Re}_{\theta t} - CF^{+}$

c) IDDES d) IDDES with $\gamma - \mathbf{Re}_{\theta t} - CF^{+}$

Fig. 1. Skin friction coefficient contours compared with experiment

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