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BOUNDARY LAYER TRANSITION PREDICTION OVER WIND TURBINE BLADE PROFILE THROUGH DETACHED EDDY SIMULATION

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Abstract. This proposed study aims at simulating slightly separated flow over the NREL S826 wind turbine blade profile with delayed detached-eddy simulation (DDES) strategy. The Reynolds number is relatively low and the angles of attack are around the stall region so that flow is not massively detached. This type of flow where boundary layer transition and laminar separation take place is difficult to simulate by DDES. To handle the problem and increase the capability of DDES, three developments that have appeared recently in literature are combined. The first one is a modification to Spalart-Allmaras (S-A) one equation, which allows setting initial eddy viscosity value as zero for apparent transition behavior. Secondly, the shear-layer-adapted subgrid length scale instead of the classical one, maximum edge length of cells, is used in the resolved mode of DDES. By this enhancement, emergence of turbulent content could be accelerated inside boundary layers in presence of instability. As a third one Bas-Cakmakcioglu (B-C) algebraic transition model is adapted to the modified S-A turbulence equation. The simulations are being performed by an inhouse solver, METUDES, and some preliminary results are demonstrated. In the final manuscript, the results will be compared with those of available data from a DDES study that uses standard subgrid length scale, and from a RANS study that employs Langtry-Menter transition prediction model.

1 INTRODUCTION

Wind turbine blades, during the operation, experience flow fields with different angles of attack and flow velocities. Consequently, having a numerical solver that can handle all flow regimes such as laminar, laminar-turbulent transition, and fully turbulent flows is essential for accurate wind turbine blade simulations. Delayed detached-eddy simulation (DDES), in recent years, is widely used by both industry and academic communities because it can supply high accuracy with low computational cost requirements in most aerodynamic problems. However, it was originally developed for massively detached flows. In fact, it models the eddy viscosity inside the boundary layer by its Reynolds-averaged

Navier-Stokes (RANS) mode and activates the large-eddy simulation (LES) mode outside the boundary layer to resolve the turbulence. Since DDES suppresses the instabilities inside the boundary layer by providing pure modeling approach, capturing the boundary layer transition is difficult to achieve.

Boundary layer transition prediction is aimed by combining three methods developed recently in literature. The first of these developments is a Spalart-Allmaras (S-A) modification [1]. This enhancement gives an opportunity to set initial eddy viscosity related term as zero. Hence, laminar flow behavior as an initial condition could be given everywhere in the computational domain unlike classical DES approaches. Secondly, a shear-layer-adapted (SLA) subgrid length scale [2] is preferred to use in DDES strategy. This length scale simply detects Kelvin-Helmholtz instability inside shear-layers, then reduces the subgrid length scale, and accelerates the LES mode. It has been shown in the previous study [3] that the combination of this length scale with the modified S-A equation reveals a laminar separation bubble inside boundary layer and shows transition behavior. However, prediction of an exact location of the transition onset requires a transition model. As a consequence, the third method to be combined with the others is an algebraic transition model called as Bas-Cakmakcioglu (B-C) model [4]. The B-C model multiplies simply an intermittency function depending on local turbulent information with the production term of the S-A equation, and thereby provides a boundary layer transition prediction.

This study aims to use DDES to accurately simulate slightly separated flow over the NREL S826 wind turbine blade section profile, where laminar-to-turbulent transition phenomenon takes place. The Reynolds number is $145,000$, and the angles of attack are around stall region such as $8°$ and $12°$. The simulations have been performed by an inhouse solver, METUDES, developed for aeroacoustic purposes in Aerospace Engineering Department in METU. The aerodynamic results will be compared with those of available data from a DDES study [5] that uses standard subgrid length scale, and from a RANS study [5] that employs Langtry-Menter transition prediction model.

2 METHODOLOGY

2.1 Flow Solver, METUDES

METUDES [6], is a time-accurate, compressible, Navier-Stokes solver. The spatial discretization is performed by a fourth-order low-dissipation low-dispersion finite volume approach defined on 3-D curvilinear grids. The temporal discretization is the preconditioning-squared approach which makes use of dual-time stepping together with a low Mach number preconditioning and matrix time stepping.

2.2 Laminar-to-turbulent Transition Prediction

Typical DES models assume the flow as fully turbulent. METUDES solves N-S equations together with the modified S-A equation[1]; thereby, initial eddy viscosity values in whole computational domain could be set as zero. This ensures that simulations start as laminar flow. On the other hand, SLA length scale [2] accelerates the activation of LES mode in case of instabilities. Nevertheless, DES is not capable to predict transition.

At this point, transition inside RANS region of the DES is aimed to be captured by a transition model.

Bas-Cakmakcioglu (B-C) model is a zero-equation algebraic transition model [4], which is based on the S-A turbulence equation. It multiplies simply an intermittency function depending on local flow information with the production term of the S-A model. The standard S-A one equation model slightly modified by B-C model is in the following form (in non-conservation form and without trip term):

$$\frac{\partial \tilde{\nu}}{\partial t} + \mathbf{V} \cdot \nabla \tilde{\nu} = \Psi + \boldsymbol{\gamma_{BC}} \Pi - \Phi \tag{1}$$

where $\tilde{\nu}$ is the eddy viscosity related term, and $\mathbf{V}$ is the velocity vector of the flow field. The terms on the right hand side of Eq.1 represent diffusion, production and destruction, respectively. Here, $\boldsymbol{\gamma_{BC}}$, the proposed intermittency distribution function, is given as

$$\gamma_{BC} = 1 - \exp(-\sqrt{Term_1} - \sqrt{Term_2}) \tag{2}$$

This function, having values from 0 to 1, hampers the production of eddy viscosity until some transition criteria is met. The terms are given as

$$Term_1 = \frac{\max(Re_\theta - Re_{\theta c}, 0.0)}{\chi_1 Re_{\theta c}}, \quad Term_2 = \frac{\max(\nu_{BC} - \nu_{cr}, 0.0)}{\nu_{cr}} \tag{3}$$

where

$$Re_\theta = \frac{Re_v}{2.193}, \quad Re_v = \frac{\rho d_w^2 \Omega}{\mu}, \quad \nu_{BC} = \frac{\nu_t}{U d_w}, \quad \nu_{cr} = \chi_2 \tag{4}$$

and $\chi_1 = 0.002$, $\chi_2 = 5.0$ are the calibration constants. The critical momentum thickness $Re_{\theta c}$ is found from empirical correlations.

3 PRELIMINARY RESULTS

Flow with Reynolds number of $145,000$ and angle of attack of 8° is simulated around NREL S826 blade profile by DDES with the standard subgrid length scale as well as with the SLA one. Fig.1 indicates that SLA length scale unlocks instability, and reveals a laminar separation unlike the standard length scale. Fig.2 shows Q-criterion isosurfaces around the blade, which demonstrate vortical structures related to eddies. As seen, while standard DDES could capture mostly 2-D vortical structures, DDES with SLA accelerates the emergence of LES content even if flow is not fully turbulent. It should be emphasized the simulations started with zero eddy viscosity initial condition thanks to the modification to S-A equation; therefore, flow turns into fully turbulent only after middle of the chord in suction side.

4 CONCLUSIONS

- DDES with SLA length scale could be used for accurate transition predictions if a suitable transition model is added into the turbulence model equations.

- In the final manuscript, the results with the use of B-C model together with the SLA length scale and the modified S-A equation will be demonstrated with comparisons.

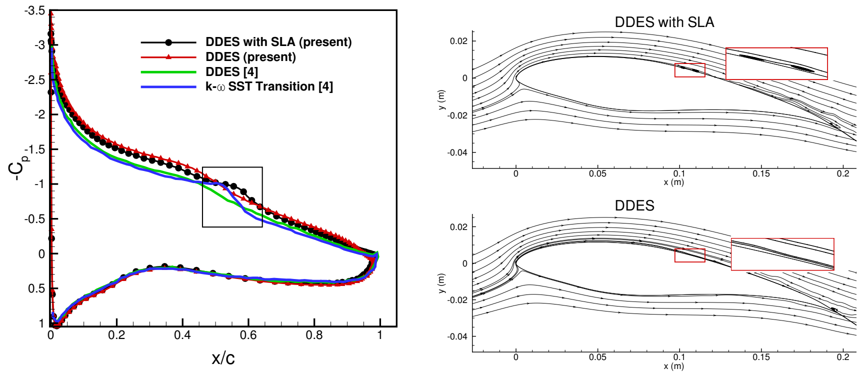

Figure 1: C_p distributions over the blade surface (left) and streamlines around the blade (right)

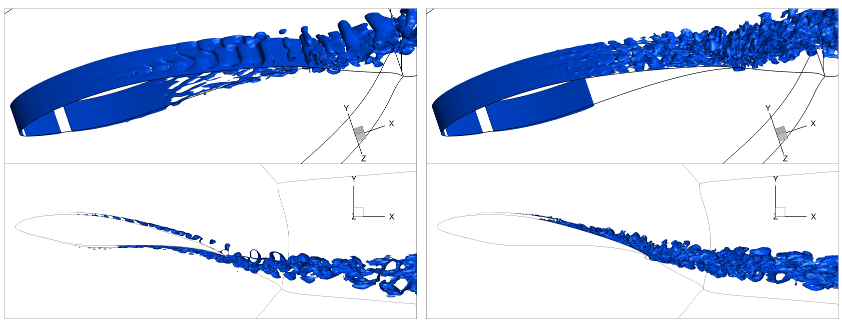

Figure 2: Isosurface of Q-criterion around the blade via DDES (left) and DDES with SLA (right)

REFERENCES

[1] Crivellini A and D'Alessandro V 2014 *International Journal of Heat and Fluid Flow* **47** 70–83

[2] Shur M L, Spalart P R, Strelets M K and Travin A K 2015 *Flow, Turbulence and Combustion* **95** 709–737

[3] Yalçın Ö, Cengiz K and Özyörük Y 2018 *Journal of Wind Engineering and Industrial Aerodynamics* **179** 125–134

[4] Cakmakcioglu S C, Bas O and Kaynak U 2018 *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* **232** 3915–3929

[5] Cakmakcioglu S, Sert I, Tugluk O and Sezer-Uzol N 2014 2-d and 3-d cfd investigation of nrel s826 airfoil at low reynolds numbers *Journal of Physics: Conference Series* vol 524 (IOP Publishing) p 012028

[6] Cengiz K and Özyörük Y 2015 Detached eddy simulation using a high-order low-dissipation low-dispersion computational method for aeroacoustic purposes *Ankara International Aerospace Conference, METU Ankara Campus*