High-fidelity numerical simulation of compressible turbulent flows

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Abstract

The first purpose in this study is to investigate the detailed mechanisms of the flow separation control with vortex-generator (VG) by using large eddy simulation (LES) of compressible turbulent boundary layer flows. The second purpose is to verify the predictability of near-wall turbulence structures in the wall-modeled LES (WMLES) by comparing with the wall-resolved LES (WRLES). In this second study, we also investigate the differences in the prediction accuracy between two inner-layer models in LES, such as an equilibrium model and dynamic non-equilibrium model.

Ref. URL: http://www.cfd.mech.tohoku.ac.jp/kawai/index.html

Reasons for using JSS2

Massively parallel computations using supercomputer is mandatory for high-fidelity simulations by wall-resolved LES because of its high computational cost to resolve the fine turbulent structures in the inner-layer. Especially, LES requires extremely high computational cost because of its high grid-resolution in near wall regions.

Achievements of the Year

(a) In this study, to clarify the detailed separation-control mechanism of the VG, we first verified the capability of the VG source term modeling in terms of the size and angle of the VG. By changing the grid-selection method of the existing VG model, it was found that the results largely depend on the grid-selection methods (Fig. 1). We then analyzed the cause of the grid-selection method dependency and proposed the modified grid-selection method that detects the flow direction vector at the grid point and automatically turns the model on and off at the grid point. The proposed VG model robustly enables to predict the flow generated by the VG for different size and angles of the VG compared to the existing models (Fig. 1). In future work, we will conduct the LES of the flat-plate turbulent boundary layer with the proposed VG model to investigate the flow physics of the interactions between the wall turbulence and longitudinal vortex induced by the VG. (b) In this study, we have carried out

wall-resolved LES (WRLES) and wall-modeled LES (WMLES) of the supersonic flat plate turbulent boundary layer and investigated the predictability of the near-wall turbulent structures using WMLES. The predictability of WMLES was investigated by comparing the instantaneous turbulence structures obtained by the WRLES and WMLES. The WMLES predicted excessive streamwise spectra compared to the WRLES at y=h_wm. The results indicate that the turbulent energy predicted by WMLES is overestimated (Fig. 2 (a)). On the other hand, when the flow is compared at y=4 h_wm, the spectra obtained by the WMLES agree well with the WRLES (Fig. 2 (b)). Also, similar results were obtained by the spanwise spectra.

We also have investigated the predictability of the wall shear stresses predicted by the wall-model. The dynamic non-equilibrium wall-modeled LES (NEQBL) predicted the instantaneous and locally generated high wall shear-stress, while the equilibrium wall-modeled LES (EQBL) cannot predict such structures (Fig. 3). In future work, we will carry out LES with a higher Reynolds number and clarify the Reynolds number effects of the turbulent structures and their predictability using WMLES.

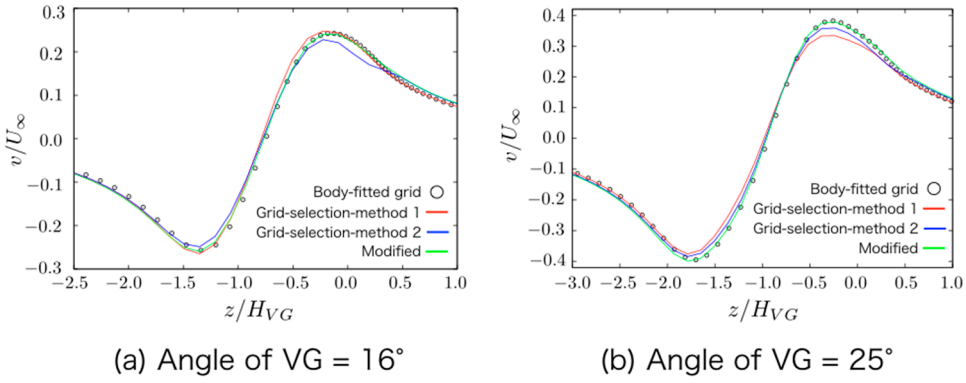

Fig. 1: Wall-normal velocity at the height of vortex center induced by VG.

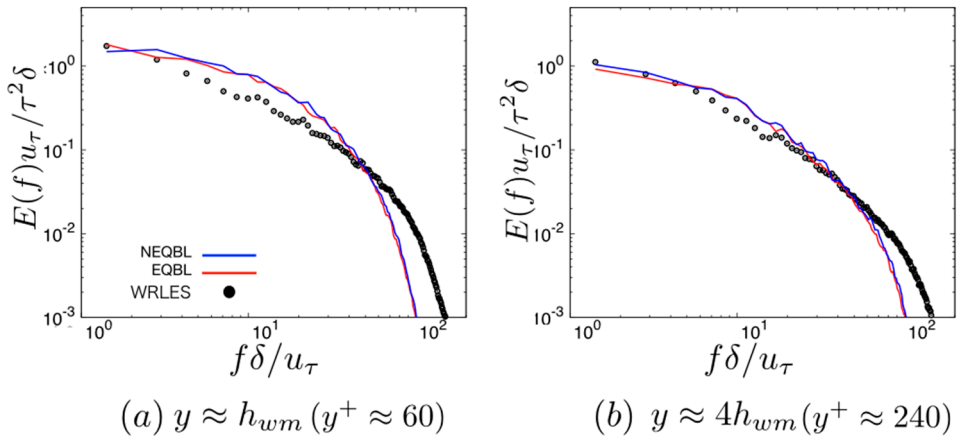

Fig. 2: Comparisons of streamwise spectra of instantaneous streamwise velocity fluctuations obtained by WRLES and WMLES.

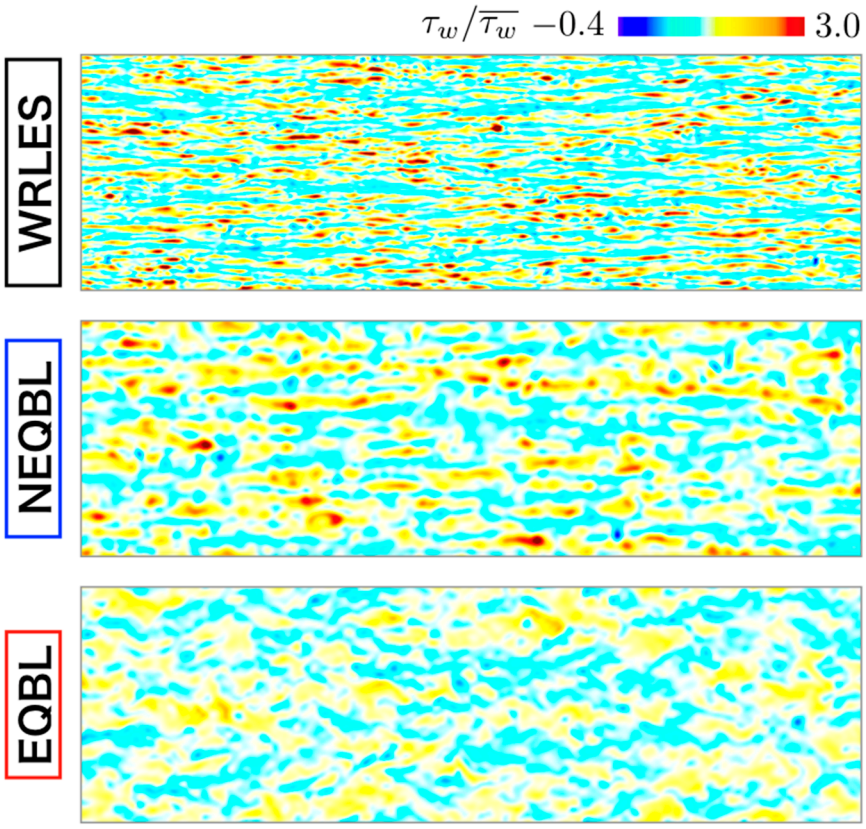

Fig. 3: Comparisons of instantaneous wall shear-stresses obtained by WRLES and WMLES.

Publications

- Oral Presentations

(1) R. Hirai and S. Kawai, “Assessments of vortex-generator source term modeling”, 50th Fluid Dynamics Conference/36th Aerospace Numerical Simulation Symposium, Miyazaki, Japan, July 2018. (2) S. Ishitsuka, Y. Fukushima and S. Kawai, “Predictability of near-wall turbulences structures in wall-modeled large eddy simulation”, 50th Fluid Dynamics Conference/36th Aerospace Numerical Simulation Symposium, Miyazaki, Japan, July 2018. (3) R. Hirai, S. Kawai, “Analysis of source term modeling of vortex generator”, SciTech2019, San Diego, California, AIAA-2019-2181, January 2019.

Usage of JSS2

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	OpenMP
Number of Processes	15 - 1920
Elapsed Time per Case	650 Hour (s)

- **Resources Used**

Fraction of Usage in Total Resources[*1] (%): 0.12

Details

Computational Resources		
System Name	Amount of Core Time (core x hours)	Fraction of Usage[*2] (%)
SORA-MA	1,044,535.42	0.13
SORA-PP	0.00	0.00
SORA-LM	0.00	0.00
SORA-TPP	0.00	0.00

File System Resources		
File System Name	Storage Assigned (GiB)	Fraction of Usage*2 (%)
/home	487.33	0.50
/data	9,870.53	0.17
/ltmp	4,101.56	0.35

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage*2 (%)
J-SPACE	0.00	0.00

[*1]: Fraction of Usage in Total Resources: Weighted average of three resource types (Computing, File System, and Archiver).

[*2]: Fraction of Usage: Percentage of usage relative to each resource used in one year.