High-fidelity numerical simulation of compressible turbulent flows

Report Number: R20EACA37
Subject Category: JSS Inter-University Research
URL: https://www.jss.jaxa.jp/en/ar/e2020/14222/

Responsible Representative

Soshi Kawai, Professor, Department of Aerospace Engineering, Tohoku University

Contact Information

Hiroyuki Asada(h.asada@tohoku.ac.jp)

Members

Soshi Kawai, Ryo Kamogawa, Hiroyuki Asada, Aya Aihara

Abstract

To accurately simulate turbulent flows with separation and reattachment using wall-modeled large-eddy simulation (LES), non-equilibrium effects, such as the effects of the pressure gradient, should be incorporated in the wall model. However, the existing non-equilibrium wall-models require solving the partial differential equations (PDEs), which increase the difficulty of implementation, especially for complex geometries. Therefore, we construct and validate a non-equilibrium wall-model based on the ordinary differential equation (ODE). First, the non-equilibrium effects of turbulent boundary layers (i.e., the pressure-gradient and convective terms) and the eddy viscosity are consistently modeled using the wall-resolved LES database of the flat-plate separating/reattaching turbulent boundary layers. Then, we perform wall-modeled LES of the flat-plate turbulent boundary layer with separation/reattachment and a near-stall airfoil flow using the proposed ODE-based non-equilibrium wall model. In both the validation cases, the wall-modeled LES using the proposed wall model show a good agreement with the reference wall-resolved LES results.

Ref. URL: http://www.klab.mech.tohoku.ac.jp/

Reasons and benefits of using JAXA Supercomputer System

In this study, a newly-proposed wall model is validated. Since the wall-modeled LES is an unsteady 3D calculation, parallel computations using a supercomputer are required. Also, to propose and validate a new wall model, several computational cases with different settings need to be conducted. Therefore, our research requires massively parallel computations using JAXA's supercomputer.

Achievements of the Year

(a)An ODE-based non-equilibrium wall model is constructed based on the wall-resolved LES database of the flat-plate separating/reattaching turbulent boundary layers. In the proposed wall model, the non-equilibrium terms, pressure-gradient and convective terms, are modeled using the flow quantities at the matching location of the wall model. Also, the eddy viscosity is modeled consistently with the pressure-gradient and convective terms. The implementation of the proposed model is easier than the existing PDE-based non-equilibrium wall model. Then, we conduct the wall-modeled LES using the proposed ODE-based wall model (ODE-NEQWM) for the flat-plate separating turbulent boundary layers and compare the results with the wall-resolved LES database as well as the wall-modeled LES using the existing PDE-based non-equilibrium wall model (PDE-NEQWM). The mean streamwise velocity and Reynolds shear stress profiles obtained by the proposed ODE-NEQWM show a good agreement with those of LES and PDE-NEQWM. The results indicate that the proposed ODE-based non-equilibrium wall model has comparable accuracy with the existing PDE-based wall model.

(b)As a more practical validation case, a high Reynolds number (the Reynolds number based on the chord length is 2.1*10^6) flow around the A-airfoil at a near-stall condition (the angle of attack is 13.3 degrees) is simulated using the proposed wall-modeled LES (ODE-NEQWM). The mean pressure coefficient and the skin-friction coefficient obtained by ODE-NEQWM show a good agreement with the reference data of the wall-resolved LES database and the wall-modeled LES using the existing PDE-based wall model. The results obtained by the proposed wall-modeled LES show a robustness to predict a more practical airfoil flow near a stall condition.

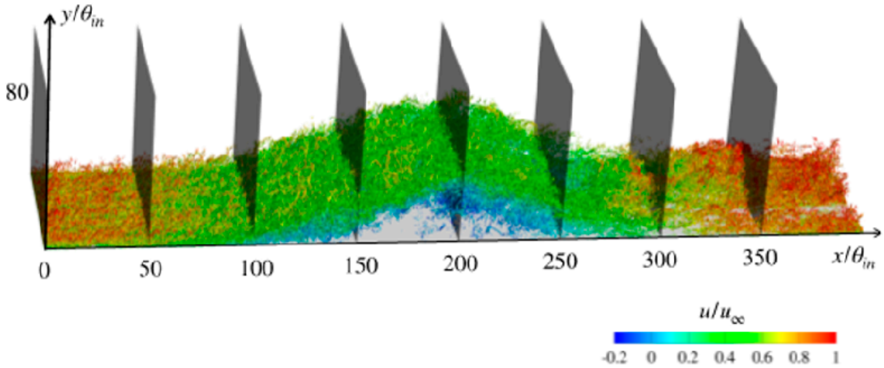

Fig. 1: Isosurfaces of the Q-criterion colored by the streamwise velocity in the flat-plate separating/reattaching turbulent boundary layer.

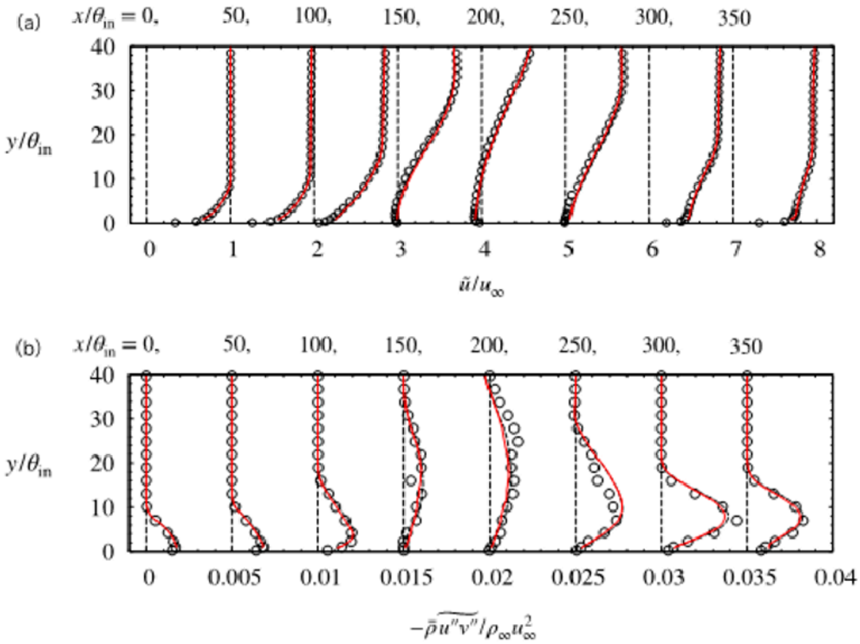

Fig. 2: Profiles of (a) the mean streamwise velocity and (b) Reynolds shear stress in separating/reattaching turbulent boundary layer (circles, wall-resolved LES; red solid lines, the proposed ODE-based non-equilibrium wall-modeled LES; black dashed lines, the existing PDE-based non-equilibrium wall-modeled LES)

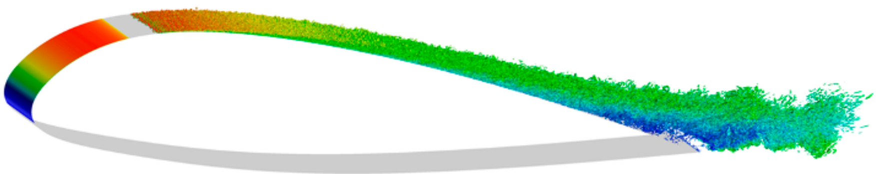

Fig. 3: Isosurfaces of the Q-criterion colored by the streamwise velocity in the flow around A-airfoil.

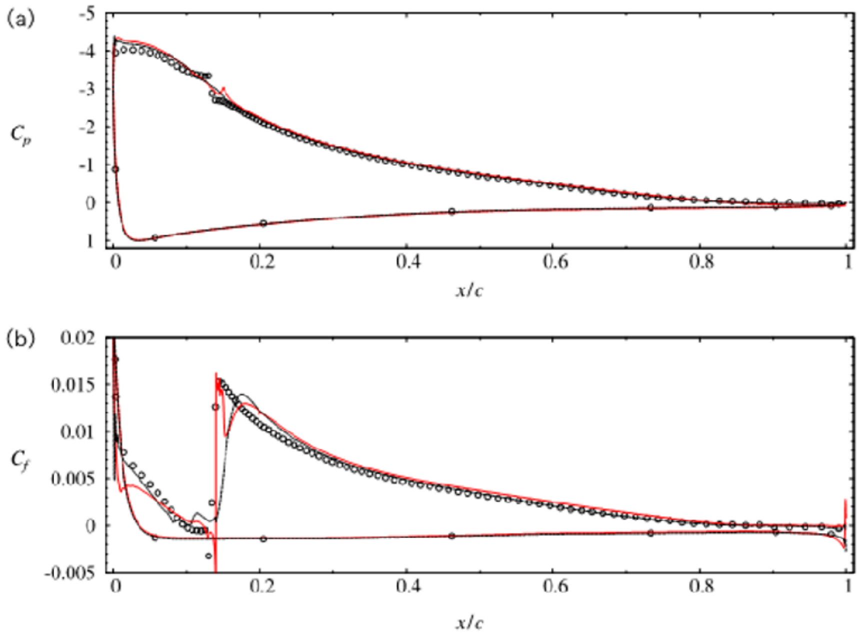

Fig. 4: Distributions of mean skin friction and pressure coefficients along the A-airfoil (circles, wall-resolved LES; red solid lines, the proposed ODE-based non-equilibrium wall-modeled LES; black dashed lines, the existing PDE-based non-equilibrium wall- modeled LES)

Publications

- Oral Presentations

(1) R. Kamogawa, Y. Tamaki, and S. Kawai, "Modeling of the non-equilibrium effects of separated turbulent boundary layer for ODE-based wall-modeled LES", 34th CFD symposium, Online, 2020.

Usage of JSS

- **Computational Information**

Process Parallelization Methods	MPI
Thread Parallelization Methods	OpenMP
Number of Processes	416
Elapsed Time per Case	200 Hour(s)

- **Resources Used(JSS2)**

Fraction of Usage in Total Resources[*1](%): 0.15

Details

Computational Resources		
System Name	Amount of Core Time (core x hours)	Fraction of Usage[*2](%)
SORA-MA	903,245.69	0.17
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	22.32	0.02
/data	3,522.01	0.07
/ltmp	4,572.09	0.39

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.

- **Resources Used(JSS3)**

Fraction of Usage in Total Resources*1(%): 0.01

Details

Computational Resources		
System Name	Amount of Core Time (core x hours)	Fraction of Usage*2(%)
TOKI-SORA	0.00	0.00
TOKI-RURI	0.00	0.00
TOKI-TRURI	0.00	0.00

File System Resources		
File System Name	Storage Assigned (GiB)	Fraction of Usage*2(%)
/home	22.52	0.02
/data	3,523.93	0.06
/ssd	225.17	0.12

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.