Numerical Simulations of Fully Developed Turbulence

Report Number: R19EACA05
Subject Category: JSS2 Inter-University Research
URL: https://www.jss.jaxa.jp/en/ar/e2019/11536/

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Abstract

Since fully developed turbulence at high Reynolds numbers plays an important role in many systems of aerospace engineering, its prediction and control are important in various projects. We need to employ a turbulence model so that we can numerically simulate such extremely-high-Reynolds-number flows. Here, we note that such a model is on the basis of the universality of small-scale statistics of turbulence. The main purpose of the present study is to reveal the physical origin of this universality of turbulent flows. In particular, we aim at revealing details of the multi-scale motions (i.e. the hierarchy of coherent vortices and its sustaining mechanism) of different kinds of high-Reynolds-number turbulence under different boundary conditions by means of direct numerical simulations.

Reasons and benefits of using JAXA Supercomputer System

Turbulent flows are one of the most important research topics in the field of the aerospace engineering. The direct numerical simulations of fully developed turbulence require a massively parallel supercomputer with sufficient amount of memories and storages. These are the reasons why we use JSS2.

Achievements of the Year

This year, we focused on the analysis on a turbulent boundary layer at a sufficiently high Reynolds number and we have deepened the understanding of the sustaining mechanism of the turbulence. Fig. 1 shows an example of our numerical analysis. In this turbulence, there exists a hierarchy of coherent multi-scale vortices and low-speed streaks associated with those vortices. We visualize, in Fig. 1, the largest-scale coherent vortices (orange objects) and low-speed streaks (blue objects) identified in the velocity field coarse-grained with a Gaussian filter. We notice that these structures are similar to the well-known near-wall coherent structures in low-Reynolds-number turbulence. This implies that the sustaining mechanism of largest-scale vortices is common irrespective of the

Reynolds number.

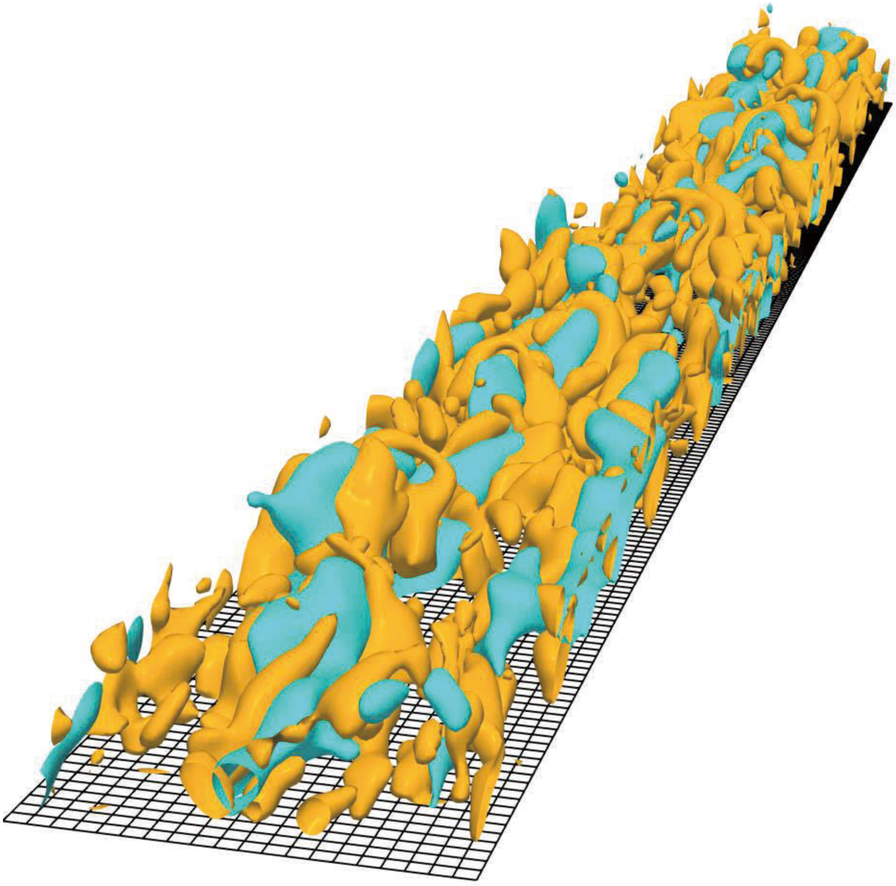

Fig. 1: Large-scale coherent vortices (orange objects) and low-speed streaks (blue objects) in a fully developed turbulent boundary layer. The Reynolds number defined by the momentum thickness is about 3000. These structures are identified for the coarse-grained velocity field obtained with a Gaussian filter.

Publications

- Peer-reviewed papers

1) Y. Motoori, S. Goto, Scale-dependent enstrophy production rates in a turbulent boundary layer, J. Fluid Sci. Tech. 14 (2019) JFST0016.

2) T. Yasuda, S. Goto, J. C. Vassilicos, Phys. Rev. Fluids 5 (2019) 014601.

- Oral Presentations

1) Y. Motoori, S. Goto, Energy cascade in turbulent channel flow, The 65th Workshop on "Investigation and Control of Transition to Turbulence"

2) S. Oka, S. Goto, Cluster of inertial particles and fluid acceleration in turbulence at high Reynolds numbers, Sixteenth International Conference on Flow Dynamics

3) R. Araki, S. Goto, Large spatial-temporal fluctuation and energy cascade dynamics in von Karman turbulence, Sixteenth International Conference on Flow Dynamics

4) S. Oka, S. Goto, Cluster of inertial particles and fluid acceleration in turbulence, 17th European Turbulence

Conference

5) S. Goto, Y. Motoori, Hierarchy of vortices in a developed turbulent boundary layer, 17th European Turbulence Conference,

6) Y. Motoori, S. Goto, Generation mechanism of the hierarchy of vortices in wall-bounded turbulence, Eleventh International Symposium on Turbulence and Shear Flow Phenomena

7) S. Goto, K. Komoda, J. Kanki, Turbulence in Precessing Containers, Eleventh International Symposium on Turbulence and Shear Flow Phenomena

Usage of JSS2

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	Automatic Parallelization
Number of Processes	64 - 96
Elapsed Time per Case	40 Hour(s)

- **Resources Used**

Fraction of Usage in Total Resources[*1](%): 0.13

Details

Computational Resources		
System Name	Amount of Core Time (core x hours)	Fraction of Usage[*2](%)
SORA-MA	932,020.14	0.11
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	1,014.71	0.85
/data	97,751.66	1.67
/ltmp	11,718.76	1.00

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.