Numerical Simulations of Fully Developed Turbulence

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Abstract

Since developed turbulence at high Reynolds numbers plays an important role in many systems of aerospace engineering, its prediction and control are crucial in various projects. We need to employ a turbulence model so that we can effectively conduct numerical simulations of such extremely-high Reynolds-number flows. Here, we note that such a model is based on 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, its sustaining mechanism and its role in transport phenomena) of different kinds of high-Reynolds-number turbulence under various boundary conditions through direct numerical simulations.

Reasons and benefits of using JAXA Supercomputer System

First, turbulent flows are one of the most important research topics in the aerospace engineering. Secondly, direct numerical simulations of developed turbulence require supercomputers with sufficient amount of memories and storage. These are the reasons why we use JAXA supercomputer System.

Achievements of the Year

In this research project, we have been investigating the origin of the universality of small-scale statistics in turbulent flows, and then, it is now evident that there exists a hierarchy of coherent vortices irrespective of flow boundary conditions. This year, we studied the role of these universal structures in turbulent transport phenomena. More concretely, we conducted a series of direct numerical simulations of particulate turbulence in a periodic cube so that we can reveal the physical mechanism of turbulence attenuation due to particle additives. In our simulations, we examined an extensive parameter range of the particle size and mass density. When the velocity relaxation time of particles is longer than the turnover time of the largest eddies in turbulence, vortices are generated around the particles due to sufficiently large relative velocity between the particles and fluid. Then, these particle-size vortices dissipate turbulent kinetic energy, resulting in turbulence attenuation. On the basis of this physical mechanism of turbulence attenuation, we also derived the condition for the attenuation and the formula of the attenuation rate.

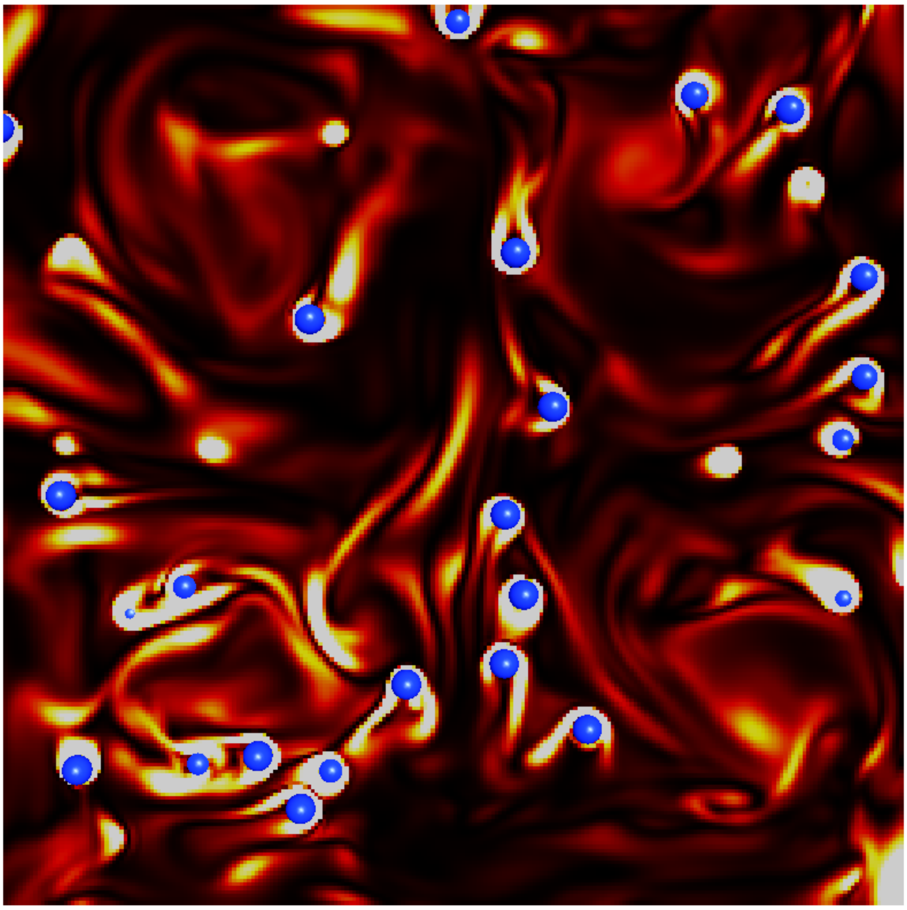

Fig. 1: Solid spherical particles (blue objects) and the vorticity field (bright regions correspond to those with larger vorticity) on a cross-section of three-dimensional turbulence. When the velocity relaxation time of solid particles is larger than the turnover time of the largest eddies, particle-size vortices are created around the particles, which leads to additional energy dissipation and results in the turbulence attenuation.

Publications

- Peer-reviewed papers

1) Sunao Oka, Susumu Goto, Attenuation of turbulence in a periodic cube by finite-size spherical solid particles, J. Fluid Mech. 949 (2022) A45.

2) Daiki Watanabe, Susumu Goto, Simple blade-less mixer with liquid-gas interface, Flow 2 (2022) E28.

3) Mikito Konishi, Masanobu Inubushi, Susumu Goto, Fluid mixing optimization with reinforcement learning, Scientific Reports, 12 (2022) 14268.

4) Yusuke Koide, Susumu Goto, Flow-induced scission of wormlike surfactant micelles under shear flow, J. Chem. Phys. 157 (2022) 084903.

5) Yutaro Motoori, ChiKuen Wong, Susumu Goto, Role of the hierarchy of coherent structures in the transport of heavy small particles in turbulent channel flow, J. Fluid Mech. 942 (2022) A3.

Usage of JSS

- **Computational Information**

Process Parallelization Methods	MPI
Thread Parallelization Methods	OpenMP
Number of Processes	64 - 128
Elapsed Time per Case	30 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources*1(%): 0.35

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage*2(%)
TOKI-SORA	4,459,541.68	0.19
TOKI-ST	1,452,487.19	1.45
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	453.35	0.03
TOKI-TST	0.00	0.00
TOKI-TGP	0.00	0.00
TOKI-TLM	0.00	0.00

File System Resources		
File System Name	Storage Assigned (GiB)	Fraction of Usage[*2] (%)
/home	5,843.00	5.29
/data and /data2	435,500.00	3.36
/ssd	44,220.00	6.13

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.

- **ISV Software Licenses Used**

ISV Software Licenses Resources		
	ISV Software Licenses Used (Hours)	Fraction of Usage[*2] (%)
ISV Software Licenses (Total)	0.00	0.00

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