

Numerical Simulations of Fully Developed Turbulence

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● Abstract

Since fully developed turbulence at high Reynolds numbers plays important roles 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 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 aerospace engineering. Direct numerical simulations of fully 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

We have acquired new knowledge on inhomogeneous turbulence such as turbulent channel flow and turbulence behind a cylinder. For the former flow, we have examined the inter-scale energy transfer and revealed that vortex stretching leads to the energy cascading events in the region away from the solid walls. This result is consistent with the classical picture by Kolmogorov. A result for the latter flow is shown in Fig. 1, which shows coherent vortices at three length scales in the flow. Gray vortices are shedding from the cylinder, around which smaller blue vortices are stretched and created. Furthermore, even smaller yellow vortices are stretched and created around the blue ones. These observations are similar to those in turbulence in a periodic cube.

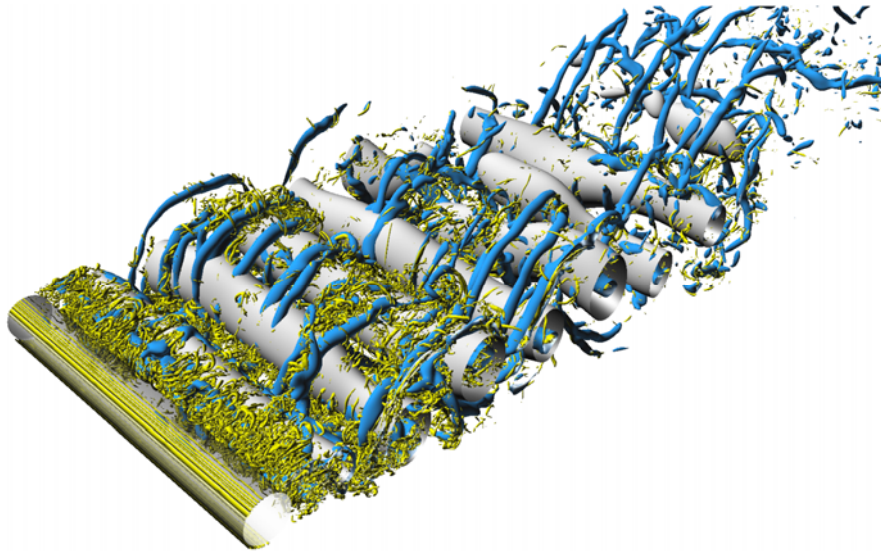


Fig. 1: Turbulence behind a cylinder in a uniform flow. The Reynolds number is about 3900. Different color objects are iso-surfaces of the second invariant of the velocity gradient tensor coarse-grained at different scales. We may observe the hierarchy of vortices in the turbulence.

● Publications

- Peer-reviewed papers

1. Y. Horimoto, A. Katayama, and S. Goto, Conical shear-driven parametric instability of steady flow in precessing spheroids, *Phys. Rev. Fluids* 5 (2020) 063901.
2. Y. Motoori and S. Goto, Hairpin vortices in the largest scale of turbulent boundary layers, *Int. J. Heat Fluid Flow* 86 (2020) 108658.
3. M. Inubushi and S. Goto, Transfer learning for nonlinear dynamics and its application to fluid turbulence, *Phys. Rev. E* 102 (2020) 043301.
4. Y. Motoori and S. Goto, Hierarchy of coherent structures and real-space energy transfer in turbulent channel flow, *J. Fluid Mech.* 911 (2021) A27.
5. S. Oka, D. Watanabe, and S. Goto, Large-scale clustering of light small particles in develop turbulence, *Phys. Fluids*, 33 (2021) 031707.
6. S. Oka and S. Goto, Generalized sweep-stick mechanism of inertial-particle clustering in turbulence, *Phys. Rev. Fluids* (in press).

● Usage of JSS

● Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	OpenMP
Number of Processes	64 - 128
Elapsed Time per Case	60 Hour(s)

● **Resources Used(JSS2)**

Fraction of Usage in Total Resources^{*1}(%): 0.47

Details

Computational Resources		
System Name	Amount of Core Time (core x hours)	Fraction of Usage ^{*2} (%)
SORA-MA	2,384,284.42	0.45
SORA-PP	7,043.67	0.06
SORA-LM	4,958.59	2.91
SORA-TPP	0.00	0.00

File System Resources		
File System Name	Storage Assigned (GiB)	Fraction of Usage ^{*2} (%)
/home	1,501.08	1.38
/data	117,282.92	2.26
/tmp	15,625.01	1.33

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}(%): 0.07

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	1,014.71	0.70
/data	88,081.40	1.48
/ssd	572.20	0.30

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.