Studies on nonlinear vortex dynamics in the later-stage of laminar-turbulent transition in compressible boundary layers

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Abstract

In hypersonic transitional flows, there are many complicated factors such as density fluctuation and temperature fluctuation due to the co-existence of the region slower than the speed of sound and the region faster than the speed of sound inside the boundary layer. Detailed investigations into the vortex dynamics occurring inside the boundary layers are expected. In this study, we aim to clarify the nonlinear vortex dynamics especially in the late-stage by conducting direct numerical simulations of laminar-turbulent transition in compressible boundary layers observed in hypersonic flows. Also, we develop a mathematical methodology to directly introduce vortices responsible for the late stage to the boundary layers, and its computational methods.

Reasons and benefits of using JAXA Supercomputer System

For the investigation of boundary layer transition of hypersonic flows, numerical simulation is a central tool because measurement is difficult due to the existence of acoustical disturbance in a wind tunnel. Because boundary layer transition is susceptible to disturbance, and in addition transition is hard to occur due to strong compressibility, powerful supercomputers that enable high-accuracy large-scale computation are necessary to get results in a short time period.

Achievements of the Year

We succeeded in developing a innovative method of "hierarchical vortex clustering" that can automatically (mechanically) extract, tag, and track almost all major vortical regions (locally connected structures with certain variables) in a turbulent flow and determine the hierarchy among them, and can also analyze mathematical terms related to local dynamics. In addition, we could elucidate the interaction between flow and sound for ring tone flow, the details of which had not yet been clarified.

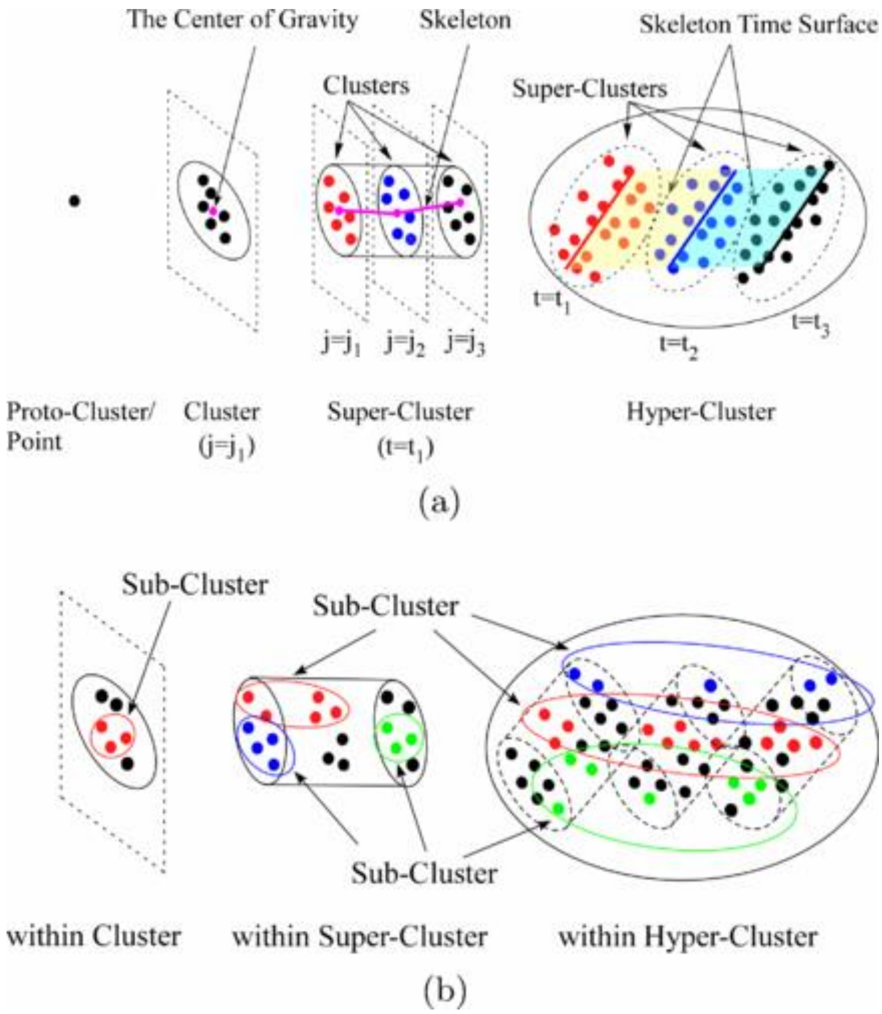

Fig. 1: Proposed hierarchical clusters and its subsets. These clusters are represented in a unified manner as p clusters, where p is replaced with proto, sub, super, or hyper (a simple cluster has no prefix). (a) Fundamental clusters of various levels. Clusters are built up from left to right, and the cluster level increases from lower to upper, accordingly. (b) Subclustering within fundamental clusters

Publications

- Peer-reviewed papers

(1) Kazuo Matsuura, Yasuhide Fukumoto,

Hierarchical Clustering Method of Volumetric Vortical Regions with Application to the Late-Stage of Laminar-Turbulent Transition, Physical Review Fluids, 7 054703, pp. 1-46 (2022).

(2)Kazuo Matsuura, Koh Mukai, Mikael Andersen Langthjem,

Computational and experimental study on the mechanism of ring tone, International Journal of Computational Methods and Experimental Measurements, WIT Press, pp. 1-14 (2022) (accepted).

Usage of JSS

- **Computational Information**

Process Parallelization Methods	MPI
Thread Parallelization Methods	Automatic Parallelization
Number of Processes	16 - 64
Elapsed Time per Case	168 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources*1(%): 0.02

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage*2(%)
TOKI-SORA	525,398.64	0.02
TOKI-ST	0.00	0.00
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	194.02	0.01
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	10.00	0.01
/data and /data2	100.00	0.00
/ssd	100.00	0.01

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.