Data-driven reduced-order modeling of transition phenomena in the object wake

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Abstract

On many fluid systems, such as aircraft and turbines, transition phenomena occur in the wake flow in which the vortex structure drasticaly changes. Since such transitions are accompanied by significant changes in flow frequency and hydrodynamic forces acting on the objects, it is essential to understand the transition phenomena. This study constructs a data-driven reduced-order model based on numerical results in order to analyze and predict the transition phenomena. By incorporating the governing equations describing the flow field into the model construction, we aim to construct a reduced-order model not only for a fast prediction but also as a tool for understanding fluid dynamics.

Reasons and benefits of using JAXA Supercomputer System

Because transitions in the wake of an object are phenomena that depend on the flow conditions, numerical simulations under a large number of conditions are required for data-driven analysis. In addition, since transitions at high Reynolds numbers occur due to the three-dimensional nature of the flow, it is essential to use a supercomputer for numerical simulations as well as for data-driven analysis.

Achievements of the Year

In this year, we found that the reduced-order model can identify the Reynolds number at which the transition occurs, using a relatively low Reynolds number flow around a circular cylinder. Using the coherent modes extracted from numerical simulations for a wide range of Reynolds numbers, we investigated whether the transitions occur by changing the Reynolds number of the flow field represented by the reduced-order models. As a result, it was found that the Reynolds number of the model and the Reynolds number of the flow field represented by the modes should be the same in order to capture the transitions. The model based on the governing equations clarifies the transfer relation of kinetic energy between the modes, and shows that the onset of instability originates

from the energy transfer in the recirculation region of the wake.

Publications

- Peer-reviewed papers

1) Yuto Nakamura, Yuma Kuroda, Shintaro Sato, Naofumi Ohnishi, Energy transfer and budget analysis for transient process with operator-driven reduced-order model, Under review.

2) Yuto Nakamura, Shintaro Sato, Naofumi Ohnishi, Simulation method for finding a fixed point of Navier-Stokes equations by symmetricity constraints, Under review.

- Non peer-reviewed papers

1) Yuto Nakamura, Shintaro Sato, Naofumi Ohnishi, Investigation of three-dimensional instability behind a circular cylinder via low-dimensional space spanned by optimal proper orthogonal decomposition modes, Proceedings of International Colloquium on Bluff Body Aerodynamics and Applications, Birmingham, UK.

2) Yuto Nakamura, Shintaro Sato, Naofumi Ohnishi, Data-driven reduced-order modeling for investigating spanwise instability in the wake of an infinitely long bluff body, Proceedings of Asia-Pacific International Symposium on Aerospace Technology 2024, Australia, Adelaide.

- Oral Presentations

1) Yuto Nakamura, Shintaro Sato, Naofumi Ohnishi, Investigation of three-dimensional instability behind a circular cylinder via low-dimensional space spanned by optimal proper orthogonal decomposition modes, 9th International Colloquium on Bluff Body Aerodynamics and Applications 11.5, 2024/7/29-8/2 (Oral presentation, Birmingham, UK).

2) Yuto Nakamura, Shintaro Sato, Naofumi Ohnishi, Data-driven reduced-order modeling for investigating spanwise instability in the wake of an infinitely long bluff body, Asia-Pacific International Symposium on Aerospace Technology 2024, 2024/10/29-10/28 (Oral presentation, Adelaide, Australia).

3) Yuto Nakamura, Shintaro Sato, Naofumi Ohnishi, Analytical approach to identifying a bifurcation point in reduced-nonlinear dynamical systems formed by shift mode and oscillation modes, 77th Annual Meeting of the Division of Fluid Dynamics, X11.00011, 2024/11/24-11/26 (Oral presentation, Salt-Lake City, USA).

Usage of JSS

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	OpenMP
Number of Processes	1 - 1296
Elapsed Time per Case	48 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources[*1](%): 0.56

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	53,126.34	0.00
TOKI-ST	4,871,527.51	5.00
TOKI-GP	0.00	0.00
TOKI-XM	0.00	0.00
TOKI-LM	24,653.68	1.78
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	0.00	0.00
/data and /data2	30,620.00	0.15
/ssd	5,020.00	0.27

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.