Efficient spatial second-order precision compressible fluid calculation method with resolution equivalent to fifth-order precision

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Abstract

In this study, we move from the MUSCL framework and use the MUSCL-THINC method, which gives the physical quantity distribution within a numerical cell as a hyperbolic function, allowing to sharply capture shock wave discontinuities.

Reasons and benefits of using JAXA Supercomputer System

The effectiveness of the method will be investigated by applying it to various flow configurations such as multiphase flow, electromagnetic fluid, and transonic buffet. These simulations require significant computational power, and therefore the use of JAXA supercomputer is necessary.

Achievements of the Year

The THINC method was originally proposed for multiphase flow interfaces, but preliminary calculations have shown that it is also effective for suppressing the diffusion of weak shock waves such as Mach 1.01. Although this method is an efficient spatial second-order precision method, it achieves a numerical solution with a resolution equivalent to the spatial fifth-order precision, and reduces three to five times the computational cost.

An improved MUSCL-THINC hybrid approach was explored to solve single-phase compressible steady and unsteady flows. We found that the use of THINC for strong shock waves results in oscillatory solutions. To overcome this defect, a new weight parameter which is sensitive to strongness of shock waves is implemented. The new method robustly solved a steady compressible flow featuring strong shock waves while maintaining high-resolution features for weak shock waves and density discontinuities.

Publications

- Peer-reviewed papers

Gaku Fukushima, Keiichi Kitamura, "Improved hybrid approach of monotonic upstream-centered scheme for conservation laws and discontinuity sharpening technique for steady and unsteady flows", Physics of Fluids, accepted

- Oral Presentations

1)Gaku Fukushima, Keiichi Kitamura, "MUSCL and THINC hybrid scheme for strong and very weak shock waves in steady and unsteady flows," 76th Annual Meeting of the Division of Fluid Dynamics, J15.00007, Washingtons DC, USA, 2023.

2) Gaku Fukushima, Keiichi Kitamura, Akihiro Sasoh, "Improvement of Very Weak Shock Capturing Using Hybrid MUSCL-THINC," The 34th International Symposium on Shock Waves, T11-0373, Daegu, Korea, 2023.

3) Gaku Fukushima, Keiichi Kitamura, "Hybridization method of MUSCL and THINC for appropriate computation of strong and weak shock waves", 37th CFD Symposium, 3401-04-04, Nagoya, Japan, 2023

Usage of JSS

Computational Information

Process Parallelization Methods	MPI
Thread Parallelization Methods	N/A
Number of Processes	48 - 480
Elapsed Time per Case	24 Hour(s)

- **JSS3 Resources Used**

Fraction of Usage in Total Resources[*1](%): 0.00

Details

Computational Resources		
System Name	CPU Resources Used (core x hours)	Fraction of Usage[*2](%)
TOKI-SORA	26,940.27	0.00
TOKI-ST	830.41	0.00
TOKI-GP	0.00	0.00
TOKI-XM	42.19	0.02
TOKI-LM	0.00	0.00
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	244.17	0.20
/data and /data2	21,263.89	0.13
/ssd	2,231.11	0.21

Archiver Resources		
Archiver Name	Storage Used (TiB)	Fraction of Usage[*2] (%)
J-SPACE	49.80	0.18

[*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)	3.35	0.00

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