論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	High-resolution positivity-preserving schemes for complex compressible flows
著者(和文)	TannSiengdy
Author(English)	Siengdy Tann
出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第11593号, 授与年月日:2020年9月25日, 学位の種別:課程博士, 審査員:肖 鋒,奥野 喜裕,青木 尊之,末包 哲也,長崎 孝夫
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第11593号, Conferred date:2020/9/25, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	Mechanical Engineering	系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of (Engineering)
学生氏名： Student's Name	TANN Siengdy		指導教員（主）： Academic Supervisor(main)	Professor Feng XIAO
			指導教員（副）： Academic Supervisor(sub)	

要旨（英文 800 語程度）

Thesis Summary（approx.800 English Words ）

When a fluid flows with a speed that March number is much greater than zero, it is called compressible flow which the density of fluid having significant change. The compressible flow is implemented in many fields such as modern high-speed aircraft, natural gas pipeline, gas turbine, and combustion chamber for car engine. The accurate and roust numerical methods for compressible flow were developed for many decades. For instance, the conservative finite volume (FV) framework, one of the classical computational fluid dynamics methods is often employed to solve compressible flow problems.

Most of the classical finite volume schemes are based on a (linear) polynomial reconstruction, which is further supplemented with a nonlinear limiter (slope limiter), (C)WENO blending, hierarchical moment limiter, artificial viscosity, etc. Among the existing FV schemes, some problems have been noticed. For example, the excessive numerical dissipation and numerical oscillation are still significant problems. Furthermore, original high order schemes may generate non-physical negative density or pressure (positivity failure) because of interpolation errors in the vicinity of very strong discontinuities or near vacuum states occur. Furthermore, this issue is one of the main challenges when simulating the compressible Euler equations supplemented with source terms (e.g., gravity, chemical reaction). These non-physical fluid properties lead to blow-up of the computation and subsequent code crash.

In this research work, novel high-resolution positivity preserving schemes for complex compressible flows are proposed and verified trough several numerical benchmark tests. To achieve high fidelity, the numerical methods should preserve the solution properties such as: Accuracy on both smooth and discontinuous profile, non-oscillatory behavior and fail-safe behavior (positivity-preserving).

We present a general formulation of reconstruction in finite volume method by integrating the boundary variation diminishing (BVD) and multi-dimensional optimal order detection (MOOD) methodologies by blending of high/low order polynomials and hyperbolic tangent reconstructions. As a concrete example, we propose a high-resolution scheme under a three-stage cascade BVD algorithm and MOOD method to fulfill the essentially non-oscillation, shock capturing and positivity-preserving properties. For BVD reconstruction strategy, the linear fifth-order upwind or piecewise quartic method (PQM) on fourth-degree of polynomial (P4) is implemented as one of the candidate reconstruction functions to capture smooth solutions. Other candidate reconstruction functions use tangent of hyperbola interface capturing (THINC) functions with different controlling the slope (jump thickness) to eliminate the numerical oscillation and to capture sharply all discontinuities. This strategy determines the candidate interpolant with three-stages cascade BVD process which minimizes the total boundary variation (TBV) in the desired cell. More precisely, TBV is the sum of the jumps generated by the reconstructed values using reconstruction candidate at cell interfaces. At each stage, BVD compare the TBV of two reconstructions of the same data or cell and choose the least dissipative one for the cell. The oscillation-free solution is obtained after stage 1 and 2 occurring. The numerical dissipation at discontinuous/steep gradients is reduced after stage 3 if needed. Moreover, an *a posteriori* MOOD loop is added to the scheme to ensure that in the case the obtained numerical solution at the next time level does not ensure fundamental properties like positivity, computer presentation, then, the solution is locally recomputed with a first-order accurate FV scheme, that is, without any reconstruction. For instance, the criteria of physical admissible detection (PAD) detects or checks the positivity of the candidate solution at the next time level, satisfies the criteria for each cell. The cells where they are satisfied, the numerical solution is accepted for the next time step. Contrarily, the cells which do not pass the criteria are marked as 'trouble', then the cells are locally recomputed by using the first-order Godunov scheme. This-order finite volume scheme produces an excessive numerical dissipation and tends to smear out the flow structures. However, it is conservative, monotone, robust and positivity-preserving.

The proposed scheme is performed via the numerical experiments of benchmark test problems which involve vacuum or near vacuum states, strong discontinuities and also smooth flows. It is demonstrated that the

present scheme provides smooth solution, can sharply capture the discontinuity, contacts, shocks for both homogenous, non-homogenous compressible Euler equations and material interfaces for multiphase flows. Moreover, due to the small but sufficient numerical dissipation, the small-scale structures are well represented, simultaneously with the prevention of the occurrence of spurious oscillations. The *a posteriori* detection loop renders the scheme extremely robust to positivity issues.
The present scheme is a limiter-free approach in the sense that mechanism of dissipation is brought by the appropriate choice of the type of reconstruction (unlimited high-order polynomial, smooth THINC, sharp THINC and piecewise constant). The purpose of this work is to provide an efficient replacement for the pair (polynomial reconstruction, limiter) used in classical FV scheme (TVD, WENO, etc.). In this approach, among several reconstructions is able to choose the most appropriate one according to some goodness criteria; the *a priori* BVD (least dissipative reconstruction), and, an *a posteriori* MOOD (robustness and fail-safe). The scheme is extremely robust to positivity issues due to the *a posteriori* treatment.