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Analysis on Numerical Performance of Gradient Methods for Solving Pure Convection Using the TVD Scheme in the In-house CFD Code Based on Unstructured Meshes

Aphaiwat Wattanakitcharoen[1], Pannasit Borwornpiyawat[1], Varangrat Juntasaro[2], Jian Wu[3], Ekachai Juntasaro[1,*]

[1]Department of Mechanical and Process Engineering, The Sirindhorn International Thai-German Graduate School of Engineering (TGGS), King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand.
[2]Department of Mechanical Engineering, Faculty of Engineering Kasetsart University, Bangkok 10900, Thailand.
[3]School of Energy Science and Engineering, Harbin Institute of Technology, West Dazhi Street, Nangang District, Harbin, 150001, P.R. China

* Corresponding Author: ekachai.j@tggs.kmutnb.ac.th

Abstract. Numerical simulation of convection-dominated flows remains one of the most challenging problems in computational fluid dynamics. It is well-known that the low-order (LO) schemes such as the first-order upwind (FOU) and HYBRID schemes suffer from excessive numerical diffusion while the traditional high-order (HO) schemes such as the second-order upwind (SOU) and central differencing (CD) schemes improve the accuracy compared to the LO schemes. However, the HO schemes may lead to the solution with spurious oscillations when the solution contains steep gradient. The high-resolution schemes (HRS) such as the total variation diminishing (TVD) scheme provide accurate and oscillation-free solutions. Many of the HRS schemes have been implemented on structured meshes in the framework of the finite volume method. For unstructured meshes, the information of gradient has been popularly used for the design of TVD schemes. The most popular gradient calculation schemes are the divergence theorem (Green-Gauss) scheme and the least-squares (LS) scheme. However, the least-squares reconstruction (QR factorization) was found to significantly improve the robustness of the solution method. In the present work, the finite-volume cell-centered method is used to solve the well-known benchmark test problem of pure convection of a transverse step profile imposed at the inflow boundaries of a square computational domain on unstructured meshes. The objective of this article is to analyze in detail the accuracy, the computational cost and the convergence speed of the TVD scheme using those gradient methods in case of steady state problems. For this steady-state test case, the QR and LS methods gain better accuracy than the Green-Gauss method. However, the QR method provides the best convergence speed while the Green-Gauss and LS methods are not converged to the satisfactory convergence criterion.

Keywords: Computational Fluid Dynamics, Finite Volume Method, Total Variation Diminishing Scheme, Unstructured Meshes, QR Factorization Method.