磁気流体力学方程式に対する多状態 AUSM 系スキーム

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Multi-state AUSM-type scheme for magnetohydrodynamics

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The magnetohydrodynamic (MHD) simulation has been extensively employed to study nonlinear dynamics in space and astrophysical plasmas. To capture high speed flows, discontinuities, and shocks in these plasmas, many modern MHD simulation codes are based on upwind schemes (Godunov methods, flux difference splitting methods, and flux vector splitting methods). Numerous studies have been devoted to develop robust and accurate schemes for MHD simulations. In particular, Miyoshi and Kusano (2005) developed the HLLD scheme that can capture the fast mode shock, the rotational discontinuity, and the contact discontinuity. By virtue of its high accuracy and robustness, the scheme becomes a de fact standard for MHD simulations of space and astrophysical plasmas.

The Advection Upstream Splitting Method (AUSM; Liou et al.1993) and its variants (e.g., Liou 1996) have been developed to solve the Euler equation in aerodynamics. The AUSM-type schemes are alternative to other upwind schemes (Godunov, FDS, and FVS), in order to improve accuracy, robustness, and computational efficiency. Recent AUSM-type schemes are formulated to extend to all-speed regimes so that they can solve complex flow problems involving a wide range of Mach numbers (e.g., Liou 2006). The schemes are also known to be robust against a multidimensional shock anomaly at a high Mach number (carbuncle phenomena), whereas familiar multi-state Riemann solvers such as Roe and HLLC(D) schemes tend to suffer from it. Since these advantages are quite useful for MHD simulations as well, the extension of the scheme has been proposed thus far (Han et al. 2009, Kitamura et al. 2019). However, their schemes are not designed to capture the rotational discontinuity, and thus the accuracy may be insufficient to resolve the Alfven wave.

In this study, we propose a new AUSM-type scheme that can capture the multiple MHD discontinuities. The numerical flux is split into mass flux, pressure flux, and magnetic tension flux that is proportional to the normal component of the magnetic field. We derive the magnetic tension flux that is consistent with the HLLD solution so as to capture the rotational discontinuity. We also modify the mass and pressure fluxes based on the Simple Low-dissipation AUSM (SLAU) schemes (Shima and Kitamura 2011, Kitamura and Shima 2013), in order to improve the robustness against the shock anomaly and the resolution of low speed flows. Various benchmark tests are conducted to evaluate the capability of the scheme. In particular, the scheme successfully solves a multidimensional MHD shock without the anomaly. Details of the scheme and its performance will be presented.