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Extension and Comparative Study of AUSM-Family Schemes for Compressible Multiphase Flow Simulations

Keiichi Kitamura[1,2,*], Meng-Sing Liou[1] and Chih-Hao Chang[3]

[1] *NASA Glenn Research Center, Cleveland, OH 44135, USA.*
[2] *Research Fellow of Japan Society for the Promotion of Science (JSPS), JAXA's Engineering Digital Innovation (JEDI) Center, 3-1-1 Yoshinodai, Chuo, Sagamihara, Japan; Previously at Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8603 Japan; Currently at Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan.*
[3] *Theofanous & Co Inc. Santa Barbara, CA 93109, USA.*

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Abstract. Several recently developed AUSM-family numerical flux functions (SLAU, SLAU2, AUSM$^+$-up2, and AUSMPW+) have been successfully extended to compute compressible multiphase flows, based on the stratified flow model concept, by following two previous works: one by M.-S. Liou, C.-H. Chang, L. Nguyen, and T.G. Theofanous [AIAA J. 46:2345-2356, 2008], in which AUSM$^+$-up was used entirely, and the other by C.-H. Chang, and M.-S. Liou [J. Comput. Phys. 225:840-873, 2007], in which the exact Riemann solver was combined into AUSM$^+$-up at the phase interface. Through an extensive survey by comparing flux functions, the following are found: (1) AUSM$^+$-up with dissipation parameters of K_p and K_u equal to 0.5 or greater, AUSMPW+, SLAU2, AUSM$^+$-up2, and SLAU can be used to solve benchmark problems, including a shock/water-droplet interaction; (2) SLAU shows oscillatory behaviors [though not as catastrophic as those of AUSM$^+$ (a special case of AUSM$^+$-up with $K_p = K_u = 0$)] due to insufficient dissipation arising from its ideal-gas-based dissipation term; and (3) when combined with the exact Riemann solver, AUSM$^+$-up ($K_p = K_u = 1$), SLAU2, and AUSMPW+ are applicable to more challenging problems with high pressure ratios.

AMS subject classifications: 76T10, 76M12, 76N99

Key words: Multiphase flow, two-fluid model, AUSM-family, stratified flow model.

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[*] Corresponding author. *Email addresses:* `kitamura@ynu.ac.jp` (K. Kitamura), `meng-sing.liou@nasa.gov` (M.-S. Liou), `chchang@theofanous.net` (C.-H. Chang)

Nomenclature

a = speed of sound [m/s]
α = volume fraction
C_p = specific heat at constant pressure, 1004.5 for air and 4186 for water [J/(kg K)]
C_p^* = interfacial pressure coefficient, 2.0
χ = function in SLAU
E = total energy per unit mass [J/kg]
$\mathbf{E}$,$\mathbf{F}$ = inviscid (numerical) flux vectors in x and y directions, respectively
ε = small positive value, such as 10^{-7}
g = gravity constant, 9.8 [m/s^2], or function in SLAU
G = cubic function
γ = specific heat ratio, 1.4 for air and 2.8 for water
H = total enthalpy [J/kg]
K_p,K_u = dissipation coefficients in AUSM$^+$-up
M = Mach number
p = pressure [Pa]
PR = pressure ratio, p_L/p_R
$\mathbf{Q}$ = conservative variable vector
ρ = density [kg/m^3]
S = area of cell interface [m^2]
T = temperature [K]
V = cell volume [m^3], or velocity [m/s]
u,v = velocity components in Cartesian coordinates [m/s]
x,y = Cartesian coordinates [m]

Subscripts
L, R = left and right running wave components
g = gas phase
j = (current) cell index
k = k-th phase (k=1, 2 or g,l)
l = liquid phase
n = normal component to cell interface
m = Newton iteration stage
∞ = freestream or reference value
1/2 = cell-interfacial value

Superscripts
int = interfacial value
max, min = maximum and minimum values
+, - = left- and right-side values at cell interface
$^-$ = arithmetically averaged value of both sides at cell interface

1 Introduction

Although the present computational fluid dynamics (CFD) technologies for compressible flows enable us to simulate a wide variety of flow physics, we still have issues in dealing with high- and low-speed flows:

1) High-speed flows ($M>1.5$, super- and hypersonic): Shock anomalies [1–4], diffi-