Zhang, Liangqi; **Zeng, Zhong**; **Xie, Haiqiong**; **Zhang, Yongxiang**; **Lu, Yiyu**; **Yoshikawa, Akira**; **Mizuseki, Hiroshi**; **Kawazoe, Yoshiyuki**

A comparative study of lattice Boltzmann models for incompressible flow. (English)

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Summary: For incompressible flow, a comparative study on the four lattice Boltzmann (LB) models, the standard model, the He-Luo model, Guo's model, and the present model, is performed. Theoretically, the macroscopic equations derived from the involved LB models are compared by the Chapman-Enskog analysis. Then, the analytical framework proposed in M. Junk's work is applied to investigate the finite difference stencils and the equivalent moment systems pertaining to the concerned LB models. Conclusions are drawn from the theoretical derivations that the truncated error terms, which differ among the concerned LB models, have effects on the accuracy of the modeled deviatoric stress. Moreover, the cavity flow in two dimensions is adopted as a benchmark test to confirm the theoretical demonstrations. The resulting velocity fields from the present model are more in line with the reference solutions in the region of high deviatoric stress than other three LB models, which is consistent with the theoretical expectations and is further confirmed by the comparisons of the truncation error terms. In addition, we also conclude from the numerical tests that the present model has the advantage of better convergence efficiency but suffers from the worse stability.

MSC:

76M28 Particle methods and lattice-gas methods
76D99 Incompressible viscous fluids

Keywords:

lattice Boltzmann model; incompressible flow; deviatoric stress; finite difference stencils

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References:

[1] McNamara, G. R.; Zanetti, G., Use of the Boltzmann equation to simulate lattice-gas automata, Phys. Rev. Lett., 61, 2332-2335, (1988)

[2] Benzi, R.; Succi, S.; Vergassola, M., The lattice Boltzmann equation: theory and applications, Phys. Rep., 222, 145-197, (1992)

[3] Succi, S., The lattice Boltzmann equation: for fluid dynamics and beyond, (2001), Oxford University Press Oxford · Zbl 0990.76001

[4] Higuera, F. J.; Succi, S., Simulating the flow around a circular cylinder with a lattice Boltzmann equation, Europhys. Lett., 8, 517-521, (1989)

[5] Higuera, F. J.; Jiménez, J., Boltzmann approach to lattice gas simulations, Europhys. Lett., 9, 663-668, (1989)

[6] Higuera, F. J.; Succi, S.; Benzi, R., Lattice gas dynamics with enhanced collisions, Europhys. Lett., 9, 345-349, (1989)

[7] Chapman, S.; Cowling, T. G., The mathematical theory of non-uniform gases, (1970), Cambridge University Press London · Zbl 0098.39702

[8] Guo, Z. L.; Zheng, C. G., Theory and applications of lattice Boltzmann method, (2009), Science Press Beijing

[9] He, Y. L.; Wang, Y.; Li, Q., Lattice Boltzmann method: theory and application, (2009), Science Press Beijing · Zbl 1229.76090

[10] Guo, Z. L.; Shi, B. C.; Wang, N. C., Lattice BGK model for the incompressible Navier-Stokes equation, J. Comput. Phys., 165, 288-306, (2000) · Zbl 0979.76069

[11] Zou, Q. S.; Hou, S. L.; Chen, S. Y.; Doolen, G. D., An improved incompressible lattice Boltzmann model for time-independent flows, J. Stat. Phys., 81, 35-48, (1995) · Zbl 1106.82366

[12] Lin, Z. F.; Fang, H. P.; Tao, R. B., Improved lattice Boltzmann model for incompressible two-dimensional steady flow, Phys. Rev. E, 54, 6323-6330, (1996)

[13] He, X. Y.; Luo, L.-S., Lattice Boltzmann model for the incompressible Navier-Stokes equation, J. Stat. Phys., 88, 927-944, (1997) · Zbl 0939.82042

[14] Qian, Y. H.; d'Humières, D.; Lallemand, P., Lattice BGK models for Navier-Stokes equation, Europhys. Lett., 17, 479-484, (1992) · Zbl 1116.76419

[15] Dellar, P. J., Incompressible limits of lattice Boltzmann equations using multiple relaxation times, J. Comput. Phys., 190, 351-370, (2003) · Zbl 1076.76063

[16] Grad, H., Note on N-dimensional Hermite polynomials, Comm. Pure Appl. Math., 2, 325-330, (1949) · Zbl 0036.04102

[17] Grad, H., On the kinetic theory of rarefied gases, Comm. Pure Appl. Math., 2, 331-407, (1949) · Zbl 0037.13104

[18] Shan, X. W.; Yuan, X. F.; Chen, H. D., Kinetic theory representation of hydrodynamics: a way beyond the Navier-Stokes equation, J. Fluid Mech., 550, 413-441, (2006) · Zbl 1097.76061

[19] Dellar, P. J., Nonhydrodynamic modes and a priori construction of shallow water lattice Boltzmann equations, Phys. Rev. E, 65, 036309, (2002)

[20] Junk, M., A finite difference interpretation of the lattice Boltzmann method, Numer. Methods Partial Differential Equations, 17, 383-402, (2001) · Zbl 0987.76082

[21] Junk, M.; Klar, A., Discretizations for the incompressible Navier-Stokes equations based on the lattice Boltzmann method, SIAM J. Sci. Comput., 22, 1-22, (2000) · Zbl 0972.76083

[22] Hou, S. L.; Zou, Q. S., Simulation of cavity flow by the lattice Boltzmann method, J. Comput. Phys., 118, 329-347, (1995) · Zbl 0821.76060

[23] Luo, L. S.; Liao, W.; Chen, X. W.; Peng, Y.; Zhang, W., Numerics of the lattice Boltzmann method: effects of collision models on the lattice Boltzmann simulations, Phys. Rev. E, 83, 056710, (2011)

[24] Yu, D. Z.; Mei, R. W.; Shyy, W., A multi-block lattice Boltzmann method for viscous fluid flows, Internat. J. Numer. Methods Fluids, 39, 99-120, (2002) · Zbl 1036.76051

[25] Yu, D. Z.; Mei, R. W.; Luo, L.-S.; Shyy, W., Viscous flow computations with the method of lattice Boltzmann equation, Prog. Aerosp. Sci., 39, 329-367, (2003)

[26] Peng, C., Lattice Boltzmann method for fluid dynamics: theory and applications, (2011), EPFL, (Master thesis)

[27] Wu, J.; Shu, C., A solution-adaptive lattice Boltzmann method for two-dimensional incompressible viscous flows, J. Comput. Phys., 230, 2246-2269, (2011) · Zbl 1391.76643

[28] Chen, Y.; Kang, Q. J.; Cai, Q. D.; Zhang, D. X., Lattice Boltzmann method on quadtree grids, Phys. Rev. E, 83, 026707, (2011)

[29] Montessori, A.; La Rocca, M.; Falcucci, G.; Succi, S., Regularized lattice BGK versus highly accurate spectral methods for cavity flow simulations, Internat. J. Modern Phys. C, 25, 1441003, (2014)

[30] Montessori, A.; Falcucci, G.; Prestininzi, P.; La Rocca, M.; Succi, S., Regularized lattice Bhatnagar-Gross-Krook model for two- and three-dimensional cavity flow simulations, Phys. Rev. E, 89, 053317, (2014)

[31] Dellar, P. J., Bulk and shear viscosities in lattice Boltzmann equations, Phys. Rev. E, 64, 031203, (2001)

[32] Frisch, U.; d'Humières, D.; Hasslacher, B.; Lallemand, P.; Pomeau, Y.; Rivet, J.-P., Lattice gas hydrodynamics in two and three dimensions, Complex Systems, 1, 649-707, (1987) · Zbl 0662.76101

[33] Shan, X. W.; He, X. Y., Discretization of the velocity space in the solution of the Boltzmann equation, Phys. Rev. Lett., 80, 65-68, (1998)

[34] He, X. Y.; Luo, L. S., Theory of the lattice Boltzmann method: from the Boltzmann equation to the lattice Boltzmann equation, Phys. Rev. E, 56, 6811-6817, (1997)

[35] Ghia, U.; Ghia, K. N.; Shin, C. T., High-Re solutions for incompressible flow using the Navier-Stokes equations and a multigrid method, J. Comput. Phys., 48, 387-411, (1982) · Zbl 0511.76031

[36] Guo, Z. L.; Zheng, C. G.; Shi, B. C., Non-equilibrium extrapolation method for velocity and pressure boundary conditions in the lattice Boltzmann method, Chin. Phys. Soc., 11, 0366-0374, (2002)

[37] Guo, Z. L.; Zheng, C. G.; Shi, B. C., An extrapolation method for boundary conditions in lattice Boltzmann method, Phys. Fluids, 14, 2007-2010, (2002) · Zbl 1185.76156

[38] Lallemand, P.; Luo, L.-S., Theory of the lattice Boltzmann method: dispersion, dissipation, isotropy, Galilean invariance, and stability, Phys. Rev. E, 61, 6546-6562, (2000)

[39] d'Humières, D., Generalized lattice-Boltzmann equations, (Shizgal, B. D.; Weave, D. P., Rarefied Gas Dynamics: Theory and Simulations, Prog. Astronaut. Aeronaut., vol. 159, (1992), AIAA Washington, DC), 450-458

[40] Du, R.; Shi, B. C.; Chen, X. W., Multi-relaxation-time lattice Boltzmann model for incompressible flow, Phys. Lett. A, 359, 564-572, (2006) · Zbl 1236.76050

[41] Wu, J.; Shu, C., An improved immersed boundary-lattice Boltzmann method for simulating three-dimensional incompressible flows, J. Comput. Phys., 229, 5022-5042, (2010) · Zbl 1346.76164

[42] Ginzbourg, I.; d'Humières, D., Local second-order boundary methods for lattice Boltzmann models, J. Stat. Phys., 84, 927-971, (1996) · Zbl 1081.82617

[43] Lätt, J., Hydrodynamic limit of lattice Boltzmann equations, (2007), (Ph.D. thesis)

[44] Caiazzo, A.; Junk, M.; Rheinländer, M., Comparison of analysis techniques for the lattice Boltzmann method, Comput. Math. Appl., 58, 883-897, (2009) · Zbl 1189.76400

[45] Junk, M.; Klar, A.; Luo, L.-S., Asymptotic analysis of the lattice Boltzmann equation, J. Comput. Phys., 210, 676-704, (2005) · Zbl 1079.82013

paper as accurately as possible without claiming the completeness or perfect precision of the matching.