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MHD compressible turbulent boundary-layer flow with adverse pressure gradient. (English)

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Summary: The effects of the magnetic field and localized suction on the steady turbulent compressible boundary-layer flow with adverse pressure gradient are numerically studied. The magnetic field is constant and applied transversely to the direction of the flow (global or local). The fluid flow is subjected to a constant velocity of localized suction, and there is no heat transfer between the fluid and the plate (adiabatic plate). The Reynolds-averaged boundary-layer (RABL) equations and their boundary conditions are transformed using the compressible Falkner-Skan transformation. The resulting coupled and nonlinear system of PDEs is solved using the Keller's box method. For the eddy-kinematic viscosity, the turbulent models of Cebeci-Smith and Baldwin-Lomax are employed. For the turbulent Prandtl number, the extended Kays-Crawford's model is used. The flow is subjected to an adverse pressure gradient. The obtained results show that the flow field can be controlled by the applied magnetic field as well as by localized suction.

MSC:

76W05 Magnetohydrodynamics and electrohydrodynamics
76F40 Turbulent boundary layers
76F50 Compressibility effects in turbulence

Keywords:

Reynolds-averaged boundary-layer equations; compressible Falkner-Skan transformation; extended Kays-Crawford's model

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References:

[1] Gad-el-Hak, M., Bushnell, D. M.: Status and outlook of flow separation control. AIAA Paper 91-0037, 1991.

[2] Arnal, D.: Control of laminar-turbulent transition for skin friction drag reduction. In: Control of flow instabilities and unsteady flows. CISM Courses and Lectures 369 (Meier, G. E. A., Schnerr, G. M., eds.), pp. 119–153. Wien New York: Springer 1996. · Zbl 0885.76025

[3] Wilkinson, S. P., Anders, J. B., Lazos, B. S., Bushnell, D. M.: Turbulent drag reduction research of NASA Langley: Progress and plans. Int. J. Heat Fluid Flow 9, 266–277 (1988).

[4] Gad-el-Hak, M., Blackwelder, R. F.: Selective suction of controlling bursting events in a boundary layer. AIAA J. 27(3), 308–314 (1989).

[5] Sokolov, M., Antonia, R. A.: Response of a turbulent boundary layer to intensive suction through a porous strip. In: Proc. 9th Symp. on Turbulent Shear Flows, Kyoto, Japan, Paper 5–3, 1993.

[6] Kafoussias, N. G., Xenos, M. A.: Numerical investigation of two-dimensional turbulent boundary-layer compressible flow with adverse pressure gradient and heat and mass transfer. Acta Mech. 141, 201–223 (2000). · Zbl 0987.76037

[7] Sumitani, Y., Kasagi, N.: Direct numerical simulation of turbulent transport with uniform wall injection and suction. AIAA J. 33(7), 1220–1228 (1995).

[8] Roy, S.: Nonuniform slot injection (suction) into a compressible flow. Acta Mech. 139, 43–56 (2000). · Zbl 1064.76093

[9] Xenos, M., Kafoussias, N., Karahalios, G.: Magnetohydrodynamic compressible laminar boundary layer adiabatic flow with adverse pressure gradient and continuous or localized mass transfer. Canadian J. Phys. 79, 1247–1263 (2001).

[10] Cebeci, T., Bradshaw, P.: Physical and computational aspects of convective heat transfer. New York: Springer 1984. · Zbl 0545.76090

[11] Rossow, V. J.: On flow of electrically conducting fluids over a flat plate in the presence of a transverse magnetic field. NACA Report 1358, 1957.

[12] Bleviss, Z. O.: Magnetogasdynamics of hypersonic couette flow. J. Aero/Space Science 25(10), 601–615 (1958). · Zbl 0082.40201

[13] Weier, T., Fey, U., Gerbeth, G., Mutschke, G., Avilov, V.: Boundary-layer control by means of electromagnetic forces. ERCOFTAC Bull. 44, 36–40 (2000).

[14] Schlichting, H.: Boundary-layer theory (trans. by Kestin, J.), 7th ed., pp. 43–44. New York: McGraw-Hill 1979.

[15] Cheng, F., Zhong, X., Gogineni, S., Kimmel, R. L.: Magnetic-field effects on second-mode instability of a weakly ionized Mach 4.5 boundary layer. Phys. Fluids 15(7), 2020–2040 (2003). · Zbl 1186.76102

[16] Resler, E. L., Sears, W. R.: The prospects for magneto-aerodynamics. J. Aeronaut. Sci. 25(4), 235–258 (1958). · Zbl 0080.21404

[17] Murray, R. C., Zaidi, S. H., Carraro, M. R., Vasilyak, L., Macheret, S. O., Shneider, M. N., Miles, R. B.: Investigation of a Mach 3 cold air MHD channel. 34th AIAA Plasmadynamics and Laser Conf., AIAA 2003–4282, 2003.

[18] Dahlburg, R. B., Picone, J. M.: Pseudospectral simulation of compressible magnetohydrodynamic turbulence. Int. Conf. on Spectral and High-order Methods for Partial Differential Equations, pp. 409–416. Amsterdam: North-Holland 1990. · Zbl 0722.76056

[19] Satake, S.-I., Kunugi, T., Smolentsev, S.: Advances in direct numerical simulation for MHD modeling of free surface flows. Fusion Engng Design 61–62, 95–102 (2002).

[20] Brandenburg, A., Dobler, W.: Hydromagnetic turbulence in computer simulations. Comp. Phys. Comm. 147, 471–475 (2002). · Zbl 1016.85002

[21] Passot, T., Vázquez-Semadeni, E.: The correlation between magnetic pressure and density in compressible MHD turbulence. Astron. \& Astrophys. 398, 845–855 (2003). · Zbl 1027.76066

[22] Pop, I., Kumari, M., Nath, G.: Conjugate MHD flow past a flat plate. Acta Mech. 106, 215–220 (1994). · Zbl 0847.76096

[23] Sutton, G. W., Sherman, A.: Engineering magnetohydrodynamics, pp. 420–424. New York: McGraw-Hill 1965.

[24] Cebeci, T., Smith, A. M. O.: Analysis of turbulent boundary layers, pp. 258–296, 329–370. New York: Academic Press 1974. · Zbl 0342.76014

[25] Bradshaw, P. (ed.): Turbulence. Topics in applied physics, vol. 12, pp. 193–195. Berlin: Springer 1976.

[26] Henkes, R. A. W. M.: Scaling of equilibrium boundary layers under adverse pressure gradient using turbulent models. AIAA J. 36(3), 320–326 (1998).

[27] Baldwin, B., Lomax, H.: Thin-layer approximation and algebraic model for separated turbulent flows. AIAA Paper 78–205, 1978.

[28] Steger, J. L.: Implicit finite difference simulation of flow about arbitrary geometries with application to airfoils. AIAA Paper 77–665, presented at AIAA 12th Thermophysics Conf., Albuquerque, New Mexico, June 27–29, 1977.

[29] Pulliam, T. H., Steger, J. L.: Implicit finite-difference simulations of three-dimensional compressible flow. AIAA J. 18(2), 159–167 (1980). · Zbl 0417.76039

[30] Tam, C.-J., Orkwis, P. D.: Comparison of Baldwin–Lomax turbulence models for two-dimensional open cavity computations. AIAA J. 34(3), 629–631 (1995). · Zbl 0900.76161

[31] Weigand, B., Ferguson, J. R., Crawford, M. E.: An extended Kays and Crawford turbulent Prandtl number model. Int. J. Heat Mass Transf. 40(17), 4191–4196 (1997).

[32] Kafoussias, N., Karabis, A., Xenos, M.: Numerical study of two-dimensional laminar boundary layer compressible flow with pressure gradient and heat and mass transfer. Int. J. Engng Sci. 37, 1795–1812 (1999).

[33] Keller, H. B.: A new difference scheme for parabolic problems. In: Numerical solutions of partial differential equations II (Bramble, J., ed.), pp. 265–293. New York: Academic Press 1970.

[34] Tannehill, J. C., Anderson, D. A., Pletcher, R. H.: Computational fluid mechanics and heat transfer, 2nd ed., pp. 134–137, 462–465. Taylor \& Francis 1997. · Zbl 0569.76001

[35] Davidson, J. H., Kulacki, F. A., Dunn, P. F.: Convective heat transfer with electric and magnetic fields. In: Handbook of single-phase convective heat transfer (Kakac, S., Shah, R. K., Aung, W., eds.), pp. 9.1–9.49. New York: Wiley 1987.

[36] Cecilio, W. A., Cordeiro, C. J., Milléo, I.S., Santiago, C. D., Zanardini, R.A.D., Yuan, J. Y.: A note on polynomial interpolation. Int. J. Comp. Math. 79(4), 465–471 (2002). · Zbl 0996.65005

[37] Chung, Y. M., Sung, H. J., Boiko, A. V.: Spatial simulation of the instability of channel flow with local suction/blowing. Phys. Fluids 9(11), 3258–3266 (1997).

[38] Howarth, L.: On the solution of the laminar boundary-layer equations. Proc. Royal Soc. London A 164, 547–579 (1938). · Zbl 64.1452.01

[39] Bush, W. B.: Compressible flat-plate boundary-layer flow with an applied magnetic field. J. Aero/Space Sci. 27, 49–58 (1960). · Zbl 0099.21204

[40] Wright Jr., R. S., Sweet, M. R.: OpenGL SuperBible, 2nd ed. San Franciso: Waite Group Press 1999.