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Scientific paper

THE INFLUENCE OF THE MAGNETIC FIELD AND THE POROSITY OF THE BODY CONTOUR ON THE IONISED GAS FLOW IN THE PLANAR BOUNDARY LAYER

O UTICAJU MAGNETNOG POLJA I POROZNOSTI KONTURE TELA NA STRUJANJE JONIZOVANOG GASA U RAVANSKOM GRANIČNOM SLOJU

Savić S.[1], Obrović B.[1], Jovanović S.[1], Hristov N.[2], Todić N.[1]

SUMMARY

This paper studies steady, planar, laminar magnetohydrodynamic (MHD) ionised gas (air) in the boundary layer. The contour of the body within the fluid is porous. The gas is electroconductive and it flows in the presence of a magnetic field. The problem is solved using a multiparametric general similarity method. The obtained so-called universal equations are solved numerically in a corresponding approximation. The influence of the magnetic field and the porosity of the body contour on the position of the boundary layer separation point is also analysed.

Keywords: ionised gas, boundary layer, magnetic field, porous wall, electroconductivity

INTRODUCTION

The generalized similarity method used in this paper was first used by Loitsianskii [1]. The method was then modified by Saljnikov [2]. Saljnikov's version was used to solve numerous problems in the MHD boundary layer theory that involved incompressible fluid flow around a body within fluid. The problems included the cases when the outer magnetic field is normal to the contour of the body within fluid, when the fluid electroconductivity is constant [3], and when the electroconductivity varies [4]. The importance of electroconductivity variation was pointed out from the practical, theoretical and methodological point of view.

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MATHEMATICAL FORMULATION

These problems are of great importance for the high speed aerodynamics, especially for the boundary layer flow management using a porous contour through which fluid of the same

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properties as the main flow fluid is either injected at velocity v_w ($v_w(x) > 0$) or ejected ($v_w(x) < 0$). Boundary layer management can be achieved through the magnetic field. Due to the effects of the outer transversal magnetic field, an electrical flow is formed which causes the occurrence of Lorentz force and Joule heat.

In the case of the ionised gas flow in the magnetic field adjacent the porous wall under the conditions of equilibrium ionization, the governing equation system of the steady laminar boundary layer is

$$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) = 0,$$

$$\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} = -\frac{\mathrm{d}p}{\mathrm{d}x} + \frac{\partial}{\partial y}\left(\mu \frac{\partial u}{\partial y}\right) - \sigma B_m^2 u, \qquad (1)$$

$$\rho u \frac{\partial h}{\partial x} + \rho v \frac{\partial h}{\partial y} = u \frac{\mathrm{d}p}{\mathrm{d}x} + \mu \left(\frac{\partial u}{\partial y}\right)^2 + \frac{\partial}{\partial y}\left(\frac{\mu}{\mathrm{Pr}} \frac{\partial h}{\partial y}\right) + \sigma B_m^2 u^2;$$

where the equations are: continuity equation, dynamic equation and energy equation, respectively:

The boundary conditions are:

$$u = 0, \quad v = v_w(x), \quad h = h_w \quad \text{for} \quad y = 0,$$
$$u \to u_e(x), \quad h \to h_e(x) \quad \text{for} \quad y \to \infty. \qquad (2)$$

In the equation system and in the boundary layer, the notation common in the boundary layer [8] is used.

Electroconductivity σ is one of the major properties of the ionised gas. In order to fully comprehend the influence of the transversal magnetic field on the boundary layer properties in [5-7] and in this paper, three characteristic electroconductivity variation laws were applied:

$$\sigma = \sigma(x) \quad (a), \quad \sigma = \sigma_0\left(1 - \frac{u}{u_e}\right) \quad (b), \quad \sigma = \sigma_0 \frac{\nu_0}{u_e^2}\frac{\partial u}{\partial y}, \quad (\sigma_0, \nu_0 = \text{const.}) \ (c). \qquad (3)$$

Modern methods for solution of the boundary layer equations of incompressible and compressible fluid are based on introduction of corresponding sets of parameters for which a momentum equation has to be obtained first. Therefore, instead of physical coordinates x, y, velocities u(x, y) and v(x, y), new variables s(x), z(x, y), and the stream function $\psi(x, z)$ are introduced first, and then, due to the porous body contour, a new stream function $\psi^*(x, z)$ is also introduced. Integrating the dynamic equation transversally to the boundary layer the corresponding momentum equation is obtained, and then three sets of parameters are introduced f_k, g_k and Λ_k. If such defined similarity parameters are accepted as new independent variables, the main equation system (1) is transformed into a system of the so-called generalised – universal equations. These equations represent a general mathematical model of ionised gas flow in the boundary layer adjacent the porous wall. Thus obtained equation system can be solved only for a relatively small number of similarity parameters. Assuming that:

$$\kappa = f_0 \neq 0, \quad f_1 = f \neq 0, \quad g_1 = g \neq 0, \quad \Lambda_1 = \Lambda \neq 0;$$
$$f_2 = f_3 = \ldots = 0, \quad g_2 = g_3 = \ldots = 0, \quad \Lambda_2 = \Lambda_3 = \ldots = 0, \qquad (4)$$

and that: $\partial/\partial\kappa = 0,\ \partial/\partial g_1 = 0,\ \partial/\partial\Lambda_1 = 0$, the transformed equation system is significantly simplified. In addition, the order of the system of differential equations (1) is decreased by the change

$$\frac{u}{u_e} = \frac{\partial\Phi}{\partial\eta} = \varphi = \varphi(\eta,\ \kappa,\ f,\ g,\ \Lambda). \tag{5}$$

Hence, the main equation system in a four-parametric three-time localised approximation has the following form:

$$\begin{aligned}
&\frac{\partial}{\partial\eta}\left(Q\frac{\partial\varphi}{\partial\eta}\right) + \frac{aB^2 + (2-b)f}{2B^2}\Phi\frac{\partial\varphi}{\partial\eta} + \frac{f}{B^2}\left[\frac{\rho_e}{\rho} - \varphi^2\right] - \frac{g}{B}\frac{\partial\varphi}{\partial\eta}\varphi + \frac{\Lambda}{B}\frac{\partial\varphi}{\partial\eta} = \\
&= \frac{F_{mp}f}{B^2}\left(\varphi\frac{\partial\varphi}{\partial f} - \frac{\partial\Phi}{\partial f}\frac{\partial\varphi}{\partial\eta}\right), \\
&\frac{\partial}{\partial\eta}\left(\frac{Q}{\Pr}\frac{\partial\bar{h}}{\partial\eta}\right) + \frac{aB^2 + (2-b)f}{2B^2}\Phi\frac{\partial\bar{h}}{\partial\eta} - \frac{2\kappa f}{B^2}\frac{\rho_e}{\rho}\varphi + 2\kappa Q\left(\frac{\partial\varphi}{\partial\eta}\right)^2 + \frac{2\kappa g}{B}\frac{\rho_e}{\rho}\varphi^2 + \\
&+ \frac{\Lambda}{B}\frac{\partial\bar{h}}{\partial\eta} = \frac{F_{mp}f}{B^2}\left(\varphi\frac{\partial\bar{h}}{\partial f} - \frac{\partial\Phi}{\partial f}\frac{\partial\bar{h}}{\partial\eta}\right).
\end{aligned} \tag{6}$$

The boundary conditions are:

$$\begin{aligned}
&\Phi = \varphi = 0, \quad \bar{h} = \bar{h}_w = const. \quad \text{for} \quad \eta = 0, \\
&\varphi \to 1, \quad \bar{h} \to \bar{h}_e = 1-\kappa \quad \text{for} \quad \eta \to \infty.
\end{aligned} \tag{7}$$

Where: η – nondimensional transversal coordinate, Φ – nondimensional stream function, $\bar{h}$ – nondimensional enthalpy, $\kappa = f_0 = u_e^2/2h_1$ – local compressibility parameter, h_1– enthalpy at the front stagnation point of the body within the fluid, f_1=f – first form parameter, g_1=g – first magnetic parameter, Λ_1=Λ – first porosity parameter, Fmp, Q – characteristic boundary layer functions, Pr –Prandtl number and a, b – constants. For the nondimensional function Q and for the density ratio ρ_e/ρ, the approximation formulas have been adopted:

$$Q = Q(\bar{h}) = \left(\frac{\bar{h}_w}{\bar{h}}\right)^{1/3}, \qquad \frac{\rho_e}{\rho} \approx \frac{\bar{h}}{1-\kappa}, \tag{8}$$

for which a concrete numerical solution of the equation system (6) was needed.

RESULTS OF INVESTIGATIONS AND DISCUSSION

Numerical solution of the system (6) was performed using a ″passage method″. Some derivatives of the variables were replaced by the corresponding finite differences ratio [8], so the solution of the partial differential equations comes down to solution of the system of linear algebraic equations which together with the boundary layer has the following form:

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$$a^{i}_{M,K+1}\varphi^{i}_{M-1,K+1}-2b^{i}_{M,K+1}\varphi^{i}_{M,K+1}+c^{i}_{M,K+1}\varphi^{i}_{M+1,K+1}=g^{i}_{M,K+1},$$
$$a^{j}_{M,K+1}\overline{h}^{j}_{M-1,K+1}-2b^{j}_{M,K+1}\overline{h}^{j}_{M,K+1}+c^{j}_{M,K+1}\overline{h}^{j}_{M+1,K+1}=g^{j}_{M,K+1};$$
$$M=2,3,\dots,N-1;\quad K=0,1,2,\dots;\quad i,j=0,1,2,\dots \qquad (9)$$
$$\Phi^{i}_{1,K+1}=\varphi^{i}_{1,K+1}=0,\quad \overline{h}^{j}_{1,K+1}=\overline{h}_{w}=const.\quad \text{for}\quad M=1,$$
$$\varphi^{i}_{N,K+1}=1,\quad \overline{h}^{j}_{N,K+1}=1-\kappa \quad \text{for}\quad M=N.$$

The coefficients a, b, c and g in the system (9) are determined by the complex expressions which are not shown in this paper. A special program in FORTRAN was written and used for solution of the given equation system.

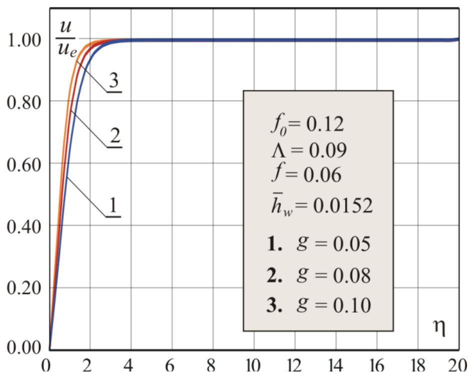

Fig. 1. Nondimensional velocity u/ue , law (a)

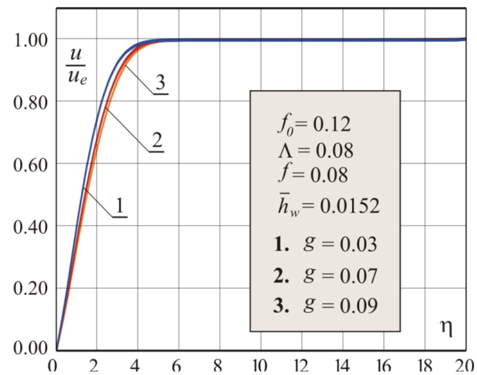

Fig. 2. Nondimensional velocity u/ue , law (b)

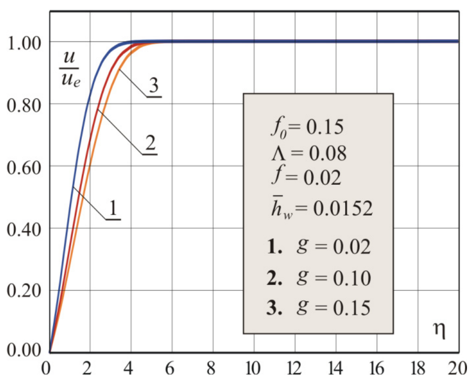

Fig. 3. Nondimensional velocity u/ue , law (c)

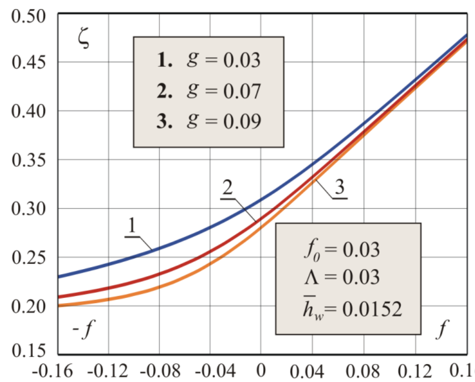

Fig. 4. Distribution of nondimensional friction function ζ , law (a)

Based on the results given in form of diagrams, it can be concluded that:

- The nondimensional velocity u/u_e at different cross-sections of the boundary layer converges fast towards unity. Neither an increase nor a decrease in the magnetic field affects the speed of convergence. The conclusion remains the same regardless of the fact whether the contour of the body is porous or nonporous. Injection or ejection of the air flow does not have an effect on the profiles of nondimensional velocities u/u_e.

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Variation of the electroconductivity σ of air also has no effect on convergence of nondimensional velocity (Figs. 1-3).

- The magnetic field (represented by the magnetic parameter g) has a significant influence on the boundary layer quantities, especially on the nondimensional friction function ζ. When the electroconductivity variation law (a) is applied, the effect of the magnetic field is negative (Figure 4). When the laws (b) and (c) (Figures 5 and 6) are used, the effect is opposite. The increase in the magnetic parameter (stronger magnetic field) postpones the separation of the boundary layer. The separation point moves downstream, so the effect of the magnetic field is positive.
- The porous wall of the body within fluid, through which the fluid is injected or ejected from the main flow has a significant influence on the boundary layer flow. The effect is the same regardless which of the three electroconductivity variation laws is used. This means that the transversal injection velocity v_w increases, the porosity parameter Λ decreases and the separation of the boundary layer is postponed because the boundary layer separation point moves downstream (Figs. 7-9). This is a favourable effect for the flow.

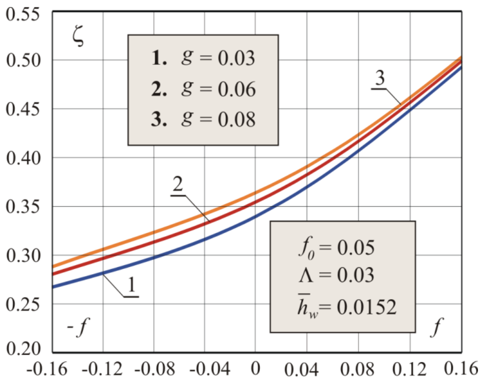

Fig. 5. Distribution of nondimensional friction function ζ, law (b)

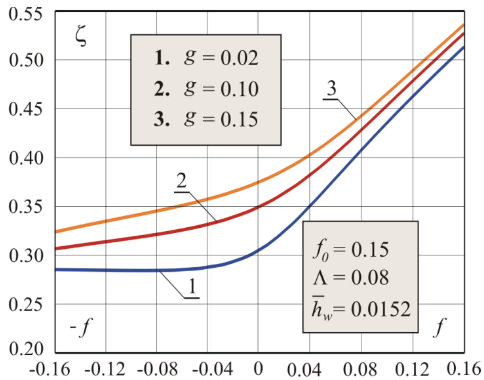

Fig. 6. Distribution of nondimensional friction function ζ, law (c)

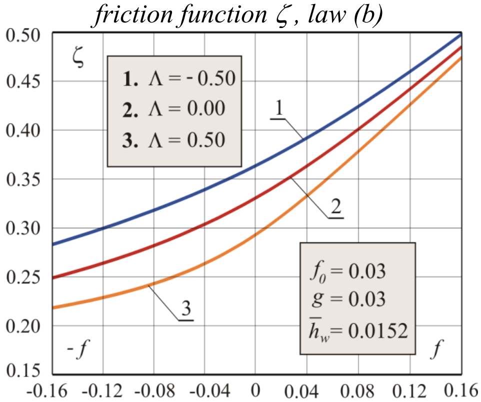

Fig. 7. Nondimensional friction function ζ, law (a)

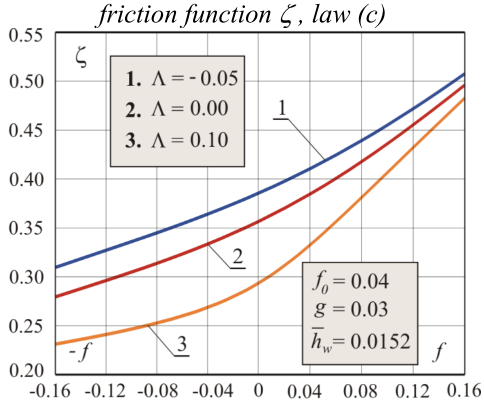

Fig. 8. Nondimensional friction function ζ, law (b)

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CONCLUSION

This paper studies a laminar boundary layer on a body of an arbitrary shape when the ionised gas flow is planar and steady and the wall of the body within fluid is porous. The main equation system is transformed into a universal form using a Saljnikov's version of the generalised similarity method. Generally, this method yields important quality results that make it possible to determine behaviour of distributions of physical quantities and characteristic properties at certain cross-sections of the boundary layer.

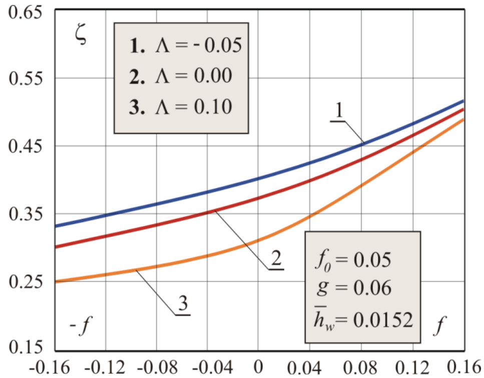

Fig. 9. Nondimensional friction function ζ, law (c)

Boundary layer management can be achieved in different ways in technical practice, and the use of a transversal magnetic field is one of successful methods. A body of a porous contour, through which fluid of the same properties as the one in the main flow is injected or ejected, is often used. Since the studied problem is very complex both from physical and mathematical point of view, this paper analyses only some aspects of the influence of the transversal magnetic field on the ionised gas flow in the boundary layer adjacent the body under the conditions of mass transfer through the porous wall.

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REFERENCES

[1.] Loitsianskii, L. G.: Liquid and Gas Mechanics (in Russian), Nauka, Moscow, Russia, 1978.

[2.] Saljnikov, V., Dallmann, U.: Generalized similarity solutions for three dimensional, laminar, steady compressible boundary layer flows on swept, profiled cylinders (in German), Institute for Theoretical Fluid Mechanics, DLR-FB 89-34, Göttingen, Germany, 1989.

[3.] Boričić, Z., Nikodijević, D., Živković, D.: One Problem of a Steady Plane MHD Boundary Layer (in Serbian), Proceedings, 19th. Yugoslav Congress of Theoretical and Applied Mechanics, Ohrid, Yugoslavia, 1990, pp 213-217.

[4.] Saljnikov, V., Boričić, Z., Nikodijević, D.: Parametric method in unsteady MHD boundary layer theory of fluid with variable electroconductivity, Facta Universitatis, 2 (1997), 7/2, pp 331-340.

[5.] Saljnikov, V., Obrović B. and Savić, S.: Ionized gas flow in the boundary layer for different forms of the electroconductivity variation flow, Theoret. Appl. Mech., 26 (2001), 1, pp 15-31.

[6.] Rossow, J.: On Flow of Electrically Conducting Fluids over a Flat Plate in the Presence of a Transverse Magnetic Field, NACA-TR-1358, 44 (1958), 1, pp 489-508.

[7.] Obrović, B.: Parametric method in the boundary-layer theory of ionized gas whose electroconductivity is a function of the longitudinal velocity gradient, Acta Mechanica, 147 (2001), 1-4, pp 35-44.

[8.] Savić, S., Obrović, B., Despotović, M., Gordić, D.: The influence of the magnetic field on the ionized gas flow adjacent to the porous wall, Thermal Science, Vol. 14, No. Suppl., pp S183-S196, 2010.

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