Časopis Naučnog društva za pogonske mašine, traktore i održavanje
Journal of Scientific Society of Power Machines, Tractors and Maintenance

TRAKTORI I POGONSKE MAŠINE

TRACTORS AND POWER MACHINES

1/2
UDK 631.372
ISSN 0354-9496
Godina 24
Dec. 2019.

Novi Sad, Srbija

Trakt. i pog. maš., Trac. and pow. mach., Vol. 24, No. 1/2, p.1-91, Novi Sad, Dec. 2019.

Časopis
TRAKTORI I POGONSKE MAŠINE

Jurnal
TRACTORS AND POWER MACHINES

Izdavač – Publisher

Naučno društvo za pogonske mašine, traktore i održavanje
Scientific Society of Power Machines, Tractors and Maintenance

Suizdavač – Copublisher
Poljoprivredni fakultet, Departman za poljoprivrednu tehniku, Novi Sad
Faculty of Agriculture, Department of Agricultural Engineering, Novi Sad

Adresa – Adress
Poljoprivredni fakultet
Trg Dositeja Obradovića br. 8
Novi Sad, Srbija
Tel.: ++381(0)21 4853 391
Tel/Fax.: ++381(0)21 459 989
e-mail: milanto@polj.uns.ac.rs

Časopis izlazi svaka tri meseca
Godišnja pretplata za radne organizacije je 1500 din, za Inostranstvo 5000 din a za individualne predplatnike 1000 din
Žiro račun: 340-4148-96 kod Erste banke

Jurnal is published four times a year
Subscription price for organization is 40 EURO, for foreign organization 80 EURO and individual subscribes 15 EURO

Rešenjem Ministarstva za informacije Republike Srbije, Br.651-115/97-03 od 10.02.1997.god., časopis je upisan u registar pod brojem 2310
Prema Mišljenju Ministarstva za nauku, Republike Srbije ovaj časopis je "PUBLIKACIJA OD POSEBNOG INTERESA ZA NAUKU"

Štampa – Printed by
Štamparija "Sitoprint“, 23210 Žitište, Cara Dušana 35
Tiraž 200 primeraka

GLAVNI MENI
SADRŽAJ
ŠTAMPAJ
SAČUVAJ
PRVA STRANA
ZADNJA STRANA
IZLAZ

Časopis Naučnog društva za pogonske mašine, traktore i održavanje
Journal of Scientific Society of Power Machines,Tractors and Maintenance

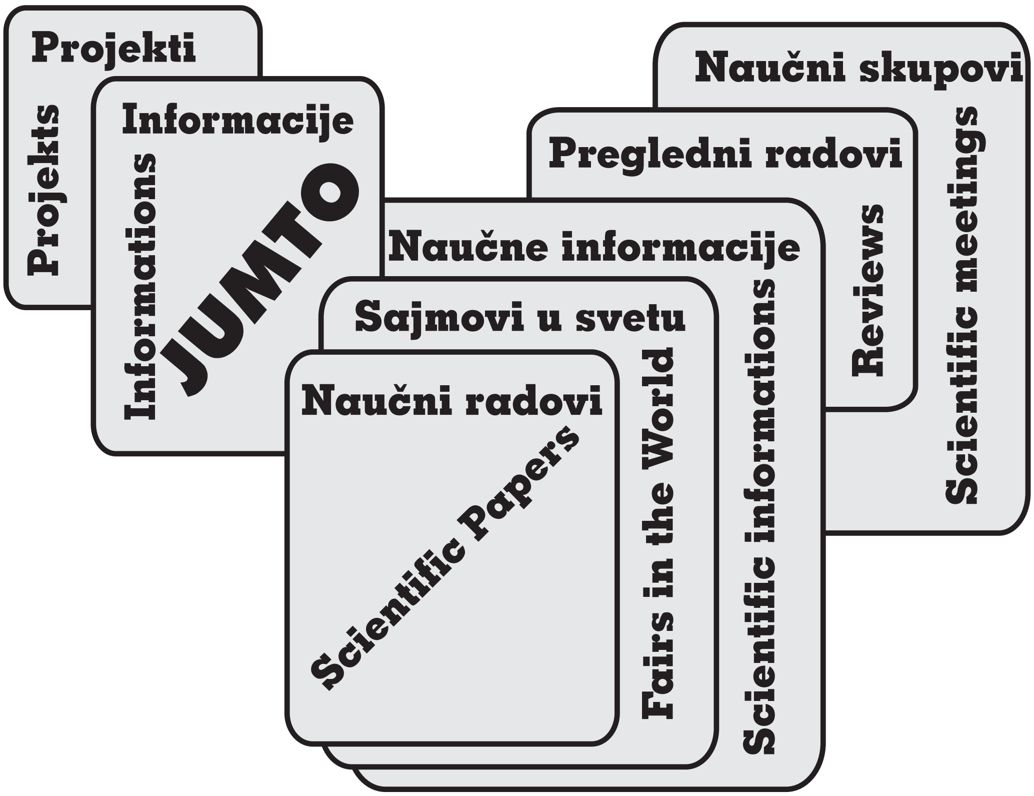
TRAKTORI I POGONSKE MAŠINE

1/2
UDK 631.372
ISSN 0354-9496
Godina 24
Dec. 2019.

TRACTORS AND POWER MACHINES

SADRŽAJ - CONTENS

UVEĆAJ
UMANJI
PRETRAŽI



Novi Sad, Srbija
Trakt. i pog. maš., Trac. and pow. mach., Vol.24, No.1/2, p.1-91, Novi Sad, Dec. 2019.

GLAVNI MENI
SADRŽAJ
ŠTAMPAJ
SAČUVAJ
PRVA STRANA
ZADNJA STRANA
IZLAZ

Časopis Traktori i pogonske mašine broj 1/2 posvećen je XXVI-om naučnom skupu "Pravci razvoja traktora i obnovljivih izvora energije"

The journal Tractors and power machines number 1/2 is devoted to XXVI scientific meeting "Development of tractors and renewable energy resources"

JUMTO 2019

Pokrovitelji skupa - Godparent of meeting

- Ministarstvo prosvete, nauke i tehnološkog razvola Republike Srbije
- Pokrajinski sekretarijat za visoko obrazovanje i naučnoistraživačku delatnost
- Pokrajinski sekretarijat za poljoprivredu, vodoprivredu i šumarstvo AP Vojvodine

Organizatori skupa - Organizers of meeting

- Naučno društvo za pogonske mašine, traktore i održavanje **JUMTO** – Novi Sad
- Poljoprivredni fakultet, Departman za poljoprivrednu tehniku, Novi Sad
- Društvo za razvoj i korišćenje biogoriva – BIGO, Novi Sad
- Agencija za bezbednost saobraćaja, Beograd
- Akademija inženjerskih nauka Srbije, Odeljenje biotehničkih nauka Beograd

UVEĆAJ
UMANJI
PRETRAŽI

Mesto održavanja - Place of meeting

Poljoprivredni fakultet, Novi Sad, 06.12.2019.

Štampanje ove publikacije pomoglo je:
Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije
Pokrajinski sekretarijat za visoko obrazovanje i naučnoistraživačku delatnost AP Vojvodine
Pokrajinski sekretarijat za poljoprivredu, vodoprivredu i šumarstvo AP Vojvodine

SADRŽAJ – CONTENS

Biblid: 0354-9496(2019) 24: 1/2, p. 48-53
UDK: 631.312.021.3:621.791.3.004.67

Naučni rad
Scientific paper

INFLUENCE OF THE MAGNETIC FIELD ON THE AXISYMMETRIC BOUNDARY LAYER OF THE IONISED GAS ADJACENT THE WALL OF THE BODY OF REVOLUTION

UTICAJ MAGNETNOG POLJA NA OSNOSIMETRIČNI GRANIČNI SLOJ JONIZOVANOG GASA PORED ZIDA OBRTNOG TELA

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

SUMMARY

This paper studies the ionized gas (air) flow in the axisymmetric boundary layer adjacent to the body of revolution. The outer magnetic field is normal to the nonporous body contour. Two different forms of the ionized gas electroconductivity variation law have been applied. The numerical results of the generalised ionised gas boundary layer equations are given in the form of diagrams. The influence of the magnetic field and ionised gas electroconductivity on certain boundary layer quantities and characteristics, especially on the boundary layer separation point, has been studied.

Keywords: ionised gas, boundary layer, magnetic field, body of revolution, electroconductivity

INTRODUCTION

The real fluid flow is defined by means of a very complex system of partial nonlinear differential equations of the second order with complex starting and boundary conditions, whose solution involves numerous mathematical difficulties. However, these equations can be solved using approximate methods, and the obtained approximate solutions are accurate enough for technical and technological practice. Approximate methods have been developed and utilised in a very important field of fluid mechanics – the boundary layer theory. The results obtained in the boundary layer theory have been successfully applied to cosmic research, rocket science, aircraft technology, automobile industry, mass and energy transfer calculations, nuclear reactor design etc.

The growing need for studies of electroconductive fluid flow under the effect of

[1] *Slobodan Savić, PhD, professor, Branko Obrović PhD, professor (retired), Nenad Todić, dipl. ing. Faculty of Engineering University of Kragujevac, Sestre Janjić 6, 34000 Kragujevac, Serbia, e-mail: ssavic@kg.ac.rs*

[2] *Nebojša Hristov, PhD, assistant professor, University of Defence in Belgrade, Military Academy, Veljka Lukića Kurjaka 33, 11000 Belgrade, Serbia*

GLAVNI MENI
SADRŽAJ
ŠTAMPAJ
SAČUVAJ
PRVA STRANA
ZADNJA STRANA
IZLAZ

electromagnetic fields gave rise to magnetohydrodynamics, which in turn enabled scientists to deal with problems such as controlling thermonuclear reactions, possible ways of direct conversion of heat and kinetic plasma energy into electric energy - MHD generators, etc.

The problem of boundary layer management in the presence of the outer magnetic field is important not only for fundamental sciences but also for a large number of applied technical and technological sciences, so these studies are always of great interest.

MATHEMATICAL MODEL

This paper studies the influence of the outer magnetic field on the ionised air flow in the boundary layer adjacent to the body of revolution. The magnetic field is normal to the nonporous body contour (Fig. 1). Due to the small thickness of the boundary layer, based on [1], the strength of this field is $B_m = B_m(x)$.

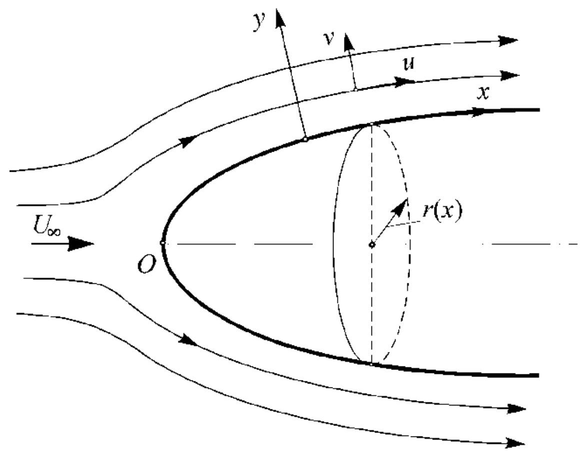


Fig. 1. Ionized gas flow adjacent to the body of revolution

Therefore, for the case of the ionised gas flow in the magnetic field under the conditions of equilibrium ionisation, the equations of the stationary laminar asymmetrical boundary layer adjacent the body of revolution [1, 2, 3] have the following form:

$$\frac{\partial}{\partial x}\left[\rho u\left(\frac{r}{L}\right)^j\right]+\frac{\partial}{\partial y}\left[\rho v\left(\frac{r}{L}\right)^j\right]=0, \quad (L=\text{const.},\ j=1),$$

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

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

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

The boundary conditions are as follows:

$$u=0,\quad v=0,\quad h=h_{\mathrm{w}}=\text{const.}\quad \text{for}\quad y=0,$$
$$u\to u_{\mathrm{e}}(x),\qquad h\to h_{\mathrm{e}}(x)\qquad \text{for}\quad y\to\infty. \qquad (2)$$

All the symbols for the physical quantities used in this paper are generally accepted and used in the boundary layer theory [4].

One of the most significant properties of the ionized gas is its electroconductivity σ. In order to fully comprehend the influence of the transversal magnetic field on the boundary layer characteristics, in this paper, like in [4, 5], two characteristic electroconductivity variation laws have been applied:

UVEĆAJ
UMANJI
PRETRAŽI

GLAVNI MENI
SADRŽAJ
ŠTAMPAJ
SAČUVAJ
PRVA STRANA
ZADNJA STRANA
IZLAZ

$$\sigma = \sigma(x) \quad (a), \qquad \sigma = \sigma_0\left(1 - \frac{u}{u_e}\right) \quad (b), \qquad (\sigma_0 = \text{const.}) \,. \tag{3}$$

In order to solve the equations (1) using the general similarity method [6], instead of physical coordinates x, y, velocities $u(x, y)$ and $v(x, y)$, new variables $s(x)$, $z(x, y)$, and a stream function $\psi(x, z)$ are introduced. Integrating the dynamic equation transversally to the boundary layer, a corresponding momentum equation is obtained. Then, two sets of parameters f_k and g_k (new independent variables) are introduced. Finally, the governing equation system (1) is transformed into the system of the so-called generalised – universal equations, which can be solved only using a small number of similarity parameters. When it is assumed that:

$$\begin{gathered} \kappa = f_0 \neq 0, \quad f_1 = f \neq 0, \quad g_1 = g \neq 0, \\ f_2 = f_3 = \ldots = 0, \quad g_2 = g_3 = \ldots = 0; \quad \partial/\partial\kappa = 0, \quad \partial/\partial g_1 = 0, \end{gathered} \tag{4}$$

the transformed equation system is significantly simplified. The order of the differential equations of the system (1) is then decreased by the change

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

Therefore, applying the law (a) for σ, the equation system for numerical integration finally takes the following form:

$$\frac{\partial}{\partial\eta}\left(Q\frac{\partial\varphi}{\partial\eta}\right) + \frac{aB^2 + (2-b)f}{2B^2}\Phi\frac{\partial\varphi}{\partial\eta} + \frac{f}{B^2}\left[\frac{\rho_e}{\rho} - \varphi^2\right] + \underline{\frac{g}{B^2}\frac{\rho_e}{\rho}(1-\varphi)} = \frac{F_m f}{B^2}\left(\varphi\frac{\partial\varphi}{\partial f} - \frac{\partial\Phi}{\partial f}\frac{\partial\varphi}{\partial\eta}\right),$$

$$\frac{\partial}{\partial\eta}\left(\frac{Q}{\Pr}\frac{\partial\bar{h}}{\partial\eta}\right) + \frac{aB^2 + (2-b)f}{2B^2}\Phi\frac{\partial\bar{h}}{\partial\eta} - \frac{2\kappa f}{B^2}\frac{\rho_e}{\rho}\varphi + 2\kappa Q\left(\frac{\partial\varphi}{\partial\eta}\right)^2 - \underline{\underline{\frac{2\kappa g}{B^2}\frac{\rho_e}{\rho}(1-\varphi)\varphi}} =$$

$$= \frac{F_m f}{B^2}\left(\varphi\frac{\partial\bar{h}}{\partial f} - \frac{\partial\Phi}{\partial f}\frac{\partial\bar{h}}{\partial\eta}\right);$$

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

(6)

Applying the electroconductivity variation law (b), only the terms underlined in (6) differ:

$$-\underline{\frac{g}{B^2}\frac{\rho_e}{\rho}(1-\varphi)\varphi}, \qquad \underline{\underline{+\frac{2\kappa g}{B^2}\frac{\rho_e}{\rho}(1-\varphi)\varphi^2}}\,. \tag{6'}$$

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, F_m, Q – characteristic boundary layer functions, Pr – Prandtl number and a, b – constants.

Fort the concrete numerical solution of the equation system (6), i.e. (6’) it is necessary to adopt the function Q and the density ratio ρ_e/ρ [7]:

UVEĆAJ
UMANJI
PRETRAŽI

$$Q = Q(\bar{h}) \approx \left(\bar{h}_w / \bar{h}\right)^{1/3}, \qquad \rho_e/\rho \approx \bar{h}/(1-\kappa). \tag{7}$$

INVESTIGATION AND DISCUSSION RESULTS

The system of the conjugated partial differential equations (6) and (6') is numerically solved by the finite differences method – using the passage method. A concrete numerical solution is performed using a programme written in FORTRAN. All the calculations in this paper are done for the concrete values of the constants a and b when a = 0.4408; b = 5.7140 that according to [6] represent the optimal values. Prandtl number is taken to be constant (Pr = 0.712). The system is solved for several values of the parameters κ and g_1 given in advance.

Based on the obtained numerical results, only some of which are shown in the form of diagrams, valuable conclusions on influence of certain characteristic quantities on solution of this flow problem have been drawn. Under the effects of the transversal magnetic field, when the electroconductivity laws ((*a*) and (*b*)) are varied, it can be clearly noticed that:

- The magnetic field has a little influence on distribution of the nondimensional flow velocity u/ue (the ratio of the longitudinal velocity and the velocity at the outer edge of the boundary layer). At different cross-sections of the boundary layer, regardless on the applied electroconductivity variation law, u/ue converges very quickly towards unity (Figures 2 and 3).
- The change in the magnetic field, i.e., magnetic parameter g has a negligible influence on distribution of nondimensional enthalpy in the boundary layer (Figures 4 and 5) for both electroconductivity variation laws.
- The magnetic parameter, and hence the magnetic field, have a great influence on the characteristic boundary layer functions B, ζ and Fm.
- The effect of the magnetic field on the boundary layer separation point is especially interesting. This effect is best seen in the diagram of nondimensional friction function ζ. When the law (a) is applied, with the increase in the magnetic parameter, the boundary layer separation point moves upstream, so the effect of the magnetic parameter is negative (Figure 6). When the law (b) is applied and the value of the magnetic parameter is increased, the boundary layer separation point moves downstream (Figure 7). In that case the effect of the magnetic field is positive because it delays the separation of the boundary layer.

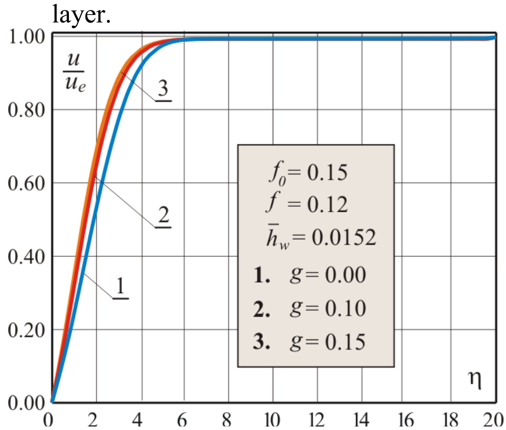


Fig. 2. Nondimensional velocity u/ue , law (a)

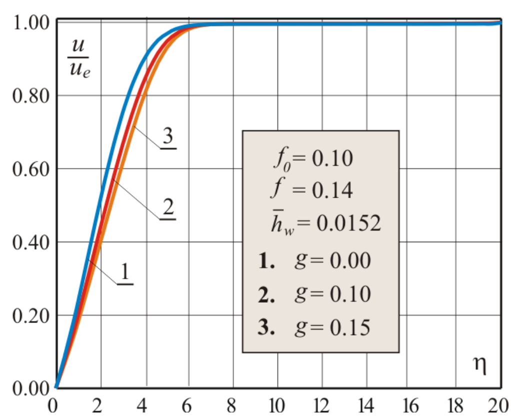


Fig. 3. Nondimensional velocity u/ue , law (b)

GLAVNI MENI
SADRŽAJ
ŠTAMPAJ
SAČUVAJ
PRVA STRANA
ZADNJA STRANA
IZLAZ

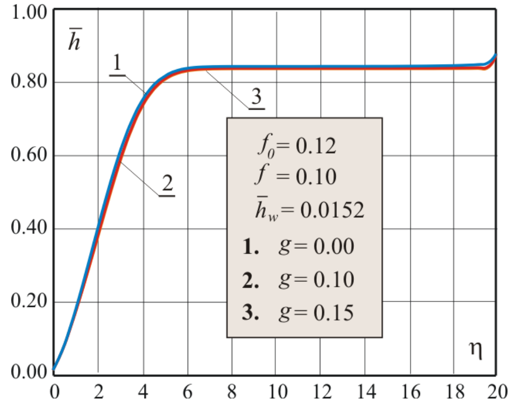


Fig. 4. Distribution of the nondimensional enthalpy, law (a)

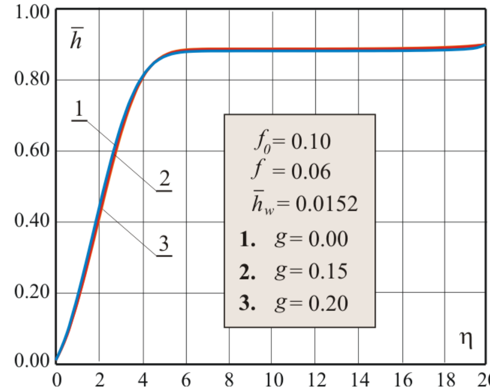


Fig. 5. Distribution of the nondimensional enthalpy, law (b)

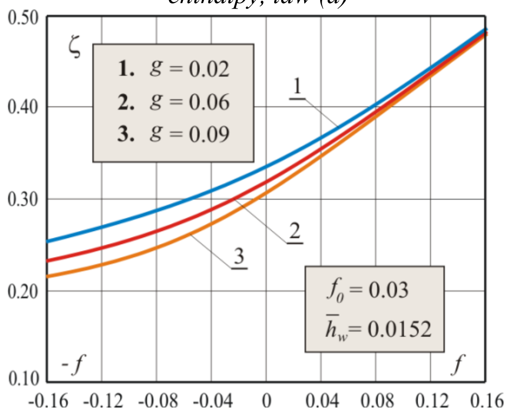


Fig. 6. Distribution of nondimensional friction function ζ, law (a)

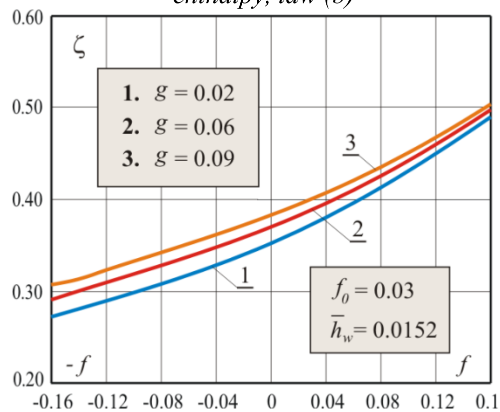


Fig. 7. Distribution of nondimensional friction function ζ, law (b)

UVEĆAJ
UMANJI
PRETRAŽI

CONCLUSION

This paper analyses the influence of the transversal magnetic field on the ionised air flow in the axisymmetric boundary layer adjacent to the nonporous body of revolution. Two electroconductivity variation laws have been applied, as recommended in the referential literature. Transformation of the governing equation system (1) into a generalised one (6) using Saljnikov's version of the generalised similarity method is a very complex procedure which has not been presented in this paper [8, 9]. It should be pointed out that the concrete numerical solutions of the conjugated equations have been used to draw general conclusions on behaviour of certain characteristics of the axisymmetric ionised gas boundary layer, which was the primary objective of this paper.

ACKNOWLEDGEMENTS

The research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia Grant OI 174014.

REFERENCES

[1.] Loitsianskii, L.G.: Laminar Boundary Layer (in German), Akademie-Verlag, Berlin, Germany, 1967.
[2.] Obrović, B.: Boundary layer of dissociated gas (in Serbian), Monograph, University of Kragujevac, Faculty of Mechanical Engineering, Kragujevac, Serbia, 1994.
[3.] Schlichting, H.: Boundary-Layer Theory (in German), G. Braun, Karlsruhe, Germany, 1974.
[4.] Saljnikov, V., Obrović B., 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.
[5.] 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.
[6.] 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.
[7.] Krivtsova, N. V.: Parameter method of solving of the laminar boundary layer equations with axial pressure gradient in the conditions of equilibrium dissociation of the gas, Engineering-Physical Journal 10 (1966), pp 143-153.
[8.] Obrović, B., Savić, S., Petrović, R.: Ionized gas boundary layer on bodies of revolution in the presence of magnetic field, Tehnički vjesnik – Technical gazette, 17 (2010), 1, pp 35-42.
[9.] Obrović, B., Savić, S., Šušteršič, V.: On the ionized gas boundary layer adjacent to the bodies of revolution in the case of variable electroconductivity, Thermal Science, 17 (2013), 2, pp 555-566.

The paper received: 13.11.2019. The paper accepted: 20.11.2019.