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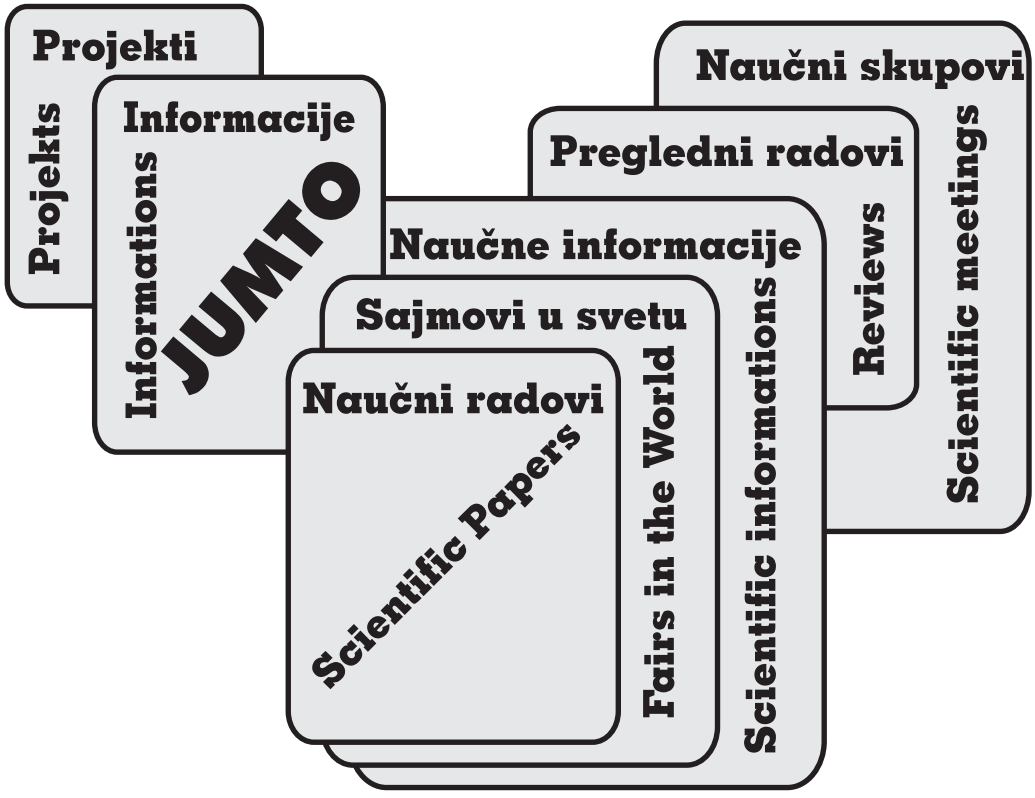

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THE INFLUENCE OF THE BODY CONTOUR POROSITY ON THE DISSOCIATED GAS FLOW IN THE PLANAR BOUNDARY LAYER

UTICAJ POROZNOSTI KONTURE TELA NA STRUJANJE DISOCIRANOG GASA U RAVANSKOM GRANIČNOM SLOJU

Savić S.[1], Obrović B.[1]

SUMMARY

This paper studies the ideally dissociated gas (air) flow in the plane boundary layer when the contour of the body within the fluid is porous. The main equation systems has been brought to a generalized form by suitable transformations. The obtained so-called universal equations are solved numerically in a corresponding approximation. Numerical results are presented in the form of diagrams. Conclusions on the influence of certain parameters on the dissociated gas flow in the boundary layer have been drawn. The influence of the body contour porosity the on certain quantities and characteristics of the boundary layer, especially on the boundary layer separation point has been analysed.

Keywords: dissociated gas, boundary layer, porous wall, porosity parameter

INTRODUCTION

Up to close to 1000 K, air can be considered a "homogenous" ideal gas whose basic components are molecular oxygen and molecular nitrogen. However, when air flows at high temperatures (e.g. at supersonic movement of the spacecraft through the Earth's atmosphere) thermochemical reactions of dissociation and recombination occur in the air and it turns into a multicomponent mixture. Then the dissociated air flow consists of molecular and atomic components which are formed by molecule dissociation. According to Lighthill, the study of the multicomponent gas mixture flow can be replaced by a model of a binary mixture consisting of only two classes of components: molecular and atomic. This mixture is known as ideally dissociated gas. Air up to close to 8000 K can be considered an ideally dissociated gas [1].

The assumption of an ideally dissociated gas can also be applied to the boundary layer flow. The mass concentrations of atoms and molecules are defined as:

$$C_A = \rho_A / \rho = \alpha, \quad C_M = \rho_M / \rho = 1 - \alpha. \tag{1}$$

The index *A* denotes the atomic and the molecular component *M* of the ideally dissociated gas.

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While flowing at high temperatures, the atoms in the dissociated gas molecules are excited into rotational and oscillatory motion. Therefore, physical parameters of the gas (specific heat, dynamic viscosity coefficient, etc.) cannot be considered constant and they depend on the temperature T and the composition α of the gas mixture [1-3]. However, the nondimensional transfer coefficients Prandtl number (Pr), Schmidt number (Sm) and Lewis number (Le) can be considered constant quantities.

The frozen flow [4] is a special case of a gas mixture flow in which there is no chemical activity of the components. In that case, a change in the concentration of the atomic component α is conditioned by convection and the diffusion process. The boundary layer in which this flow occurs is known as the frozen boundary layer. In the surrounding area of the front stagnation point of supersonic planes, an equilibrium flow is achieved, while in space crafts, a frozen flow [2] can be achieved.

MATHEMATICAL MODEL

This paper studies the flow of the ideally dissociated gas (air) in the case of the so-called frozen boundary layer, when the wall of the body within the fluid is porous. In this boundary case of the ideally dissociated gas flow, thermochemical activity is "frozen". The equation system of the laminar planar boundary layer and the frozen boundary layer, in the case of a porous wall, takes the following form:

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

$$\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}=\rho_e u_e\frac{du_e}{dx}+\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right),$$

$$\rho u\frac{\partial \alpha}{\partial x}+\rho v\frac{\partial \alpha}{\partial y}=\frac{\partial}{\partial y}\left(\rho D\frac{\partial \alpha}{\partial y}\right), \qquad (2)$$

$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=-u\rho_e u_e\frac{du_e}{dx}+\frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right)+\mu\left(\frac{\partial u}{\partial y}\right)^2+$$
$$+\rho D(c_{pA}-c_{pM})\frac{\partial \alpha}{\partial y}\frac{\partial T}{\partial y},$$

$$p=\rho T(1+\alpha)R_M.$$

These equations represent respectively: the mixture continuity equation, the dynamic equation, the equation of diffusion of the atomic component, the energy equation and the state equation of the ideally dissociated gas.

The boundary conditions:

$$\begin{array}{llll} u=0, \quad v=v_w(x), & T=T_w, & \alpha=\alpha_w & \text{for} \quad y=0, \\ u\to u_e(x), & T\to T_e(x), & \alpha\to\alpha_e(x) & \text{for} \quad y\to\infty. \end{array} \qquad (3)$$

In the above equations and in the boundary conditions, the usual notation in the boundary layer theory [1, 3] was used. $v_w(x)$ denotes the given velocity at which the dissociated gas flows perpendicularly through the solid porous wall of the body within the fluid (Fig. 1). This speed

can be $v_w > 0$ when injecting the gas into the main stream, or $v_w < 0$ when suctioning it.

Modern parametric methods used to solve boundary layer equations of the ideally dissociated gas are based on introduction of appropriate sets of parameters. In order to introduce these sets of parameters, it is necessary to introduce a momentum equation which should be derived. First, instead of physical coordinates x and y, longitudinal velocity $u(x, y)$ and transversal velocity $v(x, y)$, new variables $s(x)$, $z(x, y)$, and the stream function $\psi(s, z)$ are introduced. Then, due to the body porous contour, it is necessary to introduce a new stream function $\psi^*(s, z)$. After that, integrating the dynamic equation transversally to the boundary layer the corresponding momentum equation is obtained. Finally, two sets of parameters are introduced f_k and Λ_k. If these similarity parameters are accepted as independent variables, the main equation system (2) is transformed into a system of universal equations. Since the outer flow velocity u_e appears neither in this system of universal equations nor in the corresponding boundary conditions, this generalized equation system represents a general mathematical model of ideally dissociated gas flow in the boundary layer adjacent the porous wall. This equation system can be solved only for a relatively small number of similarity parameters [5]. In the three-parametric:

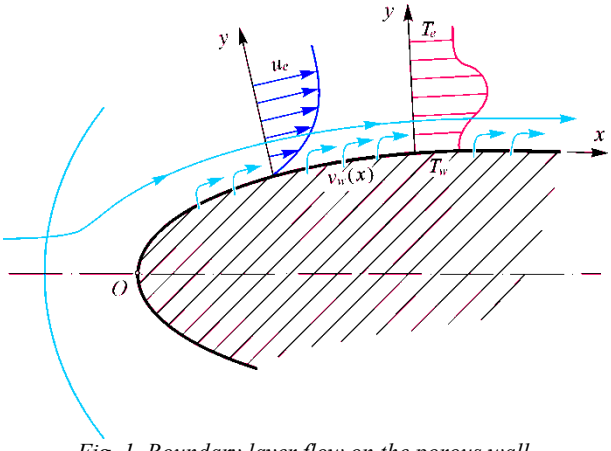

Fig. 1. Boundary layer flow on the porous wall

$$\kappa = f_0 \neq 0, \quad f_1 = f \neq 0, \quad \Lambda_1 = \Lambda \neq 0;$$
$$f_2 = f_3 = \ldots = 0, \quad \Lambda_2 = \Lambda_3 = \ldots = 0, \tag{4}$$

twice localised approximation ($\partial/\partial\kappa = 0, \partial/\partial\Lambda = 0$), the transformed equation system is significantly simplified. In addition, the order of the system of differential equations is decreased by the change

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

Thus, the main equation system is finally brought down to the following generalised form:

$$\frac{\partial}{\partial\eta}\left(Q\frac{\partial\varphi}{\partial\eta}\right) + \frac{aB^2 + (2-b)f}{2B^2}\,\Phi\,\frac{\partial\varphi}{\partial\eta} + \frac{f}{B^2}\left[\frac{1+\alpha}{1+\alpha_1}\frac{\overline{T}}{1-\kappa} - \varphi^2\right] + \frac{\Lambda}{B}\frac{\partial\varphi}{\partial\eta} =$$
$$= \frac{F_{dp}f}{B^2}\left(\varphi\frac{\partial\varphi}{\partial f} - \frac{\partial\Phi}{\partial f}\frac{\partial\varphi}{\partial\eta}\right),$$

$$\frac{\partial}{\partial\eta}\left(\frac{Q}{\mathrm{Pr}}\frac{C^*}{C_1^*}\frac{\partial\overline{T}}{\partial\eta}\right)+\frac{aB^2+(2-b)f}{2B^2}\frac{C^*}{C_1^*}\Phi\frac{\partial\overline{T}}{\partial\eta}-\frac{1+\alpha}{1+\alpha_1}\frac{2\kappa\overline{T}}{1-\kappa}\frac{f}{B^2}\varphi+2\kappa Q\left(\frac{\partial\phi}{\partial\eta}\right)^2+$$

$$+\frac{Q}{\mathrm{Sm}}\frac{D^*}{C_1^*}\frac{\partial\alpha}{\partial\eta}\frac{\partial\overline{T}}{\partial\eta}+\frac{C^*}{C_1^*}\frac{\Lambda}{B}\frac{\partial\overline{T}}{\partial\eta}=\frac{F_{dp}f}{B^2}\frac{C^*}{C_1^*}\left(\varphi\frac{\partial\overline{T}}{\partial f}-\frac{\partial\Phi}{\partial f}\frac{\partial\overline{T}}{\partial\eta}\right), \qquad (6)$$

$$\frac{\partial}{\partial\eta}\left(\frac{Q}{\mathrm{Sm}}\frac{\partial\alpha}{\partial\eta}\right)+\frac{aB^2+(2-b)f}{2B^2}\Phi\frac{\partial\alpha}{\partial\eta}+\frac{\Lambda}{B}\frac{\partial\alpha}{\partial\eta}=\frac{F_{dp}f}{B^2}\left(\varphi\frac{\partial\alpha}{\partial f}-\frac{\partial\Phi}{\partial f}\frac{\partial\alpha}{\partial\eta}\right).$$

The boundary conditions are:

$$\Phi=0,\quad \varphi=0,\quad \overline{T}=\overline{T}_w=\text{const.},\quad \alpha=\alpha_w=\text{const.}\quad \text{for}\quad \eta=0,$$

$$\varphi\to 1,\quad \overline{T}\to\overline{T}_e=1-\kappa,\quad \alpha\to\alpha_e=\alpha_1=\text{const.}\quad \text{for}\quad \eta\to\infty, \qquad (7)$$

where:

η - nondimensional transversal coordinate, Φ - nondimensional stream function, $\overline{T}$ - nondimensional temperature, $\kappa=f_0(s)$ - local compressibility parameter, α_1 - concentration of the atoms at the front stagnation point, $f_1=f$ - first form parameter, $\Lambda_1=\Lambda$ - first porosity parameter, B - characteristics of the boundary layer, F_{dp}, Q - characteristic boundary layer functions, C^*, D^*, C_1^* - nondimensional function and a, b - constants.

INVESTIGATION AND DISCUSSION RESULTS

Numerical computation of the system of equations (6) has been made using the finite differences method. For the concrete computation of the obtained equation system a corresponding program, similar to one applied in paper [6], has been written. Since the physical nature of Prandtl number is such that it negligibly depends on the temperature, in this study it is held constant. Based on [7], its value has been accepted to be Pr = 0.712, while Schmidt number is Sm = 0.509. The usual values have been accepted [8] for the constants a and b: a = 0.4408, b = 5.7140.

Only the most important numerical results are presented here in the form of diagrams on which interesting conclusions can be drawn.

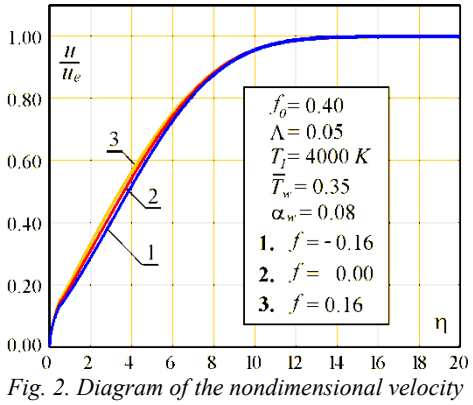

Fig. 2. Diagram of the nondimensional velocity u/u_e

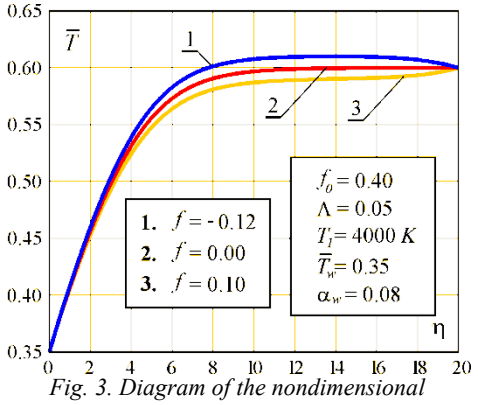

Fig. 3. Diagram of the nondimensional temperature $\overline{T}$

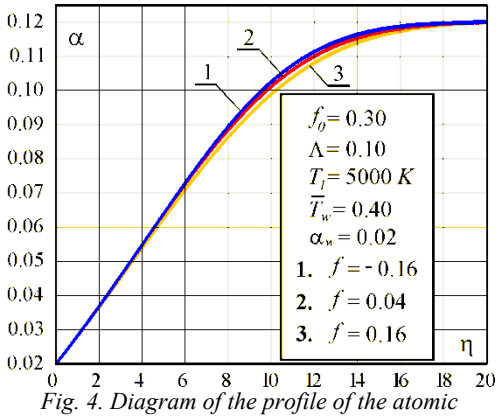

Fig. 4. Diagram of the profile of the atomic component concentration α

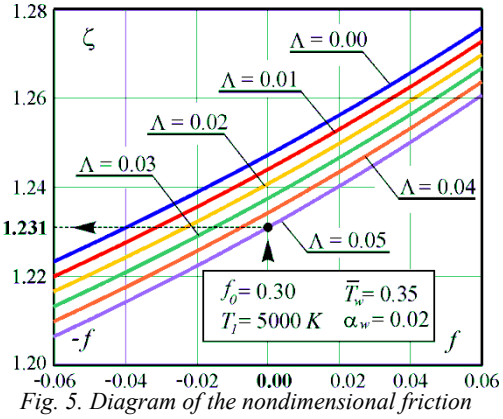

Fig. 5. Diagram of the nondimensional friction function ζ

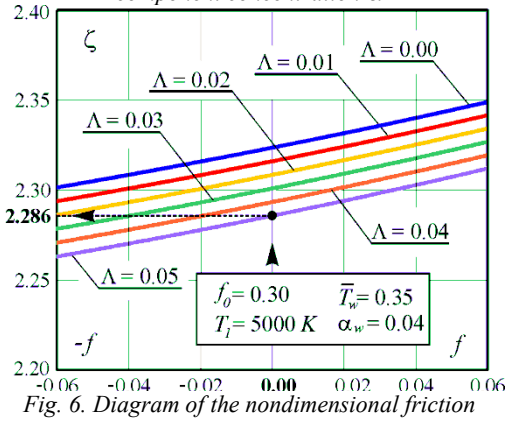

Fig. 6. Diagram of the nondimensional friction function ζ

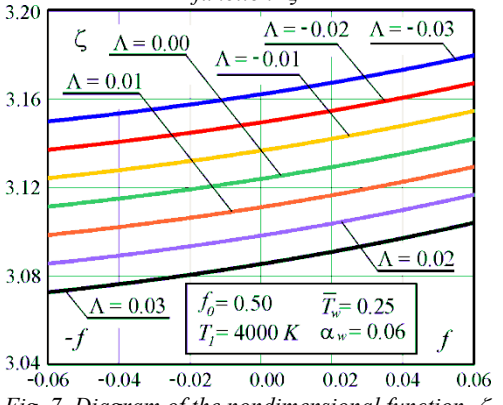

Fig. 7. Diagram of the nondimensional function ζ for negative and positive values of Λ

The dimensionless velocity u/u_e at different cross sections of the boundary layer converges very rapidly towards unity (Fig. 2). This is in complete agreement with the corresponding conclusions drawn for the equilibrium dissociated gas flow problem [7].

Based on numerous numerical results in the form of diagrams which are not shown here, a slight influence of the porosity parameter Λ on the profiles of the nondimensional velocities u/u_e can be noticed. Regardless of the fact whether the dissociated gas is injected into the main stream or ejected, the dimensionless velocity also converges very quickly towards the unity at different cross sections of the boundary layer.

In comparison with the flat plate ($f = 0.00$), there is a change in the general behaviour of the nondimensional temperature $\overline{T}$ in the diffuser region ($f < 0$) and conffuser region ($f > 0$) of the boundary layer (Fig. 3).

It has been noticed that the compressibility parameter $\kappa = f_0$ has a negligible influence both on the nondimensional velocity distribution and the concentration α (Fig. 4) in the boundary layer. Based on the diagrams that are not shown in the paper, a significant influence of the compressibility parameter on the nondimensional temperature in the boundary layer has been noticed. This parameter changes even the general behaviour of the temperature.

The atomic component concentration α_w on the wall of the body within the fluid has a significant effect on the nondimensional friction function ζ and, hence, on the boundary layer separation point. For example, at the boundary layer cross-section for which $f = 0.00$ and the porosity parameter $\Lambda = 0.05$, if α_w changes from 0.02 to 0.04, the function ζ changes from 1.231 to 2.286, i.e. 1.857 times (Figs. 5 and 6).

Figures 5-7 show diagrams of the dimensionless friction function $\zeta(f)$, which determines the friction stress on the wall of the flowing body. Therefore, this function determines the boundary layer separation point at which $\zeta=0$. It is clearly observed that the porosity parameter Λ affects the dimensionless friction function, and therefore the boundary layer separation point. If the transversal injection velocity v_w increases, the value of the porosity parameter Λ decreases. When this parameter decreases, the boundary layer separation point moves downstream. Therefore, injection of the dissociated gas into the main stream has a positive effect because it postpones the separation of the boundary layer. In contrast, the suction of dissociated gas from the main stream has a negative effect on the boundary layer because it moves the boundary layer separation point up the stream. A similar behaviour of the dimensionless friction function was observed in the ionized gas flow in the boundary layer [9].

CONCLUSION

The influence of wall porosity on the flow of the ideally dissociated air in the case of a planar frozen boundary layer was analysed. 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 properties as the main stream fluid is either injected or ejected. The paper does not present a very complex procedure of transformation of the main equation system and its generalization using Saljnikov's version of the general similarity method [6]. It should be emphasized that concrete numerical solutions of universal equations were used to draw general conclusions on the behaviour of some characteristics of the dissociated gas planar boundary layer, which, in fact was the primary goal of this paper.

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REFERENCES

[1.] Dorrance, W. H.: Viscous Hypersonic Flow, Theory of Reacting and Hypersonic Boundary Layers, New York, San Francisco, Toronto, London, 1962.
[2.] Obrović, B.: Boundary layer of dissociated gas (in Serbian), Monograph, University of Kragujevac, Faculty of Mechanical Engineering, Kragujevac, Serbia, 1994.
[3.] Anderson, John D. Jr.: Hypersonic and High Temperature Gas Dynamics, New York, St. Louis, San Francisco, McGraw-Hill Book Company, 1989.
[4.] Loitsianskii, L. G.: Liquid and Gas Mechanics (in Russian), Nauka, Moscow, Russia, 1978.
[5.] Obrović, B., Savić, S.: Dissociated gas flow in the boundary layer in the case of a porous contour of the body within fluid, Facta Universitatis, Series: Mechanics, Automatic Control and Robotics 3 (2003) 15, pp 989-1000.
[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.] Krivcova, 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.] Savić, S., Obrović, B., Todić, N., Hristov, N.: Influence of the magnetic field on the axisymmetric boundary layer of the ionised gas adjacent the wall of the body of revolution, Tractors and power machines 24 (2019) 1/2, pp 48-53.

[9.] Savić, S., Obrović, B., Jovanović, S., Hristov, N., Todić, N.: The influence of the magnetic field and the porosity of the body contour on the ionised gas flow in the planar boundary layer, Tractors and power machines 23 (2018) 1/2, pp 60-65.

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