PROFILES WITH COANDA EFFECT, NECESSARIES TO WIND TURBINES

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Abstract: *The air flow separation around profiles and the wind turbine rotor vibration leading to the blade breaking is a well known phenomenon based on which the present work is conceived. The paper is focused on theoretic and experimental researches effectuated on any profiles with Coanda effect, which are followed with the patenting of three similar profiles.*
In the frame of theoretical researches the molecular attraction forces of adhesion and cohesion in the numerical integration of viscous fluid flow around a breaking plate even to the angle of 45^o are introduced, highlighting the advantageous Henri Coanda effect.
The experimental researches are effectuated on a profile with Coanda effect, measuring with a two-component strain gauge balance the lift and aerodynamic drag forces for different profile attack angle, highlighting the increasing of the attack angle from the usual value of 11^o to over the 27^o for that profile when the flow separation takes place.

Key Words: *Henri Coanda effect. Molecular attraction forces of adhesion and cohesion. Wind turbines.*

1. INTRODUCTION

To explain the well known Henri Coanda effect we shall introduce in this paper the molecular attraction forces of adhesion and cohesion (fig.1), considered by us for the first time in the theoretical and experimental study of the patented rotational biphasic contactor [1-3] and also in paper [4] and the patent invention [5].

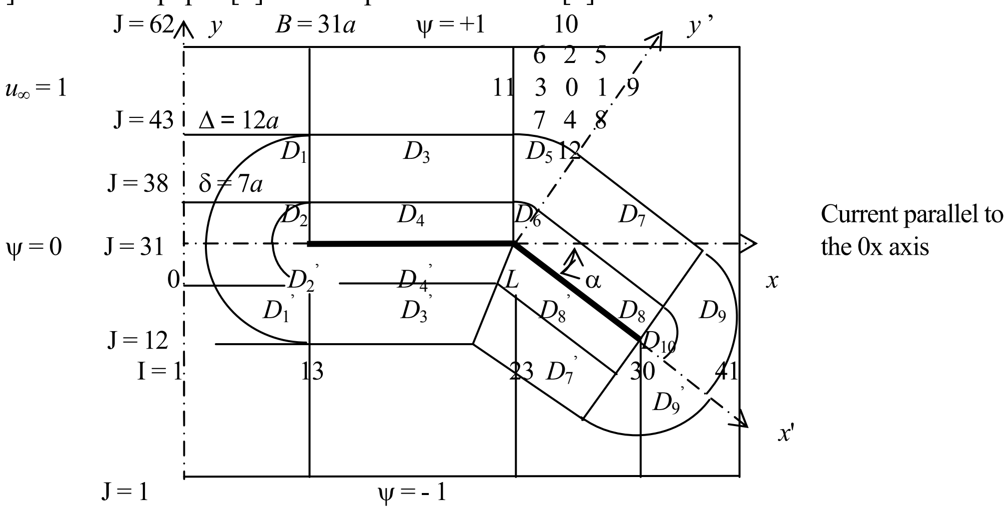

Fig. 1. The molecular forces domains and the knots numeration

2. THE VISCOUS FLUID FLOW EQUATIONS

The flow equations [6, p. 38 and p. 25] completed with the molecular attraction forces can be written taking into account that i = I – 1 and j = J – 2, I being the column number and J the line number in this network, in which we have for the points comprised in the domains D_1, D_2 and D_5, D_6, that the angle β

$$\sin\beta=\frac{\mathrm{tg}\,\beta}{\sqrt{1+\mathrm{tg}^2\beta}},\quad \cos\beta=\frac{1}{\sqrt{1+\mathrm{tg}^2\beta}},\quad \mathrm{tg}\,\beta\Big|_{\substack{D_{1,2}\\ D_{5,6}}}=\frac{Y_{i,j}}{X_{i,j}-X_{\substack{13,2\\23,2}}},\quad \beta=\mathrm{arc\,tg}\frac{Y_{i,j}}{X_{i,j}-X_{\substack{13,2\\23,2}}},$$

marking the straight line inclination, that joins the point from the calculus net X_{ij} Y_{ij} with the attraction points from the plate extremity and the fluid mass conservation being the equation (3)

$$U'_X U+U'_Y V+\frac{1}{\rho}P'_X=\upsilon\left(U''_{X^2}+U''_{Y^2}\right)-\left\{f_a\left(1-\frac{\sqrt{\left(X_{ij}-X_{\substack{13,2\\23,2}}\right)^2+Y_{ij}^2}}{\Delta}\right)\cos\beta\left(X_{ij},X_{\substack{13,2\\23,2}},Y_{ij}\right)\right\}_{D_1,D_5}+ \qquad (1)$$

$$+\left\{f_c\left(1-\frac{\sqrt{\left(X_{ij}-X_{\substack{13,2\\23,2}}\right)^2+Y_{ij}^2}}{\delta}\right)\cos\beta\left(X_{ij},X_{\substack{13,2\\23,2}},Y_{ij}\right)\right\}_{D_2,D_6},$$

$$V'_X U+V'_Y V+\frac{1}{\rho}P'_Y=\upsilon\left(V''_{X^2}+V''_{Y^2}\right)-\left\{f_a\left(1-\frac{Y_{ij}}{\Delta}\right)\right\}_{D_3}+\left\{f_c\left(1-\frac{Y_{ij}}{\delta}\right)\right\}_{D_4}-\left\{f_a\left(1-\frac{\sqrt{\left(X_{ij}-X_{\substack{13,2\\23,2}}\right)^2+Y_{ij}^2}}{\Delta}\right)\sin\beta\left(X_{ij},X_{\substack{13,2\\23,2}},Y_{ij}\right)\right\}_{D_1,D_5}+$$

$$+\left\{f_c\left(1-\frac{\sqrt{\left(X_{ij}-X_{\substack{13,2\\23,2}}\right)^2+Y_{ij}^2}}{\delta}\right)\sin\beta\left(X_{ij},X_{\substack{13,2\\23,2}},Y_{ij}\right)\right\}_{D_2,D_6}, \qquad (2)$$

$$U'_X+V'_Y=0\,. \qquad (3)$$

3. THE INTRODUCTION OF THE STREAMLINE FUNCTION

To eliminate the equation of the fluid mass conservation, unstable in the iterative numerical calculus, we introduce the streamline function by the expressions:

$$U=\Psi'_Y \qquad \text{şi} \qquad V=-\Psi'_X \qquad (4)$$

and consequently calculating their partial differentials, which intervene in the motion equations (1) and (2), and eliminating the pressure function unknown on the all domain boundaries in the virtue of Schwarz's commutative relation $P''_{XY} = P''_{YX}$ of mixed second order, the motion equations become:

$$\Psi'_X\left(\Psi'''_{X^2Y}+\Psi'''_{Y^3}\right)-\Psi'_Y\left(\Psi'''_{XY^2}-\Psi'''_{X^3}\right)=\upsilon\left(\Psi^{IV}_{X^4}+2\Psi^{IV}_{X^2Y^2}+\Psi^{IV}_{Y^4}\right)+\left\{f_a\left(1-\frac{\sqrt{\left(X_{ij}-X_{\substack{13,2\\23,2}}\right)^2+Y_{ij}^2}}{\Delta}\right)\left[\begin{array}{l}\beta'_X\cos\beta\left(X_{ij},X_{\substack{13,2\\23,2}},Y_{ij}\right)-\\-\beta'_Y\sin\beta\left(X_{ij},X_{\substack{13,2\\23,2}},Y_{ij}\right)\end{array}\right]\right\}_{D_{1,5}}+$$

$$+\left\{f_c\left(1-\frac{\sqrt{\left(X_{ij}-X_{\substack{13,2\\23,2}}\right)^2+Y_{ij}^2}}{\delta}\right)\left[\begin{array}{l}\beta'_Y\sin\beta\left(X_{ij},X_{\substack{13,2\\23,2}},Y_{ij}\right)-\\-\beta'_X\cos\beta\left(X_{ij},X_{\substack{13,2\\23,2}},Y_{ij}\right)\end{array}\right]\right\}_{D_{2,6}}, \qquad (5)$$

4. DIMENSIONLESS FORM OF THE STREAMLINE FUNCTION EQUATION

For a greater generalization of the numerical solution we obtained the dimensionless form of the equation (5) choosing as characteristic magnitudes: the calculus domain B width, the fluid flow velocity U_E and its pressure P_E in the plate exterior, the dimensionless variables and functions being:

$$x=\frac{X}{B},\quad y=\frac{Y}{B},\quad u=\frac{U}{U_E},\quad v=\frac{V}{U_E},\quad p=\frac{P}{P_E},\quad \psi=\frac{\Psi}{BU_E} \qquad (6)$$

and the similarity criteria: $\mathrm{Re}=U_E B/\upsilon$ of Reynolds number and $F_{a,c}=f_{a,c}B^2/U_E^2$ of adhesion and cohesion attraction forces.
Thus the equation (5) becomes

$$\psi'_y\left(\psi'''_{xy^2}+\psi'''_{x^3}\right)-\psi'_x\left(\psi'''_{x^2y}+\psi'''_{y^3}\right)=\frac{1}{\mathrm{Re}}\left(2\psi^{IV}_{x^2y^2}+\psi^{IV}_{y^4}+\psi^{IV}_{x^4}\right)-\left\{F_a\left(1-\frac{\sqrt{\left(x_{ij}-x_{\substack{13,2\\23,2}}\right)^2+y_{ij}^2}}{\Delta/B}\right)\left(\begin{array}{l}\dfrac{2y_{ij}^2}{\left(x_{ij}-x_{\substack{13,2\\23,2}}\right)\left[\left(x_{ij}-x_{\substack{13,2\\23,2}}\right)^2+y_{ij}^2\right]}\cos\beta+\\+\dfrac{x_{ij}-x_{\substack{13,2\\23,2}}}{\left(x_{ij}-x_{\substack{13,2\\23,2}}\right)^2+y_{ij}^2}\sin\beta\end{array}\right)\right\}_{D_{1,5}}+$$

$$+\left\{F_c\left(1-\frac{\sqrt{\left(x_{ij}-x_{\substack{13,2\\23,2}}\right)^2+y_{ij}^2}}{\delta/B}\right)\left(\begin{array}{l}\dfrac{x_{ij}-x_{\substack{13,2\\23,2}}}{\left(x_{ij}-x_{\substack{13,2\\23,2}}\right)^2+y_{ij}^2}\sin\beta+\\+\dfrac{2y_{ij}^2}{\left(x_{ij}-x_{\substack{13,2\\23,2}}\right)\left[\left(x_{ij}-x_{\substack{13,2\\23,2}}\right)^2+y_{ij}^2\right]}\cos\beta\end{array}\right)\right\}_{D_{2,6}} \qquad (5')$$

5. THE STREAMLINE ALGEBRAIC EQUATION

Developing in our proper series [7] the streamline function after the different steps: $a=\delta x=\delta X/B$ and $b=\delta y=\delta Y/B$ of a rectangular grid we obtain

$$\psi_0=\frac{1}{\left(\frac{8}{a^2b^2}+\frac{6}{a^4}+\frac{6}{b^4}\right)}\left\{\begin{array}{l}\frac{4}{a^2b^2}(\psi_1+\psi_2+\psi_3+\psi_4)-\frac{2}{a^2b^2}(\psi_5+\psi_6+\psi_7+\psi_8)+\frac{4}{a^4}(\psi_1+\psi_3)+\frac{4}{b^4}(\psi_2+\psi_4)-\frac{1}{a^4}(\psi_9+\psi_{11})-\frac{1}{b^4}(\psi_{10}+\psi_{12})+\\ +\mathrm{Re}\left\|\begin{array}{l}u_0\left\{\begin{array}{l}\frac{1}{ab^2}\left[\frac{1}{2}(\psi_5+\psi_8-\psi_6-\psi_7)-(\psi_1-\psi_3)\right]+\\+\frac{1}{a^3}\left[\psi_3-\psi_1+\frac{1}{2}(\psi_9-\psi_{11})\right]\end{array}\right\}+v_0\left\{\begin{array}{l}\frac{1}{a^2b}\left[\frac{1}{2}(\psi_5+\psi_6-\psi_7-\psi_8)-(\psi_2-\psi_4)\right]+\\+\frac{1}{b^3}\left[\psi_4-\psi_2+\frac{1}{2}(\psi_{10}-\psi_{12})\right]\end{array}\right\}+\\ +\left\{F_a\left(1-\frac{\sqrt{\left(x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}\right)^2+y^2_{I-1,J-2}}}{\Delta/B}\right)\left(\begin{array}{l}\frac{2y^2_{I-1,J-2}\cos\beta}{\left(x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}\right)\left[\left(x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}\right)^2+y^2_{\substack{I-1\\J-2}}\right]}+\\+\frac{x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}}{\left(x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}\right)^2+y^2_{\substack{I-1\\J-2}}}\sin\beta\end{array}\right)\right\}_{\substack{D_1\\D_5}}-\\ -\left\{F_c\left(1-\frac{\sqrt{\left(x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}\right)^2+y^2_{I-1,J-2}}}{\delta/B}\right)\left(\begin{array}{l}\frac{x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}}{\left(x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}\right)^2+y^2_{\substack{I-1\\J-2}}}\sin\beta+\\+\frac{2y^2_{I-1,J-2}\cos\beta}{\left(x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}\right)\left[\left(x_{\substack{I-1\\J-2}}-x_{\substack{13,2\\23,2}}\right)^2+y^2_{\substack{I-1\\J-2}}\right]}\end{array}\right)\right\}_{\substack{D_2\\D_6}}\end{array}\right\|\end{array}\right\} \quad (6)$$

and by elaborating the calculus program and by streamline drawing, one can observes in figure 2 the fluid flow cling on the broken plate even at an angle of 45^o, due to the Henri Coanda's effect, considering the attraction molecular forces of adhesion and cohesion.

6. EXPERIMENTAL RESEARCHES

The experimental installation, figured in figure 3, consists of a metallic support, with a strain gauge balance fixed to its upper side equipped with four groups of double marks for the measuring of the aerodynamic two resultant components, having fixed the blade profile with Coanda effect (fig. 4) shown bellow.

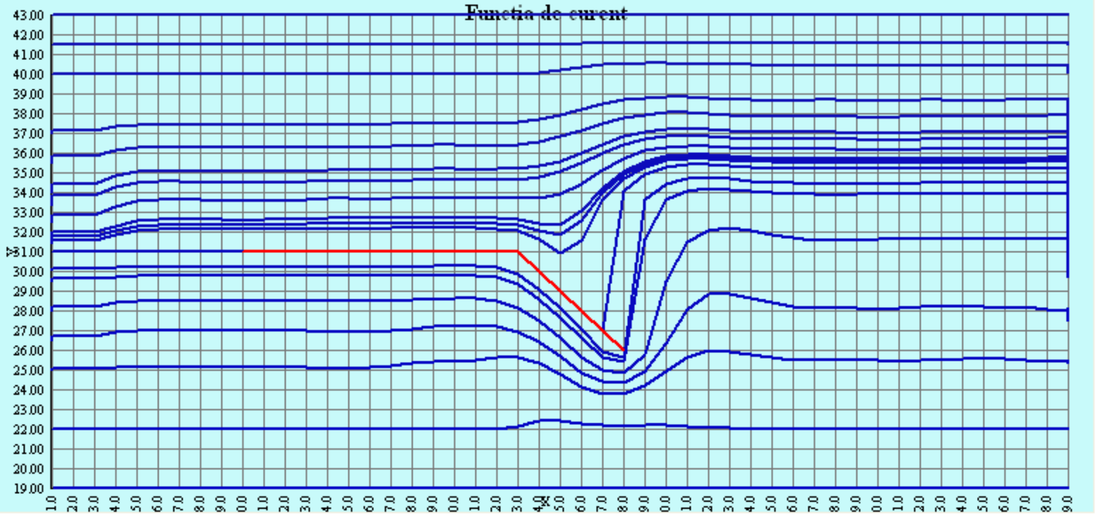

Fig. 2. The aspect of the streamline function

Fig. 3. View of the little free jet wind to determine the profile polar and the used measuring apparatus between the two limited discs.

The profile rotation angle is indicated by a protractor and has in the shaft extension two plaques, submerged in a vase full with valvoline to damp the oscillations caused by the whirls induced by the fluid flow turbulence, produced by an electro-ventilator and diminished by an uniformity calming.

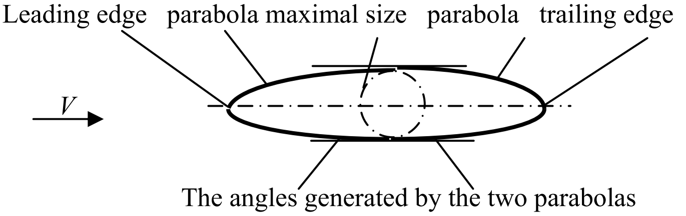

Fig. 4. The straight anti shock profile, realized by the intersection of the two parabolas

On the experimental research basis one obtains the following special result, the lift downfall having place slowly after an angle of about 27° (fig. 5), instead of the usual angle of 11°, which can be obtained at the best profile. In this zone the curve evolution is permanently growing, as well as the linear downfall after the flow separation, that permits a good flow stability of the air current.

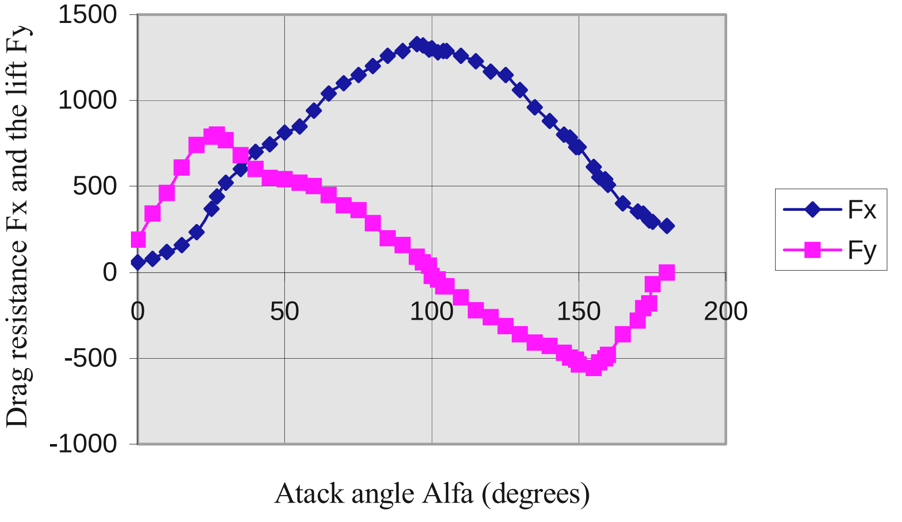

Fig. 5. The variation of the drag resistance F_x and lift force F_y with the attack angle α (degrees)

An other patented profile [5] with Coanda's effect is the following represented in figure number 6.

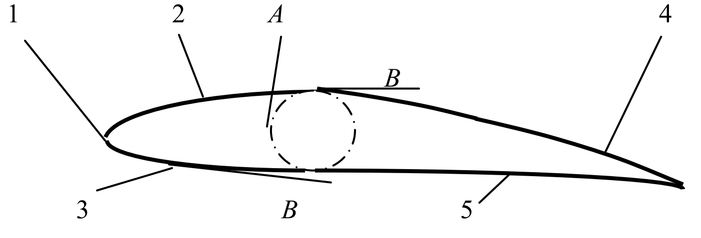

Fig. 6. A normal profile with Coanda's effect, having in the neighbouring of the profile maximal wide *a* two separation angle in the regions *B* between the upstream surfaces 2 and 3 rounded in the attack edge 1 and the two downstream surfaces 4 and 5, united in a sharp downstream edge

7. CONCLUSIONS

Considering the molecular attraction forces of adhesion and cohesion one can theoretically explain the so called Henri Coanda's effect, the efficiency of the authors patented profiles and laboratory tested, having the angle of flow separation over 27°, being possibly to be used with success for the wind turbines, due to the fact that the wind blows in gusts, in which case the blade vibration can be eliminated and thus the wind turbines life can be extended.

On this occasion we wish to express our gratitude to renowned fellow compatriot Henri Coanda, the brilliant inventor of the first jet aircraft in 1910.

8. REFERENCES

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