FLOW CONTROL INVESTIGATION USING THE COANDA EFFECT ON AIRFOILS

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Abstract: *Numerical investigations on the flow control around airfoils, in conjunction with Coandă effect, based on RANS equations are done. The circulation control uses the tangential blowing jet on the upper surface of the airfoil near the trailing edge with the rounded or modified flatback surface. Flow field spectra around such a configurations, involving the delayed of flow separation are obtained and analyzed by CFD methods. Thus can be identified the optimum domain of the geometric and jet flow parameters in which this flow control method should be used.*

Keywords: *Coandă effect, circulation control, high-lift system*

1. INTRODUCTION

One of the most important aerodynamic choices when designing an airplane wing or propeller blades is that of the appropriate airfoil, optimal first of all for the cruise flight phase or the nominal operating mode. However, for other operating phases (such as take-off, for example), it is necessary to obtain higher lift characteristics, or, more desirably, higher lift/drag- ratio.

There are currently several methods to achieve these performances. If the conventional methods, which involve slats or slotted flaps on trailing-edge or leading-edge of the wing, there are major drawback related to the complexity mechanics [1] and

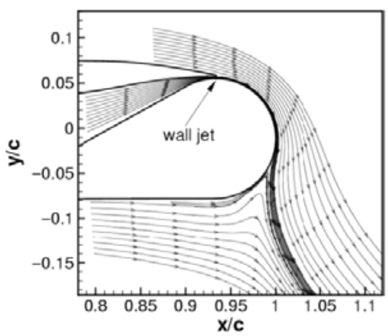


FIG. 1. Circulation control around a curved trailing edge of an airfoil.

thus of increasing the weight, the so-called gapless high-lift systems can be used, with the trailing-edge blowing [2] (Fig. 1), benefiting from the advantages of the Coandă effect to delay the flow separation [3].

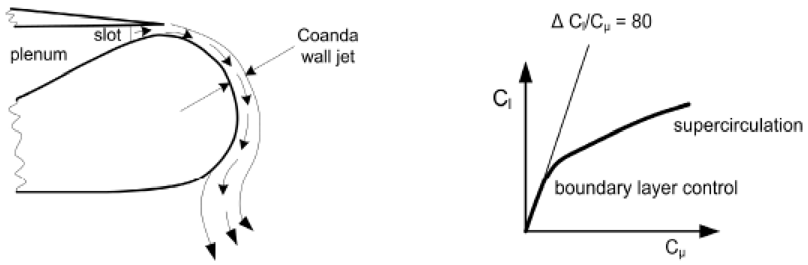
This method is one of active flow control methods and even when using a small percentage of the cold engine flow, there is a good efficiency of obtaining the necessary high-lift coefficient for the take-off or landing flight phase.

The circulation control around an airfoil is obtained by tangentially blowing of a small thickness jet over the rounded trailing edge. As a result, the jet sheet remains attached and deflected on a longer portion of the curved surface, without separation of the flow.

That is why numerical investigations and analyses are needed using a CFD solver (in this case, Ansys Fluent [14]) to evaluate the advantages and limits of this circulation control technology for airfoils.

2. THEORETICAL ASPECTS

A passive or active circulation control based on blowing jet around a Coandă surface can augment the aerodynamic characteristics of an airfoil [4- 9]. The separation is delayed (Fig. 2a) and thus an improved lift coefficient is obtained, based on additional circulation (Fig. 2b).



a) *Rounded trailing edge* b) *Schematic lift behaviour*

FIG. 2. Scheme of circulation control in conjunction with a Coandă surface.

By introducing an additional circulation term (Γ_{jet}) the reaction forces are increased:

$$P = \rho\, V_\infty \left(\Gamma_c + \Gamma_{jet}\right) \tag{1}$$

where ρ is the fluid density, V_∞ is the unperturbed fluid speed, Γ_c is circulation around the airfoil, and

$$\Gamma_{jet} = \frac{\dot{m} V_{jet}}{\rho\, V_\infty}\left(\alpha + \beta_{jet}\right) \tag{2}$$

where $\dot{m}$ is the mass flow rate, V_{jet} is the jet speed and β_{jet} is the jet deflection angle at the exit of the plenum chamber. Then aerodynamic coefficients in conjunction with Coandă jet are:

$$\begin{aligned} C_{L,jet} &= C_T \sin\left(\alpha + \beta_{jet}\right) \\ C_{D,jet} &= C_T \cos\left(\alpha + \beta_{jet}\right) \end{aligned} \tag{3}$$

where C_T is the thrust coefficient due to the Coandă jet. The enhanced total lift and drag coefficients are:

$$\begin{aligned} C_L &= C_{L,p+\tau} + C_{L,jet} \\ C_D &= C_{D,p+\tau} + C_{D,jet} \end{aligned} \tag{4}$$

where $C_{L,p+\tau}$ and $C_{D,p+\tau}$ are values of lift and drag coefficients, respectively, for the case without blowing jet.

The induced circulation is changed by the jet acting in the neighborhood of a Coandă type surface (Fig. 3), depending on the jet position [10, 11].

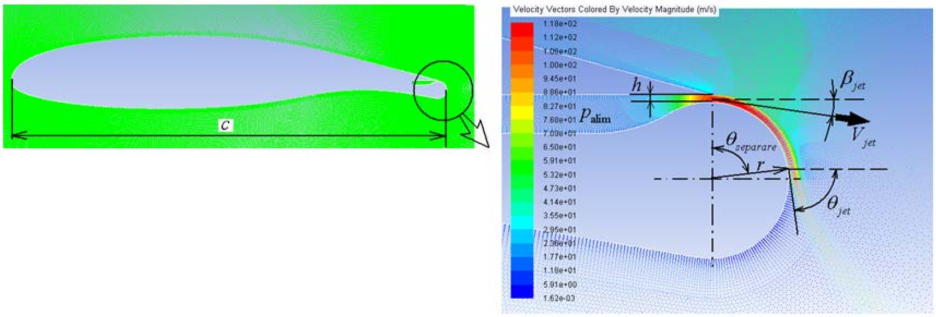


FIG. 3. Geometric data on the rounded trailing edge for the Coanda type flow

The momentum coefficient (C_μ) is one parameter in this investigation, based on thrust of the jet, obtained at the slot exit:

$$C_\mu = \frac{Thrust}{q\,S} = \frac{\dot{m} V_{jet}}{q\,S} = \frac{2\,h\,w}{b\,c}\,\frac{\rho_{jet}}{\rho_\infty}\,\frac{V_{jet}^2}{V_\infty^2} \tag{5}$$

where $\dot{m}$ is mass flow rate

$$\dot{m} = \rho_{jet} V_{jet} h\, w\,, \tag{6}$$

w = jet width, and $S = b \cdot c = 1 \cdot c$ is the reference surface.

An estimate of the total required power, P_f, can be made as the sum of required power to create the jet, P_{jet} and the lost power in the nozzle of the reservoir, P_{jet}:

$$P_f = P_{jet} + P_{rez} = \frac{1}{2}\rho V_{jet}^2 \frac{\dot{m}}{\rho} + \dot{m} V_\infty^2 = C_\mu \frac{V_{jet}}{2V_\infty}\left[1 + 2\frac{V_\infty^2}{V_{jet}^2}\right]\left(q_\infty V_\infty S\right) \tag{7}$$

Then the dimensionless parameter, the fluid power coefficient is obtained:

$$C_{P_f} = \frac{P_f}{q_\infty V_\infty S} = C_\mu \left(\frac{V_{jet}}{2V_\infty} + \frac{V_\infty}{V_{jet}}\right) \tag{8}$$

This ideal power coefficient can be expressed as a function only of the momentum coefficient C_μ and the dimensionless parameter, *h/c* ratio:

$$C_{P_f} = \frac{C_\mu^{3/2}}{2\sqrt{2(h/c)}}\left[1 + \frac{4(h/c)}{C_\mu}\right] \tag{9}$$

In Fig. 4 the variation of the ideal fluid power coefficient, C_{P_f} as function of the momentum coefficient, C_μ, is represented, for various *h/c* ratios. Figure 5 shows the dependency results for the mass flow rate, $\dot{m} = f(C_\mu, h/c)$, under certain conditions given for external flow and also for geometry ($c = 0.5\,m;\ V_\infty = 30\,m/s;\ T_0 = 291\,K$).

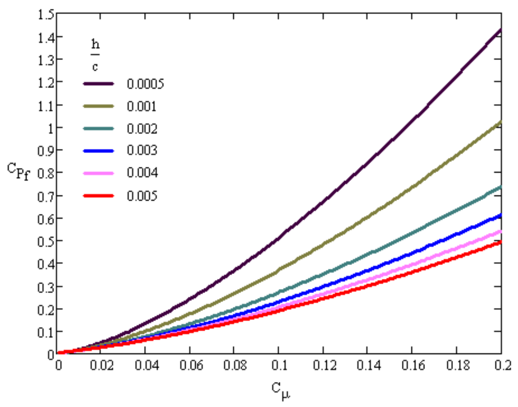


FIG.4. Required coefficient fluid power for "Coandă" type jets, for various *h/c* ratios

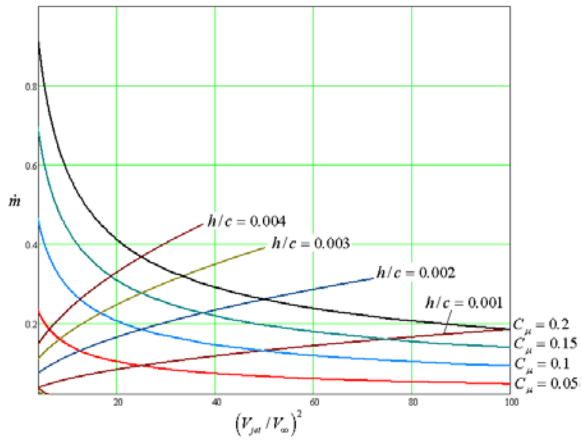


FIG. 5. Required mass flow rate for circulation control

3. NUMERICAL INVESTIGATIONS OF CIRCULATION CONTROL ON AIRFOILS WITH MODIFIED TRAILING EDGE

In recent years a lot of experiments and numerical simulations have been made to investigate and show that there are good premises for using the Coandă effect in controlling the flow around airplane wings or turbomachine blades [10 - 12].

For our numerical investigations the 17% Supercritical General Aviation Circulation Controlled Airfoil (GACC) with a round trailing edge as a Coandă surface was selected [11,12]. The geometric parameters are: *h/c* = 0.002, *h/r* =0.1, $\beta_{jet} = 0^0$ and *r/c*=2% (Fig. 6).

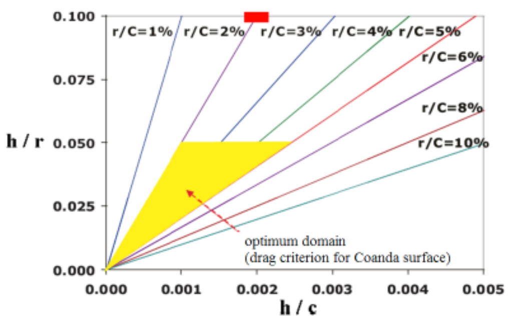


FIG. 6. Optimum geometry domain of the most effective circulation control

The momentum coefficient (C_μ) is obtained from the equation (7) and Reynolds number has a value of order of 10^6 for a fully turbulent flow.

With regard to CFD data it can be specified that a structured mesh is used (Fig. 7), where 0.4< y^+ < 1 and 25< Δx^+ <300, boundary conditions are given as usual for 2D aerodynamic analysis and to close and solve the RANS model, the $k-\omega$ SST turbulence model has been chosen [13].

Two configurations are numerically investigated based on the modified GACC airfoil and a third one is based on the DU97 airfoil with modified flat trailing edge.

Various momentum coefficients C_μ; for an undisturbed flow with velocity V_∞ = 30 m/s are basic parameters in these investigations.

3. 1 Flap with cylindrical trailing-edge. When the jet leaves tangentially the plenum chamber ($\beta_{jet} = 0^0$) it has the tendency to remain attached to the round surface on a certain length, depending on the jet momentum coefficient and on the external flow velocity (if the geometric parameters, *h*/*c* and *r*/*c*, are fixed).

For a low momentum jet the external flow on the upper side of airfoil will be quickly separate. When the jet momentum coefficient is increased, the separation occurred at an angle that exceeds 90 degrees to the direction of the initial jet, generating a virtual slat.

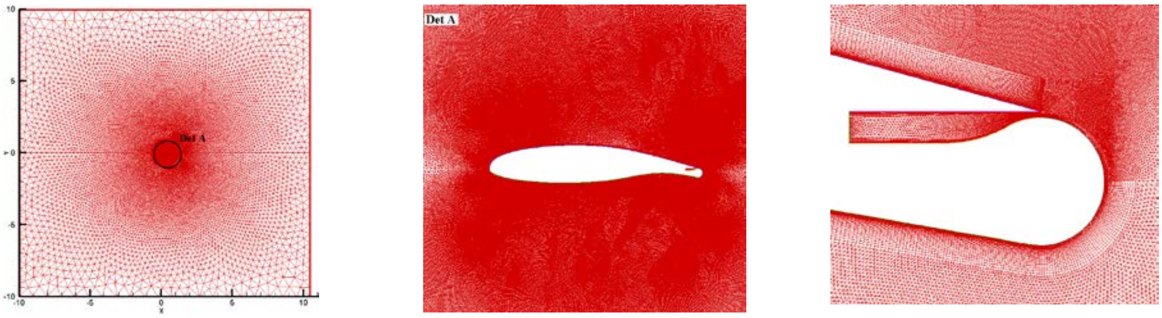


FIG. 7. Computational domain, meshing and trailing edge details

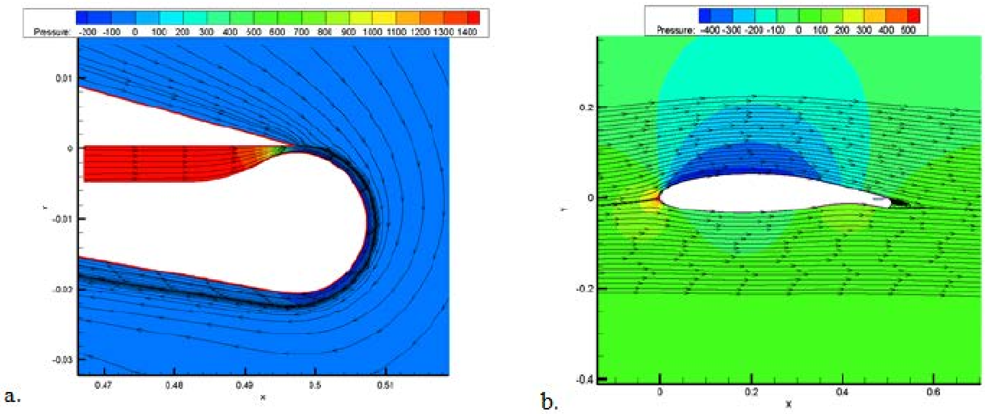


FIG. 8. Streamlines and pressures field: (a) without external flow ($V_{jet} = 9\ m/s,\ V_{\infty} = 0\ m/s$) and (b) external flow without jet ($V_{\infty} = 30\ m/s$)

Results of numerical simulations with $V_{jet} \geq 9\ m/s$ highlight that the jet is attached on the cylindrical trailing edge surface, with a value of θ_{jet} angle higher than 90^0 [10 - 12] (Fig. 8). This may have a reverse effect, that is, a decrease in the lift efficiency rate, due to the shortening of the suction portion on the lower side of the airfoil. Figures 9 and 10 show, the flow spectra (streamlines and pressure fields, with details around trailing edge (TE)), at various momentum coefficients.

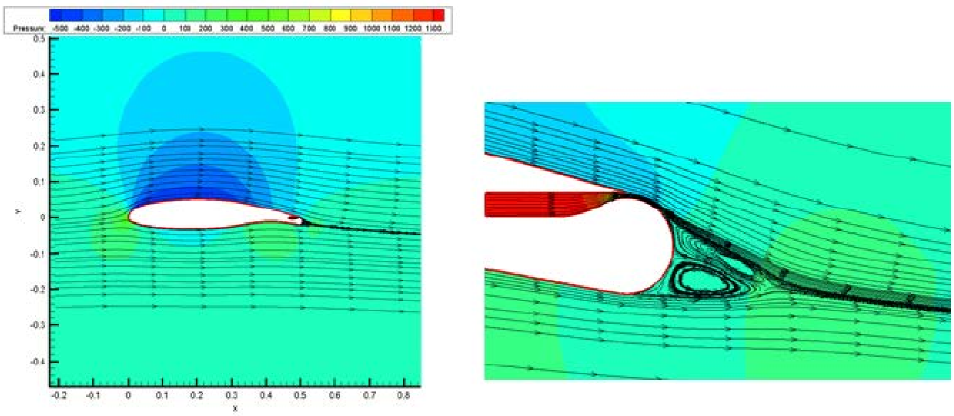


FIG. 9. Streamlines and pressures field with TE details; $V_{jet} = 9\ m/s,\ V_{\infty} = 30\ m/s$

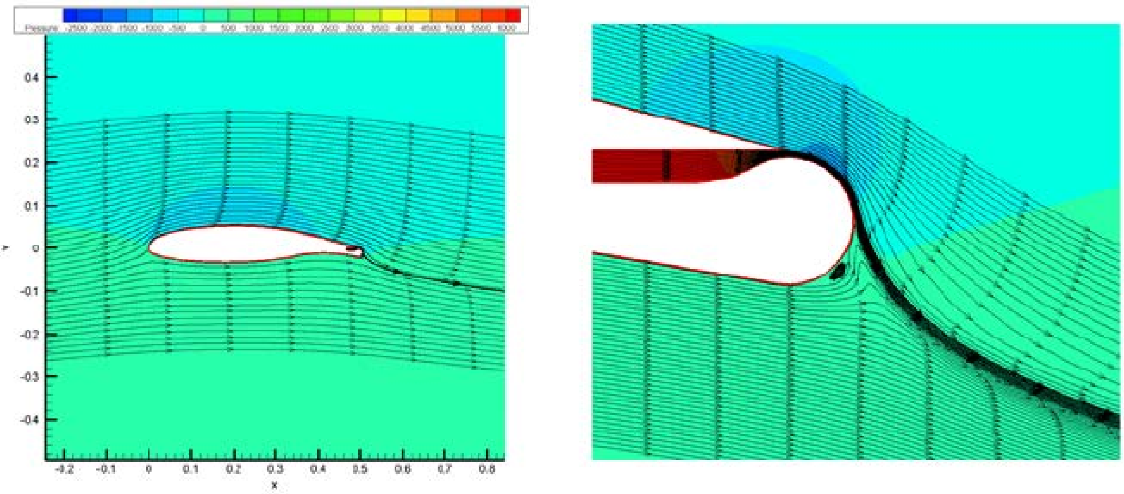


FIG. 10. Streamlines and pressures field with TE details; $V_{jet} = 20\ m/s,\ V_{\infty} = 30\ m/s$

3.2 Flap with double curvature. For this numerical simulations the configurations consists in an airfoil where the trailing edge with circular surface is replace with a flap that has a circular upper part with the same radius that in the previous test case, followed by another curved portion. For simulations, the flap is deflected with 55^0 angles.

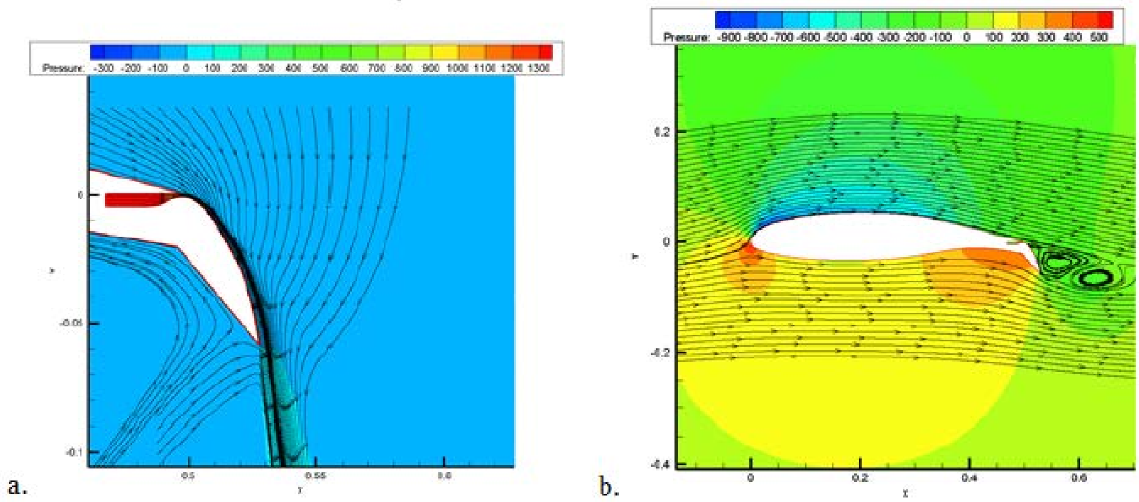


FIG. 11. Flowfield (streamlines and pressures):
(a) without external flow (V_{jet} = 9*m/s;* V_{∞} = 0*m/s*) and (b) external flow without jet (V_{∞} = 30*m/s*)

It is observed that for $V_{jet} \leq 10.549\ m/s$ and for a value of momentum coefficient $C_{\mu} = 0.0124$, the separation took place between 10^0-20^0 range on the circular zone.

For values of $V_{jet} \geq 10.55\ m/s$ the jet flow is reattached on the entire surface of the flap. In Fig. 11 and 12 these spectra of the flow can be seen. Comparing with the reference case (C_{μ} = 0:0) for this configuration, a double lift coefficient can be obtained, but must consider also and increasing drag.

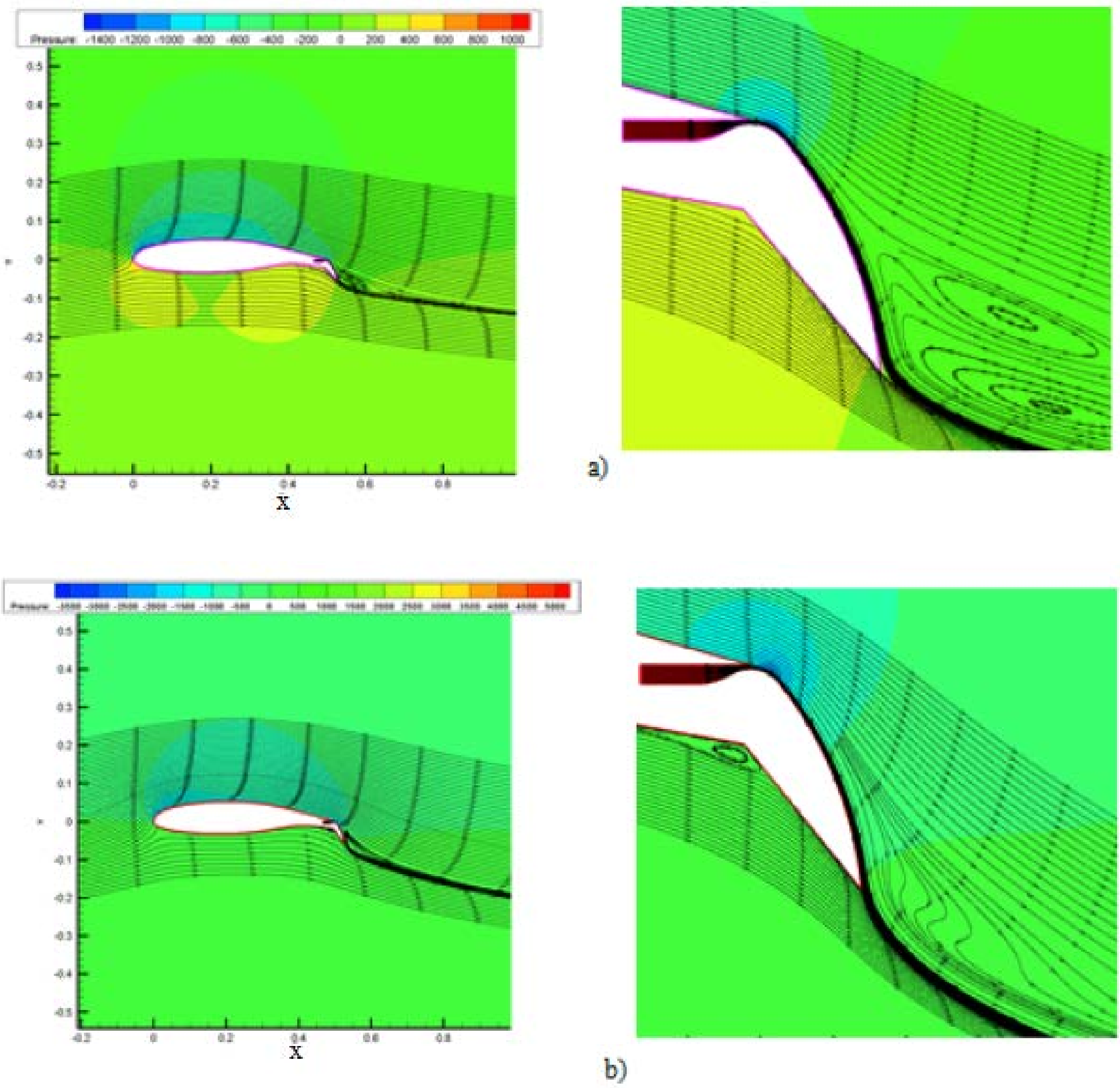


FIG. 12. Flowfield (streamlines and pressures) for two numerical simulations cases, with details: (a) V_{jet} = 10.55 *m/s;* V_{∞} =30 *m/s;* (b) V_{jet} = 20 *m/s;* V_{∞} =30 *m/s*

3.3 DU97 airfoil with modified flat trailing edge. With the development of wind turbines in last years, especially with the horizontal axis, it was necessary to use the airfoils with blunt trailing edge or called flatback airfoils, for rotor blades. Flatback airfoils provide several structural and aerodynamic performance advantages [15].

At the trailing edge, the upper side is prolonged by a cylindrical shape, up to half the thickness of the trailing edge and a linear lower portion is continued until it intersects the extension of the lower part of the airfoil (Fig. 13).

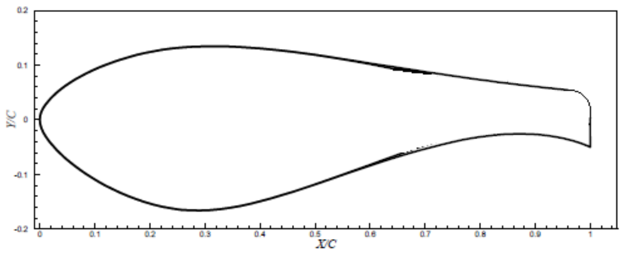
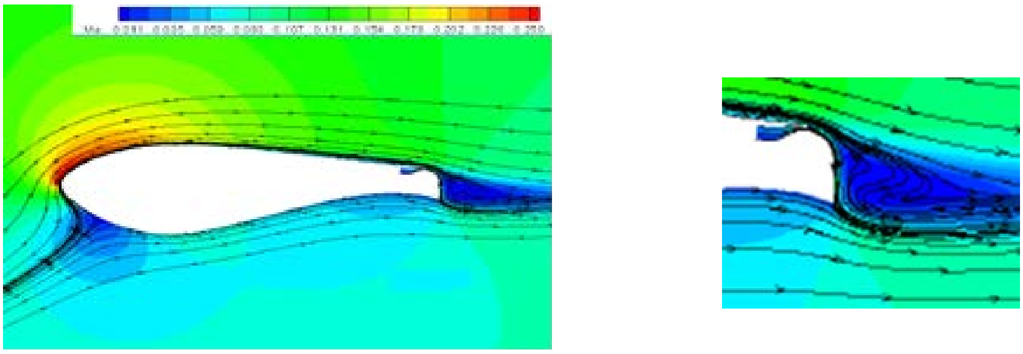


FIG. 13. Airfoil shape of DU97 with modified flatback TE.



a. b.

FIG. 14. a) Flowfield around DU97 flatback airfoil (V_∞ = 30 *m/s*, incidence angle = 15^{0}, Re=3.0x10^6, C_μ=0.030); b) detail of TE flowfield

It was therefore necessary to analyze these modified airfoil shape and found optimal circulation control necessary for obtaining enhanced aerodynamic characteristics, and, finally, increasing the amount of harvested energy from the wind (Fig. 14).

The jet is attached on the Coandă surface for the value of momentum coefficient $C_\mu = 0.030$, but if this value is increased the jet can acting as a pneumatic flap. The enhancement in lift increases with increasing of jet momentum coefficient or decreasing of the slot height.

CONCLUSIONS

Three configurations in conjunction with the Coandă effect have been numerical investigated based on RANS solver. For all cases the blowing efficiency on a curved surface ("Coandă surface") is observed, compared with the reference cases without jet.

Based on this type of circulation control, equal or greater lift coefficients that than for classical high-lift systems are obtained. However, one must consider that this increase in lift is accompanied by an increase in drag.

It is obvious that this type of circulation control has to be used in addition to other flow control methods, in order to obtain the optimal parameters for all operating phases.

Future further investigations to be made on improving these methods, must be completed and compared with experimental investigations.

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