INCOMPRESSIBLE LAMINAR BOUNDARY LAYER CONTROL BY BLOWING AND SUCTION

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Abstract

A two-dimensional incompressible laminar boundary layer and its control using blowing and suction over a flat plate and around the NACA 0012 and 661012 profiles, is studied numerically. The study is based on the Prandtl boundary layer model using the finite differences method and the Crank-Nicolson scheme. The velocity distribution, the boundary layer thickness and the friction coefficient, are determined and presented with and without control. The application of the control technique, has demonstrated its positive effect on the transition point and the friction coefficient. Both control procedures are compared for different lengths, speeds and angles of blowing and suction.
Keywords : *boundary-layer, incompressible, laminar, finite differences, blowing, suction..*

Résumé

La couche limite laminaire, bidimensionnelle et incompressible sur une plaque plane et autour des profils NACA 0012 et NACA 661012 et son contrôle par soufflage et par aspiration, est étudiée par voie numérique. L'étude est basée sur le modèle de la couche limite de Prandtl utilisant la méthode des différences finies et le schéma de Cranck-Nicolson. La distribution de vitesse, l'épaisseur de la couche limite et le coefficient de frottement, sont déterminés et présentés avec et sans contrôle. L'application du contrôle a démontré son effet positif sur le point de transition et sur le coefficient de frottement. Les deux techniques de contrôle sont comparées pour différentes longueurs, vitesses et angles de soufflage et d'aspiration.
Mots clés *: couche limite, incompressible, laminaire, différences finies, contrôle, soufflage, aspiration.*

ملخص

تمّت دراسة عددية لطبقة حدية منتظمة ثنائية البعد و غير منضغطة حول صفيحة مستوية و مقاطع جناح NACA 0012 و NACA 661012 و التحكم فيها باستعمال عملية النفث و الامتصاص.الدراسة كانت مبنية على نموذج برانتل للطبقة الحدية باستعمال طريقة الفروق المنتهية و مخطط كرنك نكو لسن. تمّ حساب السرعات و سمك الطبقة الحدية و معامل الاحتكاك و تمثيلهم عند تطبيق و عدم تطبيق تقنيات المراقبة. تطبيق تقنية المراقبة برهن على فعاليته بالنسبة لنقطة التحول و معامل الاحتكاك. تمّت مقارنة التقنيتين لمختلف أطوال، سرعات و زوايا النفث و الامتصاص.

الكلمات المفتاحية: طبقة حدية ، غير منضغط، سفحية، فروق منتهية، ، مراقبة ، نفث، امتصاص

Introduction :

The boundary layer which is the thin area in contact with the wall profile is the seat of viscous phenomena generating frictional drag [1], and the laminar boundary layer causes less friction than the turbulent boundary layer [2]. Recent studies estimate that it represents about half of the total drag [3, 4, and 5]. Any reduction of the latter would result in an increase of the aerodynamic performances or in a decrease of the energy consumption given that fossil fuel reserves are becoming scarce day by day, on one hand, and on the other hand, excessive consumption of these reserves is steadily increasing due to the increase of the world demand.
One way to achieve this goal is to maintain the boundary layer laminar as long as possible by delaying its point of separation toward the trailing edge. The present work is to study a two-dimensional laminar boundary layer of an incompressible air flow developed around a wing profile or a compressor and turbine blade and its control by suction or blowing using the Prandtl boundary layer model. The partial differential equations governing this type of problem are solved using the finite difference method and the Cranck-Nicolson scheme. The study concerns a flat plate and two NACA profiles 0012 and 66_1012 [6]. The velocity distribution, the boundary layer thickness, the friction coefficient as well as the separation point are determined and presented with and without control. The application of control by suction or blowing has shown its positive effect on the separation point and the friction coefficient distribution [7]. Indeed, the separation point has moved to the trailing edge causing a longer laminar boundary layer region, with a lower friction coefficient.

2. Mathematical modeling

The mathematical model governing the boundary layer is [8, 9]

$$\partial u/\partial x + \partial v/\partial y = 0 \qquad (1)$$

$$u\,\partial u/\partial x + v\,\partial u/\partial y = -\partial p/\partial x/\rho + \partial^2 u/\partial y^2 \qquad (2)$$

$$u(x=0,y) = u(y) \qquad (3)$$

$$v(x=0,y) = v(y) \qquad (4)$$

$$v(x,y=0) = u(x,y=0) = 0 \qquad (5)$$

The length of the laminar boundary layer with its limit point where the boundary layer changes its nature and becomes turbulent, is defined according to the classical theory by

$(\partial u/\partial y)_w = 0$.

We study the boundary layer in curvilinear coordinated (s, y), with the coordinated s representing the surface contour of the profile and the coordinated perpendicular to s. First, we must make the non dimensional mathematical model by the following changes. Generally, solving nonlinear differential equations governing physical problems makes use of suitable numerical methods [9, 10]. In this case previous studies show that the finite difference method is more suitable with the use of the scheme Cranck-Nicolson. Thus the transformation of differential equations into algebraic equations is obtained, commonly known as the discretization

$\xi = x/L, \eta = y(U_e/vs)$ et $f = u/U_e$

The mathematical model [3] is reduced

$$\xi\frac{\partial f}{\partial \xi} + \beta f' + \frac{1}{2}(\beta - 1)\frac{\partial f'}{\partial \xi} + \frac{\partial V}{\partial \eta} = 0 \qquad (6)$$

$$f'\xi\frac{\partial f'}{\partial \xi} + V'\frac{\partial f'}{\partial \xi} = (1 - f'f') + \frac{\partial^2 f\prime}{\partial \eta^2} = 0 \qquad (7)$$

$$V' = V + \frac{1}{2}\eta f'(\beta - 1) \qquad (8)$$

With the following conditions

$\beta = \frac{\xi}{U_e}\frac{dU_e}{d\xi}$,$f'(\xi,0) = 0,$

$f'(\xi,\eta_\infty) = V(\xi,\eta=0) = 0,\ \frac{\partial f\prime}{\partial \eta} = 0$ (point of detachment)

The entrance ($\xi = 0$) chosen near the edge, where the mathematical model reduces to the
Falkner- Skan equation [8] and its resolution determines the initial profile

$$f''' + \frac{1}{2}(1 + \beta_i)ff'' + \beta_i(1 - f'f') = 0$$

(9)

2.1 Numerical boundary layer resolution

Generally, solving nonlinear differential equations governing physical problems makes use of suitable numerical methods. In this case, previous studies show that the finite difference method is more suitable [8] with the use of the scheme Cranck-Nicolson. Thus the transformation of differential equations into algebraic equations is obtained

2.1.1 Momentum equation discretization

The momentum equation is discredited and rearranged [8]

$$A_{mn}f'_{m+1,n+1} + B_{mn}f'_{m+1,n} + C_{mn}f'_{m+1,n-1} = D_{mn}$$

$$A_{mn} = \frac{V^-{}_{mn}}{4\Delta\eta} - \frac{1}{2(\Delta\eta^2)} \qquad (10)$$

$$B_{mn} = f'_{mn}\frac{1}{\Delta\xi}\xi_{m+\frac{1}{2}} + \frac{1}{(\Delta\eta^2)} + f'_{mn}\beta_{m+\frac{1}{2}} \qquad (11)$$

$$C_{mn} = -\left(\frac{V^-{}_{mn}}{4\Delta\eta} + \frac{1}{2(\Delta\eta^2)}\right) \qquad (12)$$

$$V^-{}_{mn}\frac{+f'_{m,n+1} - f'_{m,n-1}}{4\Delta\eta} + f'^2_{mn}\frac{1}{\Delta\xi}\xi_{m+\frac{1}{2}}$$

$$D_{mn} = \beta_{m+\frac{1}{2}} + \frac{f'_{m,n+1} - 2f'_{mn} + f'_{m,n-1}}{2(\Delta\eta^2)} + \qquad (13)$$

2.1.2 Continuity equation discretization

The continuity equation is discredited and rearranged [8]

$$V_{m+1,n} = V_{m+1,n-1} + V_{m,n-1} - V_{m,n} + 2\Delta\eta\,(A_n^c\, f'_{m+1,n} + B_n^c\, f'_{m+1,n-1} + C_n^c\, f'_{m,n} + D_n^c\, f'_{m,n-1})_n$$

$$A_n^c = -\frac{1}{4}\beta_{m+\frac{1}{2}} - \frac{1}{2\Delta\xi}\xi_{m+\frac{1}{2}} - \frac{1}{4\Delta\eta}\eta_{n-\frac{1}{2}}\,(\beta_{m+\frac{1}{2}} - 1)$$

$$B_n^c = -\frac{1}{4}\beta_{m+\frac{1}{2}} - \frac{1}{2\Delta\xi}\xi_{m+\frac{1}{2}} + \frac{1}{4\Delta\eta}\eta_{n-\frac{1}{2}}\,(\beta_{m+\frac{1}{2}} - 1)$$

$$C_n^c = -\frac{1}{4}\beta_{m+\frac{1}{2}} + \frac{1}{2\Delta\xi}\xi_{m+\frac{1}{2}} - \frac{1}{4\Delta\eta}\eta_{n-\frac{1}{2}}\,(\beta_{m+\frac{1}{2}} - 1)$$

$$D_n^c = -\frac{1}{4}\beta_{m+\frac{1}{2}} + \frac{1}{2\Delta\xi}\xi_{m+\frac{1}{2}} + \frac{1}{4\Delta\eta}\eta_{n-\frac{1}{2}}\,(\beta_{m+\frac{1}{2}} - 1)$$

2.2 Algorithm for solving the laminar boundary layer

Tri diagonal system of the descritised equation of momentum is solved by the Thomas algorithm [11], and the numerical method of shooting [12] in the following steps

- The choice of the profile fixes through its leading edge the initial shape parameter β. This allows solving the Falkner-Skan equation, i.e. obtaining of all the values of f', f'' *and* f''' and f''' for all points of the initial station.
- The determination of the external velocity Ue(i).
- The calculation of the shape parameter β for all stations along the profile.
- The calculation of the values for all of the initial station.
- Solving the equation of momentum by the Thomas algorithm.
- The calculation of the velocity values and this new station

3. Discussions of Results

The numerical code developed tests were conducted on a flat plate, NACA0012 airfoil and a NACA 66_1012. The point of separation is determined from the velocity profiles on the profile surface. A technique for controlling the boundary layer blowing molding and suction is applied to test the influence of several parameters such as the extent of blowing and suction, the orientation of the angle of ejection or suction and the amount blown or sucked. To validate the numerical code, we carried out a comparison of the results of the profile with solid surface and those obtained by the BLASUIS method for flat plate [13].

3.1 Comparison of friction coefficients between the both control techniques

The friction coefficient on the wall subjected to blowing over the whole surface is still lower than that obtained by suction. This is explained by the fact that in the case of blowing, additional energy is injected, while in the case of suction, sucking the decelerated particles of the inner layer of boundary layer. Both friction coefficients have the ratio. Friction drag is the subject of intensive research. One strategy is to reduce turbulent friction by acting on the nature of the flow, that is to say the maximum possible extend the laminar boundary layer [14]

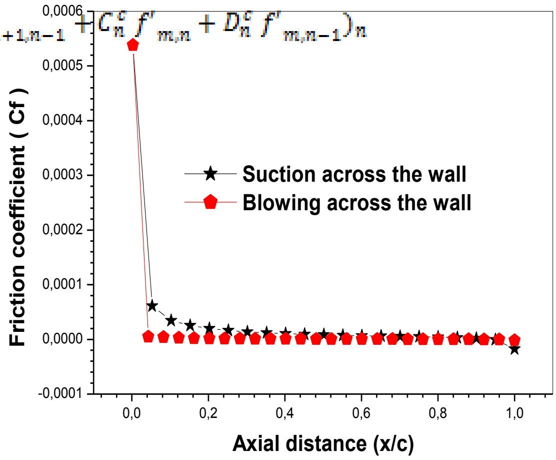

Figure (1) Friction coefficient on NACA 0012 M ∞ = 0.23, α = 0 °, θ = 10 °, vo / U ∞ = 1%.

3.2 Boundary layer thickness control for a range xp = 40%

In the following figure, we present a comparison of the boundary layer thickness on a NACA 0012 using the two control techniques blowing aspirate for scope xp = 40% of the chord. The boundary layer thickness is thinner by blowing than that obtained by suction. The explanation is introducing particle acceleration which is done only in the case of blowing, something not found with suction, where the friction is lower by blowing. We note that the effect stabilizes beyond the porous surface that is to say beyond xp = 40%

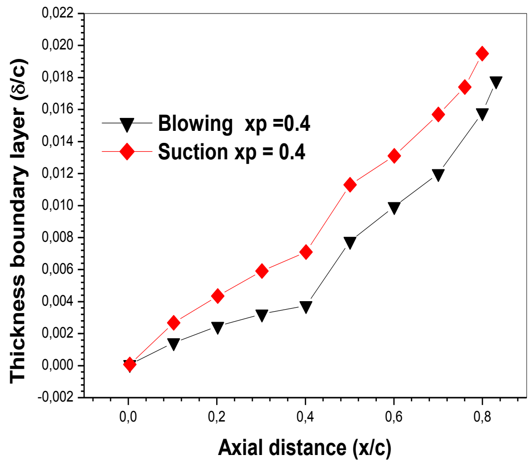

Figure (2) Thickness boundary layer on a NACA 0012. xp = 40%, M ∞ = 0.23 and α = 0 °.

3.3 Boundary layer thickness control on a NACA0012

The axial distribution of the thickness laminar boundary layer on a NACA 0012 is shown in the case of blowing molding and in the case of the suction of the boundary layer over the entire surface. It is noted that the boundary layer for the case of the blowing is thinner relative to that of suction, with an increasing effect. So, the wider the range, the greater the effect on the stability of the laminar boundary layer is important.

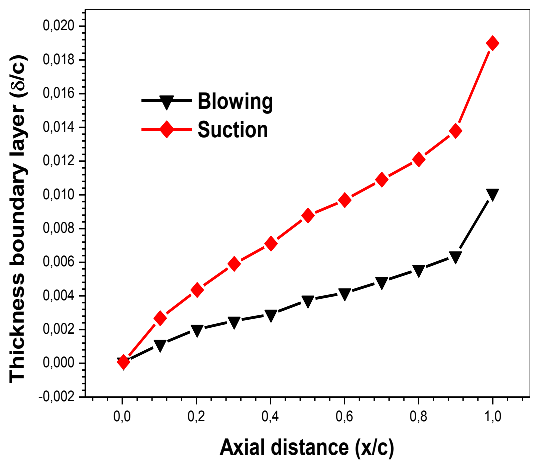

Figure (3) Thicknesses boundary layer on a NACA 0012, M ∞ = 0.23, α = 0 °, xp = 100%, vo / U = 1%.

3.4 Velocity profiles

In Figure (4), we present a comparison of the axial velocity profiles taken at the same station x / c = 30% on a NACA 0012 with and without control. The velocity profile for the solid profile develops quickly because of the important energy exchange near the wall, then it becomes slower and eventually stabilize, i.e. without meaningful exchange. The same phenomenon occurs with suction, but with less degree, but in the case of blowing trade is almost non-existent, i.e. the flow is almost potential.

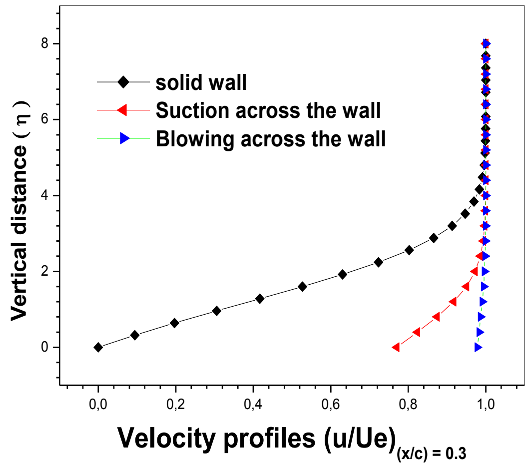

Figure (4) velocity profiles over a NACA 0012 M ∞ = 0.23, α = 0 °, xp = 100%, vo / U ∞ = 1%.

3.5 Friction total

A comparison of the friction coefficients of a NACA 0012 profile subject to blowing and to suction. We note that the control technique by blowing gives a friction coefficient lower than of the suction for the same conditions. The effect is more important with the range increase. The friction coefficients suction and blowing are in a ratio of three. So, blowing control reduces friction in ratio 1/3 compared to blowing.

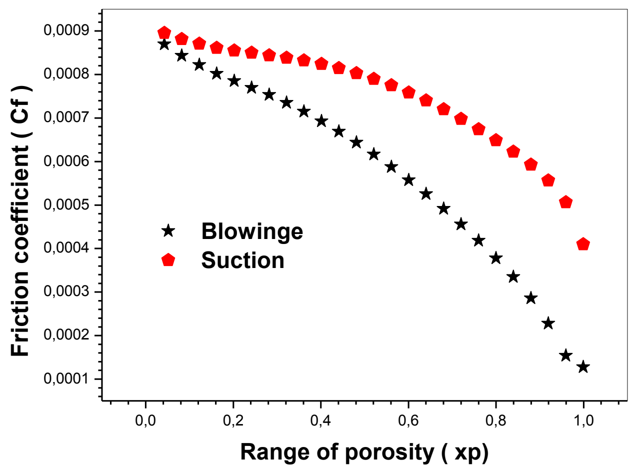

Figure (5) Friction coefficient of a NACA 0012. M ∞ = 0.23, α = 0 °, θ = 10 ° and vo / U ∞ = 1%.

3.6 Friction coefficients of solid walls

The leading edge is rounded on NACA profiles, allowing relatively good traction with respect to the flat plate. Therefore the friction coefficient is higher for the flat plate for NACA profiles at the edge of attack. On the other hand the position of the relative thickness to the more advanced for NACA 0012 than for NACA 66_1012 provides an acceleration length of flow acceleration greater on the NACA 66_1012 and therefore a friction coefficient is relatively lower. We note that the radius of the leading edge has an influence on the friction coefficient. The smaller radius of the NACA 66_1012 gives a lower friction coefficient.

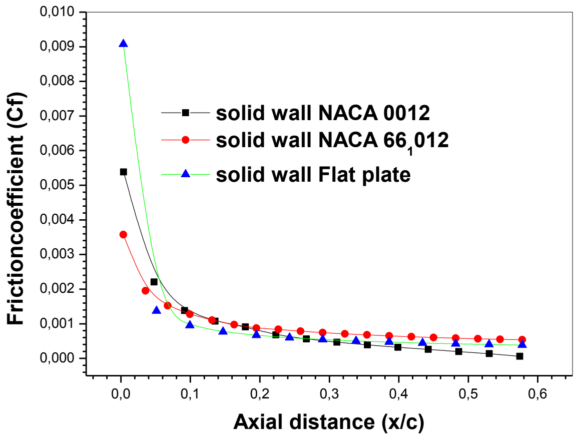

Figure (6) Friction coefficient for a flat plate, NACA 0012 and 66_1012. M∞ = 0.23, α = 0°.

3.7 Effect of the friction coefficient control

Control of the friction coefficient shows the positive effect obtained by applying the two techniques to control the boundary layer. Control gives blowing friction coefficient lower than suction, but suction for the same profile NACA 0012 and the same conditions, has a positive effect.

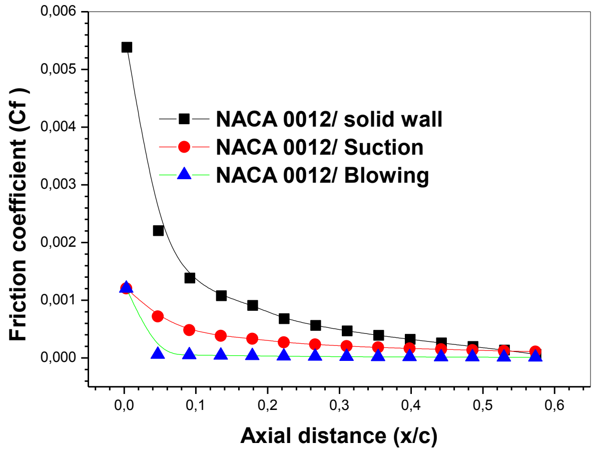

Figure (7) Friction coefficient on a NACA 0012. M ∞ = 0.23, xp = 100%, θ = 10 ° and α = 0 °.

3.8 Friction coefficients over NACA 0012 and a flat plate

We note that applying the control by blowing or sucking on a NACA 0012, we arrive at a friction coefficient lower compared to the flat plate. Without control, the flat plate gives better results than the NACA0012.

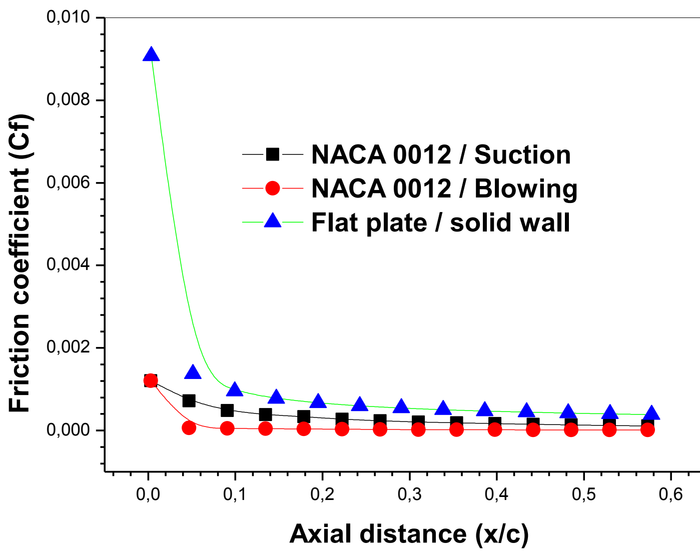

Figure (8) Friction coefficient on a NACA 0012, flat plate. xp = 60%, M ∞ = 0.23, θ = 10 ° α = 0 °.

3.9 Boundary layer thickness on a NACA 0012

The boundary layer thickness on the upper surface of the NACA 0012 profile develops along the profile by increasing due to accumulation of particles decelerated at the surface. By suction, these particles along the surface, thickening becomes lower the effect is even greater when applying the blowing. The effect is particularly important by increasing the range of suction or blowing

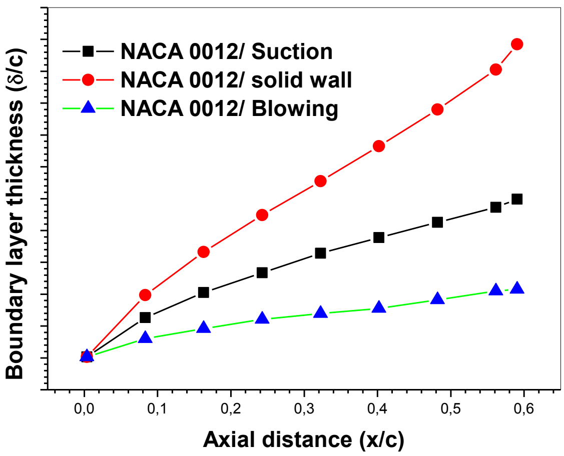

Figure (9) Boundary layer thickness of a NACA 0012. xp = 60%, M ∞ = 0.23, α = 0 °.

3.10 Boundary layer thickness on a NACA 0012 and NACA 66_1012

Solid profile NACA 66_1012 is a laminar profiles, i.e., friction produced are lower than those generated on the NACA 0012 profile solid, but control by suction on porous NACA 0012 profile, makes the boundary layer thickness thinner than that of the NACA 66_1012 and even thinner by blowing control. So the effect of control is more positive than the aerodynamic effect. The effect is even more important that the scope is great.

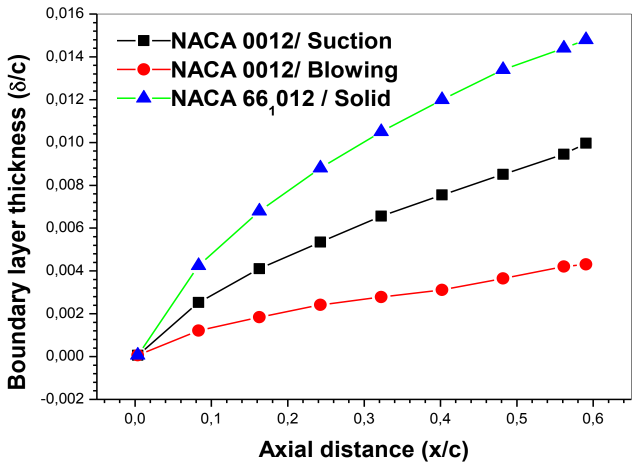

Figure (10) Boundary layer thickness on a NACA 0012 and 66_1012. xp = 60%, M ∞ = 0.23 , α = 0°, θ=10 °

3.11 Boundary layer thickness on a NACA 0012 and a flat plate

The following figure demonstrates once again the positive effect of control even compared to a flat plate. We note that the boundary layer thickness is lower on a NACA 0012 with control than a solid flat plate. The impact blowing effect is even more important. This effect increases again with the range of blowing or suction.

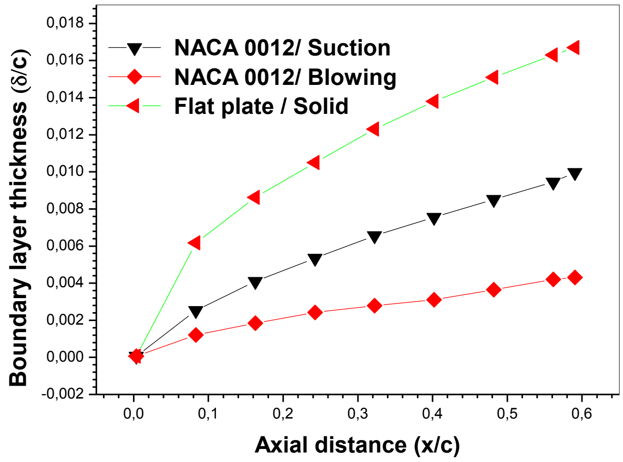

Figure (11) Boundary layer thickness on a NACA 0012, flat plate. xp = 60%, M ∞ = 0.23, α = 0 °, θ = 10 ° and vo / U ∞ = 1%.

4. Conclusion

A numerical study is proposed to analyze the behavior of an incompressible laminar boundary layer and around two-dimensional profiles. Profiles considered in this study are the flat plate, NACA 0012 and NACA 66_1012 profiles. We formulated the mathematical model based on the Prandtl equations, used for the study of the boundary layer. A change of variables is introduced to transform the system of differential equations in two variables in a single ordinary nonlinear differential equation in a single variable. Possible resolution can only be digital, so we turned to the method of Shooting and the Thomas algorithm. Was developed in this sense, a computer code written in Fortran 90. The results were used to study the influence of control by blowing and suction on the boundary layer thickness and the separation point and the friction coefficient [15]. The results showed that the control is better than blowing the suction control, but control by suction in turn has an effect if no positive control [16].

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