ENHANCEMENT PERFORMANCE OF WIND TURBINE BLADE BY COMPARISON STUDY OF SUCTION AND BLOWING TECHNIQUESUSING SEP METHOD

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ABSTRACT

In this work a new concept of flow separation control mechanism has been introduced to improve the aerodynamic characteristics of an airfoil. Control of flow separation over an airfoil at low Reynolds number is theoretically simulated under the effects of suction and blowing, based on the computation of Reynolds-average Navier-Stocks equations(the solution of each set of equations is achieved by application of the **SEP(strong explicit procedure)**solver) is carried out. Using Finite Volume Method to solve the governing equations on a body, so, a numerical model is developed. The suction and blowing control mechanism appears to be suppression of the separation bubble and reduction of the upper surface pressure to increase the lift and decrease the drag. To make section model, NACA 4421 airfoil has been chosen. In present study, the theoretical are performed with different angle of attack (20º, 22º, 23º), U_j/U (A) =6 and different chord (1c,0.9c,0.8c,0.7c). The theoretical results show that the flow separation control is possible by the proposed mechanism and benefits can be achieved by suction and blowing (for suction position at the end of the chord (0.8c) and for blowing position at the begging of the chord (0.1c)). The section performance is significantly improved due to control of flow separation by suction and blowing. It has also been found that the lift increases about 14% at the angle of attack 20º, 22ºand 23º and seen that the blowing is better than the suction.

KEYWORDS: Flow Separation Control, Aerodynamics, Suction and Blowing.

تحسين الاداء لزعنفة التوربين الهوائي بواسطة دراسة مقارنة لتقنيات الشفط والنفخ باستخدام طريقة SEP

ياسر احمد محمود / الجامعة التكنولوجية

الخلاصة :

في هذا العمل تم إدخال مفهوم جديد لألية السيطرة على انفصال الهواء وتحسين الخصائص الايروديناميكية على نموذج مطيار. السيطرة على انفصال الهواء حول المطيار بعدد رينولدز منخفض قد تم نظريا تحقيقه تحت تأثير الشفط والنفخ، اعتمادا على حسابات معدل رينولدز في معادلة نافيير – ستوك (وقد تم حل كل مجموعة من المعادلات بتطبيق السياق الضمني الشديد(**SEP**)).ولحل المعادلات الحاكمة لشبكة توافق الاجسام تم تطوير نموذج رياضي عددي باستخدام تقنية الحجوم المحددة .ان آلية السيطرة عن طريق الشفط والنفخ تظهر إخماد فقاعات الانفصال والتي تؤدي الى تقليل الضغط على السطح العلوي للجناح لزيادة الرفع وتقليل الكبح . اجريت دراسة حسابية على مقطع المطيار 4421 NACA اختير كموديل. تم اعتماد في الدراسة الحالية زواية هجوم مختلفة (23º, 22º, 20º) و6= U_j/U (A) وبأطوال اوتار مختلفة(1c,0.9c,0.8c,0.7c).بينت النتائج النظرية التي تم الحصول عليها بان السيطرة على انفصال الهواء ممكنة بواسطة الية الشفط والنفخ (موقع الشفط يكون في نهاية الوتر(0.8c) و موقع النفخ في بداية الوتر(0.1c)).تم تحسين اداء المطيار بشكل ملحوظ بسبب السيطرة على انفصال الهواء بواسطة الشفط والنفخ. وقد وجد أيضا ان الرفع يزداد حوالي14٪ في زاوية الهجوم(23º, 22º, 20º).وبينت ان عملية النفخ هو افضل من عملية الشفط .

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LIST OF SYMBOLS

A: jet ratio
c : Chord length (m).
F_1: function of Blending.
k : Turbulant kinetic energy (m^2/sec^2).
P: Pressure (N/m^2).
$\tilde{P}_k$: Turbulent kinetic of total average production rate ($N/m^2/sec$)
S : Strain rate.
U_j: Jet velocity (suction or blowing).
u, v: Mean velocity componants (m/sec.).
β : Angle between the free stream velocity direction and local jet surface(deg).
ε : Dissipation of turbulant kinetic energy (m^2/sec^2).
θ: Angle between the jet entrance velocity direction and the local jet surface (deg).
µ: Dynamic viscosity (kg/m.sec)
μ_t : Turbulent viscosity (m^2/sec)
ρ : Density (kg/m^3)
σ_k,σ_ω: Empirical constant
ω: Specific rate of dissipation of turbulent kinetic

INTRODUCTION

The boundary layer separation is the major cause of drag on airfoils. The drag due to separation is significantly higher at lower Reynolds numbers. Typical applications where such low Reynolds number flow airfoils were use a wind turbines, by delaying the separation or avoiding the separation completely, the drag on an airfoil can be significantly reduced, making the airfoils more effective .
When air flows over airfoil, the air near the surface (known as boundary layer) is slowed by friction. The air has to flow against adverse pressure over an airfoil. After traversing a certain distance the slowed down boundary layer cannot overcome the adverse pressure, and separates from the surface, creating eddies and vortices behind the point of separation. This separation causes high drag. To delay the boundary layer separation by sucking or blowing in slow moving air around surface. This will bring the faster moving air far from the surface closer to the surface, which can now overcome the adverse pressure gradient, thus preventing separation and reducing drag, Yasser et.al [2001] . To design a high-lift airfoil with slot air suction from the external flow within the framework of ideal fluid theory; a numerical-analytic method was proposed byChaoqunet.al[2008].The Suction slot is a channel with constant wall velocity. For instance, wing profile design with non-detached flows having lift coefficients C_y=2.68 and 4 and maximum relative velocities over the profile [$\nu_{max}/\nu\infty$=2 and 2.2] was effectively examined by this method. Glauertet et.al [2009], investigated the region of high angles of attack. In which consider change in the flow character that be expected from artificial aids. Formed the slot of the blown by two sheet steel pieces connected together by screws at intervals of 5 cm, to regulate the slot width by using screws. More compressed air was required. All the delivery pipes were much too small . Another study by Abzalilov et.al[2000], suggested combining numerical and analytical method of airfoil design based on inverse problems theory of aero hydrodynamics for inviscid incompressible fluid model. At constant velocities on the walls, modeled the slot by an annular channel. Using angle of attack for an impermeable airfoil and the suction mass value flow to determine the past an airfoil flow with outer-flow suction. Satisfying the solvability conditions, introduced free parameters into the initial

velocity distributions. Over a given range of angles of attack, ensuring the absence of flow separation . The numerical and analytical results revealed that the separation less flow past the airfoil was reached by eliminating the falling velocity intervals from the specified velocity distribution in two given flow regimes . Batenko et.al [2001] , confirmed that the suction and blowing are substantial factors that could be affecting on the friction and heat transfer inside of their circulation zone. The experimental results showed that the porous blowing introduce diminution of friction and of heat transfer inside the separation zone in comparison with impermeable wall. Besides, the porous suction the contrary led to their augmentation. The results show that in separation zone,the friction local characteristics and heat transfer are more sensitive to suction than to blowing. Subsequently, on the separation zone's length, the blowing and suction exert intricate influence . On the other hand, the influence of various parameters that associated with using air blowing, such as the speed air blowing ratio (Uj/U), strength on the performance of the NACA 4415 two dimensional airfoil at different angle of attack(5^o،10^o،15^o)was efficiently examined by Yasser et.al [2001] .It was found that the air blowing was entirely effective in controlling the separation through all cases. Obviously, the influence of air blowing technique on the power coefficient was greater than without blowing cases, since the power coefficient was greater at α=5 in comparison with other angles and at a tip speed ratio equal 2.5. **Passive** or active devices were effectively used to control the flow. It should be noted that the passive control devices are not energy consumptive; however, they are extremely affected by the geometry of the airfoil . On the contrary, surface suction or blowing were used as active control devices using energy. To prevent separation of either laminar or turbulent layers, the boundary layer suction was used. As the suction removes the retarded air close to the surface, it will remove the cause of separation, and this aspect leads to its use to obtain high lift coefficients from various airfoil configurations. The suction of air from the boundary layer flow into the surface of the body, causes the tired air near the surface being removed and a new boundary layer is started to reform downstream of the suction point with a consequent reduction in drag Schetz [1984],in order to study the effect of suction and blowing, jet location at the 0.8c of the suction and the 0.1c of the blowing are created in the airfoil suction side. Through these jet locations a secondary fluid is injected to the main flow of supplying additional energy to the particles in the fluid which are low in energy in the boundary layer. The transpiration cooling is the most important application of injection. A binary boundary layer occurs when different fluid is injected, this boundary layer also has a concentration field. And in other case a small amount of air is sucked from main flow by suction. The low energy fluid in the boundary layer is removed by suction before it can separate. The airfoil of a NACA 4421 constructed the model of profile. Each model has a recess cut in the upper surface, into which a sub-sonic flow separation control mechanism that could generates suction and blowing on controlling the stream over an airfoil . Hence, the aim of this study is to control the flow separation, by using the suction and blowing techniques, comparison between the two techniques of airfoil NACA 4421 and to achieve high lift coefficient .

GOVERNING EQUATION

In this work, the flow is assumed to be steady, incompressible and 2D. The continuity and momentum equations become Kianoosh**[**2013**]**:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}=-\frac{\partial P}{\partial x}+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right] \tag{2}$$

$$\rho u\frac{\partial v}{\partial x}+\rho v\frac{\partial v}{\partial y}=-\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right] \tag{3}$$

The Menter's model ($k-\omega$SST) for shear stress transport turbulence which used to solve the equations of turbulence. This model includes standard models of (k-ω) and ($k-\varepsilon$). In external flows removed the sensitivity of ($k-\omega$) model and the boundary layer flows with separate on calculations improved. The transport equations are:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho U_i k)=\breve{P}_k-\beta^*\rho k\omega+\frac{\partial}{\partial x_i}\left[(\mu+\sigma_k\mu_t)\frac{\partial k}{\partial x_i}\right] \tag{4}$$

$$\frac{\partial}{\partial t}(\rho\omega)+\frac{\partial}{\partial x_i}(\rho U_i\omega)=\alpha\rho S^2-\beta\rho\omega^2+\frac{\partial}{\partial x_i}\left[(\mu+\sigma_\omega\mu_t)\frac{\partial\omega}{\partial x_i}\right]+2(1-F1)\rho\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial\omega}{\partial x_i} \tag{5}$$

In equations (4 and (5), $\beta^*= 0.09$ and $\sigma_{\omega 2}= 0.856$. Away from the surface the blending function is equal to zero ($k-\varepsilon$ model). Switches over to one inside the boundary layer ($k-\omega$ model). To prevent turbulence build-up in stagnation regions in Menter's shear stress transport turbulence model, a production limiter, P_k , is used. All constants are computed by a blend from the corresponding constant of the $k-\varepsilon$ and the $k-\omega$ model via α(empirical constant), σ_k, σ_ω …etc [Menter [2003] and Voigt [2003]].

$$F_1=\tanh\{\{\min[\max(\frac{\sqrt{k}}{\beta^*\omega y},\frac{500v}{y^2\omega}),\frac{4\rho\sigma_{\omega 2}k}{CD_{k\omega}y^2}]\}\} \tag{6}$$

$$CD_{k\omega}=\max\left(2\rho\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial\omega}{\partial x_i},10^{-10}\right) \tag{7}$$

$$P_k=\mu_t\frac{\partial U_i}{\partial x_j}\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right) \tag{8}$$

$$\breve{P}_k=\min\left(P_k,10\beta^*\rho k\omega\right) \tag{9}$$

JET SECTION AND BLOWING TECHNIQUE :

A study of suction, blowing on the control of the NACA 4421 airfoil was performed. Present investigation was selected three effective parameters blowing and suction location (for blowing at the 10 percent of the chord length($c=1$m) and for suction at the 80 percent of the chord), speed jet ratio (A) and jet angle (θ,β).The jet velocity is set as:

$$A = U_j/U \tag{10}$$

$$u = A * (cos\,(\theta + \beta)) \tag{11}$$

$$v = A * (sin\,(\theta + \beta)) \tag{12}$$

Note; the negative θ represents suction condition and positive θindicate blowing condition (for blowing $\theta = 30$, for suction $\theta = -30$).The range of jet location, for blowing at 0.1c, suction at 0.8c and the speed of jet ratio is selected (A=6) of free-stream velocity.

RESULTS AND DISCUTION

Figures (1a) and (1b) illustrate the higher velocity air, which was formed in the body. The wall jet profile was directly formed in the boundary layer behind the point of injection [Abzalilov [2000]]. Overcome the adverse pressure by high velocity. The pressure inside the body to be higher than the pressure at the slit on the airfoil; this may be creating higher stagnation pressure inside the cavity or attained through a pump. Moreover, present results confirmed that the lift predicted by potential theory can be suppressed if the intensity of the blowing jet is sufficient.

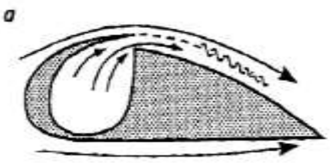
The Subsonic Airfoils: the subsonic aerodynamics of airfoils, this is a reasonable starting point for thinking about aerodynamics in attached flow. Prior its use to model flow control airfoil configurations (using suction and blowing located at a specify positions in upper airfoil surface), the Navier-Stokes solver is validated by prediction of airfoil characteristics, particularly for large angles of attack when the stall occurs, depends on the prediction of separation. Laminar and turbulent flow around NACA 4421 airfoil in the range of attack angles. This airfoil was chosen because it is commonly used in variety of applications and also would give us a better insight into the dependence of angle of attack effect on behavior of an airfoil flow. In the following, the influence of grid quality is firstly investigated for the airfoil flow at different angle of attack including stall angle. Figures(2) to (9) represent the pressure distributions and flow stream over the surface of the airfoil suction NACA 4421 with and without flow control. Means using the flow control (suction and blowing) at angle of attack (20°, 22°,23°), and using blowing at (0.1 X/C, angle of blowing =$30^{\circ}$and $U_j = 6$), suction at ($0.8\ X/C$, angle of suction$= -30$ and$U_j = 6$).

The Computer Program: The iterative solution of the discredited equations proceeds in a segregated manner with momentum equations solved first. Pressure correction next and scalar quantities last. The solution of each set of equations is achieved by application of the **SEP** solver. During the iterative sequence, on the basis of the residual sources criterion the convergence is assessed at the end of each iteration, in which over all the control volumes, compares the sum of the absolute residual source in the computational field, for each finite volume equation, with some reference value (typically the inlet flux of the relevant variable fed into the domain of calculation).

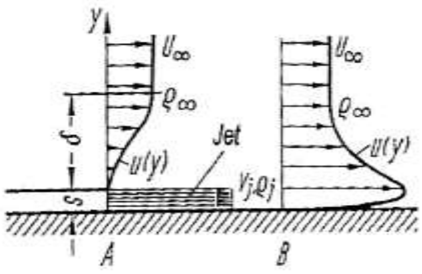
For the solution procedure, under-relaxation may be used to promote stability, and this involves depressing the predicted changes in the calculated variables below the levels, which would ordinarily be returned by the difference equations (Using an explicit formulation). When C-type grids are used, to maintain a simply connected region there will be a branch cut across the wake region. The flow variables are continuous across the cut, so the properties of the flow are specified as averages of variables one point above and below the cut line. To avoid the errors introduced by this condition. The grid should contain sufficient resolution in this region.

Suction And Blowing Effect On The Airfoil: the exceeding of the angle of attack of the stream above the critical value, the stream does not arrive the trailing edge. Before the separation, the direction of flow will be reversed. A blowing and suction technique exceeds the less energy from the flow when it separated, this use to control the airfoil stall. In this research, for controlling the airfoil stall using blowing technique at the leading edge (0.1c), because the effect of blowing is larger and perfect in this region and using suction at the trailing edge (0.8c) [9].

In this study, studies the compares between the position of suction and blowing on the upper surface of NACA 4421. This range covers more of the airfoil length to catch the good position of jet to enhancement the aerodynamic characteristic of the airfoil. All cases are under Reynolds number $2.1*10^5$and different angle of attack and beyond the stall angle. Figure (10) is the compare between the research calculation and the [9] at NACA 4421 at $Re=2.1*10^5$. As illustrated at figures (11)– (14) for NACA 4421 and $Re=2.1*10^5$ at different chord length(0.1c,0.9c,0.8,0.7c),for suction and blowing at$\alpha = 20$, it seen that the CL_{max} is larger than the without injection at fig.(10) (increase from CL_{max}=1.2974 to CL_{max}=1.7242 for suction and to CL_{max}=1.7029 for blowing, within the boundary layer, the rise of momentum injection caused delays the flow separation's position from the lower pressure surface resulting efficient CL_{max}. choose number two for jet ratio because this ratio is perfect(increase CL and decrease CD)[5].

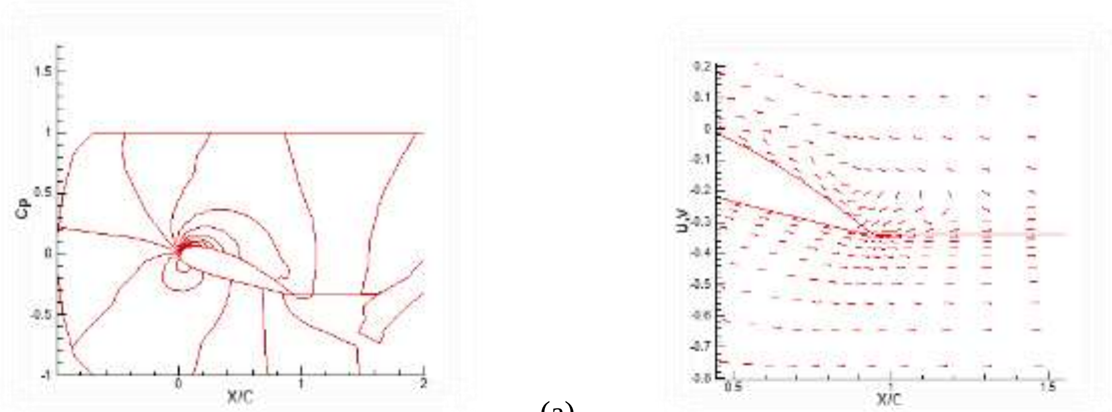


(a) Blowing of air over an airfoil



(b) Boundary layer velocities on injection of a jet of air

Fig.(1) :lowing of air over an airfoil



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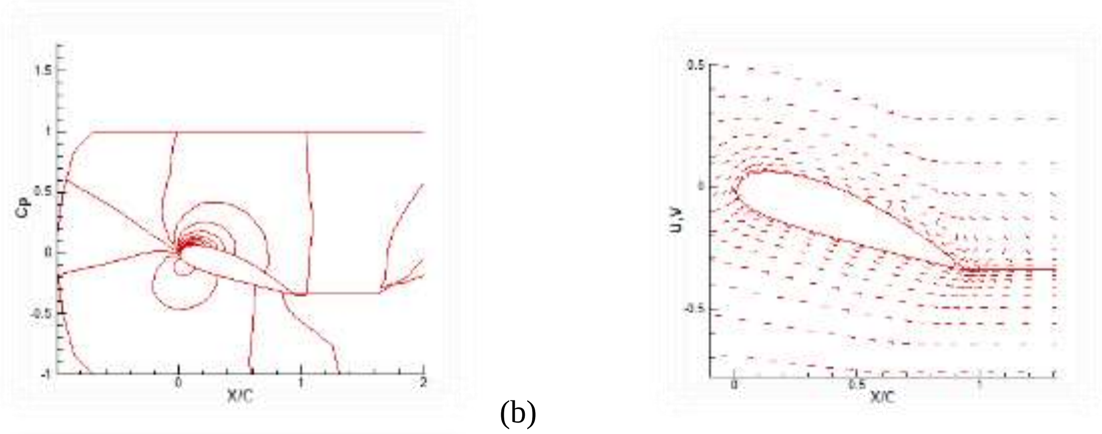

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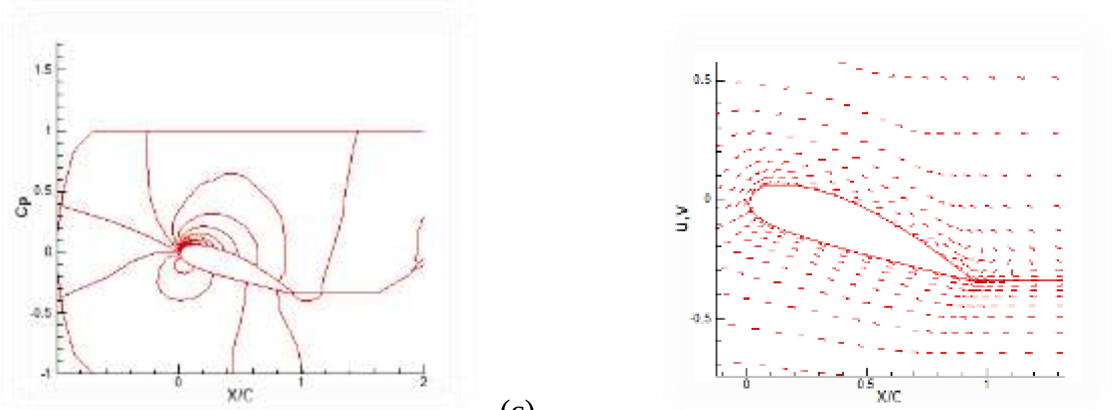
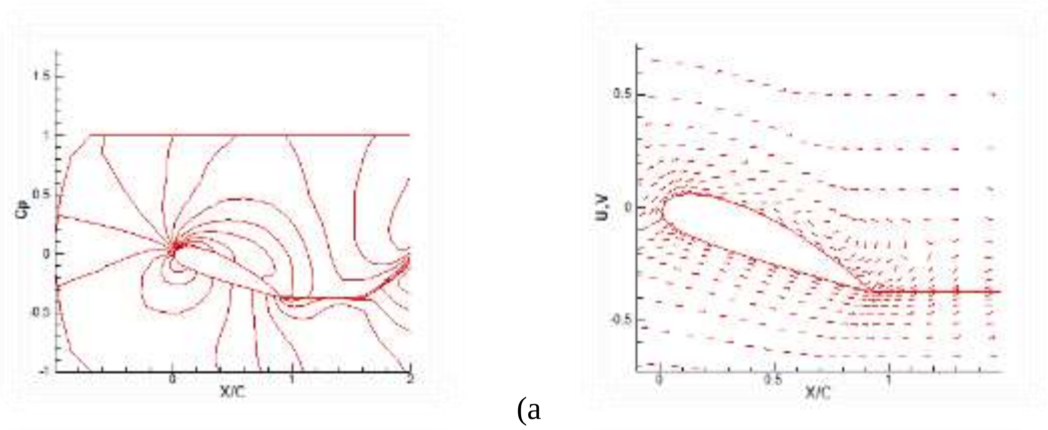


(c)

Fig.(2) Pressure distribution and flow stream of NACA 4421 at chord=1, α=20^{o} ,U=3
(a)without suction and blowing (b)with blowing at $\theta_{blowing}$=30^{o}, $U_{blowing}$=6
(c)with suction at $\theta_{suction}$=-30,$U_{suction}$=6 .



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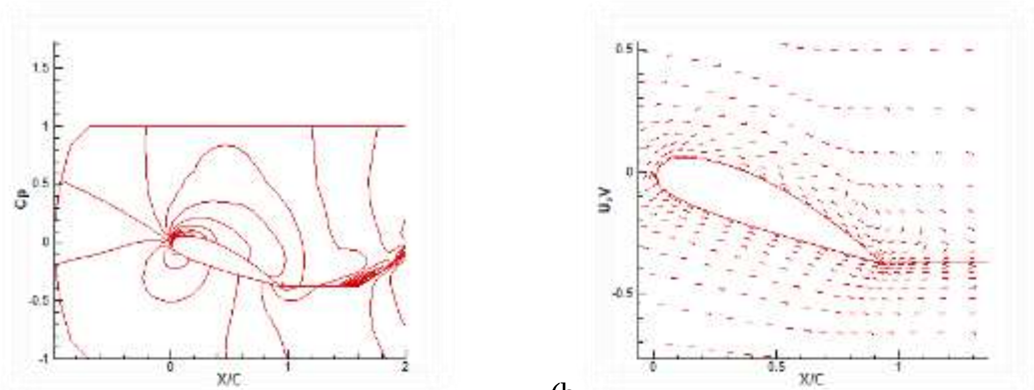

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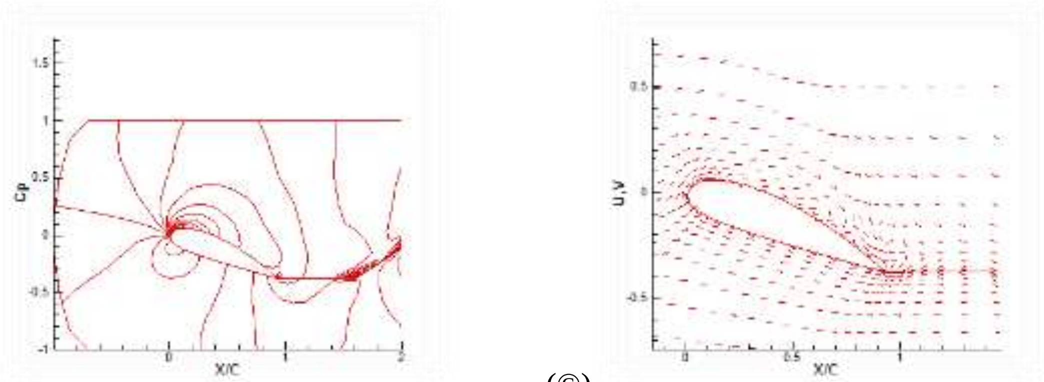
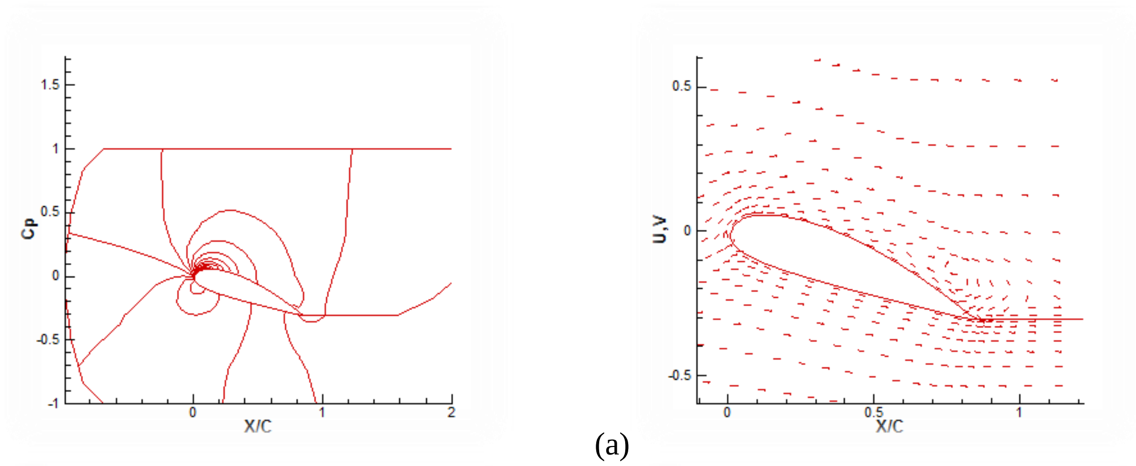


(©)

Fig.(3) Pressure distribution and flow stream of NACA 4421 at chord=1, $\alpha=22^{o}$,U=3 (a)without suction and blowing (b)with blowing at $\theta_{blowing}=30^{o}$, $U_{blowing}=6$(c)with suction at $\theta_{suction}=-30$,$U_{suction}=6$.



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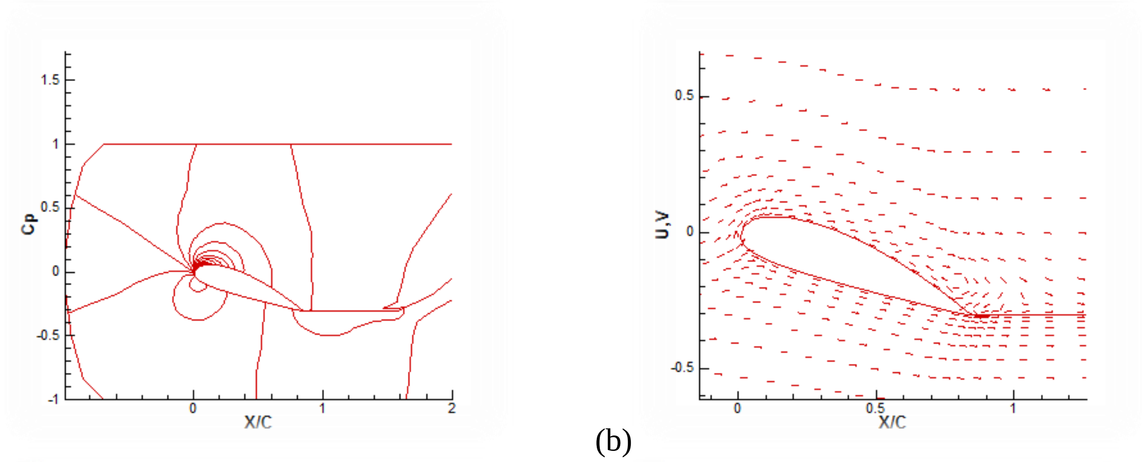

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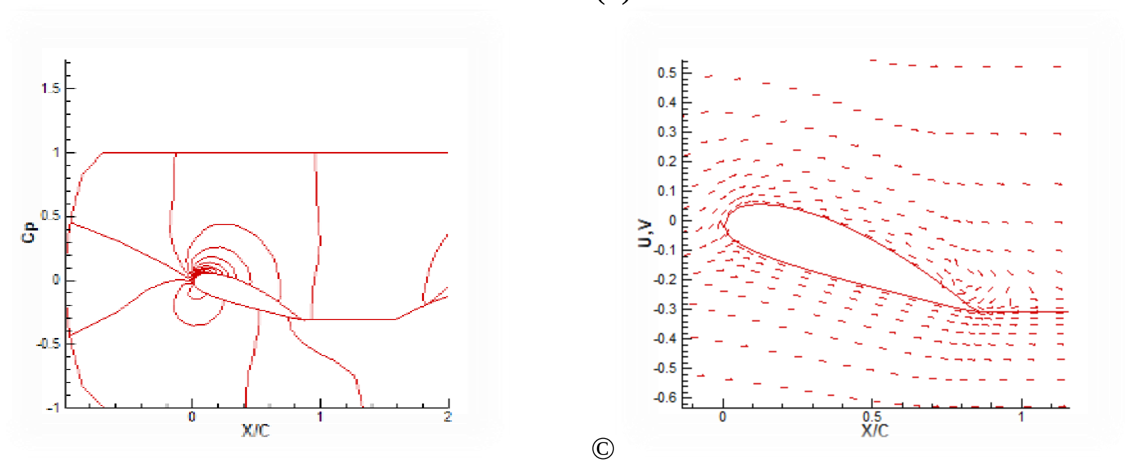

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Fig.(4) Pressure distribution and flow stream of NACA 4421 at chord=0.9, $\alpha=20^{o}$,U=3 (a)without suction and blowing (b)with blowing at $\theta_{blowing}=30^{o}$, $U_{blowing}=6$(c)with suction at $\theta_{suction}=-30$,$U_{suction}=6$.

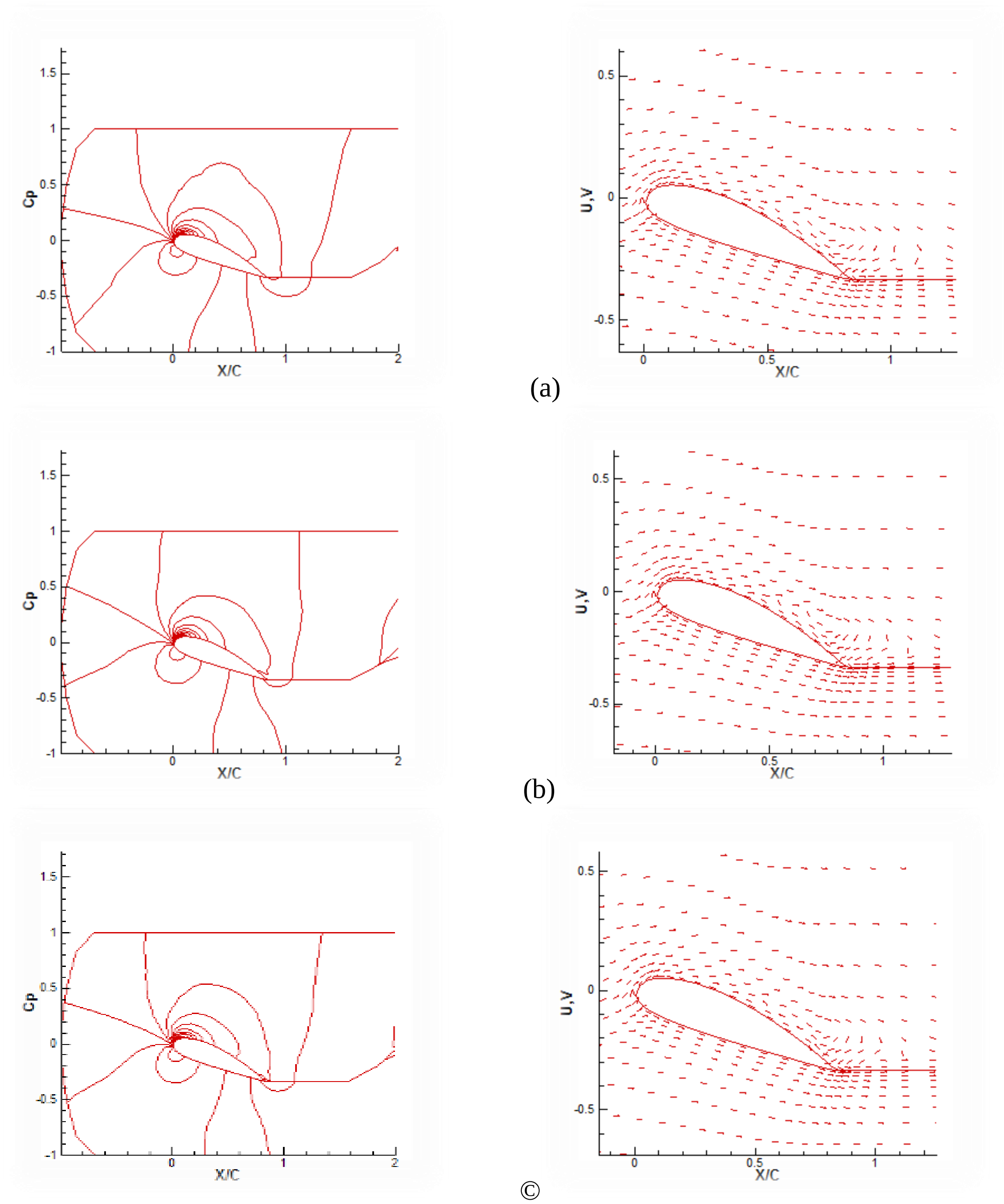


Fig.(5) Pressure distribution and flow stream of NACA 4421 at chord=0.9, $\alpha=22^{o}$,U=3 (a)without suction and blowing (b)with blowing at $\theta_{blowing}=30^{o}$, $U_{blowing}=6$(c)with suction at $\theta_{suction}=-30$,$U_{suction}=6$.

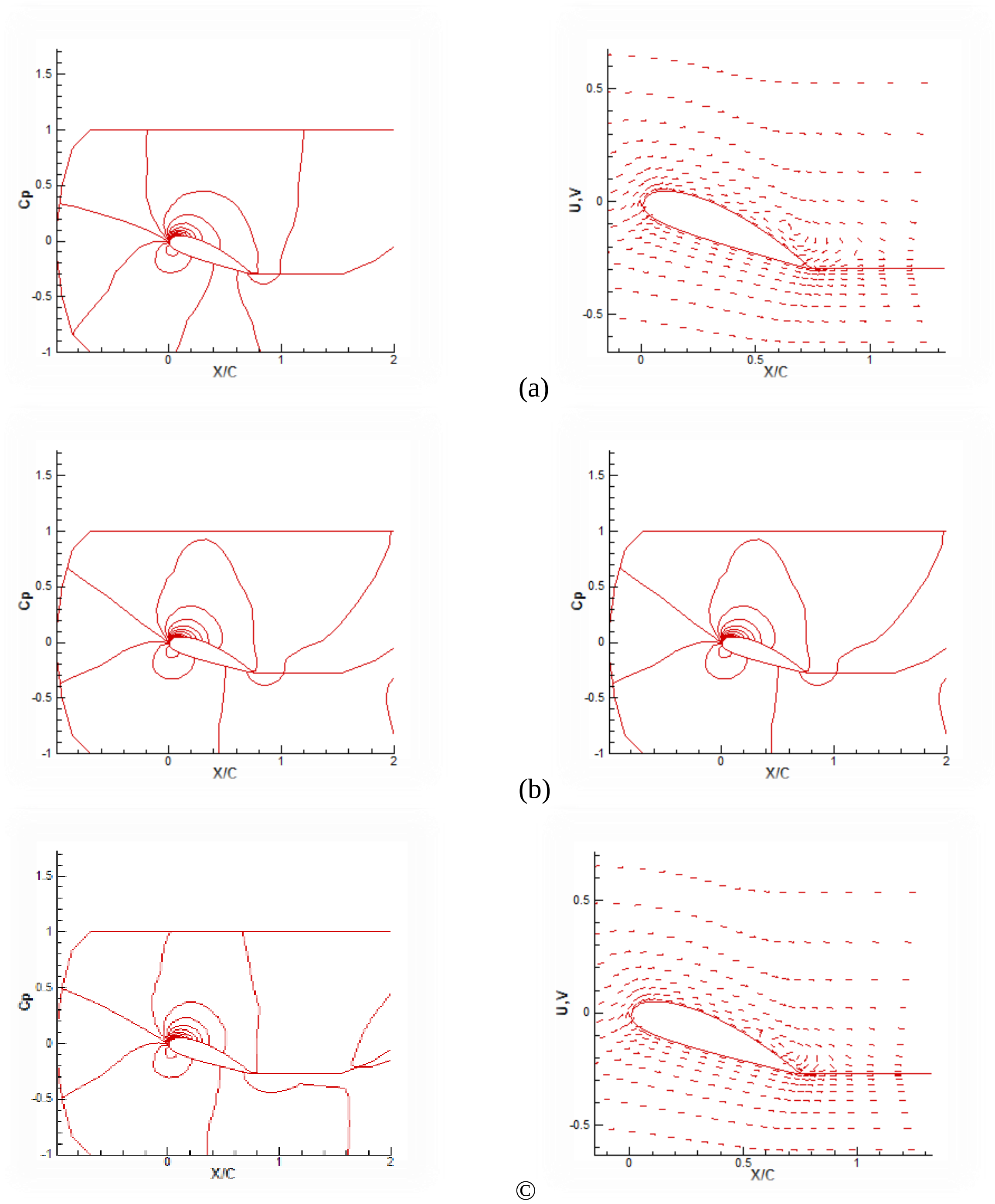


Fig.(6) Pressure distribution and flow stream of NACA 4421 at chord=0.8, $\alpha=20^{o}$,U=3 (a)without suction and blowing(b)with blowing at $\theta_{blowing}=30^{o}$, $U_{blowing}=6$(c)with suction at $\theta_{suction}=-30$,$U_{suction}=6$.

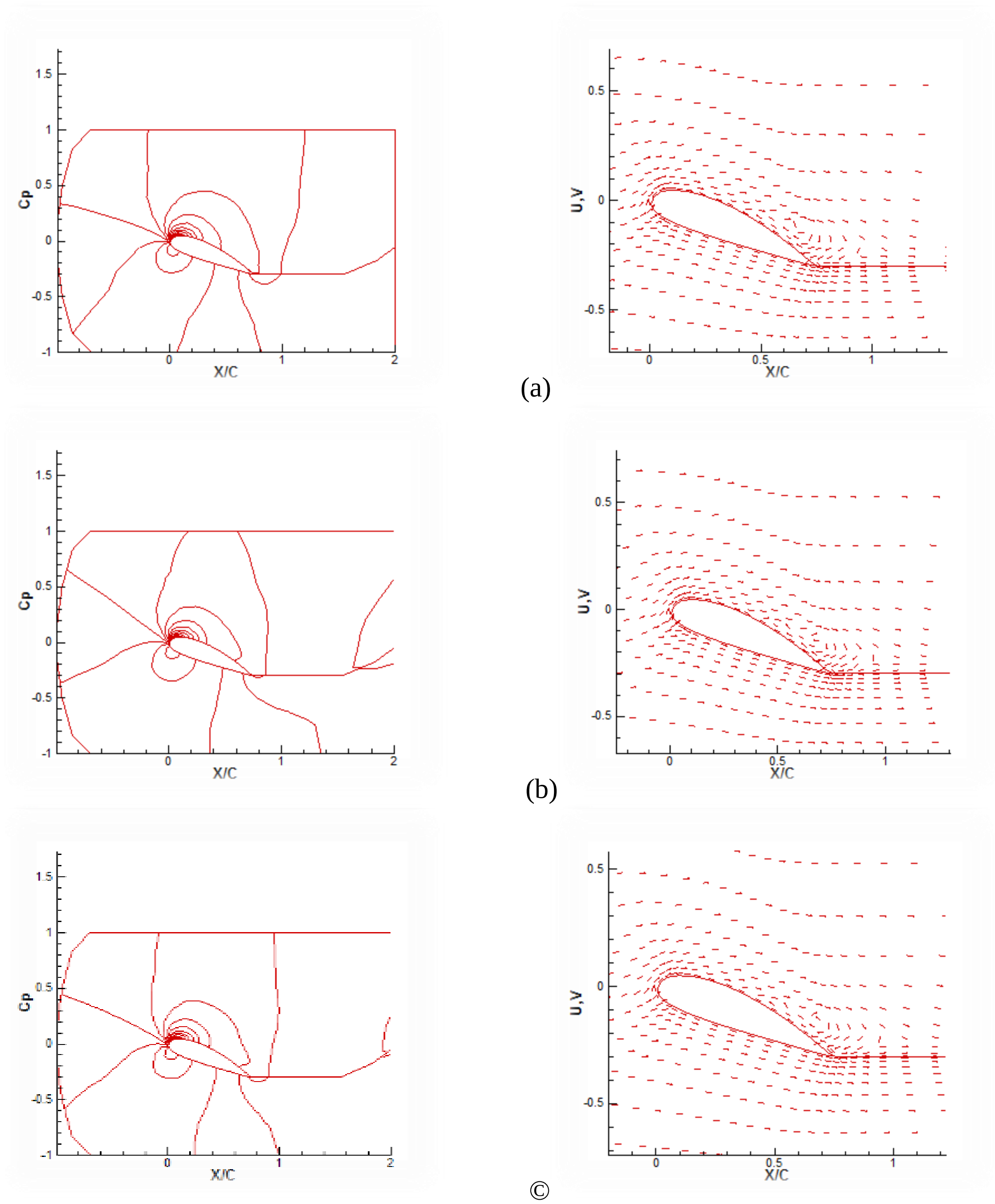


Fig.(7) Pressure distribution and flow stream of NACA 4421 at chord=0.8, α=22^{o} ,U=3 (a)without suction and blowing (b)with blowing at $\theta_{blowing}$=30^{o}, $U_{blowing}$=6(c)with suction at $\theta_{suction}$=-30,$U_{suction}$=6 .

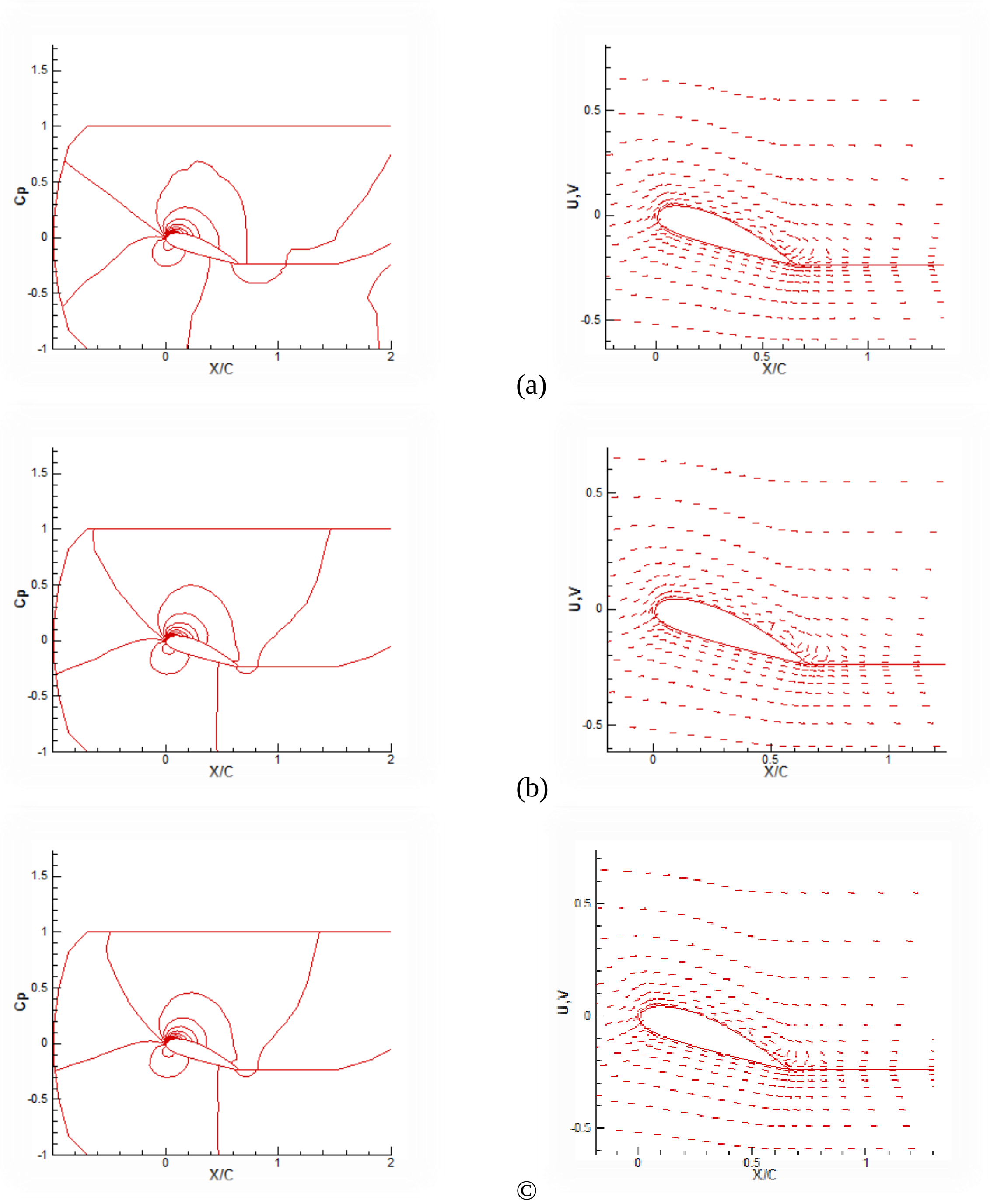
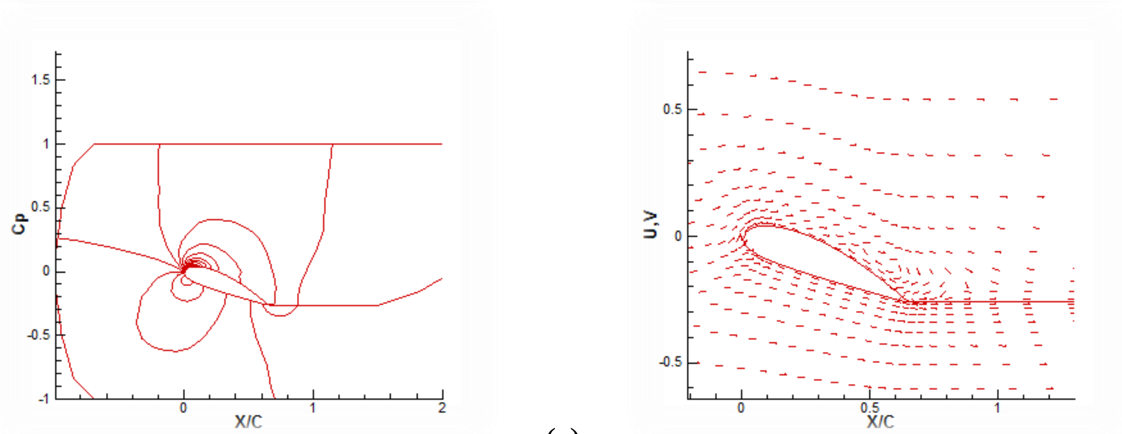


Fig.(8) Pressure distribution and flow stream of NACA 4421 at chord=0.7, $\alpha=20^{o}$,U=3 (a)without suction and blowing (b)with blowing at $\theta_{blowing}=30^{o}$, $U_{blowing}=6$(c)with suction at $\theta_{suction}=-30$,$U_{suction}=6$.



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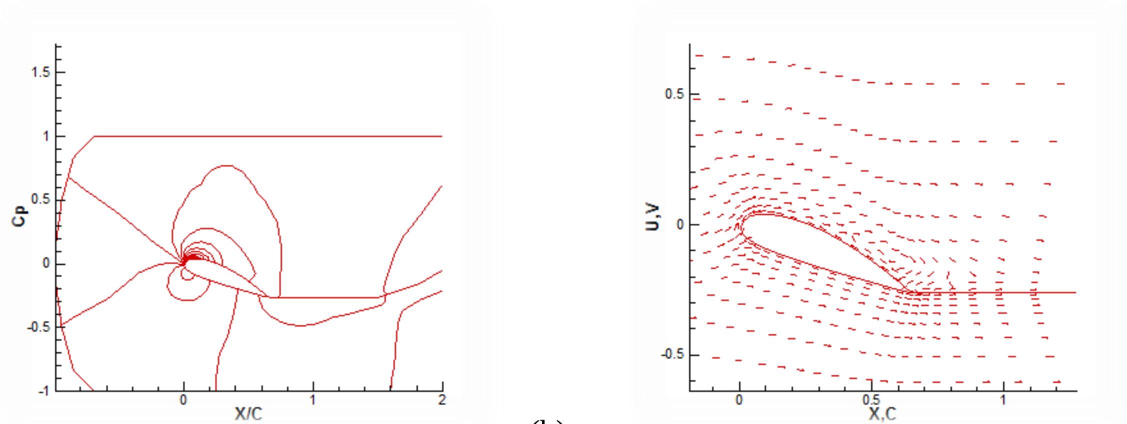

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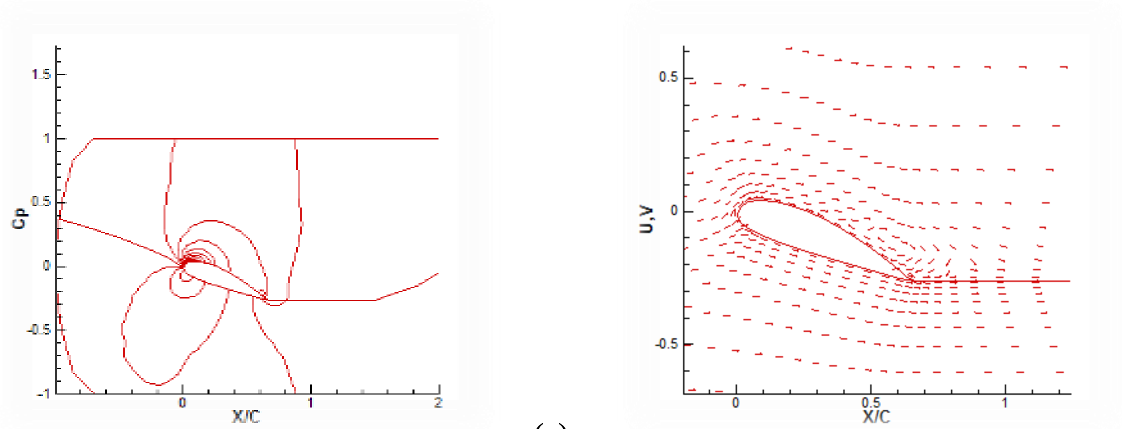

(c)

Fig.(9) Pressure distribution and flow stream of NACA 4421 at chord=0.7, $\alpha=22^{o}$,U=3 (a)without suction and blowing (b)with blowing at $\theta_{blowing}=30^{o}$, $U_{blowing}=6$(c)with suction at $\theta_{suction}=-30$,$U_{suction}=6$.

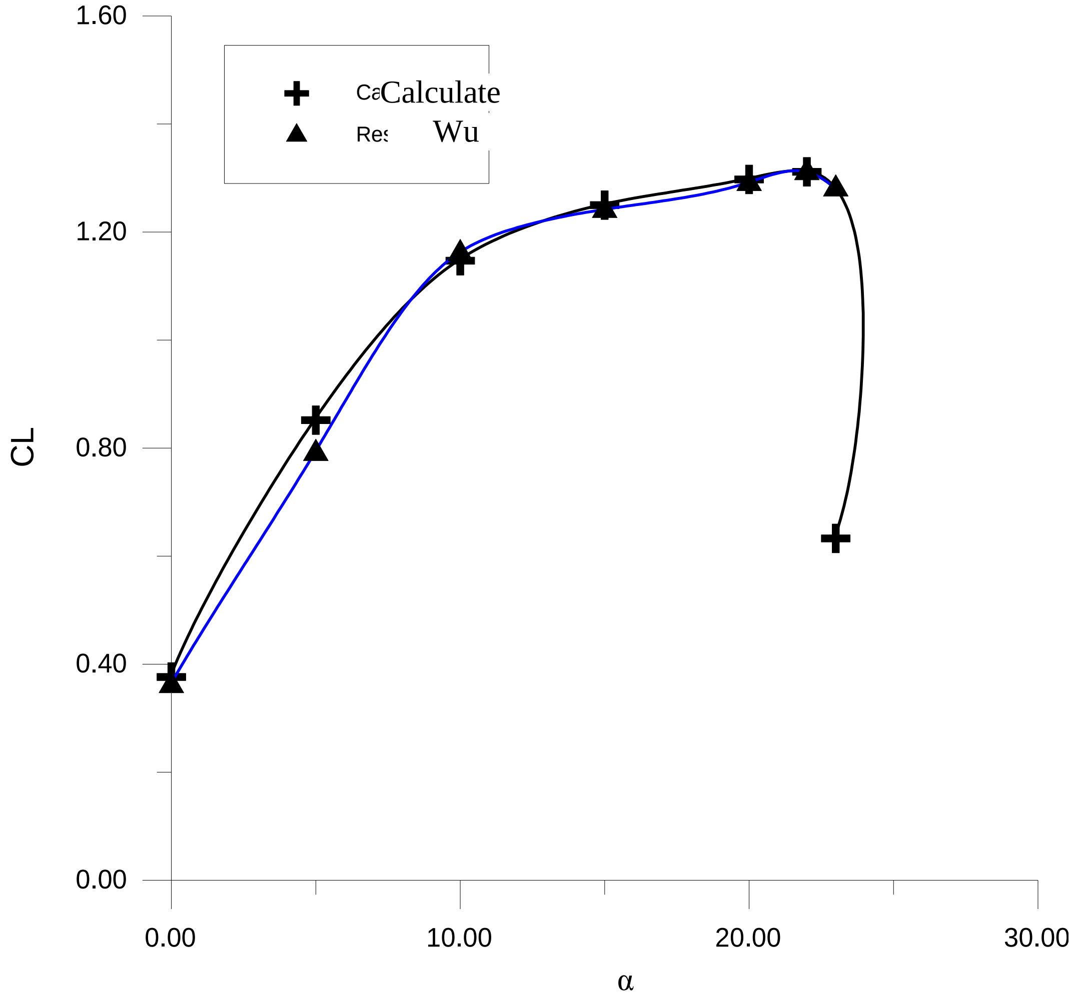

Fig.(10) The comparison between present study and [Wu[1992]] without suction and blowing

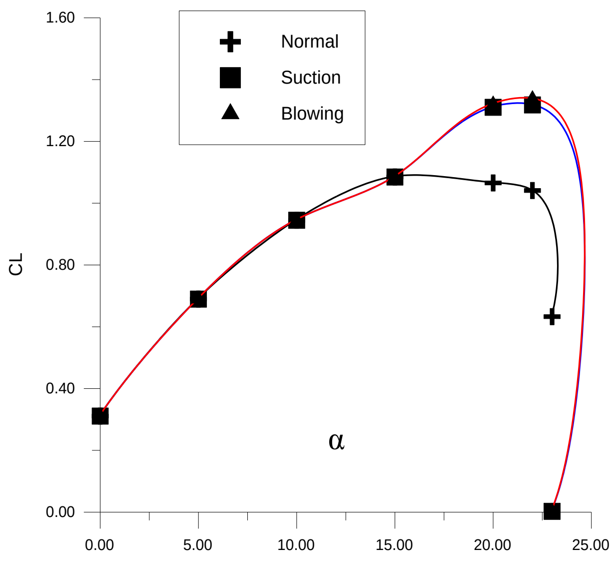

Fig.(11) Relation between CL and α at c=1

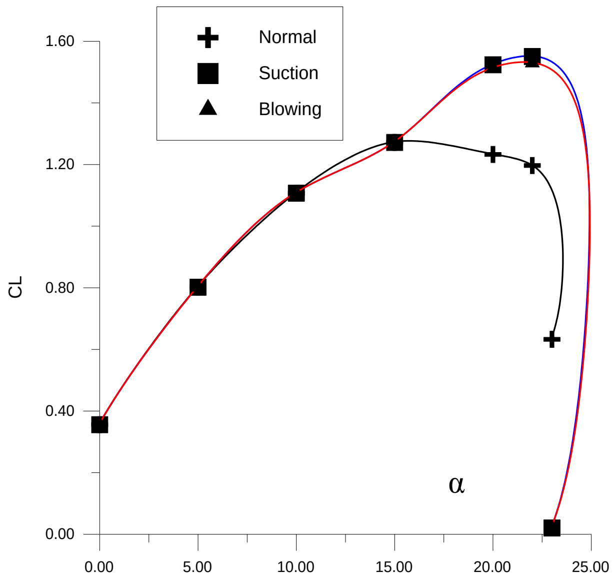

Fig.(12) Relation between CL and α at c=0.9

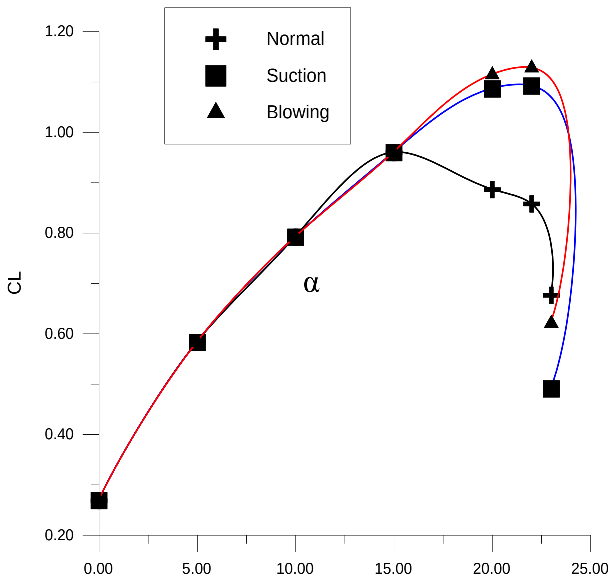

Fig.(13) Relation between CL and α at c=0.8

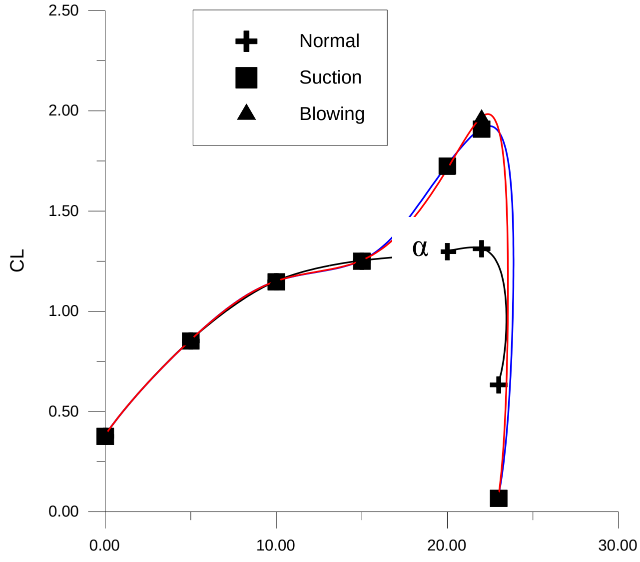

Fig.(14) Relation between CL and α at c=0.7

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