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January 10, 2022

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering00 (2014) 000–000

Procedia Engineering

www.elsevier.com/locate/procedia

“APISAT2014”, 2014 Asia-Pacific International Symposium on Aerospace Technology, APISAT2014

Investigation active flow to control the separation over an airfoil NACA 2415

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Abstract

Active flow is effective method to control flow near an airfoil. Active flow can be created in many ways. Plasma circulation control technique overcomes disadvantage of other method and is used in the paper as active flow to control separation in the airfoil NACA 2415 with free flow V=50m/s. Gambit software is used to create mesh while Fluent is applied for calculation. The result shows that with the working of active flow the lift coefficient and critical angle of attack grow up, the maximal aerodynamic performance is obtained at angle of attack α=4°. In the paper method discrete vortex is also presented to comparing with result in numerical method. Both of these methods give similar result with small angle of attack in viscous, incompressible flow and at average Reynolds number.

Peer-review under responsibility of Chinese Society of Aeronautics and Astronautics (CSAA).

*Keywords:*Type your keywords here, separated by semicolons ;

Nomenclature

ρ	air mass density
e	charge of electron
α	angle of attack
u	velocity in x direction
v	velocity in y direction
V	voltage between two electrodes of plasma actuator
U_∞	velocity free flow
V_{AC}	velocity of active flow

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1. Introduction

Many research showed that the lift over an airfoil increases up to 15 degree of attack angle. With the increasing of angle of attack (AOA) lift coefficient reduces dramatically due to separation flow. In most cases, the phenomenon occurs at the leading-edge of the airfoil. To improve the quality of airfoil we could use airfoil with higher camber. However curved line is limited, and drag of this airfoil rises with grow of camber.

Active flow is very effective method to increase lift and is the most important technology for creating short take-off and landing aircraft. This technology works in the foundation of Coanda effect, invented by HeriCoanda in the 1930s. By creating high-speed jet flow inside the boundary layer of an airfoil, the flow around the airfoil will be control. In other words, if high-speed jet flow provided sufficient energy to overcome the adverse pressure gradient, the separation will not occur and the flow will be remained potential.

P. F. Zhang [1] on his study showed that plasma actuator has significant influence on increasing lift coefficient and aerodynamic quality. At 8° of angle of attack, lift coefficient rose approximately 50% by comparison with in case plasma off.

The plasma actuator based on surface dielectric-barrier discharge. The method creating flow in this instrument was published first by Roth et al. Its diagram is described in the fig.1. The plasma actuator consists two asymmetrical electrodes that separated by a dielectric insulator. With a frequency of several kHz, and amplitude of thousands of volts between two electrodes, the air around them is ionized and formed induced flow. This flow is added in the boundary layer and has the tangential direction with the airfoil's surface.

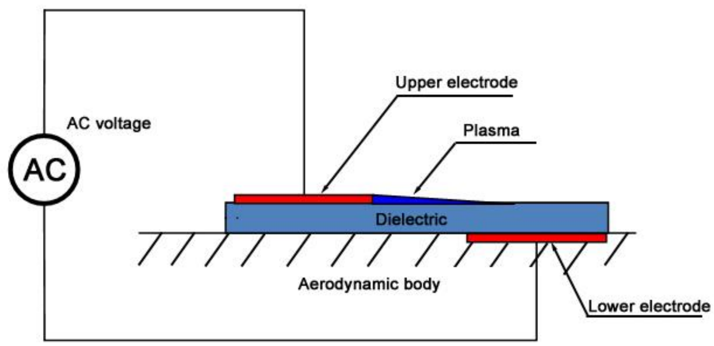

Figure 1: Diagram of plasma actuator

Since the publication of the method, many studied have been performed, the control device has even been used to test of unmanned aerial vehicle (UAV) with wind tunnel. Sven Grundmenn [5] in his research showed that, the separation angle of attack increases significantly in case plasma on at 11kV and speed of aircraft at 10 m/s, stall speed of the UAV has been decreased. Accordingly circulation control is effective method for increasing mobile of UAV. The method help improve aerodynamic performance, flying at high angle of attack and small speed, it means that the flying object could be perform short takeoff and landing. However the optimal position of place plasma actuator strictly depends on the speed and angle of attack of the object, and need more research on it, especially with flying object in higher speed.

The paper presents computational method to investigate aerodynamic parameters of the airfoil NACA 2415 at speed 50m/s with different positions of active flow at averaged Reynolds number. The whole position in the upper line of the airfoil is studied, especially in the case appearing separation angle of attack at 16°. The discrete vortex method has been also presented for comparing and checking result of the mesh in case without active flow. The flow is considered as viscous and incompressible.

2. Computational Method

2.1. Equation Navier-Stockes

To investigate, we use equation Navier-Stockes for turbulence, viscous and incompressible flow with Averaged Reynolds number. With the steady flow, equation Navier- Stockes for mass and momentum can be written as [1]:

$$\begin{aligned} &\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \\ &u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{1}{\rho}F_x \\ &u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+v\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{1}{\rho}F_y \end{aligned} \tag{1}$$

Where p- pressure, u, v- velocity in the x, y direction; F_x, F_y force produced by plasma actuator, and can be defined by following equation [7]:

$$\vec{F}=S\left(e^2 n_0\left(\frac{1}{kT_i}+\frac{1}{kT_e}\right)\phi\right)\vec{E}; \tag{2}$$

Where S- square area applied, e- charge of electron, n_0 – background plasma density, k – Boltmann’s constant, T is the temperature, ϕ is electric potential, and E- vector electric field.

The most important of studied plasma actuator is to understand the relationship between voltages input and velocity of flow output. Martiqua L.Post [7] in his study presented experimental formula of the relation:

$$U=0.0018V^{7/2} \tag{3}$$

Where U: velocity output of induced air flow, and V- voltage between two electrodes of plasma actuator. The formula showed that to create enough large velocity, we must use high voltage of plasma actuator. In this studied, the voltage rises up to 40kV.

The Navier-Stockes equation can be solved by numerical method, and the Ansys software is a excellent program to simulate aerodynamic parameters. However the results depend significant on the structure of the grid.

2.2. Discrete vortex method

The discrete vortex is very famous method for calculating potential flow. The method allows building mathematical model for a object when its characteristics is cleared .

For the airfoil, the upper and under lines are divided into n parts with constant circulation. Control points are located in the center of each part [8]. Neumann boundary condition is applied to find value of circulations. The equations can be written that:

$$\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}\begin{bmatrix} \Gamma_1 \\ \Gamma_2 \\ \dots \\ \Gamma_n \end{bmatrix}=\begin{bmatrix} V_1 \\ V_2 \\ \dots \\ V_n \end{bmatrix} \tag{4}$$

Where a_{ij}: influence coefficient of vortex at point j in collocation point i; Γ_i – circulation in I part of airfoil; $V_i=-U_\infty.n_i$;

With U_∞ – velocity of free flow, n- normal vector with airfoil surface.

The discrete vortex method is used to comparison with the result calculated by numerical method. As the outcome of the comparison we could evaluate quality of mesh.

2.3. Construction grid and choice calculating model.

The upper surface of airfoil was divided in ten parts (fig. 2), with could be simulated to place plasma actuator and produce jet flow. The Gambit software was used to create mesh and the FLUENT software used to calculate. The length of part 1 is 0.27c. Because it is no separation there anymore so we do not put the actuator there. Parts 3 to 8 are approximately the same at 0.081c, parts 2, 9, 10 are smaller at 0.057c. The calculating area has width and height dimensions 15c x 5c, and is showed in the figure 3, type of mesh elements – Quad/Map. The calculating area contains 173363 cells.

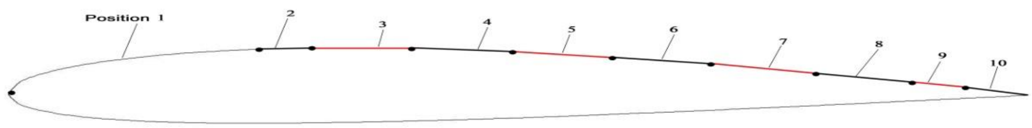

Figure 2:Airfoil NACA 2415 and its divided parts.

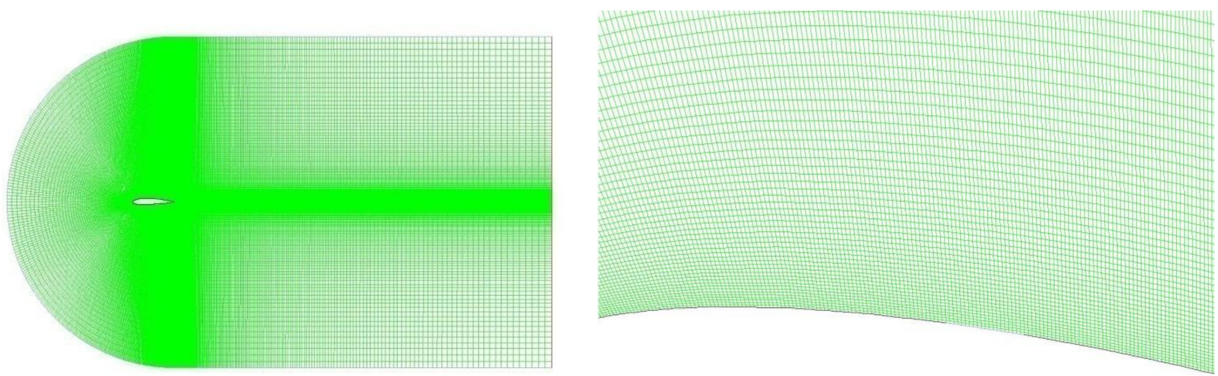

Figure 3:Dimensions of calculating area and grid distribution around the airfoil

In the paper, the one-equation Spalart-Allmarat model is used. This model solves a modeled transport equation for the kinemtic eddy viscosity in which it is not necessary to calculate a length scale related to the local shear layer thickness [4]. It was created for aerospace applications involving wall-bounded flows and give a good results for boundary layers subjected to adverse pressure gradient, especially when the mesh around object is not good enough. The boundary in Spalart-Allmarat model is replaced by some wall functions. Liu et al. in his research received a good result for control active flow over airfoil by using algebraic and Spalart-Allmaras one-equation turbylence models. The transport equation for the Spalart-Allmaras model is following:

$$\frac{\partial}{\partial}(\rho\tilde{v})+\frac{\partial}{\partial}(\rho\tilde{v}u_{ui})=G_v+\frac{1}{\sigma_{\tilde{v}}}\left[\frac{\partial}{\partial x_j}\left\{(\mu+\rho\tilde{v})\frac{\partial\tilde{v}}{\partial x_j}\right\}+C_{b2}\rho\left(\frac{\partial\tilde{v}}{\partial x_j}\right)^2\right]-Y_v+S_{\tilde{v}} \quad (5)$$

Where $\tilde{\upsilon}$ is the turbulent kinematic viscosity in the near-wall; G_υ is the production of turbulent viscosity, Y_υ – the destruction of turbulent viscosity that occurs in the near-wall region due to wall blocking and viscous damping. σ_υ and C_{b2} are constants, υ – molecular kinematic viscosity. S_υ – a user-defined source term.

3. Result and discussion

3.1. Aerodynamic parameters

The result indicated that active flow worked effectively in increasing lift coefficient. In the case with speed of free flow V=50m/s and speed of active flow V_{AC}=100m/s, active flow placed at position 8 bring the highest lift coefficient. With the low angle of attack method discrete vortex gave a good result and was closed with the other methods. At the angle of attack 14°, the lift coefficient with active flow at position 8 was increased at 60% by comparing with non active flow. At high angle of attack active flow at position 2 gave a significant grow in lift coefficient. By using active flow, not only lift coefficient but also separation angle of attack was increased (figure 4)

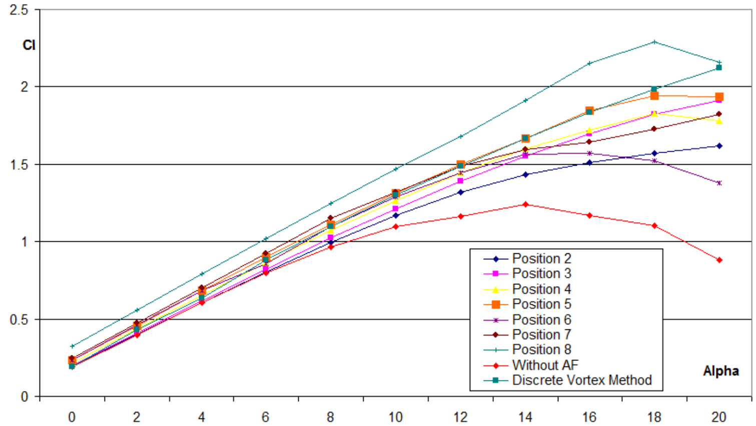

Figure 4: Lift coefficient of airfoil with different calculating method, and different positions placed active flow

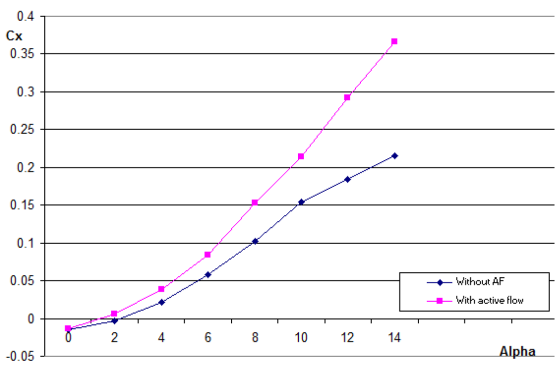

Figure 5:Drag coefficient in case with and without active flow at position 8

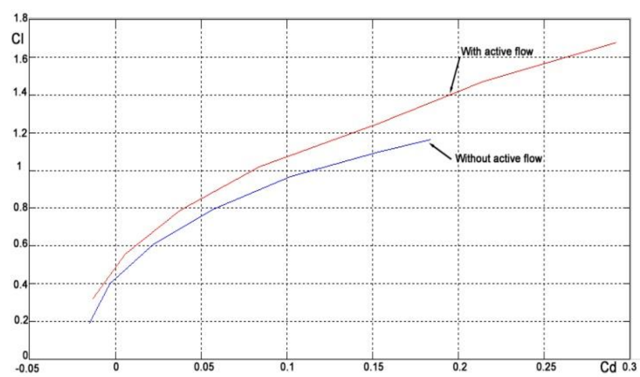

Figure 6:Aerodynamic performance in case with and without active flow at position 8

From the figure 5 and figure 6, we could see that in case with active flow, the drag coefficient of airfoil increased slightly, and the aerodynamic performance in case with active flow is higher than in case without active flow. The maximal aerodynamic performance was obtained at angle of attack α=4°.

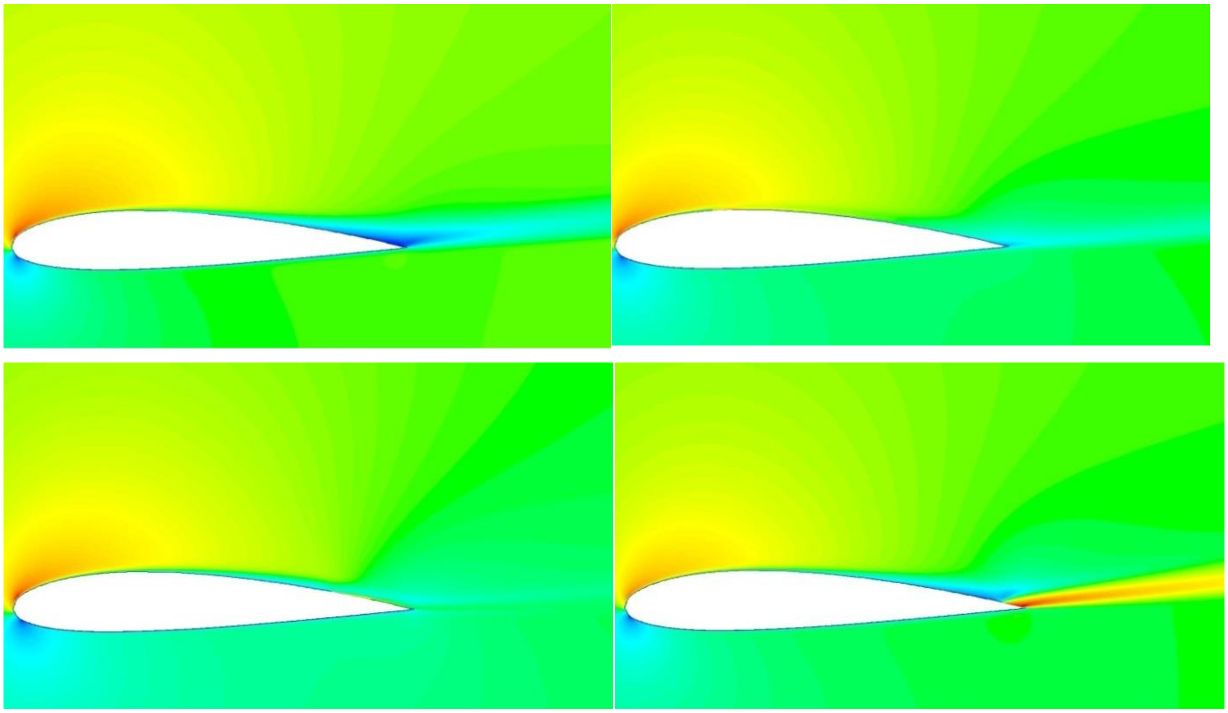

Figure 7: Distribution of speed with and without active flow (Located active flow at place 0, 2 8,10, V=50m/s, AoA =10°, V_{AF}=100m/s)

The figure 7 showed that, when the angle of attack equals 10°, speed of free flow V=50m/s and speed of active flow V_{AF}=100m/s, the active flow works efficiently in position 2. The separation flow does not occur. The most efficient place is position 8, because separation begins there. In position 9 and 10, active flow does not work, the lift of airfoil, by contrast, decreases significantly.

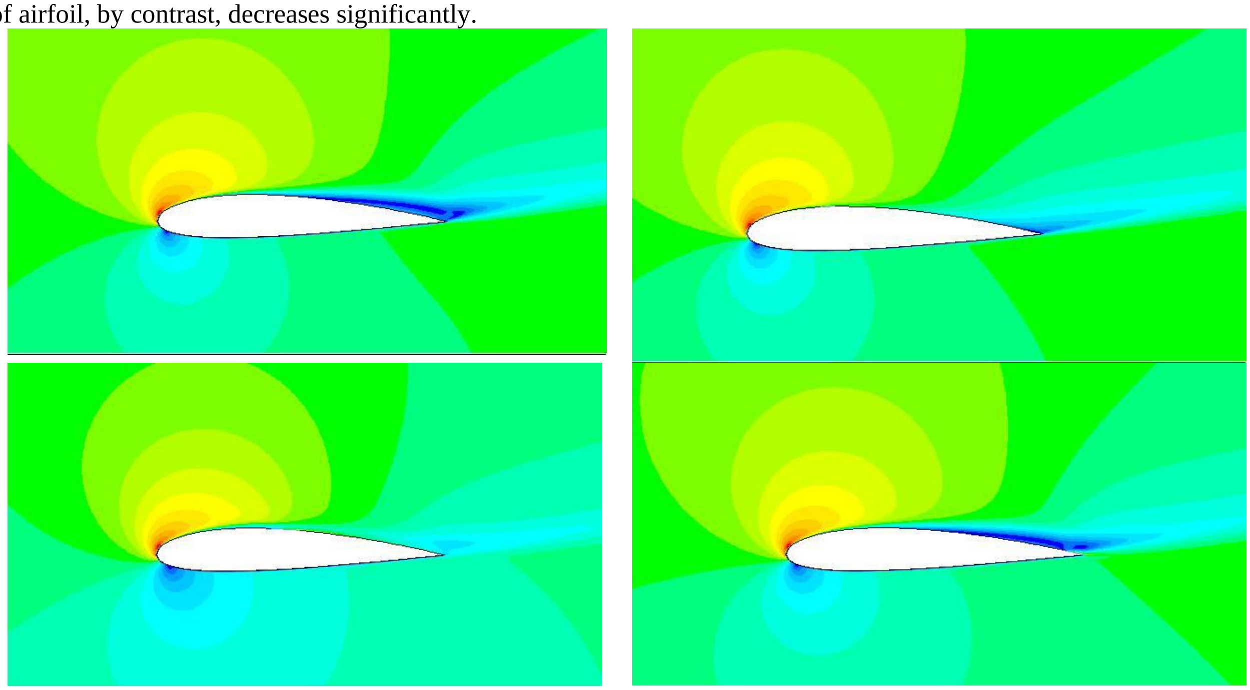

Figure 8: Distribution of speed with and without active flow (Located active flow at place 0, 2 4,10, V=50m/s, AoA =16°, V_{AF}=100m/s)

The result is the same in case angle of attack is 16°. However in this case, separation occurs in the position 5, so in position 6 and more, the active flow does not work. With the increasing angle of attack, the position of separation moves ahead and the area of vortex separation widens dramatically, placing active flow in the position near the leading-edge, for example position 2 brings not optimal aerodynamic performance but it always works. Moreover when angle of attack increases, it is necessary to rise the velocity of plasma flow, or in other word, rise the voltage of plasma actuator.

The above result showed that active flow actually works in the way to improve aerodynamic performance, especially for UAV, the object that flies in small velocity and easy to modify the wing to placed equipment for plasma actuator.

3.2. Change of lift coefficient in different position placed active flow

Investigating different place located active flow in airfoil demonstrated that with speed of free flow V=50m/s, speed of active flow V_{AC}=100m/s, angle of attack α=10°, lift coefficient increased with moving back of position placed active flow. However in the positions 9 and 10, lift coefficient decreased due to separation occurred in front of it. When the angle of attack reached to 16°, the position 5 of active flow gave the highest lift coefficient. At angle of attack equal 4°, where aerodynamic performance is maximal, the change lift coefficient is slightly with different position of active flow, and obtained maximal lift at position 8 (figure 9).

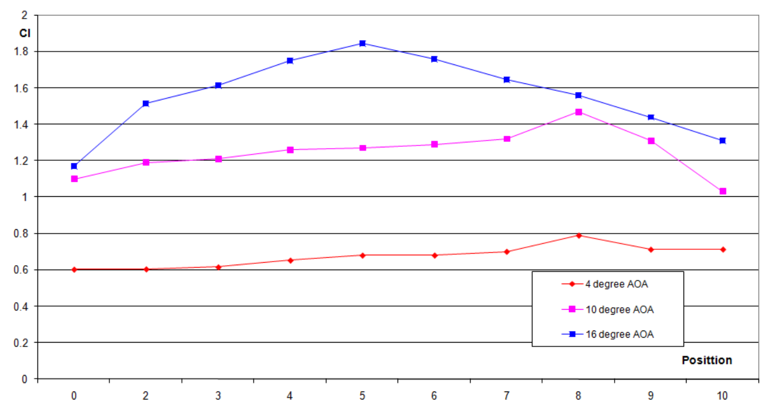

Figure 9: Lift coefficient of airfoil in different place located active flow (V=50m/s, V_{AF}=100m/s)

3.3. Depend of lift coefficient on changed-speed of active flow

Lift coefficient of airfoil increased with increasing speed of active flow, as showed in the figure 10.

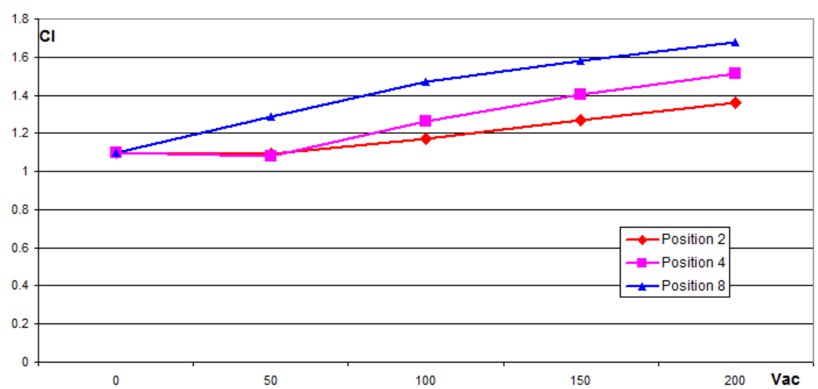

Figure 10: Lift coefficient of airfoil in different speed of active flow (Located plasma actuator at position 8, speed of free flow V=50m/s, AoA =10°)

4. Conclusions

As the result of investigation in the paper, we could make some conclusions:

Using active flow, especially plasma actuator is the most effective way to improve aerodynamic performance of airfoil. By using active flow, separation angle is also increased, that could make aircraft with short take off and landing.

When the speed of free flow V=50m/s, placing active flow near trailing-edge (position 8) give maximal lift coefficient with interval of angle of attack from 0 to 10°. When angle of attack increases, the placing active flow must move ahead following to the leading-edge.

Lift coefficient increased with grow speed of active flow.

The paper gave a good result for improving aerodynamic characteristics and reduced the oscillation over airfoil due to separation.

5. Acknowledgments

The research was supported by National Foundation for Science & Technology Development of Vietnamese government. The authors would like to thank the organization by support us coming to the conference.

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