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A Study on the Flow Characteristics around a Coanda Control Surface

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Abstract

Jet flows applied tangential to a foil surface near the leading and/or trailing edges increase the lift of the foil by delaying the separation also known as the Coanda effects. Many experimental and numerical studies have proven the effectiveness of Coanda effects on circulation control and the effects have been found to be useful in practical application in many aerodynamics fields.

Most of the previous works have studied the effects of the jet blowing near the trailing edges and investigated the influence of jet momentum on lift. A few experimental studies, however, focused on the separation bubble that develops near the leading edge and applied jet flow the edge to remove the bubble but only to find decrease in lift.

In the present paper, a Coanda foil of 20% thickness ellipse with modified rounded leading and trailing edges was investigated, and the flow around the foil was numerically studied. The blowing around the leading edge only decreased the lift, as the experiments showed, but the suction considerably increased the lift.

Keywords: Circulation Control, Coanda Effect, Elliptic foil, Leading edge blowing, Leading edge suction

1 Introduction

Henry Coanda discovered the so-called Coanda effect when he tested "Coanda-10" in 1950. Since then, the effect has been extensively studied to be applied for the practical design of airplanes in these days.

Many researches have been performed previously to understand the Coanda effects, among them, Kind and Maull (1968), Mclachlan(1989), Rhee et al(2002) and Park et al (2000) are referred in the present study.

The introduction of the jet flow usually increases the lift of foils by delaying separation of boundary layer as most all the researches have shown. Mclachlan found that jet blowing at the trailing edge generates a separation bubble near the leading edge and thought that removing the bubble can further increase the lift of circulation control foil. However, the outcome was contrary since the leading edge blowing decreases the lift.

In the present study, numerical simulations for the flow fields around an elliptic foil identical to that of Mclachlan (1989) will be performed, and it will be shown that the leading edge suction, not the blowing, will increase the lift of the circulation control foils. A commercial code by Fluent, Inc. has been used for the present computation.

2 Numerical Computations

2.1.1 Governing equations

The governing equations for mass and momentum conservation can be written as

$$\begin{aligned} &\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0 \\ &\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla P + \nabla \cdot (\bar{\tau}) \end{aligned} \qquad (1)$$

The Navier-Stokes equations written in Cartesian tensor x_i are as follows.

$$\begin{aligned} &\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0 \\ &\frac{\partial u_i}{\partial t} + \frac{\partial u_i u_j}{\partial x_i} = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} \\ &\bar{\tau}_{ij} \equiv v_e \left(\frac{\partial u_i}{\partial x_i} + \frac{\partial u_j}{\partial x_j} \right) - \frac{2}{3} \delta_{ij} k \end{aligned} \qquad (2)$$

where, ρ and p are density and pressure, respectively and u_i is the velocity components

2.1.2 Numerical methods

In the present study, numerical computations were performed with a general software by Fluent Inc. A cell-centered finite volume method (FVM) and the $k-\omega$ turbulence model are used for the computation. Convection and diffusion terms are discretized by a second order accurate upwind scheme and time derivatives by first order backward implicit schemes. A SIMPLE type segregated algorithm considers the pressure-velocity coupling.

2.2 Foil geometry

The flow field around the circulation control foil used in the Mclachlan's experiments (1989) was numerical calculated. The foil is a *20%* elliptic airfoil modified to have circular leading and trailing edges to create jet slots of *0.0015C* high, where *C* is the chord, at the upper and lower surfaces of the foil, at the locations *0.037C* and *0.963C* apart from the leading edge. The radii of the leading and trailing edges are given as *0.04 C*.

2.3 Computational mesh and boundary condition

The computational domain is $-2 \leq x/C \leq 6$ long and $-0.5 \leq x/C \leq 0.5$ wide as shown in Figure 1. The mesh consists of 82,600 quadrilateral cells and the topology is C-H type. In the present computations, non-slip boundary conditions are imposed on the foil surfaces and zero-static-pressure condition on exit boundary.

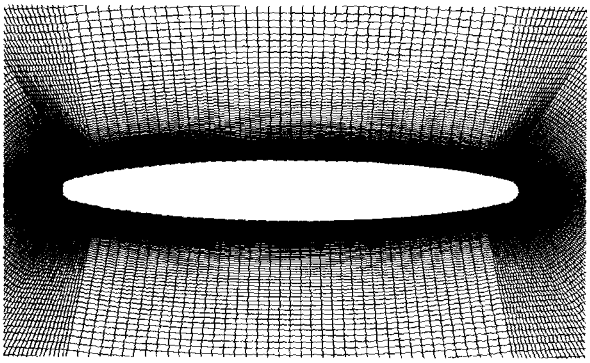


Figure 1: Computational mesh around the Coanda Foil

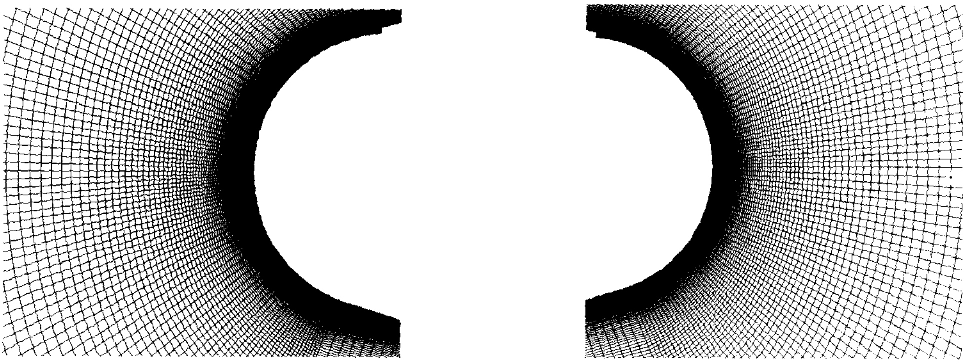


Figure 2: Computational meshes around the leading and trailing edges

2.4 Jet momentum

The non-dimensionalized coefficient of jet momentum can be defined with mass flux and jet velocity as follows;

$$C_\mu = \frac{\dot{m} \times V}{\frac{1}{2}\rho_\infty V_\infty^2 C} \tag{3}$$

where $\dot{m}$ is the mass flow and V, V_∞ ,and ρ are the jet velocity, the free stream velocity and density, respectively. These computations are carried out for $C\mu = 0.032$, 0.05, 0.0743 and 0.1 at the trailing edge and $C\mu = \pm\, 0.046$ at the leading edge.

3 Results and discussions

3.1 No jet blowing ($C\mu$'s = 0.0)

Figure 3 shows velocity contours and vectors for the case of $Rn = 2.0\times 10^5$ and $C\mu$=0.0. In the figure, flow symmetries between and separations near the upper and lower slot are apparent by vortices formed at the trailing edge slots.

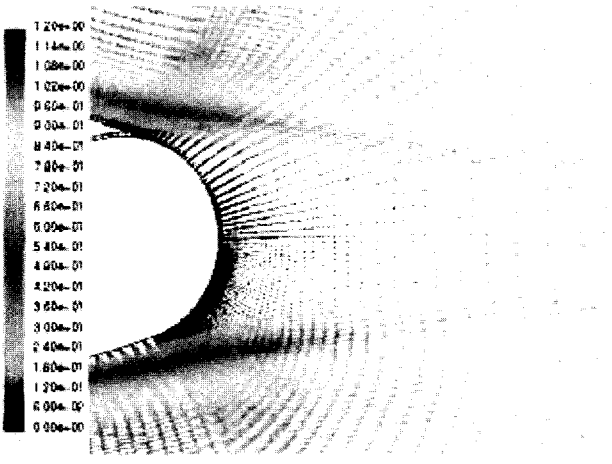


Figure 3: Velocity contours and vectors for, $Rn = 2.0\times 10^5$ and $C\mu$'s =0.0

3.2 Jet blowing at trailing edge only ($C\mu|_{LE} = 0.0$)

Figure 4 shows the results of numerical computations for $C\mu|_{TE}$ of 0.05, 0.0743 and 0.1. The figure shows changes in the U velocity contours with increase of $C\mu|_{TE}$. With the increase of $C\mu|_{TE}$, flow separation is delayed as expected.

(a) $C\mu|_{TE}$ =0.0500 (b) $C\mu|_{TE}$ =0.0743 (c) C =0.1000

Figure 4: Contours of U-velocity near the trailing edge for various $C\mu|_{TE}$, $Rn = 2.0\times 10^5$

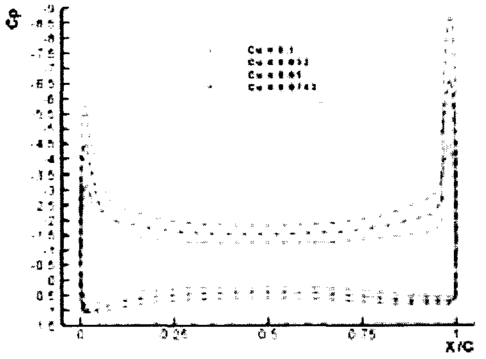


Figure 5: Pressure distribution for various $C\mu|_{LE}$

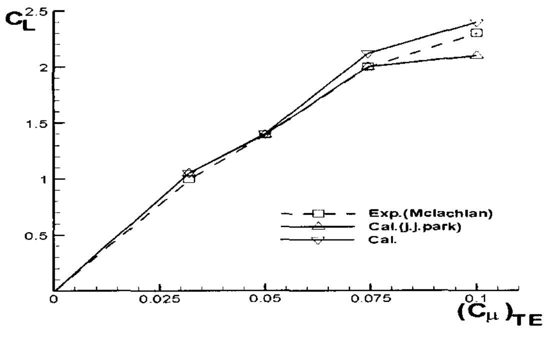
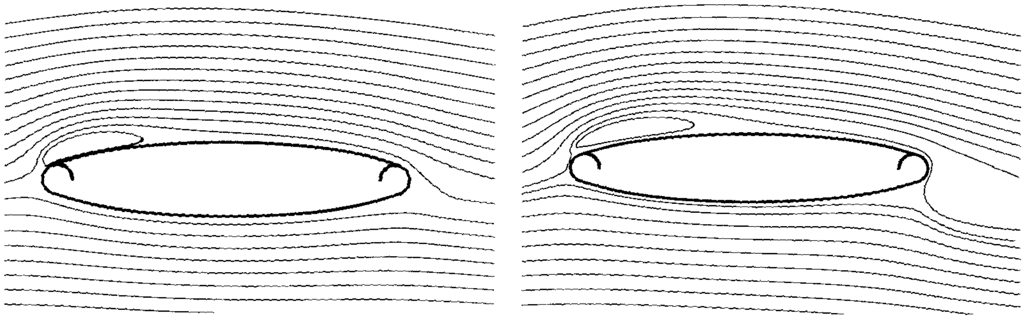


Figure 6: Comparisons of lift coefficients

Figures 5 and 6 show the effect of jet blown at the trailing edge slot. Figure 5 shows the pressure distribution along the foil surface. Areas encircled increase with increase of $C\mu|_{\mathrm{TE}}$, which increases the lift as shown in the Figure 6, where computed values are in good agreement with experimental ones by Mclachlan

3.3 Jet blowing at both leading and trailing edges ($C\mu|_{\mathrm{TE}} = 0.05$)

Mclachlan found that a separation bubble forms near the leading edge if the jet is applied at the trailing edge, and hence, the lift of the foil decreases. Then, he injected a jet flow at the leading edge to remove the separation bubble and to increase the lift. He found that, on the contrary, the separation bubble grows and lift coefficient drops with increase of $C\mu|_{\mathrm{LE}}$, as shown in Figure 8. The figure shows the computational results.



(a) ($C\mu|_{\mathrm{LE}} = 0.046$, $C\mu|_{\mathrm{TE}} = 0.05$)

(b) ($C\mu|_{\mathrm{LE}} = 0.046$, $C\mu|_{\mathrm{TE}} = 0.1$)

Figure 7: Stream Lines around the foil with leading edge blowing

Figure 9 shows the changes in the lift coefficients with increase in trailing edge blowing with and without leading edge blowing ($C\mu|_{\mathrm{LE}} = 0.0$ and 0.046).

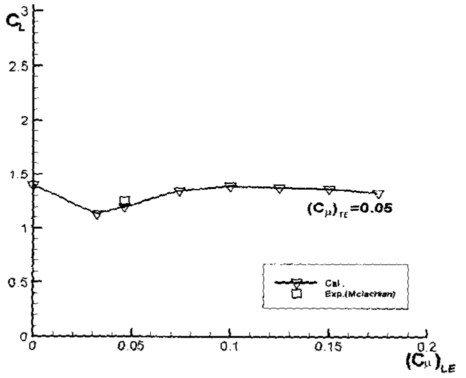


Figure 8: Effect of leading edge blowing for various $C\mu|_{\mathrm{LE}}$ ($C\mu|_{\mathrm{TE}} = 0.05$)

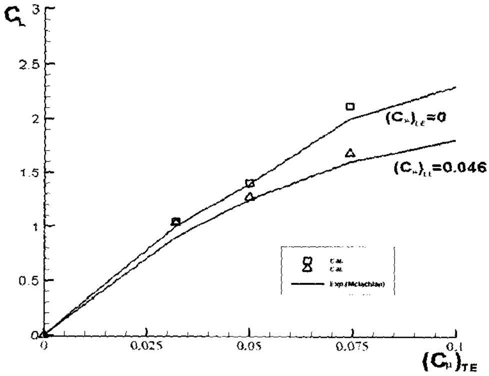


Figure 9: Effect of leading edge blowing for various $C\mu|_{\mathrm{TE}}$ ($C\mu|_{\mathrm{LE}} = 0.0, 0.046$)

3.4 Leading edge suction ($C\mu|_{\mathrm{LE}} = -0.046$, $C\mu|_{\mathrm{TE}} = 0.05$)

In the present study, instead of jet blowing at the leading edge slot as in Mclachlan's study, boundary layer suction technique was introduced. To compare with Mclachlan's experiment, $C\mu|_{\mathrm{LE}}$ and, $C\mu|_{\mathrm{TE}}$ were taken as 0.046 and 0.05, respectively. Figure 9 shows the streamlines around the foil, and the figure shows that the separation bubble disappears in this case, which is present whenever a trailing edge jet is applied.

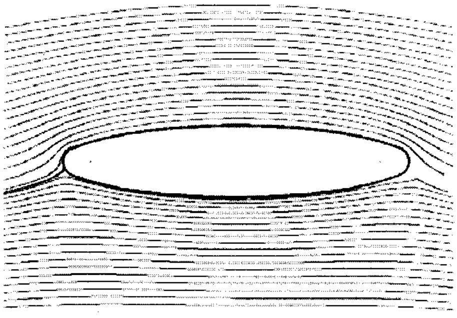


Figure 10: Streamlines, around the foil (leading edge suction $C\mu|_{\mathrm{LE}} = -0.046$, $C\mu|_{\mathrm{TE}} = 0.05$)

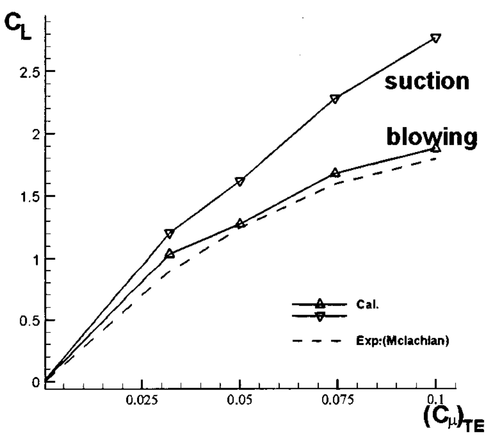


Figure 11: Leading edge Suction *vs.* blowing ($C\mu|_{\mathrm{LE}} = \pm 0.046$)

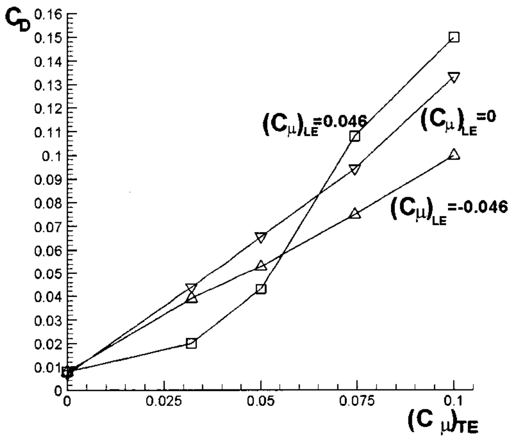


Figure 12: Drag coefficient for various cases ($Rn = 2.0 \times 10^5$)

Figure 11 shows the changes in the lift coefficients when leading edge suction is applied instead of blowing. The lift coefficients increase as much as 40% for the case of $C\mu|_{\mathrm{TE}} = 0.0743$ with the leading edge suction. Figure 12 shows the drag coefficients for the computations explained above.

In general, the drag coefficients decrease with leading edge suction and increase with blowing. However, for low values of $C\mu|_{\mathrm{TE}}$, drag coefficients were unexpectedly low, as found in the figure.

4 Conclusions

Numerical computations were performed to investigate the flow fields around a circulation control foil and following conclusions are drawn.

- Numerical results were compared to the previous experimental and numerical solutions and they were found to have good agreements.

- The leading edge blowing in Mclachlan's experiment decreases the lift of the circulation control foil.
- The leading edge suction introduced in the present study increases the lift of the circulation control foil as much as 40%.

Further studies may be necessary to investigate the effects of angle of attack and to extend the results to three dimensional cases.

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