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CFD Analysis of Co Flow Jet Airfoil

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Abstract

The performance of airfoils can be improved by using flow control techniques like Co Flow Jet (CFJ) technique. Many of the control flow techniques are applied only near leading or trailing edge, whereas the CFJ technique is applied on most of the suction surface. In this technique an injection slot is made near the leading edge through which a jet is introduced. In order to maintain the conservation of mass principle, same amount of mass is sucked through a suction slot. In this paper the performance of NACA6409 baseline airfoil is compared with three CFJ airfoils with varying positions of injection and suction slots. The performance characteristics considered are coefficient of lift, stall margin and lift to drag ratio. The analysis is done using commercial code ANSYS FLUENT. It was found that the CFJ airfoils improve the stall margin by 33% to 67% compared to the baseline airfoil. The airfoil CFJ1 has optimum position of injection and suction slots. For this airfoil the lift coefficient increased by 47% and there was no considerable change in lift to drag ratio.

Keywords: CFJ Airfoil, CFD, L/D Ratio, Stall Margin

1. Introduction

There are many active flow control techniques available to augment the lift and keep the flow attached thereby increasing the stall margin of subsonic airfoils. Co Flow Jet (CFJ) is one of the better techniques available. In this technique a jet is introduced through slots on the airfoil by using a pump and suction system. The main advantages of CFJ technique is that the improvement in lift, high lifts at higher angle of attack, increasing stall margin and ultra-high L/D ratios at cruise speeds. The other advantage is that unlike other flow control techniques which can be used only during landing and take-off this can be used during the entire duration of the flight. No moving parts are required for this and hence the implementation of the technique is quite easy compared to other circulation control techniques.

CFJ technique was studies by Ge-Cheng Zhaet.al[1]. They have used CFJ on the suction surface of the airfoil. This enhanced the lift to drag ratio, lift coefficient and stall margin. The effect of jet parameters on Co Flow Jet performance was studied by Ge-Cheng Zhaet.al[2]. A study was made to analyse the effects of injection slot and suction slot and a comparison was made with the absence of suction slot. Flow control via injection and suction slots were studied by T.L.Chng et.al[3]. The effect of injection slot size on performance of CFJ airfoil was studied by Ge-Cheng Zhaet.al[4]. This paper proved that airfoils with different geometry give different performance. It also proved that lower size of the injection slot gave better performance than the same airfoil with twice the size of injection slot. The CFJ flow control technique was conducted on a Clark Y airfoil and comparison with baseline airfoil was made. Ge-Cheng Zhaet.al[5] studied the effect of jet momentum coefficient, power coefficient and jet effects on lift and drag. They have varied the momentum coefficient from 0.1 to 0.3 and it is reported that maximum lift increase by 113 to 220% and stall margin by 100 to 153%. They have experimentally found that there is a limit of the jet mass flow rate in maintaining the stability of flow. Lefebvre. A et.al.[6] have studied the performance of CFJ airfoils under varying Mach numbers (0.03 to 0.4). They have reported that maximum lift coefficient increase with increasing Mach number, but for M=0.4, the airfoil stalls at lower angle of attack. This is due to the appearance of strong λ shock wave. This

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interrupts the jet and trigger boundary layer separation. Bertrand et.al.[7] has used discrete injection jets to enhance the performance of CFJ airfoils. They have shown that the discrete CFJ airfoils generate both stream-wise and span-wise vortex structures to achieve more effective turbulent mixing than open slot CFJ. It was found that DCFJ airfoil can achieve 50% additional increase in maximum lift, 30% increase in stall margin and a drag reduction of 300% compared to open slot CFJ.

Unlike other circulation control techniques which are applied only at leading edge and trailing edge, the CFJ technique is applied on a major part of the suction surface. In this technique two slots are created. One near the leading edged called injection slot and another near the trailing edge called suction slot. A high energy jet is injected through the injection slot and same mass flow is sucked through the suction slot. A turbulent mixing of main flow and jet happens over the airfoil surface. This enhances a lateral transport of energy and helps the main flow to overcome adverse pressure gradients. Even at higher angles of attack the main flow remains attached to the surface. The CFJ technique helps in reducing the take-off and landing distances. It is easy to implement for both low and high speed aircrafts. In this paper performance of base line and co flow jet airfoils are compared. The effect of Mach number variation, injection and suction slot positions on the aerodynamic performance of the co flow jet airfoils is also studied.

2. Methodology

Computational Fluid Dynamics (CFD) is a powerful tool which uses basic computation methods such as numerical analysis to solve fluid problems without building the prototype. CFD replaces the problem of building a physical prototype and the associated cost involved by the relatively cost effective method of building computer aided design models and running analysis on them using computer programs. CFD is also less cumbersome in terms of results and obtaining them. In this paper we have used ICEM-CFD for processing and ANSYS FLUENT commercial code for the simulation of the model. Two slots were cut on the suction surface of the airfoil one near the leading edge and other near the trailing edge. The NACA 6409 airfoil was chosen for the simulation.

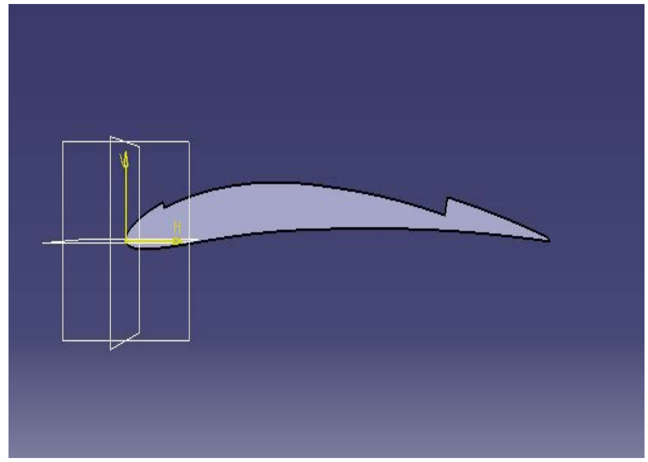

Figure 1. CFJ airfoil NACA6409 090 270.

The three main conservation equations of flow i.e. the conservation of mass, conservation of momentum and conservation were energy was used to solve the problem. The Navier Stokes equation was solved for the boundary conditions to obtain the results.

$$\rho\left(\frac{\partial V}{\partial t} + V.\nabla v\right) = -\nabla p + \nabla.T + f$$

The continuity equation is given as

$$\frac{\partial \rho}{\partial t} + \dot{\nabla}.\left(\rho\vec{u}\right) = 0$$

The conservation of energy is given as

$$\rho\left(\frac{\partial E}{\partial t} + u\frac{\partial E}{\partial x} + v\frac{\partial E}{\partial y}\right) = \nabla.(k\nabla T) - \nabla.p\vec{V}$$

The Spallart Allmaras one equation turbulence model was chosen because it adds only one term of viscosity to the Navier Stokes Equation and also reduces the computation time. This model is more suitable for analysis of external flows on aerodynamic analysis. The CFD model developed is validated with results of G.C. Zha et al[2]. The simulations were done for NACA0025 base line airfoil and NACA0025 CFJ airfoil. The free stream Mach number is 0.11 and jet mass flow rate is 0.1 Kg/s. The figure 2 shows velocity contours for the base line airfoil with stall occurring at an angle of attack (AoA) of 19^0. The figure 3 shows the Mach number contours at AoA of20^0 for NACA0025 CFJ airfoil. The contours obtained matched well with the results published by G.C. Zha et al[2].

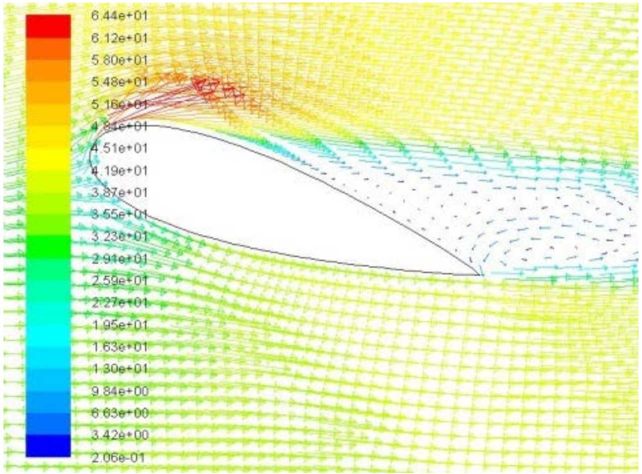

Figure 2. Velocity contours for base line airfoil at AoA 190.

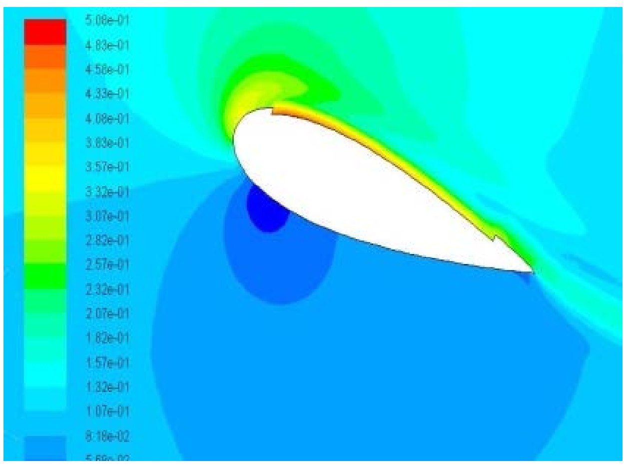

Figure 3. Mach number contours for CFJ airfoil at AoA 200

3. Results and Analysis

The un-symmetric airfoil NACA6409 which is widely used in low speed and low altitude flights is chosen for further simulations. The simulations were done for free stream Mach numbers of 0.3, 0.6 and 0.8 with free stream pressure of 101.325 kPa and temperature of 300K. It was observed that the stall margin increases with Mach number. For Mach number of 0.3 the stall occurred at 7.5 degrees whereas it increased to 8 degrees for Mach number 0.6 and for Mach number of 0.8 the stall occurred at 12.5 degrees. The stall margin and lift coefficients increase as the Mach number increases. But the Lift to Drag (L/D) ratio is better at lower Mach numbers (Figure 4) for a particular airfoil, which is desirable even though there is slight increase of stall margin. Also as shown in Fig 5 for Mach numbers 0.6 and 0.8 a λ shock appears near the tail of the aerofoil. Hence for further studies free stream Mach number of 0.3 is used. The stall margins can be further increased by the application of control flow techniques like the Co Flow Jet (CFJ) technique.

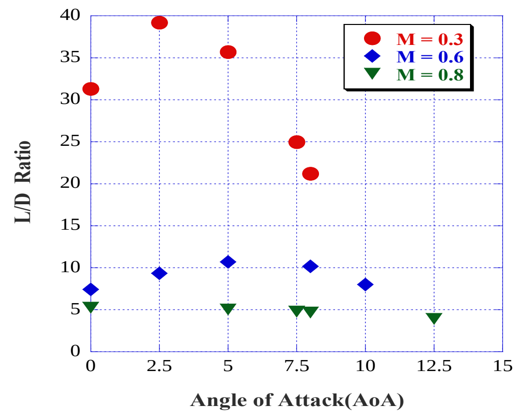

Figure 4. Variation of L/D ratio with AoA.

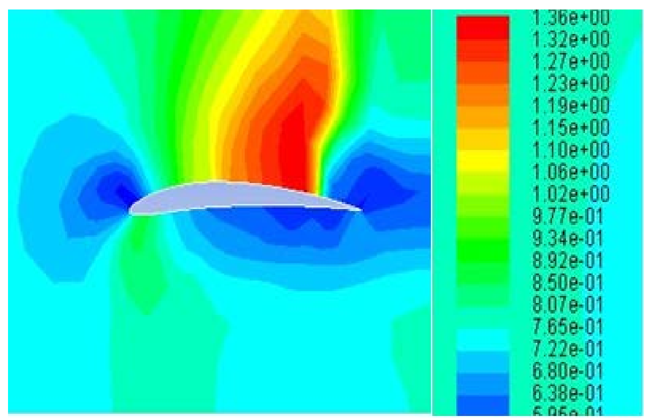

Figure 5. Mach number contours for NACA6409 for $M_\infty = 0.8$.

A Co Flow Jet airfoil was constructed from the base line airfoil NACA6409 with injection slot at a distance of 10% chord and suction slot 75% chord from the nose. The suction slot depth is 0.9% of the chord and for mass conservation the suction slot is taken as 2.7 % of the chord length. It is designated as CFJ 6409 090 270. The simulations were done with free stream conditions of $M_\infty = 0.3$, $p_\infty = 101.325$ kPa and $T_\infty = 300$K. The mass flow rate at suction is 0.2 Kg/s. The injection slot was given as pressure outlet and the suction slot as mass flow inlet conditions. The suction slot is constructed to be 3 times of injection slot for complete mass conservation to occur. The various parameters taken into effect are Lift coefficient, Drag Coefficient and stall margin. The variation of lift coefficient for baseline airfoil and CFJ airfoil with AoA is shown in figure 6. The stall occurred at an angle of attack of 7.5^0 for the baseline NACA6409 airfoil and at 12.5^0 for the CFJ airfoil NACA6409 090 270. The stall margin has increased by 66.66%. Figure 7 shows the velocity contours for CFJ airfoil at AoA of 12.5. The flow separation can be seen clearly.

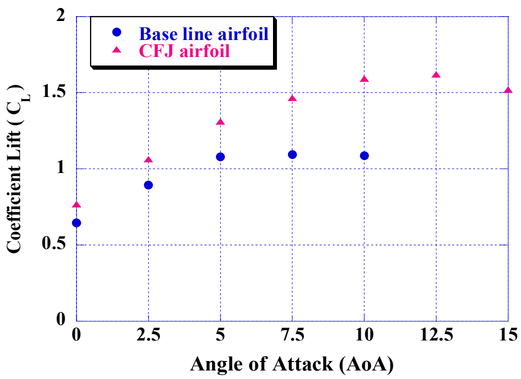

Figure 6. Comparison of coefficient of lift for baseline airfoil and CFJ airfoil NACA 6409 090 270.

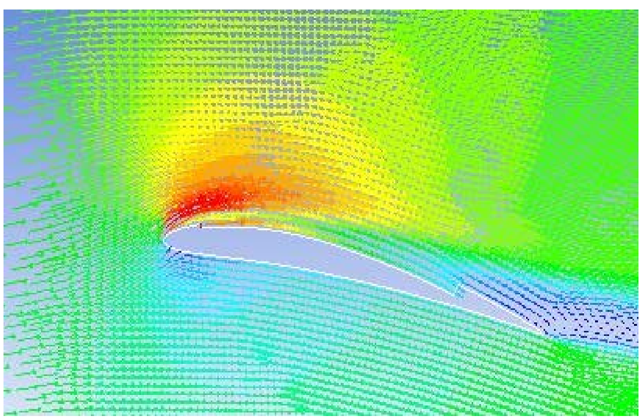

Figure 7. Velocity vectors representing Mach number at stall for NACA6409 090 270 at 12.50.

To study the effect of positions of suction slot and injection slot two more airfoils were created. The analysis was done for determining the optimum position of the slots for better augmentation of lift and increase in stall margin. In total three airfoils were used and they have been called CFJ1, CFJ2 and CFJ3. The details are as below.

- CFJ1- Injection Slot at 10% chord length and Suction Slot at 75% chord length
- CFJ2- Injection Slot at 10% chord length and Suction Slot at 65% chord length
- CFJ3- Injection slot at 5% chord Length and Suction Slot at 70% chord length.

Figure 8 shows the variation of coefficient of lift with angle of attaches for the baseline and the three CFJ airfoils. It is observed that the CFJ1 airfoil has higher stall margin than others. Stall occurred at 12.5^0 for CFJ1, 10^0 for CFJ2 and CFJ3 and at 7.5^0 for baseline airfoil. The Figure 9 shows the variation of lift to drag ratio for all the airfoils considered. It can be observed that the CFJ1 airfoil has almost same L/D ratio as that of baseline airfoil and it also has the highest stall margin among the airfoils considered. Hence CFJ1 has optimum slot positions and can be used. The stall margin for CFJ1 has increased by 67% and for CFJ2 and CFJ3 it has increased by 33% compared to baseline airfoil. It can also observe that the drag increases considerably as the angle of attack increase for all airfoils.

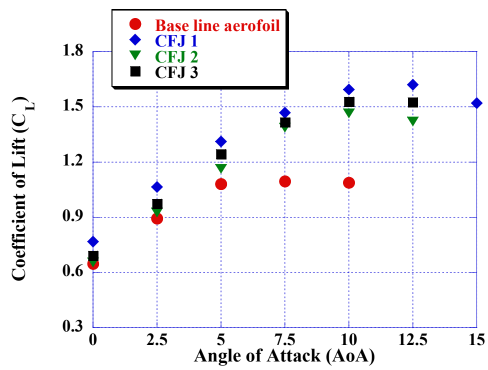

Figure 8. Variation of coefficient of lift with AoA for baseline, CFJ1, CFJ2, CFJ3.

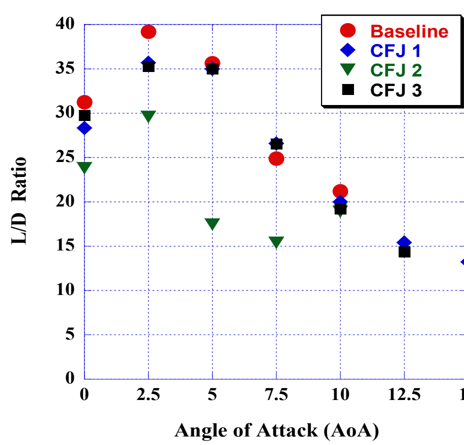

Figure 9. Variation of L/D ratio with AoA for baseline, CFJ1, CFJ2, CFJ3.

4. Conclusions

The Stall margin for the CFJ airfoils has improved by 33% to 67% compared with the base airfoil. The CFJ1 airfoil performs better than other airfoils studied. The coefficient of lift for CFJ1 airfoil has increased by 47% for maximum value of lift and the stall margin improved by 67%. The variation in slot position has shown that injection slot should be placed at position not very close or not far away from the suction slot. Sufficient span must be provided between injection and suction slot for complete mass conservation and improvement of properties.

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