DEVELOPMENT OF HIGH-LIFT LAMINAR WING USING STEADY ACTIVE FLOW CONTROL

Abhishek Rai[1], Er. Rahul Malik[2]

[1]*M.tech Student, P.M. Group of Institutions, DCRUST Murthal, Sonipat, Haryana*
[2]*Head of Department, Mechanical Engineering, P.M. Group of Institutions, DCRUST Murthal, Sonipat, Haryana*

---***---

Abstract - *Laminar airfoils have the advantage of reduced cruise drag and increased fuel efficiency. Unfortunately, they cannot perform adequately during high-lift situations (i.e. takeoff and landing) due to low stall angles and low maximum lift cause by flow separation. Active flow control has shown the ability to prevent or mitigate separation effects, and increase maximum lift. This fact makes AFC technology a fitting solution for improving high-lift systems and reducing the need for slats and flap elements.*

***Key Words*: AFC, PFC, PSF, AOA, NACA**

1. INTRODUCTION

The dramatic increase in demand for air travel worldwide combined with the air travel industry's high exposure to increasing jet fuel prices has called for as step increase in efficiency of current air travels systems and immediate advancements to improve aircrafts fuel efficiency. These factors—increased airs travels and increased cost of jets fuel—have motivated companies to pursue technologies aimed at reducing fuels consumption. During takeoff and landing (TO/L) airplanes generates increased lifts and drags to reduces grounds speeds and runways lengths. Currently, modern aircrafts uses airfoils that are turbulent in cruises with high-lifts elements such as slats and flaps, to produces the lifts necessary for TO/L. TO/L is the shortest portions of any flight; aircraft spend the majority of flight in cruises where lift requirements are lower. During cruise, turbulent flows produces higher skin friction drag which can represent over 50% of the total drag. By reducing drag, aircraft improve fuel efficiency. The use of laminar airfoils would significantly reduce skin friction drag and improve overall aircraft fuel efficiency. The benefits laminar airfoils have during cruise are significant, but their tendency to stall at low angles of attack (AoA) and low maximum lift make them impractical for TO/L situations. To address this problem, this research study was conducted to develop high-lift technology for laminar airfoils by using active flow control.

1.1 Flow Control- Flow control can be described as altering an airfoil's natural flow state and development to a more desirable state (Collis, 2004). Flow control has a long history, beginning with Prandtl's discovery of the boundary-layer (BL) in 1904 (as cited by Gad-El-Hak, 1991).

1.1.1 Passive Flow Control-To date, passive flow control (PFC) remains the most utilized form of flow control, and has many varieties such as slats, flaps, vortex generators, rib lets and strakes to name a few. These systems are used to control separation and increase lift during TO/L. Passive systems do not require power input and have the advantage of being easily implemented and maintained. Leading edge slats, and trailing edge flaps exemplify the most utilized high-lift configurations and are forms of PFC. Both slats and flaps work under the same principles where flow is accelerated from the high pressure side of an airfoil and injected over the suction side of the airfoil' This additional flow energizes the BL, enabling it to overcome more adverse pressure gradients and remain attached at higher AoA. Without these PFC systems separation occurs at high angles of attack and leads to stall.

Unfortunately PFC systems come with high drag penalties during cruise due to their mechanical nature and introduction of discontinuities to the airfoil profile. A secondary form of PFC, vortex generators (VG), are small high aspect-ratio airfoils mounted normally to lifting surfaces and ahead of the flow separation point (Figure 2). While flaps and slats use the injection of momentum into the boundary-layer to delay stall, vortex generators use the concept of vortex mixing to delay stall. VG's can be installed on various aircraft elements, including the airframe, engine nacelle and the wing. Once installed on an aircraft, VG's create tip vortices during flight which begin to entrain and mix the turbulent free-stream within the retarded BL. The addition of high speed free-stream flow reenergizes the BL, helping it overcome more adverse pressure gradients at higher angles of attack and prevent separation.

1.1.2 Active Flow Control

Active Flow Control (AFC) is not a new concept. After initially presenting the concept of two-dimensional separation in 1904 and effectively introducing Boundary-Layer Theory, Prandtl began experimenting with the effects of flow control via suction to improve flow attachment to a solid body. Since then, flow control has been further studied as a method of separation control, with benefits such as enhanced lift, reduced drag and noise emissions, and improved fuel efficiency. As previously stated, Passive Flow Control (PFC) systems such as flaps and vortex generators represent the majority of flow control systems but, due to their size and complexity, they can increase the overall weight and profile drag during cruise which, in turn, decreases the fuel efficiency of any aircraft. AFC has the capability to solve these issues and reduce the need for PFC systems. AFC systems use direct addition of momentum into the BL, typically from a slot or row of small orifices, to achieve the same results as PFC without introducing steps, gaps and other discontinuities which cause aircraft inefficiency. AFC has been demonstrated in many different forms and has been researched for uses in various fields. AFC is commonly used for separation control achieved through steady blowing, periodic (or pulsed) excitation, or acoustic excitation.

2. SOME RESEARCH STUDY RELATED TO LAMINAR WING USING AFC

Seifert (1996) and Bright (2012), and numerical studies by Pfingste (2005) and Burnazzi (2012), the researchers have investigated steady blowing and its ability to enhance lift in high-lift configurations (i.e. deflected flap). Each of these works are important to the present study because they characterize the effects of steady blowing at different chord locations, and show that steady AFC can successfully reenergize the BL, improve separations and increase CLmax. The present study looked to relate its results to these findings.

Seifert (1996) investigated the effects of steady and oscillatory blowing on four different airfoils (Figure 2.1). Of these four airfoils, a NACA 0015 airfoil was used to study steady LE blowing as well as steady blowing from a 20° deflected flap. This work showed that in both steady and oscillatory cases blowing over a deflected flap is much more effective in increasing CL, max than LE blowing alone at the same C. Only strong LE blowing, which required approximately four times the Cμ of deflected flap blowing, was able to obtain similar results as shoulder flap blowing.

Bright (2012) confirmed experimentally the effects of the TE deflected flap blowing before testing the effectiveness of additional LE blowing. Bright tested the effectiveness of the 1% slot, along with the effectiveness of the 1% and 10% slot together with varying Cμ. The most successful test utilizes differential blowing. In this test, the 10% slot Cμ is varied while the 1% and 10% slot are kept constant.

Results- Testing for this study was broken down into 5 different cases: The first case study, without the effects of AFC, is referred to as the "baseline". The next four cases examine AFC effects from each slot with varying values of Cμ. In between each run and before changing AoA, the tunnel was turned off to prevent unnecessary loading on the motor. For each case, data was taken between 0 and 10 degrees AoA:

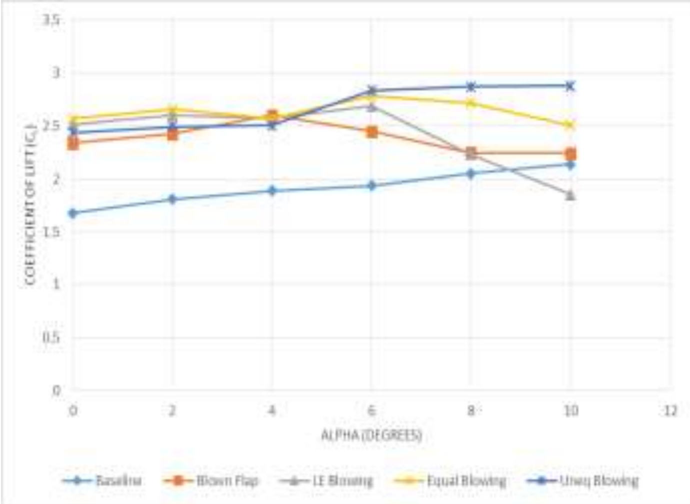

Figure 1. Lift vs. AoA for all 5 cases (q∞ =30 pa)

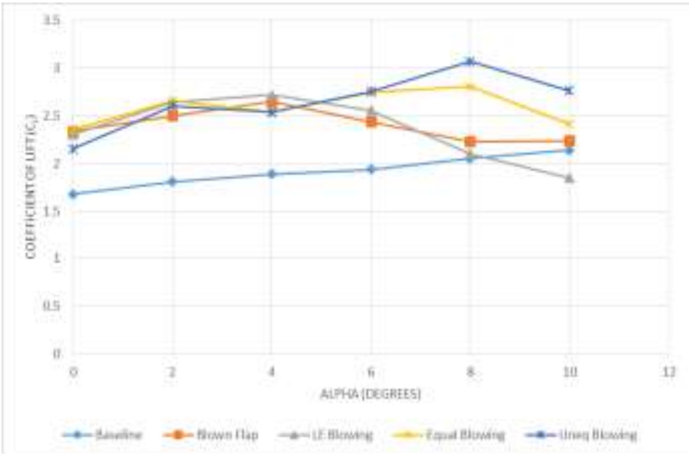

Figure 2. Lift vs. AoA for all 5 cases (q∞ =20 pa)

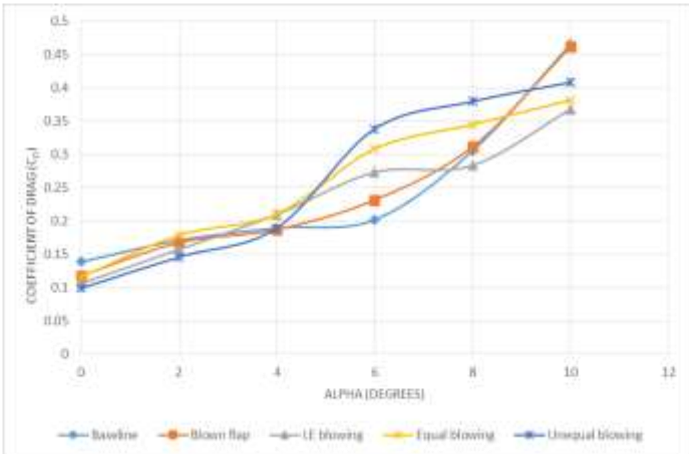

Figure 3. Drag vs. angle of attack for all 5 cases (q∞ =30 pa)

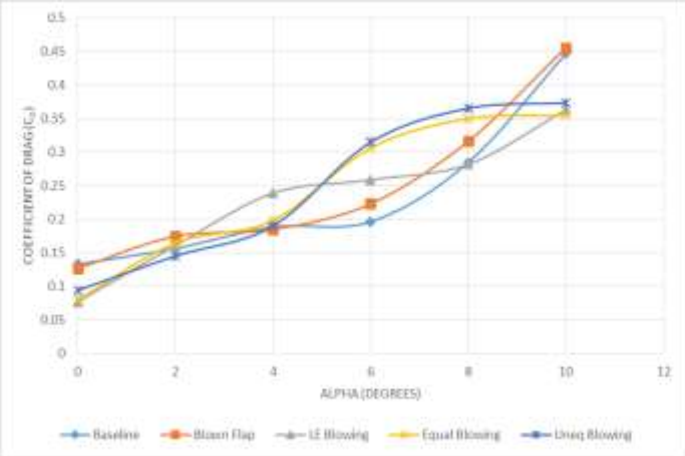

Figure 4. Drag vs. angle of attack for all 5 cases (q∞ =20 pa)

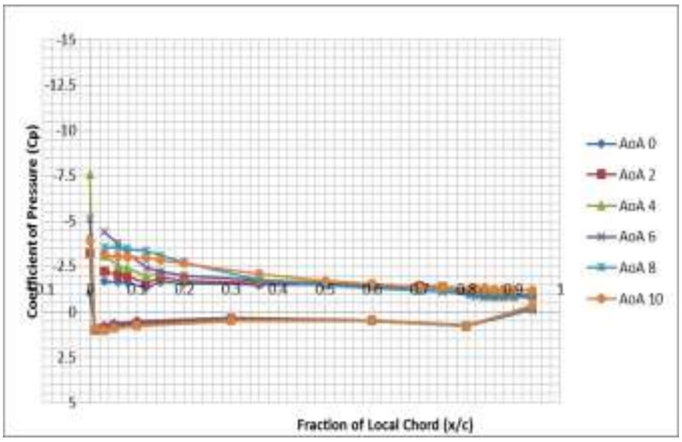

Figure 5. Pressure distributions for Baseline case (q∞ = 30pa, AoA0-10)

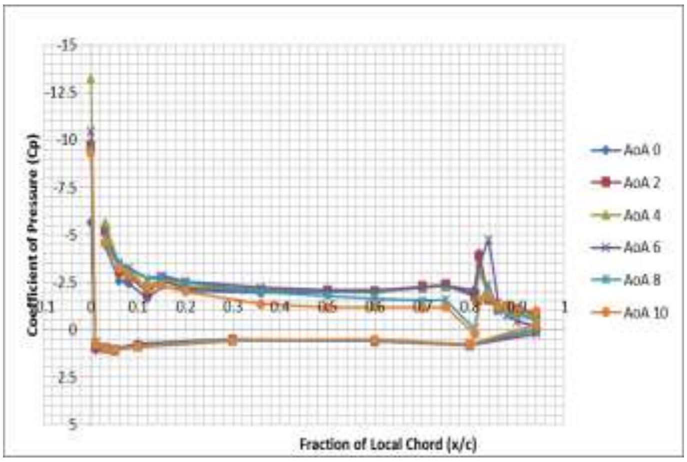

Figure 6. Pressure distributions for Blown Flap case (q∞ = 30pa, AoA 0-10)

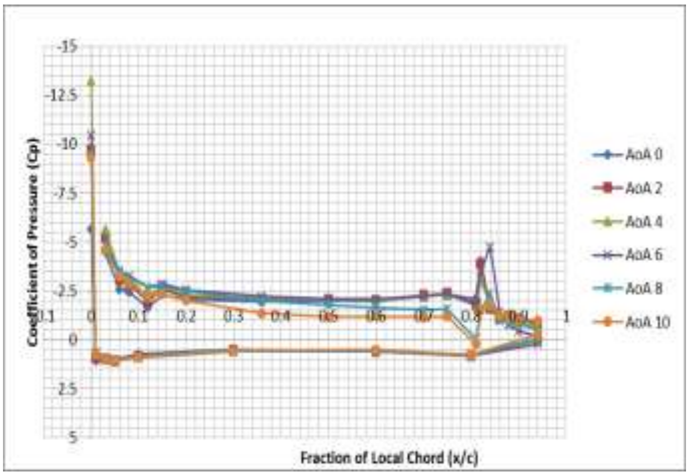

Figure 7. Pressure distributions for LE Blowing case (q∞ = 30pa, AoA0-10)

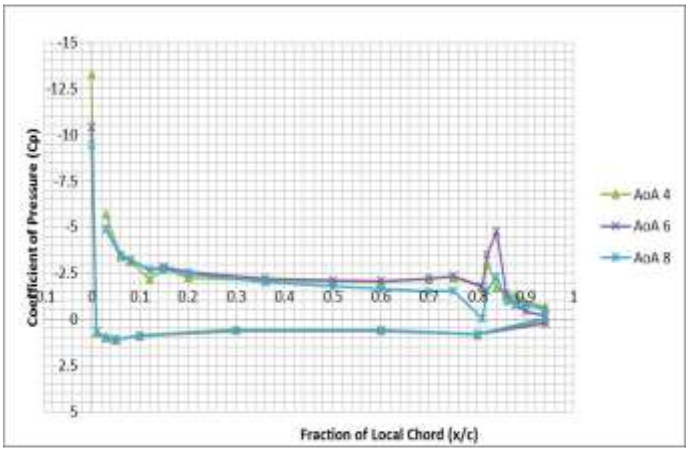

Figure 8. Pressure distributions for LE blowing case, q∞= 30 pa (AoA 4-8)

CONCLUSION

The study focused on four steady blowing AFC cases from different slot locations and varying C_μ. Each of the four cases was able to increase lift; the unequal blowing case was able to achieve the highest gain in lift, 31% and 43% over the baseline for q∞ = 30psf and 20 psf, respectively. These results are encouraging, but are under anticipated values. In comparison, both the studies by Burnazzi (2013) and Bright (2012) achieved approximately 100% increase in lift. After investigating the pressure distributions from each case, it is evident that the test were very successful in generating high-lift around the leading edge, but separation occurs over the deflected flap.

REFERENCES

[1] Abbas, A., de Vicente, J., & Valero, E. (2012). Aerodynamic technologies to improve aircraft performance. *Aerospace Science and Technology*

[2] Bright, M. M., Korntheuer, A., Komadina, S., & Lin, J. C. (2012). Development of advanced high lift leading edge technology for laminar flow wings.

[3] Collis, S. S., Joslin, R. D., Seifert, A., & Theofilis, V. (2004). Issues in active flow control: theory, control, simulation, and experiment. *Progress in Aerospace Sciences.*

[4]Greenblatt, D., & Wygnanski, I. J. (2000). The control of flow separation by periodic excitation. *Progress in Aerospace Sciences.*

[5] Joslin, R. D., & Miller, D. N. (2009). *Fundamentals and applications of modern flow control*. Reston, VA: American Institute of Aeronautics and Astronautics.

[6] Jabbal, M., Liddle, S. C., & Crowther, W. J. (2010). Active flow control systems: Architectures for civil transport aircraft. *Journal of Aircraft*.

BIOGRAPHIES

Abhishek Rai, M.tech Student at PM College of Engineering, Sonipat, Haryana.

Er. Rahul Malik, completed B.Tech (Mechanical Engineering) from Maharshi Dayanand University, Rohtak in 2008 and M.Tech. (Specialization: Design) from Deenbandhu Chotu Ram University of Science and Technology, Murthal Sonipat in 2011. Currently working as an Head of Department (Mechanical Engineering) with PM College of Engineering, Sonipat, Haryana, India.