American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-4, Issue-1, pp-103-112
www.ajer.org
Research Paper Open Access

Enhancement of Aerodynamic Properties of an Airfoil by Co Flow Jet (CFJ) Flow

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ABSTRACT : *A wind tunnel test of baseline airfoil NACA 0015 and CFJ0015-065-065 model was conducted in the Wind tunnel wall test section of the Department of Mechanical Engineering at KUET, Bangladesh. The primary goal of the test was to investigate and compare the airfoil aerodynamic characteristics over a wide range of Angle of Attack (AOA) and with a wind tunnel free stream velocity of 12m/s , Re = 1.89×10^{5}, C_μ = 0.07 at M = 0.030 kg/s. The CFJ increases $C_{L\ max}$ by 82.5% and decreases Drag by 16.5% at Stall AOA when compared to the baseline air foil. The main goal is to proof that Flow separation is controlled and delayed with the use of CFJ Technique over an Airfoil.*

KEYWORDS*- wind tunnel test, Base line airfoil NACA 0015 and CFJ0015-065-065, Aerodynamic Characteristics, AOA, Reynolds Number, Flow separation control.*

I. INTRODUCTION

Flow control is playing a more and more important role to improve aircraft aerodynamic Performance [1][2]. To enhance lift and suppress separation, various flow control techniques have been used including rotating cylinder at leading and trailing edge[3][4][2], circulation control using tangential blowing at leading edge and trailing edge[5][6] [7][8][9][10], multi-element airfoils[11][12],pulsed jet separation control[13][14][15], etc. The different flow control methods have their different features. This thesis paper applies the new flow control technique of the co-flow jet cascade to high lift airfoil since both experience severe adverse pressure gradient at high loading. Unlike the conventional circulation control airfoils, for which the jets are mostly implemented at leading and trailing edge, the co-flow jet (CFJ) airfoil is implemented on the majority area of the suction surface of the airfoil. The co-flow jet airfoil is to open a long slot on the airfoil suction surface from near leading edge to near trailing edge. A high energy jet is then injected near the leading edge tangentially and the same amount of mass flow is sucked away near the trailing edge. The turbulent shear layer between the main flow and the jet causes a strong turbulence diffusion and mixing, which enhance the lateral transport of energy and allow the main flow to overcome the severe adverse pressure gradient and stay attached at high angle of attack (AOA)[16][17][18]. An active Flow separation control technique such as CFJ technique has several advantages over conventional flow control techniques. Here The main objectives of this thesis paper is to investigate the performance of airfoil characteristics by co-flow jet (CFJ) flow control technique in order to reduce the Drag coefficient, increase the Lift coefficient, and control the Flow separation over air foil geometry.

II. MODEL DESIGN AND MODEL CONSTRUCTION

Model overview:

Co-flow jet airfoil (CFJ) geometry is slightly different from the conventional airfoil. Firstly baseline airfoil NACA 0015 has the as usual conventional nomenclature which shown in Fig.1.But The co-flow jet airfoils are defined using the following convention: CFJ4dig-INJ-SUC, where 4dig is the same as NACA4 digit convention, INJ is replaced by the percentage of the injection slot size to the chord length and SUC is replaced by the percentage of the suction slot size to the chord length. For example, the CFJ0015-065-065 airfoil has an injection slot height of 6.5% of the chord and a suction slot height of 6.5 % of the chord. The suction surface shape is a downward translation of the portion of the original suction surface between the injection and suction slot. The injection and suction slot are located at 6.72% and 88.72% of the chord from the leading edge [19]. The slot faces are normal to the suction surface to make the jet tangential to the main flow. The cambered airfoil and CFJ0015-065-065 airfoil are tested in the wind tunnel tests.

Base line Airfoil NACA 0015 model design and Construction:

Designing NACA 0015 model by using surface profile equations.

For NACA 0015, Chord of the airfoil, c= 0.3 m

Maximum wing thickness, t= last two digit × % c=15×$\frac{1}{100}$×0.3 =0.04

Maximum camber, m= first digit × % c = 0 × $\frac{1}{100}$ × 0 = 0

Distance from leading edge to maximum wing thickness, p= second digit×10% c

= 0×$\frac{10}{100}$ × 0.3 = 0

Maximum wing thickness,

$$y_t = t \times (1.4845\sqrt{x} - 0.6300\,x - 1.7580\,x^2 + 1.4215\,x^3 - 0.5075\,x^4)$$

The mean chamber line,

$y_c = \frac{m}{p^2}(2px - x^2)$ For 0 < x < p

And, $\frac{dy_c}{dx} = \frac{2m}{p^2}(p - m)$

$y_c = \frac{m}{(1-p)^2}[1 - 2p + 2px - x^2]$ For p ≤ x ≤ c

And, $\frac{dy_c}{dx} = \frac{2m}{(1-p)^2}(p - x)$

Now, coding a C-program including above equation and the upper and lower surface equation and after compiling this program, a set of data were measured for the desired airfoil [7]. Plotting these data on any data plotting software gives the profile like below:

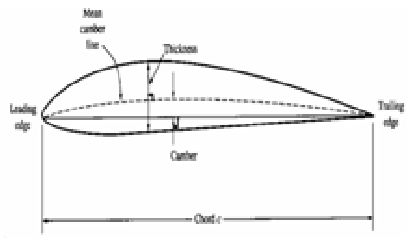


Fig.1: Airfoil nomenclature

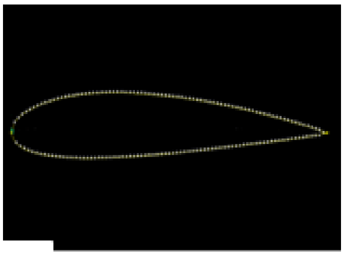


Fig.2: NACA 0015 airfoil profile

Fig.3: 3D Model view of Airfoil NACA 0015

CFJ Airfoil design and Construction:

The selected CFJ for performance investigation is CFJ 0015-065-065. That means it has suction and injection slot of length 6.5% of chord. The distance of the slot from the leading edge of the airfoil is taken as 6.72% of chord for injection slot and 88.62% of chord for suction slot. The profile of CFJ is simple obtained from the conventional equations for NACA 4 digit airfoil as discussed earlier with some simple modification in the equation of upper and lower surface. This modification is given below.

The equation of upper surface:

For x ≤0.0672 and x ≥ 0.8872 $x_u = x - y_t(x)\sin\theta$

And, $y_u = y_c + y_t(x)\cos\theta$

For 0.0672 ≤ x ≤ 0.8872 $x_u = x - y_t(x)\sin\theta$

And, $y_u = y_c + y_t(x)\cos\theta - 0.0065$

Others equations are remain same. The C-program for generate data for CFJ is attached last. The obtained CFJ 0015-065-065 airfoil profile is given below.

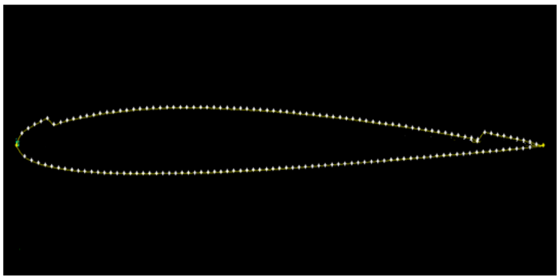


Fig. 4: CFJ 0015-065-065 airfoil.

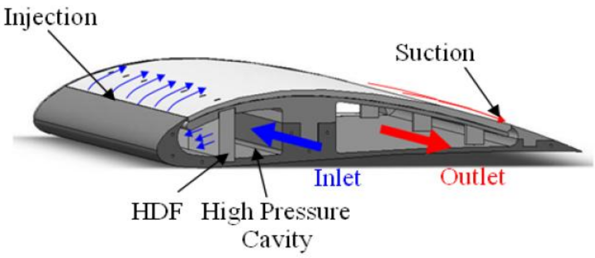


Fig.5: 3-D cross section of CFJ airfoil

III. EXPERIMENTAL SETUP AND PROCEDURE

This schematic diagram shows the overall setup of wind tunnel in Aerodynamics lab of Mechanical Engineering Department at KUET, Bangladesh.

Experimental Setup:

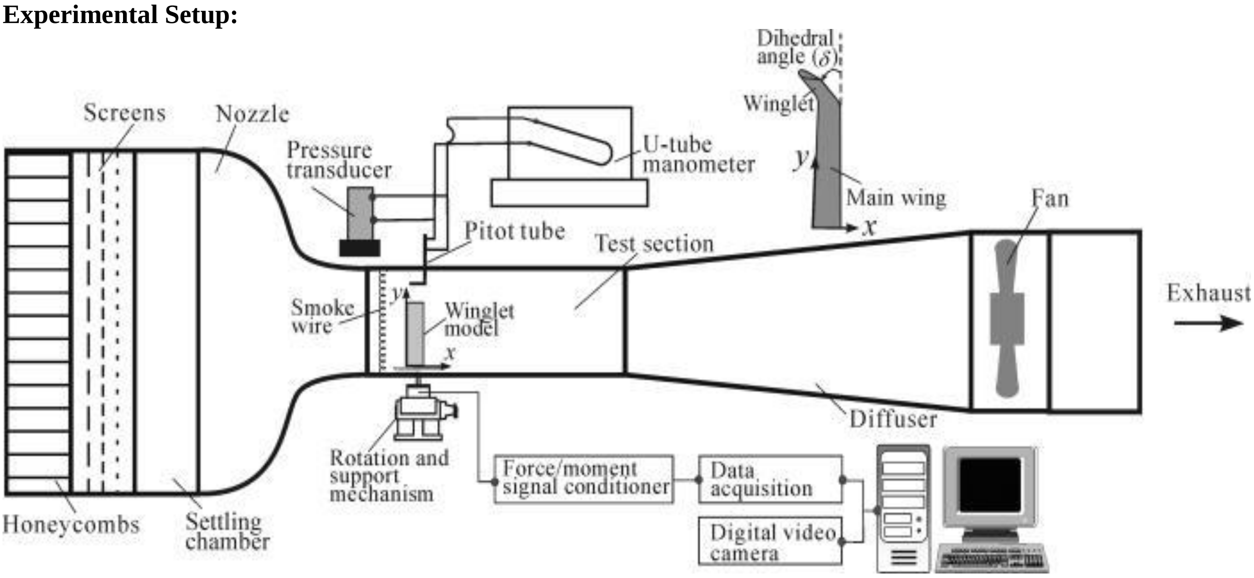
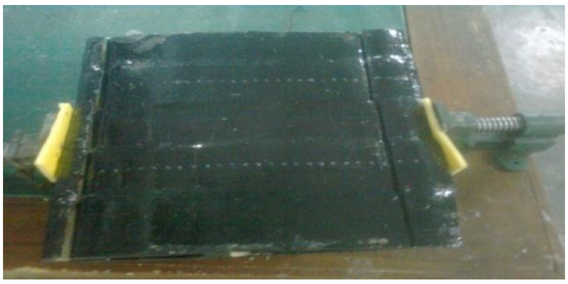


Figure 6: Schematic view of experimental setup

An Aerolab wind tunnel having tested section geometry of 1m x 1m and has an operating speed from 0-40 m/s (0-145 miles per hour). This is made possible by a 10-horse power motor that drives a fan. The applied free stream velocity is 12 m/s.



Constructed CFJ0015-065-065 Aerofoil

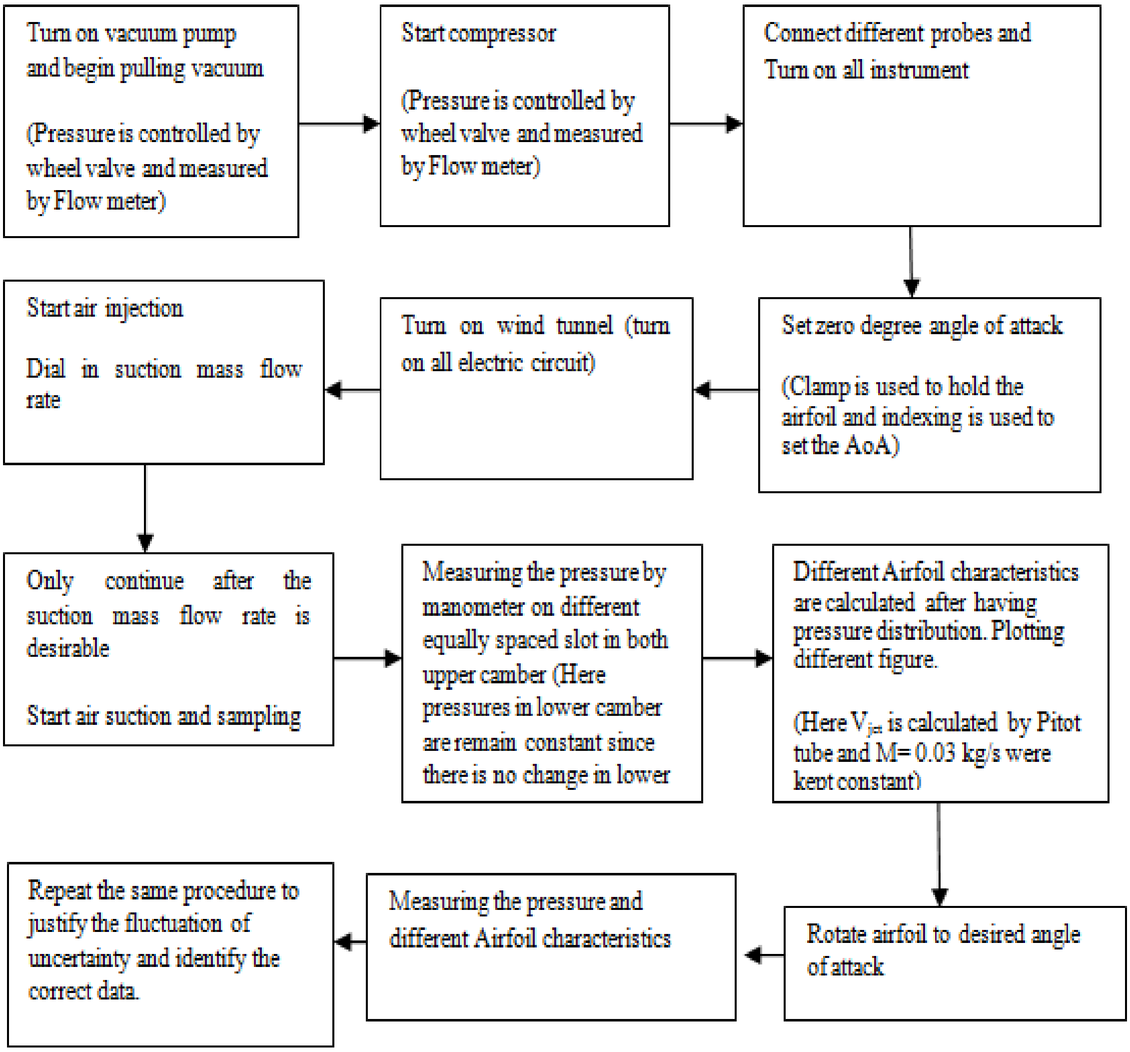
Snapshot of CFJ aerofoil placed under wind tunnel test

CFJ aerofoil connected with high pressure compressor line

Snapshot of high pressure compressor and low pressure vacuum pump

Fig.7: Photograph of experimental setup during the wind tunnel test.

Working procedure:



IV. FIGURES AND TABLES

After calculating the total pressure and temperature in injection slot, the value of Mach number were measured. Once the Mach number is found then the values of Injection velocity is calculated for different AoA and its reach to 24 m/s at M= 0.03 kg/s and it shows a steady trend over 20 to 30 deg AoA.

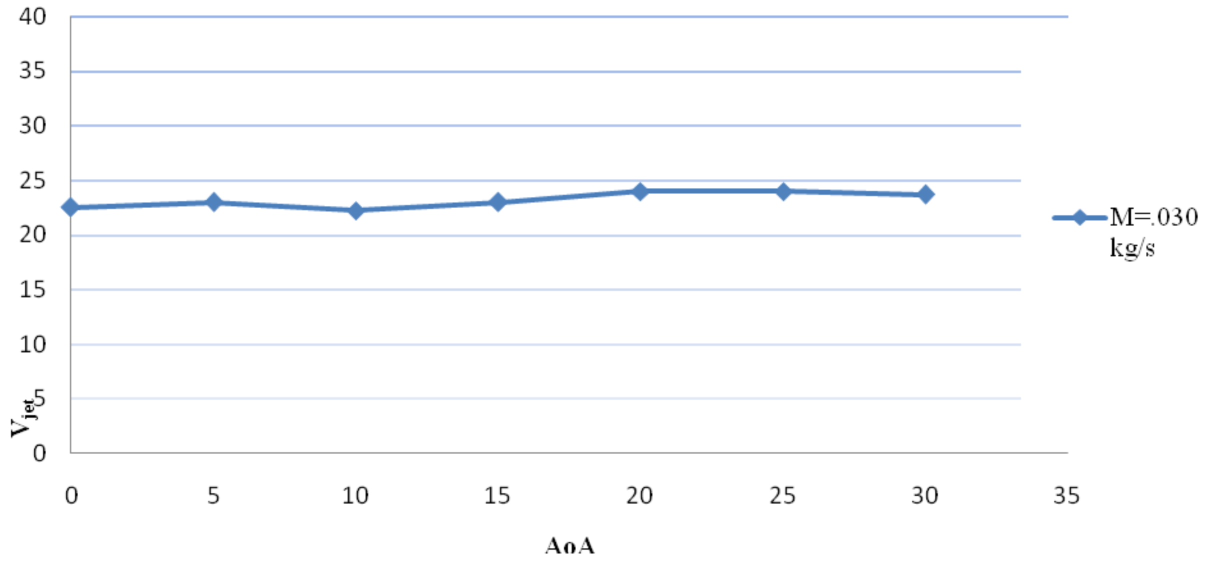


Fig. 08: Graphical Representation of Injection Velocity with AOA at M= 0.30 kg/s.

The value Jet Momentum Coefficient is calculated with the help of V_{jet} , mass flow rate, free stream velocity and Density. The value of C_μ is 0.07 at stall AoA at M = 0.030 kg/s.

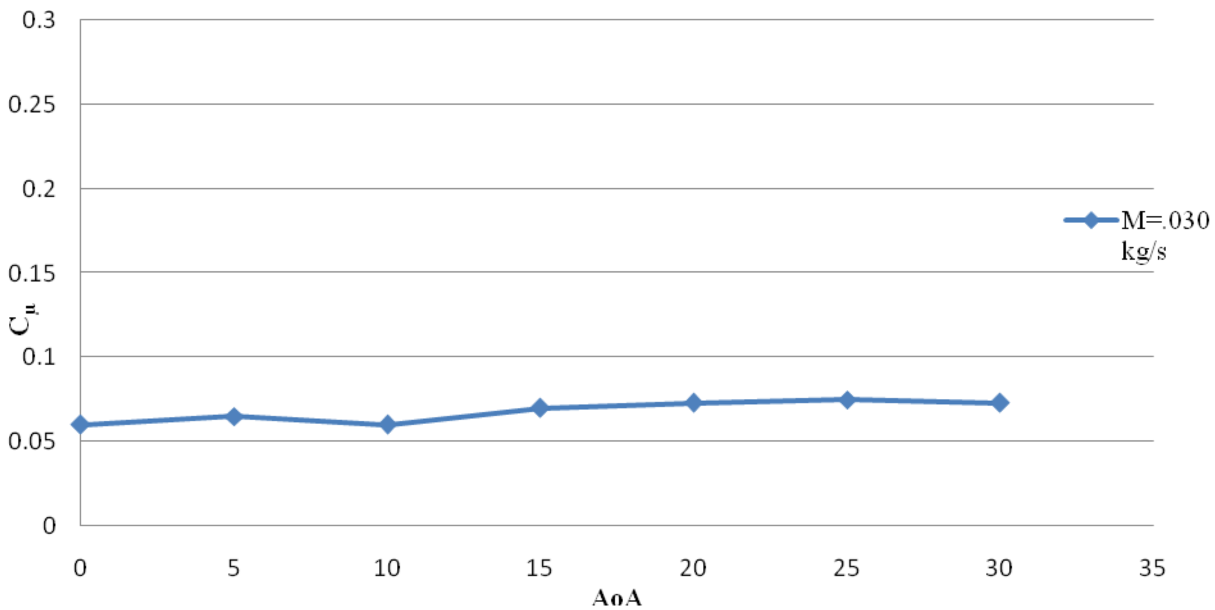


Fig. 09: Graphical Representation of C_μ with AoA at M = 0.30 kg/s

The measured value of $-C_p$ from pressure distribution along the upper camber and lower camber on both Airfoil with respect to different chord length position at different AoA are given below:

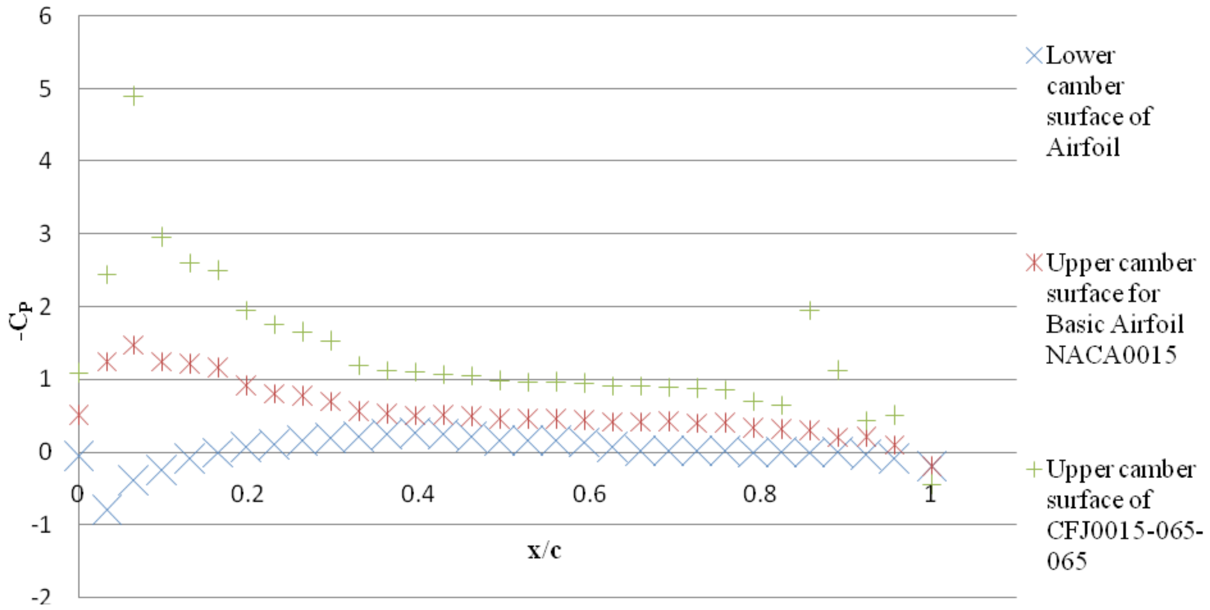


Fig. 10: Graphical Representation of -C_p with x/c at AoA= 05deg.

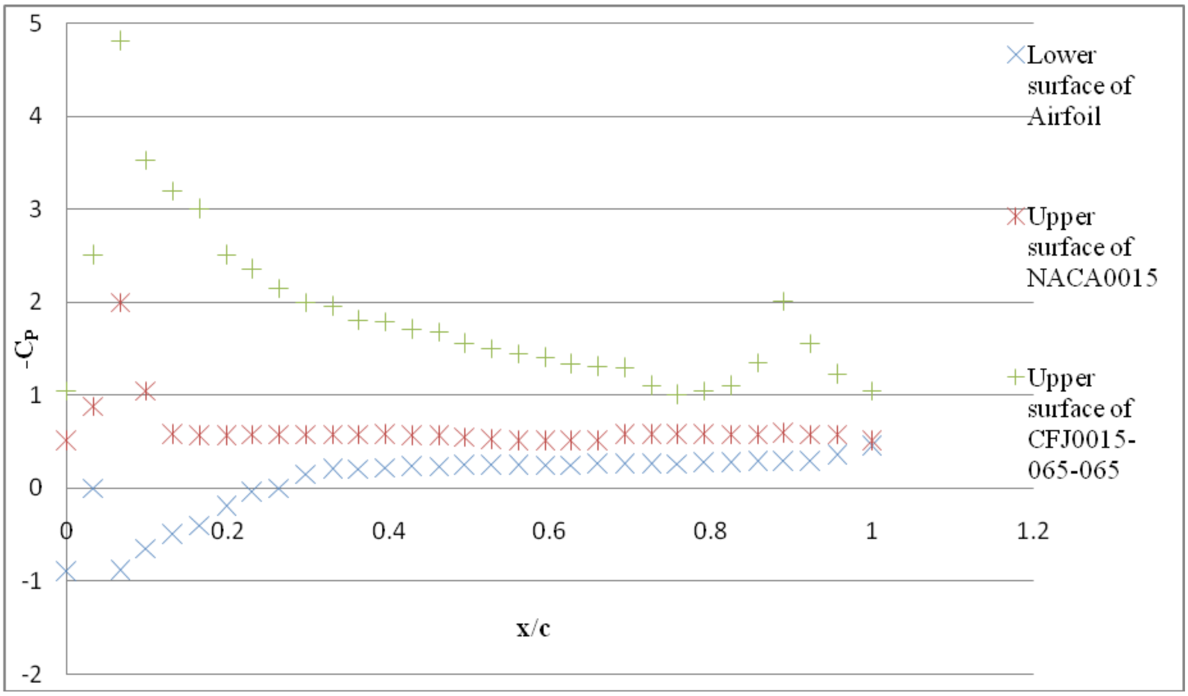


Fig. 11: Graphical Representation of -C_p with x/c at AoA= 12deg.

It was seen that at AOA = 05,12 deg the CFJ0015-065-065 aerofoil shows the steady ,smooth attached boundary layer over aerofoil geometry since the value of –Cp is quiet smooth. But for Baseline Aerofoil NACA 0015 it is also seen that at AOA = 12deg, the stall is occurred and Flow separation is start here and after that lift is reduced gradually and drag is increased bit by bit.

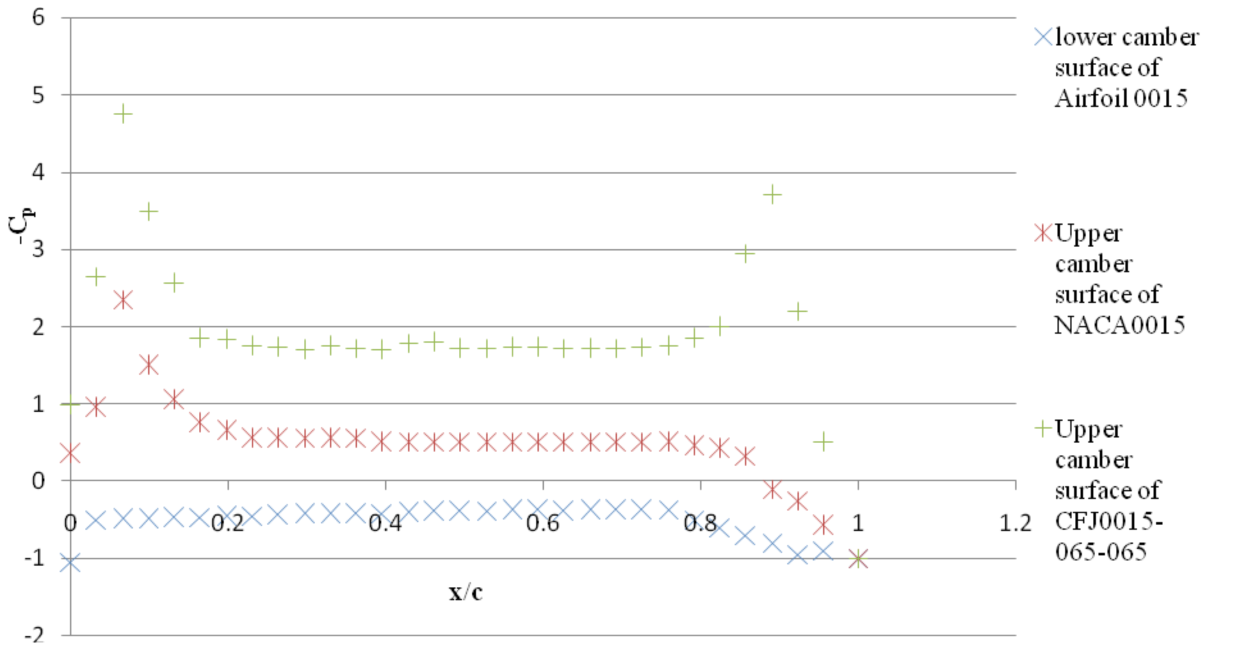


Fig. 12: Graphical Representation of $-C_p$ with x/c at AoA= 20deg.

It was seen that at AOA =20 deg. The value of –Cp is shows some abrupt changes especially in suction slot of CFJ aerofoil i.e. 20 deg. is the stall margin for CFJ0015-065-065 and after that flow is detached from upper camber surface. But in CFJ aerofoil flow is delayed to separate until 20 deg. AOA where it was starts at 12 deg AOA in case of baseline airfoil.

At C_μ =0.07, Re=1.89 × 10^5 the values of C_l for both Airfoil geometry with different AoA are given below:

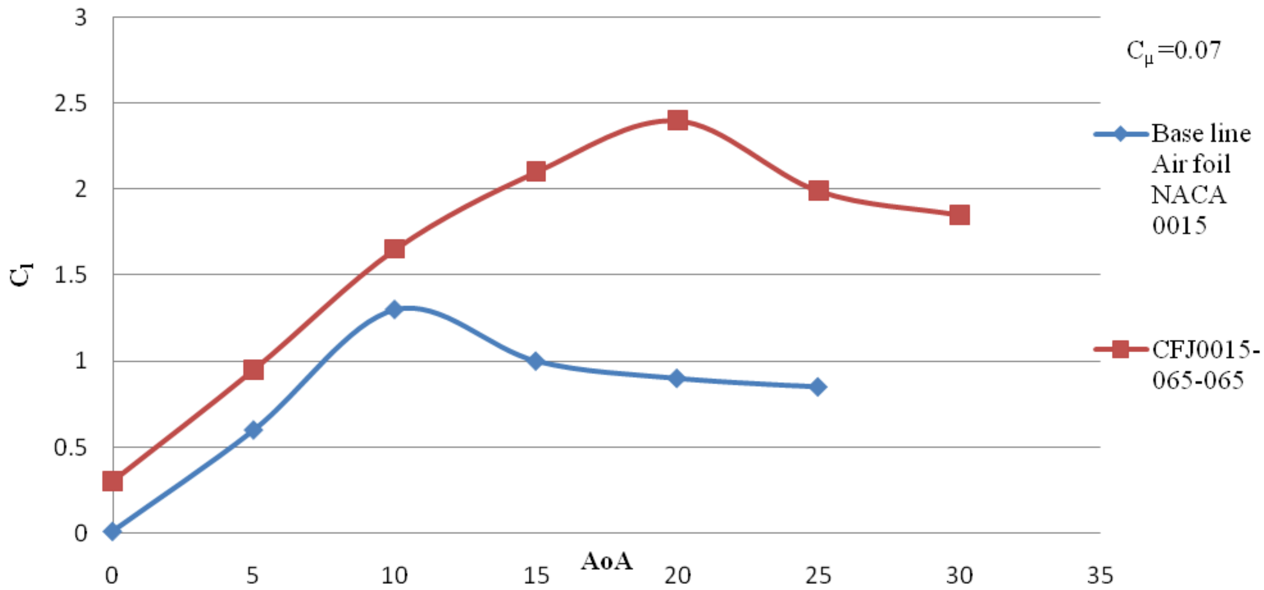


Fig. 13: Graphical Representation of Lift coefficient with angle of attack for both CFJ0015-065-065 and Baseline Airfoil at C_μ =0.07 and Re=1.89 × 10^5.

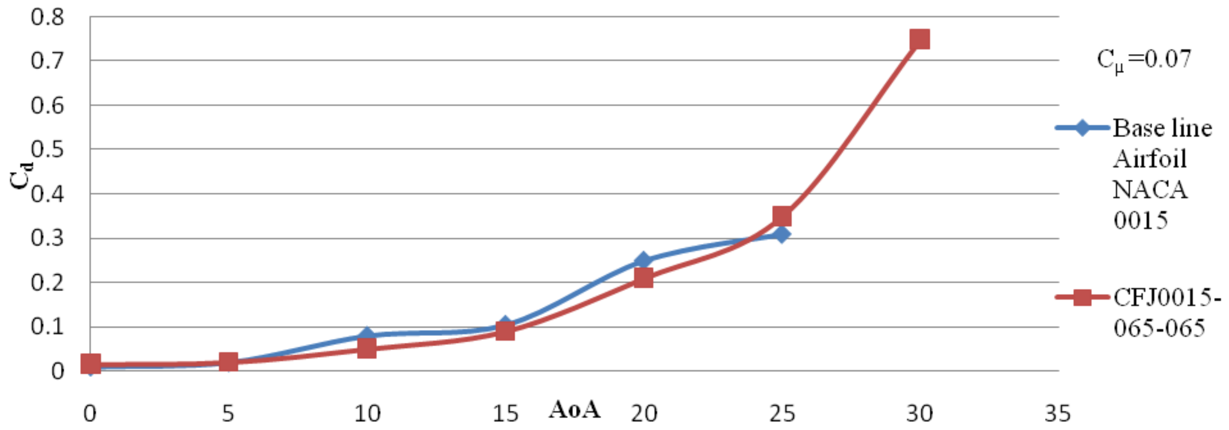


Fig. 14: Graphical Representation of Drag coefficient with angle of attack for both CFJ0015-065-065 and Baseline Airfoil at C_μ =0.07 and Re=1.89 × 10^5

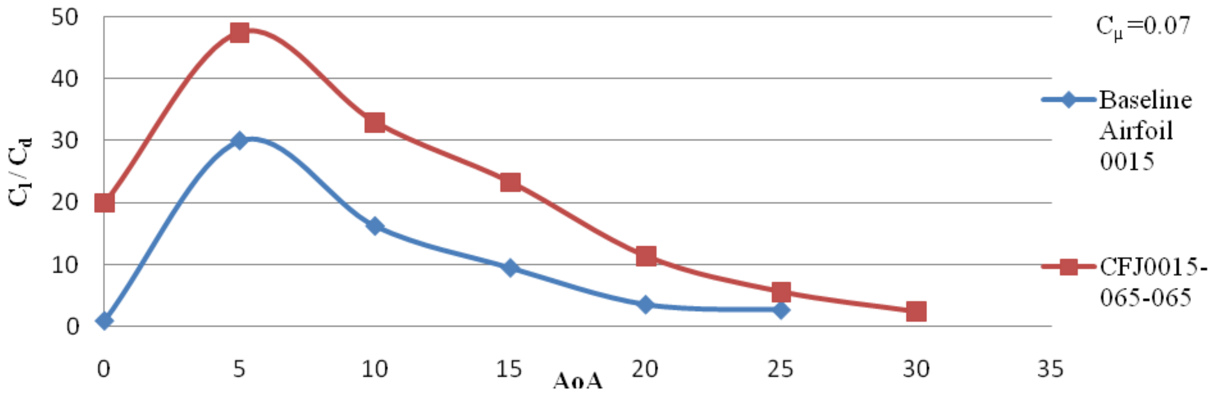


Fig.15: The change of C_l/ C_d with AoA for both CFJ0015-065-065.

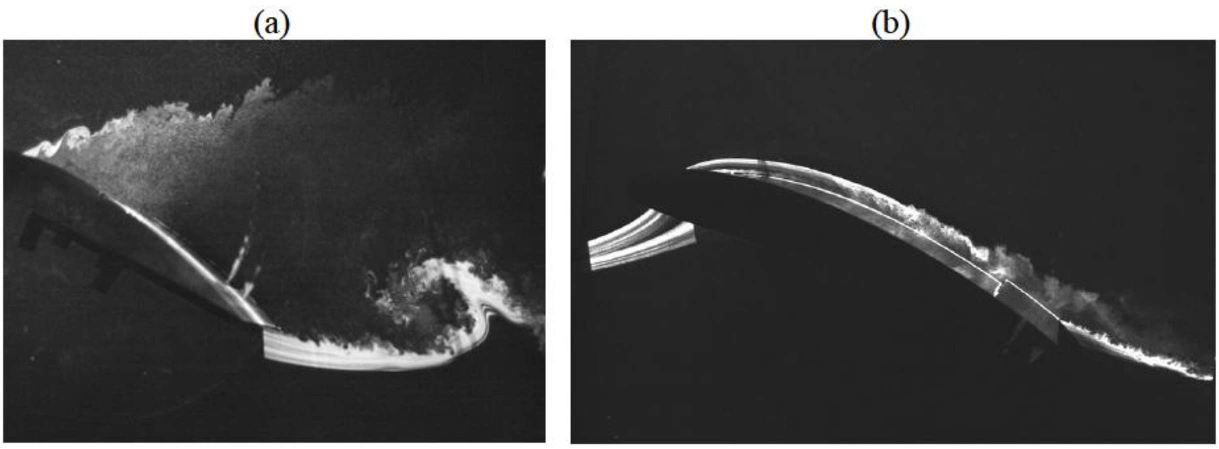


Fig.16: Smoke Flow Visualization for (a) Baseline airfoil NACA 0015 at AOA = 15 deg. and (b) CFJ0015-065-065 (C_μ =0.07) at AOA=20^o deg.

V. CONCLUSION

The Following conclusion is drawn from this research paper:

Aerodynamics characteristics	CFJ0015-065-065	Baseline Airfoil NACA0015	Remarks : considering the effect of using CFJ technique over base line aerofoil
Free stream velocity	12 m/s	12 m/s	---
Mass Flow Rate	0.030 kg/s		---
Stall AoA	20 deg	12 deg	Stall angle improved
V_{jet}	24 m/s		---
C_{μ}	0.07		----
$C_{l\ max}$	2.45	1.35	C_l Improved
Lift Improvement Drag Reduction	82.5% 16.7% (compared with Baseline Airfoil)		Both characteristics is improved
$C_{d\ max}$	0.20 at Stall AoA	0.09 at Stall AoA	Considerably low
C_l/C_d Vs. AoA	47	30	Improved
Flow separation delay time	Improved since stall AOA is increased	As usual	Improved

VI. ACKNOWLEDGEMENTS

The author is profoundly indebted to Dr. Mohammad Mashud, Professor and Former Head, Department of Mechanical Engineering, Khulna University of Engineering & Technology, Bangladesh, for his proper guidance, inspiration, suggestion and all kinds of supports in performing and completing the dissertation works in time.

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