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COMPARISON BETWEEN PARALLEL AND PERPENDICULAR SUCTION SLOT ON CO-FLOW JET AIRFOIL

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Abstract — This research paper explores the influence of co-flow jets on lift & drag generation at different angles of attack as well as comparison between perpendicular and parallel slot suction inlet. Co-flow jet technology, a method that introduces high-velocity air streams parallel to the primary airflow, has shown promising results in enhancing lift and maneuverability in various aerospace applications. The study aims to elucidate the relationship between different angles of attack and lift augmentation using co-flow jets, shedding light on its potential applications in aircraft design and performance enhancement.

Keywords: *Co-Flow Jet, Lift Augmentation, Aerodynamics, Aerospace Engineering*

Nomenclature: ***Cl : Coefficient of Lift***

Cd : Coefficient of Drag

α : Angle of Attack

CFJ : Co Flow Jet

CFD : Computational Fluid Dynamics

I. INTRODUCTION

Co-flow jet airfoil is a type of airfoil design that incorporates a co-flow jet (CFJ) propulsion system. This system involves the injection of high-speed air through the leading edge of the airfoil, where it flows parallel to the surface of the airfoil in the same direction as the free stream airflow. This co-flowing jet of air helps improve the aerodynamic performance of the airfoil in various ways.

How Co-Flow Jet Airfoil Works:

1. Jet Injection:

High-speed air is injected through slots or openings at the leading edge of the airfoil. This injected air flows parallel to the surface of the airfoil.

2. Co-Flowing Stream:

The injected air flows along the surface of the airfoil in the same direction as the free stream airflow. This co-flowing stream of air alters the boundary layer characteristics on the airfoil's surface.

3. Boundary Layer Control:

By injecting high-speed air parallel to the airfoil surface, Co-flowing jets assist in boundary layer management. The thin layer of air next to the airfoil surface, where viscous effects are prominent, is known as the boundary layer. By manipulating the boundary layer, the co-flow jet can delay boundary layer separation, reduce drag, and improve lift.

4. Lift Enhancement:

The co-flow jet enhances the lift characteristics of the airfoil by energizing the boundary layer, reducing flow separation, and preventing stall at higher angles of attack. This is especially beneficial for aircraft during takeoff and landing, where high lift and good control are crucial.

5. Drag Reduction:

By controlling the boundary layer and delaying flow separation, the co-flow jet airfoil can reduce drag, leading to increased efficiency and fuel savings for aircraft.

6. Maneuverability:

Co-flow jet airfoils can enhance the maneuverability of aircraft by providing better control authority, especially at high angles of attack. This is important for fighter aircraft and other high-performance vehicles.

SuperCritical Airfoil:

NASA SC(2)-0612 is a supercritical airfoil designed to delay the wave drag generated in the transonic speed range. It has a different structure as compared to conventional airfoil. The top surface of supercritical airfoil is flatter whereas the bottom surface has more curvature. Also, due to delay flow separation and lower amplitude of shockwaves, it provides a higher mechanical efficiency.

II. OBJECTIVE

This paper's main goal is to use a combination of experimental and numerical methods to thoroughly investigate the aerodynamic properties and performance improvements of a co-flow jet airfoil. The research specifically seeks to accomplish the following goals:

1. Analyze the impact of co-flow jet characteristics on the airfoil's aerodynamic performance like production of lift and reduction of drag.
2. To compare visual representations of the flow behavior between baseline and CFJ airfoil by locating vortices, separation points, and other important aerodynamic phenomena.
3. Compare the parallel slot & perpendicular slot.

III. Literature Review

Bertrand Dano, Gecheng Zhaet. al.[1] says that When you make the injection jet size smaller and use more jets, it makes the pumping pressure higher and uses more power. According to the findings in this study, the DCFJ airfoil concept could be a significant part of improving how airplanes and rotorcraft work together in the future.

Craig Paxton and Alexis Palewicz et. al.[2] They talk About Result that An airfoil typically produces more lift, has a higher speed at the front edge, and a further back stagnation point when it has more suction at the leading edge. This extra suction creates a forward pressure force, which either helps produce thrust or reduces drag.

Haolin ZHI, Zhenhao ZHU et. al.[3] Says that increasing the suction slot angle will augment the reaction force and thus decrease the effective drag. Increasing the suction slot angle makes the cross-section of the suction tube more parallel to the tangential freestream and intuitively require more energy expenditure.

Alexis M. Lefebvre and Gecheng Zha et. al.[4] Study of Paper tells about the study shows that where the jets are placed and the angle of attack (AoA) affect how efficiently energy is used and how well the airfoil works. To make it work better, the jet should be positioned just after or slightly behind the point where the airfoil has the lowest pressure on its suction side. This helps by reducing the energy needed to pump air.

Ruochen Wang and Gecheng Zha et. al.[5] the study highlights the influence of various parameters on the aerodynamic performance of the CFJ-equipped NACA2412 airfoil and provides insights into optimizing lift, drag, and overall aerodynamic efficiency.

Xu-Dong Yang, Wei-Rong Jiang et. al.[6] the study examines how the Co-flow jet technique influences dynamic stall control, with numerical simulations revealing its ability to suppress stall and maintain flow attachment. The vortex layers created by CFJ contribute to these effects. Additionally, the study emphasizes the importance of careful jet momentum coefficient selection for achieving effective flow control.

Ge_Cheng Zha , Wei Gao et . al .[6] In this paper, the researchers used a method called "control volume analysis" to study how jets affect airfoils. They looked at two cases: one where jets blow air out and suck air in, and another where jets only blow air out. They also came up with a way to calculate the forces acting on the duct that affect how much lift and drag the airfoil generates. They used computer simulations based on a specific mathematical model to show how lift and drag come from different forces on the airfoil surface and from the forces in the jet duct.

Ge-Cheng Zha , Adam Wells et . al .[7] This research used computer simulations to explore a new idea. They found that with a special airfoil design and high-speed jets, it's possible to achieve more lift than what was previously thought achievable without considering air resistance. This happens because the fast jets create strong suction on the airfoil.

He-Yong Xu, Shi-LongXing .et. al .[8] In this study, the researchers systematically examine the use of co-flow jets with the NREL S809 airfoil. They perform simulations with different configurations, including one where the jet channel is turned off, to understand how co-flow jets impact the airfoil's aerodynamic properties. They also run simulations with co-flow jets at three different levels of jet momentum to see how it affects the overall aerodynamic performance and how key aerodynamic characteristics change with varying jet momentum.

IV. METHODOLOGY

1. Conventional Airfoil

2D CFD analysis of supercritical Airfoil at various angles of attack and depicting lift and drag characteristics using pressure, velocity, and turbulence contours, We use a NASA SC(2)-0612 supercritical airfoil, and the computational domain for the airfoil is height= 5000mm, length = 12500mm. There are 176277 nodes used in this. As seen in fig. 3, the airfoil models were initially prepared and then exported into ANSYS for fairfield and meshing. Here, the air was forced to flow at a steady 43 m/s while its density was measured at 1.225 kg/m3. The air had a temperature of 300K.

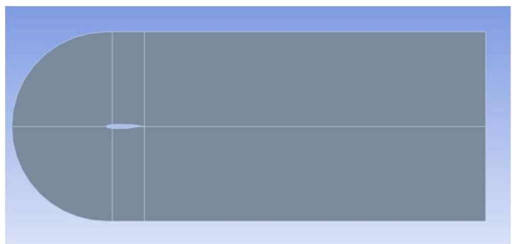

Fig1: Domain

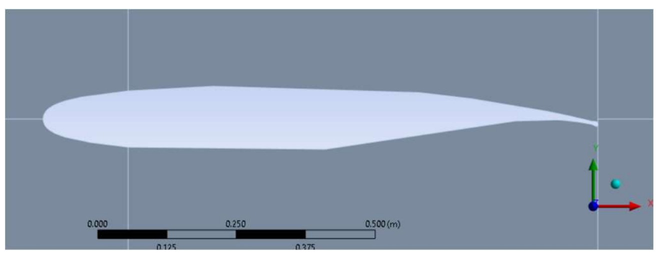

Fig2: NACA 20612 Airfoil

Meshing: Dividing computational domain into 6 parts to make meshing easier. Using Number of Divisions feature to maintain equal element sizes at airfoil and computational domain boundaries respectively. Face Meshing all the 6 faces to sync the mesh into Quadrilaterals for better solving of governing equations. Biasing some edges to generate Boundary layers near the airfoil surface and denser mesh surrounding the airfoil region.

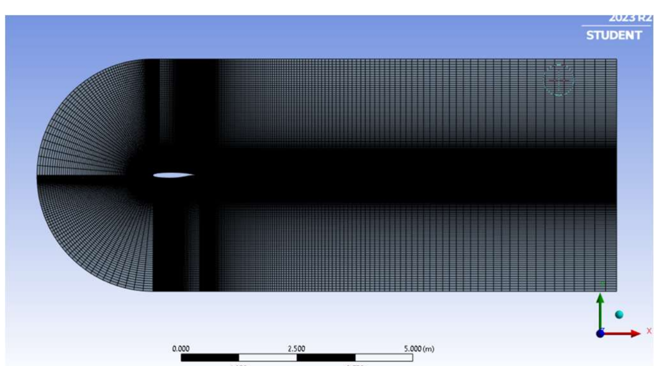

Fig3: Meshing

For the solving boundary condition the velocity that we use is 43 m/s. We tried on different angles of attack i.e. 0, 5, 15, 20, 25, 28, 30. The K-omega SST Turbulence Model & Coupled scheme that we used for the airfoil. It is a widely used two-equation RANS model in CFD. Overall this model strikes a balance between computational efficiency and accuracy, making it a popular choice in many engineering simulations.

In Table1, gives the values of cl & cd at a particular angle of attack. As you see the value of cd is continuously increasing as increasing the angle of attack.

α	Cl	Cd
0	0.307	0.016
5	0.704	0.050
10	1.084	0.112
15	1.492	0.197
20	1.616	0.290
25	1.878	0.417
28	1.760	0.749
30	1.323	0.752

Table1: cl cd values of conventional airfoil

2. Co-Flow Jet Airfoil

A high-velocity jet is injected tangentially in the direction of the main flow from an injection slot that is opened at the leading edge of the CFJ airfoil. This allows the main flow to overcome an unfavorable pressure gradient by transferring energy from the jet to it. A suction slot on the trailing edge, which pulls in the same amount of air as is injected from the injection slot, keeps the flow coupled.

We use a similar airfoil & give the same domain as use for the conventional airfoil. The cord length for the airfoil is 1000mm. Firstly the airfoil is made in the solidworks using the coordinates of NASA SC(2)-0612 airfoil as you can see in Fig 5. The same boundary conditions that were previously applied to conventional airfoils were utilized here: velocity = 43 m/s, air density = 1.225 kg/m3, and air temperature = 300 K. Additional boundary condition of mass flow rate = 0.1 kg/s was added.

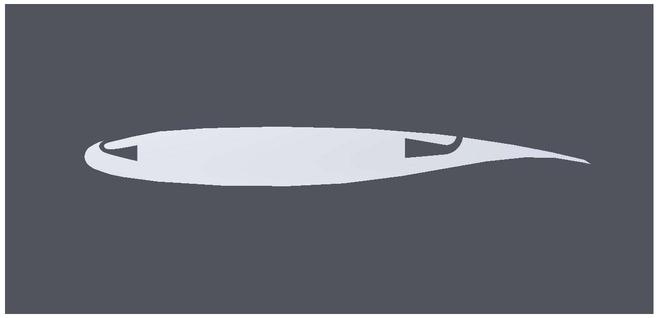

Fig4: NACA 20612 Airfoil

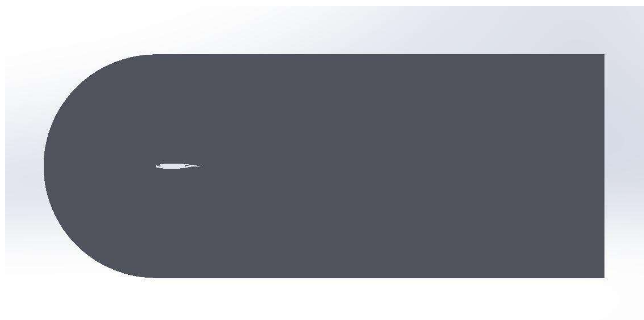

Fig5: Domain

Meshing: Computational domain divided into 7 parts to make meshing easier & effective. Face Meshing all the 6 faces to sync the mesh into Quadrilaterals for better solving of governing equations.There are 234607 nodes & 233310 elements are used for parallel slot & 249660 nodes, 247973 elements are used for perpendicular slot CFJ airfoil.. Biasing some edges to generate Boundary layers near the airfoil surface and denser mesh surrounding the airfoil region. Used a property of fine mesh for this airfoil.

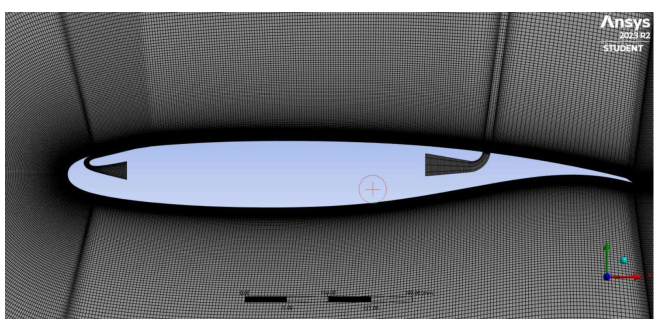

Fig6: Meshing for Parallel Slot CFJ airfoil

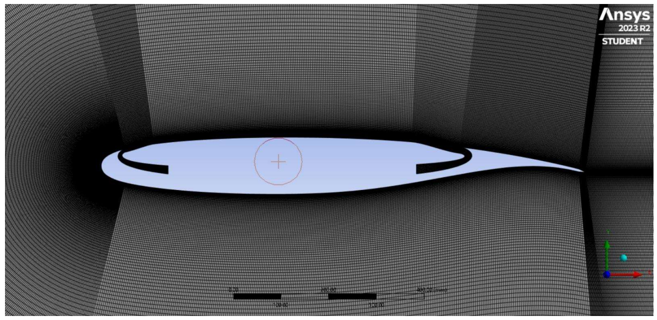

Fig6: Meshing for Perpendicular Slot CFJ airfoil

α	Cl	Cd
0	0.1922	0.0592
5	0.7488	0.0443
10	1.2929	0.01162
15	1.8127	-0.0362
20	2.302	-0.0949
25	2.776	-0.1528
28	3.0764	-0.0308
30	3.199	-0.0308
35	3.7073	-0.02419

Table2: Cl Cd values of co-flow jet airfoil of parallel slot

α	Cl	Cd
0	0.4005	0.00162
5	0.6111	-0.022
10	0.8115	-0.0633
15	0.9991	-0.1219
20	1.17	-0.1976
25	1.3307	-0.2927
28	1.4254	-0.3626
30	1.4754	-0.4102

Table3: Cl Cd values of co-flow jet airfoil perpendicular slot

Giving the boundary conditions & tired on different angles of attack as same used as before in conventional airfoil. The same equation is used as conventional airfoil i.e. K-epsilon Turbulence Model & Coupled scheme. In Table 2,3, add the values of Cl & Cd at a particular angle of attack of a parallel & perpendicular slot. .

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RESULTS & DISCUSSION

1. Results for Validation

As per [9] we validated the procedure implemented, by analyzing the same geometry for baseline as well as CFJ airfoil. Meshing parameters, Model and scheme used were the same along with all the boundary conditions. Overall computational error was under 6% for the values generated from our analysis and the values from [9]. The following graphs reflect the comparison made between the two.

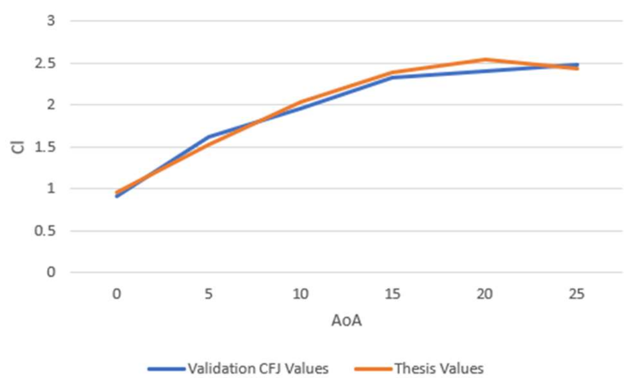

Fig7: Validation Values vs Thesis Values of Cl graph

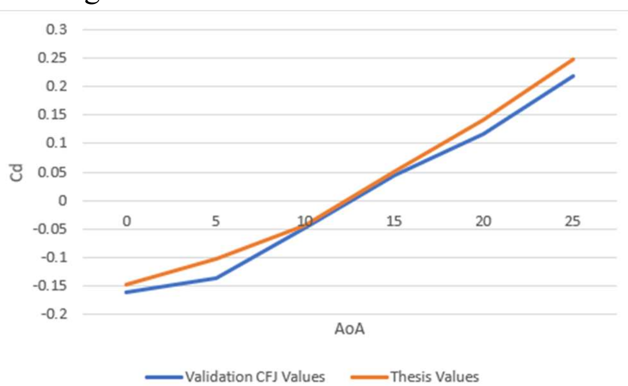

Fig8: Validation Values vs Thesis Values of Cd graph

2. Results for Conventional Airfoil

As you see in the fig 9, the graph of Cl vs AOA increases gradually but after one point decreases continuously. At 0 AoA, the value of cl is 0.317 is increasing till at 25 Aoa, cl is 1.878 & decreasing afterwards as you see at 28 Aoa, cl is 1.76 .In the fig 10, the graph of cd vs Aoa is continuously increasing. At 0 Aoa cd 0.016 is increasing continuously, the cd is 0.752 at 30 Aoa is higher than the lower Aoa. In graph cl vs cd, it increases continuously till one point then decreases. when we get the high value of cl/cd that means this airfoil is effective for take off.

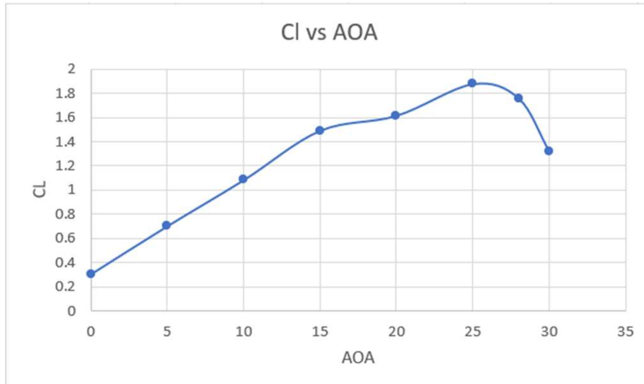

Fig9: CL vs AOA graph

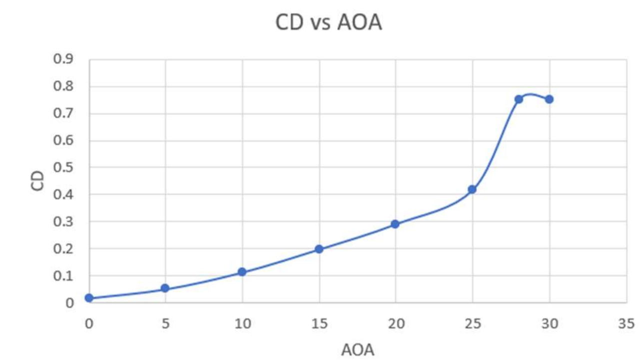

Fig10: Cd vs AOA

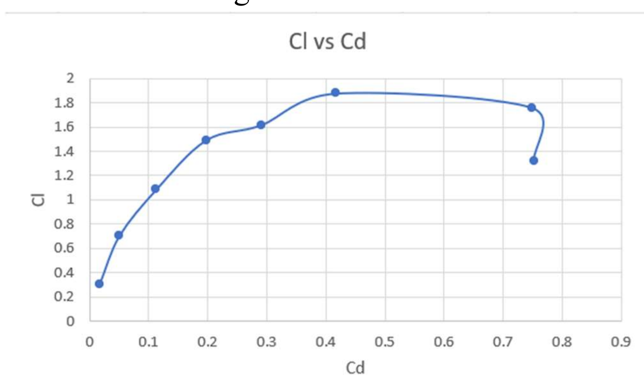

Fig 11: Cl vs Cd

3. Results for Co-flow jet airfoil

As you can see in the graph of Cl vs AoA, the value of Cl is continuously increasing when the angle of attack is increasing, which gives more lift force & it helps for the takeoff. The Cl of the parallel slot is higher than the perpendicular slot. In fig 13, Cd decreases continuously till one point then increases, when the value of Cd is negative which means this airfoil generates a thrust force.

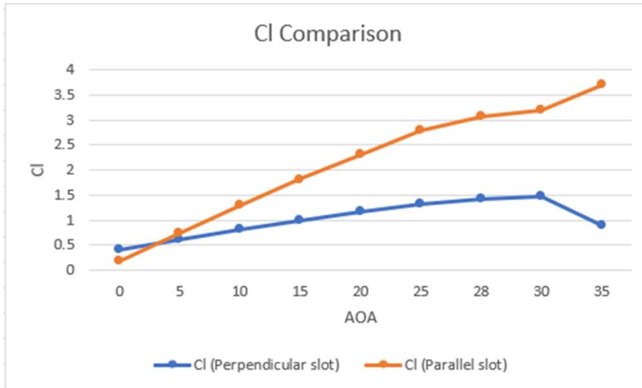

Fig12: Cl vs α

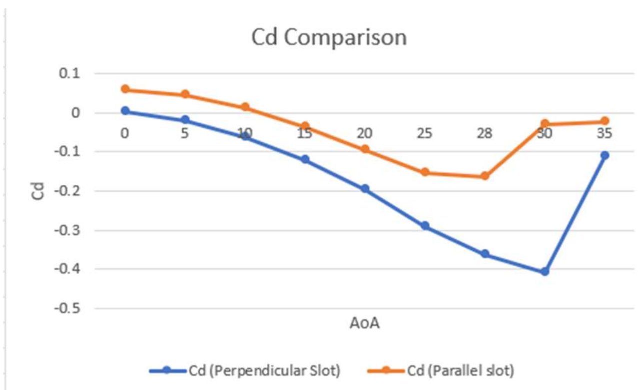

Fig13: Cd vs AoA

4. Comparison between Conventional & Co-Flow Jet Airfoil

In th fig 14, as we can see the graph of cl comparison between conventional & co-flow jet airfoil in this the *Cl* of co-flow-jet airfoil of parallel slot is continuously increasing as compared to conventional airfoil & co-flow-jet airfoil of perpendicular slot, it means that the co-flow jet airfoil(parallel slot) gives a high lift force & it is indicating a efficient airfoil. From fig 15, the *Cd* of co-flow jet airfoil(parallel & perpendicular slot) is continuously decreasing as compared to conventional airfoil, that's why the co-flow jet airfoil generates a thrust force when *Cd* is negative.

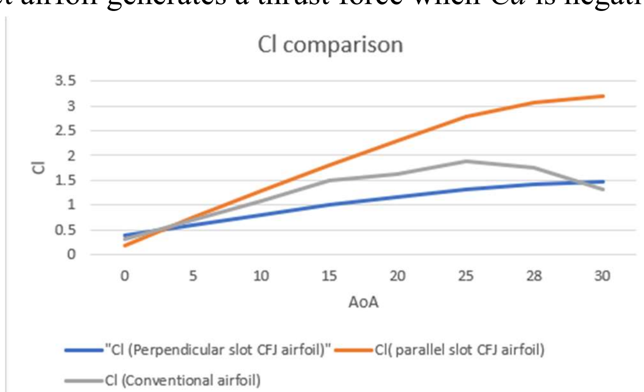

Fig14: Cl comparison of conventional & co-flow jet airfoil

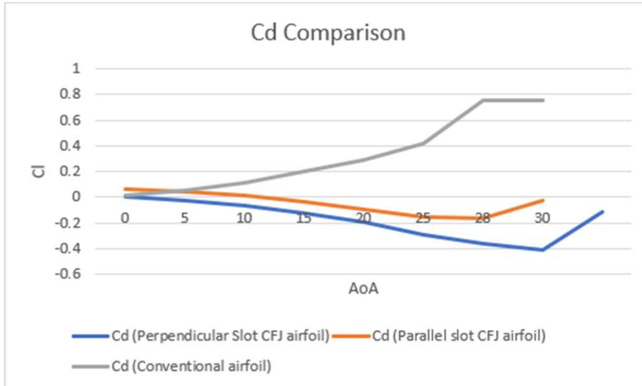

Fig15: Cd comparison of conventional & co-flow jet airfoil

V. CONCLUSION

The results from validation proved to be helpful in selecting the correct meshing parameters and CFD model for further analysis on NASA SC(2)-0612 airfoil. The k-omega Model along with the COUPLED Scheme is a right fit for this analysis by helping to converge the solution within limited iterations and saving computational time.

The comparison between conventional airfoils and co-flow jet airfoils reveals distinct advantages and limitations for each design. Conventional airfoils are well-established and widely used in various applications, offering predictable aerodynamic performance. They provide reliable lift and drag characteristics, making them suitable for many standard aerospace and industrial applications.

On the other hand, co-flow jet airfoils represent an innovative approach that leverages active flow control techniques to enhance aerodynamic performance. By injecting high-velocity jets of air at the trailing edge of the airfoil, co-flow jet airfoils can achieve superior lift and reduced drag, leading to enhanced overall efficiency.

Moreover, the parallel suction slot gives much better results than the perpendicular slot as seen from the graphs shown above. The values of Cl being significantly greater whereas the Cd value being very close to the perpendicular suction slot.

VI. ACKNOWLEDGEMENT

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