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*Original Article*

# Performance of Supercritical Aerofoil using the CO-Flow Jet

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***Abstract*** - *The paper aims to evaluate the behavior of a supercritical aerofoil at cruise conditions. The simulation study was performed using the pressure-based solver with the turbulence model of Spalart Allmaras at cruise conditions level. The obtained data proved that the supercritical aerofoil using the co-flow jet method increases the lift coefficient by 43% and lowers the drag by 3% compared to the regular aerofoil. The proposed work's novelty is the co-flow jet's design over a transonic aerofoil by introducing the design behind the mid of chord, which was used to evaluate and improve the performance through the jet velocity concept of a supercritical aerofoil. In traditional methods, the injection suction is positioned close to the leading and trailing edges, respectively. The suggested method can be used in commercial, Military, and wind turbine-related applications.*

***Keywords*** - *Aerofoil, Cruise, Coefficient of Drag, Coefficient of Lift, Jet velocity.*

## 1. Introduction

Recently, the number of air transport modes has been increasing rapidly worldwide. It creates a way to introduce high-speed aircraft with innovative designs to ensure the passengers' and aircraft's safety and security. Performance improvement can be achieved by controlling the boundary layer. It can be achieved using the active mechanism of injection and suction methods. This carried over the top surfaces of an aerofoil creates the attached flow, and the amount of air injected and removed is equal. The following portion provides detailed literature about the co-flow jet work carried out to date.

Liu, Z., & Zha, G. [1] numerically evaluate the Co-Flow Jet (CFJ) flow control technique to enhance the cruise efficiency of a transonic supercritical airfoil (RAE2822). Results show that CFJ improves lift by 25.6% and aerodynamic improves to 14.5% at peak efficiency, highlighting its potential for significant performance gains with minimal energy expenditure. Boling, J. S., & Zha, G [2] analyze CFJ 3D transonic wing using NASA SC(2)-1010 and RAE-2822 airfoils, demonstrating a 10% increase in cruise efficiency and lift coefficient at zero sweeps. Optimizing CFJ jet strength and limiting injection to the inner span enhances aerodynamic performance while reducing power consumption. The author previously evaluate passive and active flow control methods to enhance aerofoil performance, showing that the Improved Blowing Suction System (IBSS) boosts efficiency by 100%, while inward dimples increase the stall by 50%. Active control proves to be more highly controlled in boundary layer management than passive methods. Karuppiah B& Wessley. [3] the study conducted on the effect of the IBSS on the NACA 6321 airfoil showed that increased mass flow rate enhances aerodynamic performance. A flow of 0.10 kg/s improves the stall by 60% and the lift by 50%, optimizing wing efficiency. The author experimentally validate the IBSS for aerofoil performance enhancement, achieving a 40% higher stall angle, 54% greater lift, and 33% lower drag. Optimal injection near peak thickness improves efficiency across all flight phases. Ruochen, W. A. N. G., et al. [4] study explores combining a CFJ airfoil with a parabolic flap to improve aerodynamic performance, using RANS simulations with the S-A turbulence model. The optimized design achieved a 32.1% lift increase and a 93.8% boost in lift-to-drag ratio at a 4° angle of attack. Raj, Y. et al. [5] investigate how streamlining compression and Sanal flow choking affect aerodynamic performance in transonic aircraft, using simulations of CD-shaped stream tubes at various angles of attack. Results show that shock wave formation and increased entropy from choking significantly degrade performance, highlighting the need for optimized airfoil design to mitigate these effects. Fernandez, M. G. [6] analyzes the impact of placing a CFJ downstream of a normal shock wave on a transonic supercritical airfoil. Results show that this positioning reduces CFJ power consumption, shifts the shock downstream, and enhances cruise efficiency by improving lift and aerodynamic performance. Lefebvre, A. et al. [7] the Aerospace Sciences Meeting is a premier annual event where global aerospace scientists and engineers share research on cutting-edge technologies. Topics span aerodynamics, aircraft design, space exploration, systems engineering, and more, including a 2013 paper on CFJ performance at varying Mach numbers. Thomas, B., & Agarwal, R. K. [8] analyze the potential of CFJ active flow control to enhance the efficiency of transonic truss-braced wings (TTBW) for next-generation aircraft. It evaluates aerodynamic performance improvements and the power requirements of the CFJ system for energy efficiency. Zha, G. C. [9] used the CFJ airfoil as a zero mass flow active control system using embedded micro-compressors to enhance lift and delay stall. It achieves ultra-high lift coefficients, remains effective in transonic conditions, and improves aerodynamic efficiency with minimal energy use, making it a transformative aviation technology. Boling, J. S. [10] investigates transonic CFJ flow control to enhance aircraft performance, particularly in high-lift and cruise conditions. It uses high-fidelity CFD simulations to explore CFJ effects on supercritical airfoils, transonic wings, and VTOL designs, demonstrating significant aerodynamic efficiency improvements without conventional flap systems. Payne, J. et al. [11] conduct numerical simulations of the supersonic jet in a subsonic crossflow using three turbulence models, comparing results with available data. While a Spalart-Allmaras model performed well downstream, the k-ε and k-ω models better captured near-field jet behavior but overpredicted vortex strength and lift-off height. Lei, Z., & Zha, G. [12] investigate CFJ flow control for lift enhancement on a supersonic thin airfoil, demonstrating significant performance gains. A dual CFJ configuration on a flapped airfoil improves lift efficiency while reducing power consumption, offering a high-effectiveness method for supersonic applications.

Wang, Y., & Zha, G. [13] numerically analyze the effect of Mach number on the cruising behaviour of three-dimensional CFJ wings across various aspect ratios. Results show increased lift with Mach number but reduced aerodynamic efficiency due to induced drag, with high-aspect-ratio CFJ wings demonstrating significant performance gains at subsonic speeds up to Mach 0.50. The author analyze the effect of Vortex Generators (VGs) on different airfoils, showing improved stall angles without increasing drag. Experimental and numerical results confirm enhanced aerodynamic efficiency, making VGs effective for subsonic aircraft performance. Jeon, J. et al. [14] evaluate Flapped Co-Flow Jet (FCFJ) and regular CFJ airfoils for fixed-wing flight on Mars, where low Reynolds numbers pose aerodynamic challenges. Simulations show that FCFJ airfoils can achieve high lift and efficiency, especially at Mach 0.26, making them strong candidates for Martian exploration aircraft. Goc, K. A., et al. [15] employ Large-Eddy Simulation (LES) with advanced turbulence modeling to study flow over the NASA CRM, highlighting key sensitivities like transition modeling, grid design, and mounting effects. Findings suggest that strategic grid topologies and transition triggers improve LES accuracy, with results offering valuable insights for turbulence modeling in transonic aircraft flows. The author examine the performance of a reconfigured NACA 6321 aerofoil using the CFJ method, having the injection suction slots at 20% and 80% chord length, respectively. Results show a 27% improvement in lift and a 33% enhancement in stall AOA, demonstrating CFJ's behaviour in boundary layer control for improved aircraft efficiency. The author previously investigate the effect of dimples on an airfoil to improve aerodynamic performance by minimizing drag and delaying flow separation. Through computational (CFD) and experimental analysis, dimpled surfaces—circular, heart-shaped, and elliptical—demonstrate improved lift characteristics and reduced takeoff distance by increasing the stall angle. Lefebvre, A. et al. [16] analyzed the behaviour of a CFJ airfoil through numerical and experimental analysis, focusing on lift improvement and reduction of drag across Mach 0.03–0.4. Results show a 120% increase in peak lift coefficient, improved cruise performance at low angles of attack, and efficiency comparable to a baseline airfoil.23.

Lauer, M. G., & Ansell, P. J. [17] explores the integration of boundary-layer ingestion and distributed propulsion into wing sections for future commercial aircraft. Using a specialized optimization framework, it demonstrates up to 11% drag reduction and 35% mechanical power savings. Dhakal, Subash, et al. [18] evaluate the lower speed performance of CFJ airfoils, demonstrating significantly higher lift coefficients than conventional designs. The CFJ-NASA-SC(2)-0714 airfoil achieves a super lift 9.1, suggesting CFJ technology can enhance takeoff and landing performance without conventional flaps.

The above literature discloses the various studies conducted using active and passive methods for aircraft performance improvement. It shows that the majority of the work is carried out for commercial and helicopter-related operations. There are limited amounts of papers available on the transonic aerofoils (High-speed) relevant study. Also, the major work on transonic is directly implementing the subsonic aircraft design concept. In this aspect, the paper's objective is to analyze the behaviour of transonic aerofoil using the flow jet method with the innovative design of injection and suction placed behind mid-chord, as well as mass flow inlet modified with jet velocity, which is studied in detail.

## 2. Methods

The supercritical aerofoil selected for this study is available in the market. The simulation methods are carried out from the design, meshing, and analysis. The methodology obtains the performance parameters of lift, drag, and flow visualizations.

### *2.1. Design*

The aerofoil identified for this study is RAE 2822. There are two models designed for the research purposes. The first model is used to predict the baseline aerofoil performances, which is used for the references. The second model placed the injection and suction mechanism over the top of an aerofoil near the trailing edge. The baseline aerofoil has a chord length of 1000mm. In the CFJ method, the injection is placed at the position of 55% of the chord, and suction is placed at the position of 77.5% of the chord, with a depth of 1 cm at both suction and injection locations. The baseline and co-flow jet aerofoil with the domain are mentioned in Figures 1(a) and 1(b).

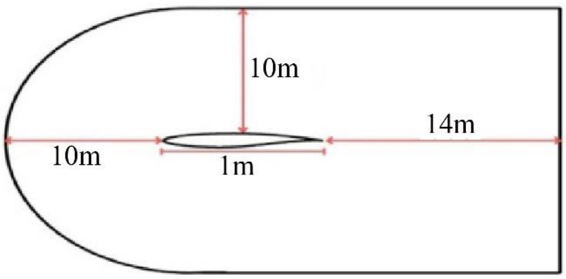


**Fig. 1(a) Baseline Aerofoil with domain**

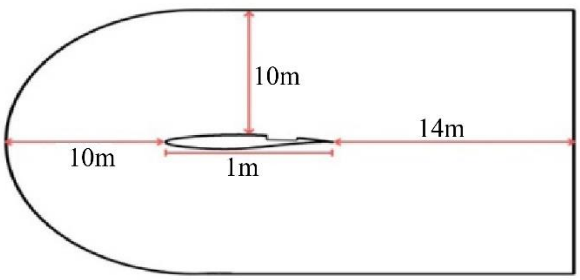


**Fig. 1(b) CFJ Aerofoil with domain**

### *2.2. Meshing*

The designed aerofoils with domains are further divided into a small number of nodes and elements. The number of elements and nodes is decided using the grid study, as mentioned in the literature [4]. Based on the study, the number of nodes finalized is 1157060 with elements of 1105120 and the orthogonal quality of 0.534, as shown in Figures 2(a) and 2(b). The meshed model is clearly named for further processing.

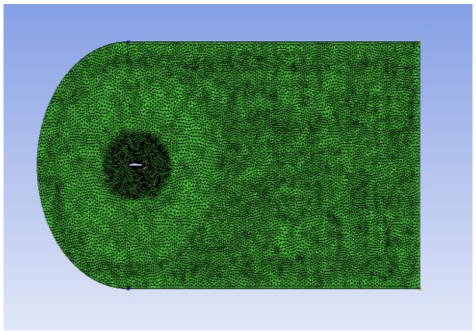

**Fig. 2 Meshing of an aerofoil**

### *2.3. Simulation Analysis*

The two-dimensional analysis of the baseline and co-flow jet model used the pressure-based solver utilized for this study, the Reynolds Average Navier Stokes, and the energy equation utilizing the spalart allmaras turbulence model. Figure 3 indicates and finalizes the turbulence model and boundary conditions imposed on this study. The validation study proved that the proposed method follows a similar trend in the literature [2]. The type of turbulence model selected for this work is finalized. The boundary conditions fixed for this work are mentioned in Table 1. Numerical studies are conducted between -2 degrees to 5 degrees to predict the behaviour of cruise conditions.

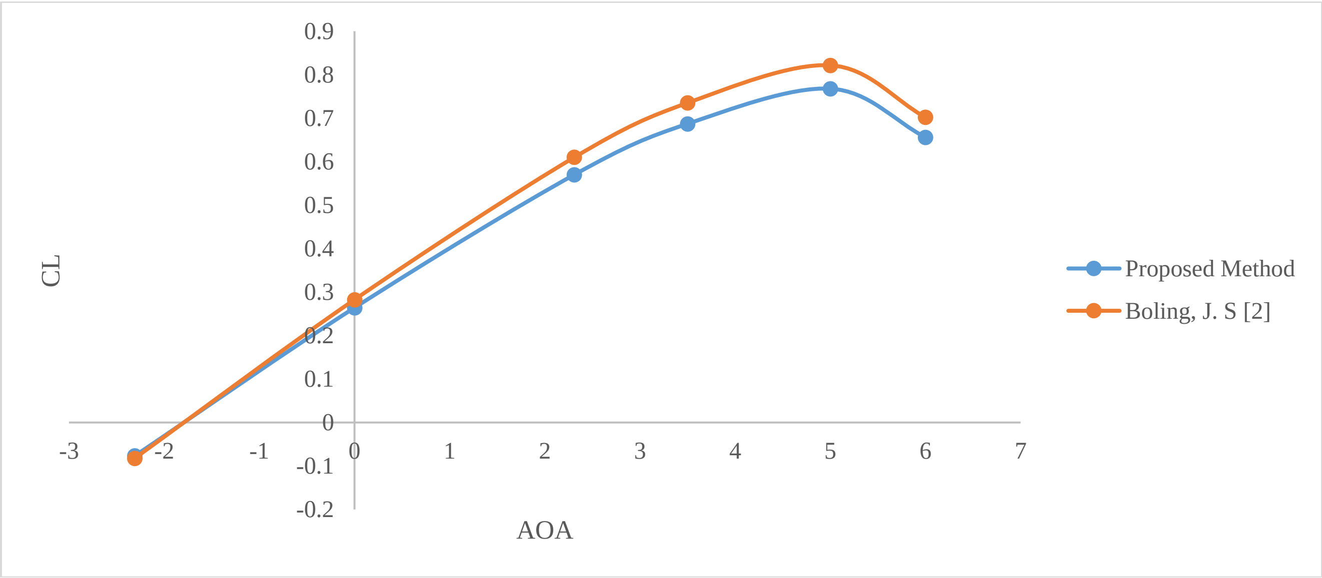


**Fig. 3 Validation study**

**Table 1. Boundary conditions**

| Sr.no | Variables | Details |
|---|---|---|
| 1 | Mach number | 0.8 |
| 2 | Temperature (K) | 223 |
| 3 | Density(m3/sec) | 0.413 |
| 4 | Inlet | Velocity at inlet |
| 5 | Outlet | Pressure at outlet |
| 6 | CFJ Injection | 0.03Kg/sec |
| 7 | CFJ Suction | 0.03Kg/sec |

## 3. Results and Discussion

The designed aerofoil is conducted using a detailed numerical study with a variation of the angles from -2 to 5 degrees. The angle selection clearly indicates that the analysis was carried out under cruise conditions.

The output parameters are predicted in terms of drag, lift coefficient, and flow visualizations. The following portions provide detailed information about the comparison of baseline and proposed aerofoil at cruise conditions and performance behaviour at different jet velocities.

### *3.1. Case 1: Performances of the Proposed Co-Flow Jet Method*

Case 1 deals with the proposed concept of a co-flow jet after the mid-section performances are observed and compared with the regular aerofoil. The parameters are observed in terms of drag and lift coefficients as well as flow visualizations methods.

*3.1.1. Lift Coefficient Curve*

Figure 4 reveals the performance measurement of the coefficient of lift at different angles. It discloses that the increase of the angle is used to increase the lift coefficient from low to high angles. The graph proved that the maximum lift values improved by 43%, with the average lift coefficient during the cruise conditions being 27% compared with the existing aerofoil. In transonic cases, the effective implementation of the injection solution leads to the flow being more attached, which leads to an increase in the lift coefficient. The results are similar to the literature of subsonic aircraft model literature. The proposed co-flow jet method can effectively work at high speed to achieve more performance during the cruise conditions.

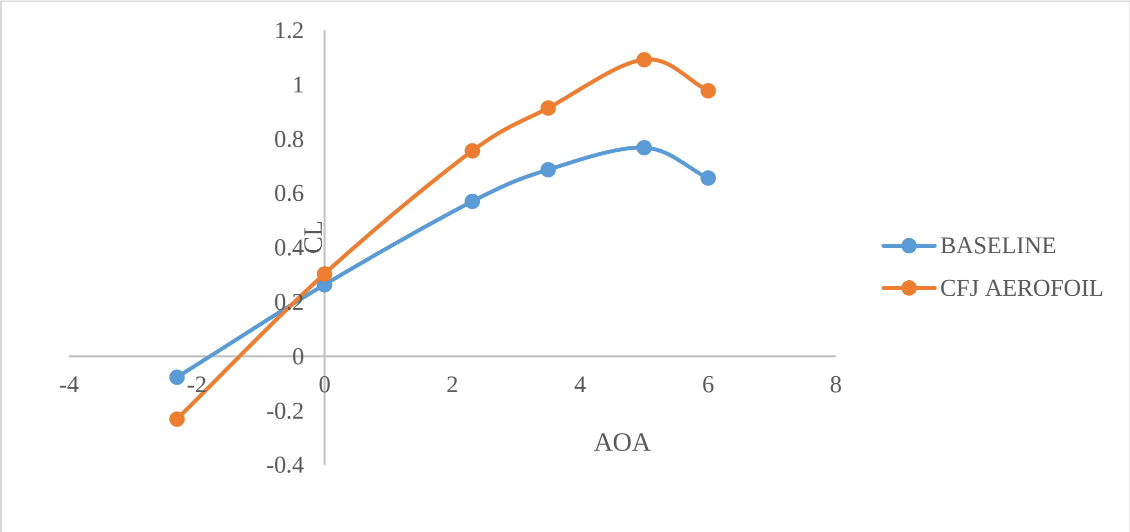


**Fig. 4 Lift curve**

*3.1.2. Drag coefficient Curve*

Figure 5 displays the deviation of the drag coefficient from the negative to the positive angle of attack. It shows that there is a 3% reduction in drag overall. The proposed CFJ method at cruise conditions is used to develop a more fixed flow and avoid the wake region. In the end, it provides less drag and more lift.

The maximum lift formation time produced a drag coefficient of 2%. The obtained results follow a similar trend of literature [3]. In a detailed manner, this proposed method proved that the supercritical aerofoil efficiently uses the CFJ method to enhance the aerofoil efficiency.

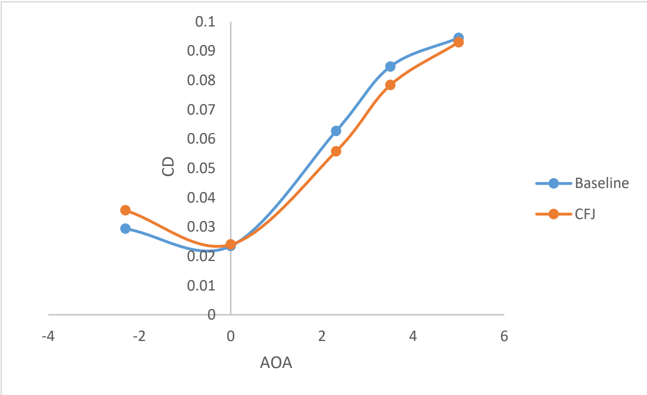


**Fig. 5 Drag curve**

*3.1.3. Contour Plot*

Figure 6 shows the velocity contour of the baseline and CFJ method of supercritical aerofoil at the angle of 2.31 degrees. It indicates that the proposed co-flow jet method over an aerofoil at the downstream portion created the secondary flow, which fills the wake region and makes more velocity over a top-side aerofoil compared to the existing aerofoil. At the same time, in the baseline aerofoil, the wake region remains the same.

Figure 7 shows the pressure contour of the proposed model and the existing model of co-flow jet aerofoil. It indicates that the injection of secondary flow over a top surface of aerofoil leads to creating the minimum pressure over a top surface, and at the same time, the bottom of aerofoil creates more pressure.

The pressure variation created over an aerofoil leads to an improved lift and minimizes the drag. It ultimately improves the performance of an aircraft during cruise conditions.

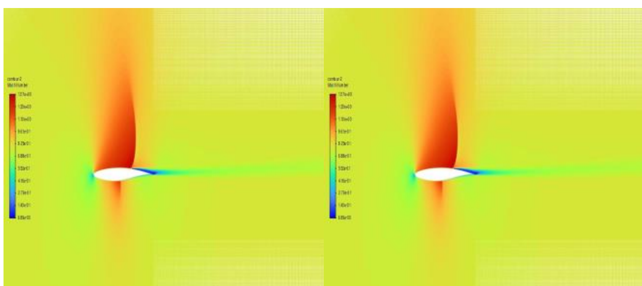

**Fig. 6 Velocity contour of Baseline and CFJ with AOA 2.31 degree**

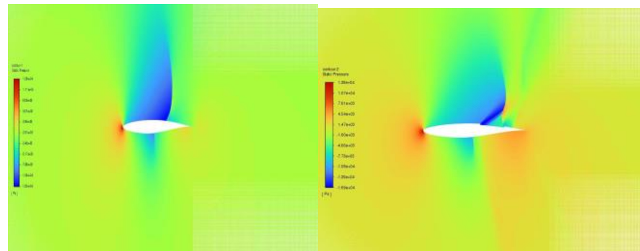

**Fig. 7 Pressure contour of Baseline and CFJ with AOA 2.31 degree**

***3.2. Case 2: Performance with different Jet Velocity***

The second case of the proposed study involves injecting different jet velocities to measure the performance of cruise-level conditions. These performances are evaluated through the lift and drag coefficient curve of different jet velocities of 50 m/sec,60 m/sec, and 70m/sec.

*3.2.1. Jet Velocity Lift Coefficient Curve*

Figure 8 indicates the analysis of different jet velocities performances over a co-flow jet method. In the usual co-flow jet methods, the performances will be measured from the mass flow parameters. In this proposed method, the performances are monitored by using jet velocities. The incremental jet velocity is used to improve the performances of co-flow jet aerofoil without improvement of stall angle. The amount of lift coefficient improvement is 30% higher than the baseline aerofoil. The injection jet velocities create the high-velocity flow over an aircraft wing's top surfaces, leading to the flow being more attached. It proves that the input of jet velocity over the CFJ method can improve the aerodynamic performances of aerofoil.

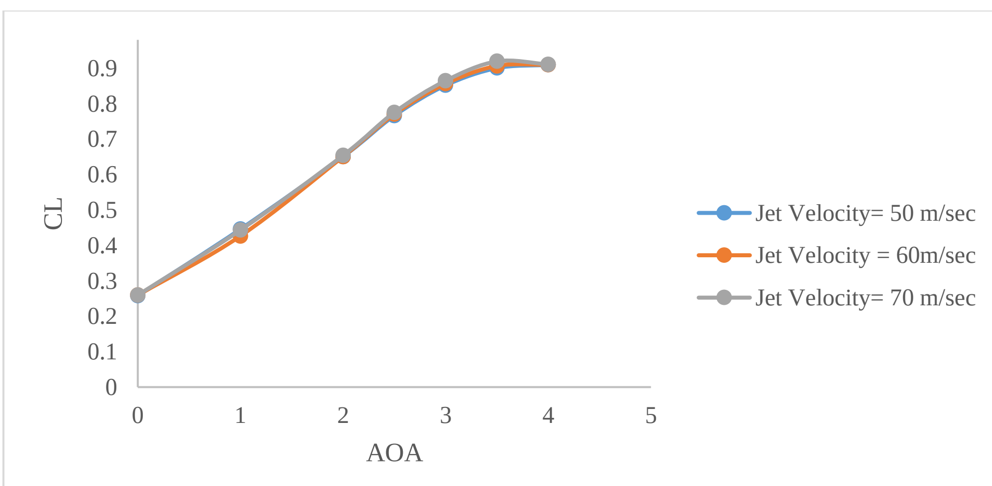


**Fig. 8 Performance of lift curve at various jet velocities**

*3.2.2. Jet Velocity Drag Coefficient Curve*

Figure 9 indicates the effect of the drag coefficient concerning the different jet velocities. It reveals the increase of jet velocity used to minimize the drag over an aerofoil. The amount of drag decrement for every 10 m/sec is minimized by up to 7%, which is a similar trend in the literature. The amount of drag reduction happened due to the effect of jet velocities, which decreases the wake region and makes the flow more attached. The amount of flow injected will decrease the drag further. It proves that the proposed jet velocity concept is used to minimize the drag with high aerodynamic performances from low to higher velocities.

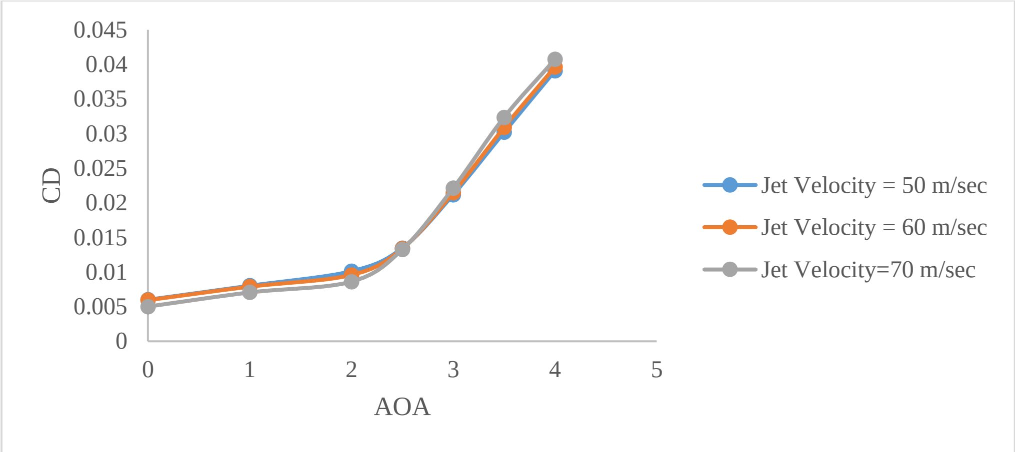


**Fig. 9 Performance of drag curve at various jet velocities**

## 4. Conclusion

The supercritical aerofoil of RAE 2822 selected for this study is designed as regular and proposed co-flow jet method introduced behind the mid of the chord. Both aerofoils are numerically investigated at the cruise conditions level and it brought the following conclusions

- The introduction of co-flow jet methods behind the midsection of supercritical aerofoil improves the aerodynamic performances at cruise level with effective control of boundary layer
- The Peak lift coefficient increased by 43% compared to the existing models. This indicates that the introduction of the secondary flow near the trailing surfaces fills the wake region and develops a more attached flow.
- The amount of drag reduction achieved during the cruise conditions is 3% due to the delaying of the boundary layer and attachment of flow over the object.
- The performance of the jet velocity method is the perfect alternative method for the existing co-flow jet method to improve the performances
- The incremental jet velocities are used to enhance the lift coefficients as well as decrease the drag coefficient at low and high angles of attack during the cruise conditions

The overall study proved the concept of the introduction of co flow jet behind the mid of the chord used to enhance the flight performance at cruise conditions. The future scope of this study is to evaluate the performance at takeoff and landing conditions, massflow-related optimizations, and experimental work.

## References

[1] Zixiang Liu, and Gecheng Zha, "Transonic Airfoil Performance Enhancement Using Co-Flow Jet Active Flow Control," *8th AIAA Flow Control Conference*, Washington, D.C, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[2] Jeremy S. Boling, and Gecheng Zha, "Numerical Investigation of Co-Flow Jet 3D Transonic Wings," *AIAA Aviation 2021 Forum*, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[3] Balaji Karuppiah, and Jims John Wessley, "Study on the Influence of Mass Flow Rate Over a National Advisory Committee for Aeronautics 6321 Airfoil Using Improved Blowing and Suction System for Effective Boundary Layer Control," *SAE International Journal of Aerospace*, vol. 14, pp. 219-233, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[4] Ruochen Wang et al., "Numerical Investigation of Co-Flow Jet Airfoil with Parabolic Flap," *Chinese Journal of Aeronautics*, vol. 36, no. 5, pp. 78-95, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[5] Yash Raj et al., "Investigation of Area Ratios in Convergent-Divergent Streamlines for Assessing Transonic Aerodynamic Performance Across Varied AoA in Different Airfoils," *AIAA AVIATION FORUM AND ASCEND 2024*, Las Vegas, Nevada, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[6] Michael G. Fernandez, Jonathan Hoffmann, and Gecheng Zha, "Transonic Super-Critical Airfoil Enhancement by Coflow Jet Downstream of Normal Shock," *2018 Flow Control Conference*, Atlanta, Georgia, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[7] Alexis Lefebvre et al., "Performance of a Co-Flow Jet Airfoil with Variation of Mach Number," *51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition*, Grapevine, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[8] Bryce Thomas, and Ramesh K. Agarwal, "Application of a Co-Flow Jet Airfoil in Development of a Transonic-Truss Braced Wing," *AIAA SCITECH 2025 Forum*, Orlando, FL, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[9] Ge-Cheng Zha, "Ultra-High Efficiency Co-Flow Jet Airfoil and the Transformative Aircraft," *AIAA Journal*, pp. 1-9, 2017. [Google Scholar] [Publisher Link]

[10] Jeremy S. Boling, "*Numerical Study and Application of CoFlow Jet Active Flow Control for Transonic Flows*," PhD Thesis, University of Miami, 2020. [Google Scholar] [Publisher Link]

[11] Jeffrey Payne, Christopher Roy, and Steven Beresh, "A Comparison of Turbulence Models for a Supersonic Jet in Transonic Crossflow," *39th Aerospace Sciences Meeting and Exhibit*, Reno, NV, U.S.A, 2001. [CrossRef] [Google Scholar] [Publisher Link]

[12] Yang Wang, and Gecheng Zha, "Study of Mach number Effect for 3D Co-Flow Jet Wings at Cruise Conditions," *AIAA Scitech 2020 Forum*, Orlando, FL, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] Zhijin Lei, and Gecheng Zha, "Lift Enhancement of Supersonic Thin Airfoil at Low Speed by Co-Flow Jet Active Flow Control," *AIAA Aviation 2021 Forum*, Virtual Event, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[14] Jaehyoung Jeon, Yan Ren, and Gecheng Zha, "Flapped CoFlow Jet Airfoil for High Lift Cruise at Low Reynolds Number in Martian Atmosphere," *AIAA SCITECH 2024 Forum*, Orlando, FL, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[15] Konrad A. Goc et al., "Studies of Transonic Aircraft Flows and Prediction of Initial Buffet Using Large-Eddy Simulation," *Journal of Aircraft*, pp. 1-21, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[16] A. Lefebvre et al., "Performance and Energy Expenditure of Coflow Jet Airfoil with Variation of Mach Number," *Journal of Aircraft*, vol. 53, no. 6, pp. 1757-1767, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[17] Matthew G. Lauer, and Phillip J. Ansell, "Aeropropulsive Shape Optimization of an Airfoil System in the Transonic Regime," *Journal of Aircraft*, vol. 62, no. 1, pp. 166-179, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[18] Subash Dhakal et al., "Numerical Investigation of Low Speed Performance of Transonic Coflow Jet Airfoil," *35th AIAA Applied Aerodynamics Conference*, Denver, Colorado, 2017. [CrossRef] [Google Scholar] [Publisher Link]