Section A-Research paper
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PERFORMANCE STUDY OF ROTARY WING AEROFOIL USING CO FLOW JET METHOD

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ABSTRACT

This paper aims to improve the performance of rotary wing aerofoils by controlling the boundary layer using a Co flow jet. By supplying additional mass flow close to the foremost edge and removing the equal amount of mass flow from the trailing edge, the co-flow jet method produces circulation over an aerofoil top surface. The NACA 0015 aerofoil equation of state is used to simulate at Mach 0.05 with the k-omega SST equation. The results proved that stalling angle improved by 40% and the coefficient of lift improved by 83% compared to the existing aerofoil for rotary wings. A helicopter blade can be made lighter and more aerodynamic by using this method.

Keywords: Boundary Layer, CFD, CFJ airfoil, Lift Coefficient, Drag Coefficient, NACA 0015.

1. INTRODUCTION

Nowadays, there is an increase in helicopter service throughout the entire world and operators are looking for helicopters that have a high performance and less weight. In addition to modifying the design, researchers are conducting detailed study on different helicopter components. The regulation of the aerofoil's boundary layer is another important topic to meet the needs of the operator. Different active and passive techniques are used for managing the boundary layer over a wing. In this study, simulation and experimental analysis was studied using the co-flow jet method.

Ge-Cheng Zha et al.[1] study performed using CFJ0025-065-196 and NACA 0025 aerofoils. Researchers found that CFJ aerofoils exhibited greater lift by 113% to 220%, resulting in a 153% increase in stall margin and a 30% reduction in drag coefficient from 127%. Baoyuan Wang et al.[2] investigated the aerodynamic efficiency of various injection slot sizes using the 3D RANS CFD solver. Due to the lower injection (CFJ0025-033-065) holes, AOA has increased, but lift coefficient has decreased. Because of this, the injection hole size affects the performance of the CFJ aerofoil. Bo Li et al[3] analyzed the flow characteristics of the NACA 0025 aerofoil using the plasma co-flow jet method (PCFJ). By suppressing boundary layers using the PCFJ method, higher aerodynamic efficiency is demonstrated. Abdolamir B. Khoshnevis and Shima Yazdani[4] applied SST and k-omega turbulence models to analyze NACA 0025 aerofoils with various Reynolds numbers. The study found that aerodynamic performance is better at Reynolds numbers less than 10^5. Abdolamir Bak Khoshnevis et al.,[5] research project with CFJ method investigated four different symmetrical aerofoils on a $3*10^5$ Reynolds number wind turbine. Researchers found that NACA0012 and NACA0015 aerofoil produced more lift at lower angles of attack, while NACA0018 and NACA0021 produced more lift at higher angles of attack with an optimum moment coefficient of 0.05. Kewei Xu and Gecheng Zha[6] Using IDDES, a 3D analysis was performed on the NACA 0012 aerofoil with a moment coefficient of 0.26, which resulted in 99.25% lift and a 52% reduction in drag for the NACA 0012 model. This system could have been improved to use less energy. Chua Bing Liang et al[7] numerical analysis of the NACA 0012 aerofoil was conducted to determine its optimum moment coefficient and injection location for a velocity of 15.62 m/sec. Several different injection positions were tested along with varying coefficients of moment. The study determined that the ideal site for injection is at the chord's 80 percent, and the ideal coefficient of moment is $2.25*10^{-4}$.Ge Cheng Zha et al.[8] Study of flow properties over an aerofoil at different angles of attack using CFD's RANS solver. In comparison with the baseline aerofoil, the results show a 200% lift and a 153% stall margin increase. According to the study, high thrust was generated at low AOA and higher drag at high AOA. Ge-Cheng Zha and Wei Gao[9-11] Flow investigation was conducted on two different aerofoils with two different configurations. One with injection-suction and the other with only injection, to determine their properties. According to this study, CFJs generally lack rams and reduce drag, but only injection results in equal drag on aerofoils. As a result of the CFJ aerofoil, lift is increased to 220%, while stall limit is increased to 153%. In comparison with only-injection aerofoils, the CFJ with an injection-suction aerofoil had a smaller wake region and a better aerodynamic performance. As a result, aerofoils with both injection and suction are better performing than those with only injection. K.Balaji and G.Jims john Wessley[12] conducted simulation work to control boundary layer on NACA 6321 aerfoil with novel method Improved Blowing Suction System used to increase the stalling angle 60%, lift coefficient 37.5% compare to baseline aerofoil. and Small aircrafts. K.Balaji and G.Jims john Wessley [13] performed experimental investigation on NACA 6415 aerofoil by using modified co flow jet method. The results proved that stalling angle of attack improved 5 degree and lift increases up to 43% compare to baseline aerofoil. Zixiang Liu and Ge-Cheng Zha[14] carried out simulation work on transonic aerofoil to control the boundary layer with co flow jet method. It concluded that lift coefficient is improved by 25.6% and aerodynamics efficiency values are decreasing slightly. Roopesh Kumar et.al[15] Experiments were conducted in a subsonic wind tunnel with various Mach numbers and attack angles. In this paper, it is shown that a CFJ aerofoil improves lift and decreases drag when compared to a baseline aerofoil.Amzad Hossain et.al [16] Using a Low-speed Wind Tunnel, test estimate the aerodynamic performance of the baseline and CFJ aerofoils using a co-flow jet utilizing the NACA 0015 aerofoil.. According to this paper, CFJ aerofoils generate 82.5 percent more lift than baseline aerofoils while generating 16 percent less drag. CFJ aerofoils also had a higher stall angle of attack. Through modelling work, Balaji and Jims John Wessley[17] determine the ideal mass flow for the injection suction approach. Using the co flow jet approach, Balaji et al.,[18] improved the performance of fixed wing aero foils. According to the study, the lift coefficient and stalling angle were 27% and 33% better than with a conventional aerofoil. The review study by Balaji and Jims John Wesley[19] described the research effort conducted in co flow jet technologies and its research gap very well.

In the above literature survey, it is stated that the co-flow jet mechanism is used to control the boundary layer effectively, however, few papers have examined the results of changing settings like mass flow and injection location. Experimental methods are very limited in this study. This study's goal is to evaluate aerodynamic performance of rotary wing aerofoils controlled by a boundary layer on a NACA 0015 aerofoil through numerical and experimental investigation. In order to achieve this, a co flow jet method is used and aerodynamic performance is analyzed.

2. Design

The coordinate points of this NACA series were generated using an airfoil generator. A baseline aerofoil is designed in a systematic manner. Co-flow jet aerofoils can be designed with different configurations based on injection and suction locations. The co flow jet model is created using injection at 20% of the chord length and suction at 80%. The aerofoil's chord length and span are 30 cm and 15 cm, respectively. The total area of the aerofoil will be 450 square centimetres. The same dimensions of each aerofoil are fabricated with light weight poly lactic Acid material using 3D printing. CFJ injection and suction holes are integrated to obtain the flow without any disruption, as shown in Fig.1 a & b.

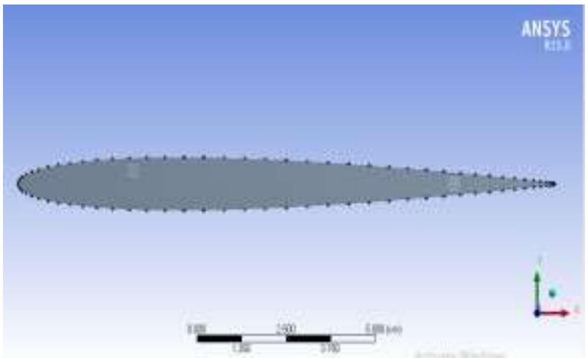

Fig.1.a. Simulation Model

Fig.1.b. Experimental Model

3. Meshing

ICEM CFD software is used to conduct meshing. All aerofoil meshing is conducted using the tedra hedra shape with unstructured mesh. The number of elements plays an important part in matching the results with experimental data. Grid independent study is performed to fix this number. The fixed number of nodes for this work is 5,81,923 according to the grid-based impartial study.

4. Numerical Analysis

By using boundary conditions, the meshed model is tested with actual aircraft conditions to obtain simulation results. For this work, turbulence models are studied to select the appropriate model to solve the numerical problem. Therefore, k-omega SST method is consistent with experimental readings. To further investigate the pressure-based solver used to converge the problem as earlier compared to other methods. For different angles of attack, the same models are used, and the flow direction changes according to the needs. The analysis is iterated to a maximum of 5000 times in order to arrive at a convergent solution.

5. Experimental Analysis

Baseline and Co flow jet models are tested in a subsonic wind tunnel at Sanjay Ghodawat University, Kolhapur in figure 2. To obtain accurate results, the wind tunnel is calibrated before each test. The baseline models are tested on a regular basis. The CFJ models are tested with small adjustments in the test section. Models are tested with a velocity of 15 m/sec. Additional mass flow is introduced by using a modified external pump that will provide 0.05 kg/s over an aerofoil without disturbing the main flow. Aerodynamic parameters are collected from component balances.

Fig.2. Wind tunnel Testing

6. Result and Discussion

In addition, a rotational wing blade was simulated and analyzed under various conditions. Results are shown in Table 1.

Table 1. Juxtaposition of Numerical and Experimental Results

AOA	BASELINE		EXPERIMENTAL CFJ		SIMULATION CFJ	
	CL	CD	CL	CD	CL	CD
0	-0.119	0.014	0.063	0.011	0.066	0.011
2	0.117	0.018	0.333	0.013	0.351	0.014
4	0.352	0.022	0.603	0.016	0.635	0.017
6	0.502	0.026	0.818	0.019	0.862	0.020
8	0.652	0.031	1.034	0.022	1.088	0.024
10	0.990	0.047	1.267	0.033	1.334	0.038
12	0.812	0.056	1.489	0.041	1.567	0.043
14	0.521	0.072	1.712	0.053	1.803	0.056
16	0.369	0.133	1.663	0.097	1.750	0.102

6.1 Lift coefficient curve

Fig.3. shows an efficient way to enhance rotary blade performance is by using co-flow jets. Stalling angle for existing aerofoils is 10 degrees. In experimental and simulation methods, the stalling of the Co flow method is improved by 14 degrees. As a result of attached flow over an aerofoil, the stalling angle for numerical and experimental is improved by 40% and the lift coefficient is increased by 82% & 73%, respectively. Thus, the co flow jet method improved the aerodynamic efficiency of rotor blades at different phases of flight.

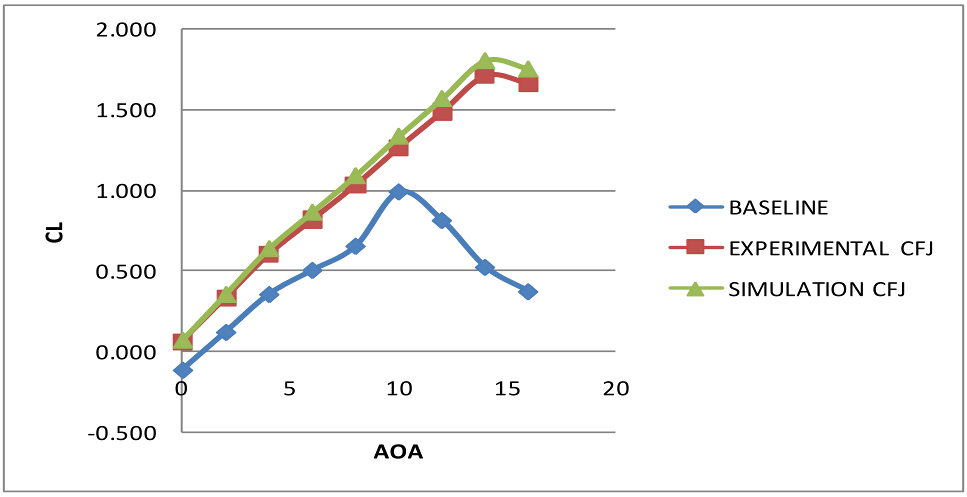

Fig3.comparision of lift coefficient curve

6.2 Drag coefficient curve:

Fig.4 shows the drag coefficient variations for base line and co flow jet aerofoils of rotary wings. The simulation and experimental results indicate that the co flow jet method produces less drag than baseline aerofoils since the boundary layer is suppressed. When an aerofoil reaches stalling angle of attack, its drag increases significantly. Because there is no removal of surface over an aerofoil in the experimental model, the drag is slightly lower than in simulations. Simulation and experimental lift coefficients decreased by 27% and 22%, respectively, when compared with the baseline aerofoil.

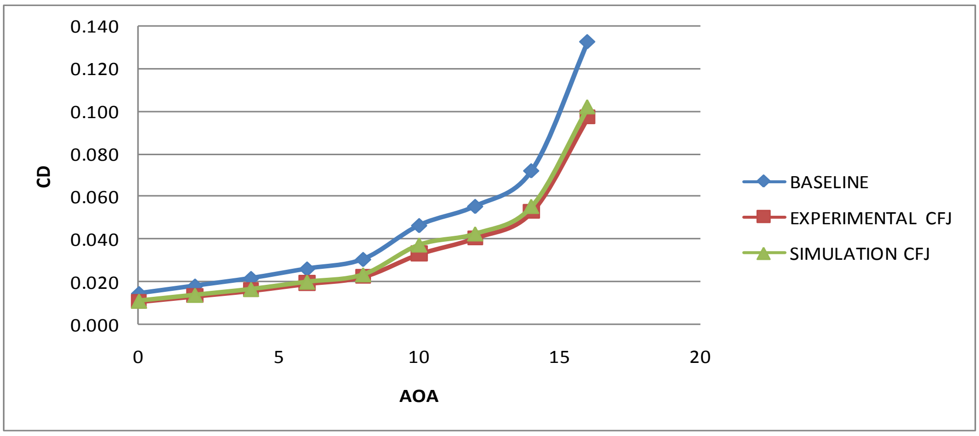

Fig.4. comparison of Drag coefficient curve

6.3 Aerodynamic efficiency curve

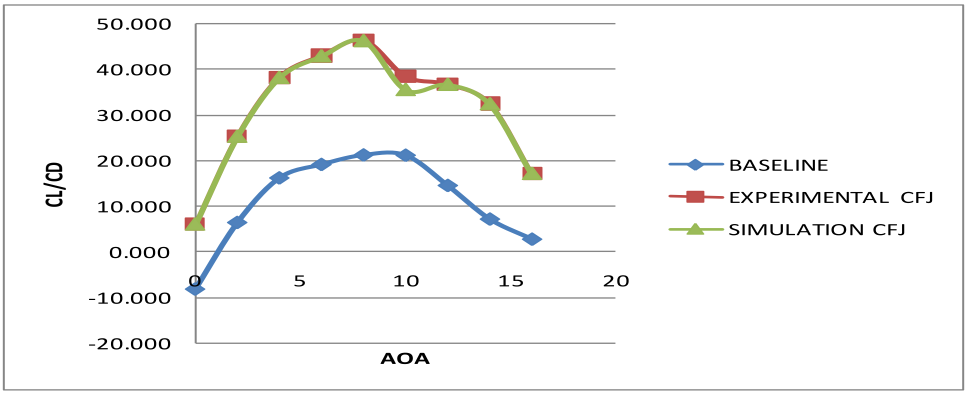

Fig.5. comparison of aerodynamic efficiency curve

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Fig.5. display the result of implementation of co flow jet concept into rotary wings shows improvement of aerodynamic efficiency over aerofoil. Increasing aerodynamic efficiency by controlling the boundary layer led to enhanced aerodynamic performance. The aerodynamic performance improvement for simulations and experiments is more than 175% over the baseline aerofoil.

6.4 Drag Polar curve:

Drag polar curve shown in Fig.6. The co flow jet method over a rotary wing is used to improve lift coefficient by reducing drag coefficient. Additionally, aerodynamic performance associated parameters are improved. Also, the peak coefficient of lift achieved by co flow jet method is 1.803 compared to baseline coefficient of lift of 0.99. The slope of the drag polar curve was also improved by using co flow jet method.

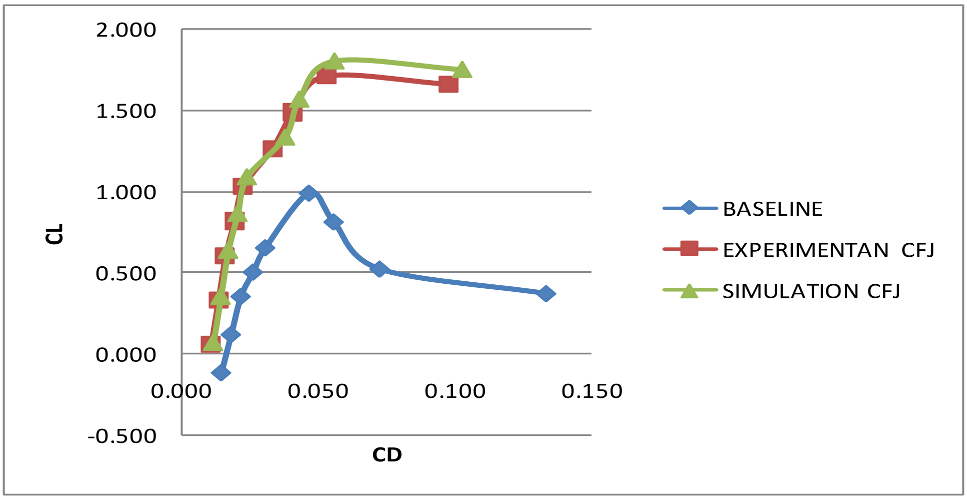

Fig.6. Comparison of Drag Polar curve

6.5 Comparison of Lift curve:

Fig.7. shows an augmentation in lift at various angles of attack. This study showed that all aerofoils increase lift until the stall angle is reached. Due to the implementation of co flow jets, the lift characteristics of aerofoils are improved better than baseline aerofoil. The overall lift increment for experimental and simulation methods is 114% and 125% respectively compared to the baseline aerofoil. Therefore, co-flow jet aerofoils have improved aerodynamic performance

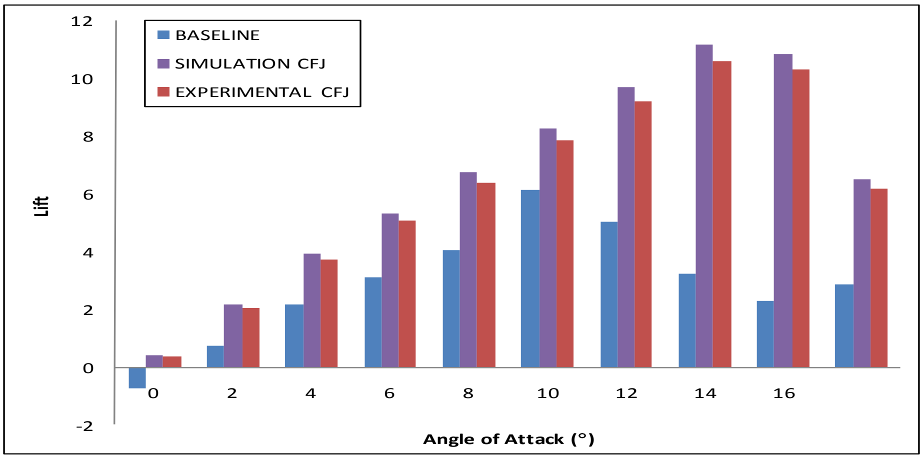

Fig .7 Increment of Lift at different angle of attack

6.6 Comparison of Drag curve:

Fig. 8 shows that coefficient of drag reduces as angle of attack improves in comparison to baseline aerofoil. Experimental and simulation CFJ methods provided nearly the same results, which are lower than baseline aerofoils. Over all drag decrement by using co flow jet method is 22% and 27% form simulation and experimental results due to control of boundary layers

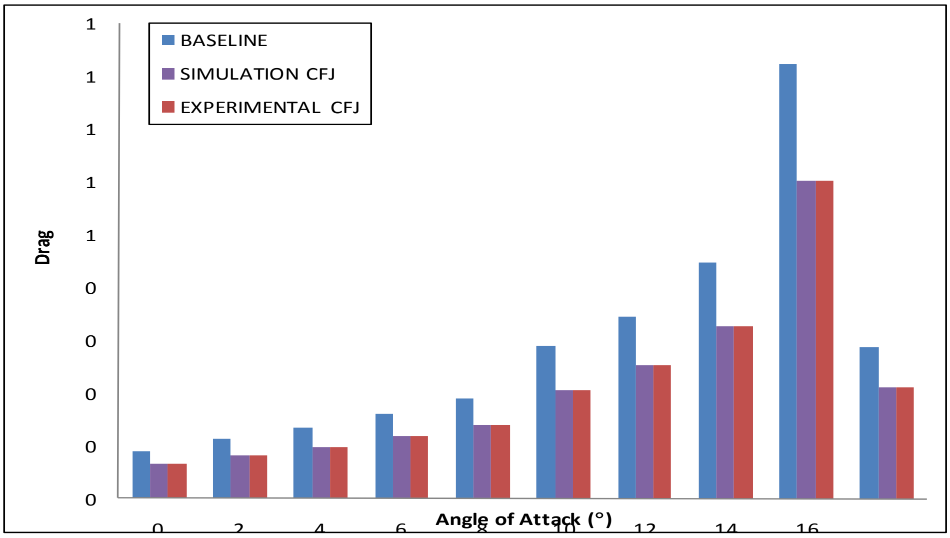

Fig .8 Decrement of Drag at different angle of attack

7. Conclusion

Using simulation and experimental performance analysis of rotary wing aerofoils, the following conclusions are drawn:

- Use of a co flow jet method is used to control the boundary layer to dominion the aerodynamic performance of rotary wings:
- It increases the stalling angle of attack by 40%
- Overall, the simulation and experimental method of CFJ increase the Lift coefficient by 77%
- The overall drag reduction in simulation and experimental co flow jet methods is 24% compared to baseline aerofoils
- Simulations and experiments are validated to a level of 5% difference
- In the CFJ method, secondary control surfaces are removed from the aircraft wings to reduce weight
- With CFJ aerofoils, existing flow control mechanisms are minimally modified in practice to delay boundary layer separation

The CFJ wing design helps helicopters to control the separation of boundary layers and improves aerodynamic efficiency, thus solving a major problem in modern helicopters.

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