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Optimization of Pitching Moment in Semi-Tailless Small UAV Using Reflexed Airfoil

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Abstract

Small UAVs (less than 5 pounds) have become increasingly popular in recent years. Although they are essentially the same as large aircraft, there are differences in requirements, payloads, and cost that make a greater number of viable concepts possible. Many new concepts have also been put forth, but some older ideas that were never implemented for large aircraft may work for small UAVs. One such concept is Blohm & Voss's semi-tailless concept from 1944, which placed the stabilizer surfaces out board and a ft of the wing tips of a highly swept main wing, allowing for the removal of the empennage, which reduced the amount of wetted area and empty weight and improved a number of performance parameters. Applying this concept to small UAVs could have some draw backs but also offer new opportunities. This project focuses on are flexed airfoil to this design rather than on its application to tiny UAVs, which has been explored. According to earlier research, the reflexed airfoil configuration would increase the pitch moment and increase the aerodynamic performance of the aircraft in addition to the benefits of the original design. Using the basic geometry developed by Blohm & Voss, trade studies will be doneto determine reflexed airfoil effects. The configuration will be then modelled with CATIA and CFD analysis will be done through ANSYS to determine the pitching moment of the design, through which we will get to know the aerodynamic performance of the design. The result will be the improvement of pitching moment for better aerodynamic performance.

Keywords
Semi-Tailless, UAV, Blohm & Voss, Reflexed Airfoil, CFD

I. INTRODUCTION

The use of unmanned aerial vehicles, or UAVs, has increased dramatically in recent years. These applications include precision agriculture, disaster relief, surveillance, and reconnaissance. Ensuring the stability and control of these tiny unmanned aerial vehicles is crucial to their effective and safe functioning. Pitching moment is one of the most important aerodynamic elements affecting stability. This research explores the optimization of pitching moment using reflexed airfoils as a means of improving the aerodynamic properties of small, semi-tailless UAVs. Conventional tailless or semi-tailless UAV designs have frequently encountered stability issues, particularly in unfavourable flying circumstances. One special chance to overcome these difficulties is offered by retracted airfoils, which are distinguished by a curvature that turns upward towards the trailing edge. This work intends to reduce pitching moment changes across different angles of attack by utilizing the unique characteristics of reflexed airfoils, hence improving the stability and control of small UAVs. Reflexed airfoil technology brings a unique combination of functionality and design to small unmanned aerial vehicles (UAVs). In contrast to traditional airfoil designs, reflexed airfoils include features that naturally aid in lowering pitching moments. This decrease is especially significant for semi-tailless systems, where pitch stability must be carefully taken into account due to the lack of a traditional tail. With reflexed airfoils, we conduct a thorough investigation into the pitching moment optimization procedure for tiny, semi-tailless UAVs in this study. We aim to create an optimized airfoil design that not only minimizes fluctuations in pitching moment but also maintains the manoeuvr ability and operational flexibility necessary for small UAV applications by integrating computational tools and experimental validations This study holds significance not only for the advancement of small UAV technology but also for its potential implications across various domains, including environmental monitoring, precision agriculture, and emergency response. As wedelve into the intricacies of aerodynamic optimization, we anticipate uncovering insights that will contribute to the ongoing evolution of UAV design and performance, thereby propelling these unmanned systems toward greater reliability and effectiveness in real-world applications.

II. LITERATURE STUDY

El Adawy et al. [4] investigates and analysis about Fixed-wing Unmanned Aerial Vehicle. The study highlights the method and consideration that needs to be done in design phase of an UAV

Harish et al. [5] highlights the methodology of design and the calculations that should be considered while designing a small aircraft. It also highlights detail methodology of Computational fluid dynamic (CFD) analysis of a wing through ANSYS Fluent.

Wong et al. [8] highlights the Analysis of different reflexed airfoil is studied and the criteria to choose the better airfoil is noted. The major criterion to meet longitudinal static stability of UAV is to have an airfoil that produces a zero-angle-of attack pitching moment coefficient greater than zero.

Sreelakshmi and Jagadeeswar [3] highlights the importance of CFD analysis for Aerodynamic analysis for an UAV. The study is carried out at low Mach number i.e., 0.1 to 0.19 and the detail procedure for meshing in CFD analysis through ANSYS Fluent is a point of interest.

Wisnoe et al. [10] investigates about the aerodynamic performance of UAV intended to be capable for low subsonic operation. The study highlights the Generation of 3-D model using CATIA and CFD analysis of the model using FLUENT is studied.

Zakaria et al. [6] highlights the elimination of both horizontal and vertical stabilizer to obtain more aerodynamic efficiency, less power requirement due to less weight, less drag generated. The study of Tailless UAV can be seen and the issues that are faced while designing the tailless UAV. CFD analysis of tailless UAV can be studied which can be used for semi-tailless analysis.

Tipton and Smith [1] highlights the unique design of semi-tailless aircraft configuration. in this study Blom & Voss design is studied and analysed. The design had advantages such as reduction in weight, less drag generation and less power required. There was lot of draw backs noted due to the elimination of horizontal stabilizer, major one was longitudinal stability.

III. METHODOLOGY

Selection of Airfoil

The main criteria for the selection of an airfoil are to meet the longitudinal stability of the UAV. The reflex type of airfoil is selected as this type of airfoil can balance the pitching moment produced from generating lift and thus suitable for tailless UAVs. There are eight commonly used reflex airfoils chosen for the analysis, namelyE186, HS 522, MH 60, MH 78, MH 82, MH 92, S 5020, and Sip kill 1,7/10B, as shown in Figure 1. In figure 2the graph of lift-to-drag ratios of these airfoils against angles of attack. This figure 2 shows that S 5020 airfoil has the highest lift-to-drag ratio. One of the criteria to meet the longitudinal static stability of UAV is to have an airfoil that produces a zero-angle-of-attack pitching moment coefficient Cm0 greater than zero. This could help to neutralize the pitch down effect of the wing's lift. From this criterion, only two airfoils (MH92 and MH78) are qualified, which are shown in Figure 13. Between MH92 and MH78, both have a region where Cma > 0 in a certain range of positive angle of attack, but MH 78 has a shorter range. Thus, MH 78 is chosen as the airfoil for the small semi-tailless UAV. Even though MH 78 is having the lowest lift coefficient, but it has a sufficient lift-to-drag ratio of 25.

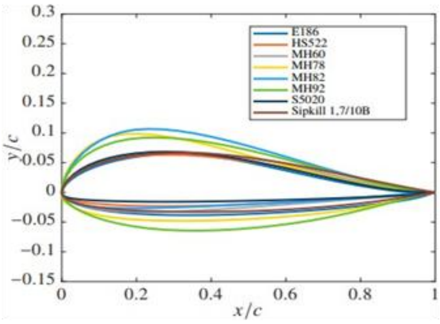


Figure 1

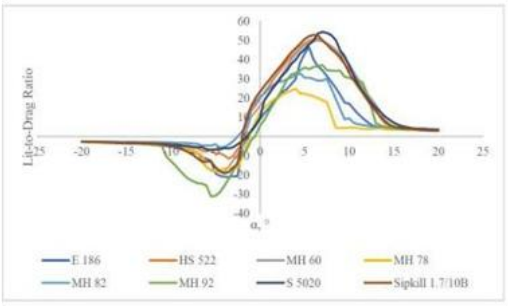


Figure 2

MH78 (Martin Hepperle 78) is the airfoil selected after a lot of study and analysis of different reflexed airfoils.

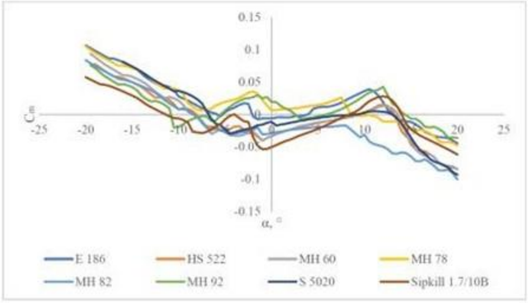


Figure 3

Sizing Calculation and design of a Semi-tailless small UAV

Size calculation

Wing sizing

Sizing of the wing is the main criteria as through which fusel age and horizontal stabilizer sizing is done. As per the study we have done

Wing span for the model is 780 mm.

Chord length is 100 mm
Maximum Thickness 14.4% at 22.1% chord
Maximum Camber 1.9% at 17.9% chord

Fuselage Sizing

Fuselage Length

Fuselage length should be approximately 75% of the wing span length.

Fuselage length = 75% X Wing Span length Fuselage length = 75% X 780mm
Therefore, fuselage length = 595 mm

Fuselage Height

Fuselage height should be 10 to 15% of fuselage length.

Fuselage height 15% X fuselage length Fuselage height = 15% X 595 mm
Therefore, fuselage height = 90 mm

Horizontal Stabilizer Sizing

Horizontal stabilizer area should be 15-20% of the wing area.

Wing Area = Span Length X Chord Length
Wing Area = 780 mm X 100 mm = 78000 mm²
Horizontal Stabilizer Area = 19% of 78000mm² = 15000 mm²
Horizontal stabilizer dimensions: 125 mm X 120 mm

Development of a Semi-tailless Small UAV

From the above size calculation, we designed a 3-D model through CATIAV5. We have designed three models; first one is 3-D model of small UAV with a Normal Cambered wing (NACA 0015) with a swept angle of 30° as shown in figure 4. The second one is a 3-D model of small UAV with a Reflexed wing (MH78) as shown in figure 5. The third one is a 3-D model of small UAV with a Reflexed wing (MH78) with a swept angle 30° as shown in figure 6.

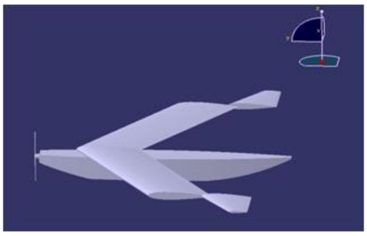


Figure 4

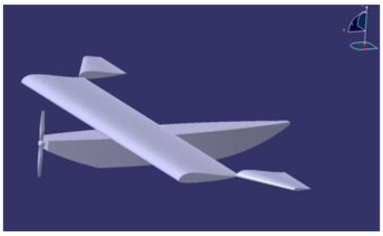


Figure 5

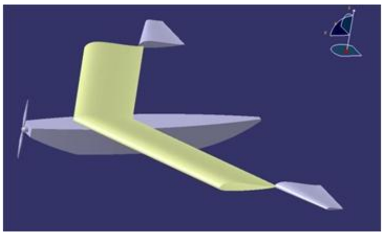


Figure 6

CFD Analysis

Computational fluid dynamics is the branch of fluid dynamics that utilizations numerical strategies and calculations to examine the issues. It is a PC based instrument for reproducing the conduct of frameworks including liquid stream, heat exchange, and other related physical procedures. It works by explaining the conditions of liquid stream (in an exceptional structure) over a locale of enthusiasm, with determined conditions on the limit of that area. The procedure of playing out a solitary CFD reproduction is part into 4-segments:

- Creating the Geometry of a model/Mesh involves geometry parameters and domain shape and size.
- Defining the Physics of Model includes flow properties, heat transfer and boundary condition.
- Solving the CFD Problem involves iterations and numerical scheme.
- Visualizing the Results in the Post-process or involves contours and streamlines.

IV. EXPERIMENTAL DETAIL

Mesh Details

The elemental size for the mesh is considered as 0.1 mm. The mesh details are same for all the 3 models as shown in figure 7.

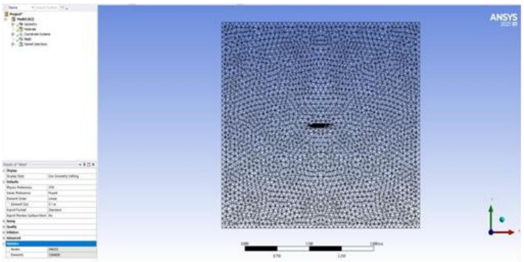
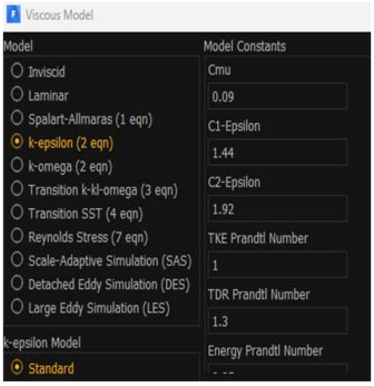


Figure 7

Boundary Condition

At 0°AOA: The boundary condition at0°angle of attack as shown in figure 8 and figure 9.

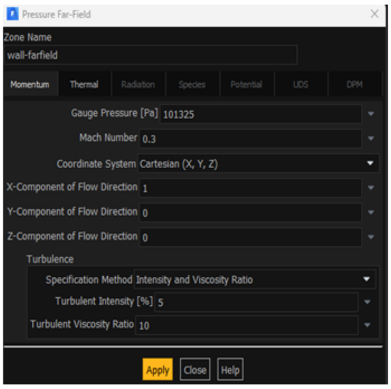


Model
○ Inviscid
○ Laminar
○ Spalart-Allmaras (1 eqn)
● k-epsilon (2 eqn)
○ k-omega (2 eqn)
○ Transition k-kl-omega (3 eqn)
○ Transition SST (4 eqn)
○ Reynolds Stress (7 eqn)
○ Scale-Adaptive Simulation (SAS)
○ Detached Eddy Simulation (DES)
○ Large Eddy Simulation (LES)

k-epsilon Model
● Standard

Model Constants
Cmu 0.09
C1-Epsilon 1.44
C2-Epsilon 1.92
TKE Prandtl Number 1
TDR Prandtl Number 1.3
Energy Prandtl Number

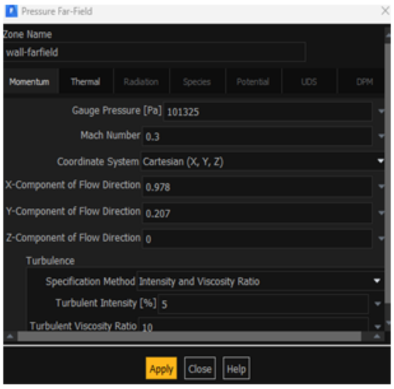
Figure 8



Zone Name: wall-farfield
Gauge Pressure [Pa] 101325
Mach Number 0.3
Coordinate System Cartesian (X, Y, Z)
X-Component of Flow Direction 1
Y-Component of Flow Direction 0
Z-Component of Flow Direction 0
Turbulence
Specification Method Intensity and Viscosity Ratio
Turbulent Intensity [%] 5
Turbulent Viscosity Ratio 10

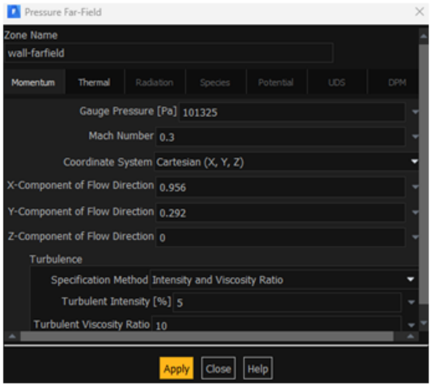
Figure 9

At 12° AOA: The boundary condition at 12°of angle of attack as shown in figure 10.
At 17° AOA: The boundary condition at 17° of angle of attack as shown in figure 11.



Zone Name
wall-farfield
Gauge Pressure [Pa] 101325
Mach Number 0.3
Coordinate System Cartesian (X, Y, Z)
X-Component of Flow Direction 0.978
Y-Component of Flow Direction 0.207
Z-Component of Flow Direction 0
Turbulence
Specification Method Intensity and Viscosity Ratio
Turbulent Intensity [%] 5
Turbulent Viscosity Ratio 10

Figure 10

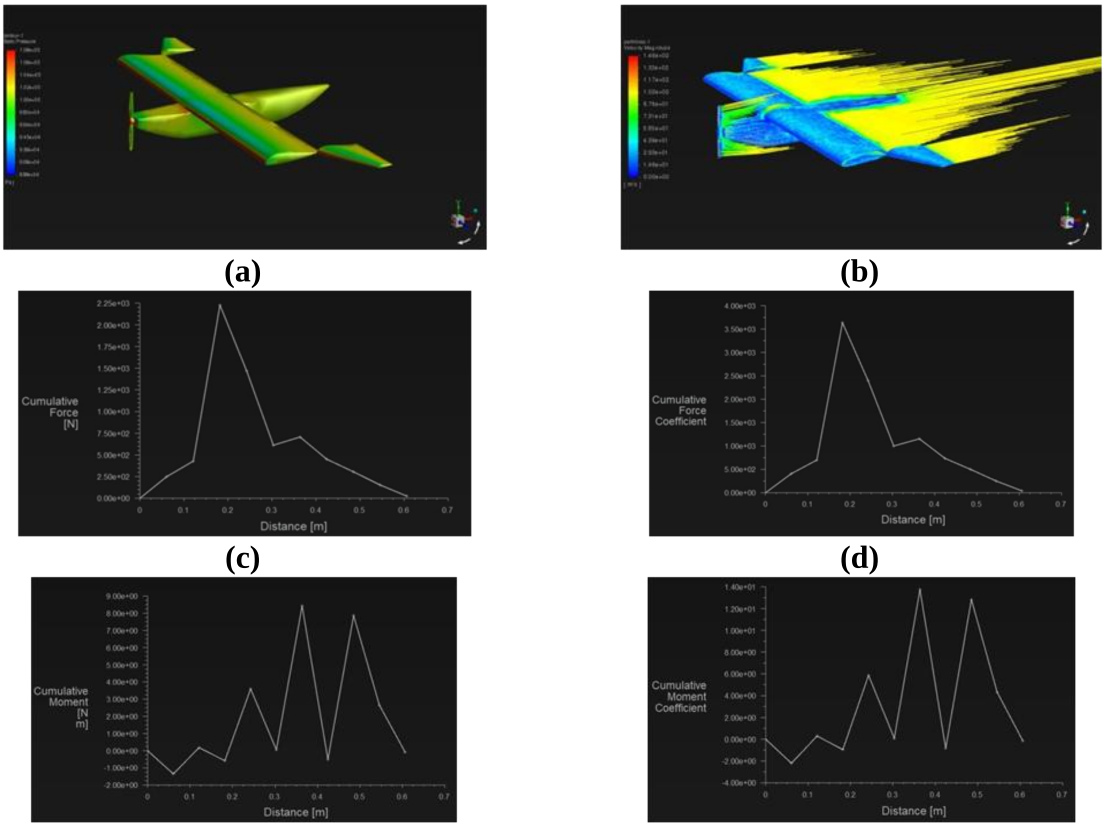


Zone Name
wall-farfield
Gauge Pressure [Pa] 101325
Mach Number 0.3
Coordinate System Cartesian (X, Y, Z)
X-Component of Flow Direction 0.956
Y-Component of Flow Direction 0.292
Z-Component of Flow Direction 0
Turbulence
Specification Method Intensity and Viscosity Ratio
Turbulent Intensity [%] 5
Turbulent Viscosity Ratio 10

Figure 11

V. RESULTS AND DISCUSSION

The pressure and velocity contour, Force and Moment curve for the MH78 wing small UAV at 0°AOA is as shown in Figure 12.



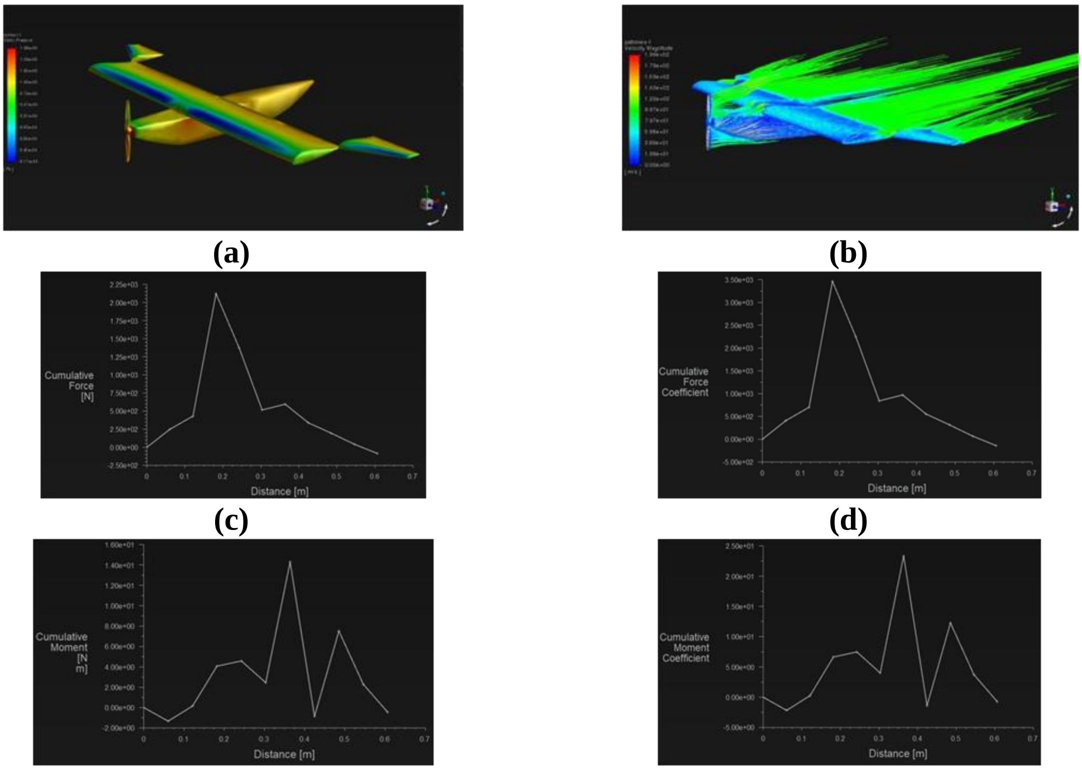
(a) (b)

(c) (d)

(e) (f)

Figure 12

The pressure and velocity contour, Force and Moment curve for the MH78 wing small UAV at 12° AOA is as shown in Figure 13.



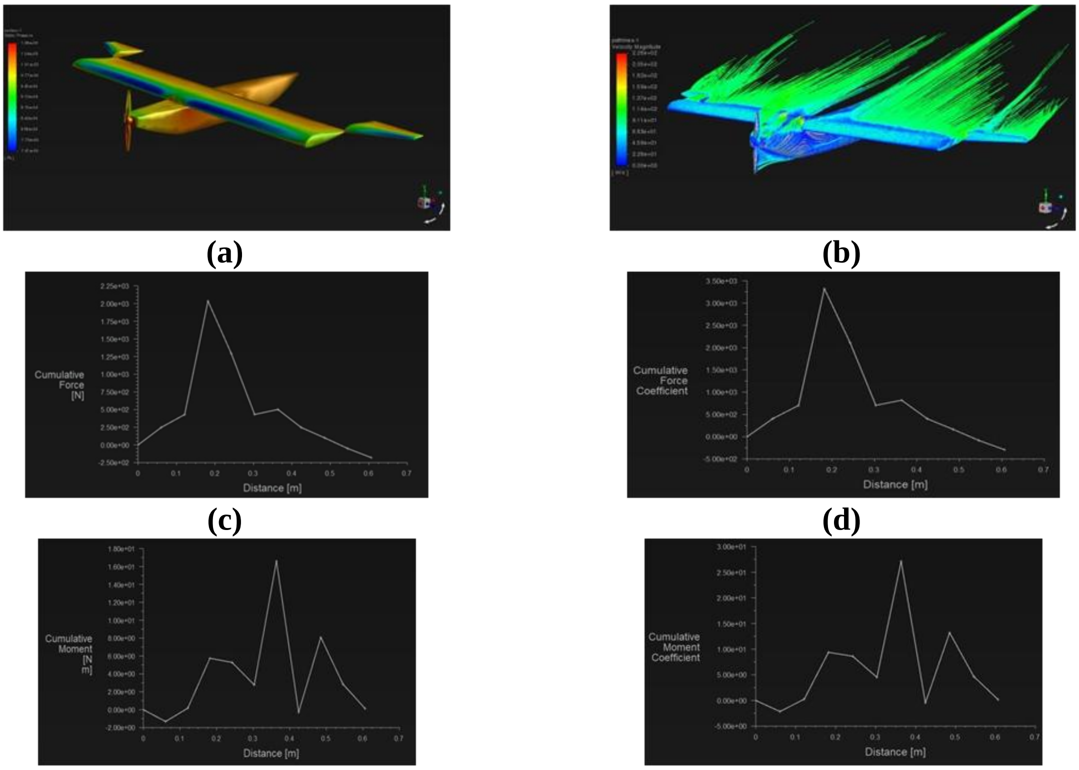
(a) **(b)**

(c) **(d)**

(e) **(f)**

Figure 13

The pressure and velocity contour, Force and Moment curve for the MH78 wing small UAV at 17° AOA is as shown in Figure 14



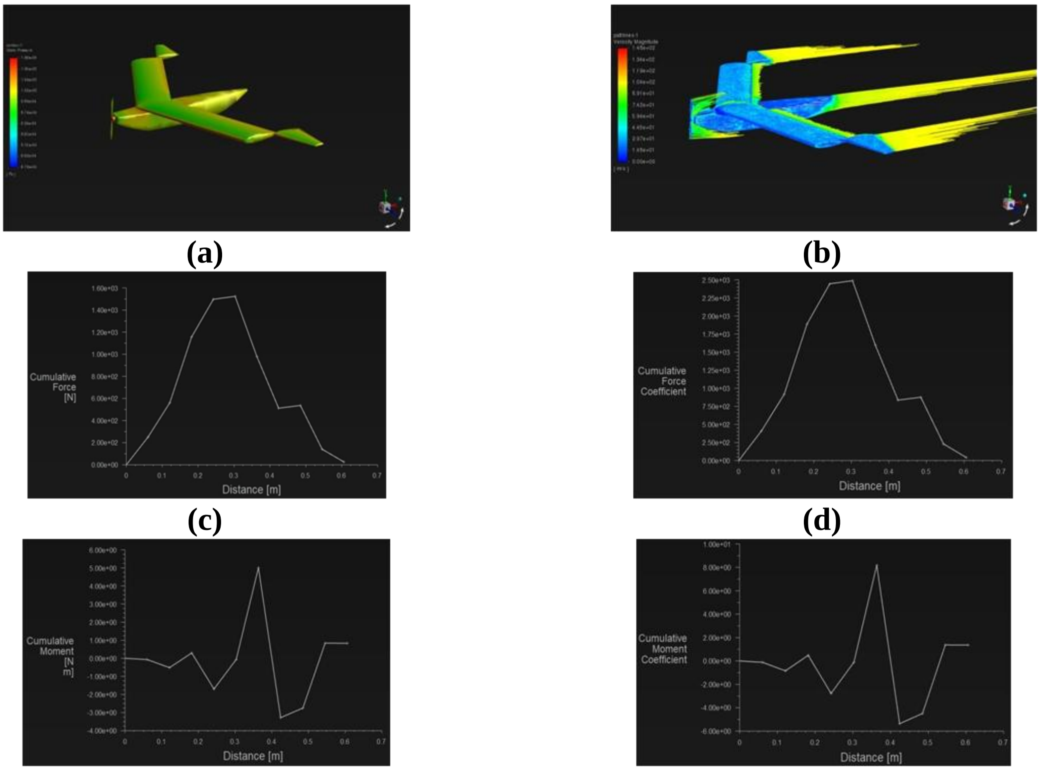
(a) **(b)**

(c) **(d)**

(e) **(f)**

Figure 14

The pressure and velocity cont our, Force and Moment curve for the MH78 swept wing small UAV at 0° AOA is as shown in Figure 15.



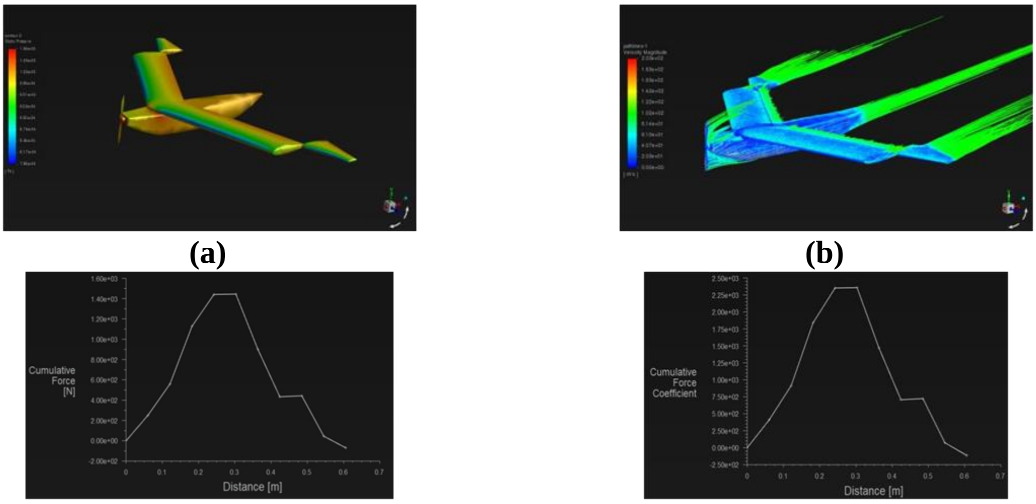
(a) (b)

(c) (d)

(e) (f)

Figure 15

The pressure and velocity cont our, Force and Moment curve for the MH78 swept wing small UAV at 12° AOA is as shown in Figure 16.



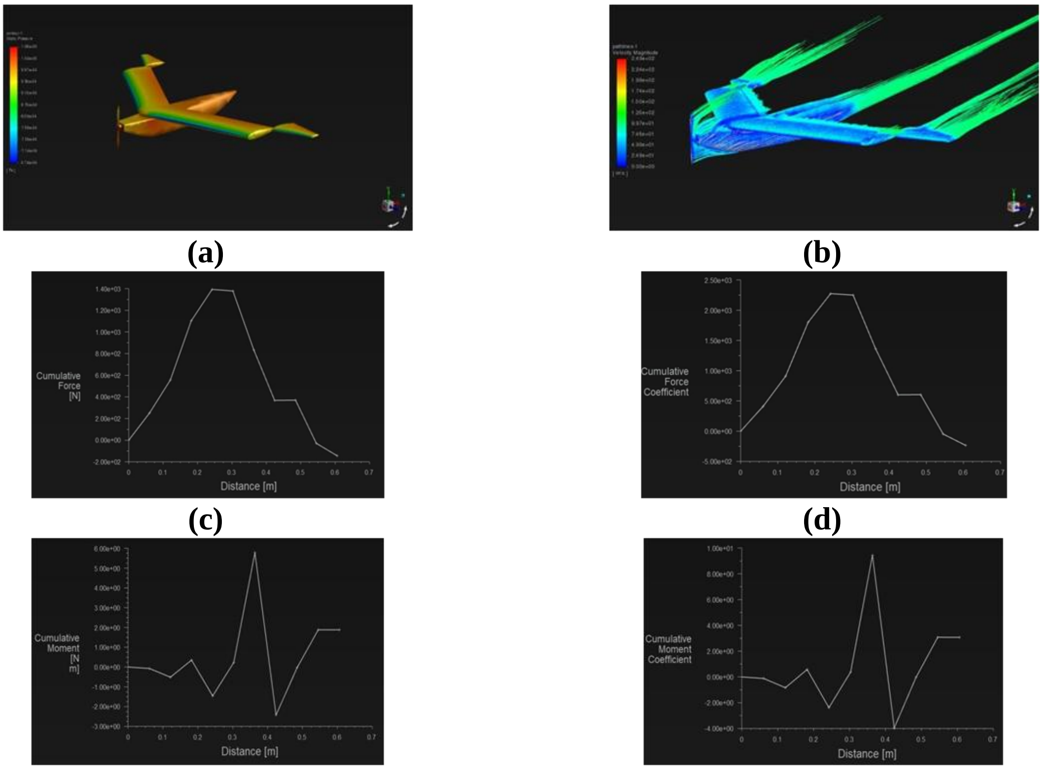
(a) (b)

(c) (d)

(e) **(f)**

Figure 16

The pressure and velocity cont our, Force and Moment curve for the MH78 swept wing small UAV at 17° AOA is as shown in Figure 17.



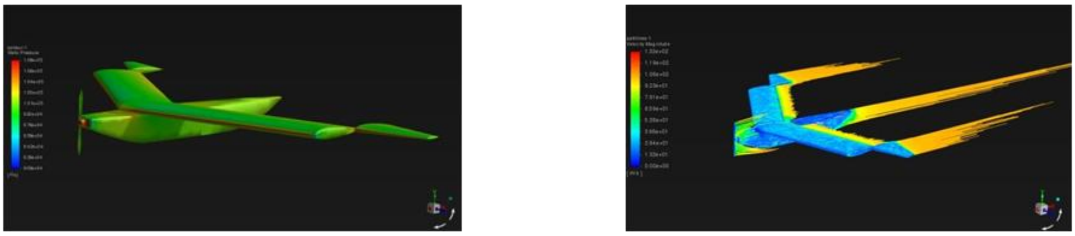
(a) **(b)**

(c) **(d)**

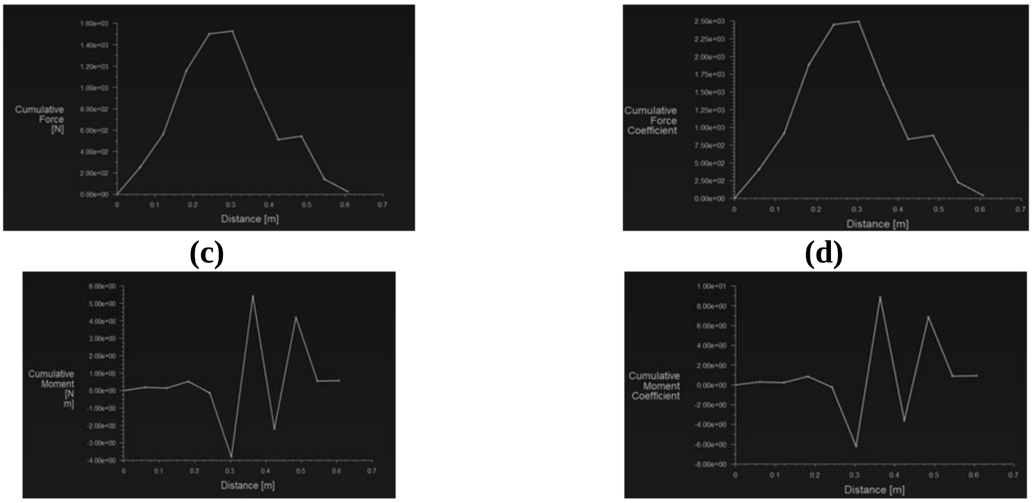
(e) **(f)**

Figure 17

The pressure and velocity cont our, Force and Moment curve for the NACA0015 swept wing small UAV at 0°AOA is as shown in Figure 18.



(a) **(b)**

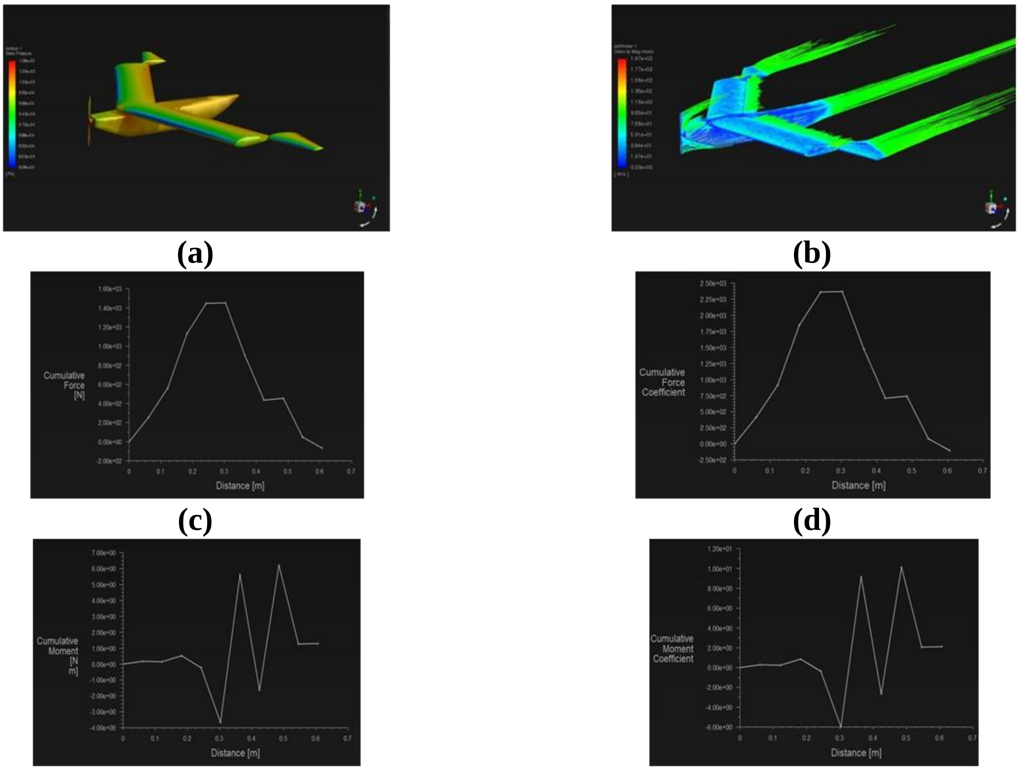


(c) **(d)**

(e) **(f)**

Figure 18

The pressure and velocity cont our, Force and Moment curve for the NACA0015 swept wing small UAV at 12° AOA is as shown in Figure 19.



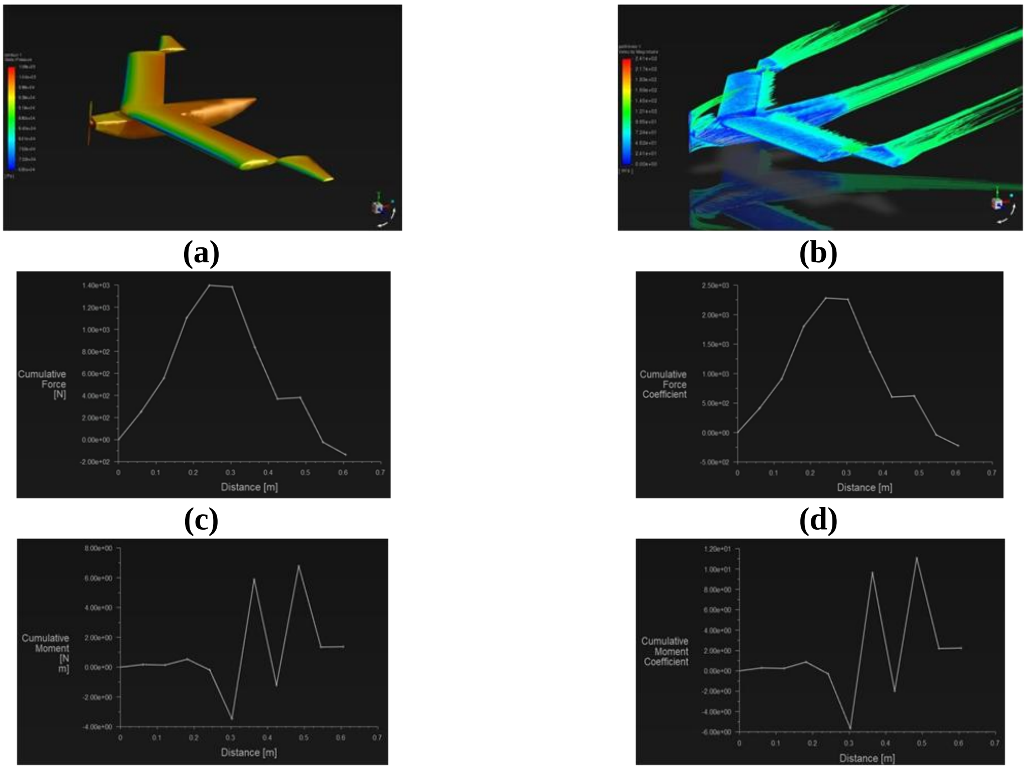
(a) **(b)**

(c) **(d)**

(e) **(f)**

Figure 19

The pressure and velocity cont our, Force and Moment curve for the NACA0015 swept wing small UAV at 17° AOA is as shown in Figure 20.



(a) (b)

(c) (d)

(e) (f)

Figure 20

From the above cumulative moment coefficient curves we can plot Pitching moment coefficient vs Angle of Attack curve as shown in figure 21.

Table of values for the curve:

AOA	MH78 (SWEPT)	NACA0015 (SWEPT)	MH78 (Normal)
0	1.4	0.96	-0.2
12	2.34	2.1	-0.4
17	3.1	2.2	0.1

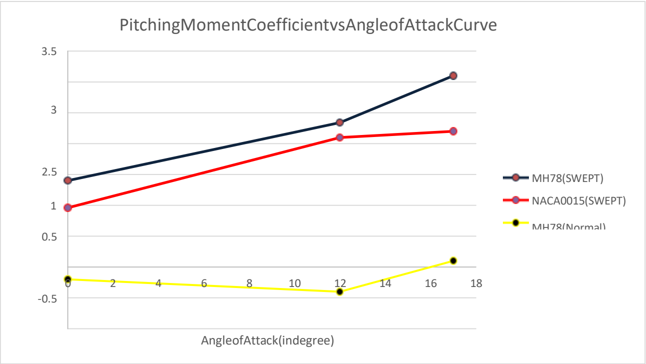


Figure 21

VI. CONCLUSION

As UAVs have been gaining significance in the research field, more and more patents and scientific articles are being published about new and upcoming designs. This rapidly expanding market paves way for more efficient and reliable models. The tailless configuration is a field which is gaining a lot of attention with it setting itself apart from the conventional design. This project concentrates on the optimization of the pitching moment of a semi-tailless configuration which enables for a better aerodynamic performance. This is achieved by using a re flexed airfoil-MH78 with a swept angle of 30°and the analysis was done in comparison with a conventional airfoil. The results were obtained by completing the CFD analysis and the outcome validated the improvement of the pitching moment over the conventional design with the focus being on aerodynamic stability at different angle of attacks. The designs provided a picture about the future prospect of the applications of the re flexed airfoils in the UAVs and conclude the semi-tailless designs can achieve better aero dynamics.

VII. REFERENCES

[1] B. Tipton, and D. Smith, "The preliminary design analysis of a unique semi-tailless aircraft configuration," *SAE Technical Paper*, 1995.

[2] D. Raymer, *Aircraft Design: A Conceptual Approach*, AIAA, 2018.

[3] K. Sreelakshmi, and K. S. R. Jagadeeswar, "Aerodynamic analysis over Unmanned Aerial Vehicle (UAV) using CFD," *IOP Conference Series: Materials Science and Engineering*, 2018.

[4] M. El Adawy, E. H. Abdelhalim, M. Mahmoud, M. A. Abo Zeid, I. H. Mohamed, M. M. Othman, G. S. ElGamal, and Y. H. ElShabasy, "Design and fabrication of a fixed-wing Unmanned Aerial Vehicle (UAV)," *Ain Shams Engineering Journal*, vol. 14, no. 9, 2023.

[5] M. Harish, N. Sankara Narayanan, G. Aswin Kumar, and J. Subramani, "Design, fabrication and aerodynamic analysis of RC powered aircraft wing," *International Research Journal of Engineering and Technology*, vol. 9, no. 7, 2022.

[6] M. Y. Zakaria, M. M. Abdallah, and M. A. Elshafie, "Design and production of small tailless unmanned aerial vehicle," *AMME Conference*, 2012.

[7] N. Qin, A. Vavalle, A. Le Moigne, M. Laban, K. Hackett, and P. Weinerfelt, "Aerodynamic Considerations of Blended Wing Body Aircraft," *Progress in Aerospace Science*, vol. 40, no. 6, pp. 321-343, 2004.

[8] S. M. Wong, H. W. Ho, and M. Z. Abdullah, "Design and Fabrication of a Dual Rotor-Embedded Wing Vertical Take-Off and Landing Unmanned Aerial Vehicle," *Unmanned Systems*, vol. 9, no. 1, 2021.

[9] S. S. Hedge, S. Nayak, R. Kishan, and N. Chavan, "A systematic approach for designing, analyzing and building a model RC plane," *International Journal of Engineering Research & Technology*, vol. 3, no. 12, 2014.

[10] W. Wisnoe, R. E. M. Nasir, W. Kuntjoro, and A. M. I. Mamat, "Wind Tunnel Experiments and CFD Analysis of Blended Wing Body (BWB) Unmanned Aerial Vehicle (UAV) at Mach 0.1 and Mach 0.3," *International Conference on Aerospace Sciences & Aviation Technology*, 2009.