International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Optimization of a3D Aircraft Morphing Wing with highly controllable Aerodynamic Performance

Anmol Krishna Mohan Chaudhary, Deepan C, Latshathipathi A, Arun S.R, Rakesh Kumar Shah

***Abstract:** the sole purpose of this project is to compare the aerodynamic performance of the modernistic wing with morphing techniques to the conventional one (i.e. wing with ailerons and flaps). The morphing wing is capable of enhancing the mission profiles through its significant geometrical changes in the surface areas (upper and lower area of wing). The primary aspiration is to calculate the C_L and C_D (coefficient of lift and drag) of real aircraft with conventional control surfaces and to compare its result with morphing wing. The morphing techniques also enables various prevention of aerodynamic losses (drag, vortices, noise, etc) caused due to geometrical discontinuities of conventional wing with aileron and flap in operating conditions (take-off, cruise, loiter, landing).Catia modelling of proposed wing is analysed by CFD method and to compare and contrast the aerodynamic performance with the conventional (hinged) wing.*

***Keywords:** Adaptive wing, Ansys, Catia, CFD, Fluent, metamorphosis, morphing, wing contour,*

I. INTRODUCTION

Within one century the aircraft industries have seen an exponential growth in the research and development of various aircraft components like flaps, stringers, slots, slats, stringers and elevator and empennage designs. The cross-section of the wing which is basically an aerofoil is used to provide the lift to an aircraft during several flights and take-off conditions. It also produces drag, the force acting opposite to lift. Drag is a major nuisance during the flight, but it plays an inevitable role during landing. The lift required for an aircraft depends on its purpose. Heavy aircraft requires more lift while the lighter ones need less amount of lift. Lift is the main source of the force for making an aircraft to fly (which is actually the perpendicular force to the thrust produced by the aircraft engine). Hence, knowing the coefficient of lift, the lift can be calculated. One cannot get something with nothing, so does the aircraft's lift is accompanied by the drag (a force opposite to the thrust produced by the engine) which reduces the performance of the aircraft resulting in more fuel consumption and lesser aerodynamic performance.

Inspired form birds, the dream of every aircraft designer is to design the most aerodynamically stable wing for the better performance of the aircraft, as wing is the major source of lift producing component for any aircraft. Also, they have to design it in such a way that it is operable in all flying conditions along with high aerodynamic performance. Currently all the aircraft wing's can be seen with conventional single point design (i.e. wing with flap and aileron). Thus, the unification in the design techniques with all the scientific methods for manufacturing of wing made available today helps to the greater innovation and credit in "morphing disciplines".

The benefits and challenges of morphing structures are well documented in works of literature. Given the recent advances in smart materials like reducing the weight and complexities of morphing systems, this advancement could make a significant step increase in aerodynamic efficiency. The morphing lifting surfaces for in-flight flow control resulted in drag reduction during the cruise and enhanced the lift performance during take-off and landing in a study conducted by NASA [1].

Wing morphing concept which seemed difficult and challenging in past is now being classified into three types, which is compartmentalized in Fig 1.

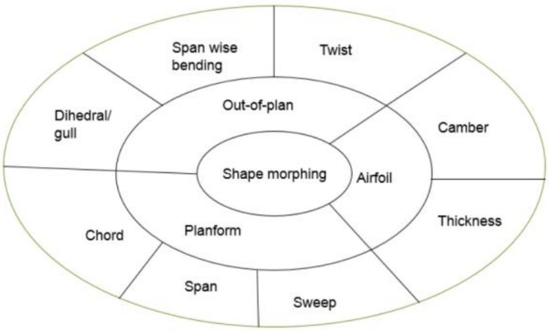

Fig 1. Morphing classification

Manuscript received on March 15, 2020.
Revised Manuscript received on March 24, 2020.
Manuscript published on March 30, 2020.
* Correspondence Author
Anmol Krishna Mohan Chaudhary*, Aeronautical Engineering, Excel Engineering College, komarapalayam, India. Email: anmolchaudhary243@gmail.com
Deepan C, Aeronautical Engineering, Excel Engineering College, komarapalayam, India. Email: deepan5798@gmail.com
Latshathipathi A, Aeronautical Engineering, Excel Engineering College, komarapalayam, India. Email: lachulatsha@gmail.com
Arun S R, Assistant Professor, Aeronautical Engineering, Excel Engineering College, Komarapalayam, India. Email: srarun900@gmail.com
Rakesh Kumar Shah, Aeronautical Engineering, Excel Engineering College, Komarapalayam, India. Email: rakeshkumarshah70@gmail.com

Airfoil adjustment is the less explored morphing technology. Airfoil adjustment is mainly concerned with cambered variation, although various research is being carried out in thickness change Austin et al. used variable-length trusses to reshape the airfoil and carried research.

The linear displacement actuators are placed diagonally inside the wing to perform airfoil adjustment morphing. [2]

Morphing mechanism using several frames elements which are moved by servo mechanism to perform the trailing morphing is used, which replaces the conventional control surfaces leading to weight reduction, quick maintenance, and improving aerodynamic performances due to various noise produced at the geometrical discontinuities formed when flaps and aileron are at operating conditions. Also, the morphing trailing edge would seal the gaps present at the end of the control surfaces in both chord wise and span-wise directions, eliminating the small pockets known for their high vorticity and a significant source of aerodynamic noise. [1]

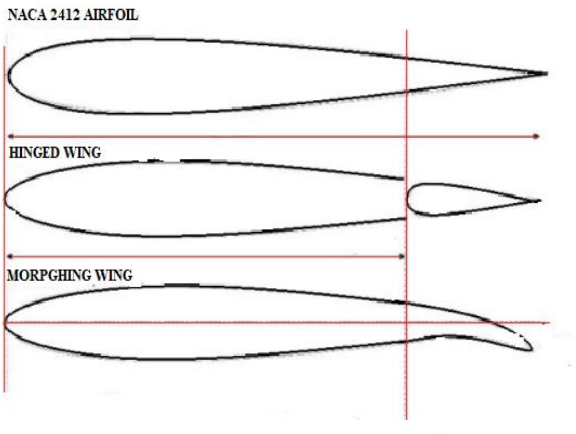

Fig 2. Different modifications of NACA2412 Airfoil Wing

II. AIRFOIL SELECTION

An airfoil is the cross-sectional shape of a wing when moving through a fluid produces an aerodynamic force. The force which is normal to the direction of the airflow is known as lift. The force parallel and opposite to the direction of movement of the aircraft and the engine thrust produced is called drag. Subsonic flight airfoil a rounded leading edge, followed by a sharp trailing edge. The lift is produced as the result of the airfoil's angle of attack. When oriented at an angle, a force results on the airfoil in the direction opposite to the deflection. This force is the aerodynamic force called lift and drag. The airfoil shape requires a positive angle of attack to generate lift, but cambered airfoil can generate lift at zero angles of attack.

In this study, the wing is modeled with NACA 2412(Fig 3.) airfoil. The NACA 4-digit series is used due to its smooth C type curve in the leading edge of the airfoil which can be used to house 3 different blocks which later can be used as the stiffness provider to the wing. The detailed information of the four digits airfoil is that the NACA 2412 is the unsymmetrical airfoil which has a maximum camber of 2% located at 40% from the leading edge, with a maximum thickness of 12%. The unsymmetrical airfoil produce lift even at zero-degree angle of attack.

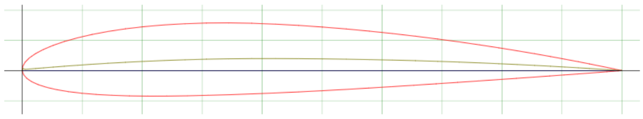

Fig 3. NACA 2412 Airfoil

The coefficient of lift for the various angle of attacks are simulated and experimentally measured as shown in figure.4

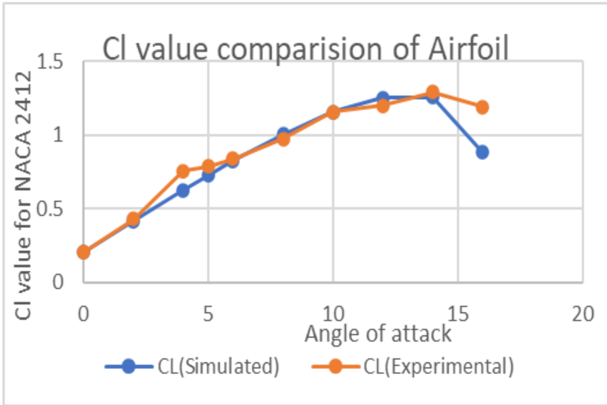

Fig 4, C_L comparion of NACA2412 at different angles of attack

III. WING DESIGN

The wing is the central part of an aircraft that produces lift while moving in a fluid-like air. The airfoil is an streamline body which is the cross section of the wing. The airfoil is the design which has the ability to produce more lift with less drag. When an airfoil is placed in an angle in the flow, an aerodynamic force lift will be generated. The lift is the upward pushing aerodynamic force that is produced due to the pressure difference created by the wing in a stream. According to Bernoulli's principle "when air flows along with the wing structure it creates a high pressure under the wing and a low pressure on the upper surface of the wing", by nature high pressure tends to move towards low pressure this transition results in the form of lift as shown in below figure.5.

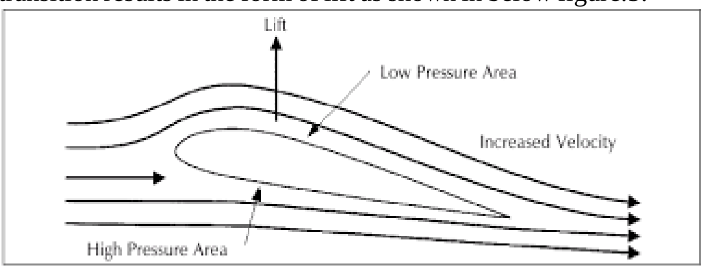

Fig 5. Pressure Distribution

The lift can be calculated from the pressure differences, the air velocity above and below the wing surface, or the momentum of the deflected air. Bernoulli's principle states that there is a mathematical relationship between the speed of the fluid and its pressure; hence if one of these parameters is known, it is straightforward to calculate the other. According to Bernoulli, the pressure difference occurs accompanying the difference in velocities. The lift for a wing can be determined from the lift equation. The equation is (1)

$$L=\frac{1}{2}\rho v^2 S c_L \qquad .1$$

Retrieval Number: F9141038620/2020©BEIESP
DOI: 10.35940/ijrte.F9141.038620
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The lift produced by a wing depends of a handful of factors, including the density(ρ) of the air, the velocity of the either the airflow or the speed of the aircraft, the viscosity and compressibility of the air, the wing surface area(S), the airfoil shape of the wing and the co efficient of lift(C_L).

The aircrafts that are being used are made up the same features which is not essential for all aircrafts. The wing of an aircraft has a rounded leading edge and a sharp trailing edge. An aircraft is maneuverer using primary and secondary control surfaces, the primary controls include the ailerons, elevators and flaps. The secondary control include flaps, slats, slots, tabs etc... The wing consists of ailerons, one of the primary control surfaces and most of the secondary control surfaces. (Fig 6.)

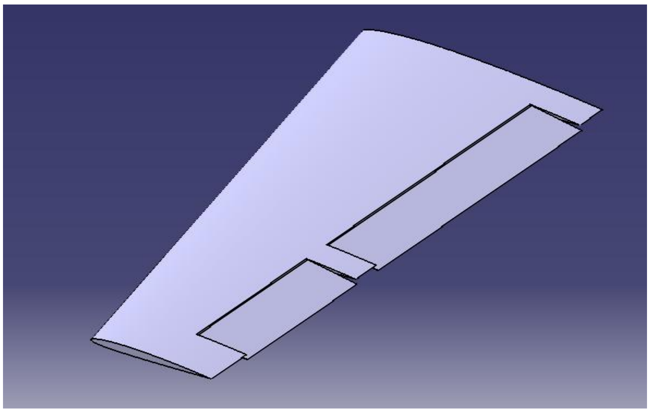

Fig 6. Conventional Wing

In this project, the main aim is to remove the control surfaces and to perform their function using trailing edge morphing. For designing of the morphing, the wing parameters of gulfstream III is selected and bend for the convenience of efficient functioning and processes. The wing is taken in a scaled ratio of 10:1 and the parameters are given in Table 1.

Span, b (m)	2.3
Chord, c (m)	0.5(root) 0.25(tip)
Wing area, S (m^2)	0.766
Aspect ratio, AR	6.906
Taper ratio, λ	0.5
Sweep angle, ʌ (°)	12.96
Twist angle, θ (°)	0

Table 1.-Wing parameters

The concept is morphing the trailing edge by varying the camberness. To obtain the deformation, the concept features camber morphing with multiple degrees of freedom. The morphing is done by moving compliant truss, which is connected to an electrical actuation system through runners. [4]

In the morphing operation, the actuating systems need a support from the morphing structure that can shape under actuation, provide loading capacity by eliminating unwanted degrees of freedom and from the profile of the air foil. As shown Fig.7 the segment consists of a solid wing box which occupies the 40% of the chord from the leading edge, a flexible upper surface, independent truss elements and solid trailing edge. The actuation systems are the lower surface of the segment, the trusses are hinged to the upper surface of the segment and runners run through it on the lower surface connected to electronic servo mechanism. The trusses have a Span wise shift to prevent interference with the neighboring trusses with low vertex angle of 60°. This compromises between the overall stiffness of the structure and the number of trusses. When the truss moves along with the runner, the morphing structure will bend or straighten, resulting in the change in the camber. The upper covered skin and the runners present on the lower surface will maintain a smooth curvature that assures aerodynamic efficiency [5]. The small elastic deformations undergone by the trusses are accommodated by their compliance. [4]

An advantage of this morphing structure is that it morphs with multiple degrees of freedom providing a wide range of camber line shapes. This is made possible by the independent actuation of the trusses and the rigid trailing edge. [4]

Morphing strategy	**Purpose**	**Morphing level**
Variable Camber	Performance C_L/C_D Noise reduction Flight control (roll, pitch, yaw)	Low
Variable thickness	Performance C_L/C_D Low-speed performance improvement	Low
Twist morphing	Flight control (roll, pitch)	Medium
Span morphing	Performance C_L/C_D Flight control (roll)	High
Variable sweep	Performance C_L/C_D Flight control (turn radius) Disturbance rejection (crosswind)	High
Folding wing	Performance C_L/C_D	High

Table 2. Morphing strategies and purposes [6]

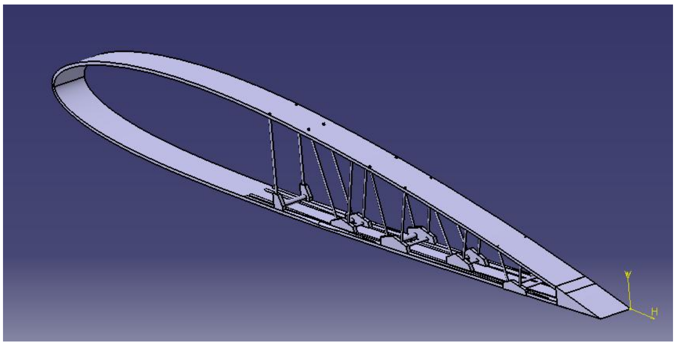

Fig 7. Cut-Section of Morphing Mechanism

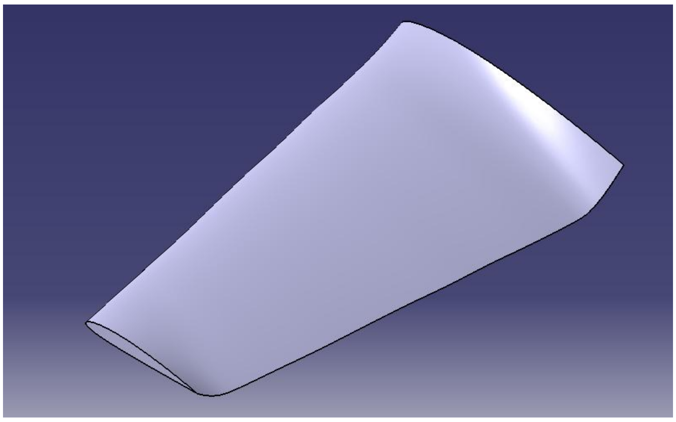

Fig 8. Morphing with Control surfaces at 10°

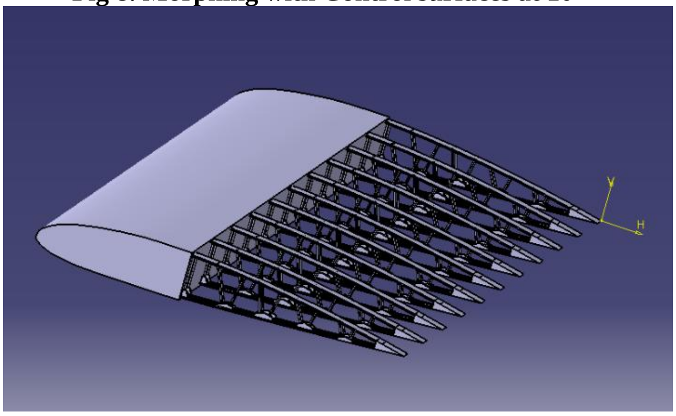

Fig 9. Wing with proposed Morphing Mechanism

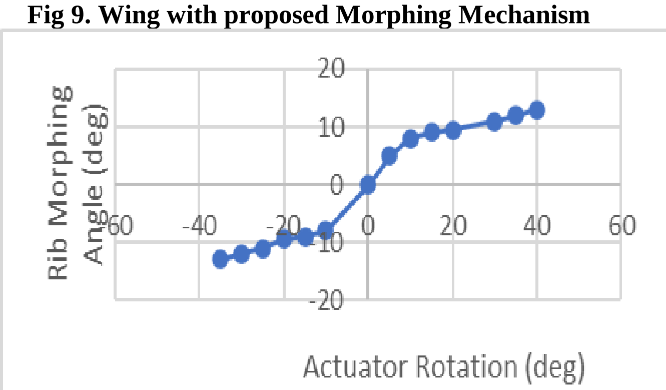

Fig 10. Rib morphing angle vs actuator rotation graph

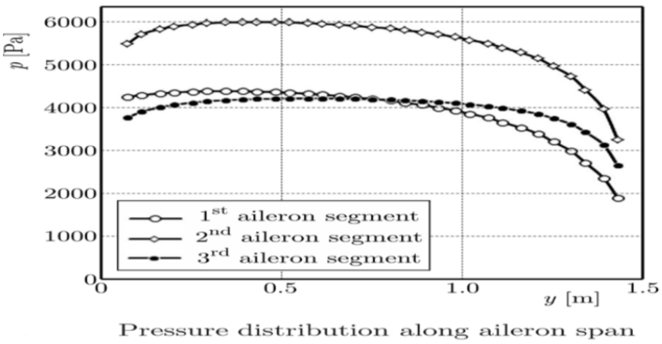

Fig 11. Pressure distribution along aileron span

IV. PROBLEM DEFINITION

Computational fluid dynamics (CFD) analysis of the statically morphed wing is compared with a conventional wing (i.e. hinged flaps and aileron) with the help of analysis software. All configurations were studied at a Reynolds number based on the chord length of Re=0.62×10^6, and a Mach number of 0.147. A range of Angle of Attack (AoA) from 8° to 16° was considered for the steady analysis. The scale ratio of the actual wing to the wing geometry in Ansys is 10:1. The Shear Stress Transport (SST) model was utilized to model in all studied configurations whose performances were evaluated for a range of angles of attack. It was found that the morphing wing displays an increased aerodynamic efficiency compared with the hinged flap configuration at low angles of attack, yet the performance of the morphed wing deteriorates at higher AoA while the hinged wing performs consistently. [1]

V. THEORETICAL CALCULATION

In this simulation, three-dimensional flow features have been observed. Also, the vortices forming downstream on the trailing edge of the wing, due to interaction of high- and low-pressure zones is visualised. The lift coefficient of the morphing wing is calculated by considering aerofoil as a part of an infinite wing. The airfoil used is unsymmetrical, hence it produces lift even at zero-degree angle of attack. From the calculation of slope for an infinite wing using its characteristics a_0 was calculated.

From this, a lift curve slope for the finite wing can be corrected for a swept wing. This correction is required since the free stream Mach number is not seen by the entire wing and instead the wing sees a lesser Mach number, delaying the onset of a shock and increasing the critical Mach number.

$$a = \frac{a_0 \cos\Lambda}{\sqrt{1+\left(\frac{a_0 \cos\Lambda}{\pi AR}\right)^2+\frac{a_0 \cos\Lambda}{\pi AR}}} \quad .2$$

To use above equation, Aspect ratio formula was used:

$$AR = \frac{b^2}{S} \quad .3$$

Where b is the span and S is the planform area of the wing.

For finite wings, the lift curve lower than for infinite wings was seen due to 3D effects. After which the coefficient of lift for the wing was calculated by formula:

$$Cl0 = a\,(\alpha - \alpha L) \quad .4$$

For unsymmetrical aerofoil α_L is not equal to 0. Also, for the incompressible flow regime, correction at M=.146 is required which is given by formula:

$$Cl = \frac{C_{l0}}{\sqrt{1-M_\infty{}^2}} \quad .5$$

Retrieval Number: F9141038620/2020©BEIESP
DOI: 10.35940/ijrte.F9141.038620
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

VI. AERODYNAMIC CALCULATION

ANSYS-FLUENT is being used to calculate the aerodynamic characteristic of the morphing profile and wing section. The conditions selected in for CFD computations are tabled below

flight velocity V	50 m/s
air density ρ	1.225 kg/m3
Viscosity μ	1.789e-5 kg/m-s

Table 3: CFD parameters

k-omega SST model was used for analysis with an incompressible condition and several other conditions (compressible) was also carried out. The δm was considered as the morphing deflection of the airfoil resulting the deflection of the entire wing, and different δm were calculated: δm=0°, δm =8°, δm =10°, δm =12°, δm =14° and δm =16°. All these configurations were analyzed in a zero angle of attack. During analysis, lift coefficient (C_L) and drag coefficient (C_D) were calculated. The aerodynamic characteristics for the different morphing deflection were analyzed in order to find the optimum deflection angle where high lift and low drag can be generated at zero angle of attack. The pressure and velocity contour for the morphing wing with control surfaces at 10° is given in Fig 12. And Fig 13.

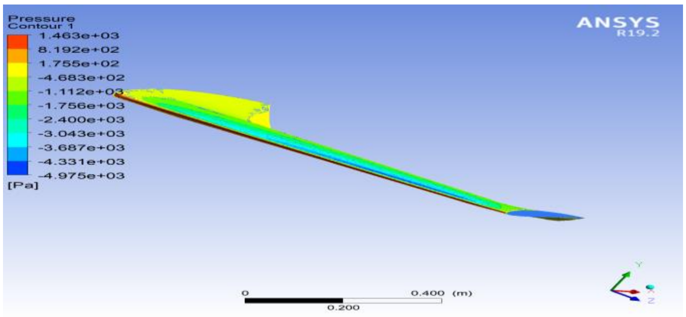

Fig 12. Pressure Contour of Morphing Wing.

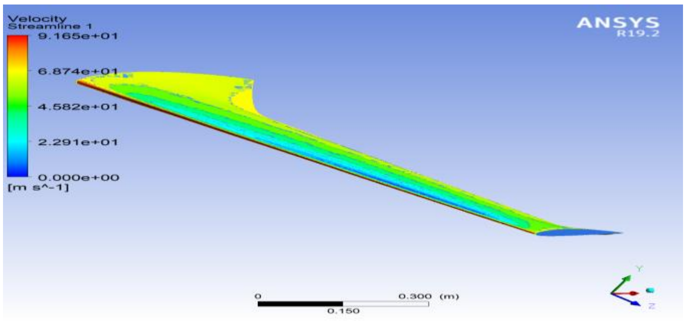

Fig 13. Velocity Contour of Morphing Wing.

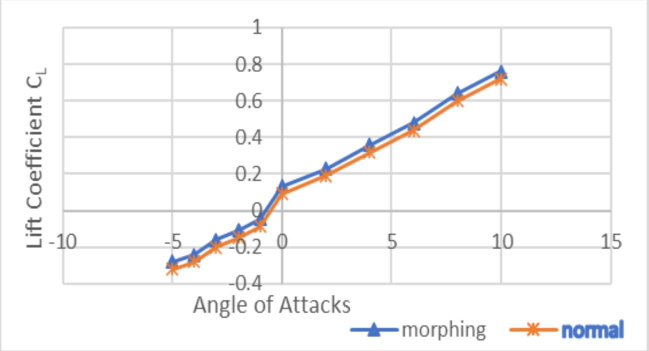

Fig 14. C_L variation in morphing and conventional wing

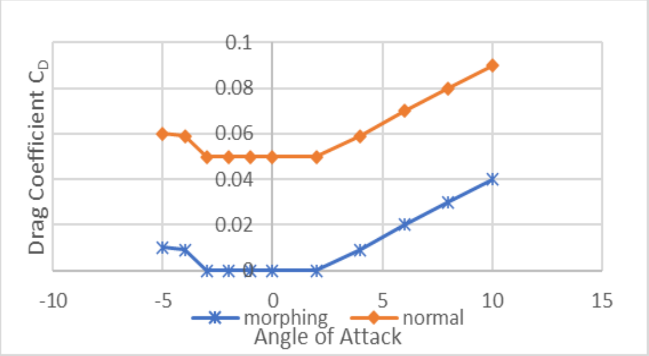

Fig 15. C_D variation in morphing and conventional wing

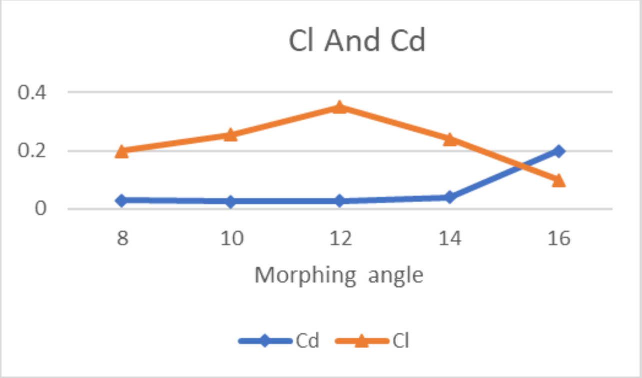

Fig 16. C_L and C_D graph for morphing wing

VII. CONCLUSION AND FUTURE WORK

The proposed morphing wing was analysed in ANSYS along with the conventional wing (with aileron and flaps being deflected). The various aerodynamic parameters were thus plotted in excel sheet to see the percentage increase in the performance of the morphing wing occurred due to the elimination of the aerodynamic losses due to the geometrical discontinuity observed in the conventional wing. It was seen that 40 % better aerodynamic efficiency due to the flawless transition contribution to the lift in comparison with the conventional wing [1] was verified successfully. Also, it was seen that morphed wing revealed deteriorating performance at higher angles of attack while conventional wing shown consistency in its aerodynamic performance.

The results achieved through this analysis will give a promising future for this design in either real aircraft wing or any Remotely piloted aircrafts (RC's planes).

Finally, wind tunnel test will be done with the entire wing with morphing concept. This is mainly to verify the aerodynamic performances of the real scaled working model. The work followed is to fabricate the working model of morphing wing with a 3D printed parts, assembled with the servo actuators for controlling the aerodynamic surface of the wing contour. The wing will be analysed experimentally in our own subsonic wind tunnel with the speed of 20 km/hr to get more characterization. The morphing deflection considered will in the range of 8° to 16° as per the theoretical calculation for high aerodynamic performances.

ACKNOWLEDGMENT

We might want to accept this open door to offer our significant thanks and profound respect to Mr. S. R Arun for his praiseworthy guidance, valuable criticism and consolation all through the length of the research. We might likewise want to give our earnest appreciation to all the companions and partners of TEAM 2020 [7], without which this exploration would be fragmented. We do thanks to almighty for keeping us healthy during the successful completion of this project.

REFERENCES

1. Chawki Abdessemed, Yufeng Yao, Abdessalem Bouferrouk, Pritesh Narayan. "Analysis of a 3D Unsteady Morphing Wing with Seamless Side-edge Transition", 2018 Applied Aerodynamics Conference, 2018 Analysis of a 3D Unsteady Morphing Wing with Seamless Side-edge Transition Chawki Abdessemed, Yufeng Yao, Abdessalem Bouferrouk, Pritesh Narayan Department of Engineering Design and Mathematics, University of the West of England, Coldharbour Lane, Frenchay, Bristol BS16 1QY, United Kingdom.
2. Joan Marc Martinez, Domenico Scopelliti, Cees Bil, Robert Carrese, Pier Marzocca, Enrico Cestino, Giacomo Frulla. "Design, Analysis and Experimental Testing of a Morphing Wing", 25th AIAA/AHS Adaptive Structures Conference, 2017.
3. Antonio Concilio, Leonardo Lecce. "Historical Background and Current Scenario", Elsevier BV, 2018http://team2020.rf.gd
4. www.research.manchester.ac.uk.
5. R. Wu, C. Soutis, S. Zhong, A. Filippone. "A morphing aerofoil with highly controllable aerodynamic performance", The Aeronautical Journal, 2016.
6. Daochun Li, Shiwei Zhao, Andrea Da Ronch, Jinwu Xiang et al. "A review of modelling and analysis of morphing wings", Progress in Aerospace Sciences, 2018.
7. http://team2020.rf.gd

AUTHORS PROFILE

Mr. Anmol Krishna Mohan Chaudhary currently pursuing final year of Aeronautical Engineering. Research interest includes Propulsion, Aerodynamics, Structural Integration of the Aircraft and Aircraft modelling (RCs and UAVs). Also, into the research of Jet Engine optimizations. anmolchaudhary243@gmail.com

Mr. Deepan C, currently pursuing final year of Aeronautical Engineering. Research interest includes Propulsion, Aerodynamics, Structural Integration of the aircraft and Aircraft modelling (RCs and UAVs). deepan5798@gmail.com

Mr. Latshathipathi A, currently pursuing final year of Aeronautical Engineering. Research interest includes Propulsion, Aerodynamics, and Structural Integration of the aircraft. **lachulatsha@gmail.com**

Mr. Arun S R, Assistant Professor in department of Aeronautical Engineering. Pursuing research in the field of Missile guidance systems. Having six years of teaching experience in Aeronautical Engineering. Published more than 10 papers in conferences and journals. Also, into the research in morphing technology. **srarun900@gmail.com**

Mr. Rakesh Kumar Shah, currently pursuing Second year of Aeronautical Engineering at Excel Engineering College, Tamil Nadu, India. Research interest includes Aerodynamics, Propulsion, Aircraft Model designing (RCs and UAVs). Also, into the Research of Structural Integration of Aircrafts. **rakeshkumarshah70@gmail.com**