

Design, Analysis and Experimental testing of a new wing morphing structure

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in
Aeronautical Engineering

By

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DEPARTMENT OF AERONAUTICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade “A” by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Hrithik S Vichare (Reg. No. 37260016)** and **Shreejesh Muruges (Reg. No. 37260040)** who carried out the project entitled "**Design, Analysis and Experimental testing of a new wing morphing structure**" under our supervision from November 2020 to March 2021.

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DECLARATION

We **Hrithik S Vichare (Reg. No. 37260016)** and **Shreejesh Muruges (Reg. No. 37260040)** hereby declare that the Project Report entitled “**Design, Analysis and Experimental testing of a new wing morphing structure**” done by us under the guidance of **Dr. Boomadevi Ph.D** is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering.

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SIGNATURE OF THE CANDIDATE

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ABSTRACT

Aircraft flight performance can be increased by improving the wing design. But these fixed wings are not efficient as these wings are not able to provide maximum flight conditions at all flight conditions. So the need for wings to evolve became necessary and a method was proposed that will change its structure so it favors the present flight condition. This method was known as morphing wing. Morphing wing can be classified into three types like wing planform alteration, wing out of plane transformation and airfoil adjustment. Each morphing concept has the possibility in improving the aircraft performance in multiple mission flight. Morphing wing surfaces change its shape during flight with view to improve the aerodynamics and flight performances of aircraft. This idea was inspired from bird flight which was able to change its wing shape depending on different situation. Such wing will enable the aircraft to perform flight missions more efficiently and will also be able to accommodate multiple flight regimes and obtain better flight performance. This method offers simpler mechanism to replace those active control devices implementation on actual aircraft design.

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LIST OF SYMBOLS AND ABBEREVIATIONS

UAV	Unmanned Aerial Vehicle
CST	Class-Shape function Transformation
MLE	Morphing Leading Edge
LE	Leading Edge
RC	Remote Control
b	span, m
c	chord, m
S	wing area, m ²
AR	aspect ratio
λ	taper ratio
Λ	sweep angle, deg
θ	twist angle, deg

ρ	density, kg/m ³
μ	viscosity, kg/s*m
V	velocity, m/s
C_L	Lift coefficient
C_D	Drag coefficient
C_M	moment coefficient
FEM	Finite Element Method
CNC	Computer Numerical Control

CHAPTER 1

INTRODUCTION

Flying industry has been looking profoundly into the methods of accomplishing better execution efficiently and Maximizing lift to drag proportion altogether flight conditions. Presently and for the most part fixed wings are being utilized generally wherever yet the outcomes are not as the specialists and originators would consider. So to conquer this scientists returned to when Wright Flyer was utilizing turn transforming, from here they got a thought of using and improving transforming wing innovation. Since the fixed wing can not be utilized adequately and productively on the whole flight conditions, the transforming wing is the most ideal approach to accomplish elite efficiently and furthermore it expands lift to drag proportion taking all things together flight conditons by changing its shape contingent upon the circumstances.

Morphing wing or wings which have the ability to change shape and geometry have interested many scientist over this technology as it reduces the time required and the complexity of the design. This morphing wing structure can reduce the opposing forces acting on an aircraft. These structures have a great advantage over the conventional wing structure as conventional wing structures contains discontinuous section which causes aerodynamic losses, which helped researchers to find this morphing wing technology.

1.1 MORPHING AIRCRAFT TECHNOLOGY

In the age of Industrial Revolution many forefathers used morphing technology for aviation purposes this type of technology was inspired by birds, bats and many specific biologically evolved features which provided flight for most species. Earlier the manmade flight was through ornithoptors or flapping wings powered by man-power. Leonardo da Vinci in 15th century introduced some design which were inspired by birds and bats and were designed with the inspiration of their exo-skeleton. In today's age their are morphing wing aircraft are currently used, each with the intension of enchanting the flight performance.

1.2 CONVENTIONAL WING

This wing structures contains many different moving parts which help the aircraft to easily maneuver the flight in any direction. Every part is a discontinuous section which moves according to the command of the pilot.

1.3 MORPHING WING

This wing structure can automatically or manually adapt to the rapid change in terrain and can adjust according to the surrounding to get the best aerodynamic efficiency which can be given in a flight condition. These structures have less or no moving parts which are discontinuous to the wing surface. The internal of the wing adapt to the rapid change and move accordingly. There are mainly three types of morphing wing classification all these type can be used to achieve greater aircraft performance. We can also use two of different type to improve the performance even higher of the aircraft during flight.

1.3.1 Types of Morphing wing

- 1) Airfoil
- 2) Out-of-plane
- 3) Planform

1.3.1.1 *Airfoil*

The change in the shape of the airfoil while morphing is one type of morphing which can change its camber and thickness. Change of camber or thickness can reduce drag and provide with a more efficient flight.

1.3.1.2 *Out-of-plane*

The change in the wing structure with the help of external mechanism to change its twist, dihedral/gull and bending is called as out-of-plane morphing. This type of morphing can change the wings angle with twisting of the wing or by making the wing dihedral.

1.3.1.3 Planform

The change in measurement of the wing through extension or contraction is planform morphing. This change in measurement can be in its sweep, span or chord and affects the aerodynamic of the wing and provide with efficient drag which can adjust according to the need of the flight with the help of some actuators.

1.4 MORPHING WING AIRCRAFT

Numerous Aircrafts utilized transforming wing innovation since the hour of Wright Brothers, Following are the rundown of Morphing wing airplanes:

Table 1.1 : List of morphing wing aircraft

AIRCRAFT	YEAR	MORPHING TYPE
Wright Flyer	1903	Twist
Pterodactyl IV	1931	Sweep
MAK-10	1931	Span
IS-1	1932	Bi-to monoplane
LIG-7	1937	Chord
MAK-123	1947	Span
X 5	1951	Sweep
XF10F	1952	Sweep
F 111	1964	Sweep

XB 70	1964	Span Bending
SU 17 IG	1966	Sweep
MIG 23	1967	Sweep
SU 24	1967	Sweep
Tu 22 M	1969	Sweep
F 14	1970	Sweep
FS 29	1972	Span
B 1	1974	Sweep
Tornado	1974	Sweep
AD 1	1979	Obliquing
Tu 160	1981	Sweep
AFTI/F 111	1985	Mission adaptive wing
F/A 18	2002	Active Aeroelastic Wing

CHAPTER 2

LITERATURE SURVEY

Benjamin Jenett, Daniel Cellucci, Kenneth C. Cheung, Neil Gershenfeld, Nick Cramer, Sam Calisch and Sean Swei (2017) Digital Morphing Wing: Active Wing Shaping Concept Using Composite Lattice-Based Cellular Structures.

Essential specialized test tended to by this work is the utilization of this strategy to design and fabricate low thickness, profoundly protest mechanical design with spatially tuned solidness. The determination in this design, examination, creation and execution of a flexible continuum mechanical technology structure with heterogeneous properties in the form of span-wise twisting wing.

Andreas Hauffe, Florian Dexl and Klaus Wolf (2020) Multidisciplinary multi-objective design optimization of an active morphing wing section.

The point of this is to discover primary designs of morphing wings that empower efficiently improved shape changes without characterizing the objective state of deduced. This paper gives the technique to join the enhancement of the dynamic design of a wing segment, defined by Lindenmayer cell frameworks, with a streamlined assessment. The conclusion is a improvement of the inner surface of a functioning morphing wing area including direct compression and development actuators.

Mauricio Vicente Donadon, Lorenzo Iannucci (2014) A Numerical study on smart material selection for flapped and twisted morphing wing configuration.

Investigation of material relying upon the variables including quick unique reaction, low weight, ability to work over a wide scope of flight conditions and low force utilizations. A survey on smart materials advancements for UAV morphing wing. The fundamental examination present in this paper recommends single crystal (PZN-PT) materials as possible possibility for smart morphing wing structure

because of its quick reaction with greatest proficiency for both morphing arrangements concentrated in this work.

K Arunkumar, K Veeranjanyulu, M Srikanth, Om Prakesh and Shreekanth Sura and (2020) Mechanism and performance analysis of morphing wing.

String bar system is introduced at the trailing edge of the wing to wrap. Relative displacement among upper and lower skin of wing prompts have twisting wing. It finished up dependent on the twisting system on the trailing edge, morphing wing execution has been examined at lower approach. Wrapping displacement could be made in a straight wing by putting string rod mechanism at the threading edge.

Erdogan Kaygan, Ceren Ulusoy (2018) Effectiveness of twist Morphing wing on Aerodynamic performance and control of an aircraft.

In this paper viability of contort fluctuated wing setups for airplane control and performance is portrayed it involves changing wing twist angle of the wing. The conclusion involves variable wing twist concept has been numerically investigated.

Abdesselam, Beufferok, Chawki Abdessemed, Pritesh Narayan, and Yufeng Yao (2017) Unsteady parametrization of a morphing wing design for improved aerodynamic performance.

The point is a philosophy that utilizations adjusted parametrization strategy to characterize transforming calculation and applies client characterized capacities to produce dynamic cross section around it for flimsy stream investigation. The investigation of morphing wing utilizing a changed CST technique and a client characterized work was introduced.

Vishesh Gupta, Jake Salzman, Dylan King and Jason Lohn (2012) Intergration and Control of morphing wing structures for efficiency/performance.

The purpose of this project is to investigated distributed wing-shape morphing flight control for increased fuel efficiency and performance. The study concluded that parallelization of the simulation model to increase run-time performance.

Allan Daniel Finistauri (2012) Conceptual Design of a Modular Morphing wing

A new modular design method for morphing wings is presented a design method was created, applying modularity and reconfigurability to a morphing wing system. This dissertation presented the conceptual design of a modular morphing wing.

Haisong Ang, Hongda Li (2016) Preliminary airfoil design of an innovative adaptive variable camber compliant wing.

An advancement versatile variable camber agreeable wing, with skin that can change thickness and following edge transforming component that is planned dependent on another sort of fake muscles installed in, this following edge morphing system is amazingly light in weight and proficient in reconfiguration of the wing sectional profile. This close a versatile variable camber protest wing, which can change thickness and transform following edge with driving component made of another sort of fake muscles implanted in skin, is designed.

David Communier, Tony Wong, Franck Le Besnerais and Ruxandra Mihaela Botez and (2019) Design, Manufacturing and Testing of a New concept for a morphing leading edge using a subsonic blow down wind tunnel

This study present the design and wind tunnel test consequences of a wing including a morphing leading edge for a medium automated flying vehicle with a greatest wingspan of 5m. The outcome in this paper in regards to investigation of MLE framework conduct in a subsonic air stream have shown that this framework can follow up on the slow down point as LE fold, and accordingly that a MLE is a decent option in contrast to a LE fold.

Andrea Da Ronch, Anton Rudenko, Daochun Li, Shiwei Zhao, Hans Peter Monner, Jinwu Xiang, Jernej DroFelnik, Johannes Kirn, Yongchao Li, Lu Zhang, Yining Wu, Markus Kintscher, Shijun Guo, Weilong Yin, Stefan Storm, Roeland De Breuker (2018) A review of modelling and analysis of morphing wings.

This review talks about the most conspicuous instances of morphing ideas with applications to two and three dimensional wing models. This finished up many demonstrating and investigation techniques for morphing ideas have been proposed, a couple have been tried. More flight test ought to be directed for morphing wing airplanes to check the modeling and analysis strategies.

Haipeng Gu, Huajie Hong (2020) Research and improvement on design method of morphing wing aircraft.

A sensible examination of the streamlined format of the airplane wing is done, and countless information research is done on the main aileron. It concluded the development of linear variable wingspan aircraft and possible technical routes are analyzed, and different technical routes are also theoretically analyzed.

Dr. R Rajendran Govind, Yogeshwara V Bhat, Vishisht Adithyan, Ananya C (2020) Analysis of Morphing Airfoil Structures and Experimentally Reviewing its Performance.

This paper briefs about the morphing airfoil with variable camber and it utilizes agreeable rib system. Lightweight framework for activation, agreeable inward construction and an adaptable skin are a portion of the critical necessities for such components. It closes the system was verified for captivating streamlined just as primary effectiveness. The plan was manufactured and the structural analysis was experimentally verified.

Nathanael J Curiale, David W Zingg (2018) Morphing Wing: A study using Aerodynamic shape optimization.

Through high-constancy streamlined shape improvement, different types of morphing wings are evaluated for a speculative local class airplane. This came about Aerodynamic shape improvement has been applied to a theoretical local class airplane to investigate the impacts of morphing wings and evaluate the potential advantages this innovation can have on an airplane.

Mugeshwaran A, Guru Prasad Bacha, Rajkumar S (2018) Design and experimental analysis of morphing wing based on biomimicry.

This paper describe about investigation of streamlined in the multi-area transforming wing variety of pattern setup to camber arrangement. A morphing wing, utilizing six rib area with dc engine and basic linkage framework installed inside the wing was planned as intends to fluctuate the state of a wing dependent on biomimetic.

Richard W. Guiler (2007) Control of a swept wing tailless aircraft through wing morphing.

This paper talks about the control which can be achieved by on a tailless swept wing with the help of morphing wing in aircraft. This research project built up a versatile washout morphing component for the command of a swept wing tailless airplane.

Manoranjan Majji, Bong Su Koh, John L. Junkins, Othon K. Rediniotis, Sunil C. Patel (2005) Morphing Wing: A Demonstration of Aero Servo elastic distributed sensing and control.

This paper details efforts made in the design, analysis, and control of a novel morphing wing for NASA utilizing cutting edge intelligent material technology. It concluded the PRAND2G FORTRAN code has been modified and used to show its applicability for future comparison with the wind tunnel testing result. The aerodynamic characteristic of the morphing wing are multi-linearly dependent on the three twisting sections.

Yvan Wilfried, Tondji Chendjou (2016) Morphing wing: Experimental boundary layer transition determination and wing vibrations measurements and analysis.

This worldwide project comprise of configuration, production and testing of a transforming wing box equipped for changing the state of the adaptable upper skin of a wing utilizing an actuator framework introduced inside the wing. These commitments incorporate the obtaining, post-preparing and understanding of the

pressing factor trial information during IAR-NRC air stream tests on a morphing wing tip.

R. M. Botez (2015) How the airfoil shape of a morphing wing is actuated and controlled in a smart way.

Two morphing wings were planned, and afterward produced and furnished with a few actuators and pressing factor sensors.

L. F. Campanile (2005) Compliant morphing wing

Viewpoints like the contention between the principle necessities of deformability, load-carrying capacity and low weight just as the job of a coupled mechanical plan are addressed in detail. Bio-inspired approach to flight offer a huge improvement potential with respect to conventional aircraft as far as performance and efficiency is concerned.

CHAPTER 3

AIM AND SCOPE OF THE PROJECT

3.1 AIM OF THE PROJECT

In this project, a new type of morphing wing structure is proposed which with the help of mechanism can change its structure which has a bio-motivated design structure. This structure can execute out of plane modification through the process of cord wise bending. This modal is inspired from the structure of fish-bone and has the same internal wing structure as the skeleton of a fish. The ribs have a different structure from the conventional wing and can change its profile with the help of mechanism such as actuators and rotating mechanism. This deviation gets carried downward the wing trailing edge and make the wing change its shape according to the mission need.

This project also focus on the development of morphing wing for Cessna 180 produced in the year between 1953 and 1981, which was used as a base modal for the RC plane Precedent T240 and have the same orientation and modal of Cessna 180. It is a single engine aircraft with a capacity of around 4 or 6 passengers and is been used in both the military as well as civil application. The parameter of the original wing such as the chord, span and the wing area were followed to prepare the design of the morphing structure.

3.2 SCOPE IN DEVELOPMENT OF MORPHING WING

Due to the growing concern on the changing environment due to pollution made by the use of aero fuel and the growing global air traffic growth. In aviation, performance of an aircraft in the environment has become a major factor in commercial and market competitiveness. So the need of better and environment friendly aircraft arises. As better technology are developed for the aviation industry to reduce the emission of carbon in the environment to reduce pollution the reduction of aircraft drag is considered as one of the major topic for reduction of carbon emission as well. The development of technology which can reduce drag

are needed. One of which is morphing wing technology which helps to reduce the drag caused during flight to reduce and have a higher fuel economy without effecting the nature.

This technology can have their own advantages as well as disadvantages. Some of the people and researchers are too sceptical to accept the benefits to adopt a morphing wing design as the cost, complexity or weight of these wing can cause of affect on the production of them. However, due to the wide availability of newer and smarter technology these newer design has been proposed using these smarter technology and actuation system. The morphing wing can be considered as an necessity technology for the development for ultra-efficient aircraft.

The main motive of morphing wing is to increase aircraft performance in different flight phases. Parameters that can be developed with the morphing wing concept; are important parameters in a flight such as maximum speed, fuel consumption, maneuverability, carrying capacity, range, durability, stability. Improving any one parameter or all of these parameters will give a tremendous increase in flight efficiency and also can increase the possible mission profiles that the aircraft can perform.

Morphing wing also connects different possibility in different sector of need. It have a huge influence by materials such as shape memory alloys, shape memory composite, shape memory polymers, elastic composites. and many more material can be used for this technology. These technology have a higher tendency to resist the forces which are exerted on the aircraft during flight and can be proven efficient in the development of the morphing wing technology.

Morphing wings would create smoother streamlined surfaces, making an aircraft more acrobatic and proficient than an aircraft that has conventional wing structure containing flaps and ailerons. These technology can also be proven profitable in the field of UAVs and military aircraft use as spying drones for the betterment of the unmanned aircrafts technology. As the morphing wing is in the developing stages of its state but it has proven much useful for the development of aircraft which uses these technology.

CHAPTER 4

DESIGN, EXPERIMENT, ANALYSIS AND MATERIAL

4.1 DESIGN

An design for the development of a morphing wing for the Cessna was proposed with a continuous structure. This design was proposed for a RC aircraft Precedent T240 having the same model as of the Cessna 180. There were many design proposed for the structure of morphing wing but one was selected for development and testing. The design parameter and configuration are similar as the original wing shape, with all the measurement being similar. the wing used for the perpose of this project was NACA 2412.

This new wing structure is capable of lifting the aircraft entire load which is approximately 6.48 kg with the weight of the wing being included in it. The other parameter such as the wing area(S), span(b) and chord(c) were followed as per the design of the conventional wing.

Table 4.1 Wing specification

b	c	S	AR
(m)	(m)	(m ²)	(-)
2.39	0.349	0.82	6.79

The design of this newer morphing wing has to hold out against the aerodynamic forces furthermore, load because of flight moving at each flight condition. A g-force of a maximum 2g was reviewed for the flight envelop of the RC model. This design of the model wing has to guarantee a better performance then the old customary wing from the streamlined perspective including C_L , C_D , C_M , Range and Endurance. This must be executed without being excessively heavier than the conventional wing in order to not displace the center of balance of the aircraft to guarantee the same T/W ratio and payload capacity.

4.2 DIFFERENT DESIGN PROPOSED

There were many different design idea for the development of a new morphing wing structure with different material for different design proposed. These different design were tested to their full potential and the best design was selected for the final project. Every design have its uniqueness and advantage over the other design and have a great advantage over the conventional wing.

4.2.1 First Design Proposed

The first design have many different internal structure and this structure are connected with each other to perform the give task. The design comprises of a fish-bone rib core structure which is supported by an arm and is connected to the leading edge with the help of beam and rod.

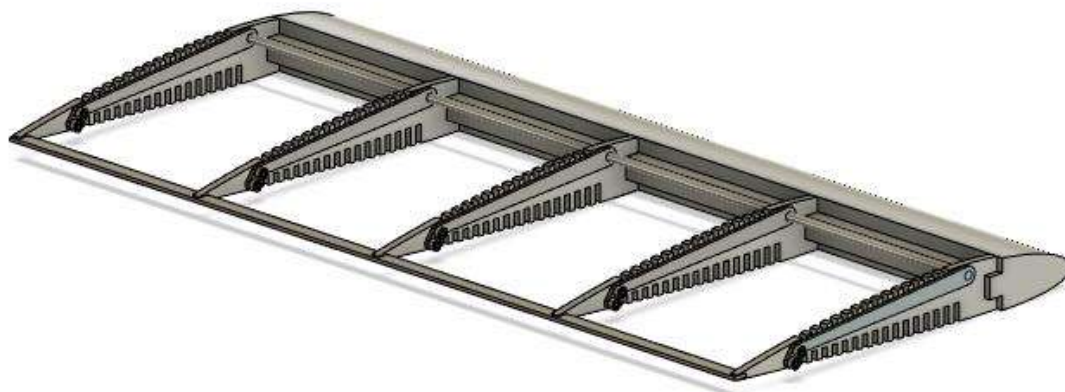


Fig:4.1 First design full wing view

This design has a leading edge which is made from balsa wood, the rod and the beam structure are made of aluminium which extend along the span. The ribs are made of a TPA (Thermoplastic Polyamide) material and the arm supporting the ribs structure is made of PLA (Polylactic Acid) material. The connection were secured with the help of aluminium screw which are connected for ribs and arm.

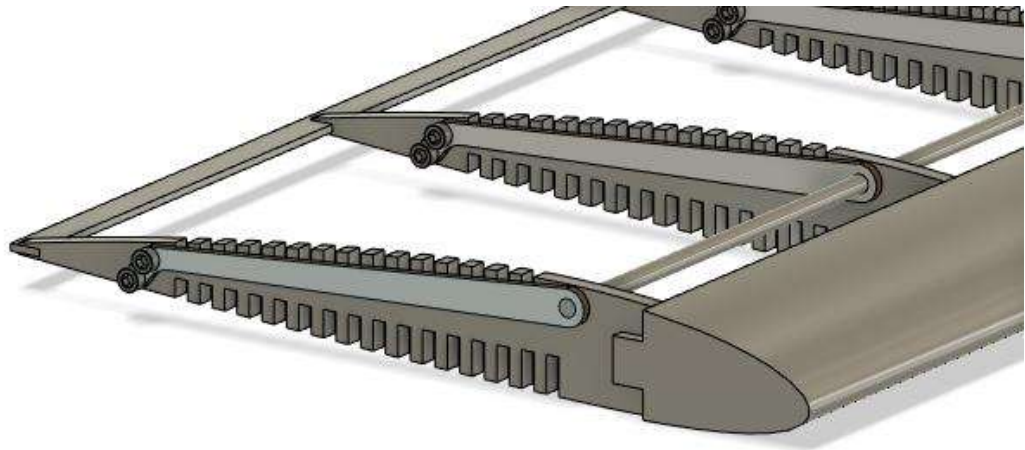


Fig:4.2 First Design Detailed view

4.2.2 Second Design Proposed

The second design have a continuous fish-bone like structure throughout the span of the wing. It is a continuous structure which is connected to the leading edge with a trailing edge od a newer design.



Fig: 4.3 Second Design full wing view

The design contains of a leading edge made of balsa wood. The ribs which are made of aluminium are attached to the leading edge of the wing. This design has a trailing edge of a PLA (Polylactic Acid) material which is attached to the ribs of the wing structure. The ribs are continuous all throughout the span of the wing which make the structure the heavier then the others. This structure is also very costly and is not very efficient as the other designs.

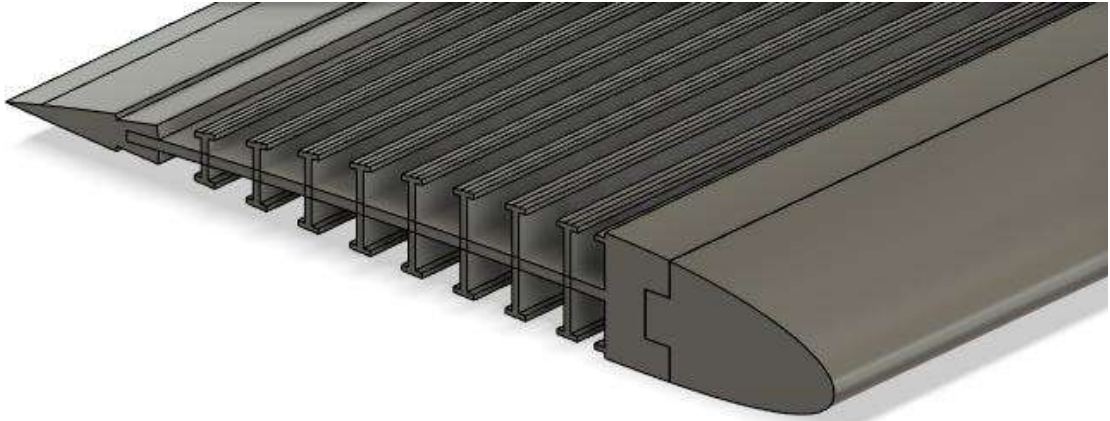


Fig: 4.4 Second Design detailed view

4.2.3 Third Design Proposed

The third design is a continuous structure which is made up of a continuous skin and internal structure of beams supporting the skin of the wing structure. The structure has a continuous span of the internal structure throughout the wing structure. The structure contains of N-type beam throughout the chord of the wing.

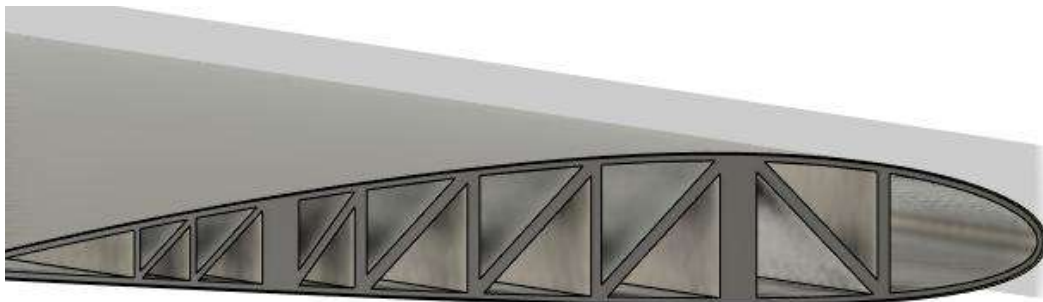


Fig: 4.5 Third design wing structure

The structure contains of the aluminium structure throughout the internal and skin structure. This structure has a thick beam and the slant beam to support the skin of the structure. As the whole structure is continuous the aluminium used for the structure is high and has a greater load then any other wing design. Due to the

continuous structure and of containing material such as aluminium the controlling of the structure is also difficult which make the use of heavy actuators.

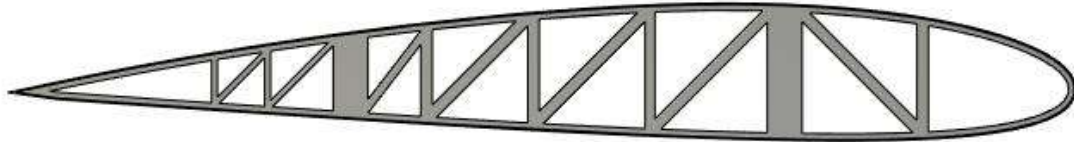


Fig: 4.6 Third design side view

4.2.4 Fourth Design proposed

The fourth design proposed is a derivative design of the first wing structure. This wing contains of a fish-bone structure that has the ribs spike lean back towards the trailing edge. The ribs are connected to the leading edge with the help of rod and the rib is supported with the help of arms which also provide control over the structure. The rib spikes have a 45° of lean towards the back for making the structure more fish bone like.



Fig: 4.7 Fourth Design full wing view

The structure has a similar looks as the first design and the materials used for this design are similar too. The leading edge made up of balsa wood, the trailing edge

beam made up of aluminium. The ribs made of TPA (Thermoplastic Polyamide) material and the arms supporting the ribs are of PLA (Polylactic Acid) material with the connection secured by aluminium screws.

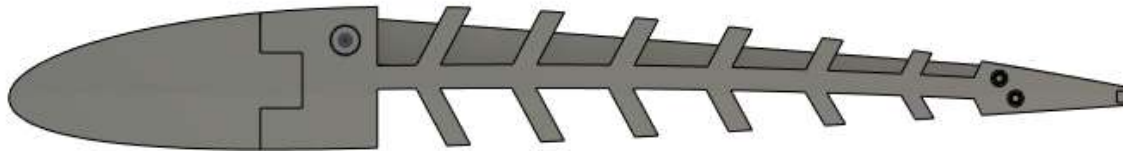


Fig: 4.8 Fourth design side view

4.2.5 Fifth Design Proposed

This design has the similarity as the first design and is a derivative of the first and fourth design. This design has the same material and the structural configuration as the first design but has a fish-bone like structure which has its spike forward tilt. This tilt is towards the leading edge of the wing structure. The spikes are tilted at an angle of 45° towards the leading edge of the wing.



Fig: 4.9 Fifth Design full wing view

The material used for this design are the same as which were used in first design, the leading edge made of balsa wood and the beam of trailing edge made of

aluminium beam. The ribs are made up of TPA (Thermoplastic Polyamide) material and the arm supporting the rib structure is made up of PLA (Polylactic Acid) material. These two are supported by an aluminium rod which is connected to the leading edge and the control used to control the ribs and arm are attached to the aluminium beam.

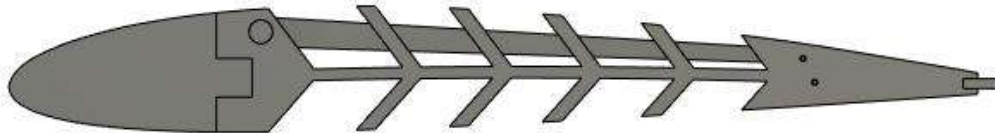


Fig: 4.10 Fifth design side view

4.3 MATERIAL SPECIFICATION

The material used for the fabrication and testing the model for computer analysis were different kind of thermoplastic, polymer and alloys etc. These material were appropriate for the analysis of these morphing wing structure. The material which are used and the purpose of those material are as follows.

These material are available in market for low price and does not cost much price for the fabrication of those.

- 1) Balsa Wood
- 2) Aluminium
- 3) PLA
- 4) TPU
- 5) Elastomeric fabric

4.3.1 Balsa wood

Balsa wood is a delicate and light, with a rough, open grain. These wood are mainly used for the modelling of aircraft as it is light weight and durable. The density of the wood is around 40-350 kg/m³, with a common density around 150

kg/m³. It has a low density however it is high in strength. It is very useful for light, stiff structure such as model bridge, model buildings and model aircraft. The leading edge for most of the design contains balsa wood. The leading edge made out of balsa wood has a curve leading edge which has to be laser cutted.

4.3.2 Aluminium

Aluminium is mostly compounded with other metals to form alloys. Aluminium has a density lower than the other common metals. The density is around 2.70 g/cm³ and having a Poisson ratio of 0.35 and the Young's Modulus is around 70 GPa. Aluminium is more elastic than rubber and has a nice tendency to regain its shape after bending. The aluminium used in this model is for rods, beams and screws of the model. The rod passes through the leading edge of the ribs and arm connecting them all through the span of the wing. The aluminium beam is used for trailing edge of the wing and the screw is to connect the ribs and the arm parts together.

4.3.3 PLA

PLA also called as Polylactic acid or Polylactide is a thermoplastic polymer. This material has a high economy demand as it is economically produced from renewable resources. It is also widely used in the world of 3-D printing and many structures are prepared from this material. It has a density of 1.210-1.430 g/cm³. Also the Young's Modulus of the PLA is 2.7-16 GPa and the Poisson ratio is around 0.38. The PLA in this models is used for the arms which support the ribs structure of the wing. They are stiff compared to other plastic and do not bend on application of small load. The arms are connected one side to the aluminium rod and the other is connect to the ribs. As the stiffness of it is high it helps the ribs to adjust its angle and bend according to the condition required for flight.

4.3.4 TPU

TPU also called as Thermoplastic Polyurethane is an elastomer which is thermoplastic with numerous properties including resistance to oil, elasticity, abrasion and grease. It falls under the classification of TPE Thermoplastic Elastomers. It is a fusion of both rubber and plastic and having high durability and flexibility. The density of these material is around 1.28-1.66 g/cm³ it also has a Young's Modulus of 2410 N/mm². The Poisson ratio of this material is 0.39. The ribs of the wing are designed using this material which are flexible and easily

regains its shape when it deforms. This is connected to the rod for the control of the wing and the trailing edge is connected to the aluminium beam for the change in angle of attack.

4.3.5 Elastomeric Fibre

Elastomeric fibres are those fibres that possess extremely high elongation at the break and can recover fully and rapidly from high elongation up to their breaking point. The material used in this model is 80% spandex and 20% cotton which is used for the skin of the model. This material exhibits an elastic property which helps with the bending of the internal structure and helps the internal structure under the skin so it does not get exposed and the skin acts as the continuous aircraft skin which has the airflow over it and does not cause any losses in drag due to moving structure like conventional wing.

4.4 STATIC ANALYSIS

Several structural tests were conducted on the structure to prove its reliability and which structure is proven efficient then other, it also helped to test the morphing system and to estimate the structural properties of the morphing wing which was carried out by means of experimental test and numerical data. The FEM analysis of the structure containing both ribs and arms mechanism was conducted.

The load was applied at the trailing edge of the ribs and arm structure and the computed result was studied.

The deformation only took place at the trailing edge where the TPU material was deformed only the PLA did not have much effect of the load. All the five models were computed with the static analysis and the loads applied were same for every design. Some design performed well and some did not perform as expected. The load of 100N was applied over the trailing edge of all the wing design and the displacement was found out.

4.4.1 Static Analysis of first design

The first design was computed with giving the correct boundary material property for each and every element in the design. After that the mesh was created for static analysis and the Boundary condition were applied. The leading edge roots were fixed and 100N of uniformly distributed load was applied at wings trailing edge.

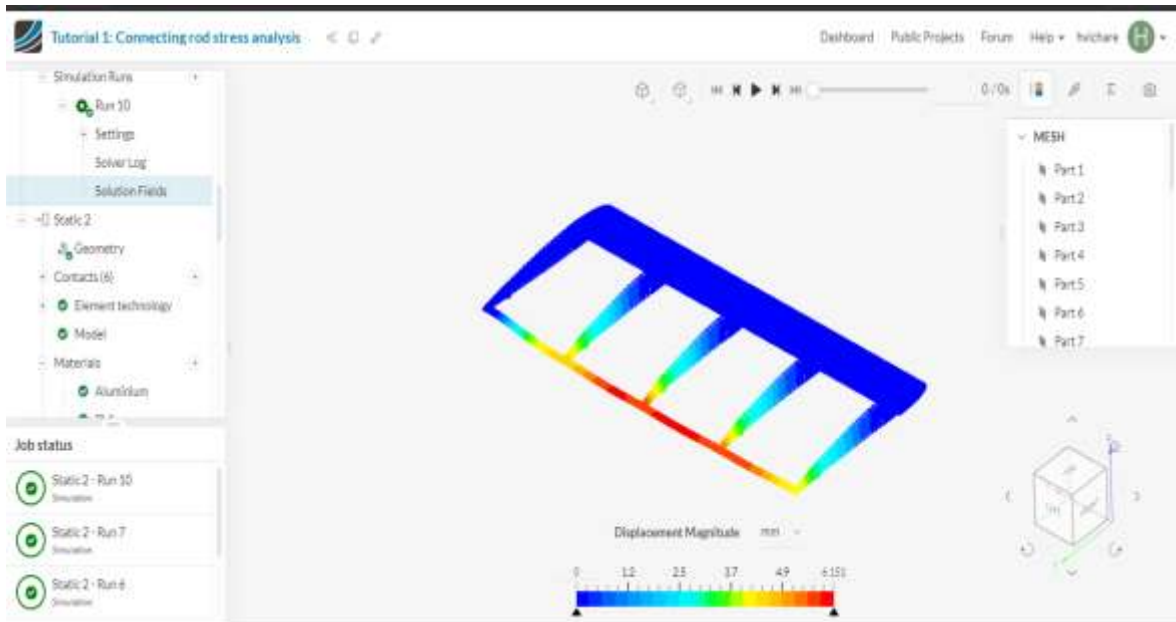


Fig: 4.11 First design static analysis

The design computed successfully and the deflection or displacement because of the load applied was found out to be 6.151 mm. This deflection was maximum at the middle of the trailing edge beam.

4.4.2 Static Analysis of second design

The second design was computed giving the material properties as per the design requirement. The second design had a continuous structure which is of aluminium material. The mesh was created and the boundary condition was applied with the leading edge and the root being fixed and a load of 100N uniformly distributed load was applied at the trailing edge.

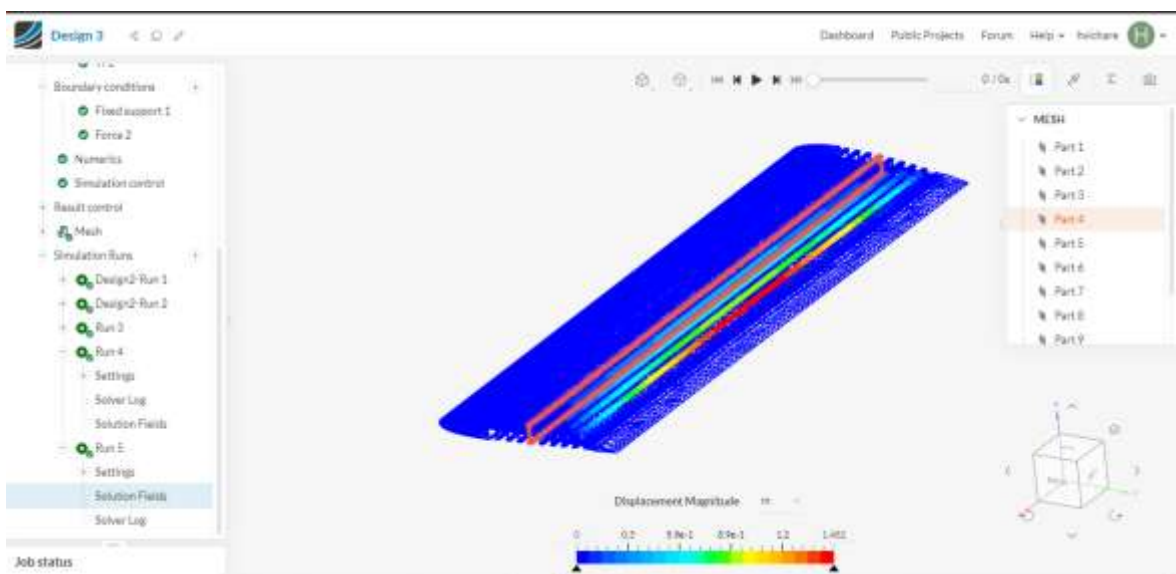


Fig: 4.12 Second design static analysis

The design computed successfully and the model failed to withstand the applied load and was deformed at a large deflection. The deflection was found out to be 1.44 m. The deflection was maximum at the middle of the model.

4.4.3 Static analysis of third design

The third design was computed by applying the materials to the design. As the design was a continuous wing structure with the skin and internal structure being same the material used throughout was aluminium. The mesh was prepared and the boundary condition was applied with the root and leading edge being fixed and a load of 100N applied uniformly throughout the trailing edge.

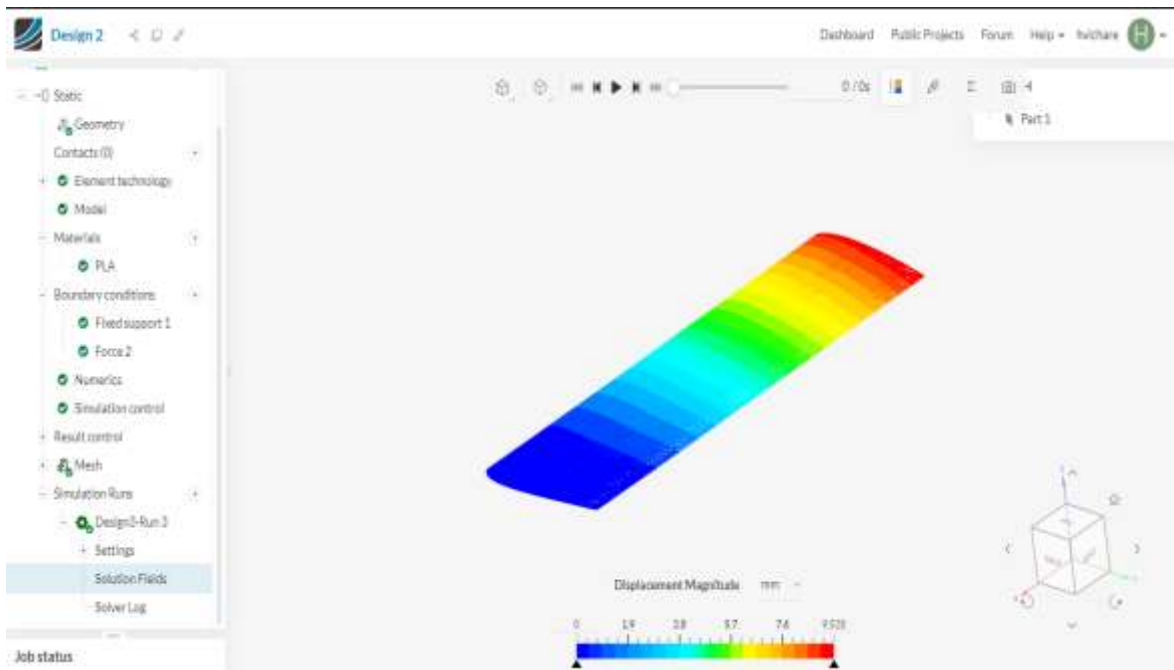


Fig: 4.13 Third design static analysis

The model was computed successfully and the result were drawn. The deflection or the displacement was found out to be 9.35 mm. The highest deflection was at the end tip of the wing. The result were not efficient as the First design result.

4.4.4 Static analysis of fourth design

The fourth design was computed by applying the material on each surface. Mesh was created and the boundary condition were given, the root and the leading edge

of the wing was fixed and 100N of uniformly distributed load was applied at the trailing edge of the model.

The model got computed successfully but the model failed the test. The deflection or the deformation was recorded to be 23.56 mm. It was a large deformation on the model so the model was rejected. The maximum deformation was found out the middle of the trailing edge.

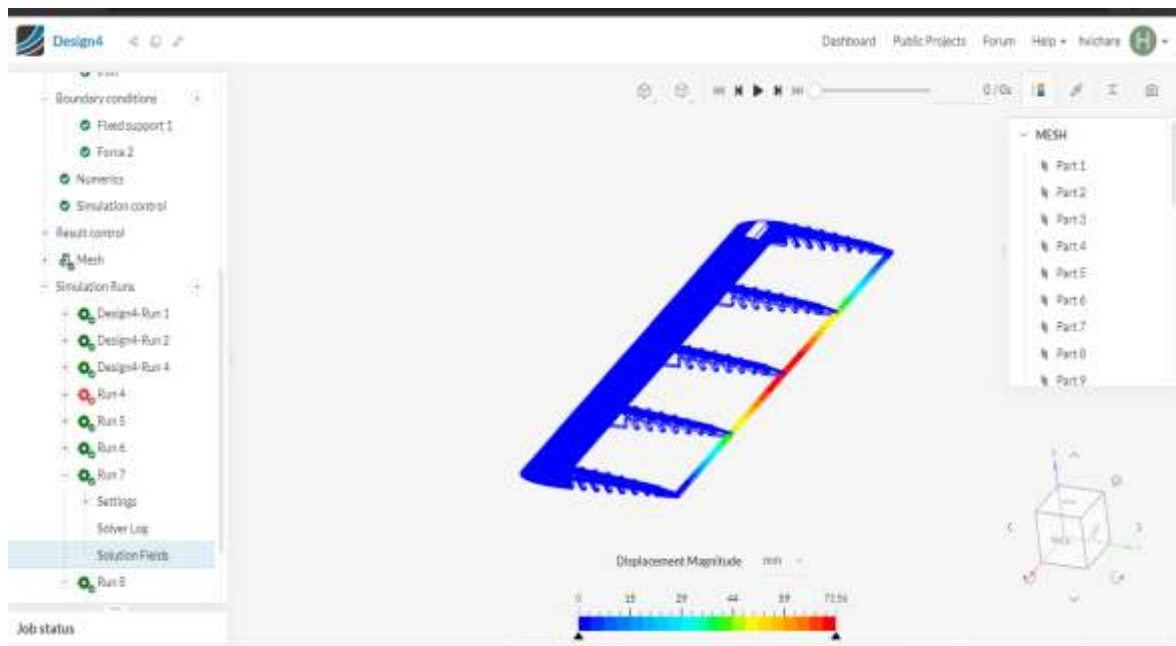


Fig: 4.14 fourth design static analysis

4.4.5 Static analysis of fifth design

The fifth design was the final proposed design and the material were assigned for computing the deflection. Mesh was prepared and boundary condition were applied with the leading edge and root being fixed and a load of 100N uniformly distributed throughout the trailing edge.

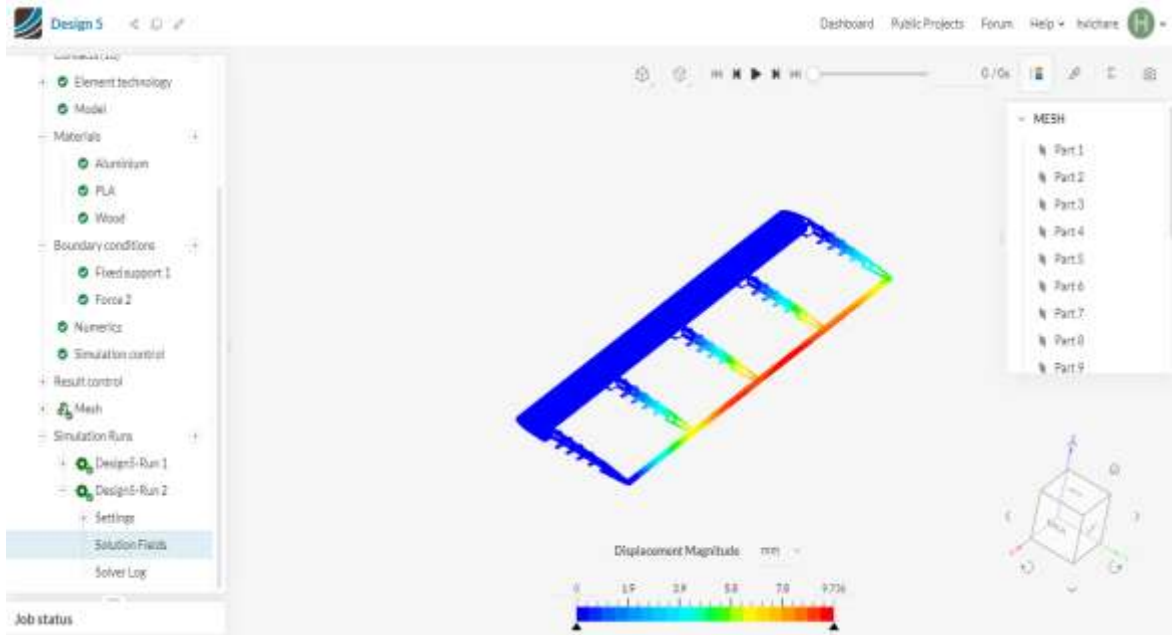


Fig: 4.15 Fifth design static analysis

The model was computed successfully and the results were recorded. The deflection or deformation was found out to be 9.73 mm. The maximum deflection was recorded at middle of the trailing edge.

4.5 AERODYNAMIC ANALYSIS

The aerodynamic characteristic of the different design of morphing wing were evaluated using the software AUTODESK CFD. The following condition for the computation were selected $V = 17.88$ m/s or 40 miles/hr, $\rho = 1.225$ kg/m³ and $\mu = 1.789 \times 10^{-5}$ kg/m.s . The design had a similar airfoil structure so the values does not vary from each other. The drag coefficient (C_D) and lift coefficient (C_L) was found out for every design. There is small changes in the velocity magnitude with each and every design change.

4.5.1 Aerodynamic analysis of first design

The first design was computed for aerodynamic analysis and the testing was carried out. An environment was created with applying the above condition on the face where the leading edge is facing and the face where the trailing edge is facing had zero pressure for wind tunnel testing.

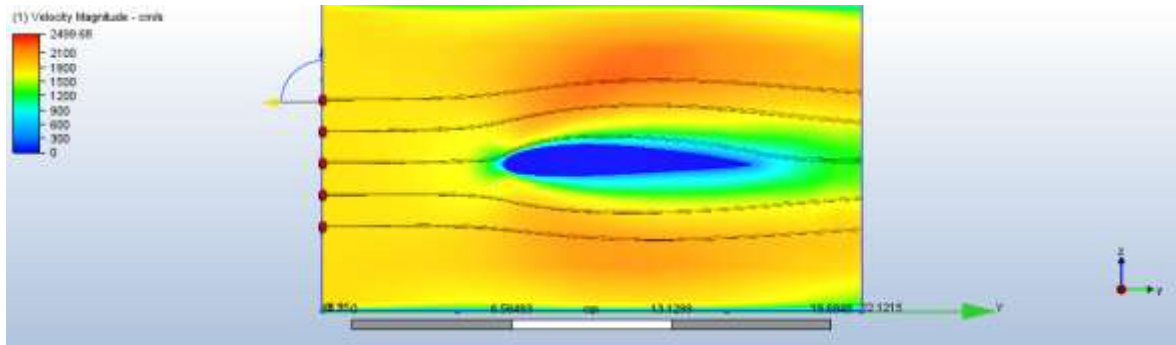


Fig: 4.16 First design aerodynamic analysis

The design computed successfully and the velocity magnitude was found. The velocity magnitude was 2499.68 cm/s.

4.5.2 Aerodynamic analysis of second design

The second design was computed for aerodynamic analysis and the testing was carried out. An environment was created with applying the above condition on the face where the leading edge is facing and the face where the trailing edge is facing had zero pressure for wind tunnel testing.

The design computed successfully and the results were noted. The velocity magnitude for this model was 2579.42 cm/s.

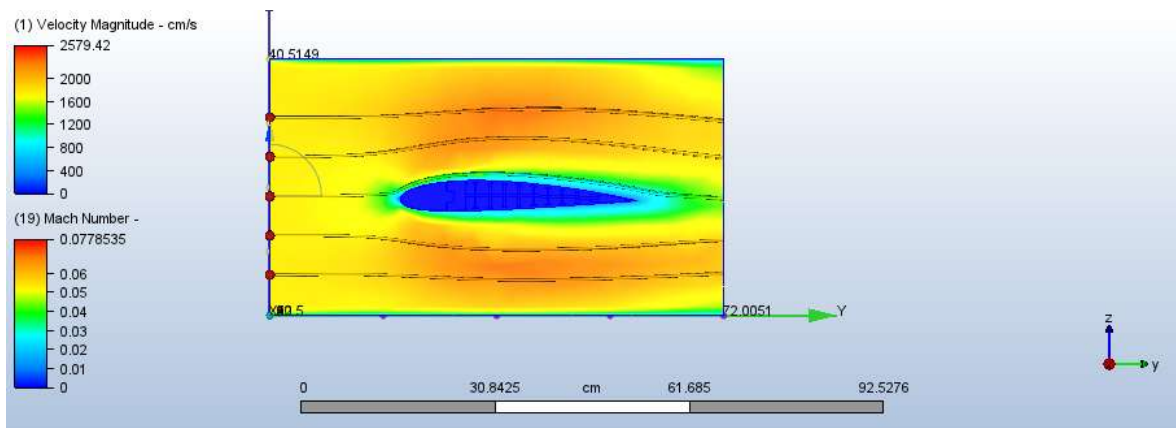


Fig: 4.17 Second design aerodynamic analysis

4.5.3 Aerodynamic analysis of third wing

The third design was computed for aerodynamic analysis and the testing was carried out. An environment was created with applying the above condition on the

face where the leading edge is facing and the face where the trailing edge is facing had zero pressure for wind tunnel testing.

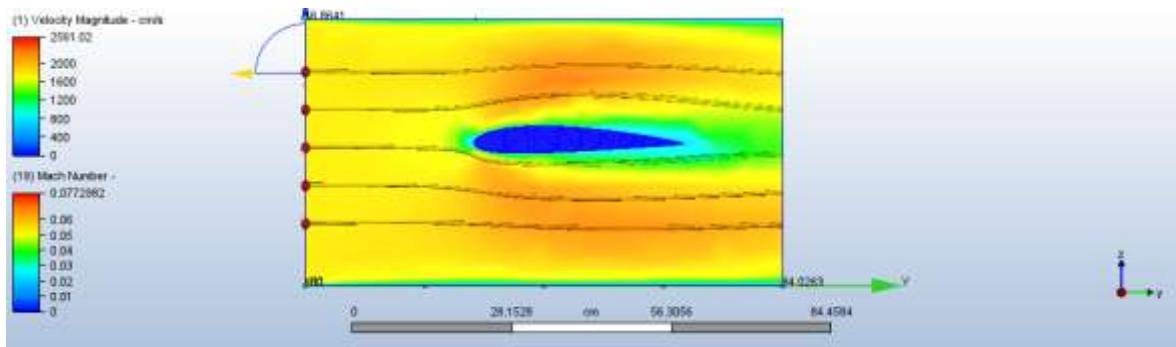


Fig: 4.18 Third design aerodynamic analysis

The design was computed successfully and the results were drawn. It was found out that the velocity magnitude was 2561.02 cm/s.

4.5.4 Aerodynamic analysis of fourth wing

The fourth design was computed for aerodynamic analysis and the testing was carried out. An environment was created with applying the above condition on the face where the leading edge is facing and the face where the trailing edge is facing had zero pressure for wind tunnel testing.

The design was computed successfully and the results were found out. It was noted that the velocity magnitude was 3288.59 cm/s.

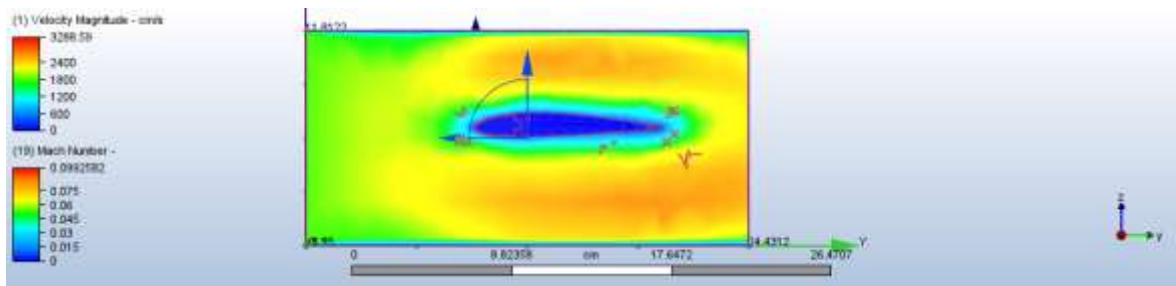


Fig: 4.19 Fourth design aerodynamic analysis

4.5.5 Aerodynamic analysis of fifth design

The fifth design was computed for aerodynamic analysis and the testing was carried out. An environment was created with applying the above condition on the

face where the leading edge is facing and the face where the trailing edge is facing had zero pressure for wind tunnel testing.

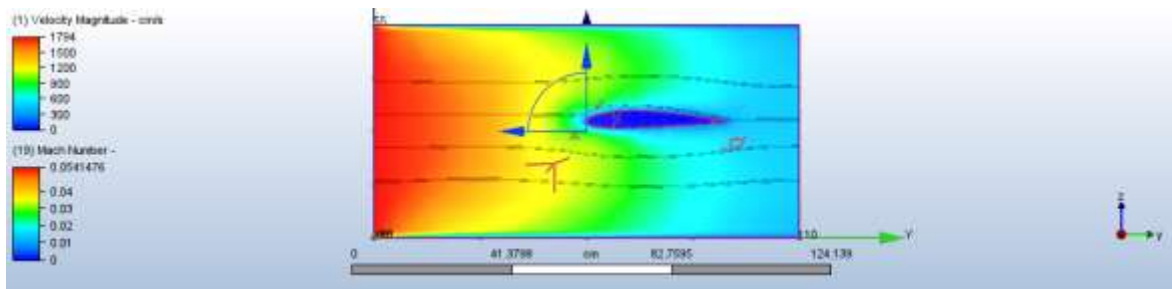


Fig: 4.20 Fifth design aerodynamic analysis

The model was computed successfully and the results were drawn. It was found out that the velocity magnitude was 1794 cm/s.

4.6 MODAL ANALYSIS

Due to the design of the morphing wing being structure focused, the need for doing modal analysis was generated. Due to the vibration created during flight the testing of model for different frequency is required to see how the model performs during the vibrations. The displacement for five frequency were found and the total modal displacement was calculated.

4.6.1 Modal analysis of first design

The design was provided with the appropriate material property according to the design requirement. The boundary condition were applied and the mesh was created for testing the model.

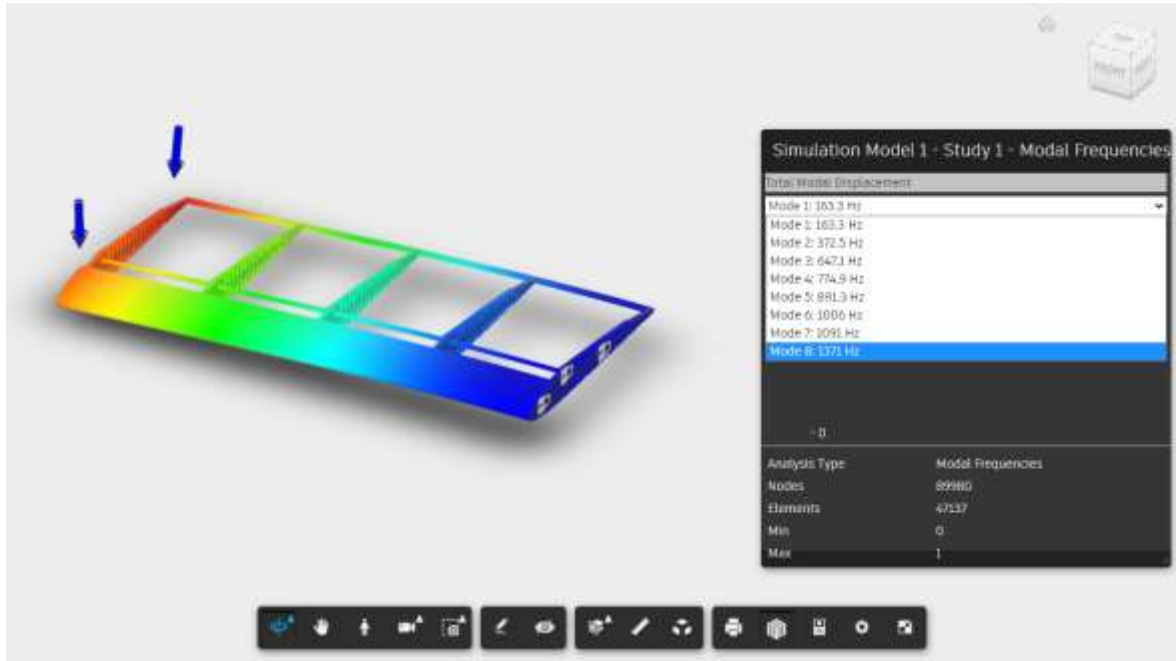


Fig 4.21 Modal frequencies of first design

The modal was computed and the frequencies were found out. Five frequency were found for the modal at 163.3 Hz, 372.5 Hz, 647.1 Hz, 774.9 Hz, 891.3 Hz.

4.6.2 Modal analysis of second design

The design was provided with the appropriate material property according to the design requirement. The boundary condition were applied and the mesh was created for testing the model.

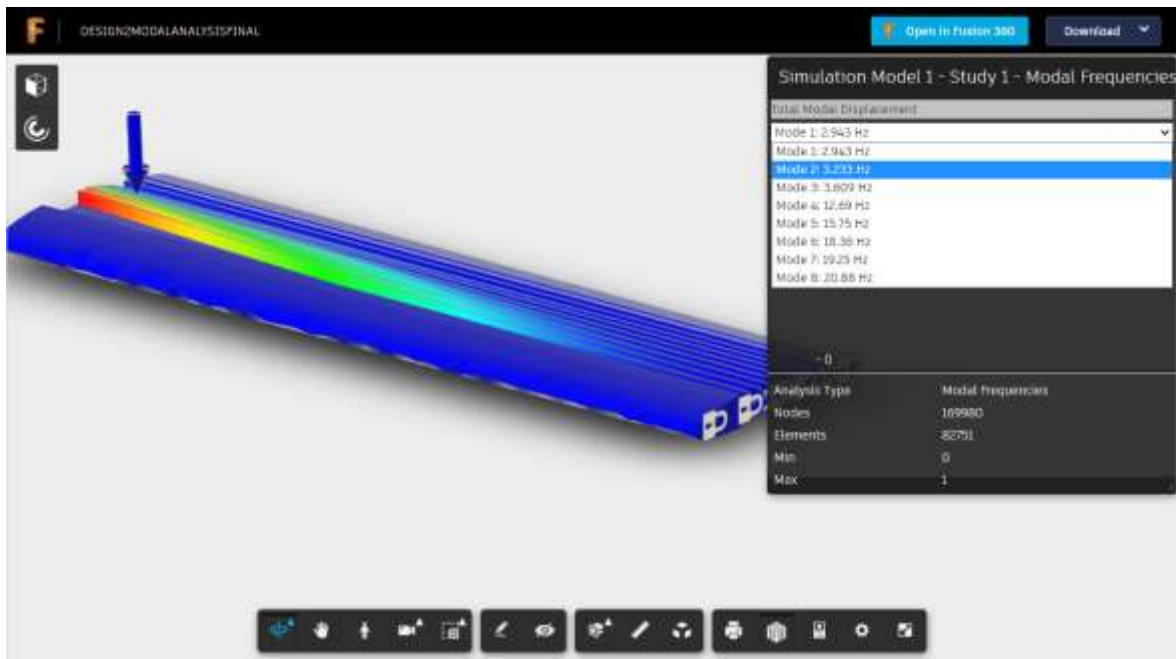


Fig: 4.22 Modal frequencies of second design

The model was computed and the frequency were found out. There were five frequency noted 2.943 Hz, 3.233 Hz, 3.609 Hz, 12.69 Hz, 15.75 Hz.

4.6.3 Modal analysis of third wing

The design was provided with the appropriate material property according to the design requirement. The boundary condition were applied and the mesh was created for testing the model.

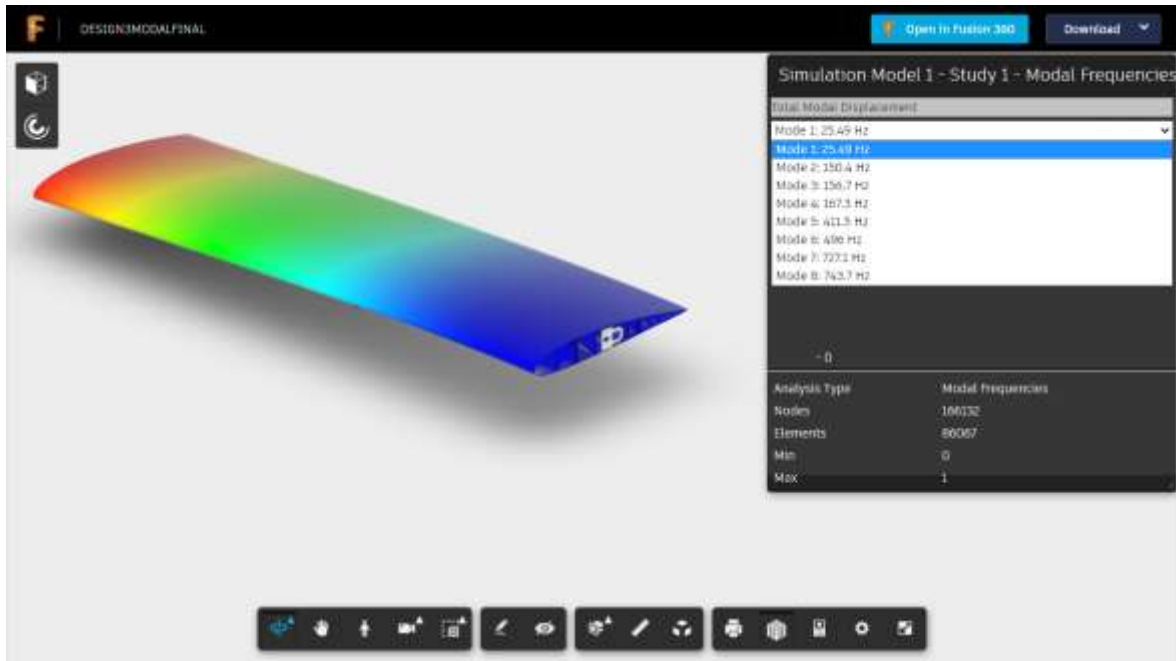


Fig: 4.23 Modal frequencies of third design

The model design was computed successfully and the results were drawn. The five frequency which were noted were 25.49 Hz, 150.4 Hz, 156.7 Hz, 167.3 Hz, 411.5 Hz.

4.6.4 Modal analysis of fourth wing

The design was provided with the appropriate material property according to the design requirement. The boundary condition were applied and the mesh was created for testing the model.

The model was computed successfully and the results were noted. The five frequency that were found were 112.6Hz, 264.6 Hz, 507.4 Hz, 565.1 Hz, 651.6 Hz.

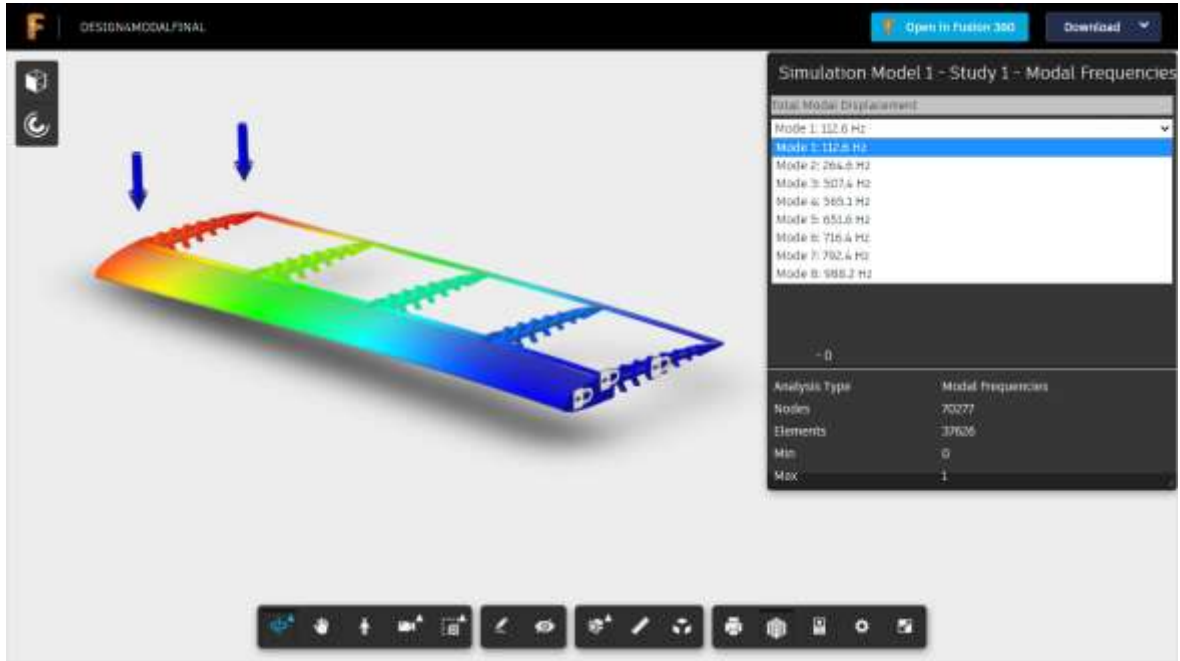


Fig: 4.24 Modal frequencies of fourth wing

4.6.5 Modal analysis of fifth wing

The design was provided with the appropriate material property according to the design requirement. The boundary condition were applied and the mesh was created for testing the model.

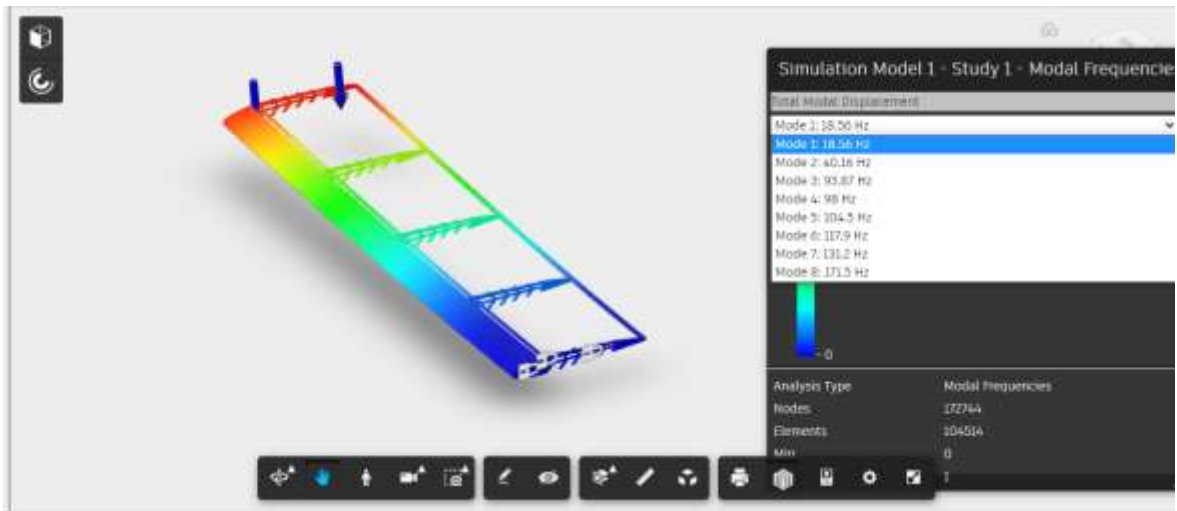


Fig: 4.25 Modal frequencies of fifth wing

The model was computed and the following result were noted. The five frequencies that were found are 18.56 Hz, 40.16 Hz, 93.87 Hz, 98 Hz, 104.5 Hz.

CHAPTER 5

PERFORMANCE ANALYSIS AND RESULT

5.1 PERFORMANCE ANALYSIS

The computation of all the designs were noted and were compared with each other design. These results were based on the computer analysis of those design structure and were only computed using software analysis. The static, aerodynamic and modal analysis were needed to be calculated for the design to been proven trusted and safe. Out of those design two design failed in static analysis which proved that those design were not structural trusted for fabrication. The other three design were structural efficient.

In aerodynamic analysis of the designs were computed and the best design with the great lift coefficient and drag coefficient was selected. The structure which was selected for the design was having a very efficient flight condition. The modal analysis was given for all the model design to find the frequency and the vibration of those and the minimum design with vibration was selected for the fabrication of the wing.

5.1.1 First design performance analysis

The first design was proven to be having greater stiffness and was having less displacement then the other models. The aerodynamic analysis was also proven efficient then the other. The modal analysis gave the different vibration frequency which the design can handle and were calculate.

5.1.2 Second design performance analysis

The second design failed the static analysis as the displacement from the load was very large. The aerodynamic analysis resulted in great efficiency. The modal analysis were also used to find the frequency of vibration of the model.

5.1.3 Third design performance analysis

The third design was proven to be having a great load resistance as the bending due to the application of load was minimum but was greater then the first design. The aerodynamic analysis proved the efficiency of the model in the flight, which was proven good. The modal analysis gave the vibration for different frequencies which occur during flight condition.

5.1.4 Fourth design performance analysis

The fourth design failed the static analysis as the deflection caused by the applied load on the model was found to be large. The aerodynamic analysis was efficient as the model has the same profile as the others. The modal analysis gave different vibration for different frequency in a flight condition.

5.1.5 Fifth design performance analysis

The fifth design was proven to be having a satisfactory resistance to the deflection was small then the third. The aerodynamic analysis was efficient as the modal has the same profile as the others. The modal analysis gave frequencies for different vibration in flight condition.

5.2 TESTING AND RESULT

The first design was fabricated with the ribs structure and was tested and the graph for the different load condition was drawn.



Fig: 5.1 Ribs structure 3-D printed



Fig: 5.2 Ribs and arms fabricated using 3-D printer

The fabricated parts were tested for the static analysis and the deflection of the parts were noted. The deflection of the ribs and arms were noted for different load condition and a graph comparing the test result and the computed result was drawn. The graph was plotted and the difference in both was show. The tested results were showing nearly same defection as of the computed result.

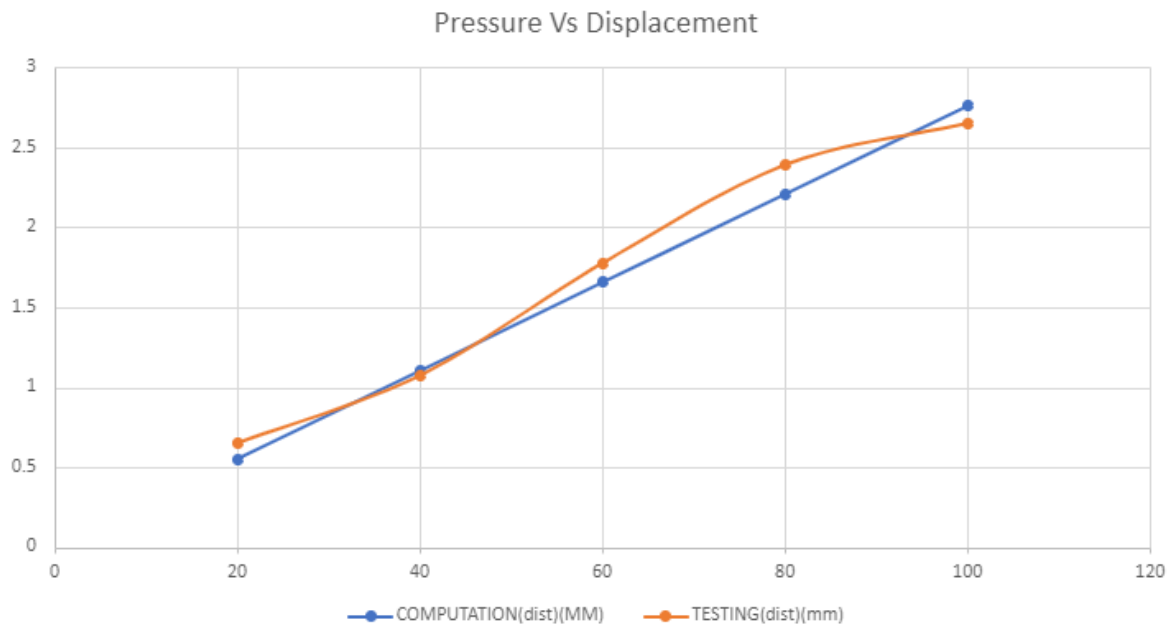


Fig: 5.3 Pressure vs Displacement graph

Table 5.1 : Tabulation for graph

Pressure (N)	Displacement (Computation) (mm)	Displacement (Testing) (mm)
20	0.552	0.613
40	1.103	1.091
60	1.655	1.723
80	2.207	2.401
100	2.758	2.2693

The first design was proven to be efficient then any other design proposed in this project as it out performed all the other design in every analysis and was having a great lead over any other design. The fabrication was also made based on the first design and the model was fabricated. The fabrication was done with the help of 3-D printer and CNC machine for the ribs, arms and rod, beam and leading edge respectively. This model was smaller from the original wing and the wing which was computer analysis for testing purpose.

CHAPTER 6

CONCLUSION

In this project, a new morphing wing structure was proposed in the intention to obtain a new wing concept which does not get affected by the aerodynamic losses which are produced from the geometric discontinuity of the conventional wing structure such as wing-flap assembly. This model allows to adopt a wing flap without any discontinuity along the wing span. The main structure of the wings which are the ribs were inspired by the fish-bone structure and were prepared with the help of elastomeric and plastic material. The result which were found out were pretty promising and had a future for this kind of innovation and specifically this type of design. The highlight of this work is the simplicity of the design which is simple than other proposed and current morphing wing and the use of less technology which helped to obtain in this morphing wing design.

For real purpose of this wing, the main goal is to apply this wing in a real flight condition. To make that possible the wing structure has to be optimized internally and a better skin structure has to be selected. Also the material which are currently selected has to be updated and optimized to have a better flight.

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modest drag and increment the flight productivity at various moving, pitching and yawing moments