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DESIGN IMPLEMENTAION AND STRUCTURAL ANALYSIS OF AIRFOIL USING SIMULATION TECHNIQUES

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ABSTRACT

The paper focuses on the structural design and analysis of an ultralight aircraft's high wing. The wing design includes initial considerations such as planform selection, aircraft location, and structural design calculations for airfoil selection, wing area, wing loading characteristics, and wing weight. The design is done corresponding to the calculated values using the design software CATIA, and the analysis is done to show the structural deformations and stress for the applied loading conditions using the analysis software ANSYS 14.0, as well as the drag polar for the applied flow conditions using the flow analysis software ANSYS FLUENT.The objective of this project is to compare the results obtained for different materials like Al 2024-T3, Al 6061-T6, Al 7075-T651 & Al 7075 + 15% FLY ASH MMC using analysis software. From the results we will conclude which material is having better properties.

KEYWORDS: Ultralight Aircraft, Wing Structural Design, Structural and flow analysis, CATIA, ANSYS.

I.INTRODUCTION

Wing and its structure

Wings generate the majority of a heavier-than-air aircraft's lift. Wing structures bear some of the aircraft structure's heavier loads. The design of a wing is determined by a variety of factors, including the aircraft's size, weight, speed, rate of climb, and intended use. The wing must be built in such a way that it maintains its aerodynamic shape even under the extreme stresses of combat manoeuvres or wing loading. Most modern aircraft have similar wing construction. In its most basic form, a wing is a metal-covered framework made up of spars and ribs.

Spars are the wing's primary structural members. They extend from the fuselage to the wingtip. The spars support the entire weight of the wing. The spars are built with high bending strength in mind. Ribs shape the wing section and transfer air load from the wing covering to the spars. Ribs run from the wing's leading edge to its trailing edge. Some wings have a false spar in addition to the main spars to support the ailerons and flaps. Most aircraft wings have a removable tip, which streamlines the outer end of the wing.

Ultralight Aircraft:

Ultralight aircraft are generally called microlight aircraft whose definitions, the weight and the speed limits differ from country to country. Ultralight aircraft, as a group, are designed primarily for recreational flying for distances of not more than 165.4 kilometers from a home base. However, recent several models have been developed to include aerobatic flying and have been considered by the military for front line reconnaissance.

Fig. 1. An ultralight aircraft

Ultralight aircraft designs, which are classified by the type of structure:

- The first generation ultralights were actually "hang gliders" with small engines added to them, for self-launching.
- The second generation ultralights are powered aircraft having "2-Axis" control systems.

The third generation ultralights have strut-braced wings and airframe structure use "3-Axis" control systems.
This article is about aircraft wings. For bird wings, see Wing configuration (birds).
The Spitfire wing may be classified as: "a conventional low wing cantilever monoplane with unswept elliptical wings of moderate aspect ratio and slight dihedral".

Fixed-wing aircraft, popularly called aeroplanes, airplanes, or just planes, may be built with many wing configurations.

This page provides a breakdown of types, allowing a full description of any aircraft's wing configuration. For example, the Supermarine Spitfire wing may be classified as a *conventional low wing cantilever monoplane with straight elliptical wings of moderate aspect ratio and slight dihedral*.

Sometimes the distinction between types is blurred, for example the wings of many modern combat aircraft may be described either as cropped compound deltas with (forwards or backwards) swept trailing edge, or as sharply tapered swept wings with large leading edge root extensions (or LERX).

All the configurations described have flown (if only very briefly) on full-size aircraft, except as noted.

Some variants may be duplicated under more than one heading, due to their complex nature. This is particularly so for variable geometry and combined (closed) wing types.

Note on terminology: Most fixed-wing aircraft have left hand and right hand wings in a symmetrical arrangement. Strictly, such a pair of wings is called a wing plane or just plane. However, in certain situations it is common to refer to a plane as a wing, as in "a biplane has two wings", or to refer to the whole thing as a wing, as in "a biplane wing has two planes". Where the meaning is clear, this article follows common usage, only being more precise where needed to avoid real ambiguity or incorrectness.

Number and position of main-planes

Fixed-wing aircraft can have different numbers of wings:

- **Monoplane**: one wing plane. Since the 1930s most aeroplanes have been monoplanes. The wing may be mounted at various positions relative to the fuselage:
- **Low wing**: mounted near or below the bottom of the fuselage.
- **Mid wing**: mounted approximately halfway up the fuselage.
- **Shoulder wing**: mounted on the upper part or "shoulder" of the fuselage, slightly below the top of the fuselage. A shoulder wing is

sometimes considered a subtype of high wing.[1][2]

- **High wing**: mounted on the upper fuselage. When contrasted to the shoulder wing, applies to a wing mounted on a projection (such as the cabin roof) above the top of the main fuselage.
- **Parasol wing**: raised clear above the top of the fuselage, typically by cabane struts, pylon(s) or pedestal(s).

II.LITERATURE REVIEW

In 1986, T.V. Baughn and P.F. Packman [1] used finite element analysis to determine the structural integrity of a high-wing cable-supported ultralight aircraft. A simple, symmetrical, half-structure macro-model was examined and tested under level flight and two-wheel landing loading conditions. Flexural and bending stiffness were also determined for the supported and unsupported wings. A preliminary damage tolerance analysis was performed, in which selected cable elements and wing compression struts were removed, redistributed loads were calculated, and various aircraft flight configurations were investigated. All cable loads, displacement of each structural node (for each loading condition), displacement plots, and potential highly stressed regions can be generated by the model.

In the same year, 1986, Baughn, T., and Johnson, D. [2] proposed a design change from high-wing cable-supported to strut-supported aircraft. The high wing cable supported ultralight is one of the most common designs. Because of its simple shape and construction method, owners like to modify the structure and aerodynamic surfaces to try to improve the aircraft's performance. One of the most common modifications is the conversion of a cable-supported aircraft to a strut-supported aircraft. The modification's goal is to reduce drag and improve the ultralight's performance. The goal of their research is to determine the structural performance of cable-supported aircraft and compare it to the structural performance of conventional aircraft.

Girish S. Kulkarni [3] completed a Finite element method based structural design to analyse the behaviour of an aeroplane under Aerodynamic loading in 1987 using all of the design guidelines provided by Baughn, T as well as considering critical conditions in unaccelerated flight.

In the year 2000, Zdobyslaw Goraj [4] completed a conceptual design of the main wing, body, and empennage for a high altitude long endurance aerial vehicle. A main spar, ribs, shell, and strut arrangement for a high aspect ratio main wing and tailplane has been proposed. This paper includes a number of characteristics (stiffnesses, mass distributions, moments of inertia, and so on) that are required for flutter calculations. The NASTRAN programme is used to compute structural characteristics. The conventional U -G method was used to determine the critical flutter speed for empennage.

The Doublet-Point-Method (DPM) for non-coplanar configuration was used to compute the unsteady aerodynamic forces. Aerodynamic model of empennage includes 168 aerodynamic panels. This analysis can be treated as a starting point for further wing optimisation. The main goal is to obtain the structure lighter and aerodynamically more efficient - the feature - being very important in long endurance missions.

L. Pascale & F. Nicolosi [6] in 2006, proposed a new design which is based on the idea to built a 4-seat aircraft with two light engines (Rotax 912S, usually used for ultralight aircraft) and to enter the market with a twin - engine aircraft with the same weight of a single engine aircraft. The present paper shows all main criteria on which the design of the aircraft and the choice of the configuration have been based. At Dipartimento di Ingegneria Aerospaziale (DIAS) ofUniversity of Napoli "Federico II" a deep aircraft aerodynamic investigation has been performed both numerically and experimentally through an extensive wind-tunnel test campaign. All tests and research activities have been focused on the analysis and optimization of aircraft aerodynamics. Detailed measurements of fuselage and nacelle aerodynamic effects. Design and tests of winglets to improve rate of climb in OEI (One Engine Inoperative) condition.

Huiwen Hu and Huaien Kao [7] in 2009, presented the validation of finite element model (FEM) of an ultralight aircraft structure by using experimental modal analysis (EMA). The main structure of ultralight aircraft consists of the wings, the fuselage and the empennage structures, which are fabricated by means of aluminum tubes through the bolts, rivets and the brackets. A commercial code, ANSYS, is used to establish the FEM. Normal mode analysis is performed to obtain the natural frequencies and mode shapes under a completely free boundary condition. EMA is conducted on the wings, the fuselage and the integral structures to obtain their natural frequencies and mode shapes, respectively. The FEM is then validated and updated according to the correlation of natural frequencies and mode shapes between EMA and FEA. It is essential to assure that the FEM is equivalent to the real aircraft structure for the further structural analysis.

Metal matrix composites [MMC] were published in 2014 by Kesavulu A, F.Anand Raju, and Dr. M.L.S. Deva Kumar [8]. MMC are the most important materials used in recent industrial and engineering works. Fl y ash particles, which are low in cost and density and are available in large quantities as a waste byproduct in power plants, are used in metal matrix composites. By combining fly ash and aluminium reinforcement in a stir casting process, the cost and density of aluminium material can be reduced. When compared to other metals, metal composite processes have improved mechanical properties such as strength, hardness, low density, and good wear resistance. The chemical analysis of aluminium clad and fly ash is studied before and after mixing and forming as particulate in their study.

The ultralight aircraft differs from country to country based on speed and weight. During 19th century the ultralight aircraft weight ranges above 1000 kg. Now a days, the weight of ultralight varies from 155kg in USA to 750 kg in Brazil. But in India, the gross weight of ultralight aircraft is 450 kg.

III. WING DESIGN

i. Wing Design Parameters

Wing span, wing twist, taper ratio, wing sweep, wing thickness, wing aspect ratio, and wing dihedral are all calculated and designed in CATIA R20. The total takeoff weight and the actual wing loading values can be used to calculate the actual wing area. After comparing the wing loading for various flight conditions such as stall and cruise, it is discovered that the stall constraint yields the lowest wing loading. This is assumed to be the actual wing loading value.

Total takeoff weight, W_0 = 300.61kg
= 4.4187lbs/f
The actual wing loading, W/S $1.6kg/m^2$

Wing Area S = W_0/ (W/S)
Total takeoff weight, W_0 = 300.61kg
The actual wing lo= $4.4187lbs/ft^2$= $1.6kg/m^2$
Wing Area S = W_0/ (W/S)
= 662.75/4.4187
= 149.98 ft2 ≈ 150 ft2 S = 13.935 m2

This is the actual wing area for our design process.
Then the wingspan can be calculated as follows

b = (S*A.R) ½ (2)
b = (150*6)1/2
b = 9.144m
The half span value is, b/2 = 4.572m

Chord length can be calculated from,
c = S/b (3)
c = (150/30)
c = 1.524 m

The mean aerodynamic chord is calculated by
$M.A.C = 2/S \int_0^{b/2} c2dy$ (4)
= (2/150)*(25*15)
M.A.C= 4.99875 ft =1.524m

Weight of the wing

$$(W)_{Wing}=96.948\{[WT_0*n/10^5][A.R/\cos(\wedge 1/4)]*0.57[S_w/100]\ [(1+\lambda)/2(t/c)]\ 0.36+[1+V_{cruise}/500]0.5\}0.993 \tag{5}$$

V cruise = cruise airspeed at S.L. in knots= 45.59 m/s(or) 88.433knots

WT = take-off weight in lbs = 662.948 lb =
0 300.68

N = ultimate load factor

1/ 4 = wing quarter chord sweep

S_w = wing area in ft^2 =150

λ = taper ratio = 1

t /c = maximum thickness ratio = 11.725

A.R = 6

The load factor value has been obtained as 1 now we are going to substitute all the above values to find out the weight of wing.

$(W)_{Wing}$ = 110.84 lbs

$(W)_{Wing}$ = 50.27 kg

The above expression is valid for light conventional metal airplanes. Ultralight airplanes use „Dacron‟ as the skin material, fly considerably lower-speeds. Therefore, it was decided to reduce the weight by say 23%

Now the weight of the wing will be reduced by 25.49 lbs

$(W)_{Wing}$ =110.84 – 25.49

$(W)_{Wing}$ = 85.35 lbs

$(W)_{Wing}$= 38.714 kg

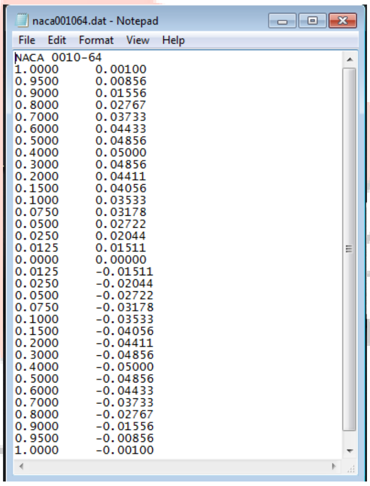
The below parameters are needed to design in CATIA

Wingspan = 9.144 m
Wing chord = 1.524 m
Rib thickness = 4.572 mm
Number of ribs = 15
Spar thickness = 3.0 mm
Number of spars = 2
Skin thickness = 1mm

The distance between each rib = 9144/15 = **609.6** mm

Thickness of all rib is same which is equal to 45.72 mm, and this value is taken from the survey of rib design for ultralight aircraft‟s wing having almost same specifications. Clark Y is the name of a particular aerofoil profile, widely used in general purpose aircraft designs, and much studied in aerodynamics over the years. The airfoil has a thickness of 11.7 percent and is flat on the lower surface from 30 percent of chord back. The flat bottom simplifies angle measurements on propellers, and makes for easy construction of wings on a flat surface. Clark-Y airfoil coordinates are used to design the wing.

Wing design in CATIA



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0.4000      0.05000
0.3000      0.04856
0.2000      0.04411
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0.1000      0.03533
0.0750      0.03178
0.0500      0.02722
0.0250      0.02044
0.0125      0.01511
0.0000      0.00000
0.0125      -0.01511
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0.2000      -0.04411
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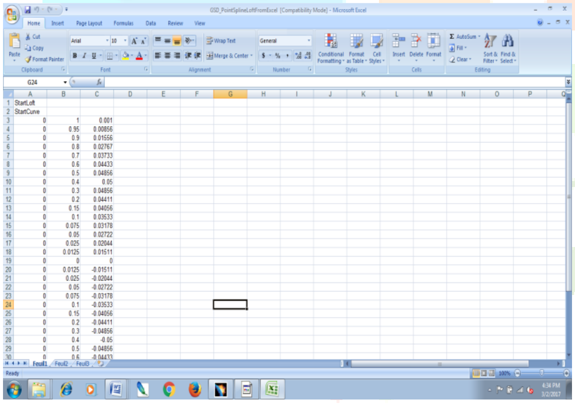
0.4000      -0.05000
0.5000      -0.04856
0.6000      -0.04433
0.7000      -0.03733
0.8000      -0.02767
0.9000      -0.01556
0.9500      -0.00856
1.0000      -0.00100
```

NACA 0010-64

1.0000	**0.00100**
0.9500	**0.00856**
0.9000	**0.01556**
0.8000	**0.02767**
0.7000	**0.03733**
0.6000	**0.04433**
0.5000	**0.04856**
0.4000	**0.05000**
0.3000	**0.04856**
0.2000	**0.04411**
0.1500	**0.04056**
0.1000	**0.03533**
0.0750	**0.03178**
0.0500	**0.02722**
0.0250	**0.02044**
0.0125	**0.01511**
0.0000	**0.00000**

0.0125	**-0.01511**
0.0250	**-0.02044**
0.0500	**-0.02722**
0.0750	**-0.03178**
0.1000	**-0.03533**
0.1500	**-0.04056**
0.2000	**-0.04411**
0.3000	**-0.04856**
0.4000	**-0.05000**
0.5000	**-0.04856**
0.6000	**-0.04433**
0.7000	**-0.03733**
0.8000	**-0.02767**
0.9000	**-0.01556**
0.9500	**-0.00856**
1.0000	**-0.00100**

1. open localdisk====next program files===next dassault systemes==next b20 ==intel-a==code==command==copy to gsd_ponitsplineloftformexcel==paste to desktop
2. copy to NASA CODE in gsd_ponitsplineloftformexcel paste here



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2	StartCurve		
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4	0	0.95	0.00856
5	0	0.9	0.01556
6	0	0.8	0.02767
7	0	0.7	0.03733
8	0	0.6	0.04433
9	0	0.5	0.04856
10	0	0.4	0.05
11	0	0.3	0.04856
12	0	0.2	0.04411
13	0	0.15	0.04056
14	0	0.1	0.03533
15	0	0.075	0.03178
16	0	0.05	0.02722
17	0	0.025	0.02044
18	0	0.0125	0.01511
19	0	0	0
20	0	0.0125	-0.01511
21	0	0.025	-0.02044
22	0	0.05	-0.02722
23	0	0.075	-0.03178
24	0	0.1	-0.03533
25	0	0.15	-0.04056
26	0	0.2	-0.04411
27	0	0.3	-0.04856
28	0	0.4	-0.05
29	0	0.5	-0.04856
30	0	0.6	-0.04433

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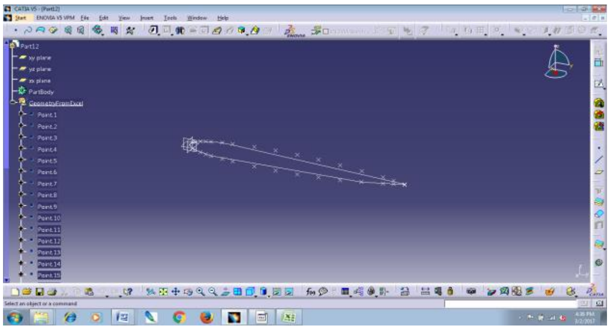


IV. WING ANALYSIS

A.MESH MODEL

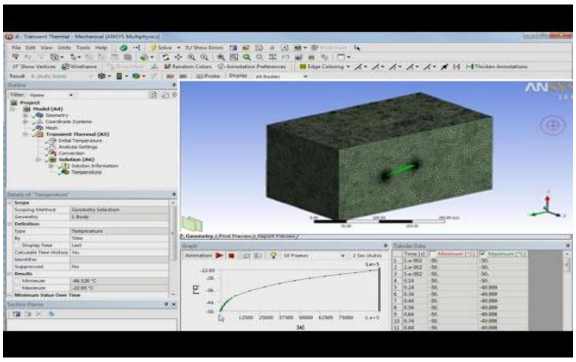


Fig 2. Flow Analysis

No. of nodes= 221821 &

No. of elements= 1251417,

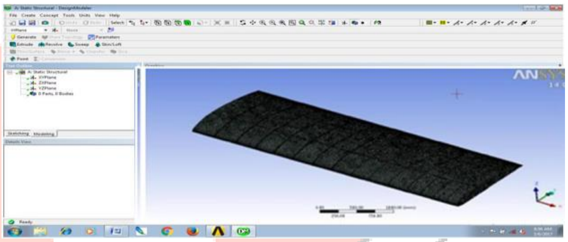


Fig 3: Structural Analysis With Skin

No. of nodes= 124944

& No. of elements= 86897 and

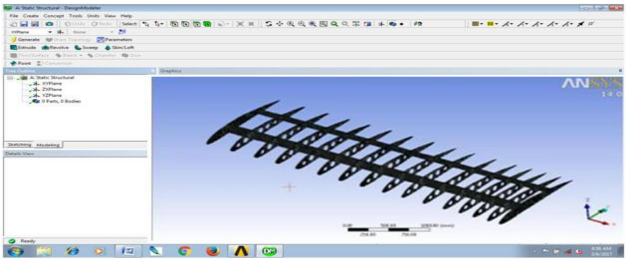


Fig 4: Structural Analysis Without Skin

(C) MESH

No. of nodes= 94297

& No. of elements= 42964.

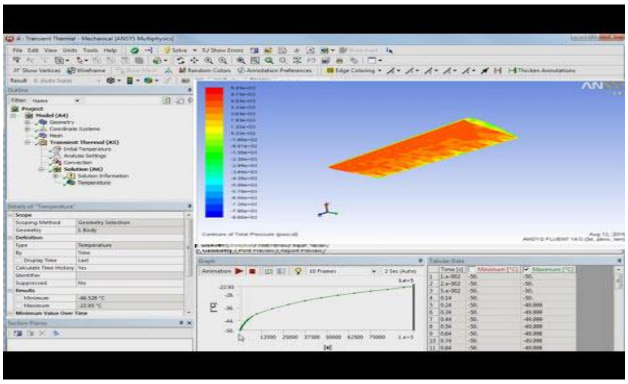
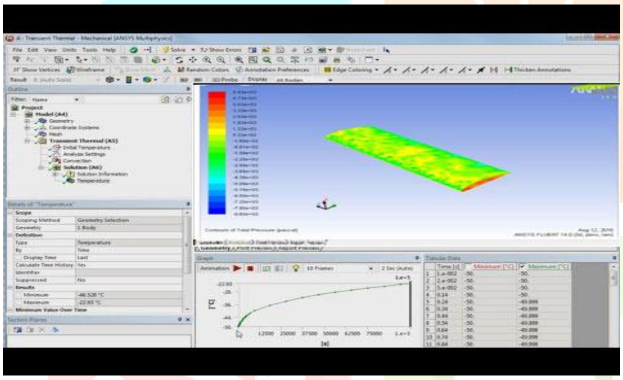


Fig.5. Total Pressure (A) On The Bottom Portion Of Wing

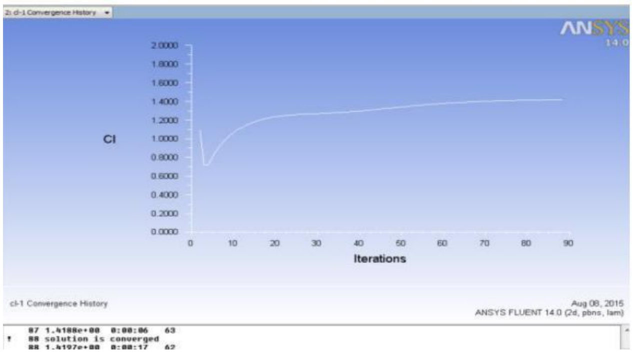
Fig (a) shows the maximum Pressure acting on the bottom portion of the wing is 5.43x103 Pascal



(B) Total Pressure On The Top Portion Of The Wing

(b) shows the maximum Pressure acting on the top portion of the wing is $1x10^2$ Pascal. As the pressure on the bottom region is greater than the pressure on the top region of the wing, Lift is produced. Cross section of the wing is taken and C_L & C_D graphs are plotted as shown in Fig. 5.

Fig. 6. Convergence a) Of Lift Coefficient (A) LIFT VALUE: Is 1.4197 Fig. (a) shows coefficient of Lift value for the wing obtained through analysis is 1.4197



```
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!    88 solution is converged
     88 1.4197e+00  0:00:17   62
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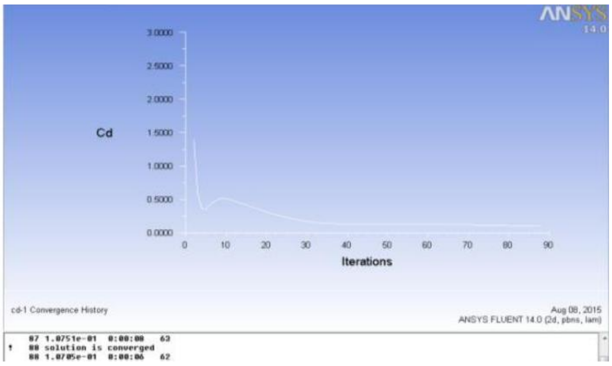

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!    88 solution is converged
     88 1.0705e-01  0:00:06   62
```

Fig.(B) Of Drag Coefficient.DRAG VALUE: IS 0.107

(b) shows coefficient of drag value for the wing obtained through analysis is 0.107.

The results were obtained from the CFD for the wing in form of graph. From the graphs we came to know that lift achieved is as per our theoretical calculations. So our design and the CFD analysis is correct. The CFD result of the wing and graph CL and CD are plotted. From this analysis we can get the pressure load for the structural analysis of the wing, we can apply this result to structural analysis using software ANSYS FLUENT 14.0

B. STRUCTURAL ANALYSIS

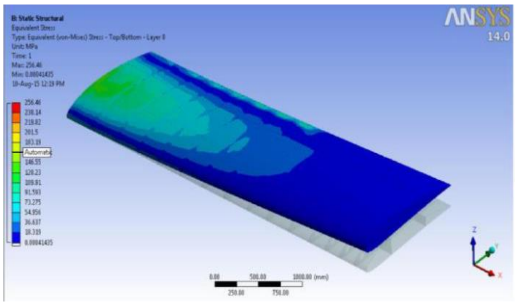
In this structural analysis, the chord area is fixed as a cantilever beam and pressure load is applied. The pressure force is imported from the results from the CFD analysis. The pressure that flow over the wing in the CFD analysis is applied as the pressure load on the top and bottom surface of the wing. This is done using software ANSYS FLUENT 14.0. The analysis is done for Al 2024-T3, Al 6061-T6, Al 7075-T651 & Al 7075+15% Fly Ash MMC having the properties as follows.

Table 1 Material properties

Material	Young's Modulus E (GPa)	Poisson's Ratio - μ	Ultimate Tensile Strength (Mpa)	Tensile Yield Strength (Mpa)	Density (Kg/m3)
Al 2024-T3	73.1	0.33	483	345	2 767.99
Al 6061-T6	68.9	0.33	310	276	2 698.79
Al 7075-T651	71.7	0.33	572	503	2 823.35
Al 7075+15%Fly Ash	71	0.3	591.3	469.7	2809.51

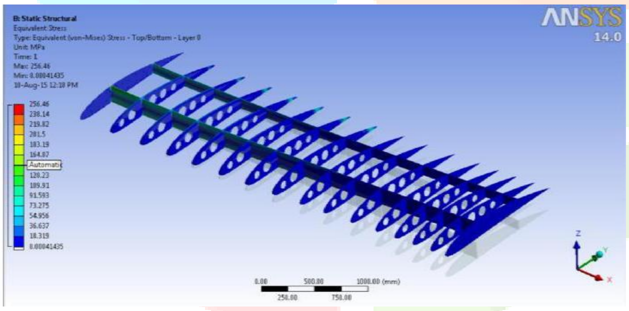
The structural analysis of ultralight aircraft wing has variation in deformation, strain and Factor of safety. Stress value for all the Materials remains same as Stress is function of Load and Area. In this case Pressure load applied and Area of the wing is constant in all the calculations.

Fig. 7. von-Mises Stress a) Wing with Skin



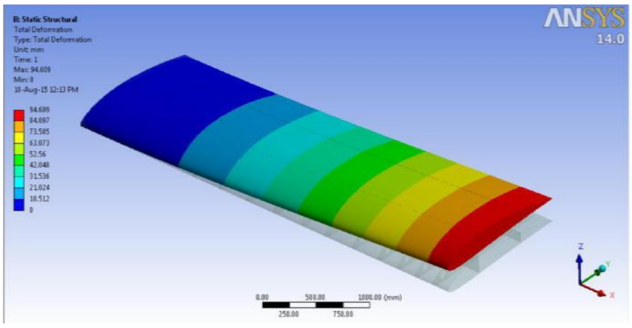
Maximum Equivalent (von-Mises) Stress value obtained for the applied pressure load is 256.46 MPa.

b) Von-Mises Stress Wing without Skin



Structural analysis outputs for the Al 2024-T3 wing is as follows.

Fig. 8. Al 2024-T3 wing (a) Deformation



Deformation: 94.609 mm.

(a) Maximum deformation for the applied pressure load occurs at the wing tip at a value of 94.609 mm.

(b) Al 2024-T3 wing Elastic Strain

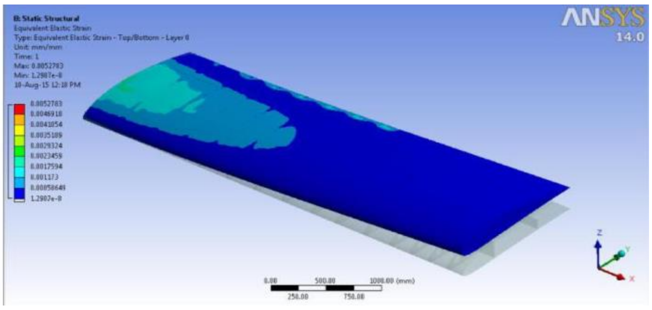


Fig: (b) Maximum Equivalent elastic Strain value obtained for the applied pressure load is 0.00527.

(c) Al 2024-T3 wing Safety Factor

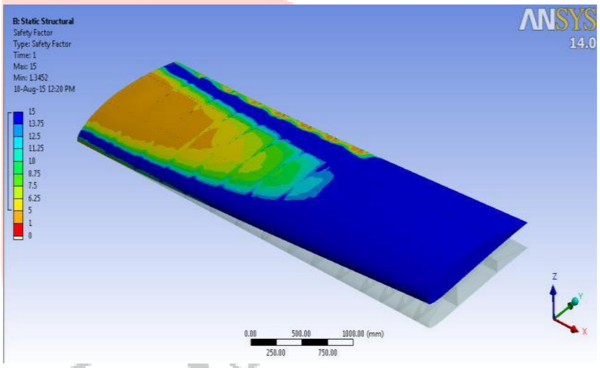


Fig (c) Factor of Safety of the Al 2024-T3 wing is 1.3452 minimum. As the minimum FOS value is greater than 1, the wing can with stand the maximum pressure load which it encounters during the flight.

Structural analysis outputs for the Al 6061-T6 alloy wing is as follow.

Fig. 9. Al 6061-T6 wing (a) Deformation

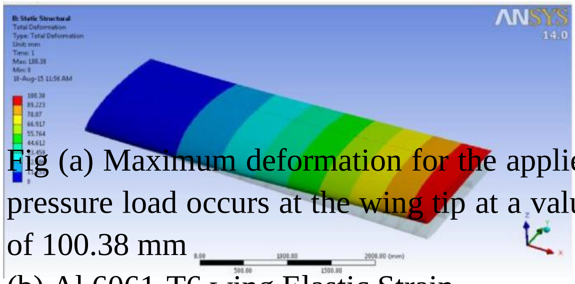


Fig (a) Maximum deformation for the applied pressure load occurs at the wing tip at a value of 100.38 mm

(b) Al 6061-T6 wing Elastic Strain

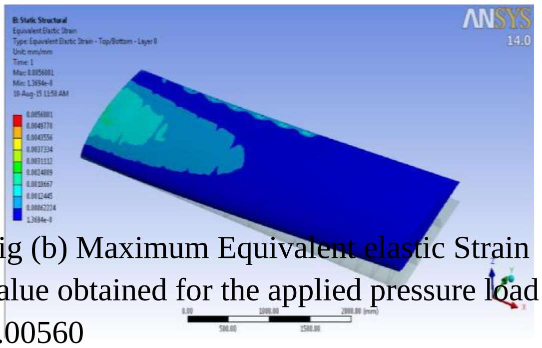


Fig (b) Maximum Equivalent elastic Strain value obtained for the applied pressure load is 0.00560

(c) Al 6061-T6 wing Safety Factor

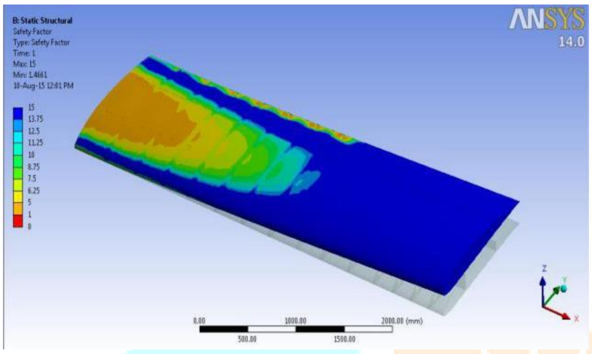


Fig (c) Factor of Safety of the Al 6061-T6 wing is 1.4661 minimum. As the minimum FOS value is greater than 1, the wing can with stand the maximum pressure load which it encounters during the flight.

Structural analysis outputs for the Al 7075-T651 alloy wing is as follow.

Fig. 10. Al 7075-T651 wing (a) Deformation

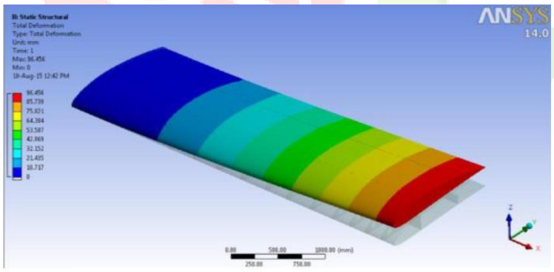


Fig (a) Maximum deformation for the applied pressure load occurs at the wing tip at a value of 96.456 mm.

(b) Al 7075-T651 wing Elastic Strain

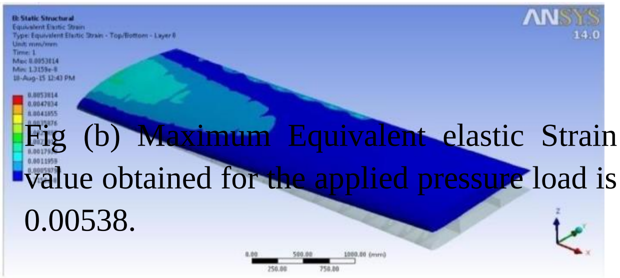


Fig (b) Maximum Equivalent elastic Strain value obtained for the applied pressure load is 0.00538.

(c) Al 7075-T651 wing Safety Factor

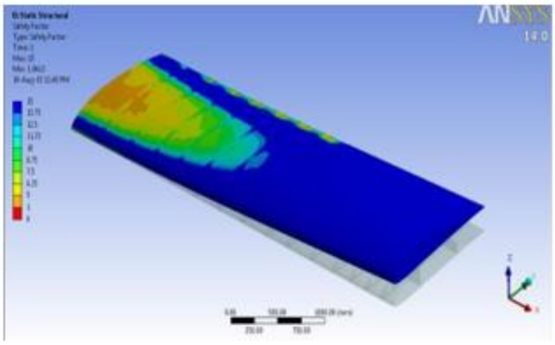


Fig (c) Factor of Safety of the Al 7075-T651 wing is 1.9613 minimum. As the minimum FOS value is greater than 1 and nearly equal to 2, the wing can with stand the twice the maximum pressure load which it encounters during the flight.

Structural analysis outputs for the Al 7075 + 15% Fly Ash MMC wing is as follows.

Fig. 11. Al 7075 + 15% Fly Ash MMC wing

(a) Deformation

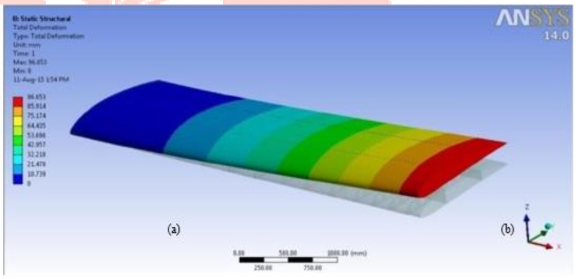


Fig (a) Maximum deformation for the applied pressure load occurs at the wing tip at a value of 96.653 mm..

(b) Al 7075 + 15% Fly Ash MMC wing Elastic Strain

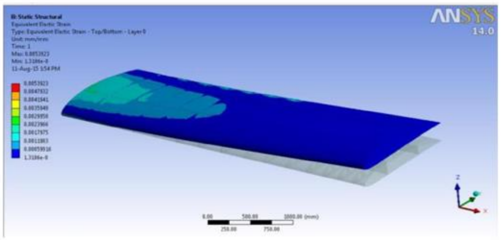


Fig (b) Maximum Equivalent elastic Strain value obtained for the applied pressure load is 0.00539.

(c) Al 7075 + 15% Fly Ash MMC wing Safety Factor

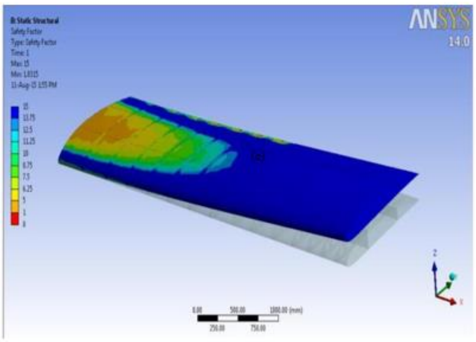


Fig (c) Factor of Safety of the Al 7075+15% Fly Ash MMC wing is 1.8315 minimum. As the minimum FOS value is greater than 1, the wing can with stand the maximum pressure load which it encounters during the flight.

V.RESULTS

Table 2
Structural analysis results comparison

Material	Deformation (mm)	Elastic Strain-e	von-Mises Stress (MPa)	Factor of Safety
Al 2024-T3	94.609	0.00539	256.46	1.3452
Al 6061-T6	100.38	0.00560	256.46	1.4661
Al 7075-T651	96.456	0.00538	256.46	1.9613
Al 7075+15%Fly Ash	96.563	0.00539	256.46	1.8315

Pressure load results from the CFD analysis is applied on the wing top and bottom surfaces, structural analysis is done and results are tabulated as shown above Table 2.Al 7075-T651 material has better structural characteristics than other Alloys.

VI. CONCLUSION

According to the calculated design requirements, the wing of an ultralight aircraft was modelled using the design software CATIA V5R20, and flow analysis was performed to visualise the flow pattern over the wing section and its behaviour such as pressure distribution, lift and drag curves were plotted. The structural analysis of the wing section was performed using ANSYS FLUENT for materials such as Al 2024-T3, Al 6061-T6, Al 7075-T651, and Al 7075 + 15% FLY ASH MMC, and the results were compared. We would like to conclude from the comparisons that Al 7075-T651 material has better structural characteristics than other Alloys. However, using Al 7075 + 15% Fly Ash MMC reduces the weight of the wing because the 15% weight of the Aluminium 7075 is replaced by 15% Fly Ash, which helps to increase the aerodynamic characteristics by reducing drag due to weight. Even the Metal Matrix Composite's Factor of Safety (1.8315) exceeds the required value. The Margin of Safety=FOS-1 value of 0.8315 is also greater than 0 and nearly equal to 1. As the demand for lighter material with good structural characteristics increases in aerospace and automotive industries, Metal Matrix Composites can be the low cost solution than the Laminated Composite Materials.

Different materials can be tested under the same conditions in the future to find a more suitable material with good aerodynamic and structural characteristics, the number of main load carrying members can be changed, and analysis can be performed.

FUTURE SCOPE

The scope draws the aircraft for future work for advancement of the proposition.

1. Now that designers are interested in creating Ultralight Aircraft, this analysis can be expanded to include

Different materials can be tested under the same conditions in the future to find a more suitable material with good aerodynamic and structural characteristics, the number of main load carrying members can be changed, and analysis can be performed.

REFERENCES

T.V. Baughn and P.F. Packman. "Finite element analysis of an ultralight aircraft", Journal of Aircraft, Vol. 23, No. 1(1986), pp.82-86.

Baughn, T. and Johnson, D., "Structural Design Considerations for Ultralight Aircraft," SAE Technical Paper 861388, 1986, doi:10.4271/861388.

Girish S. Kulkarni, A thesis of „Structural Design and Analysis of an Ultralight Airplane‟, IIT Kanpur, 1987.
Zdobyslaw Goraj, „Ultralight wing structure for high altitude long endurance UAV‟, ICAS 2000 Congress.

William Zimmerman and Howard W. Smith, „Report on test set-up for the structural testing of air mass sunburst in Ultralight aircraft‟ 2001
L. Pascale, F. Nicolosi, "Design and Aerodynamic analysis of a light twin-engine propeller aircraft" ICAS 2008.

Huiwen Hu and Huaien Kao, "Model Validation of an Ultralight Aircraft Using Experimental Modal Analysis" Journal of Aeronautics, Astronautics and Aviation, Series A, Vol.41, No.4 pp.271 - 282 (2009).

Kesavulu A, F.AnandRaju & Dr. M.L.S. Deva Kumar, "Properties of Aluminium Fly Ash Metal Matrix Composite" Vol. 3, Issue 11, November 2014, ISSN: 2319-8753.