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# Design and Analysis of NACA0016 Wing Rib and Stringers by using al-7075 and Kevlar

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***Abstract:*** ***The aircraft wing consists of multiple airfoils shapes that are called "ribs". These ribs are connected with stringers to form a shape of Skelton and then cover it with aluminium-alloy sheets to make a wing. In this paper, a NACA0016 airfoil ribs with stringers were designed in CATIA V5 by using three types of aluminium-alloys (AL-2024, AL-6061, and AL-7075) and then analysed in ANSYS workbench to determine the deformation, stress and safety factor values. The stringer's material was then changed from al-alloy to cfrp and Kevlar in order to find which combination of materials will give less deformation, stress and high safety factor. The results show that using cfrp material can reduce the weight up to 30% but the stress will increase while using Kevlar nearly reduces stress, deformation and weight up to 252Mpa, 25% and 33%, respectively. It concluded that AL-7075-t6 and Kevlar materials give less stress and high strength to weight ratio.***

***Index Terms: Ribs, Stringers, NACA0016, Al-alloys, cfrp, Kevlar, Ansys, CATIA, Design foil.***

## I. INTRODUCTION

Wings are the main lifting surfaces for plane. The NACA airfoils are airfoil shapes for airplane wings advanced by the National Advisory Committee for Aeronautics (NACA) and the profile of the NACA airfoils is termed by sequences of digits following the name "NACA". The parameters in the numerical code can be entered into equations to exactly create the cross-section of the airfoil and determine its properties [1, 2].

FOUR-DIGIT SERIES (NACA0016):

The NACA four-digit wing sections explain the shape by:

The NACA 0016 airfoil is symmetrical, the 00 showing that it has no camber. The 16 shows that the airfoil has a 16% thickness to chord length ratio: it is 16% as thick as it is long [2, 3].

1) EQUATION FOR A SYMMETRICAL 4-DIGIT NACA AIRFOIL:

The Thickness formula [1, 4] for the shape of a NACA 0016 foil, with "16" being replaced by the percentage of thickness to chord is 0.16.

$$y=\frac{t}{0.2}c\left[0.2969\sqrt{\frac{x}{c}}-0.1260\left(\frac{x}{c}\right)-0.3516\left(\frac{x}{c}\right)^2+0.2843\left(\frac{x}{c}\right)^3-0.1015\left(\frac{x}{c}\right)^4\right] \quad (1)$$

Where:

- c is the chord length,
- x is the position along the chord from 0 to c,
- y is the half thickness at a given value of x (centerline to surface), and
- t is the maximum thickness as a fraction of the chord (so t gives the last two digits in the NACA 4-digit denomination).

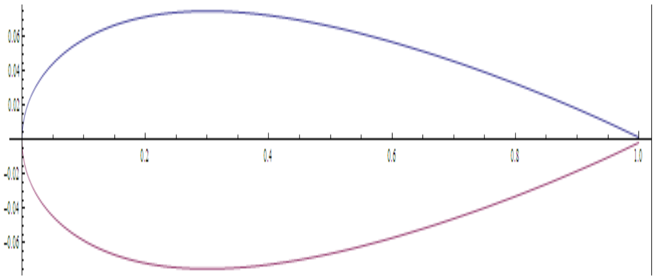


**Fig.1 Plot of a NACA 0016 foil, generated from formula**

RIB: In an airplane, ribs are forming elements of the structure of a wing, especially in traditional construction and its provide the shape to the wing section, support the skin (avoid buckling).By similarity with the anatomical meaning of "rib", the ribs fasten to the main spar, and by being repeated at frequent intervals, form a skeletal shape for the wing. Usually ribs incorporate the airfoil shape of the wing, and the skin adopts this shape when stretched over the ribs. [5] STRINGER (LONGERON): The stringers are axial supporters used to do the best bending capacity [6].In airplane and launch vehicle construction, a longeron, or stringer or stiffener, is a thin strip of material to which the skin of an airplane or propellant tank may be fastened [7].

## II. LITERATURE REVIEW

T.V. Baughn and P.F. Packman [1] in 1986 accomplished a finite element analysis to find the structural safety of a high-wing cable-supported very light weight airplane. A symmetrical, half-structure macro-model was evaluated and undergo to level soaring loading and two-wheel-landing loading status. Flexural and bending stiffness for the supported and unsupported wing were also resolved.

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A principal harm acceptance analysis was made in which selected cable elements and wing compression props were eliminated, the redistributed loads calculated, and possible aircraft flight configurations examined. Baughn and Johnson [2] in the same year suggested a design modification from high-wing cable-supported to prop supported airplane.
The aim of the adjustment is to decrease the pull and upgrade the act of the ultralight. The objective of their research is to define the structural act of the cable supported airplane and distinguish it to the structural act of a prop supported version of the same airplane and to supply an evaluation of the modification in pull connected with the transformation from cable supported to prop supported. Girish S. Kulkarni [3] in 1987, with the help of all the design guidelines provided by Baughn along with considering critical condition in un-accelerated flight, accomplished a Finite element process based structural design to analyse the action of an aircraft under Aerodynamic loading.

## III. METHODOLOGY AND MATERIAL SELECTION

In this methodology, The NACA 4-digit series 0016 is used to create the airfoil shape for airplane wing with the help of DESIGN FOIL software and MS excel spreadsheets, the wing rib of 2mm thick with stringers is designed in part design module by using CATIA V5 then analysed it in ANSYS WORKBENCH. The material properties of isotropic type is used with three types of aluminum alloys (AL-6061, AL-2024, and AL 7075 T6) applied for both ribs and stringers to calculate the static results for deformation, stress & safety factor. From all these alloys we got the best results for AL-7075T6 material. Here was changed stringer material from Al-7075 to CFRP and KEVLAR to see what will happen in stresses and it will be like (al-7075&cfrp, al-7075&Kevlar). The boundary conditions applied for the analysis are that wing rib was fixed from translational and rotational movements with the application pressure 200 MPa. In conclusion by comparing all results we can define which stringer material will produce less stress and high safety factor**.**

## IV. DESIGN OF WING RIB

To create the airfoil shape NACA0016 here was used DESIGN FOIL software (fig.2)

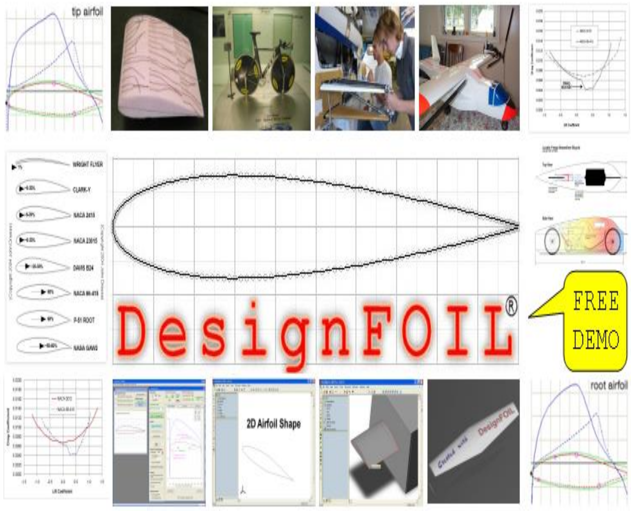


**Fig.2 Design Foil**

After open design foil software and select file NACA4 DIGIT series we will get below window (figs. 3) then enter NACA0016 it will create airfoil shape with 71 key points (see fig. 4)**.**

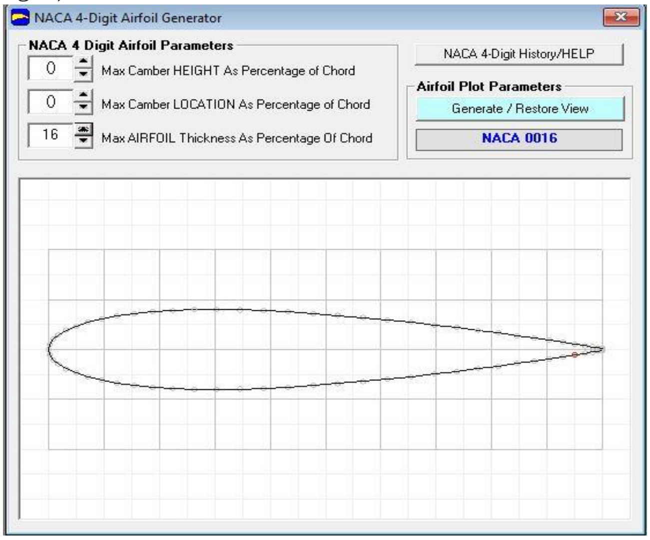


**Fig.3 NACA 0016 shape**

| NACA 0016 | | | | INDEX | X_Coord | Y_Coord | | |
|---|---|---|---|---|---|---|---|---|
| INDEX | X_Coord | Y_Coord | 24 | 0.263066 | 0.079593 | INDEX | X_Coord | Y_Coord |
| 1 | 1.000000 | 0.001680 | 25 | 0.224551 | 0.078104 | 49 | 0.303487 | -0.080019 |
| 2 | 0.997987 | 0.002056 | 26 | 0.188255 | 0.075527 | 50 | 0.345492 | -0.079433 |
| 3 | 0.991965 | 0.003176 | 27 | 0.154469 | 0.071861 | 51 | 0.388739 | -0.077907 |
| 4 | 0.981981 | 0.005014 | 28 | 0.123464 | 0.067135 | 52 | 0.432883 | -0.075528 |
| 5 | 0.968117 | 0.007529 | 29 | 0.095492 | 0.061399 | 53 | 0.477568 | -0.072399 |
| 6 | 0.950484 | 0.010669 | 30 | 0.070776 | 0.054724 | 54 | 0.522432 | -0.068628 |
| 7 | 0.929224 | 0.014367 | 31 | 0.049516 | 0.047199 | 55 | 0.567117 | -0.064324 |
| 8 | 0.904509 | 0.018552 | 32 | 0.031883 | 0.038918 | 56 | 0.611260 | -0.059597 |
| 9 | 0.876536 | 0.023146 | 33 | 0.018019 | 0.029977 | 57 | 0.654508 | -0.054557 |
| 10 | 0.845531 | 0.028066 | 34 | 0.008035 | 0.020463 | 58 | 0.696513 | -0.049303 |
| 11 | 0.811745 | 0.033228 | 35 | 0.002013 | 0.010452 | 59 | 0.736934 | -0.043936 |
| 12 | 0.775448 | 0.038547 | 36 | 0.000000 | 0.000000 | 60 | 0.775448 | -0.038547 |
| 13 | 0.736934 | 0.043936 | 37 | 0.002013 | -0.010452 | 61 | 0.811745 | -0.033228 |
| 14 | 0.696513 | 0.049303 | 38 | 0.008035 | -0.020463 | 62 | 0.845531 | -0.028066 |
| 15 | 0.654508 | 0.054557 | 39 | 0.018019 | -0.029977 | 63 | 0.876536 | -0.023146 |
| 16 | 0.611260 | 0.059597 | 40 | 0.031883 | -0.038918 | 64 | 0.904509 | -0.018552 |
| 17 | 0.567117 | 0.064324 | 41 | 0.049516 | -0.047199 | 65 | 0.929224 | -0.014367 |
| 18 | 0.522432 | 0.068628 | 42 | 0.070776 | -0.054724 | 66 | 0.950484 | -0.010669 |
| 19 | 0.477568 | 0.072399 | 43 | 0.095492 | -0.061399 | 67 | 0.968117 | -0.007529 |
| 20 | 0.432883 | 0.075528 | 44 | 0.123464 | -0.067135 | 68 | 0.981981 | -0.005014 |
| 21 | 0.388739 | 0.077907 | 45 | 0.154469 | -0.071861 | 69 | 0.991965 | -0.003176 |
| 22 | 0.345492 | 0.079433 | 46 | 0.188255 | -0.075527 | 70 | 0.997987151 | -0.00205609 |
| 23 | 0.303487 | 0.080019 | 47 | 0.224551 | -0.078104 | 71 | 1 | -0.00168 |

**Fig.4 NACA 0016 key points**


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From The above Key points The Shape Was Developed in Catiav5 module as shown in (fig.5).

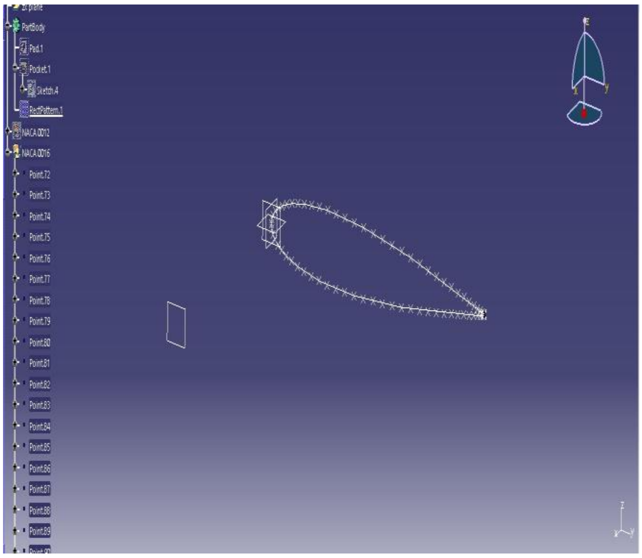

**Fig.5 CATIA Developed Model by Using Key points**

Then by using PAD we are going to extrude that shape with 2mm thickness (fig 6).

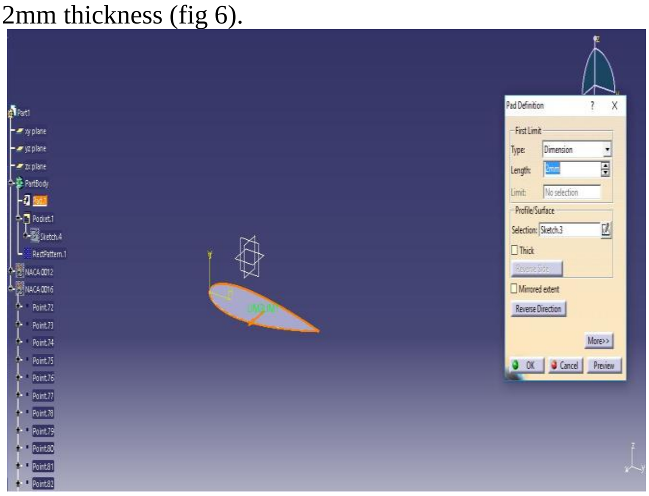

**Fig.6 wing rib**

By using pattern command we create 8 no. of wing ribs with the span distance of 500mm. To insert stringers we also made holes by using pocket option (see fig 7).

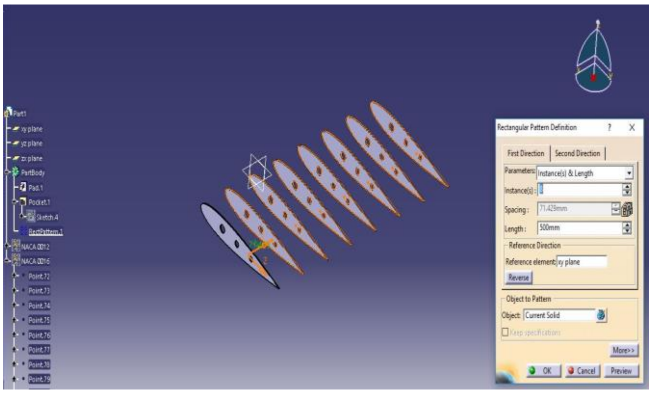

**Fig.7 wing ribs with stringer holes**

After saving individual ribs and stringers we arranged them into single object to assemble. To do that import individual objects into assembly window and fix all ribs, then import stringers by using co-incident constraint and distance constraint to arrange them as shown in (fig 8).

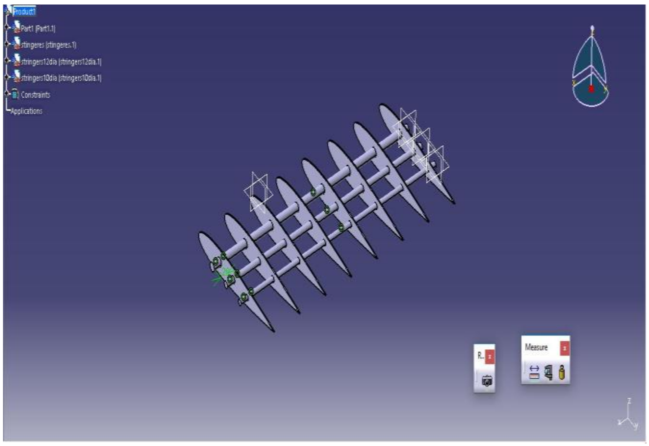

**Fig.8 Ribs and Stringers Assembly**

## V. FINITE ELEMENT ANALYSIS OF WING RIBS AND STRINGERS

FEA of both wing rib and stringers was used for observing the structural behaviour by the structural static analysis. The FEA's chief intention is only to show the behaviour of both wing rib and stringer in the form of stress and displacement analysis. After performing the analysis test, results of both wing rib and stringer was demonstrated.

### A. Meshing

The meshing is very significant for the analysis at all structural object or body. Meshing is the method of discretization of a body into smaller parts for precision of the results and the set of nodes and elements is known as mesh. Generally, there are two methods of meshing are used: one is Quad and another one Tria [8, 9]. In the project the Quad type is used for meshing (see fig.9).

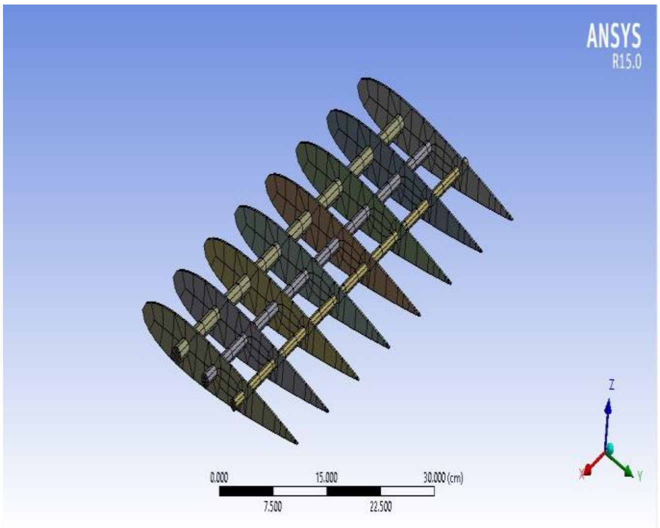


**Fig.9 Meshing Model**

### B. Material Properties

Table1 show we are selected three different al-alloys to find out among all these types which one will give high strength to weight ratio


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**Table1: material Properties for AL-Alloy**

| | Al-6061 | Al-2024 | Al-7075-t6 |
|---|---|---|---|
| Young's modules (pa) | $70E^9$ | $73.1E^9$ | $71.7E^9$ |
| Poisson's ratio | 0.33 | 0.33 | 0.33 |
| Density (kg/m$^3$) | 2680 | 2780 | 2810 |
| Yield strength (Mpa) | 260 | 324 | 503 |

### C. Loads and Boundary Conditions

Select model assign same material properties for both ribs and stringers then fix one end with transverse and rotation support. Then apply pressure120 MPa on wing ribs, Fig.10 shows loads and boundary conditions on both wing rib and stringers.

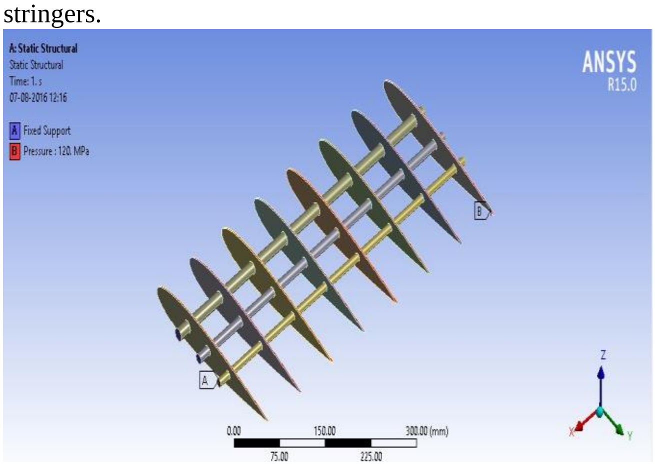
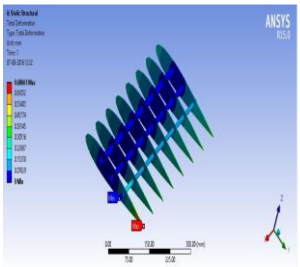



**Fig.10 Boundary conditions on model**

## VI. RESULTS BY USING AL-ALLOY MATERIALS

### A) Displacement Plot of Rib and stringers with al-alloys



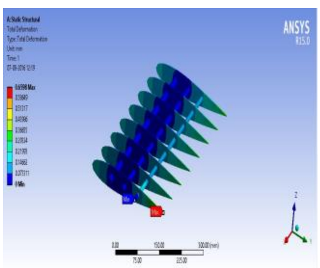


**Fig.11 Al-6061 deformation** **Fig.12 Al-7075 deformation**

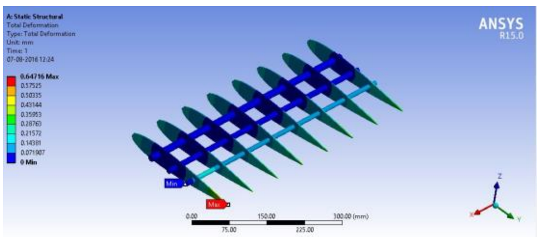
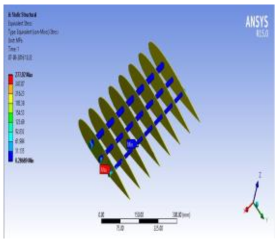


**Fig.13 AL-2024 deformation**

From the results of deformation we can see al-7075t6 material have less deformation (see Table 2).

### B)Stress Plot of Rib And Stringers With Al-Alloys



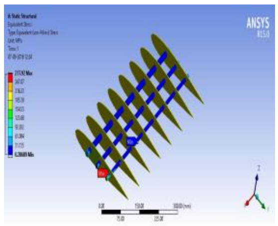


**Fig.14 Al-6061 stress** **Fig.15 Al-2024 stress**

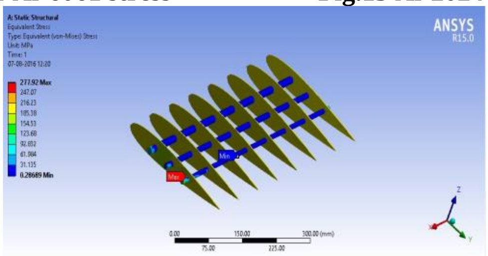
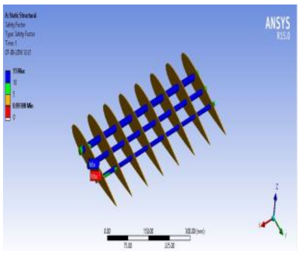


**Fig.16 Al-7075-t6 stress**

Figs. 14, 15 &16 shows the stress values are remaining same for all alloys.

### C) Safety Factor Plot Of Rib And Stringers With Al-Alloys



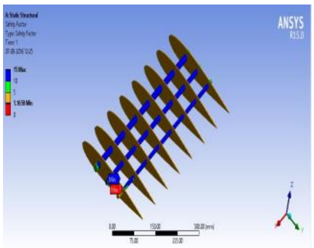


**Fig.17 Al-6061 safety factor** **Fig.18 Al-2024 safety factor**

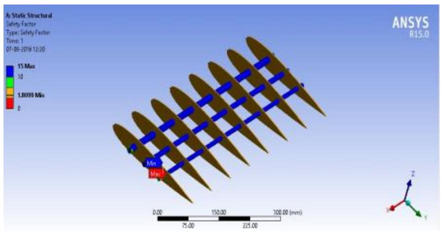


**Fig.19 Al-7075-t6 safety factor**

From the above figures the stress values are same for all but the strength has been changed; but from all these al-7075-t6 have very high strength (see Table 2).

**Table2: the static results of AL-Alloy**

| | AL-2024 | AL-6061 | AL-7075 |
|---|---|---|---|
| DEFORMATION | 0.67416 | 0.68661 | 0.6598 |
| STRESS | 277.92 | 277.92 | 277.92 |
| FOS | 1.1658 | 0.993 | 1.8099 |

Table 2 shows three types of Al-Alloy for static results of deformation, stress and safety factor values. So we conclude al-7075 is having high safety factor values therefore we can say that al-7075 having more strength compare to other two materials.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And to improve its performance here we are replacing stingers material with cfrp90 and Kevlar material then we calculated results again.

## VII. RESULTS BY USING CFRP90 & KEVLAR MATERIALS

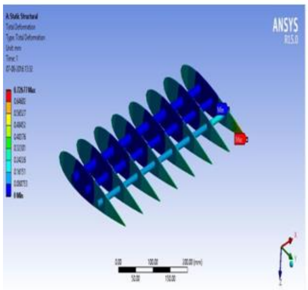
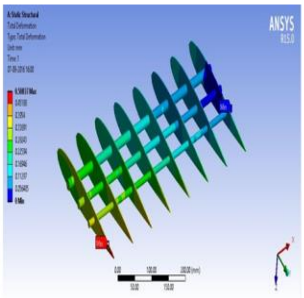



**Fig.20 Al-7075 and cfrp90deformation Fig.21 Al-7075 and Kevlar deformation**

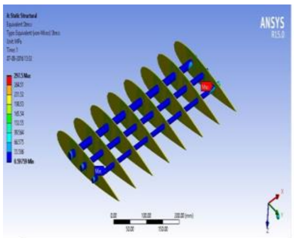
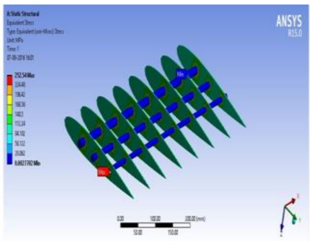



**Fig.22 Al-7075 and cfrp90 stress Fig.23 Al-7075 and Kevlar stress**

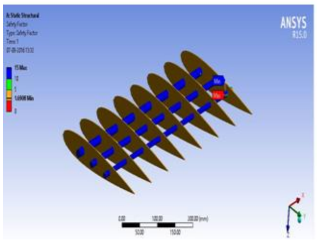
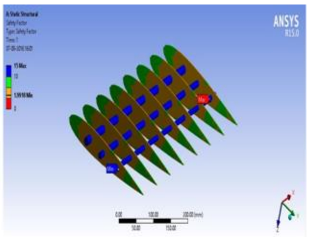
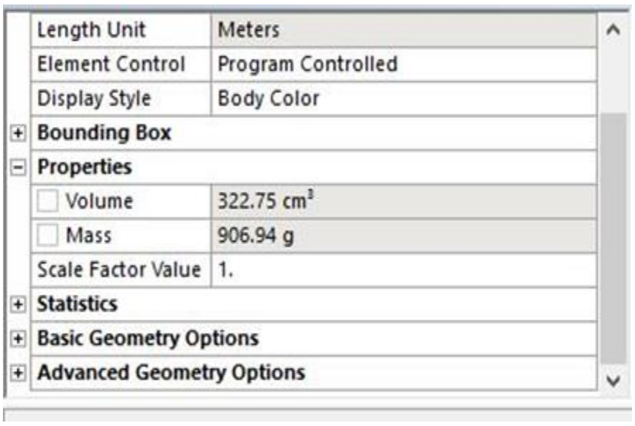



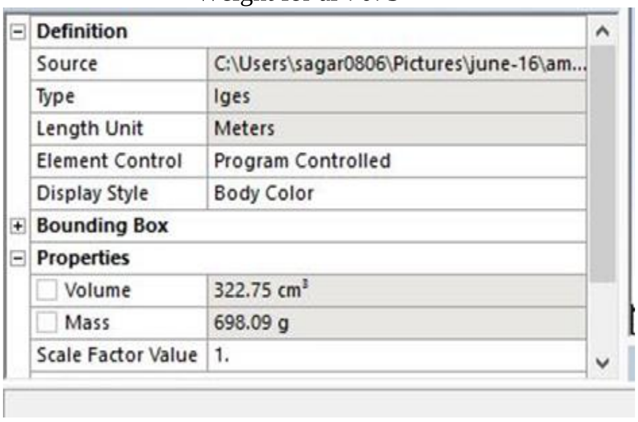
**Fig.24 Al-7075 and cfrp90 safety factor Fig.25 Al-7075 and Kevlar safety factor**

From the above results we can say when we are used al-7075 for stringers we got 272Mpa stress, and when we changed stringers material from al-7075 to cfrp90 material (figs.20, 22&24) we got 297Mpa stress it means the stress has been increases but it is under yield limit because it show safety factor is 1.69. So by this change it won't get any breakage and also we will reduce weight up to 30%.But when changed al-7075 to Kevlar (figs. 21, 23&25) then the stress has been decreases to 252Mpa and high safety factor 1.9 compares to others and also reduces weight (see results in Table 3).



| | |
|---|---|
| Length Unit | Meters |
| Element Control | Program Controlled |
| Display Style | Body Color |
| Bounding Box | |
| Properties | |
| Volume | 322.75 cm³ |
| Mass | 906.94 g |
| Scale Factor Value | 1. |
| Statistics | |
| Basic Geometry Options | |
| Advanced Geometry Options | |

Weight for al-7075



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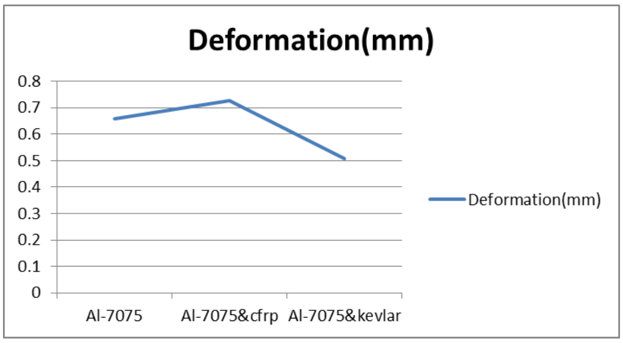
|---|---|
| Definition | |
| Source | C:\Users\sagar0806\Pictures\june-16\am... |
| Type | Iges |
| Length Unit | Meters |
| Element Control | Program Controlled |
| Display Style | Body Color |
| Bounding Box | |
| Properties | |
| Volume | 322.75 cm³ |
| Mass | 698.09 g |
| Scale Factor Value | 1. |

Weight for Al-7075&cfrp90

**Table3: the static results for stringer by using different materials**

| | Al-7075 | Al-7075& cfrp | Al-7075& Kevlar |
|---|---|---|---|
| **Deformation (mm)** | 0.6598 | 0.72677 | 0.50837 |
| **Stress (Mpa)** | 277.92 | 297.5 | 252.54 |
| **Safety factor** | 1.8099 | 1.6908 | 1.9918 |




**Graph1: deformation**

Graph 1 show the deformation results when we change stringer material for al-alloy 7075 to cfrp deformation has been increased then for Kevlar deformation decreases.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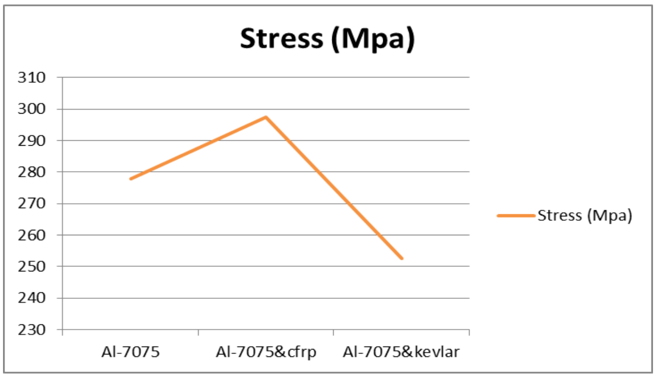
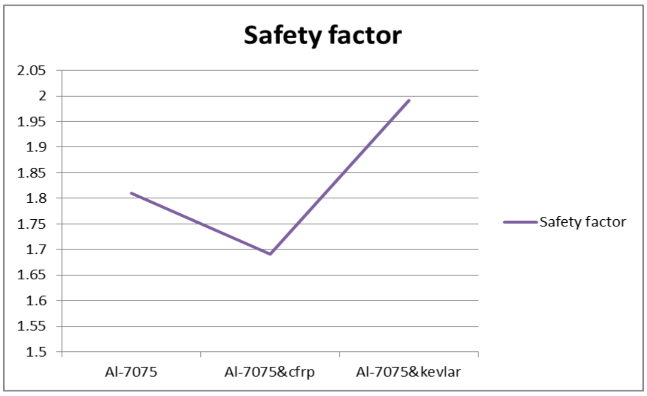



**Graph2: stress**

The Graph 2 shows the stress results when we change stringer material for al-alloy 7075 to cfrp the deformation values has been increased then for Kevlar stresses decreases.




**Graph3: safety factor**

The Graph 3 shows the safety factor results when we change stringer material for al-alloy 7075 to cfrp safety factor has been decreased then for Kevlar material safety factor has been increased.

## VIII. CONCLUSION

In this project, the ribs and stringers with three of al-alloys (AL-2024, AL-6061, AL-7075) were designed and analysed to determine the static results like deformation, stress and safety factor values from that we achieved the best results for al-7075-t6 material, but to reduce the stress value here the stringer's material was changed from al-7075-t6 to cfrp and then Kevlar. In this case by using cfrp we can reduce the weight up to 30% but the stress will increases. In other hand by using Kevlar for stringer we nearly reduces stress 252Mpa and decreases25% of deformation and increases strength as 1.9 safety factor and also decreases weight up to 33%. Finally we can conclude from all results al-7075-t6 &Kevlar material will give less stress and high strength to weight ratio.

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