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STRUCTURAL DESIGN & OPTIMIZATION OF AIRCRAFT WING SPAR

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***Abstract*— The ribs gives the proper aerodynamic shape to the wing. And spar will take most of the bending loads in wing structure. In the present work ribs, spars and wing structure is optimized for twisting, bending and axial loads in terms of size and shape for a particular 10 seater aircraft. CFRP is considered for the material configuration of the wing. Cruise load is considered for the analysis of the wing. Design has been made using Catia V5 R21 and Analysis has been carried out using ANSYS 14.5 workbench. The results are validated using standard design of the 10 seater Cessna 402 aircraft.**

***Keywords*— CFRP-carbon reinforced polymer, Ribs, Spar, Cruise load, axial loads.**

I. INTRODUCTION

The main objective is to optimize the wing structure by changing the cross section of the spar by introducing the angle between the web and flange in I section spar. To increase the strength to weight ratio of the wing. To use a composite materials in the construction of wings. To analyze the components of wing and the wing for different loads (bending, torsion, fatigue).

The proposed system is the wing spar design by varying the physical dimension of I section spar mainly the angle between the web and the flange, which reduces thickness of the web and to design a ribs that suited for the spar design and by designing the wing and using the carbon fiber composites in its construction. The advantages of the design is that it increase the space in the spar for carrying out inspection and thereby ease the process of maintenance. Decreases the thickness of the airfoil which helps in reducing drag of the aircraft and in turn increasing the efficiency. It Increase the strength to weight of the wing.

II. LITERATURE STUDY

The most of the literature survey focused on the designing and analysis of the aircraft wing by using computer software and some by analytical and numerical approach. In the above mentioned journals the study is concerned about the weight reduction and design optimization by using tapered section spars, cutouts in spar web and using of composites in construction of wings. However they have not focused on design optimization of a wing spar by changing its shape.

III. MATERIAL PROPERTIES, DESIGN AND ANALYSIS.

MATERIAL PROPERTIES:

MATERIAL	:	CARBON FIBER REINFORCED POLYMER.
FIBER / MATRIX PERCENTAGE	:	70/30.
DENSITY	:	1800Kg/
YOUNG'S MODULES	:	181 Gpa.
COEFFICIENT OF THERMAL EXPANSION	:	2.1*
ULTIMATE TENSILE STRENGTH	:	1500MPa.
ULTIMATE COMPRESSIVE STRENGTH	:	750MPa.

AIRCRAFT SPECIFICATION:

• WING	:	RECTANGULAR
• CHORD	:	1.56m
• AEROFOIL	:	NACA23018
• CAPACITY	:	10 SEATER
• WING SPAN	:	13.45m
• WING AREA	:	21m^2
• MAX TAKEOFF WEIGHT	:	3107kg
• MAX SPEED	:	428km/hr
• WING LOADING	:	148kg/m^2
• CRUISE ALTITUDE	:	27000ft

CATIA V5 R21 DESIGN:

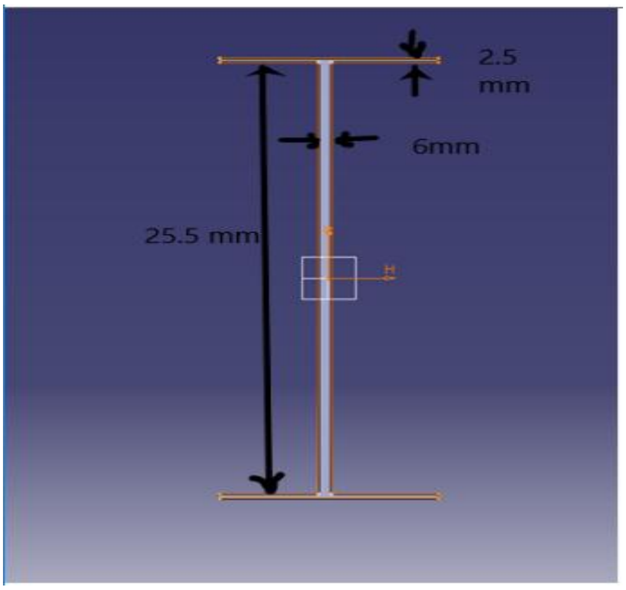

Fig 1. I-Section

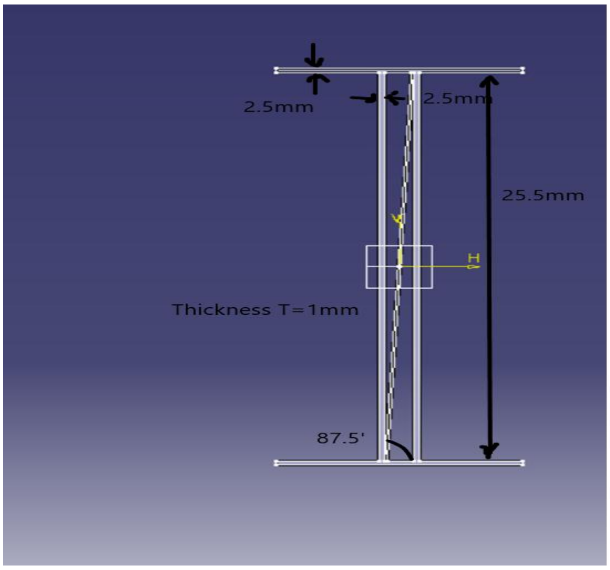

Fig 2. Optimized I-Section

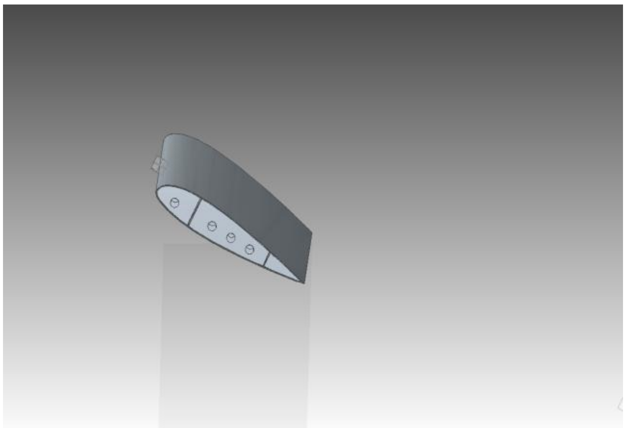

Fig 3. Solid Wing Design

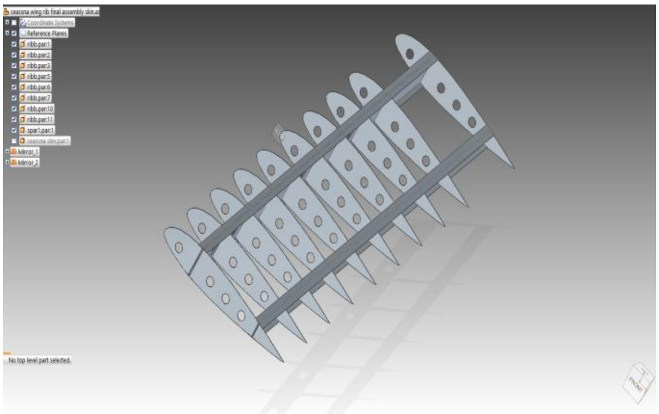

Fig 4. Solid Ribs and Spar Design

ANSYS 14.5 WORKBENCH STRUCTURAL ANALYSIS:

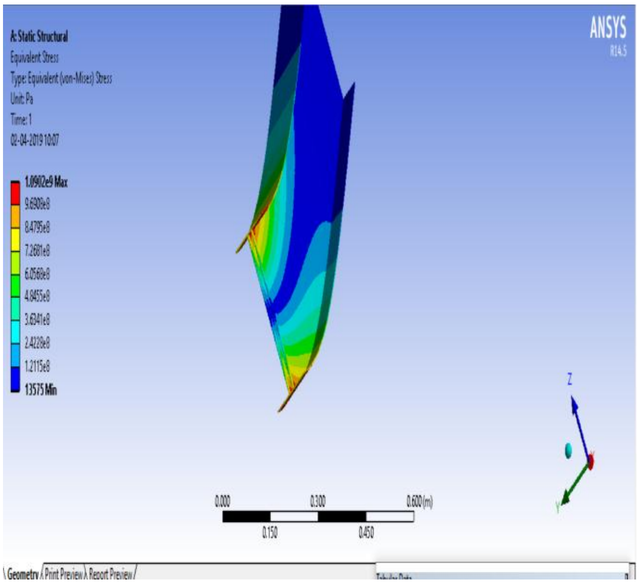

Fig 5. Equivalent Stress value after Bending load of 35KN

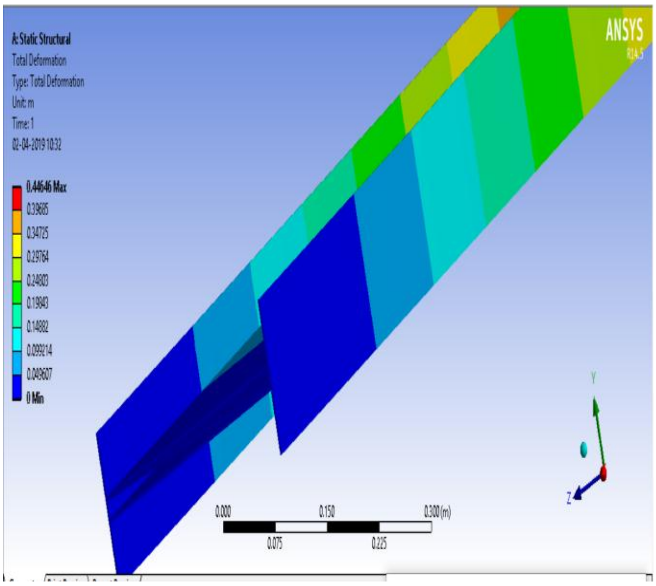

Fig 6. Deformation due to bending at 35 KN

LOAD VARIATION GRAPHS:

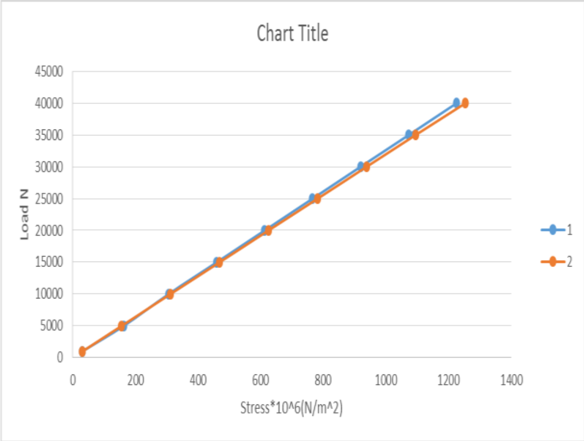

Fig 7. Load Vs stress

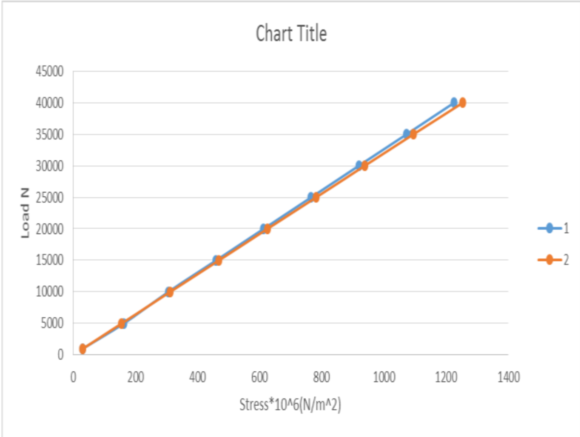

Fig 8. Load Vs Strain

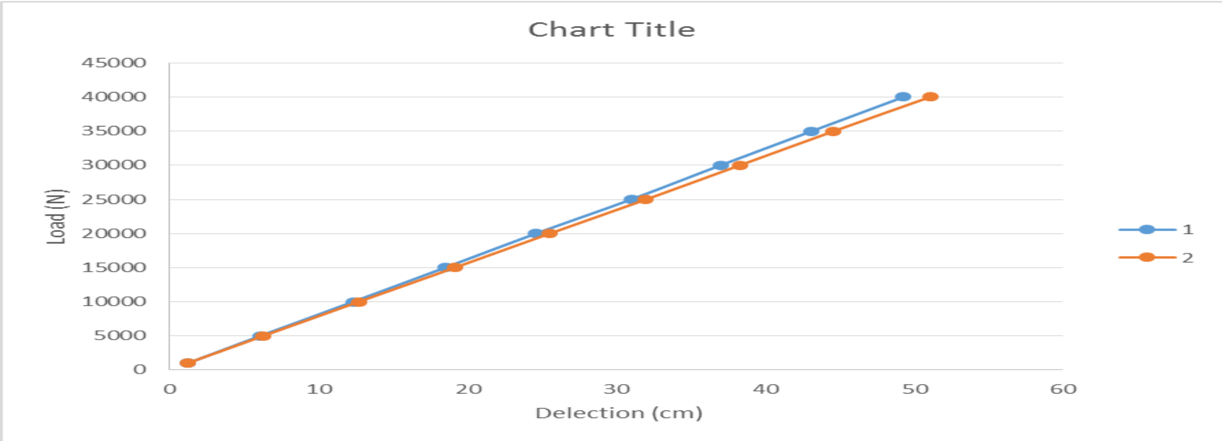

Fig 9. Load Vs Deflection

From the above graphs it is observed that both the "I" and optimized 'I' section spar have shown same behavior under bending loads.

TORSIONAL ANALYSIS:

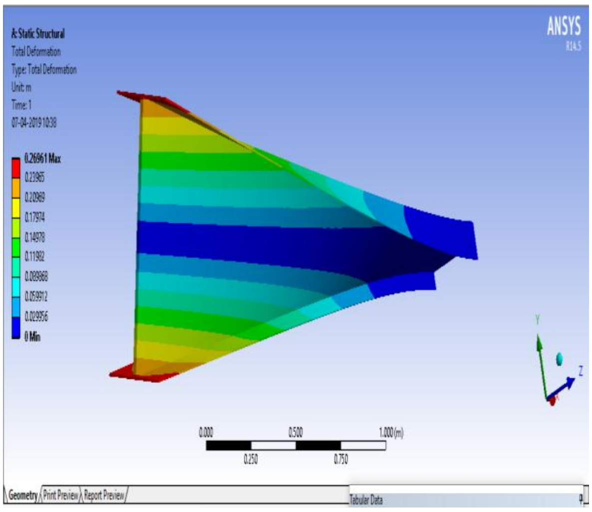

Fig 10. I-section Torsional Analysis

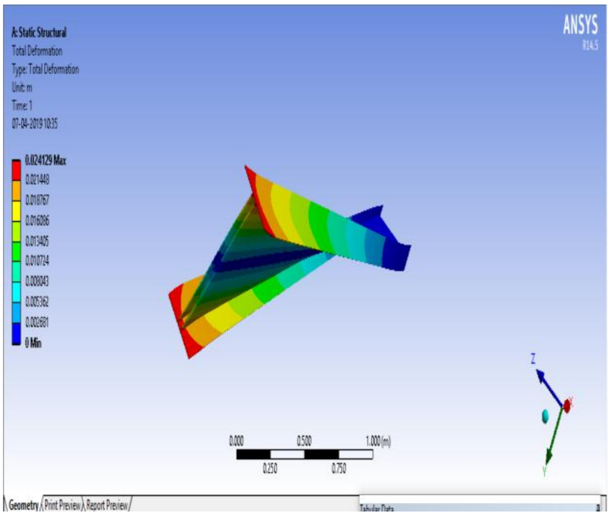

Fig 11. Optimized I-section Torsional Analysis

TORSIONAL GRAPHS:

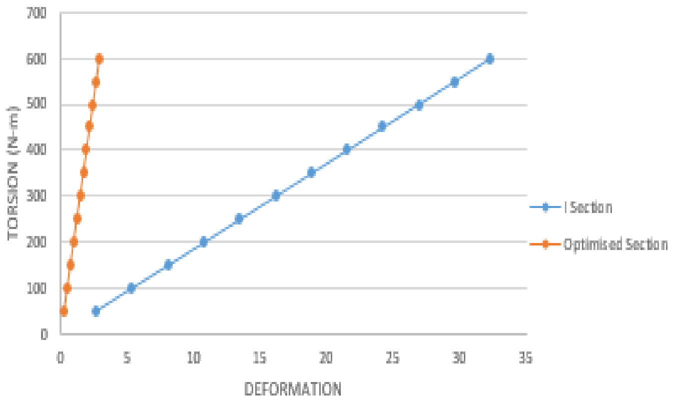

Fig 12. Torsion Vs Deformation

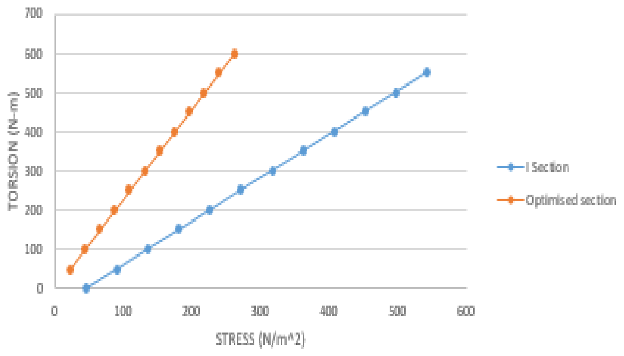

Fig 13. Torsion Vs Stress

Fig

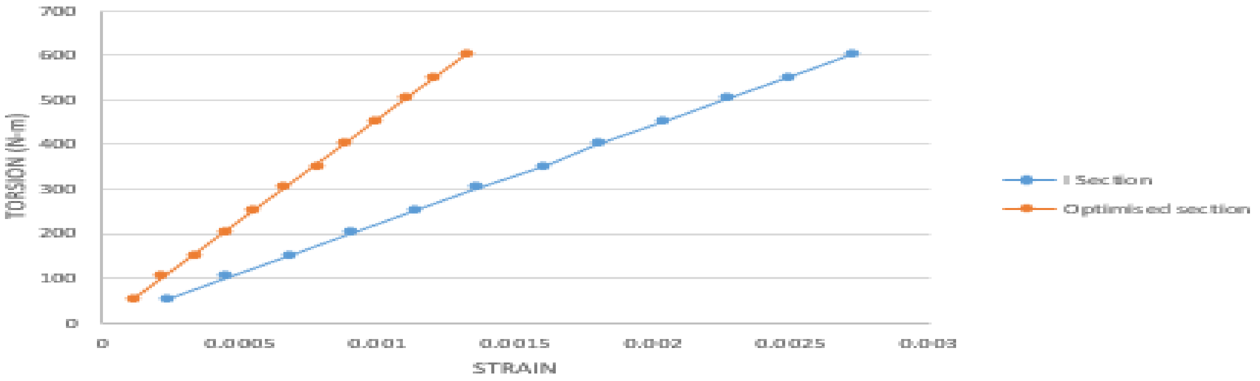

Fig 14. Torsion Vs Strain

From the above graphs the optimized 'I' section spar is more rigid than the normal "I" section spar under the torsional loads. And with this, the assumption of aircraft is rigid structure can be taken during design calculations.

STRESS CONCENTRATION ANALYSIS:

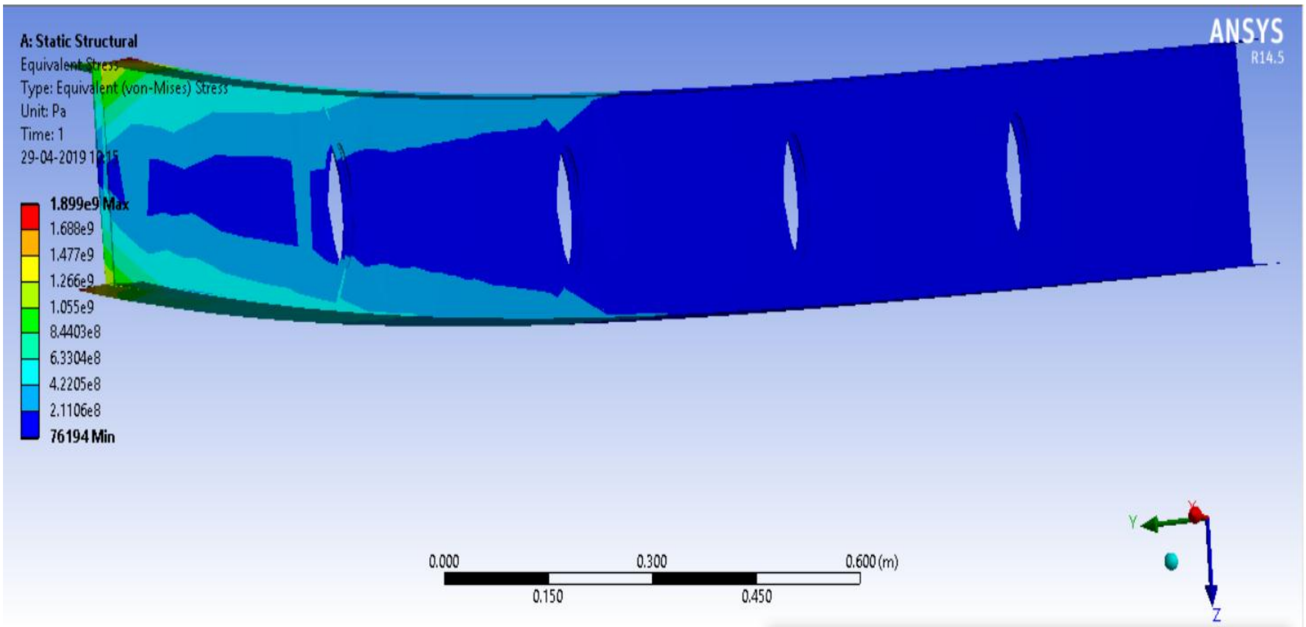

Fig 15. Stress Intensity analysis with four cut-out holes on the Spar at 20000N Load

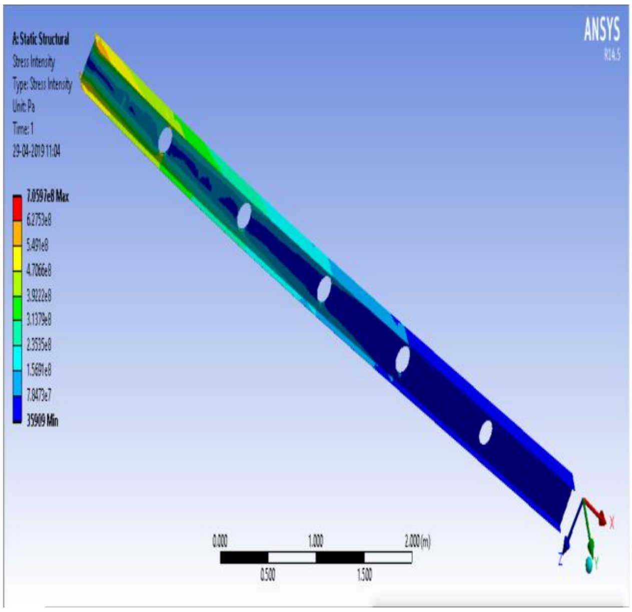

Fig 16. Stress Intensity analysis with five Cut-out holes on the Spar at 20000N Load

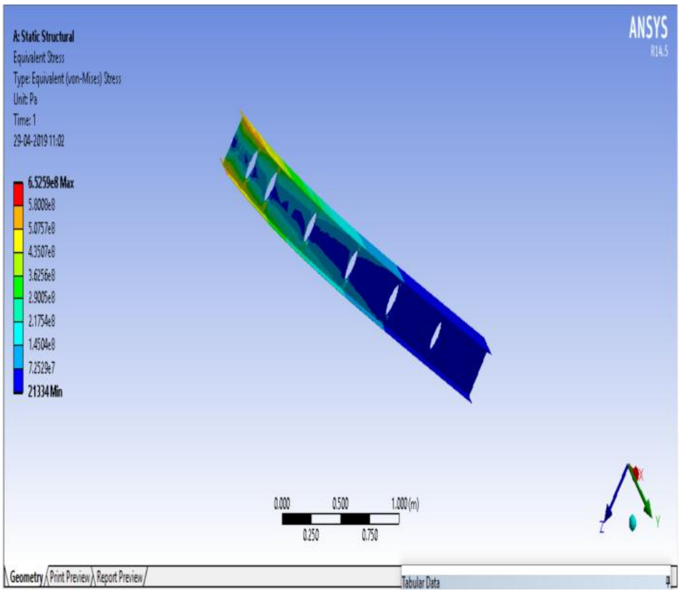

Fig 17. Stress Intensity analysis with Six cut-out holes on the Spar at 20000N Load

BENDING ANSLYSIS OF WING:

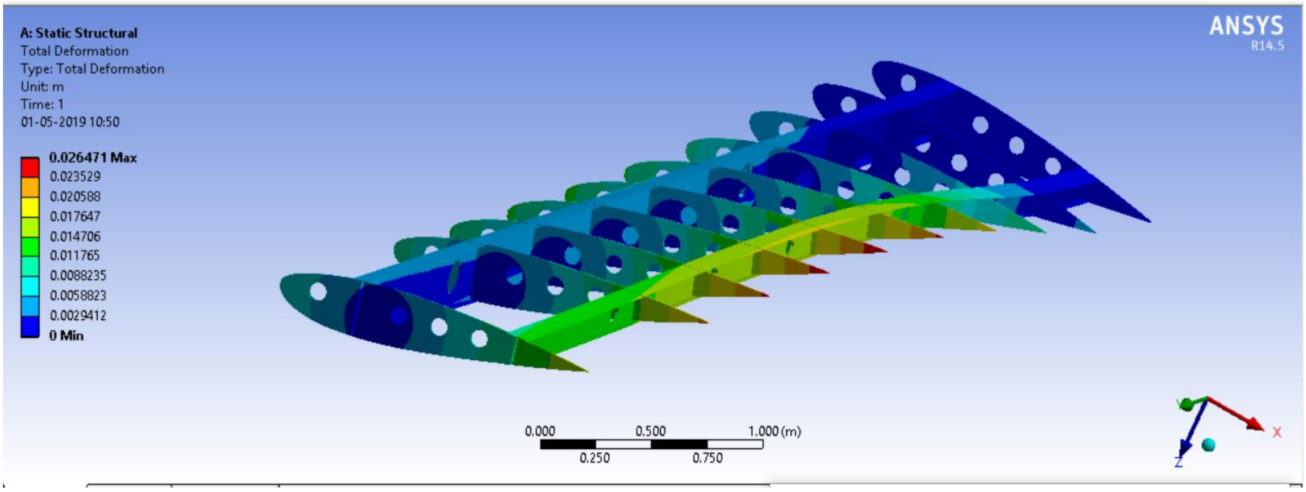

Fig 18. Bending analysis of wing

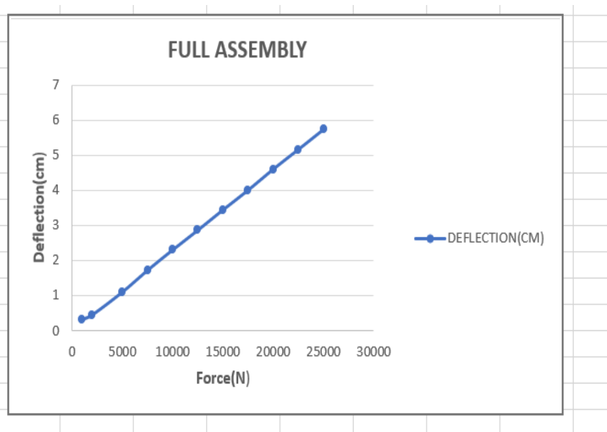

Fig 19. Bending Load Vs Deflection

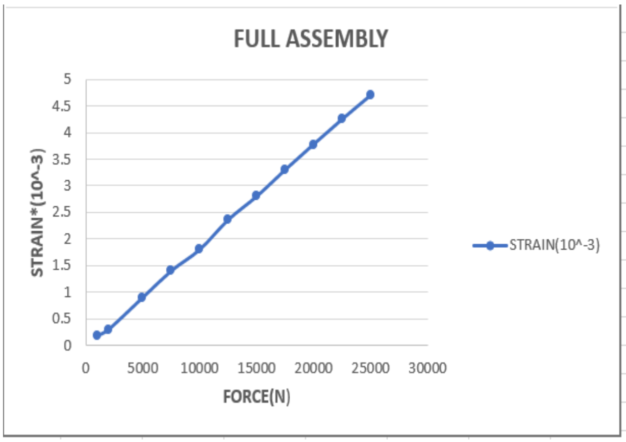

Fig 20. Strain Vs Force

MODAL ANALYSYS OF WING:

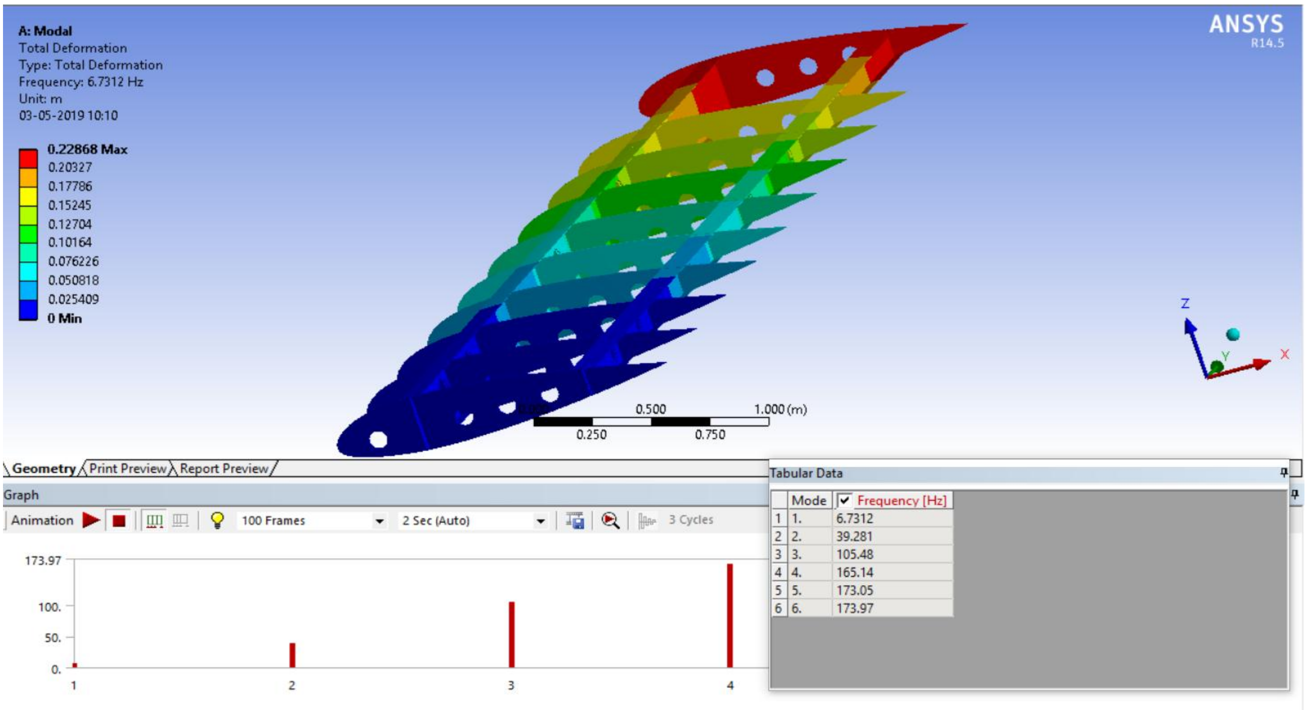

Fig 21. Modal Analysis of Wing

The natural frequency is found to be 6.73HZ and is above the testing frequency of ground vibration test for Boeing it is about 5-6 Hz. This type of testing comes under the hazardous flight testing.

SAFETY FACTOR AT CRUISE LOAD i.e. 16000N:

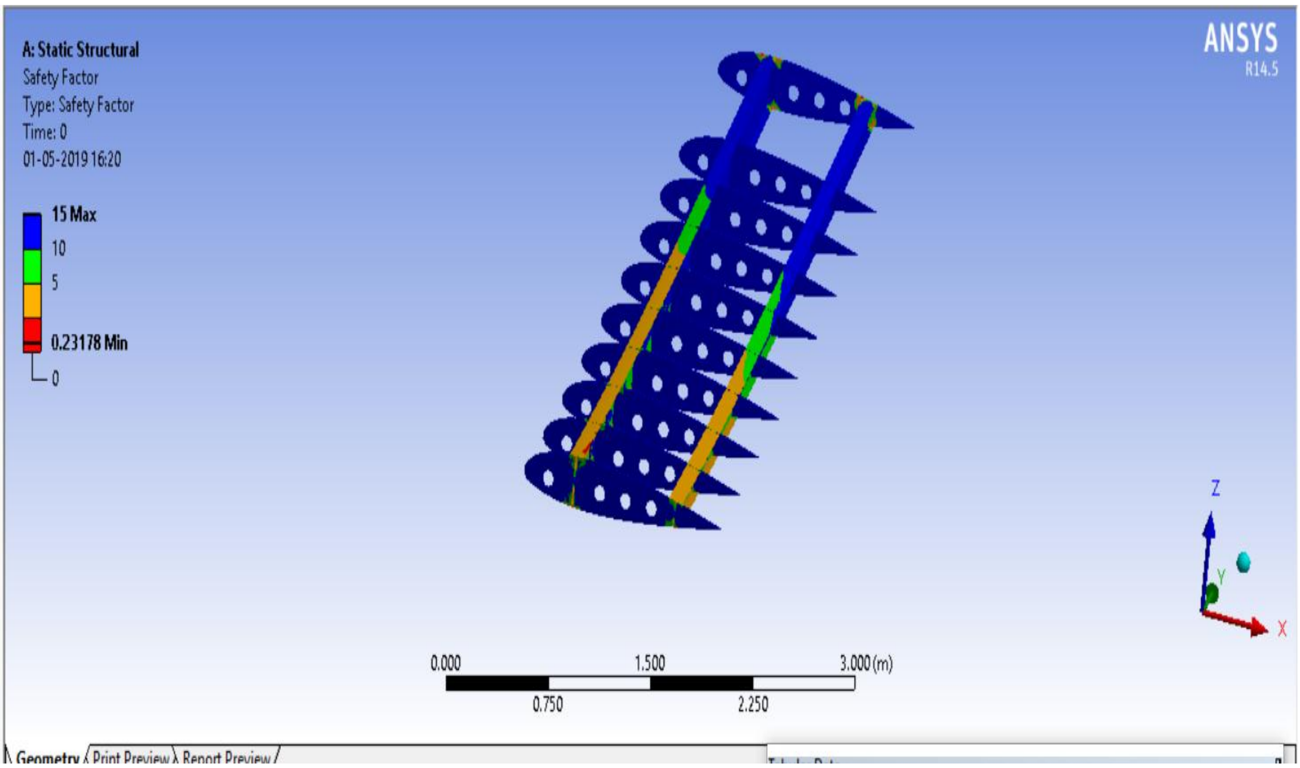

Fig. 22. Safety factor at cruise load

Safety factor of the whole wing assembly is greater than the 1.5 and at some places due to point loading its showing less than desired value.

IV. VALIDATION

TABLE 1

Serial No	component	"I" section	Optimized "I" section
1	Ixx	1.5*10^7 mm^4	1.56*10^7 mm^4
2	**Iyy**	4.21*10^5mm^4	4.3*10^5 mm^4
3	Spar weight	24.21 kgs	23.85 kgs
4	Deflection of spar at 20000N	24.6cm	25.53cm
5	Equivalent stress of spar at 20000N	613*10^6 Pa	625*10^6 Pa
6	Deflection of spar under torsional load of 100N-M.	5.3cm	0.48cm

V.CONCLUSION

- Recapitulating the whole project, below mentioned important concepts are validated and also provides an advantageous and optimised outcomes.
- This optimised 'I' section behaves same as that of the "I" section under the bending loads.
- Optimised section is more rigid than the "I" section spar under the torsional loads which acts on the material at the time of control surface deflections.
- Strength to weight ratio of the optimised section is 5% more than the "I" section
- Weight of the wing is 280kgs which is of 15% of the empty weight of the wing and it is within the limits (i.e. 15-20% of empty weight.
- Number of cruise cycles it can be operated is about 1,50,000
- Significant values of Safety factor (i.e. between 2 to 3) under the cruise load.
- No extra efforts for maintenance and acquires general inspection methods.

VI. REFERENCE:

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