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STUDY OF WEIGHT OPTIMIZATION ON SPAR BEAM FOR THE WING OF AN AIRCRAFT

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ABSTRACT

The structure of an airframe represents one of the finest examples of strength to weight ratio in the field of Aeronautical Engineering. The aim of this project is to study about the various types of aircraft wing spar structure and to optimize an aircraft wing spar beam for a six seater aircraft.

The efficient design will be achieved by the use of strength of material approach. Software packages are to be used to design an aircraft wing spar structure and Finite Element Method (FEM) also be used to calculate the stresses developed at each station for a given bending moment. Several iterations will be carried out for the design optimization of the spar beam. The spar beam may be designed to yield at the design limit load.

The results from the conventional design approach and the optimized design are compared. Material saving and economical design for operation, through the design optimization is studied.

1. INTRODUCTION

From the analysis of existing and future air travel conditions above, it is possible to postulate a new type of airline service; one that is aimed at the profitable business travel market. The project study involves the development of a spar structure for a six seat aircraft.

An airplane design to meet the functional, operational and safety requirements set by ultimate user. The actual process of design is a complex and long drawn out engineering task involving selection of aircraft type and shape, determination of geometric parameters, selection of power plant, structural design and analysis of various components. The structural and functional testing of airplane components is carried out simultaneously with the design work and prototype construction. The newly built aircraft spar is tested for strength and dependable functioning of its system using software’s.

2. INTRODUCTION TO SPAR

An aircraft wing is mainly subjected to lift, fuel, and engine, and landing gear, inertial, structural, non structural and other aerodynamic loads. The main load-bearing members in the wing are called spars. The spars are the principle structural members. Spars are strong beams which run span wise in the wing and carry the force and moments due to the span wise lift distribution. The figure 2.1 shows the schematic diagram of the loads acting on the wing.

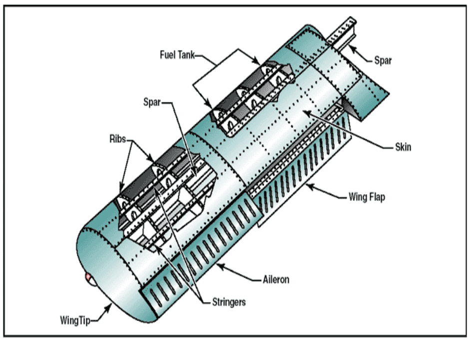

Figure 2.2: **WING STRUCTURE**

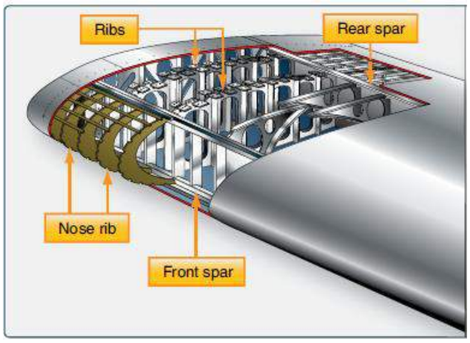

Figure 2: **Spars**

Wings of aircraft are attached at the root to the fuselage. A wing has two spars. One spar is usually located near the front of the wing, and the other about two-thirds of the distance toward the wing's trailing edge (Fig 4.3). Spar run parallel to the lateral axis of the aircraft, from the fuselage toward the tip of the wing, and are usually attached to the fuselage by wing fittings, plain beams, or a truss.

3. DESIGN OF UNIFORM SPAR

3.1SELECTION OF BASIC PARAMETERS:

General Performance characteristics

AIRCRAFT SPECIFICATIONS

- Six seater aircraft
- All up weight of wings = 2000 Kg
- Load factor = 3 g condition
- Factor of safety = 1.5
- Design limit load = 6000 Kg
- Design ultimate load = 9000 Kg
- Lift load on wings = 4800 Kg
- Load on each wing = 2400Kg
- Load on spar = 1800Kg

General Performance characteristics:

- Cruise speed : 905 Km/hr
- Max speed : 950 km/hr
- Range : 9070 km
- Max wing loading : 7975.5 N/m^2
- Minimum thrust/weight 0.287

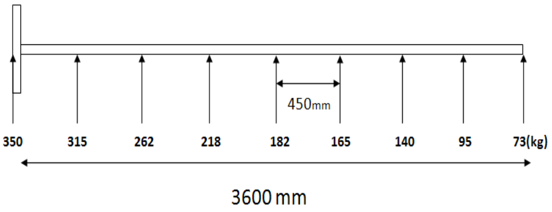

Figure 3.1: **Cantilever beam load distribution**

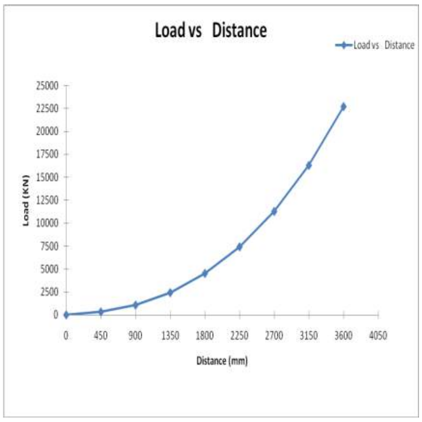

Figure 3.2: **Graph load – distance**

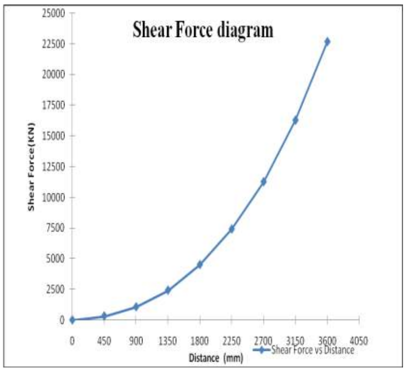

Figure 3.3: SHEAR FORCE DIAGRAM

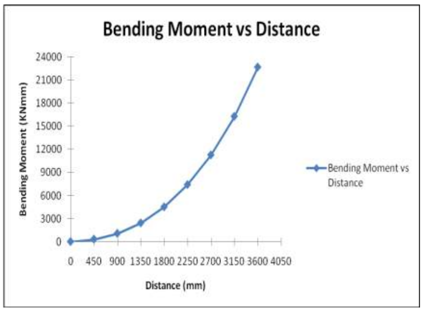

Figure 3.4: BENDING MOMENT DIAGRAM

3.3DESIGN CALCULATIONS

Bending moment at the root, M

$$= 73 \times 3600 + 95 \times 3150 + 140 \times 2700 + 165 \times 2250 + 182 \times 1800 + 218 \times 1350 + 262 \times 900 + 315 \times 450$$

$$= \underline{2310.75 \times 10^3} \text{ kgmm.}$$

Taking yield strength of Aluminium 2024 - T3

$$\sigma = 35 \text{ kg/mm}^2 \ (344 \text{ N/mm}^2)$$

From engineering bending theory

$$(M / I) = (\sigma / Y)$$

$$M = \sigma Z$$

$$Z = 2310.75 \times 10^3 / 35$$

$$= \underline{66021.4} \text{ mm}^3.$$

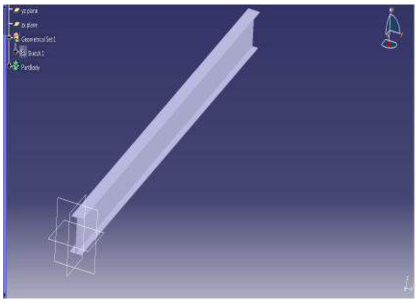

Figure **3.5 GEOMETRICAL MODEL OF UNIFORM SPAR**

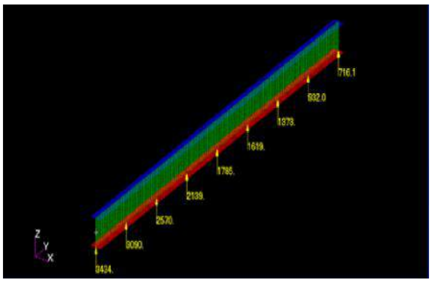

Figure 3.6: **Two dimensional finite element model of spar**

The fig.3.6 shows the two dimensional finite element model of spar with loads applied. Upper and lower flanges are shown in blue and red color respectively for ease of identification and web is in green color.

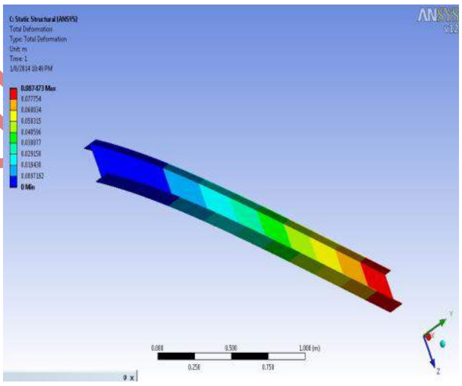

Figure 3.7: **displacement contour of uniform spar**

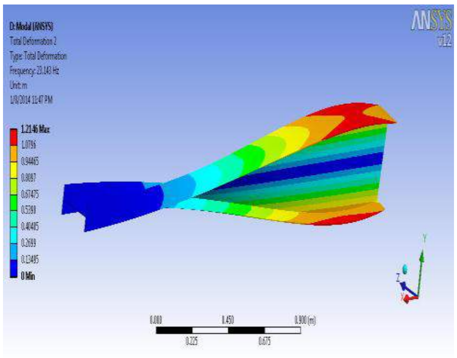

Figure 3.8: **Modal Analysis of uniform spar**

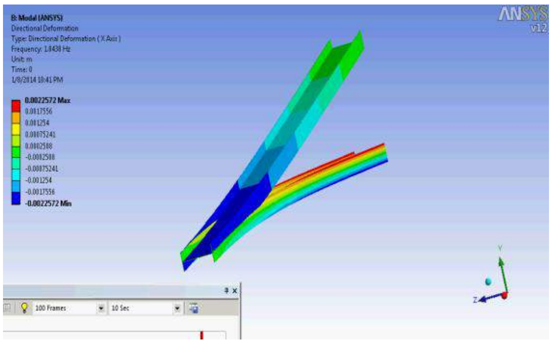

Figure 10: **Directional Deformation of uniform cantilever spar**

Mass of the tapered spar beam is 21.977 kg.

Weight of the tapered spar beam is 215.562kN.

4. DESIGN OF TAPERED SPAR

Stress analysis of the uniform spar shows that stress values at other stations on the beam except at the fixed end is lower than the design stress value. So our aim is to design a beam in such a way that the designed stresses at every station should be same for the same loads acting on the beam. Unwanted material can be removed so that weight of the beam can be optimized through this method. For this maximum bending moment at corresponding station is calculated that leads to determine the cross-section dimensions.

4.1 Calculations

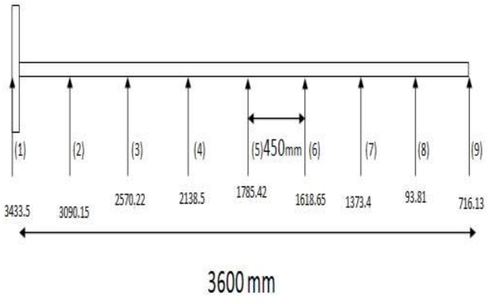

Figure4.1:**TAPEREDBEAM**

CROSSECTIONS

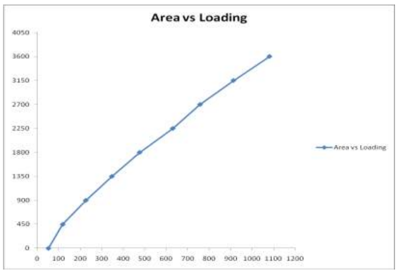

Figure4.2:**Geometric configuration of the tapered beam**

Geometric modeling is carried out by using CATIA V5 software. Each cross-section and its dimensions of CAD model are shown below. All dimensions are in mm

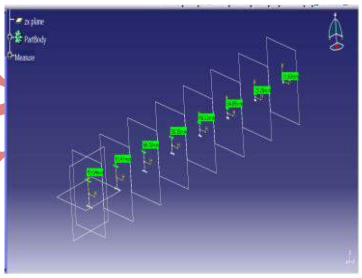

Figure4.3: (a) Design of tapered beam

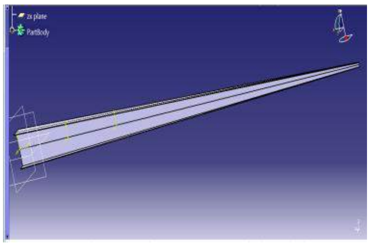

Figure4.3: (b) Design of tapered beam

4.2 Shear force diagram

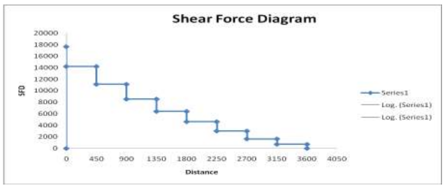

Figure13:**Shear force diagram of tapered spar**

The shear force diagram of the spar is plotted in the above figure.

4.3 Bending moment diagram

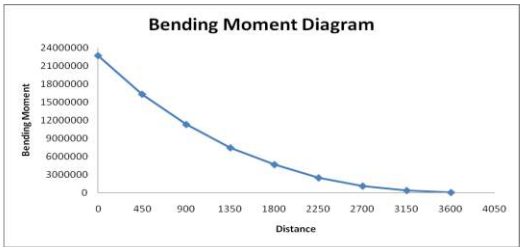

Figure4.4: **bending moment diagram of tapered spar**

The bending moment diagram of the spar is plotted in the above figure.

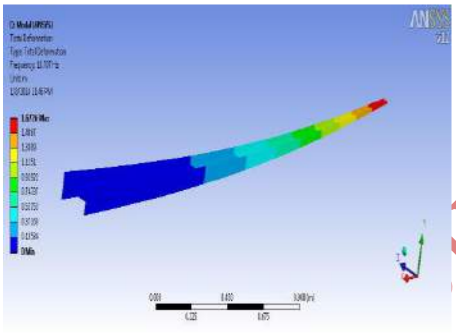

Figure15: **Displacement contour of tapered spar**

Mass of the tapered spar beam is 10.329 kg.

Weight of the tapered spar beam is 101.3279kN

5. WEIGHT OPTIMISATION

Weight optimization of the tapered beam can be done again by introduction of cut outs. These are also known as lightening holes introduced on the minimum stress regions in the web. The introduction of lightening holes is done to enhance the weight reduction. Cut outs introduced are circular and its dimensions determined based on the minimum stress region as shown in figure. Holes are carefully placed considering the various strength of material aspects on the spar web. Thus reducing the material used and there by weight.

6. HOW DO YOU DECIDE WHERE TO PLACE THE LIGHTENING HOLES IN THE WING BOX?

- Where nothing inside will leak out (fuel), and where nothing outside will leak in (rain)
- Generally where the shear is fairly low, i.e. not on heavily loaded ribs.
- Thus the lightening holes are placed around points on the neutral axis because the stress variation in the vicinity of the neutral axis is negligible.
- That being said, you can probably design lightening hole reinforcement that minimizes their effect on panel strength.
- Besides the many excellent guidelines regarding lightening holes in structures provided above, I would propose one more. A carefully configured and located opening in a structural member can sometimes be beneficial in altering the stress flow in a part, such that it reduces stress concentrations at the attachment interfaces.

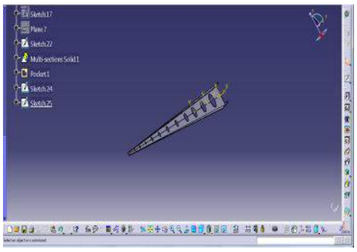

Figure6.1: Design of tapered spar with cut outs

7. Results from Analysis

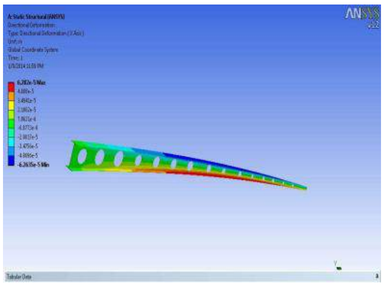

Figure7.1: Directional Deformation of

the spar

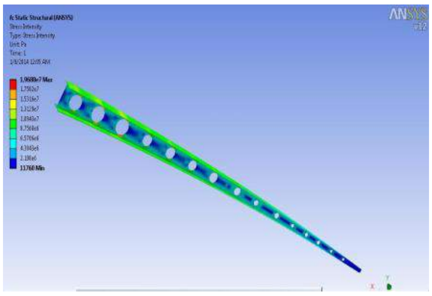

Figure7.2: stress intensity of spar

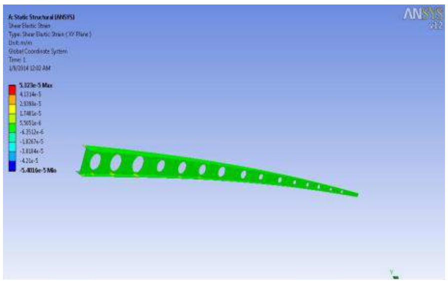

Figure7.3: Shear Elastic Strain of Spar

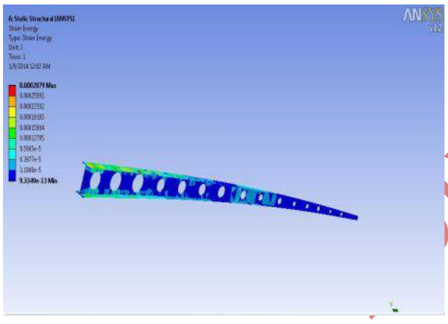

Figure7.4: Strain Energy of Spar

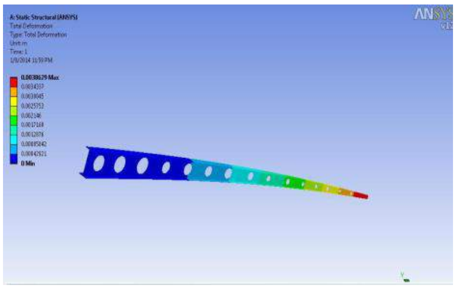

Figure7.5: Total Deformation of Spar

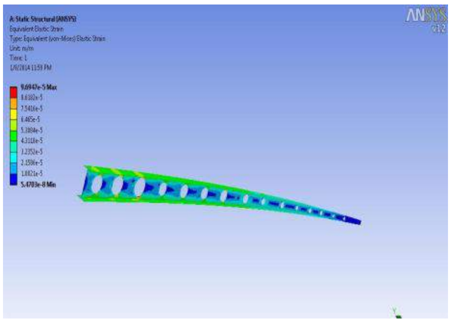

Figure7.6: Equivalent Elastic Strain of Spar

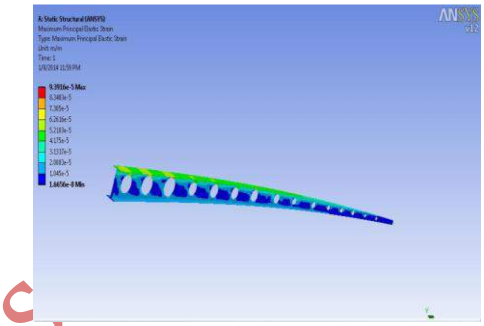

Figure7.7: Maximum Principal Elastic Strain

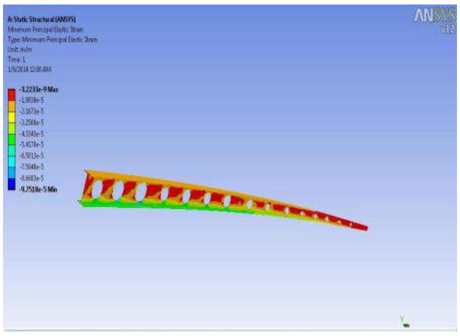

Figure7.8: Minimum Principal Elastic Strain

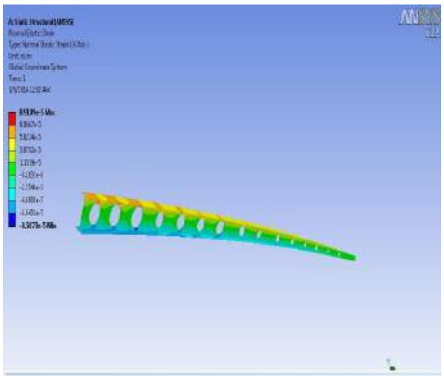

Figure7.9: Normal Elastic Strain

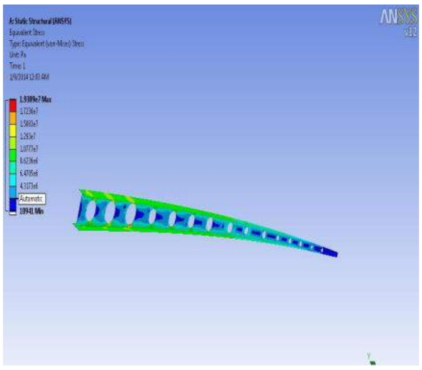

Figure7.10: Equivalent Stress

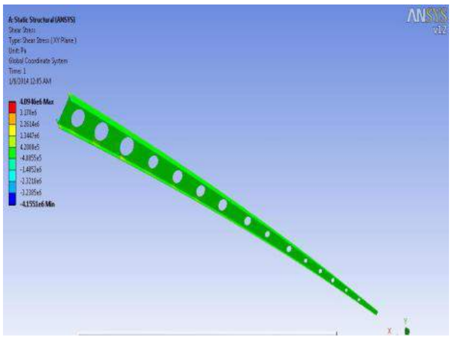

Figure7.11: Shear Stress of Spar

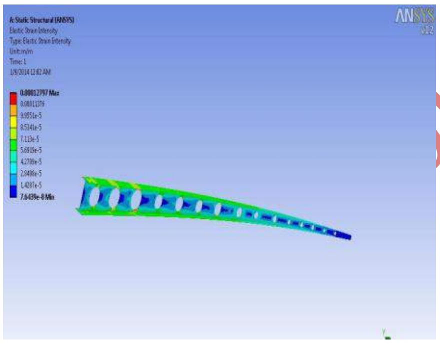

Figure7.12: Elastic Strain Intensity

Mass of the tapered spar beam is 9.3025 kg.

Weight of the tapered spar beam is 91.257kN

8. RESULT AND DISCUSSION

The primary aim of my project is to design an aircraft spar beam was to increase the structural properties of the prototype design of spar without compromising its strength or load carrying capability. The conceptual design started with the collection of design parameters from the existing aircraft spar. This is probably the most important phase since it helps us to roughly size our aircraft spar and to modify and improve its design.

A spar beam is designed using simple strength of material approach. Series of stress analysis has been done with the help of finite element method. This results weight of the uniform spar the mass of 21.977 kg has reduced to 10.329 kg by introducing a tapered section. And again by introducing cut outs in the tapered section again the mass of the same spar beam can be optimized from 10.329 kg to 9.3025 kg. So l weight reduction of 9.93% percentage could be obtained by introducing cut outs and structurally an efficient beam has been designed and optimized.

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