STRUCTURAL INTEGRITY OF FRONT SPAR OF WING OF AIRCRAFT VEHICLE USING FEA

Ajay Kodag[1], Dr. L. Chandrasagar[2]
[1]M.Tech Scholar, [2]Professor & HOD, Department of Mechanical Engineering
Dr. Ambedkar Institute of Technology Bangalore, Karnataka, India

Abstract: Structural safety with the minimum weight is the requirement in the aircraft design and development process. A medium size trainer civilian aircraft wing front spar design is considered in the current study. A typical aluminum material 2024-T351 is chosen for the design. This current project outlines the wing front spar and is considered as beam with several stations, spars are the principal structural members of wing, they correspond to the longerons of fuselage, they run parallel to the lateral axis of the aircraft from the fuselage toward the tip of the wing and the design is carried out as for the external Bending Moment at each station. A finite element approach is used to calculate the stresses developed at each station for a given bending moment Linear static analysis is used for the stress analysis.
Keywords: Spar, Stress analysis, Wing, structural integrity Aircraft, FEA.

I. INTRODUCTION

Aircraft is the image of a superior mechanical structure, which can fly with an auxiliary safety record. Occasionally an airplane falls short because of excessive static load in the middle of his life administration. The important parts of the aircraft are wing, fuselage, tail and control surfaces. Each part has special abilities and should aim to ensure that these capabilities can be done safely. Any slight disappointment of these segments can cause a catastrophic disaster causing massive destruction of life and property. At the time planning an air ship, it comes to finding the ideal measure of the heaviness of the vehicle and payload. Strength is an essential variable. Also, if a section falls flat, it is still possible for the plane to float to a protected landing place only if the aerodynamic shape is carried out as the basic integrity. Wing is similar to a fin produces aerodynamic forces to allow the movement of aircraft through air and other gases. The aerofoil shape of the wing helps in producing upward lift. The aerofoil cross-section is produced by making use of ribs, stringers, spar and skin. The ribs, stringers and spar are used to strengthen the bending stiffness of the wing. Wing is the important component of the aircraft as it shares the maximum amount of load. The wing is attached to the fuselage either directly or by making use of cables or wires. The lift in the aircraft is produced by the relative velocity between the wind and the aircraft. Either the aircraft has to move with greater speed or the wind. The ribs give the aerofoil shape to the wing such that the air flowing above the wing flows with greater velocity and the air flowing below the wing flows with velocity less than the upper air velocity. Thus according to the Bernoulli's principle the velocity is related to the pressure. The low pressure zone above the wing produces a smaller downward force on the top most portion of the wing than the higher upward pressure force generated at the bottom portion of the wing. And hence a resultant upward force acts on the wing and this causes the lift of the aircraft. The pilot can control the surface area and shape of the wing by making use of flaps and helps in changing the flight characteristics of the aircraft. Spar forms the main and major supporting structure of the wing. It runs along the length of the wing starting from the fixed end at the fuselage till the root tip of the aircraft. Spars can be made up of different materials as it depends on the strength criteria and also on the design requirement. Most of them are made of light weight materials like aluminium alloys and composite. Bending loads will be acting on the spar structure and they transfer the same to the fuselage i.e. Loads due to lift force and also by its weight when at its rest condition.

II. OBJECTIVE

A. Problem Defnition

Structural safety with the minimum weight is the requirement in the aircraft design and development process. For design, a small size two seater trainer civilian aircraft wing of front spar is considered in the current study. Design of a aircraft wing front spar using strength of material approach and Finite Element Method.

B. Methodology

The wing of an aircraft is considered as a cantilever beam since it is attached at one end to the fuselage and other end is free, here we considered front spar as a beam.

- Analytical solution for calculating I-Beam cross-section and moment of inertia for uniform stress development at each station using westerman equation.
- Modeling of the I-Beam is done exactly by the dimensions obtained from westerman equation. And the tool used is CATIA v5.
- Meshing of the I-Beam using MSC PATRAN and NASTRAN.
- Analysis of the I-Beam using MSC PATRAN and NASTRAN.
- Validation of the FE results with analytical solution.

III. MODELLING OF FRONT SPAR

A front spar made up of aluminium (Cantilever beam) having length of 2890mm and load acting at tip 1860Kg is considered. Its Ultimate strength is 343.35 MPa the section for a beam is considered from evaluating the cross section for a given load, finally arrived with 'I" section. Westerman equation is used to obtain the I-Beam with varying cross-section is calculated. The I-Beam is divided into several stations(junction of the ribs, stringers with spar).

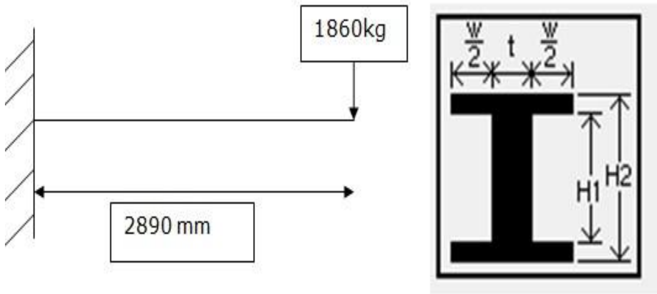

Fig.1, load acting on the beam.

D = 2B, d = 2b, b = 0.9B, t = 0.05D
D=H2
d=H
B=W
b/2=w/2

$$I_M = \left(\frac{BD^3}{12} - 2\left(\frac{\frac{b}{2}d^3}{12}\right)\right)$$

$$I_M = \left(\frac{\frac{DD^3}{2}}{12} - 2\left(\frac{.9}{2} * \frac{D}{2}\right) * \left(\frac{\left(\frac{2*.9*D}{2}\right)3}{12}\right)\right)$$

$$I_M = \left(\frac{D^4}{24} - \frac{.9^4 D^4}{2*12}\right)$$

$$I_M = (41.666 * 10^{-3} D^4 - 27.3375 * 10^{-3} D^4)$$

$$I_M = .0143285 D^4$$

From the Bending Equation

$$\frac{M}{I} = \frac{\sigma_b}{y} = \frac{E}{R}$$

$$I_M = .0143285 D^4 = \frac{M*y}{\sigma_b}$$

The bending stress is the design limit stress of 343.35MPa with the Factor of safety of 1.4.The stress is assumed to be constant at all the stations, the bending moment, the moment of inertia and the distance between the outer fiber and the neutral axis changes.

A. Calculation for Cross-sectional dimensions and moment of inertia at stations.

At 0th station

$$.0143285 D^4 = \frac{1860 * 9.81 * 2890}{343.35} * \frac{D}{2}$$

$D = 175mm$
$B = 87.5mm$
$d = 157.500\ mm$
$b = 78.75mm$

$$\frac{b}{2} = 39.375mm.$$

$t = 8.750. I_M = 13.439 * 10^6 mm^4$

Similar calculations are done at remaining stations and the results are tabulated below.

Table I. Westerman table

STATION	LENGTH	MOMENT	D	B	b/2	d	t	I_M
10	0	0	40.608	20.304	9.137	36.547	2.030	.038*10e6
9	289	52732674	81.216	40.608	18.274	73.094	4.061	.622*10e6
8	578	10546535	102.340	51.170	23.037	92.106	5.117	1.569*10e6
7	867	15819802	117.151	58.575	26.359	105.436	5.858	2.698*10e6
6	1156	21093070	128.941	64.470	29.012	116.047	6.447	4.496*10e6
5	1445	26366337	138.877	69.439	31.218	124.989	6.944	5.317*10e6
4	1734	31639604	147.600	73.800	33.210	132.840	7.380	6.800*10e6
3	2023	36912872	155.383	77.691	34.961	139.845	7.769	8.352*10e6
2	2312	42186139	162.455	81.228	36.553	146.210	8.123	9.978*10e6
1	2601	47459407	168.960	84.480	38.016	152.064	8.448	11.672*10e6
0	2890	52732674	175	87.5	39.375	157.500	8.750	13.430*10e6

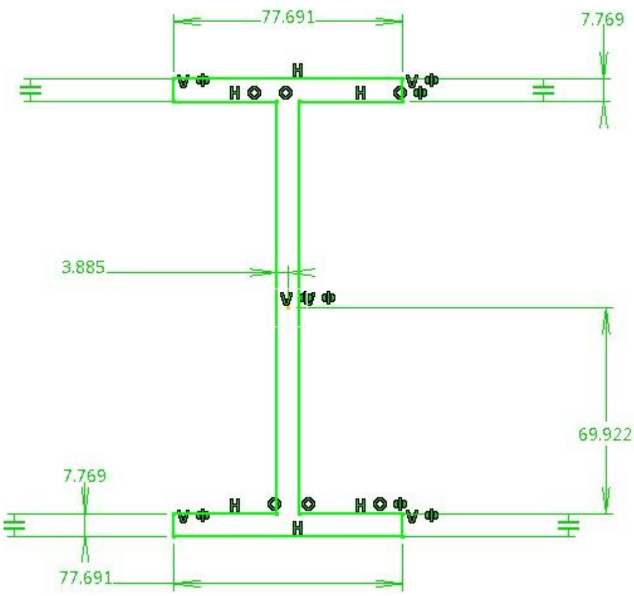

Fig.2, Cross-Sectional view of station 3.

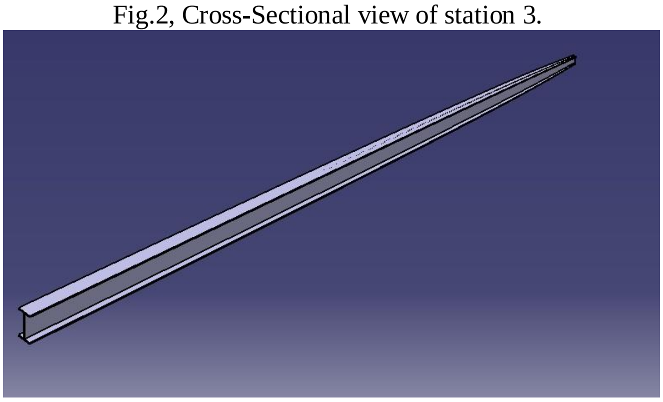

Fig.3, Isometric view of the beam.

B. Meshing of I-beam using MSC patran and nastran.
The part from catia is imported for meshing. The spar is meshed using one dimensional beam element; the beam element is assigned with first order polynomial displacement function. The total number of elements is 10 and the nodes generated are 11. The number of elements is equal to the number of stations present.

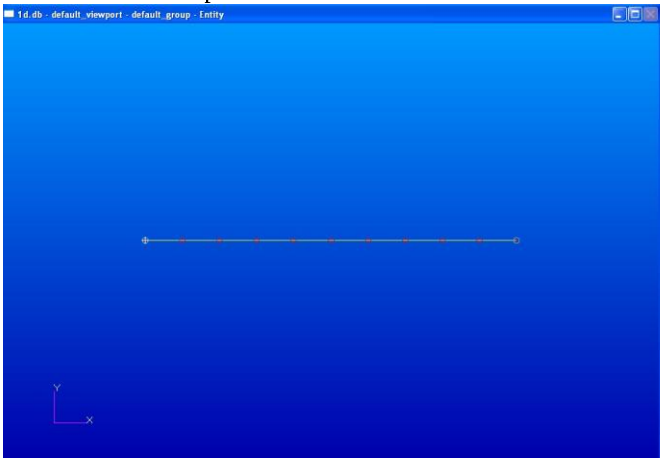

Fig.4, meshed component.

Aluminum 2024-T351 material property is added to PATRAN
Young's modulus: 7000N/mm2
Poisson's ratio: 0.33

C. Loads Cases and Boundary Conditions.
Static analysis provides calculation of the time independent displacements as well as stresses and strain in one body or multiple bodies by the applied restraints and loads. The outcome of the analysis helps to examine whether the component or body is deformed in an undesired way or also if critical stress occurs in the component. In static analysis constraints are defined (displacement boundary conditions) and loads (force boundary conditions). It is mandatory to provide at least one displacement constraint in every coordinate direction to track the position or movement of the structure. The beam is a cantilever beam and hence all the degree of freedom is arrested at the fixed end. A useful point load is applied at the free end of the beam.

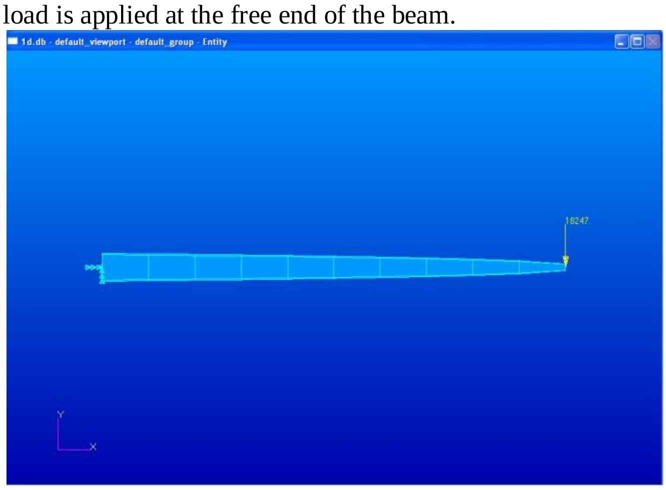

Fig 5, loads and boundary condition.

D. Displacement Contour of spar.
The [Fig6] shows the deflection of the spar. The displacement of the beam is in the y-direction and it is decreasing as it moves near to the fixed end in x-direction. The maximum and minimum displacement is identified as red (max) and dark blue (min).the maximum displacement is 2.62e3mm.

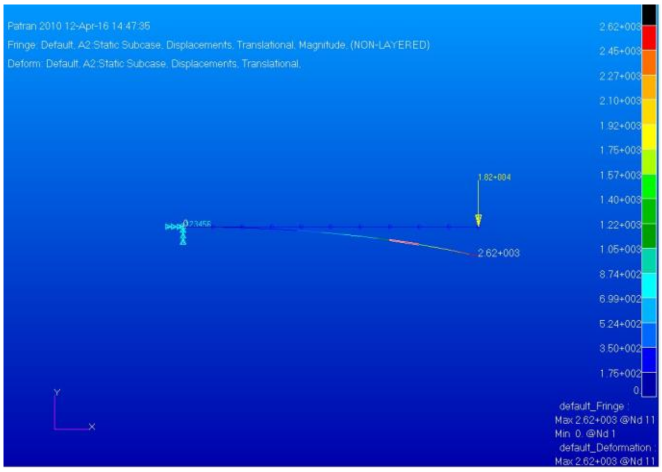

Fig.6, displacement contour.

E. Stress Contour of spar.
The [Fig7] shows the stress contour of spar. Stress at each element (station) is calculated to check whether the design of spar is correct are not, the design of spar is producing same stress at all the stations as it was considered during design of spar. Since FEM is a numerical (approximate) method the stress obtained is 318N/mm2 and the analytical stress obtained is 343.35N/mm2 and therefore the percentage error between the numerical method and analytical calculation is of 7.3831%.

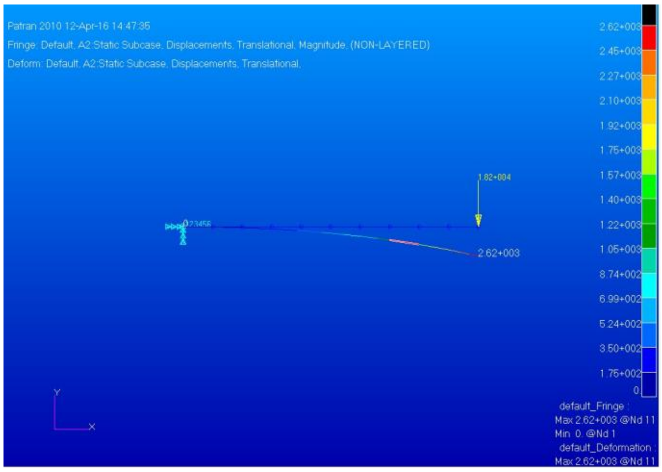

Fig.7, stress contour.

F. Conclusions and Scope for Future Work
Conclusion: the stresses generated 318N/mm^2 are uniform and are within the limit stress value 343.35N/mm^2 and hence the design is safe for the obtained dimensions of I-Beam.

Scope of future work: Weight optimization can be carried out. The Design can be checked for different cross sections also.

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