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FATIGUE AND VIBRATION ANALYSIS OF DIFFERENT WING SPARS

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AbstractIn a fixed-wing aircraft, the spar is the chief structural element of the wing, running span wise at right angles to the fuselage. The spar carries flight loads and the weight of the wings while on the ground. Other structural and forming members such as ribs may be attached to the spar or spars, with stressed skin construction also sharing the loads where it is used. Spars are also used in other aircraft airfoil surfaces such as the tail plane and fin and serve a similar function, although the loads transmitted may be different from those of a wing spar.

This paper focuses on fatigue & Vibrational analysis of aircraft wing Spar. Three different types of spars (I-C-L) sections are considered. Lift load on wing spar is calculated using analytical method. CAD model of an aircraft wing spars are modeled in CATIA software. Using ANSYS 14.5 workbench software fatigue life and safety factor is calculated in static structural analysis. Number of cycles to failure results were compared and found that I-Section spar has more life cycles and safety factor. Vibrational analysis is carried out by using I-Section spar.

Keywords—Fatigue, Vibration, Safety Factor, Life Cycles,Spars, Flange, Web.

I. INTRODUCTION

Fatigue is the auxiliary harm that outcomes from repeated or generally fluctuating pressure which never achieves a level adequate to cause Failure in a solitary application. The most noteworthy pressure that a material can withstand for an endless number of cycles without breaking is called fatigue limit or endurance limit. Stress at which fracture occurs after indicated number of cycles. The design loads connected on aircraft are lift load, drag load, side load and torsion load. Lift is the upward power made by the wind current as it disregards the wing, drag is the hindering power that constrains the aircraft speed, side load is the restricting acting internal way of rigging leg and torsion load is connected when the air makes structure rotates. The spar has a cantilever shape and there are two spars on the wing. Front spar is located at 15-30% and Back spar is located at 65-75% of the wing. The material used for the spar is 7075-T6 aluminium alloy.

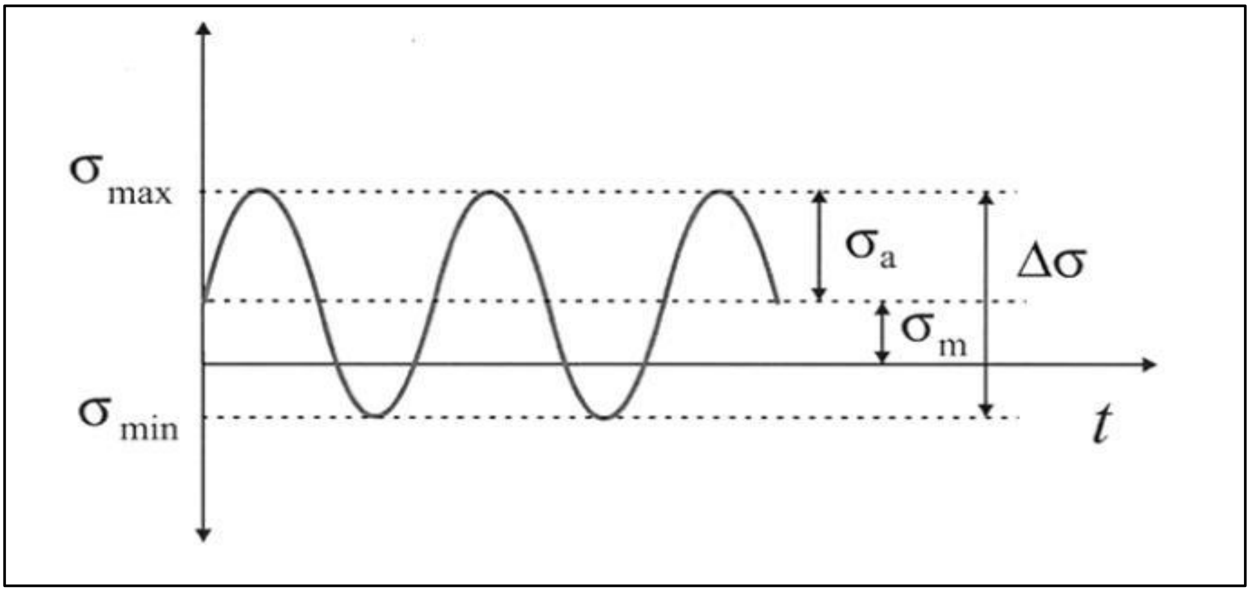


Fig. 1 stress amplitude curve

Δσ= Stress Range,Δσ= alternating stress, σ_m = mean stress, σ_{max} = maximum stress, $\sigma_{\min}$ = minimum stress.

II. ANALYTICAL CALCULATION

1) Lift Load Calculation

Piper PA-38 Tomahawk Aircraft Specifications.

Density = 0.7385 Kg/m^3

Velocity = 45 m/s

Chord Length = 1.2m

Wing Area = 10*1.2=12 m

Coefficient of Lift (CL) = 1.5

Maximum Takeoff Weight =757 Kg

Aspect Ratio = 8.3 m

Airfoil Nasa/Langley Ls (1)-0417 (Ga (W)-1)

Lift Load L = $\frac{1}{2}\rho V^2 S C_l$

=0.5*0.7385*$(45)^2$*12*1.5

L= 13459.1625N

2) Fatigue life calculation

$$N_f = \frac{2}{(m-2)AY^m \Delta\sigma^m}\left[\frac{1}{a_0^{\left(\frac{m-2}{2}\right)}} - \frac{1}{a_f^{\left(\frac{m-2}{2}\right)}}\right]$$

For M≠2

Where,

$\Delta\sigma$=?,A=2, m=3, Y=2.43(data taken from reference book for Aluminum alloy)

N_f = number of cycles of failure, a_0 = initial crack size, a_f = final crack size

$\Delta\sigma$ = stress range, A, m =material constants, Y = geometrical correction factor

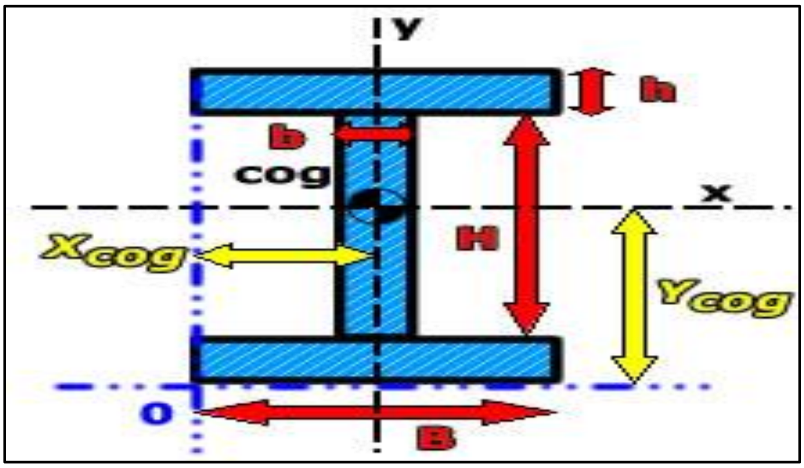


Fig. 2I-Section Spar

Where,

H = Flange-flange inner face height, B = Width, h = Flange thickness, b = Web thickness, L = Length

X_{cog} =COG distance in x direction, Y_{cog}=COG distance in y direction.

- CROSS SECTIONAL AREA

$A = 2Bh + Hb$

$= 2(82\times8.2) + (147.6\times8.2)$

$A = 25.551\ cm^2$

- *MOMENT*

$M_x = F\times D$

$= 13469\times20$

$M_x = 269.382$ KNmm

- Area Moment of inertia at x

$I_{xx} = H^3b/12 + 2[h^3B/12 + hB(H+h)^2/4]$

$= (147.6)^3\ 8.2/12 + 2[(8.2)^3\ 82/12 + (8.2)82(147.6+8.2)^2/4]$

$I_{xx} = 10365646\ mm^4$

- Area Moment of inertia at Y

$I_{yy} = b^3H/12 + 2(B^3h/12)$

$= (8.2)^3 147.6/12 + 2((82)^3\ 8.2/12)$

$I_{yy} = 760318.062\ mm^4$

- Centre of Gravity at x

$x_{cog} = B/2$

$= 82/2$

$x_{cog} = 41$ mm

- Centre of Gravity at Y

$y_{cog} = H/2 + h$

$= 147.6/2 + 8.2$

$y_{cog} = 82$ mm

- Stress

$\frac{M}{I} = \frac{\sigma}{Y}$

$\sigma = \frac{M_x Y}{I_{xx}}$

$\sigma = \frac{269.382y}{10365646}$

$\sigma = 2.5988\times 10^{-5}(Y)$

$\sigma = 2.13\times 10^{-3}\ \frac{KN}{mm^2}$

Table I
Stress at corner points

SI. NO	Y AXIS	σ STRESS $\frac{KN}{mm^2}$
1	82	2.13×10^{-3}
2	82	2.13×10^{-3}
3	73.8	1.91806×10^{-3}
4	73.8	1.91806×10^{-3}
5	73.8	1.91806×10^{-3}
6	73.8	1.91806×10^{-3}
7	-73.8	-1.91806×10^{-3}
8	-73.8	-1.91806×10^{-3}
9	-73.8	-1.91806×10^{-3}
10	-73.8	-1.91806×10^{-3}
11	-82	-2.13118×10^{-3}
12	-82	-2.13118×10^{-3}

- Stress Range

$\Delta\sigma = \sigma_{max} - \sigma_{min}$

$= 2.13\times 10^{-3}$-(-2.13×10^{-3})

$\Delta\sigma = 0.00426\ \frac{KN}{mm^2}$

- Number of cycles to failure

$$N_f = \frac{2}{(m-2)AY^m\Delta\sigma^m}\left[\frac{1}{a_0^{(\frac{m-2}{2})}} - \frac{1}{a_f^{(\frac{m-2}{2})}}\right] \qquad \text{For } M\neq 2$$

a_0=0.1 mm,

a_f=10 mm,

$\Delta\sigma$= 0.0048 KN/mm^2,

A=2, m=3, Y=2.43

$$N_f = \frac{2}{(3-2)2\times(2.43)^3(0.00426)^3}\left[\frac{1}{0.1^{(\frac{3-2}{2})}} - \frac{1}{10^{(\frac{3-2}{2})}}\right]$$

N_f=1565635 cycles.

III.DESIGN AND MODELLING OF THREE DIFFERENT SPARS

Table II

I Section Spar Specifications

Sl no.	Parameters	Dimensions
1.	Height (D)	164 mm
2.	Width of the flange(B)	0.5D (82 mm)
3.	Thickness of the flange(t)	0.05D (8.2 mm)
4.	height of the web (d)	0.9D (147.6 mm)

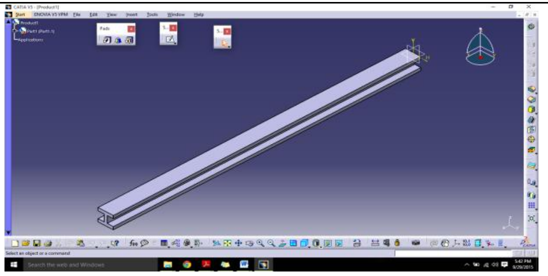


Table III

L Section Spar Specifications

Sl no.	Parameters	Dimensions
1.	Height (D)	164 mm
2.	Width of the flange(B)	0.5D (41 mm)
3.	Thickness of the flange(t)	0.05D (8.2 mm)
4.	height of the web (d)	0.9D (138.8 mm)

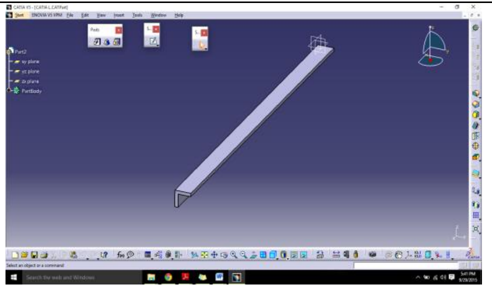
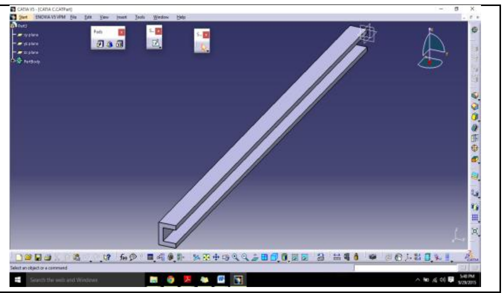


Table IV

C Section Spar Specifications

Sl no.	Parameters	Dimensions
1.	Height (D)	164 mm
2.	Width of the flange(B)	0.5D (41mm)
3.	Thickness of the flange(t)	0.05D (8.2 mm)
4.	height of the web (d)	0.9D (147.6 mm)



IV. STRUCTURAL ANALYSIS

1) *Stress Analysis On Spars*

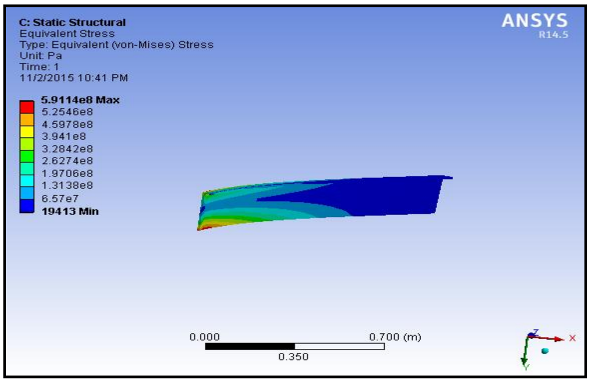


Fig. 3 I-Section Stress Cycles 2.1656e^{8}

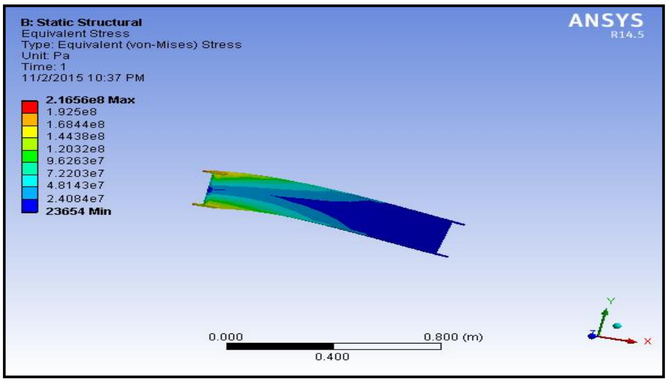


Fig. 4 L-Section Stress Cycles 5.911e^{8}

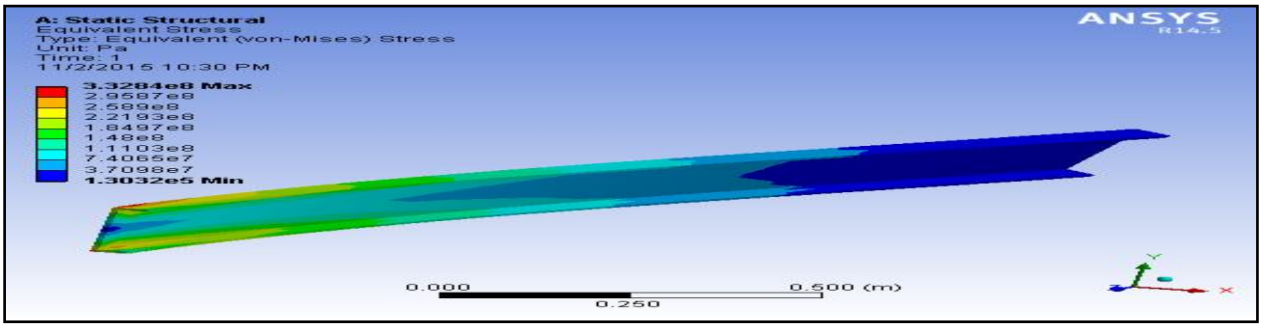
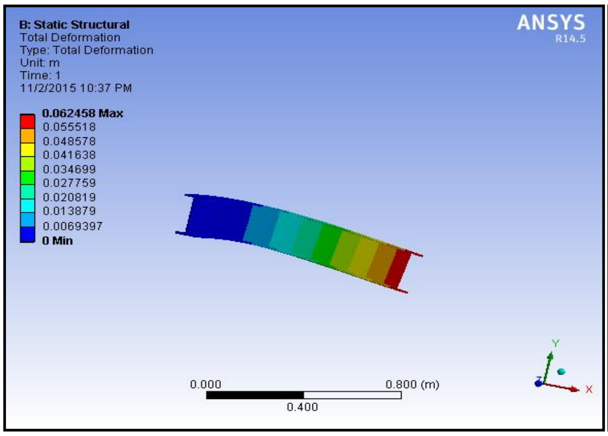


Fig. 5 C-section stress cycles $3.328e^{8}$

2) *Total deformation analysis on spars*



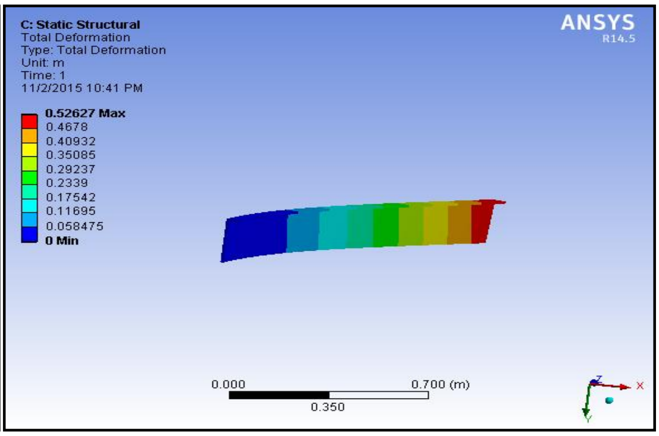


Fig. 6 I-Section Deformation = 0.062458 m *Fig. 7 L-Section Deformation = 0.52627m*

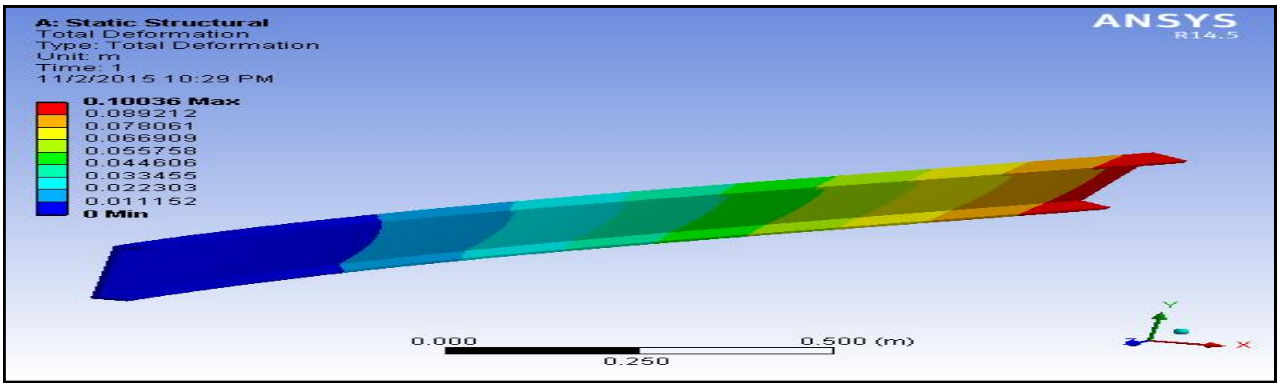
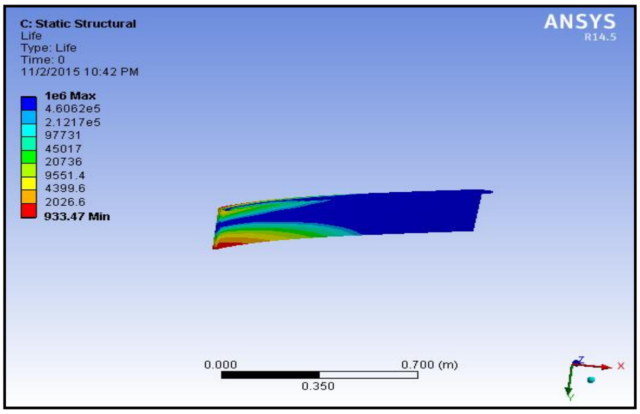


Fig. 8 C-Section Deformation = 0.10036m

3) Fatigue Analysis On Spars



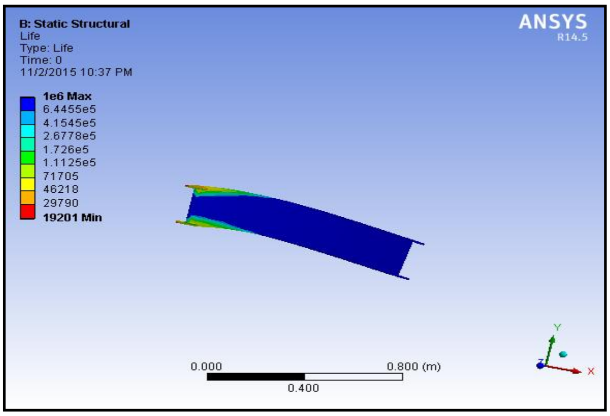


Fig. 9 I-Section Life Cycles $6.4455e^{5}$ *Fig. 10 L-Section Life Cycles* $4.6062e^{5}$

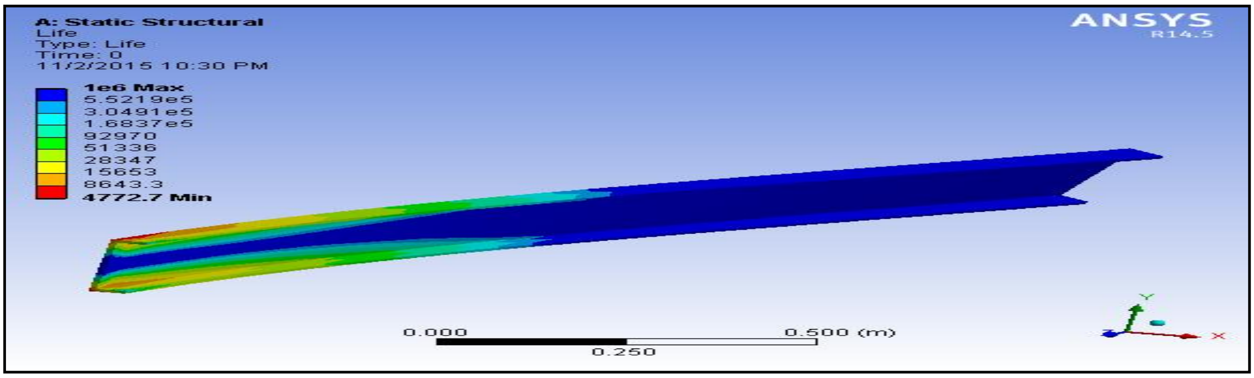


Fig. 11 C-Section Life Cycles 5.5219e^5

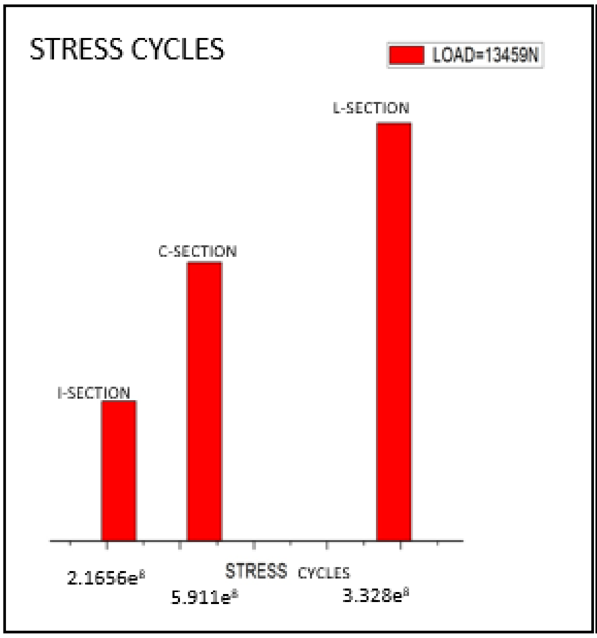


Fig. 12 Stress Cycles

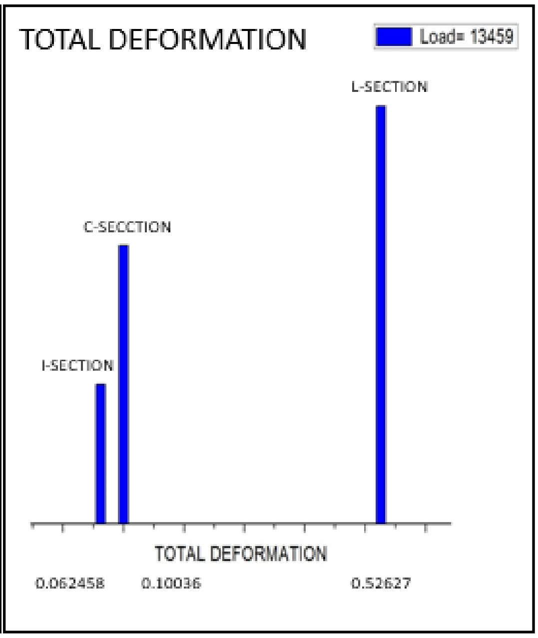


Fig. 13 Total Deformation

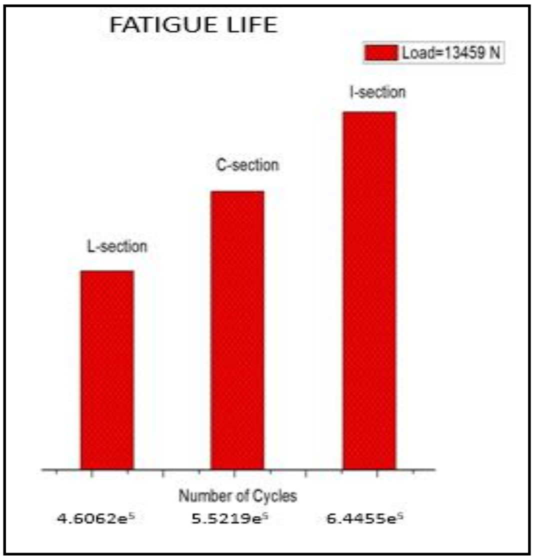


Fig. 14 Fatigue Life

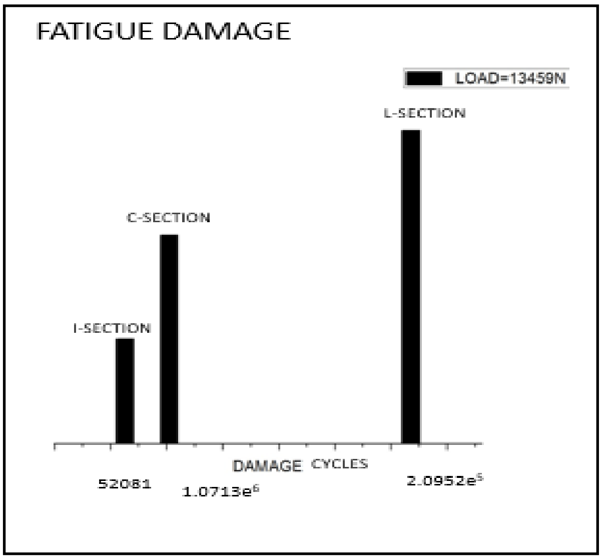
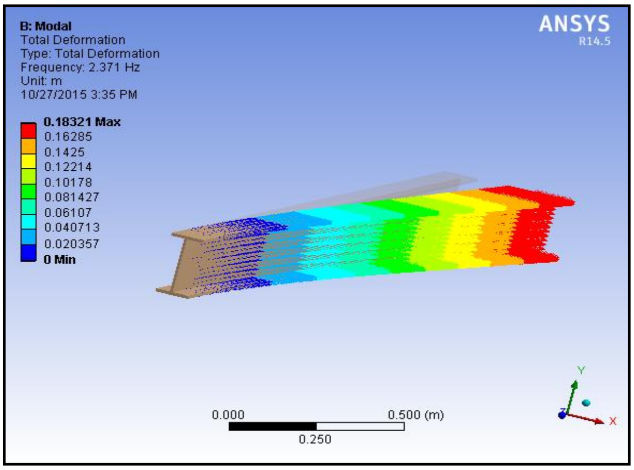


Fig. 15 Fatigue Damage

4) Vibration Analysis On Spars



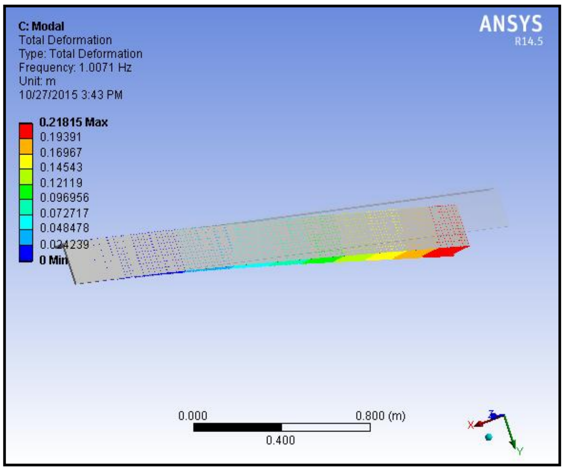


Fig. 16Deformation=0.183mFrequency=2.3 HZFig. 17Deformation=0.218mFrequency=1.007 HZ

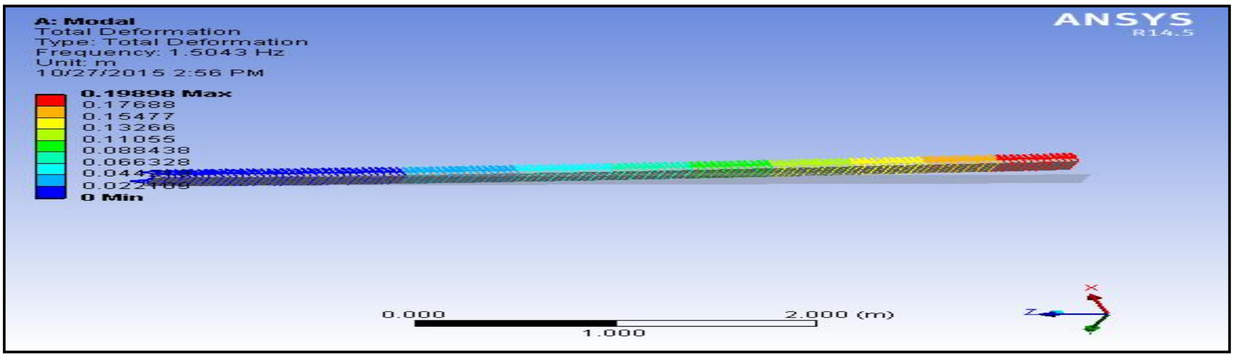


Fig. 18Deformation=0.19898 m, Frequency=1.5043 HZ

V. RESULT COMPARISION

Table V

Comparison of Fatigue Result

SPAR MODEL	EQUIVALENT STRESS (pa)	TOTAL DEFORMATION (m)	FATIGUE LIFE (cycles)	FATIGUE DAMAGE (CYCLES)
I SECTION	MAX=$2.1656e^{8}$ MIN= 23654	0.062458	MAX= $6.4455e^{5}$ MIN=19201	MAX=52081 MIN=1000
L SECTION	MAX=$5.911e^{8}$ MIN=19413	0.52627	MAX=$4.6062e^{5}$ MIN=933.47	MAX=$1.0713e^{6}$ MIN=1000
C SECTION	MAX=$3.328e^{8}$ MIN=$1.3032e^{5}$	0.10036	MAX=$5.5219e^{5}$ MIN=4772.7	MAX=$2.0952e^{5}$ MIN=1000

Table VI

Comparison of Vibration Result

SPAR MODEL	TOTAL DEFORMATION (m)	FREQUENCY (HZ)
I-SECTION	0.18321	2.371
L-SECTION	0.21815	1.0071
C-SECTION	0.19898	1.5043

VI. CONCLUSION

From Fatigue investigation, I-Section was found to have Less Stress, Less Deformation, High Fatigue Life Cycle, Less Fatigue Damage, when compared with L and C Section Spar. And from vibrational analysis I-Section was found to have less Total Deformation, More Frequency.

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