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Fatigue Analysis of Lug Joint in the Main Landing Gear

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***Abstract*— This project deals with the design and analysis of a typical lug joint in the main landing gear attachment of a light transport airplane. The Lug joint is designed for six to nine seated commercial aircraft. During takeoff, static and dynamic loads are acting on the lug joint which leads to the structural failure of the component. The objective of this project is to design a lug joint which will provide safety against the failure of lug. The proposed design of the main landing gear lug joint is against the failure of static and fatigue loading conditions at the time of takeoff. The takeoff loads are calculated by using aerodynamic calculations. The dimensions of the lug is obtained by Strength of material approach for the material Al T6 7075. Finite Element Analysis will be carried out in order to estimate the maximum local stress which will be required in the fatigue analysis of the lug joint. Fatigue life, safety factor and maximum deformation of the lug joint at the region of high stress during the time of takeoff are estimated.**

Keywords*— Al T6 7075, Deformation, Fatigue Analysis, Lug joint, Strength of Material approach.

I. INTRODUCTION

An aircraft is a machine which is used for good air transport system. It is used to travel one place to another place (long or short distance) in a short period of time and it can able to carry high load i.e., in commercial aircraft passengers, cargo, flight crew, fuel tank, scientific instruments or equipment., in military aircraft warheads, bombs etc., Landing gear is the most important component of the aircraft. It can able to carry the whole weight of an aircraft at the time of takeoff, landing and taxing. Many types of landing gears are used. There are single, main, tricycles, quadricycle, tricycle, tail gear, multi bogey, releasable rail and skid. In most of the commercial aircraft, tricycle landing gear is used. It can be retractable or fixed. In modern aircraft to minimize the drag, retractable landing gear is used. Tri cycle landing gear has one nose landing gear and two main landing gears. In landing gear, lug joint is the most important structure. Lug is the structural member which can able to absorb high impact load at the time of takeoff and landing. And then the load is transvers through other components or members. So, the design of the lug joint is very much important. When design the lug joint of the main land gear, considered takeoff configuration. While takeoff, total weight of the aircraft is carried by the main landing gear [11].

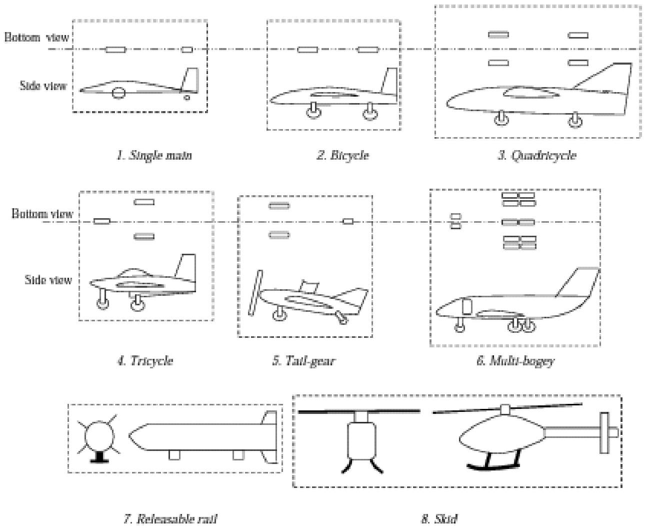

Fig.1. Different configurations of different landing gear arrangements

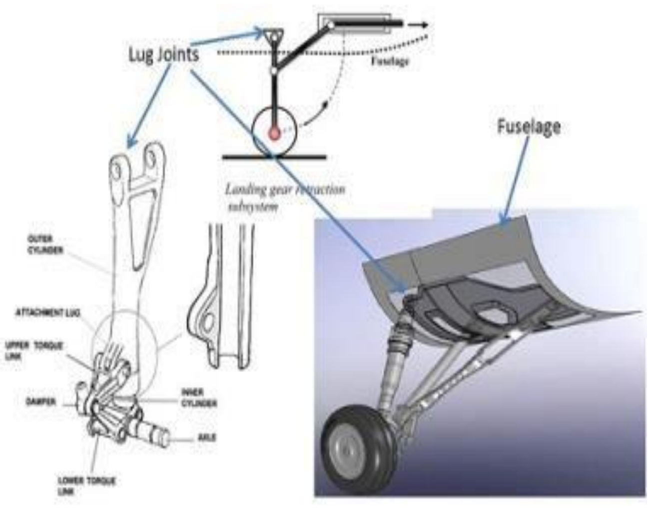

Fig.2. Location of lug joint in an aircraft

II. MATHEMATICAL APPROACH

A. Load calculation

Let as considering the light weight passenger aircraft of 6 to 9 seating capacity. The parameters used in calculation are mentions below [8] [10] [11] [13],

Wing Section: $GA(W)2$

t/c Of wing=15%

AR -Aspect Ratio=8.4

e -Efficiency=0.8

η_P -Propeller efficiency=0.5

Wing Chord

At root- C_r =2.65m

At tip- C_t =0.85m

T -Wheel track=3.20m

B -Wheel base=6.465m

D_{prop}- Propeller diameter=2.16m

ΔH_{clear} -Propeller ground clearance=1.3m

S -Wing, gross=25.7m^2

m -Max Takeoff mass=6100kg

V_C -Cruising Speed=400km/hr

V_{stall} -Stalling speed=145km/hr

$d_g w_g$ -Main wheel dimensions=2.6*0.875

P -Power Plant=2*634KW

$\frac{c_f}{c}$ -25% slotted flap

$\Delta C_{L_{flap}}$ =1.1

μ =0.035

$C_{D_{lg}}$ = 0.3

$C_{d_{min}}$ =0.025

Load acting on the main landing gear is given by [1] [11],

$$F = F_{st} + F_{dy} \tag{1}$$

Formulas, which are used to find the force "F" is given below,

$$F_M = \left(\frac{B_n}{B}\right) \times W \tag{2}$$

Assume that main wheel will carry 95% of total aircraft static weight [11],

By using base length relation [11],

$$0.95W = \left(\frac{B_n}{B}\right) \times W \tag{3}$$

In tricycle landing gear, main gear is divided between left and right gear. So, each wheel will carry one half of the main gear load,

$$\text{So, } F_{st} = \frac{F_M}{2} \tag{4}$$

The dynamic loading on the main gear during take-off acceleration with an acceleration of a_T will be determined as follows,

$$F_{dy} = \left(\frac{a_T W H_{cg}}{gB}\right) \tag{5}$$

Distance between center of gravity and ground is determined by as follows,

$$H_{cg} = \left(\frac{\Delta H_{clear} + D_{prop}}{2}\right) \tag{6}$$

Acceleration a_T at the time of takeoff is determined by,

$$a_T = \left(\frac{T - D - F_f}{m}\right) \tag{7}$$

Friction at the time of ground rolling is given by,

$$F_f = \mu N \tag{8}$$

$$F_f = \mu(W - L_{TO}) \tag{9}$$

Lift at the time of takeoff is calculated by,

$$L_{TO} = \frac{1}{2}\rho V_R{}^2 S_{ref} C_{L_{TO}} \tag{10}$$

Ground rolling velocity is determined by,

$$V_R = 1.1V_S \tag{11}$$

Co-efficient of lift is calculated by,

$$C_{L_{TO}} = C_{L_C} + \Delta C_{L_{flap}} \tag{12}$$

Co-efficient of lift at the cruise level can be determined by,

$$C_{L_C} = \frac{2W}{(\rho V_C{}^2 S)} \tag{13}$$

$$L_{TO} = \frac{1}{2}\rho V_R{}^2 S_{ref} C_{L_{TO}} \tag{14}$$

Drag due to takeoff is calculated by,

$$D_{TO} = \frac{1}{2}\rho V_R{}^2 S_{ref} C_{D_{TO}} \tag{15}$$

Co-efficient of drag due to takeoff is determined by [9] [11],

$$C_{D_{TO}} = C_{D_{0,TO}} + K C_{L_{TO}}{}^2 \tag{16}$$

$$K = \frac{1}{(\pi e AR)} \tag{17}$$

Takeoff zero lift drag co-efficient is given by [8],

$$C_{D_0,TO} = C_{D_0,clean} + C_{D_0,flap-TO} + C_{D_0,LG} \tag{18}$$

Zero drag co-efficient of single slotted flap at takeoff is calculated by,

$$C_{D_0,flap-TO} = \frac{c_f}{c} A \varphi_f{}^B \tag{19}$$

Zero drag co-efficient of leg at takeoff is determined by,

$$C_{D_{0,LG}} = C_{D_{lg}} \frac{S_{lg}}{S} \tag{20}$$

Frontal area of wheel is calculated by,

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$$S_{lg} = d_g W_g \tag{21}$$

The clean configuration is the configuration of an aircraft when it is at a cruise flight condition.
Clean zero drag co-efficient at cruise level is given by,
Considered, $C_{D_0,clean} = 3(C_{D_0,W})$ at cruise
Zero drag co-efficient of wing is calculated by,

$$C_{D_0,W} = C_{fw} f_{tcw} f_M \frac{S_{wet}}{S} \left(\frac{C_{D_{min,w}}}{0.004} \right)^{0.4} \tag{22}$$

Skin friction co-efficient of wing is determined by,

$$C_{fw} = \frac{0.455}{(\log_{10} \mathrm{Re})^{2.58}} \tag{23}$$

Reynolds number [8],

$$\mathrm{Re} = \frac{\rho V c}{\mu} \tag{24}$$

Mean aerodynamic chord is calculated by,

$$c = \frac{2}{3} c_r \left[1 + \lambda - \frac{\lambda}{(1+\lambda)} \right] \tag{25}$$

Taper ratio is determined by,

$$\lambda = {c_t}/{c_r} \tag{26}$$

Function of thickness ratio of the wing is calculated by,

$$f_{tcw} = 1 + 2.7 \left(\frac{t}{c} \right)_{max} + 100 \left(\frac{t}{c} \right)_{max}^4 \tag{27}$$

Function of Mach number is determined by,

$$f_M = 1 - 0.08 M^{1.45} \tag{28}$$

Mach number,

$$M = {V}/{a} \tag{29}$$

Wetted area of the wing is calculated by,

$$S_{wet,w} = 2 \left[1 + 0.5 \left(\frac{t}{c} \right)_{max} \right] bc \tag{30}$$

Thrust produced by turboprop engine is calculated by [11],

$$T = \frac{P \eta_P}{V_R} \tag{31}$$

By using these formulas,
F =31265N
Or
F =31300N

B. *Material Selection*

The material of lug joint must be carefully selected. So that it can able to withstand for high applied load. Thus there are several materials can be used for manufacturing the lug joint. Considered the strength and weight is very much important. The strength must be high and weight must be less to reduce dead weight of the aircraft during fly [5]. Here Aluminum Alloy is considered to design the Lug joint. Selection of material depends upon [4] [5].

*stiffness
*strength
*durability
*damage tolerance
*Corrosion.

Al 7075-T6 has high strength, lower fracture toughness. Used for tension application where fatigue is not critical. It also has low short transverse properties and low stress corrosion resistance [1].

TABLE I. ULTIMATE AND YIELD STRENGTH OF MATERIAL

Material	Ultimate Stress (σ_{ut})		Yield Stress (σ_{yt})	
	MPa	*Kg/mm²*	*MPa*	*Kg/mm²*
Al T6-7075	572	58.30	503	51.27

C. Dimension of lug calculation

Before calculate the dimensions of the lug considered, factor of safety of the lug. Design of lug can able to withstand not only the desired load. It can able to withstand beyond the expected load or actual load. The system is purposefully built much stronger than the needed for normal usage to withstand emergency situations.

Generally, in aircraft design, the factor of safety ranges between 1 and 2 [1]. Therefore, considered factor of safety is 1.5 times the applied load. i.e., FOS =1.5
So, vertical load is applied on the main wheel is,

$$F_{VM} = FOS \times F \tag{32}$$

F_{VM} =46950N or 47000N

Material used: Al T6 7075
Here, design is based on yield stress [1] [3],

$$\sigma_{yt} = \frac{P}{\left(2\pi d^2 / 4 \right)} \tag{33}$$

d =8mm

Bearing stress is calculated by,

$$\sigma_{bearing} = \frac{P}{D \times t} \tag{34}$$

Bearing strength=0.5*ultimate strength (35)

$\sigma_{bearing}$=251.5MPa
t =24mm
$b = t$ and h =2 d from the paper,
h=16mm

III. GEOMETRICAL CONFIGURATION

Final dimensions of Lug joint,
d =8mm

$t = b$ =24mm

h =16mm

Lug modeled by using design software has been shown in figure 3 and 4.

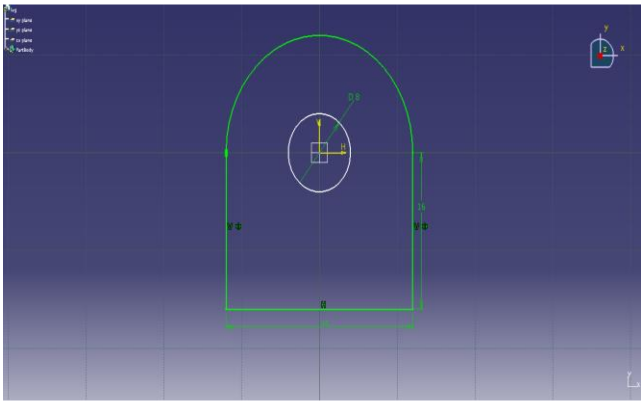

Fig.3. 2D view of lug

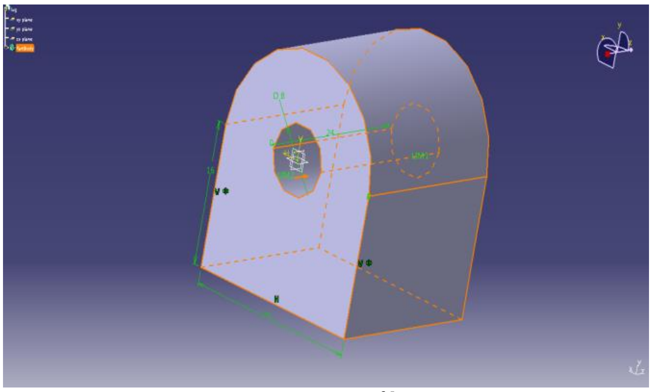

Fig.4. 3D view of lug

A. *FINITE ELEMENT ANALYSIS OF LUG ATTACHMENT*

In this project FEA tool is used as the pre-processing and post-processing purpose. The pre-processing includes building the geometric model by importing lug and generating mesh, giving the correct material properties, and setting loading conditions. Analysis is done in Fatigue analysis solver. The analysis stage simply solves for the deformation, safety factor, stress and fatigue life. In the post processing stage, the results are evaluated and displayed. The accuracy of these results is postulated during the post processing task. Special care is to be taken for meshing at the region around the hole of lug.

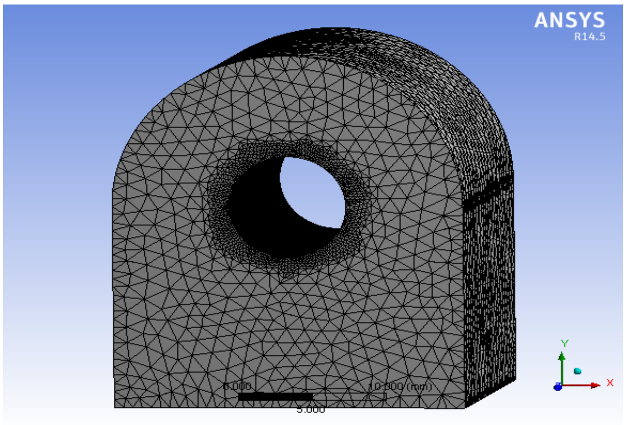

Fig.5. Meshed lug

B. Fatigue analysis

Fatigue is the structural damage occurs when material is subjected in the cyclic load. Two type of the fatigue are there. There are high fatigue and low fatigue. High fatigue is the low stress which is lower than the yield strength of the material is acting in a longer period of time. Fatigue strength is about 10^3 to 10^7 cycles. Low fatigue is the high load which is higher than the yield strength of the material is acting in a short period of time. Fatigue strength is about less than 10^3 cycles. A stress in the structure is compared to the fatigue limit of the material.

Fatigue limit of the material is calculated by finding alternating stress with respect to number of cycle [2],

$$S_a = 1.62 S_u \left(N_f\right)^{-0.085} \quad (36)$$

TABLE II. ALTERNATING STRESS FOR AL T6 7075

N_f	MPa
1	815
10	670
100	551
1000	461
1.00E+04	372
1.00E+05	306
1.00E+06	252
1.00E+07	207
1.00E+08	170
1.00E+09	140
1.00E+10	115

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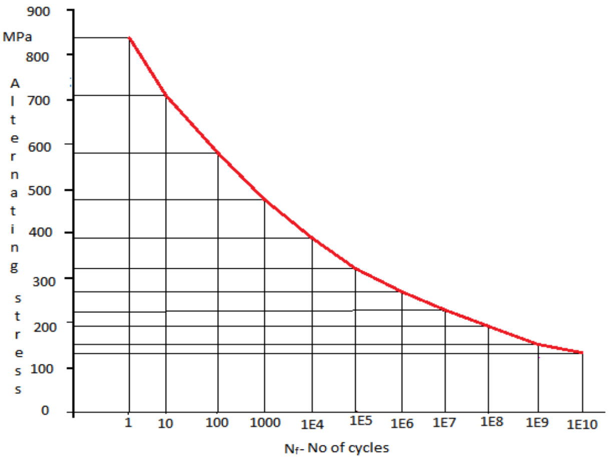

Fig.6. SN curve for Al T6 7075

In SN curve, any loading condition which is above the curve is unsafe, which is below the curve is safe. Keep the loading conditions lower than the endurance limit of the material. So, it can never fails due to fatigue and it can run infinite number of cycles. If the loading condition exceeds the endurance limit at the time load is coincided or above the SN curve. So, fatigue failure will occur to the corresponding cycle.

C. Stress distribution

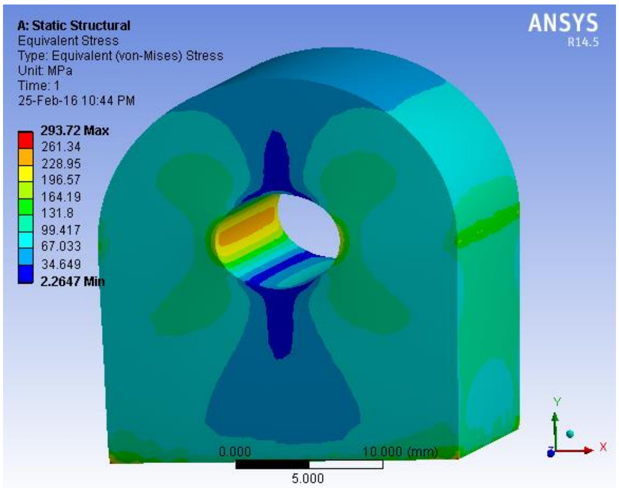

Fig.7. Stress distribution over lug

The stress distribution for the given loads has been observed and the stress is distributed uniformly over the lug structure. Maximum stresses are developed nearer to the hole of lug section which is shown in figure 7. The magnitude of maximum principal stress developed here is 293.72MPa.The structure is safe because the stress magnitude which was obtained from the analysis is less than the yield strength of the structural material.

C. Fatigue life

Fatigue life is defined as the number of stress cycles of a specified character that a specimen sustains before failure.

Three types of life are there. There are safe life, fail life and infinite life. In safe life, within the life duration there will be no damage occurs. After that the structure must be replaced. In fail safe, if there is any damage occurs within the life period no need to replace the component. Remaining members are able to carry the load. After the end of life period the structure must be replaced. If infinite life, designed stress always below the fatigue limit. So the part can be subjected to many millions of cycles.

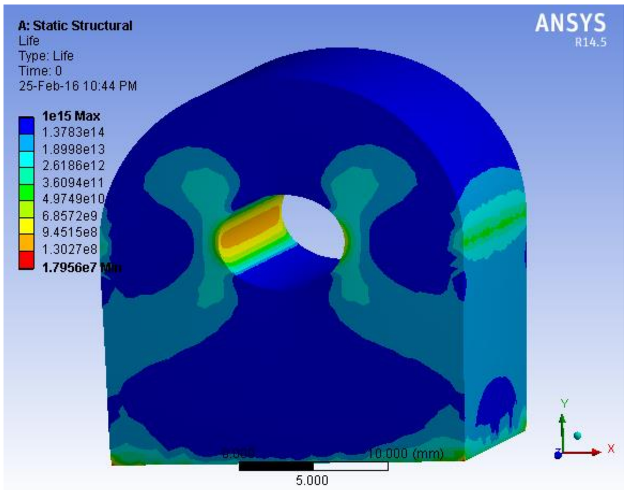

Fig.8.Fatigue life of lug

From figure 8 fatigue life of the lug is $1.8*10^7$ cycles. It is the high cycle fatigue. Before this limit the structure of the lug is safe and need to check for damage after $1.8*10^7$cycles and replace it.

D. Deformation of the lug

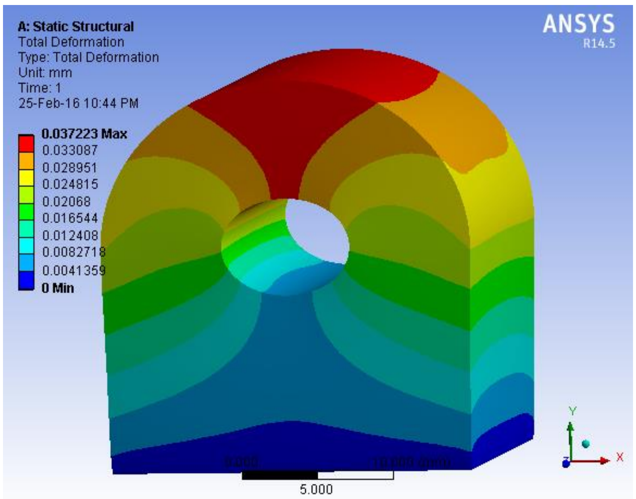

Fig.9. Deformation of the lug

Deformation of the lug under fatigue loading condition is shown in figure 9. Here, deformation maximum at the region near the hole of lug. The deformation is found to be 0.037mm only. It is very small value compared to the dimension of lug. Also, the applied load is less than the yield strength of the material. So, in this condition lug can able to regain in its original shape without any fail. Thus the design is safe.

IV. CONCLUSION

This journal work presents a computational model for the fatigue analysis of the lug. The dimensions of the proposed model are obtained by the strength of material approach and the stress analysis and the fatigue life is estimated. For this estimation finite element analysis tool is used. Stress analysis of the lug is carried out and maximum stress is identified around the hole of lug which is found out to be lower than yield strength of the material. So, the lug design is safe. The fatigue analysis is carried out to predict the structural life of the lug. Life of the lug is $1.8*10^7$ cycles. Before this limit the structure of the lug is safe and need to check for damage after $1.8*10^7$cycles and replace it.

In the future work damage tolerance, crack initiation, crack propagation and structural failure evaluation can be carried out. As well as lug optimization can also be carried out to meet the appropriate factor of safety of the lug in the main landing gear. Experimental approach can also be carried out.

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