Modal, Fatigue and Fracture Analysis of Wing Fuselage Lug Joint Bracket for a Transport Aircraft

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Abstract – *A transport aircraft carries the load in terms of tonnages, fuselage structure has to bear the loads as it connects the crew, passengers and cargo. The weight of the structure is a major concern, apart from strength to bear loads. Structure will undergo vibration during the cruse. The main source of the stresses induced in structure is due to internal pressure at high altitude caused by change in cabin pressure and reduction of the outside pressure with increase in height. The attempt is made to study the dynamic behavior of wing fuselage lug Joint bracket and natural frequency were determined using ANSYS simulation. Fracture analysis was also carried out and found that the crack initiation is at curved panel. It is possible to identify the mode of fracture and estimate crack tip plastic zone shape and size from theses. The crack developed which may cause to catastrophic failure of structure, hence the life estimation is calculated by FEA and validated through Goodman formula. It was found that the fatigue is high cycle.*

***KeyWords*: Fuselage, Stress, Modal, Fatigue, Fracture, Goodman**

1. INTRODUCTION

The efficiency of the aircraft depends on the light weight structures and high operating stresses. Efficient structure should have the ability to perform the specified function, high service life and capable to produce at lower cost. The major part of the aircraft structure contains the panels of sheets and stringers, like wing, fuselage skin panels, spar webs and stiffeners. With those their will be cut outs provided in the fuselage for windows, doors, for beacon light, teir will be cut outs for fuel access etc. These cut outs reduce the stiffness and the total load-carrying capacity of the structure. The fuselage is the main Aircraft structure carry crew, cargo and passenger. A fuselage should withstand may loads and stresses, apart from it must also has low weight. The main origin of stresses in the structure could be due to pressure developed internally at higher altitude caused by the difference of cabin pressure and decrease in outside pressure as there will be change in altitude, but structure may also take up the other loads such as bending, torsion and thermal loads, etc. Therefore there is the necessity to increase the stiffness of the fuselage by adding doublers or bonded reinforcements.

It is very important to have design criteria and analysis methods to ensure that the damage tolerance of aircraft attachment lugs are the primary structural elements in airframe structure widely used in connecting different components. E.g., aircraft engine-pylon support fittings, wing fuselage attachment and landing gear linkages where various attachment lugs configurations could be determined. The catastrophic failure occurring may cause a separation in lug joint bracket. Therefore, FEA(static) and experimental (numerical) data can be studied and analyzed.

FEA was carried out on the given geometry of the wing-fuselage attachment bracket of a transport airframe structure [1 Failing of aircraft due to a static force overload during its service life is very rare phenomenon [2]. The combined effect of high level of acceleration and complicated maneuvers will generate high value of loads on the wings surface [3]. The maximum bending moment will be at the root of the wing which leads to highest stress concentration at that location [4]. Wings are attached to the fuselage structure with the help of brackets. The bending moment and shear loads from the wing were transferred to the fuselage by these attachments [5]. Brackets are connecting elements widely been used as supports in airframe structure of aircraft. In this project a detailed FEA of the fuselage attachment for worst loading condition was studied. A dynamic and fatigue analysis of bracket has been carried. Harmonic analysis was also performed to study the frequency Vs amplitude graphs. The stresses induced from FEA were used to determine the life estimation of the component using Goodman diagram. From the static analysis it was found that the wing fuselage attachment bracket is safe for all the the static load cases. But, however it was also found that the fuselage bracket has infinite life cycle only for the load case of upto '3g'. From the harmonic analysis it can be seen that the fuselage attachment bracket is safe for the developed stresses by dynamic loads. Life estimation of the wing fuselage attachment bracket was also done for the stresses developed due to dynamic loading[6]. FEA for structure of Wing fuselage lug attachment was carried out using quad elements. It was seen that Maximum elongation was at the spar and maximum stress location at the riveted holes. The material used here was Aluminium AA 2024 for this design. Stress in most cases was a due to an external loads and geometry. Materials properties will also have influence on strains but not on stress in FE Calculation (linear elastic conditions).The fatigue life which was also determined and shows that the maximum allowable working period of the designed wing fuselage lug attachment [7]. FEM approach was used for stress analysis of wing fuselage lug attachment brackets.

Maximum equivalent stress for the Al alloy, Ti alloy and CFRP were found to be safe because the maximum stress is lesser than the yield stress. CFRP wing-fuselage attachment material weight is very less compared to Al alloy and Ti alloy [8].

1.1 Geometric Configuration

The following geometric configuration has been used for analysis;

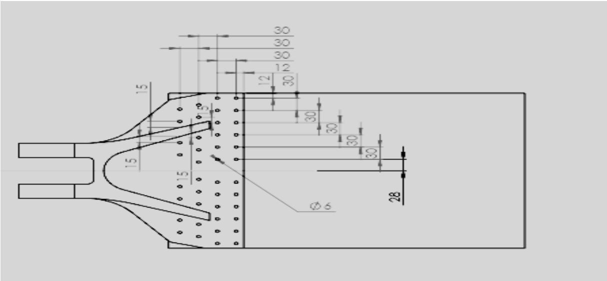

Fig-1 Top view of wing fuselage lug joint bracket [8]

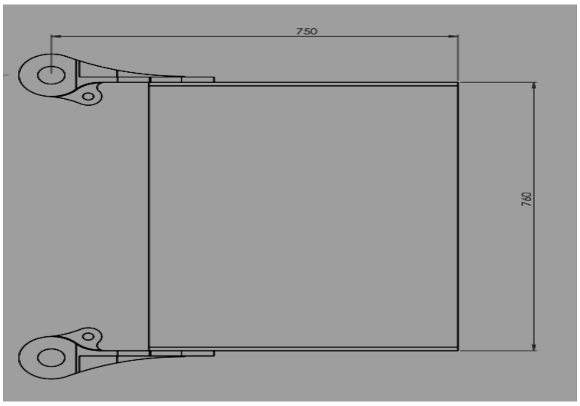

Fig-2 Front view of wing fuselage lug Joint bracket [8]

1.2 Material and Mechanical Properties

The material used for the current study for the I section of wing spar and rivets joint is aluminum alloy-2024T351.

1. Density = 2800kg/mm^3

2. Young's Modulus, E = 70000N/mm^2

3. Poison's Ratio, μ = 0.3

4. Yield Strength, бy =378N/mm^2

5. Ultimate Strength, бu = 485N/mm^2

2. MODELLING AND ANALYSIS OF LUG JOINT BRACKET

The modelling and meshing of lug joint bracket has carried out using ANSYS software according to specified geometrical configuration.

Hexa Meshing Method was used for meshing, where a free hex dominant mesh was created. This method is highly recommended for bodies that cannot be swept. The power of parallel processing was automatically applied to cut down the time. The number of element is 76285 and nodes are 42520

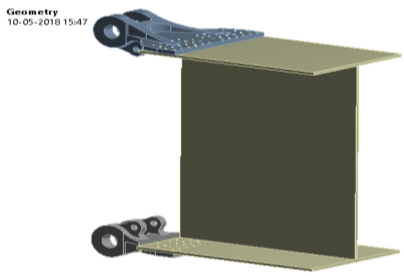

Fig-3 Isometric view of the lug joint bracket [8]

Fig-4 Hex Dominant Meshing [8]

2.1 Boundary condition

The bottom and top lug holes of the wing fuselage Lug attachment bracket have been constrained with six DOF at the semicircular circumferential surface. [8].

2.2 Modal analysis

Modal analysis is also important as a static structural analysis, because different aircrafts will may also experience different blow winds (which may cause turbulence) and vortex having high force.If the aircraft structure should be properly design to with stand such high frequencies (i.e. for the force frequency not to be equal to the natural frequency of our structure), it may cause catastrophic failure of the structure. Natural frequency of structure may change, depending mainly on three parameters. First is the shape of the structure (stiffness/aero elasticity), next the material used and its damping ratio. It is known that as higher the response of our structure to these force frequency, the lower will its natural frequency, while damping ratio tend to increase.

In this current work the attempt is made to study the six modes of vibration of a Lug Joint Bracket of a aircraft structure.

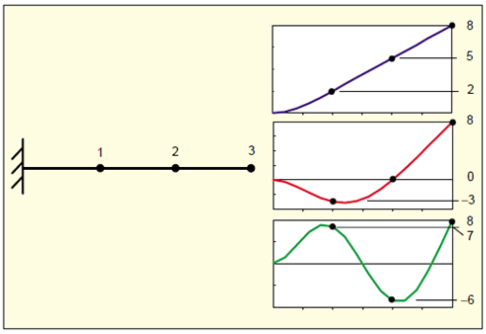

Fig-5 A 3 DOF model of a beam

Tabular Data

	Mode	Frequency [Hz]
1	1.	68.609
2	2.	75.703
3	3.	83.557
4	4.	118.77
5	5.	142.8
6	6.	158.27

Fig-6 initial six modes and corresponding natural frequency for the applied load condition

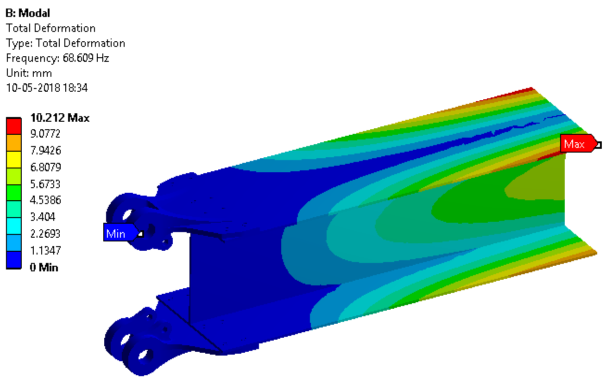

Fig-7 first mode and natural frequency at 68.609 hz

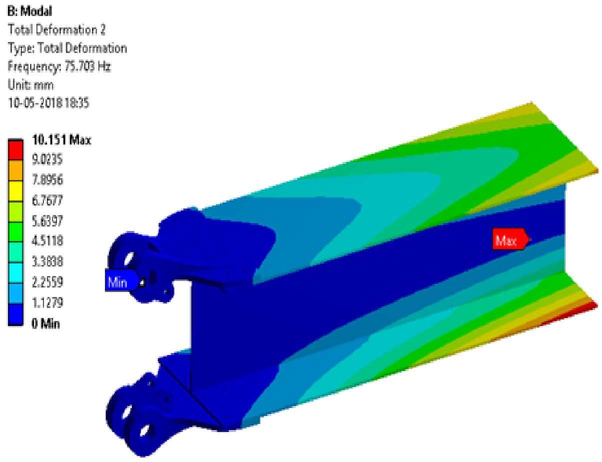

Fig-8 Second mode and natural frequency at 75.7 hz

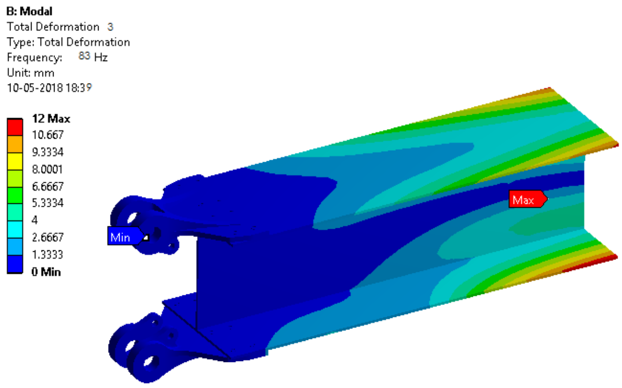

Fig-9 Third mode and natural frequency at 83.55 hz

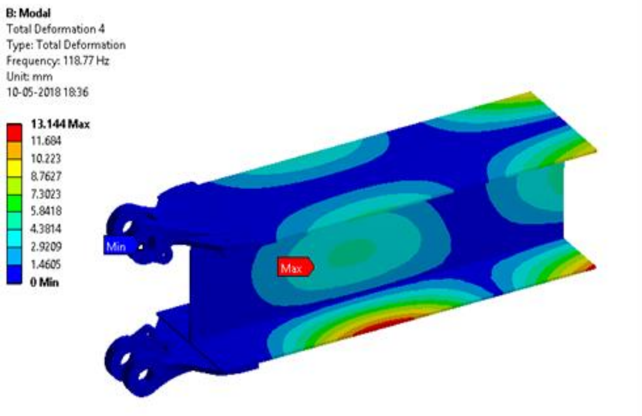

Fig-10 fourth mode and natural frequency at 118.77 hz

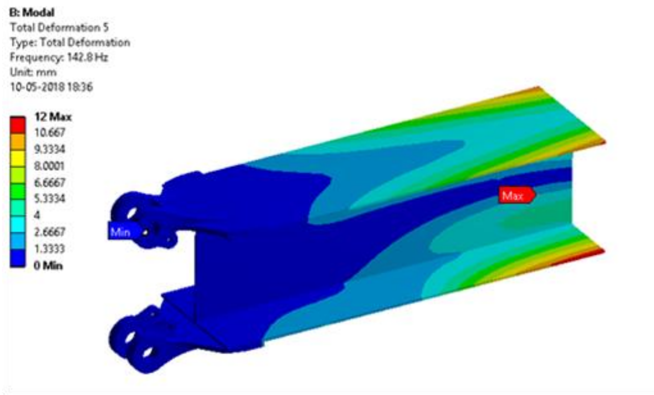

Fig-11 fifth mode and natural frequency at 142.8 hz

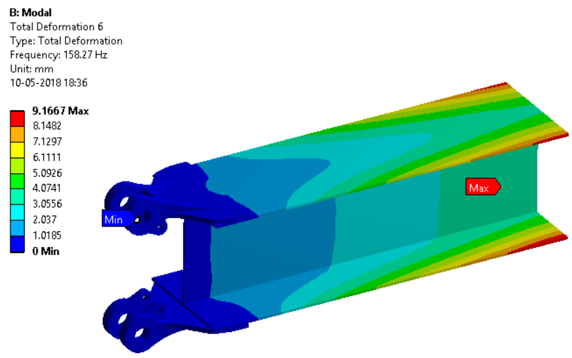

Fig-12 sixth mode and natural frequency at 158 hz

2.3 Fracture Mechanics Analysis of Wing-Fuselage

In the ansys package a sub modelling capabilities which helps to evaluate the distrubution of stress and intensity factor at the tip of the crack.Figure 13 shows the zone for fracture analysis, the circumferential crack inatiated in the curved panel can also be seen. The maximum equivalent stress obtained is 1717 Mpa . These results are essential for the prediction of residual strength

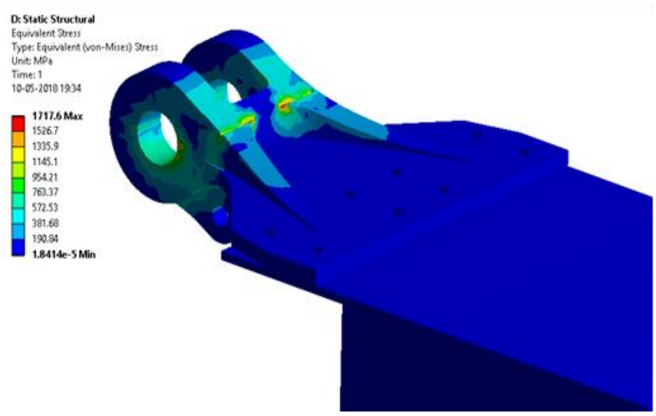

Fig-13 maximum equivalent stress 1717 Mpa for the applied load condition

2.4 Fatigue Analysis of Wing-Fuselage Attachment Fitting Of Aircraft

From the stress analysis of the fuselage the location of maximum tensile stress was determined. A fatigue crack will initiate from the location having the maximum tensile stress ie. at one of the rivet hole [8]. For performing fatigue calculations the constant amplitude loading was considered Calculation of fatigue life was calculated by using Good man criteria. The various correction factors are considered in the calculation of fatigue

Cycles

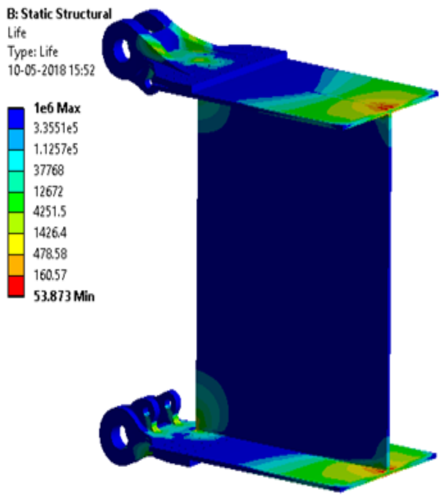

Fig- 14, life estimation is 1000000 cycle

2.5 Validation of Life Estimation

Goodman diagram

Mean Stress can be calculated from,

$$\sigma_{mean} = \frac{\sigma_{von}}{2}$$

$$= \frac{305.2}{2} == 152.5\text{mpa}$$

Where

σ_{von} = Equivalent von-Misses Stress

$$\sigma_a = \frac{\sigma_1 - \sigma_2}{2}$$

$$= \frac{317.36 - 50}{2}$$

=133.68 mpa

Where

σ_1= Maximum Principal Stress

σ_2= Minimum Principal Stress

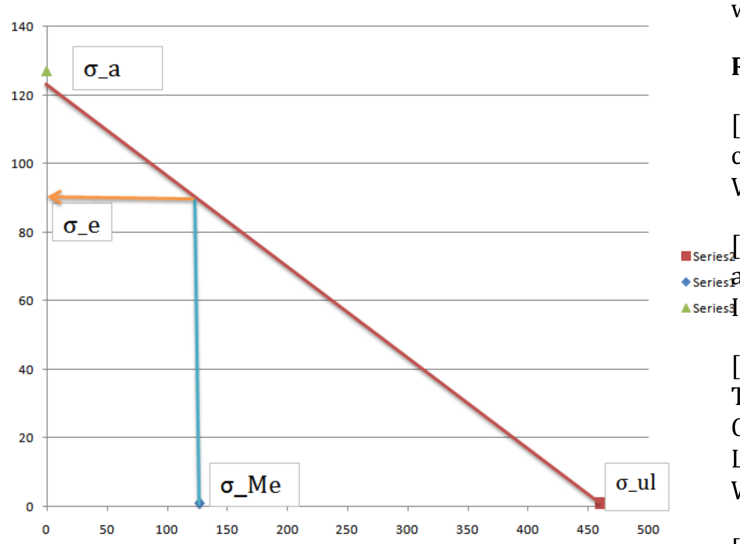

Fig- 15, Goodman diagram

Number of cycles:

$$N_f = \left\{ \frac{[\sigma_{ult} - \sigma_{ult}(\frac{1}{fos} - \frac{\sigma_a}{\sigma_e})]}{\sigma_a} \right\}^{\frac{1}{0.08}}$$

Where,

N_f =Fatigue life

σ_{ult}=Ultimate stress

fos=Factor of Safety

σ_e=Endurance limit

b = Fatigue strength exponent

σ_a=Alternating stress

$$N_f = 5.4 \times 10^6$$

The resulting life of failure obtained by analytical method is greater than 10^6 Cycles hence it is high cycle fatigue.

3. Result and conclusions

To determine the inherent dynamic characteristics of lug joint bracket the modal analysis was carried out and natural frequencies were determined. Life estimation of Wing-Fuselage Attachment Fitting Of Aircraft in FEM approach was determined and it is validated in analytical method, 1000000 cycles for wing-fuselage attachment is obtained by FEM where as in analytical it was observed that 5.4×10^6 cycles it was found that the fatigue is high cycle.

REFERENCES

[1]Stress and fatigue analysis of modified wing-fuselage connector for Agricultural aircrafts, Lujan witek, P 773-778, Volume: 43, Issue 3, Journal of Aircraft (2006).

[2] Failure analysis of wing-fuselage connector of an agricultural aircrafts, Lujan witek, P 572-581, Volume 13, Issue 4, Engineering Failure Analysis (2006).

[3] Damage tolerance assessment of aircraft attachment lugs. T.R. Brussat, K. Kathiresan and J.L. Rudd, LockheedCalifornia Company, Burbank, CA 91520, U.S.A., AT&T Bell Laboratories, Marietta GA 30071, U.S.A., AFWAL/FIBEC, Wright-Patterson Air Force Base, OH 45433, U.S.A.

[4] Stress intensity factors for cracks at attachment lugs. R. Rigby and M. H. Aliabadi, British Aerospace, Filton, Bristol BS99 7AR, U.K., Wessex Institute of Technology, Ashurst Lodge, Ashurst, Southampton S040 7AA, U.K.

[5] Failure in lug joints and plates with holes. J. Vogwell and J. M. Minguez School of Mechanical Engineering, University of Bath, Bath BA2 7AY, U.K., Facultad de Ciencias, Universidad Del Pais Vasco, Bilbao, Spain.

[6] Dynamic Analysis and Fatigue Life Estimation of Wing Fuselage Attachment Bracket of an Airframe Structure, N.Bhaskara Rao,K.Sambasiva Rao, IJSRD - International Journal for Scientific Research & Development| Vol. 4, Issue 12, 2017 | ISSN (online): 2321-0613.

[7] Design Structural Analysis and Fatigue Calculation of Wing Fuselage Lug Attachment of a Transport Aircraft, Abraham J ,Mr. Damodara Reddy, International journal & magazine of Engineering, Technology. Managment and Research. Volumeno4,2017,issue8, August2017,ISSN:2348-4845,60-65.

[8] Static Structural Linear Analysis of Fuselage Lug Joint Bracket for a Transport Aircraft with Mid Wing Configuration, Amith Kumar S.N, Dr.T.N Raju, Srinath T, International Research Journal of Engineering and Technology (IRJET), Volume: 07 Issue: 11,Nov 2020.