Design and Analysis of Wing fuselage attachment bracket for fighter aircraft

Shashikumar.C, Nagesh.N, Ganesh

Assistantprofessor, MRITS,Udayagiri,Nellore,shashi300sagar@gmail.com,7026155693.

Assistantprofessor, Kuppan Engineering College,Kuppam.

Assistantprofessor, Kuppan Engineering College,Kuppam

Abstract— Fighter aircraft is a highly complex structure. The aircraft needs to execute complicated maneuvers while fighting with enemies. Complicated maneuvers will require instant change in acceleration. The combination of high level of acceleration and complicated maneuvers will introduce high magnitude of loads on the wings. Normally the fighter aircraft will have wing-fuselage attachments at more than one location. Rarely an aircraft will fail due to a static overload during its service life. For the continued airworthiness of an aircraft during its entire economic service life, fatigue and damage tolerance design, analysis, testing and service experience correlation play a pivotal role. In the current project, an attempt will be made to predict the fatigue life of wing-fuselage attachment bracket in a fighter airframe. In a metallic structure fatigue manifests itself in the form of a crack which propagates. If the crack in a critical location goes unnoticed it could lead to a catastrophic failure of the airframe. Fatigue cracks will appear at the location of high tensile stress locations. These locations are invariably of high stress concentration. Fatigue life calculation will be carried out for typical service loading condition using constant amplitude S-N data for various stress ratios and local stress history at stress concentration.

Keywords— Fatigue life , Fighter aircraft , Finite element method , service loading condition, static load, stress concentration, wing-fuselage.

INTRODUCTION

An aircraft is a complex structure, but a very efficient man-made flying machine. Aircrafts are generally built-up from the basic components of wings, fuselage, tail units and control surfaces. The load-bearing members of these main sections, those subjected to major forces, are called the airframe. The airframe is what remains if all equipment and systems are stripped away. In most modern aircrafts, the skin plays an important role in carrying loads. Sheet metals can usually only support tension. But if the sheet is folded, it suddenly does have the ability to carry compressive loads. Stiffeners are used for that. A section of skin, combined with stiffeners, called stringers, is termed a thin-walled structure.

Fighter aircraft : A fighter aircraft is a high-speed military or naval airplane designed primarily for air-to-air combat with other aircraft, as opposed to a bomber, which is designed primarily to attack ground targets by dropping bombs (i.e., to destroy enemy aircraft in the air). It is a fast maneuverable fighter plane designed to intercept enemy aircraft. The hallmarks of a fighter are its small size, speed and maneuverability.

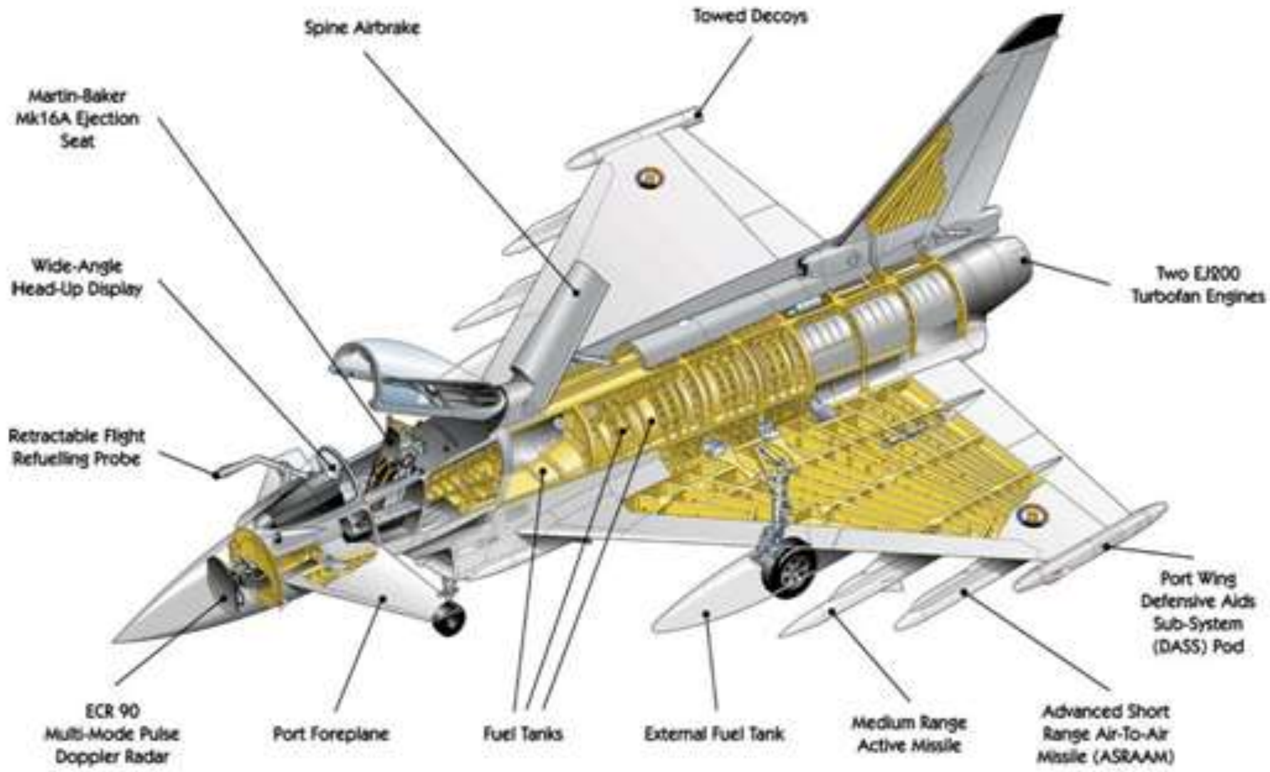

Fig.1: Euro fighter aircraft.

LITERATURE SURVEY

Literature papers from different international journals are collected and presented in the following sections. The literature papers collected are from the following international journals.

- International Journal of Fatigue
- Engineering Fracture Mechanics
- Engineering Failure Analysis
- Computers and Structures

The literature topics are more relevant to the design and analysis of wing fuselage attachment bracket as a part of aircraft design and development.

PROBLEM DEFINITION

- To design of a wing fuselage attachment bracket against fatigue failure.
- Linear static stress analysis of the wing fuselage lug attachment bracket.
- Calculation of the fatigue life to crack initiation in the wing fuselage lug attachment bracket.

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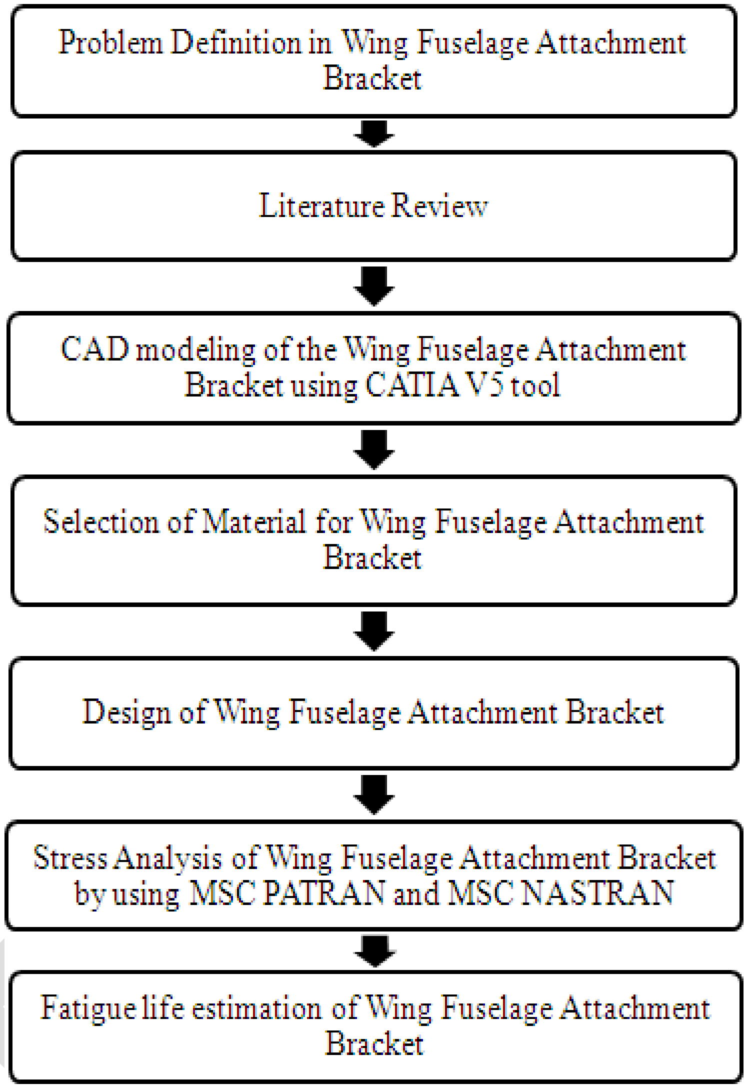

Fig.2: Methodology for Design and analysis of wing fuselage attachment bracket for fighter aircraft.

The above flowchart represents the sequence of operations which are going to performed on the present work respectively.

The below figure represents the Production drawing of Wing fuselage attachment bracket for fighter aircraft it represents the Top view and Front view of fuselage attachment bracket based upon this design production of wing fuselage is to be manufactured.

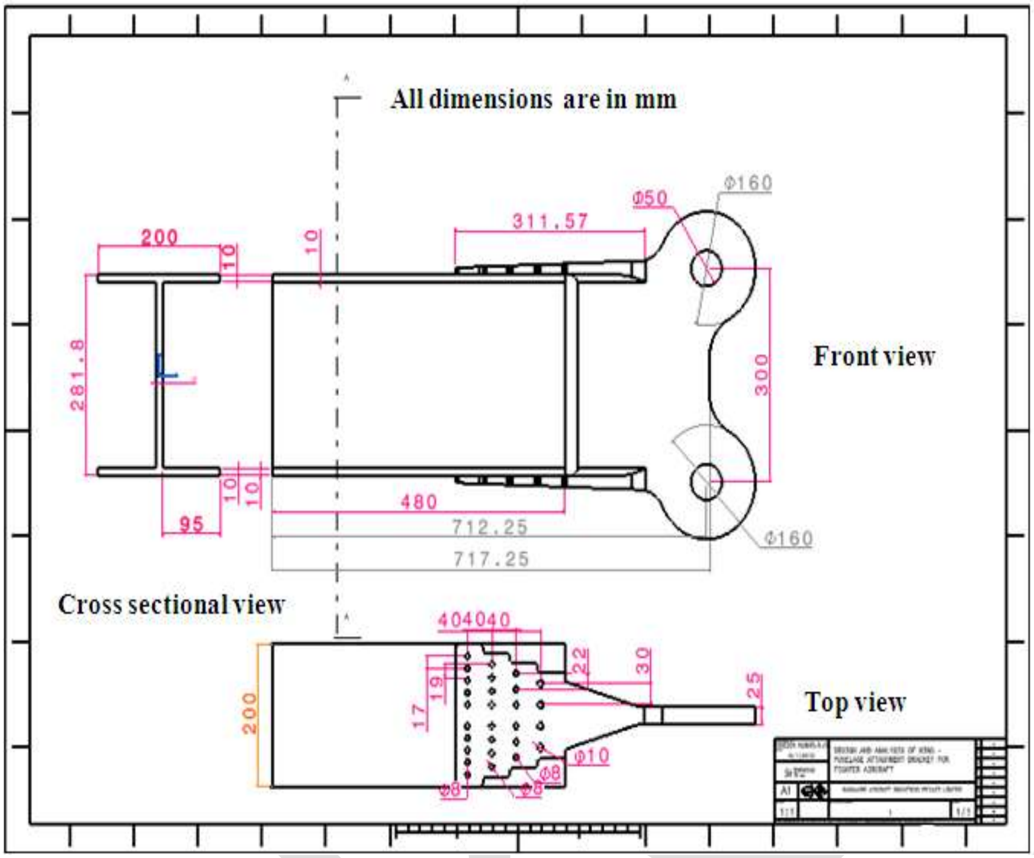

Fig.3: 2-D views of the wing- fuselage attachment bracket.

MATERIAL SPECIFICATION

- The material used for the lug attachment bracket of the structure is Steel Alloy; Heat Treated AISI-4340, with the following properties.
- The material used for the I-sectional spar and rivets of the structure is Aluminium Alloy – 2024-T351, with the following properties.

Table.1: Material Properties for Fuselage attachment bracket for fighter aircraft.

S.NO	**PARAMETERS**	**Steel Alloy,AISI-4340**	**Aluminum Alloy-2024-T351**
1	Young's Modulus(N/mm^2)	203000	72400
2	Poison's Ratio	0.32	0.33
3	Ultimate Tensile Strength (N/mm^2)	1835	503.7
4	Yield Stress, $б_y$ (N/mm^2)	1600.8	472.6

LOAD CALCULATION FOR THE WING FUSELAGE ATTACHMENT BRACKET

Aircraft category = medium size of fighter aircraft

Total weight of the aircraft = 6000kg = 58800N

Load factor considered in design = 6g

Design limit load on the structure = 58800*6 = 352800N

Factor of safety considered is = 1.5

Design ultimate load = 352800*1.5 = 529200N

Distribution of lift load on fuselage and wing = 35% and 65%.

Total load acting on the wings = 529200*0.65 = 343980N

Load acting on the each wing = 343980/2 = 171990N

Number of sparse in the wing = 3

Load sharing by spares is a) spar 1 = 30% b) Spar 2 = 45% c) Spar 3 = 25%

The wing fuselage attachment considered for the current analysis is at spare 3.

Therefore, load acting on the spare 3 = 171990*0.25 = 42997.5N

Therefore, Total load acting on the wing-fuselage (lug) attachment bracket is P_1 = 90584.62N.

FINITE ELEMENT ANALYSIS

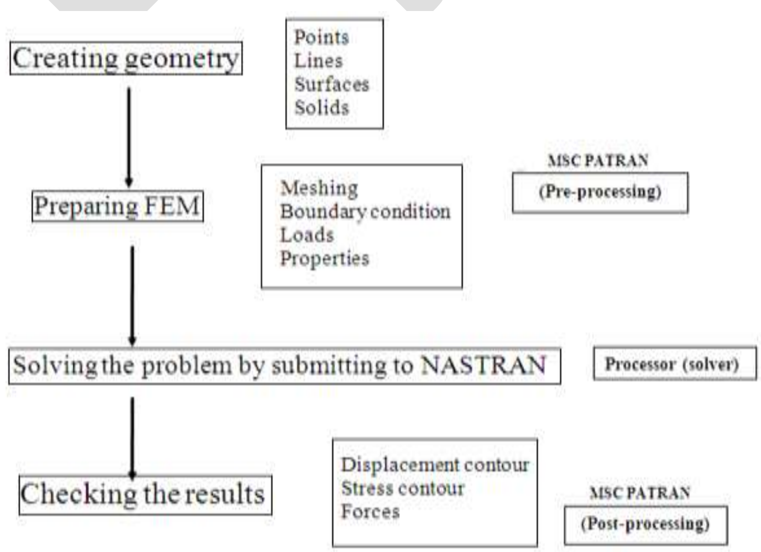

Fig.4: Different Stages of Finite Element Analysis

Developing a finite element model manually is a time consuming, tedious and error prone activity making sense of the large stake of finite element computer output is also a considerable challenge.A finite element pre and post processors (such as MSC/PATRAN) is a graphic based software package primarily designed to aid in the development of Finite Element Model (Pre processing) and to aid the display and interpretation of analysis results (Post processing). MSC/ PATRAN software is a mechanical computer aided engineering tool created for design engineers.

Elements

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Formulate Element Stiffness Matrices from element properties, geometry and material properties

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Assemble all element stiffness matrices in to global stiffness

↓

Apply Boundary Condition to constraint model

↓

Apply loads to the model (forces, moments, pressure etc)

↓

Solve the matrix equation {F} = [K] {Q}

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Calculate Element Stresses

Fig.5: Flow chart of basic steps in MSC/PATRAN

PHYSICAL STRUCTURE OF WING FUSELAGE ATTACHMENT BRACKET IN FEA

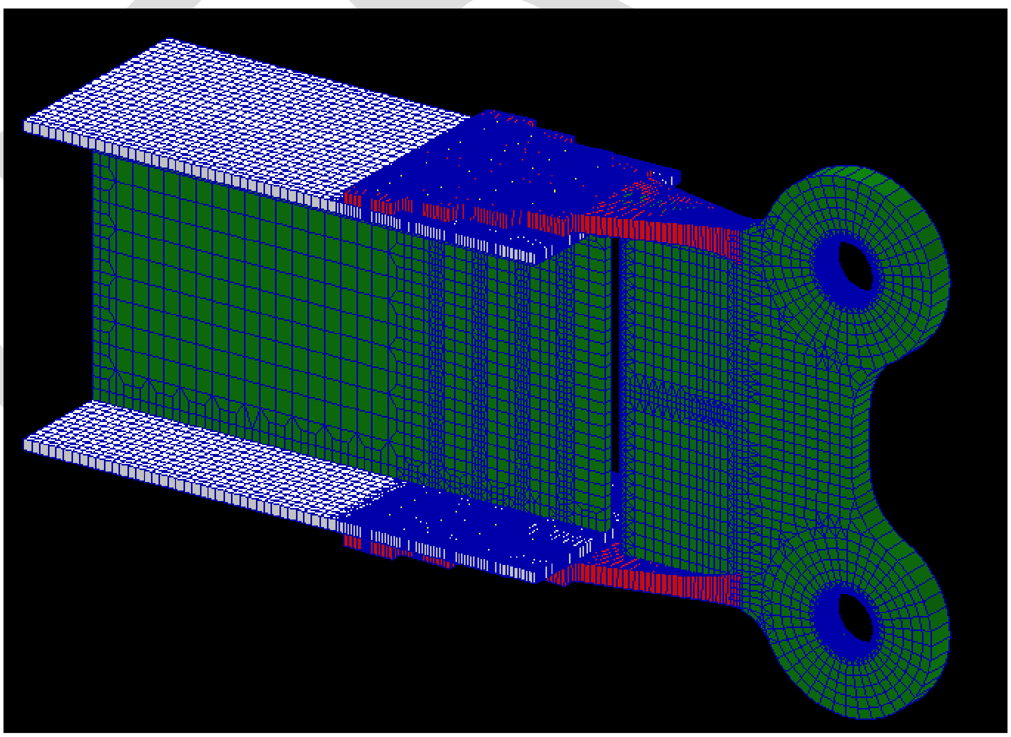

Fig.6: Physical structure of wing fuselage attachment bracket in FEA

As per the design calculations from the previous section the dimensions of the wing fuselage attachment bracket at the pin hole are used in the actual model of the lug attachment bracket.

LOADS AND BOUNDARY CONDITIONS

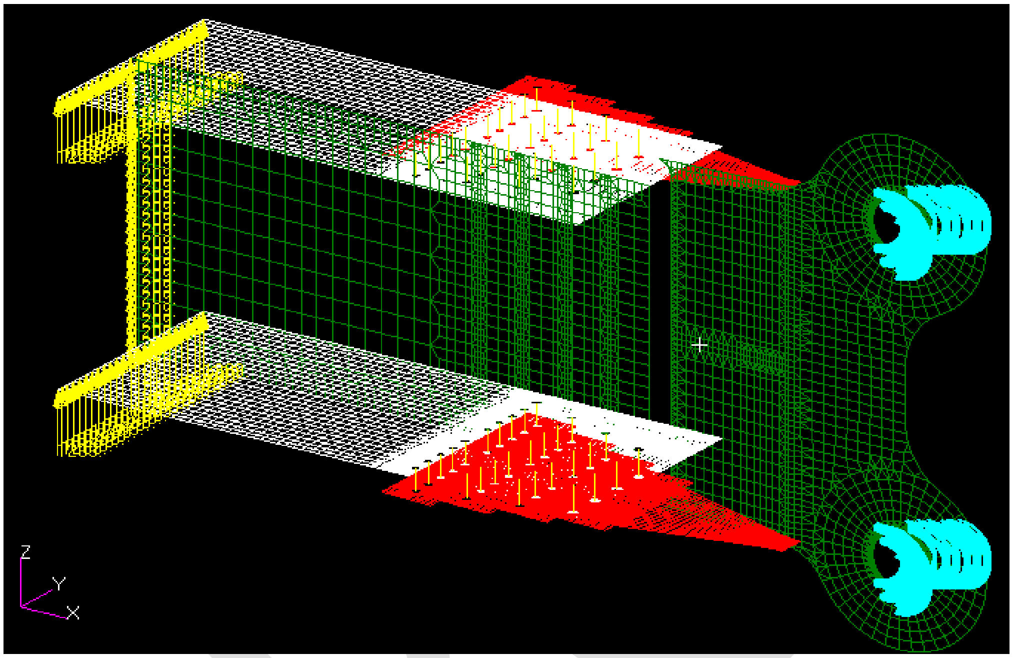

Fig.7: Loads & boundary conditions applied to the wing fuselage attachment bracket

The loads and boundary conditions along with the finite element model are shown in the Fig.7.A load of 90,584.62N is introduced at one end of the spar beam. This load will essentially create the required bending moment at the root.

MAXIMUM STRESS & MAXIMUM DISPLACEMENT IN WING FUSELAGE ATTACHMENT BRACKET

The stress values at the lug attachment bracket hole and the displacement contours are shown in the Fig.8 and Fig.9 respectively. A maximum stress of 968N/mm^2 is observed at the midpoint of the attachment hole section. Ultimate strength of Steel Alloy, Heat treated AISI-4340 is 1835 N/mm^2**.** Here max. Stress is less than the ultimate strength of structure; therefore we can say structure is safe for applied load.

The stress values at the lug attachment bracket hole and the displacement contours are shown in the figure 9 respectively. A maximum stress of 427N/mm^2 is observed at the riveted joints in I- sectional spar. Ultimate strength of Aluminium Alloy – 2024-T351 is 503.7N/mm^2.

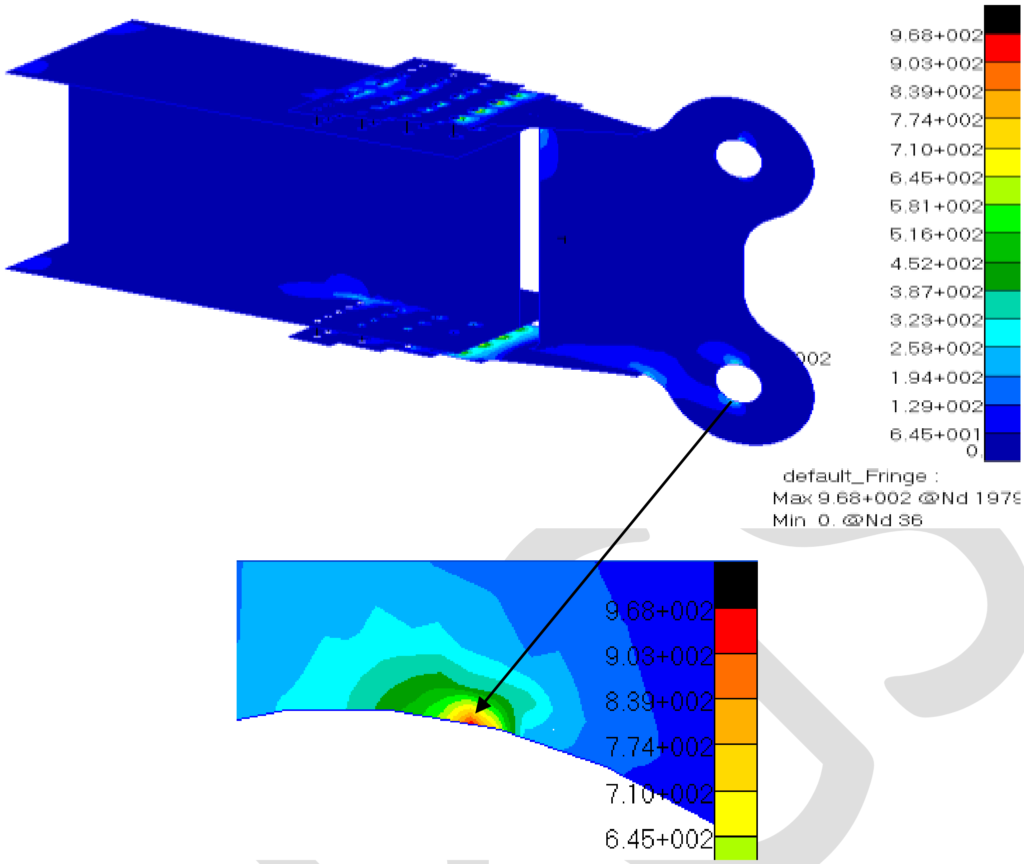

Fig.8: Max. Stresses in wing fuselage attachment bracket and Maximum stress at lug hole.

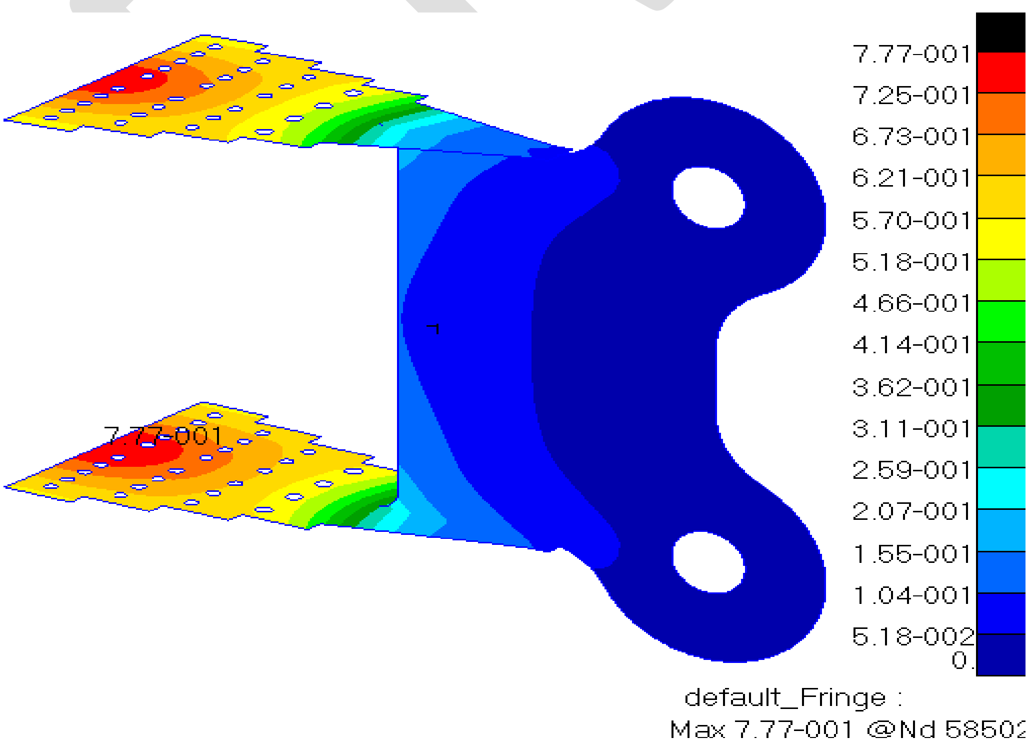

Fig.9: Maximum Displacement in wing fuselage lug attachment bracket.

FATIGUE LIFE

Fatigue is a phenomenon caused by repetitive loads on a structure. It depends on the magnitude and frequency of these loads in combination with the applied materials and structural shape. Structural members are frequently subjected to repetitive loading over a long period of time. Often machine members subjected to such repeated or cyclic stressing are found to have failed even when the actual maximum stresses were below the ultimate strength of the material, and quite frequently at stress values even below the yield strength. The most distinguishing characteristics are that the failure had occurred only after the stresses have been repeated a very large number of times. Hence the failure is called fatigue failure.

FACTORS THAT AFFECT FATIGUE LIFE

Geometry: Notches and variation in cross section throughout a part lead to stress concentrations where fatigue cracks initiate.

Material Type: Fatigue life, as well as the behavior during cyclic loading, varies widely for different materials, e.g. composites and polymers differ markedly from metals.

Residual stresses: Welding, cutting, casting, and other manufacturing processes involving heat or deformation can produce high levels of tensile residual stress, which decreases the fatigue strength.

Size and distribution of internal defects: Casting defects such as gas porosity, non-metallic inclusions and shrinkage voids can significantly reduce fatigue strength.

Direction of loading: For non-isotropic materials, fatigue strength depends on the direction of the principal stress.

Environment: Environmental conditions can cause erosion, corrosion, or gas-phase embrittlement, which all affect fatigue life. Corrosion fatigue is a problem encountered in many aggressive environments.

Temperature: Higher temperatures generally decrease fatigue strength.

MAXIMUM STRESS OBTAINED BY ANALYSIS OF WING FUSELAGE ATTACHMENT BRACKET (STEEL ALLOY AISI-4340)

In above analysis of wing fuselage lug joint, we considered the maximum loading condition and factor of safety. Therefore by considering the maximum conditions the stress in the structure is 968N/mm^2.The damage calculated at different g range with reference from S-N data is tabulated in the table 7.6 below.

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Table 2: The range of "g", the damage accumulated from miner's formula

Range of "g"	**Applied no of cycles (ni)**	**No of cycles to failure from graph(Nf)**	**Damage accumulated from miner's formula (D_i)**
0.5 g to 1.0 g	15000	$>10^8$	1.5×10^{-4}
1.0 g to 1.5 g	25000	$>10^8$	2.5×10^{-4}
1.5 g to 2.0 g	10000	$>10^8$	1×10^{-4}
2.0 g to 2.5 g	12000	$>10^8$	1.2×10^{-4}
2.5 g to 3.0 g	15000	$>10^8$	1.5×10^{-4}
3.0 g to 3.5 g	20000	$>10^8$	2×10^{-4}
3.5 g to 4.0 g	5000	$>10^8$	0.5×10^{-4}
4.0 g to 4.5 g	450	$>10^8$	0.3×10^{-4}
4.5 g to 5.0 g	350	$>10^8$	0.1×10^{-4}
5.0 g to 5.5 g	250	$>10^8$	0.025×10^{-4}
5.5 g to 6.0 g	150	$>10^8$	0.015×10^{-4}

MAXIMUM STRESS OBTAINED BY ANALYSIS OF I-SECTIONAL SPAR(ALUMINIUM ALLOY 2024-T351)

IN ABOVE ANALYSIS OF I -SECTIONAL SPAR IN WING FUSELAGE ATTACHMENT BRACKET, WE CONSIDERED THE MAXIMUM LOADING CONDITION AND FACTOR OF SAFETY. THEREFORE BY CONSIDERING THE MAXIMUM CONDITIONS THE STRESS IN THE STRUCTURE IS 427N/MM^2.

Table 3: The range of "g", the damage accumulated from miner's formula

Range of "g"	Applied no of cycles(n_i)	No of cycles to failure from graph(N_f)	Damage accumulated from miner's formula (D_i)
0.5 g to 1.0 g	15000	$>10^8$	1.5×10^{-4}
1.0 g to 1.5 g	25000	$>10^8$	2.5×10^{-4}

1.5 g to 2.0 g	10000	$>10^8$	1×10^{-4}
2.0 g to 2.5 g	12000	$>10^8$	1.2×10^{-4}
2.5 g to 3.0 g	15000	$>10^8$	1.5×10^{-4}
3.0 g to 3.5 g	20000	$>10^8$	2×10^{-4}
3.5 g to 4.0 g	5000	$>10^8$	0.5×10^{-4}
4.0 g to 4.5 g	450	$>10^8$	0.3×10^{-4}
4.5 g to 5.0 g	350	$>10^8$	0.1×10^{-4}
5.0 g to 5.5 g	250	4800	0.025×10^{-4}
5.5 g to 6.0 g	150	3700	0.015×10^{-4}

RESULTS & DISCUSSIONS

The maximum stress value is found in the case of bearing mode. As per the design consideration the maximum allowable stress in the lug attachment bracket is 40% of the UTS which is 1530 N/mm^2. Therefore the configuration used in wing fuselage attachment bracket for geometry is found to be satisfactory.

Table 4: Modes of failure with stress in N/mm^2

S. NO	modes of failures	Max stress(σ_{max}) in N/mm^2
1	Net-section failure	78.472
2	Bearing Failure	172.168
3	Shearing Failure	56.63

ANALYSIS OF WING FUSELAGE ATTACHMENT BRACKET

The max. Stress obtained in the structure, material used for the structure, ultimate strength of the material. In both the cases max. Stress is less than the ultimate strength of the material. According to stress-strain diagram of respective material, structure will not fail for applied load (i.e. load acting on wing fuselage attachment bracket is $90.677\times e^3$N). When the max. Stress is greater than or equal to the ultimate strength of structure than only structure is going to fail.

Table 5: Max. Stress obtained in the structures in N/mm^2

S.NO	Name of the structures	Material used	Ultimate strength of the material (in N/mm^2)	Max. stress by FEA(in N/mm^2)
1	wing fuselage lug attachment bracket	Steel Alloy, Heat treated AISI- 4340	1835	968
2	I-sectional spar	Aluminium Alloy –2024-351	503.7	427

FATIGUE LIFE ESTIMATION

The Total damage accumulated in both structure is 0.000296, which is less than 1. Therefore a crack will not get initiated from the location of maximum stress in both structures (i.e. wing fuselage attachment bracket) for given load spectrum.

Table 6: Fatigue Life Estimation.

S.NO	Name of the structures	Material used	Ultimate strength of the material (in N/mm^2)	damage accumulation per block (D_a)
1	wing fuselage lug attachment bracket	Steel Alloy, Heat treated AISI- 4340	1835	0.000296<1
2	I-sectional spar	Aluminium Alloy –2024-351	503.7	0.000296<1

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CONCLUSION

Stress analysis of the wing fuselage attachment bracket is carried out in this paper and maximum tensile stress is identified at one of the lug-holes. FEM approach is followed for the stress analysis of the wing fuselage attachment bracket.A validation for FEM approach is carried out by considering a plate with a circular hole. Maximum tensile stress of 968N/mm^2 is observed in the lug hole. Several iterations are carried out to obtain a mesh independent value for the maximum stress. A fatigue crack normally initiates from the location maximum tensile stress in the structure. The fatigue calculation is carried out for an estimation of life to crack initiation. From the calculations maximum damage fraction of 0.000296. The value of damage fraction is much less than 1. hence the crack will not get initiated for the given load spectrum. Therefore design is safe.

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