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Design Structural Analysis and Fatigue Calculation of Wing Fuselage Lug Attachment of a Transport Aircraft

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ABSTRACT

There are two classes of loads which acts on the aircrafts which are surface forces and body forces. Surface forces include aerodynamic and hydrostatic pressure forces while body forces are due to gravitational and inertial effects on the volume of the structure of an aircraft. In these aerodynamic forces are more severe.With the pressure load which occurs due to the production of lift force, Bending moment and shear forces will be acting on the wing. Theses are the most important cases of forces while studying about the Wing and Fuselage attachmmet connections.

With the help of Shear force, Shear force due to torsion and bending moment values, we can get the design of the Spar inside the wing. The spar is the main part in the wing which carries the aerodynamic loads to the fuselage. From the end of the spar only the wing-fuselage lug attachment starts. Some rivets are also used to attach the upper plate to the spar flange. Different loads acting on the rivets also must be calculated to find which pattern of riveting is going to use.Connection of lug attachment to fuselage is a machined bulkhead. Several configurations are available for lug attachments such as configuration a, b,c etc.

In these, "configuration a" only used here as it divides loads equally to two lugs. Fatigue life of the lug attachment is also calculated using stress life approach. Design of the model is done in CATIA V5, finite element modelling in Hypermesh12.0 and analysis in Nastran-Patran.

INTRODUCTION

Man has always wanted to overcome the challenges to move through air, water and ground etc. When man succeeded to travel through water and on ground, he dreamed to soar with the birds. These dreams made an Aircraft. An aircraft is one of the most advanced designs that man has ever made. A typical aircraft structural breakdown is shown in the fig below.

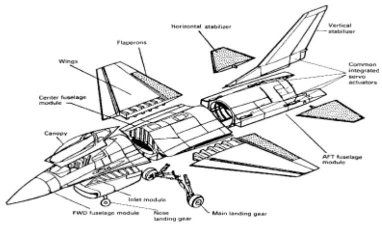


Figure 1 : Aircraft structural Breakdown

The connection between wing and fuselage of an aircraft must be explored. Since the loads that are produced by the wing are transferred to the fuselage through these attachments only. So failure of lug joints may lead to the catastrophic failure of the whole structure. The consequence of lug failure will be very severe that sometimes the wing and fuselage get separated and result in accidents. Finite element analysis helps the designer to safeguard the structure from catastrophic failure.

Objectives

- Main Objective of our project is to design a Wing Fuselage Lug attachment for a transport aircraft with mid wing configuration.
- To make good structural analysis for different types of loads on lug attachment and make it

usable as per our design requirement and to find the fatigue life of the attachment.

LITERATURE SURVEY

We are considering here a transport aircraft with mid wing configuration. Different loads acting on the aircraft has to be found and how it transfers from wing to fuselage is also required to be found. Rivets also have to be used to attach spar flange to the lug attachment. So different loads acting on the rivets also must be calculated due to the Shear force and bending moment caused by the pressure load on the wing.

A finite element model has to be prepared and must be taken in for analysis. Fatigue is the progressive deterioration of strength of the structural component during service such that the failure occurs at much lower level of ultimate stress. This is due to repetitive loads acting for a longer time. There is stress life and strain life approaches available to calculate the fatigue life of a structure. With the help of stress life approach, the fatigue life of the lug attachment can be calculated.

Stress Analysis of Wing-Fuselage Lug Attachment Bracket of a Transport Aircraft

b.k. sriranga, dr. c.n. chandrappa, r. kumar and dr. p.k. dash

Civil transport aircraft is used for carrying passengers from one place to another. Aircraft is a highly complex flying structure. Generally transport aircraft undergoes nominal maneuring flights. During the flight when the maximum lift is generated, the wings of the aircraft will undergo highest bending moment. The bending moment will be maximum at the root of the wing which caused highest stress at this location. Wings are attached to the fuselage structure through wing-fuselage attachment brackets. The bending moment and shear loads from the wing are transferred to the fuselage through the attachment joints.

In this project bending load transfer joint is considered for the analysis. First one needs to ensure the static load carrying capability of the wing-fuselage attachment bracket. Stress analysis will be carried out for the given geometry of the wing-fuselage attachment bracket. Finite element method is used for the stress analysis. 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

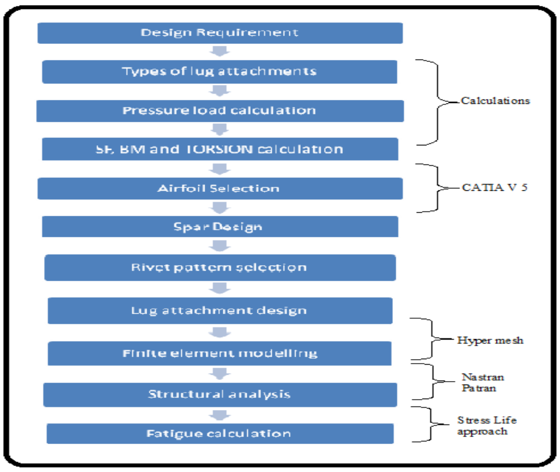
Aircraft Structures for Engineers

vijay k. goyal, ph.d., vinay k. goyal, ph.d.

Aerospace structures are one of the most challenging courses to teach. It enclosed many advanced topics while introducing some fundamental thin-walled structural analysis. This book is written for students with a background in mechanical engineering, although the concepts are presented in a fundamental approach allowing students from all backgrounds to benefit from the material in this book.

This book is intended to provide a foundation of the finite element and optimization techniques. Practicing engineers will also benefit from the integration approach to obtain very impressive and useful results. Thus, we can assure that this book will fill up a void in the personal library of many engineers who are trying to, or planning, to design and analyze thin-walled structures. A background in solid mechanics and calculus is required.

Methodology



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IRFOIL DESIGNED

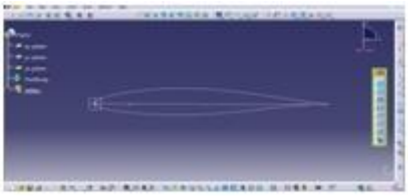

Figure 2: Wing cross section- Airfoil imported in

CATIA V 5.0

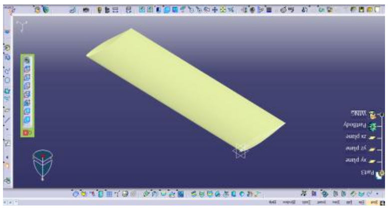

Figure 3: Wing made in CATIA V 5.0

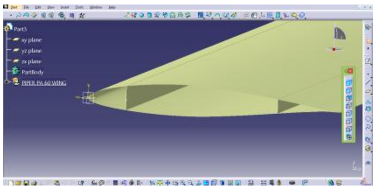

Figure 4: Location of Spars on the wing cross section

Finite element model of Wing Fuselage Lug Attachment

The part we had designed in the CATIA V 5.0 is imported in the HyperMesh. So that our Wing-fuselage lug attachment become .hm file this was .CATPART earlier. Now it is required to find the mid surface of our design. As our design is having two lengths much higher than the other, we will mesh accordingly, may be 2D mesh only as shown in the figure below.

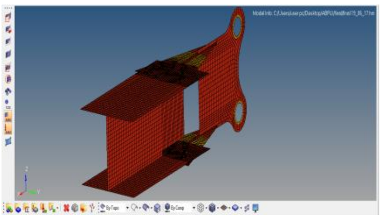

Figure 5: Finite element model of Wing Fuselage Lug Attachment

Thus we got the Finite element model of our designed wing fuselage lug attachment. Now it is required to do the structural analysis.

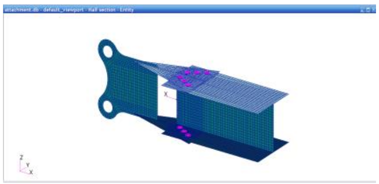

Figure 6: Finite element model imported in Patran

First we will consider Spar only:

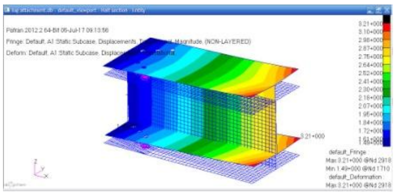

Figure 7: Displacement in spar due to applied loads

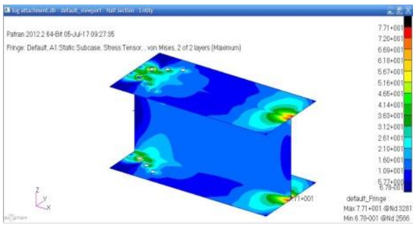

Figure 8: Von-mises stresses in spar

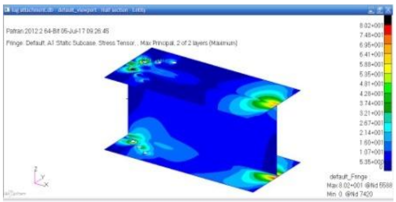

Figure 9: Maximum principle stresses that act on spar

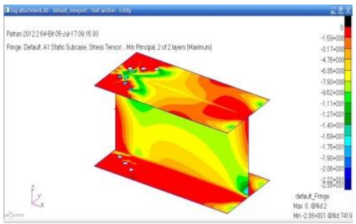

Figure 10: Min principle stresses in spar

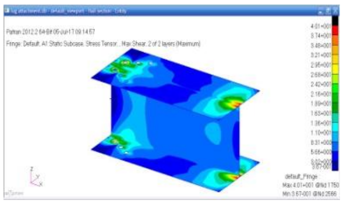

Figure 11: Max shear stresses in spar

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Now we consider the lug part only:

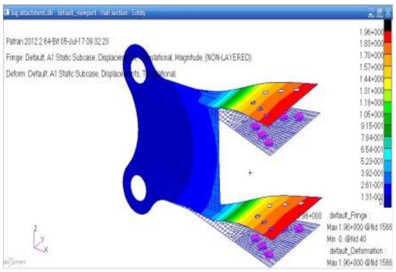

Figure 12: Deformation on lug part

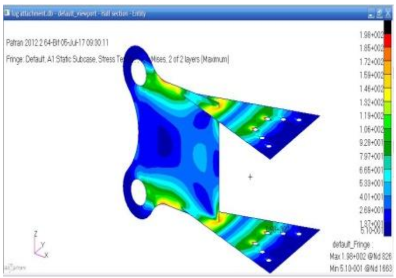

Figure 13: Von-Mises stress in lug part

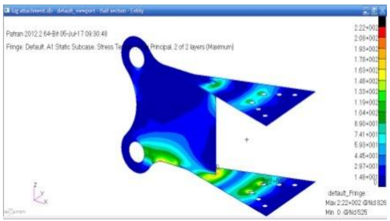

Figure 14: Maximum principle stress in lug part

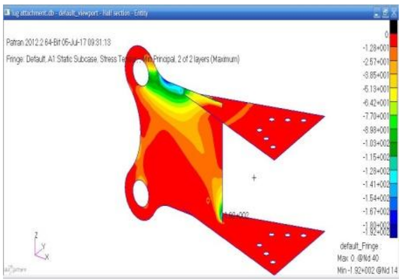

Figure 15: Min principle stress on lug part

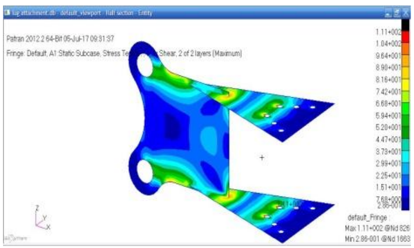

Figure 16: Max shear stress on lug part

Now we will consider the full wing-fuselage lug attachment:

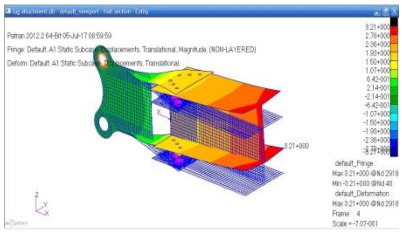

Figure 17: Displacement on wing fuselage lug attachment

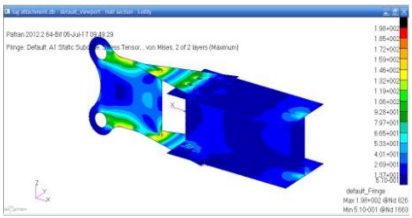

Figure 18: Von-mises stresses on wing fuselage lug attachment

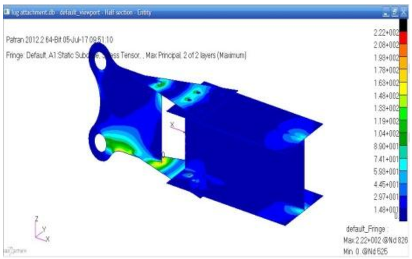

Figure 19: Max principle stress on wing fuselage lug attachment

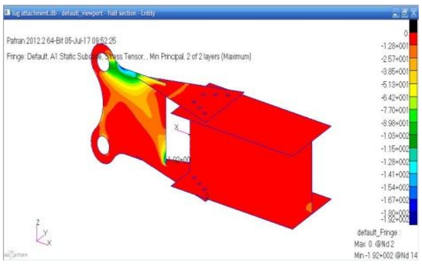

Figure 20: Min principle stress on wing fuselage lug attachment

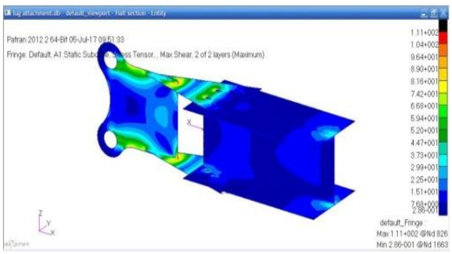

Figure 21: Max shear stress on wing fuselage lug attachment

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Fatigue calculation

Now it is required to find the fatigue life of the wing-fuselage lug attachment. We will use the stress life approach to find the fatigue life of the Attachment. Theses equations are as per ref [15]

S_{ut} : 427MPa S_y: 345 MPa

σ_{max}: 198MPa σ_{min}: 0.51MPa

σ_a: $(\sigma_{max}+\sigma_{min})/2 = 99.25$ MPa

σ_m: $(\sigma_{max}-\sigma_{min})/2 = 98.75$ MPa

σ_r: $\sigma_{max}-\sigma_{min} = 197.5$ MPa

$A = \sigma_a / \sigma_m = 1.005$

As per Goodman's criteria,

$\sigma_m > 0$ and $\sigma_{max} < S_y$

Then $Seq = (Sa)/(1-(\frac{Sm}{Sut}))$

Where $S_a = S_{nf} \times \sigma_a = 1.5 \times 99.25 = 148.875$ MPa

$S_m = S_{nf} \times \sigma_m = 1.5 \times 98.75 = 148.125$ MPa

Thus

$Seq = (Sa)/(1-(\frac{Sm}{Sut})) = 227.63$ MPa

Now we know the number of cycles is $N = \left(\frac{S}{a}\right)^{\frac{1}{b}}$ From Goodman's criteria

Where $a = \frac{f \times Sut}{10^{3b}}$ and $b = \frac{1}{(3-Ge)} \times \log(\frac{f \times Sut}{Se})$ are constants

Where G_e=6 for Aluminium AA2024 and f=1.5 which all are design factors.

Then we can calculate a &b as,

b = -0.1497 and a= 1804.22

Thus $N = \left(\frac{227.63}{1804.22}\right)^{\frac{1}{-0.1497}} = 10, 16, 771$ cycles

Consider scatter factor of 4, then we can say that the total number of fatigue loading cycles will be 2, 54, 193 cycles by Goodman's method.

Validation

For any analysis, validation is a must. We are considering factor of safety here for validation.

Factor of Safety: Factor of safety can be defined as the ratio of ultimate strength to the design strength. It is a constant factor that is considered for designing of machine components or structure beyond its working strength.

F.O.S= Ultimate strength/Designed load

As per ref [14] lug part and spar is designed with two materials as below:

Lug part: Alloy steel

E = 201105N/mm3

μ = 0.3

Spar: AA2024 T3

E = 70000 N/mm3

μ = 0.3

In our design we had considered only AA2024 T6 for entire lug attachment. Now if we go as per ref [14], we will get the von-mises stress as below:

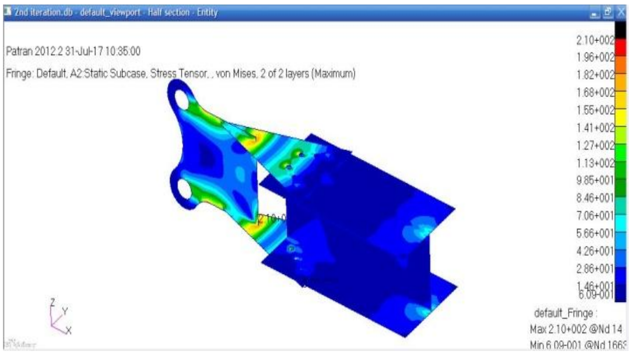

Figure 22: Von-mises stress for different materials on spar and lug

Thus we can consolidate our results as shown below:

Table 1: Consolidated stress data

	Full model as AA2024 T6	Separate materials for spar and lug [14]
Max. Von-Mises stress (MPa)	198	210
Reserve Factor	2.15	2.02

Thus it can be concluded that lesser stress is obtained when AA2024 is used for full section. As per the aircraft considerations, industry will go for higher Factor of Safety only. Thus our design is good and is a valid result.

Now if we go for the fatigue life considerations, there also this design is much helpful. Fatigue life reduces as stress increases in higher factor i.e. as stress doubles fatigue life reduce by a factor of 2^{10}. So by comparing these, model which is having lesser stress is preferred. Thus the design and the analysis are valid.

The displacement that we computed (3.2 mm) comes to be within 1.3% of total length of our model. This is allowable as per aircraft industry standards.

Conclusion

- The structural analysis of wing fuselage lug attachment for this project has a safe life as per the loading conditions discussed earlier.

- Finite element analysis for structural analysis of wing fuselage lug attachment is carried out using quad elements.
- Maximum elongation is observed at the spar only and maximum stresses are observed at the rivet holes which are near to lug i.e. the lug to bulkhead connecting area.
- Aluminium AA 2024 can be used as one of the best material for this design as it has a factor of safety of 2.15.
- Stress is in most cases function of external loads and geometry. Materials properties will have influence on strains but not on stress in FE calculation (linear elastic conditions).
- The fatigue life which was calculated shows the maximum allowable working period of the designed wing fuselage lug attachment.
- This project summarizes, how to design a wing fuselage lug attachment, how to obtain the input loads such as shear forces and bending moments and structural analysis, and fatigue life calculation based on stress life approach and Goodman's criteria and will also predict that the geometry is safe on the basis of static structural analysis.

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