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Design, Static Structural Analysis and life estimation of Splice Joint in Aircraft Fuselage

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Abstract -*The greatest single thing of the fuselage structure is the skin and its stringer. It is furthermore the most segregating structure since it passes on most of the fundamental burdens as a result of fuselage curving, shear, torsion and inside pressure. End to end of stringers is associated by splice joint. The investigations are carried out on splice joints for a stringer in aircraft fuselage to access stress concentration, Linear static analysis is carried out for various load conditions, Joint sensitive analysis for Z stringer, and change in structural design has been made to bring in the behavioral difference in the structure for same material with two different structures.*

Key Words: **Aircraft Fuselage, Splice Joint, Stringer, Z Stringer, Omega Stringer, Unigraphics NX, ANSYS Workbench**

1. INTRODUCTION

An aircraft is a flying machine that flies by picking up backing from the air. It counteracts the force of gravity by means of either static lift or the dynamic lift of an air foil, or now and again the downward thrust from plane motors. The human commotion that encompasses aircraft is called flight. Run aircraft are flown by a locally available pilot, however unmanned prominent vehicles might be indirectly controlled or self-controlled by installed PCs. Airplane might be gathered by different criteria, for example, lift sort, aircraft impetus, use and others. Heavier aircrafts, for instance, planes, must find way to deal with push air or gas downwards, so that a reaction happens (by Newton's laws of development) to push the aircraft upwards. This dynamic improvement through the air is the wellspring of the term aerodyne. There are two approaches to manage bring into being quick up push that is streamlined lift, and controlled lift as engine push. Aircraft are composed taking into account numerous variables, for example, client and maker request, security convention, physical and financial requirements. For some writes of aircraft, the outline procedure is managed by national airworthiness powers. The key parts of an aircraft are generally divided into three categories: 1. The structure involves the principal load-bearing components and coupled hardware. 2. The drive framework includes the force source and related hardware. 3. The flight comprises of the control, route and correspondence frameworks, generally electrical in nature.

1.1 Aircraft Structure

The aircraft consist of five essential auxiliary segments, viz, 1. Fuselage: The fuselage is the basic body structure to which each and every other section are annexed. The fuselage contains the cockpit or flight deck, voyager compartment and cargo compartment. 2. Wings: The wings are the majority elementary lift-conveying component of the aircraft. Wings change in setup depending on the aircraft sort and its stimulation. Most planes are sketched out so that the outer tips of the wings are elevated than where the wings are linked with the fuselage. 3. Empennage (tail structures): Empennage or also the tail offers security and be in command of the plane. 4. Power plant (propulsion system): Aircraft power plants are characterized into five types. Turbo-prop engines for decently low speeds, Ramjet engines are for speedy aircrafts, Turbo-fan engines for Mach 0.3 to Mach 2, Turbojet engines which are for fast planes, besides the engines for fundamental low speed aircrafts. 5. Undercarriage: An undercarriage of the aircraft sustains the plane onto the ground, smooth moving, hold staggers of exploring and landings

1.2 Stringers and Splice joint

In aircraft fuselage, stringers are connected to formers (likewise called casings) and keep running in the longitudinal heading of the aircraft. These are fundamentally in charge of switching the streamlined burdens subsequently on the skin into the edges and the formers. In wing or the stabilizer, longerons run traverse shrewd and connect among the ribs. The essential capacity here likewise is to exchange the twisting burdens following up on the wings onto the ribs and fight. Here and there the expressions "longeron" and "stringer" are used then again. Longerons frequently pass on greater weights than stringers moreover trade skin weights to inward structure. Longerons reliably associate with housings or ribs. Stringers routinely are not affixed to anything other than rather the skin, where they pass on a portion of the fuselage turning minute through vital stacking. It is not sensational to have a mix of longerons and stringers in the same significant fundamental fragment.

2. Literature Survey

Aircraft structure is an area where in many researches are being carried out. It provides lots of research to the fellow researchers. Everyday there is a scope of improvement in the field of aircrafts, be it in the aircraft structure, its efficiency, and various other fields. In the literature review it is observed that almost many experimental works have been conducted on either prototypes or they are just thesis reports. Maximum analysis is being made through ANSYS software in which some of the literature survey as most significant that has been analyzed through ANSYS on the experimental study of aircraft structures.

Vijayraja L and A R Anwar Khan [1] present the simulation and design of splice joint in the fuselage using ANSYS software. In this study the connection of Z-Stringer splice joint present in Aircraft fuselage skin with three blends that is metallic, composite and metallic and composite. The stringers are utilized as a part of aircraft fuselage to abstain from clasping of fuselage skin. The stringer is amassed to fuselage skin by jolts. The stringers are connected end to end by splice joint. The 3D displaying of stringer in ANSYS Workbench, by applying plan condition for static structural assessment by limited component strategy for these blends is made. It is concluded that the behavior of splice joint of stringer in an aircraft fuselage structure composite stringer is more resourceful and preferable compared to conventional material.

Basil Sunny and Richu Thomas [2] present the anxiety examination of a splice joint in an airplane fuselage with forecast of weakness life to break start. The principal goal of this paper is to look at different properties of a splice joint in an airplane fuselage with the expectation of weakness life to split ignition utilizing composite material. The utilization of the composite material in the aircraft will expand the quality to weight proportion. The Aluminium compounds are utilized as a part of the splice joints.

Channabasavarj B.Dharani, Shivraj and Sai Sachin [3] presents the stress analysis of a critical splice joint in the fuselage structure of an airframe and fatigue life estimation due to pressurization cycles. In this study they consider fundamental joints as the essential helper parts in the airframe structure. To guarantee the fundamental dependability of the airframe one needs to concentrate on every one of the joints first. Stress examination accepts a key part in perceiving the tremendous zones. This foresees depicts about the anxiety examination of a splice joint in a vehicle aircraft. The reply of the splice joint will be surveyed throughout restricted segment examination. Lodge pressurization is the fundamental weight case for the fuselage structure. Fuselage encounters enduring plentifulness load cycles in light of pressurization.

Adarsh Adeppa, K. E. Girish and Dr. M. S. Patil [4] present the anxiety examination and weakness life expectation for the splice joint in an aircraft fuselage utilizing FEM approach. In this study Aluminium Combination 2024-T351 material is considered for all the basic components of the board for creation of the airplane body. Power because of Lodge pressurization is considered as one of the basic burden cases for the fuselage structure for investigation. This hypothesis consolidates the anxiety examination of a splice joint in a vehicle aircraft. A two-dimensional restricted segment examination will be finished on the splice joint board. Scattering of locks weights and neighborhood stress field at jolt regions will be researched using constrained segment examination. The work moreover attracts the alterations required to change the point of confinement effects of the board. Splice joint is the major locality for fatigue crack to grow. In the study prediction of fatigue life for crack opening will be carried out at a maximum stress location.

Arunkumar K. N and Lohith N [5] present the study on impact of ribs and stringer separating on the heaviness of airplane composite structures. The two essential targets of this study are minimal effort and decreased weight. This study stresses after landing at ideal separating of ribs and stringers and stringer cross segment for least weight of clasping outline driven segments, with respect to the assembling requirements for a suitable configuration and along these lines shaping a rule for the choice of these parameters at the early periods of basic configuration process.

Dr.C.Udaya Kiran and Y.Vijaya Kumar [6] present a study on the static and element examination of aircraft solidified board. In their study they describe that a solidified board is a section in an aircraft that is used to append the stiffener and the skin. These are the instrument that pass on and assign the stores all through the surface of the fuselage or the wing. These sheets are there in both fuselage and wings. Stiffener or longeron or stringer is a thin metal strip that is used as an uneven or solid part in fuselage and wing. With a particular deciding objective to elucidate this issue they have arranged a solidified board which can experience to shirking and push levels. By changing the set board sections and by fluctuating the material of the skin, the aircraft skin can continue on through the distortion. Usually T-territory hardened board is used yet there is a drawback of using

T-section, it can't prepare for distortion. So, they have made an I-portion solidified board (since) I-region is more defiant to twisting) in CATIA and Lattice in Hypermesh and Investigation is done in ANSYS.

Joseph Clint, Santhosh Kumar and Nazumuddin Shaik [7] present the clasping examines the aircraft fuselage structure skin. Fuselage clasping of a cemented composite chamber is a greatly flighty marvel that incorporates complex relations between the skin and the stiffeners. Considering dissimilar setups of the skin and stiffener, particular sorts of catching dissatisfaction modes and frustration weights are seen in cemented barrels. Hence by taking this examination as an example a 3D model has been considered with some constrains to get closure to accuracy of the structure. A 3-D constrained segments model is fused which carries with record the accurate geometric setup and the orthotropic properties of the stiffeners and shell. In perspective of restricted parts appear, a common contention is made on the particular fastening frustration modes viewed.

2.1 Summary of literature Survey

Studying the literature survey, we can arrive at a conclusion that at present the most suitable and preferable structure for manufacturing of stringer and splice joint is either Z stringer or Omega structure. Various other structures have been considered for the study of stringer and splice joint but they are not as efficient and effective as the above-mentioned structures. Also, in the previous literature survey the design of the stringers and splice joints calls for optimization. Hence taking all these factors into consideration, the study aims for design optimization of the stringer and splice joint and comparison is made between Z stringer and Omega stringer. Finally, the most optimal and better design is considered for the stringer and splice joint.

3. PROBLEM DEFINITION

The circular frames provide circumferential stiffness to the structure without allowing the structure to buckle and the design and simulation of these circular frames is very challenging. The stringers are linear structure which provides axial stiffness to fuselage. Splice joints are used for the fuselage structure. Force due to Cabin pressurization can be considered as one of the critical load cases for the fuselage structure. The splice joint is one of the critical locations for fatigue crack to initiate. So, in order to avoid failure of these splices a robust design has to be made which bears the capabilities of overcoming such issues.

3.1 OBJECTIVE

The objectives of the study are, the investigations of splice joints for the fuselage structure in aircraft to access stress concentration. Linear static analysis for various load conditions. Joint sensitive analysis for Z stringers and Omega stringers, to bring in the behavioral difference in the structure for similar joint with two combinations. Bilinear analysis and modal analysis for various load conditions is carried out.

4. METHODOLOGY

The objectives of the thesis are obtained by methodology explained as 1: Creation of Geometric model: modelling is carried out using Unigraphics NX-11 software. 2: Meshing: The meshing is done using the ANSYS Workbench and the models are meshed using Hexa dominant elements available is ANSYS Workbench. 3: Applying the boundary condition: Application of the boundary condition takes place wherever required. 4: Importing data in ANSYS Solver: The importing of the model takes place and the further process is carried out using ANSYS Solver. 5: Linear and bilinear analysis done in ANSYS Workbench: After importing the data in solver, linear and bilinear analysis is carried out in Workbench and results of different structure are obtained with respect to different materials. 6: Comparative analysis and Graphical representation: studying all the models we can compare pre-modified structure with post-modified structure to know which design model is better.

5. MODEL DESCRIPTION:

5.1 material properties:

Table -1: Material properties of Aluminium 2024 T-351

Description	Stringer	Splice Joint	Bolt
Material Name	Aluminium Alloy 2024 T-351	Aluminium Alloy 2024 T-351	Aluminium
Density (g/cm3)	2.78	2.78	2.78
Young's modulus	73.1 GPa	73.1 GPa	73.1 GPa
Poisson's ratio	0.3	0.3	0.3
Yield Stress (Mpa)	280	280	280

5.2 Geometry

The 2D geometry both models are developed using the software Unigraphics NX and analysed in ANSYS Workbench.

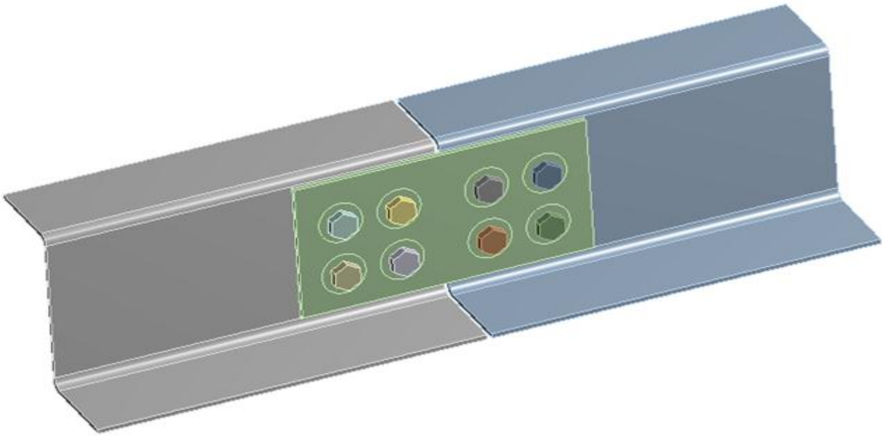

Figure 1: Isometric View of 2D Model of a Z-shaped Stringer and Splice Joint

DIMENSIONS:

Stringer Height: 35mm

Stringer Width: 20

Stringer Length: 80mm

Thickness of splice: 10mm

No. of bolts: 8

Bolt dimension: 4mm

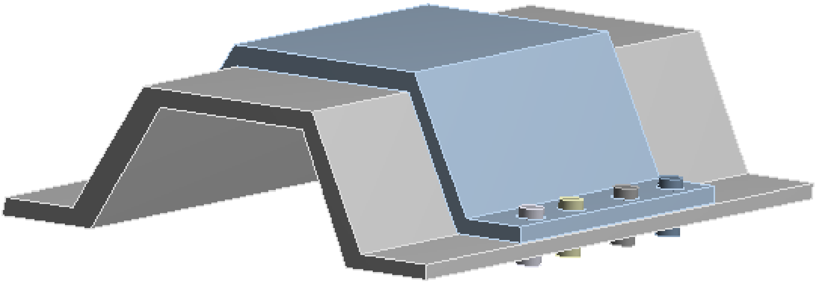

Figure 2: Isometric View of 2D Model of a Omega-shaped Stringer and Splice Joint

DIMENSIONS:

Stringer Height: 35mm

Stringer Width: 20

Stringer Length: 80mm

Thickness of splice: 10mm

No. of bolts: 8

Bolt dimension: 4mm

5.3 Meshing Process

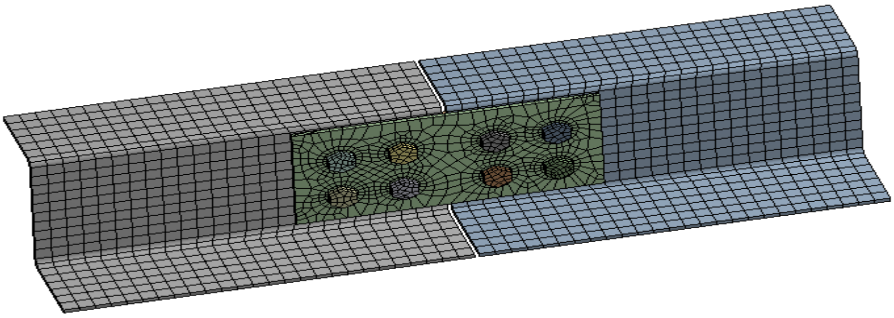

Figure 3: Meshing of Z Stringer and Splice Joint

FINITE ELEMENT METHOD DATA INFORMATION:

Method : Hexa-Dominent

Element type used: 8 node184

Nodes present: 28674

Elements: 6182

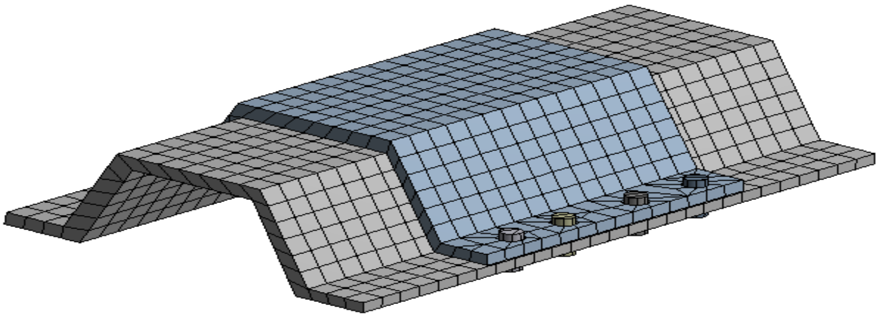

Figure 4: Meshing of Omega Stringer and Splice Joint

FINITE ELEMENT METHOD DATA INFORMATION:

Method : Hexa-Dominent

Element type used: 8 node184

Nodes present: 10021

Elements: 1903

5.4 Boundary Conditions:

The below figure shows the boundary conditions applied for Z stringer

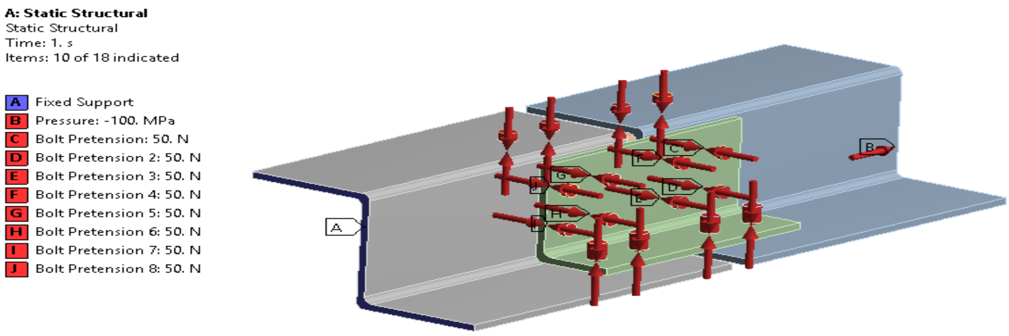

Figure-5: Application of Loads.

A Bolt pretension load of 50 N is applied for each bolt. Number of bolts used is 8. Apart from that tensile load of 100Mpa is applied to one end of the stringer which is shown in red colour and another end is fixed which represents in blue

The below figure shows the boundary conditions applied for for Omega stringer for linear static analysis

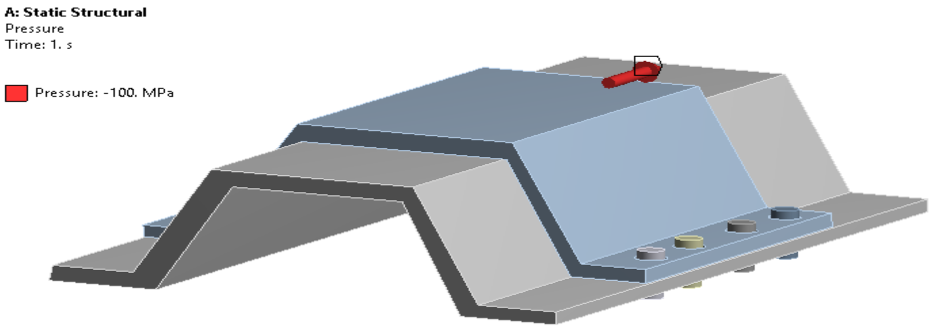

Figure 6: Application of Pressure on the Omega Stringer and Splice Joint

One end is fixed and at another end, tensile load is applied of 100Mpa for linear static analysis.

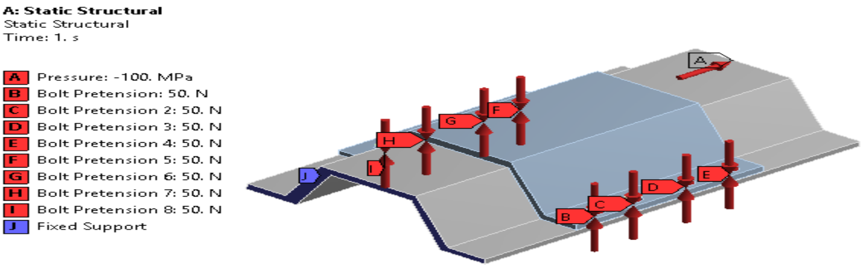

Figure 7: Application of Bolt Pretension Load.

A Bolt pretension load of 50 N is applied for each bolt. Number of bolts used is 8. Apart from that tensile load of 100Mpa is applied to one end of the stringer which is shown in red color and another end is fixed which represents in blue.

6. ANALYSIS RESULTS

6.1 model 1: linear static analysis

Equivalent Stress

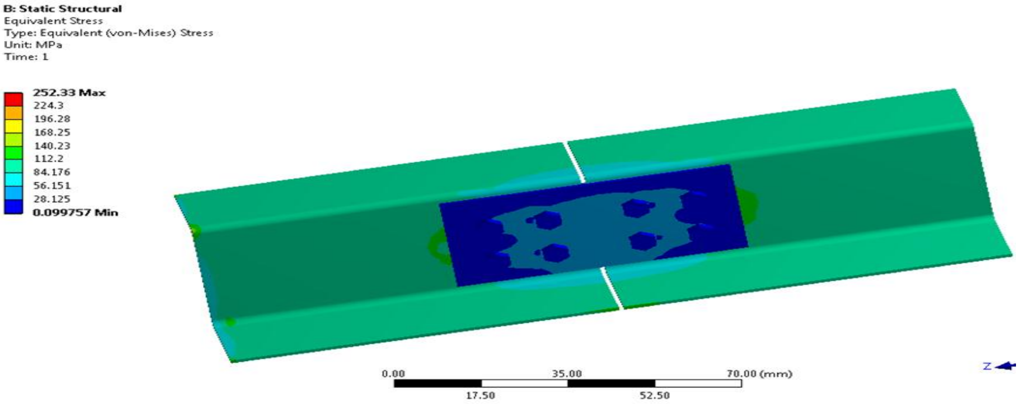

Figure 8: Equivalent Stress Developed in the Z Stringer and Splice Joint

The maximum stress developed due to the application of pressure is 252.33Mpa. Since the result is under yield stress, the design is safe.

Maximum Principal Stress:

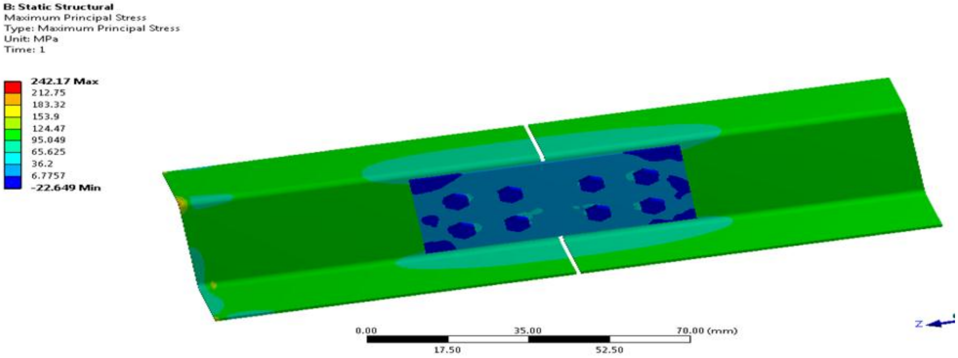

Figure 9: Maximum Principal Stress Developed in the Z Stringer and Splice Joint

The maximum stress developed due to the application of pressure is 242.17Mpa. Since the result is under yield stress, the design is safe.

Minimum Principal Stress:

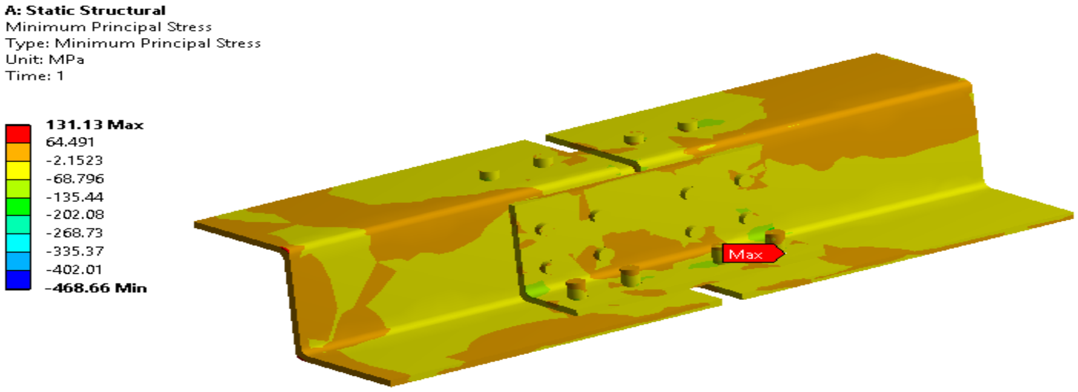

Figure 10: Minimum Principal Stress Developed in the Z Stringer and Splice Joint.

The maximum stress developed due to the application of pressure is 131.13Mpa. Since the result is under yield stress, the design is safe.

Total Deformation

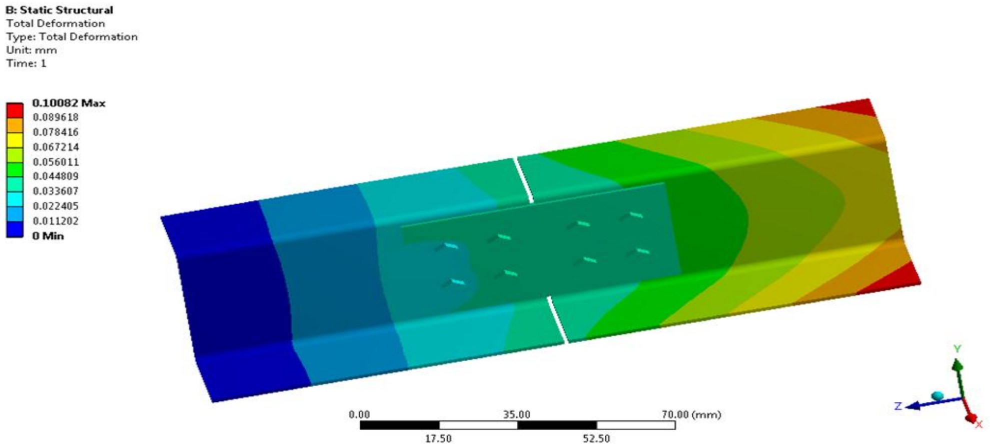

Figure 11: Total Deformation due to Stresses Developed

The maximum total deformation of 0.10082mm is observed.

6.2 model 2: linear static analysis

Equivalent Stress

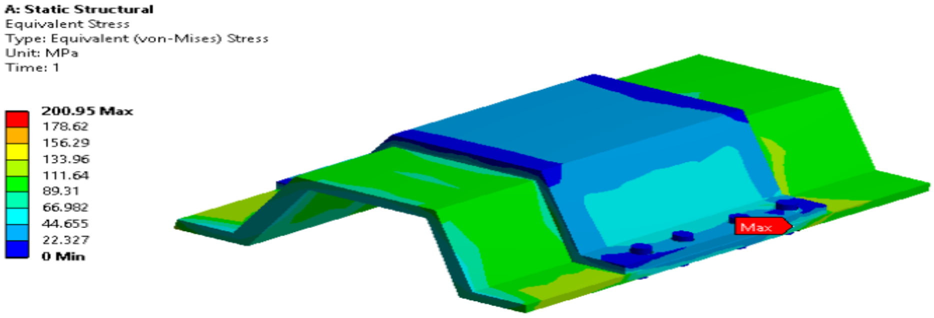

Figure 12: Equivalent Stress Developed in the Omega Stringer and Splice Joint

The maximum stress developed due to the application of pressure is 200.95Mpa. Since the result is under yield stress, the design is safe.

Maximum Principal Stress

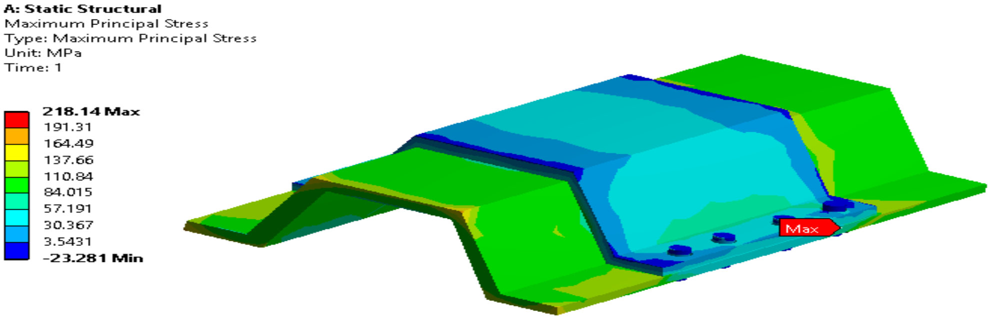

Figure 13: Maximum Principal Stress Developed in the Omega Stringer and Splice Joint

The maximum stress developed due to the application of pressure is 218.14Mpa. Since the result is under yield stress, the design is safe.

Minimum Principal Stress

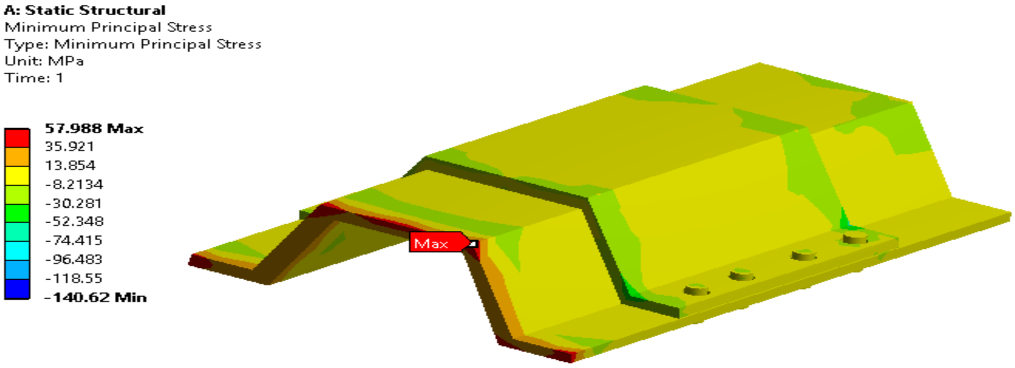

Figure 14: Minimum Principal Stress Developed in the Omega Stringer and Splice Joint

The maximum stress developed due to the application of pressure is 57.99Mpa. Since the result is under yield stress, the design is safe.

Total Deformation

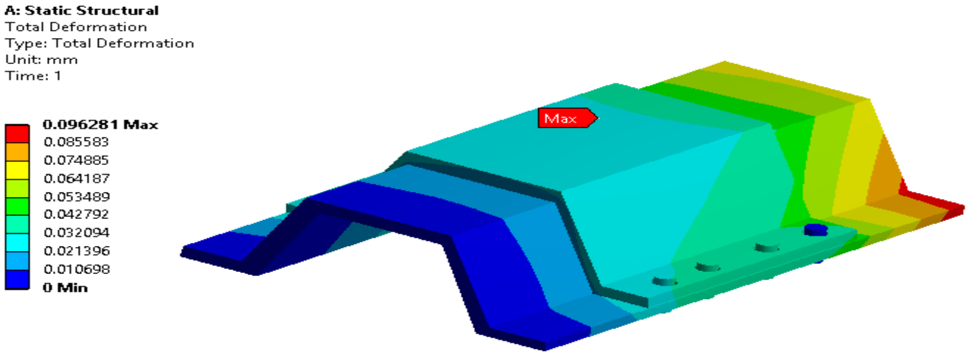

Figure 15: Total Deformation due to Stresses Developed

A total deformation of 0.096281mm is observed is observed which shows red in colour. Since the total deformation is in the safer limits hence the design is safe.

6.3 MODAL ANALYSIS

Modal Analysis of model 2 Omega stringer for Aluminium Alloy is carried out.

Table 2: Modal Analysis for Omega stringer Aluminium Alloy

MODE NUMBER	FREQUENCY (Hz)	DEFORMATION (mm)
Mode 1	921.92	193.41
Mode 2	1067.7	194.19
Mode 3	2439.3	253.09
Mode 4	2671.1	134.04

The table above shows the various modes at which the stringer vibrates. Based on the frequencies of the different modes follows the deformation in the model. Each frequency has a particular value and deformation which is clearly shown in the following figures.

Mode 1:

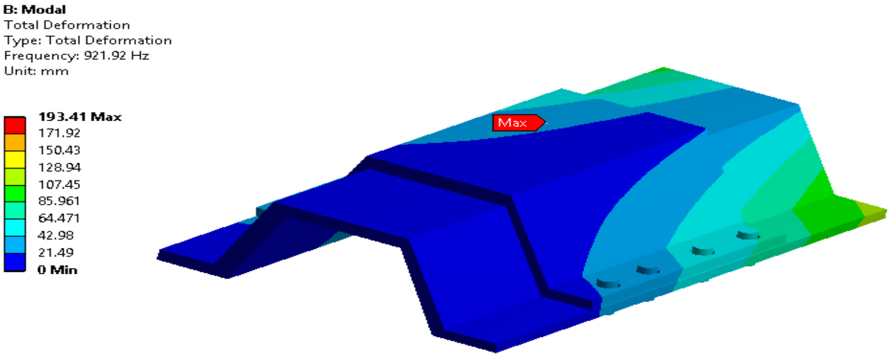

Figure 16: Mode 1 Frequency of Omega Stringer and Splice Joint

The value of frequency for the mode 1 is 921.92Hz. The deformation caused due to the vibration in the stringer is 193.41mm.

Mode 2:

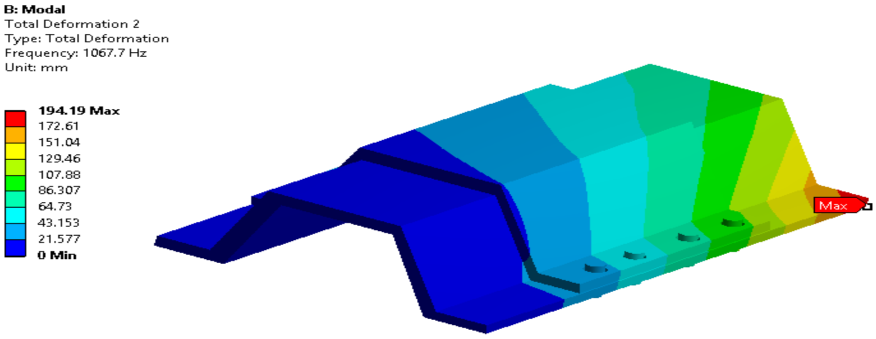

Figure 17: Mode 2 Frequency of Omega Stringer and Splice Joint

The value of frequency for the mode 2 is 1067.7 Hz. The deformation caused due to the vibration in the stringer is 194.19mm.

Mode 3:

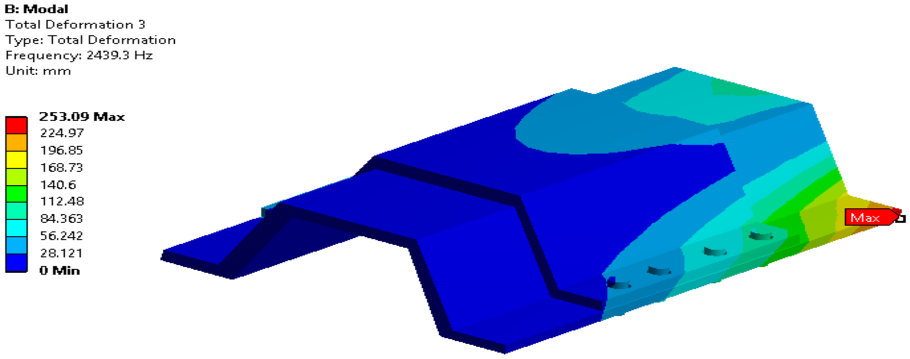

Figure 18: Mode 3 Frequency of Omega Stringer and Splice Joint

The value of frequency for the mode 3 is 2439.3Hz. The deformation caused due to the vibration in the stringer is 253.09mm.

Mode 4:

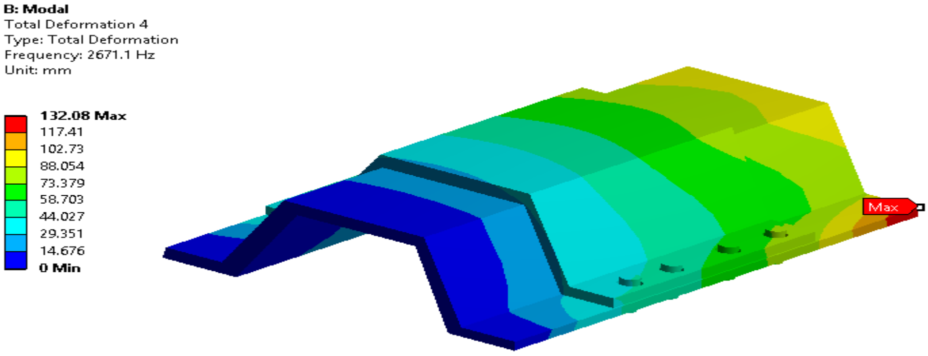

Figure 19: Mode 4 Frequency of Omega Stringer and Splice Joint

The value of frequency for the mode 4 is 2671.1Hz. The deformation caused due to the vibration in the stringer is 132.08mm.

7. LIFE ESTIMATION OF SPLICE JOINT

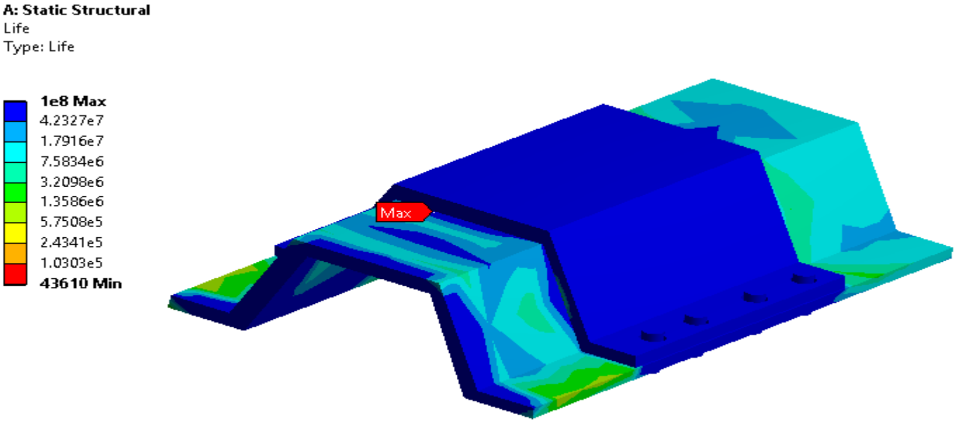

Figure-20: Life of Omega Stringer and Splice Joint

The life estimation of splice joint is determined by fatigue analysis. The failure of the splice occurs when it is constrained to cyclic loading in which the stress continuously changes in oscillating kind of motion which is less than yield stress of a static loading. The minimum life of the component is 43610 cycles and the component will sustain up to 1x10^8 cycles

8. COMPARATIVE ANALYSIS AND GRAPHICAL REPRESENTATION:

8.1 Comparison of Z stringer (Model-1) with Omega Stringer for Aluminium Alloy (Model-2):

Table 3: Comparison of Z stringer with Omega Stringer for Aluminium Alloy

Sl No.	Results	Z-Stringer (model 1)	Omega Stringer (model 2)
1.	**Equivalent Stress (Mpa)**	252.33	200.95
2.	**Maximum Principal Stress (Mpa)**	242.17	218.14
3.	**Minimum Principal Stress (Mpa)**	131.13	57.988
4.	**Total Deformation (mm)**	0.10082	0.096281

The table shows the comparative analysis between Z stringer (model 1) and Omega Stringer for Aluminium Alloy (Model 2). From the table it is evident that equivalent stress of Omega Stringer for Aluminium Alloy (model 2) is less than Z Stringer (model 1).
The maximum principal stress of Omega Stringer for Aluminium Alloy (model 2) is less than Z Stringer (model 1).

The total deformation of Omega Stringer for Aluminium Alloy (model 2) is less than Z Stringer (model 1).

Hence it can be concluded that Omega Stringer for Aluminium Alloy (model 2) is a better design than Z Stringer (model 1).

8.2 Graphical Representation

The graphical representation is done in order to understand and compare the structural behaviour as well as material behaviour with respect to the loading. We can easily able to differentiate how good is the post-modified structure when compared to pre-modified structure. In order to get this properly we have divided into 2 categories and they are,

Stress comparison of Z stringer and Ω stringer with aluminium alloy.

Total deformation of Z stringer and Ω stringer with aluminium alloy.

Graphical Representation on Stress Comparison between Z stringer and Ω stringer with aluminium alloy.

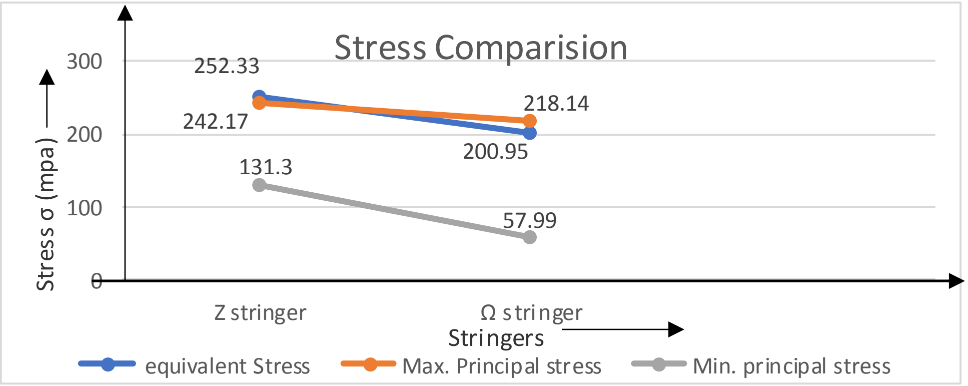

Chart-1: Stress v/s Stringers with materials

The graph clearly shows the equivalent stress which is represented in blue line, initially has 252.3mpa showing in Z stringer with Aluminium Alloy and the post modified structure that is Omega stringer with Aluminium Alloy is showing 200.95mpa. Hence the change in structure and the has decreased the stress on stringer.

The graph clearly shows the Maximum principal stress which is represented in red line, initially has 242.17mpa showing in Z stringer with Aluminium Alloy and the post modified structure that is Omega stringer with Aluminium Alloy is showing 218.14mpa. Hence the change in structure has decreased the stress on stringer and splice joint.

The graph clearly shows the Minimum principal stress which is represented in green line, initially has 131.3mpa showing in Z stringer with Aluminium Alloy and the post modified structure that is Omega stringer with Aluminium Alloy is showing 57.99mpa. Hence the change in structure has decreased the stress on stringer and splice joint.

Graphical Representation on Total Deformation between Z stringer and Ω stringer with aluminium alloy.

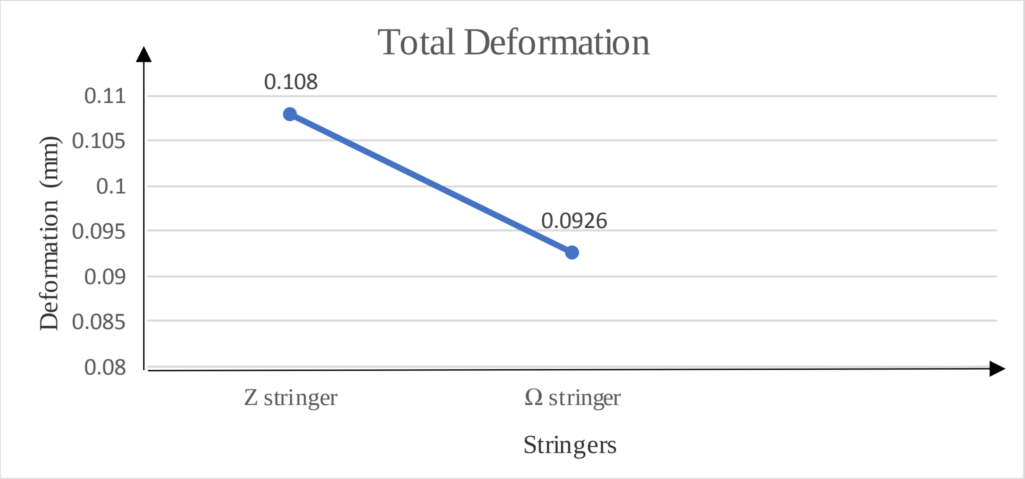

Chart-2: Total deformation v/s Stringers with splice joints

The graph clearly shows the Total deformation which is represented in blur line, initially has 0.108mm showing in Z stringer with Aluminium Alloy and the post modified structure that is Omega stringer with Aluminium Alloy is showing 0.0926mm. Hence the change in structure has decreased the stress on stringer and splice joint.

9. CONCLUSION OF THE STUDY:

The design of the stringer and the splice joint along with the material used for its manufacturing holds a major role in the aircraft structure. Since stingers and splice joints provide the basic structural stability of the aircraft structure and in this scenario the fuselage of the aircraft, they have to be robust and should posses' mechanical advantages. Earlier the design of the stringer was a Z shaped structure whose analysis results have been discussed in detail. A new design of the stringer in the shape similar to omega is analysed. Based on the analysis and comparison of Z-stringer and Omega stringer, the post-modified structure is considered.

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