Fail-Safe Design Analysis of an Aircraft Fuselage with Crack Stopper Strap

K Veeranjaneyulu, M Satyanarayana Gupta, Omprakash, G Sravanthi, Sai Prakash

Abstract: This paper reveals one of the design philosophies, fail-safe is used to arrest the crack propagation of airframe. The two important cracks considered for the design of pressurized fuselage are circumferential and longitudinal. The fuselage cabin pressurization and depressurization cycle create a fatigue load on the airplane structure and produce cracks where the tensile stress is maximum on the structural components. If the crack propagation is not controlled, they propagate during the flight and eventually land on the complete loss of the airplane structure. The design feature introduced into the airframe bulkheads to stop the crack propagation during the flight is crack tear straps. The approach utilizes a finite element modeling and analysis to assess the damage in the bulkheads and stringers with crack stopper straps and without crack stoppers. The design and analysis tools used in the in this work are Catia V5 and ANSYS. The analysis is carried out under fixed support conditions of the fuselage structure at the maximum design load conditions. The fatigue life of the stiffened panel with tear strap is more than the panel without tear strap. The deformation under cyclic loads for the panel with strap is less than the fuselage stiffened panel without crack strap

Keywords— Fail safe, stiffened panel, tear strap, Crack

I. INTRODUCTION

The Aircraft structure consists of basic components of wings, fuselage, tail units, landing gear and control surfaces. Some of the components are designed for fail –safe design criteria and few components are designed for safe-life. The cracks on the aircraft structures are developed due to cyclic loads or fatigue loads. These cracks are propagated during the flight. The cracks developed in the aircraft structure must be stopped to ensure a safe flight. There are different methods to stop the propagation of the crack strap is the one of the promising approaches to stop the propagation of the crack in the flight. The optimum proportion of the structural weight and payload to be carried by the vehicle is considered for the design of the airplane. The structure should be strong and stiff enough to withstand all the forces during its operation. The Reliability of the components is also important for the sustainable flight. The failure of the one component do not advance to the complete loss of the aircraft.

The aircraft accident investigations during the past two decades depict the importance of fatigue crack in the fuselage design. The incorporation of tear strap in the fuselage design significantly revamps the fatigue life of the airframe by minimizing the crack propagation and aircraft sustains damage produced due to initial fatigue crack. Fig1.1b illustrates a reinforced splice on the fuselage skin near the bulk head and longeron. It is known as crack strap, or fail-safe strap. The Tear straps are the metal strips fixed circumferentially to the skin of the fuselage. The circumferential stress on the fuselage joint can be reduced by the strap and the stress that causes the bulging of the joint is more than hoop stress for the axial crack of the monocoque cylinder. A well-designed tear strap is able to induce flapping and houses the damage between two tear straps. The crack straps are made up of aluminum alloys and are inserted in between the bulkhead and skin and they run below the bulkhead as shown in the fig1.1. Experimental results are used to estimate the geometry and the specifications of the tear strap. The initial crack in the bulkheads of the stiffened panel with and without the existence of tear strap is studied. The maximum cabin altitude is taken for the analysis of the fuselage with and without crack stopper.

The design software, CATIA V5 is used for modeling and design of fuselage structure and ANSYS tool is used for stress analysis. Finally we are going to find out the crack in the structure and in order to stop crack we will be using crack stopper strap.

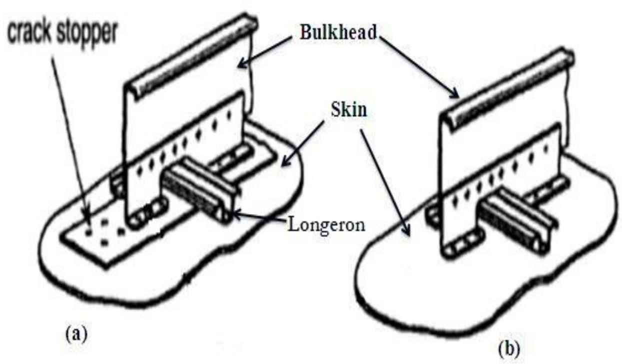

Fig.1.1 (a) Fuselage Frame with crack stopper (b)Fuselage Frame without crack stopper

Manuscript published on November 30, 2019.
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II. LITERATURE REVIEW

The airplane Fuselage structure is an assembly of skin panels, frames, bulkheads, longerons and stringers.

The cabin pressure develops a radial growth in the skin and the radial growth is resisted by the frames and stringers in the longitudinal and circumferential splice joints. The curved panels are subjected to biaxial tension due to cabin pressure. The airplane fuselage may suffer from the damage due to longitudinal cracks and circumferential cracks under hoop stress and vertical bending of the fuselage. Pir M. Toor [5] focuses his attention on the fail-safe design of aircraft fuselage structure. Aircraft fuselage is subjected to tension, compression, torsion and buckling. The effect of initial stress on the buckling analysis of the stiffened panel is studied by [16]. The fuselage structural members are fabricated by different materials.Dr.Vivek [15] gives an insight into some of the materials used in the fuselage construction.Logitudinal and circumferential spice joints[17] are import in the crack development and progress The propagation of longitudinal and circumferential cracks and their arrest feature is one of the main aspect of the damage tolerance design of the pressurized fuselage cabin. The fatigue cracks are initiated at a point where the tensile stress is maximum under fuselage pressurization. The longitudinal and circumferential cracks are initiated at different locations on the fuselage and grow during pressurization and de-pressurization of the fuselage. The propagation of these cracks can be arrested by the crack stopper or tear stop. The cracks in the brittle material spread very rapidly with little or no plastic deformation. these cracks in the brittle material will continue to grow and increase in magnitude once they are initiated.one more important mechanism of crack propagation is the way in which the it advances or travels through the material. A crack that passes through the grains within the material is known as trans granular fracture. The effect of stress intensity factor is computed in [11].

$$K_I = \lim_{\gamma \to 0} \sqrt{2\pi\gamma}\ \ \sigma_{yy}(\gamma, 0)$$

$$K_{II} = \lim_{\gamma \to 0} \sqrt{2\pi\gamma}\ \ \sigma_{yx}(\gamma, 0)$$

$$K_{III} = \lim_{\gamma \to 0} \sqrt{2\pi\gamma}\ \ \sigma_{yz}(\gamma, 0)$$

2.1 Circumferential crack

A circumferential splice joint with the circumferential crack is shown in the fig2.1The crack is formed in between two stringers and near the frame of the fuselage.

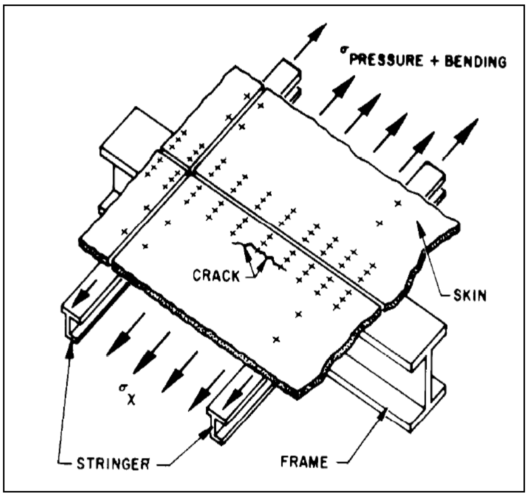


Fig.2.1 Circumferential splice joint with circumferential crack

2.2 Longitudinal Crack

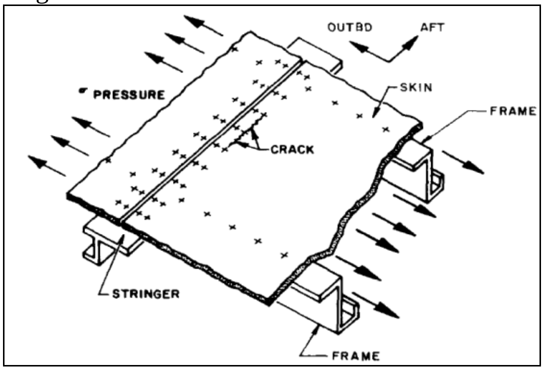


Fig.2.2 Longitudinal splice at stringer with longitudinal crack

A longitudinal crack is developed near and parallel to the stringer and In between the two frames of the fuselage. Fig2.2 depicts the longitudinal crack on the fuselage.

3.0 Modeling of a fuselage stiffened panel

III. MODELLING OF STIFFENED PANEL

3.1 Stiffened panel

The fuselage is a cylindrical shell which is stiffened by the stiffeners as shown in Fig3.1.A react angular stiffened panel with the relevant loads and boundary conditions are taken for the analysis.

The material selected for the stiffened panel is 2024-T3 Aluminum alloy.

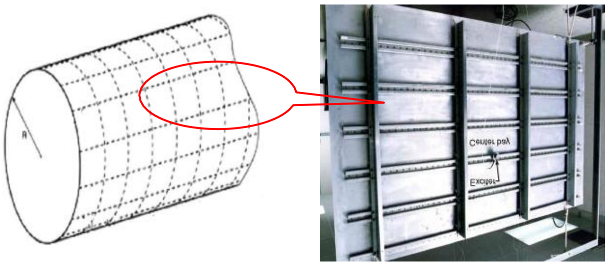


Fig.3.1 Fuselage Stiffened panel

Retrieval Number: D9149118419/2019©BEIESP
DOI:10.35940/ijrte.D9149.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

3.2 The stiffened panel configuration

The modeling of the stiffened panel with tear strap is executed by using CATIA V5 software. The Geometric specifications and CAD model of each and individual structural member of the stiffened panel are illustrated.

a) Skin

The fig 3.2 shows the geometry and dimensions of the skin of stiffened panel. The skin thickness is 1.5 mm. The fuselage skin houses Bulkheads, Longerons, crack strap and stringers

Table -I-Skin size

Inner dia	98.8mm
Outer dia	78.8mm

Longeron :

The Longerons are the longitudinal structural members of the fuselage structure. There are three longerons in the panel, which are 200 mm apart from each other.

The fig 5.10 shows geometric dimensions and fig 5.11 shows the CAD model. The length of the longeron is 1200

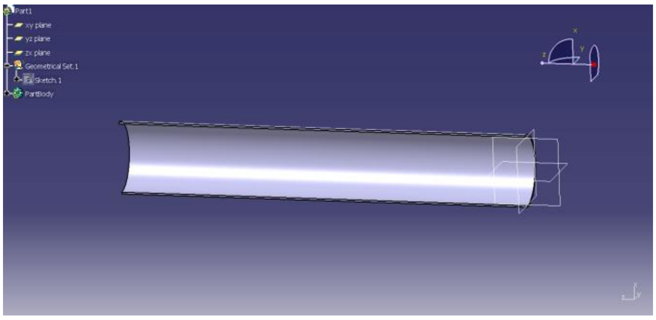


Fig.3.2. Fuselage skin

Bulkhead

The Bulkhead is one of the lateral structural members of the fuselage. It imparts aerodynamic shape to the fuselage and acts as a stiffener in the circumferential direction. There are five bulkheads in this stiffened panel. All the dimensions of the bulkheads are shown in fig 3.3 and CAD model is shown in fig 3.4.

Table-II-Bulk head specifications:

Bulk head type	**Z-secion**
Web	**18mm**
Flange	**15mm**
Thickness	**2mm**

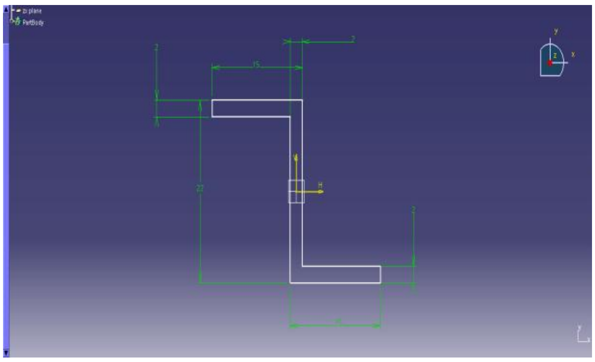


Fig.3.3 The bulkhead cross-section

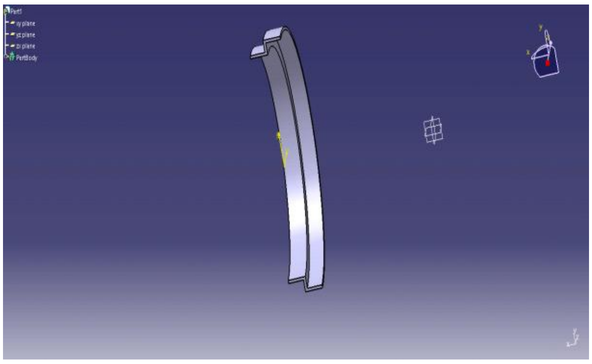


Fig.3.4 The bulkhead

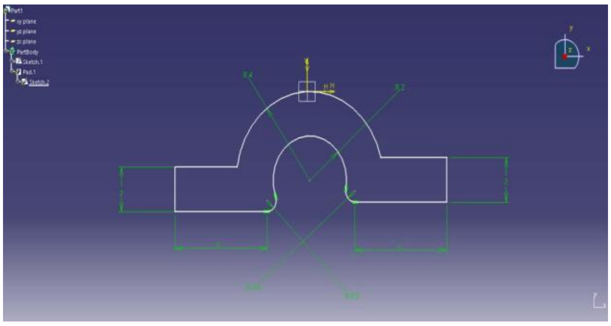


Fig 3.5 front view of the Longeron

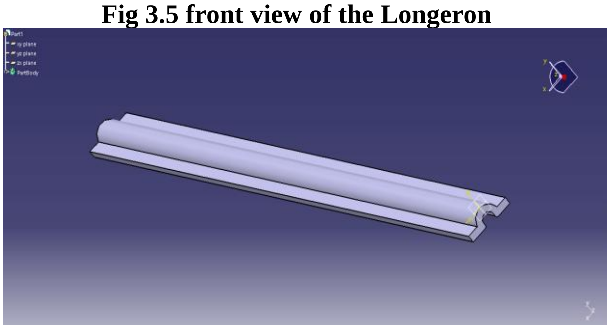


Fig.3.6 The longeron

The Crack stopper strap

The Crack stopper straps are also known as tear straps. These tear straps run in circumferential direction below the bulkhead which are fastened with skin. Fig 3.8 shows the geometric dimensions of the tear strap is 2 mm thickness. Length of the strap is 20mm

Table-III-Strap dimensions

Inner dia	**100mm**
Outer dia	**98.8mm**

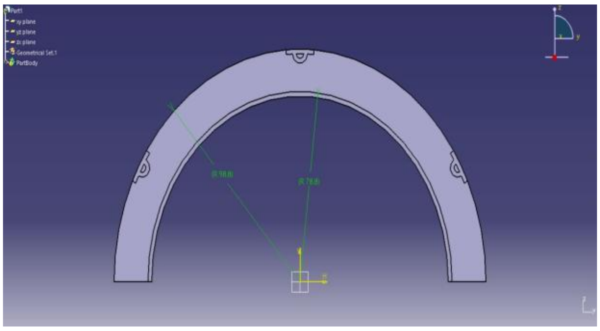


Fig 3.7 Tear strap (crack stopper strap)

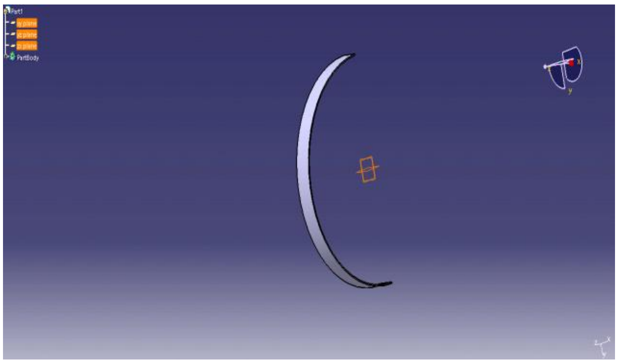


Fig 3.8 side view Tear strap

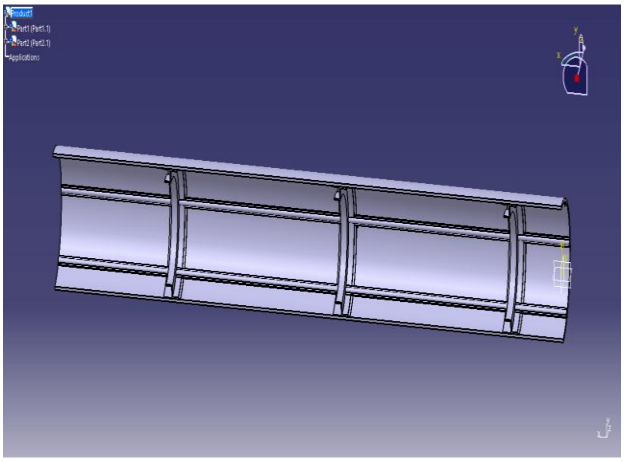


Fig.3.9 Circular panel with strap

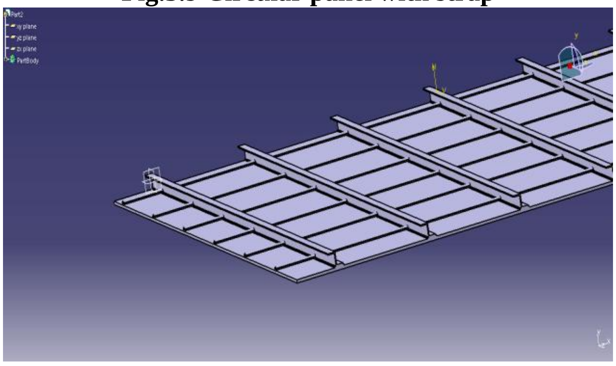


Fig 3.10 Rectangular stiffened panel without strap

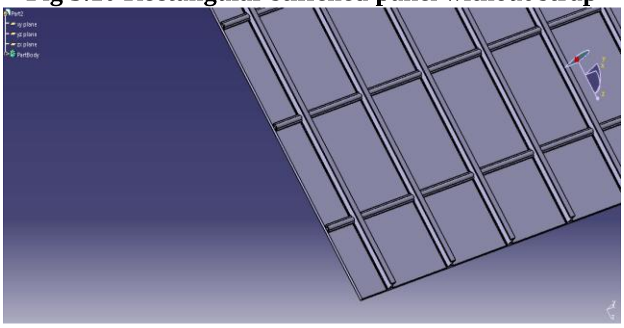


Fig.3.11 Rectangular stiffened panel with strap

IV. ANALYSIS OF THE FUSELAGE STIFFENED PANEL

The structural analysis of the fuselage stiffened panel with and without tear strap using Finite Element method has been performed in this work. In Finite element meshing, different areas are meshed with different size elements. The size of the element is reduced and the mesh is refined in the critical sections of the stiffened panel.

Fig4.1 shows the meshed model of the circular stiffened panel. In the analysis, all the edges are fixed and all the degrees of freedom are constrained. The maximum cabin altitude pressure is applied in the analysis of the problem. The material selected for the is 2024-T351 Aluminum alloy. The material composition of the alloy is tabulated in the table 4.1 and the mechanical properties are listed under

- Modulus of Elasticity, E = 70GPa
- Yield Strength, σ_y = 350 N/mm^2
- Ultimate Tensile Strength, σ_u = 420 N/mm^2
- Poisson's Ratio, μ = 0.3

Table-IV-composition of 2024-T351 Aluminium Alloy

Element	Percentage by weight	Element	Percentage by weight
Al	90.7-94.7	Mn	0.3-0.9
Cr	0.1	Si	0.5
Cu	3.8-4.9	Ti	0.15
Fe	0.5	Zn	0.25

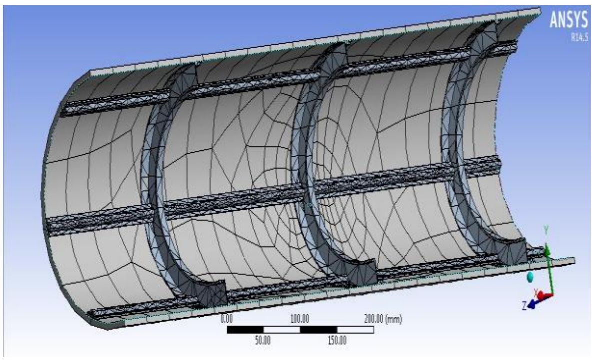


Fig 4.1 Meshed model of a circular panel

CASE 1: WITHOUT STRAP
Total deformation of the stiffened panel
a)Maximum=0.027067
b)Minimum=0

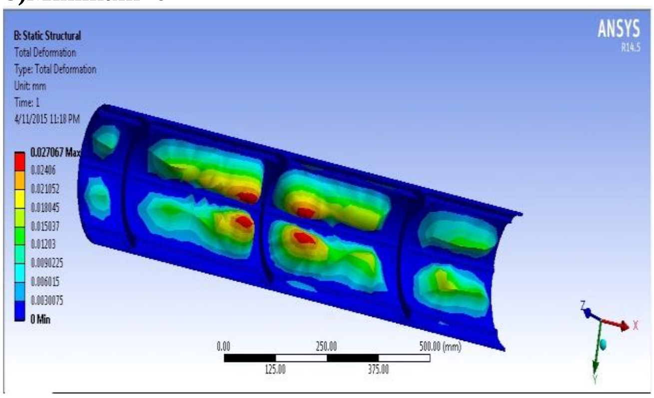


Fig.4.2 Total deformation contour of the stiffened panel

Case 2: WITH STRAP
Total deformation:
a)Maximum=0.0027255
b)Minimum=0

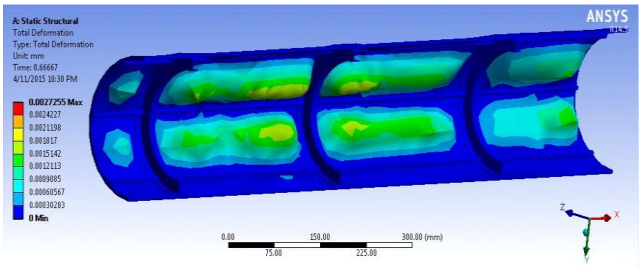


Fig.4.3 Total Deformation Of Stiffened Panel

4.1 RECTANGULAR STIFFENED PANEL

CASE1: WITHOUT STRAP

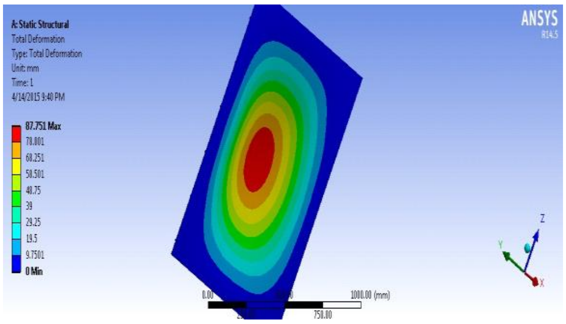


Fig.4.4Total Deformation without strap

2. Stress intensity factors

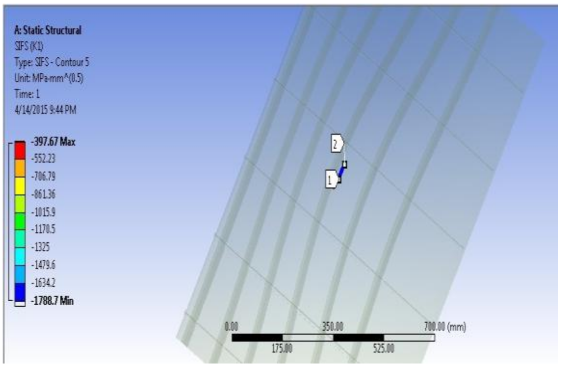


Fig.4.5 a. Stress intensity factor1

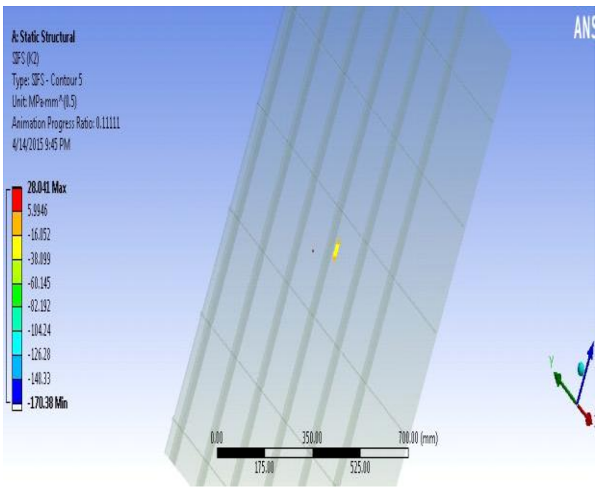


Fig.4.5 b. Stress intensity facto2

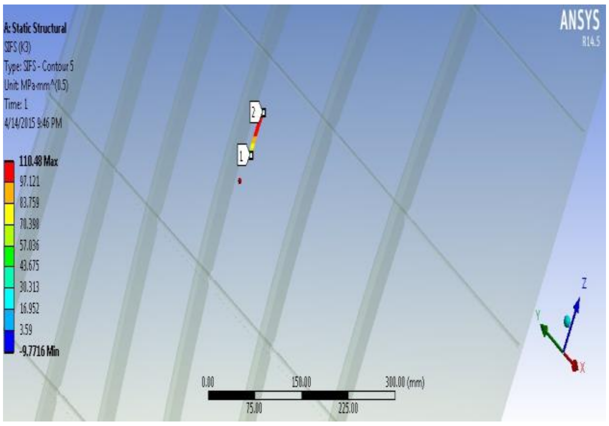


Fig.4.5 c. Stress intensity factor3

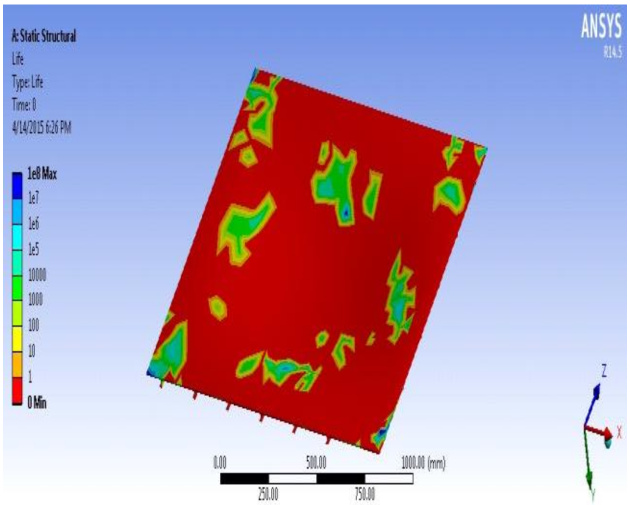


Fig .4.6 Fatigue Life without strap

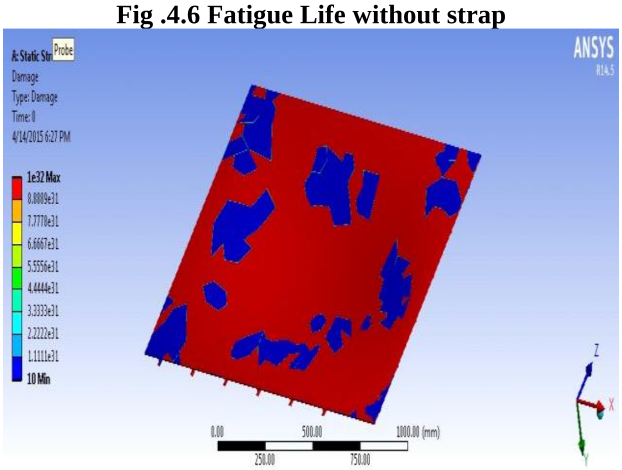
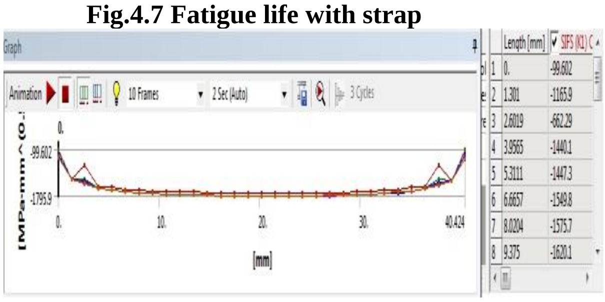
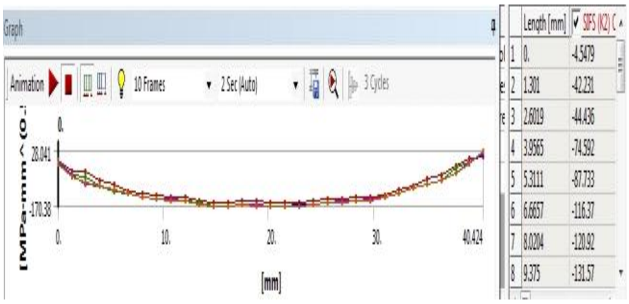


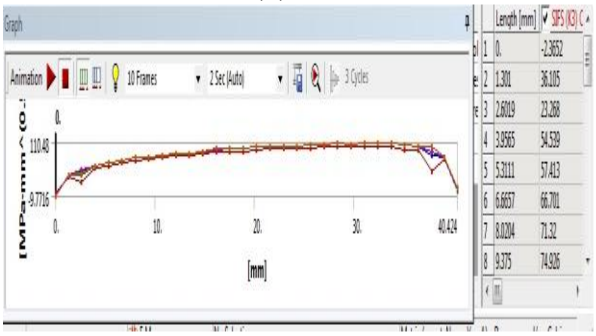
Fig.4.7 Fatigue life with strap



(a)



(b)



(c)

Fig.4.8 (a),(b),(c) Stress intensity factors

CASE1:

Longitudinal panel with strap

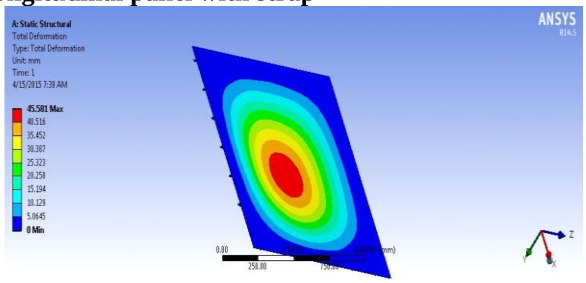
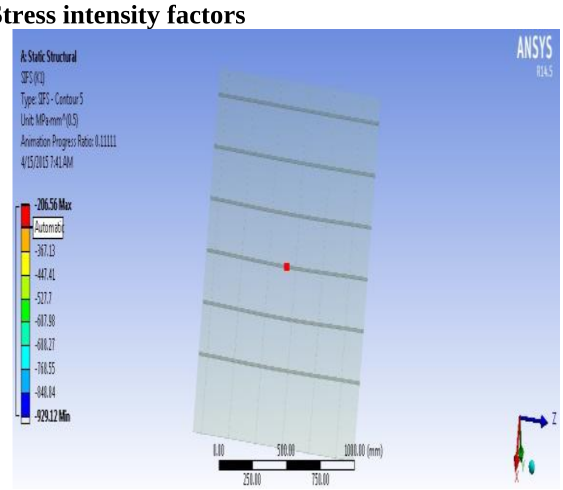
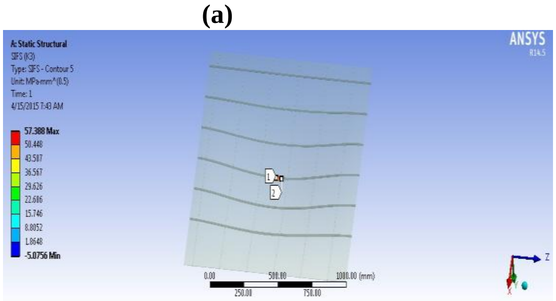


Fig.4.9 Deformation of longitudinal panel with strap

2. Stress intensity factors



(a)



(b)

Fig.4.10 (a),(b) Stress intensity factor

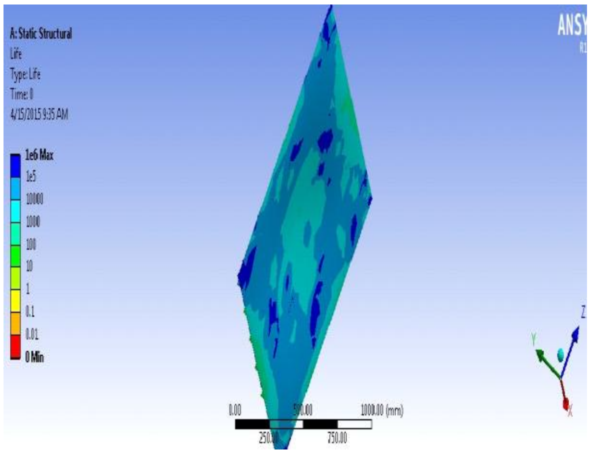


Fig.4.11 Fatigue Life cycle

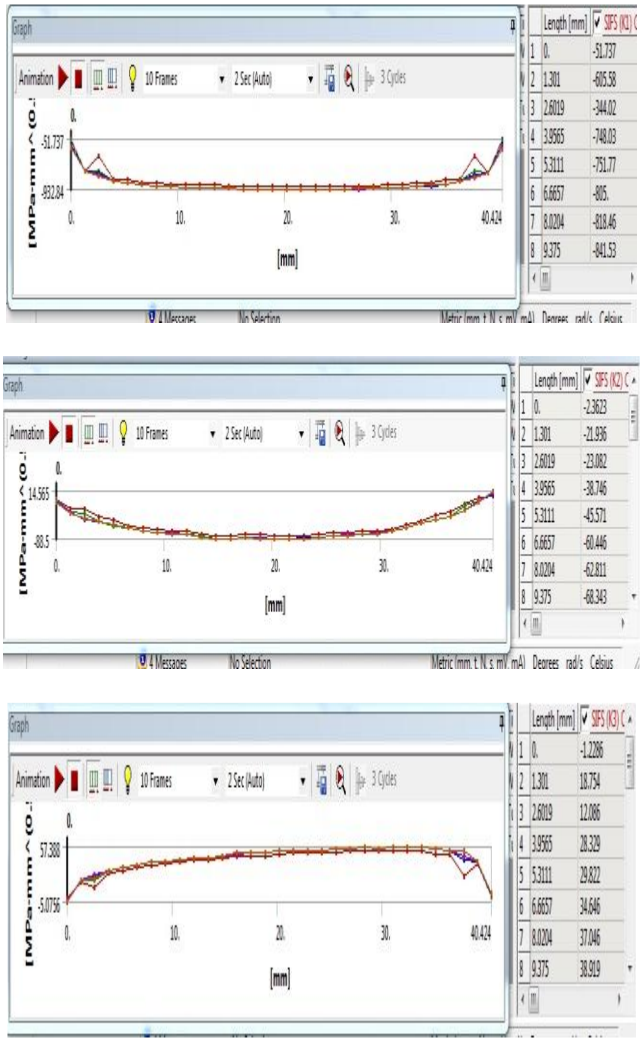


Fig.4.12 Stress intensity factors

V. RESULTS AND DISCUSSION

A finite element analysis of the rectangular panel with and without tear strap under maximum cabin altitude has been carried out in this work. The results obtained in the analysis are tabulated in the table-V. The panels are compared based on the stress intensity factor, total deformation and fatigue life cycle. The stress intensity factor for the panel with strap are less than the without strap.

The total deformation for panel with tear strap is around half of the panel without tear strap. The fatigue life cycles for the rectangular panel without tear strap are less than the panel with the strap.

Table-V- Rectangular panel with strap and without strap

	Without strap		With strap	
Parameters	Min	Max	Min	Max
Stress intensity(k1)	-1788.7	-397.67	-929.12	-206.56
Stress intensity(k2)	-170.38	28.041	-88.5	14.565
Stress intensity(k3)	-9.7716	110.48	-5.0756	57.388
Total deformation	0	87.751	0	45.581
Fatigue Life	0	1.00E+06	0	1.00E+08

VI. CONCLUSION

The fatigue life and damage tolerance of a rectangular fuselage panel with strap and without strap are analyzed using finite element analysis. The conclusions derived from the analysis are

The fatigue life of the fuselage structure with tear strap is more than the stiffened panel without fuselage.

The deformation under the maximum cabin altitude for the panel with tear strap is less than the panel without tear strap.

The stress intensity factor for the fuselage panel without tear strap is more than the panel with tear strap.

The accuracy of the results can be improved by a refined mesh and element aspect ratio

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