Fatigue Crack Growth Arrest Capability of Stiffened Structures

[1]Jagadeesh Reddy M, [2]K.N Balan, [3]Rajesh Talluri
[1]Post Graduate Student, [2]Assistant Professor, [3]Design Engineer
[1&2]Dept. of Mechanical & Production Engg, Sathyabama University, Chennai-600119
[3] E-Mug Technologies Private Limited, Hyderabad-500038
[1]jagga.cad106@gmail.com , [2]knb5463@yahoo.in, [3]raj_3553@yahoo.com

***Abstract*-The aircraft fuselage shell is composed of stressed skin, longitudinal stringers, and circumferential frames. The skin is connected to the stringers and frames mostly by rivets. Due to presence of large number of rivet holes, the fuselage skin has a large number of high stress locations and these are locations of potential crack initiation. When the fuselage is pressurized and depressurized during each take-off and landing cycle of aircraft, the metal skin of fuselage expands and contracts resulting in fatigue crack initiation. In the present work, aircraft fuselage was selected as stiffened structure, Airbus A340 and Airbus A380 was selected for the process and modeling was done accordingly. The response of structure for the hoop stress and longitudinal stress developed in the fuselage due to cabin pressurization is studied by using finite element analysis technique. In addition, the tear strap can be used as bending material to increase the frame stiffness and static strength. The midway tear strap is installed by riveting. The possibility of starting a crack at a midway tear strap would be reduced if the strap were bonded to the skin without additional rivets. The tear strap will reduce the deformation and stress in the fuselage skin and the results are compared.**

***Keywords*— Stiffened structure, cabin pressure, hoop and longitudinal stresses.**

I. INTRODUCTION

An aircraft is a very efficient man-made flying machine, but it has a complex structure. Aircrafts are generally built-up from the basic components of wings, fuselage, tail units and control surfaces. Fuselage is typically a curved stiffened panel construction in which different types of stresses are developed due to the cabin pressurization [1]. The aircraft must be capable of successfully completing a flight during which likely structural damage occur as a result of bird impact as specified in Federal Aviation Regulations 25.631 [3]. Any small failure of any of these components may lead to a catastrophic disaster causing huge destruction of lives and property. Thomas Swift [5] focused on Development of the Fail-safe Design Features of Aircraft Structures. When designing an aircraft, it’s all about ending the optimal proportion of the weight of the vehicle and payload. It needs to be strong and stiff enough to withstand the exceptional circumstances in which it has to operate.

H. Vlieger [6], proposed an analytical approach using finite element method with inclusion of a crack tip element to analyse stiffened panels. In most modern aircrafts, the skin plays an important role in carrying loads. M. Gosz and B. Moran [7] studied the effect of small cracks emanating from riveted hole of lap joint of fuselage structure. Sheet metals can usually only support tension. But if the sheet is folded, it suddenly does have the ability to carry compressive loads. A section of skin, combined with stiffeners, called stringers, is termed a thin- walled structure, the airframe of an aircraft is its mechanical structure, which is typically considered to exclude the propulsion system. One must also consider crack formation at the fastener holes [8], crack propagation, interaction between adjacent crack tips [9-12], and residual strength criteria to reach the final life prediction [9-12].Airframe design is a field of engineering that combines aerodynamics, materials technology, and manufacturing methods to achieve balances of performance, reliability and cost. The fuselage will experience a wide range of loads from a number of sources.

The internal forces due to longitudinal and hoop stress developed in the fuselage act on fuselage section in biaxial directions and subject the stiffened panel to tensile forces in perpendicular directions. The force due to hoop stress acts in a direction parallel to bulkhead and force due to longitudinal stress acts in the direction parallel to stringer. Finite element analysis is widely used [2] to understand the response of the structure to such types of loads and it is quite interesting to study different alternative geometrical shape of stringers cross-sections that can be used in advanced aircraft designing of structure. Conventional methods of representing the structure in FE Model lead to inappropriate stress distribution and incorrect identification of critical locations [2]. Appropriate FE modelling techniques was used to represent the details of the stiffened panel [4].

In this paper the response of geometrical shape of the fuselage cross-section over the material properties of the structure was studied. The structural deflection for cabin pressurization and stresses developed in the fuselage due to cabin pressurization was simulated. UNIGRAPHICS was used for modelling the structure and ANSYS 14.0 was used as a solver for this analysis.

II. METHODOLOGY

A. Material Selection

Mechanical properties of the skin, stiffening members and rivets are required for finite element models. Aluminum 2024-T3 and 2117-T4 is used for components fuselage, tear strap and rivet respectively. Table 1 describes material properties used for analysis.

Table 1: Material properties used for the Analysis

Property	**Aluminum 2024-T3**	**Aluminum 2117-T4**

Young’s Modulus	72 GPa	71.7 GPa
Poisson’s Ratio	0.33	0.33

B. Finite Element Modeling

Finite Element Modeling involves in pre-processing stage, processing stage and post processing stage. Pre-processing stage involves details of mesh, load & boundary conditions. An appropriate finite element analysis was used to represent necessary structural details to obtain correct structural behaviour of stiffened structure. The results of different modelling approaches with tear strap were compared.

B. *Loads acting on Stiffened structure*

The stresses that are developed in the fuselage due to cabin pressurization are of two types:

a) Hoop stress (Circumferential stress)
In circumferential direction the hoop stress (1) was developed, which is equivalent to tensile stress due to equivalent tensile force in that direction.

Hoop stress = $\frac{P*r}{t}$ ……. (1)
P = Cabin differential pressure = 8 psi = 0.055 kg/mm^2
r = Radius of the fuselage = 2640 mm
t = Thickness of the skin = 4 mm
Hoop stress= 36.3 kg/mm^2

b) Longitudinal stress
In the fuselage axial direction, longitudinal stresses (2) were developed, which is equivalent to stress due to equivalent tensile force in the axial direction.

Longitudinal stress = $\frac{P*r}{2t}$ …… (2)
Longitudinal stress= 18.15 kg/mm^2

III. METHODOLOGY

The hoop and longitudinal stresses values was calculated. The details of fuselage structure necessary for finite element modeling were obtained from the structure. Care was taken while meshing the fuselage structure, stringer and bulkhead to obtain nodes at the riveted joint holes and windows. Appropriate finite element modelling techniques for representing necessary structural details of the fuselage structure was identified. Both fuselage structures are considered about 5000mm length for analysis. The loads and boundary conditions were applied to the finite element model. The uniform pressure of 8psi was applied as internal pressure to fuselage structure. The fuselage deformation and maximum stress was studied for both the structures Airbus A340 and Airbus A380.

Tear straps are introduced in order to reduce the deformation and stress of the fuselage structure. A tear strap is a 1.5mm thick strip, which is installed in between skin and longerons. The analysis was done by assuming same boundary and load conditions, the results are compared.

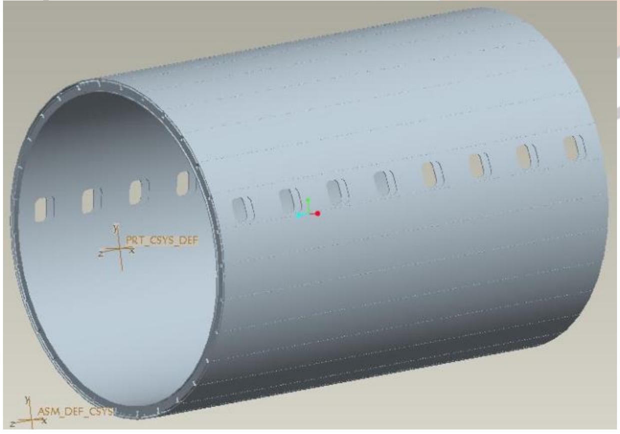

Fig 1: Airbus A340 fuselage

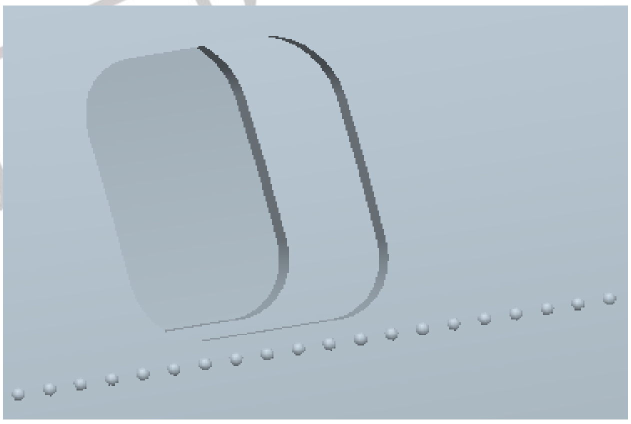

Fig 2: Rivets as fasteners

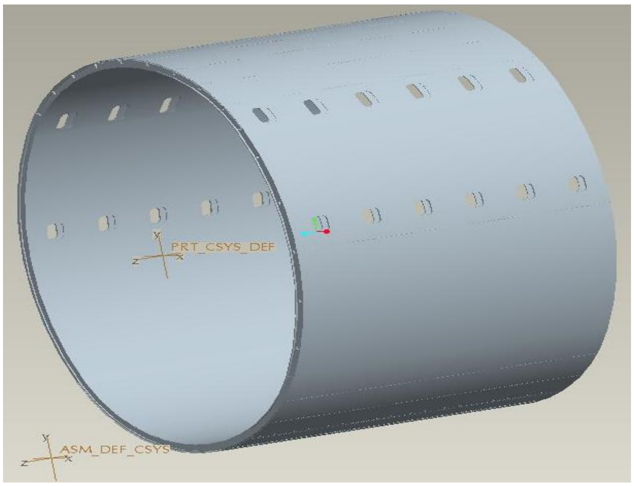

Fig 3: Airbus A380 fuselage

IV. RESULTS AND DISCUSSION

The finite element analyses of fuselage structures are analyzed under 8 psi uniform pressure. Assuming that the structure is in flight mode, analysis results are studied. When the cabin pressure acts inside the fuselage, the deformation that takes place and the maximum stresses developed in the structures are figured below respectively.

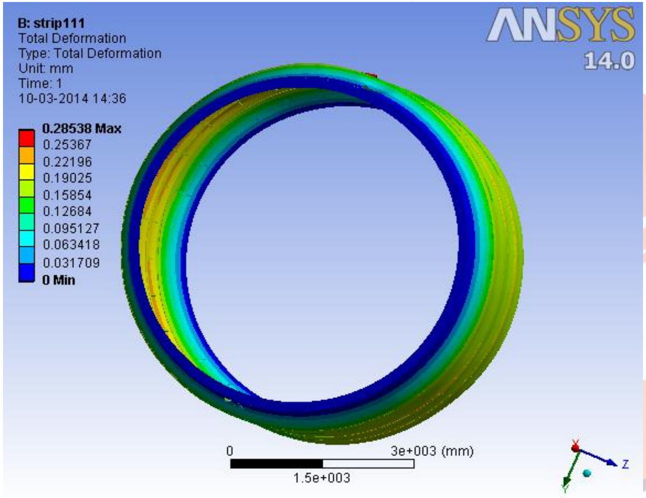

Fig 4: Deformation of fuselage

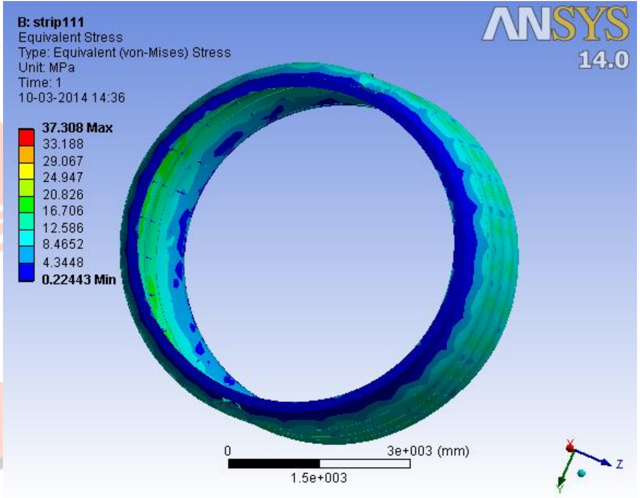

Fig 5: Equivalent stress of fuselage

The above figures 4 and 5 shows the deformation and stress of the fuselage, when internal pressure acted. The tear strap is introduced in order to arrest longitudinal skin cracks. Figures 6 and 7 shows the resultant deformation and stress of the fuselage after installing tear strap of 1.5mm thick and 60mm width.

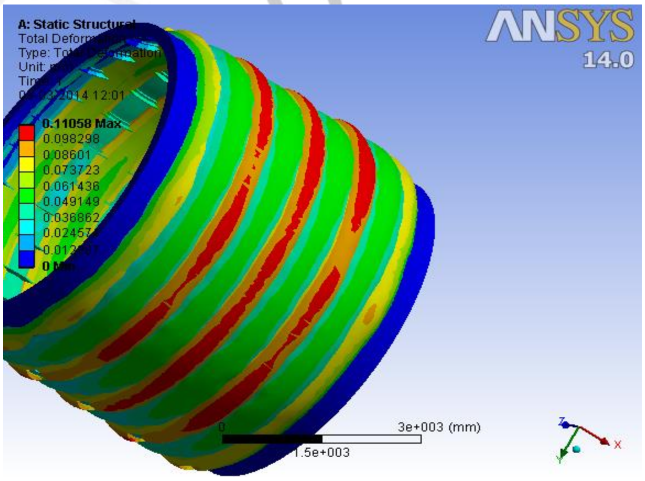

Fig 6: Deformation of Fuselage with tear strap

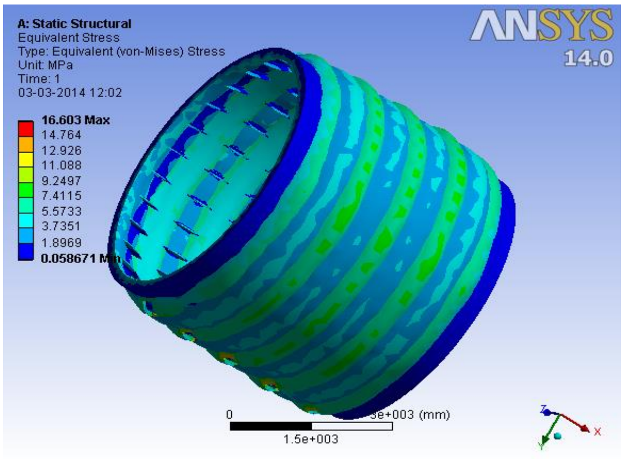

FIG 7: EQUIVALENT STRESS OF FUSELAGE WITH TEAR STRAP

TABLE 1: COMPARISON OF RESULTS

MODEL	DEFORMATION (MM)	DEFORMATION (WITH TEAR STRAP) (MM)	EQUIVALENT STRESS (MPA)	EQUIVALENT STRESS (WITH TEAR STRAP) (MPA)
AIRBUS A340	0.285	0.110	37.3	16.6
AIRBUS A380	0.310	0.192	36.8	18.2

By introducing tear strap, the fatigue cracks on the skin can be reduced, so that by increasing the life of the fuselage structure. In future work, by increasing the thickness of the tear strap and without change in width, analysis can be carried and further stress and deformation may be reduced.

REFERENCES

[1] Niu, Michael. C. Y. 1999. Airframe Stress Analysis and Sizing, 2nd Edition. Hong Kong Conmilit Press Ltd, Hong Kong, chapter 3.

[2] Rao, Singiresu. S. 2004. The Finite Element Method in Engineering, 4th Edition. Elsevier Science & Technology Books.

[3] P. M. S. T. de Castro, S. M. O. Tavares, V. Richter Trummer, P. F. P. de Matos, P. M. G. P. Moreira, L. F. M. da Silva, Damage Tolerance of Aircraft Panels, volume 18, pp 35-46, 2010.

[4] Lynch, C.; Murphy, A., Price. M., Gibson, A. 2004. The computational post buckling analysis of fuselage stiffened panels loaded in compression. Journal of Thin-Walled Structures, Vol. 42, pp. 1445–1464.

[5] Thomas Swift, Development of the Fail-safe Design Features of the DC-10, Damage Tolerance in Aircraft Structures, ASTM Special Technical Publication 486, presented at the 73rd annual meeting American Society for Testing and Materials, Toronto, Ontario, Canada, pp 164-214, 21-26 June, 1970.

[6] Vlieger H., The Residual Strengths Characteristics of Stiffened Panels Containing Fatigue cracks, Engineering Fracture Mechanics, Vol. 5, pp. 447-477, 1973.

[7] Gosz, M., Moran, B., Stress-Intensity Factors for Elliptical cracks emanating from countersunk rivet holes, DOT/FAA/AR-95/111, 1998.

[8] Vleiger, H, "Results of Uniaxial and Biaxial Tests on Riveted Fuselage Lap Joint Specimens", Presented at the FAA/NASA International Symposium on Advanced Structural Integrity Methods for Airframe Durability and Damage Tolerance, May 4-6, 1994, Hampton, VA.

[9] Moukawsher, E. J, Grandt, A.F, Jr., and Neussl, MA ‘Fatigue Life of Panels with Multiple Site Damage’, Journal of Aircraft. Vol. 33, No. 5, September-October 1996, pp. 1003-1013.

[10] Wang H.L., Buhler, K., and Grandt, A.F., Jr. "Evaluation of Multiple Site Damage in Lap Joint Specimens," Proceedings of the 1995 USAF Structural Integrity Program Conference, ASIP Volume 1, August 1996, pp.21-38.

[11] Heinimann, M.B. and Grandt, A.F., Jr., "Analysis of Stiffened Panel with Multiple Site Damage", 1996 USAF Structural Integrity Program Conference, San Antonio, Texas, December 3-5,1996.

[12] Grandt, A.F, Jr., Sexton, D.G, Golden, P.J, Bray, G.H., Bucci, R.J., and Kulak, M., "A Comparison of 2024-T3 and 2524-T3 Aluminum Alloys under Multi-Site Damage Scenarios," ICAF 97 Fatigue in New and Aging Aircraft. Volume U, Poster Papers, Editors: R. Cook and P. Poole, Proceedings of the 19th ICAF Symposium, International Committee.