Damage Tolerance Analysis of Aircraft Fuselage Riveted Joint Panel

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***Abstract*— The design philosophy in the field of aircraft construction is getting transfer from fail safe design to damage tolerance design. Damage tolerance design improves the life of a component. A two seater aircraft structural member was found to have an expected life of ten thousand hours. The fatigue life of the aircraft if increased, could give an improvement to the life of the aircraft too. The aircraft had a history of structural failures at the rear part of the fuselage, at the wing spars etc. The rivets used are areas of greater stress concentrations and thereby chances of failures due to them are high. The riveting pattern is what determines the amount of stress concentrations there. Also the residual stresses add to this factor. In this project a piece similar to the fuselage skin, of same material and the riveting pattern is tested for deformation, fatigue and multi site damage. Then the riveting pattern is changed to other types of riveting and tested again. The data obtained are then compared. This could be used as an improvement to the skin structure of that aircraft. The testing is to be one both with FEA software and also experimentally done.**

Keywords — Construction; failures ; rivets ; skin ; software

I. INTRODUCTION

One of the main trouble of aeronautical structures is damage due to fatigue, an occurrence accentuate in areas of stress concentration, as for example the connections of fuselage panels, often prepared by riveting. The Aloha Airlines accident in 1988 warned aircraft manufacturers and aeronautical regulators for the progressing require improving design rules by a deeper considerate of phenomena such as multiple site damage. As an example of the effort is the understanding of these phenomena and to the enhancement of manufacturing processes and design rules of the aircraft fuselage riveted joints.

Fail-safe design concept assumes the possibility of multiple load paths and crack arrest features in the structure so that a single component failure does not lead to immediate loss of the entire structure. The load carried by the broken member is immediately picked up by adjacent structure and total fracture is avoided. It is essential; however, that the original failure be detected and promptly repaired, because the extra load they carry will shorten the fatigue lives of the remaining components.

We consider a two seater aircraft structural member was found to have an expected life of ten thousand hours. The fatigue life of the aircraft if increased, could give an enhancement to the life of the aircraft too. In this project a piece similar to the fuselage skin, of same material and the riveting pattern is tested for deformation, fatigue and multi site damage. Then the riveting pattern is changed to other types of riveting and tested again. The data obtained are then compared. This could be used as an improvement to the skin structure of that aircraft.

II. AEROSPACE RIVETED JOINTS

Rivets are permanent, non-threaded, one-piece fasteners that join parts together by fitting through a pre-drilled hole and deforming the head by mechanically upsetting from one end. Rivets are the most widely used mechanical fasteners especially in aircraft fuselage structures. Hundreds of thousands of rivets are utilized in the construction and assembly of a large aircraft. Solid rivet with universal head is one of the most widely used rivet type in aircraft fuselage manufacturing and repairing processes. A riveted joint, in larger quantities is sometimes cheaper than the other options but it requires higher skill levels and more access to both sides of the joint A rivet is a cylindrical body called a shank with a head. A rivet is inserted in to hole passing through two clamped plates to be attached and the heads supported whilst a head is formed on the other end of the shank using a hammer or a special shaped tool. The plates are thus permanently attached.

III. THE COLD WORKING PROCESS

Problems related with ageing aircraft may be reduced by enhancing the fatigue performance, especially in critical zones acting as stress raisers, such as access holes and riveted holes. Fastener hole fatigue strength may be enhanced by creating compressive residual circumferential stresses around the hole. Cold working has been used in the aeronautical industry for the past thirty years to delay the initiation of fatigue cracks and to retard their propagation.

The cold working process creates a compressive residual stress field that decreases the value of the stress intensity factor in cracks emanating from the edge of the hole when compared with the stress intensity factor of cracks in non-cold-worked holes. Furthermore, there is a minimum threshold value of the remote tensile stress that is needed to open cracks in cold worked rivet holes. The compressive circumferential residual stress field around the rivet holes is created by applying pressure on the hole surface by means of a mandrel. Once the pressure is removed, the desired residual compressive stress field is achieved. The main benefits associated with the improvement of the fatigue life are the reduction of unscheduled maintenance, increasing the time between inspection intervals, reduction of maintenance costs and improvement of aircraft readiness.

IV. ENGINEERING DESIGN

A. Aircraft panel design

We consider two seater aircraft riveted joint panel in station 95.09 and to modeling the panel from required software, Aircraft skin and rivet material are Aluminum alloy 2024 T3.

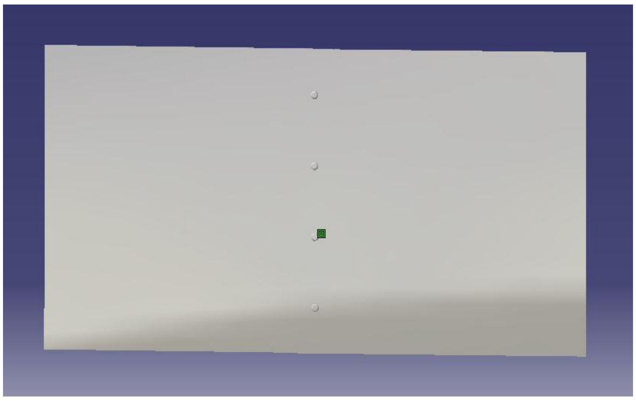

Fig 1 Aircraft design panel in modeling software

Specification of panel

Length of the specimen: 160mm

Breath of the specimen: 150mm

Thickness of the specimen: 01mm

B. Aerospace Rivets design

Rivets are used to connect together permanently two or more plates. In case of riveting, the holes are made in the plates which are to be connected and rivets are inserted in to the holes of the plates. Due to the holes in the plates, the strength of the original plate is reduced.

1) Lap joints

In case of lap joints, the edges of the plates to be jointed together overlap each other.

2) Chain riveted joints

A chain riveted joint, in which every rivet of a row is opposite to the other rivet of the other row.

3) Zig-zag riveted joint

A zig-zag riveted joint, in which the spacing of the rivets in staggered in such as way, that every rivet is in the middle of the two rivets of the opposite row.

C. Rivets design calculation

1) Diameter of the rivets

The diameter of the rivet is calculated by using the relations,

$$d=1.6\sqrt{t} \qquad (1)$$

where,

d=diameter of the rivets

t=thickness of the sheet

Rivet hole diameter = d+(0.05 to 0.12) in mm

From represented aircraft:

Rivet diameter =2.9mm

2) Pitch of the rivets(p)

From represented aircraft:

Pitch =35mm (No of the rivets = 4)

From design philosophy:

Let,

p=2d+8(Single riveted lap joint- tighten)

=13.8mm (No of rivets = 9) (2)

p=2.6d+15(Double riveted lap joints- tighten)

=22.25mm (No of the rivets = 12) (3)

3) Diameter of the rivet head

$$D=1.6d \qquad (4)$$

From represented aircraft:

D=4.74mm

4) Length of the rivet shank(l)

$$l=\sum t+1.5d \qquad (5)$$

5) Height of the rivet head(h)

$$h=0.7d \qquad (6)$$

From represented aircraft:

h=2.03mm

V. FAILURE ANALYSIS

Failure of aircraft riveted joints:

A. Failure Due to Tearing of the Plate between the Rivet hole and the Edge:-

A joint may fail due to tearing of the plate at an edge as shown in below figure. This can be avoided by keeping the margin, m=1.5d, where “d” is the diameter of the rivet

B. Failure Due to Tearing of the Plate between the Rivets of a Row:-

Tearing resistance required to tear off the plate per pitch length,

$$P_t = A_t.\sigma_t$$

$$= (p-d)\ t.\sigma_t \qquad (7)$$

Where,

p = pitch of the rivets;

d = diameter of the rivet hole;

t = thickness of the plate:

σt = permissible tensile stress for the plate material

C. Failure Due to Shearing of Rivet:-

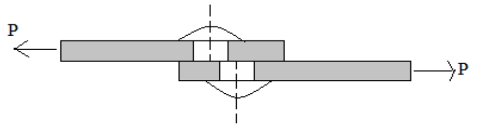

Fig 2 Rivet in single shear

Thus shear strength is,

Ps = n π /4 d2 *Tmax* - for single shear and

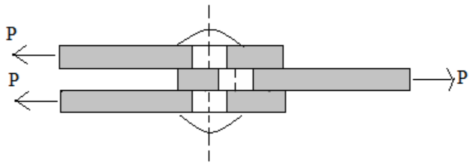

Fig 3 Rivet in double shear

Ps = 2 x n π /4 d2 *Tmax* - theoritically in double shear and

Ps = 1.875 x n π /4 d2 *T* - for double shear, according to Indian boiler regulations

(8)

Where,

Tmax = Shear strength of rivet;

n = number of rivets.

D. Failure Due to Crushing (or bearing) of Rivet or Plate

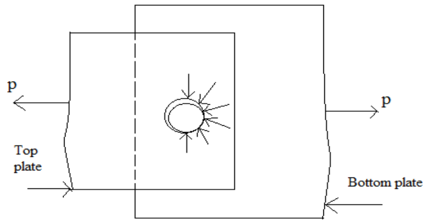

Fig 4 Crushing of the plate

The crushing strength is,Pc = n d t σc (9)

Where,

σc = Crushing strength of rivet;

n = no of rivets under crushing;

d = diameter of rivet = 6.1 √t ;

t = thickness of plate

E. Efficiency of riveted joint

$$\eta = \frac{\text{Strength of the joint in the weakest mode}}{\text{Strength of the un punched plate}} \quad (10)$$

VI. SIMULATION

The finite element method has become a powerful tool for the numerical solution of a wide range of engineering problems. Applications range from deformation and stress analysis of automotive, aircraft, building and bridge structure.

A) Mesh preparation

While complex three-dimensional regions can be effectively filled by tetrahedral elements, similar to triangular elements filling a two-dimensional region, it is easier to divide the regions in to eight-node brick.

Mesh type : Tetrahedral (3D)

Mesh type : Fine

Load value: 5KN

S.NO.	Joint type in fuselage panel	Environment temperature	Mesh size In m	Statistics	
				No of elements	No of nodes
1	Original aircraft riveted joint	22°C	$8x10^{-4}$	146969	299030
2	Single riveted joint			277986	537917
3	Double zig-zag riveted joint			290032	554153
4	Double chain riveted joint			287684	552448

Table 1 Details of mesh elements

B) Simulation for tensile load

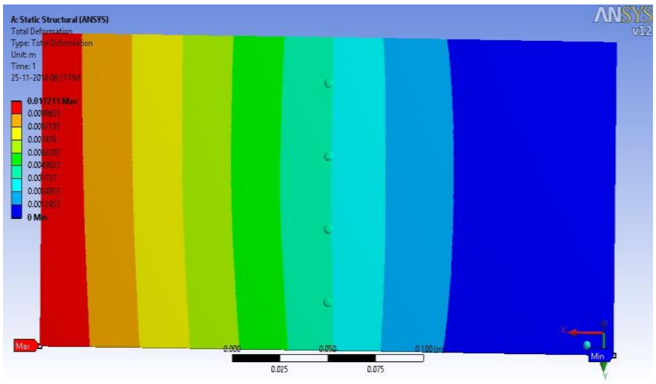

Fig 5 Structural Deformation for Represented aircraft skin riveted joint

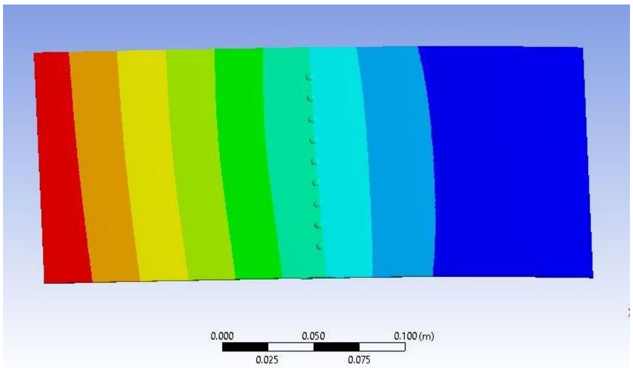

Fig 6 Structural Deformation for aircraft skin single riveted joint

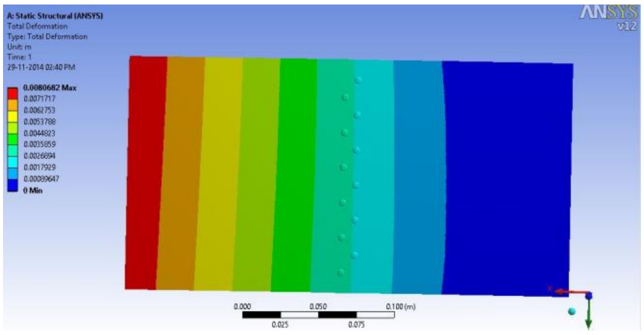

Fig 7 Structural Deformation for aircraft skin double zig-zag riveted joint

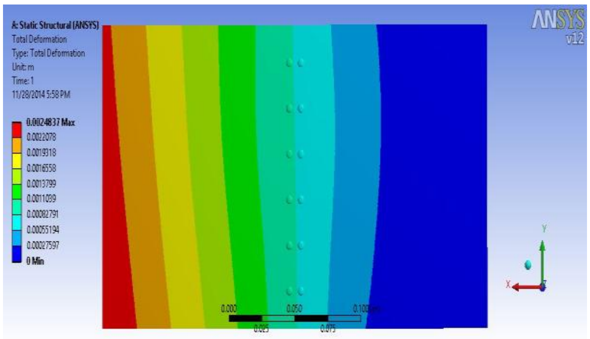

Fig 8 Structural Deformation for aircraft skin double chain riveted joint

C) Simulation result

S.NO.	Joint type in fuselage panel	Pitch in mm	Mass of the panel in lb	Deformation in mm	
				Max	*Min*
1	Original aircraft riveted joint	35	0.2941	11.211	1.2457
2	Single riveted joint	13.8	0.2954	10.552	1.097
3	Double zig-zag riveted joint	22.25	0.2962	8.0682	0.89647
4	Double chain riveted joint	22.25	0.2962	2.4837	2.7597

Table 2 Details of Simulation result

VII. EXPERIMENTAL WORK

A) Fabrication for aircraft panel

Aluminum alloy 2024 T3 Sheet (1mm thickness) and rivets (2.9 mm diameter) ,To drill the plate use Industrial Type Bench Drilling Machine Z4125 and chamfering and rivet fixing work is done.

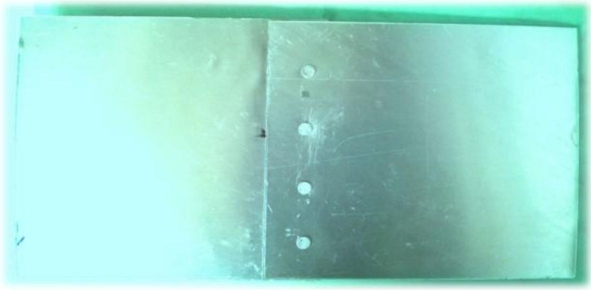

Fig 9 Represented aircraft skin riveted joint in Aluminum alloy 2024 T3

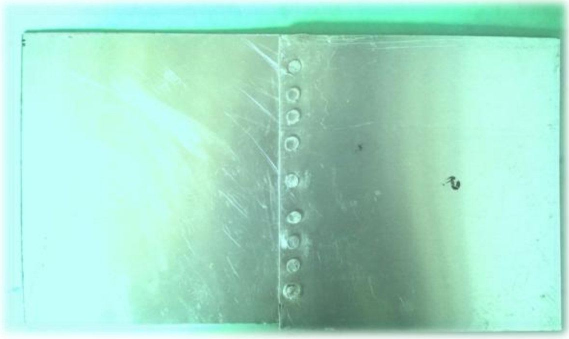

Fig 10 Aircraft skin single riveted joint in Aluminum alloy 2024 T3

Fig 11 Aircraft skin double zig-zag riveted joint in Aluminum alloy 2024 T3

Fig 12 Aircraft skin double chain riveted joint in Aluminum alloy 2024 T3

B) Experimental test

Experimental work is done from Si'Tarc is accredited by NABL (National Accreditation Board for testing and calibration Laboratories, Department of Science and Technology, India in accordance with standard ISO / IEC 17025:2005 for its facilities in the field of Electrical, Mechanical, Chemical and Calibration

Fig 13 UTME Machine

400 KN Universal Testing Machine and Electronic Extensometer:

Capacity	:	400kN
Range	:	0-40kN, 0-100kN 0-200kN,0-400kN
Accuracy	:	± 1.0 %
Testing type	:	Tensile testing

C) Experimental result

S.NO.	Joint type in fuselage panel	Pitch in mm	Mass of the panel in lb	Ambient temper 8C	Breaking Load (N)
1	Original aircraft riveted joint	35	0.2941	33.6	960.0
2	Single riveted joint	13.8	0.2954	33.6	2080.0
3	Double zig-zag riveted joint	22.25	0.2962	33.5	2480.0
4	Double chain riveted joint	22.25	0.2962	33.6	3760.0

Table 3 Details of Experimental result

VIII. CONCLUSIONS

The present work provides understanding the damage tolerance design philosophy of aircraft fuselage riveted joints panel. The work determined the details of basic design of aircraft skin with riveted joints. The result of simulation work provides total deformation of aircraft fuselage riveted panel. The data obtained are then compared. This could be used as an improvement to the skin structure of that aircraft. To evaluate breaking load value is to be experimental work is done. Then the riveting pattern is changed to other types of riveting and tested again. The data obtained are then compared. This could be used as an improvement to the skin structure of that aircraft. In future work is to commit the fatigue test is experimentally.

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