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Appraisal of an Aircraft Window Cutout Stiffener Frame Work

Mr. C Vivek Raj*, Asst. Professor, Department of Aerospace, Sandip University, Nashik Specialization in Aerospace Structures and Materials. Email Id: sriguruharikrupra@gmail.com.

Mr. Akshay Gharat, Asst. Professor, Department of Aerospace, Sandip University, Nashik.Email Id: akshay.gharat@yahoo.com.

Ms.Anushka Vaidya, UG Scholar, B. Tech Aerospace Engineering, Sandip University, Nashik. Email Id:*vaidyaanushka90@gmail.com*

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Abstract
Today's aircraft industries are struggling to overcome the challenge of increasing weight, high-efficiency performance and better structural stability and also a longer life at a reduced cost. Military and commercial aircraft are critical structures and their main assembly is based upon stiffeners and joints. Herein, the geometry consists of two types of stiffeners, 'L' and 'I' stiffener, made up of Al. The load acting on the geometry is the result of fuselage cabin pressurization. The virtual modeling of the geometry is done in CATIA V5 and the structural analysis is done in ANSYS. The analysis is done for the prediction of stress values (hoop stress), strain, and the deformation. It is observed that the window cutout fails due to the hoop stress acting on it.

Keywords: *Fractures toughness, Hoop Stress, Window Cutout*

I. INTRODUCTION

In the study of aircraft structures, cutouts play a cardinal role in practical consideration. The cutouts are means for the various electrical and mechanical systems to pass through and as well as for the hydraulic lines. A variation of loads acting on these cutouts can cause them to fail. Some of the main functions of an aircraft structure is the protection of passengers and forming an aerodynamic shape. This is only possible if each element of the aircraft, including the window cutout, is thoroughly designed and tested. And as the main role served by an aircraft structure is transmission and resistance of the load, the airframe structure has to be a perfect structural model.

A. Material

The structure and the properties of each element vary with respect to the change in material. Stress is related to Young's Modulus; thus, stress will also change with the change in material. The material's load-carrying capacity depends on the alignment of fibers in the material. This property makes a material isotropic or non-isotropic. To exclude this variation, homogenous and isotropic material is used for this study.

B. Stiffeners Used

1. Without Stiffener
2. I – Section
3. L – Section

C. Importance of Present Study

The present study throws light on the structural integrity of the window cutout of an aircraft. The window cutout segment is an essential component from the structural point of view. The location of maximum stress in the panel is identified. ANSYS was the software used for performing the static structural analysis. The study helps in estimating the

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stress, deformation and strain values for the window cutout panel.

D. Problem Sequence

The analysis is carried out for different types of stiffeners. The window cutout panel has 'L' and 'I' stiffeners, and it is subjected to a load of 9 Psi by calculation of hoop stress for estimating the point of maximum tensile stress. A Finite Element Approach is used to solve the problem. The stress analysis is done on a fuselage segment. Hoop stress and longitudinal stress are both introduced by cabin pressurization. Virtual modeling is done in CATIA V5.

II. PROBLEM DESCRIPTION AND FORMULATION

ANSYS is a finite element software basically used for designing products as well as it is a tool designed to aid the development of the finite element model and analysis results.

CATIA V5 is a multi-platform software used for the virtual modeling and for Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM) and Computer-Aided Engineering (CAE).

A single window cutout is used for the current study. The analysis is done with two stiffeners. First using 'L' stiffener on both sides and the 'I' stiffener on both sides of the window cutout panel.

The total length of the panel is 900 mm and the width is 700 mm. The gap between the placements of the two stiffeners is 600 mm.

A. Material Specifications

The material considered for the current study is Al 2024 –T3. This material is used to model many aircraft components. Other materials in the same series, such as T4 were also used for modelling. Some of the vital properties of material are as follows:

1. Density
2. Young's Modulus
3. Ultimate Tensile Strength
4. Yield Strength
5. Fatigue Strength
6. Damage Tolerance

B. Material Properties

Property	Value
Density	2.77 g/cm3
Ultimate Tensile Strength	483 MPa
Tensile Yield Strength	362 MPa
Young's Modulus	72 GPa
Poisson's Ratio	0.33
Fracture Toughness	105 MPa√m

Table 1

The above table shows the properties of the material used for analysis purposes.

The main role of fuselage in aircraft is

1. Passenger Load and Cargo
2. Weapons, in case of Military Aircraft
3. The fuselage is the interconnecting link between all the other parts of the aircraft like the wing, empennage, and thus, it carries the wing loads, tail loads and air loads.
4. It also carries the aircraft systems such as avionics, hydraulics, etc.
5. It houses the undercarriage and bears the loads transmitted on it.
6. Cabin Pressurization: In the current study, the load applied is cabin pressurization.

Circumferential Stress/ Hoop Stress:

These are the stresses acting in the circumferential direction. Hoop stress is also equivalent to tensile stress which acts due to tensile force. P = Cabin Pressure = 9 Psi = 0.0620 MPa

d = Diameter of Fuselage = 1946 mm

t = Thickness of window cutout panel = 2 mm

Hoop Stress = Pd/2t

= 0.0620x1946/2x2

= 30.16 MPa

Hoop stress on stiffener = Pd/2t

= 40.12 MPa

Force per unit length on the cutout panel due to hoop stress = Hoop stress x Cross-Sectional Area = 54288 N

Stress Intensity Factor:

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Stress intensity factor is used to describe the state of stress at the tip of the crack.

K = √ (G.E)

Where G = strain energy release rate

Stress intensity factor can also be calculated by integrating the product of the weight function, m (x, a), and the stress distribution normal to the crack, σ(x)

$$K_I(a) = \int_0^a m(x,a)\sigma(x)dx$$

The weight function can be calculated as

$$m(x,a) = \frac{2}{\sqrt{(\pi a)}}\frac{G(x/a, a/t)}{(1-a/t)^{3/2}\sqrt{1-(\frac{x}{a})^2}}$$

Where

t = thickness of the specimen

a = crack length

x= co-ordinate from the edge of the specimen in the crack plane

G = function of combination of g_i functions

The residual stress distribution is given by

$$\sigma_F(x) = \frac{4F}{\pi s}\frac{1}{\left\{1+\left(\frac{x}{s}\right)^2\right\}^2} + \frac{F}{t}\left(3 - \frac{6x}{t}\right).\left\{-0.0256875+1.4278859\frac{s}{t} - 0.4780998\left(\frac{s}{t}\right)^2\right\}$$

$$\sigma_y(x) = \sum_{i=0}^{n} A_i\, P_i(x)$$

Where

A_i = Polynomial coefficient

$P_i(x)$ = Orthogonal polynomial

F= Virtual Force

The polynomial can be in various forms such as Legendre Polynomials, Power Series or Trigonometric series.

Stiffness and Mass Matrix :

The stiffness matrix for the combination of plate and stiffener is given by

$$[K] = [K_p] + [K_s]$$

Similarly, the overall mass matrix is given by

$$[M] = [M_p] + [M_s]$$

Visualizing crack development, we get,

L- Stiffener

x = 150 mm

s = 150 mm

t = 2 mm

F = 54288 N

$\sigma_F(x)$= 49.74*10^{6}N/mm^2

I- Stiffener

x = 143 mm

s = 143 mm

t = 2 mm

F = 54288 N

$\sigma_F(x)$= 47.41*10^{6}N/mm^2

C. Load and Boundary Conditions

Internal pressure (cabin pressure) is applied on the window cutout. The tensile and longitudinal stresses are a result of internal pressure. The critical load acting on the cutout is due to hoop stress.

III. RESULT DISCUSSION

A. *Virtual Model in CATIA*

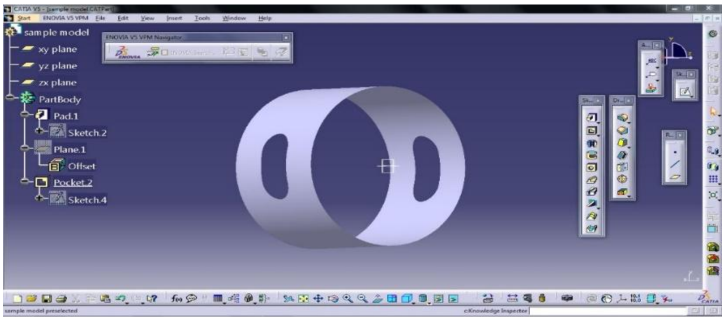

Figure 1: Without Stiffener

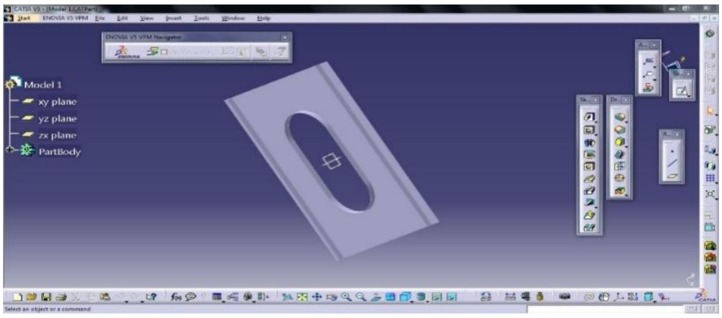

Figure 2: With 'L' Stiffener

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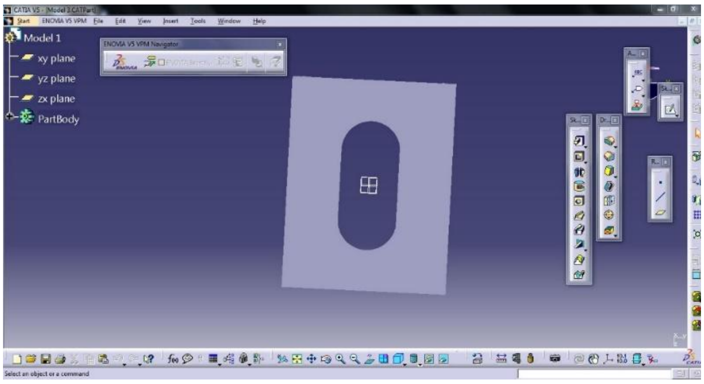

Figure 3: With 'I' Stiffener

Equivalent Stress Results:

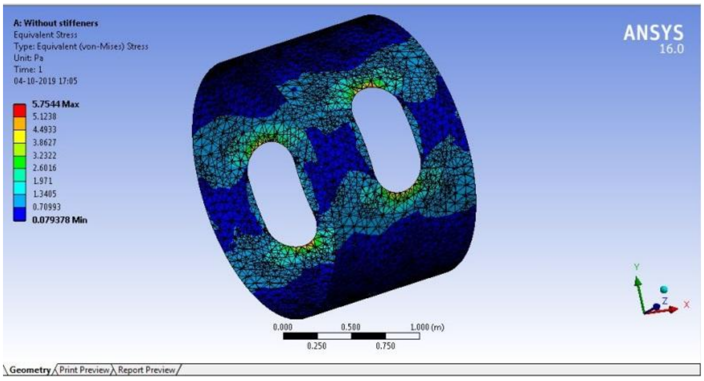

Figure 4: Without Stiffener

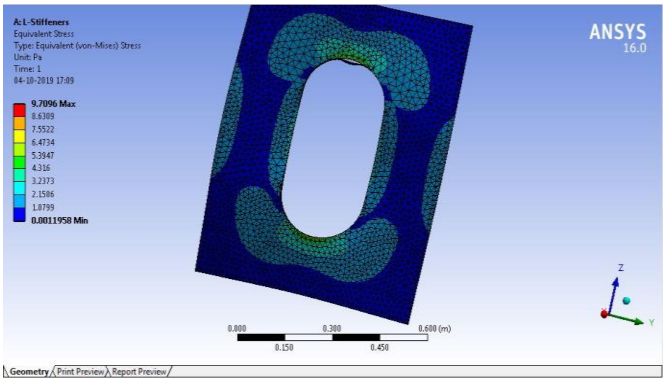

Figure 5: With 'L' Stiffener

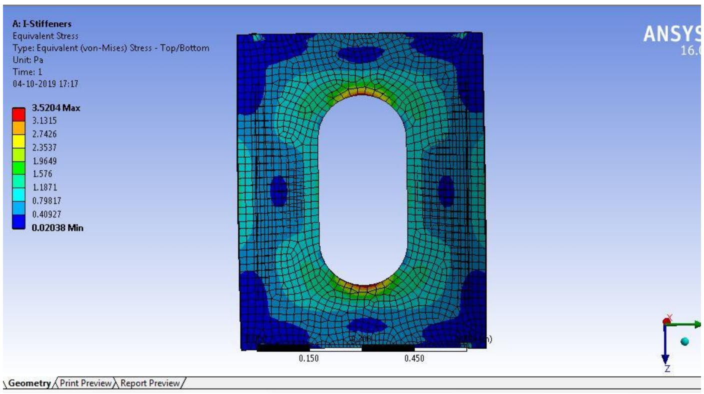

Figure 6: With 'I' Stiffener

Deformation Results:

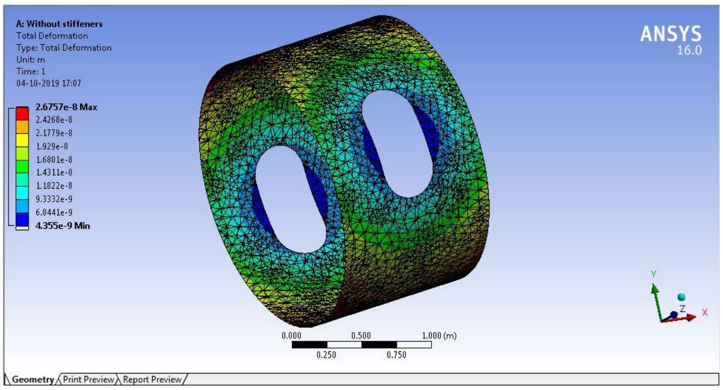

Figure 7: Without Stiffener

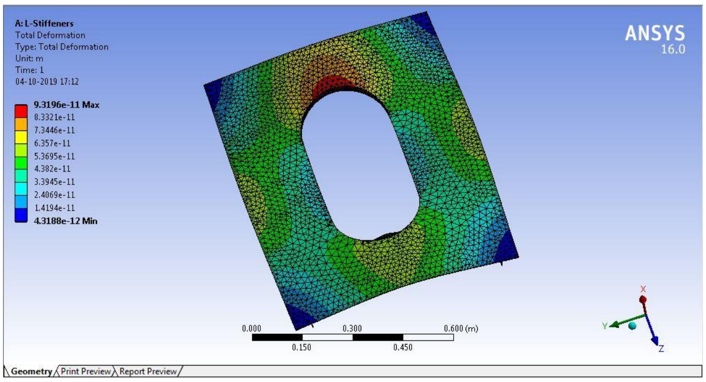

Figure 8: With 'L' Stiffener

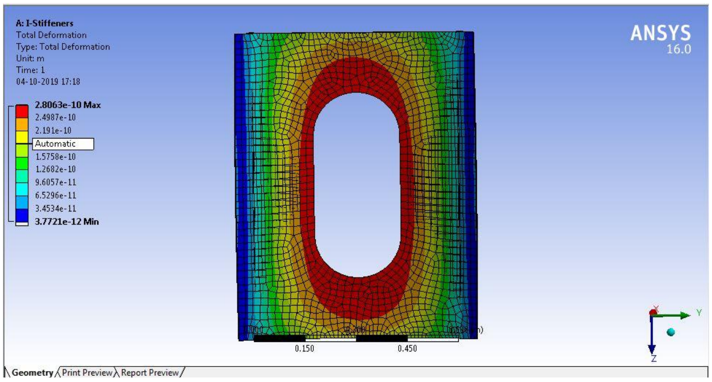

Figure 9: With 'I' Stiffener

Strain Results:

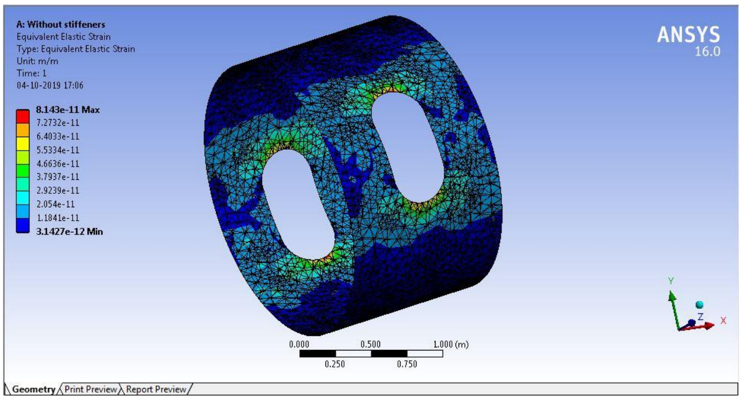

Figure 10: Without Stiffener

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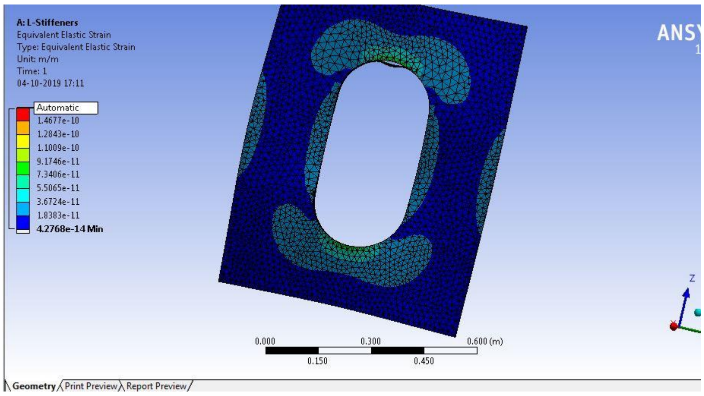

Figure 11: With 'L' Stiffener

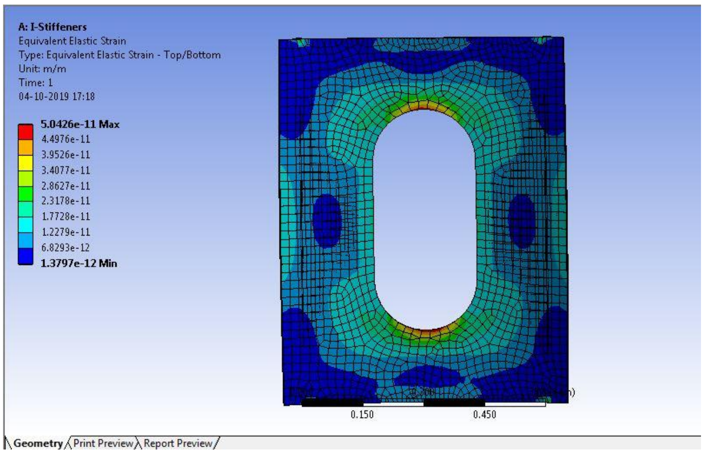

Figure 12: With 'I' Stiffener

As observed from the above images, the main objective of the study was to analyze the stress, strain, and deformation on the window cut-out when different types of stiffeners are used. Also, it is observed that the maximum stress concentration is in the area around the window cut-out due to sudden change in the area. And thus, the maximum deformation also occurs in the same area.

On doing a comparative study between the two stiffeners, it is observed that the stress value increases from 5.75 Pa (without stiffener) to 9.70 Pa for 'L' stiffener and decreases to 3.52 Pa for 'I' stiffener.

Maximum Values

	Stress	Strain	Deformation
Without Stiffener	5.7544 Pa	$8.143 * 10^{-11}$	$2.6757 * 10^{-8}$
L Stiffener	9.7096 Pa	$1.4677 * 10^{-11}$	$9.3196 * 10^{-11}$
I Stiffener	3.5204 Pa	$5.0246 * 10^{-11}$	$2.8063 * 10^{-10}$

Table 2

Minimum Values

	Stress	**Strain**	Deformation
Without Stiffener	0.07937 Pa	$3.1427 * 10^{-12}$	$4.355 * 10^{-9}$
L Stiffener	0.001195 Pa	$4.2768 * 10^{-14}$	$4.3188 * 10^{-12}$
I Stiffener	0.02038 Pa	$1.3797 * 10^{-12}$	$3.7721 * 10^{-12}$

Table 3

The above two tables show the maximum and minimum values of stress, strain, and deformation for the window cut-out panel.

IV. CONCLUSION

1. Structural Analysis was performed on Fuselage Window Cutout using Finite Element Method.
2. The window cut-out was modeled in CATIA V5.
3. Structural Analysis was done on the window cut-out using the software ANSYS.
4. The analysis gave the values of maximum stress, strain, and deformation for various stiffeners ('L' and 'I').
5. The maximum stress concentration is observed in the area near the cut-out due to sudden change in the area.
6. The maximum and minimum stress locations are identified.
7. Sudden failure is occurred at the site of maximum tensile stress due to the initiation of fatigue crack.
8. Maximum value of stress is observed for L stiffener.Due to which I- stiffener is recommended over L-Stiffener.

V. FUTURE SCOPE

1. A similar model can be used for performing different analyses like modal, fatigue life estimation, etc.
2. The same analysis can be done using different materials and thus, the material

behavior under the loading conditions can be studied.

3. The results can be further analyzed by changing the mesh (element size, element shape).
4. The values for residual stress, strain and stress intensity factor can also be calculated by using above give formulae.

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AUTHORS PROFILE

C VIVEK RAJ, Asst. Professor, Department of Aerospace, Sandip University, Nashik Specialization in Aerospace Structures and Materials.

ANUSHKA VAIDYA, UGScholar, B. Tech Aerospace Engineering, Sandip University, Nashik.

AKSHAY GHARAT, Asst. Professor, Department of Aerospace, Sandip University, Nashik.