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Linear Static Analysis of a Curved Shell with Circular Cutout Subjected to Tensile Load Using Finite Element Approach

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Abstract-- Aircraft is a complex mechanical structure that must be designed with a very high structural safety. Aircraft will rarely fail due to a static overload during its service life. As the aircraft continues its operation, fatigue cracks initiate and propagate due to fluctuating service loads. Normally fatigue cracks will initiate from stress concentration locations, and the stress is more in the area of cutout. Here in this work, a beacon light hole on the fuselage of an aircraft is considered. The main objective of this study is to find the maximum stress during fatigue load testing. Finite Element Method (FEM) is used for analysis. Here, Finite Element Analysis (FEA) software used is MSC/NASTRAN V 7.0.

Key words— Cut outs, Beacon light, fuselage and stress concentration.

1. INTRODUCTION

The basic fuselage structure essentially a single cell thin walled tube with many transverse frames or rings and longitudinal stringers to provide a combined structure which can absorb and transmit the many concentrated and distributed applied forces safely and efficiently. The fuselage is essentially a beam structure subjected to bending, torsional and axial forces. The ideal fuselage structure one free of cutouts and discontinuities, however a practical fuselage must have many cutouts. Here, the skin of the fuselage is supported by the frames and stringers. During static load simulation, beacon light holes will be drilled on the fuselage to pass fatigue load agitators on to the frame which applies point loads on the floor beams. Due to these holes, the stringers and bulkheads will be cut at that region and there will be loss of stiffness. So, in order to regain its stiffness, an additional element made of isotropic material called doubler is provided in order to reduce the stress concentration near the hole region.

2. METHODOLOGY USED

Below figure 1 shows methodology for problem solving of shell structure with cut out.

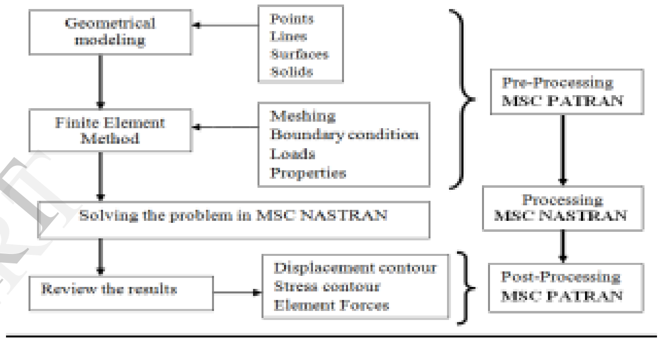

Figure 1. Steps involved in Finite Element Analysis

The finite element method is a numerical technique for solving engineering problems. It is most powerful analysis tool used to solve simple to complicated problems. The pre-processing stage involves the preparation of nodal co-ordinates & its connectivity, meshing the model, load & boundary conditions and material information for finite element models. The processing stage involves stiffness generation, modification and solution of equations resulting in the evaluation of nodal variables, run in MSC NASTRAN. The post-processing stage deals with the presentation of results, typically the deformed configurations, elemental stresses and forces etc.

2.1 Geometrical Modeling

Below figure 2 shows the fuselage with beacon Light hole and Doubler

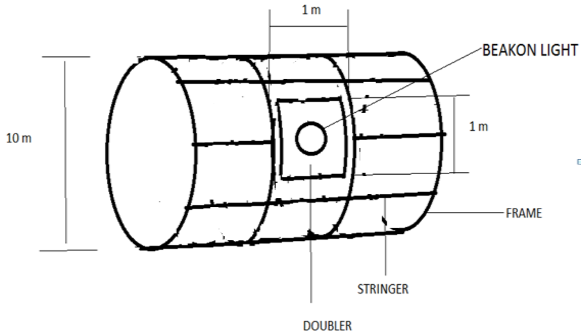

Figure 2. Fuselage with beacon light hole and doubler

2.2 Finite Element Modeling

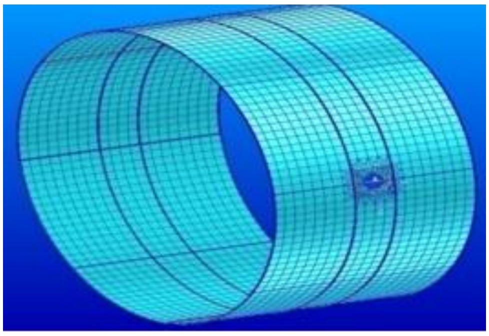

Figure 3. Finite Element Modeling of Fuselage with frames and Stringers.

Below Figure. 4 Shows the Finite Element Modeling of Fuselage at Beacon cutout.

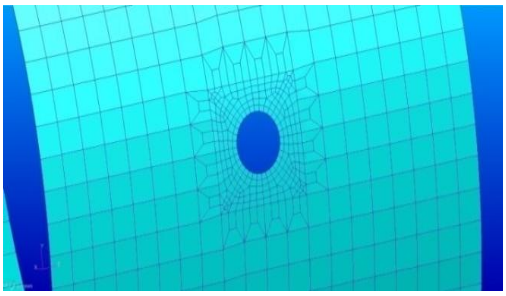

Figure 4. Finite Element Modeling of Fuselage at Beacon cutout.

Table 1 gives details of FE model for shell structure with cutout

Table.1 FE Model details

Product Description	Type of Element	No. of Elements
Skin	QUAD4	66820
Frame	QUAD4,TRIA3	38428
Stringer	QUAD4	4280

2.3 Loading and Boundary Conditions

2.3.1 Load Case

Axial Tension +Internal Pressure

The loads considered here are Tensile Load of 60e6N and Pressure of 0.09 Mpa.

Below Figure. 5 Shows the Axial Tension on Fuselage.

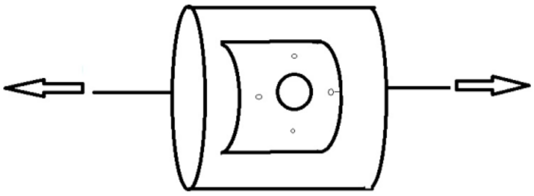

Figure. 5 Axial Tension on Fuselage

2.3.2 Boundary Condition

Boundary value problems are similar to initial value problems. A boundary value problem has the conditions specified at the extremes “boundaries” of the independent variable in the equation whereas an initial value problem has all of the conditions specified at the same value of the independent variable.

Here in this case, there is no rotational motion in the shell at all the edges except the loading edges are constrained with respect to rotation. There is no transverse motion with respect to force so edge 2 and edge 3 are constrained in transverse direction. There should not be axial motion in edge 3. So edge 3 is constrained in axial direction.

2.4 Fastener Analysis

A fastener is a mechanical device that joins or affixes two or more objects together. The purpose of the fastener is to connect all the different parts together in primary structural areas, secondary structural areas, pressurized and non-pressurized applications, and to transfer loads from one part to another. Here, the doublers are attached to the fuselage by using fasteners. Generally, for the fastener modeling a spring type element (CBUSH) is used, and it should be done as Mesh-independent. The number of fasteners used in this work is 8.

Below figure 6 shows the bush elements in fuselage - doubler1

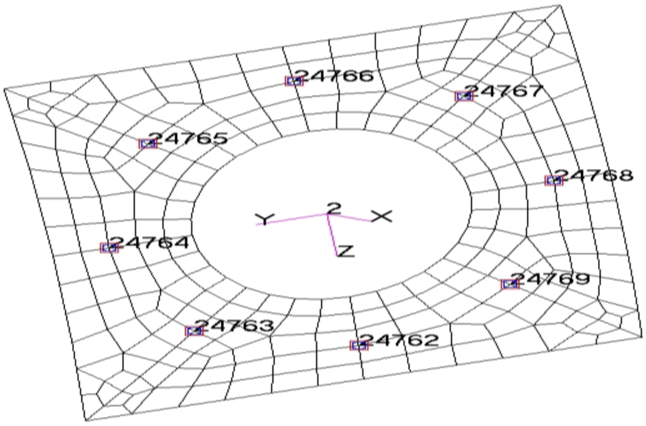

Figure 6 Bush Elements in fuselage - Doubler1

Below figure 7 shows the Bush Elements in Doublers1-Doubler2

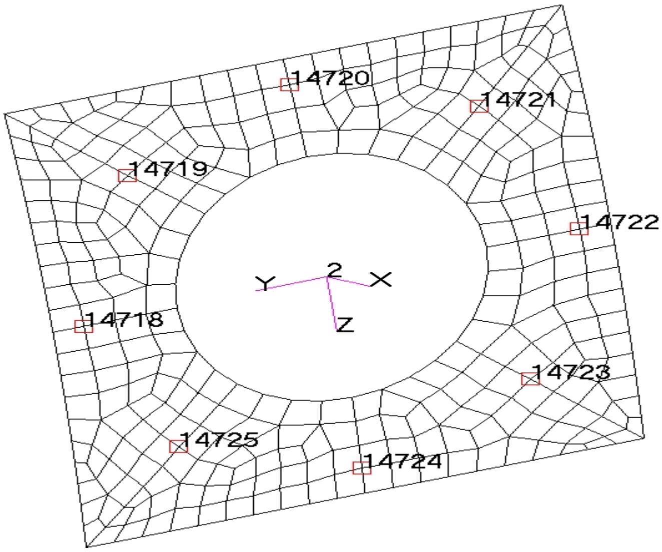

Figure 7: Bush Elements in Doublers1- Doubler2

Allowable Bearing Strength of fastener
P_{BRG} =1.5*$b_{0.1}$ *D*t (where b_{10} is the 1% of bearing stress)
P_{BRG} = 216000
Bolt bearing reserve factor = P_{BRG}/ $P_{applied}$
Bearing reserve factor = 1.8

2.5 Material Properties

Below Table 2. Shows the Material properties of Fuselage

Table2. Material properties of Fuselage
Material: High Modulus Carbon Fibers (HMCF)

Property	
Young's Modulus E_{11} (GPa)	85
Young's Modulus E_{12} (GPa)	85
Shear Modulus G_{12} (GPa)	5
Poisson's ratio γ_{12}	0.1

Below Table 3. Shows the Material properties of Doubler

Table3. Material properties of Doubler:
Material Steel – Titanium Alloy

Property	
Young's Modulus (GPa)	116
Poisson's ratio γ_{12}	0.32

Below table 4 shows the material properties of a fastener

Table 4. Material properties of fasteners
Material: Steel-Ti Alloy Ti-15/3/3

Property	
Ultimate Tensile Stress (MPa)	1250
Yield stress (MPa)	900
Shear Stress (MPa)	750
Plate thickness (mm)	6
Bolt radius (mm)	9.6
Edge distance(mm)	50

3. RESULTS AND DISCUSSIONS

Beacon and Doubler Optimization Analysis:
Stresses around Beacon cutout:

Case-1: Fuselage without Doubler

Load case	Maximum Stress (MPa)
Tension	366

Case–2: Fuselage with doubler 1 (thickness = 4.5mm)

Load Case	Maximum Stress (MPa)	
	Fuselage	Doubler
Tension	299	145

Case–3: Fuselage with Doubler 1 (thickness = 4.5mm) and doubler 2 (thickness = 3mm)

Load Case	Maximum Stress (MPa)		
	Fuselage	Doubler 1	Doubler 2
Tension	295	140	57

Case–4: Fuselage with doubler1 (thickness = 4.5mm) and Doubler 2 (thickness = 4.5mm)

Load Case	Maximum Stress (MPa)		
	Fuselage	Doubler 1	Doubler 2
Tension	290	134	83

Case–5: Fuselage with doubler1 (thickness = 4.5mm) and Doubler 2 (thickness = 6mm)

Load Case	Maximum Stress (MPa)		
	Fuselage	Doubler 1	Doubler 2
Tension	289	134	84

Case–6: Fuselage with doubler1 (thickness = 4.5mm) and Doubler 2 (thickness = 6mm)

Load Case	Maximum Stress (MPa)		
	Fuselage	Doubler 1	Doubler 2
Tension	265	141	86

Below figure. 8 Maximum Stresses in Fuselage for Tension and Pressure

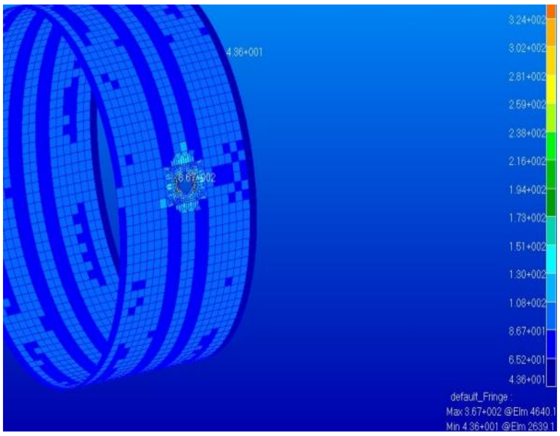

Figure 8. Maximum stresses in Fuselage for Tension and Pressure.

Below Figure. 9(a) and (b) shows Doubler 1 with CBUSH elements and Doubler 1 and 2 with CBUSH Elements

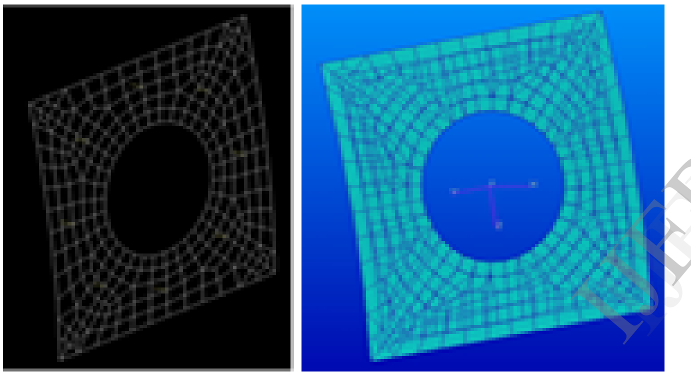

Figure 9. (a) and (b) Doubler 1 with CBUSH elements and Doubler 1 and 2 with CBUSH Elements.

Below Figure 10.shows the Max Stresses of Fuselage with doubler1 (thickness = 4.5mm) and Doubler 2 (thickness = 6mm with Tension + Pressure

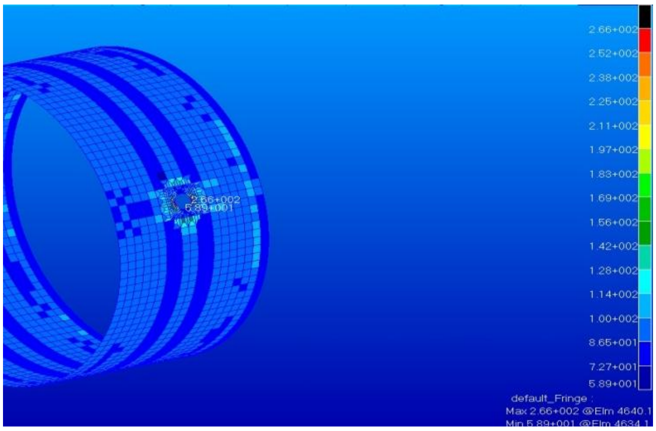

Figure 10. Max Stresses of Fuselage with doubler1 (thickness = 4.5mm) and Doubler 2 (thickness = 6mm with Tension + Pressure

Below Figure8. shows the Max Stresses for of Fuselage with doubler1 (thickness = 4.5mm) and Doubler 2 (thickness = 6mm) (Tension + Pressure in Doubler 1)

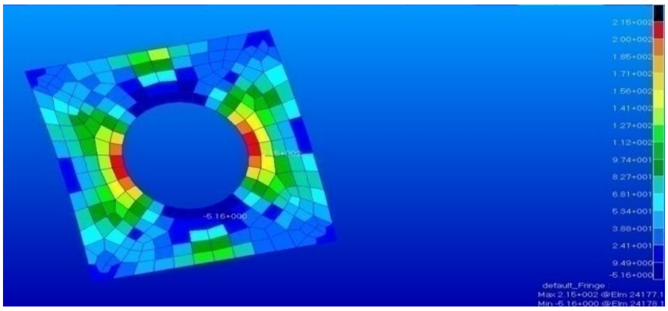

Figure 8. Max Stresses for of Fuselage with doubler1 (thickness = 4.5mm) and Doubler 2 (thickness = 6mm) (Tension + Pressure in Doubler 1)

Below Figure 9. Shows Max Stresses of Fuselage with doubler1 (thickness = 4.5mm) and Doubler 2 (thickness = 6mm) (Tension + Pressure in Doubler 2)

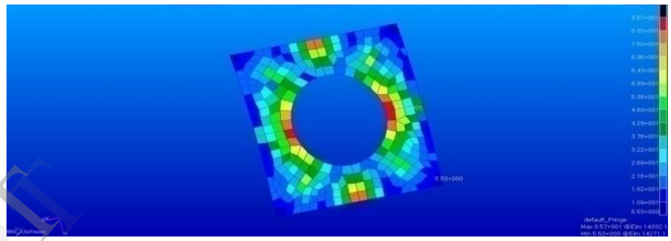

Figure 9. Max stresses of Fuselage with doubler1 (thickness = 4.5mm) and Doubler 2 (thickness = 6mm)(Tension + Pressure in Doubler 2).

4. CONCLUSION

1. Linear static analysis of a curved shell without hole for axial tension loading case along with pressure and found that the stress within the allowable limit.
2. Linear static analysis of curved shell with hole is done for tension load case along with the pressure and found that the stress within the allowable limit.
3. Linear static analysis of curved shell with hole and with doubler and found that the stress within the allowable limit.
4. Analysis of doubler is done and the stresses induced in the doubler are found to be within the allowable limit.
5. Optimization of the doubler is done.
6. Analysis of fastener is done and is found that it is within the limit.

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