Stress Analysis of Door and Window of Boeing 787 Passenger Aircraft Subjected to Biaxial Loading

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***Abstract*— The Composite plate is taken as a fuselage of Boeing 787 passenger aircraft. The fuselage of any passenger aircraft is considered as a shell with a large radius of curvature and having multiple openings like doors and windows. The presence of such cut-outs in the shell structure causes perturbations in the original stress system, resulting in an increase in the local stress levels. Almost all the major failures during the service of an aircraft occur due to initiation of cracks in the region of maximum stress. Thus, Study and evaluation of maximum stress concentration is vital. Various methods are presented in the literature to find Stress Concentrations around various geometries, but for Rectangular cut outs with Circular radius in an Anisotropic Plate.**

The report deals with the stresses and stress concentration phenomenon around the doors and windows of Boeing 787TM aircraft. As the diameter of fuselage is very large compared to the dimensions of doors and windows, the problem have been modelled as an Infinite Plane with Multiple Openings under Biaxial Loading. The Analytical solution of the stress concentrations is found by Finite Element Analysis using ANSYS.

***Keywords*— Boeing 787, Complex Stress Functions, SCF, Anisotropic Elasticity, Biaxial Loading.**

I. INTRODUCTION

Many engineering structures are primarily designed to transmit force, and it is of great importance for the designer to know how the forces will be transmitted in terms of stress distribution within particular components. Otherwise, the component may fail to serve the purpose for which it is designed. The determination of the state of stress at all points within a component is called as stress analysis.

Stress analysis helps in finding out the magnitudes and directions of stresses at various points in the structure as well as locating the weak spots where maximum stress concentration occurs. This localization of stresses is known as stress concentration. Stress concentration is measured using Stress Concentration Factor, defined as the ratio of maximum stress to the nominal stress and is given by:

$K_t = \frac{\sigma_{\max}}{\sigma_{\min}}$ And $K_s = \frac{\tau_{\max}}{\tau_{\min}}$ for normal and shear stresses respectively.

The aircraft Fuselage consists of multiple openings such as passenger doors, emergency exit doors and windows. These openings of cut-outs in the shell structure causes a perturbation in the original stress system, so that in the original region of the cut-outs the local stress level in the sheet may be increased many times. There is a possibility of crack initiation from the location having maximum stress concentration. Crack flaws cannot be neglected in engineering analysis; even microscopic crack flaws can grow over time, ultimately resulting in fractured components. Structures that may have been blindly deemed “safe” could fail disastrously, causing injuries to its users, or in the grimmest of cases, causing the loss of life.

There are various numerical techniques to solve for stress concentration across various geometrical cut outs in Isotropic and anisotropic cases. Systematic use of complex variable theory in plane elasticity to find different values of stress at different points was proposed by Kolosov-Muskhelishvili’s [1] complex variable approach, Savin [2] and Lekhnitskii [3] found stress concentrations around circular, elliptical, triangular and square holes, mainly in isotropic media. The analytic solutions for stress analysis of infinite anisotropic plate with irregular holes are presented by Ukadgaonker and Rao [4], [5] and Ukadgaonker and Kakhandki [6]. In this paper variation of stress concentration factor along the cut-out is observed and effect of change in dimensions along with the presence of 2 cut-outs nearby and its effect on Stress concentration are observed.

II. BOEING 787 PASSENGER AIRCRAFT

The Boeing787 Dreamliner is a midsized, wide-body, twin-engine jet airliner currently under development by Boeing Commercial Airplanes. Its maximum seating capacity in a one-class configuration is between 290 to 330passengers depending on the variant. Boeing states that it will be more fuel-efficient than earlier Boeing airliners and will be the first major airliner to use the composite materials for most of its construction. Boeing’s development of the 787 has involved a large-scale collaborative with numerous suppliers [7]. Following figures shows the Technical Factsheet of Boeing 787 and Material Distribution.

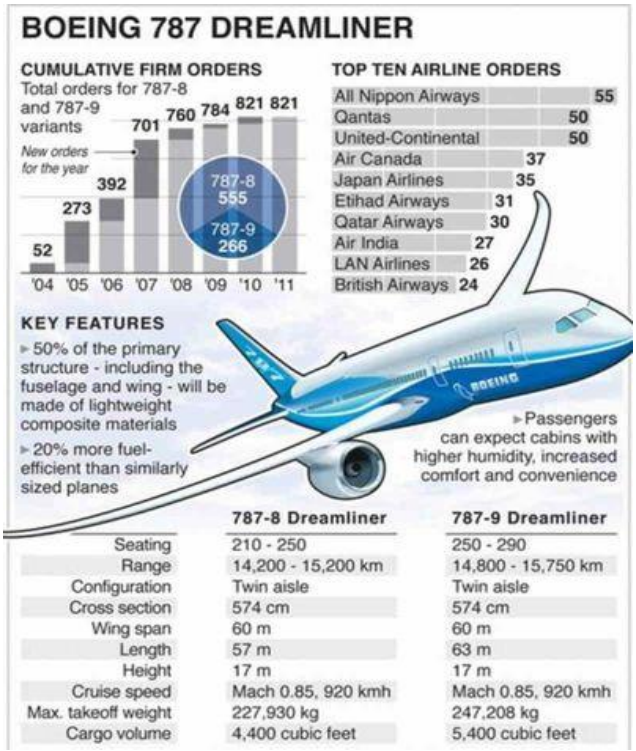

Fig. 1 Showing Technical Fact Sheet of Boeing Dreamliner[7]

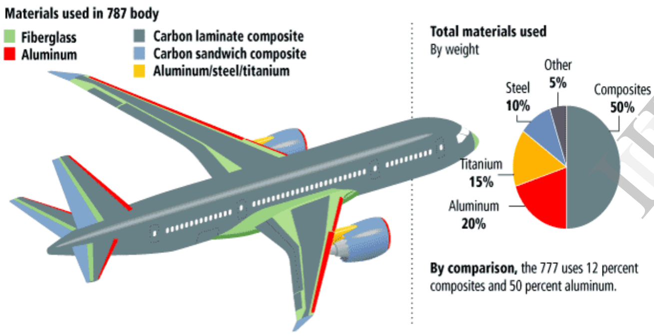

Fig. 2 Showing Material Distribution of Boeing 787[7]

III. ARBITRARY BIAXIAL LOADING CONDITIONS

In order to consider several cases of in-plane or bending loads the arbitrary biaxial loading condition is introduced into the boundary conditions. This condition has been adopted from Ukadgaonkar and Rao[4] solution for an triangular hole. By means of these conditions, solutions for biaxial loading can be obtained without the need of superposition of the solutions of the uniaxial loading. This is achieved by merely introducing the biaxial loading factor λ and the orientation angle β into the boundary conditions at infinity. An infinite plane with an arbitrary shape of hole subjected to in-plane loading under arbitrary biaxial loading condition is shown in Figure

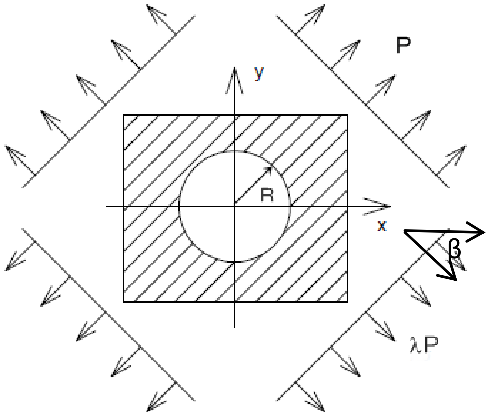

Fig. 2 Arbitrary Biaxial Loading Condition

The Boundary conditions for in plane loading condition is as follows:

$$\sigma_x^\infty = \lambda P,\ \sigma_y^\infty = P,\ \tau_{xy'}^\infty = 0 \text{ at } |z|\to\infty \qquad ...13$$

Where, σ_x^∞, σ_y^∞ are stresses applied about x, y axes at infinity respectively. By applying stress invariance into above boundary conditions, boundary conditions about XOY can be written as:

$$\sigma_x = \frac{P}{2}\left[(\lambda+1)+(\lambda-1)\cos 2\beta\right]$$

$$\sigma_y = \frac{P}{2}\left[(\lambda+1)-(\lambda-1)\cos 2\beta\right] \qquad ...14$$

$$\tau_{xy} = \frac{P}{2}\left[(\lambda-1)\sin 2\beta\right]$$

Where, $\lambda = ½$ & $\beta = 0$, for current study.

IV. STRESS ANALYSIS

1. INTRODUCTION

The finite element analysis (FEA) is a numerical technique for finding approximate solutions of partial differential equations (PDE), as well as integral equations. The solution approach is based ether on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta, etc.

For Stress Analysis we do FEA using ANSYS as a platform in which an Anisotropic Plate containing a hole is subjected to remotely applied load at its outer edge while the edges of hole are free from loading. Following are the steps that we need to follow, *2. ANSYS[ref: ANSYS Help]:*

ANSYS is commercial finite element analysis software with the compatibility to analyse a wide range of different problems. It can handle problems from structural to electromagnetic fields. It can also handle both simple linear, non-linear, transient ones. A typical ANSYS analysis involves three steps.

1. Pre-processing: In this step using PREP7 processor providing input data such as element type, geometry dimensions, material properties, and material constants to the program.
2. Solution: Using solution processor defining the type of analysis, setting boundary conditions, apply loads and initiate finite element solution.
3. Post processing: Using POST1 or POST27 extract the results through graphic display and tabular listings.

A. Pre-Processing:

For Material Properties we select Orthotropic thin plate with Plane Strain condition. The Young's modulus (E) and Modulus of Rigidity (G) for plate material are taken as

$E_1=139.3GPa$, $E_2=11.3GPa$, $G_{12}=6GPa$

The Poisson's ratio is taken as $v_{21}=0.3$, $v_{23}=0.4$

The external dimensions of the plate are taken as large enough to satisfy the condition of infinite plate.

For PLATE,
Length: *1000 in* Width: *1000 in*

For DOOR,
Length, *a=42 in*
Width, *b=74 in*
Corner radius, *r=7.0 in*

For WINDOW,
Length, *a=10.74 in*
Width, *b=18.44 in*
Corner radius, *r=5.0 in*

Distance between Door and Window *58.95 in*

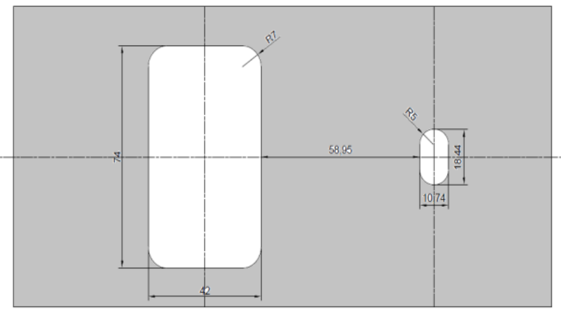

Fig. 3 Showing Dimensions of PLATE having DOOR and WINDOW

Next is to define the Element Type, which is taken as PLANE82. It is a higher order version of the 2-D, four node element (PLANE42). It provides more accurate results for mixed (quadrilateral-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The 8-node elements have compatible displacement shapes and are well suited to model curved boundaries. The 8-node element is defined by eight nodes having 2 degrees of freedom at each node. The element may be used as a plane element or as an axis symmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

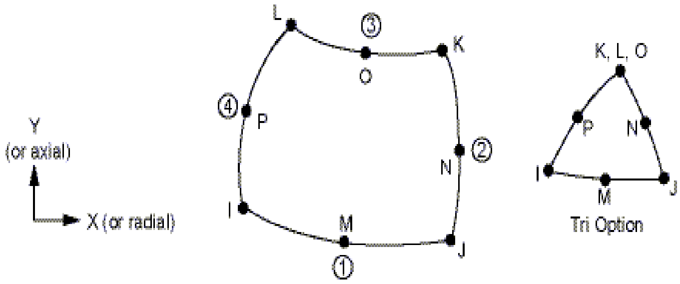

Fig. 4 PLANE 82 Element Type

Next the Area formed is Meshed according to the Element Type. Following are the Meshed Model Door and Window,

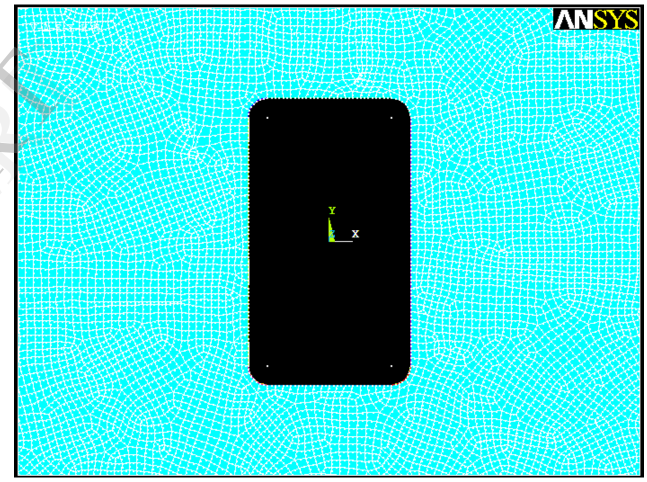

Fig. 4 Meshed Model of Door

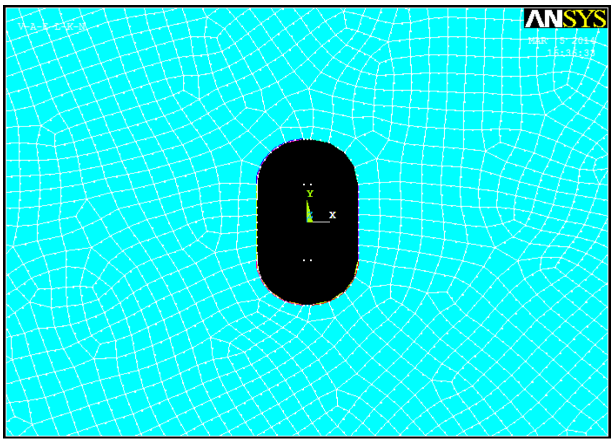

Fig. 5 Meshed Model of Window

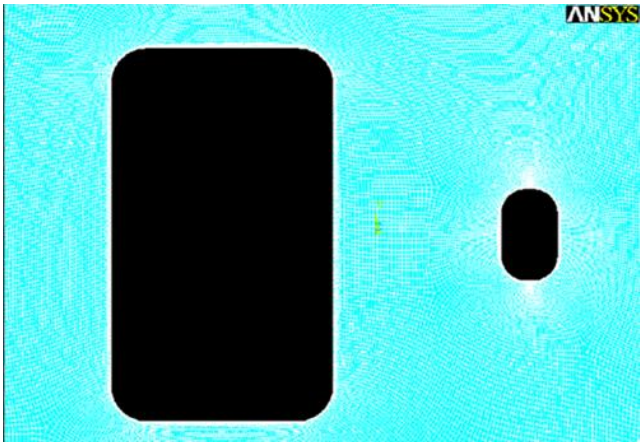

Fig. 6 Meshed Model of Door and Window

B. Solution and Post-Processing

Following Figure shows the final plots from ANSYS showing variation of Stress Concentration along the Rectangular cut-outs,

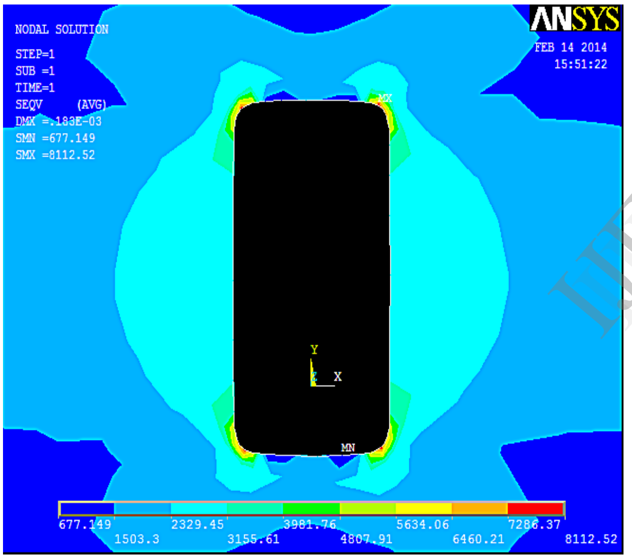

Fig. 7 Final Plot of DOOR

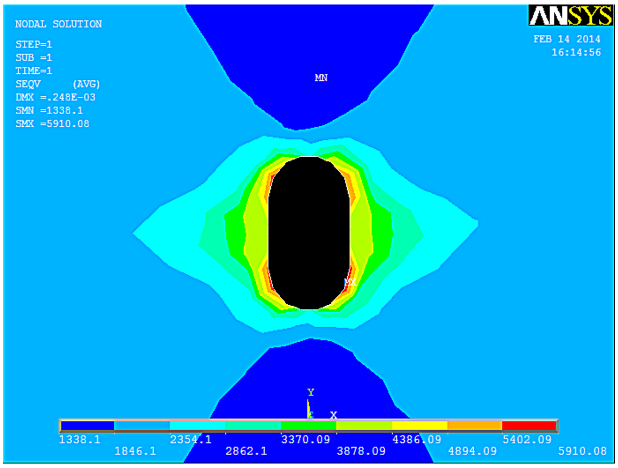

Fig. 8 Final Plot of WINDOW

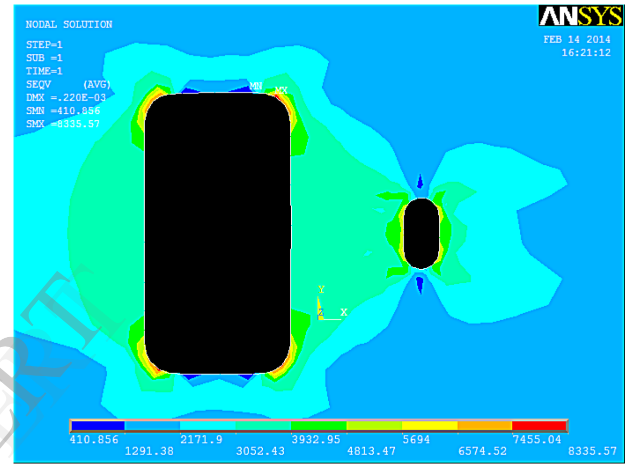

Fig. 9 Final Plot of DOOR and WINDOW together

Following were the results Observed from the Plots,

Geometry	SCF	
	Min	Max
DOOR	*0.677*	*8.112*
WINDOW	*1.338*	*5.91*
DOOR & WINDOW	*0.41 Door 1.29 Window*	*8.33 Door 6.57 Window*

V. CONCLUSIONS

AFollowing are the conclusions deciphered from the results obtained by Finite ElementAnalysis,

1. The present method of study helps to analyse stress concentration around a Rectangular Hole with circular corners, which can be further utilised to study for other geometry as well.

2. Maximum Stress Concentration occurs at the corner locations.

3. Window has a lower value of maximum stress concentration factor as comparedto door because of more curved corners.

4. When Door and Window are analysed together there is a significant change in the Max Stress Concentration around window than around Door, as there is some interaction effect between the two which can be further analysed.

4. The value of SCF does not depend on the amount of Load Applied as for different loads it remains the same.

5. The Stress Concentration around a given shape of hole depends on combination of different parameters related to the material of laminate, shape of hole, type ofloading.

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