Relative Comparison of Geometrical Shapes for Cutouts

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Abstract - Cutouts are passages, used for electrical wires, control rods, hydraulic lines in aircraft structural design, induce stress concentration leading to failure of the structure. With advancement in the manufacturing industry, various geometrical shapes can be possible that can be applied to the requirements mentioned above. Most of the previous studies are based on the cutouts having regular shapes like the circular, triangular and rectangular shapes. As the technology is improving, with the help of 3D printing it is now possible to create any shape instead of the regular shaped cutouts, other geometrical shaped cutouts can also be used after thoroughly analyzing its behavior. So all the geometrical shapes have to be analyzed for the static and modal analysis and conclusions have to be drawn. These analyses are carried out in ANSYS. Moreover, there is lack of information concerning the modal analysis of the plates having cutout. Most of the studies on aircraft cutouts are based on static analysis, Modal analysis is not discussed. But the aircraft must be tested or analyzed for both the static and dynamic load carrying capacity. In this paper, we are studying about the various geometrical shapes and analyzing the static and modal analysis in order to provide information about the analyses. From the analysis it is observed that modal analysis also plays a vital role. As the shapes changes, the frequency changes accordingly and the deflection. All the results have been tabulated and compared for ease of comparison of the behavior of all geometrical shapes in terms of frequency and deflection. A new shape is also included that is the plus sign made of two rectangles. It is an experiment to study its behavior when loads are acted. It is observed that all the geometric shapes will behave differently depending on the number of sides present in each shape.

Keywords: Cutouts, modal analysis, static analysis, stress concentration, 3D printing.

I. INTRODUCTION

Cutouts in the aircraft structure are designed during the design stage for providing easy access to all the internal requirements like the electrical wires, cables, fuel requirements etc. the shapes of cutouts have always been the circle, square, triangle or ellipse shapes. The shapes have been constrained because of the inefficiency of the manufacturing techniques to produce different shapes.

Now there is a question about why are the different shapes not considered? Different shapes have not been considered because of the lack of technology in creating shapes or making cutouts in the plate. We have 3d printing available now. Latest technology helps us to create any shape with ease.

What is 3D Printing?

3d printing is a process of making three dimensional solid objects from an inputted digital file. It is not printing with ink like the traditional printing. Printing can be done with any type of material like the plastics, metals, glass, polymers, human tissue, wax, edible food, sand and glue mixes.

A three dimensional object is printed by laying down successive layers of material until the entire object is created. It is creating many new opportunities in many industries. All the industries will prefer 3d printing because of the ease of manufacturing i.e with the touch of a button.

Cutouts in aircraft industries:

The cutouts are an important part of the aircraft structure. The aircraft structure is a monocoques design, so there can't be different parts that can be joined to the structure. In order to produce a safe design only single shell (monocoques) is considered. For these monocoques, cutouts will be made to provide access for any requirements. For example, the fuselage, i.e. the skin of the aircraft is a monocoques design having cutouts for windows. So the windows here are the cutouts provided. Similarly for the wing spar, there are many requirements for fuel, cables, wires etc. for these requirements, different shapes of cutouts are chosen in order to provide safe design.

Cutouts in automobile industries:

A flexure bearing is a bearing which is just one part joining two other parts that allows motion by bending a load element.
Example is a hinge made by attaching a long strip of flexible element to a door and to the door frame.

Figure 1: Hinge (type of flexure bearing)

Many flexure bearings are combined with other elements. For example, many motor vehicles use leaf springs. The spring both holds the position of the axle as the axle moves (flexure bearing) and provides force to support the vehicle (springing). In many cases it is not clear where flexure bearing leaves off and something else takes up. For example, turbines are often supported on flexible shafts so an imperfectly balanced turbine can find its own center and run with reduced vibration. Seen one way, the flexible shaft includes the function of a flexure bearing; seen another, the shaft is not a "bearing".
Flexure bearings are a key technology for many long-life, spacecraft-borne cryogenic refrigerator (cryocooler) designs. The bearing provides frictionless, non-wearing, linear movement and radial support for reciprocating machines.
Now a day linear motor compressors are commonly used in miniature cryocoolers instead of rotary compressors because rotary compressors apply large radial forces to piston, which provide no useful work, cause large amount of wear and usually require lubrication. Recent trends however favor flexure supported configuration for long life.

Figure 2: Diaphragm Flexural bearing ; Diaphragm spiral bearing ; spiral disc springs

Diaphragm flexures are utilized to guide out-of-plane motion of a high-end microscope.
Spiral disc springs are used to maintain the alignment of the piston within the cylinder. They are photo etched from thin sheet which can easily generate the curved shapes required.

Flexure bearings are used for precision applications such as PFM, linear compressor. In order to achieve desired motion objectives various shapes are provided. In linear compressor these types of bearings are used to support shaft which transmits power from linear motor to compressor. The advantages of using flexure bearings are they are Light-weighted, compact, low friction and easy to repair and also as they are fixed in their places there will not be any wear problems.
Cutouts in various industries:
Cutouts are not only present in aircrafts but also in our daily life appliances like in automobiles, washing machine, computer's CPU, and many more electrical appliances. Cutouts can be made on any type of material like

plastics, metals, thermo cols for prototypes making etc. Making a cutout is not a difficult task but making a cutout that makes the plate to function as before is important and also the plate should not be a failure after having a cutout.

So it is clear that cutouts play an important role in almost all the appliances of our daily life. In order to reduce the failure of the structure, the cutout made on the plate must be in such a way that the strength of the plate should remain the same with or without the cutout. In other way, making a cutout must not have large effect on the functionality of the structure.

II. LITERATURE REVIEW

Dharmendra S Sharma (2011) studied that the stress concentrations around circular, elliptical and triangular cutouts in laminated composite infinite plates subjected to arbitrary biaxial at infinity are obtained by using Muskhelishvili's complex variable method. Author also stated that depending on the cutout shapes, bluntness and rotation effects on stress concentration vary.

D.B.Kawadkar (2012) studied the plates with cutouts in structural members. The main objective of the study is to find out stress concentration in plate with various cutouts and bluntness with different cutout orientation using ANSYS considering three parameters namely bluntness, shape and rotation of the cutout.

Mohan Kumar (2013) studied that increase in bluntness results in increase of stress concentration irrespective of the shape and rotation. And more importantly found that as the cutouts become more oriented to the baseline, the stress concentration increases. Different cutout shapes in structural elements are needed to reduce the weight of the structure or provide access to other parts of the structure.

Paul Kuhn (1942) stated that there are no published records of any attempt at a purely theoretical solution, the nearest approach being a general, but extremely laborious, method of computing the stress in a web with plain holes. Author conducted experiments for 18 shear webs with round lightening holes having 45^o flanges to extend the range of a previous investigation to larger ratios of holes diameter to web depth and of web depth to web thickness.

Dinesh Kumar (2010) studied about the buckling and post buckling response and strengths under positive and negative in-plane shear loads of simply supported composite laminate with various shaped cutouts of various sizes using FEM.

M.V.Kavade & C.B.Patil have studied on optimization of flexure bearing using FEA for linear compressor has concluded that flexure bearings with 720^o spiral angle can develop less equivalent stress in linear compressor.

Ashvini.T.Thombare & D.Y.Dhande have stated that flexure bearings have numerous applications which can range from linear compressor to high precision manufacturing. The authors have concluded that the flexure bearing with triangular profile has maximum equivalent stress and axial deformation.

Fayaz H.Kharadi and Mayur S.Jadhav have done analysis for different geometries by keeping the thickness, material and deformation constant. They have concluded that among all the geometry shapes chosen, helical armed geometry was suitable for flexure bearing application because of it gives minimum equivalent stress for same deflection.

III. METHODS AND PROCESS

For the modal analysis the method followed is as described. Finite element analyses are carried out for the frequency of perforated steel plates. The dimensions of the steel plate are 200 m (x-direction), 200 m (y-direction), and 10 m (z-direction). Material properties are Young's modulus of 1100MPa, poissons ratio of 0.3 and density of 0.000728kg/m^3. The cutout is located at the center of the plates. To observe the stress concentration clearly, the plate size is modeled as large for the cutout size. ANSYS is used for analysis. A quad 4-node (PLANE 182) and brick 8-node (PLANE 185) solid element is used for modeling. The plate is constrained at one edge. The area of the cutout is considered same for all the geometric shapes that are 2826m^2.

MODAL ANALYSIS OF THE PLATES WITH CUTOUTS:

Modal analysis is done for the following figures

a) Circle
b) Triangle
c) Square
d) Pentagon
e) Hexagon
f) Heptagon
g) Octagon
h) Nonagon
i) Decagon
j) Plus

In this project for ease of analysis, we are considering a plate and all the geometrical shaped cutouts are of the same area.
Conditions for the plate are as follows
Element type: PLANE 182, SOLID 185
Material properties: E=11E8, PRXY=0.3, DENSITY=0.000728
AREA of the cutout = 2826m^2

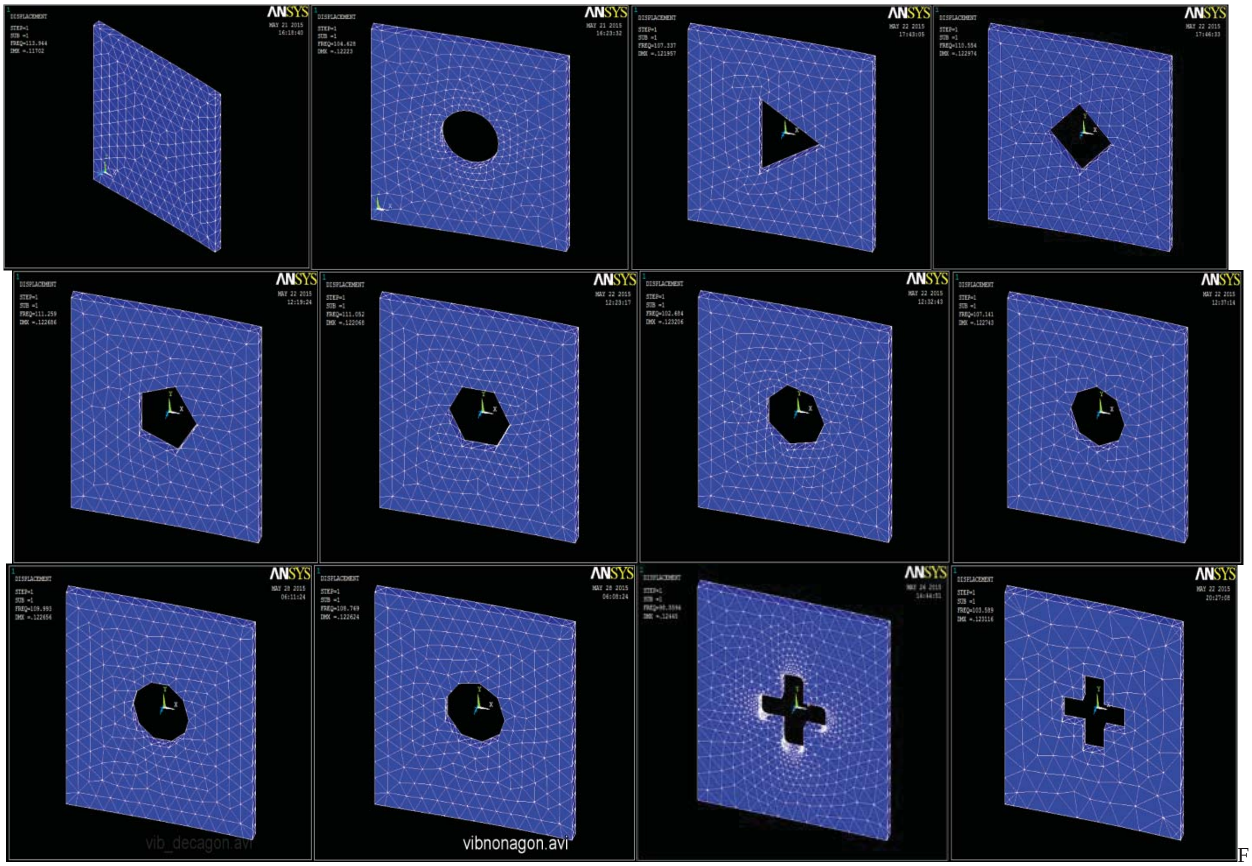

Figure 1: Modal analysis of all the geometrical shapes including the plus shaped cutout

Table 1: MODAL ANALYSIS OF GEOMETRICAL SHAPES

SHAPES	FREQUENCY	DEFLECTION
Plate without hole	113.944	.117020
Circular	104.628	.122230
Triangular	107.337	.121957
Square	110.554	.122974
Pentagonal	111.259	.122686
hexagonal	111.052	.122068
Heptagonal	102.684	.123206
Octagonal	107.141	.122743
Plus	103.589	.123116

From the table it is observed that the heptagon has least frequency and plus shape also has less frequency compared to the other shapes.
The deflection is almost the same for all the shapes; i.e the deflection is not much affected in the modal analysis.
STATIC ANALYSIS OF THE PLATES WITH CUTOUTS
For the static analysis the method followed is as described. Finite element analyses are carried out for the stress concentration of perforated steel plates. The dimensions of the steel plate are 200 m (x-direction), 200 m (y-direction), and 10 m (z-direction). Material properties are Young’s modulus of 200 MPa and poissons ratio of 0.3. The cutout is located at the center of the plates. To observe the stress concentration clearly, the plate size is modeled as large for the cutout size. ANSYS is used for analysis. A quad 4-node solid element is used for modeling. The

plate is fixed at one edge and the loading condition is 20 MPa pressure is applied at other edge. The area of the cutout is considered same for all the geometric shapes that are $2826m^2$.
Static analysis is done for the following figures

a) Circle
b) Triangle
c) Square
d) Pentagon
e) Hexagon
f) Heptagon
g) Octagon
h) Nonagon
i) Decagon
j) Plus

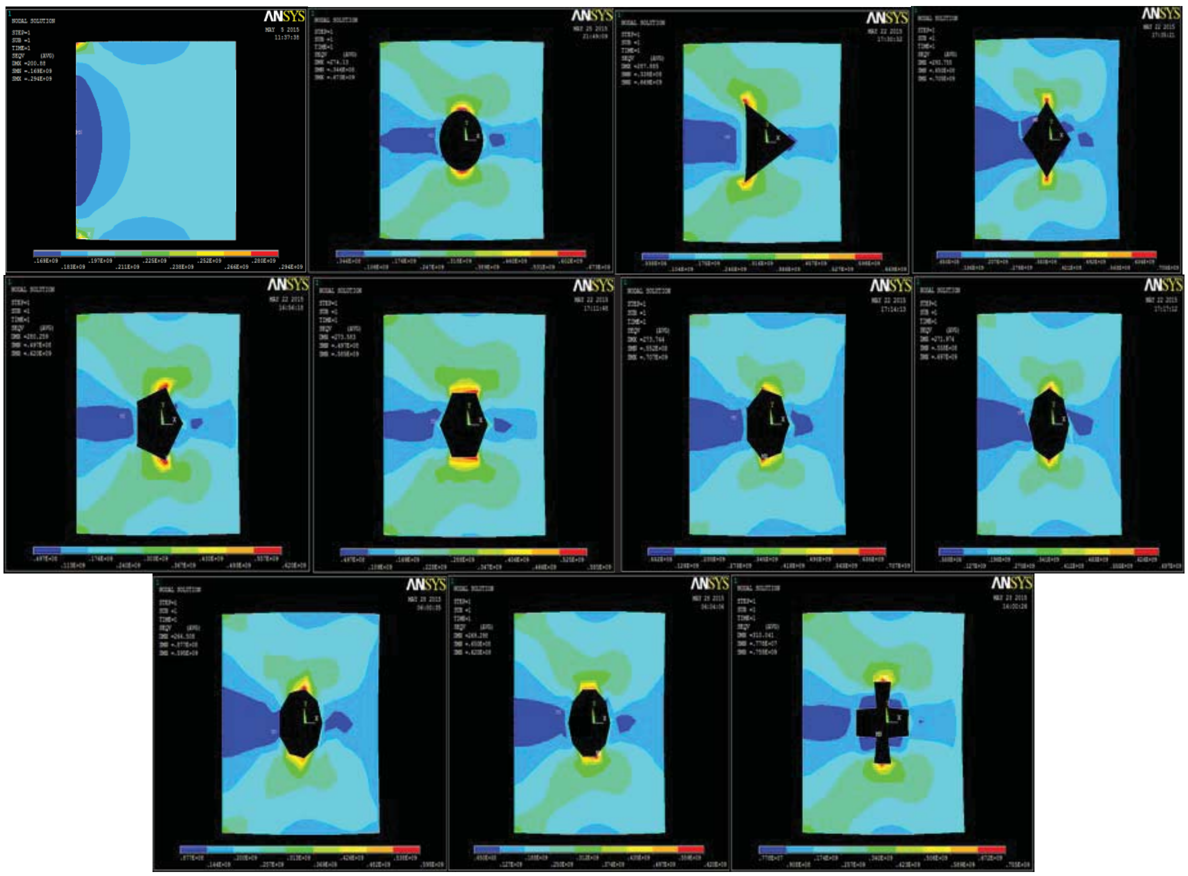

Figure 3: Static analysis of geometrical shapes of cutouts including plus shaped cutout

Table 2: STATIC ANALYSIS OF PLATE WITH GEOMETRIC SHAPED CUTOUTS

SHAPES	DEFLECTION	SMN	SMX
Without hole	200.88	.169E+09	.294E+09
Circular	274.13	.346E+08	.673E+09
Triangular	287.885	.338e+08	.669E+09
Square	293.755	.650E+08	.705E+09
Pentagonal	280.259	.497E+08	.620E+09
Hexagonal	273.583	.497E+08	.585E+09
Heptagonal	273.744	.552E+08	.707E+09
Octagonal	271.974	.558E+08	.697E+09
Plus	310.041	.778E+07	.755E+09

IV. RESULTS & DISCUSSIONS

In this paper, the data that has been input is just for sample and is not exact to the aircraft design structure. Here, we are analyzing the plate at the same loading conditions and finding out the behavior of the cutouts on the plate which are having same area.

For modal analysis, change in shapes results in change in frequency and it has less effect on deflection.

As seen from table 1, heptagon has least frequency and plus shape also has less frequency.

From the observations of static analysis, it is observed that, changes in shapes results in both the stress and deflection changes.

For deflection as the number of sides increase, the deflection decreases.

From the table2 it is clearly seen that the deflection is maximum for plus, but the stress is also least for plus.

Octagon has the least deflection. But the stress is more when compared to the circular cutout.

Hexagonal cutout has less deflection compared to the circular cutout, but the stress minimum is more than the circular cutout and the stress maximum is less.

In conclusion, all the geometrical shapes have been analyzed for the static and modal analysis and all necessary data has been provided in the form of a table. The results obtained are a relative comparison of indicative study.

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