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DESIGN STUDIES ON THE EFFECT OF STRESS CONCENTRATION IN A SANDWICH PANEL

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ABSTRACT

This report presents the computational design studies on the behavior of mechanically loaded Aluminium sandwich panels with cut-outs. The study is more focused on arriving at the intensity and distribution of local stresses developed around the cut-outs. For the study purpose, a typical sandwich panel with Aluminium Honeycomb core and Aluminium face sheets were chosen having various shapes and sizes of the cut-outs. Though sandwich panels with the above construction constitutes much part of the satellite structure due to its light weight, presence of cut-outs makes them weaker. Moreover, these cut-outs are very much essential and are un-avoidable. They are provided for inspection, accessing, fuel and electrical lines crossing, etc.

The report brings out various parametric studies which are carried out to reduce the effect of stress concentration generated due to the presence of cut-outs. The effect and influence of these cut-outs on the behaviour / response of panels as a whole are studied. Strength, stiffness and stability parameters of the panels are considered as a measure of extensively used to validate/ compare the results done though the basic theoretical calculations.

Keywords: Aluminium, Cut-outs, Sandwich panel, Stiffness, Stress concentration

I. INTRODUCTION

Stress Concentration is a problem which designers have to worry about when they are designing any structure or mechanical components or machines, because the stress concentrators can cause failure to the structure. It mainly occurs due to discontinuities in flow. It has been found that structures failure in ships, boilers, structure carrying payload in outer space is due to stress concentration. Due to stress concentration the magnitude of the maximum stress occurring in any discontinuity is comparatively higher than the nominal stress. Stress concentration cause strength degradation and premature failure of structures because of fatigue cracking and plastic deformation occurring at these points. Therefore, designers should try to eliminate this problem as far as possible. It should pay particular attention to analyse in the best way possible stress concentration for designs that are made to work properly and be reliable as possible

Strain gauge measurement is one of the most popular and widely accepted for strain measurements and stress analysis. The strain gauge consists of a grid of strain-sensitive metal foil bonded to a plastic backing material. Any change in length will result in a change of resistance. Thus measurement of this resistance change with suitably calibrated equipment enables a direct reading of linear strain to be obtained [1].

The brittle-lacquer technique of experimental stress analysis relies on the failure by cracking of a layer of a brittle coating which has been applied to the surface under investigation. Specially prepared lacquers are usually applied by spraying on the actual part. Pattern of small cracks appear on the surface of this coating where the strain is high indicating the presence of stress concentration. [2].

1.1 Methods of Mitigation

The presence of stress concentration cannot be totally eliminated but it may be reduced to some extent. The mitigation of stress concentration means that the stress flow lines shall maintain their spacing as far as possible. Stress Concentration can be reduced by avoiding sharp edge corners and replacing them by fillets. By doing this, the stress flow lines will be uniform i.e. the load will be distributed uniformly which helps in reducing the stress concentration [3].

The stress concentration in a plate with a hole can be reduced by removing the material and adding auxiliary holes in the vicinity of desired hole. This will make stress flow lines smoother and hence we get less stress concentration than before [4].

The stress concentration can be reduced by giving some extra thickness around the discontinuity so as to increase the strength to prevent from failure. If weight is a problem, the rings of composite materials can be added in an isotropic plate which will strengthen the structure while taking care of weight[5].

II. COMPOSITE MATERIALS

Composite materials are multiphase materials obtained through the artificial combination of different materials in order to attain properties that the individual components by themselves cannot attain. Unlike alloys, which can comprise two more components but are formed naturally through processes such as casting, Composite materials can be tailored for various properties by appropriately choosing their components, their proportions, their distributions, their morphologies, their degrees of crystallinity, their crystallographic textures, as well as the structure and composition of the interface between components. [6].Another example of a composite material is a lightweight structural composite that is obtained by embedding continuous carbon fibers in one or more orientations in a polymer matrix. The fibers provide the strength and stiffness, while the polymer serves as the binder. In particular, carbon fibers have properties like low density, high strength, high stiffness, corrosion resistance, good fatigue and creep resistance etc. This is the beauty of composite materials that by combining two or more different materials in a particular manner we can get desired mechanical properties [7].In a single crystal, the physical and mechanical properties often differ with orientation. It can be seen from looking at our models of crystalline structure that atoms should be able to slip over one another or distort in relation to one another easier in some directions than others.

2.1 Isotropic Materials and Anisotropic Materials

The materials which have same or identical properties in all directions are isotropic materials i.e. Young's modulus does not change with direction. Their properties do not change with the direction of load applied. Examples of Isotropic Materials are metals, glass [5].The materials which have different physical properties in different directions relative to the crystal orientation of the materials. Their properties depend on the direction of load applied. Examples of Anisotropic materials are composite materials [5].

2.2 Fabrication of Sandwich Structure

The mixture of reinforcement/resin does not really become a composite material until the last phase of the fabrication, that is, when the matrix is hardened. After this phase, it would be impossible to modify the material, as in the way one would like to modify the structure of a metal alloy using heat treatment, for example. This can be done by molding, sheet forming, profile forming etc [8].

2.3 Sandwich Structure

A structural sandwich is a special form of a laminated composite comprising a combination of different materials that are bonded to each other so as to utilize the properties of each separate component to the structural advantage of the whole assembly. Typically a sandwich composite consists of three main parts; two thin, stiff and strong faces separated by a thick, light and weaker core. The faces can be both metallic and nonmetallic based on the requirement of the problem [9].The design principle of a sandwich composite is based on an I-beam, which is an efficient structural shape because as much as possible of the material is placed in the flanges situated farthest from the center of bending or neutral axis. Only enough material is left in the connecting web to make the flanges act in concert and to resist shear and buckling loads. In a sandwich, the faces take the place of the flanges and the core takes the place of the web. The difference is that the core of a sandwich is of a different material from the faces and it is spread out as a continuous support for the faces rather than concentrated in narrow web. The faces act together to form an efficient stress couple or resisting moment counteracting the external bending moment. The core resists shear and stabilize the faces against buckling or wrinkling. The bond between the faces and the core must be strong enough to resist the shear and tensile stresses set up between them. The adhesive that bonds the faces to the core is of critical importance [10].

2.4Design of Composite piece

The following characteristics properties always have to be kept in mind by the designer:

- Fibre orientation enables the optimization of the mechanical behaviour along a specific direction.
- The material is elastic up to rupture. It cannot yield by local plastic deformation as can classical metallic materials.
- Fatigue resistance is excellent.
- The safety factors for predesign to take care of uncertainties:
- Magnitude of mechanical characteristics of reinforcement and matrix.
- The stress concentrations
- The imperfection of the hypotheses for calculation
- The fabrication process
- The aging of materials.

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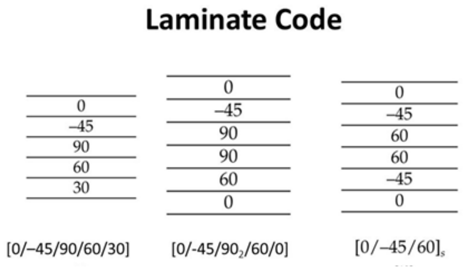

Fig2.1 Laminate orientation, plynotations.[11]

For example, in the figure 2.1, first notation is for the five layers with different orientation values. The second one is the six layer ply with orientations while the third one has a mid-plane symmetry denoted by s when we write the ply notations.

2.5 Failure of laminates

Delamination of fibres is a major concern for the composite components to take care of. It is the separation of adjacent layers due to weakening of interface layer between them. The geometry of the laminates exposes the material for damages. These can be free edges, notches and cut outs and bounded joints. This reduces the strength and stiffness of the material and gives rise to the stress concentration in load bearing plies and local instability leading to a further growth of delamination which results in the compressive failure of the laminates. The methods generally used to prevent delamination of the materials include precision and accuracy while manufacturing and following the correct process. It can also be prevented by using more material thickness of same or different material, i.e., the use of doublers, around the cut outs and areas prone to damage. The other technique is ply drop in which the thickness of the ply of doublers is decreased gradually with each laminate.

This technique is used in the project that was done. On the shear panel, doublers with ply drop were introduced in order to reduce the chances of delamination due to high amount of stress concentration on the cut-outs, as shown in the figure 2.2

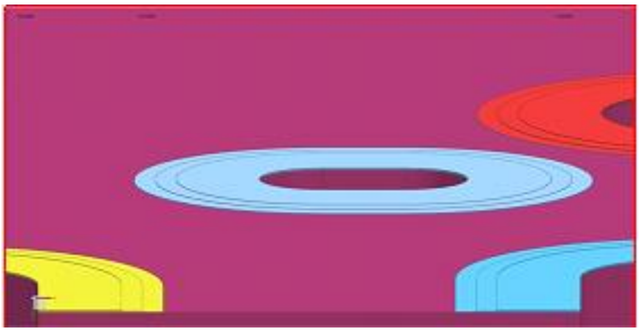

Fig2.2 Plydrop techniqueusedon acut out

III. STRESS CONCENTRATION

The stress concentration on any material is an important concern as it can cause any failure. For the research work and a better understanding of certain concepts we compared the theoretical studies with the numerical analysis done on the different materials and shapes. These analyses were done using different software for designing and the analysis of those designs. The designing was done on the

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Siemens NX Nastran and the major part of analysis was carried out on the MSC Nastran and Patran, including the meshing, material assigned, applying load and boundary conditions and then finding out the results.

IV. FINITE ELEMENT ANALYSIS

Finite element method is the most important numerical method. It is a numerical technique used to determine the approximated solution for a partial differential equation (PDE) on a defined domain. To solve the PDE, the primary change is to create a function base that can approximate the solution. There are many ways of building the approximation base and how this is done is determined by the formulation selected. The finite element method has a very good performance to solve partial differential equations over complex domains that can vary with time. The accuracy of the results can be increased by increasing the number of nodes or points of calculation. To prove this a simple activity was performed. Consider a plate of dimensions 1m×1m×0.1m. Two boundary conditions were applied. To one plate a 2 D meshing is done and to the other plate 3D meshing is done. A total load of 51000N is applied.

Table 2 Stress and deflection on a plate with same dimensions with different meshing

S.No	**Particulars**	**2Dmesh**	**3Dmesh**
1	Load(N)	51000	51000
2	σ_{max}(N/m^2)	12.6× 10^5	19.1× 10^5
3	σ_{min}(N/m^2)	4.24× 10^5	2.60× 10^5
4	σ_{nom}(N/m^2)	6.46× 10^5	7.01× 10^5
5	τ_{max}(N/m^2)	6.65× 10^5	9.99× 10^5
6	τ_{min}(N/m^2)	3.51 × 10^5	1.31× 10^5
7	τ_{nom}(N/m^2)	2.37 × 10^5	3.6× 10^5
8	δ (m)	7.98 × 10^3	9.14× 10^3

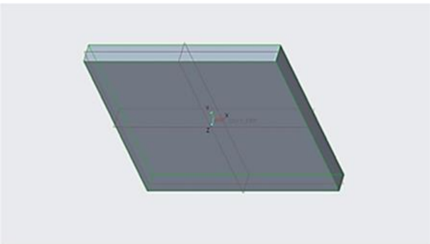

Fig: 4.1 Plate of dimension (1m×1m×0.1m)

This shows that with 3d meshing, we increase the number of calculation points and get more accurate result

4.1 Isotropic Plate with a hole of different d/w ratio

The next experiment was done in order to see the effect on stress concentration on plate with a hole varying the d/w ratio. An isotropic plate with dimensions 1m×1m×0.01m is taken. The plate is made up of aluminum (Al). A total load of 41000N is applied on the plate in all the different conditions of d/w ratio. A proper procedure of designing, meshing, assigning the material, applying load and boundary conditions is followed. After doing all these steps, the file for analyzing is ready and the results are achieved. The values of maximum stress, minimum stress and nominal stresses are recorded. This helps us to find out the stress concentration factors which are compared.

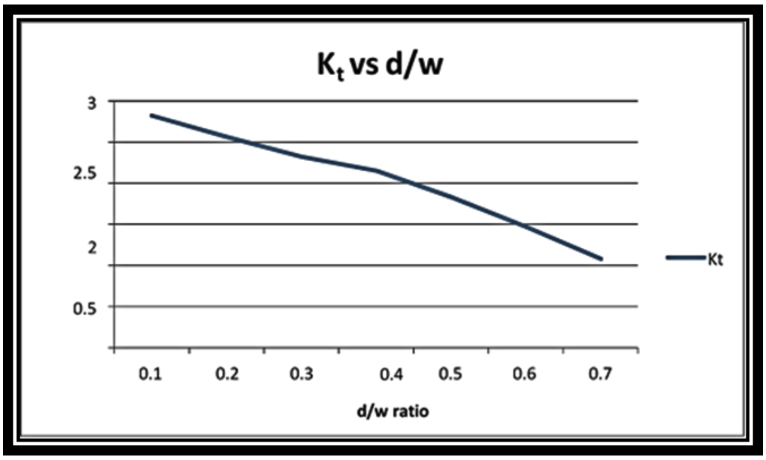

Fig: 4.2 Graph of Kt Vs d/w ratio

4.2 Plate with Elliptical hole

In this experiment, the plate with an elliptical hole was tested. The hole was kept in transverse and horizontal direction as well. The isotropic material of aluminum (Al) is used of dimensions1m×1m×0.01m.The elliptical hole with major axis 200mm and min or axis100mmisremovedfromthesolidplate.Theobjectiveof the experiment is to prove that the elliptical hole intransverse direction can have more stress concentration and hence more chances of failure

Table 3 Stress and stress concentration of a plate with elliptical hole.

S.No	Particulars	Longitudinal	Transverse
1	σ_{max} (N/m^2)	1.24×10^6	1.91×10^6
2	σ_{min} (N/m^2)	0.0580×10^6	0.05×10^6
3	σ_{nom} (N/m^2)	0.373×10^6	0.546×10^6
4	K_t	3.32	3.46
5	τ_{max} (N/m^2)	6.22×10^5	9.64×10^5
6	τ_{min} (N/m^2)	0.309×10^5	0.262×10^5
7	τ_{nom} (N/m^2)	1.88×10^5	2.76×10^5
8	δ (m)	1.71×10^4	9.60×10^3

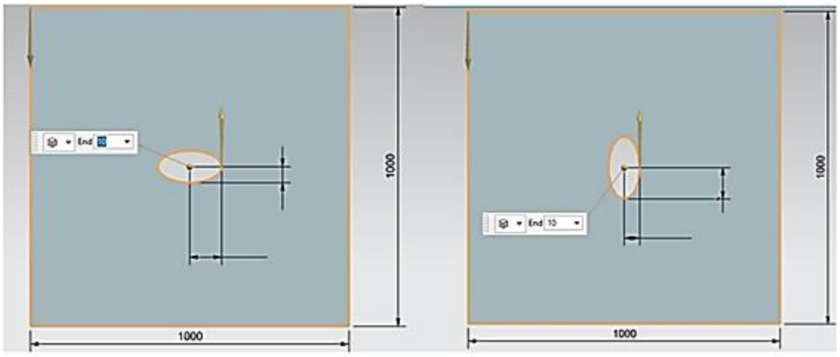

Fig: 4.3 Elliptical hole longitudinal and transverse to the load applied.

Therefore, from this experiment, it is clear that the level of stress generated in transverse is more as compared to the longitudinal direction. Same way the value of stress concentration is more in the transverse direction. This indicates that the elliptical hole should be designed in such a way that it suffers longitudinal load for better structural strength.

4.3 Plate with multiple holes.

Stress concentration arises due to the non-uniform flow around the cut out. To decrease the value of stress concentration around a hole, the flow is made uniform around the cut out by introducing other holes around the main cut out section. Holes on both the sides are cut in sizes less than the major hole. It makes the flow pattern uniform which reduces the stress value and hence the stress concentration. An experiment is done to prove the point that adding multiple holes to the plate on the sides of the main hole reduces the value of stress concentration. Equal amount of load/force is applied on two plates. One plate is with a single hole on the center while the other plate has two extra holes inserted.

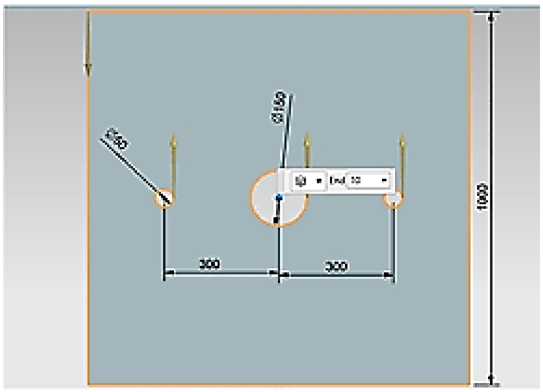

Fig: 4.4 Plate withmultiple Holes

Table 4 Results for the plate with single and multiple holes

S.No	Particulars	Single Hole	Multiple Hole
1	σ_{max} (N/m^2)	12.2×10^6	3.43×10^6
2	σ_{min} (N/m^2)	0.854×10^6	4.95×10^4
3	σ_{nom} (N/m^2)	3.89×10^6	0.950×10^6
4	δ (m)	6.47×10^{-5}	2×10^{-5}

This in turn produces the following values of stress in the structure. From this, it is proved that with insertion of holes, stress can be reduced on the component

4.5Sandwich Structure

In the next experiment, when we did the composite structure with different d/w ratios, it was noted that the results were similar to the results of an isotropic plate with holes of different d/w ratio. It proves that stress concentration is a cross sectional property and not a material property. A sandwich structure of dimensions (1m×1m×25.5mm) is applied a load of 41000N. The face sheets are made of Al and core is a Low density core (LDC). The thickness of face sheets is 0.25mm and the core is 25mm.The following results are obtained for the sandwich structure with different d/w ratios. It is well noted that the values of stress does change by using the sandwich structure instead of an isotropic plate, but the stress concentration factor is same in both the cases. Therefore, stress concentration is a cross sectional property and is independent of the material used.

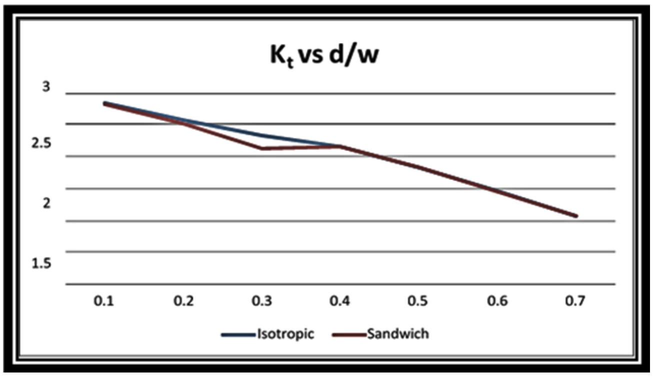

Fig: 4.5 Sandwich Structure and Isotropic Plate with different d/w ratio

4.6Intermediate Deck

Design of any satellite is very typical and is very important that all the considerations are kept in mind. The work was to analyse the intermediate deck of this satellite for various considerations and the impact of stress concentration on the cut outs in the deck. These cut outs causes the stress concentration to increase while these cannot be avoided. These are required by the propulsion lines, electric lines and for various other purposes. The installation of other components has to be made on the cut outs. The picture shown(figure 4.6) below is the intermediate deck with some installation of components, non- structural mass and also some cut outs left empty for various purposes. The design of deck is imported from solid works software.

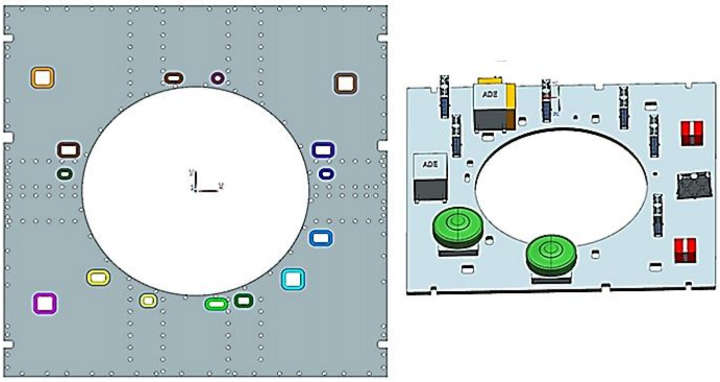

Figure 4.6 Intermediate Deck of the Satellite with non-structural mass

The intermediate deck is meshed using the software Hypermesh which is very effective for the preprocessing of the structure. The component is divided into equal and measurable size of the elements. This helps to determine the results in each individual element with accuracy and precision. Elements of the component can't be divided as some random shapes and sizes. There are also a huge number of applications based upon meshing software's. The proper high accurate meshing software's are high in cost and probably they were used again based on the application of the problems. There are some checks, called mesh checks, to be done which are: Min/ Max. Element Size, Aspect Ratio, Skew Angle, Warpage, Jacobian Ratio, Chordal deviation, Tria element percentage.These ensure the correctness of the mesh that is done. After completing the mesh of the component, it is check for rigid body modes without applying any force and or boundary conditions. The frequencies should be about zero to get a verified meshing where all the points are connected. The stiffness of the structure was calculated when a doubler of thickness 1mm is inserted on all cutouts. It gives the normal modes of frequency, where first frequency is 81.946 N/m. The stiffness of the structure increase when the doubler of thickness 1.5mm is inserted instead of 1 mm. The stiffness now is 82.177 N/m.When the deck was analyzed for all the cutouts without any doubler and considering the hard points which are otherwise the points for the joints and assembly, the stiffness of the structure is 80.248 N/m.

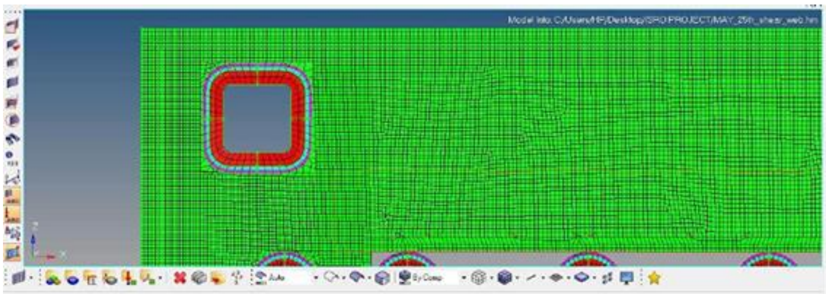

Fig: 4.7 Meshing in Hypermesh

Table 5: The results of the Stress on the deck

S.No	Particulars	1 gin x	1 giny	1gin x	10 gin x	10 giny	10 gin z
1	σ_{max} (N/m^2)	1.59 e^6	1.64 e^6	2.74 e^6	1.59 e^7	1.64 e^7	2.74 e^7
2	σ_{min} (N/m^2)	5.51 e^3	5.79 e^3	3.21 e^3	5.51 e^4	5.79 e^4	3.21 e^4
3	σ_{nom} (N/m^2)	4.27 e^7	4.41 e^5	7.32 e^5	4.27 e^6	4.41 e^6	7.32 e^6
4	δ (m)	1.11e^{-6}	1.34e^{-6}	5.97e^{-7}	1.11e^{-5}	1.34e^{--5}	5.97e^{-4}

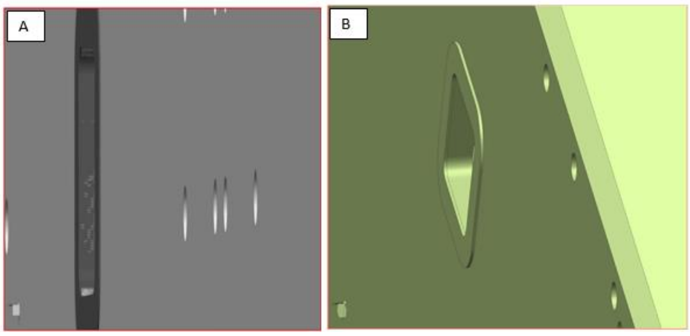

Fig: 4.8A.Cutout with doubler of thickness 1mm, B .Cutout with doubler of thickness 1.5 mm

A doubler of 1mm thickness is inserted on the cutouts. The results changes is shown in table 6

Table 6 Results withdoublerof1mm thickness

S.No	**Particulars**	1 gin x	1 giny	1gin x	10 gin x	10 giny	10 gin z
1	σ_{max} (N/m^2)	1.48 e^6	1.56 e^6	3.11 e^6	1.48 e^7	1.56 e^7	3.11 e^7
2	σ_{min} (N/m^2)	3.64 e^3	2.77 e^3	1.24 e^3	3.64 e^4	2.77 e^4	1.24 e^4
3	σ_{nom} (N/m^2)	3.98 e^5	4.17 e^5	8.29 e^5	3.98 e^6	4.17 e^6	8.29 e^6
4	δ (m)	1.05e^{-6}	1.29e^{-6}	5.69e^{-7}	1.05e^{-5}	1.29e^{--5}	5.69e^{-4}

A doubler of 1.5mm thickness is inserted on the cutouts. The results changes is shown in table 7

Table 7 Results with doubler of thickness 1.5 mm

S.No	**Particulars**	**1 gin x**	**1 giny**	**1gin x**	**10 gin x**	**10 giny**	**10 gin z**
1	σ_{max}(N/m^2)	1.45 e^6	1.54 e^6	3.36 e^6	1.45 e^7	1.54 e^7	3.36 e^7
2	σ_{min}(N/m^2)	2.02 e^3	2.56 e^3	1.87 e^3	2.02 e^4	2.56 e^4	1.87 e^4
3	σ_{nom}(N/m^2)	3.89 e^5	4.11 e^5	8.96 e^5	3.89 e^6	4.11 e^6	8.96 e^6
4	δ (m)	1.03e^{-6}	1.28e^{-6}	5.64e^{-7}	1.03e^{-5}	1.28e^{--5}	5.64e^{-4}

The result is with installing the doubler we can decrease the value of stress generation and also stress concentration factor on the structure.

Table 8 Comparison of cut out without and with doubler

Particulars		**Without Doubler**	**Doublerof1mm**
100×100	f_1	42.068	43.49
	f_2	66.288	67.06
	f_3	77.279	77.27
	f_4	78.251	78.251
200×200	f_1	41.279	43.446
	f_2	60.495	63.054
	f3	77.308	77.308
	f4	78.154	78.153

The subsystem mass was initially considered to be 15 Kg, which is changed to a value of 25 kg. The mass increase makes the section even more critical. This decreases the stiffness on the sandwich panel.

V. CONCLUSION

The experiments performed on different structures of isotropic and anisotropic plates and other structures with different considerations. There are various inferences made based on the experiments. Stress concentration factor changes when the d/w ratio of hole and plate changes. It is a cross sectional property and does not depend upon the material of the plate. When introducing an elliptical hole in the plate, it should be longitudinal to the direction of force applied to make it safer and much reliable. The methods we read theoretically to mitigate the stress concentration have been proved experimentally in this report. They are to introduce fillets, add multiple holes near the cut out for a continuous flow and to add a doubler of certain thickness to the cut out. In the intermediate panel, it can be seen that the stress induced on the panel decreases when the thickness around the cut out, which is a critical region, while the stiffness increase in the same trend. When only one cut out is considered and all the researches were done it gave the proper demonstration, the cut out size increase cause the stiffness to decrease. As the doubler thickness increases, the stiffness in turn also increases. To increase the stiffness of the material, the core thickness in increased which in turn increases the moment of inertia. By increasing the mass around the cut out section, the stiffness falls. Therefore, when any structure is made it is always a trade-off between the desired properties and the impact it causes.

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