Experimental Investigation of the Aircraft Stiffened Panel Structure under Pressure Loads

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Abstract - An Aircraft is a light weight air breathing semi-monococque complex aerostructure comprising of longerons, bulkheads, stiffeners, stringers, lugs, bolts and joints, ribs and other special forms of structures. In its service, it has to sustain mainly aerodynamic, structural, propulsive, fatigue and impact loads. Even though the load carrying agents are the stiffening materials, the loads are firstly faced by the aircraft skin in the form of shear loads and later on transferred to the stiffening structures inside. These loads give rise to bending, buckling, shear, torsion and warping effects in different magnitudes on the semi-mococque structures. The implementation of the stiffened panel structure can be found inside the fuselage, wings and horizontal and vertical stabilizers of an aircraft. While in operation, an aircraft must resist all the loads said above in all kinds of mission profiles, that is from passenger, cargo, military, reconnaissance to combat situations with varying load spectrum. So it becomes very important and necessary to analyse an aircraft stiffened panel structure subjected to assumed static structural loads and dynamic (modal) loads.

Keywords - Aircraft, Static, Modal, Stiffened panel, All sides clamped, FEA - ANSYS WORKBENCH 14.5.

I. INTRODUCTION

An Aircraft on the outside, only skin is visible to the naked eye. But on the inside it is composed of semi-monococque structures as illustrated in the figure 1 below. Stiffeners are secondary sections which are attached to flanges or plate structures to stiffen them against the out of plane deformations. There are many varieties of cross sections that have been used for stiffening purpose and are illustrated in the figure 2 below.

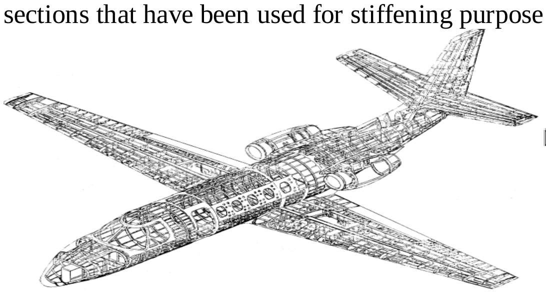


Figure 1. Semi monococque structure of an aircraft

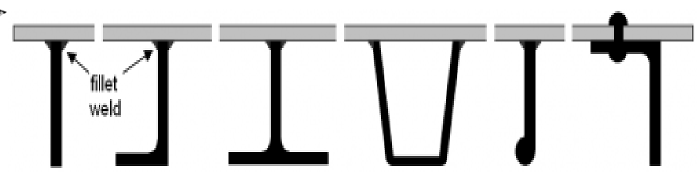


Figure 2. Many varieties of cross sections of stiffeners

Panels stiffened with attached stiffeners are frequently used in aerospace, naval, civil, mechanical and architectural structures and find its applications in the units of aircraft, spacecraft, ship, stadium, bridges etc when structural weight is an important concern. They are illustrated in the following figures.

Figure 3. Fuselage of an aircraft

Figure 4. Bridge

Figure 5. Metro station

Figure 6. Oil & gas industry

Figure 7. Ship Deck

Stiffened panels are further categorized into open type and closed or box type configurations.

II. LITERATURE SURVEY

The stiffened panels can carry a considerable amount of loads after buckling in the elastic range. This post-buckling strength of thin plates is well known since many investigators, such as von Karman, Marguerre and Wagner, studied these problems. The linear buckling theory is no longer useful to analyze the post buckling behavior of a thin plate and the buckling strength cannot be used as a design criterion for such structures. Since the problem is too complicated to be treated mathematically, in general, several empirical formulae have been put forward based on GALCIT and MIT tests. The linear buckling theory of the plate in the strain hardening range based on the effective moduli of the material after yielding can furnish the appropriate design criterion which predicts the ultimate strength of the panels.[36]

The stiffened panel structures has increased load handling capabilities with excellent stiffness, strength to weight ratios and factor of safety which would be otherwise achieved by increasing the thickness of the material which increases the structural weight. The theory of stiffened panel emerged from the concept of effective width of a plate analysis, in which the theory was developed to observe the post buckling theory of plates subjected to biaxial compressive loads that made considerable weight savings providing exceptional load handling characteristics.[27] This theory was implemented in the wings and stabilizers so as to provide the strength, stiffness and stability required for the structure. In the wing, the stiffening structures are stiffeners or stringers, spar elements, wing ribs and spar caps. In the fuselage structure, Ring shaped frames, stiffeners or stringers, longerons and bulkheads constitutes the stiffening structures.

Most of the stiffened plates have used stiffeners in the two mutually orthogonal constant directions. Earlier, these directions used to coincide with the length and breadth of the plate. However, there are now some examples of stiffeners being placed in geodesic fashion depending upon the loads that are applied to the panel. By continuously varying the stiffener orientation, we can align the stiffeners along the load paths for the static case and in a way that can drive the natural frequencies away from the resonance frequencies for a dynamic case. This was the motivation behind the study and making of this paper. Hence the objective of this paper is to analyse a stiffened panel subjected to static and modal analysis.[36]

III. METHODOLOGY

Experimental Analysis-

A plate with longitudinal and transverse stiffeners is considered in the figure 9 with all edges clamped. A constant pressure of 0.05 N/mm^2acts on the underside of the shell (i.e. the pressure acts in the +z direction). The dimensions of the plate and stiffeners are shown in the table 1 below.

Table 1. Dimensions of a quarter stiffened panel

SI No	Description	Nomenclature	Dimensions (mm)
1	Thickness of the plate	H1	5
2	Height of transverse stiffeners	H2	15
3	Height of longitudinal stiffeners	H3	20
4	Length of the plate	L1	750
5	Width of the plate	W1	250
6	Thickness of the transverse stiffener	W2	2
7	Thickness of the longitudinal stiffener	W3	2

The stiffened panel structure created using ANSYS 14.5 is shown in the figure below.

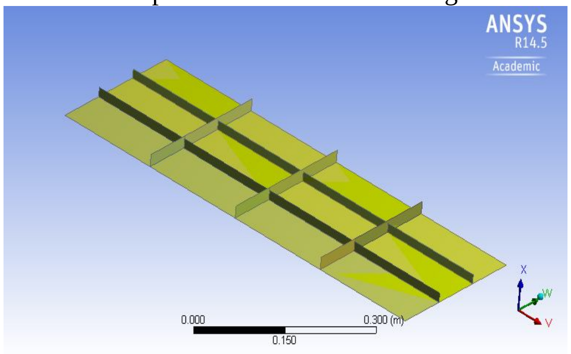
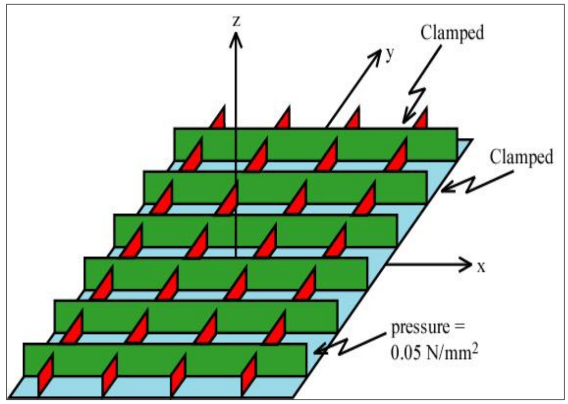


Figure 9: Stiffened panel



The properties of the materials used in the analysis are shown in the table 2 below.

Table 2. Material properties of the structure

SI No	Material	Modulus (E & G)(Pa)	Poisson's Ratio	Density (kg/m^3)
1	Structural Steel	2E11	0.3	7850
2	Aluminium Alloy	71E9	0.33	2770
3	HYBOR/Boron Compoite	E_1= 282.64 E9 E_2=8.9631 E9 E_3=8.9631 E9 G_{12}=4.1368 E9 G_{13}=4.1368 E9 G_{23}=4.1368 E9	ν_{12}=0.25 ν_{13}=0.25 ν_{23}=0.45	1965.2732

IV. RESULTS & DISCUSSIONS

The results of Static and Modal analysis are as shown in the table below:

Table 3 & 4. Results of static and modal analysis

Case	Results of Static Analysis								
	Max Normal Stress			Max Shear Stress			Directional Deformation		
	σ_{xx}	σ_{yy}	σ_{zz}	τ_{xy}	τ_{yz}	τ_{xz}	Def in x	Def in y	Def in z
1. Stifeners and Plate both are Steel	**77.838**	**133.35**	**52.924**	**42.417**	**37.396**	**19.261**	**5.785e-11**	**5.4512e-11**	**7.7356e-10**
2. Stiffeners and the Plate both are Aluminium alloy	**90.895**	**152.89**	**50.84**	**48.498**	**39.292**	**26.502**	**1.6461e-10**	**1.5607e-10**	**2.2019e-9**
3. Stiffeners and the Plate both are Hybor Composite material	**148.56**	**204.75**	**41.261**	**14.927**	**18.836**	**14.109**	**3.612e-10**	**2.814e-10**	**4.55e-9**
4. When Stiffeners are made of HYBOR/Boron Composite Material and the Plate by Steel	**88.35**	**143.75**	**15.648**	**48.542**	**7.3358**	**4.1324**	**8.413e-13**	**6.9368e-13**	**1.021e-9**
5. When Stiffeners are made of HYBOR/Boron Composite Material and the Plate by Aluminium alloy	**85.075**	**137.02**	**38.545**	**43.877**	**16.882**	**9.5108**	**2.06e-10**	**1.745e-10**	**2.562e-9**

Case	Results of Modal Analysis											
	Mode Shape 1		Mode Shape 2		Mode Shape 3		Mode Shape 4		Mode Shape 5		Mode Shape 6	
	Disp	Freq	Disp	Freq	Disp	Freq	Disp	Freq	Disp	Freq	Disp	Freq
1. Stifeners and Plate both are Steel	**0.6779**	**106.82**	**0.981**	**152.35**	**1.0585**	**294.62**	**0.969**	**326.25**	**1.1403**	**566.3**	**1.1403**	**566.3**
2. Stiffeners and the Plate both are Aluminium alloy	**1.1418**	**106.66**	**1.6566**	**152.12**	**1.7724**	**294.43**	**1.6354**	**327.01**	**2.3792**	**563.89**	**1.9078**	**566.14**
3. Stiffeners and the Plate both are HYBOR/ Boron Composite material	**1.5027**	**92.08**	**2.12**	**128.85**	**2.116**	**250.71**	**2.0215**	**290.12**	**2.5543**	**473.23**	**2.5543**	**473.23**
4. When Stiffeners are made of HYBOR/ Boron Composite Material and the Plate by Steel	**0.7064**	**95.16**	**1.0026**	**130.04**	**1.0496**	**270.42**	**1.125**	**275.23**	**1.4153**	**478.32**	**1.4153**	**478.32**
5. When Stiffeners are made of HYBOR/ Boron Composite Material and the Plate by Aluminium alloy	**1.1835**	**100.37**	**1.6704**	**138.82**	**1.788**	**284.2**	**1.7162**	**291.49**	**2.4852**	**523.79**	**2.4852**	**523.79**

Following the table above, a bar graph is plotted below for the comparison of frequencies which displays the changes in displacements for different mode shapes.

By comparing the values it can be noted that the deformations for the material in case 3 (HYBOR/Boron) is obtained at the most lowest values of frequencies implying that it is the most suitable material that can be used for stiffening and extreme heat applications in the Aerospace industry.

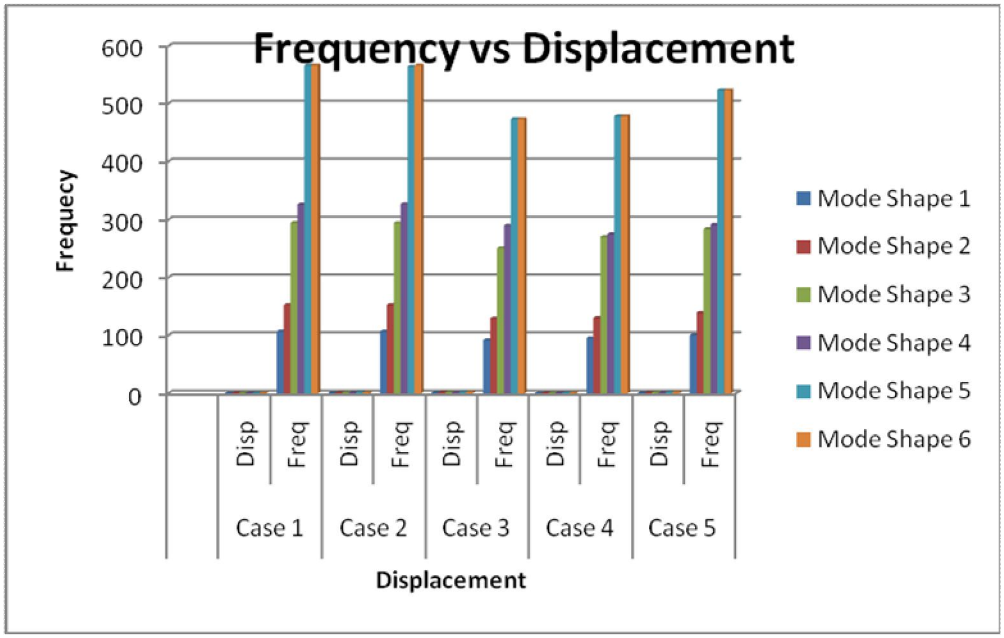
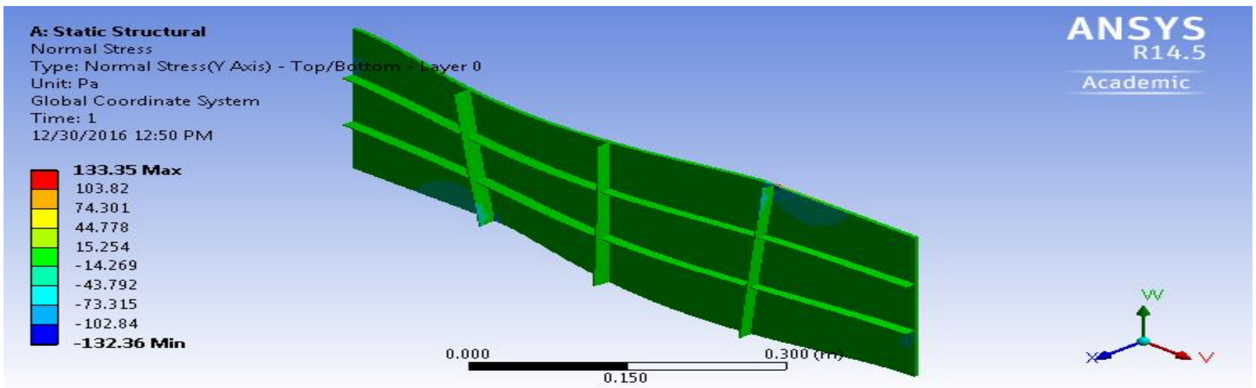
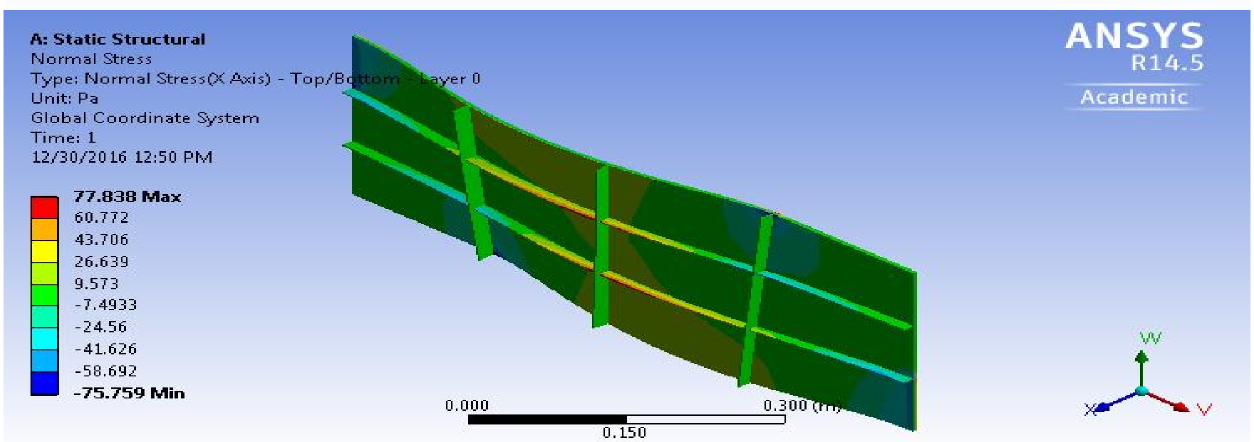


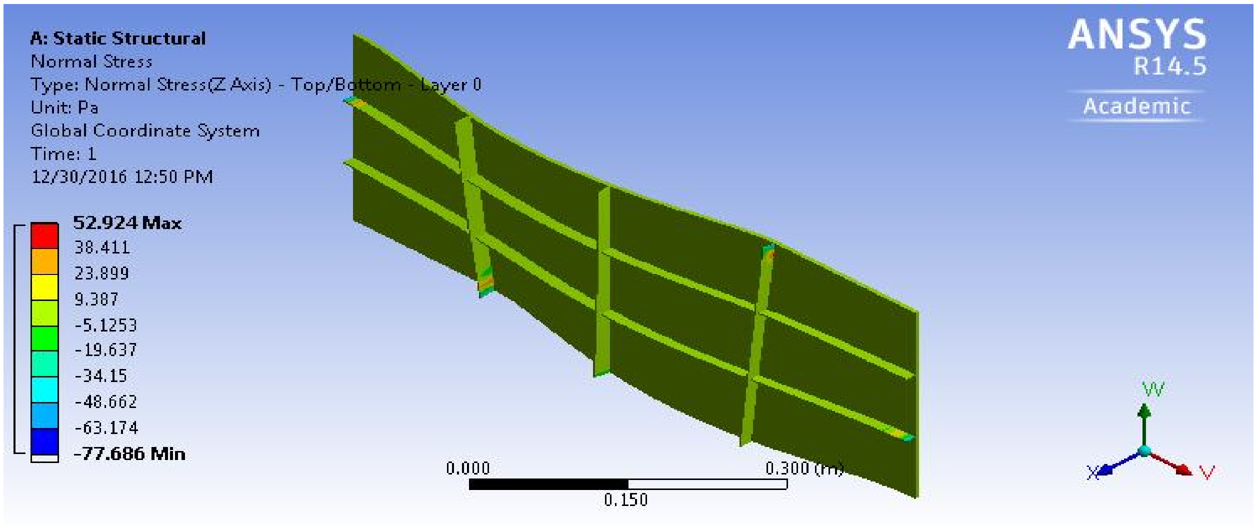
Figure 10. Frequency vs Displacement

The contour plots for all cases are shown below.

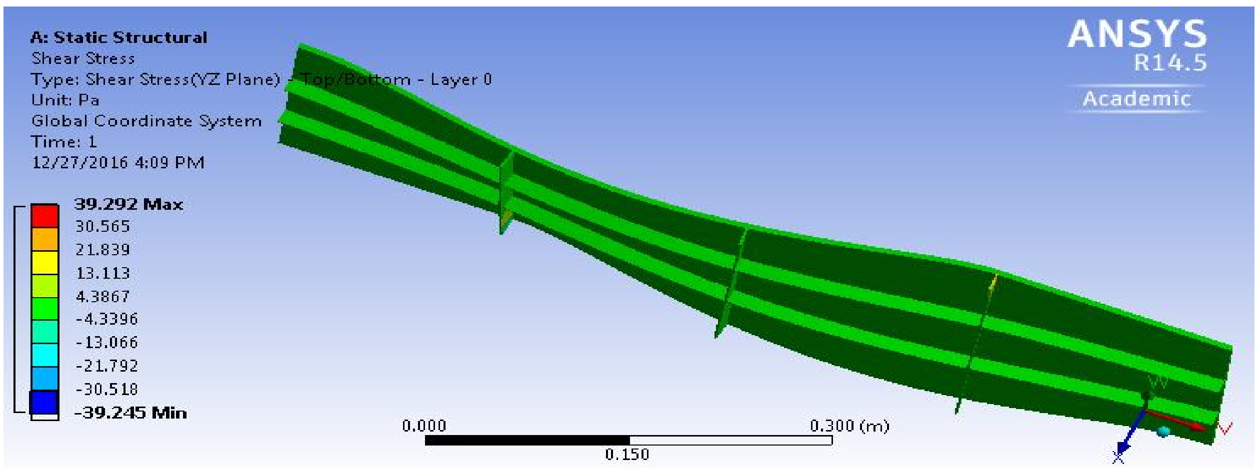
1. When Stifeners and the Plate both are made of Steel material.
   Normal stresses are shown.

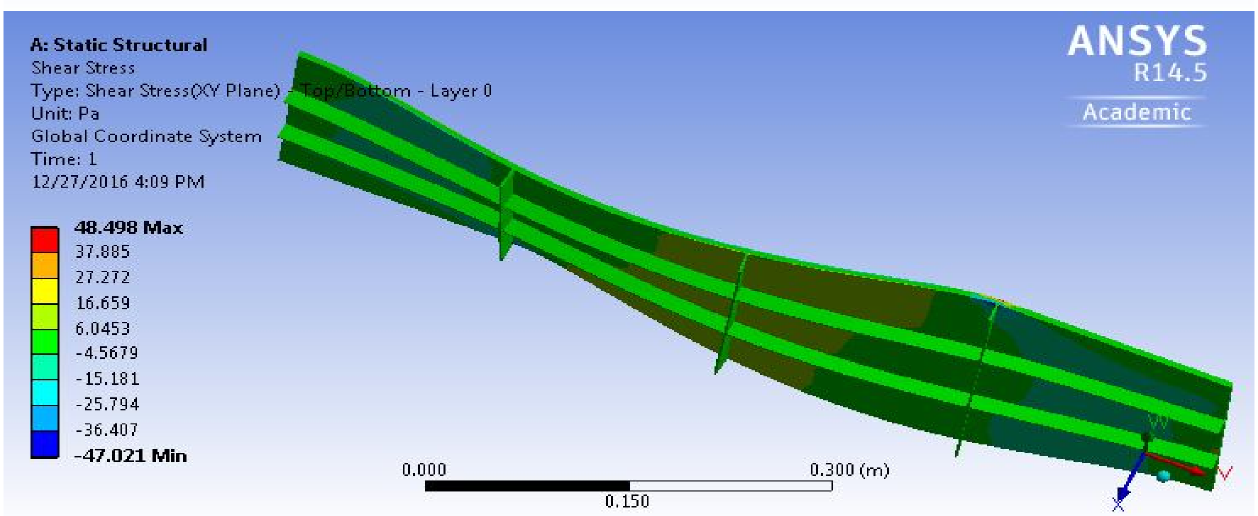


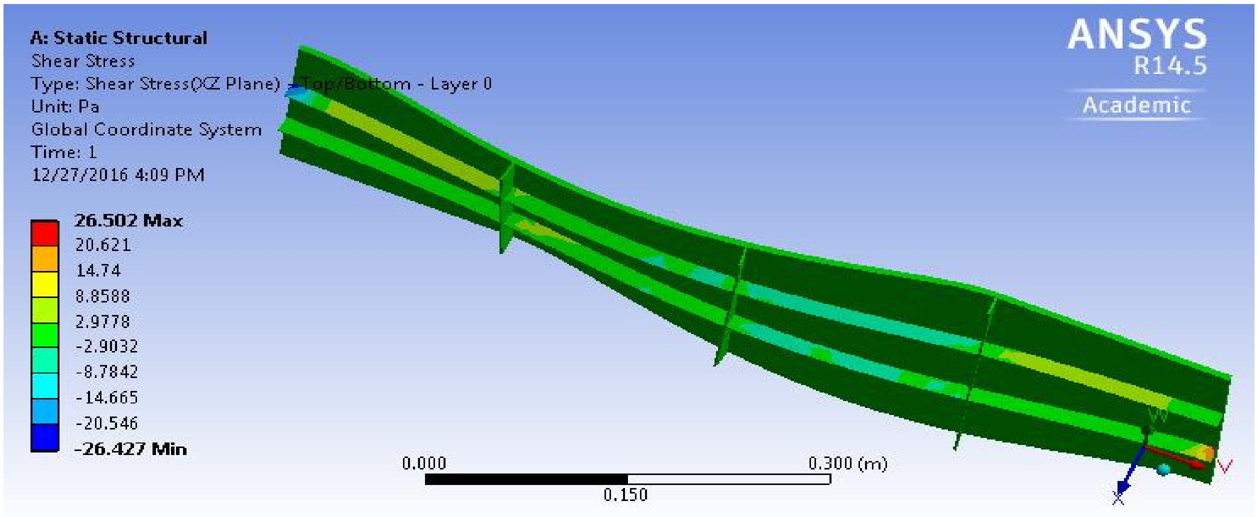




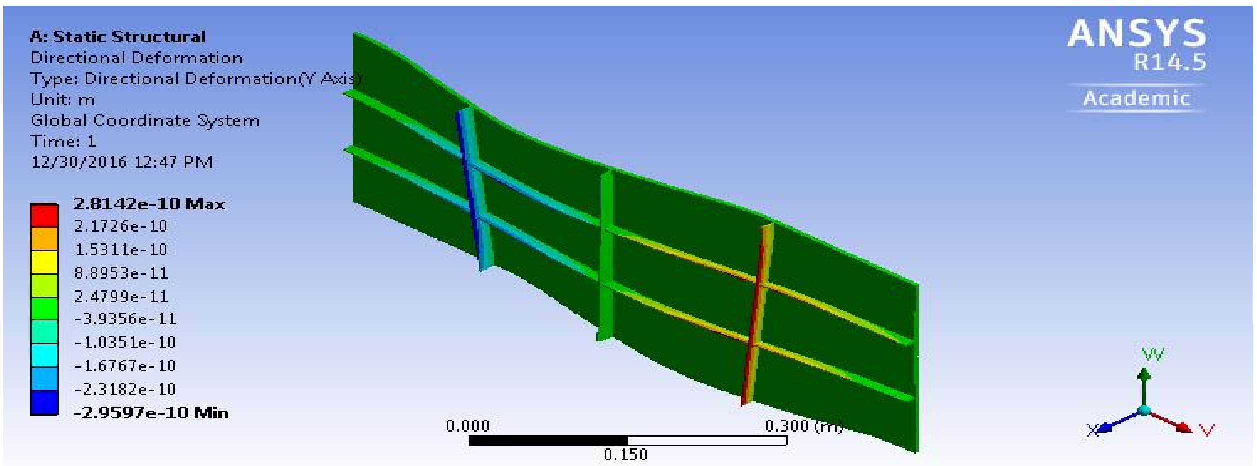
2. When Stiffeners and the Plate both are made of Aluminium alloy.
   Shear stresses are shown.

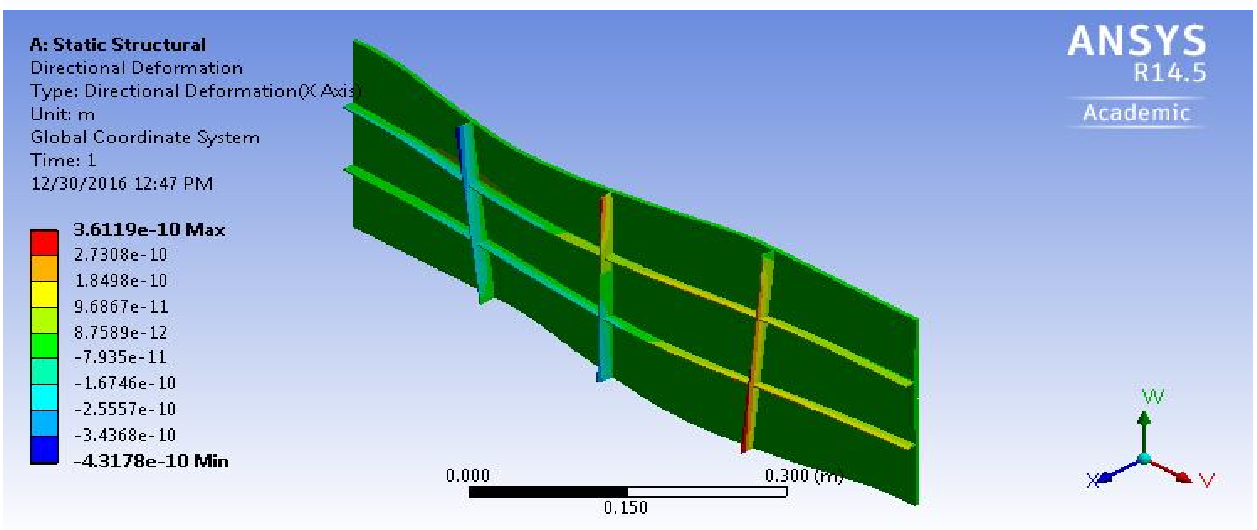


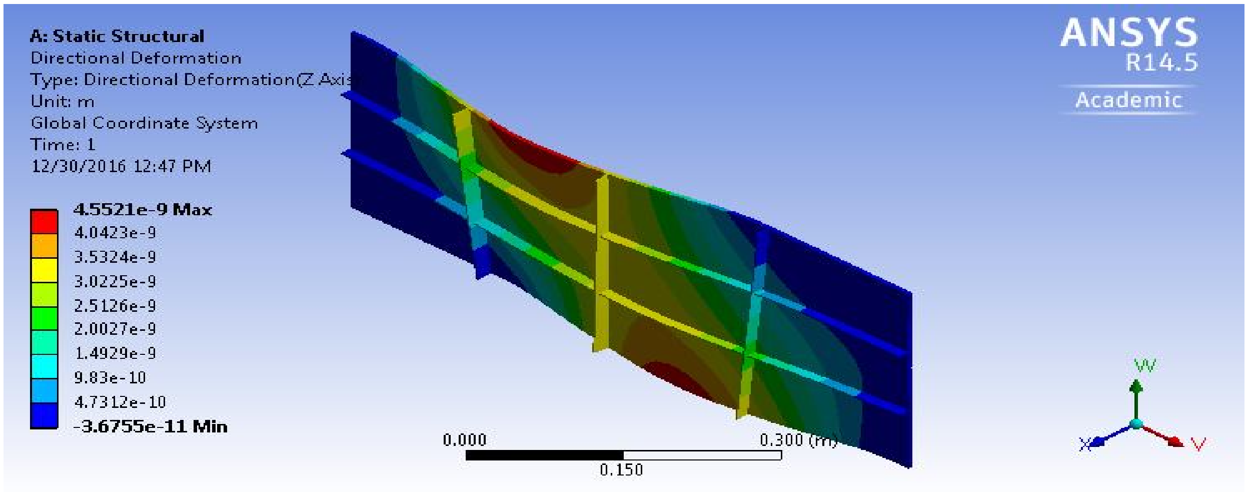




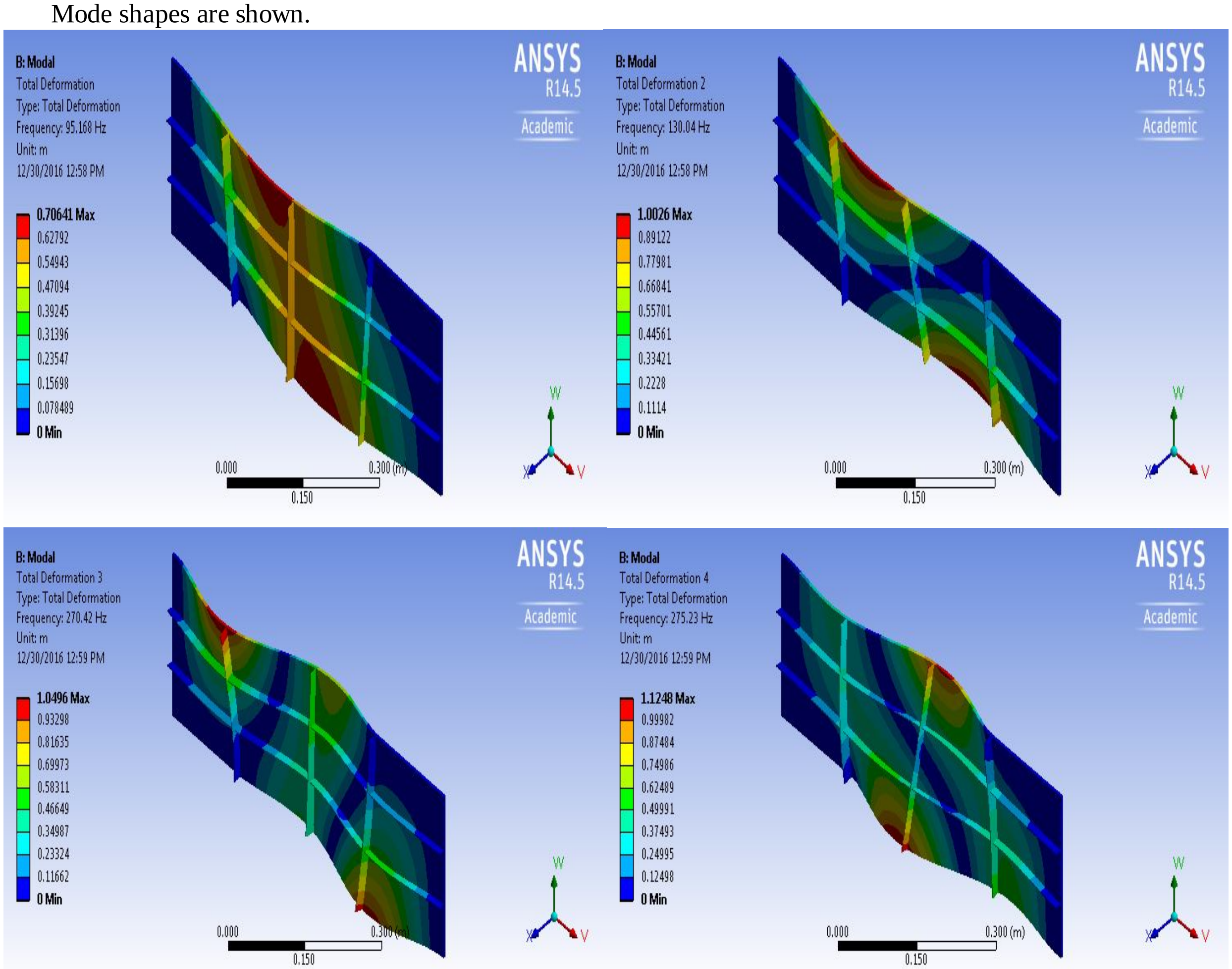
3. When Stiffeners and the Plate both are made of HYBOR/Boron Composite material. Directional deformations are shown.

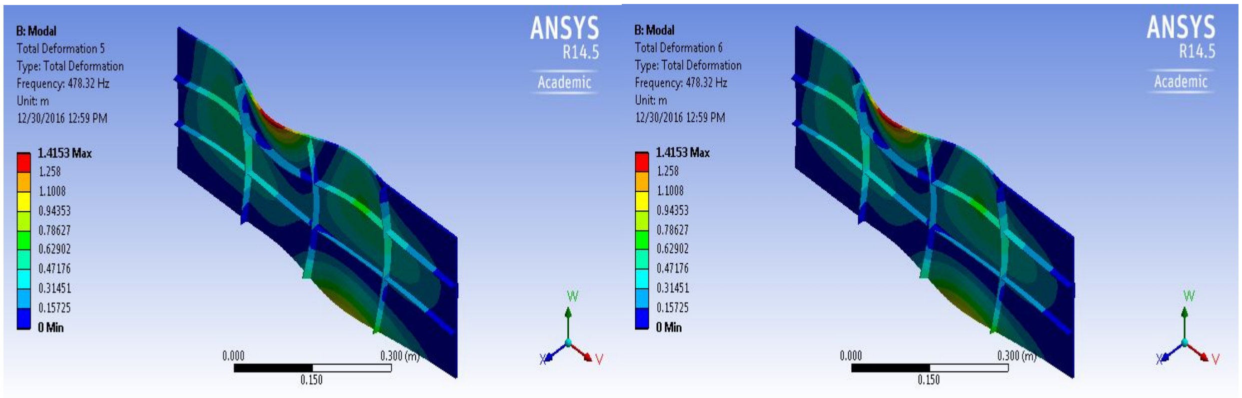




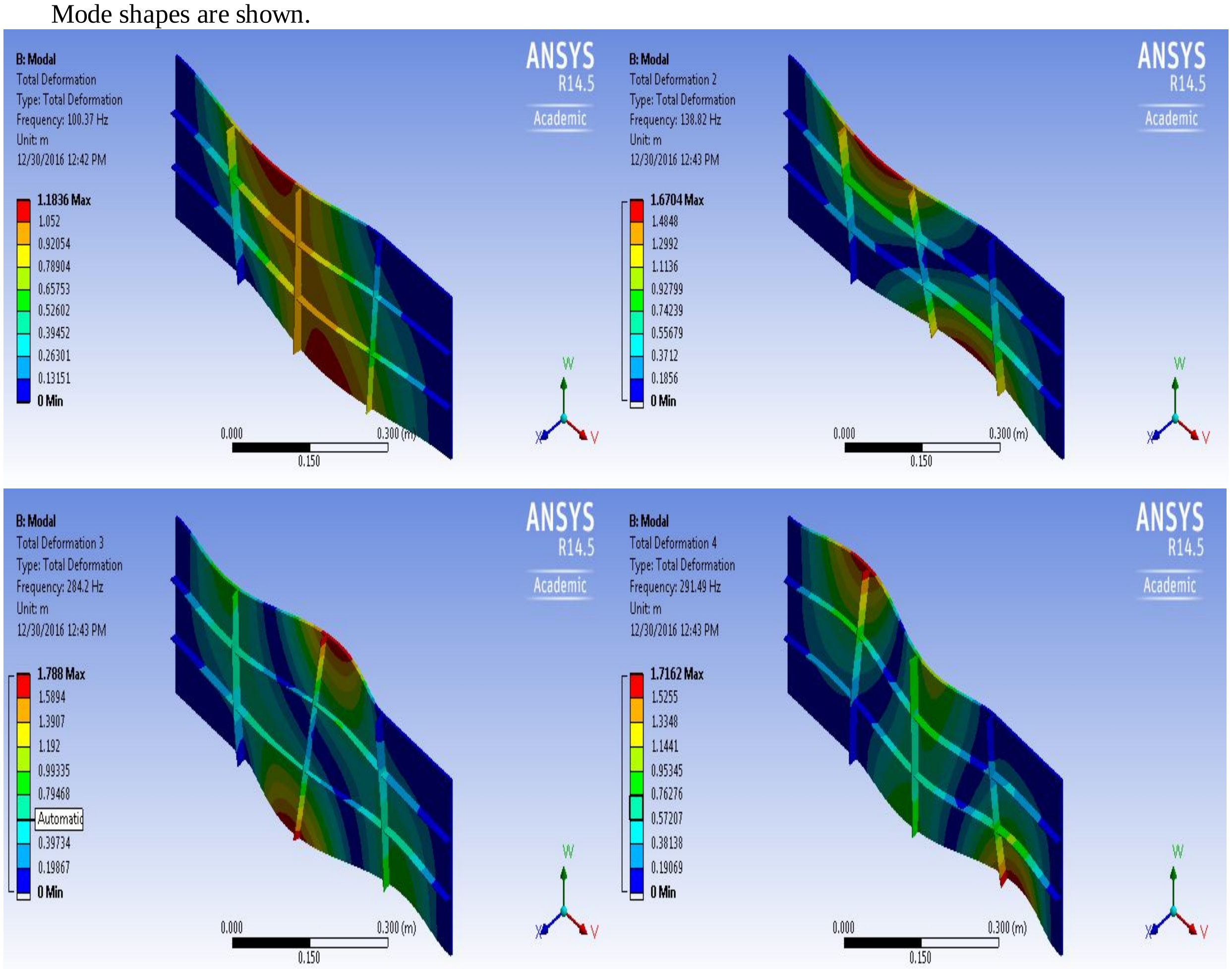


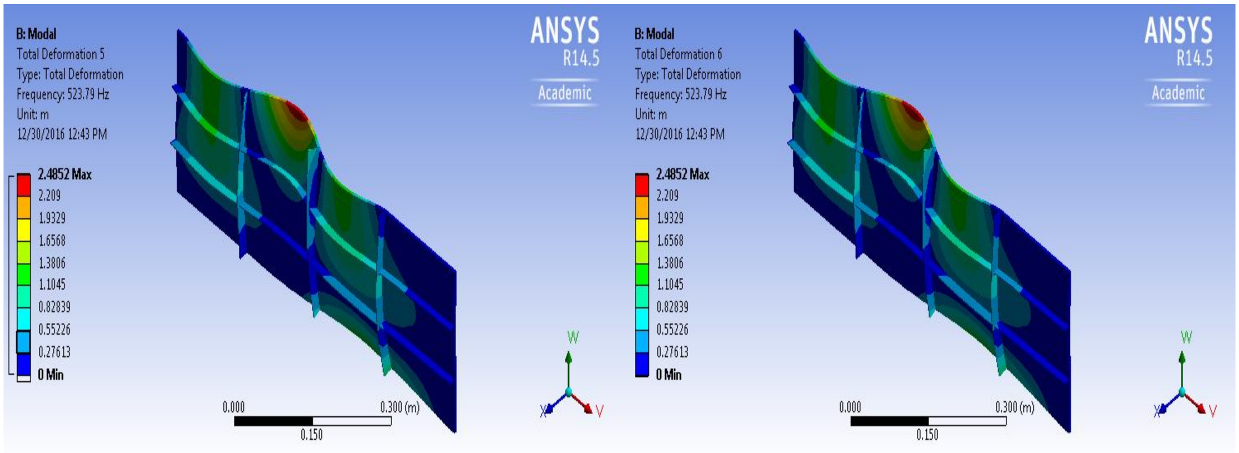
4. When Stiffeners are made of HYBOR/Boron Composite Material and the Plate by Steel.
   Mode shapes are shown.





5. When Stiffeners are made of HYBOR/Boron Composite Material and the Plate by Aluminium alloy. Mode shapes are shown.





V. CONCLUSION

In the present study, a stiffened panel structure of an aircraft is imitated with clamped – clamped boundary conditions. Different case studies are obtained by applying bending (pressure) loads on the plate and varying the material properties of the plate and the stiffener. From the FEM static analysis made in ANSYS, it can be noted that the least stresses and comparatively less deformations are obtained for the structure made of HYBOR/Boron Composite stiffener and Aluminium alloy plate material (case 5). Also from the results of modal analysis, least deformations can be observed for least frequencies exhibited by the material of case 3. Also the materials of Case 4 and 5 have showed similar response to the modal analysis. Hence, the combination of HYBOR/Boron Composite and Aluminium and steel is the most suitable material that can be used for stiffening and extreme heat applications that finds applications in re-entry vehicles in the Aerospace industry (Airframe). For the ordinary missions of aircraft like civil aviation, cargo, reconnaissance etc, The materials used in case 1,2,4 and 5 can be employed. For the missions like space exploration, re-entry and hypersonic applications, combinations of composites, metals and alloys are used.

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