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Free vibration investigation of thin plates under various circumstances using Finite Element Method

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Abstract - *Due to their strong resistance to shocks and vibrations, composite plates have found extensive use in a variety of engineering fields, including the aerospace, marine, and automotive industries. The vibratory behavior of thin plates has evolved into a significant and crucial factor that must be taken into consideration when designing structural elements because it is at the core of many issues that can destroy structures. The positions into which a structure will predictably be displaced are described by mode shapes. Structures cannot be considered safe based on their load-carrying capacity, but they should also be safe considering structural dynamic aspects. The offending mode is identified using modal analysis. This work explores the effect of material, laminate stacking sequence, geometry, and edge conditions on modal behavior. For the analysis, carbon-epoxy and T300/5208 graphite/epoxy composite materials are taken into consideration, and aluminum alloy is taken into consideration for isotropic plate simulations. To investigate how fiber orientation affects natural frequencies and associated mode shapes, the fiber angle is altered. The mode shapes and initial six natural frequencies are obtained. Based on the findings, a better boundary condition is suggested for applications with a narrow operating frequency range.*

Key Words: *Modal Analysis, Isotropic, Mode Shapes, Laminate Stacking Sequence, Fibre Orientations, Natural frequencies.*

1.INTRODUCTION

Laminated composites are frequently employed in heavy industrial applications because of their physical and mechanical characteristics. Structures composed of composite materials are also referred to as smart structures since they may be developed to get different qualities in a controlled way. The exceptional physical and mechanical properties of these materials make them ideal for engineering applications. Most engineering structures should pass the fundamental tests before being used in actual working conditions. Modal analysis, also known as vibration analysis, is one of these primary tests.

Several researchers have developed numerous solution methods in the last 20 years. Crawley calculated the natural frequencies and mode shapes of 8-ply graphite/epoxy cantilever plates and shells with various laminates and aspect ratios using experimental and theoretical analysis. There was limited agreement about frequencies, however, there was a great agreement between the observed and predicted mode shapes[1]. A couple of 12-employ graphite/epoxy plates' regular frequencies and mode states were provisionally and conceptually resolved by Anderson and others. The cross-ply, quasi-isotropic, and 15°–30° plate layouts were evaluated. Each layup was tested in three distinct ways: cantilever, free-hanging, and fixed-fixed[2]. Analytically, Barai, and Durvasula investigated how the vibration and buckling characteristics of curved panels made of hybrid laminates were affected by the aspect ratio, curvature, ply orientation, and stacking sequence. They concluded that the natural frequencies, which are more common on thin plates, are enhanced by curvature[3]. Rajeshkumar and V. Hariharan also examined the effects of fiber orientations ranging from 0 to 90 and aspect ratios ranging from 45 to 120 under various boundary conditions in their paper[4]. To analyze free vibrations on composite laminates and learn more about their vibrational characteristics, Kamal and colleagues employed the Rayleigh-Ritz energy technique, layered, composite plate theory, and modified shear deformation[5]. The natural frequency and damping characteristics of different S-glass, carbon, and Kevlar fiber combinations were studied by Erkling et al. The numerical outcomes for completely fixed conditions are evaluated against previously released findings. Combining fixed (C), simply supported (SS), and free(F) boundary conditions, they investigated hybrid composites. They demonstrated that the highest and lowest recurrence values occurred individually in the CFCF and CFFF edge situations. To analyze the static and free vibration characteristics of shear deformable thin and thick laminated composite plates[6].Dai et al. developed a mesh-free approach by using higher-order shear deformation theory. To successfully enforce necessary boundary conditions to produce natural frequency and static deflection, the penalty approach was applied. Studies presented on the frequency vibration characteristics of hybrid laminates are less in-depth according to the literature that is currently accessible[7].

Analytical techniques formed the foundation of many studies. Literature. Our goal is to investigate how the natural frequencies of laminates are affected by the order in which various layers of composite plates are laminated. The plates were put through a simulation of a quasi-isotropic stacking sequence made up of layers with fiber orientations of 0°, 30°, 60°, and 90°. The results of the investigation into the impact of the inner layers' orientation on natural frequencies are then presented.

3. FINITE ELEMENT ANALYSIS

Carbon/epoxy composite plates are thought of with one end as fixed to perform the modal analysis and obtain the first five mode shapes. Each ply of the four laminates under consideration has a thickness of 2.5mm (about 0.1 in) and is rectangular. Using a T300 composite and aluminum alloy plate with all edges simply supported, an FEA was also conducted to further examine the impact of a material change. The software's database contains information about the properties of aluminum alloy. Table 1 lists the material characteristics of the T300/502 graphite/epoxy composite, carbon/epoxy composite material, and aluminum alloy.

PROPERTY	T300 COMPOSITE	CARBON EPOXY	Al ALLOY
Density (kg/m^3)	1800	1490	2770
Young's Modulus Ex (GPa)	132.38	121	71
Young's Modulus Ey & Ez (GPa)	10.76	8.6	71
Poisson's Ratios Vxy, Vyz &Vzx	0.24, 0.24 & 0.49	0.27, 0.4 & 0.27	0.33
Modulus of Rigidity Gxy (GPa)	5.65	4.7	26.7
Modulus of Rigidity Gyz, Gzx (GPa)	5.65,3.38	3.1,4.7	26.7

Table 1. Analyzed properties of the material

As shown in Fig. 1, cantilever boundary conditions, such as clamped at one end (CFFF), all sides clamped (CCCC), and simply supported (SSSS), were examined for laminated composite plates. This allowed us to investigate how boundary circumstances affect natural frequencies. where,

C: Clamped; F: Free end; S: Simply supported.

A plate with a 1 m dimension was fixed to the edge.

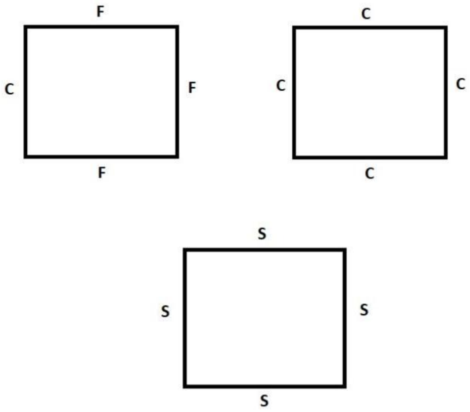


Fig 1. Considered boundary conditions for representation a) CFFF b) SSSS and c) CCCC

Additionally, finite element analysis was used to investigate how hybridization affected modal frequencies. To conduct the study, carbon epoxy composite plates with laminating stacking sequences of [0/0/0/0], [0/30/30/0], [0/60/60/0], and [0/90/90/0] under various boundary conditions were used.

Carbon/epoxy composite plates of p=2m length, q=1m width, and t=10 mm thickness (Plate A) and p=4m length, q=1m width, and t=10 mm (Plate B) is used for the investigation of aspect ratio on natural frequency.

With the aid of ANSYS and the ACP(Pre) design modeler, two plates were modeled.

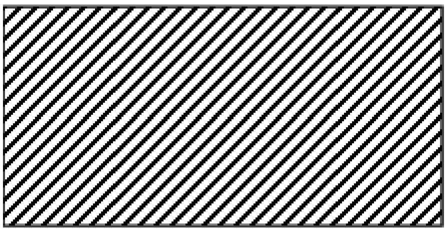


Plate A

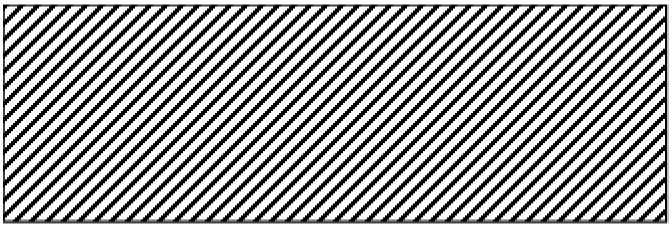


Plate B

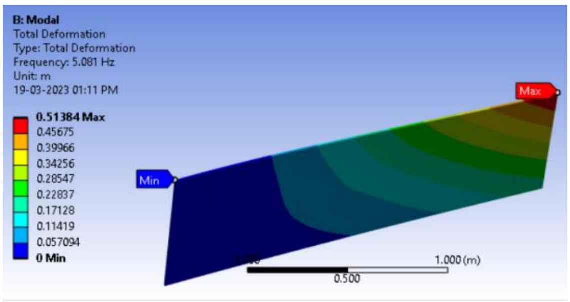
Fig.2. Rectangular laminate plates in design modeler

4. RESULTS

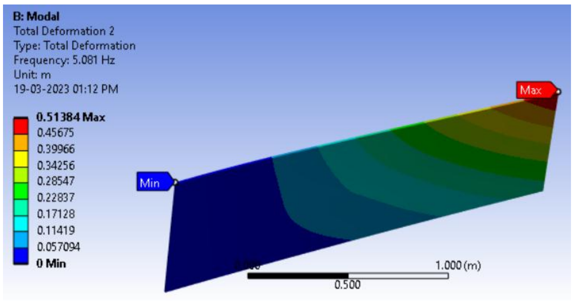
Finding mode shapes and examining the impact of boundary conditions, laminate stacking order, aspect ratio, and material on the natural frequencies were the objectives of this work..

4.1. Mode shapes:

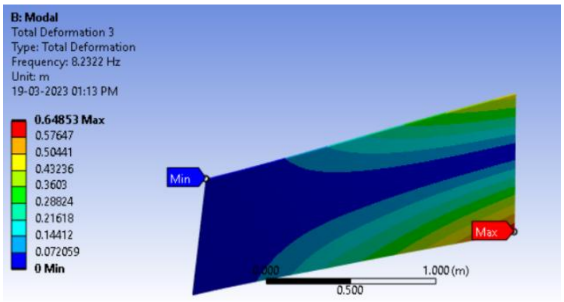
A four-layer laminated plate made of carbon epoxy composite underwent numerical simulations with [0/0/0/0] ply orientation and under cantilever condition i.e, CFFF boundary condition. The figure depicts the mode forms corresponding to the frequency of the boundary conditions mentioned previously.



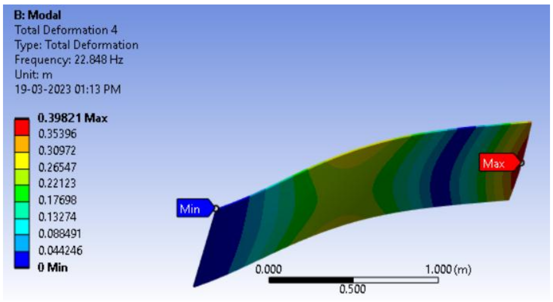
Mode 1



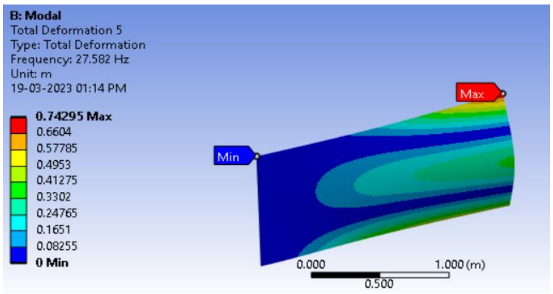
Mode 2



Mode 3



Mode 4



Mode 5

Fig 3. Mode shapes for a rectangular cross-ply (0°/0°/0°/0°) plate for the boundary condition CFFF.

4.2. Effect of Boundary Conditions on Natural Frequencies:

Three border-related situations CCCC, CFFF, and SSSS are considered for the simulation of carbon epoxy composite plates of dimensions 2m X 1m X 10mm and fiber orientation [0/90/90/0]. The results clearly show that the all-fixed boundary condition, which has noticeably higher natural frequencies than other boundary conditions, is best suited for situations where the operating frequency range is broad. The natural frequencies were varied as,

Mode	Boundary Condition		
	CFFF	SSSS	CCCC
Mode 1	4.5297	38.163	46.996
Mode 2	7.832	65.342	79.206
Mode 3	21.495	86.485	118.23
Mode 4	26.808	100.9	127.74
Mode 5	41.857	103.22	134.32
Mode 6	55.429	142.75	174.17

Table 2. Modal frequencies in different boundary conditions

4.3. Effect of Laminate Stacking Sequence:

The rectangular carbon epoxy composite plate's ply orientation for varied boundary conditions. A two-meter-long rectangular carbon epoxy composite plate was analyzed for several fiber orientations, including [0/0/0/0], [0/30/30/0], [0/60/60/0], and [0/90/90/0]. The results are shown below,

4.3.1.All fixed(CCCC):

	Mode1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
[0 0 0 0]	35.69	77.29	77.55	106.04	130.93	139.17
[0 30 30 0]	37.26	76.93	84.14	111.06	130.59	148.42
[0 60 60 0]	42.93	78.15	104.6	122.75	130.56	168.18
[0 90 90 0]	46.99	79.20	118.23	127.74	134.32	174.17

Table 3. Modal frequencies with different orientations when all edges are fixed

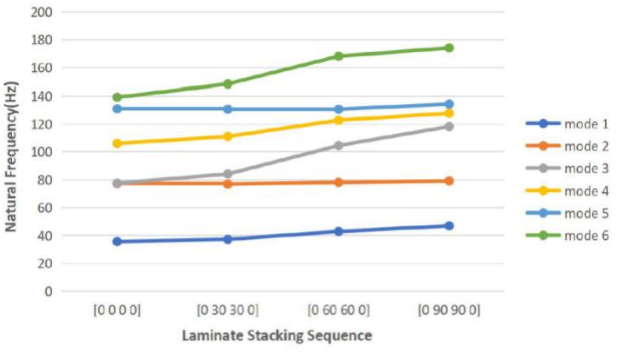


Fig 4. Variation of first six natural frequencies with respect to orientations for carbon epoxy plates (CCCC)

4.3.2. Cantilever Condition (CFFF):

	Mode1	Mode2	Mode3	Mode4	Mode5	Mode6
[0 0 0 0]	5.081	8.23	22.848	27.582	27.874	46.215
[0 30 30 0]	4.8942	8.75	22.107	28.059	30.72	50.417
[0 60 60 0]	4.6019	8.53	21.522	27.774	37.329	53.132
[0 90 90 0]	4.5297	7.83	21.495	26.808	41.857	55.429

Table 4. Modal frequencies with different orientations when one edge is fixed

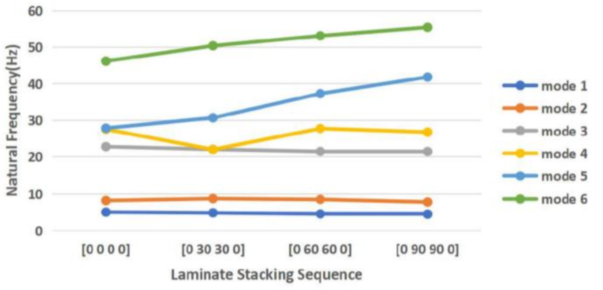


Fig 5. Variation of first six natural frequencies with respect to orientations for carbon epoxy plates (CFFF)

4.3.3. Simply supported (SSSS):

	Mode1	Mode2	Mode3	Mode4	Mode 5	Mode 6
[0 0 0 0]	26.594	59.109	63.619	87.18	107.11	113.79
[0 30 30 0]	29.331	65.137	66.705	94.414	106.52	124.04
[0 60 60 0]	34.542	65.404	80.241	99.864	104.97	143.01
[0 90 90 0]	38.163	65.342	86.485	100.9	103.22	142.75

Table 5. Modal frequencies with different orientations when all edges are simply supported

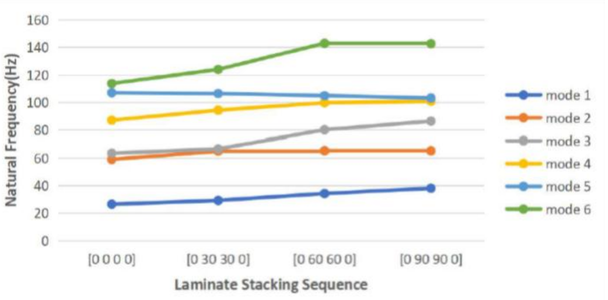


Fig 6. Variation of first six natural frequencies with respect to orientations for carbon epoxy plates (SSSS)

4.4. Effect of Material:

For investigating the effect of material, three materials with the same orientations [0 90 90 0] and when simply supported on all sides (SSSS) are used. The results are displayed in a table and compared using a graph

	T300 COMPOSITE	CARBON EPOXY	ALUMINUM ALLOY
Mode1	36.976	38.163	44.894
Mode2	62.935	65.342	67.96
Mode3	84.363	86.485	92.43
Mode4	98.216	100.9	118.38
Mode5	98.889	103.22	135.9
Mode6	138.33	142.75	138.79

Table 6. Effect of material on natural frequencies

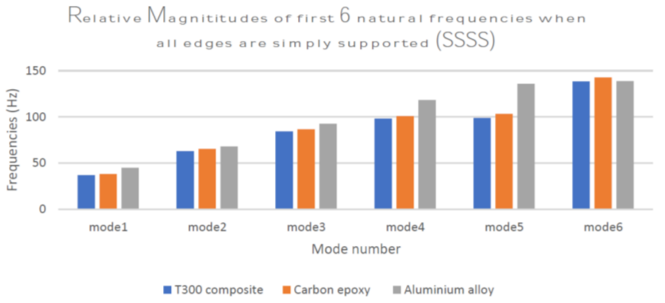


Fig 7. Relative Magnitude of First Three Natural Frequencies of Carbon Epoxy, T300 Composite and Aluminum Alloy

4.5. Effect of Aspect Ratio on Modal Frequency Values:

By considering the two plates with dimensions of 2m X 1m and 4m X 1m, the topic of the study was extended to better understand how the length-to-breadth ratio affects the vibration properties of laminated composite plates.

Plate 1: 2m X 1m X 10 mm

Plate 2: 4m X 1m X 10 mm

Mode	**CCCC**		**CFFF**		**SSSS**	
	Plate 1	**Plate2**	**Plate1**	**Plate2**	**Plate1**	**Plate2**
1	46.996	40.865	4.5297	0.856	38.163	34.276
2	79.206	44.171	7.8324	2.715	65.342	36.899
3	118.23	52.204	21.495	5.368	86.485	43.822
4	127.74	66.364	26.808	9.331	100.9	56.205
5	134.32	86.793	41.857	15.026	103.22	72.105
6	174.17	111.03	55.429	19.348	14.75	75.046

Table 7. Variations of Modal Frequencies with Boundary Conditions

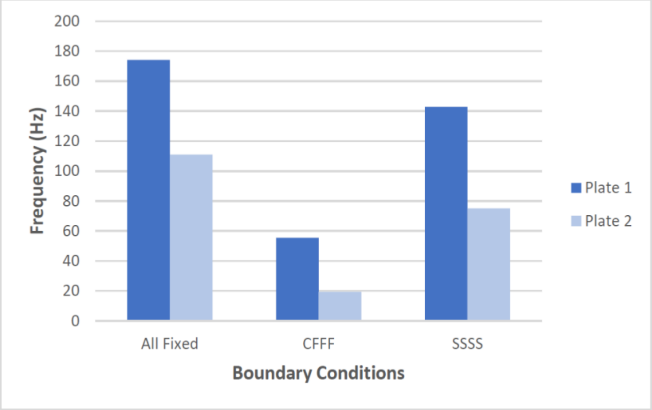


Fig 8. Variations of Natural Frequencies with Aspect Ratio

Table 7 lists the outcomes that were obtained. It is clear from Tables 7 and figure 8 that raising the aspect ratio of the plate significantly decreased the system's natural frequency in all three boundary conditions.

5. CONCLUSIONS

In the current work, laminated composite modal analysis is carried out using FEA. The impact of fiber orientation, material type, and boundary conditions on the natural frequency of the composite plate is investigated. The main lessons drawn from this research are:

1. Under various boundary conditions the first six natural frequencies are produced.

2. Compared to the CFFF and SSSS boundary conditions, the CCCC boundary condition has much higher natural frequencies, making it best suited for applications with a wide operating frequency range.

3. The effects of fiber orientation on the natural frequencies of vibration of composite laminated plates are analyzed under varied boundary conditions. The natural frequency rises as the fiber angle for the inner layers' increases.

4. A decrease in the natural frequency values occurs when the length of the plate is increased without changing the other dimensions.

5. Aluminum plates are found to have greater natural frequencies than composites. Comparing carbon epoxy plates to T300 graphite/epoxy plates, the natural frequencies of carbon epoxy plates are greater.

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