Structural dynamic analysis of turbine blade

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Abstract. In any gas turbine design cycle, blade design is a crucial element which needs maximum attention to meet the aerodynamic performance, structural safety margins, manufacturing feasibility, material availability etc. In present day gas turbine engines, most of the failures occur during engine development test and in-service, in rotor and stator blades due to fatigue and resonance failures. To address this issue, an extensive structural dynamic analysis is carried out to predict the natural frequencies and mode shapes using FE methods. Using the dynamics characteristics, the Campbell diagram is constructed to study the possibility of resonance at various operating speeds. In this work, the feasibility of using composite material in place of titanium alloy from the structural dynamics point of view. This is being attempted in a Low-pressure compressor where the temperatures are relatively low and fixed with the casings. The analysis will be carried out using FE method for different composite material with different lamina orientations chosen through the survey. This study will focus on the sensitivity of blade mode shapes to different laminae orientations, which will be used to alter the natural frequency and tailor the mode shapes. Campbell diagrams of existing titanium alloy are compared with the composite materials with different laminae at all critical operating conditions. The existing manufacturing methods and the proven techniques for blade profiles will also be discussed in this report.

1. Introduction
For many decades, researchers have steadily worked on improving the performance of gas turbine engines. Major advances were made in the areas of materials, structures, controls, reliability, thermal cycles, thrust to weight ratio, and overall pressure ratios. Improving performance, reducing operating cost, lowering emission and noise, and enhancing structural reliability of gas turbine engines are prudent to meet the challenges of the new century. Production of lighter engines than conventional engines with higher efficiency and improved reliability compared to present technology is essential. composites are versatile materials have so far been best known for their weight saving contribution to nacelles, thrust reversers, ducts, guide vanes and other items outside the engine proper. Polymer composites are temperature limited and therefore unsuitable for use in engine hot sections but not in case of cold sections. Designers consider most benefit in the large fan blades i.e. Low-Pressure compressor blades, found at the front of turbofan engines that power the airliners of today.
Weight reduction is always a strong driver in aeronautics and a set of fan blades that is lighter than any that existed hitherto will automatically help in producing lighter engines that reduce fuel burn while increasing payload and range. However, the dynamics of a fan multiply the weight-saving significance several times over. Blades on fans in current generation turbofan engines can experience centrifugal loadings of around 100 tons-equivalent to the weight of a diesel locomotive hanging on each blade. Typical military gas turbines will revolve at 10,000 rpm in cruise for LP Compressor Spool and the centrifugal load experienced by the rotor blades increase with centre of gravity location, rotational speed and with blade mass. Radius and speed are determined by aerodynamic design considerations, but anything the designers can do to reduce blade mass will reduce loadings hence it is advantageous to change from conventional titanium alloy blades to composites and sandwich structures. This provides over 35-40% weight reduction and also provides good dynamic characteristics.

2. Scope of the project
The scope of the project is to carry out the modal analysis of a trial blade profile which may be used in gas turbines by applying composite materials including pre-stressed effects and to find out the natural frequencies and mode shapes. To plot the Campbell diagram and to predict the occurrence of resonance for different speeds. To achieve the above, the following objectives have to be carried out Selection of the best composite material by carrying out the modal analysis of different type of composite materials in a rectangular plate and best orientation of fibres in the plate. Analysing the blade profile available for dynamic characteristics using the available FEM software like ANSYS. Identify the occurrence of resonance, if any at operational conditions and make require changes in the design phase of the structure of the component so as to avoid the resonance at different operating conditions.

2.1. FEM in ANSYS
The finite element method (FEM) is the most popular simulation method to predict the physical behaviour of systems and structures. Since analytical solutions are in general not available for most daily problems in engineering sciences numerical methods have been evolved to find a solution for the governing equations of the individual problem. Although the finite element method was originally developed to find a solution for problems of structural mechanics it can nowadays be applied to a large number of engineering in which the physical description results in a mathematical formulation with some typical differential equations which can be solved numerically.

2.2. Static analysis
Static analysis is used to calculate the effects of steady loading conducting on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. Static analysis is to determine displacements, stresses, strains and forces in structures or components caused by loads that do not include significant inertia and damping effects.

2.3. Dynamic analysis
Under the dynamic analysis comes Vibration, free vibration, forced vibration, natural frequency, modes, mode shapes, resonance, pre-stressed modal analysis

2.4. Campbell diagram
In rotating machinery, as the structure undergoes rotation the centrifugal load on the blades varies with RPM along with the associated aerodynamic parameters such as pressure and temperature. Due to the variation in the temperature and centrifugal loads, the structural stiffness changes which ultimately results
in the change in natural frequency. This change in natural frequency needs to be predicted at the design stage and the possibility of any resonance need to be studied and avoided, if possible.

Mainly two types of excitation namely: Mechanical and Aerodynamic.

Mechanical Excitation: Due to unbalance force in terms of mass rotating with its centre of gravity i.e. \( U = m* e* \omega^2 \), which varies with speed is always a dominating excitation force in rotating machinery. This force will invariably present in the structure and produces an excitation force. The excitation frequency will be equal to the first harmonic of rotor speed i.e. \( 1X = \omega / 60 \times 1 \). Similarly, other harmonics arise due to excitation frequencies corresponding to looseness, circumferential ovality and so on. Each harmonics of rotor speed has specific relation to a mechanical phenomenon and explained in detail in the following reference [1].

Aerodynamic Excitation: The fluid passing over the structural members like blades, vanes and supporting frames do expand completely and results in a smooth flow. However, the vortices leave the structural member at the trailing edge of the aerofoil and exerts a pulsating force which impinges on the next stage. This again produces an excitation frequency corresponding to the no. of disturbances seen in one revolution. For example, if the no of stator blades in a stage corresponds to 47, then the next following rotor blade will face 47 pulsations in one revolution. The excitation frequency corresponding to that will be 47*RPM/60 and this is termed as 47X in a Campbell diagram. This gives the possibility of resonance to the structural member where the excitation frequency matches with the natural frequency. This information can be inferred from the Campbell diagram (In Fig 3.).

where the variation of natural frequency (Y axis) is plotted against speed (X-axis) along with the engine order lines (i.e. 1X, 2X, 47X…so on) applicable to the stage. From the Campbell diagram, it is possible to identify the possibility of resonance at higher RPM’s or at regimes where the engine will dwell for longer time and it can be avoided at the design stage.

2.5. Pre-stressed modal analysis

First, the modal analysis for 0 rpm is carried out in the structure using Block Loncoz method and the natural frequencies are noted down. Then, the inertial load is given and a static analysis is carried out with considering the pre-stressed effects due to the inertial load. Then finishing that static analysis, the modal analysis is carried out with switching on the include pre-stress effects option and the natural frequencies are obtained.

3. ANALYSIS OF TRIAL BLADE PROFILE

3.1. INTRODUCTION

Modal Analysis is carried out for the given Trial blade profile by applying Composites and comparing its Frequency values with the conventional Titanium blade. The blade profile is shown below:
3.1.1 ANALYSIS OF BLADE PROFILE WITH TITANIUM

The Blade profile is analysed with Titanium material with following material properties

| MATERIAL  | YOUNG’S MODULUS, $E$ (Gpa) | DENSITY $\rho$ (Kg/m3) | POISSON RATIO $\nu$ |
|-----------|----------------------------|-------------------------|---------------------|
| Titanium  | 110                        | 4500                    | 0.3                 |

The table below gives the Frequency values of first four modes of the given blade profile for various Rpm with the help of Pre-stress effects.
Table 2. Frequency values for titanium at different RPM

| MATERIAL | 0 Rpm Frequency (Hz) | 7500 Rpm Frequency (Hz) | 9000 Rpm Frequency (Hz) |
|----------|----------------------|-------------------------|-------------------------|
| Titanium | 455.42               | 601.32                  | 680.37                  |
|          | 1182.6               | 1326.6                  | 1401.9                  |
|          | 1469.5               | 1530.2                  | 1581.3                  |
|          | 2233.7               | 2265.4                  | 2271.7                  |

3.1.2 MODES SHAPES OBTAINED WITHOUT PRE-STRESS EFFECTS

The first three mode shapes of the Titanium blade profile without pre-stress effects are given below,

**FIG 3** First mode shape of titanium without pre-stress effects

In the first mode, the maximum displacement will be at the tip and at the root there is minimum deformation
In the second mode, the deformation will be at both the root tip and there will be minimum deformation (-.2295 m) at the middle of the blade profile. In the third mode the deformation will be all over the blade.

3.1.3 MODE SHAPES OBTAINED WITH 7500 RPM

The First three mode shapes of Titanium blade profile with 7500 Rpm are given below,

In the first mode shape with 7500 rpm, the deformation is similar to mode shape with pre-stress effect.
In the second mode with 7500 rpm the deformation will be minimum at the trailing edge and maximum at leading edge of the tip. In the third mode with 7500 rpm, deformation will be all over the blade profile but when compared to mode shape of pre-stress effect the mode shape is varied slightly.

3.1.4 MODE SHAPES OBTAINED WITH 9000 RPM

FIG 7 Second mode shape of titanium with 7500 Rpm
FIG 8 Third mode shape of titanium with 7500 Rpm

FIG 9 First mode shape of titanium with 9000 Rpm
FIG 10 Second mode shape of titanium with 9000 Rpm
All the mode shape found at 9000 rpm are similar to the mode shapes found at 7500 rpm, which are shown above, but the frequency values only varies

3.1.5 CAMPBELL DIAGRAM FOR TITANIUM

FIG 11 Third mode shape of titanium with 9000Rpm

FIG 12 Campbell diagram for titanium blade
3.2 ANALYSIS OF BLADE PROFILE WITH THREE LAMINA COMPOSITE MATERIAL

As a pre-step of applying best Composite material in give blade profile, study was done on four different composite materials which are given below,

- Carbon epoxy
- Graphite epoxy
- Glass epoxy
- Aramid epoxy

Based on Structural Dynamics point of view, Modal analysis was performed for all the above Composite material and from the obtained frequency values Campbell diagram was generated, and as a result best Composite material was chosen. The material properties of lamina were calculated with the help of Micromechanics approach.

The material properties of above composite materials are given below,

**TABLE 3 Material properties of composite materials**

| COMPOSITES      | E1 (In GPa) | E2 (In GPa) | Nu12 | Nu21 | G12 (in GPa) | DENSITY (Kg/m3) | MASS (Kg) |
|-----------------|-------------|-------------|------|------|--------------|-----------------|-----------|
| Carbon epoxy    | 124.83      | 10.46       | 0.3  | 0.025| 3.33         | 1512            | 0.1007    |
| Graphite epoxy  | 150.69      | 9.45        | 0.3  | 0.019| 3.365        | 1590            | 0.1058    |
| Glass epoxy     | 56.44       | 9.04        | 0.235| 0.03764| 3.497    | 2045            | 0.1362    |
| Aramid epoxy    | 81.79       | 9.243       | 0.339| 0.03831| 2.065    | 1330            | 0.0885    |
The Modal analysis for above four Composite material with different Orientation for Three Lamina is analysed. From the Modal Analysis of above different composite materials, the Frequency values are tabulated as shown,

**TABLE 4** Frequency values of different composite materials for Three Lamina

| Ply       | Carbon | Graphite | Aramid | Glass |
|-----------|--------|----------|--------|-------|
| 0/0/0     | 242.38 | 225.46   | 240.05 | 194.85|
|           | 613.06 | 573.8    | 593.96 | 497.02|
|           | 804.8  | 766.44   | 745.94 | 666.07|
|           | 1236.9 | 1183.2   | 1122.6 | 1020.4|
| 30/45/60  | 299.64 | 293.95   | 271.05 | 229.9 |
|           | 760.08 | 739.82   | 692.23 | 590.89|
|           | 981.92 | 961.09   | 880.91 | 770.34|
|           | 1396.9 | 1347.5   | 1279.8 | 1110.7|
| 45/60/90  | 385.04 | 384.19   | 339.16 | 287.06|
|           | 944.27 | 936.12   | 843.79 | 707.62|
|           | 1150.3 | 1144.6   | 1014   | 866.24|
|           | 1614.6 | 1605.2   | 1431.8 | 1210.1|
| 90/90/90  | 679.75 | 704.96   | 585.56 | 436.07|
|           | 1135.7 | 1135     | 994.15 | 839.61|
|           | 1534.8 | 1541.2   | 1327   | 1087.4|
|           | 1654.7 | 1669.9   | 1450   | 1220.1|

From the table that carbon epoxy and aramid epoxy has good dynamic characteristics. So, further study on lamina orientation is analyzed on carbon epoxy and aramid epoxy as shown,
TABLE 5 Frequency values of carbon &aramid composite materials

| orientation | carbon epoxy | Aramid epoxy |
|-------------|--------------|--------------|
| 0/45/0      | 251.02       | 245.69       |
|             | 647.53       | 621.93       |
|             | 904.39       | 828.36       |
|             | 1327.8       | 1233.3       |
| 45/0/45     | 268.52       | 243.11       |
|             | 732.68       | 669.98       |
|             | 1063.1       | 976.07       |
|             | 1487.6       | 1371.1       |
| 0/90/0      | 297.97       | 279.91       |
|             | 743.37       | 690.01       |
|             | 1088.2       | 943.7        |
|             | 1406.5       | 1236.3       |
| 90/0/90     | 672.86       | 578.78       |
|             | 1160.5       | 1000.4       |
|             | 1544.9       | 1323.6       |
|             | 1693.1       | 1476.4       |

3.2.1 COMPOSITE BLADE WITH 3 LAMINA ORIENTATION

FIG 13 Composite blade with 3 laminas
From the TABLE 5 above it is evident that Carbon Epoxy exhibits its good Dynamic characteristics. Also, Carbon Epoxy has high temperature regime compared to aramid epoxy. So now carbon epoxy is analyzed with pre-stress effects (i.e. with RPM of 7500 and 9000).

**TABLE 6 Frequency values of carbon epoxy for different Rpm**

| Orientation | 0 Rpm Frequency(Hz) | 7500 Rpm Frequency(Hz) | 9000 Rpm Frequency(Hz) |
|-------------|---------------------|------------------------|------------------------|
| 0/45/0      | 251.02              | 456.93                 | 548.49                 |
|             | 647.53              | 871.06                 | 940.48                 |
|             | 904.39              | 1009.7                 | 1121                   |
|             | 1327.8              | 1519.4                 | 1607.3                 |
| 45/0/45     | 268.52              | 470.76                 | 562.85                 |
|             | 732.68              | 971.28                 | 1094.1                 |
|             | 1063.1              | 1121.6                 | 1162.2                 |
|             | 1487.6              | 1703.2                 | 1729.2                 |
| 0/90/0      | 297.97              | 485.95                 | 573.72                 |
|             | 743.37              | 969.68                 | 1071.8                 |
|             | 1088.2              | 1150.3                 | 1211.4                 |
|             | 1406.5              | 1529.6                 | 1593.7                 |
| 90/0/90     | 672.86              | 770.86                 | 829.74                 |
|             | 1160.5              | 1210.4                 | 1239.1                 |
|             | 1544.9              | 1623.2                 | 1635.3                 |
|             | 1693.1              | 1709.2                 | 1741.1                 |

From the above table, it is evident that Carbon Epoxy shows very good Dynamic characteristics for 90/0/90 ply orientation.

**3.2.2 MODE SHAPES OF THREE LAMINA CARBON EPOXY WITHOUT PRE-STRESS EFFECT FOR 90/0/90 ORIENTATION**

From the Modal Analysis of three lamina Carbon Epoxy without pre-stress, the first 3 mode shapes are extracted as shown,
In the first mode shape the maximum displacement will be at the leading edge of the tip of blade while the minimum displacement will be at the root of the blade. In the second mode shape the maximum displacement will be at leading edge of the tip while the minimum displacement will be at the trailing edge of the tip. In the third mode shape, maximum displacement will be at both the leading and trailing edge of tip, while the minimum displacement will be at the middle portion of the leading edge of the blade.
3.2.3 MODE SHAPES OF THREE LAMINA CARBON EPOXY WITH 7500RPM FOR 90/0/90 ORIENTATION

![Mode Shape 1](image1.png)  
**Fig 17** First mode shape of carbon epoxy for (90/0/90) orientation with 7500Rpm

![Mode Shape 2](image2.png)  
**Fig 18** Second mode shape of carbon epoxy for (90/0/90) orientation with 7500Rpm

![Mode Shape 3](image3.png)  
**Fig 19** Third mode shape of carbon epoxy for (90/0/90) orientation with 7500Rpm

The first mode shape of the carbon epoxy for three lamina orientation with 7500 rpm is similar to the first mode shape without pre-stress effect. The second mode shape with 7500 rpm is also similar to the second mode shape without pre-stress effect. The third mode shape with 7500 rpm varies from the third mode shape without pre-stress effect, such that the minimum displacement region from the middle portion of the leading edge to the middle portion of the tip of the blade.
3.2.4 MODE SHAPES OF THREE LAMINA CARBON EPOXY WITH 9000RPM FOR 90/0/90 ORIENTATION

![First mode shape of carbon epoxy for (90/0/90) orientation with 9000Rpm](image1)

**Fig 20** First mode shape of carbon epoxy for (90/0/90) orientation with 9000Rpm

![Second mode shape of carbon epoxy for (90/0/90) orientation with 9000Rpm](image2)

**Fig 21** Second mode shape of carbon epoxy for (90/0/90) orientation with 9000Rpm

![Third mode shape of carbon epoxy for (90/0/90) orientation with 9000Rpm](image3)

**Fig 22** Third mode shape of carbon epoxy for (90/0/90) orientation with 9000Rpm
The first mode shape with 9000 rpm is similar to the first mode shape without pre-stress effect. Second mode shape with 9000 rpm is also similar to that of second mode shape without pre-stress effect. The third mode shape with 9000 rpm varies with the third mode shape with 7500 rpm, such that the minimum displacement region completely shifted from the leading edge to the middle portion of the tip of the blade.

3.2.5 CAMPBELL DIAGRAM FOR THREE LAMINA CARBON EPOXY FOR 90/0/90 ORIENTATION

![Campbell diagram for 90/0/90 orientation](FIG 23)

FIG 23 Campbell diagram for 90/0/90 orientation

3.3 ANALYSIS OF BLADE PROFILE WITH FIVE LAMINA COMPOSITE MATERIAL

Now extending the similar analysis for five lamina orientation as shown below, first all the four composite materials are analyzed for five lamina orientation. The Frequency values are tabulated as
Similarly, from the above table it is clear that Carbon Epoxy and Aramid epoxy has good Dynamic characteristics. So, further study on lamina orientation is analyzed on Carbon Epoxy and Aramid epoxy for five different stacking sequence as shown,

**TABLE 7** Frequency values of composite materials with 5 lamina orientation

| Orientation | Carbon Frequency(Hz) | Graphite Frequency(Hz) | Aramid Frequency(Hz) | Glass Frequency(Hz) |
|-------------|----------------------|------------------------|----------------------|---------------------|
| 0/30/45/60/90 | 363.98               | 353.17                 | 341.56               | 269.06              |
|             | 913.18               | 893.95                 | 839.41               | 674.63              |
|             | 1184.1               | 1191.2                 | 1056                 | 851.01              |
|             | 1646.6               | 1645.3                 | 1473.5               | 1208                |
| 90/60/45/60/90 | 654.96               | 682.52                 | 564.97               | 414.99              |
|             | 1173                 | 1180.4                 | 1041.9               | 828.81              |
|             | 1580.4               | 1617.8                 | 1363.6               | 1076.2              |
|             | 1749.2               | 1769.7                 | 1546.4               | 1246.8              |

**TABLE 8** Frequency values of carbon &aramid epoxy for 5 lamina orientation

| Orientation | Carbon Frequency(Hz) | Aramid Frequency(Hz) |
|-------------|----------------------|----------------------|
| 45/45/0/45/45 | 264.95               | 238.37               |
|             | 727.62               | 665                  |
|             | 1021.6               | 943.67               |
|             | 1472.7               | 1361.5               |
| 90/45/0/45/90 | 644.14               | 555.41               |
|             | 1211.3               | 1067.5               |
|             | 1577.4               | 1359.4               |
|             | 1800.2               | 1587.5               |
3.3.1 COMPOSITE BLADE WITH FIVE LAMINA ORIENTATION

Similar to three lamina orientation along the given trial blade profile, five laminae also prove that Carbon Epoxy has very good Dynamic Characteristics. So, Carbon Epoxy is analyzed for different Rpm condition. From the frequency values, it is understood that (90/45/0/45/90) ply orientation gives better values than other orientation. So, this particular orientation is used to extract Mode shapes and the Campbell diagram is generated.

**TABLE 9** Frequency values of 5 ply Carbon Epoxy with different RPM

| Orientation    | 0 Rpm Frequency(Hz) | 7500 Rpm Frequency(Hz) | 9000 Rpm Frequency(Hz) |
|----------------|---------------------|-------------------------|-------------------------|
| 45/45/0/45/45  | 264.95              | 468.72                  | 561.19                  |
|                | 727.62              | 966.96                  | 1084.6                  |
|                | 1021.6              | 1080                    | 1125.5                  |
|                | 1472.7              | 1644                    | 1667.5                  |
| 90/45/0/45/90  | 644.14              | 747.84                  | 809.39                  |
|                | 1211.3              | 1276.5                  | 1312.1                  |
|                | 1577.4              | 1667.5                  | 1725.3                  |
|                | 1800.2              | 1825.8                  | 1833.5                  |
3.3.2 MODE SHAPES OF CARBON EPOXY WITH (90/45/0/45/90) PLY WITHOUT PRE-STRESS EFFECTS

**FIG 25** First mode shape of Carbon Epoxy with (90/45/0/45/90) ply orientation

**FIG 26** Second mode shapes of Carbon Epoxy with (90/45/0/45/90) ply orientation

**FIG 27** Third mode shape of Carbon Epoxy with (90/45/0/45/90) ply orientation
In first mode shape for carbon epoxy for five lamina orientation without pre-stress effect, the maximum displacement will be at leading edge of the tip, while the minimum displacement will be at root of the blade.

In second mode shape for carbon epoxy for five lamina orientation without pre-stress effect, the maximum displacement will be at leading edge of the tip, while the minimum displacement will be at trailing edge of the blade. When compared to the mode shape of the carbon epoxy for three lamina orientation the minimum displacement region is increased. The third mode shape of the carbon epoxy for five lamina orientation completely differs from the mode shape of carbon epoxy with three lamina orientation.

3.3.3 MODE SHAPES OF CARBON EPOXY WITH (90/45/0/45/90) PLY WITH 7500RPM

![Fig 28](image1.png) First mode shape of Carbon Epoxy with (90/45/0/45/90) ply orientation

![Fig 29](image2.png) Second mode shape of Carbon Epoxy with (90/45/0/45/90) ply orientation

![Fig 30](image3.png) Third mode shape of Carbon Epoxy with (90/45/0/45/90) ply orientation

The first mode shape with 7500 rpm is similar to the first mode shape without pre-stress effect. The second mode shape with 7500 rpm is similar to the second mode shape without pre-stress effect, the only difference is minimum displacement region is decreased slightly. The third mode shape with 7500 rpm completely varies from the third mode shape without pre-stress effect, such that the minimum displacement region is shifted from leading edge to tip of the blade.
3.3.4 Mode shapes of carbon epoxy with (90/45/0/45/90) ply with 9000rpm

The first mode shape with 9000 rpm is similar to the first mode shape without pre-stress effect. The second mode shape with 9000 rpm is similar to second mode shape with 7500 rpm, but the only difference is minimum displacement region is decreased. The third mode shape with 7500 rpm is similar to the third mode shape with 7500 rpm.
3.3.5 CAMPBELL DIAGRAM FOR CARBON EPOXY WITH (90/45/0/45/90) PLY

![CAMPBELL DIAGRAM FOR CARBON EPOXY WITH (90/45/0/45/90) PLY](image)

**FIG 34** CAMPBELL DIAGRAM FOR CARBON EPOXY WITH (90/45/0/45/90) PLY

3.3.6 MASS COMPARISON OF ALL MATERIAL

The drastic variation in the Mass of different Composite materials and Titanium is shown,

![Mass comparison between Composites & Titanium](image)

**FIG 35** Mass comparison between Composites & Titanium

It can be inferred from the chart that, the Composite material has less than 50% of the Mass of conventional Titanium material used. From the above chart it is seen that, Carbon Epoxy has only 41.4gms of mass while Titanium has 123.4gms each blade.
3.3.7 FREQUENCY VALUES

The first three modes frequency values of different Composite material are compared below,

**FIG 36** Comparison of Frequency range among Composite materials

From the chart it is inferred that, Carbon Epoxy has higher Frequency range compared with other composite materials. Even all its mode frequency is higher than other material. Also from previous inference we understand that, Carbon Epoxy has good Dynamic Characteristics compared to other composite materials under study.

The Frequency values of various orientation of three ply Carbon Epoxy composite is shown below,

**FIG 37** Comparison of Frequency range of various orientation of 3ply Carbon Epoxy
FIG 38 Comparison of Frequency range of various orientation of 5ply Carbon Epoxy

FIG 39 comparison charts
The charts above gives the comparison of Frequency values in (Hertz) between 3 ply, 5ply Carbon Epoxy composite material with Titanium alloy.

4. RESULT

- In this pilot work, the following issues are studied in detail to arrive at the feasibility of using composite laminates in place of metallic alloys such as titanium:
  - Predict the natural frequencies and mode shapes of a typical titanium alloy blade configuration
  - Calculate the weight of the blade configuration
  - Predict the natural frequencies and mode shapes of the same blade configuration using the different composite materials identified for gas turbine usage.
  - Calculate the weight at each case
  - Analyze the structural dynamic characterization of each case and choose the feasible material
  - Study the same material with different lamina orientations such as 0/0/0 and no of laminas along the thickness such as 3,5, etc.
  - Choose the best possible configuration i.e. good improvement in natural frequency and mode shapes

The following table summarizes the results of good Composite materials in Dynamics point of view, from different composite material under study such as

- Carbon Epoxy
- Aramid epoxy
- Graphite epoxy
- Glass epoxy

For same orientation (90/0/90) for 3ply & (90/45/0/45/90) of 5ply composite material,
### TABLE 10 Comparison of satisfied 3ply composite material with titanium alloy

| MATERIAL          | FREQUENCY (Hz) | % IMPROMENT IN 1s MODE FREQUENCY |
|-------------------|----------------|----------------------------------|
| **Carbon Epoxy**  |                |                                  |
| (90/0/90)         | 672.86, 1160.5, 1544.9, 1693.1 | 47.7                             |
| **Aramid epoxy**  |                |                                  |
| (90/0/90)         | 578.78, 1000.4, 1323.6, 1476.4 | 27                               |
| **Titanium alloy**| 455.42, 1182.6, 1469.5, 2233.7 | Reference                        |

### TABLE 11 Comparison of satisfied 5ply composite material with Titanium alloy

| MATERIAL          | FREQUENCY (Hz) | % IMPROMENT IN 1st MODE FREQUENCY |
|-------------------|----------------|-----------------------------------|
| **Carbon Epoxy**  |                |                                   |
| 90/45/0/45/90     | 644.14, 1211.3, 1577.4, 1800.2 | 41.4                             |
| **Aramid epoxy**  |                |                                   |
| 90/45/0/45/90     | 555.41, 1067.5, 1359.4, 1587.5 | 21.9                             |
| **Titanium alloy**| 455.42, 1182.6, 1469.5, 2233.7 | Reference                        |
From above analysis, it’s evident that carbon epoxy composites with 3 ply & 5 ply shows a better structural dynamic characteristic.

From weight comparison between composites and titanium alloy, carbon epoxy shows significant weight reduction in %.

**FIG 41** mass comparison charts

And carbon epoxy is chosen for further analysis to study in detail and the results for various orientation are presented below.

**FIG 42** frequency comparison charts
From above results it is evident that, the orientation (90/0/90) with no of lamina (Three) gives the natural frequency which has an improvement of (47.7%) over the Titanium alloy. And the orientation (90/45/0/45/90) with no of lamina (Five) gives the natural frequency which has an improvement of (41.4%) over the Titanium alloy. So, carbon epoxy with above orientation is considered for design.

CONCLUSION
This result proves that it is possible to tailoring the mode shape, in case it is required by the designers. This mode shape tailoring is basically to avoid the high vibratory stresses at critical section in a blade. A wide variety of literature is available in this topic and the scope of the work is to only identify the possibly of change. A detailed work shall be carried out in future to study the implications of change in mode shapes and their relevance to gas turbine design.

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