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Analysis of Flutter in a Flat Composite Plate

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Abstract:- Composite materials provide design flexibility in that fiber placement and orientation can be specified and a variety of material forms and manufacturing processes are available. It is possible, therefore, to tailor the structure to a high degree in order to meet specific design requirements in an optimum manner. Flutter is a dangerous phenomenon encountered in flexible structures subjected to aerodynamic forces. This includes aircraft, buildings, telegraph wires, stop signs, and bridges. Flutter occurs as a result of interactions between aerodynamics, stiffness, and inertial forces on a structure. In an aircraft, as the speed of the wind increases, there may be a point at which the structural damping is insufficient to damp out the motions which are increasing due to aerodynamic energy being added to the structure. This vibration can cause structural failure and therefore considering flutter characteristics is an essential part of designing an aircraft.

Keyword:- Flutter, Tailoring, T300 property, Frequency, Ansys solving

I. METHODOLOGY

The study of flutter phenomena and aeroelastic tailoring, Consider composite plate wing like structure (chord=250mm, span=400mm) with clamped-free boundary conditions. Make structure modeling and do dynamic analysis; use unidirectional CFRP lamina (T300 properties) to construct the laminates (0/90/90/0), (45/-45/-45/45),(0/90/-45/45/90/0);keep the thickness of the laminates same for all the three cases Compare the natural frequencies and study the effect of ply orientation by help of analysis software. Build the aerodynamic model and do the flutter analysis for the three cases considering the flight condition: sea level density, Mach no=0.2.

II. AERODYNAMIC FLUTTER

Flutter is a dangerous phenomenon encountered in flexible structures subjected to aerodynamic forces. This includes aircraft, buildings, telegraph wires, stop signs, and bridges. Flutter occurs as a result of interactions between aerodynamics, stiffness, and inertial forces on a structure. This vibration can cause structural failure and therefore considering flutter characteristics is an essential part of designing an aircraft.

A. Flutter Motion

The basic type of flutter of aircraft wing is described here. Flutter may be initiated by a rotation of the airfoil (see t=0 in Figure 1). As the increased force causes the airfoil to rise, the torsional stiffness of the structure returns the airfoil to zero rotation (t=T/4 in Figure 1). The bending stiffness of the structure tries to return the airfoil to the neutral position, but now the airfoil rotates in a nose-down position (t=T/2 in Figure 1). Again the increased force causes the airfoil to plunge and the torsional stiffness returns the airfoil to zero rotation (t=3T/4). The cycle is completed when the airfoil returns to the neutral position with a nose-up rotation. Notice that the maximum rotation leads the maximum rise or plunge by 90 degrees (T/4). As time increases, the plunge motion tends to damp out, but the rotation motion diverges. If the motion is allowed to continue, the forces due to the rotation will cause the structure to fail.

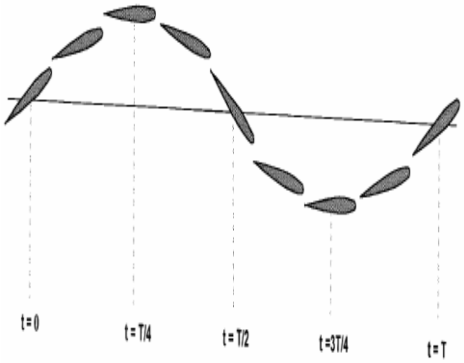


Fig.1: Rotation and Plunge Motion for an Airfoil Exhibiting Flutter

This flutter is caused by the coalescence of two structural modes – pitch and plunge (or wing-bending) motion. This example wing has two basic degrees of freedom or natural modes of vibration: pitch and plunge (bending). The pitch mode is rotational and the bending mode is a vertical up and down motion at the wing tip. As the airfoil flies at increasing speed, the frequencies of these modes coalesce or come together to create one mode at the flutter frequency and flutter condition. This is the flutter resonance.

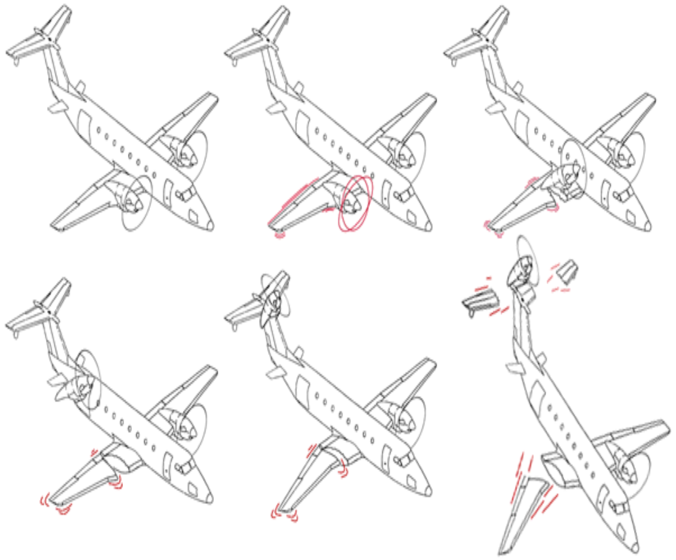


Fig.2: Engine Whirl Flutter

B.Aeroelastic Tailoring

Aeroelastic tailoring is the embodiment of directional staidness into an aircraft structural design to control aeroelastic deformation, static or dynamic, in such a fashion as to eject the aerodynamic and structural performance of that aircraft in a biennial way. In recent years there has been lot of studies in aeroelastic tailoring with the advent of composites. Advanced composite materials combine vastly superior specie staidness and strength characteristics and can be designed (tailored) to meet specie directional staidness requirement. Design technique for aerodynamic surfaces in which the strength and stiffness is matched with the likely aerodynamic loads that may be imposed on it.

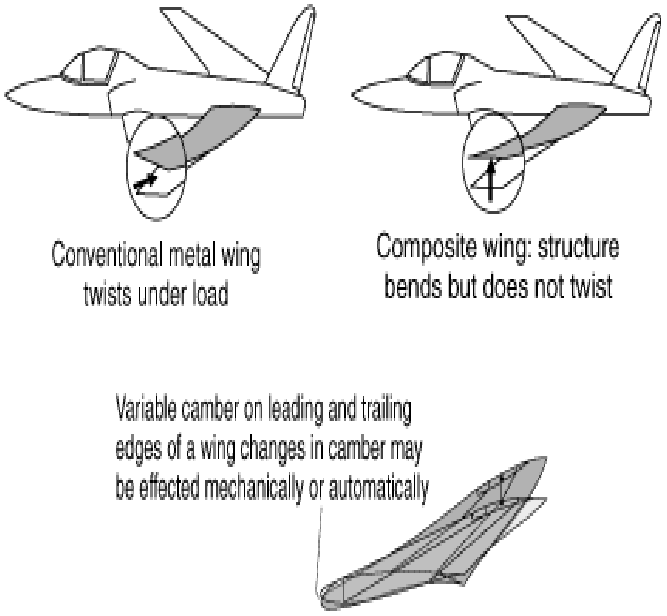


Fig.3: Aeroelastic Tailoring

Two examples of aero elastic tailoring. In the case on the top composite wing structures are used to meet the needs of forward swept wing. In the case at the bottom variable camber is used on the leading and trailing edges of the wing to overcome twisting and deformation of the wing during maneuvers

III. MECHANICS OF COMPOSITE

Isotropic: The material properties are a function of loading direction. Strength and stiffness is generally much higher along the fiber direction (isostrain) than perpendicular to the fiber direction (isostress)

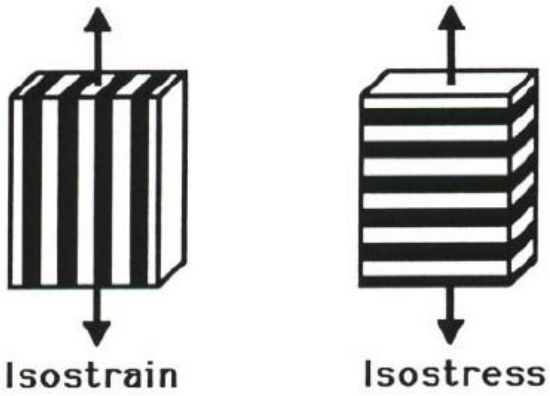


Fig.4: Geometry of Idealized Unidirectional Composite Materials

Composite Laminates are formed by combining individual layers (lamina) into a multi-layered structure. Continuous fiber composites combine Unidirectional Lamina (fibers aligned) into a layered structure with different layers in a laminate generally having the fibers oriented in different directions as depicted in Figure 4.

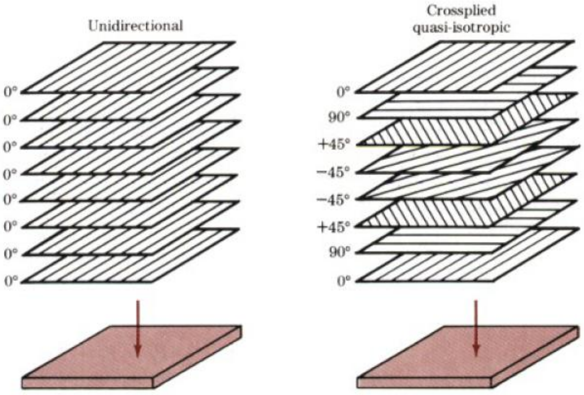


Fig.5: Schematic Illustration of Lamina being combined to form a Laminate.

- The properties of that new structure are dependent upon the properties of the constituent materials as well as the properties of the interface.
- Additionally, where metal alloys have isotropic characteristics, composites can have very selective directional properties to meet specific application needs.
- ANSYS allows you to model composite materials with specialized elements called layered elements. You can perform any structural analysis (including nonlinearities such as large deflection and stress stiffening).

IV. PROPERTY AVERAGING

As mentioned previously, the mechanical behavior of fiber reinforced composite materials is highly dependent on the direction of loading. For instance, considering a unidirectional laminate, the elastic modulus Parallel to the fiber direction, EL, (Isostrain – referred to as the Longitudinal direction) is significantly different from the elastic modulus Perpendicular to the fiber direction, ET, (Isostress – referred to as the Transverse direction).First order approximations of these moduli can be calculated from the elastic constants of the constituent materials by considering the Isostrain and Isostress models.

When a Unidirectional Composite is loaded parallel the fiber direction, then the composite strain (εc) = matrix strain (εm) = fiber strain (εf),

$$\varepsilon_c = \frac{\sigma_c}{E_c} = \varepsilon_m = \frac{\sigma_m}{E_m} = \varepsilon_f = \frac{\sigma_f}{E_f} \qquad (1)$$

where c -> Composite Property,
m -> Matrix Property, and
f -> Fiber Property.

In the Isostrain case, the Load carried by the Composite (Pc) is approximately equal to the sum of the Matrix Load (Pm) and the Fiber Load (Pf), thus

$$P_c = P_m + P_f \rightarrow \sigma_c A_c = \sigma_m A_m + \sigma_f A_f \qquad (2)$$

Combining (1) and (2) and recognizing that the matrix and fiber area fractions (Am and Af) are proportional to the volume fractions (Vm and Vf),

$$E_c = V_m E_m + V_f E_f = E_L \qquad (3)$$

where Vm = vm/vc and Vf = vf/vc. Note the Vm = 1 – Vf. Equation (3) is known as the **“Rule of Mixtures”** and implies that the contribution of a constituent is directly proportional to its volume fraction. The expression for determination of Composite Density has the same form. Isostress (Loading Parallel to the Fibers)

When a Unidirectional Composite is loaded Perpendicular to the fiber direction, then the Stress in the Composite is approximately equal to the Matrix Stress which equals the Fiber Stress

$$\sigma_c = \sigma_m = \sigma \qquad (4)$$

In this case, the Composite Elongation (ΔLc) in the direction of loading is equal to the sum of the Matrix Elongation (ΔLm) and the Fiber Elongation (ΔLf) thus

$$\Delta L_c = \Delta L_m + \Delta L_f \qquad (5)$$

Since elongation is the product of strain and thickness, and layer thickness is proportional volume fraction,

$$\varepsilon_c = V_m \varepsilon_m + V_f \varepsilon_f \qquad (6)$$

Writing the strains in terms of stresses (assuming elastic behavior) and noting equation (4), we find

$$\frac{1}{E_c} = \frac{V_m}{E_m} + \frac{V_f}{E_f} = \frac{1}{E_T} \qquad (7)$$

Equation (7) is known as the **“Inverse Rule of Mixtures”** and implies that the fibers are much less effective in raising the composite modulus under conditions of Isostress.Isostrain and Isostress represent the extreme conditions for a composite material as depicted in which illustrates that the transverse modulus is not appreciably increased beyond the modulus of the less stiff constituent, the matrix, at the fiber volumes usually encountered in engineering composites (Vf = 0.5 – 0.6). Particulate composites generally exhibit behavior between the Isostrain and Isostress conditions.

The L and T directions are generally referred to as the “Material Axis” and, if the composite is loaded in either of these directions, the corresponding strains can be calculated. However, if a stress is applied at an acute angle, θ, to the fiber direction, the elastic response along the “Loading Axis” (1 and 2 Directions) can be calculated from the properties measured along the “Material Axis” (L and T) where

$$E_1 = E_L\left[\cos^4\theta + \frac{E_L}{E_T}\sin^4\theta + \frac{1}{4}\left(\frac{E_L}{G_{LT}} - 2\nu_{LT}\right)\sin^2 2\theta\right]^{-1} \qquad (8)$$

$$\text{and } E_2 = E_L\left[\sin^4\theta + \frac{E_L}{E_T}\cos^4\theta + \frac{1}{4}\left(\frac{E_L}{G_{LT}} - 2\nu_{LT}\right)\sin^2 2\theta\right]^{-1} \qquad (9)$$

Notice that in Equations (8) and (9), the material parameters needed include Transformation Angle (θ), In-Plane Shear Modulus (GLT), In-Plane Poisson’s Ratio (νLT) and the Longitudinal and Transverse Elastic Moduli (EL and ET).

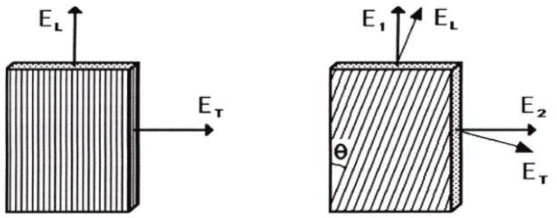


Fig.6: Illustration of Shear Strain Produced

$$G = \frac{E}{2(1-\nu)}. \qquad (10)$$

For Unidirectional Composites, In-Plane Shear Modulus follows the Inverse Rule of Mixtures and can be determined from the constituent matrix and fiber properties Gm and Gf. Thus the In-Plane Shear Modulus (GLT) for a Unidirectional Composite can be approximated as

$$\frac{1}{G_{LT}} = \frac{V_m}{G_m} + \frac{V_f}{G_f}. \qquad (11)$$

The major Poisson’s Ration, νLT (a Longitudinal Stress causing Transverse Strain), can be determined by applying the Rule of Mixtures where

$$\nu_{LT} = V_m \nu_m + V_f \nu_f. \qquad (12)$$

What about νTL (a Transverse Stress causing Longitudinal Strain); should it be equal to νLT? νTL is generally NOT equal to νLT, but can be easily determined as follows:

$$\nu_{TL} = \frac{E_T}{E_L}\nu_{LT}. \qquad (13)$$

The transformation of νLT (along the material axes) into ν12 (along the loading axes) is given by :

$$\nu_{12} = \frac{E_L}{E_L}\left[\nu_{LT} - \frac{1}{4}\left(1 + 2\nu_{LT} + \frac{E_L}{E_T} - \frac{E_L}{G_{LT}}\right)\sin^2 2\theta\right] \qquad (14)$$

One of the most important phenomena that occur during off-axis loading of a unidirectional composite is the production of a shear strain from a purely tensile stress state. As illustrated in Figure 9, if a 90o reference angle is inscribed on the sample prior to loading, this angle will change as the sample is loaded uniaxially indicating the existence of a shear strain. This clearly should not occur in isotropic materials or in a uniaxial composite loaded along one of the material axes (θ = 0o or θ = 90o). The mount of change in the 90o angle (measured in radians) that occurs upon stressing of the uniaxial composite is the shear strain, γ12. The Shear Coupling Coefficient, β, relates the applied normal stress, σ1, to the resulting shear strain

V. MATERIAL SELECTION

The Carbon Epoxy (T300) Composite is selected because of its superior strength than other natural fibers .So it is used for Manufacturing of automotive panels and some domestic appliances. The laminated composite Plate properties were shown in Table 1

Fibres on their own have a very high Young's Modulus in the direction of the fibre axis - about 250 GPa up 400 GPa for very carefully produced, small diameter fibres. Ultimate tensile strength ranges from 2200 MPa to 2800 MPa, again dependent on fibre diameter. In a direction perpendicular to the fibre axis, these properties are much, much lower.

CFRPs have extremely variable properties, depending on layup direction, choice of polymer, volume fraction of fibres etc. Just as an exmaple, in a unidrectional layup, with a volume fraction of 60%, one can expect Young's modulus to be about 220 GPa in the fibre direction, 7 Gpa perpendicular, with a UTS around 1400 MPa in the fibre direction. The density is around 1.8-2 g/cm^3.

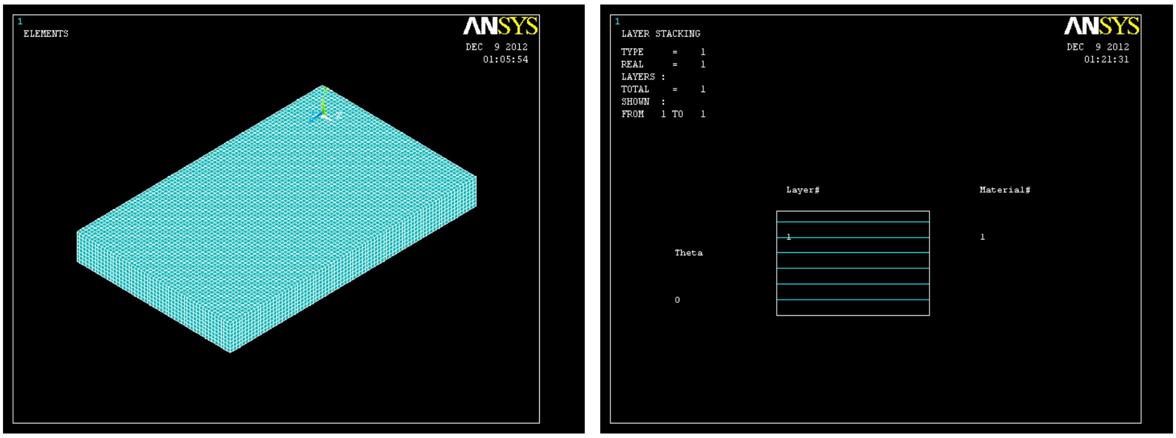
Carbon fiber, alternatively graphite fiber, carbon graphite or CF, is a material consisting of fibers about 5–10 μm in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment gives the fiber high strength-to-volume ratio (makes it strong for its size). Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric.

Material name	**Density, ρ (g/cm^3)**	**Elastic Modulus, E (GPa)**	**Poisson’s ratio, ν**	**Shear Modulus, G (GPa)**
Carbon	1.76-1.85	E_f= 220	0.25	91.7
Epoxy	1.10 – 1.15	E_m= 3.6	0.35	1.33
T300/934 Carbon/Epoxy Unidirectional Prepreg	E_{11}=148	E_{22}=9.65	V_{12}=0.3 V_{21}=0.019	G_{12}=4.55

Table 1: Material Properties

VI. MODELING OF COMPOSITE PLATE

Consider composite plate wing like structure (chord=250mm, span=400mm) with clamped-free boundary conditions.The unidirectional laminate; keep all the layer fiber orientation as 0^0 shown in fig 7



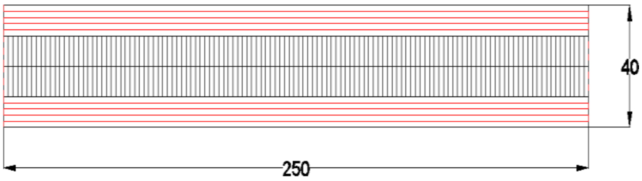


Fig.7: Orientation Fibers

VII. ANALYSIS OF LAMINATES

A. Aeroelastic Frequencies

An important class of problems in dynamics concerns the free vibrations of systems. (The concept of free vibrations is important; this means that although an outside agent may have participated in causing an initial displacement or velocity–or both– of the system, the outside agent plays no further role, and the subsequent motion depends only upon the inherent properties of the system. This is in contrast to ”forced” motion in which the system is continually driven by an external force.) We shall consider only undamped systems for which the total energy is conserved and for which the frequencies of oscillation are real. This forms the basis of the approach to more complex studies for forced motion of damped systems. We saw in Lecture 13, that the free vibration of a mass-spring system could be described as an oscillatory interchange between the kinetic and potential energy, and those we could determine the natural frequency of oscillation by equating the maximum value of these two quantities. (The natural frequency is the frequency at which the system will oscillate unaffected by outside forces. When we consider the oscillation of a pendulum, the gravitational force is considered to be an inherent part of the system.) The general behavior of a mass-spring system can be extended to elastic structures and systems experiencing gravitational forces, such as a pendulum. These systems can be combined to produce complex results, even for one-degree of freedom systems. We begin our discussion with the solution of a simple mass-spring system, recognizing that this is a model for more complex systems as well.

B. Aeroelastic Frequency of Unidirectional Laminates

1. (0/90/90/0) LAMINATE

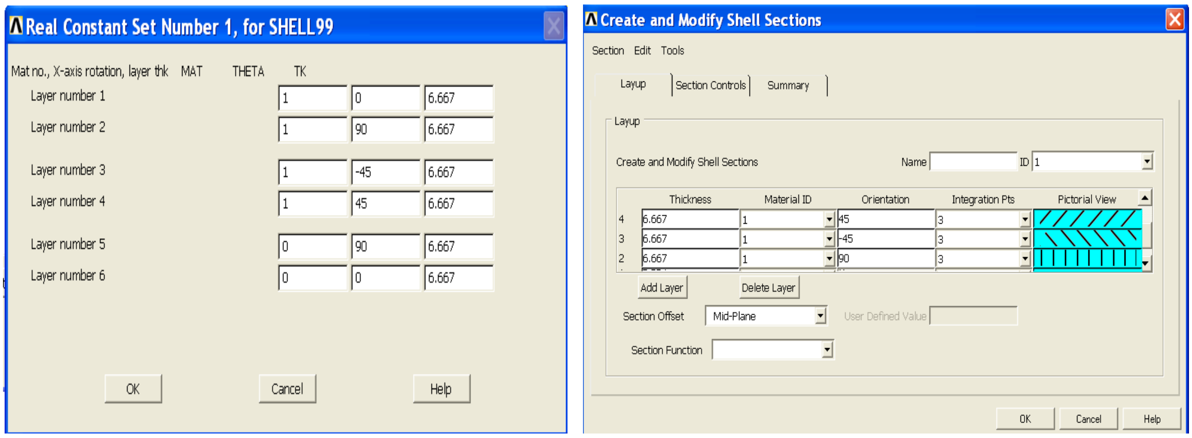
Set	time/freq	load step	substep	cumulative
1	0.95178e-05	1	1	1
2	0.19199e-04	1	2	2
3	0.26994e-04	1	3	3
4	0.39702e-04	1	4	4
5	0.59539e-04	1	5	5
6	0.81740e-04	1	6	6
7	0.87164e-04	1	7	7
8	0.89619e-04	1	8	8
9	0.10866e-03	1	9	9
10	0.11210e-03	1	10	10

2. (45/-45/-45/45) laminate

Set	time/freq	load step	substep	cumulative
1	0.85187e-05	1	1	1
2	0.26032e-04	1	2	2
3	0.41480e-04	1	3	3
4	0.44553e-04	1	4	4
5	0.66211e-04	1	5	5
6	0.74663e-04	1	6	6
7	0.89298e-04	1	7	7
8	0.90105e-04	1	8	8
9	0.10680e-03	1	9	9
10	0.10823e-03	1	10	10

3. (0/90/-45/45/90/0) laminate

Set	time/freq	load step	substep	cumulative
1	0.11637e-04	1	1	1
2	0.29894e-04	1	2	2
3	0.38344e-04	1	3	3
4	0.49533e-04	1	4	4
5	0.81173e-04	1	5	5
6	0.89542e-04	1	6	6
7	0.10507e-03	1	7	7
8	0.11829e-03	1	8	8
9	0.11953e-03	1	9	9
10	0.12465e-03	1	10	10



Real Constant Set Number 1, for SHELL99

Mat no., X-axis rotation, layer thk	MAT	THETA	TK
Layer number 1	1	0	6.667
Layer number 2	1	90	6.667
Layer number 3	1	-45	6.667
Layer number 4	1	45	6.667
Layer number 5	0	90	6.667
Layer number 6	0	0	6.667

Create and Modify Shell Sections

Layup

Create and Modify Shell Sections Name ID 1

	Thickness	Material ID	Orientation	Integration Pts	Pictorial View
4	6.667	1	45	3	
3	6.667	1	-45	3	
2	6.667	1	90	3	

Section Offset: Mid-Plane

Section Function

Fig.8: Real constant layout & Add-delete layer layout

VIII. CONCLUSION

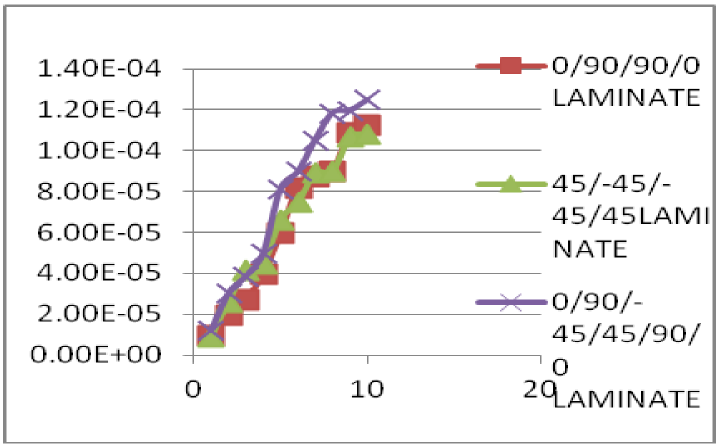


Fig.8: Effect of ply orientate of laminates

The natural frequency of laminate with different fiber orientation was carried out by help of ansys show in the graph the natural frequencies with respect to the mode shape and the effect of ply orientation were plotted. The plot shows that carbon has higher material properties.

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