FINITE ELEMENT MODELING AND ANALYSIS OF NANOCOMPOSITE AIRFOIL STRUCTURES

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By

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Dedicated to my beloved parents
And my elder brother

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CERTIFICATE

*This is to certify that the thesis entitled, **"FINITE ELEMENT MODELING AND ANALYSIS OF NANOCOMPOSITE AIRFOIL STRUCTURES"** submitted by **Mr. Himansu Sekhar Sethi,** Roll No. **213ME1393** in partial fulfillment of the requirements for the award of **Master of Technology** Degree in **Mechanical Engineering** with specialization in **"Machine Design and Analysis"** at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.*

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ABSTRACT

An airfoil or aerofoil is the cross-sectional shape of a wing or blade of a turbine, rotor or propeller. An aerodynamic force is produced when an airfoil moves through a fluid. These forces are the very reason of lift produced in an aircraft or to produce a downward force on an automobile to improve traction. The efficiency of an airfoil is characterised mainly on its profile section and its aerodynamic design. In the present study a NACA 2412 AIRFOIL model is selected and analysed. The material used for the analysis of airfoil is nanocomposite, because of its unique and better mechanical properties than the conventional materials. Nanocomposites are the materials which consist of two or more constituents combined at a nanoscale regime in such a manner that it gives improved properties (such as elastic, damping, wear and corrosion resistant etc.) as compared to other conventional materials. In the present study, free vibration and static structural analyses are cared out in order to investigate the effect of carbon nanotube content on the static and dynamic responses of NACA 2412 aerofoils.

The effective elastic properties of carbon nanotube based nano-composites are determined using Halpin Tsai model where carbon nanotubes are assumed to be uniformly distributed and randomly oriented through the matrix. The properties thus obtained are used for further analysis. NACA 2412 airfoil profile was taken from readily available database and point clouds was imported to Solidworks in order to make 3D model. The solid model thus generated used in ANSYS to perform free vibration analysis. To find the lift and drag forces that the airfoil generates are found from computational fluid dynamics module available in ANSYS work bench. Finally the calculated lift and drag forces are utilised to perform static structural analysis. Several parameters such as total deformation, equivalent stresses and shear stresses are measured for different carbon nanotube content, airflow rate, and orientation of the airfoil. Increase in elastic properties is seen with increase in volume fraction of CNT in nanocomposite. From the study it is also observed that the natural frequency on the nanocomposite increases with increase in the percentage of carbon nanotubes with a drastic decrease in deflection.

CONTENTS

Contents	Page No.

LIST OF FIGURES

LIST OF TABLES

Nomenclature

CNT	Carbon Nanotube
CMNC	Ceramic Matrix Nanocomposites
MMMC	Metal Matrix Nanocomposites
PMNC	Polymer Matrix Nanocomposites
SWCNT	Single Walled Carbon Nanotubes
MWCNT	Multi Walled Carbon Nanotubes
AFM	Atomic Force Microscopy
CFD	Computational Fluid Dynamics
CRPF	Carbon Fiber Reinforced Polymer
AEH	Asymptotic Expansion Homogenization
FSDT	First-Order Shear Deformation Plate Theory
DWCNT	Double-Wall Carbon Nanotubes
SEM	Scanning Electron Microscopy
CVD	Chemical Vapour Deposition
RVE	Representative Volume Element
TEM	Tramission Electron Microscopy
NACA	National Advisory Committee for Aeronautics

CHAPTER 1

INTRODUCTION

In the earliest days, the only means of locomotion was by walk when man was in the early stages of development of his livelihood. Since then, man has achieved faster and more comfortable ways of travelling such as bikes, cars, trains and specially airplanes. From the day of its invention airplanes have been gone through many stages of advancement and today it is considered as one of the fastest option of transportation available. In World War II it had got the popularity as a modern war machine and had played an important role in the war. Popularity of airplanes in today's era has led to many innovative research and inventions to manufacture faster and more cost effective planes. The present study is all about to determine how to attain maximum performance from an airfoil section made up of nanocomposite structure.

An airplane's airfoil is a cross-section of the wing which is somewhat similar to the cross section of wings of a bird. The main objective airfoil is to provide vertical lift to an aircraft during the take-off and when it is in flight. The airfoil structure also has a negative effect called Drag, which opposite to the forward motion of the airplane. The magnitude of lift required by a plane is decided according to the purpose for which it is to be used. The planes which are heavy and which are used to transfer heavier loads require more lift while plane used for lighter loads need less lift. Thus, airfoil section is designed depending on its weight and upon the use of airplane. Lift force thus produced acknowledges the vertical motion of the plane, which depends on the horizontal velocity of the aircraft. So, by calculating the coefficient of lift, the lift force can be determined. Once lift force and vertical acceleration is calculated the next step is to determine the horizontal velocity produced.

Aerodynamics is a field of science which focuses mainly on concentrating on the behavior of air movement, when associated with a solid model, such as turbine blade, propeller, airfoil etc. An aerodynamic energy is handled by the model based on airfoil when it travels through a fluid environment. The power produced during flight and which is perpendicular to the direction of movement is termed as lift. The force which acts opposite to the direction of travel is called drag. In designing of an airplane's wing these are the primary parameters to be considered. For a given magnitude of thrust the task of a designer is to minimize drag as much as possible and to maximize lift to increase its efficiency and reduce fuel consumption. The lift of an airfoil changes according to its approach and shape.

Leading edge: The edge of the airfoil which faces the direction of travel of the plane is called as leading edge. This edge cuts the air in such a way that the air gets deflected in two directions, along the upper surface and lower surface. Generally the velocity of air along the upper surface is more than the velocity of air along the lower surface.

Trailing edge: The edge where the airfoil section ends is called as trailing edge. It is located at the back of airfoil and generally its shape is pointed in nature.

Chord line: Chord line may be defined as the line which joins the trailing edge and the leading edge. This line bisects equally the airfoil section into two halves in case of a symmetric airfoil.

Angle of attack: The angle made by the chord line with the direction of motion is known as angle of attack. By changing the angle of attack we can observe a considerable changes in lift and drag, hence it is an important parameter to be considered while designing the airfoil.

Chamber line: It may be defined as a line which joins leading edge to the trailing edge and divides the airfoil section into two equal halves.

1.1. Composites

Composite materials has been used in a wide range of applications in various engineering fields such as ships, submarines, aerospace structures, civil engineering structures, machine components, chemical industrial applications, etc. In the recent years the importance of composite materials has been recognized by many researchers and commercial organizations. These organizations have put a lot of effort in developing innovative and better techniques to improve the properties of composite as per human needs.

1.2. Nanocomposite

In 1986 the term Nanocomposite first appeared in some of the early literatures dealing with composites. And around 1992 first polymer nanocomposites were proposed and discussed.

Nanocomposite is a multiphase material in which one of the phase exists in nanoscale range. These consist of reinforcements which are dispersed in the polymer matrix either in evenly distributed or random fashion. Polymers are basically made up of long, repeating sequences of organic molecules. Polymers can be divided into two categories: thermoplastic and thermoset. Thermoplastic polymers can be heat softened, melted and reshaped as many times as desired whereas thermoset polymers cannot be melted or reshaped with application of heat or pressure. Thermoplastic matrix components can be used over a wide range of temperature. In structural composite components thermosets are widely used as a matrix material in fibre reinforced composites. Further thermosets can be divided into five categories

i. Polyester resin
ii. Epoxy resin
iii. Vinyl ester resin
iv. Phenolic resin
v. High performance resin

In the past, the materials which are used for nanocomposites were of low technology: clay, soot and ash. After a long research it was found that S-glass and carbon fibers or boron nitride whiskers can be used as reinforcements. As polymer can be treated as mechanically weak link, many research considered the techniques for improving interaction between reinforcements. According to the matrix materials nanocomposites can be categorized into three different categories:

i. Ceramic Matrix Nanocomposites(CMNC),
ii. Metal Matrix Nanocomposites(MMNC) and
iii. Polymer Matrix Nanocomposites(PMNC).

In the work of Niihara [1] the usefulness of ceramic matrix nanocomposite was revealed. Incorporating high strength nanofibers into ceramic matrix the properties of advanced nanocomposites has improved a lot with high toughness and better failure features when compared to sudden failures of conventional ceramic materials. The material which consists of a ductile metal or alloy matrix and in which some nanosized reinforcement is implanted is referred to as metal matrix nanocomposites. Metal matrix nanocomposites combine the features of metal and ceramic together, i.e. combination of ductility and toughness with high modulus and strength. Due to ease of production, ductile nature and lightweight polymer matrix nanocomposites are widely used in various industries. These consist of nanofillers or nanoparticles which are dispersed in the polymer matrix. These materials however have some disadvantages such as low strength and modulus compared to metal and ceramics. Considering these disadvantages whiskers, fibres, particles or platelets as reinforcements is added to the polymer matrix to improve the mechanical properties.

1.3. Hybrid Composites

Strength, toughness, energy absorption, stiffness, ductility, damping, thermal stability and low weight are the important properties which are desired from any composite. As the conventional materials cannot provide all the above mentioned properties it is desired to form composites where we can obtain the properties of materials as per our needs. There has been extraordinary increase in mechanical properties by incorporating reinforcement of nanoscale in polymer composites as compared to pure polymer. The combination of two or more different materials, such as an organic polymer and an inorganic ceramic, results into hybrid composites.

1.4. Carbon Nanotubes

Since its discovery carbon nanotubes (CNTs) have played a very important role in the field of engineering. These are cylindrical macromolecule which consists of carbon atoms that are arranged in a repetitive hexagonal structure. Carbon nanotubes were discovered by Sumio Iijima in 1991. After its discovery there has been an extensive research work in the field of nanocomposites to predict their effective properties. In order to obtain exceptionally superior mechanical properties of CNTs, broad research is being carried out for developing CNT-reinforced composites. CNTs are allotropes of carbon with a cylindrical structure which can be capped on the ends with buckyballs or can be open ended. These are entirely composed of sp^2 bonds and these bonds are the sole reason for the unique properties of CNTs. Because of its improved and unique properties (such as mechanical, electrical and thermal properties), CNTs are used widely as reinforcing materials at nanoscale for developing new improved nanocomposites. Incorporating CNTs into polymer matrix can significantly develop improved stiffness and strength properties of composites in comparison with the nanocomposite in which carbon fiber are used as reinforcement.

1.4.1. Types of CNTs

There are basically two types of carbon nanotubes: single walled carbon nanotubes (SWCNT) and multi walled carbon nanotubes (MWCNT). These two types differ in the arrangements of their grapheme cylinders. Only one single layer of graphene cylinder is present in SWCNTs while there are multiple layers of graphene cylinders present in MWCNT as shown in Fig: 1.3 MWCNTs are more resistant to chemical changes than that of SWCNT. There are two models which appropriately describe the constructional feature of MWCNT. The first is the Russian Doll in which many sheets of graphene (single sheet of graphite is called as graphene) are arranged as concentric cylinders, and the second is the Parchment model in which a sheet of graphene is rolled around itself like a scroll or parchment or a newspaper rolled as a cylindrical shape. The distance between graphene layers in graphite is more than the interlayer distance in MWCNTs. CNTs depending on its atomic arrangements may be of armchair, chiral and zig-zag, because of their mechanical and physical properties.

1.4.2. Application of CNTs

The extraordinary properties have led researchers and companies to consider using CNTs in several fields such as electrical, electromagnetic, chemical, biological field and microporous structure. In electrical field CNTs can be used in vacuum electronics as field emitter and also as electrodes, capacitors, fuel cell, Li battery etc. Sensors, AFM tips, DNA sequencing are some of the applications of CNTs in the biological field. It has been researched that carbon nanotubes are outstanding materials for super capacitor electrodes. These are potentially used in Lithium Ion batteries because of their highest reversible capacity than any carbon material. Carbon nanotubes are also used as hydrogen storage. Single walled carbon nanotubes can store hydrogen and releasing them adequately in hydrogen fuel to be used in automobiles. Thin carbon nanotubes can also act as speakers which are cheap, flat, transparent, flexible, magnet free and stretchable. MWCNTs can be used as electrodes, which are three times efficient than the conventional types, which converts waste heat from industrial plants, pipelines into electricity. The device which does this task is named as Nanotube Thermocell. Also carbon nanotubes can serve as artificial muscles which are electrically powered called as Aerogels.

1.5 Motivation of the Present Work

Composites made up of carbon nanotubes play a very important role in engineering field because of its unique physical, mechanical and thermal properties. Some of its useful properties are superior length-to-diameter ratio, has diameter of 3 to 9 nm, length is in millimeter range, they are efficient electrical conductors; these can act both as thermal conductors and thermal insulators, better wear and corrosion resistance, also good fatigue resistant and has good elevated temperature properties. It is possible to construct the directional effective properties of CNT based composites thereby providing the ability to control wear, corrosion, deformation and dynamic response of the system. Composites are two or more phase composites in which constituents are mixed up to form hybrid in a hierarchical manner. Carbon fibers are distributed uniformly in the nanocomposite matrix to form the hybrid composite which is required for analysis. The nanocomposite used here is developed by dispersing randomly oriented CNTs into the polymer matrix. Halpin-Tsai method is used to model the nanocomposite. NACA 2412 AIRFOIL model is proposed in this analysis to be modeled for analysis based on the elastic properties of nanocomposite. The present research focuses on two main ideas. The first objective is to perform the modal analysis of the airfoil structure and determine the different mode shapes for different frequencies. The second objective is to analyze the airfoil model and determine the various forces acting on the model during the CFD analysis. The CFD study mainly concentrates on the coefficient of lift as well as coefficient of drag. After determining the lift and drag forces static structural analysis is performed to predict the stress pattern simulating the conditions which a conventional aircraft wing is subjected to airspace environment.

1.6 Aim and Scope of the Present Thesis

The aim of the present work is to develop an airfoil model for uniformly distributed single walled carbon nanotubes based nanocomposite using ANSYS program and evaluate its effective properties by applying various boundary conditions. A finite element model is proposed for the analysis and subjected to discretization. As discussed earlier in recent years laminated composite shell panels are being widely used in various engineering fields where they are subjected to large amplitude vibrations. Hence the airfoil model which is to be analyzed in this study is made up of nanocomposite structure. The application of nanocomposites is either weight critical such as in aerospace or performance critical as in non-corrosive and non-magnetic nanocomposites in naval industries. Though the scope of nanocomposites in the field of aviation is abundant, the scarcity of ample knowledge of researchers around the world until now has been very much restrictive. Hence a lot of effort has been put forward and dedicated to develop newer and innovative approaches to impart knowledge on nanocomposites materials, structural analysis and structural mechanics. The present study is an attempt to present unified and assimilated approach to nanocomposite materials and its application in aviation field.

1.7 Objective

i. Material modeling for the properties of nanocomposite, which has been modeled using Halpin-Tsai method.
ii. Modeling of airfoil of NACA 2412 airfoil model.
iii. Determination of drag and lift coefficient of airfoil model in working environment.
iv. Modal analysis of the airfoil model.
v. Static structural analysis of the model.

CHAPTER 2

LITERATURE REVIEW

Lu [1] investigated using an empirical force constant model the elastic properties of carbon nanotubes and nanoropes. It was found that the elastic moduli of single and multiwall nanotubes are insensitive to structural variables such as helicity, radius and the number of walls**.** Gultop [2] determined the impact perspective degree on Airfoil performance. The main reason for this study was to find out the conditions where the ripple conditions can be avoided throughout wind tunnel tests. This resulted increase in the aeroelastic insecurities at Mach number 0.55, which came out to be higher than the wind tunnel Mach number of velocity of 0.3. Goel [3] used Quansi – 3D analysis codes to devise a method of optimization of Turbine Airfoil. In his paper the complexity of 3D modeling is solved by modeling it in multiple 2D airfoil sections and then joining them in radial direction using first and second order polynomials which leads to no roughness in the radial direction. Prabhakar [4] analyzed the NACA 4412 airfoil profile and studied its profile for consideration of an airplane wing .The NACA 4412 airfoil was created using CATIA V5 and analysis was carried out in ANSYS 13.0 FLUENT software at an inlet speed of 340.29 m/sec for different angles of attack of 0˚, 6, 12 and 16˚. Standard k-ε turbulence model was assumed for Airflow. Fluctuations of dynamic pressure and static pressure are presented graphically in form of filled contour. Habali and saleh [5] discussed a selection procedure for airfoil section and aerodynamic design of a rotor blade. They used Glass Fiber Reinforced Plastic for designing the rotor blade and conducted a static proof load test to determine the load carrying capacity. Feistauer et al [6] presented a brief study on numerical simulation of interaction of two dimensional incompressible viscous fluids and vibration analysis of airfoil with large amplitude. Gharali and Johnson [7] used ANSYS Fluent 12.1 to stimulate numerically flow of an oscillating freestream over a stationary S809 airfoil. A comparison study is performed in this study to choose the model. Several simulations were conducted based on different Reynolds numbers from 0.026

to 18. Qu et al [8] carried out a numerical simulation on the landing process of a NACA 4412 airfoil considering the influence of dynamic ground effect (DGE). Murugan et al [9] studied variable camber morphing airfoil incorporating compliant ribs and flexible composite skins. A hierarchical modeling framework is utilized in this study to decouple the compliant ribs and airfoil skin. Koziel and Leifsson [10] presented an automated low-fidelity model selection procedure is presented. A comparison study is carried out in this paper to compare the standard and proposed approach within the scope of aerodynamic design of transonic airfoil. Huang et al [11] conducted a research on plunging motion, varying pitching, and varying incoming flow for NACA 0012 airfoil section. This study mainly concentrates on observing the real characteristics and response of airfoil of rotor blades in unsteady flow field.

Li et al [12] successfully fabricated the interlaminar reinforced and toughened CFRP composites in which MWNTs-EP/PSF (polysulfone) hybrid nonofibers with preferred orientation were directly electrospun onto the carbon fiber/prepegs. The facture toughness was attained a maximum at 10 wt% MWNTs-EP loading and then decreases. With increased MWNTs-EP loading the flexural properties and interlaminar shear strength of composite are improved. Shokrieh and Rafiee [13] developed a stochastic multi-scale modeling technique to estimate the mechanical effective properties of carbon nanotube rein forced polymers. A full range multi scale technique is implemented to consider parameters of nano, micro, meso and macro-scales and developed full stochastic integrated modeling procedure. It has been proved that mean values can be replaced with that of random distribution of carbon nanotube length and volume fractions. Rafiee et al [14] studied the nonlinear free vibration of carbon nanotubes/fiber/polymer composite multiscale plates with surface- bonded piezoelectric actuators. First order shear deformation theory (FSDT) and von karman geometrical nonlinearity are used as the governing equations for the piezoelectric nanotubes/polymer/fiber multiscale laminated composite plates. Modeling is accomplished using the Halpin-Tsai equations and fiber micromechanics in hierarchy to predict the effective properties of the hybrid composite. Sharma and Shukla [15] discussed the dispersion of carbon nanotube and effect of functionalization on the effective properties of multiscale carbon epoxy composites. Young's modulus, inter-laminar shear strength and flexural modulus increased by 51.46%, 39.62% and 38.04%, respectively with the addition of CNTs(1.0wt%) in the resin. Halpin-Tsai equations and micromechanics modeling were used to evaluate the bulk properties of multiscale composites. Halpin and Kardos [16] developed the micromechanics relationships for semi-crystalline polymers, which formed the operational base for the composite analysis. Ramakrishna et al [17] investigated the tensile modulus of two sets of electrospun fibers: nylon-6 and montmorillonite (MMT) reinforced nylon-6. An increase in modulus is seen due to greater alignment of polymeric molecules with reduction of fiber diameter close to nano-scale. Hundley et al [18] presented a framework to predict the nonlinear behavior of metal-composite interfaces in titanium-graphite fiber metal laminates. To characterize the physical and chemical state of the interface x-ray diffraction and electron microscopy techniques were used. Benveniste [19] reconsidered and reformulated the Mori-Tanaka theory and adopted the direct approach of defining and evaluating moduli. Two phase composites with anisotropic elastic materials and an inclusion phase consisting of aligned or randomly oriented particles are used for the analysis. Rafiee et al [20] investigated the nonlinear stress analysis and modeling of piezolaminated CNTs/fiber/polymer composite plates under a combined mechanical loading. Von Karman and first-order shear deformation plate theory (FSDT) are used as governing equations for the analysis. Large deflection response and stress analysis of nanocomposite plates are determined by an analytical solution. Song and Youn [21] used asymptotic expansion homogenization (AEH) method to investigate the effective elastic properties of nanocomposites reinforced with CNTs. CNTs are oriented randomly in the nanocomposite and a control volume finite element method (CVFEM) is employed to predict the effective elastic tensor. The surface of CNT is treated with oxygen plasma in order to improve the interfacial bonding between the CNT and matrix. Liu and Chen [22] evaluated the novel mechanical properties of CNT-based composites using a 3-D nanoscale representative volume element (RVE). The formulation is based on continuum mechanics and finite element method (FEM). For estimating the effective Young's modulus of the RVE an extended rule of mixtures is applied which is based on the strength of materials theory. It was found that addition of CNTs in matrix at volume fractions of only about 2% and 5% can give an increase in stiffness by 0.7 and 9.7 times, respectively. Seidel and Lagoudas [23] obtained the effective elastic properties of CNTs using a composite cylinders micromechanics technique. Self-consistent and Mori-Tanaka methods are then used to obtain effective properties of composite consisting of single or multi-walled CNTs embedded in a polymer matrix. Gojny et al [24] using a standard calandering technique produced nanocomposites consisting of double-wall carbon nanotubes (DWCNTs) and an epoxy matrix. An increase of Young's modulus, strength and strain to failure at nanotube content of only 0.1 wt% is observed. Mathur et al [25] using scanning electron microscopy (SEM) analyzed the characteristics of CNTs which are grown by chemical vapour deposition (CVD) on different carbon fibre substrates. These substrates may be unidirectional carbon fibre tows, bi-directional (2D) carbon fibre cloth and 3-D carbon fibre felt. Other methods for analyzing can be transmission electron microscopy (TEM) and thermal gravimetry (TGA). Garcia et al [26] described a hybrid composite of CNTs. Advanced fibers and a matrix. Standard mechanical and electrical laminate tests are used for CNT synthesis and characterization. Gojny et al [27] evaluated different types of nanofillers, its influence on novel properties of epoxy-based nanocomposites. Influence of nanofillers, aspect ratio, amino-functionalization, specific surface area and the varying dispersibility are discussed in details.

CHAPTER 3

METHODOLOGY

3.1 Element Description

In this analysis solid185 model is used for 3D modeling of the airfoil structures. The model has a total of 8 nodes which has three degrees of freedom at each node. All the three degrees of freedom are translation in the x, y, and z directions. The element has plasticity, hyperplasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. It also allows for prism and tetrahedral degenerations when used within irregular regions. Various element technologies such as B-bar, uniformly reduced integration, and enhanced strains are supported.

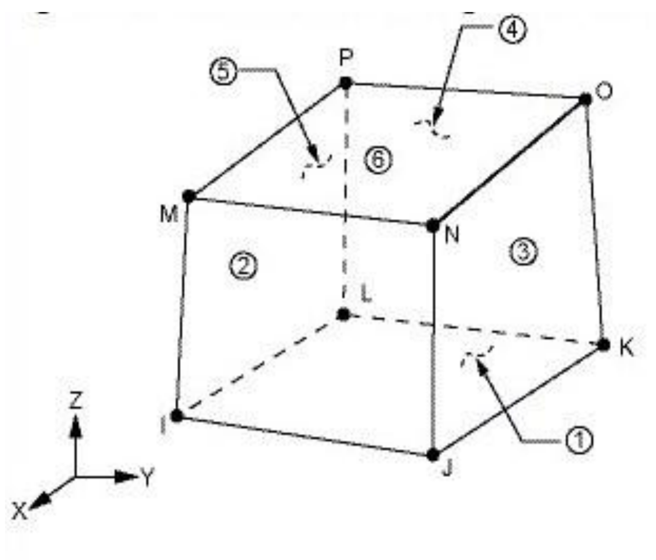

Figure 3.1: Structural Solid Geometry of the Element [34].

As shown in the above figure the nodes are named as I, J, K, L, M, N, O, P, which has 3 degrees of freedom at each node, which are translation in the direction of three axes as UX, UY, UZ. Young's modulus, Poisson's ratio, rigidity modulus are the material properties in all the three directions. The model can bear surface loads in all the 6 faces in the geometry. Simplified enhanced strain formulation is used for analyzing the model which prevents shear locking in bending-dominated problems. When used with the mixed-up formulation, the simplified enhanced strain formulation gives the same results as the enhanced strain formulation. All internal DOFs are introduced automatically at the element level and condensed out.

The solution output of the element used in the analysis is in two forms: nodal displacements which are included in the overall nodal solution and the additional element output. There are some assumptions and restrictions related to the element which has been used in the analysis which are: Zero volume elements are not allowed. Elements may be numbered as shown in the Figure 3.1 or may have planes MNOP and IJKL interchanged. The element must not be twisted such that the element attains two separate volumes. All the elements used must have eight nodes.

3.2 Material Modeling

A CNT based nanocomposite model of uniform thickness is proposed. The mixture used consists of isotropic matrix which is basically the epoxy resin and CNT. For the polymer matrix through the thickness the CNTs are aligned uniformly. The CNT which is used in the modeling are assumed to be isotropic. That is they are assumed to have similar properties along all the direction of orientation. The CNTs are also assumed to be randomly oriented and uniformly distributed throughout the matrix. The bonding between the CNTs used and the matrix is assumed to be perfectly bonded. The dispersion of CNT in the matrix is assumed to be uniform and perfect. As the dispersion is also considered as isotropic so each CNT has same mechanical properties and aspect ratio. Due to simplicity of the experiment all CNTs are taken as straight CNT and it is assumed that there is no void present in the matrix. In the hybrid analysis the fiber-matrix bonding is also considered as perfect. All the constituent materials are considered to be linearly elastic throughout the deformation.

The elastic material properties of the nanocomposite can be predicted by combining first CNT and polymer using the Halpin-Tsai model to form two phase nanocomposite. The effective material properties of the two phase nanocomposite are known to be isotropic and can be predicted by using the below given equations.

The tensile modulus of nanocomposites according to the Halpin-Tsai model can be expressed as: [15]

$$E^{MNC} = \frac{E^{MER}}{8}\left[5\left(\frac{1+2B_{dd}V_{CN}}{1-\beta_{dd}V_{CN}}\right)+3\left(\frac{1+2\left(\frac{l^{CN}}{d^{CN}}\right)\beta_{dL}V_{CN}}{1-\beta_{dl}V_{CN}}\right)\right] \quad (1)$$

Where,

$$\beta_{dl} = \frac{\left(\frac{E_{11}^{CN}}{E^{MER}}\right)-\left(\frac{d^{CN}}{4t^{CN}}\right)}{\left(\frac{E_{11}^{CN}}{E^{MER}}\right)-\left(\frac{\ell^{CN}}{2t^{CN}}\right)}, \quad (2)$$

$$\beta_{dd} = \frac{\left(\frac{E_{11}^{CN}}{E^{MER}}\right)-\left(\frac{d^{CN}}{4t^{CN}}\right)}{\left(\frac{E_{11}^{CN}}{E^{MER}}\right)+\left(\frac{d^{CN}}{2t^{CN}}\right)}, \quad (3)$$

Where,

E_{11}^{CN} = Young's modulus of CNTs,

V_{CN} = volume fraction of CNTs,

ℓ_{CN} = length of CNTs,

d_{CN} = outer diameter of CNTs,

t_{CN} = thickness of CNTs,

V_{MER} = volume fraction of isotropic epoxy resin matrix,

E^{MER} = Young's modulus of isotropic epoxy resin matrix.

From the above formulations the volume fraction of CNTs could be expressed as

$$V_{CN} = \frac{w^{CN}}{w^{CN} + \left(\rho^{CN} / \rho^{MER}\right) - \left(\rho^{CN} / \rho^{MER}\right) w^{CN}} \tag{4}$$

Where,

w_{CN} = mass fraction of CNTs,

ρ_{CN} = mass density of CNT,

ρ_{MER} = mass density of epoxy resin matrix.

And the Poisson's ratio and mass density of nanocomposite could be expressed as

$$v^{MNC} = v^{MER}, \tag{5}$$

$$\rho^{MNC} = V_{CN}\rho^{CN} + V_{MER}\rho^{MER}, \tag{6}$$

where,

ρ^{CN} = density of CNTs,
ρ^{MER} = density of matrix,
v^{MER} = Poisson's ratio of epoxy matrix,
v^{MNC} = Poisson's ratio of nanocomposite.

3.3 Methodology

3.3.1 Geometry Formation

In the present study a NACA 2412 airfoil model is selected with suitable grid points and dimensions. From the airfoil database the airfoil coordinates are obtained in Dat file format which is to be imported to Microsoft excel. These points or coordinates are then imported to Solidworks to create a profile of the airfoil. If the dimensions of the coordinates are in millimeter then it is to be scaled properly to evaluate in meter units. Figure 3.2 shows the profile of NACA 2412 model after drawing the spline over the specified grid points and importing it to Ansys workspace. The 2D profile is then extruded to form a 3D solid model and upon which CFD and modal analysis is carried out.

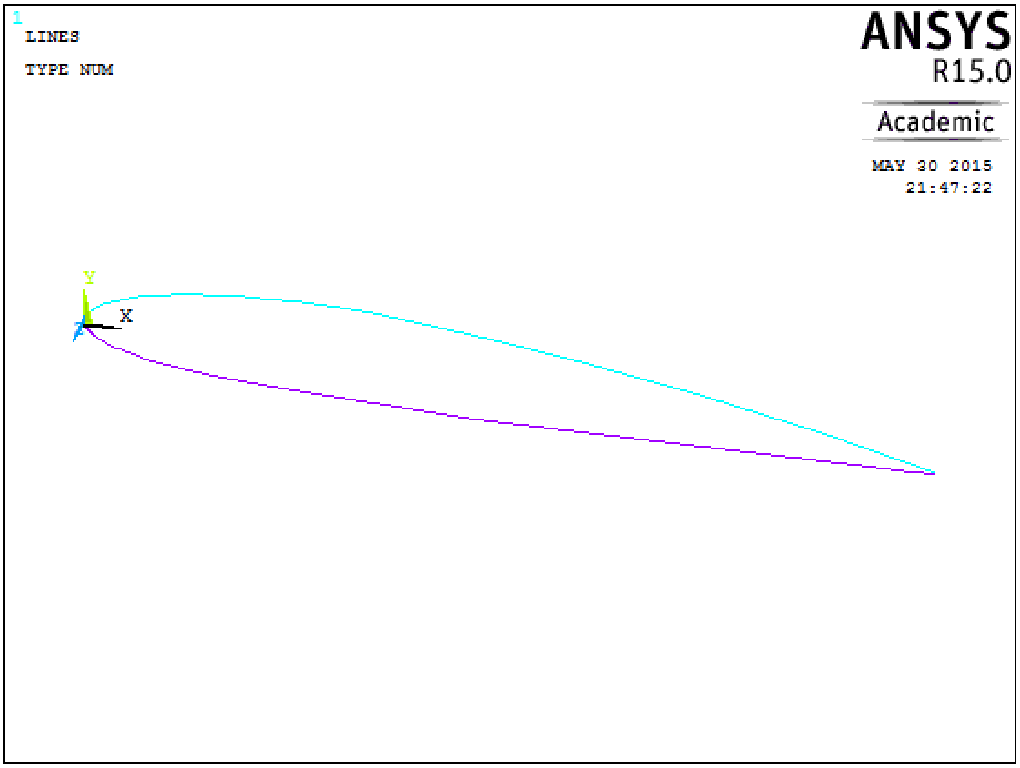

Figure 3.2: Profile of NACA 2412 airfoil model

3.3.2 Creating the 3D Model

The grid points thus imported from excel create points and a spline over the points in the workspace of solidworks. In solidworks using these points and spline a solid model of airfoil is created with appropriate dimension. In addition to the airfoil model an enclosure is also created here which resembles to a fixed volume of fluid flowing over the airfoil wing. The enclosure created is named as wall and the model to be tested is named as airfoil. Then with the help of Boolean operation the airfoil model is subtracted from the solid enclosure so that the airfoil model unites with the enclosure.

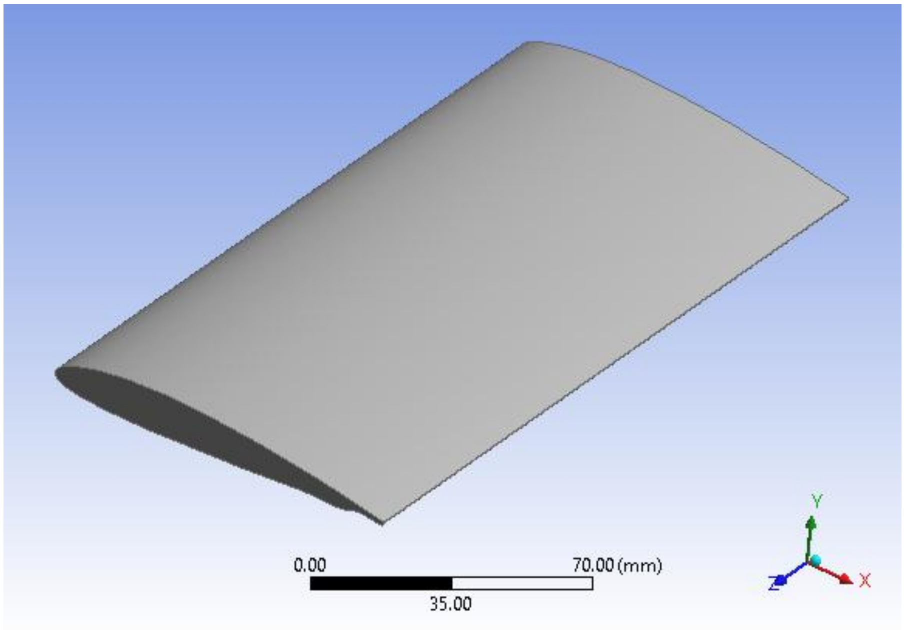

Figure 3.3: Solid Ansys model of airfoil

3.3.3 Save and Export

After creating the airfoil model in Solidworks it is saved as IGES file format. The generated profile is then further exported to carry out simulation in Ansys. The file can also be saved in stp, parasolid, catia, ACIS format and can be used in ansys.

3.3.4 Meshing

The next step of analysis of airfoil is to generate mesh on its surface. In Mesh section of Ansys, small grids are generated with nodes. Ansys provides options to make grids in the workspace as per our needs, we can select either the whole geometry at once and can specify which type of element it is and the spacing in between two grids or we can select the growth ratios on each surface. The size of grids can be set as coarse grid, medium grids or fine grids. In the present study we have chosen medium grids to have better results. The mesh contains 14045 numbers of nodes and 2432 number of elements. Meshing divides the enclosed area or volume into numerous numbers of small grids which helps us to analyze the working phenomenon and evaluate the results accurately. The values of any parameter at the nodes are found out to give exact condition of the parameter during the simulation part.

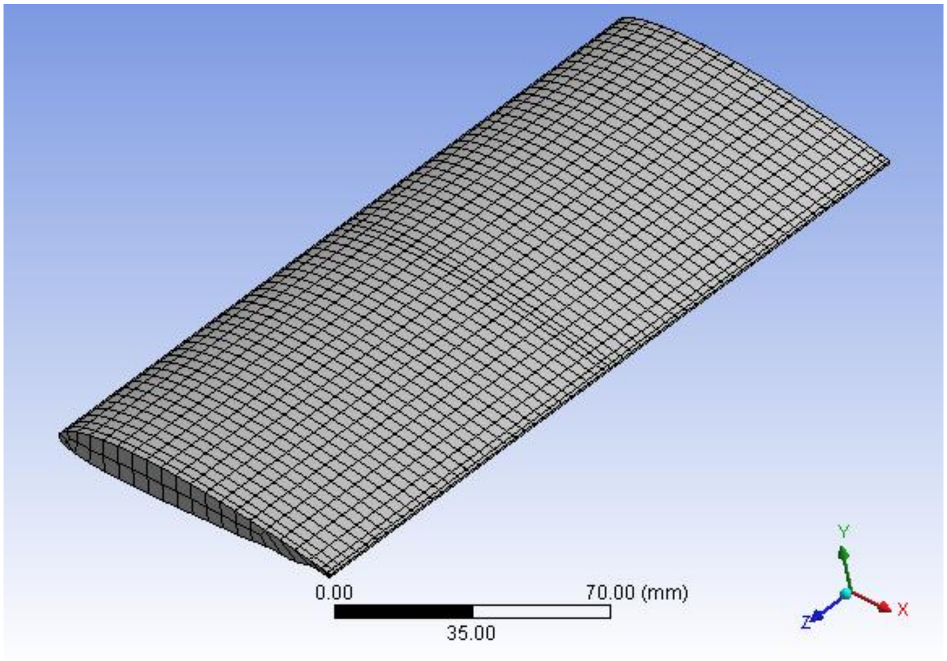

Figure 3.4: 3D Meshed model of airfoil

3.3.5 Setup and Solution

After the completion of formation of grid on the surface the data is saved and the mesh window is closed. The setup bar in the Ansys-fluent window is selected next where the meshed geometry is automatically imported for further analysis. The inlet and outlet sections are defined by selecting create named selection by selecting the surface of the model. The model used for the test the viscous laminar model to simulate the aerodynamic environment.

The cell zone condition in the interior of the body is defined to be as air with density of 1.225 kg/m^3 and viscosity of 0.0000178 kg/m-s. Inlet velocity of air is specified in the boundary where the velocity value is defined to be 133 m/s. The gauge pressure is specified to zero at the outlet by default and no slip boundary condition for the wall is defined. After defining all the input data the calculation is performed with 300 numbers of iterations. When the calculation is completed the contours of velocity and pressure profiles of inlet, outlet and wall can be obtained by selecting the contour tab. Results are obtained in the form of lift force and drag force. These forces are used in further static structural analysis.

In the static structural analysis the lift and drag forces obtained by the above method is acted upon the wing model as pressure forces. Here we are interested to calculate the total deformation, shear stress, stress intensity, and equivalent stress, which is also known as Von-mises stress. One end of the wing is fixed as the boundary condition. The lift force acts in an upward direction tending the wing to lift upwards and the drag acts perpendicular to the trailing edge along the direction opposite to the motion of airfoil. In this analysis the properties of nanocomposite at various CNT percentages is incorporated in the airfoil model.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Material Modeling

The elastic properties of nanocomposite are determined from the above different methodology. A Matlab program is used to formulate the above stated equations and the results thus obtained are plotted to compare the properties obtained from different methods. The result obtained is in good agreement with the paper used as reference for this study. The elastic properties obtained from Halpin-Tsai method are found to be higher than that of elastic properties obtained from Mori Tanaka method which is obvious as referred to some published literature. A plot has been presented below showing variation of Young's modulus obtained from both Halpin-Tsai and Mori Tanaka method with different percentage of volume fraction of CNTs.

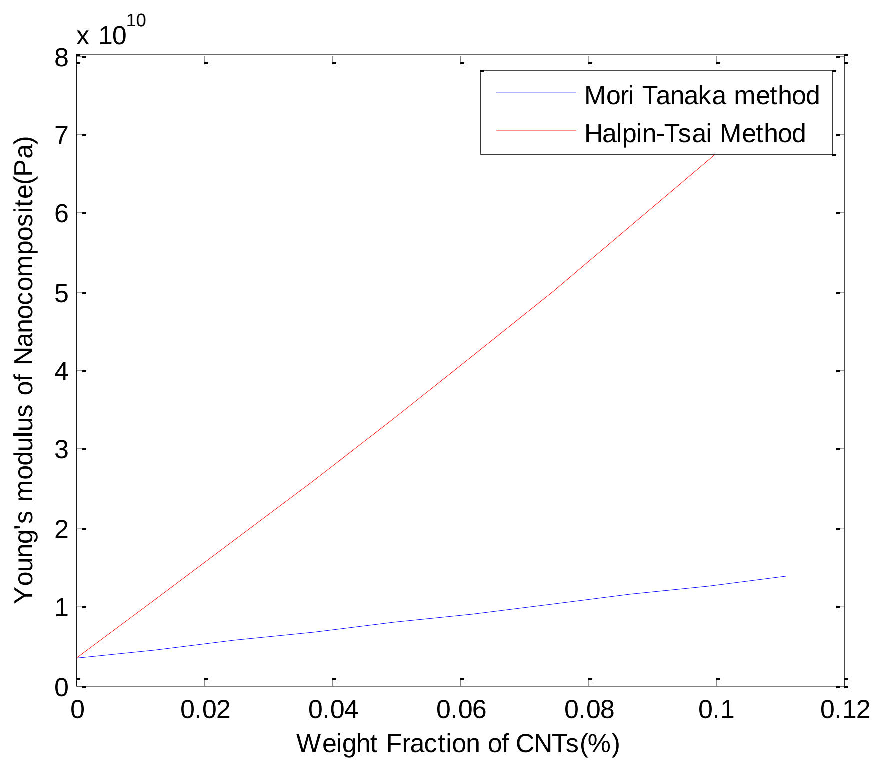

Figure 4.1: Variation of Young's modulus with different percentage of carbon nanotube

Figure 4.1 shows the variation of Young's modulus with different percentages of CNTs. It is found that with increase in the percentage of CNTs in the nanocomposite there is gradual increase in the eastic properties of the nanocomposite thereby improving the mechanical strength of the material. The elastic properties obtained from material modeling of nanocomposite is found to vary with increase in volume fraction of CNTs. Incorporating the novel properties of nanocomposite into the solid airfoil model CFD analysis is carried out in Ansys-fluent workspace. The cruising speed of an airplane i.e. 133 m/s is defined as the velocity of flow of air over the airfoil surface. Then lift and drag coefficient for various angle of attack of the airfoil is calculated in the CFD analysis which is tabulated below.

Table 4.1: Variation of lift coefficient with angle of attack

Angle of Attack(degrees)	Lift force(N)
0	131.43
2	82.33
4	118.8
6	66.54
8	48.57
10	96.089
12	89.425

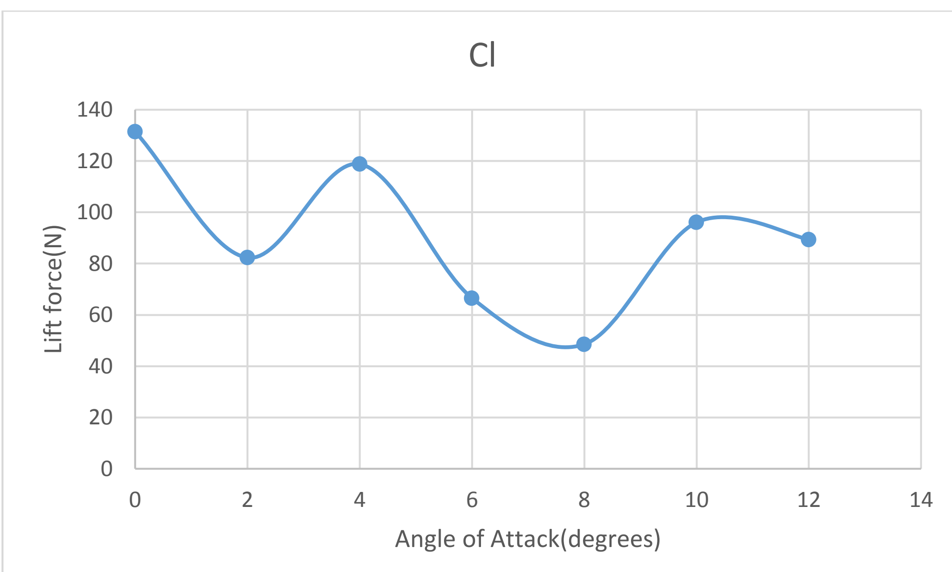

Figure 4.2: Plot between Lift force and Angle of Attack.

Figure 4.2 shows the plot between lift force and angle of attack which has an undulated pattern. By changing the orientation of the airfoil different angle of attacks is achieved and for different angle of attacks we can get different lift force and drag force.

Table 4.2: Variation of drag coefficient with angle of attack

Angle of Attack(degrees)	Drag force(N)
0	435.73
2	516.38
4	681.14
6	841.49
8	1266.36
10	1689.7
12	2201.87

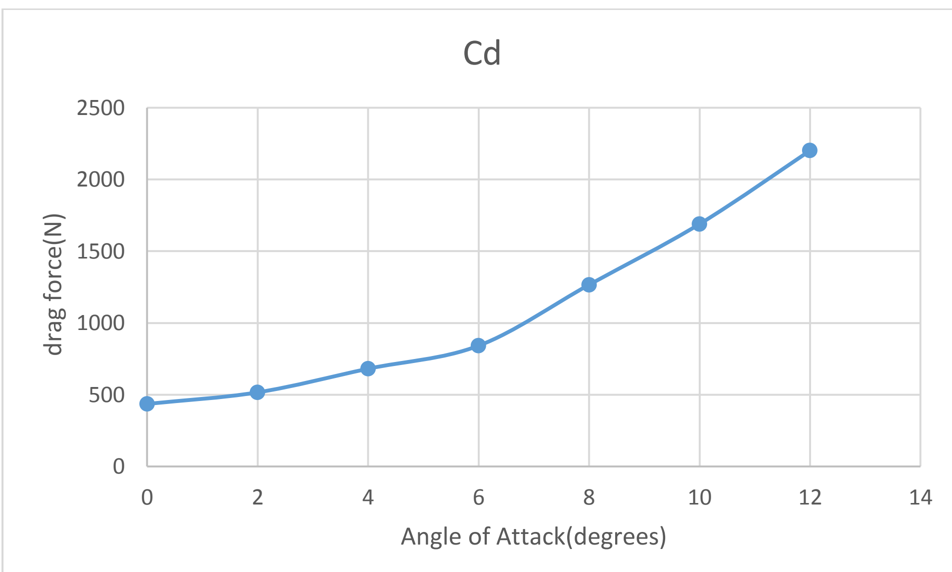

Figure 4.3: Plot between Drag force and Angle of Attack

From the above tabulation and graphical representation of variation of lift and drag forces with that of different angle of attack we can conclude that lift force increases with increase in angle of attack. The same effect is observed in case of drag. It has been observed in this analysis that after a particular angle of attack the lift and drag force is found to decrease. This angle is known as stall angle of attack. Drag force is an unwanted force and should be avoided as much as possible but it is also seen that there is a gradual increase in drag coefficient which is not favorable from the aerodynamic point of view. Pressure and velocity contours on the airfoil model are obtained and are shown as below:

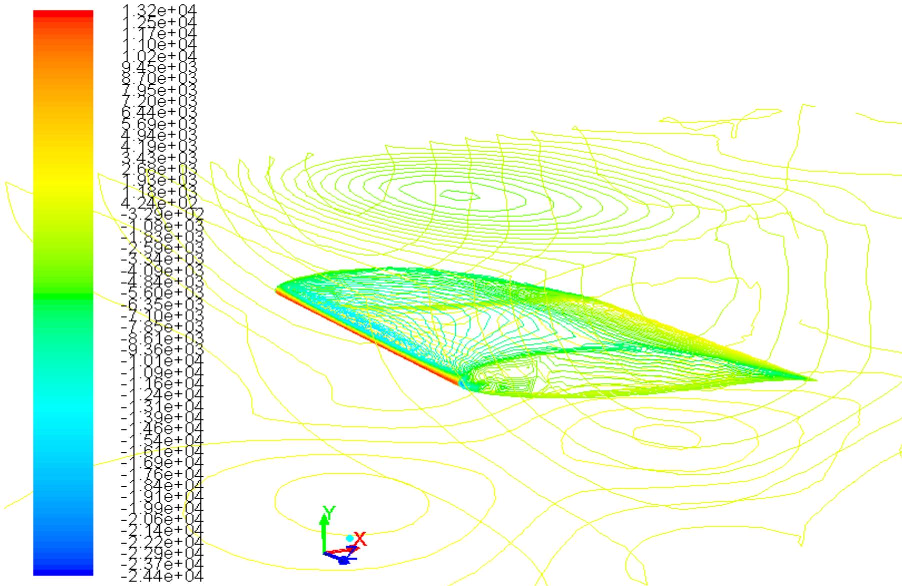

Figure 4.4: Pressure contours on the airfoil model

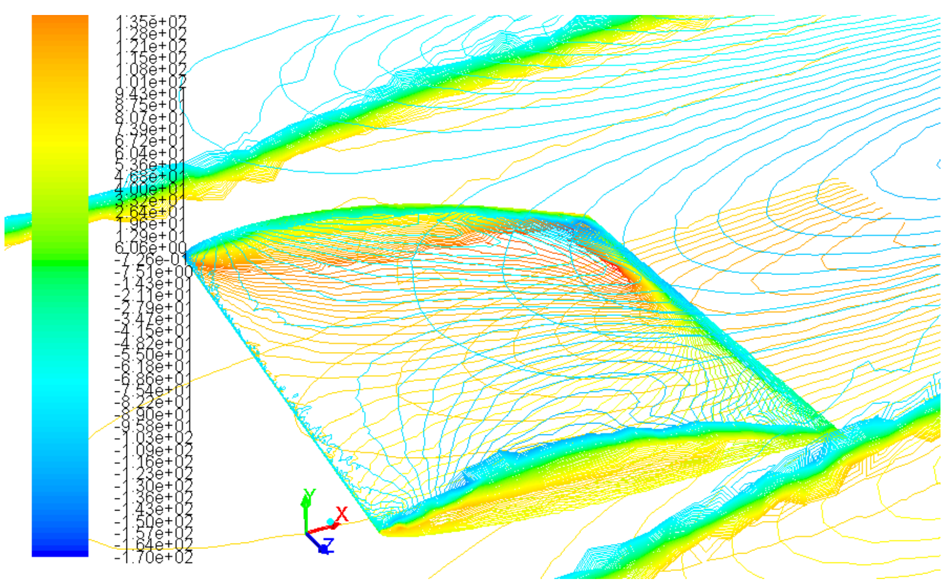

Figure 4.5: Velocity contours on the airfoil model

Figure 4.4 shows the pressure contour of the airfoil model where the red zone indicates high pressure zone and the blue zone indicates low pressure zone. As it can be seen that on the upper portion of the airfoil there are some blue zones which indicates that there is low pressure in that region which is the cause to produce the necessary lift force on the airfoil. Figure 4.5 shows the velocity contours on the airfoil model.

4.2 Modal Analysis

In the modal analysis of the airfoil the different modes of vibration is determined and observed. It is noticed in this study that the natural frequency of the airfoil made up of nanocomposite material increases with increase in volume fraction percentage of CNTs. Below is the tabulation of data observed during the experiment representing the first, second and third natural frequency for different volume fraction of CNTs.

Table 4.3: Variation of natural frequency with different carbon nanotube percentage.

Percentage of carbon nanotube (%)	Density(kg/m^3)	First Natural Frequency(Hz)	Second Natural Frequency(Hz)	Third Natural Frequency(Hz)
0	1200	2.4231	8.6659	15.404
0.0111	1201.7	2.808	10.043	17.851
0.0222	1203.3	3.1465	11.253	20.003
0.0333	1205	3.4527	12.348	21.949
0.0444	1206.7	3.7344	13.356	23.740
0.0556	1208.3	3.9967	14.294	25.407
0.0667	1210	4.2426	15.173	26.970
0.0778	1211.7	4.4758	16.007	28.453
0.0889	1213.3	4.6987	16.804	29.870
0.1	1215	4.7730	17.056	31.127

The first six mode shape of the airfoil modal analysis is shown in the below given figures:

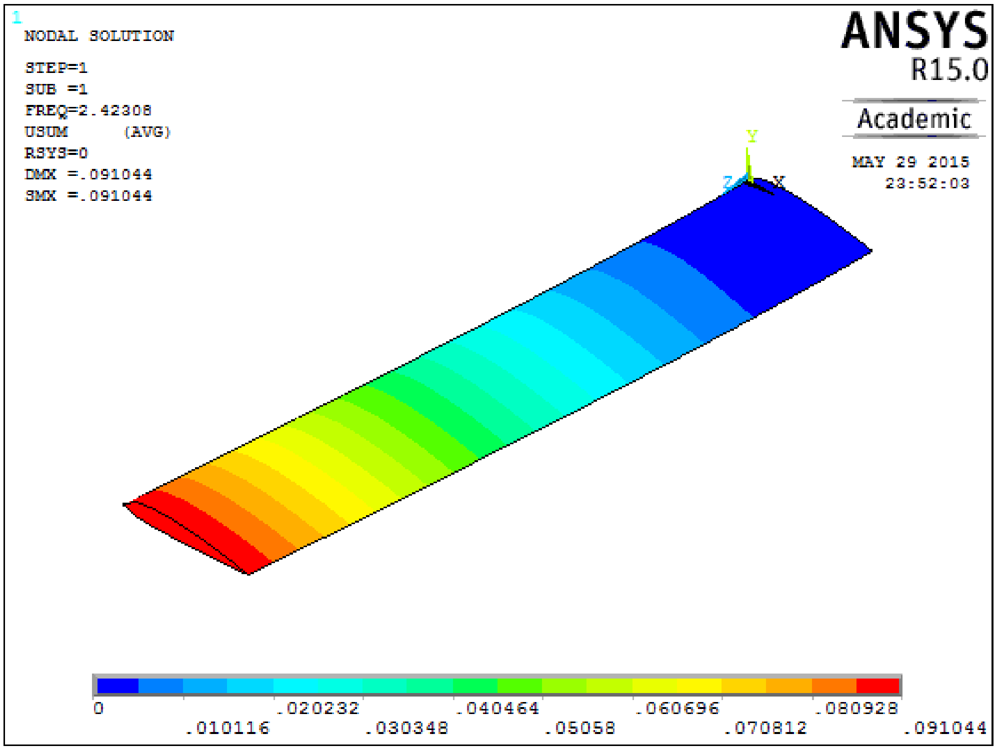

Fig 4.4: First mode shape of the airfoil model

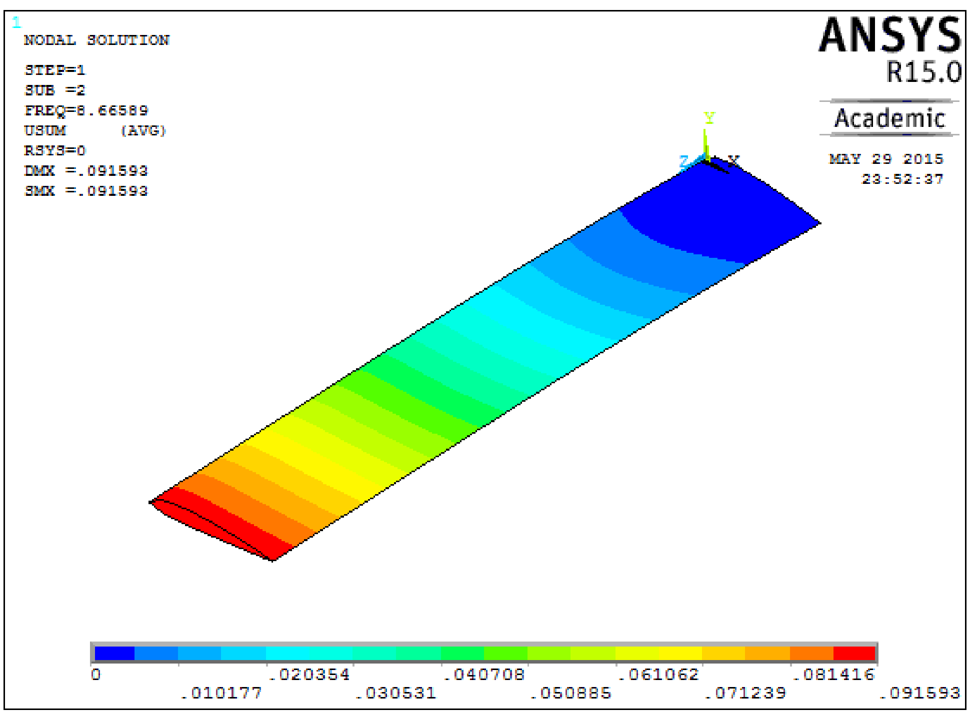

Fig 4.5: Second mode shape of the airfoil model

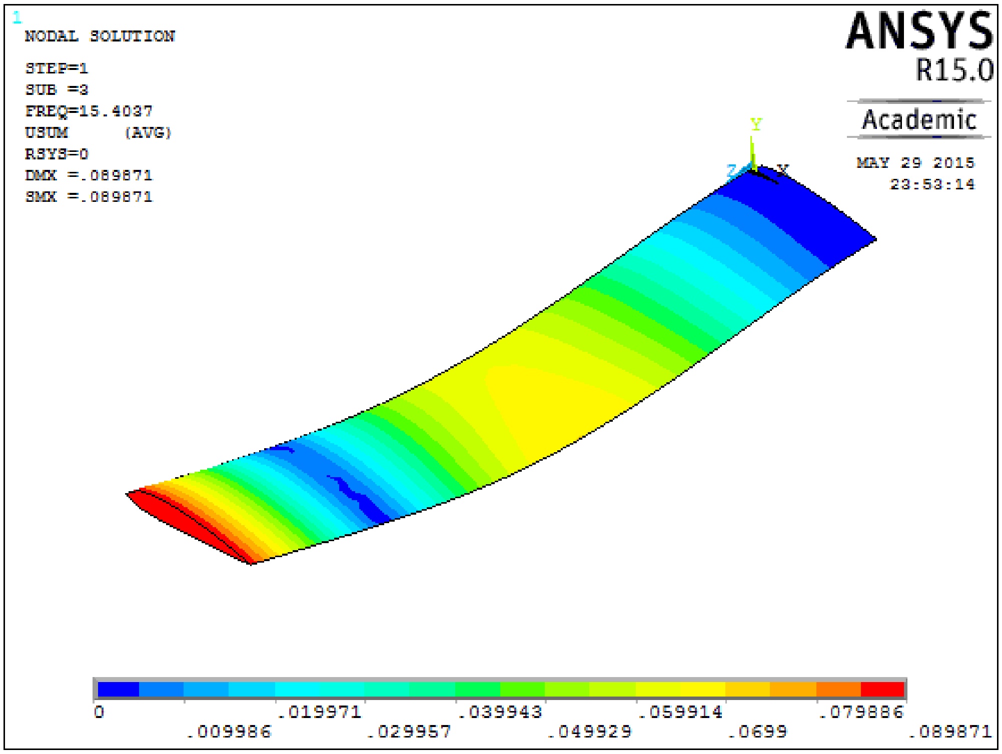

Fig 4.6: Third mode shape of the airfoil model

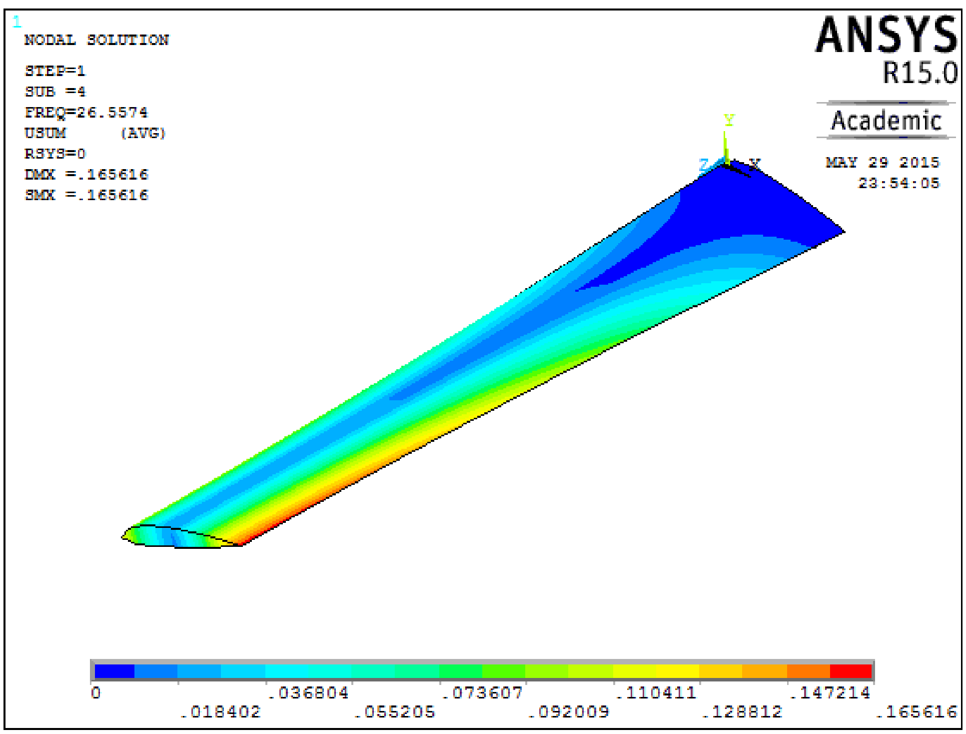

Fig 4.7: Fourth mode shape of the airfoil model

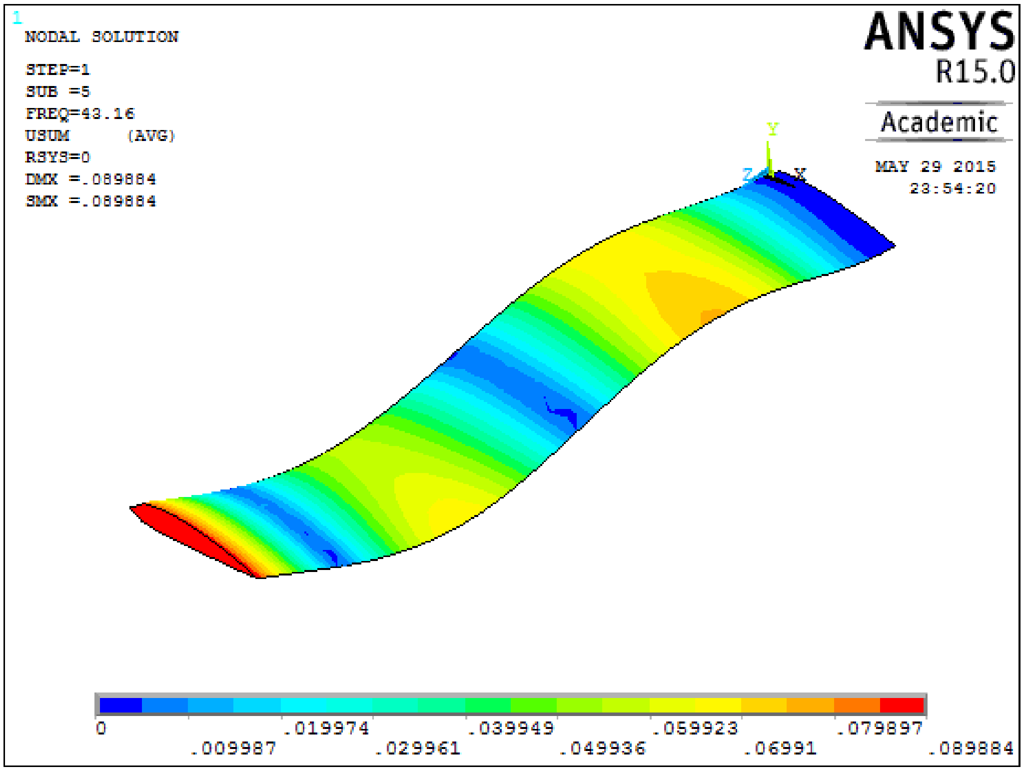

Fig 4.8: Fifth mode shape of the airfoil model

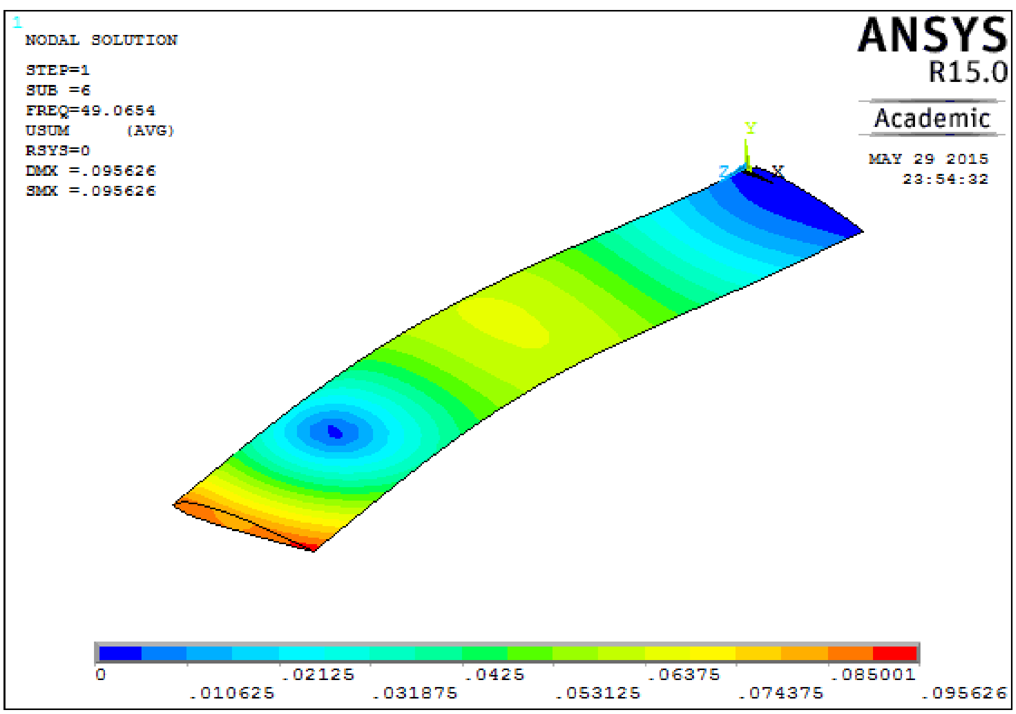

Fig 4.9: Sixth mode shape of the airfoil model

4.3 Static Structural Analysis

In the following section we will discuss the results obtained from the static structural analysis. Here the material properties of nanocomposite are incorporated in the solid airfoil model to carry out the analysis. The model is then acted by the lift and drag forces as pressure forces along upward direction and along direction opposite to the direction of motion respectively. In this analysis we are concentrating to determine the total deformation, shear stress, shear intensity and equivalent stress, also known as von-mises stress. In the table below the maximum value of all these parameters for a particular orientation of airfoil is shown in a tabular form.

Table 4.4: Maximum values obtained of total deformation and various stresses on the airfoil.

Total deformation(mm)	0.05596
Equivalent stress(MPa)	0.57592
Shear stress(MPa)	0.023453
Stress intensity(MPa)	0.61288

Following figures are the various contours of the above mentioned stresses and deflection.

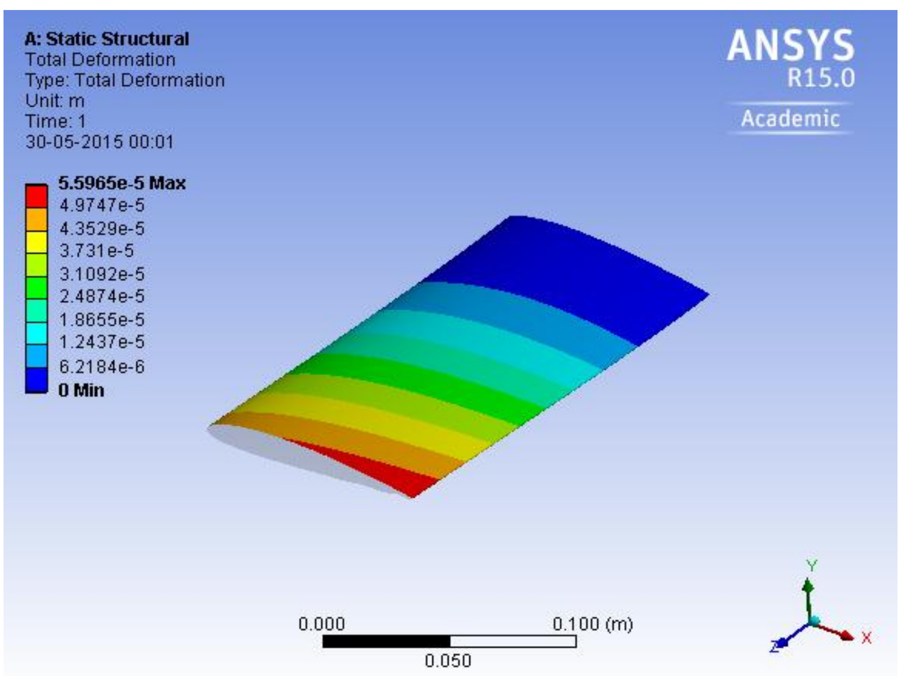

Fig 4.10: Total deformation of the airfoil model

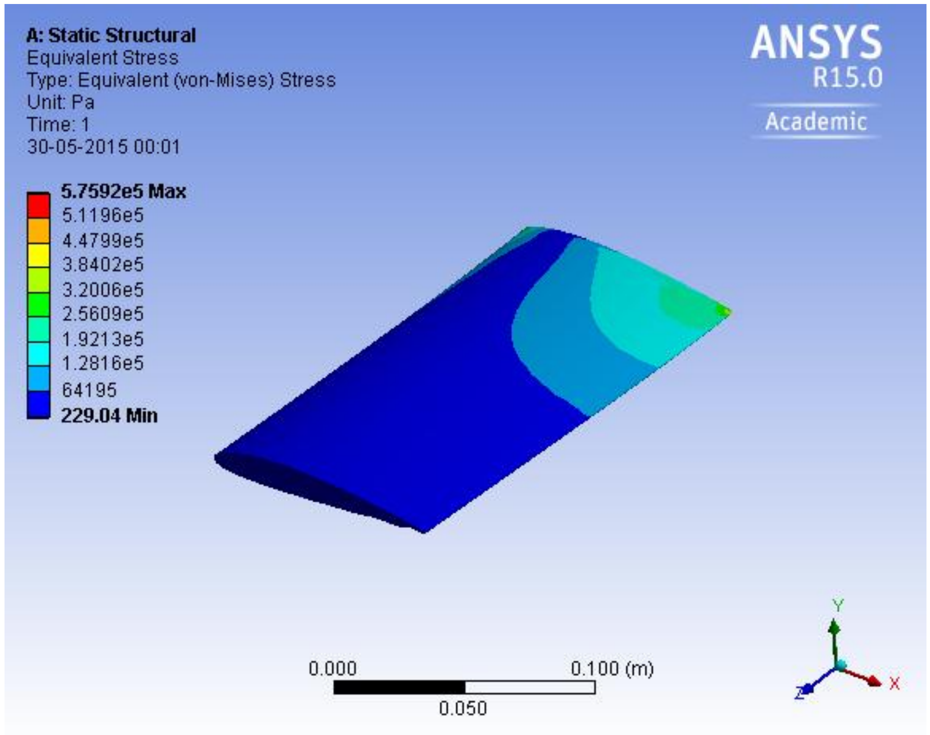

Fig 4.11: Equivalent (von-mises) stress distribution of the airfoil model

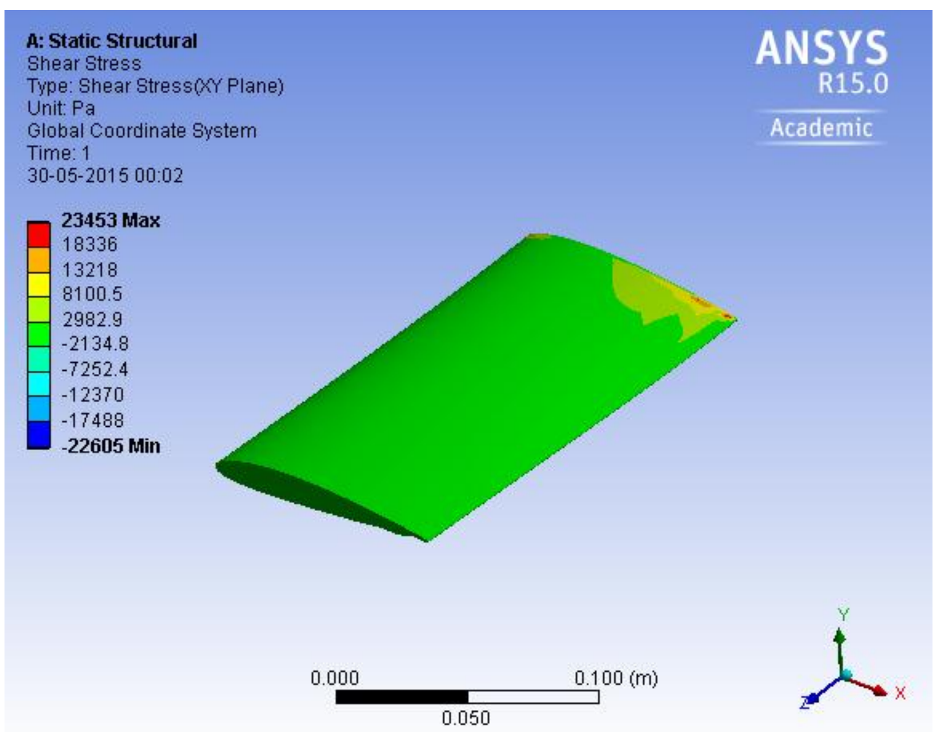

Fig 4.12: Shear stress distribution of the airfoil model

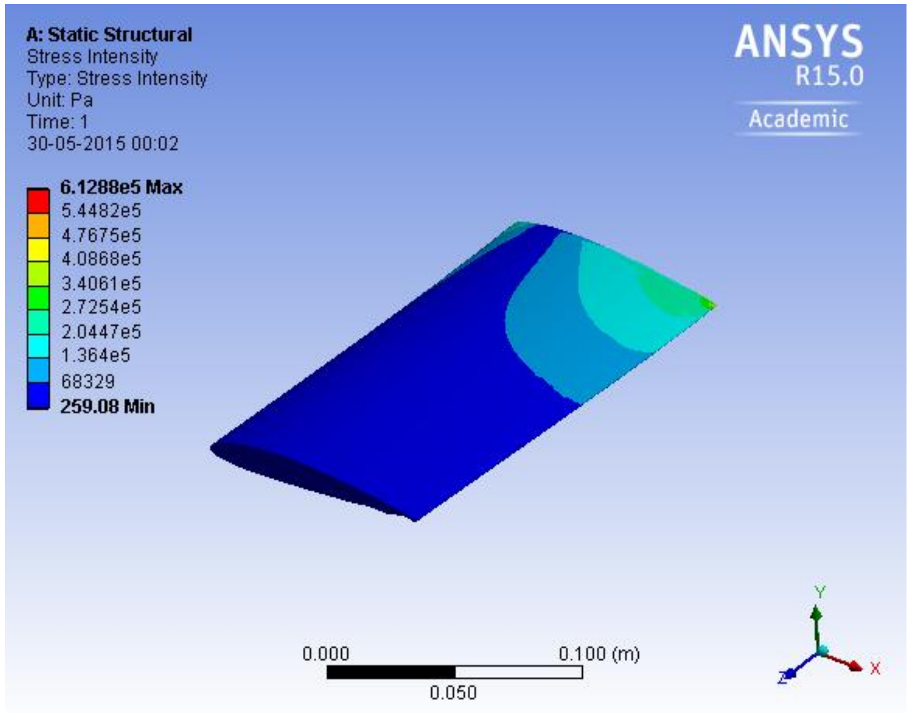

Fig 4.13: Stress intensity distribution of the airfoil model

Figure 4.10 shows the total deformation of the airfoil model when subjected to the lift and drag forces acting in upward and opposite direction to the motion of travel respectively. It is observed that it has the maximum deformation at the end which is opposite to the fixed end. Figure 4.11 shows Equivalent stress, also known as von-mises stress, distribution contours which indicates that it has the maximum value at the fixed end and along the trailing edge. Figure 4.12 shows the shear stress distribution contours which have also its maximum value at the fixed end along the trailing edge. Figure 4.13 represents the stress intensity of the airfoil model when lift and drag forces is acting upon it.

Below Table 4.5 represents the variation of deformation along the three axes individually by varying the orientation of the airfoil and also by varying the CNT volume fraction. From the results obtained it is observed that by increasing the CNTs volume fraction in the nanocomposite the deformation along all the axes gets reduced by some amount. It means that by adding more amount of CNT we are improving the properties of nanocomposite.

Table4.5: Variation of deformation along the three axes of the airfoil model with varying percentage of CNTs.

Orientation of airfoil section(degrees)	Percentage volume fraction of CNTs (%)	Density(kg/m^3)	Deformation along x axis (mm)	Deformation along y axis (mm)	Deformation along z axis (mm)
2	0.0111	1201.7	8.657	3.04	3.329
2	0.0333	1205	5.994	4.91	5.43
2	0.0556	1208.3	4.79	5.16	1.516
4	0.0111	1201.7	8.118	3.15	5.615
4	0.0333	1205	5.345	9.85	6.942
4	0.0556	1208.3	4.052	9.15	2.644
6	0.0111	1201.7	9.961	8.93	7.74
6	0.0333	1205	6.487	2.91	8.348
6	0.0556	1208.3	4.889	8.92	3.693

CHAPTER 5

5.1 CONCLUSION

In this study, material modelling of nanocomposites is performed to determine the effective properties of nanocomposites by using the Halpin-Tsai method. A matlab program was used to evaluate the elastic properties of the nanocomposite and the determined values are in good agreement with the values of the referred literatures. Then an investigation of the NACA 2412 airfoil model made up of nanocomposite material is performed and analysed. The airfoil model is then subjected to CFD analysis where the aim is to determine the different forces acting on an airfoil model when it is operational in its working environment. Lift and drag are the two forces acting on the airfoil model and due to these forces an airplane gets its required lift. These forces are computed with the help of modeling software Ansys-Fluent. Lift and drag for various angle of attack is computed and plotted which shows an increase in lift and drag forces as the angle of attack increases. Free vibration analysis of the selected airfoil model is performed by developing a model using Ansys (APDL) workspace. Different mode shapes are obtained in this analysis with different frequency. At last using thelift and drag forces obtained from the CFD analysis static structural analysis is performed to determine total deformation, shear stress, equivalent stressand stress intensity. Here in this study it is shown that the proposed method successfully simulates the flow around a conventional wing. The method employed here is under the same conditions as those used by various authors and the comparison results are found to be satisfactory.

The main conclusions that can be drawn are:

- With increase of percentage of volume fraction of CNTs the elastic properties of nanocomposite increases.
- Natural frequency of nanocomposite increases with increase in percentage of volume fraction of CNTs.
- Total deflection of the model decreases with increase of percentage of volume fraction of CNTs.
- Lift and drag forces of the airfoil section increases with increase in angle of attack.
- Static structural analysis is carried out with satisfactory results.

5.2 FUTURE SCOPE

Above study is an approach which can be applied to solve problems which are more complex in nature. Below are some problems on which future analysis can be carried out.

- Two way fluid structure interaction analysis of airfoil structure can be performed to get better simulation of aerodynamic environment.
- Transient analysis coupled with static structural.
- Thermal analysis
- Incorporating ribs instead of solid material and carrying out the above analysis.
- Considering damping of carbon nanotubes.

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