The literature survey and the critique on literature are presented in the following sections:

2.1 Literature Survey:

In wind turbine technology, the turbine blades play an important role as it directly comes in contact with the wind. Wind turbine blades are shaped to generate maximum power from the wind at minimum cost. The blades should be designed for longer life as they are subjected to continuous fatigue loads.

D. T. Yen Nakafuji, C. P. Van Dam, R. L. Smith and S. D. Collins [1], used MEM Microtabs for obtaining better aerodynamic characteristics, results increasing in the section lift coefficient with a minimal drag penalty. Computational and experimental wind tunnel results for a representative airfoil using fixed as well as remotely actuated tabs are compared. The results presented demonstrate the significant potential for using Microtabs for active load control. Chalothorn Thumthae and Tawit Chitsomboon [2] performed numerical simulation of horizontal axis wind turbines with untwisted blade in steady state condition, to investigate the condition for the optimal pitch that produces the highest power output. The rotating frame technique was used, wherein the blades are fixed in relation to the rotating frame. The
computation results have shown the good agreement with experimental results.

Ferhat Kurtulmus, Ali Vardar and Nazmi Izli [3] have investigated the angle of attacks for 4 various blade profiles, Re Numbers and correlations between lift and drag rates. Snack 2.0, computer software has been used and lift, drag, moment and minimum pressure coefficients are calculated. For all evaluated blade profiles and all Re rates in the provided highest sliding rates most convenient angle of attack was determined in the range of $3^\circ$ and $9^\circ$. The results shown the highest drag rates are found corresponding to Re 20000. Nazmi Izli, Ali Vardar and Ferhat Kurtulmu [4] have conducted various simulation programs to find lifting and drifting coefficients for 14 different Reynold numbers, 4 different NACA profiles by using snack 2.0 computer program. Out of all correlations the most convent angle of attack and 14 different Reynold Numbers, lifting numbers and angle of attack have been revealed and depicted in chart form. In addition for the 14 various Reynold numbers correlation between the lifting and drifting rates has been found out.

SHEN Zhen-hua, YU Guo-liang [5], used FFA-W3-211 airfoil in the blade model development and conducted a small low speed tunnel and varied the installation angles between 6-14$^\circ$C and a wind velocity ranges from 8-15 m/s. The results showed that under all conditions the wind
power utilization factors of the tested wind turbines are more acceptable when a gurney flap is added. F. Wang, L. Bai, J. Fletcher, J. Whiteford, D. Cullen[6], developed a methodology using physical methods including boundary layer theories and wind tunnel experiments and computer modeling using CFD and investigated the wind energy capture improvements at low wind speeds. Optimization of a Scoop design and validation of CFD model. With the final design of scoop boosts the air flow speed and corresponding wind turbine power output. Power curves are developed experimentally and a good agreement was found with CFD model.

Scott J Schreck and Michael C. Robinson [7] examined the full scale turbine blade aerodynamic blades and current modeling methodologies to better understand the physical and numerical attributes that determined modal performance. RS Amano, R.J Malloy [8] investigated the possibility of increasing the efficiency of the turbine blades at higher wind speeds while maintaining the efficiency at lower wind speeds by selecting the appropriate orientation and size of the air foil cross sections based on low oncoming wind speed and given constant rotation rate. Swept blade profile was implemented to achieve the efficiency at higher wind speeds. Performance was investigated using CFD.
P. Migliore [9] described the results of wind tunnel Aeroacoustic tests conducted on a typical small wind turbine blade in the open-jet test section. Tim Fischer [10] studied the influence of the integrated design of the rotor-nacelle-assembly for obtaining the optimizing structure at reduced cost. With an integrated approach, the characteristics and the control of the turbine are used to simultaneously reduce aerodynamic and hydrodynamic loads especially with respect to fatigue.

T K Barlas and G A M Van Kuik [11], focused on the research regarding active rotor control and smart structures for load reduction. The work is carried with a goal to provide a prospective on current status and future directions of the specific area of research, which includes the specifications of unsteady loads, modern control for load reduction and detailed active aerodynamic control. Feasibility steadies and preliminary performance evaluation and novel computational and experimental research approaches are reviewed. W. Devenport, R.A. Burdisso, H. Camargo, E. Crede, M. Remillieux, M. Rasnick, and P. Van Seeters [12] carried out the research work to improve the understanding of wind turbine Aeroacoustics.

Nitin Tenguria [13] has developed an optimization method for a HAWT blade of VESTAS 1.65 MW horizontal axis wind turbine according to Indian wind condition. BEM theory was used for developing the
optimization method. NACA 634221 airfoil was used and the data is evaluated according to the properties of the airfoil. Power coefficient curve with varying parameters like tip speed ratio, lift and drag coefficient, chord distribution and twist distribution by using a computer program. Results are compared and found good with the reference data from literature. S.Laín, B. Quintero and Y. Lopez [14] investigated the aeromechanical evaluation of HAWT Blade using a strategy based on the combination of an aerodynamic module, which provides the three dimensional distribution on the blades. Pressure forces are taken as input data for computing blade deformation and strain and stress distributions over the blade. The aerodynamic module combines the three dimensional non-linear lifting surface theory approaches.

Juan Mendez and David Greiner [15] shown a method to compute the chord and twist distributions in wind power blades the distributions are computed to maximize the mean expected power depending on the Weibull wind distribution at specific site. BEM theory is used to optimize chord and twist distributions. The implementation is validated by comparing power prediction with experimental data of the Riso test turbine. Donny R. Cagle, Anthony D. May, Brian D. Vick and Adam J. Holman [16] have carried out the performance test on the new set of designed, fabricated blades using NREL S822, NREL S823 airfoils. A maximum power coefficient of the system was 0.41 for the new blades.
The water pumping capacity was doubled when the turbine is rotated with new blades and compared with Bergey blades.

K. Turgut Gursel, Tufan Coban, Aydogan Ozdamar [17] have studied the natural frequencies of the rotor blades of NACA 4415 and NASA / Langley LS (1) 421 MOD series of wind power plants. Rayleigh’s method was used to find the natural frequencies and further by using finite element method. Resonance analysis is also carried out on both rotor blades is found out by the excitation of external forces. K.R. Ajao, I.K. Adegun [18] evaluated the rotor aerodynamics of a wind turbine using Blade Element and Momentum Theory. The research content is directed toward the physics of power extraction by wind turbines at both near and far wake regions. The generalized Fokker-Planck equation which is a partial differential equation satisfied by the probability density function is employed in modeling the turbine power.

L.J. Vermeer, J.N. Sorensenb, A. Crespo [19] studied the aerodynamics of horizontal axis wind turbine wakes. The emphasis is put on measurements in controlled conditions and the experimental and numerical works related to the physics of power extraction by wind turbines is reviewed. Dr. S. P. Vendan, S. Aravind Lovelin, M. Manibharathi and C. Rajkumar [20] have designed a wind turbine for tapping the low speed wind in the urban locations. The NACA 63415
Airfoil is considered for analysis of wind turbine blade. The CFD analysis is carried out using STAR-CCM+ at various angle of attack from 00 to 160. The coefficient of lift and drag values are calculated for low Reynolds number and the pressure distributions are plotted. The results show that NACA 63415 is showing its suitability for its application on wind turbine blades.

Franck Bertagnolio, Niels S_rensen, Jeppe Johansen and Peter Fuglsang [21] have carried out experiments using the 2D Navier-Stokes solver EllipSys2D on numerous sets of airfoil measurements and validated the results. A study correlating the available data and classification is performed the result show that a poor quality is obtained because of the transition modeling to a large extent. Finally some advices are given for elaborating future airfoil design processes that would involve numerical code the EllipSys2D and transition modeling. Richard E. Wirz. and Perry M. Johnson [22] developed a multiplane inboard configuration to provide attractive aero-structural performance for wind turbine blades. A biplane approach is used and cross-sectional properties of a thick monoplane are compared with this. Numerical simulations are developed to show the lift to drag ratio of a biplane and is found significantly greater than the lift to drag ratio of the thick monoplane. Finally these results that biplane blade approach is an attractive design for the next section of wind turbine blades.
Branko Klarin [23], have invested the procedure and results of applying an adaptive airfoil for wind turbine blades. Flow and elastic deformation are investigated with CFD/FSI analysis. Simulation of working characteristics of wind turbine with adaptive airfoils results in a positive energy yield when compared to the stiff airfoil shape. Further numerical and experimental investigations are proposed and described.

**Materials and Fabrication of Wind Turbine Blades**

S.M. Habali, I.A. Saleh [24], have discussed a selection procedure of a airfoil section and the aerodynamic design of the blade for a small wind turbine of 5m long. Two different two different air foils mixed at the outer third of the span will be sufficient and demonstrated good strength and aerodynamic characteristics. The results of static proof load test indicated that blade could withstand loads 10 times the normal working thrust, and a field performance test showed that the rotor blade has a 41.2% measured average power coefficient. Dayton A. Griffin [25] carried out a research work to develop cost effective scaling-up of the current commercial blade designs and manufacturing methods. Self-gravity loads, transportation and environmental considerations are the parameters considered. A trade-off study is performed to evaluate the incremental changes in blade cost, weight, stiffness, fabric types and manufacturing processes.
Dayton A Griffin, Thomas D Ashwill [26] performed a study concerning blades for wind turbines using commercial blade designs and manufacturing methods, and candidate innovations in composite materials, manufacturing process and structural configurations were assessed. In the present work, preliminary structural designs are developed for hybrid carbon fiber / fiber glass blades. Dale Retallack, P.Eng [27] designed a Wenvor 25kW wind turbine blade produced from engineered wood at reduced manufacturing cost. In this project they performed benchmark testing on existing fiber glass and carbon fiber blades and this information was used to design the wood blade. FEA was used in reference testing. Operational testing was conducted and found the results produced are very close to carbon fiber blades.

Ted Hubbard, P.Eng [28], have analyzed the performance of wind turbine blades using engineered wood and determined the fatigue life safety factor and design load survival based on finite element analysis. This analysis has been verified by comparing stiffness testing to predicted FEA results. These values have not been tested experimentally because no destructive testing was carried out. C. Kong, J. Bang, Y. Sugiyama [29], have developed a design of 750 kW HAWT, with E-glass / epoxy blades. Structural analysis was performed on blade models using finite element method. The blade structure was conformed to be safe and stable under various load conditions. Fatigue life of the blade
was calculated by S-N linear damage theory, the service load spectrum and the Spera’s empirical equations. The results shows that the prototype blade was successful in meeting the certification requirements by international certification institute, GL (Germanisher Lloyd) in Germany.

Bulent Eker, Aysegul Akdogan [30] investigated the importance of composite materials in wind turbine blades. Their research was based on the theories of material science and wind technology. Some practical results shown that the composites can decrease the danger factor, can control the structural vibration and produce high magnitude of power. P. K. Chaviaropoulos, E. S. Politis, D. J. Lekou, N. N. Sørensen [31], carried a project with a main objective of developing a damped wind turbine blade with unique composite damping mechanism. A full scale laboratory test was conducted on a 19 m glass / polyester damped blade and modal analysis showed nearly 80% increase in the damping ratio of the both first flap and lag modes.

John W Holmes, Bent F. Sorensen [32] studied the issue of reliability as a critical concern when wind turbines are located in remote region where the cost of inspections and repairs can be high. In the present work wind turbine blades are subjected to various complex loadings and deformation modes are assessed. They concentrated on
recent advances in methods used to characterize adhesive joints in wind turbine blades and the manner in which laboratory data is used to predict the structural response of wind turbine blades. Brian Hayman, Jakob Wedel Heimen [33] have studied the necessity of achieving adequate stiffness to prevent excessive blade deflection, preventing buckling failure, ensuring adequate fatigue life under variable wind loading combined with gravitational loading, minimizing the occurrences and consequences of production defects and also developed the concept based on the use of fiber composite materials in the production of wind turbine blades. The important observation is made on blade deflection, buckling failure, and adequate fatigue life and production defects.

Andrew Corbyn & Matthew Little [34], have developed practical guide which is designed to show the process of producing a wind turbine blade from fibre-glass. This guide stemmed from work trying to produce a 1.8m blade for a 1kW version of Hugh’s design for use in the Philippines. Povl Brondsted, John W. Holmes, Bent F.Sorensen [35], have focused on various materials used in the manufacture of wind rotor blades along with their importance. Uday K. Vaidya [36] used vacuum assisted resign transfer molding technique for producing composite integral armor (CIA) and studied the repair of S2-glass / epoxy composites subjected to a clean perforation type of ballistic impact
scenario and post-repair flexural response of the composite panels. Static and fatigue test were conducted under flexural loading.

Leon Mishnaevsky Jr, Peter Freere, Ranjan Sharma [37], used a comprehensive program of experimental computational analysis of strength and reliability of wooden parts of low cost wind turbine possibilities prediction of strength and reliability of different types of wood. Microstructure base correlations between micro structure, strength and service properties of wood established. Pongtorn Prombut [38] carried out the experiments by manufacturing a prototype blade for a small wind turbine with an objective to implement simple manufacturing process suitable for fabricating small blades, yet capable of extending to the construction of larger blades. Flap wise bending test was performed on the blades in cantilever beam configuration. The results showing the new blade boasts 7% higher stiffness than original one, when load Vs tip deflections are compared.

Wagner Sousa de Oliveira and Antonio Jorge Fernandes [39] performed cost analysis of material composition of the wind turbines for Wobben wind power / ENERCON GmbH model E-82 by considering relationship between material / cost and the factors limiting the conceptual design of wind turbines include static and fatigue strength, rotor mass, stiffness of the blades. Linus Fagerberg and Karl Otto
Stromberg [40] applied the numerical modeling techniques and evaluated the turbine blade performance which was built using Sandwich techniques, carbon fiber reinforcements and infusion of epoxy in rigid mould. In this study they described how optimization using method of moving asymptotes was used in the design of a wind turbine blade.

Changduck Kong, Suhyun Choi, Hyunbum Park and Sanghoon Kim [41] have proposed a specific structural design and analysis procedure for development of a low noise 500 Watts class wind turbine system that will be applicable to relatively low wind speeds. The proposed structural feature has a skin-spar-foam sandwich composite structure with E-Glass / Epoxy face sheets and Urethane Foam Core for lightness, structural stability and analysis including load cases, sizing, stress, deformation, buckling and vibration was performed using the rule of mixture and the finite element method. R.P.L. Nijssen, D.R.V. van Delft, P.A. Joosse, A.M. Van Wingerde [42] carried out the experiments on Optimat blades for calculating reliability of the use of composite materials for wind turbines.

LGJ Jansen, AM Van Wingerde [43] has developed industrial objectives and strategic aspects of materials for the construction of reliable and optimal wind rotor blades. James Locke, Ulysses Valencia [44] have selected four different hybrid design systems for the
construction of wind turbine blade using TPI composites, Finite element analysis was carried out and corresponding maximum deflections along with strains are determined according to wind conditions.

M. Jureczko, M. Pawlak, A. Mezyk [45] developed a computer program package to enable the optimization of wind turbine blades with regard to the number of criteria.

**Finite Element Analysis of Wind Turbine Blades**

Jason R. Gregg, M.S.M.E. [46] conducted experiments on specifically design wind turbines which can produce power at low speeds. Reynolds number flow, separation and low wind speed power generation are addressed. In the experiment number of blades are varied from two, three and four and tip-speed ratios of 1, 3 & 7. The experiment resulted the performance was improved reaching up to 126% increase in power output at a wind speed of 10 mph. A. S. Grinspan, P. Suresh Kumar, U. K. Saha [47] developed a Savonius rotor configuration suitable for small scale rural application. Two distinct blade shapes i.e., an airfoil type and a twisted type rotor have been and tested in three bladed rotor systems. Performance characteristics of the developed rotor blades have been evaluated and compared.
Turaj Ashuri M.B. Zaaijer [48] has applied a classical up-scaling law and a finite element models are used to perform the assessment of wind turbine blades. Based on the results of the simulation some guidelines were proposed. Alireza Maheri and Askin T. Isikveren [49] have demonstrated a wind turbine blade tool, developed on the concept of variable-state design parameter. The design code can be utilized to convert the ordinary blades of a constant speed horizontal axis wind turbine, with or without pitch control system into passive smart blades with the main objective of maximizing the rotor power and minimizing the blade loading. At the end optimum rotor radius, chord and pre-twist distributions along with a metric indicating the required level of elastic coupling in the smart blade are obtained.

MN Nahas, M Akyurt [50] did performance analysis for a wind mill that features cam-guided flaps. A single-flap wind mill is treated as a slider-crank mechanism with variable eccentricity. The cylinder axis is also considered alterable. The resulting computer program is used in connection with the AL-YASEER Software package to study the performance of the system under various wind as well as rotor speed. The results are compared with wind tunnel experimental results. N.M. El Chazly [51], analyzed the lift and the drag forces created in a steady wind conditions by using consistent mass matrix in finite element analysis. NACA 0015 airfoil series was used to test the constant chord, tapered
blades for the survival at rated wind speeds. The validity of the computer program used was verified by applying it to a standard cantilever box beam using the beam theory. Results showed that maximum stresses occurred at the root of the blades for all configurations and the twisting of the blade lead to the increase of the stiffness and the decrease of the stresses.

M.E. Bechly, P.D. Clausen [52], have performed finite element analysis of a 2.5m long fiberglass composite wind turbine blade and compared with static bending and twisting deflections of the blade and with the first two natural frequencies of vibration. Optimization is done for getting the final blade shape by minimizing both tip deflection and the maximum value of stress. Ladean R. McKittrick, Douglas S. Cairns, P.I., John Mandell, David C. Combs, Donald A. Rabem, and R. Daniel VanLuchene [53] have developed a composite blade design for the Atlantic Orient Corporation (AOC) using finite element modeling techniques by keeping some assumptions and goals in the initial design phase.

Gunner C. Larsen, Morten H. Hansen, Andreas, Baumgart, Ingemar Carlen [54] has determined the natural frequencies, damping characteristics and mode shapes of the wind turbine blades by using modal analysis. The experimental results of LM19 m blade has been
compared with results from a FE-Modeling and the modal analysis respectively. L.G.J. Janssen, A.M. Van Wingerde [55], have investigated the structural behavior of composite rotor blades and extracted results based on the conditions like variable amplitude of loading, complex three dimensional stresses, environmental conditions etc.

Henrik Broen Pedersen, Ole Jesper Dahl Kristensen [56] has determined the natural frequencies, damping and mode shapes for wind turbine blades using modal analysis. In experimental campaigns different excitation techniques are used and a pendulum hammer was used and further modified to get improved hammer and test was carried out. Finally the results obtained from modal analysis carried out a wind turbine blade are compared with results obtained from the Stig Oyes blade_EV1 program. Jianhui Zhang [57] used flow solver XFOIL to predict pressure distribution and compared with EllipSys2D airfoil section. The flow around the line is simulated with the CFD Tool EllipSys2D to build up the pressure field.

Duran, Serhat [58] used BEM theory to obtain an optimum rotor. The blade shape is modified such that the modified blade will be lightly loaded. When the designed blade is modified the resulted power output is reduced about 10% and the length of the modified blade is about 5% for the same required power. G.S. Bir [59] developed preComp (pre-
processor for computing composite blade structural properties) to compute the stiffness and inertial properties of the composite blades the code may also be used to compute the structural properties of a metallic blade by treating it as a special case of an isotropic composite material.

CHEN Jia-Quan, YANG Xin-Yan [60], computed blade parameters based on the vortex theory, a kind of new program design method is offered to display the section and 3D model of wind turbine blades. Firstly, the data of the airfoil of blades are revolved and converted to form the data of the 3D-block body of blades on the ground of coordinate conversion. Secondly, the 3D model is drawn based on the 3D theory. On one hand, the method provides a reference for the design of blades and other analog complicated structures on the other hand, the model is convenient for its analysis. F.M. Jensen, B.G. Falzon, J. Ankersen and H. Stang [61], have carried experiments on a full scale 34m composite wind turbine blade was tested to failure under flap-wise loading. Local displacement measurement equipment was developed and displacements were recorded throughout the loading history. FE simulation results are compared with experimentation and concluded that local displacement results can be used to identify the location of failure initiation which leads to catastrophic failure.
J Wang, D Qin, and Q Zhang [62] adopted finite element and thin-walled structure theory to develop a mathematical model and to predict the natural frequency and blade behavior of a horizontal axis wind turbine under constant wind speed and turbulence condition. Detailed expressions for centrifugal and Coriolis forces are obtained. The stress on the root and displacement at the tip are analyzed in detail. The blade deflection in the turbulent conditions is simulated and shown to mostly influence flap-wise blade deformation. Scott Michael Larwood [63] carried out a dynamic analysis for swept wind turbine blades. Adams TM dynamic software was used to develop the codes. The outputs obtained from the codes are validated with field test data. The designs showed a 5% increase in annual energy production and a decrease in flap-bending over the straight blade designs.

Emrah Kulunk and Nadir Yilmaz [64] developed a computer program to estimate the aerodynamic performance of the existing HAWT blades and used for the further performance analysis of the designed 100 kW HAWT rotor. Blade element momentum (BEM) theory was used to design the blades. Anyuan Chen [65], Investigated on a new flux switching permanent magnet machine with 12 stator poles and 14 rotor poles and compared with the same stator but 10 rotor poles. Two prototypes were studied by both FEA and experiments. Results are
showing that 12/14 pole prototype can provide more torque than the second one.

Chao Liu [66] carried out vibrational analysis on a wind turbine system. Finite element analysis was done to extract mode parameters and excitation forces on the blades using harmonic analysis. Cui Yanbin [67] used finite element analysis software ANSYS to determine the characteristics of composite laminated plate blade. Modal analysis is made to obtain modal parameters and the natural frequency spectrum of the blade. The results have laid a foundation for further study of Wind Turbine Blades vibration, structural dynamics and other issues.

Jun-Yong Lee [68] have developed the shape design of 1 kW-class SWT Rotor Blade for hybrid power generation system using BEM theory. Investigations are carried out on Aerodynamic performance production, including the lift and drag forces by using CFD analysis. Arvind Singh Rathore [69] has carried finite analysis on 750 kW HWT blade of length 21.0m which was developed by using S809 airfoil. The post processed results of stress and deflection from ANSYS are found to be good with the existing results.

Nitin Tenguria, N.D. Mittal and Siraj Ahmed [70] have carried out modal analysis on a HAWT Blade of length 38.95m, which is designed for
V82-1.65 MW horizontal axis wind turbine. NACA 634221 airfoil is taken for blade development. ANY SYS 12.0 is used to carry out the finite element analysis. The results show the natural frequency is lower in the case of single web spar. Habtamu Beri and Yingxue Yao [71] used CFD analysis to show the effect of modified airfoil at the trailing edge on self starting of VAWT at low tip ratios.

Ricardo Alvarez Cervera[72] studied the analysis of airfoils using ANSYS by applying the conditions of the boarder and displaying the results in a stage of the post processing of the simulator. Fluid structural analysis, modal simulation and fluid analysis are carried out to obtain aerodynamic design. Lovre Krstulovic-Opara, Branko Klarin [73] evaluated experimentally the stress distribution based on thermal stress analysis performed on a wind turbine blade at the second modal vibration regime. SWT Blade was exposed to a simple accelerating movement, similar to the real movement when the blade mounted on a wind turbine rotor. Infrared thermal imaging the camera is used to detect the energy dissipation due to the elastic stress in the structure. Global structural behavior is also evaluated using finite element modal frequency analysis.

Xinzi Tang [74], have presented the design and FEA of a 10KW fixed-pitch variable-speed wind turbine blade with five different
thickness of airfoil shape along the span of the blade. The main parameters of the wind turbine rotor and the blade aerodynamic geometry shape are determined based on the principles of the blade element momentum (BEM) theory. Based on the FE method, deflections and strain distributions of the blade under extreme wind conditions are numerically predicted. The results indicate that the tip clearance is sufficient to prevent collision with the tower, and the blade material is linear and safe. Nobuyuki Fujisawa[75], have investigated the aerodynamic performance and the flow fields of Savonius rotors at various overlap ratios by measuring pressure distributions on the blades and visualizing the flow fields in and around the rotors with and without rotations. Experiments conducted on 4 rotors having two semicircular blades with different overlap ratios ranging from 0 to 0.5. Observations show that the static torque performance is improved by increasing the overlap ratio especially on the returning blade. The torque and power performance of the rotating rotor reaches a maximum at 0.15 overlap ratio.

P.D. Clausen, D.H. Wood [76], have discussed the current developments in technology, which should increase the level of small turbine technology towards that of large machines. Anindya Ghoshal, [77], have used different damage detecting techniques on wind turbine blades like transmittance function, resonant comparison, operational
deflection shape, and wave propagation methods. Piezoceramic sensor patches and laser Doppler Vibrometer are used to measure the vibration response of the blade. The sensitivity of the techniques to detect a reversible damage simulated by a steel plate clamped to a section of a wind turbine blade is compared.

**Structural Testing and Experiments on Wind Turbine Blades**

Russell Lee Evertz [78] has investigated on balsa core sandwich panels, thin laminates and transitions from sandwich panels to thick and thin laminates. Sandwich panels were tested in tension, resulting in strengths slightly above the thin laminate without the balsa core in place. Finite element models were created for use as a design tool to evaluate the transition behavior and validated experimental data. Walter D Musial, Ben Bourne, Scott D. Hughes [79] investigated the ultimate strength of PS Pultruded blade section experimentally under four point bending. Thirteen 8–foot long full scale blade segments were individually tested and maximum moment carrying capability was determined. Three Air Foil Bending configurations were tested. They suggested that a redundant load path may be providing strength to the section in the post-buckling region, making the on-set of panel buckling a poor predictor of ultimate strength for the PS enterprise pultrusion.
Gunner C. Larsen [80] carried out experiment to demonstrate the mode shapes developed on the turbine blades and these mode shapes are used to identify and locate possible structural defects. Further “filter” method was used to exclude insignificant damages. Chia Chen Ciang [81], discussed on structural health monitoring system (SHM), a non destructive testing and evaluation method to improve wind turbine safety considerations, to minimize down time, reducing sudden break downs which attracts huge maintenance and logistic costs and to provide reliable power generation from wind turbine.

Erik R. Jorgensen, Kaj.K. Borum, Malcolm Mc Gugan [82] experimented on 25m wind turbine blade for failure when subjected to a flap-wise load. The failure was at three different locations. Acoustic emission was successfully used as sensor for the detection of damage in the blade during the test. The total deflection of the blade, the local deflection of the skin and the load carrying main spar and also measurement of the strain all as a function of the applied load and up to failure of the blade. D Corbus, A.C. Hansen, J. Minnema [83] carried a testing project on the small wind research turbine with a goal of better characterizing both small wind turbine loads and dynamic behavior. The main purpose of the testing was to produce high quality data sets for model development and validation and to help the wind industry further their understanding of small wind turbine behavior, including furling.
FAST and ADAMS aeroelastic simulators are used in summarizing the results related to torsional stiffness.

J.P. Baker, E.A. Mayda, C.P. Van Dam [84], conducted wind tunnel experiments on flatback airfoils. Three airfoils of various trailing edge thicknesses were tested under free and fixed boundary layer transition flow conditions at different Reynolds numbers. The results of the investigation show that lift increases and the well documented thick airfoil sensitivity to leading edge transition reduces with increasing trailing edge thickness. MA Drewry and G.A Gerogiou [85] have reviewed the current state of NDT of wind turbines at manufacture and in-service, and to establish the most promising the NDT methods for detecting flaws of most concern.

Peter Berring, Kim Branner, Christian Berggren and Henrik W. Knudsen [86] have investigated experimentally on two different eight meters long wind turbine blade sections to determine 3D static responses. An advanced 3D digital optical deformation measuring system (ARAMIS 2M and 4M) was applied in this work. This system measures the full-field displacements (ux, uy and uz) of the blade surface. J. Paquette, J. van Dam and S. Hughes [87], Designed a three 9 m carbon fiber wind turbine blades through a research program initiated by Sandia National Laboratories. The individual designs feature such innovations
as carbon spar caps, material-induced twist-bend coupling, and flatback airfoils. The blades were subjected to flap wise loading to simulate the extreme wind loads expected for each design. The blades were loaded with a three-point whiffle-tree arrangement. Upon obtaining the predetermined test load, the blades were subsequently loaded to failure. Load, deflection, strain, and acoustic emissions were monitored throughout the experiments. Finally, acoustic microphones were able to detect areas where damage was occurring, and indicated the beginnings of failure.

K. Sinclair and A. Bowen [88], have conducted small wind turbine certification testing on 4 different turbines with in specified wind regimes using the standards adopted by IEC and in compliance with American wind energy association. Annejungert, Christian U Grosse [89] experimented to detect and localize the damages within the turbine blades using the technique of ultrasonic waves. The pulse eco-technique is used to detect the flaws in the bonding areas. Local resonance spectroscopy was used for simple tapping tests.

Amy Bowen, Arlinda Huskey, Hal Link, Karin Sinclair, Trudy Forsyth, David Jager [90] carried out the experiments to evaluate power performance, power quality, noise, safety and function of small wind turbines. The results are summarized for the better selection of wind
turbines suitable according to the climatic conditions. Jorge Elizondo, Jaime Martínez, Oliver Probst [91], conducted experiments on a small prototype battery charging wind turbine designed for low and medium wind regimes. Observations were made on theoretical cut-in speeds, inertia effect instabilities arising in situations of transition. Good agreement was observed for actual power curves with a detailed aerodynamical and electromechanical model of the turbine for wind speeds above theoretical cut-in speed.

A. Blanken [92] focused the research on thermoplastic glass fiber composites, concerning material properties as well as manufacturing and assembling processes, for the application of composites in a rib-spar-skin design of a turbine blade. The design of a hat-stiffened panel as an alternative for a sandwich structure, which is used as a skin modern wind turbine blades. A sandwich panel was isolated from a turbine blade design and it is used as a reference for the design of a hat-stiffened panel. A scale version of the designed hat-stiffened was constructed to use experiments. T. Y. Kam [93] presented the development process of a SWT blade with 0.3 efficiency for a 1 kW power system the blade composed of glass / epoxy skin and foam core was designed according to IEC standards to sustain the wind pressure of 50m/s. The blade was subjected to static, dynamic and fatigue test and validated the performance of the wind turbine system is found acceptable.
D. Todd Griffith, Thomas G. Carne [94], conducted structural tests including modal, static and fatigue on wind turbine blades by considering techniques for experimental quantification of uncertainty in the modal parameters; insight into model calibration using both static-load-deflection data and the modal parameters and novel test techniques for reducing the uncertainty in the root boundary condition using a seismic-mass-on-airbag boundary condition; and development of validated structural models. L.C.T. Overgaard, E. Lund, O.T. Thomsen [95], tested wind turbine blades under a flap wise static test. The wind turbine blade response during loading and after collapse was assessed and evaluated by conducting experiments and with numerical model predictions. The ultimate strength of the blade which is governed by instability phenomena in the form of delimitation and buckling. Interaction between both instability phenomena occurs causing a progressive collapse of the blade structure.

Jorge Antonio Villar Ale, Gabriel da Silva Simioni, Joao Gilberto Astrada Chagas Filho [96] have tested a small wind turbine in laboratory including methodology for evaluation of static bending test and cyclic loads for small wind turbines using as references standards and procedures. E. Stammes [97] conducted experiments on a subcomponent which represents a structural detail of a blade for investigating the influence of manufacturing and repair methods.
Lovre Krstulovic-Opara, Branko Klarin and Zeljko Domazet [98] have performed thermal stress analysis on a wind turbine blade at the second modal vibration regime. SWT blade was exposed to a simple oscillating movement, similar to the real movement when the blade is mounted on a wind turbine rotor energy dissipation due to elastic stresses in the structure are deducted with an infrared thermal imaging camera. Global structural behavior and the results of thermal stress analysis are evaluated by using the finite element modal frequency analysis of the 3-D scanned model. Puneet Malhotra [99] has investigated on different blade testing methods and improvements to novel concepts for tri-axial testing of large wind turbine blades. The hydraulic system and linear guide rail requirements which are used to excite the blade in flap wise and edge wise directions are analyzed. The cost estimation is done and recommended for implementation as it will serve as an efficient way of testing wind turbine blades.

Paul S. Veers [100] investigated the fatigue life of wind turbine blades that are exposed to the random loading environment of atmospheric winds using random data analysis procedures. Probability density functions are utilized to determine the stresses caused by incident winds, while the fatigue life Vs stress level relationship is treated deterministically using damage density function to express fatigue damage as a function of wind speed. Robert Michael Reed, [101]
presented the results of the initial phase of a study on long term fatigue resistance of composite materials for the use in wind turbine blades. Tests were run on a servo hydraulic machine equipped with hydraulic grippers under sinusoidal tensile fatigue loading. Results include cycles to failure, damage development, stiffness changes and surface temperature changes.

Herbert J. Sutherland and Paul S. Veers [102] have compared several techniques currently in use based on fatigue life analyses. The experiments conducted on Sandia / DOE 34-m test bed are found excellent for matching the body of the distribution of cyclic loads and for extrapolating the tail of the distribution using Weibull fitting technique. D.L. White and W.D Musial [103] conducted experiments showing the importance of load phase angle variations with respect to fatigue damage an aggregate probability distribution for the actual phase angles between the peak in-plane and peak out-of-plane loads was determined. The FEM nodal damage distribution at specific blade cross-sections are compared for the constant and variable phase angle cases. Results showing that the variable phase angle case results in higher damage on the critical nodes.

Jayantha A. Epaarachchi, Philip D. Clausen [104] have proposed a fatigue model for glass fiber reinforced plastic composites that includes
the non-linear effect of stress ratio and load frequency on the fatigue life. With a minimum number of tests the fatigue behavior was identified and is found to be good in agreement with all experimental data adequately accounting for the influence of test frequency and stress ratios on the fatigue life of composites. Christoph W. Kenche [105] studied some fatigue and lifetime aspect on wind turbine rotor blades made of composite materials. This includes an historical part in connection with glider technology, the presentation of relevant S-N curves not only for the 0° – Oriented fibres representing the spar cap also for ± 45° – Lay-Ups in shear web and shell.

Jayantha A. Epaarachchi and Philip D. Clausen [106] carried experiments on 2.5 meters long glass fibre reinforced plastic composite wind turbine blade to determine the fatigue life using a mechanically operated test rig. The results of fatigue testing indicate that predictions are close to the measured fatigue life of the blade. Dick Veldkamp [107], investigated on the economic design based on fatigue life of wind turbine and has provided a relative importance of stochastic parameters influencing fatigue loads and strength. The partial safety factors giving minimum unit electricity cost is derived.

Changduk Kong, Taekhyun Kim, Dongju Han, Yoshihiko Sugiyama [108], determined the fatigue life of a 750 kW HAWT using S-N damage
equation. Further proposed a specific static procedure using Mandell, empirical coefficients derived from Goodman diagram with the modified stress ratio and the required design life. Christopher James Nosti [109] investigated experimentally on full scale mode to determine the fatigue life using accelerated fatigue loads in order to monitor the damage accumulation in the blade. MATLAB software package was used to estimate the maximum stress occurring within the blade in response to changes in the wind velocities.

T. Harris, J.H. Rumbarger, C.P. Butterfield [110] developed the design criteria, calculations methods and applicable stands recommended for in performance and life analysis of wind turbine parts. V. Sellappan and M. Ozen [111], The problem of mechanical design, performance prediction and material selection for a prototypical 1 MW horizontal-axis wind turbine (HAWT) blade is investigated using various computer-aided engineering tools.. In addition, composite-material laminate lay-up can be specified and varied in order to obtain a best combination of the blade aerodynamic efficiency and longevity. A simple procedure for HAWT-blade material selection is also developed which attempts to identify the optimal material candidates for a given set of functional requirements, longevity and low weight.
J.C. Marin, A. Barroso, F. Paris and J. Canas [112], have inspected on a 300 kW wind turbine blades and detected the damages, which are developed due to fatigue behavior. A simplified evaluation procedure to determine the fatigue life using GL standard was used and failures were detected in the period of time in which it happened. V.A.Passipoularidis, T.P. Philippidis [113], investigated on the influence of damage accumulation metric, constant life diagram formulation and cycle counting method on life prediction schemes for composite materials under variable amplitude (VA) loading. Experiments are conducted on the glass epoxy laminate cycled with 3 different loading spectra to determine the residual strength. The effect of CLD and cycle counting method is used in life prediction. Results indicate that a net improvement is achieved when linear strength degradation is implemented as damage metric in life prediction schemes. A single SN curve developed to describe the fatigue response under any loading condition.

Patricio Andres Lillo Gallardo [114] used finite element models of the wind turbine blades to analyze the static stresses and fatigue response in cold climates. The work was focused on the stress in the root of the composite blades, specially two common blade hub connection methods like embedded root carrots and T-Bolts. The simulation results shown that the cold climates improve the fatigue strength of the
saturated composite materials in the blade. John F. Mandell[115] have provided an overview of the results of their studies on composite laminates used in the construction of wind turbine blade. Apart from the calculation of stiffness and strength, the blade materials are analyzed according to their fatigue behavior. Through experiments low strain damage failures are identified at higher cycles of loading.

P. Thoft-Christensen, P.R. Pedersen and SRK Nielsen [116] have analyzed the possibility of reducing the expected damage accumulation using tower passage by modifying the wind turbine tower design from a traditional mono tower to a tripod. Due to a narrow stagnation zone the stress reversals and hence the damage accumulation in the blades is substantial smaller in the tripod tower design compare to the mono tower.

**Power Performance**

Warlock [117] has carried out the experiments on a 2-blade, 1.8 m diameter wind turbine rated with 1 kW @ 12.5 m/s to calculate the power and efficiency at different tip-speed-ratios. Results shown a maximum efficiency of 30% at a TSR of 11.6 is obtained. Hiroyuki Hirahara [118], have developed a very small wind turbine system for multi-purposes having a rotor diameter of 500mm. performance was evaluated based on energy output, turbine speed, power coefficient and
the torque of the turbine. It was confirmed that the actual flow passed through the blades was about 20% slower than the ideal flow.

Julia Gottschall and Joachim Peinke [119] have developed a new method to determine the wind turbines power output and compared with the standard procedure IEC 61400-12-1. In the new method the governing coefficients are reconstructed from the data, and the power characteristic is extracted on the stationary states of the deterministic behavior. Results proved that the dynamical approach enables one to grasp the actual conversion dynamics of a wind turbine and to gain most accurate results for the power curve, independent of site-specific influences. John Bird [120], Calculated the rotational kinetic power produced in a wind turbine at its rated wind speed. With the knowledge that it is of critical economic importance to know the power and therefore energy produced by different types of wind turbine in different conditions. This is the minimum wind speed at which a wind turbine produces its rated power.

K.D.Visser [121], The Wind Tamer concept utilizes a diffuser to increase the power produced by an open rotor wind turbine. The current configuration combines several concepts into a functionally attractive design that eliminates the need for furling and reduces the noise typically generated with smaller turbines. The Wind Tamer design
concept has indicated an efficiency or power coefficient, Cp based on the rotor area, of approximately twice that of current small turbines, from recent experimental data and numerical predictions. K.R. Ajao and I.K. Adegun [122], have tested a three blade horizontal wind turbine by using Mansonia Altissima wood for the fabrication of blades. Power output was measured at different wind speeds and power curves are drawn. Angle of attack also determined.

R. Lanzafame, M. Messina [123], have evaluated the geometric characteristics, an innovative methodology for controlling the power curve of the wind turbine. Numerical codes based on BEM theory are used for designing a micro wind turbine. Wind tunnel tests were conducted to determine rotor dynamics and wind turbine startup velocity. Seyit Ahmet Akdag and Onder Guler [124], have compared the power curves of 6 different wind turbine models of ranging from 335 to 1000 kW. Hourly average wind data measured at 50m height. Results are showing that the energy output is smaller for 3 models and 1 model estimates high energy output. In some cases error of energy output estimation can reach to 80 %.

Navin Kumar Kohli and Eshan Ahuja [125], studied the sustainability of renewable energy technology with special reference to performance of horizontal axis wind turbine. The different existing
performance and reliability with various problems related to wind turbine components for wind energy system have been discussed along with different techniques for enhancement of performance of HAWT wind energy system. R. Saravanan and K. K. Padmanabhan [126], have developed a prototype wind turbine with a capacity of 3 kW and the performance is evaluated for installation at rural / urban and small scale industries of south region in India. Techno-Economic Analysis has been done in this work, to study the Return on Investment (ROI) and the issues related to its implementation.

P. Srinivasarao, P. Ravinder Reddy and K. Baba Saheb [127], have designed a power generation system using hybrid solar-wind power generation system to use extensively in the industries with low cost and free from pollution. Sandip A. Kale, S. N. Sapali [128], have developed a new comprehensive model which uses comparative scale is developed for assessment of multi rotor wind turbine designs. These innovative wind turbines are evaluated on the basis of feasibility, technological advantages, security of expected power performance, cost, reliability, impact of innovative system, comparison with existing wind turbine design. The findings of this work provide guidelines for the practical and economical ways for further research on the multi rotor wind turbines.
Habtamu Beri and Yingxue Yao [129] have studied about the camber airfoil effect on self starting VAWT at low Reynolds number. The investigation of 2-dimensional unsteady flow around the turbine was found by using a moving mesh technique. NACA 2415 camber airfoil was used in the blade geometry. The turbine model was developed in Gambit and fluid flow analysis was done in Fluent. The simulations of the model were conducted at various TSR values. The results show that these camber airfoils are having the capacity to self start at reduced power coefficient.

2.2 Critiques on Literature:

Literature shows that most of the investigations done on various airfoils design and analysis by using wind tunnel studies, the aerodynamic evaluation using various simulation tools [1 - 24]. CFD analysis was effectively used by most of the researchers for aerodynamic analysis of airfoils for the development of small size wind turbine blades.

Various fabrication techniques for producing wind turbine blades, advancements in material technology and thus improving the material properties. These improvements are reliable and hence these technologies were effectively focused in the research area. Finite element analysis techniques were effectively used by most of the researchers as it
offers potential advantages in approximating the performance of wind turbine blades.

Different methods of experiments were conducted to evaluate the structural strength, fatigue life and integrity of wind turbine blades. But there is no perfect procedure to imply them in accordance with the real time working conditions of the wind turbine. The procedures used in the analysis of wind turbine blades, their performance evaluation and field analysis of wind turbines are restricted to a particular location as it depends on climatic conditions and availability of wind in that particular place.

**Formulation of the Work:**

In the present work the research is carried with the inclusion of the following aspects:

Selection of airfoil, aerodynamic analysis of 2D airfoil and 3D extruded blade model, finite element analysis of various blade models developed by using standard airfoil, fabrication of prototype blades, conducting experiments such as load deflection test, cyclic load bench test and field analysis using power performance test.

The proposed approach is a full-fledged approach to determine the performance of wind turbine blade models in R21 and R22 profiles with
different material compositions in various aspects. In the present work six different blade models are considered and a better performing blade model is identified.