ngress and Exhibition on
Renewable Energy
0, 2016 Berlin, Germany

Computational Aerodynamics Optimization of Wind Turbine's Blade Twist Angle

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roduction

- Scarcity of traditional sources of energy and the environmental concerns related to the use of these sources has driven researchers in the direction of developing methods and technologies for the harvesting of renewable energy from its different sources.

- Wind energy has proven to be an excellent source of clean and affordable energy.

- Capturing wind energy depends on the availability of a wind turbine in most of the cases and that has four major parts: base, tower, nacelle and blades.

- Blades use lift to capture the wind’s energy, thus the design of the blade is essential to ensure optimum energy harvesting.

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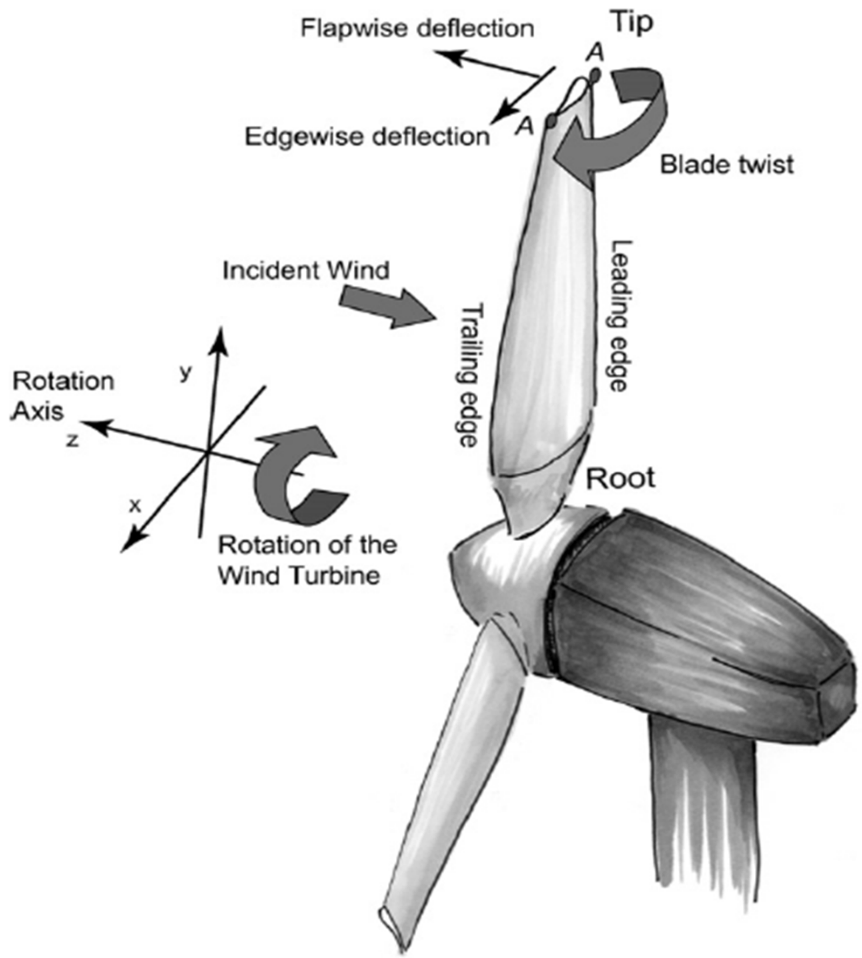
- The cost of manufacturing blades accounts for (15–20%) of the total cost of a wind turbine and any significant increase in total power generation must be economically reasonable and justified when taking into complexity of the blade design/total cost.



search Objectives

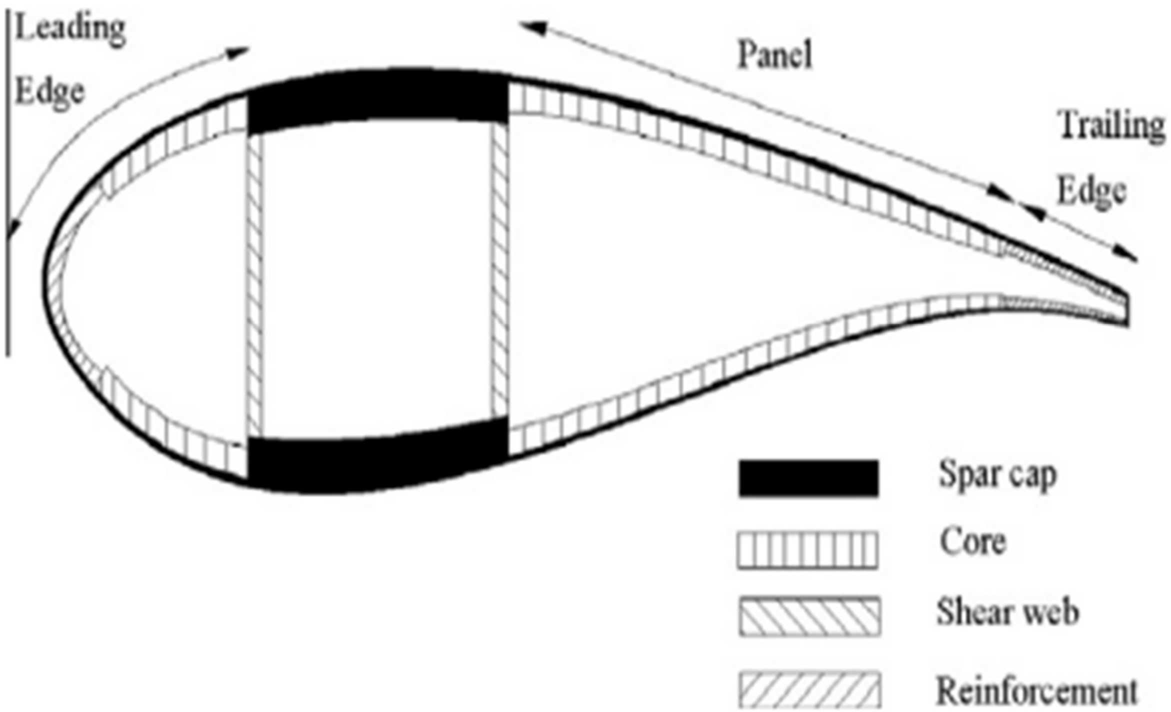
- In this work, different geometries of wind turbine blades are designed using a CAD Software and then analyzed to study the potential areas of improving aerodynamic and structural characteristics of the blade yielding to an increase of the energy generation efficiency and reduce the cost of energy production.

- The study aims at providing an enhanced blade design based on optimum twist angle with optimum shear webs location inside the wind turbine blade to minimize wind pressure and shear stresses affecting the top section of the blade.

- The expected outcome is to develop ideal wind turbine blade's design based on structural, aerodynamic and dynamic analysis results.

ade Design

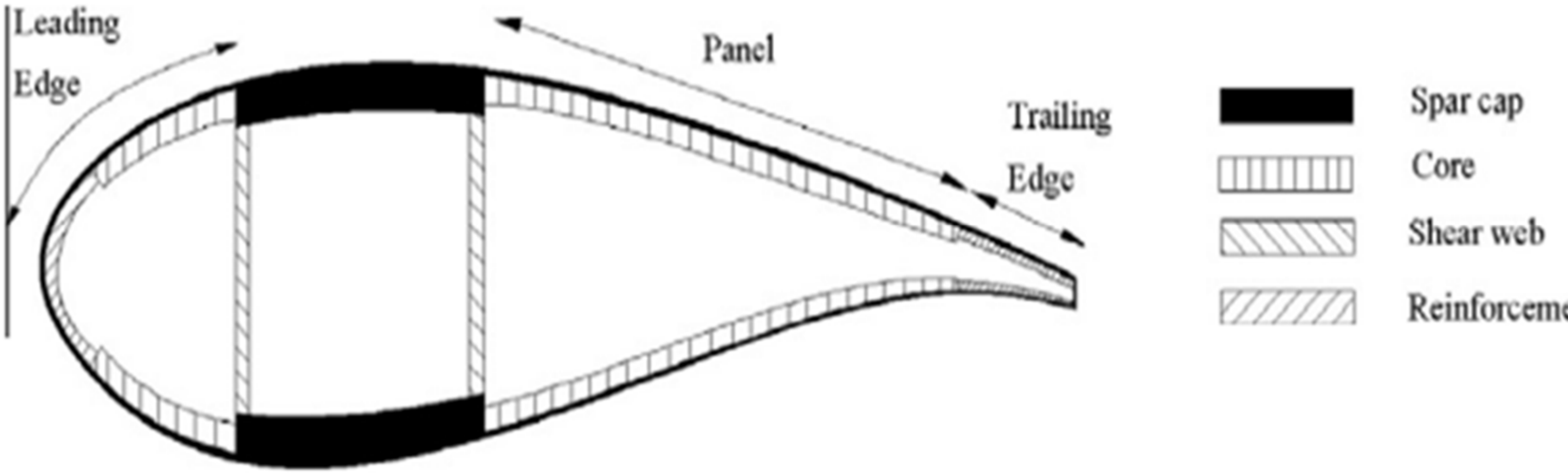
Chen et al., (2012) presented a modified blade geometry and showed that, compared to the initial blade design, the mass of the optimized blades is decreased and specifically for the location of blade spar cap was seen as one of the variables, which exhibit more mass saving.



ade Design

Based on the optimum design dimensions reported in (Chen et al., 2012). The main dimensions selected through the design process were:

Rotor radius = 32m
Hub height = 82m
Chord length = 3.2m
Maximum twist angle: 12.5º.



The two webs in the initial design were located at 24% of the chord and 54% of the chord respectively. The position of the two webs will be used to define the spar cap location of the wind turbine blade, which will be taken as design variable.

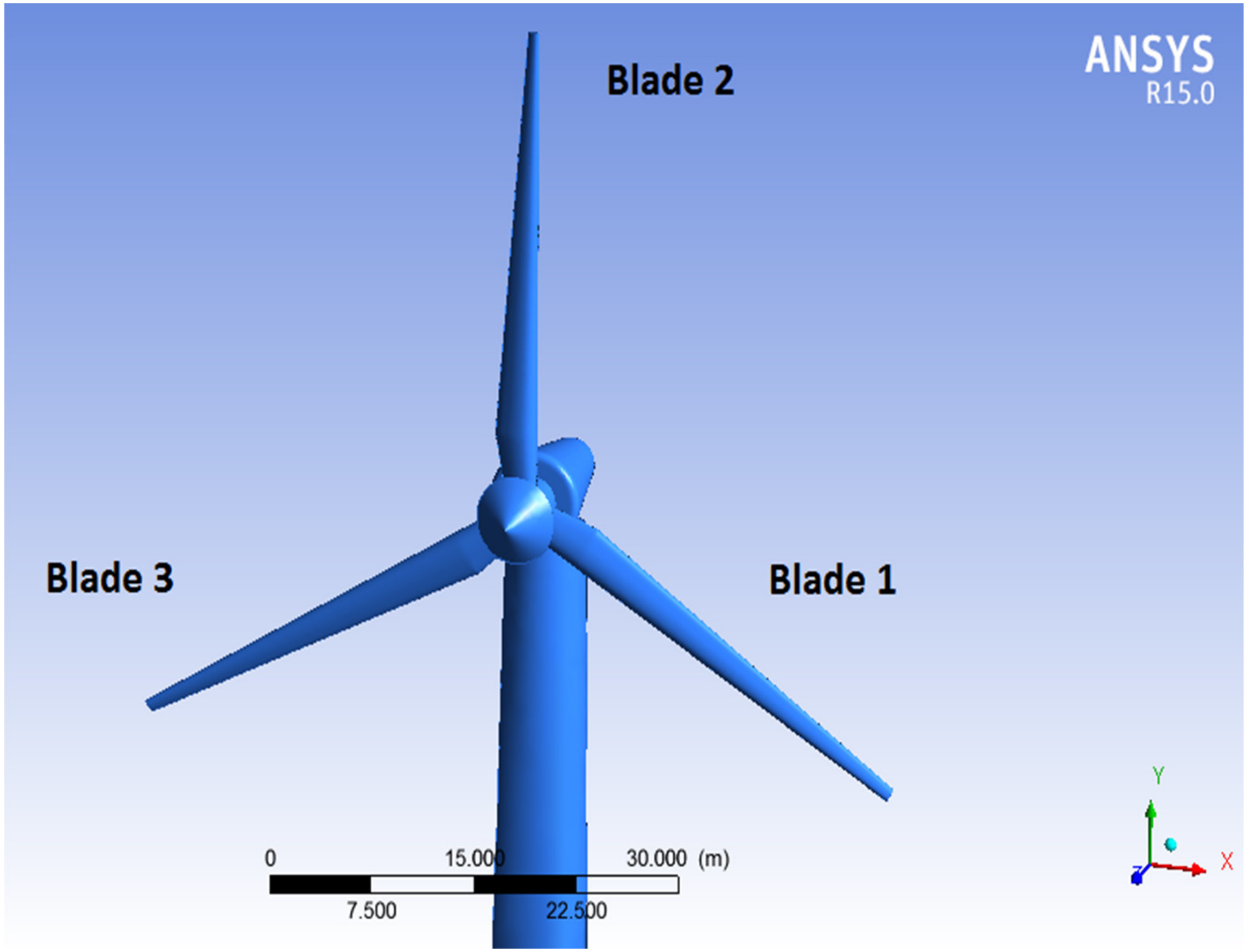
terial Properties

The structural analysis for the wind turbine system was carried out while considering all potential stresses, strains and deformations that affected the wind turbine blades in order to obtain the wind turbine design with optimum aerodynamic and structural characteristics.

The blades' material is Epoxy matrix reinforced with unidirectional Carbon fibers having the following material properties:

Young's Modulus (GPa)	209 (x)	9.45 (y)	9.45 (z)
Poisson's ratio	0.27 (xy)	0.40 (yz)	0.27 (xz)
Shear modulus(GPa)	5.5 (xy)	3.9 (yz)	5.5 (xz)
Density (kg/m^3)	1540		

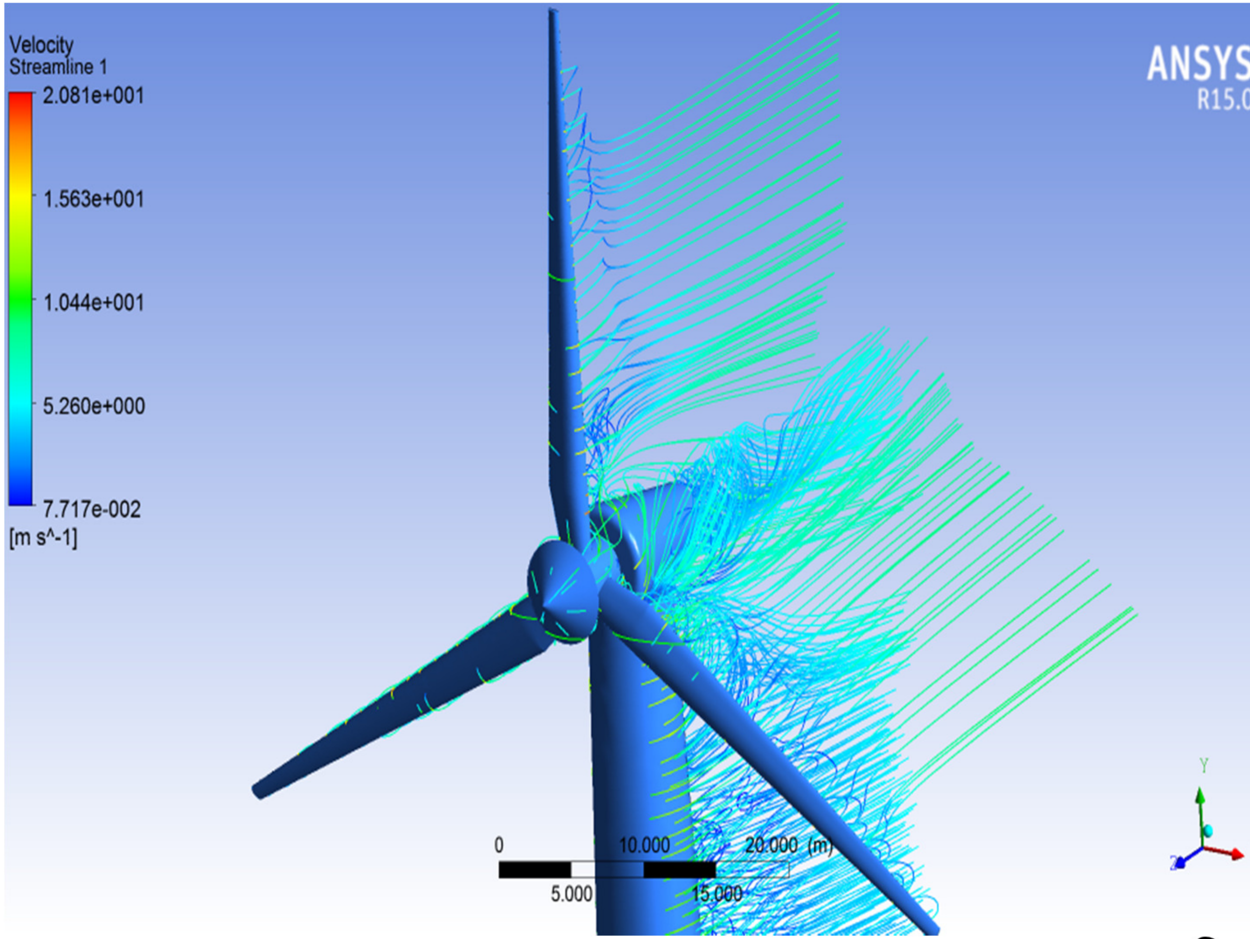
terial Properties



rodynamic Analysis

The boundary conditions were applied on the geometry considering all potential loads that will affect the performance of the wind turbine.

Streamlines of the air flowing with a velocity of 10m/s was simulated and the values of pressures, wall shear stresses, eddy viscosity and turbulence kinetic energy at wind turbine blades were extracted from the output files.



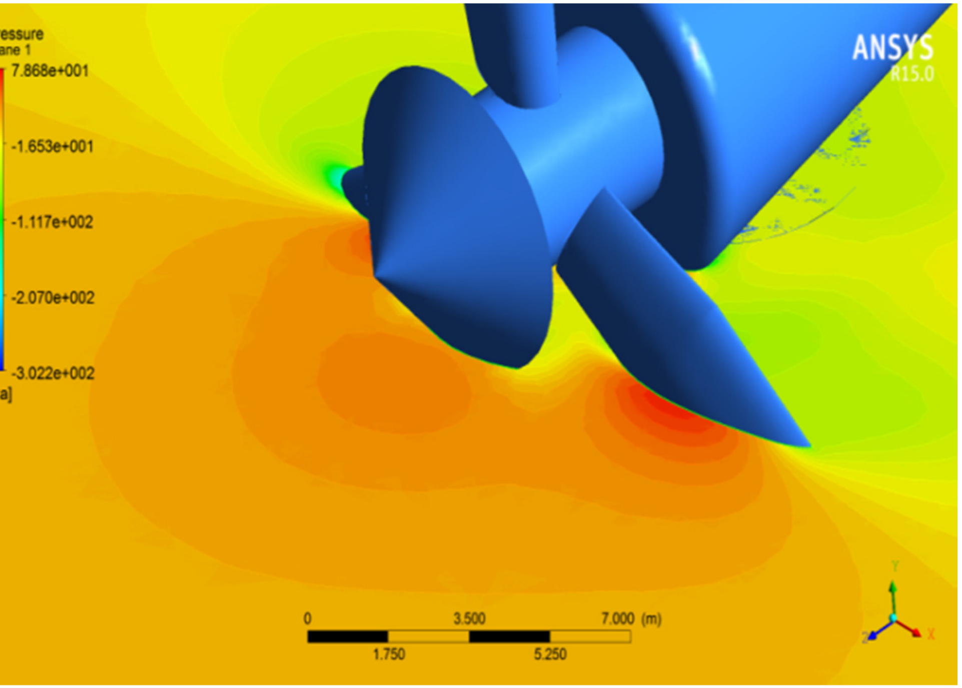
rodynamic Analysis

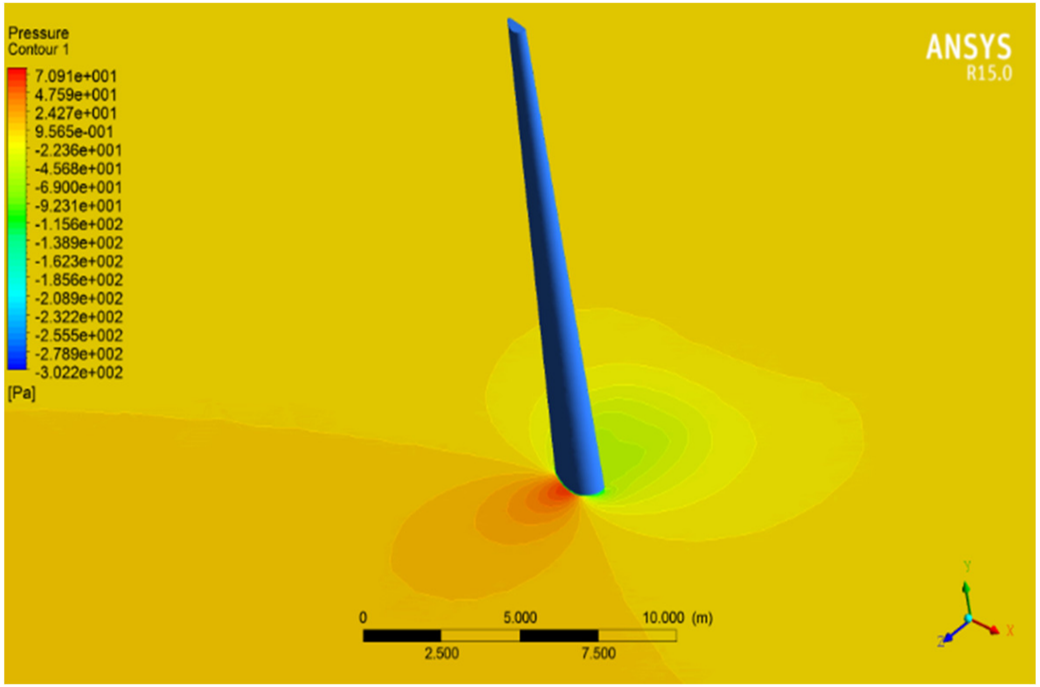
The aerodynamic performance of the wind turbine blades was investigated against many variables such the blade thickness, the shear webs locations, the twist angle of the blades and the hub height.

The relationships between the variables under investigation; shear webs location given as a percentage of the blade's chord and the blade twist angle were studied.

rodynamic Analysis

Wind turbine critical design areas that were exposed to large wind pressure were ocated at 80m of turbine height (blade 1) and 100m of turbine height (blade 2)

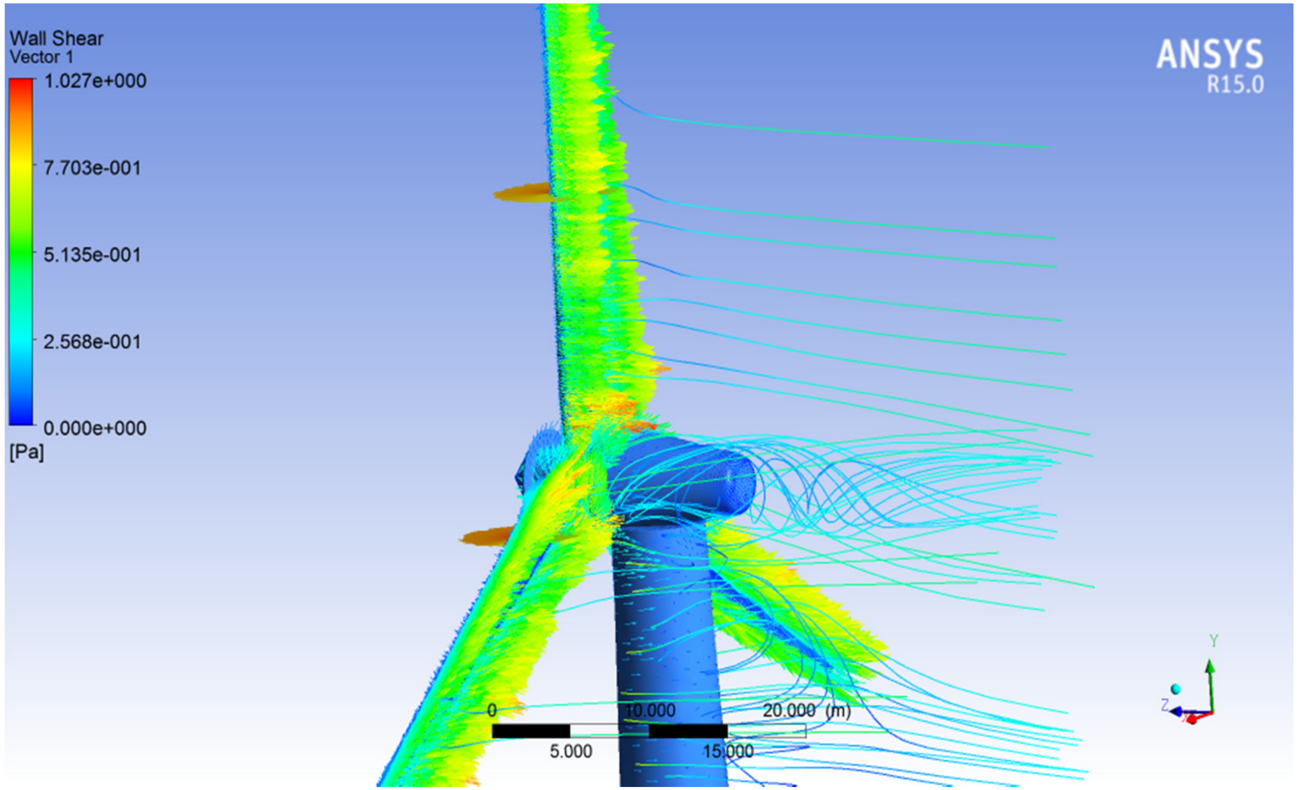




Pressure distribution at the front face of wind turbine system at heights of 80m & 100m

rodynamic Analysis

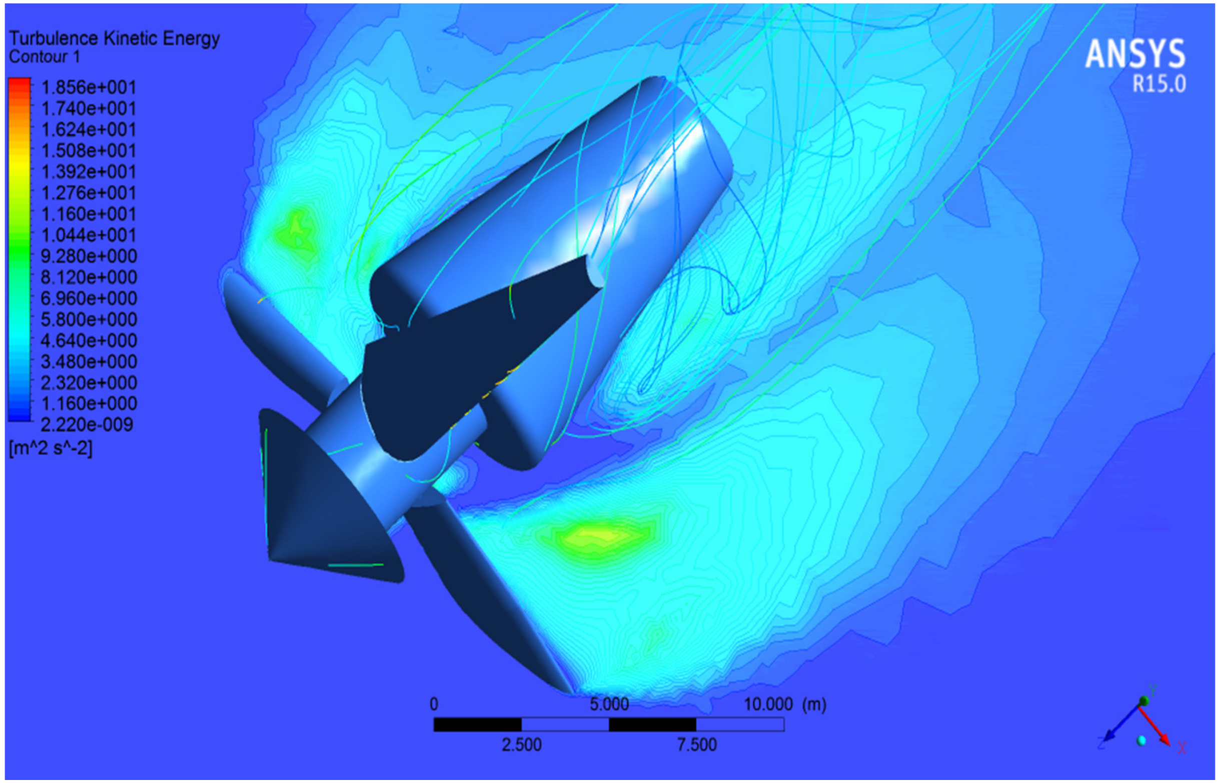
The wall shear stress, eddy viscosity and turbulence kinetic energy for the wind turbine system were studied at critical design locations



Eddy viscosity distribution at the front face of wind turbine system at 80m height

rodynamic Analysis

The wall shear stress, eddy viscosity and turbulence kinetic energy for the wind turbine system were studied at critical design locations



Turbulence kinetic energy distribution around the wind turbine system at 80m height

rodynamic Analysis

A preliminary aerodynamic analysis was carried out to select the best optimum designs from different design configurations of the blade.

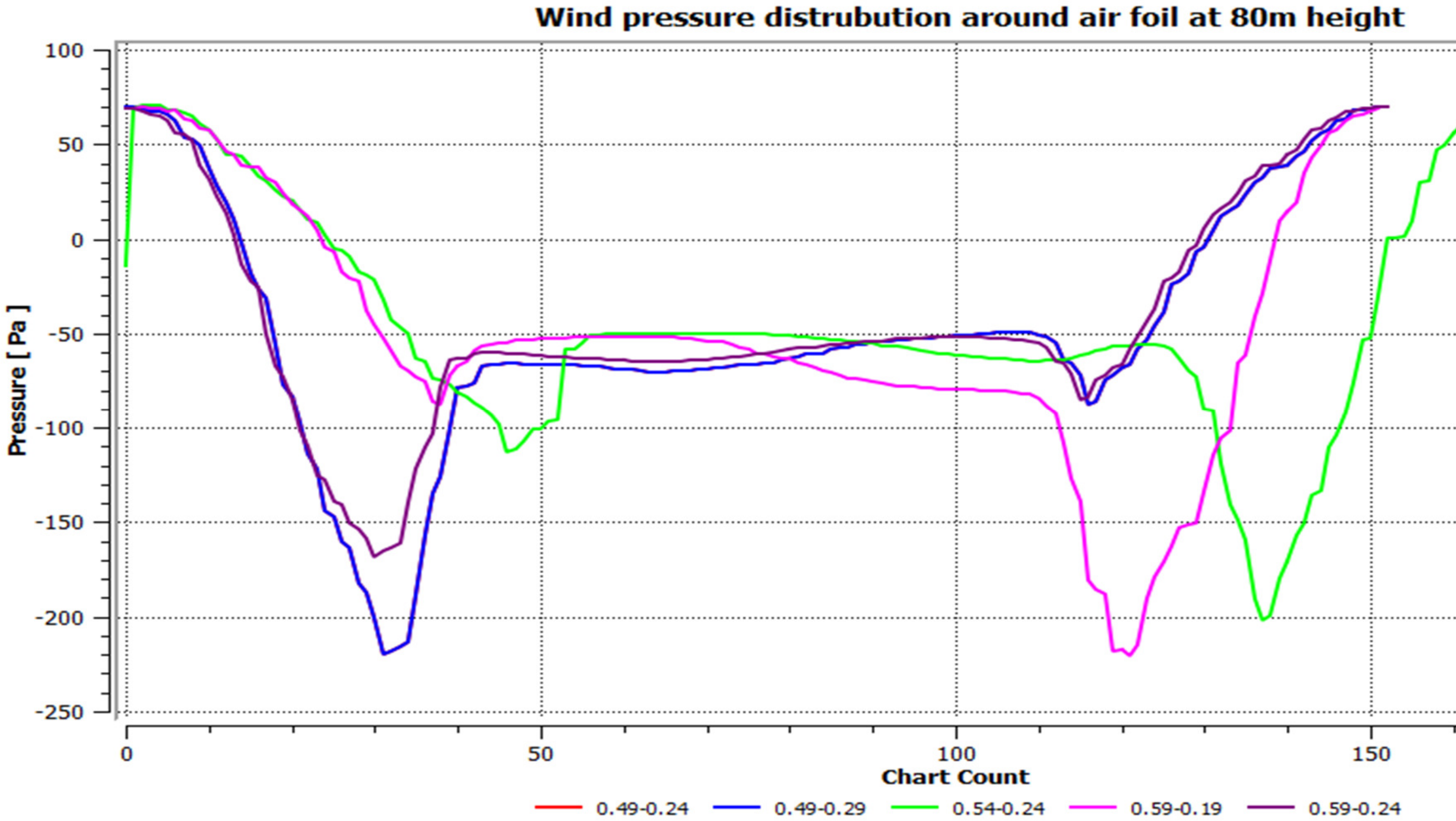
The twist angle of the blade was altered from 2.5^{o} up to 32.5^{o} with an increment of 10^{o} n each step i.e (2.5^{o}, 12.5^{o}, 22.5 ^{o} and 32.5 ^{o}).

Each twist angle was tested based on five shear webs locations inside the blade given as percentage of the blade chord length (0.49-0.29=20%, 0.49-0.24=25%, 0.54-0.24=30%, 0.59-0.24=35% and 0.59-0.19=40%).

Optimum design configurations were obtained based on minimizing wind pressure, wall shear stress, eddy viscosity and turbulence kinetic energy from the simulation software

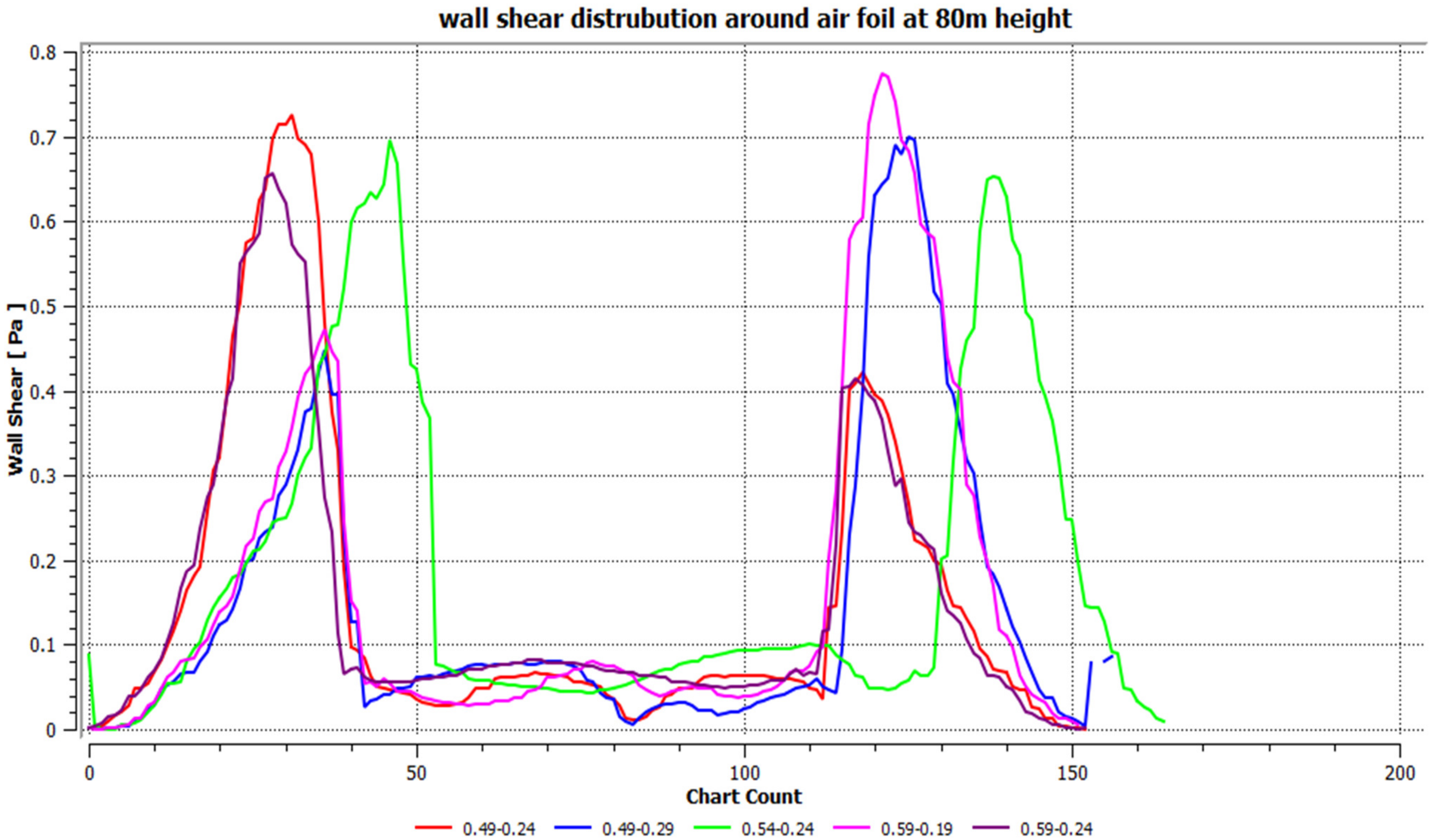
sults

twist angle at 20% ear webs location: sults showed that the de has a twist angle of o and shear webs ation (0.29*blade chord) d (0.49*blade chord) is e optimum design for rodynamic loads. The ection of this shear webs ation was taken out of 5 ferent shear webs ations



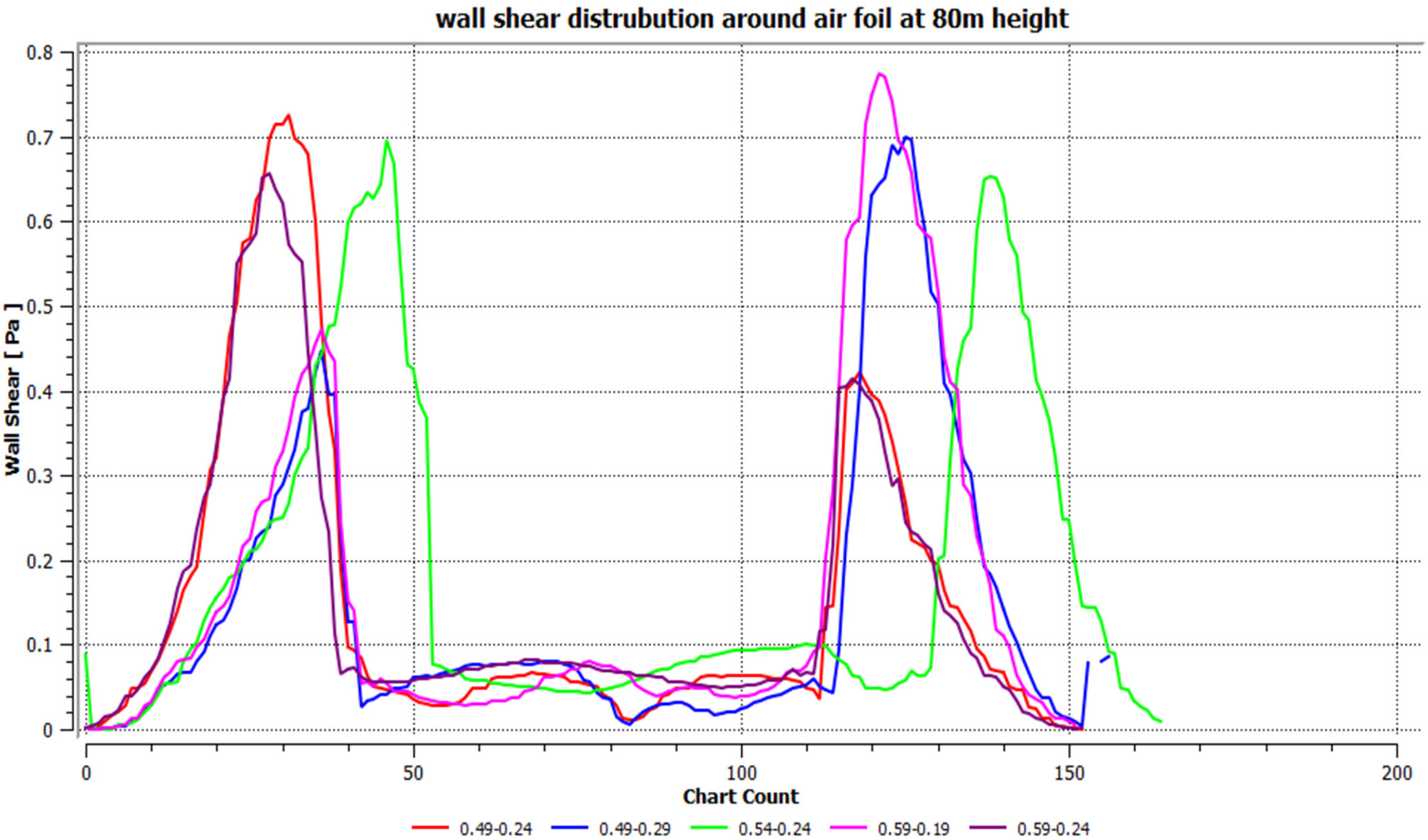
(Wind Pressure (Blade1)

sults



Wall Shear Stress (Blade1)

sults



Wall Shear Stress (Blade1)

sults

nilar analyses/results were carried out for the remaining cases, namely:

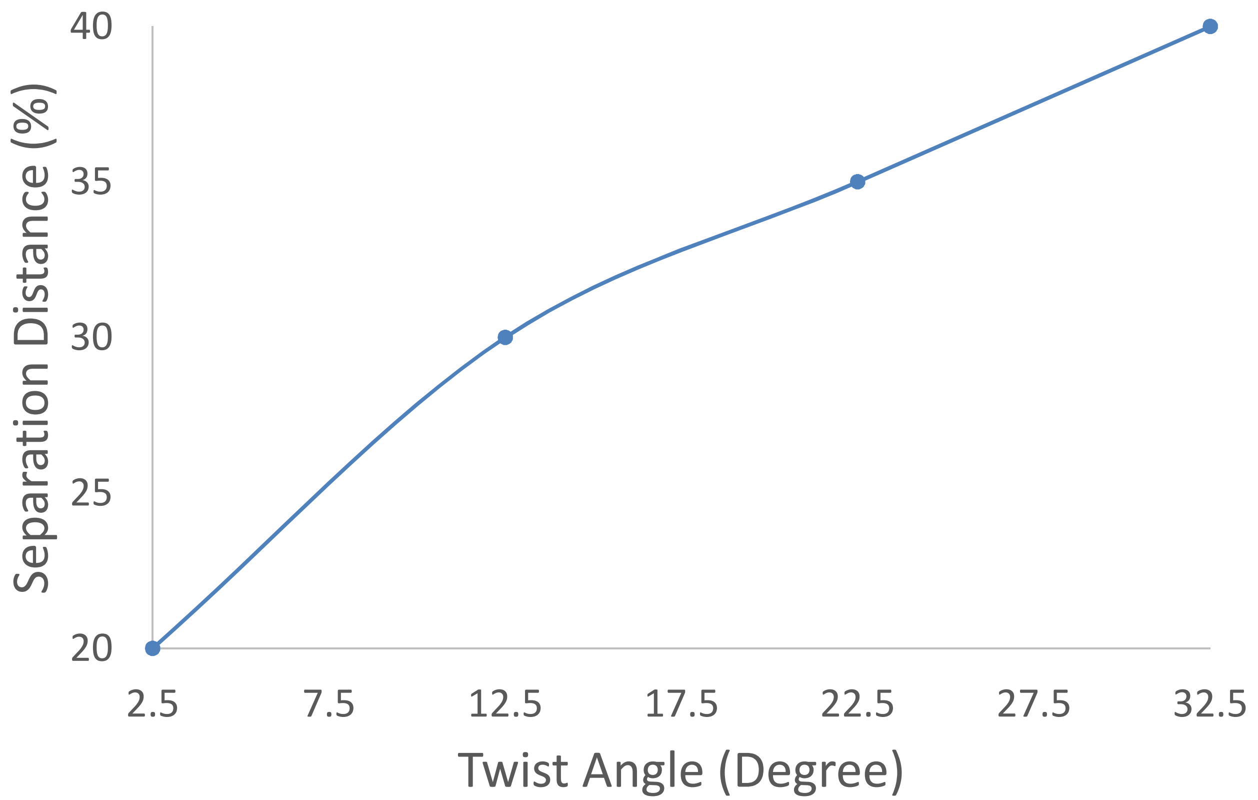
5 twist angle at 30% shear webs location: the optimum aerodynamic design was at 5° twist angle and 0.54-0.24=30% of blade's chord length.

5 twist angle at 35% shear webs location

5 twist angle at 40% shear webs location

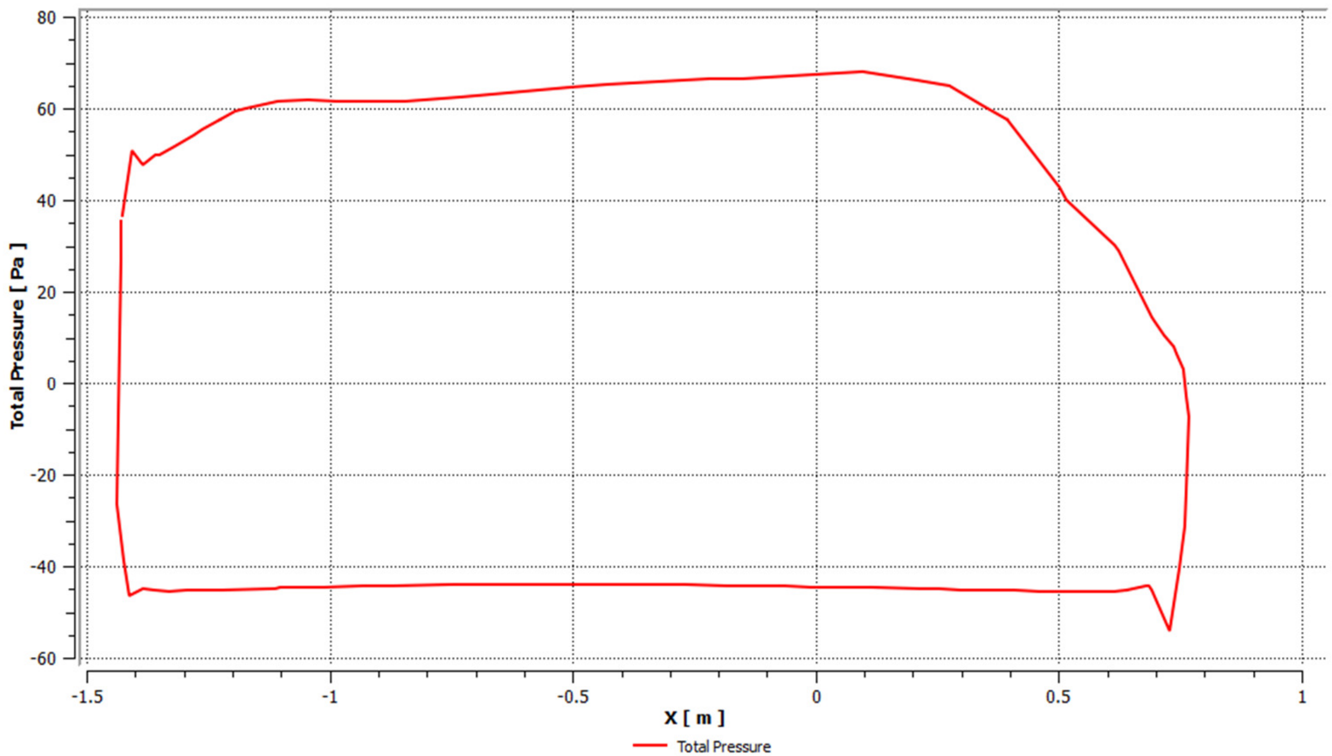
sults

sed on the aerodynamic analysis, the relationship between the shear webs location and twist angle for the optimized wind turbine's blade design is positive and linear as the paration distance between the shear webs increases the twist angle also increases:



rification of the aerodynamic loads

e aerodynamic loads resulted from the analysis were verified against the study nducted by Chen et al., (2012)

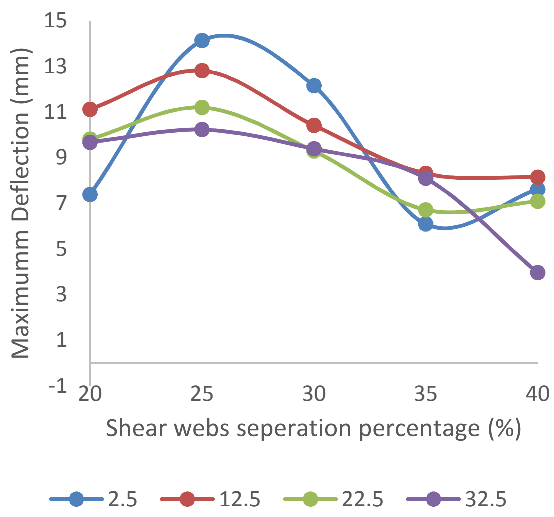


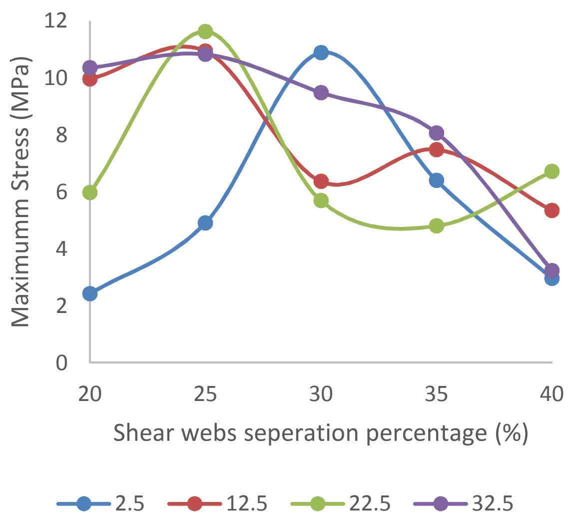
Pressure distribution at the blade's span wise located at 100m height of wind turbine system

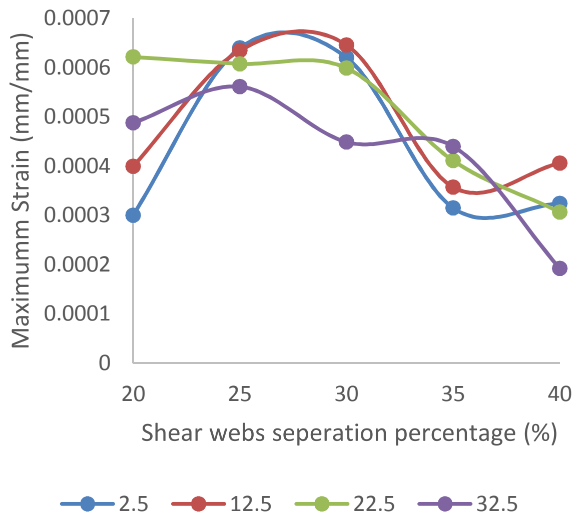
atic Structural Analysis

flection, stresses and strain for the wind turbine system with real dimensions and for ividual blade were investigated based on the computational fluid dynamic forces ported from the simulation software and mapped at the top face of the wind turbine des.

e effect of the twist angles (2.5-32.5) on the total deflection, stresses and strains are:



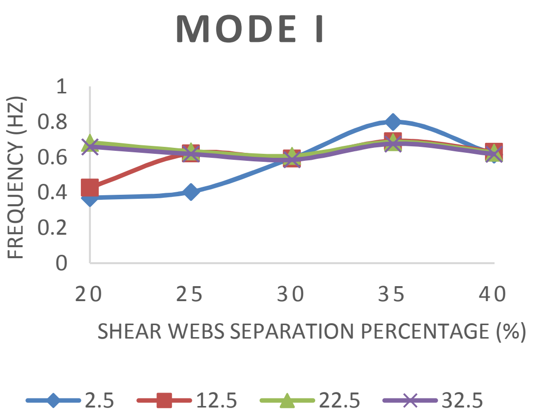


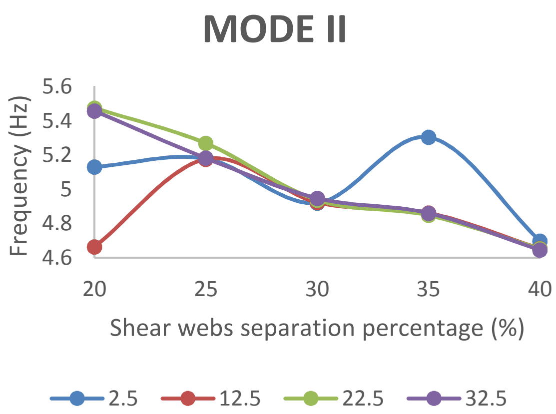


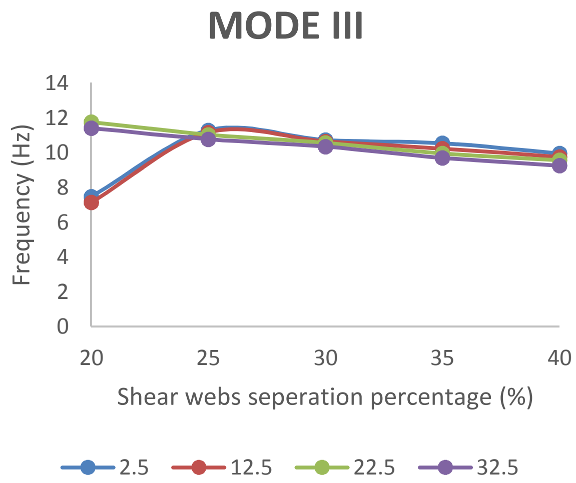
namic analysis for the wind turbine blades

e pre-stressed frequencies of the wind turbine blades were applied to investigate the namic response of wind turbine's blade at different shear webs distances.

e blade with lower twist angles (2.5° and 7.5°) have a higher stressed vibration ponse as the distance between the shear webs increases (mode shape II) while the de with higher twist angles (22.5° and 32.5 °) having a lower stressed vibration as the ear webs separation distance increases.







nclusions

- The preceding analysis presented a tool for optimizing wind turbine's blade design based on geometry and aerodynamic analysis.

- Both structural and dynamic characteristics of the blade were included in the analysis.

- A number of configurations where analyzed; shear webs separation angle and blade's twist angles were varied to seek the optimum configuration/geometry for the design.

- Results showed that the distance between the shear webs and the twist angle of the wind turbine blade control the aerodynamic, structural and dynamic characteristics of the wind turbine system.

nclusions

- Based on the conducted analysis, it was found that the optimum blade configuration has a twist angle of 22.5^{o} and has two shear webs located inside the blade separated by 35% of the blade chord length.

- The findings of this work are significant to the industry as they present a valid method for analysis and could help reduce the cost of energy generation by adopting an optimum blade design.

- It can further help to reduce failure threat to other major components in a wind turbine. Particularly the gear box.

спасибо 谢谢

GRACIAS

THANK YOU

ありがとうございました MERCI

DANKE धन्यवाद

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