turbinethe rotational speed of the blade can surpass that of the wind (*Wind Energy*).

When air flows over an object such as an airfoil, the air stream is forced to move around it as depicted in Figure 1. Typically the object is shaped in such a way difference in flow speeds creates a pressure differential. The pressure difference creates a kind of circulation around the airfoil which speeds up the flow above and slows the flow below. This results in the force commonly known as lift. Lift is perpendicular to the wind direction (Figure 1).

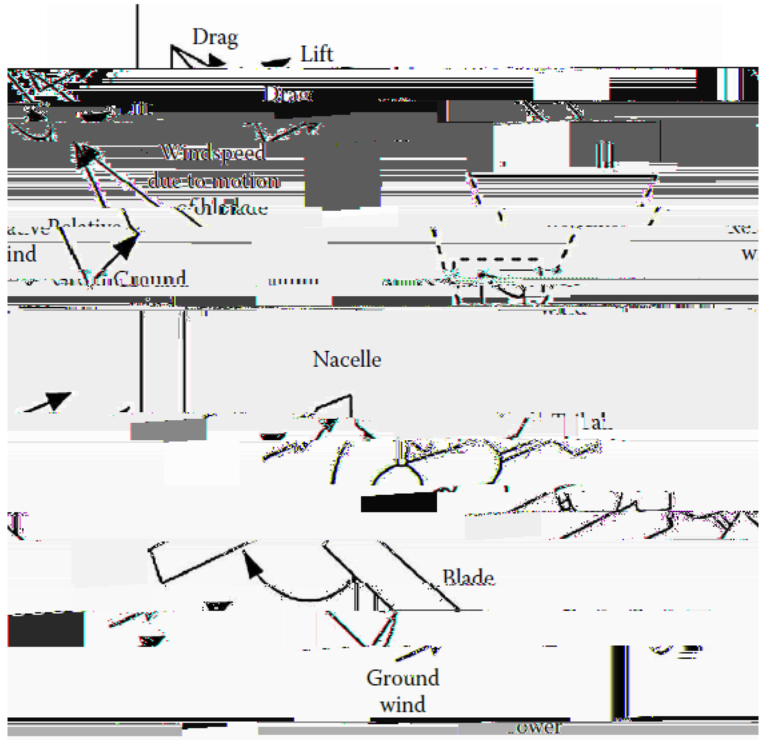
In practice, an airfoil is not generally aligned with the air flow. The angle at which an airfoil makes with the oncoming wind is known as the angle of attack. Generated lift is heavily dependent on the angle of attack. The lift coefficient is linearly proportional to the angle of attack, and has an approximate slope of $2\pi$/radian (*Aerodynamics*). There is a limit at which the angle of attack will no longer increase lift. At this point, the airfoil stalls. At high angles of attack the drag component caused by pressure, which is normally miniscule, becomes very large. The boundary layer of the air also begins to separate.

The drag force is created by the air as it flows over the airfoil. Because of the no-slip condition, a fluid exerts a tangential shear force on the surface of the airfoil. This force is in the direction of motion of the fluid. Normal pressure forces exerted by the air also have components which contribute to drag. Drag acts to oppose the motion of the airfoil. And in doing so, drag reduces the efficiency of a wind turbine.

Coefficients are used as a way to quantify the lift and drag forces on an object (Cengel). These coefficients are determined by the frontal area, wind speed, density of the fluid, and the force experienced by the object due to the fluid flow.

$$C_L = \frac{2F_L}{\rho V^2 A}, \qquad C_D = \frac{2F_D}{\rho V^2 A}$$

In the case of a wind turbine, the airfoils are mounted around an axis. As they rotate, the blades experience a combination of air flows. First is the obvious air flow from wind. Second is a flow due to the rotation of the blade. This flow from the rotation is, in an



## Materials and Methods

CFD software was

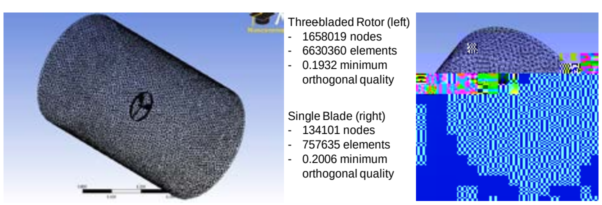
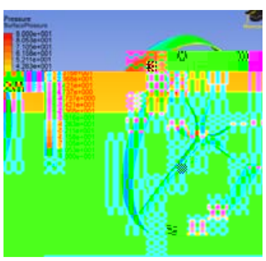


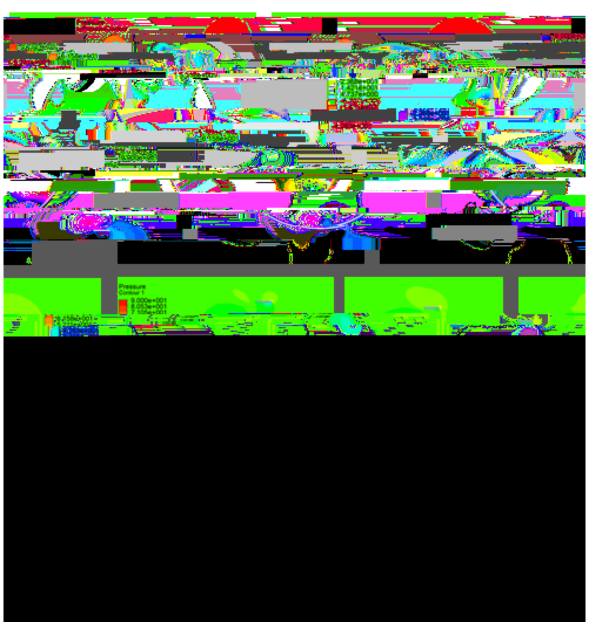

Figure 3 – (left) wireframe mesh of the 3-bladed rotor, (right) wireframe mesh of the single propeller blade

for the specification of magnitude and direction of the fluid flow. The fluid flow was allowed to leave the system through the flat sides, which were also treated as pressure outlets. Ideally the meshes are large enough so that any flow patterns caused by the boundaries are not influential to the flow around the objects.

Reference values needed to be set within Fluent. Some values were temperature, enthalpy, pressure, velocity, viscosity, etc. Temperature was changed to 0 degrees Celsius. Pressure was set to 0Pa gauge or atmospheric in order to meet standard temperature and pressure conditions. Enthalpy was defined as 0kJ/kg, since the model as setup does not consider heat transfer. Viscosity is determined by the fluid, which is air. Velocity was altered between simulations. Simulations were primarily run with velocities of 3m/s, 5m/s, and 10m/s. These velocities are comparable to low altitude wind speeds in the West Haven area.



**Results and Discussion**



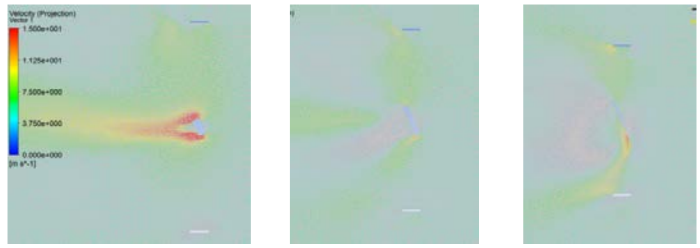



Figure 7 – Velocity vector plots at (a) 0.015m, (b) 0.025m, (c) 0.035m from the axis of rotation. Flow is from right to left.

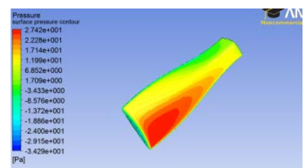



Figure 8 – surface pressure on the propeller blade

The second series of simulations focused on flow over a single propeller blade. This geometry is a more developed airfoil than a comparable blade taken from the previous geometry. This airfoil was also tested with varying wind speeds. Results from the 5m/s simulation will be discussed. This particular simulation ran for 2500 iterations and had a residual continuity of 3.93E-03. The convergence is of an acceptable order of magnitude. leaade..29 T7.45hisas.614 0 Td (-)T03(a)-20(g) 0.226 Tw -10 Pe1[(03.)14n

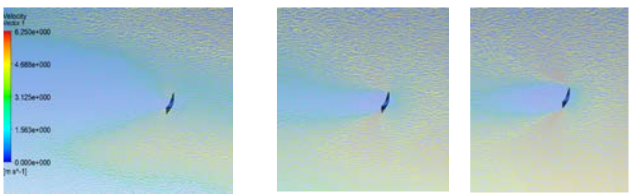



Figure 9 – velocity vector plots at (a) 0.02m, (b) 0.04m, and (c) 0.06m from the axis of rotation.