III. Results & Discussion

A number of calculations have been carried for a three-bladed horizontal axis wind turbine tested at NREL. The configuration was made of untapered, untwisted blade sections.

Figure 1 shows a typical H-O grid around one of the blades. For wind directed along the axis of the rotor, the flow properties are periodic from one blade to the next, and only a single blade needs to be considered. The user may specify the number of cells along the chord, radial and normal directions. As stated in section I, the grid generation process is extremely fast, and may be done in a matter of minutes on workstations.

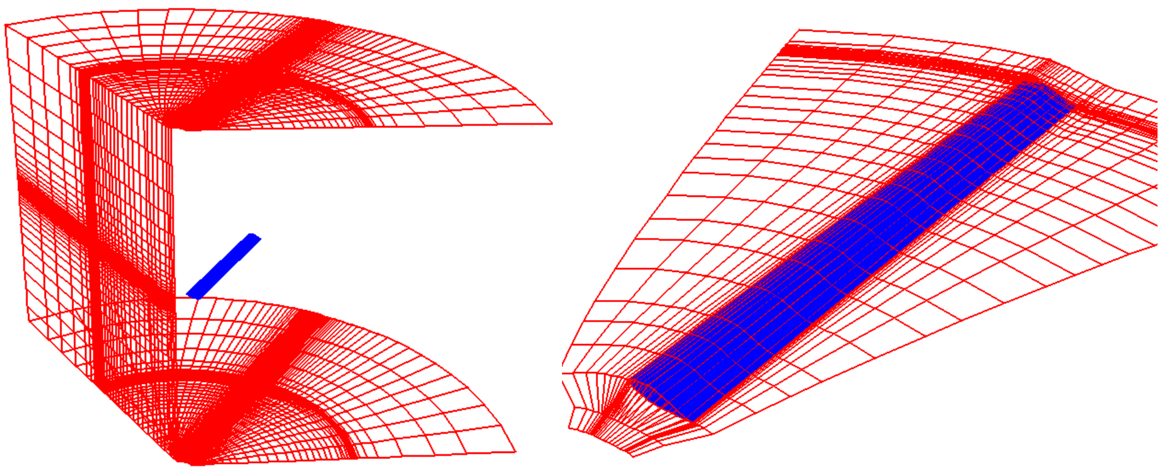

Figure 1. Body Fitted Grid Around the Wind Turbine Blade

Calculations have been carried out for the Phase II rotor at three wind conditions: 10, 15 and 20 meters per second. Figure 2 shows the comparisons with measured data. In general good agreement with measured data at attached flow conditions (10 m/s) and under stalled conditions was observed. In these calculations, the transition point was assumed to be at 40% chord, based on the 2-D calculations carried out by Wolfe et al. [Ref. 18, 19]. Downstream of the transition location, and in the wake, the eddy viscosity was calculated using the Baldwin-Lomax turbulence model.

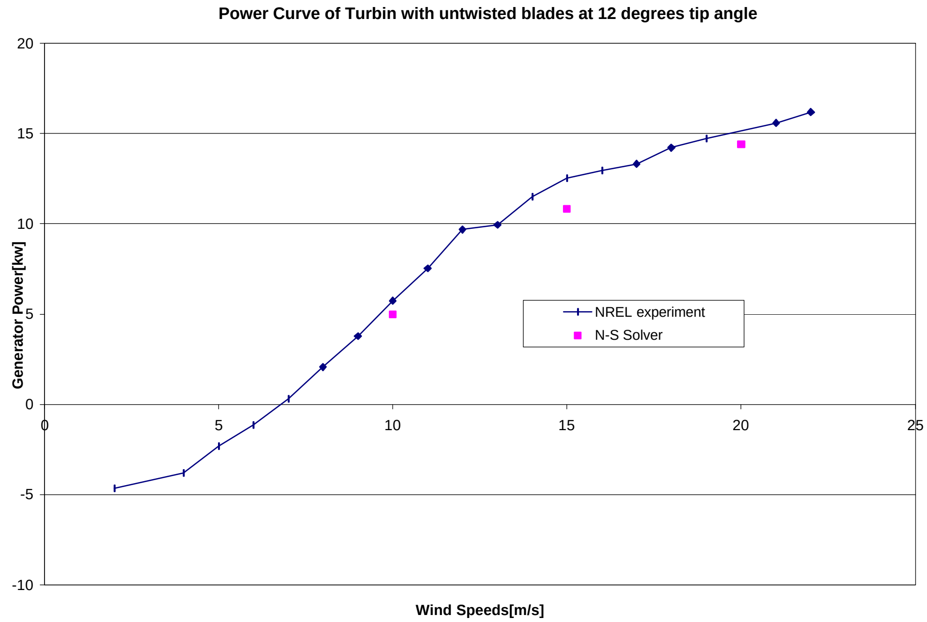

Figure 2. Comparison of Calculated vs. Measured Power for the Phase II Rotor

The lifting line based computer code YAWDYNE has been downloaded from the NREL web site, and calculations have been carried out for the Phase II rotor at these wind conditions. Comparisons between the lifting line code and the hybrid code have been made of the lift and drag properties at a number of radial locations. Figure 3 shows a typical comparison for the 20 m/s wind condition. In general good agreement is observed between the present first-principles based method and the lifting line theory. Near the blade root the high wind conditions, along with the small chord-wise velocity Ωr of the blade causes the flow to be massively separated, limiting the lift generation. The present simulation tends to predict lower lift values near the blade root than the lifting line theory. This discrepancy does not cause a significant difference between the present method and the blade element theory in the prediction of generation, power, however. This is due to the fact that most of the power is generated at the outboard sections, where a higher dynamic pressure exists.

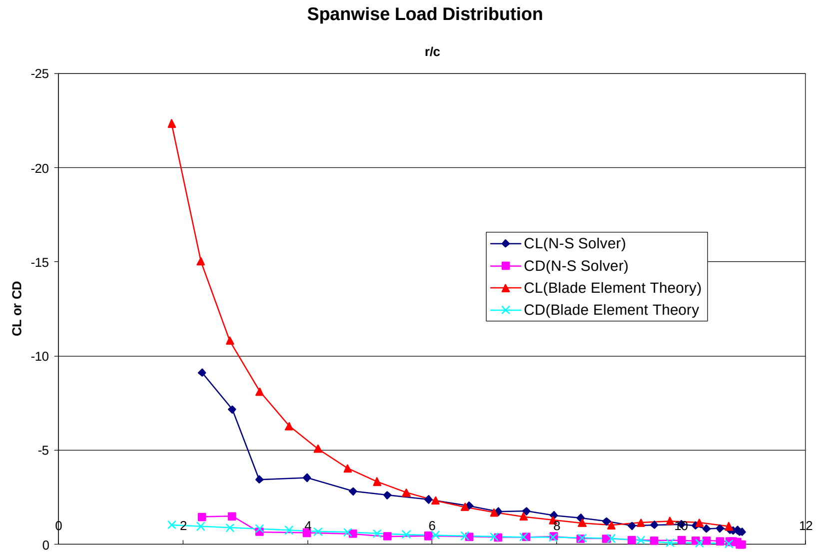

Figure 3. Comparisons of Spanwise Lift and Drag Distribution Between the Georgia Tech Analysis and YAWDYNE

With the aid of scientific visualization software such as FAST, the flow field over the entire rotor may be analyzed. This feature is very useful in designing new rotor blades, and in identifying hot spots (transition location, flow unsteadiness, separation) in the flow field. Figure 4 below shows the pressure distribution over the rotor blade upper surface for the 20 m/s wind condition. The atmospheric pressure, for reference, is $1/\gamma$ (~ 0.72). In this figure, the blue region indicates regions of lowest pressure, while the red and pink regions indicate regions of higher pressure. It is seen that green (low pressure) regions are present only in the outboard regions, indicating that the flow is stalled inboard.

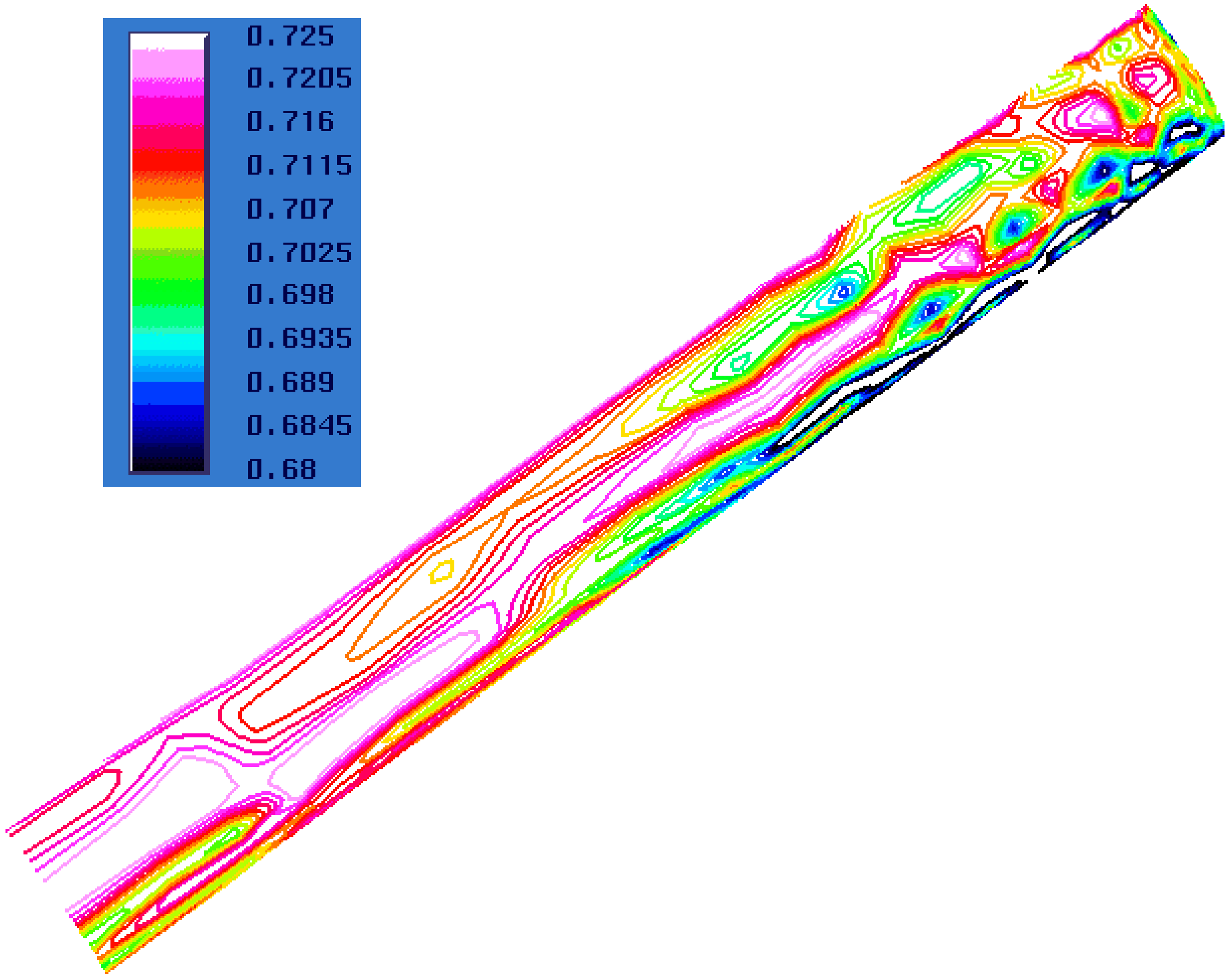

Figure 4. Pressure Distribution over the Upper Surface of the Rotor (20m/s)

Figures 5a and 5b show the streamlines at 20 m/s wind speed over the rotor blade, at a typical radial location, and over the entire upper surface, respectively. It is seen that the flow field is separated over the entire upper surface.

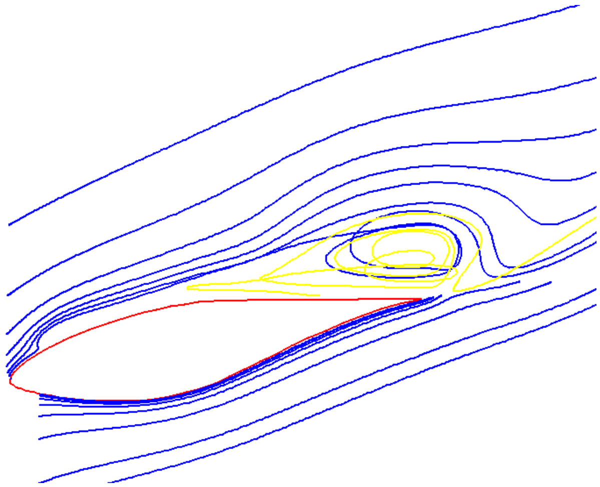

Figure 5a. Streamlines at a typical span station at 20m/s

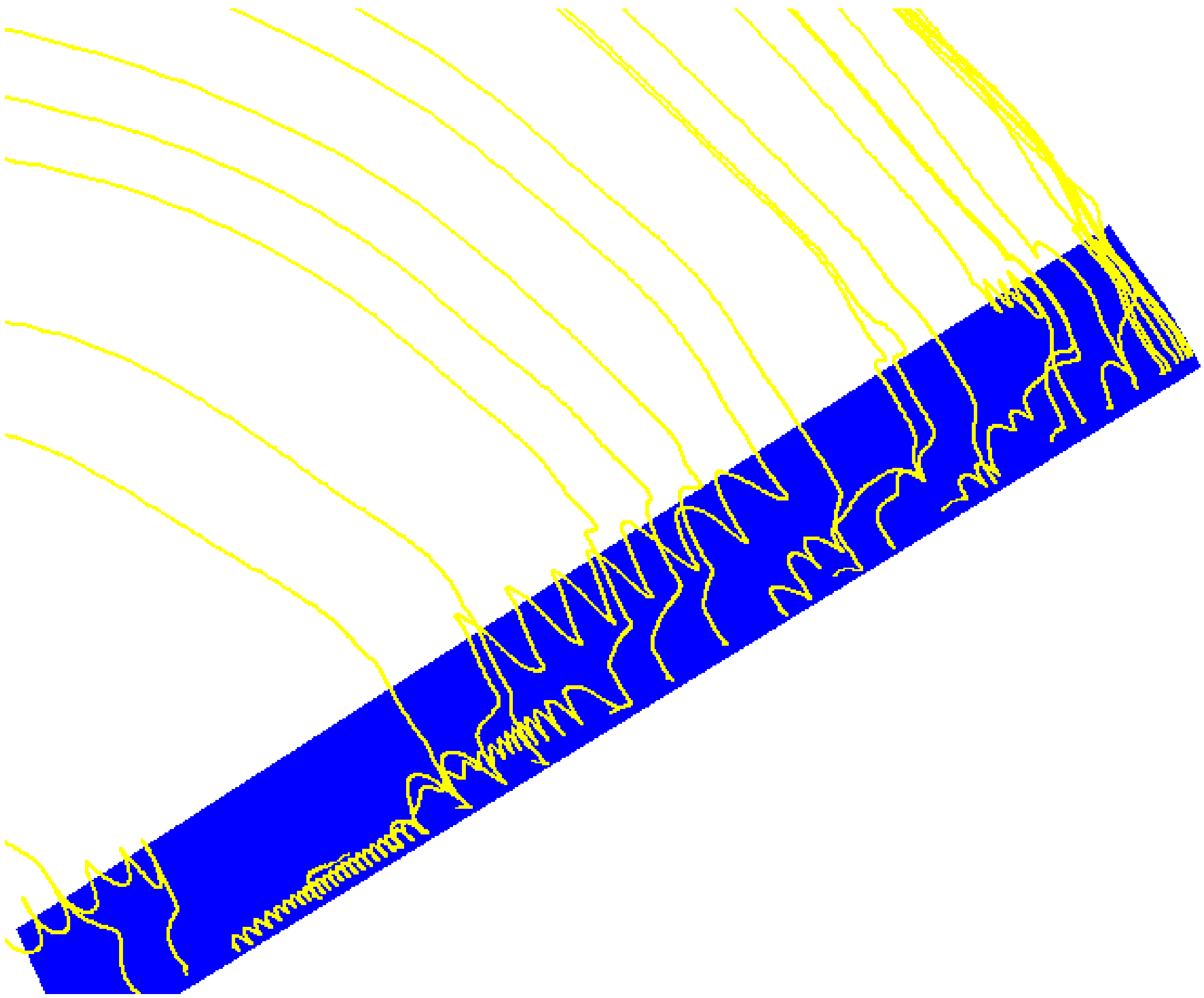

Figure 5 b. Streamlines over the rotor upper surface at 20m/s.

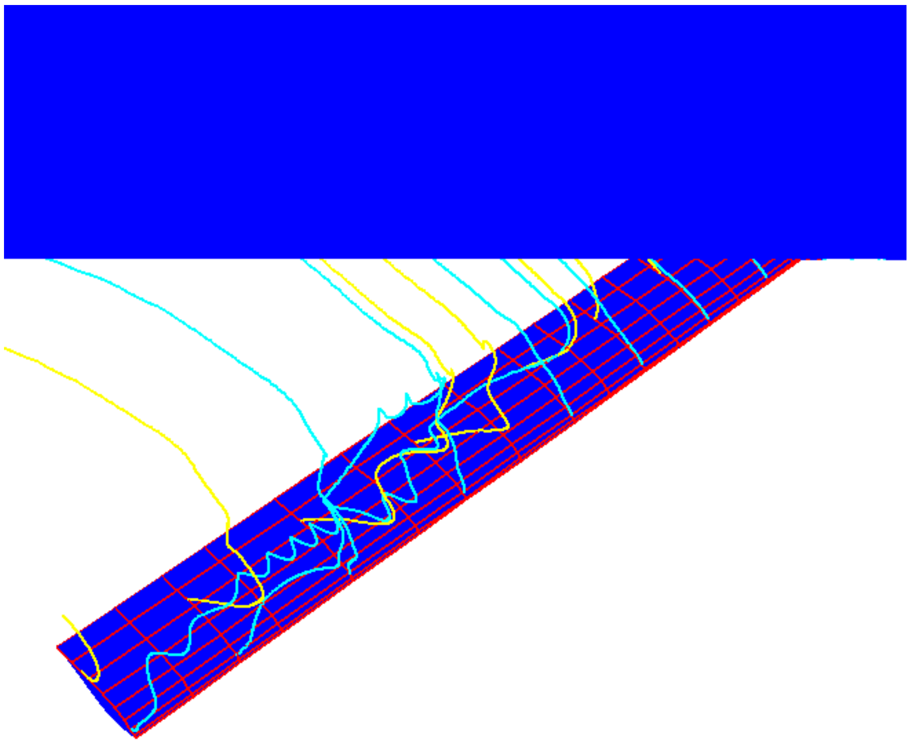

Figure 6. Streamlines over the Rotor Upper Surface at 10m/s Wind Condition

At lower wind conditions (e.g. 10 m/s) the flow is well attached, over the outer 50% of the rotor, as shown in figure 6. Only the inboard stations are separated.