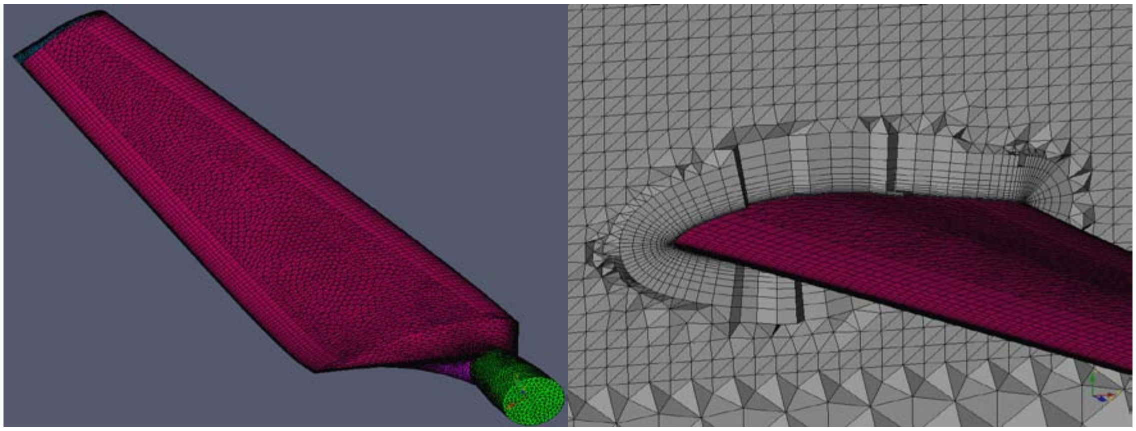
Wind Turbine Fluid-Structure Interaction

Variations in blade loading of wind turbine rotors is an important concern that wind power engineers need to account for in design and analysis. As the rotor turns, variations in local wind speed due to tower effects and atmospheric turbulence generate a time varying pressure field across the blades. This leads to vibration of the blades and unsteady loading within the gearbox. At the current time, improving the robustness and extending the life of gearboxes is a key challenge that needs to be overcome in order to increase the viability of large scale wind power generation.

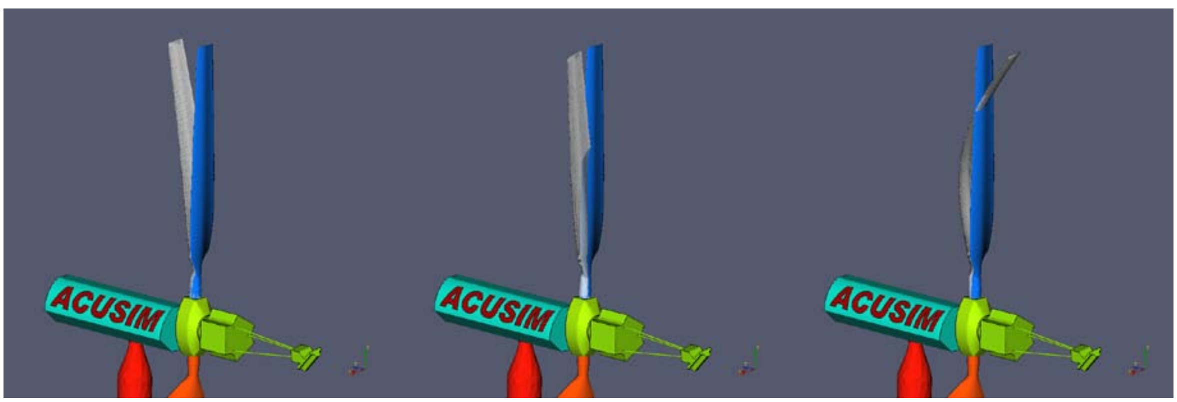
ACUSIM Software provides valuable technology for addressing the analysis needs of wind turbine designers. AcuSolve has unique capabilities that allow for accurate simulation of rotating and deforming wind turbine assemblies. AcuSolve utilizes its Practical Fluid-Structure Interaction (P-FSI) technology in conjunction with its robust Arbitrary Lagrange Eulerian (ALE) mesh motion techniques to predict the unsteady response of the wind turbine and provide an unprecedented level of insight into the behavior of the turbine design. Using this technology, engineers can not only determine the fluctuating loads on the blades as they rotate, but also evaluate the impact of the resulting deformation on the aerodynamic performance and structural integrity of the machine.

In this case study, the turbine design from the NREL Phase VI Unsteady Aerodynamics Experiment (UAE) was used to demonstrate the FSI capabilities of AcuSolve. The UAE used a twisted and tapered two-bladed rotor design having a diameter of approximately 10 meters. The blade tip speed was approximately 37 m/s, corresponding to a tip Reynolds Number of approximately 1.5e6.

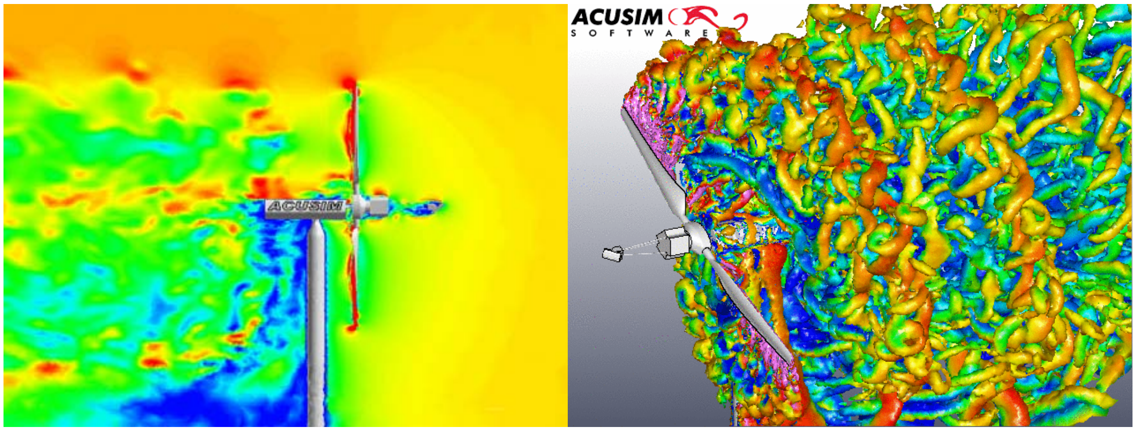
AcuConsole, the GUI preprocessor for AcuSolve, was used to import the CAD model of the UAE and generate an unstructured mesh. The leading and trailing edges of the blades were meshed using anisotropic surface elements and the mesh was clustered normal to the surface of the blades to resolve the steep near wall gradients present in the boundary layer. The geometry of the UAE turbine, as well as images of a representative mesh are shown in the following figures:



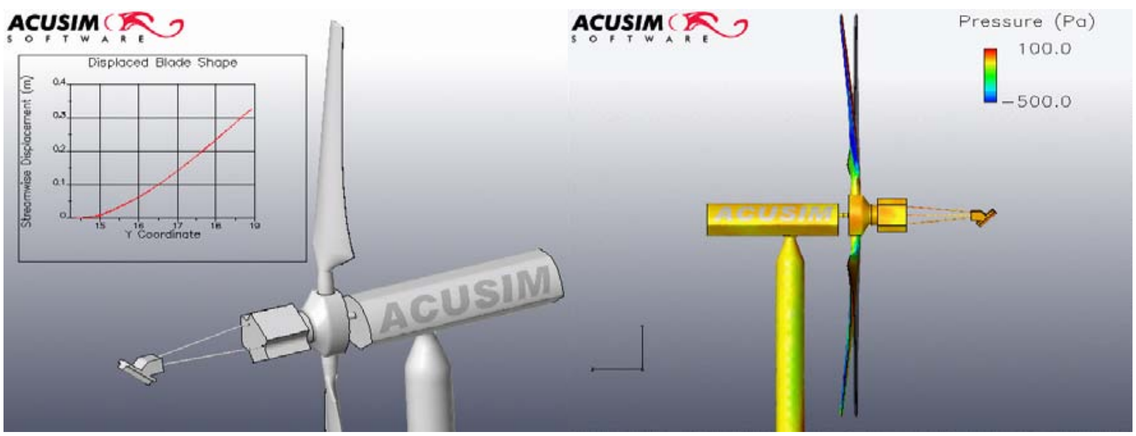
A linear modal analysis of the UAE blade was performed using Abaqus/Standard and imported into AcuConsole. The resulting mode shapes were projected onto the blade surfaces of the CFD model. This information, in conjunction with the eigenvalues of each mode, is required by AcuSolve to perform the P-FSI simulation. All computations are performed within AcuSolve in a distributed memory parallel environment with no need for coupling to third party packages. The first three bending modes of the blade are shown in the following sequence of images.



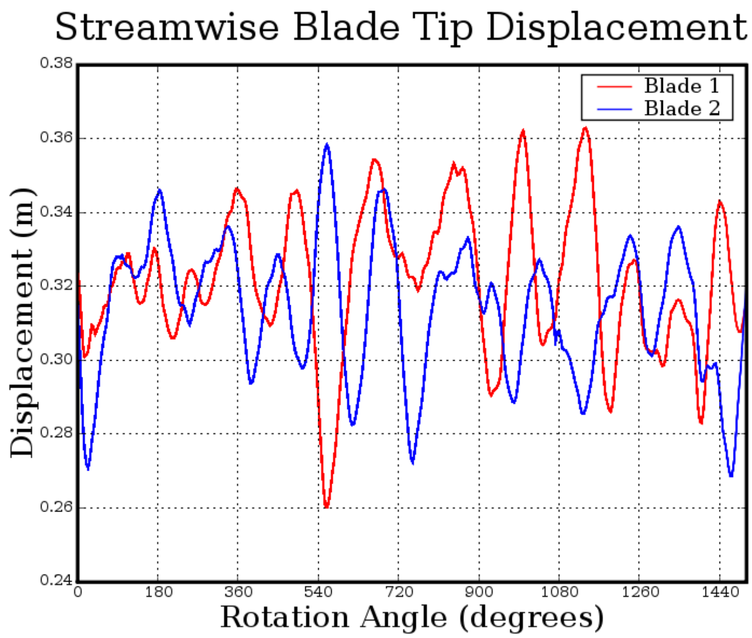
The Delayed Detached Eddy Simulation (DDES) model based on the Spalart-Allmaras formulation was used to simulate the transient flow over the blades. A timestep size corresponding to 2 degrees of rotor revolution per step was used to simulate the flow. As can be seen in the following images, complex 3-dimensional turbulent structures are generated in the wake of the turbine. These turbulent structures play a key role in producing the unsteady loads on the blades that contribute to the fluid-structure interaction.



The CFD results were visualized at regular intervals to illustrate the displaced shape of the blade. The following images show the instantaneous deformation of the blade at a single timestep. Note that the actual material properties of the blade were not known at the time of the simulation, so the displacements are based on the assumed properties.



A time history plot of the streamwise tip displacement of each blade reveals the unsteadiness of the tip deflection. This plot indicates the extent of vibration of the blades.



The following animation illustrates the behavior of the rotating and deforming turbine model. Notice the displacement of the blades as they pass the tower. Click on the animation for a larger view.