ACTIVE CONTROL OF FLOW SEPARATION AND STRUCTURAL VIBRATIONS OF WIND TURBINE BLADES

Sponsor: Ney York State Research and Development Authority (NYSERDA), and National Science Foundation (NSF) through the GK-12 program directed by Debbie Kaminski
Funding: $100,000 for 15 months (started: February 2008)
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PROJECT DESCRIPTION

This research project is funded through the New York State Research and Development Authority (NYSERDA), which seeks to promote the growth of renewable energy used in New York using current and developing technology. The majority of this renewable energy is produced using wind turbines in large-scale wind farms for electrical grids with the goal of increasing renewable energy usage from the current 19.3% to at least 25% by 2013. Achieving this goal will require a combination of increasing wind turbine installations and improving their aerodynamic efficiency beyond existing levels.

The research aims to use active flow control technology, specifically *synthetic jet actuators* embedded inside the wind turbine blade to provide an efficient, rapid and compact means to alter the aerodynamic characteristics of the blade. The flow control system is designed to operate in a closed-loop fashion with sensor feedback, providing three key benefits to wind turbine design:

1. Increase the efficiency of the turbine by improving its energy capture capability at low wind speeds by maintaining flow attachment over the blade at high angles of attack (preventing aerodynamic stall) thereby increasing energy extraction.
2. Reduce loads at high wind speeds and during wind gusts. Gusts can result in a sudden increase in the effective angle of attack of the blade, which can yield high unsteady loads on the blade leading to structural failures. The quick response and distributed nature of the synthetic jets along the blade span has the ability to shed excess wind loads off the blade.
3. Reduce vibration in the turbine blades by selectively increasing or decreasing aerodynamic loads along the blade span. The reduction of vibrations is an enabling technology that promotes the development of longer blades needed to develop more efficient turbines.

The following figure represents the wind turbine model tested in a closed return wind tunnel at RPI having a 15 inch wing span, 6 inch root cord, and a taper ratio of 0.5 (tip chord divided by root chord). A combination of instrumentation including a 6-component load cell, strain gauges, pressure scanner, and particle image velocimetry (PIV) were used to acquire the various data.

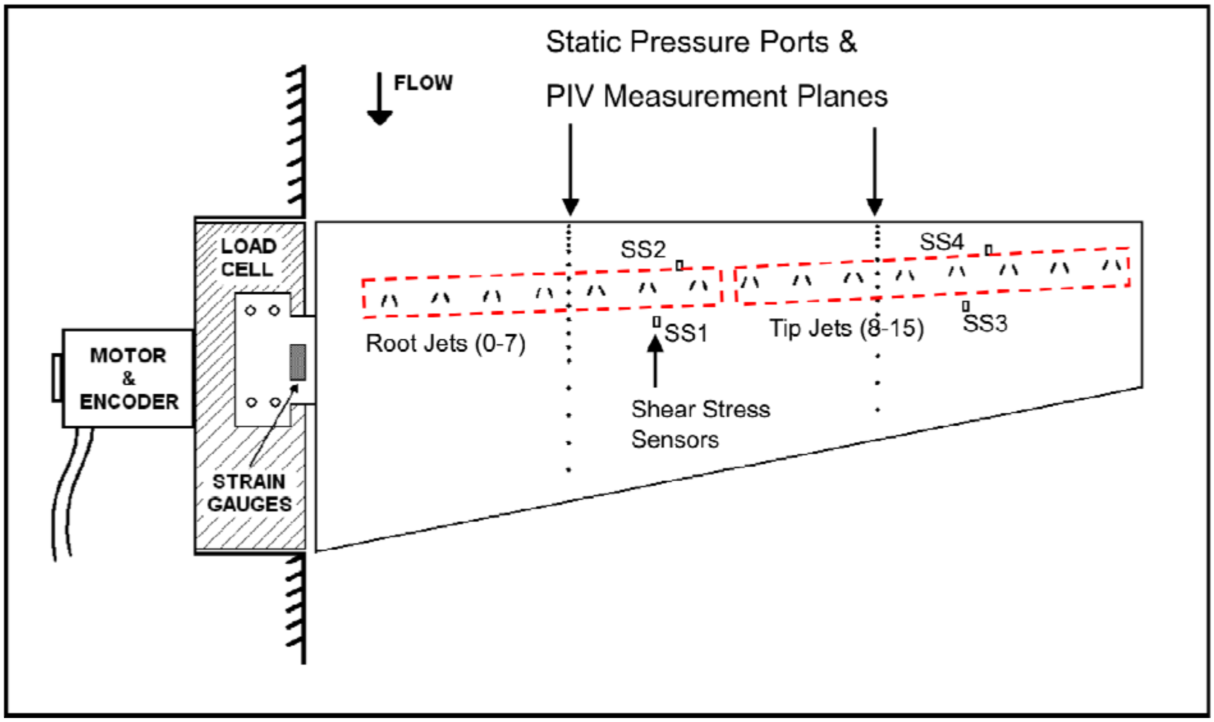

Figure 1. Wind turbine model schematic

Figure 2 includes plots of the lift and pressure distribution for the baseline case (with no synthetic jet actuation) black line and various synthetic actuation waveforms whereby the stall angle of attack is delayed by 2 degrees and the maximum lift coefficient is increased by 12%. This suggests that improved energy capture is possible at high angles of attack (above 15 degs).

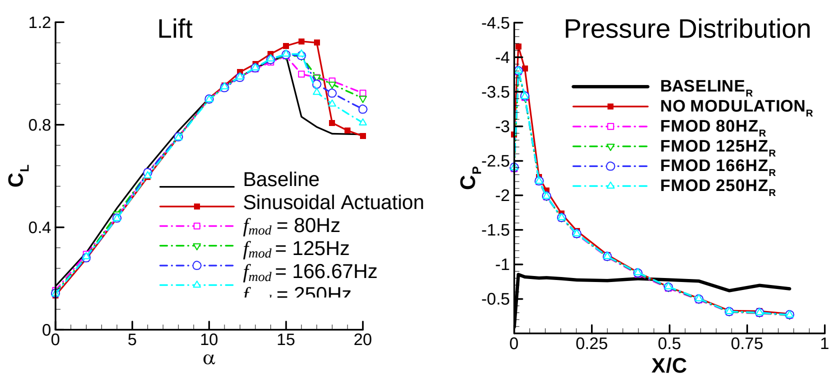

Figure 2: Lift and Pressure Distribution

Figure 3 represents the tip deflection of the wind turbine blade measured by a strain gauge mounted at the root of the model. The baseline case is again given in black where the maximum amplitude of vibration is shown to be about ~1mm. Using sinusoidal actuation, the amplitude is reduced by about an order of magnitude (ten times). However, using pulse modulation waveforms, the effect is reversed where actuation actually increases the amplitude of vibrations for a pulse modulation of 166.67Hz. The last part of the figure represents the power spectral density (PSD) of the associated frequencies of the blade model under operation. The largest frequency peak occurs at 21 Hz, which is the natural frequency of the wind turbine. Other frequencies such as the shedding frequency of the flow from the model and the modulation frequencies are also captured. Of importance to note is that the peak power associated with the amplitudes at 21Hz is reduced by two orders of magnitude (100 times) when actuating the synthetic jets with sinusoidal actuation.

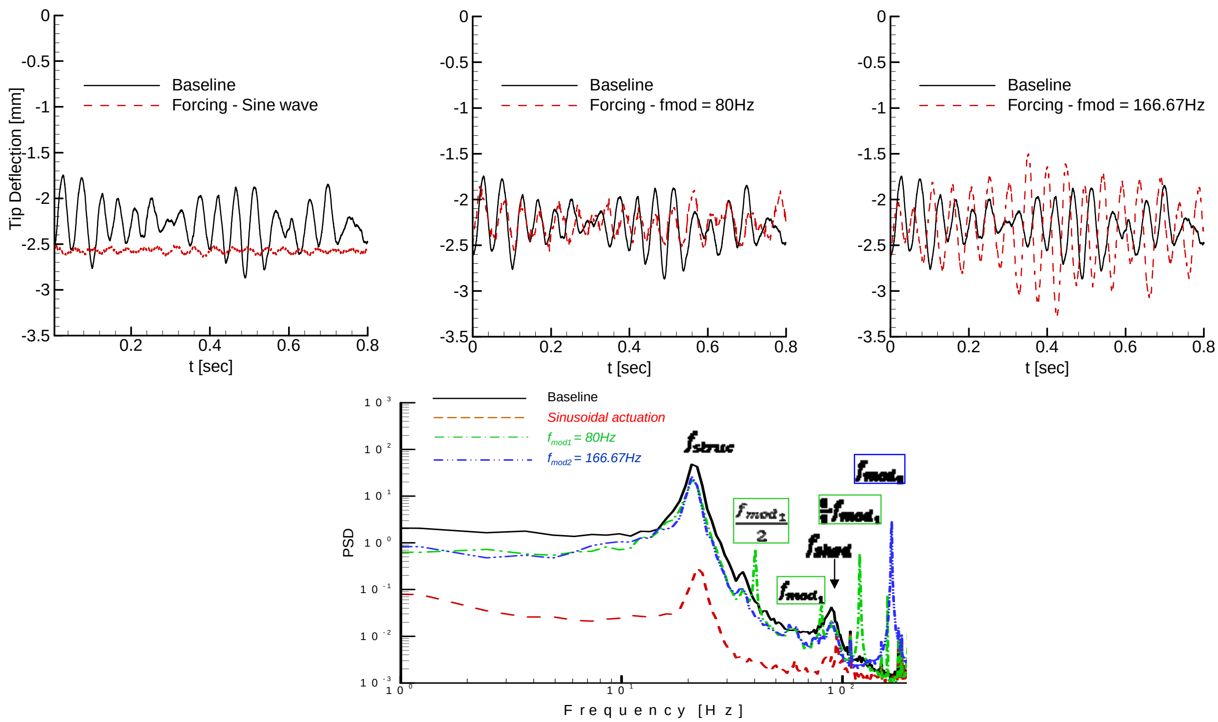

Figure 3: Tip Deflection and PSD