Analysis of the Cycle-to-Cycle Behavior of Dynamic Stall on Thick Airfoils

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Abstract
Dynamic stall remains a challenging phenomenon in rotating blade aerodynamics. While many studies use phase-averaged analysis to examine measurements, certain conditions appear to exhibit data concentrated around two states (bifurcation), rendering averaged results misleading. This work examines dynamic stall data on a cycle-to-cycle basis in order to better characterize the description of the phenomena important for deeper understanding and for validation of models.

Keywords: Dynamic Stall, Validation, Unsteady Flow

Introduction:

A significant aerodynamic challenge present in wind energy generation is dynamic stall, which is an unsteady flow phenomenon experienced by airfoils that results from turbulence in the atmosphere, the profile of the atmospheric boundary layer, and the orientation of the turbine rotor, among other sources. Understanding this phenomenon is important, as improved comprehension will lead to better blade designs and improved turbine performance. In past decades, many studies have been conducted with the ultimate intent of developing a predictive model of aerodynamic forces and moments observed in dynamic stall [1, 2, 3]. Often, this work involves the fabrication of one or more blades from a specific airfoil family (eg. NACA, DU) that are dynamically pitched in a wind tunnel to produce conditions relevant to wind turbine blades. In most cases, unsteady pressure data are taken during dynamic testing and are analyzed using phase-averaging. This technique collapses the data to simplify its consideration, but some information is lost in this process. For instance, when observing the averaged pressure data, there is often a large amount of scatter throughout the downstroke of each pitch cycle. In certain cases, the data seems to suggest that the flow takes on separate states (i.e. it bifurcates). The objective of this work is to characterize these bifurcations and suggest new means of analyzing such data to address such cases. For example, are there instances where the flow preferentially follows one of multiple paths during reattachment? If this occurrence can be adequately described, then improved validation of dynamic stall simulations will be possible. To address these issues, data previously collected at the University of Wyoming are reexamined from a cycle-to-cycle perspective.

Experimental Setup:

The data used in this study [3, 4] were acquired in a low speed, open return wind tunnel with a $0.61 \times 0.61 \times 1.22m$ test section that is capable of operating at speeds up to $50m/s$. Dynamic pitching of the airfoils was performed using a four-bar linkage powered by a 24VDC motor that rotated the airfoil about its quarter chord. Angle of attack mean and amplitude could be varied with this device. Pitch control was achieved using PID control, which used two incremental encoders for feedback. The dynamic pitching system allowed for accurate airfoil oscillations as high as $20Hz$.

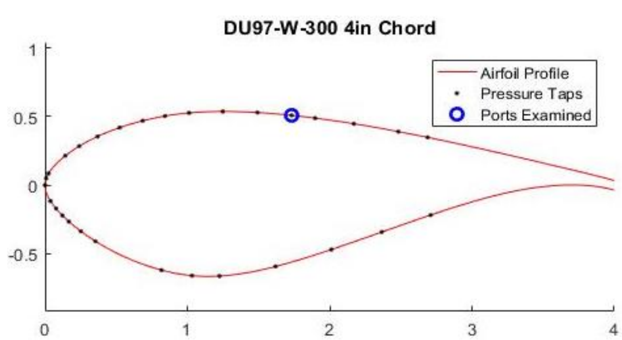

Figure 1: DU97-W-300 Wind Turbine airfoil geometry. Pressure Tap locations are listed as black points, and the blue circle pinpoints the port examined in the results section.

Though most of the airfoil studies considered here measured unsteady pressure and the flow field, this work will only consider the former in its analysis. Each airfoil that was fabricated for dynamic testing was outfitted with an array of pressure ports spanning the suction and pressure surfaces of the airfoil. These taps were routed to tubing that were connected to two Electronically Scanning Pressure (ESP) transducers that sampled the pressures.

The tests used here considered a variety of airfoils used in rotating applications. Among these are wind turbine airfoils from the DU97 and NACA series, on which this study will be conducted. As an example of the bifurcation phenomenon described above, data from a $101.6mm$ chord model of the DU97-W-300 are used. Figure 1 presents the airfoil geometry for this model and shows the pressure port from which the data was collected for the proceeding images.

Results:

During the testing of each airfoil, pressure information for hundreds of cycles was collected for analysis. Figure 2(a) shows all pressure data recorded during a single test for the single port shown in Figure 1 with its respective pitch position. For reference, the phase-averaged line has been included. Clearly, the pressure exhibits low scatter until approximately α=24° on the upstroke where the onset of dynamic stall is observed as indicated by the pressure plateau. Here, the scatter of pressure increases dramatically as would be expected of a stalled flow. However, at roughly 24° on the downstroke, the flow appears to diverge into two distinct modes of reattachment. With all points plotted, it is difficult to discern how the flow actually behaves from this point on. Hence, Figure 2(b) shows eight randomly chosen pitch cycles in addition to the phase-averaged line. It is evident that a large portion of the cycles reattach early in the downstroke while the rest remain separated until the end of the pitch cycle.

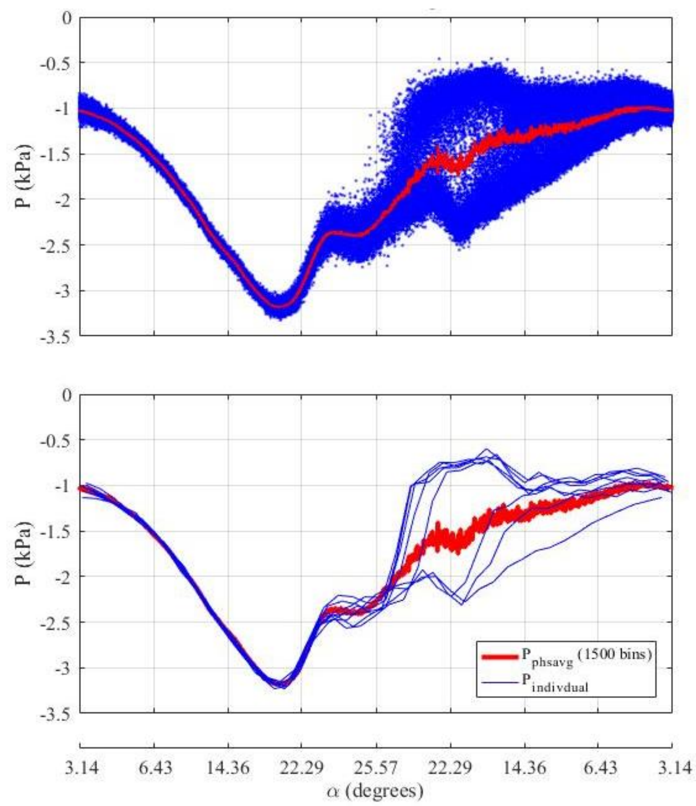

Figure 2: for the DU97-W-300 airfoil, 14° ± 10°, x/c = 0.4332 (top): (a) All pressure data with Phase Averaged data for reference. (b) Averaged data compared with data from eight arbitrary pitch cycles.

Conclusion:

The existence of cycle-to-cycle variations has an impact on our understanding of dynamic stall. Clearly, better descriptions of this process are necessary for both characterizing these flows as well as using the experimental results for model validation. Identifying the extent of conditions for different airfoils under which such two-state solutions exist remains to be completed. In addition, means of identifying and describing these bifurcations are needed.

References

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