Development of a Low-Speed Oscillatory-Flow Wind Tunnel

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Aircraft are often exposed to flows in which the angle-of-attack and relative flow speed change simultaneously. Common examples are fixed and rotary wing aircraft undergoing rapid maneuvers, where the resulting changes can produce dynamic stall. Similar scenarios are also observed on wind turbine blades. The global objective of this work is the design of a low speed wind tunnel, for the express purpose of generating unsteady flow simultaneously with variations in angle-of-attack. To achieve this, a blow-down wind tunnel was built with a test section designed to produce dynamic pitching of an aerodynamic body, while simultaneously allowing full access for optical measurement techniques, see Figure 1(a). This abstract describes details of a louver mechanism used to produce oscillatory flow in the tunnel. Preliminary experiments have been performed under quasi-steady and dynamic conditions. The final version of this paper will present the full dynamic characterization of the tunnel together with simultaneous dynamic airfoil pitching.

The louver mechanism, equipped with 13 counter rotating vanes, was attached to the exit of the tunnel. Each vane had a chord length of 70mm and spanned the entire length of the test section width, as can be seen in Figure 1(b). The vanes could be adjusted between fully-open and fully-closed states in order to vary the tunnel wind speed. Furthermore, individual vanes could be removed allowing operation between fully-open and partially closed states. A 750 Watt servomotor, with a 5:1 gear ratio, coupled with a PLC controller, was used to drive the louver vanes dynamically thus creating different temporal velocity profiles within the test section located upstream.

Figure 1. The test setup: (a) the test section; (b) the louver mechanism and servo-motor drive
A set of quasi-steady experiments were conducted, where the angular position of the vanes was varied between 0° and 90°, see Figure 2. In addition, the blower’s angular velocity was also varied between 300 and 500 rpm, see Figure 3. For each blower angular velocity, dynamic and static pressure measurements were made as a function of the vanes’ angular position. In addition, the velocity was revalidated at several different points. The data show that the louver vanes produce a near-sinusoidal forcing of the tunnel flow velocity.

Figure 2. Velocity variation vs. vanes’ angle of attack. Left: blower at 300rpm; right: blower at different rotational speeds.

Following quasi-static testing, the louver vanes were driven dynamically at frequencies \( f = \frac{\omega}{2\pi} \) between 0.25Hz and 4Hz. The data for the velocity amplitude ratio and phase-lag are shown in Figure 3. Also shown is the solution to a heuristic first order model of the system, namely:

\[ \tau \dot{U}_\infty + U_\infty = U_{\infty,\text{max}} \sin \omega t \]

The comparison shows that the response of the tunnel can be adequately modeled by means of a first order system, with a time constant \( \tau=237 \text{msec} \).

Figure 3. Frequency Response comparison of experimental data with a first-order model.