

Dynamic lift measurements on a FX79W151A airfoil via pressure distribution on the wind tunnel walls

Gerrit Wolken-Möhlmann¹, Pascal Knebel¹, Stephan Barth² and Joachim Peinke¹

¹ForWind - Center for Wind Energy Research, University of Oldenburg, Germany

²ECN Wind Energy, Energy research Centre of the Netherlands

E-mail: gerrit.wolken-moehlmann@forwind.de

Abstract. We report on an experimental setup for measurements of dynamic stall for airfoils via the pressure distribution over wind tunnel walls. This measuring technique, hitherto used for lift measurements under static conditions, is also an adequate method for dynamic conditions until stall occurs. A step motor is used, allowing for sinusoidal as well as non-sinusoidal and stochastic pitching to simulate fast fluctuating flow conditions. Measurements with sinusoidal pitching and constant angular velocities were done and show dynamic stall characteristics. Under dynamic stall conditions, maximum lift coefficients were up to 80% higher than the maximum for static lift.

1. Introduction

Blades are fundamental parts of wind turbines, so it is important to understand their aerodynamics in detail. Particularly, the dynamic stall is of interest.

In steady flows under static angles of attack ($\dot{\alpha} = 0$), airfoils are commonly described by the lift and drag coefficients $c_l(\alpha)$ and $c_d(\alpha)$, respectively. Starting from the neutral angle $\alpha = 0$ and increasing, c_l increases until the airfoil starts to stall, where separation at the suction side of the airfoil occurs. This becomes apparent by a distinct fall of the lift force.

Dynamic stall, also observed in helicopter technique, is a phenomena that appears during a fast change in the angle of attack of airfoils. In contrast to static lift values, there is an overshoot in lift due to stall delay and leading edge vortices, cf. [1].

For wind turbine blades, changes in the angle of attack can be generated by atmospheric turbulence, fast pitching of the blades, vibrations of the blades, or yaw between the wind turbine and the wind direction. Dynamic loads are the consequences and must be taken into account during design process in order to reach the destined lifetime for wind turbines of about 20 years. This points out the need of a better understanding.

For modelling dynamic stall, helicopter aerodynamics models are often used and modified for thick wind turbine blades [2]. However, this is often only verified by older sets of data and for a few different foils [3]. Other experimental dynamic stall research points to helicopter aerodynamics and is not necessarily comparable to wind turbine foils [4].

Here we present a new experimental setup for the investigation of the dynamic stall by measuring the pressure distribution over the wind tunnel walls. In particular we study the transition to stall onset and the maximum lift coefficient as a function of the angular velocity.

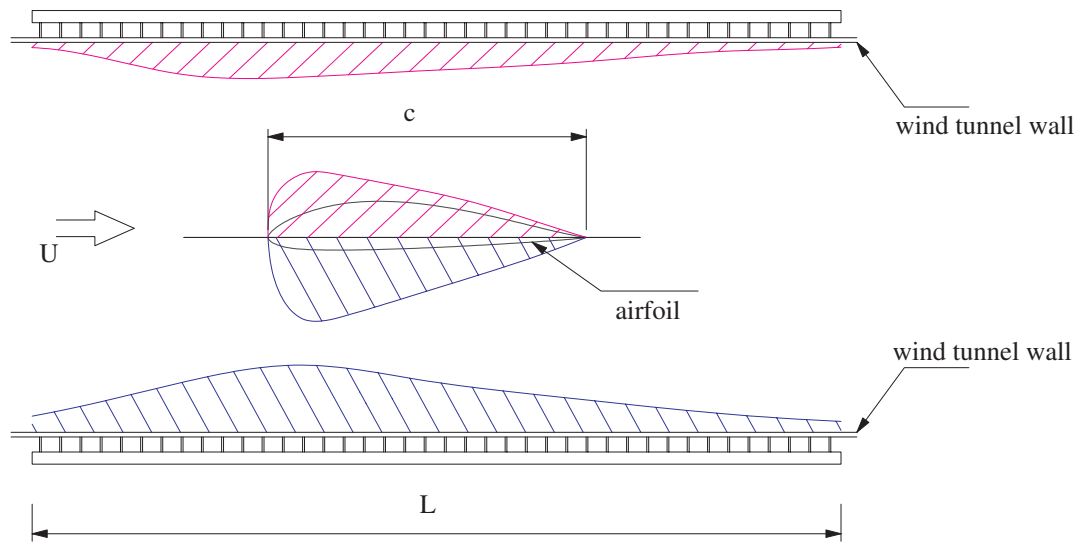


Figure 1. Sketch of the pressure distribution over the foil and the windtunnel walls.

2. Experimental setup

The classical way of measuring lift and drag is by determining the acting forces via balances. A more convenient method often used for dynamic stall research measures the pressure distribution over the foil by pressure tabs. Here, there is difficulty with preparing the foil with an adequate number of sensors.

Another method of measuring the lift and drag forces acting on a aerofoil requires measuring the counterforce acting on areas around the foil, e. g. the wind tunnel walls for lift (figure 1) or a rake behind the foil for drag measurements. This method was proposed and verified for static measurements by Althaus [5]. Due to the non-infinite length of the windtunnel walls, a correction has to be applied (for further details see [6]).

The lift coefficient c_l is given by

$$c_l = \frac{(p_p - p_s)}{q} \cdot \frac{L}{c} \cdot \frac{1}{\eta}, \quad (1)$$

where p_p and p_s are the overall pressures on the pressure and suction side of the foil, respectively, q is the dynamic pressure of the flow, L is the length of the active windtunnel walls, c the chordlength and η the so called “Althaus-Faktor” for non-infinite walls. In our case, a value of 0.94 for η is suitable for the angular range used (compare figure 3).

The method of using a rake in the wake can be used for drag measurements under steady conditions. Due to strong spatial movements of the wake and strong turbulences and vortex shedding under dynamic conditions, this method seems not to be appropriate for measuring the drag coefficient c_d during dynamic stall experiments.

The experiments are carried out in the wind tunnel of the University of Oldenburg. It is a closed-loop wind tunnel with a nozzle of 1,0m x 0,8m and an open test section of 1.8m in length. The maximum wind speed is 50m/s, which limits the Reynolds number to $Re = 700000$ for an airfoil with a chordlength of $c = 0.2m$. The turbulence intensity is under $I_t = 0.3\%$ [7].

For lift and (static) drag measurements, a closed test section was constructed. Both walls of the test section contain 40 pressure sensors along the center line (figure 2). The distance

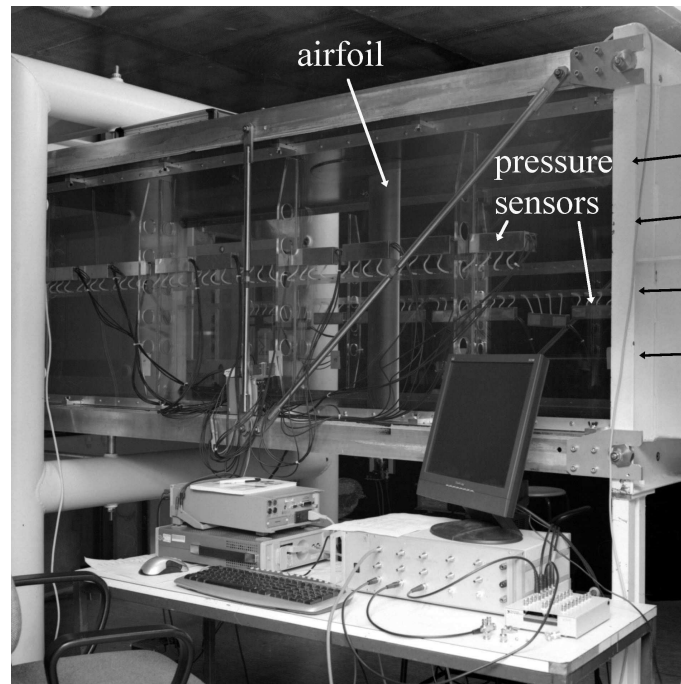


Figure 2. Closed test section with mounted airfoil. Pressure sensors can be seen on the center line of both wind tunnel walls.

between two sensors is 5cm , beginning 0.7m upstream of the $1/4$ point of the foil. Each of the 80 signals are acquired individually by an A/D converter and are calibrated and integrated by a software. This is necessary to compensate for the time delay from the pressure field traveling from the foil to the sensors at different distances with sonic speed. Wind velocity is investigated via the pressure difference between the settling area and the test section.

The blade element (FX79W151A with a thickness of 15.2%) is mounted vertically between plates in the upper and lower part of the closed test section. For weight reduction, the plates and the airfoil are constructed from aluminium. A step motor is installed on the upper side, and an angular transmitter detecting changes in the angle of attack α with an accuracy of $1/10^\circ$ is attached to the lower side. Like previous measurements in dynamic stall research (e.g. [3]), we started with sinusoidal oscillations of the airfoil with different values for mean angle $\bar{\alpha}$, amplitude A , and reduced frequency k . Angular velocities above $350^\circ/\text{s}$ were reached.

To quantify the quality of our setup, we have repeated static lift force measurements for different Reynolds numbers. The static measurements reported in [8] could be reproduced as shown in figure 3. A slightly higher maximum c_l may be explained by the surface quality of the airfoil.

3. Experimental results

In comparison to static lift curves, the c_l curves for dynamic stall show the typical overshoot of c_l until a maximum lift coefficient $c_{l,max}$ is reached. Then the lift decreases during the full stall period and the period of $\dot{\alpha} < 0$. In contrast to other experimental results, the c_l for decreasing angle of attacks in the range of $\alpha < 5^\circ$ is below the value for increasing angles, which may point to delay problems whose origin is not identified yet.

As can be seen in figure 4, there are further local maxima of the lift force and a higher fluctuation for the c_l -curve in the dynamic stall region for higher reduced frequencies k and

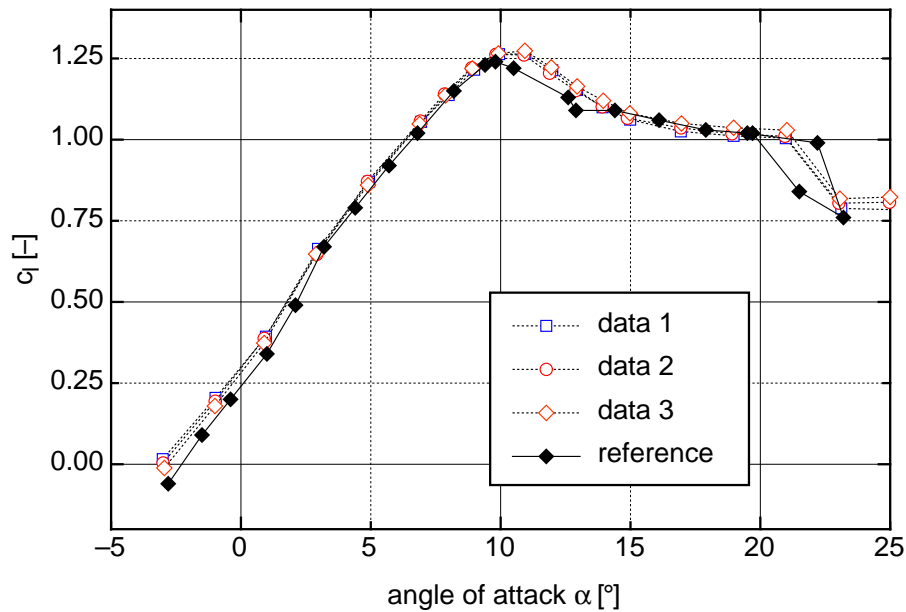


Figure 3. Lift force measurements performed with our setup in comparison with results reported in [8]. All measurements for $Re=600\ 000$.

amplitudes A . An explanation may be a vortex shedding, but it still must be studied whether these vortices directly contribute to the force acting on the foil.

The results show a distinct correlation between the maximum lift coefficient $c_{l,max}$ and the parameters $\bar{\alpha}$, A , and k . In particular, the angular velocity around the maximum lift coefficient ($\dot{\alpha}_{c_{l,max}}$), which is affected by these parameters, is of importance. The point of separation needs a certain amount of time to travel from the trailing edge to the leading edge for a full stall.

Lift-curves for measurements with various constant $\dot{\alpha} > 0$ can be seen in figure 5. The angular velocity $\dot{\alpha}$ varies from $156^\circ/s$ to $250^\circ/s$. In figure 6, $c_{l,max}$ vs. the angular velocity $\dot{\alpha}$ is plotted. From our results we see a clear increase in the maximum lift as angular velocity increases. For a first characterisation, we have used an exponential fit to the data and obtained

$$c_{l,max} = 1.22 + 0.025 \cdot \exp\left(\frac{\dot{\alpha}}{67}\right) \quad (2)$$

The results, however, do not allow us to predict the development of $c_{l,max}$ yet. An exponential fit was done, but also more complex coherences could be possible. The complexities could arise from stall delay and leading edge vortices being two different causes for dynamic stall.

Beside the maximum lift coefficient, it should be noted that the additional local maxima are not present in the static measurements. For strong wind velocity fluctuations on short time scales and thus for fast changes in the angle of attack for wind turbine blades, such secondary maxima may cause additional shaking forces. In [9, 10] it has been reported that for different wind fields there is typically a large probability of such large short time wind fluctuations.

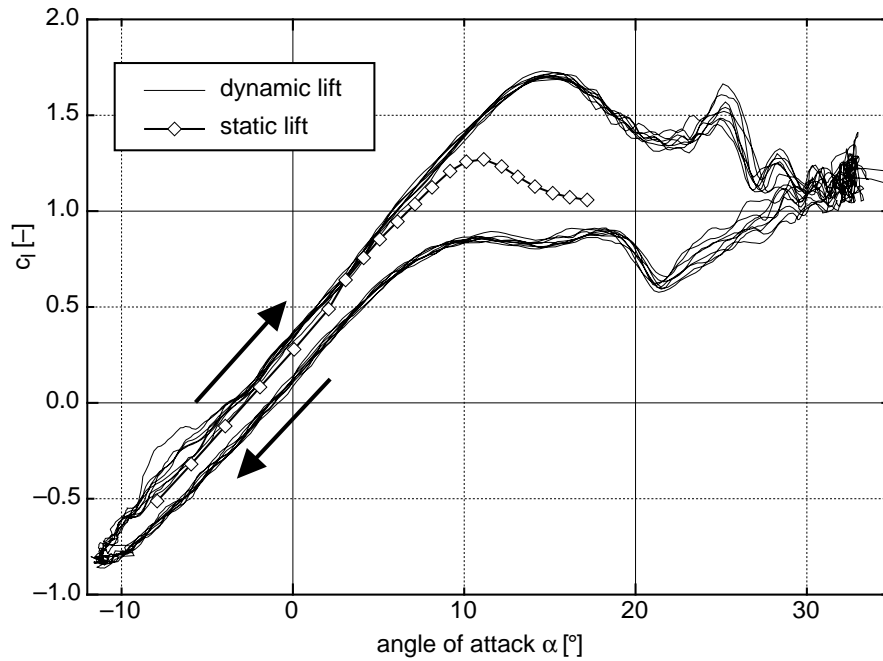


Figure 4. Plot of static and dynamic measurements of lift for $Re=600\,000$, $\bar{\alpha} = 10.5^\circ$, $A = 22^\circ$ and $k = 0.03$. The angular speed at the maximum lift is about $\dot{\alpha} \approx 320^\circ/s$.

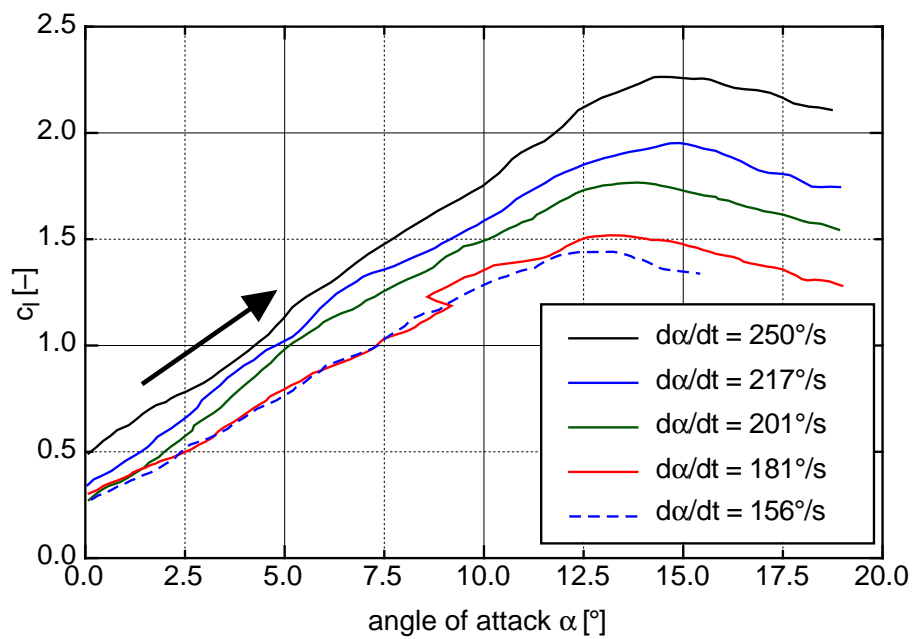


Figure 5. Measurements of the dynamic lift force for different angular speeds ($Re=600\,000$). The Results were averaged over 10 measurements.

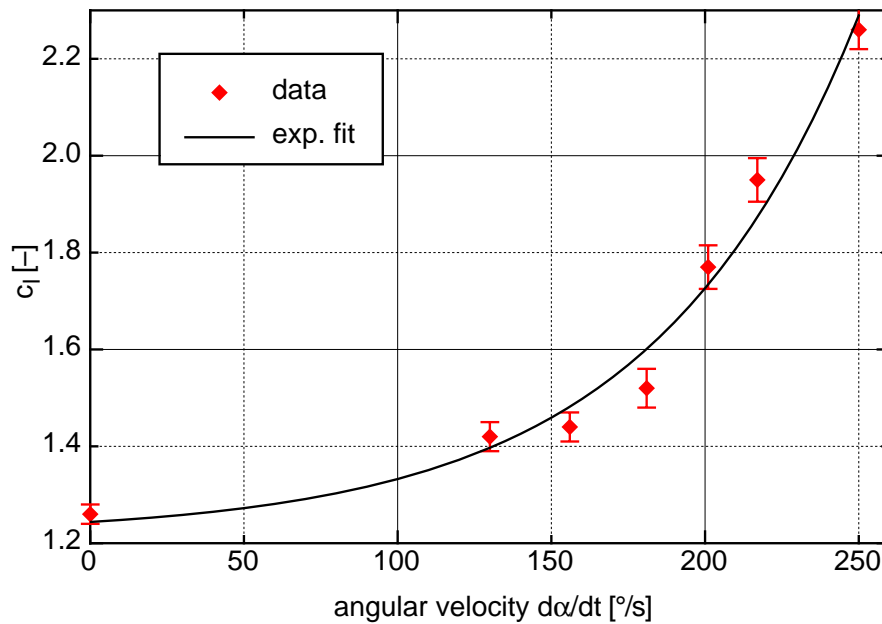


Figure 6. Maximum values of the dynamic lift force as a function of the angular velocity $\dot{\alpha}$.

4. Conclusions

It has been shown that measurements of the pressure distribution over wind tunnel walls is an appropriate instrument for measuring the maximum lift under dynamic conditions until the onset of stall is reached. As a first result, the maximum lift coefficient $c_{l,max}$ increases with higher angular velocities as expected. So far, the highest observed c_l is 80% larger than the static maximum of c_l .

In contrast to measurements with pressure sensors implemented in the foil, our setup enables the easy possibility of dynamic stall tests with different airfoils. Due to the use of a step motor for turning the airfoil, defined non-sinusoidal oscillations can be achieved. In further experiments, the foil shall be pitched corresponding to realistic changes in the angle of attack extracted from wind field measurements and the help of BEM.

Acknowledgments

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