Mitteilung

Fachgruppe: Wind Energy

Wall Pressure of Separated Flows: Flat Plate and Airfoil

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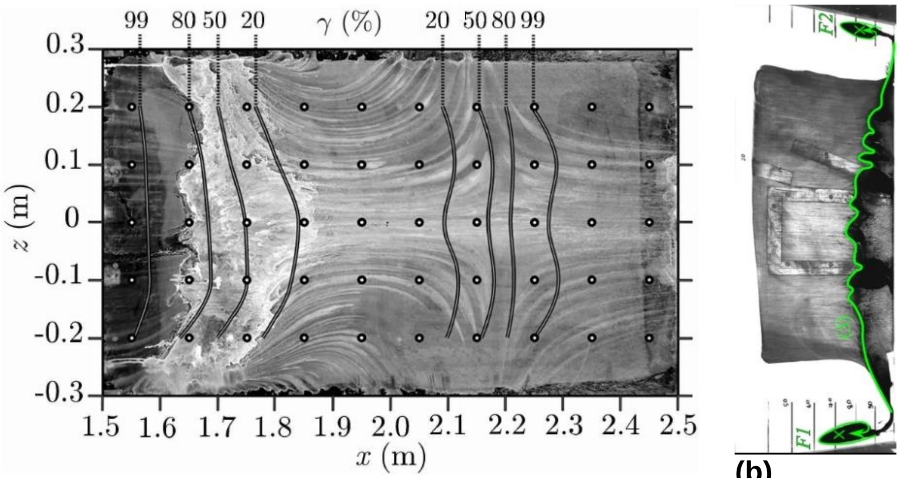
When almost a third of the electricity produced in Germany already comes from wind energy, and with the target of 2030 to develop it into a leading contributor in the energy mix (More & Murray, 2023), development of a larger capacity productions using wind power is a priority. Facing on-site environmental conditions, it is necessary to improve the performance and reliability of wind turbines from the design-chain standpoint and the operational standpoint with the use of on-board sensors and AI-lead real time monitoring.

One of the environmental conditions is the proximity of wind parks near residential areas need to comply with the noise regulations. With poor design and imprecise monitoring, the flow may separate from the blade's surface, reducing the wind turbine's efficiency and amplifying its noise emission. Therefore, tracking flow separation on wind turbine blades is thus essential not only aerodynamically but also acoustically. The first step in tracking flow separation is to better understand the physics of separated flows and the mechanisms driving the wall-pressure fluctuations beneath a separating turbulent boundary layer. In this study we aim to derive the flow separation topology from wall-pressure measurements. One of the reasons behind this is practicability. Wall pressure sensors are easily mountable on a wind turbine blade and are relatively nonobstructive to the boundary layer.

Two databases are available for the present study. (1) The velocity field of a family of turbulent separation bubbles was recently measured using 2D-2C PIV in the boundary layer wind tunnel of ÉTS Montréal-University of Québec (Le Floc'h, 2021). Three distinct turbulent separation bubbles were investigated at $Re_\theta = 5000$: (a) Large with a 41 cm long recirculation region, (b) Medium, 11 cm long, and (c) Small with no backflow. (2) In investigating flow separation noise, the wall pressure of the DU96-W-180 was measured at the Acoustic Wind tunnel Braunschweig (AWB) at DLR-Braunschweig (Suryadi & Herr, 2015). The airfoil's angle of attack was set up to 14.7°, where massive flow separation has happened but the airfoils is still below the stall angle. Assuming the same phenomena can take place either near the trailing edge of an airfoil at high angle of attack or on a flat plate due to the presence of an adverse pressure gradient, then the same flow physics will produce the same results for both configurations. This paper investigates the relevant similarities of flow separation between the flat plate and the airfoil at high angle of attack.

Figure 1 depicts the two oil films for the Large TSB and the airfoil at an angle of attack of 12 degrees. The skewness of wall-pressure distributions associated with the oil films in Figure 1 are presented in Figure 2. Skewness is typically a measure of asymmetry of a probability density function. The skewness presented in Figure 2 is a measure of the length of each density function *tail*. Namely, the more predominant pressure sign will have a longer tail, which results in a larger skewness magnitude. Interestingly, the two skewness distributions indicate the same pattern near the separation region (highlighted region in Figure 2): a predominantly positive wall pressure fluctuation is subsequently followed by a negative one. Skewness was utilized in a study of flow separation of a linear compressor cascade, which links positive pressure fluctuations to separation onset (Zambonini & Ottavy, 2015). They also illustrated the fact that the low frequency dominates precisely in the upstream portion of the separated region (Le Floc'h, 2021).

In the final paper, a detailed review of the skewness of pressure and velocity in the family of TSBs will be provided, and analogies between flat plate and airfoil should be drawn with respect to the airfoil incidence and the associated amount of predicted backflow. Such results will be valuable for the noise modeling of separated flows on the DLR wind turbine project.



(a) (b)

Figure 1(a) Oil film visualization on a flat plate, flow goes from left to right. Iso-lines of γ(%), the forward flow fraction (Simpson, Chew, & Shivaprasad, 1981), are superimposed; (b) on a DU96-W-180 airfoil, flow goes from left to right. Separation line is highlighted in green.

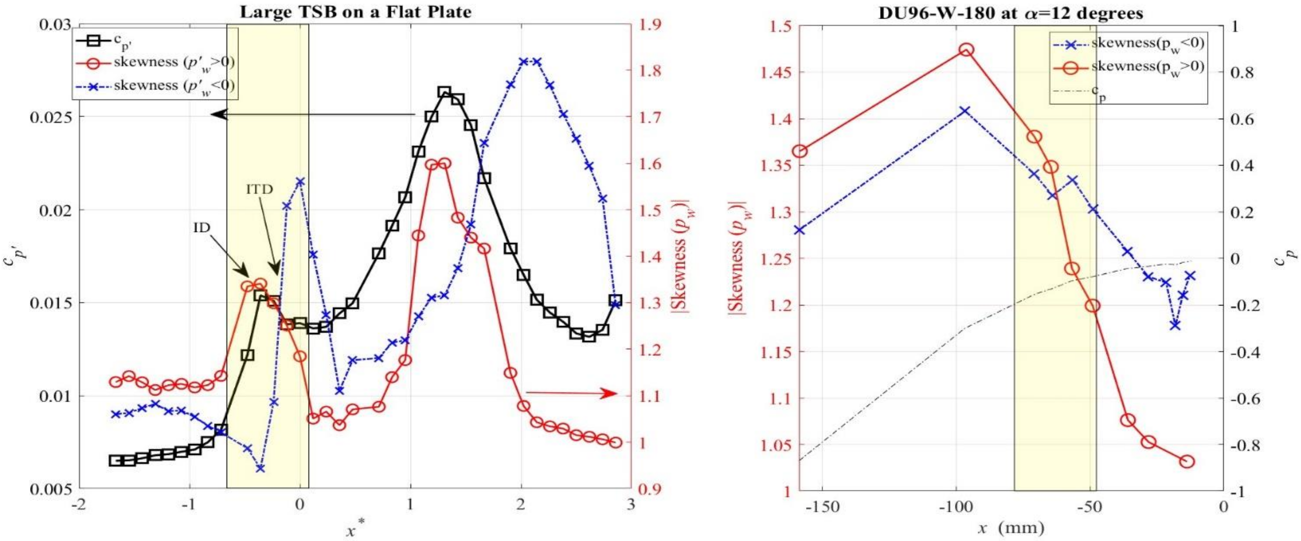


Figure 2 Comparison of wall-pressure skewness between the flat plate and trailing edge separations shown in Figure 1. The onset of separation is identified by the fluctuating pressure coefficient C_{p}, for the flat plate and by the mean pressure coefficient c_p for the DU96-W-180

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