Quantitative rotorblade surface condition measurement by means of thermographic flow visualization

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1. Introduction

The leading edge condition (*LEC*) of rotorblades has a direct effect on the boundary layer flow and, thus, affects performance and acoustic emissions. Leading edge surface attributes such as the original surface roughness and erosion level, and the surface contamination affect the *LEC*, and can trigger an early laminar-turbulent transition [1]. Although *LEC* is known to have a significant effect on the wind turbine performance [2], an automated quantification of the *LEC* is missing.

To determine the rotorblade surface condition, a semi-automated contactless measurement method is developed, which is based on the thermographic localization of the laminar-turbulent transition [3,4]. After an optical distortion correction and transforming the data to the local geometry of the rotorblade, chord-based *LEC* is calculated for individual rotorblade sections. The method is demonstrated on a GE1.5 sl wind turbine with 1.5 MW rated power.

2. Objectives

Thermographic flow visualization measurements → Quantitative boundary layer information → **Leading edge condition level (LEC)** → Performance change due to surface condition

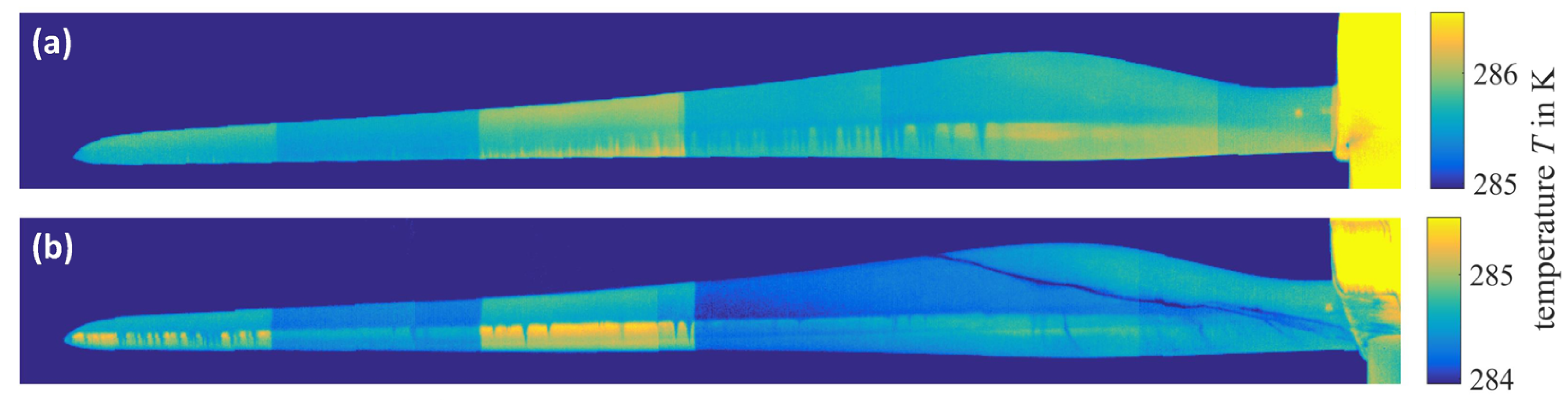

Figure 1. Comparison of thermographic flow visualization measurements on the suction side of a rotorblade on a 1.5 MW wind turbine in operation with a rotor radius of 38.5 m. Surface condition **(a)** before a heavy rain and **(b)** after the heavy rain has removed most of the contamination.

3. Methods

Thermographic images of rotor blades in operation are acquired by a high-speed, actively cooled thermographic imaging system, which is triggered optically at each blade pass. Integration times below 1600 µs in combination with a tele-photo lens permit acquiring nearly blur-free images.

Automated evaluation of the temperature gradient at each radial position. Maximum in temperature gradient as a measure for the transition position [5,6]

↓

Actual transition position $p_{tr,act}$ with subpixel accuracy [3] → Weighted linear least squares solver for $p_{tr,act}$ → Natural transition position $p_{tr,nat}$

↓

Transformation of the transition positions to the known geometry of individual blade sections r_i, $i = 1,\dots,5$ (Fig. 2)

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Comparison of actual and natural transition position and calculation of a leading edge condition: $LEC = 1 - \frac{p_{tr,act}}{p_{tr,nat}}$

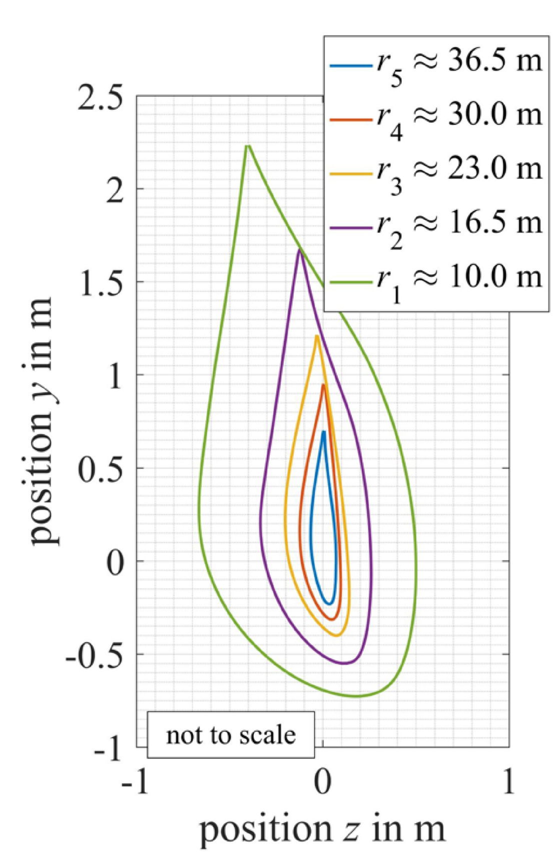

Figure 2. Individual blade sections of the rotorblade shown in figure 3 at the radial position r_i, $i = 1,\dots,5$.

4. Measurement results

An example for the results of the image processing and the transformation to the blade geometry are shown in Fig. 3 (a) and 3 (b), respectively.

A comparison of the actual and the natural transition location for all of the 5 known radial sections (±1.5 m) is shown in the thermographic measurement in Fig. 4 and the results are summarized in Tab. 1.

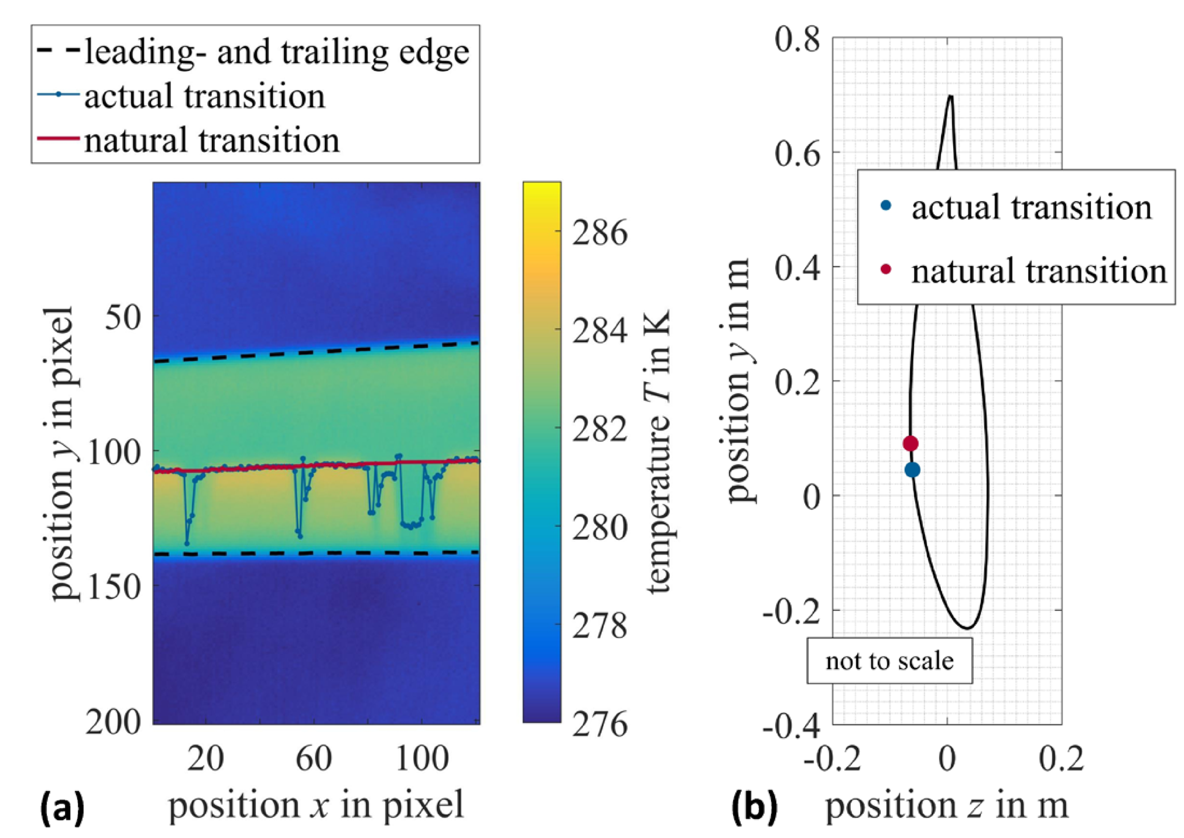

Figure 3. (a) Example for the results of the thermographic image processing for the localization of the actual and the natural transition and **(b)** the transformation of coordinates to the rotorblade geometry.

Table 1. Quantification of the leading edge condition at 5 positions with known blade geometry

Radial Position r	$r_1 \approx 10{,}0$ m	$r_2 \approx 16.5$ m	$r_3 \approx 23{,}0$ m	$r_4 \approx 30{,}0$ m	$r_5 \approx 36.5$ m
$p_{tr,act}$	0.338	0.356	0.378	0.386	0.457
$p_{tr,nat}$	0.345	0.356	0.391	0.406	0.453
LEC	**2 %**	**0 %**	**3,3 %**	**4,9 %**	**2,3 %**

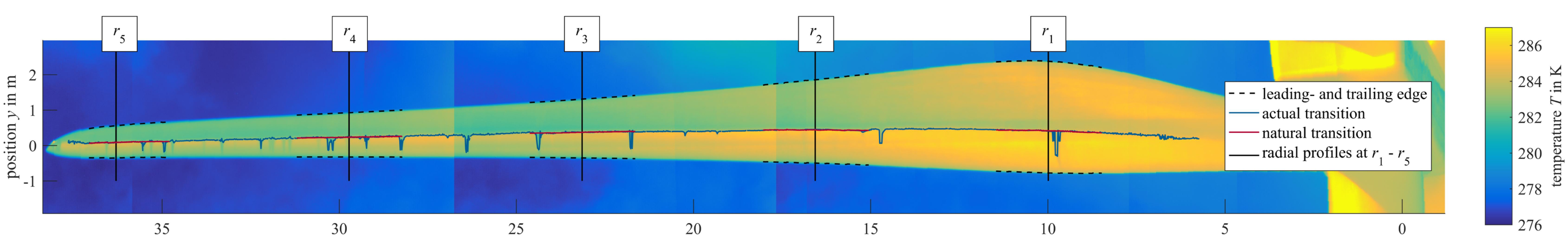

Figure 4. Surface condition measurements on the suction side of the rotorblade with a rotor radius of 38.5 m. The results at the five radial positions r_i, $i = 1,\dots,5$, are summarized in Tab.1.

5. Conclusions and Outlook

- The leading edge condition (*LEC*) of a rotorblade was determined using thermographic flow visualization measurements
- An image processing algorithm was developed, which measures the location and extent of affected regions
- Applications: validation of boundary layer models, operational angle of attack analysis, evaluation of blade erosion and roughness level, quality control of LEP (leading edge protection) application, etc.
- Future work: *LEC* subdivision in LEC_s (Surface) and LEC_c (Contamination)

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