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Thermographic boundary layer visualisation of wind turbine rotorblades in operation

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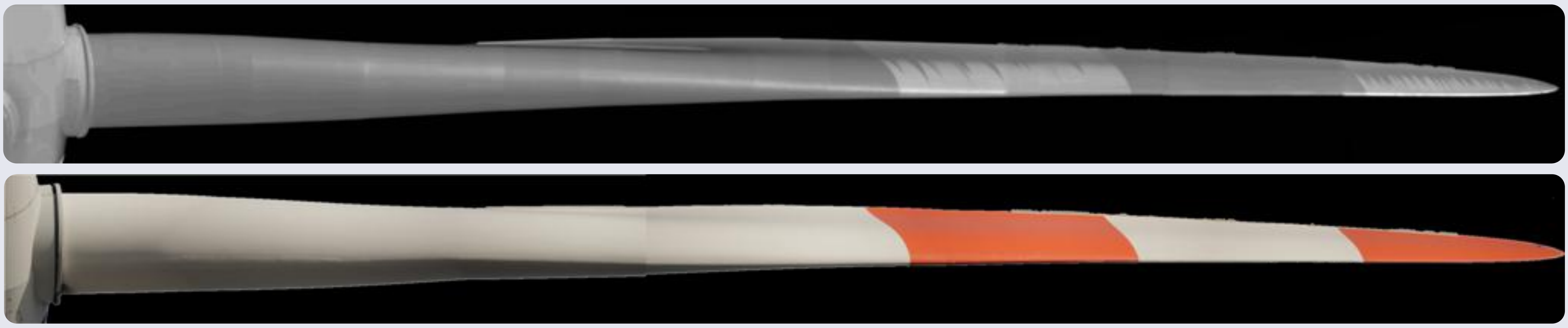

Fig. 1: Thermographic and optical image of the pressure side of a rotor blade

Fig. 2: Measuring setup

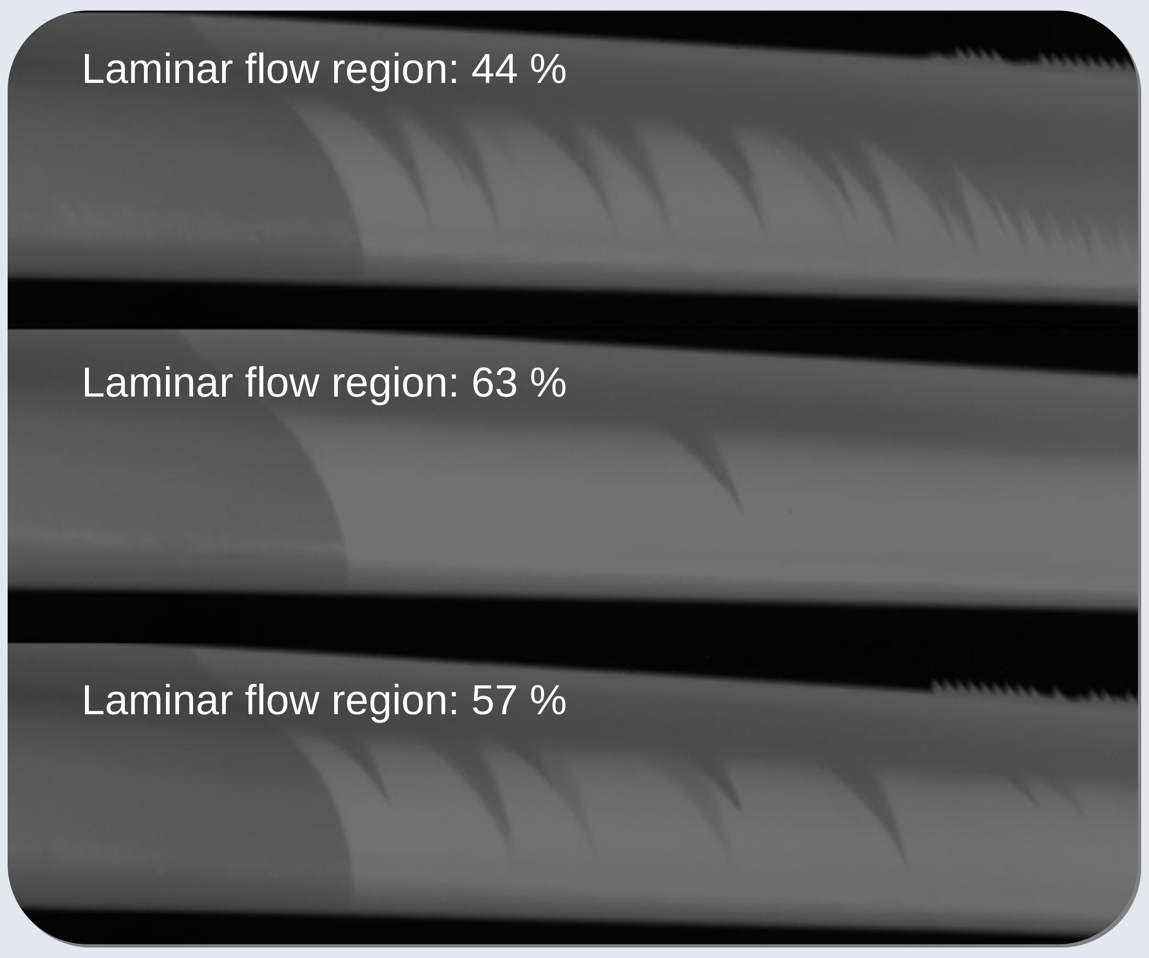

Fig. 3: Thermographic images of the middle section

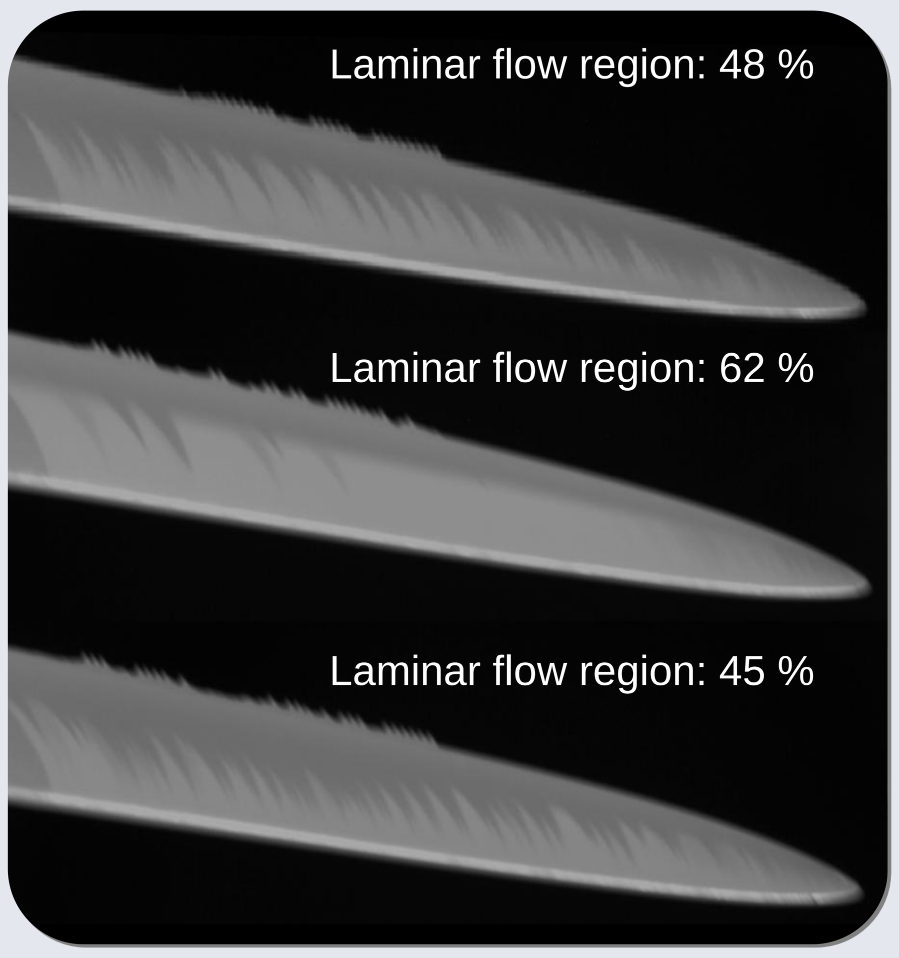

Fig. 4: Thermographic images of the tip section

Abstract

The location of the laminar-turbulent transition has a direct effect on the performance of an airfoil. Approximately 10 % more laminar flow region results in a 10 % lower drag-coefficient [1]. Thermography has been a valuable tool for boundary layer visualisation for several years in both wind tunnels and other applications [2]. The use of high-speed, high sensitivity thermal imaging systems in combination with long focal length lenses allows applying this method to megawatt range wind turbines in operation, in which the investigated rotorblade and the measurement position are several hundred meters apart (Fig. 2). Preliminary measurements deliver qualitative information regarding the transition location along the rotorblade, and allow comparisons between different operational states and conditions.

Methods

Boundary layer flow conditions affect the heat flux between the rotorblade surface and the surrounding air; hence a temperature difference between rotorblade and surrounding air is necessary to perform measurements [3]. In the case of wind turbines, best results are obtained when the sun is heating the rotorblade surface. Under these circumstances the temperature on the laminar flow region is higher than on the turbulent flow region, because turbulent flow enhances heat transfer. Measuring the temperature distribution permits detecting the boundary layer condition on the rotorblade indirectly. This method has been validated in wind tunnel tests using the same measuring equipment, on models with a similar surface material, as an accurate method to determine the laminar-turbulent transition location [4].

Tip speeds of 75 m/s require fast shutter speeds (short integration times) to reduce motion blur. A high speed actively cooled 640x512 pixels InSb-focal-plane-array with a thermal resolution better than 0.025 K is used together with a telephoto lens (Fig. 5) to acquire high resolution thermal images of rotorblades in operation.

Fig. 5: Thermographic imaging system with telephoto lens.

Results

The images presented allow the identification of the different flow regions on the rotorblade. Leading edge contamination and erosion can reduce the extent of the laminar region or make it disappear altogether. Turbulence wedges that begin at locations other than the leading edge region, are most probably imperfections or damages on the rotorblade surface, and should be investigated. The method permits the inspection of flow control add-ons and their effects on the boundary layer (Fig. 6 and Fig. 7).

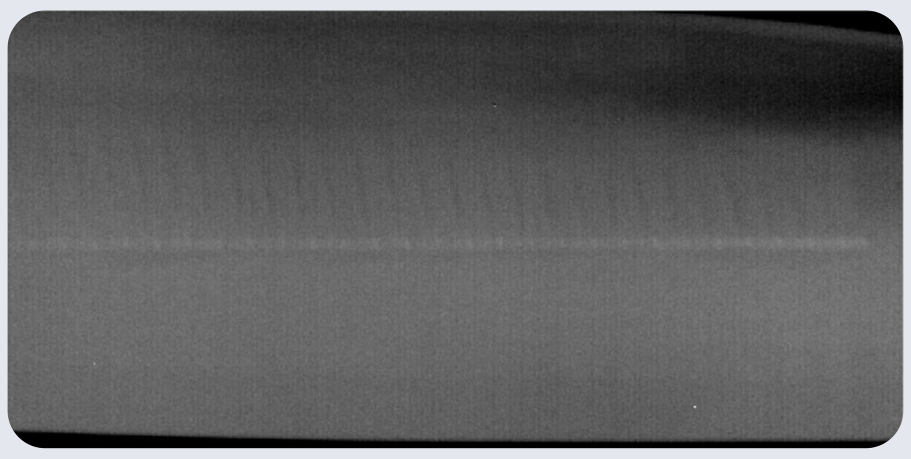

Fig. 6: Vortex generators

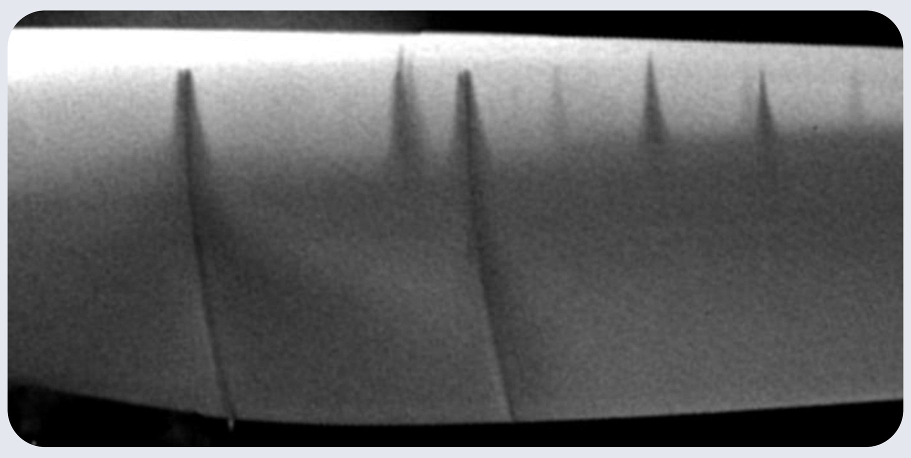

Fig. 7: Boundary layer fences (Different WEC)

Conclusions

Thermographic measurements were successfully performed on wind turbines in operation (Fig. 1, Fig. 3 and Fig. 4). The method, which requires no preparation of the rotorblades, permits verifying predictions and evaluating operational conditions, such as areas with an early laminar-turbulent transition due to leading edge contamination, erosion, manufacturing irregularities or the effects of leading edge protection on the transition location. The laminar regions can be additionally compared between blades and blade positions, in order to further analyse effects like wind shear and tower influence. Missing flow control add-ons, such as vortex generators or zig-zag tape sections are also clearly noticeable.

References

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