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# Measurability of changes of the laminar-turbulent transition on wind turbines by means of thermographic flow visualization and a co-rotating measurement platform

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## Summary:

Changes of the laminar-turbulent flow transition due to unsteady wind conditions influence the efficiency of wind turbines. In order to clarify the feasibility of monitoring these changes by means of thermographic flow visualization, a coupled thermal-flow simulation is performed indicating a feasible temporal resolution down to 50 ms, i.e. well below one rotor revolution. Further, a co-rotating measurement platform is presented that enables the continuous image acquisition of a rotor blade section at wind turbines.

**Keywords:** Thermography, co-rotating system, coupled thermal-flow simulation

## Introduction

The laminar-turbulent flow transition position affects the efficiency of the wind turbine. Unsteady weather conditions as well as changing rotor blade positions during one revolution lead to varying laminar-turbulent transition positions. Hence, measuring these flow changes allows for future improvement and failure detection of the rotor blades.

Simon et al. [1] used infrared thermography (IRT) on a flat plate to determine the flow transition from laminar to turbulent and came to the conclusion that it is also suitable for measurements under unsteady flow conditions. Raffel and Merz [2] introduced differential infrared thermography (DIT) by subtracting one thermal image from another. This enables a visualization even before the surface has fully responded to the flow condition. DIT was shown by Gleichauf et al. [3] to be in principle capable of visualizing changes of the laminar-turbulent flow transition on wind turbines, with an image separation time of 50 s. Therefore, two open question are, if an increased temporal resolution in the order of a few seconds or even tenths of seconds is theoretically feasible, and how to realize a continuous image recording even during the blade rotation?

This work aims at both: approximating the theoretically achievable temporal resolution via simulation and create a measurement setup for visualizing changes close to that resolution.

## Co-rotating measurement setup

The BIMAQ and the Deutsche WindGuard together are the first to develop a multisensor co-rotating platform to visualize the flow conditions on the rotor blades of wind turbines. The platform is shown in Fig. 1. It features an infrared camera for measuring the flow condition and a laser scanner as well as a visual light camera with the same field of view that allows to detect any deformations of the rotor blade. Additionally, it has four visual light cameras that picture the full rotor blade. The wind turbine's position and speed are detected with a small setter camera to control the co-rotation of the carrier platform including a kinematic compensation for the perspective distortion. The co-rotating measurement setup continuously visualizes the boundary airflow with a sampling period of the infrared camera which is 4 ms.

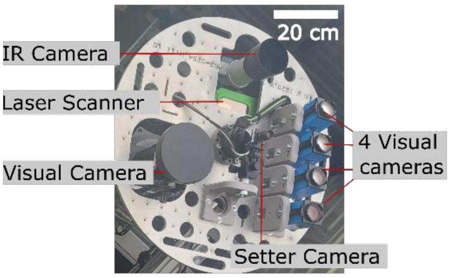

*Fig. 1:* Co-rotating measurement platform

## Temporal resolution limit

For approximating the time $t_{CNR}$ until a change of the boundary airflow is visible in the thermographic image, a thermal Computational Fluid Dynamics-simulation of a rotor blade segment is carried out. The rotor blade is modelled as a semi-infinite flat plate consisting of a 3 mm polyurethane (PU) coating on 17 mm glass-fiber-reinforced Polymer (GFRP), shown in Fig. 2.

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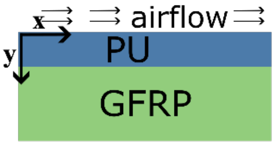

*Fig. 2: 2D model of rotor blade*

Convection is assumed to be the dominant heat transfer mechanism, which is supported by the fact that the Biot number is higher than one:

$$Bi = \frac{hL_s}{k_s} \geq 1.7\ , \qquad (1)$$

where $L_s = 2$ cm is the layer thickness, $k_s = 0.36\frac{W}{m\cdot K}$ is the weighted averaged thermal conductivity ($k_{GFRP} = 0.38\frac{W}{m\cdot K}$ [5], $\mathrm{k_{PU}} = 0.226\frac{\mathrm{W}}{\mathrm{m\cdot K}}$ [6]), and $h > 30\frac{W}{m^2 K}$ (cf. Fig. 3) is the convective heat transfer coefficient. The heat transfer coefficient, which depends on the boundary airflow, is determined with a coupled Reynolds-Averaged Navier-Stokes (RANS) simulation. Here, an outer rotor blade section is studied for a Reynolds-number of $2.5 * 10^6$ considering a DU 96-W-180 blade profile as well as a solar-induced blade-air temperature difference of 5 K.

Fig. 3 shows the calculated heat transfer coefficient for two different blade angles of attack ($AOA$) over the chord-normalized position x/c. The laminar-turbulent transition is at $\frac{x}{c} = 0.25$ for an AOA of 4° and at $\frac{x}{c} = 0$ for an AOA of 18°.

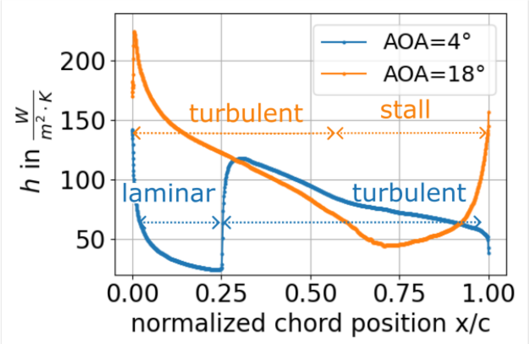

*Fig. 3: Reynolds-Averaged Navier-Stokes (RANS) simulation of the heat transfer coefficient on a rotor blade profile at a Reynolds number of* $2.5 \cdot 10^6$.

Considering the relative position $\frac{x}{c} = 0.25$, a change of the AOA thus leads to a change of heat transfer and therefore results in a step response of the surface temperature of the material that is simulated and shown in Fig. 4. The surface temperature declines after the boundary airflow has changed to turbulent. Already after $t_{CNR} = 50$ ms, the temperature difference is higher than the NETD given by the camera manufacturer InfraTec, which promises a theoretically reachable temporal resolution well below one second.

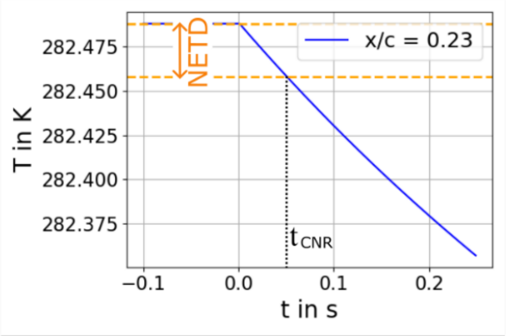

*Fig. 4: Step response of the temperature after a boundary flow change from laminar to turbulent*

## Conclusion and outlook

The presented simulation results show that it is possible to thermographically visualize changes of the airflow with a contrast-to-noise ratio > 1 already 50 ms after a sudden change in the boundary airflow conditions. Furthermore, a co-rotating measurement system is realized for the first time that enables continuous thermographic images with a sampling period of 4 ms during the turbine revolutions and, hence, possibly facilitating measurements of flow changes close to the estimated temporal resolution limit.

The planned future research work is the use of the thermal images of the co-rotating platform to visualize position changes of the laminar-turbulent platform by means of DIT.

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