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PIV MEASUREMENT OF WAKES PAST STATOR WHEEL INSIDE AIR TEST TURBINE VT-400 IN TWO AXIAL×TANGENTIAL PLANES

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Abstract: *VT-400 is a single-stage test turbine working with ambient air located at the University of West Bohemia in Pilsen. Inside this turbine, we perform a PIV (Particle Image Velocimetry) measurement of the flow field in two planes oriented in axial × tangential direction. There planes are located between the stator wheel and rotor wheel; first one is near the hub, second one at the middle of blade height. The spatial distribution of velocity fluctuations displays system of wakes and jets oriented diagonally over the studied area. The jets are represented by higher mean velocity and lower turbulence, the wakes oppositely. The spatial size of fluctuations is analyzed in terms of autocorrelation function: the size of correlated region is comparable with the wake width, additionally, there is apparent a wave in the stream-wise direction. At different turbine working parameters, we observed at least two distinct wavelengths. The neighboring wakes do not interact in the limits of studied areas.*

Keywords: Particle Image Velocimetry, turbine, stator wheel, wake, autocorrelation function.

1. Introduction

Steam turbines are still very important machines for energy production. They transform the energy from the form of high pressure and high enthalpy to the rotational kinetic energy (Burdin, 1824). Higher efficiency of is reached by adding the *stator wheel* before the rotor wheel. Its role is to deflect the direction of the flow from fully axial direction in a such way, that after the passage through rotor wheel, the fluid direction could be fully axial and thus having smallest kinetic energy (and thus larger fraction of energy being processed by the turbine rotor). The classical approach just takes into account the velocity deflection, but the stator is realized as a grid of high-lift blades, which naturally produce wakes – fluid region, which is significantly influenced by the previous presence of solid body. Typically, the mean flow velocity is slower and fluctuations stronger inside the wake region (in comparison with the region between wakes – jets).

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In the past, the flow inside turbines has been explored mainly numerically (Denton and Pullan, 2012; Sieverding and Manna, 2020) or by using pressure measurements (Klimko and Okresa, 2016; Ilieva, 2017; Klimko et al., 2021; Porreca et al., 2007). Our recent work uses Particle Image Velocimetry to map flow in some selected planar area past the rotor (Duda et al., 2021) or stator wheel (Duda et al., 2024). Very interesting apparatus exists at Baltimore university: their experimental configuration uses turbines made of transparent materials (Chow et al., 2002; Uzol et al., 2002).

2. Methods

The current contribution focuses to the axial × tangential plane past the stator wheel of single-stage test turbine VT-400 (Klimko and Okresa, 2016). The plane is studied at two heights – approx. 4.5 mm above the endwall and second approximately in the middle of blade height, see Fig. 1. Due to perspective effects, the bottom plane covers slightly larger area than the upper one. Both, illumination and observation is done through a *groove* in the turbine body, which usually serves for traversing pressure probes. The illumination lasersheet has to be reflected by a mirror placed inside the turbine but above the wheels, therefore we hope, that it does not affect the flow field. For other details about the camera, laser, particle seeding, etc., we refer our previous work (Duda et al., 2024), which is published in "open-access" mode.

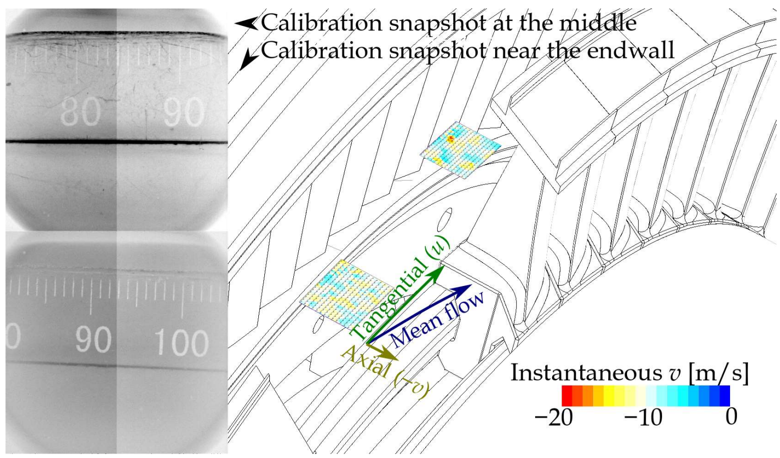

Fig. 1: Sketch of the position of studied planes inside the turbine with negatives of calibration snapshots.

3. Results

The measurements have been performed at two rotational speeds of the turbine rotor and at five pressure gradients. These gradients were adapted for the output angle α to match the values of $-40\,°$ to $+40\,°$. Unfortunately, it was not possible to measure three states at the middle plane because the mirror inside the turbine become dirty by some oil (surprisingly it was not Safex used as tracer particles). The droplets on the mirror surface caused uneven reflections, which caused the horizontal strip of extremely high fluctuations at the panel in third column and second line in Fig. 2. The rest of the column was too damaged for some data processing – this is the reason for white space in the Figs. 2 and 3.

The spatial size of fluctuations can be shown by the autocorrelation, Fig. 3. Single point in the wake has been chosen as the reference point, which automatically correlates with its neighborhood (blue spot). We observe the wavy character of fluctuations displayed as the near areas of anticorrelation. We do not observe any crosstalk with the neighboring wakes, which suggests that the fluctuation source is at the stator wheel, not in the inlet large-scale turbulence. Note the presence of two wavelengths: e.g. in the middle plane at lower speed (left column of Fig. 3) the wave is longer at $\alpha = -20\,°$, while at $\alpha = 0\,°$, the wave is half and later at $\alpha = +20\,°$, there appears a longer wave again, but now it is modulated by the shorter wave.

Acknowledgement

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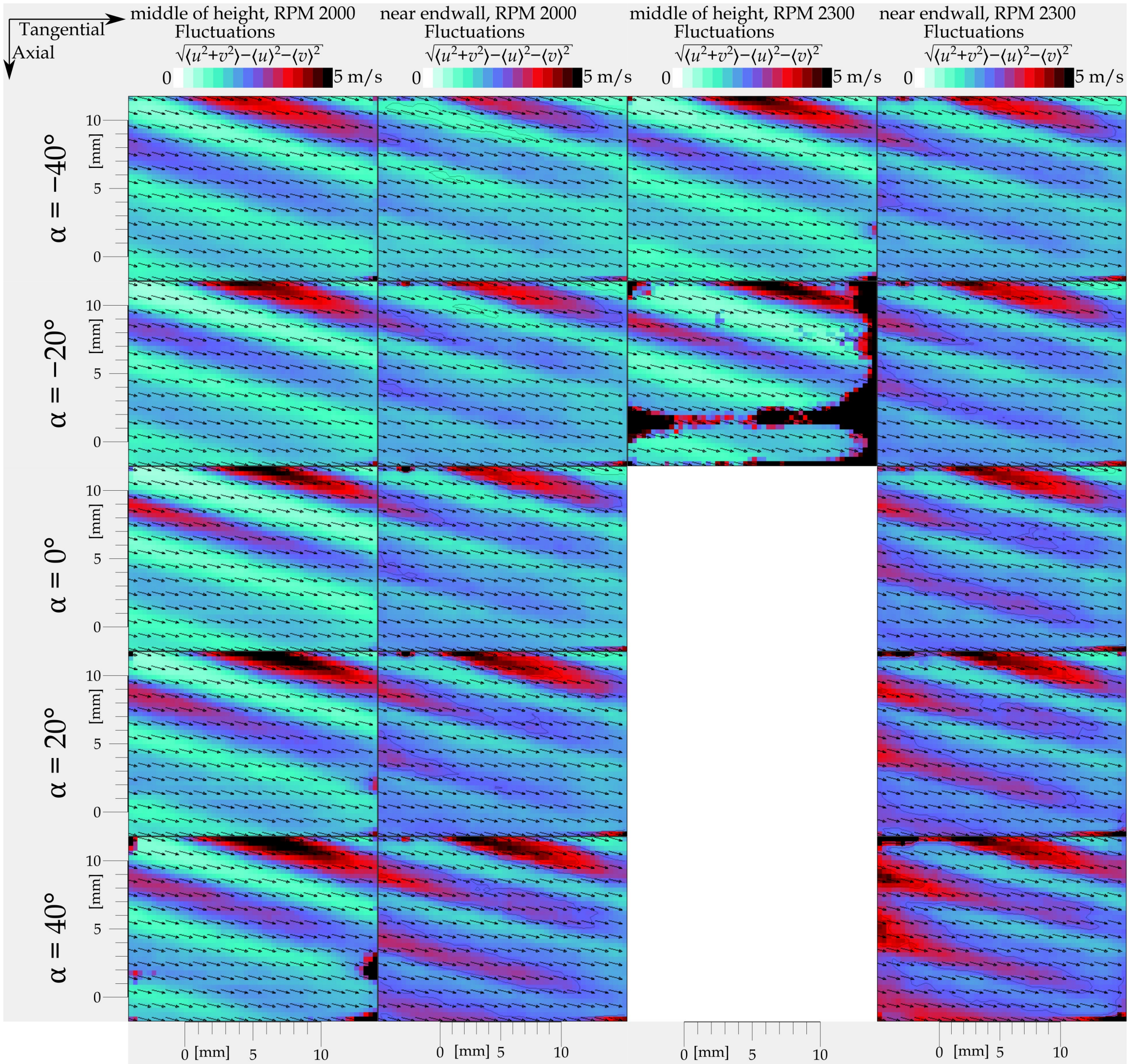

Fig. 2: Spatial maps of the measured standard deviation of the in-plane velocity, $\sqrt{\sigma_u^2 + \sigma_v^2}$.The limits of the colormap are from 0 to 5 m/s. It is important to note, that the contribution from fluctuations in radial direction is not measured. First and second columns display the results at turbine rotational speed of 2 000 rpm, the third and fourth one at 2 300 rpm. The first and third show the plane near the middle, the second and fourth column display the plane near hub.

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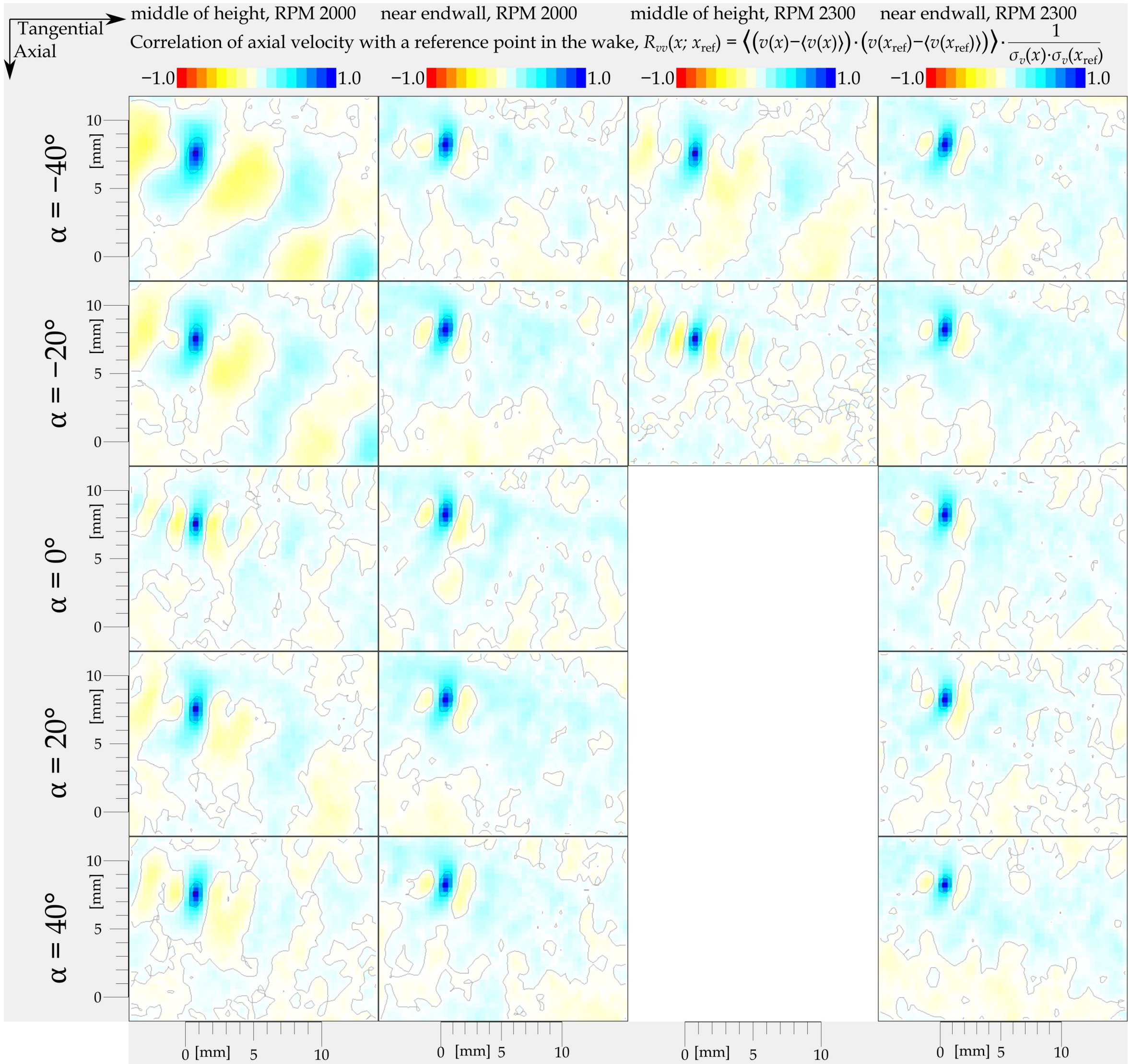

Fig. 3: Autocorrelation function of the axial velocity with a point inside the wake (comp. Fig. 2). Blue areas represent the region, where the fluctuations correlate with the fluctuations in the probed point. The yellow means anticorrelation, i.e. the wave nature of fluctuations in the wake. The more distant areas of light blue and yellow do not correlate, but the experimental noise causes, that the calculated correlation is never zero exactly.

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