Mitteilung

Fachgruppe: Drehflügler

Analysis of Configurational Parameters on the Vortex System of a Rotor

Alexander Heintz, Clemens Schwarz, C. Christian Wolf and Markus Raffel
German Aerospace Center, Bunsenstr. 10, 37073 Göttingen,
alexander.heintz@dlr.de, clemens_a.schwarz@web.de, christian.wolf@dlr.de,
markus.raffel@dlr.de

Introduction

The wake of a rotor is a complex three-dimensional flow, which is dominated by unsteady aerodynamic effects. In general, the wake is characterized by the helix-shaped trailing blade tip vortices, the blade shear layers, the rotor-induced downwash velocity field and the external flow conditions. The interaction of these mechanisms results in the breakdown of the vortex system with its downward propagation. The blade tip vortices, which are initially well defined, begin to decompose with increasing wake age. Due to its complexity, the numerical simulation of this breakdown is still challenging and therefore part of current research activities. The vortex interaction and decomposition are highly relevant to the efficiency and noise development of rotors, especially for hover flight cases. Accordingly, these effects need to be investigated in detail. In recent publications additional s-shaped vortex worms, in between the blade tip vortices, were observed. A so formed vortex system is sketched in Fig. 1a. This presentation will also focus on their contribution to vortex breakdown.

Experimental Setup

The experiments were conducted at the Hover Test Stand (HVG) of the German Aerospace Center in Göttingen. It was designed to investigate the aerodynamics of an isolated rotor in hover out of ground effect. This facilitates an easier comparability with numerical methods, in particular for a detailed comparison of the vortex decomposition.

The rotor is mounted on a solid support structure with a built-in electric traverse system to change the height of the rotor plane, see Fig. 1b label 2. This allows for a measurement in different axial distances from the rotor without changing the PIV setup. In order to change the tip vortex spacing, the mounted rotor head allows to vary the blade number to one, two and four blade configurations. For force and torque measurements a six-component piezoelectric balance is mounted directly below the propulsion system.

To measure both, primary and secondary vortices, instantaneous flow fields were acquired in two perpendicular PIV planes, as sketched in Fig. 1b with the corresponding laser light sheets. As shown in Fig. 1a, the secondary structures should be visible in the horizontal FOVs as their axis is perpendicular to the PIV plane and the primary blade tip vortices. A high-speed PIV system was used in the horizontal plane, to allow a temporal and statistical evaluation of the secondary vortex structures. It consists of a camera system (two Phantom VEO640L, see Fig. 1b label 3) with an acquisition frequency of 950 Hz, to acquire 50 images per rotor revolution. In addition, a low-speed PIV system was used to investigate the primary blade tip vortices and the overall wake structure in the vertical plane. Two pco DIMAX S4 cameras were used for imaging, see Fig. 1b label 1.

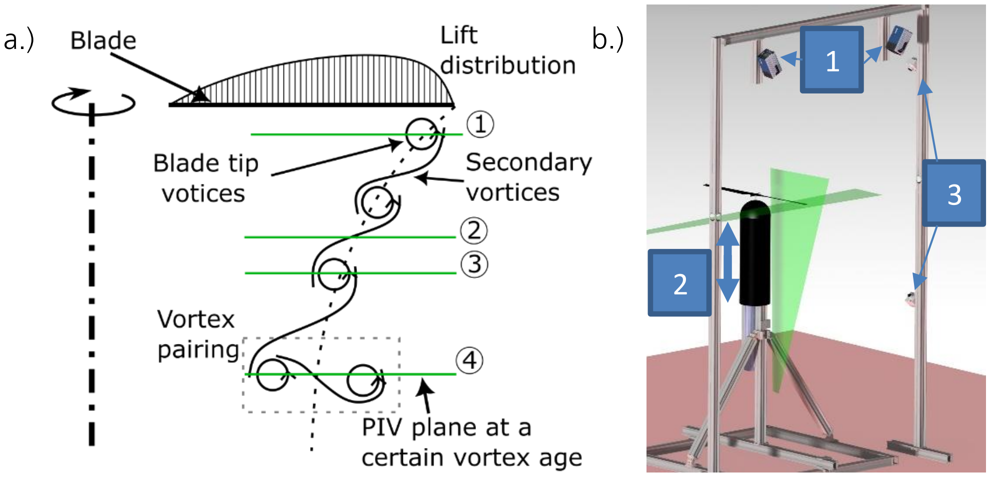

Fig 1: An example overview over the vortex system with secondary vortices and vortex pairing (left), and a sketch of the test stand with the PIV planes (right).

In addition to PIV, we also used a high-speed camera to track the position of the blade tips and conducted hotwire measurements at up to 588 points in a vertical plane. Both methods were only used for selected cases. The setup of this system will be explained in detail in the final presentation.

The following table lists the variation of configurational parameters of the current study:

Number of blades n_B	Frequency f	Blade loading C_T/σ	Blade-to-blade pitch offset $\Delta\theta$
1	$f = 19\,Hz, \sqrt{2}f, f/\sqrt{2}, f/2$	$0.059, 0.071, 0.085, 0.098, 0.106$	-
2	$f = 19\,Hz, \sqrt{2}f, f/\sqrt{2}, f/2$	0.085	$0°, 0.2°, 0.5°. 1°$
4	$f = 19\,Hz$	0.085	$0°, 0.2°, 0.5°. 1°$

Additionally, different blade shapes were studied (constant radius of 0.76m, constant thickness of 15% and constant chord length of 0.061m):

Name	Airfoil	Twist	Blade tip shape	Origin
SpinBlades BlackBelt	Symmetric	$0°$	Parabolic	Commercial
SpinBlades BlackBelt	Symmetric	$0°$	Rectangular	Commercial modified
DLR HEL-0	NACA23015	$0°$	Rectangular	Own design
DLR HEL-18	NACA23015	$-18°$	Rectangular	Own design

Sample Results and Discussion

In the following, a few sample results are shown. The PIV data from the vertical FOV were used to extract the primary tip vortices and will be shown in connection with the horizontal FOV data in the final presentation.

In this abstract, however, we will focus on some results of the evaluation of the secondary structures. An instantaneous sample of the flow field in the horizontal PIV plane is shown in Fig. 2. The secondary structures are marked by red circles in both pictures. These data are used to quantify the secondary structures in terms of wake age, respectively distance from the rotor. Owing to the high spatial resolution, the field of view is limited to an azimuthal range of 22.5°. Therefore, the average number of secondary vortices over the entire azimuth is calculated by:

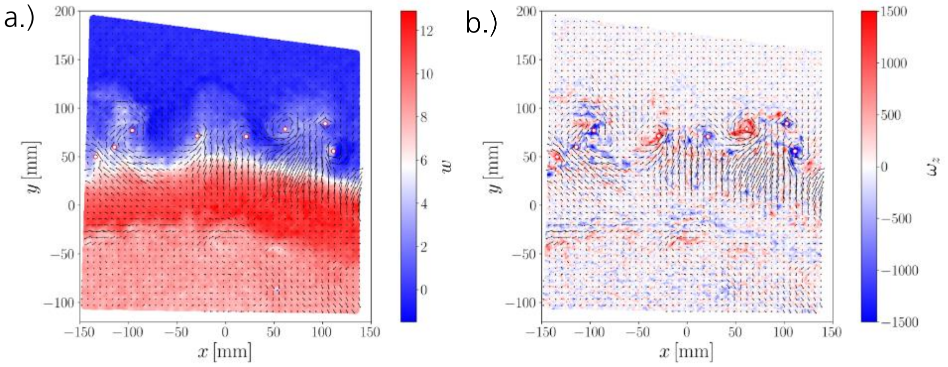

Fig 2: Sample PIV fields from the horizontal PIV plane together with the detected secondary vortices

$$n_{v,mean} = Avg\left(\frac{n_{sec,i} \cdot 360°}{22{,}5°}\right)$$

While the number of vortices detected in the i^th sample is given as $n_{sec,i}$. Thus, the average number of secondary vortices in a certain distance from the rotor could be extracted. The evolution of $n_{v,mean}$versus the distance $-z/R$ is shown in Fig. 3. In a similar experiment Schwarz et. al. (2022) suspected an influence of the pitch offset on secondary structures. As can be seen in Fig. 3a this theory cannot be confirmed by this experiment. Nevertheless, it can be shown, that other factors such as the number of blades, see Fig. 3b, have a significant influence. In the final presentation we will discuss additional configurational parameters, which mainly effect the occurrence of secondary structures, e.g. the influence of the blade passing frequency. Moreover, the circulation and statistical characteristics were studied and evaluated. These results will then be combined to get a show how secondary vortices influence blade tip vortex break-down.

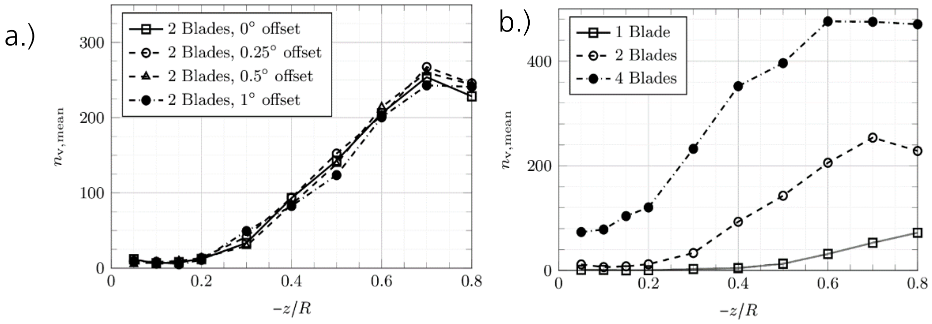

Fig 3: Development of the number of secondary structures per rotation over the distance to the rotor plane

Schwarz et. al. (2022): Schwarz, C., Bodling, A., Wolf, C. C., Brinkema, R., Potsdam, M., and Gardner, A. D., "Development of Secondary Vortex Structures in Rotor Wakes," Experiments in Fluids, Vol. 63, No. 1, 2022, p. 4. https://doi.org/10.1007/s00348-021-03348-8.