Mitteilung

Fachgruppe: Drehflügler

Towards Tip Vortex Measurements on Rotors in the
High Pressure Wind Tunnel Göttingen (HDG) of the DLR

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Introduction

The wake of a helicopter rotor features vortices originating from the blade tips. The vortices are relevant for the rotor noise and rotor performance, hence, the analysis of their propagation, growth and decay is of particular interest. It is widely believed that the vortex Reynolds number, defined as the ratio of the vortex circulation to the fluid viscosity, is an important factor in this process. Being related to turbulence and instability mechanisms, the Reynolds number effect on the vortex evolution is difficult to capture in numerical simulations. Therefore, experiments with a variation of the Reynolds number are required.
Atmospheric subscale test facilities cannot reproduce the Reynolds numbers encountered on full-size helicopter rotors due to size limitations, whereas field measurements on free-flying helicopters are affected by the engine exhaust flow, wind gusts, blockage of the fuselage, tail rotor, etc. Furthermore, neither approach enables a variation of the Reynolds number independently of the rotational speed and the rotor dimensions. Therefore, we chose DLR's High Pressure Wind Tunnel Göttingen (HDG) for measurements with a varying Reynolds number. The current work discusses the experimental methodology and sample results from a pretest.

Experimental Setup

The HDG is a closed-loop wind tunnel which can be pressurized up to 100 bar. The test section has a 0.6 m x 0.6 m cross-section and can be accessed through an air lock while keeping the tunnel itself pressurized. Optical access is given by two portholes in the sidewall and one porthole in the ceiling of the test section. A "C"-shaped support structure is placed in the test section, with a cylindrical tube stretching in upstream direction and serving as a rotor mount. The tube has an outer diameter of 75 mm and a length of 750 mm. It is equipped with load cell with thermal insulation, a 4.5 kW motor, and temperature/vibration monitoring.
The tip vortices were visualized using Background Oriented Schlieren (BOS). The system consists of a pressure-resistant LED array mounted on top of the test section and inside the pressure hull, a retroreflective background with a random dot pattern (D = 0.1 mm) on the floor of the test section, and two cameras (pco.panda 26, f = 85 mm, sampled at 6 fps, 0.2 m x 0.4 m combined field of view) outside of the pressure hull and close to the top porthole, see Fig.1.

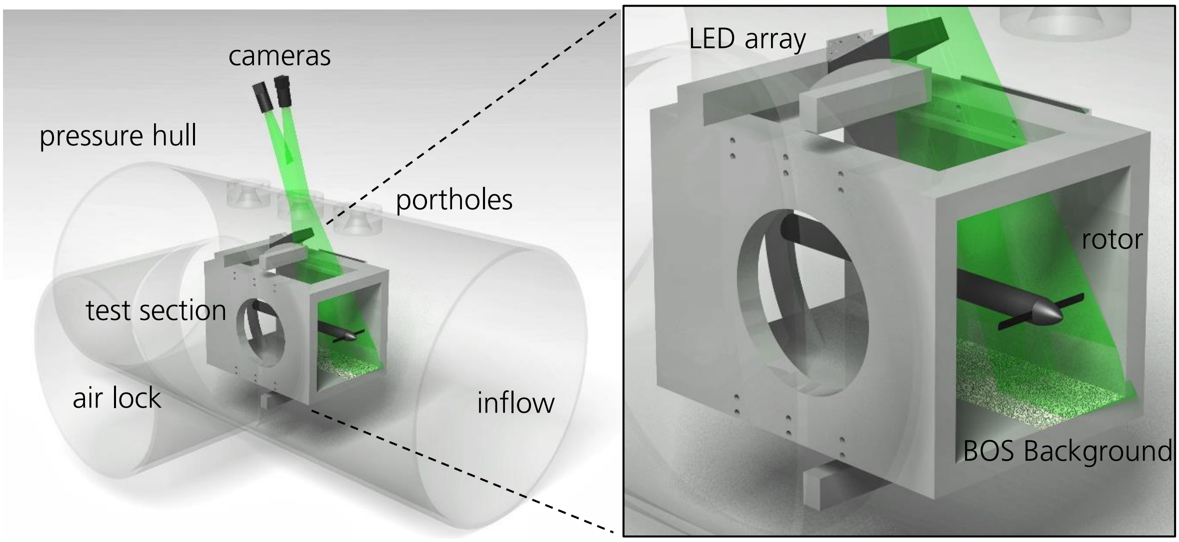

Figure 1: HDG test section with rotor assembly and instrumentation; camera view field in green

In the current pretests, the wind tunnel flow was switched off, and the rotors were operated in hover-like conditions. Due to safety concerns, the rotor was placed upstream of the glass windows. Hence, the cameras had to be slightly tilted in forward direction, viewing the wake downstream of the rotor plane. The BOS cameras were triggered by a light barrier for phase-locked Schlieren images of the vortex system. The BOS sensitivity, defined as the relation of pixelwise displacement on the camera sensor to an observed density gradient, is approximately proportional to $(1/Z_D + 1/Z_A)^{-1} L_{\mathrm{Fov}}^{-1}$. Z_D and Z_A are the camera-to-density-object and density-object-to-background distances, respectively. L_{Fov} is the size of the field of view. In the current setup, the sensitivity is limited by the short observation distances, and the tip vortices could only be visualized with a sufficient signal-to-noise ratio for tunnel pressures of about 14 bar and above. Higher tunnel pressures also lead to higher thrust values, which increases the accuracy of the thrust measurement.

Sample Results and Discussion

Data was taken at 16 bar, 32 bar and 64 bar and rotational speeds between 1000 rpm and 5000 rpm. For the current pretests, three different off-the-shelf model airscrews with a radius of R = 0.15 m, a chord length of C = 25 mm at a radial position of r/R = 0.75 and different blade pitch angles were selected as rotors (Master Airscrew Carbon 12x4″, 12x6″ and 12x8″). Operation at high tunnel pressures led to a strong deformation of the rotors. Later tests will use much stiffer DLR-designed model rotors milled from aluminum.

The blade tip vortices were remarkably stable even for the highest tunnel pressure, yielding a chord-based Reynolds number of $\mathrm{Re}_{C,0.75}$ = 7x10^6 at r/R = 0.75. For the observed vortex ages from ζ = 0° to about ζ = 1200°, no pronounced vortex instabilities were identified, see Fig. 2.

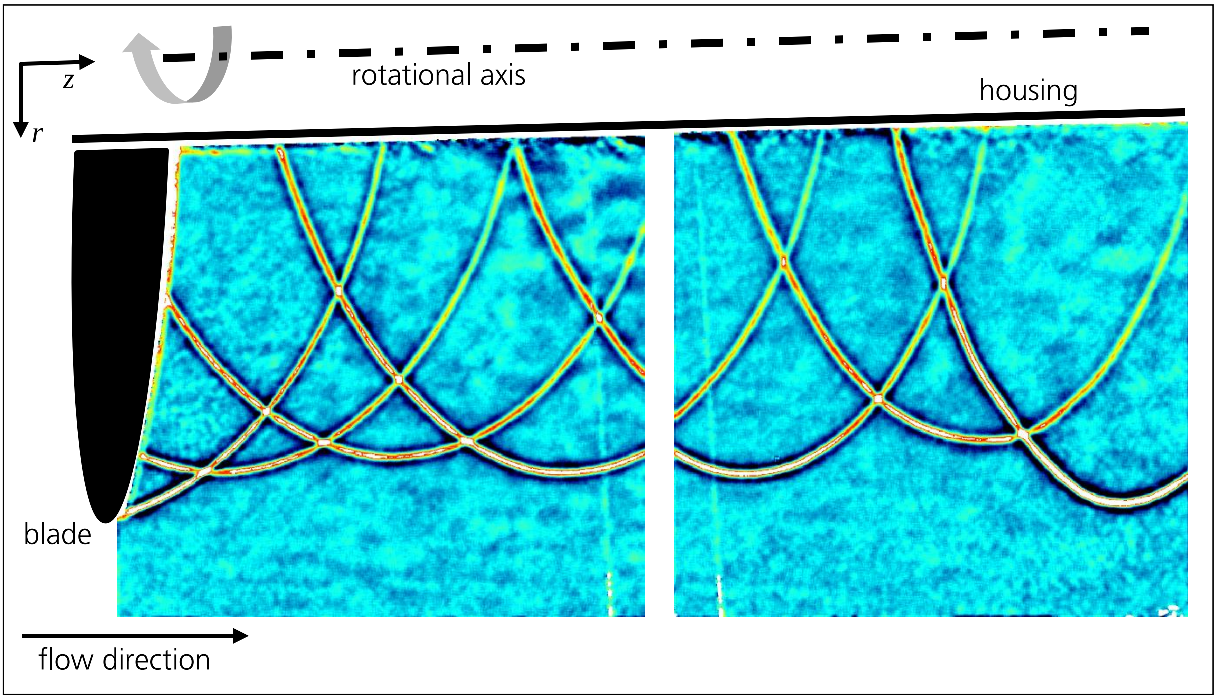

Figure 2: BOS sample result, 2D-Divergence of the BOS displacement; Master Airscrew Carbon 12x6″ at 5000 rpm, wind tunnel pressure of 16 bar

Fig. 3 shows the rotor thrust coefficient, C_T, as a function of the chord-based Reynolds number. The data comprises the different tunnel pressures and different rotor rpm for the lowest-pitch rotor, 12x4″. The deformation of the higher-pitched rotors, 12x6″ and 12x8″, was too large to result in meaningful and reliable thrust data.

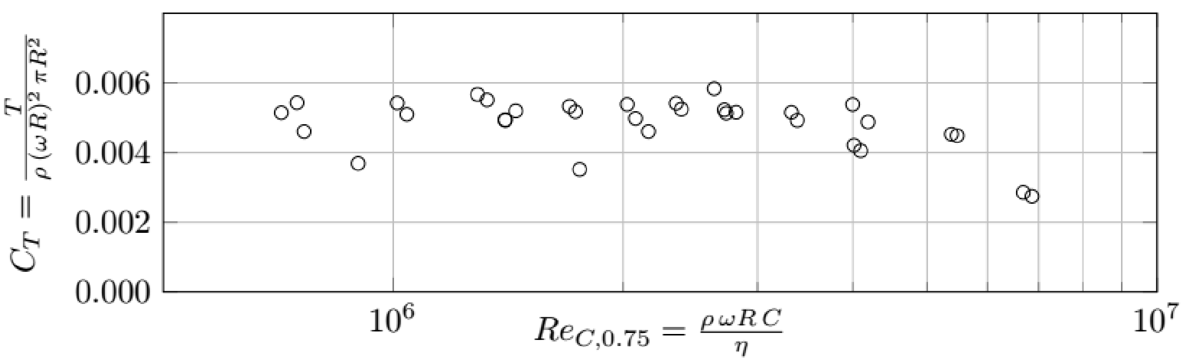

Figure 3: Thrust coefficient over $\mathrm{Re}_{C,0.75}$, for the 12x4″ rotor