AN EXPERIMENTAL STUDY ON THE STABILITY OF THE TIP VORTICES BEHIND A SMALL-SCALE MODEL TURBINE

Ylva Odemark[a)] & Jens H. M. Fransson
Linné FLOW Centre, KTH Royal Institute of Technology, 100 44 Stockholm, Sweden

Summary The stability of the tip vortices behind a small-scale model turbine was investigated experimentally in a wind tunnel. Phase-locked hot-wire measurements were performed in vertical planes surrounding the tip vortices, at several different downstream positions. By introducing a disturbance in the rear of the nacelle, the stability of the tip vortices could be studied. The evolution of the vortices and the location of the tip vortex breakdown were investigated for different disturbance frequencies.

INTRODUCTION

The production losses and inhomogeneous loads of wind power turbines placed in the wake of another turbine is a well-known problem when building new wind power farms, and a subject of intensive research [1]. The present work aims at developing an increased understanding of the behaviour of turbine wakes, with special regard to the stability of the trailing vortices, which are an important source of rotor noise and blade vibration [2]. By introducing a periodic disturbance to the flow, the evolution and breakdown of the tip vortices as a function of the disturbance frequency could be studied.

EXPERIMENTAL SETUP

The experiments were performed in a wind tunnel with a test section with the dimensions 7 $\times$ 1.2 $\times$ 0.8 m (length $\times$ width $\times$ height). Two single hot-wire probes were used; one stationary to monitor the wake meandering (the shifting of the wake from side to side) and one that was traversed through the wake. In order to monitor the model, the power output, the thrust force and the rotational frequency were also measured before and after each hot-wire measurement. All measurements were phase-locked, based on the passage of one of the blades, the meandering of the wake and the added disturbance frequency. The triggering signal consisted of the sum of the output voltages from these three signals, which were added using a non-inverting adder. The free stream velocity was 6.5 m/s.

Turbine model

The model had a diameter of $D = 0.178$ m, and the height of the support was 0.4 m, which placed the model in the middle of the test section. The airfoil was a non-twisted Göttingen 417a, with a chord length varying from 15 to 26 mm. The pitch angle was set to 12 degrees, for which the maximum power output was obtained. The tip speed ratio (ratio between the speed of the blade tip and the free stream velocity) was kept at 3.5.

Disturbance generation

The disturbances were introduced in the form of two pulsed jets, directed perpendicular to the main flow. The jets came out through two orifices located in the rear of the nacelle. The disturbance was controlled by two fast-switching valves that could be set at different frequencies. A compressor was used to generate a high pressure in a large accumulator tank, which was connected to a second accumulator tank through a precision regulator. The fast-switching valves and a pressure sensor was then connected to the second accumulator tank. The pressure was measured before and after each hot-wire measurement to ensure that it was kept constant. For more information regarding the setup of the pulsed jets, see [3].

RESULTS

In Figure 1, phase averaged time series for a point in the middle of the vortex are shown. The point considered is located at the edge of the vortex core, and when moving downstream, the vertical coordinate remains the same, whereas the horizontal coordinate is shifted with regard to the spreading of the wake. Figure 1a shows the case without disturbances, and Figure 1b shows the case with a periodic forcing frequency of 42 Hz. It can be seen that the correlation between different sets is higher for the undisturbed case. It should be noted that to obtain these results, the amplitude of the disturbance needed to be fairly high. In this case, the maximum velocity of the jet is higher than the free stream velocity.
The measured planes were 5 $\times$ 5 cm (surrounding the tip vortices). The tip vortex energy in each point was calculated by integrating the spectrum around the tip vortex frequency. In order to appropriately follow the energy evolution associated with the tip vortex frequency in the downstream direction, the energy content was integrated within a specific contour line to get the total energy E_v. The corresponding area A_v enclosed by the contour line is here used as a measure of the tip vortex size. The results are shown in Figure 2. Both the total tip vortex energy and the size of the vortices are clearly

a) Corresponding author. E-mail: ylva@mech.kth.se

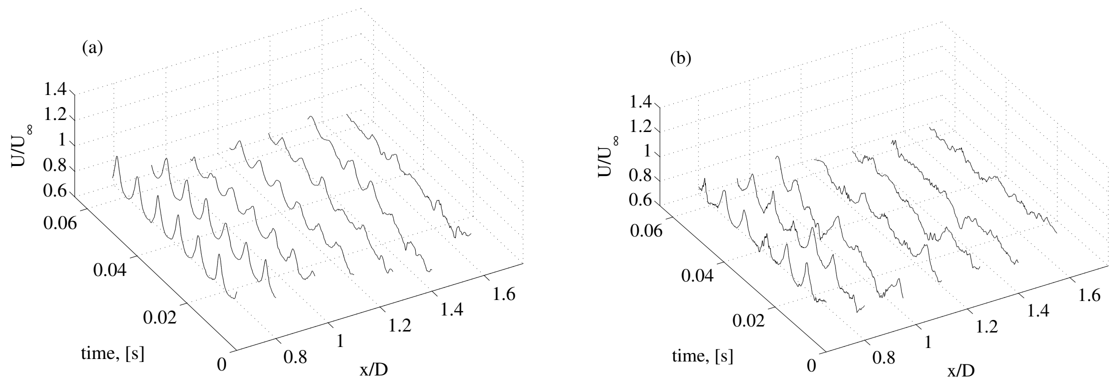

Figure 1. Phase averaged time series for the case without disturbance (a) and with a disturbance frequency of 42 Hz (b). The downstream distance x is scaled with the rotor diameter D.

smaller in the disturbed cases.

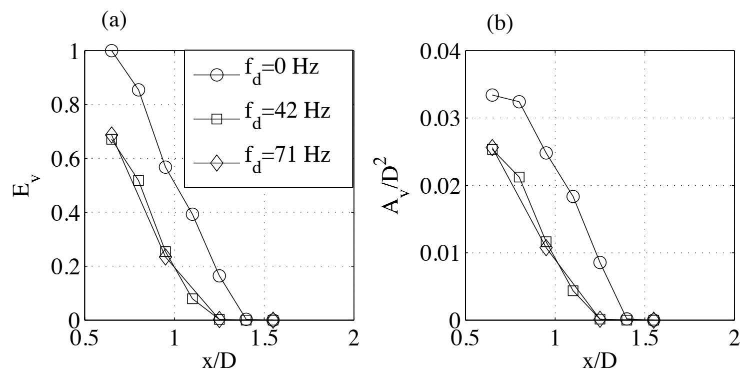

Figure 2. Tip vortex energy E_v as a function of downstream distance (a) and tip vortex size A_v as a function of downstream distance (b). The tip vortex energy is scaled with the first value in the undisturbed case, and the tip vortex size A is scaled with the model diameter D. Three cases are presented: without any disturbance, disturbance frequency 42 Hz and disturbance frequency 71 Hz.

SUMMARY AND CONCLUSIONS

The stability of the tip vortices behind a small-scale model turbine was investigated experimentally in a wind tunnel. Phase-locked hot-wire measurements were performed in vertical planes surrounding the tip vortices, and at several different downstream positions. By following the vortices downstream with and without an added secondary instability, the evolution and breakdown of the vortices could be studied. The results show that the vortices are fairly stable to this type of disturbance, but at an high enough disturbance amplitude, an earlier breakdown can be seen. However, more measurements need to be performed to further investigate these results.

References

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