Topic for Master Project

Contents

Aerodynamic Aspects of Atmospheric Irrigation with Wind Turbines

Introduction

At the Wind Energy Technology Institute (WETI) of Flensburg University of Applied Sciences, a system has been invented (patent pending) that allows using wind turbines (WTs) to impact on the natural water circuit of the atmosphere. The motivation for this invention is to mitigate the problem of aridity and water scarcity.

The idea revolves around the fact that the aerodynamic properties of state-of-the-art WTs are very advantageous for vaporizing water. Hence water, or water vapor, is emitted by the WT blades. It is expected that this emission has an impact on the aerodynamic performance of the blades, which is why this impact shall be assessed in a master thesis project.

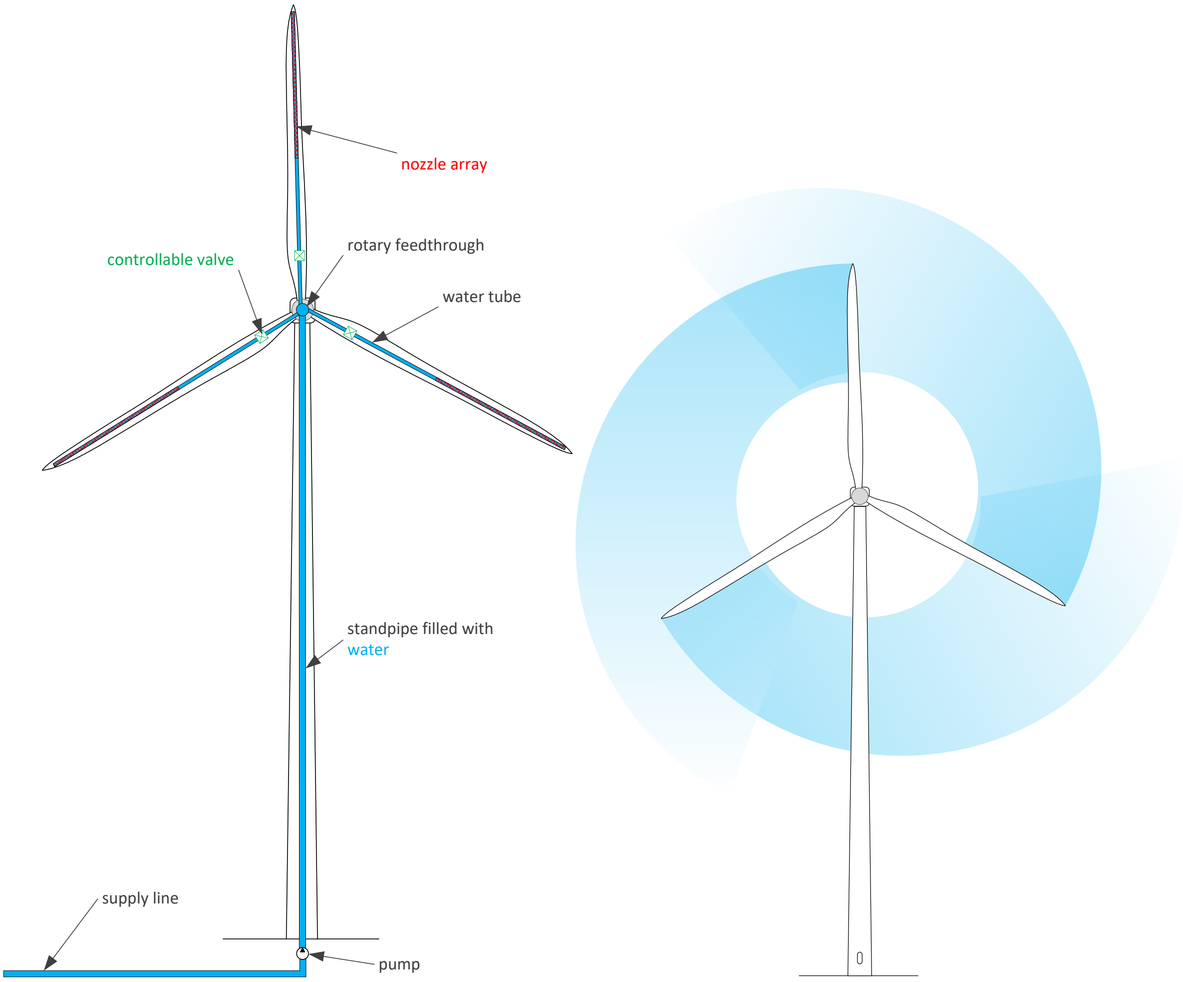
A Brief Introduction to Atmospheric Irrigation with Wind Turbines

The Atmospheric Irrigation with WTs (in the following called "irrigation system") utilizes some advantageous characteristics of modern WTs to emit water into the atmosphere. A detailed description of how the irrigation system interacts with the atmosphere, both in proximity of the WT and farther away, shall be omitted here. Instead, it shall be sufficient to mention that water is emitted either for vaporization or as droplets. Water vapor can be transported over long distances and the latent heat of vaporization can be used for local cooling. Droplets are emitted if the water is to be used for irrigating areas in the wake, and in proximity, of the WT.

In an advanced design variant, the irrigation system can also be used for desalinating seawater. However, this shall not be within the scope of this master thesis project.

Irrigation System in a WT

Figure 1 (a) illustrates a WT with irrigation system and its main components. Figure 1 (b) visualizes qualitatively how the irritation system emits water into the atmosphere; for the sake of illustration, the widening up of the wake is exaggerated.



(a) **(b)**

Figure 1 (a) Main components of the irrigation system in a WT. (b) Qualitative representation of how the irrigation system emits water into the atmosphere.

As shown in Figure 1, the water emitting nozzle arrays are located in approximately the outer half of the rotor blades. The nozzle arrays could also be located in any other section of the blades, but the outer half is advantageous for vaporization, as outlined in the following section.

Factors Facilitating Vaporization

Vaporization of water is, among other factors, determined by temperature (of both the water to be vaporized, as well as the surrounding air), pressure and the velocity of the air. The temperature of the air cannot be influenced by a WT. The possible variability of the water temperature shall be neglected here. Hence, the remaining factors, namely pressure and velocity of air, are discussed in the following. For this discussion it has to be kept in mind that vaporization is facilitated by low pressure and high airflow speed.

Figure 2 shows an airfoil of a rotor blade and the qualitative speed and pressure on the suction side of this airfoil.

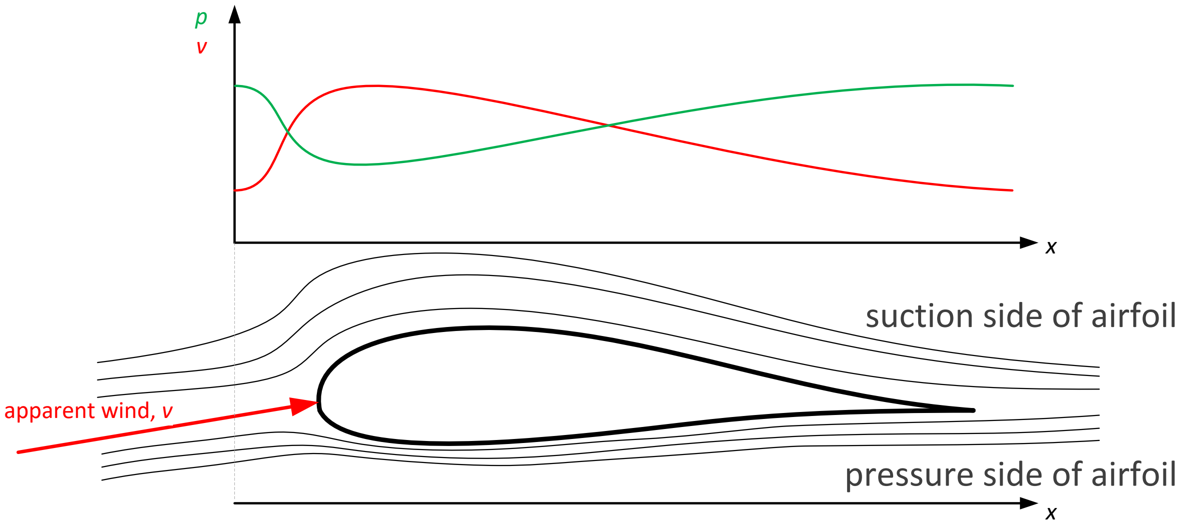


Figure 2 Bottom: Air flows around the airfoil of a rotor blade. Top: Qualitative representation of the pressure, *p*, and the air speed, *v*, on the suction side of the airfoil. The horizontal dimension, *x*, is the same in both graphs.

From the diagram in the top of Figure 2 it becomes obvious that the pressure on the suction side of the airfoil is advantageous for vaporizing water. Hence, it is advantageous to locate water-emitting nozzles on the suction side of the airfoil, see Figure 3.

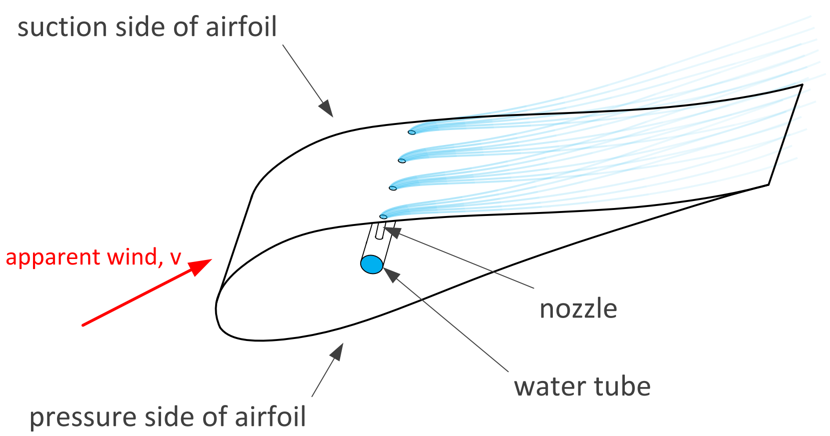


Figure 3 Section of a rotor blade with water tube inside the blade and with nozzles in the surface of the suction side of the airfoil.

Although Figure 2 also shows that the air is accelerated when flowing across the suction side of the airfoil, this effect is of subordinate relevance. The most increase in airflow speed can be achieved from the fact that the apparent wind, which hits the leading edge of a rotor blade, is the vector sum of ambient wind speed and rotating wind speed. To illustrate the effect, Figure 4 shows the apparent wind, v_0, the rotating wind, v_R, and the resulting apparent wind, v, for an arbitrary example. From Figure 4 it becomes obvious that, for the purpose of vaporization, the nozzles should be located in the outer half of the rotor blade, as there the apparent wind is very high.

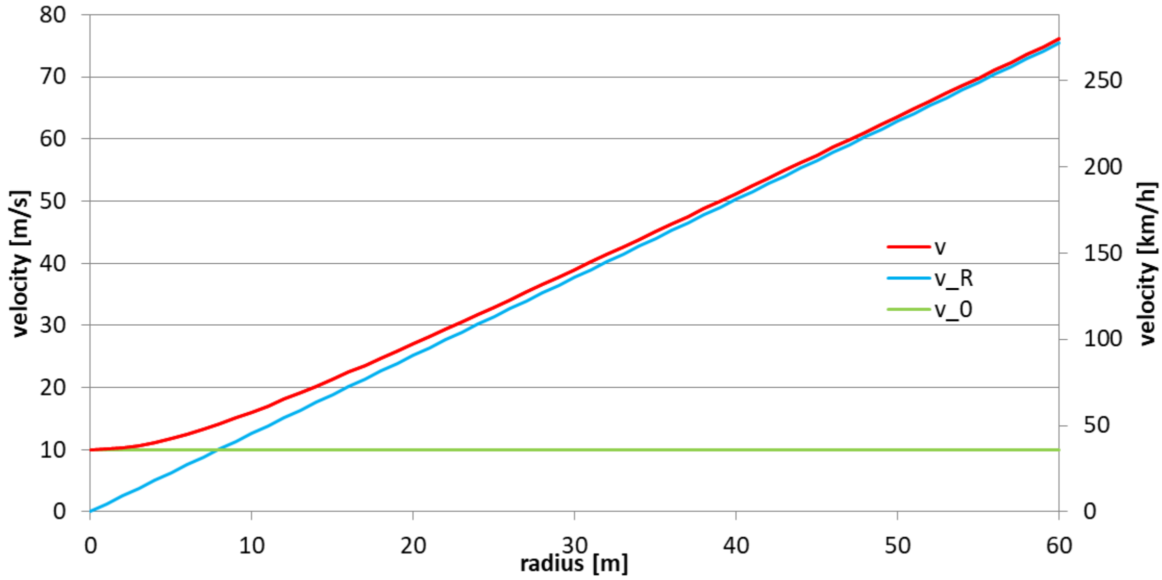


Figure 4 Ambient wind speed, *v_0* = 10 m/s, rotating wind speed, *v_R*, and resulting apparent wind speed, *v*, along the length of a rotor blade. The rotor has a radius of 60 m and rotates with a speed of 12 RPM.

Aerodynamics Effects of the Irrigation System

The aerodynamic properties of rotor blades can be improved with different mechanisms. Many of these mechanisms aim to improve the boundary layer between the surface of the suction side of the airfoil and the laminar air flow. Blowing air into the boundary layer or sucking air out of the boundary layer can increase the aerodynamic lift coefficient by up to 60 % [1].

The traditional motivation for applying mechanisms to improve the aerodynamic properties of rotor blades is to increase the energy yield and to reduce the mechanical loads. Increasing the energy yield improves the profit of the WT. Reducing mechanical loads saves material in the rotor blades and in the entire support structure of the WT. Hence, also load reduction is ultimately an aspect of economic efficiency.

In state-of-the-art WTs, active elements to improve the aerodynamics are still largely avoided, because these increase system complexity more than they reduce costs [2]. Passive vortex generators are applied in state-of-the-art WTs due to their low complexity. Vortex generators add energy to the boundary layer in order to reduce stagnation of the air very close to the surface of the airfoil. This mitigates the problem of separation of air flow from the suction side and stalling of the blades [1].

A similar effect can be achieved with blowing a fluid into the boundary layer of the suction side, which also adds energy and reduces the risk of flow separation. Different of such blowing techniques were tested in the past, which allowed proving their positive effect on the aerodynamic drag [3].

Active elements for blowing air into the boundary layer to improve aerodynamic properties are a well-known technology in aviation [4]. The complexity of such systems has to date prevented their application in WTs, as it would make WTs uneconomic.

The irrigation system also blows a fluid (water vapor and water droplets) into the boundary layer on the suction side of the airfoil. Hence, its effect on the aerodynamics of the rotor blades shall be assessed in this master thesis project.

Tasks for the Master Thesis Project

In Figure 3 the water-emitting nozzles are shown in an arbitrary location on the suction side of the airfoil and the emitted water is visualized in light blue. The overall task is to analyze the effect of emitting water into the boundary layer with nozzles on the suction side of a rotor blade by means of Computational Fluid Dynamics (CFD) simulations, e.g. with OpenFOAM (https://openfoam.org/). The following tasks have to be accomplished:

1. Vary the location of the nozzles on the suction side of the airfoil from leading edge to trailing edge and assess the effect of these different locations on lift and drag.
2. Vary the pressure with which the nozzles blow water spray (tiny droplets that will vaporize quickly after emission) into the boundary layer and assess the effect on lift and drag.
3. Vary the volumetric flow of the emitted water and assess the effect on lift and drag.
4. Vary the size of the droplets of the emitted water from very small (quick vaporization) to larger droplets (no complete vaporization) and assess the effect on lift and drag.

References

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