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Performance of AeroMINEs for Distributed Wind Energy

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AeroMINE (Motionless, INtegrated Extraction) wind harvesters provide distributed power generation with no external moving parts. Their patent-pending design easily integrates into buildings and can operate stand-alone or in conjunction with rooftop solar photovoltaics. Here, the AeroMINE configuration of a single-pair of opposing foils is investigated in wind tunnel tests. Through various geometric optimizations (foil spacing, angle-of-attack and air-jet configuration) a mechanical efficiency of approximately 1/3 of the Betz limit is achieved. Intermittent operation at significantly higher efficiency (approaching ½ of the Betz limit) is demonstrated for higher angles-of-attack, but steady operation is impeded by an aerodynamic instability. In addition to pressure and anemometry, particle image velocimetry is utilized to characterize the flow around and through the AeroMINE pair.

I. Nomenclature

A_{exit} = exit area (largest dimension) of unit
A_{jet} = total area of air-jets (orifices) in foil surface
AoA = angle-of-attack (half-angle between foils)
CFD = computational fluid dynamics
$c_p(x)$ = representation of surface pressure on foils
Δp_{jet} = pressure-drop over jets
Δp_{choke} = pressure-drop over jets
γ = representative jet discharge coefficient
L = chord length
LCOE = levelized-cost-of-electricity
Power = power of the AeroMINE unit
PIV = particle image velocimetry
PV = photovoltaic
ρ = air density
Re = Reynolds number based on chord
u_{jet} = flow velocity at the air-jets
U_∞ = free-stream velocity
V_{jet} = total volume flow through all air-jets

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II. Introduction

AeroMINE (Aero Motionless, INtegrated Extraction) distributed wind power generators have no external moving parts and easily integrate into buildings (Fig-1a). By sweeping a large area of wind with a reliable design, AeroMINEs overcome the challenges that have plagued other distributed wind solutions and have hindered distributed wind from playing a significant role in energy markets [1].

Incident wind creates low-pressure regions between the mirrored airfoil-pairs, and this suction pulls air from orifices (air-jets) in the skins of the foils, from the hollow airfoil interiors, supplied by a manifold which incorporates a turbine-generator (Fig-1b). The turbine-generator is located inside the building, away from extreme weather conditions. Additional details on AeroMINE operation are available in Houchens *et al.* [2].

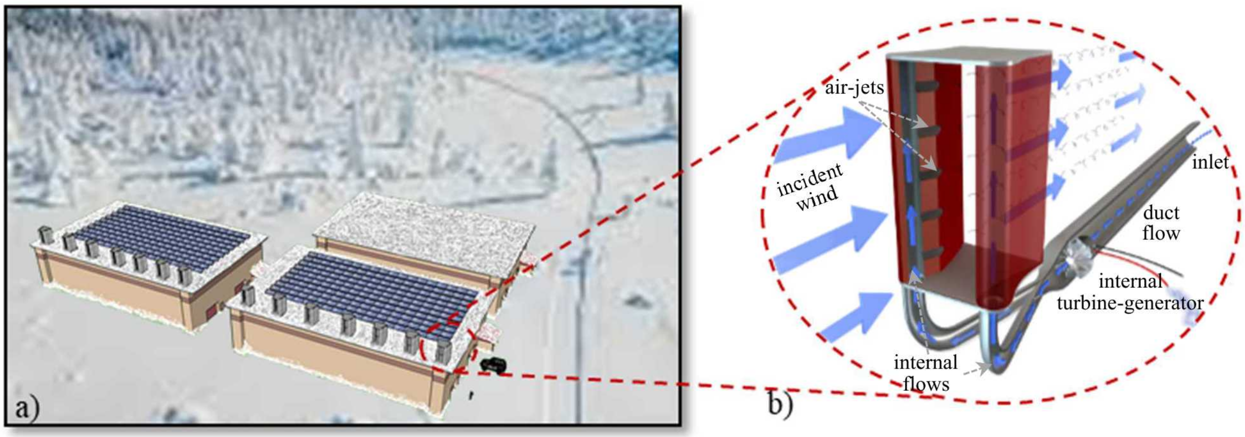

Fig. 1 Renderings of a) 14 AeroMINE pairs on warehouses coupled with a 180 solar PV panels as a functional distributed energy system for inclement settings, and b) schematic of operation of an AeroMINE pair.

III. Experiments

A 0.5 m chord AeroMINE pair of S1210 foils was mounted as shown in Figure 2 in Texas Tech University's National Wind Institute wind tunnel (Figure 3). The cross-section of the tunnel is 1.22 m x 1.83 m (4-feet high by 6-feet wide). Testing on the rapid prototyped foils was performed at freestream velocities between 5 and 15 m/s, corresponding to chord-based Reynolds number (*Re*) between ~130,000 and 400,000, respectively. This testing was carried out at 10° AoA, previously determined to be near optimum performance based on the measured inlet duct velocity [2]. A choke was placed at the inlet flow to the duct to simulate the load of the turbine-generator (Figure 4).

Fig. 2 A 0.5 m chord AeroMINE pair mounted in the wind tunnel.
The green ribs contain static pressure taps along the low-pressure side of the foils.

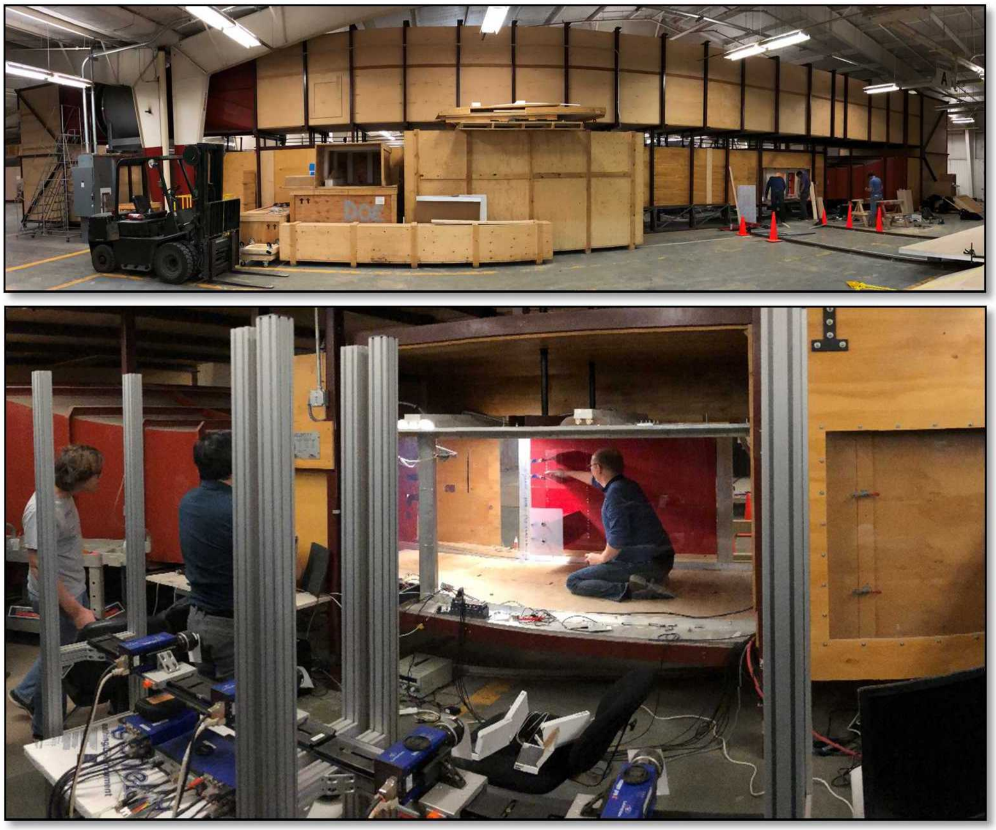

Fig. 3 Wide-angle photos of both sides of the National Wind Institute wind tunnel at Texas Tech University, including the PIV camera array on the transparent side, looking into a smaller array of 2 AeroMINEs.

The freestream velocity was measured forward of the AeroMINE and just off the wall of the wind tunnel with a vane anemometer. The foil pressure profiles were sampled along the low-pressure sides of the foils via static pressure taps in the green insert shown in Figure 2. Pressures were also measured on either side of a choke near the duct inlet and the average velocity was measured inside the duct, allowing calculation of a mechanical power, as shown in Figure 4. The choke simulates the turbine-generator under various loading conditions. Additionally, PIV measurements of the flow field were taken to better understand the acceleration between the foils and the wake structure.

Fig. 4 Duct inlet outside the wind tunnel with choke section and close-up of choke and hot wire anemometer.

IV. Summary of Results

First the mechanical efficiency of the system is discussed. Then flow instabilities observed at higher AoA are described. Together these provide an estimate of potential full-scale system efficiency and insights into sensitivity to flow instabilities which limit the maximum viable AoA for steady performance.

A. Mechanical Efficiency

The mechanical efficiency provides a measure of the maximum power extraction. By varying the choke size it is possible to produce a power curve for the system.

First, the mechanical power was calculated using the measured pressure drop across the choke, multiplied by the duct area and the average duct velocity

$$Power = \Delta P_{choke} \times A_{duct} \times u_{duct} .$$

The power available for extraction from the wind in the swept area of the AeroMINE represents the maximum possible power of the system. Dividing the $Power$ by the maximum possible power gives the efficiency of the system. The peak measured efficiency was determined to be 18%, which equates to roughly 1/3 of the Betz limit.

B. Flow Instabilities

Operation at higher AoA than reported in the above section has the potential to increase the energy extraction of the system by producing a lower pressure between the foils. For an individual S1210 foil alone and for *Re* at and above 200,000 the lift continues to increase dramatically up to and past AoA of 20° [3]. Thus, operating at a higher AoA is expected to increase the power of the AeroMINE system. Note that, in some cases, this increased energy extraction may not offset the increase in swept area, such that while the power might increase, the efficiency could decrease due to a more than proportionally larger increase in swept area. Nevertheless, in building installations, the optimum design may correspond to a non-optimum efficiency, driven by capital expenditure and geometric constraints. Thus, higher AoAs were investigated to better understand subtleties of this optimization.

At higher AoA it is observed that AeroMINEs experiences a flow instability not observed for a single S1210 airfoil. Efficiencies at these higher AoAs can reach as high as 27%, but are subject to instabilities which significantly reduce the power production and result in efficiencies around 10%, well below the stable value of 18% observed at lower AoA. This apparent separation will be discussed in detail, supported by pressure measurements on the foil surfaces and PIV.

Acknowledgments

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