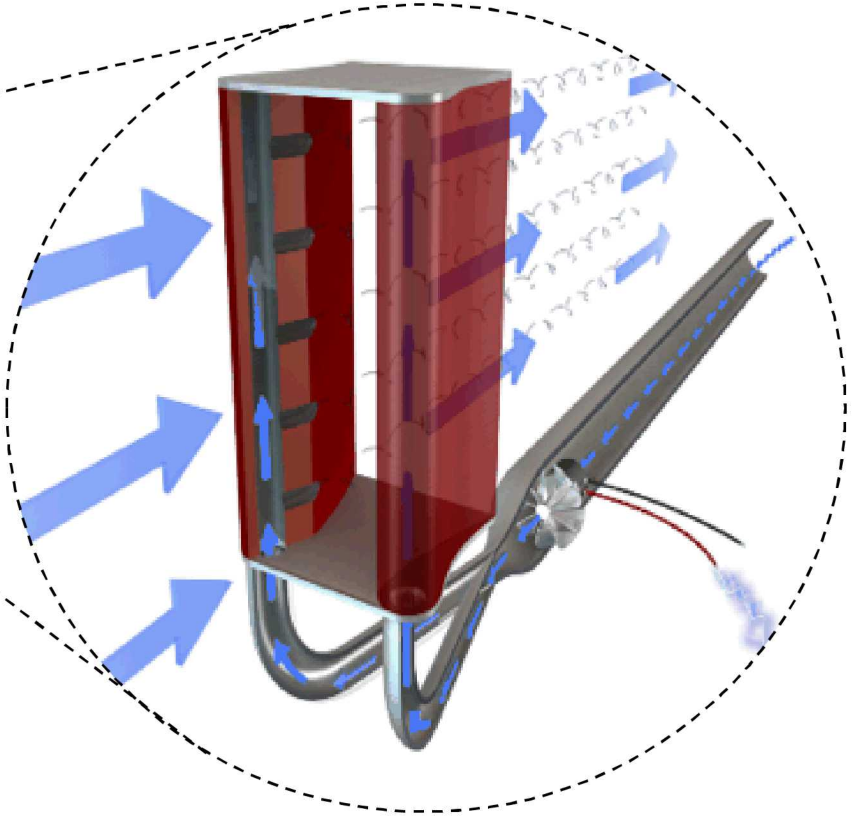
SAND2019-14415C

Flow Instabilities during High-performance Operation of a Wind Energy Harvester with No External Moving Parts

Brent C. Houchens, David V. Marian, Suhas Pol, Carsten H. Westergaard



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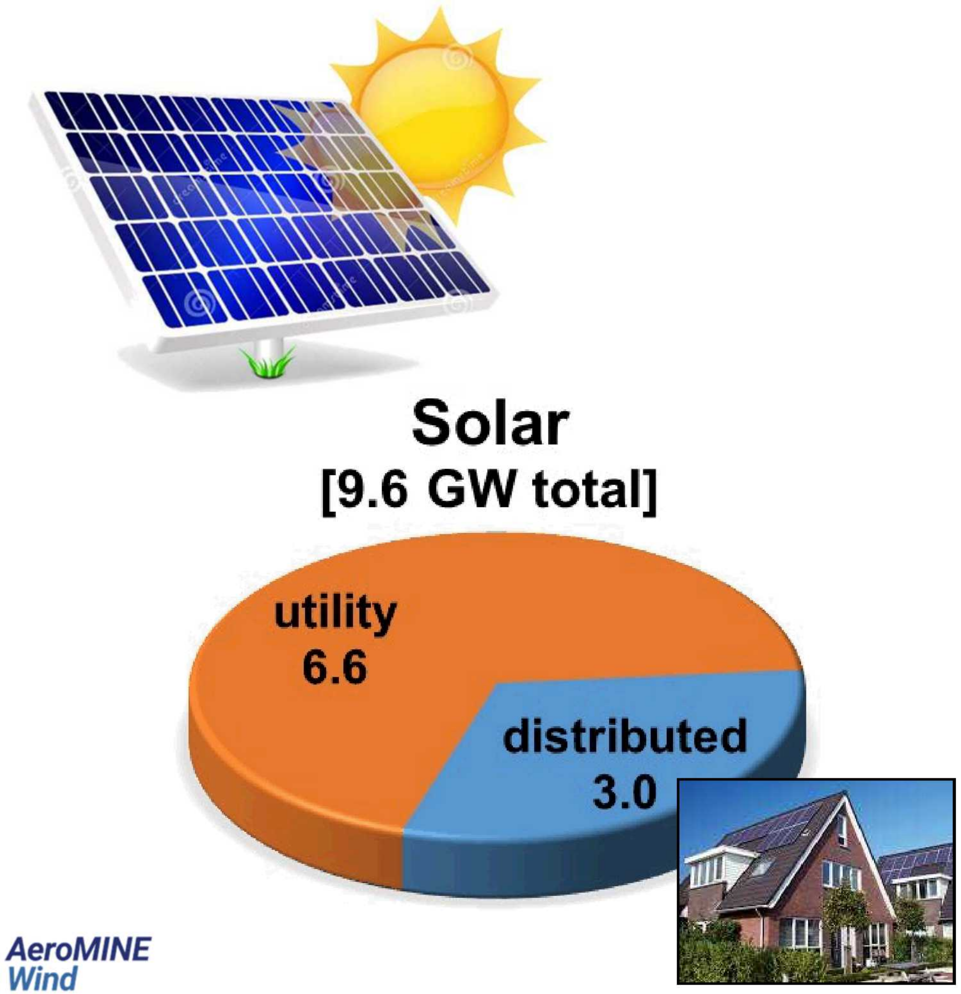
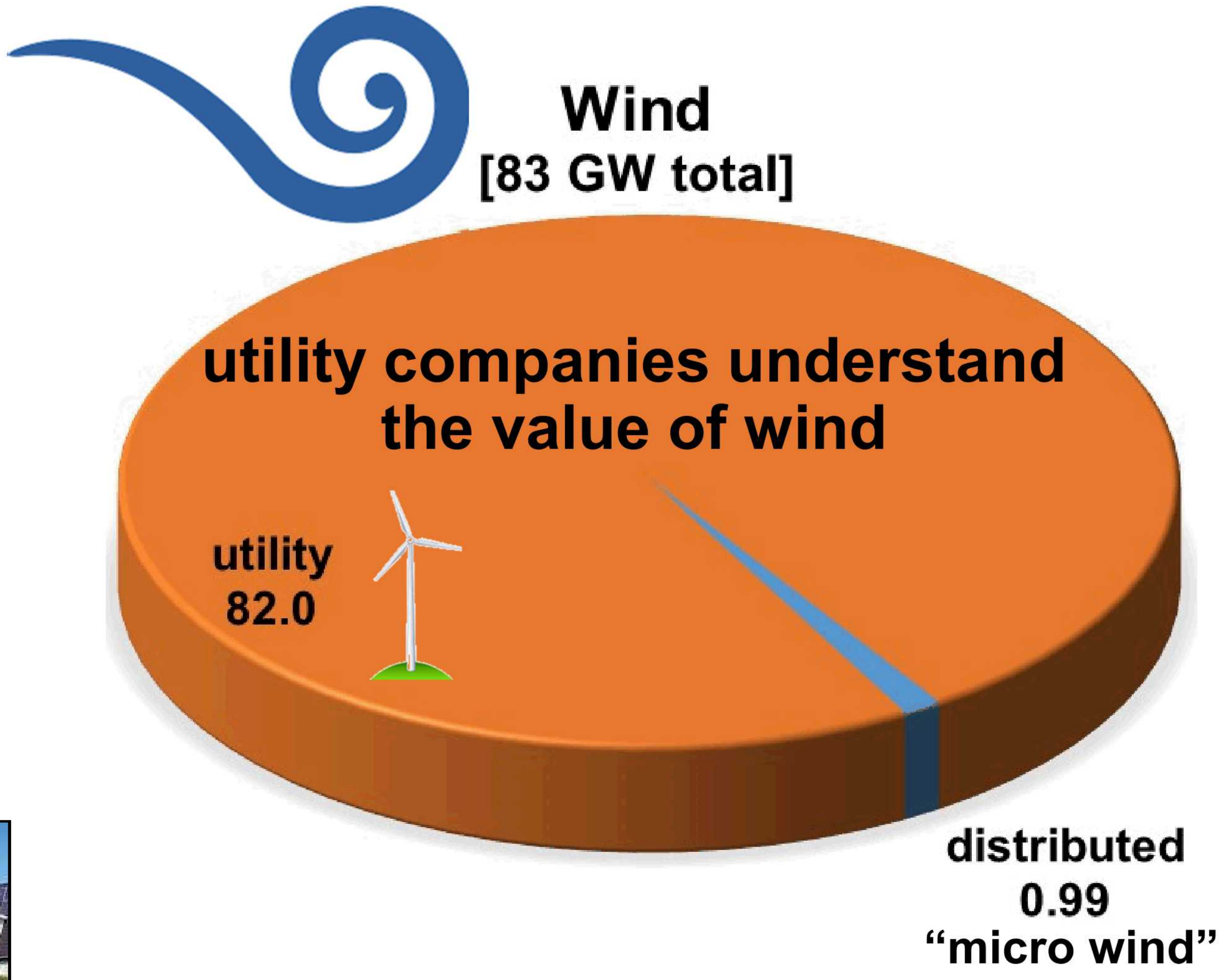
Untapped distributed wind market





Weaknesses of existing distributed wind

Small swept area
→ energetically ineffective

Many complex components
→ unreliable

Fast moving external blades
→ unsafe and noisy

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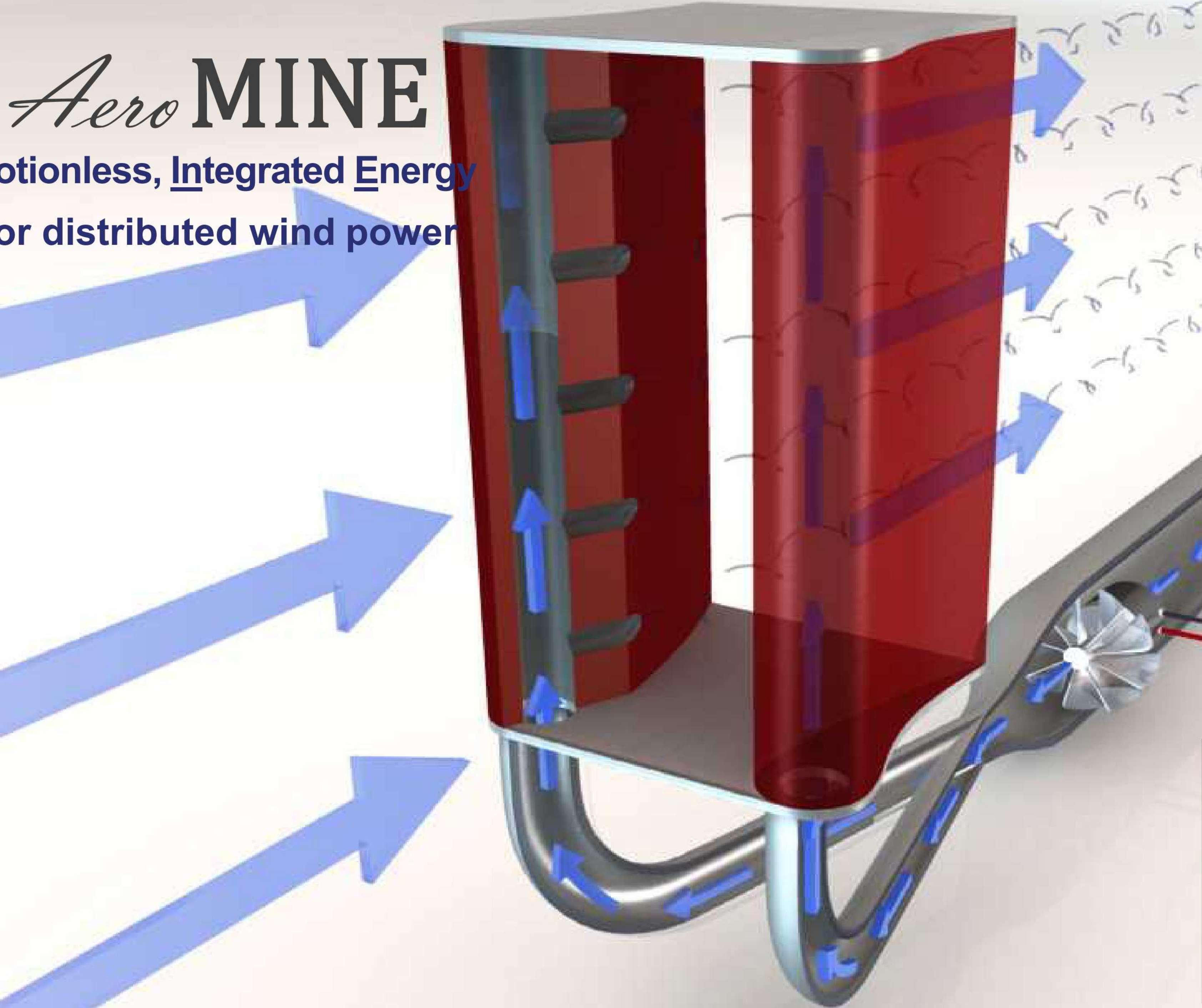
Motionless, Integrated Energy
for distributed wind power



Large swept area
→ **large power** ✓

No external moving parts
→ **reliable** ✓
→ **safe** ✓
→ **quiet** ✓

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Motionless, INtegrated Energy

Wind tunnel testing at ~1/6-scale (0.25 m chord)

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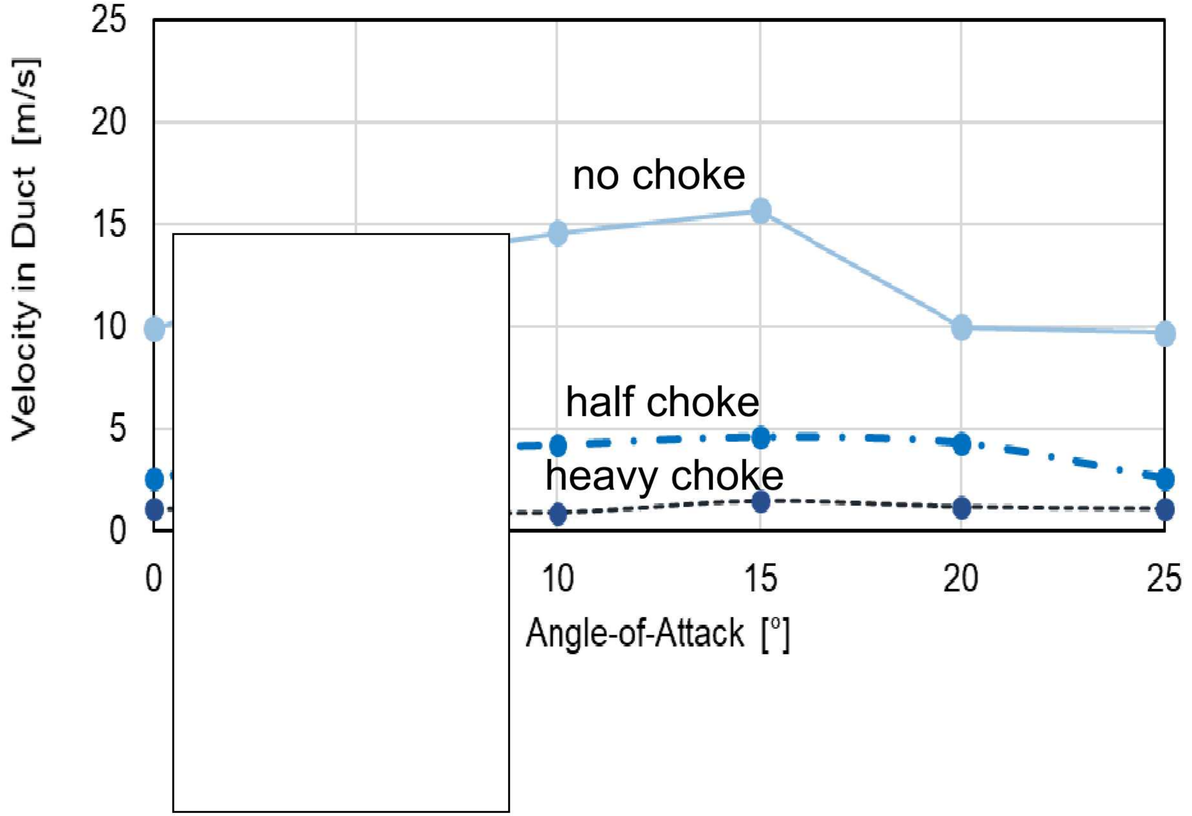
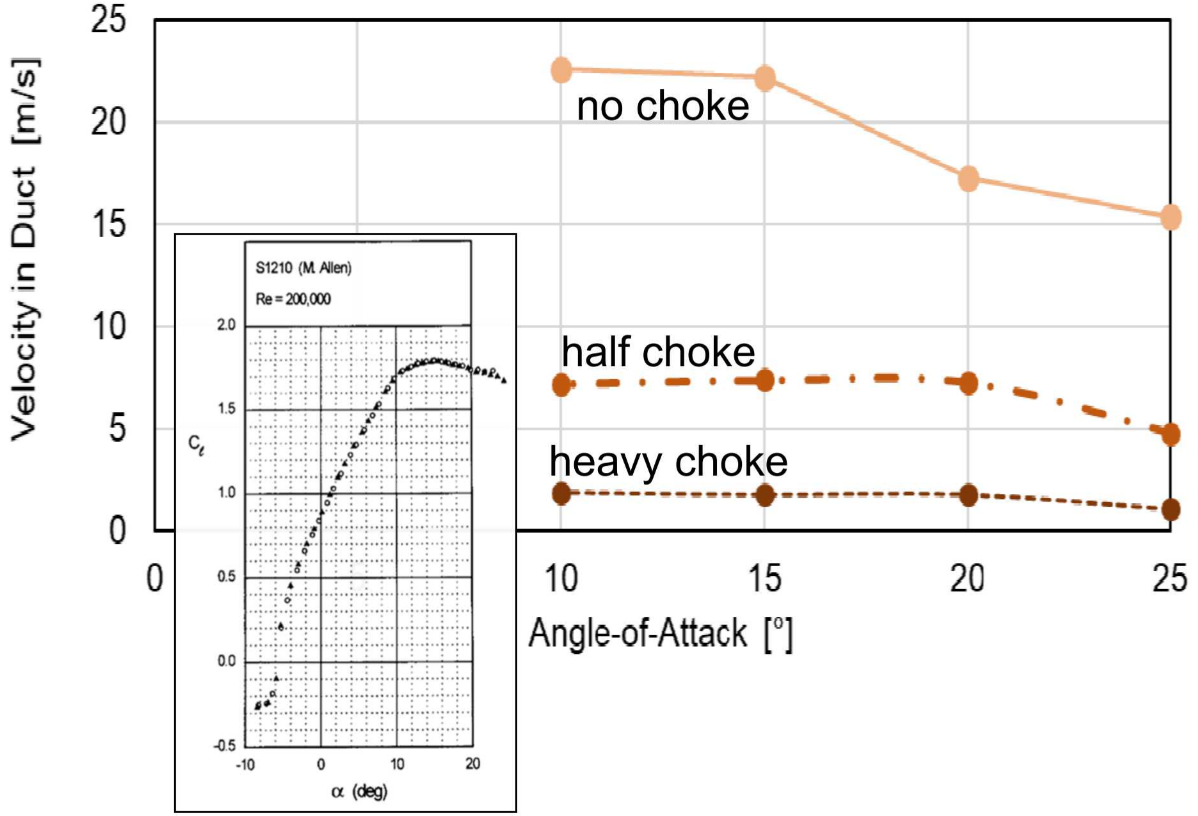
Optimum Angle-of-Attack at 1/6-scale (0.25 m chord)

S1210-based foil selected for excellent lift over wide ranges of *Re* and AoA

U_∞ = 10 [m/s], *Re* = 170,000



U_∞ = 15 [m/s], *Re* = 225,000



Selig, M.S., Guglielmo, J.J., Broeren, A.P. and Giguere, P. Summary of Low-Speed Airfoil Data, Vol. 1, 1995.

see Houchens, Marian, Pol and Westergaard, A Novel Energy-conversion Device for Wind and Hydrokinetic Applications. *Proc. ASME-JSME-KSME 2019 Joint Fluids Eng. Conf.*, AJKFLUIDS2019- 5542, San Francisco, 2019.

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1/3-Scale wind tunnel testing for power

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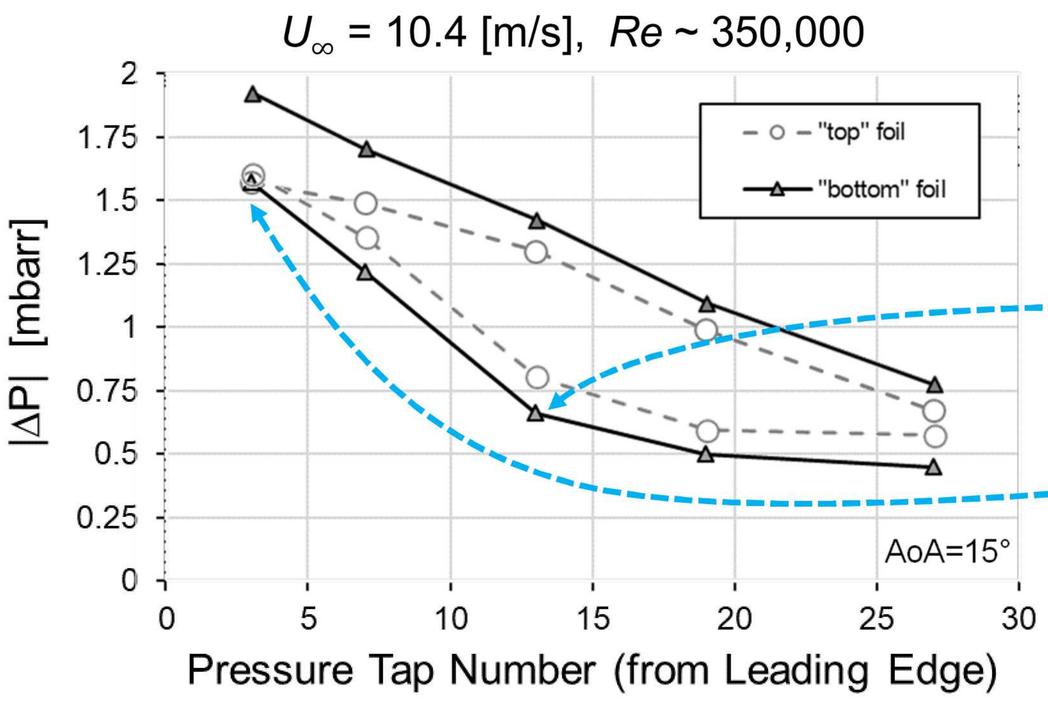
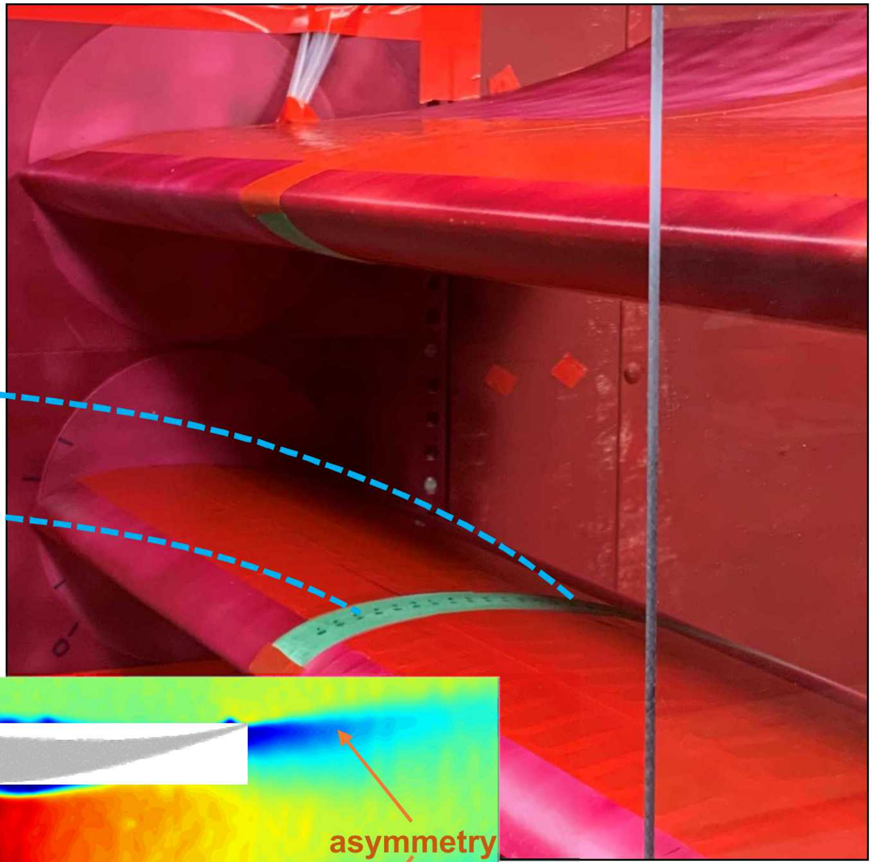
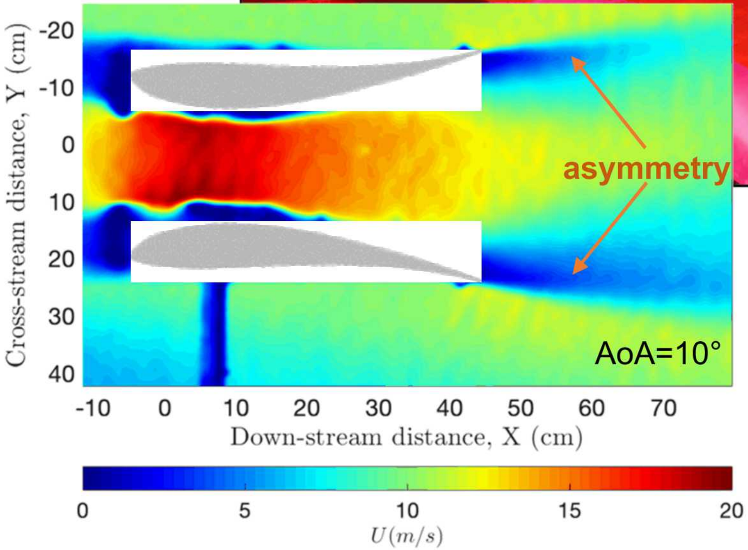
Airfoil pressure measurements on suction side

Static pressure measured by taps on surface with **all air-jets closed**







Asymmetry observed between foils

- confirmed to switch sides in repeats
- also observed in PIV, even at lower AoA

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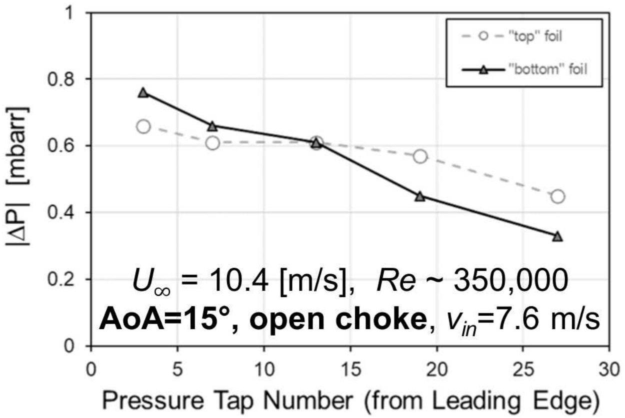
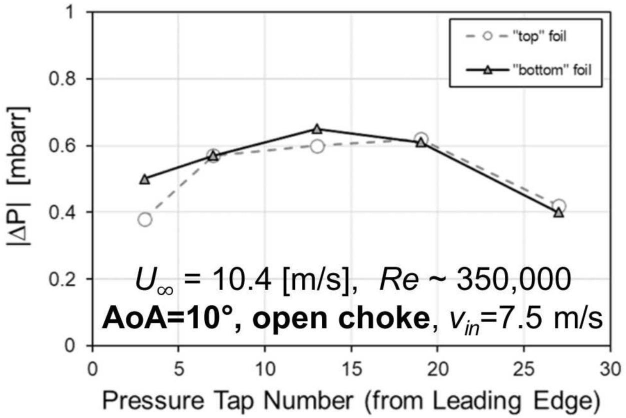
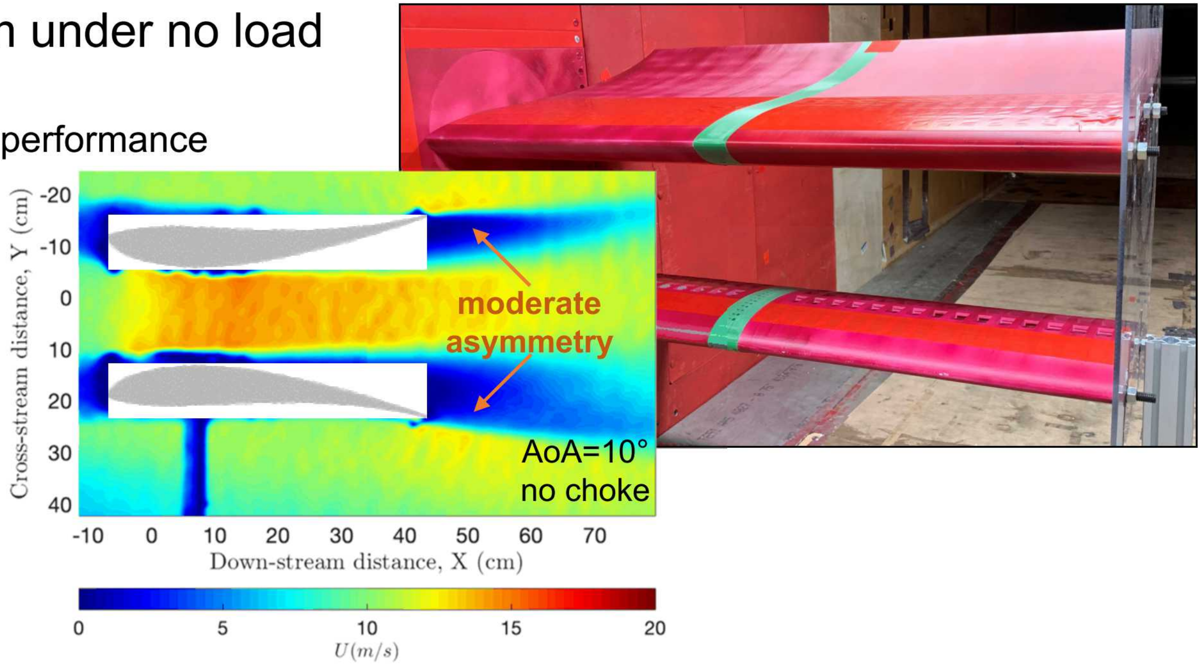
Pressure measurements during air-jet operation

Asymmetry also occurs with air-jets functioning and system under no load

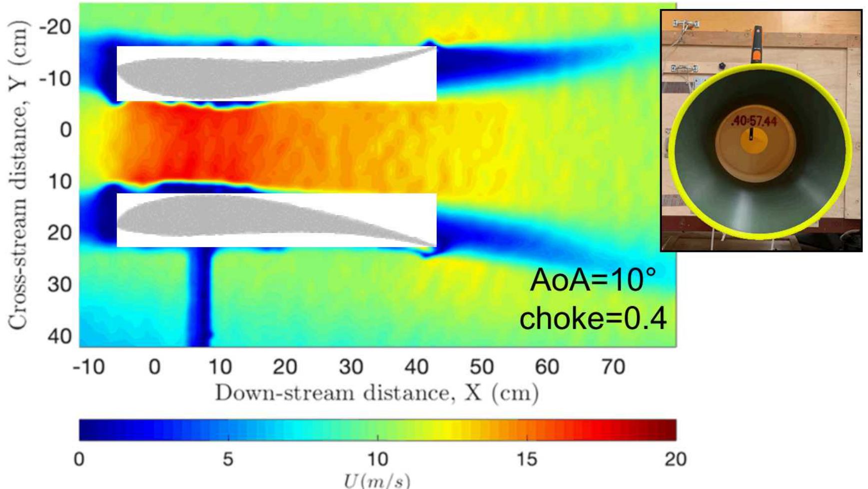
- fully open choke = no power production
- can reduce asymmetry by reducing AoA ⇒ pay a high price in performance

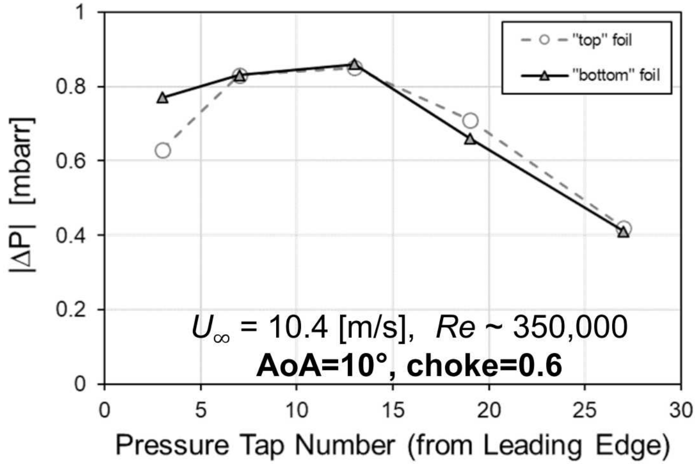






With air-jets functioning, instability and associated asymmetry can be lessened with a load (over a wide range)





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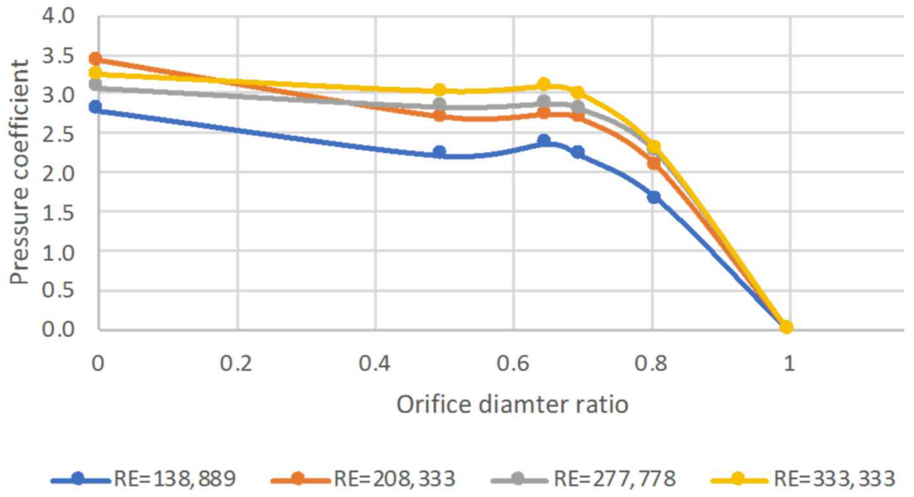
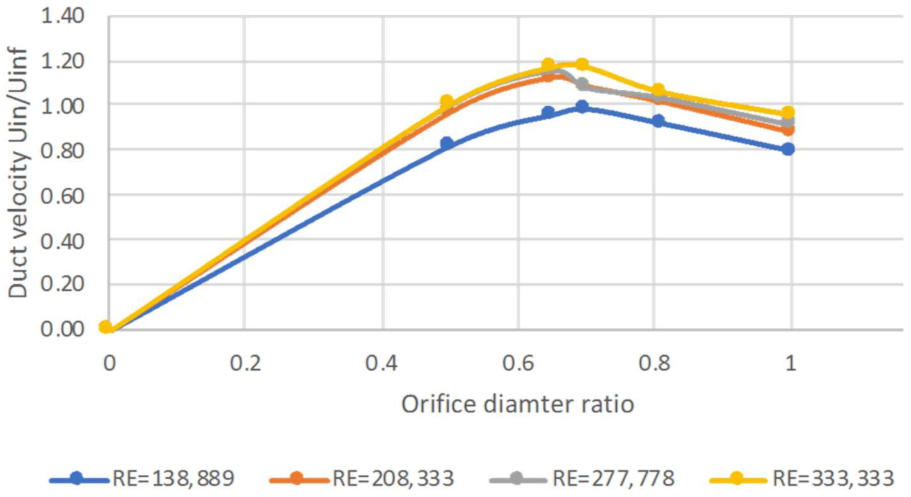
Power curves for stable operation

Mechanical power measured across inlet orifice by measuring pressure drop and velocity

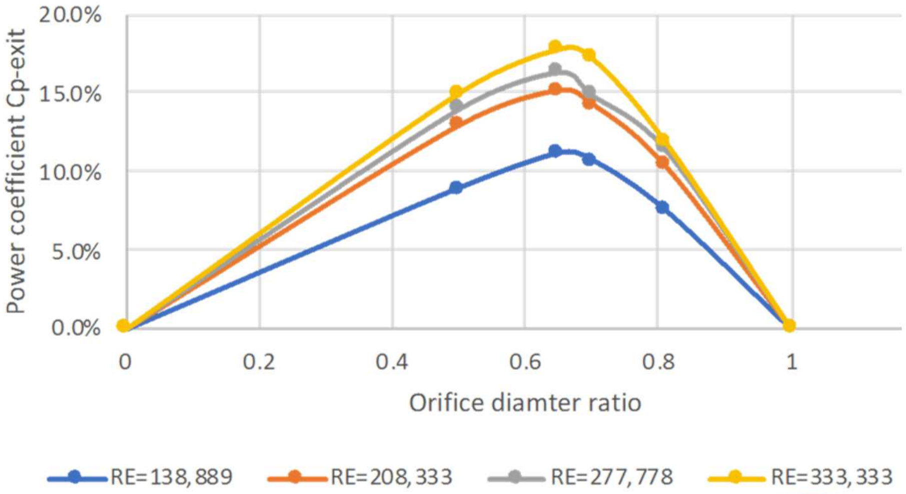




18% efficiency achieved in stable operation

- approximately 1/3 of Betz

- unstable mode hits nearly ½ Betz in symmetric operation



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Conclusions and future directions

Experimentally demonstrated

- optimum angle-of-attack
- not shown
  - optimum spacing between foils
  - scaling with length (slightly better than 2x increase with doubling height

Observed asymmetries likely due to flow instabilities

- reduces viable AoA range
- most dramatic in closed air-jet and no-load configurations

18% (~1/3 of Betz limit) mechanical efficiency achieved in stable operation

- ~1/2 of Betz limit intermittently achieved in unstable mode

Full-scale pilot planned for spring 2020

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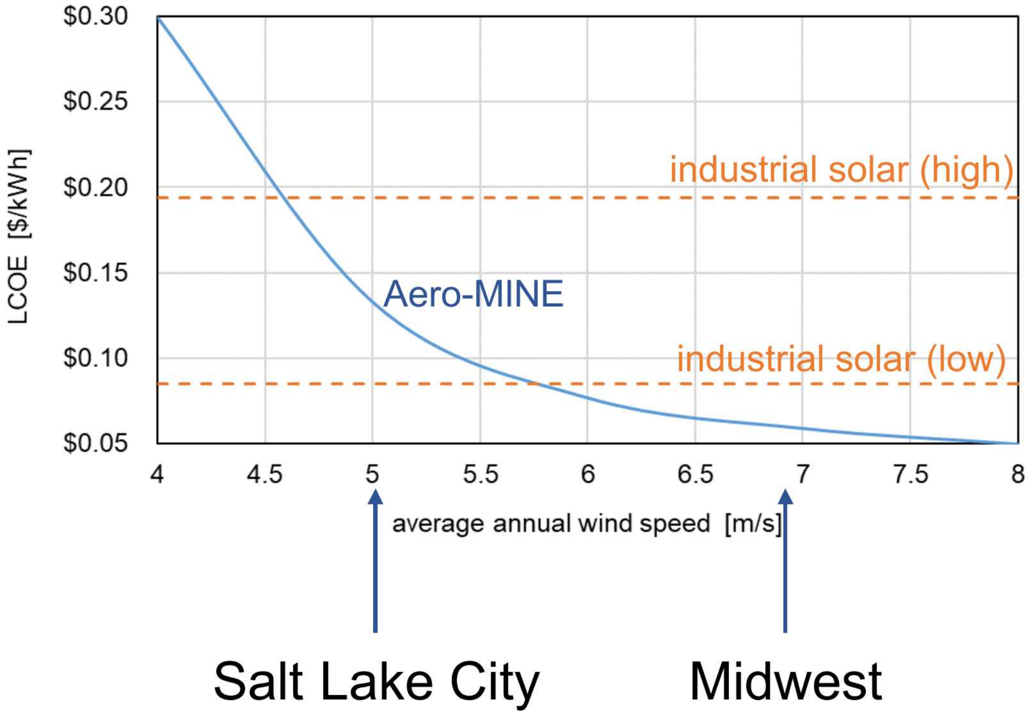
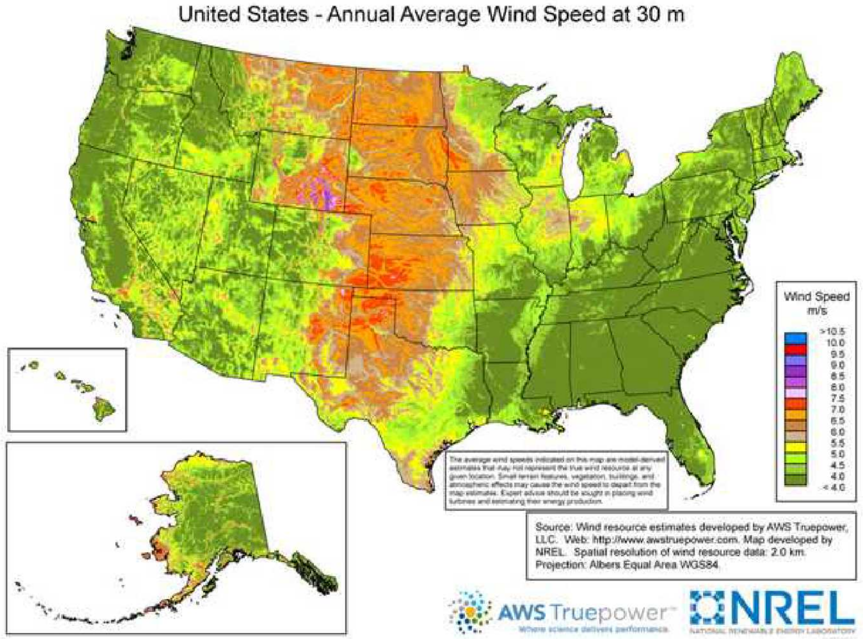
End Presentation

LCOE compared to solar (including O&M)





Aero-MINE is competitive or better than solar across much of U.S.

Production is more consistent, reducing strain on grid

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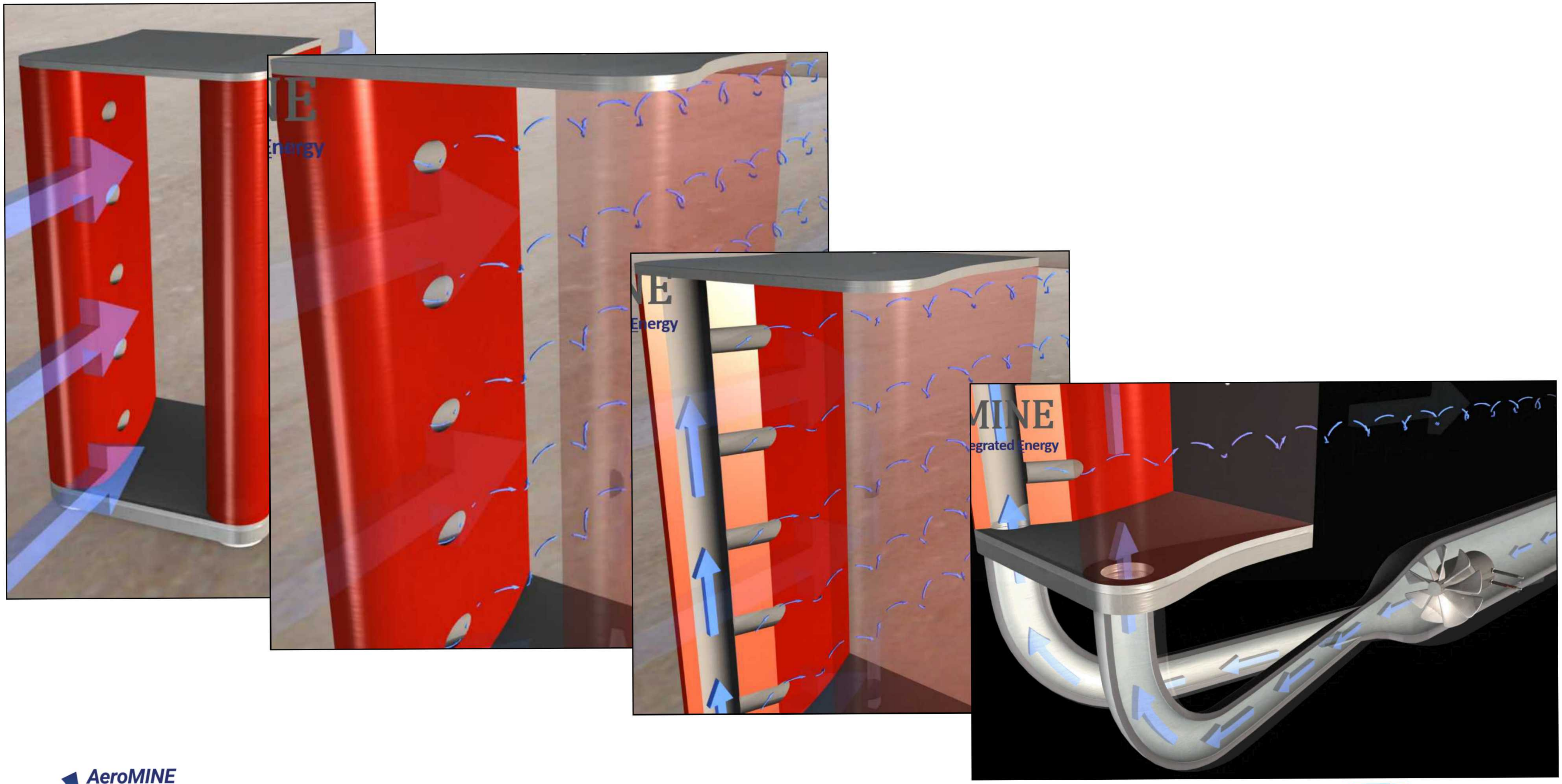

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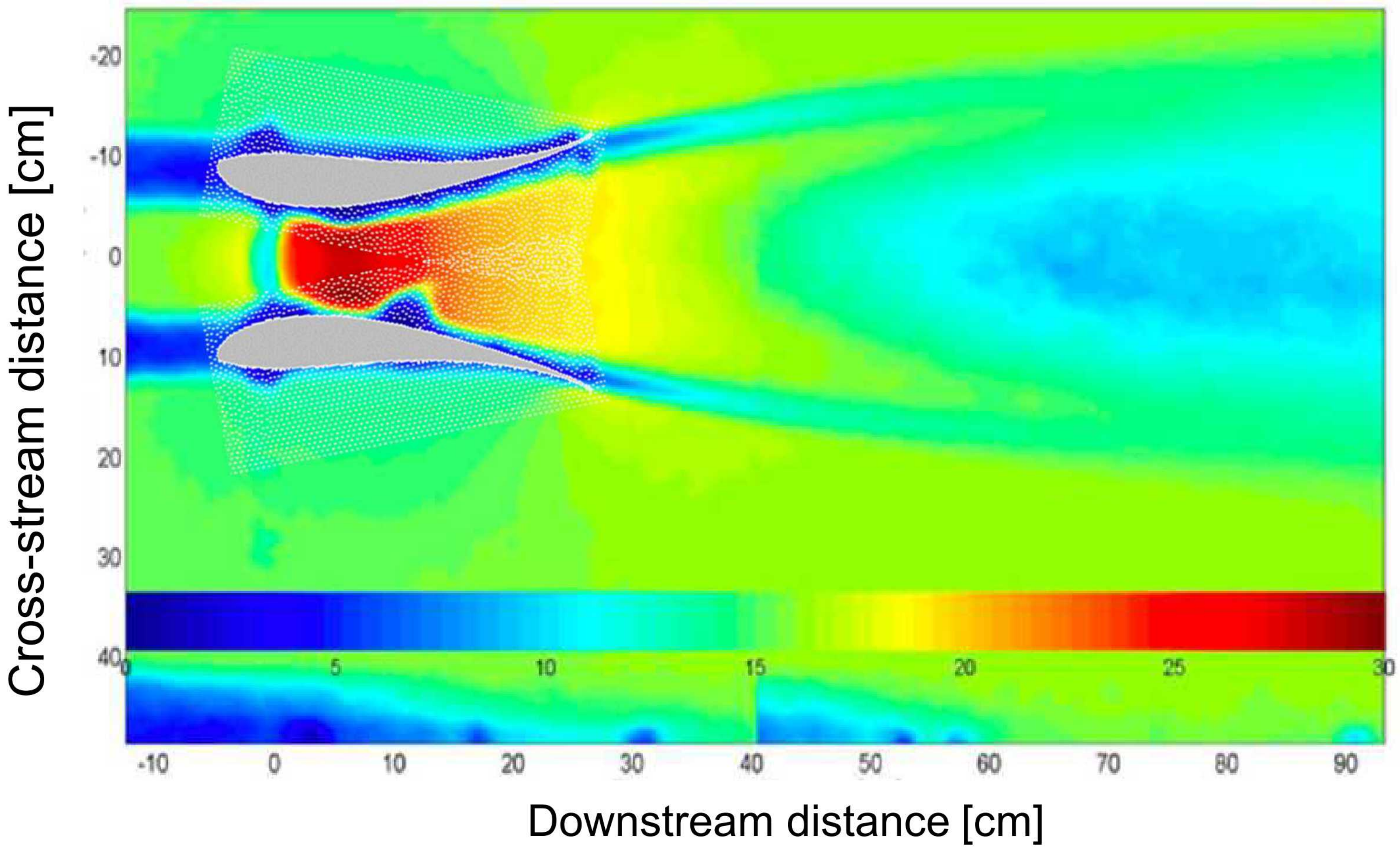
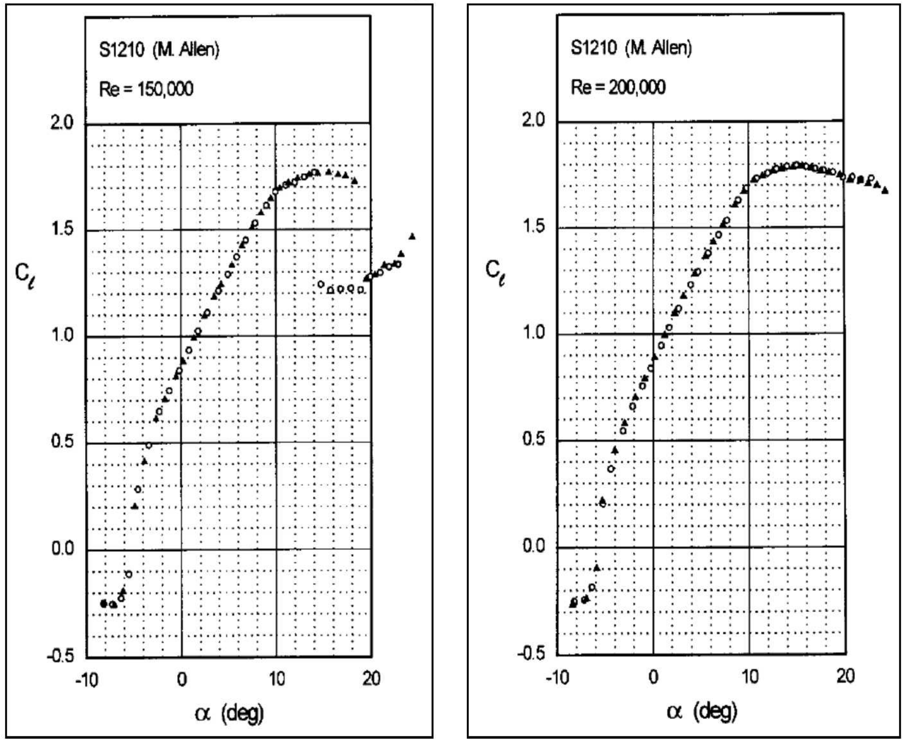
PIV flow field (1/6-scale) for S1210-based foils

U_∞ = 15 [m/s], *Re* = 225,000



S1210 foil selected for excellent lift over wide ranges of *Re* and AoA



Selig, M.S., Guglielmo, J.J., Broeren, A.P. and Giguere, P. Summary of Low-Speed Airfoil Data, Vol. 1, 1995.

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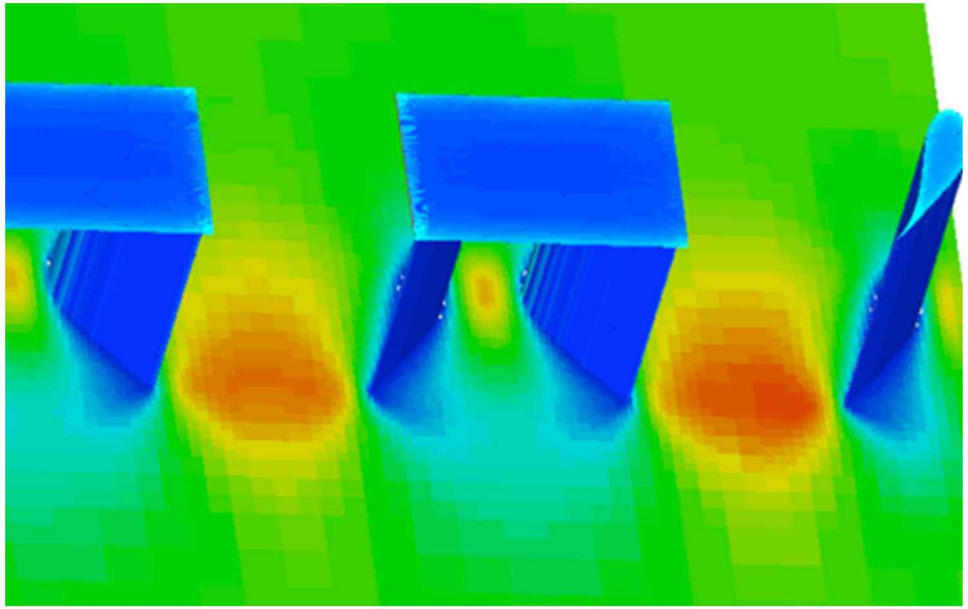
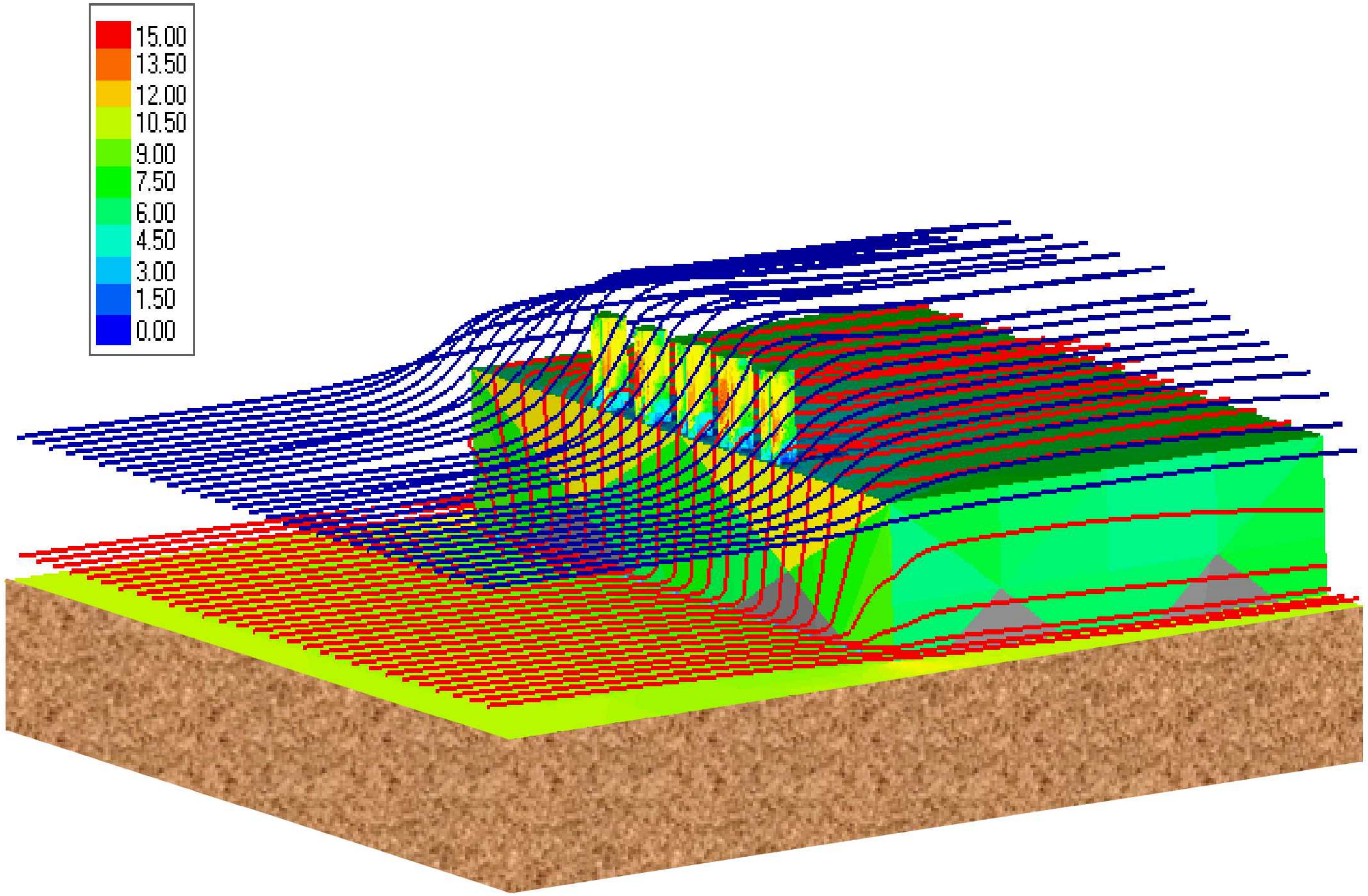
Modeling drives design



Multi-pair optimization studies



Enhanced performance from rooftop speedup

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Fundamental fluid mechanics

Pressure differential from inside to out of foils (across air-jets)

$$\Delta p = \frac{1}{2} \cdot \rho \cdot c_p(x) \cdot U_\infty^2 = \frac{1}{2} \cdot \rho \cdot \frac{1}{\gamma} \cdot u_{jet}^2$$

where γ is loss coefficient including energy extraction.

Power is product of pressure differential and volume flow $V_{jet} = u_{jet} \cdot A_{jet}$ through jets:

$$Power = \Delta p \cdot V_{jet}$$

Eliminating u_{jet} and Δp gives

$$Power = \frac{1}{2} \cdot \rho \cdot c_p(x) \cdot U_\infty^2 \cdot A_{jet} \cdot \sqrt{c_p(x) \cdot \gamma} \cdot U_\infty$$

Design and power correlation

For power given by

$$Power = \frac{1}{2} \cdot \rho \cdot c_p(x) \cdot U_\infty^2 \cdot A_{jet} \cdot \sqrt{c_p(x) \cdot \gamma} \cdot U_\infty$$

Normalizing by the maximum free stream available power $0.5\rho A_{exit} U_\infty^3$ gives a correlation for each AeroMINE design

$$Coef_{power} = c_p(x)^{3/2} \cdot \sqrt{\gamma} \cdot \frac{A_{jet}}{A_{exit}}$$

Experiments have shown γ is unique to each configuration (air-jet design, spacing and AoA)

- roughly constant with incident windspeed

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Retailer and Warehouse Implementations

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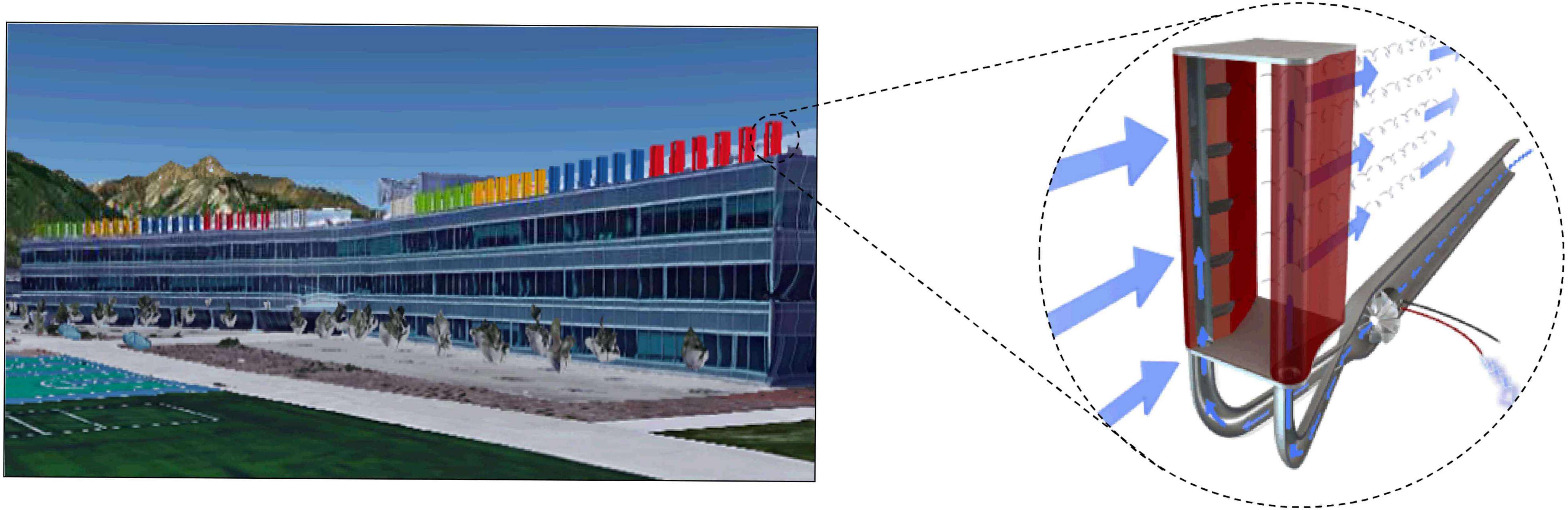
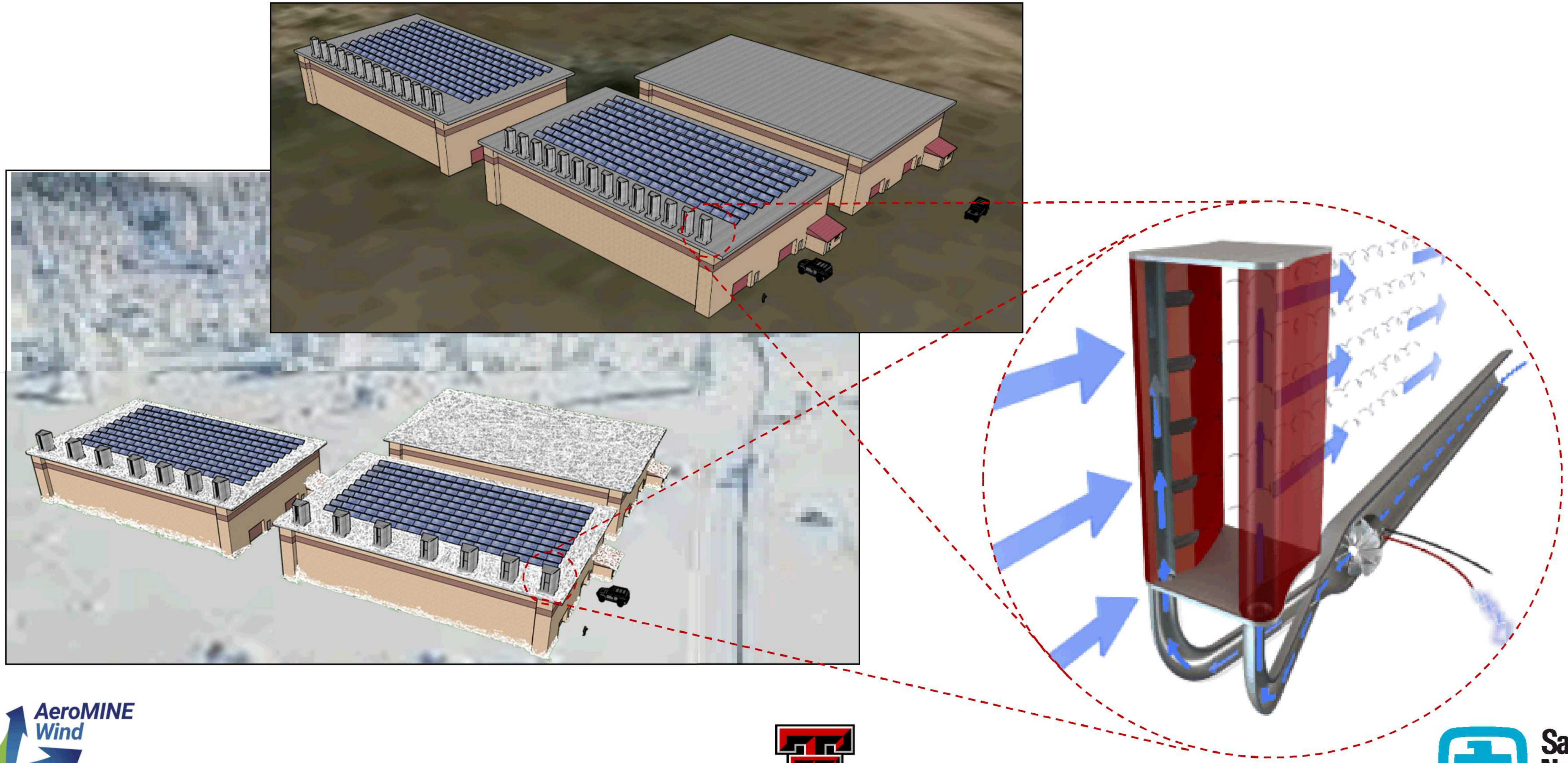
Office Building Implementations



Remote Power Implementations



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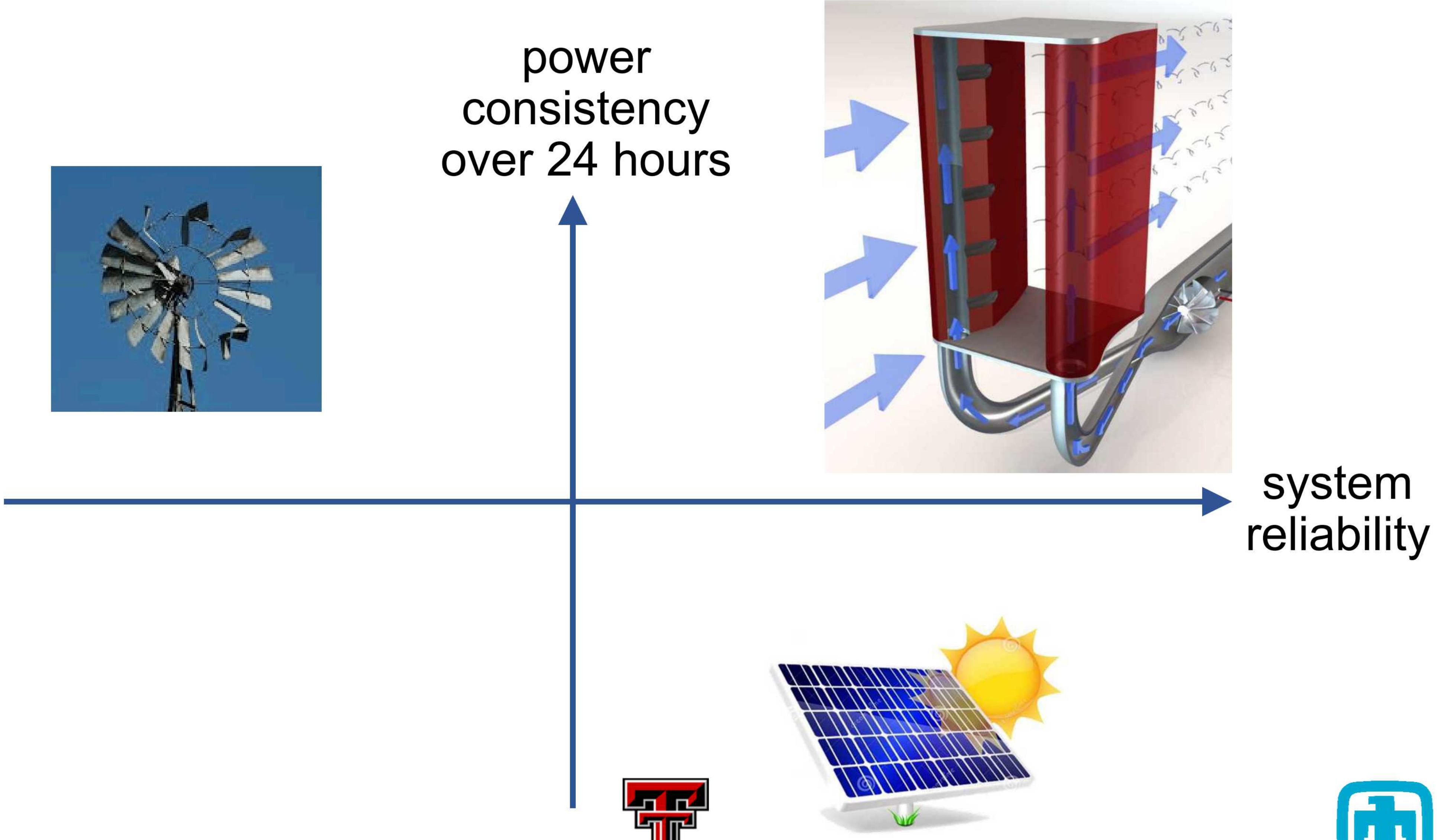
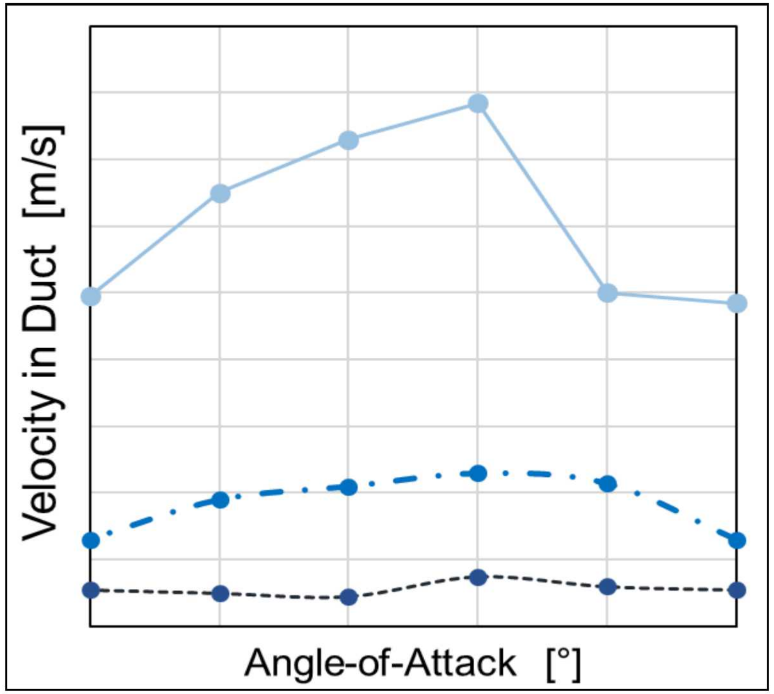
Technical advantages



Wind tunnel experiments verify performance

patents pending design



Confirms expected optimum geometry