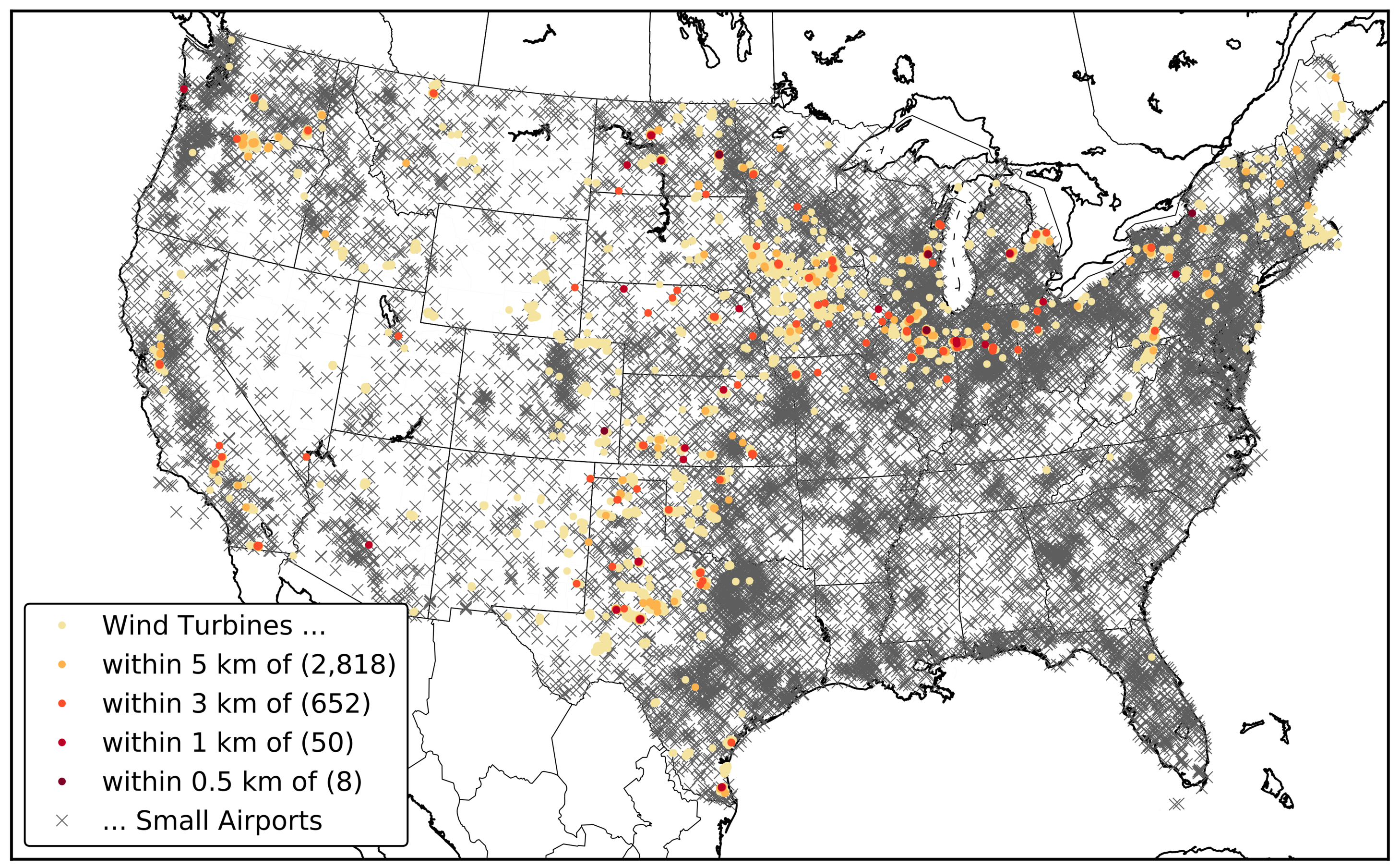
Do wind turbines pose roll hazards to light aircraft?

Jessica M. Tomaszewski[1], Julie K. Lundquist[1,2], Matthew J. Churchfield[2], and Patrick J. Moriarty[2]
[1]Department of Atmospheric and Oceanic Sciences, University of Colorado – Boulder; [2]National Renewable Energy Laboratory
Contact: Jessica.Tomaszewski@colorado.edu

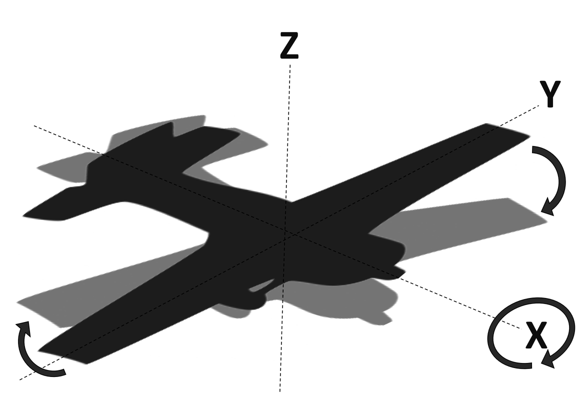
Introduction

Recent general aviation (GA) airport data (OurAirports; FAA, 2016) and wind turbine data (USGS, 2014) show that:
- There are 48,000+ turbines total in the United States (below)
- 40% are within 10 km of a small airport; 5% are within 5 km



Wind turbines create wakes (below) characterized by wind speed deficit, increased turbulence downwind

Rolling moment = torque about x-axis, caused by turbulence in wind field



Motivation

Concerns for wake-generated roll hazards have yielded conflicting estimates on the extent of wakes' hazardous influence:
- KU study suggests that wind turbine wakes pose a significant roll hazard to GA aircraft as far as **2.84 miles** downwind [1]
- CAA study indicates that the wake poses no roll hazards for aircraft 5 rotor diameters (**0.25 miles**) downwind [2]

The KU findings have been used in multiple states to limit wind energy development:
- Pratt wind farm project in Kansas was relocated further away from the airport [3]
- Used as a warning to aviators in Virginia [4]

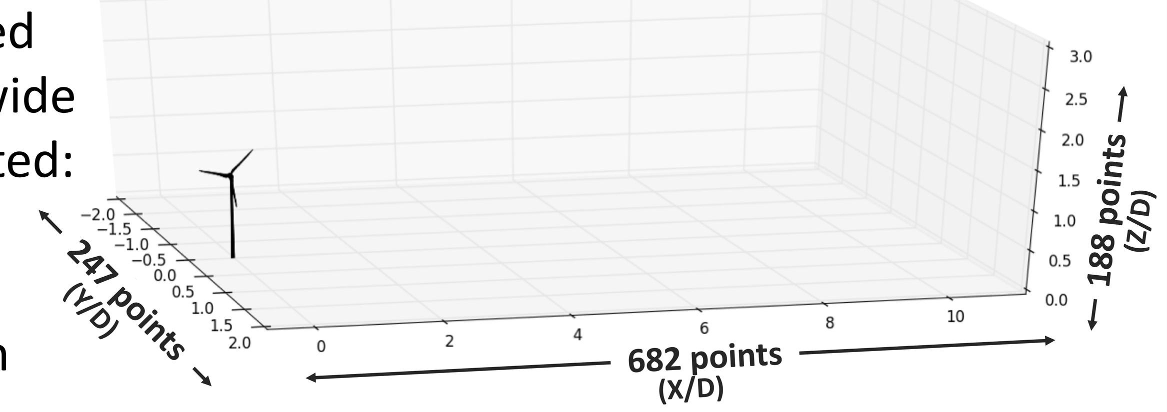
Simulations

Model used: Simulator fOr Wind Farm Applications (SOWFA)
- Based on OpenFOAM, a library of LES solvers

Turbine introduced into model: DOE GE 1.5 MW SLE
- Rotor diameter (D) = 77 m
- Hub height = 80 m
- Widely deployed turbine worldwide

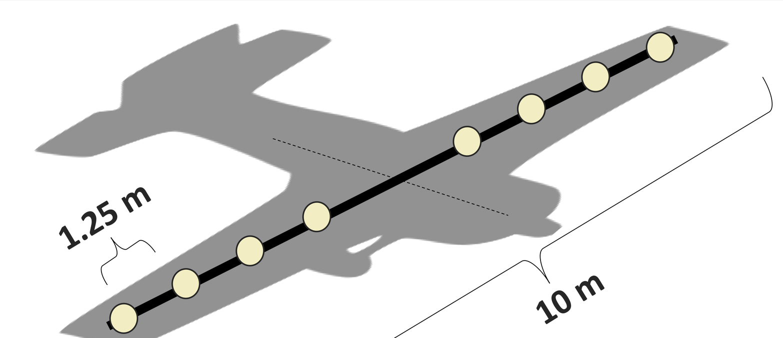
Conditions simulated:
- Neutral, 7 m/s
- Stable, 9 m/s

Resolution: 1.25 m



Data Analysis

We represent a typical GA aircraft (Cessna 172) as a line in LES data
- Wingspan ≈ 10 m
- Planform area (S) ≈ 16 m^2
- Aspect ratio (β) ≈ 7



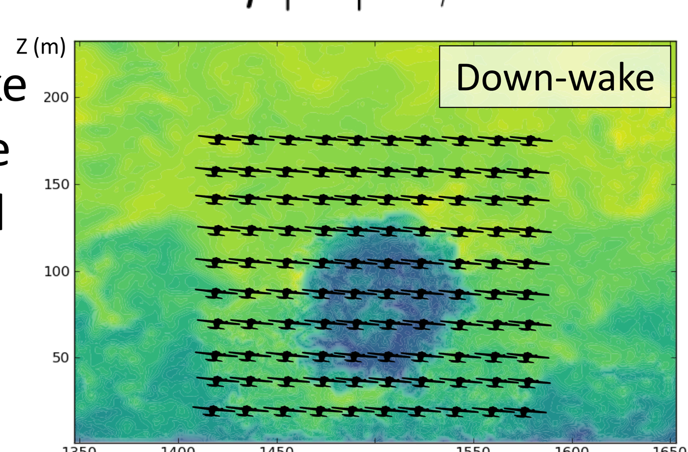
At each point determine:

1. Angle of attack
$$\alpha \equiv \tan^{-1}\frac{w}{V}$$
2. Lift coefficient
$$C_l = 2\pi\alpha + C_{lo}$$
3. Lift
$$L_i' = 0.5 C_l \rho |\vec{V}|^2 A$$

Integrate L_i' across points to obtain:

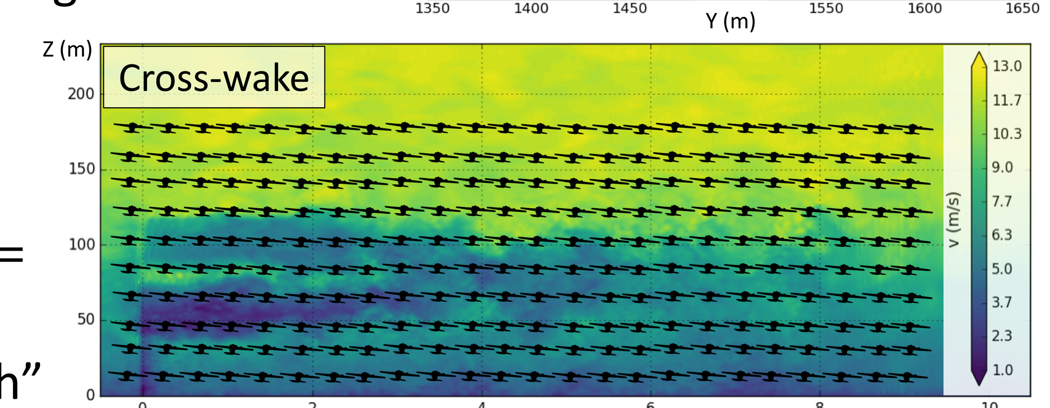
4. Total rolling moment
$$M_{roll} = \sum_{i=1}^{N} L_i' r_i$$
5. Rolling moment coefficient
$$C_{roll} = \frac{2M_{roll}}{\rho|\vec{V}|^2 S\beta}$$

We define 540 flight tracks in down-wake and cross-wake orientations through the LES data to sample the wind vectors and make the above calculations.



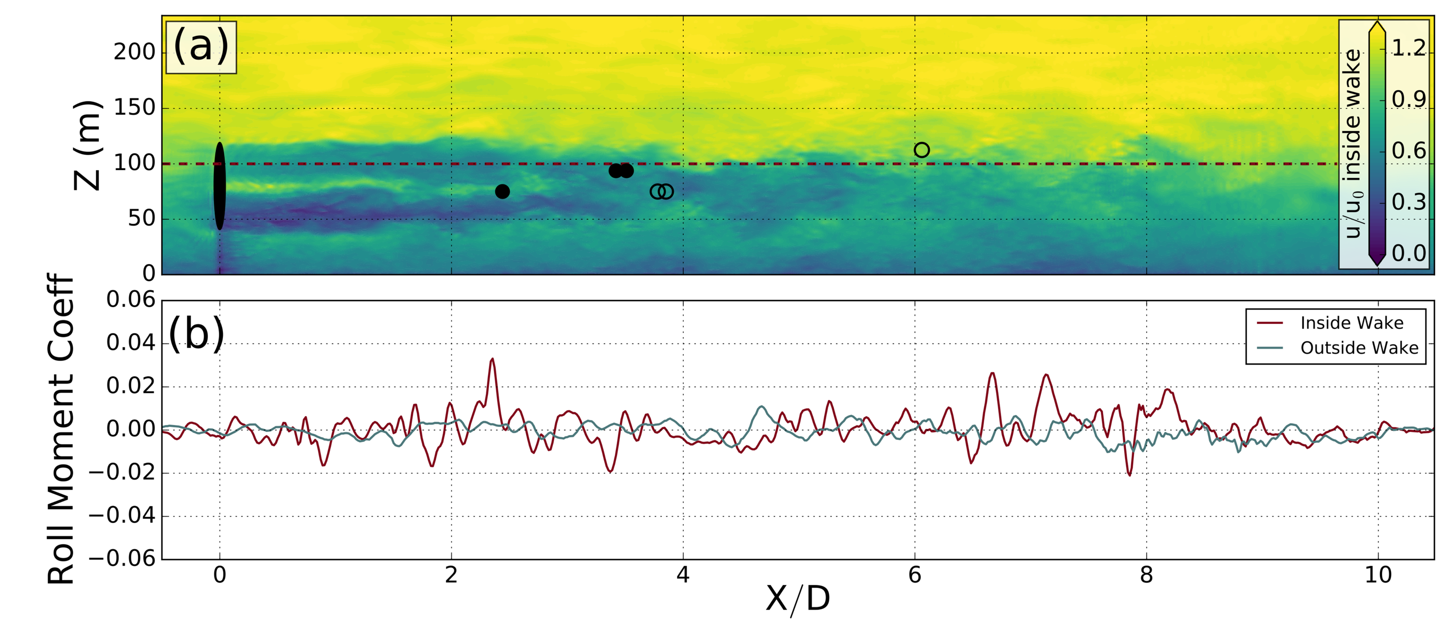
C_{roll} is calculated for all 540 aircraft transects for 100 s, yielding 17,688,000 roll hazard calculations.

- $|C_{roll}| < 0.1$ = "low"
- $0.1 < |C_{roll}| < 0.28$ = "medium"
- $|C_{roll}| > 0.28$ = "high"

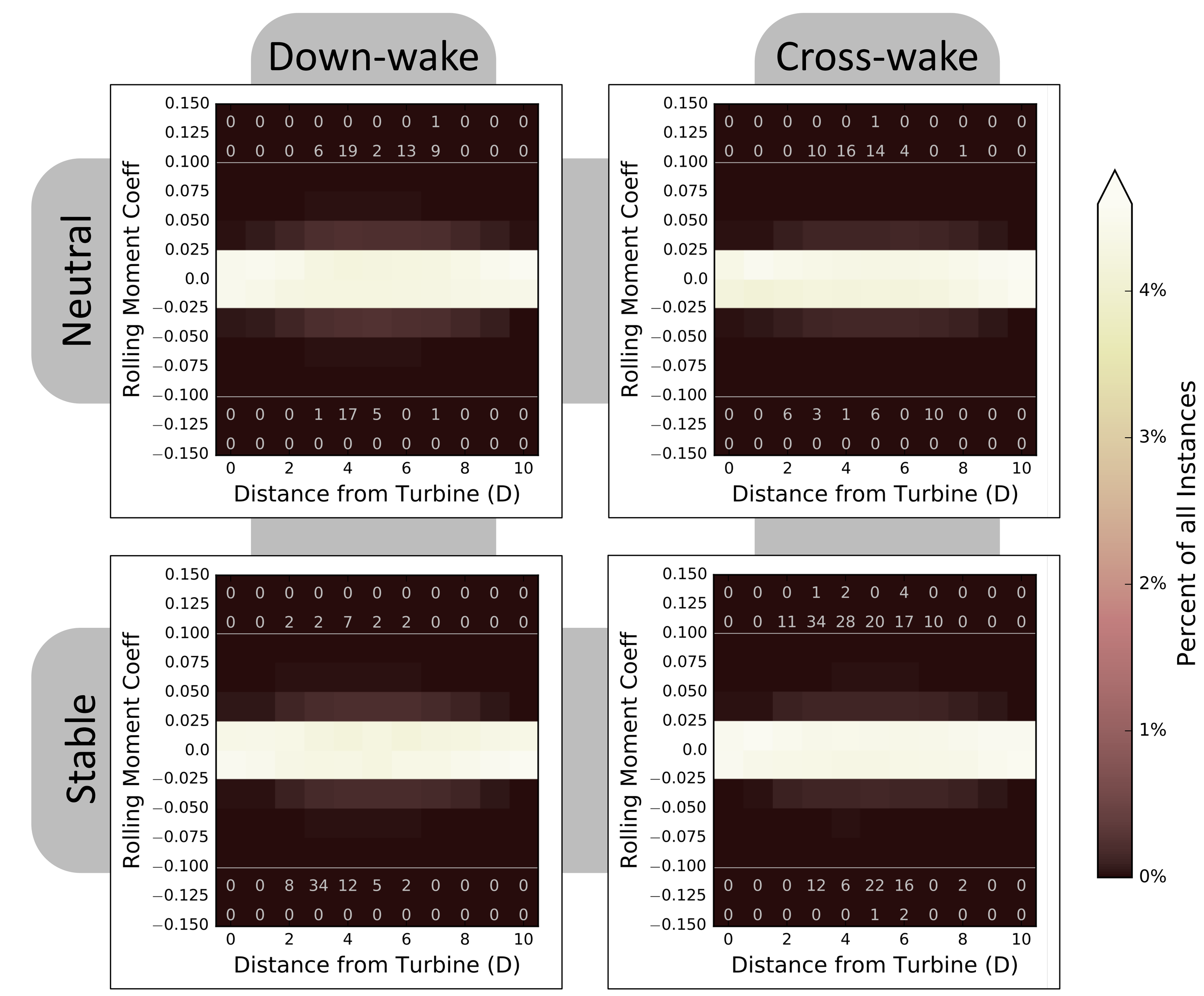


Results

Sample flight paths in and out of the wake at z = 100 m in stable case:



Summary of all flight paths through the wake:



Conclusions

1. As expected, aircraft within a turbine wake experience higher rolling moments than those outside the wake
2. However, **>99.99%** of rolling moment instances are classified as **"low" roll hazards** in both stabilities and flight orientations
3. The largest rolling moments occur most frequently about 5D downwind in both stability conditions

✈ Future work could include: higher wind speeds, multiple turbines, experimental validation with lidar, RPAS

References
[1] Mulinazzi, T. E. and Z. C. Zheng (2014). "Wind Farm Turbulence Impacts on General Aviation Airports in Kansas". Technical Report: *K-TRAN: KU-13-6.* [2] Wang, Y., M. White, and G. Barakos (2015). "Wind Turbine Wake Encounter Study. CAA Technical Report". [3] Williams, M. (2014). Wind farms could endanger small aircraft, study says — The Kansas City Star. [4] Hamilton, P. (2014). "State Aviation Journal - Spring 2014". *Issuu.*

Acknowledgments
This work was supported by a seed grant from Renewable and Sustainable Energy Institute (RASEI) with cooperation from the National Renewable Energy Laboratory (NREL). Computing resources for hazard calculations were provided by the Extreme Science and Engineering Discovery Environment (XSEDE), supported by National Science Foundation Grant No. ACI-1053575. JMT's work was supported by the National Science Foundation Graduate Research Fellowship under Grant No. 1144083.