

Estimating the Likelihood of Bat Barotrauma using Computational Simulations and Analytical Calculations

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The Problem

Given that bats have the remarkable ability to detect and avoid moving objects through echolocation [1], the high fatality rate of bats around wind turbines is somewhat surprising. One proposed explanation is the barotrauma hypothesis [2], which predicts that bats are injured and possibly killed by hemorrhaging in the lungs that results from sudden exposure to the low-pressure regions that form near the suction side of turbine blades and in blade tip vortices.

To date, few studies have investigated the likelihood that barotrauma is a significant contributor to bat deaths from an aerodynamics perspective, where the actual pressure fields around operating turbines are considered.



(Top) The hoary bat is one of the most common bat species killed by wind turbines. Courtesy of Michael Durham/Minden Pictures, Bat Conservation International

(Left) The tip vortex of an operating wind turbine visualized using smoke flow visualization. Photo by Lee Jay Fingersh, NREL 09996

Objective

The project goal is to study the aerodynamic characteristics of a modern utility-scale wind turbine to estimate the likelihood of barotrauma as a significant cause of turbine-related bat deaths.

Methods

Blade suction-side pressure estimates: computational fluid dynamics (CFD) simulations and analytical calculations were performed to estimate the pressures that bats experience when flying near the suction side of a turbine blade.

Tip vortex pressure estimates: Analytical vortex theory calculations and CFD simulations were performed to estimate the pressure bats experience when flying through the tip vortex.

Turbine model and operating conditions:

- RThe 1.5-MW WindPact turbine model was used for all analysis work
- RWind speeds between 5 m/s (turbine cut in) and 15 m/s (highest wind speed at which bats are expected to fly) were considered

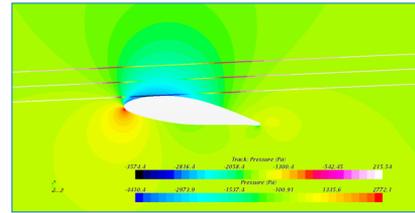
Estimating harmful pressures:

- RPressures that bats are predicted to experience were compared to survival pressures for rats to estimate the likelihood of barotrauma fatality because no bat data are available
- RA conservative estimate is that rats can survive a pressure drop of 23 kPa [3].

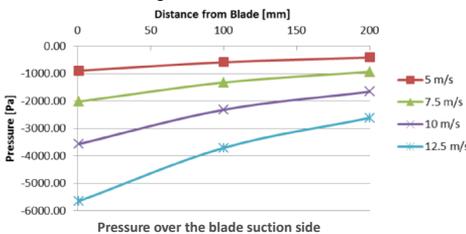
Blade Suction-Side Pressure

Two-dimensional RANS CFD to estimate pressure near the blade suction-side surface:

- RFlight paths are considered at <1 mm, 100 mm, and 200 mm from the blade surface
- RFour wind velocities are considered: 5, 7.5, 10, and 12.5 m/s
- RA worst-case scenario at 90% blade span is considered
- RA grid study is performed to confirm solution convergence.



Track pressure and fluid dynamic pressure at an oncoming flow velocity of 12 m/s (kPa)



Maximum Pressure Drops at 12 m/s (kPa)

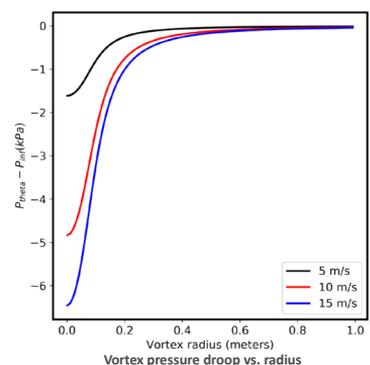
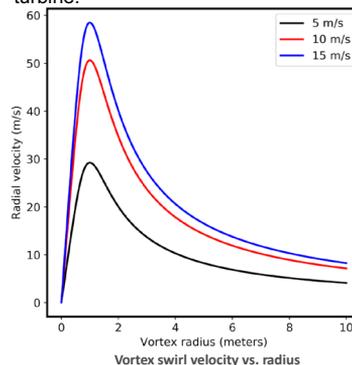
CFD	Bernoulli theory check calculation
5.56	5.54

Tip Vortex Pressure

Analytical vortex model: A second-order Vatistas vortex model was used to calculate the vortex pressure and swirl velocity following the methods of Moriarty [4]. In the equation to the right, the vortex strength (Γ) was calculated using the blade element momentum theory, and the vortex core (r_c) was assumed to be 0.05 times the mean chord of the 1.5-MW WindPact turbine.

$$v_{\theta} = \frac{\Gamma_{vortex}}{2\pi r_c} \frac{\bar{r}}{\sqrt{1 + \bar{r}^4}}$$

$$p_{vortex} - p_{\infty} = \frac{\rho \Gamma^2}{8\pi^2 r_c^2} \left[\tan^{-1} \left(\frac{r^2}{r_c^2} \right) - \frac{\pi}{2} \right]$$



Discussion, Conclusions, and Future Work

- RPressure drop experienced near the suction side of the turbine blade is a **factor of four lower than the lethality threshold for rats** at a wind speed of 12.5 m/s
- RThe **low-pressure region over the blade suction side is extremely localized** → bats that experience the low-pressure region are likely to impact the blade
- RThe minimum pressure in the tip vortex is approximately a **factor of three lower than the lethality threshold for rats** at a wind speed of 12.5 m/s
- RIt is unknown how bat survival pressure correlates to that of rats → follow on work is needed in this area
- ROverall, it seems **unlikely that barotrauma is a significant contributor to turbine-related bat deaths.**

References

[1] P. H.-S. Jen and J. K. McCarty, "Bats avoid moving objects more successfully than stationary ones," *Nature*, vol 275 1978.
 [2] E. F. Baerwald, G. H. D'Amours, B. J. Klug, and R. M. R. Barclay, "Barotrauma is a significant cause of bat fatalities at wind turbines," *Curr. Biol.*, vol. 18, no. 16, pp. R695–R696, Aug. 2008.
 [3] Houck, D. 2012, "Computational fluid dynamics simulations of bats flying near operating wind turbines: Quantification of pressure-time histories of likely flight paths." The U.S. Department of Energy Office of Science, Office of Workforce Development for Teachers and Scientists Application Review System, https://www.nationalwind.org/wp-content/uploads/assets/research_meeting_ix_presentations/7_1_Houck.pdf.
 [4] Moriarty, P. "The strength of a wind turbine tip vortex." Unpublished report, 2005.