

A Computational and Analytical Study of Bats Flying near Wind Turbines: Implications Regarding Barotrauma



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SUMMARY OF BAROTRAUMA STUDIES

Trauma caused by rapid changes in atmospheric pressure due to pressure drops around operating wind turbines

Summary of barotrauma studies:

- Baerwald found that 90% of bats recovered in one study had injuries inconsistent with impact trauma alone
- Grodsky found that 80% of carcasses dropped off a nacelle had no new broken bones
- Rollins' forensic pathology examination suggests that barotrauma is, at best, a minor etiology

There is no reference data for survivable pressure-time histories for bats

Best comparisons are studies on blast overpressure and blast underpressure

- Studies put mammals in shock tubes and expose them to positive and negative shock waves

WHAT ARE THE SURVIVABLE PRESSURES FOR MAMMALS?

Blast overpressure:

- Is pressure change pressure change?
 - Divided into “long” and “short” duration blasts by mortality
 - If long, peak pressure is the only factor in survivability
 - If short, peak pressure and duration matter (animals can withstand higher pressures if duration is short enough)
- Lethal dose scales with animals' masses
 - Studies used mice, which have same mass as bats
- 0% mortality in mice for overpressures below 30 kPa

Blast underpressure:

- Used rats, which are 10 times heavier than bats
- Rats survived pressure drops as large as -64.2 kPa without injury
- Correlation suggests that 30 kPa of overpressure is equivalent to -23 kPa of underpressure
- Injuries are comparable between underpressure and overpressure

METHOD

Performed 2D and 3D simulations using Star CCM+ to predict pressure fields around rotating turbine blades from a typical utility-scale turbine in current use

- 2D simulations: Evaluate pressure drop on the suction side of the turbine
- 3D simulations: Evaluate pressure drop in trailing tip vortex of the turbine

Used Lagrangian particle tracking to study possible pressure-time histories experienced by bats flying near operating wind turbines

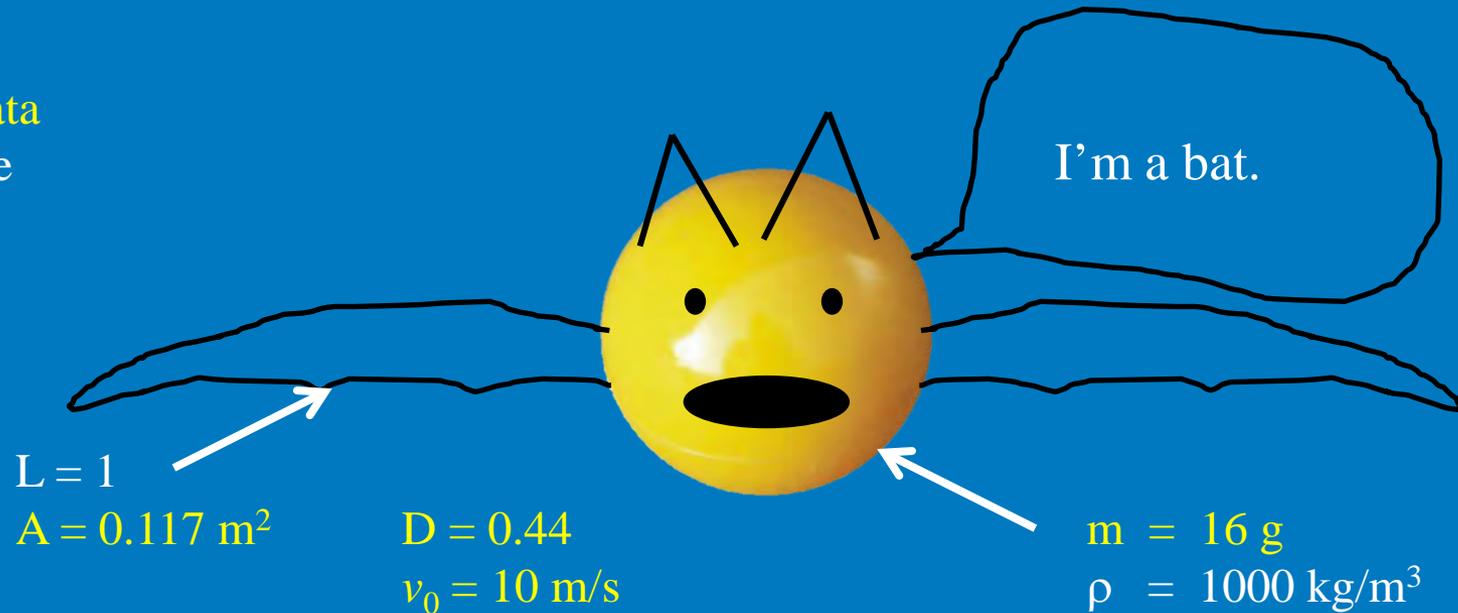
- “Bat” particles are injected into the flow field and pressure is tracked along their paths

Compared tracked pressures to measured data from overpressure and underpressure studies on other mammals to determine potential for barotrauma

LAGRANGIAN PARTICLE TRACKING

Particle's trajectory is determined by its properties and interaction with the flow field

From data
Estimate



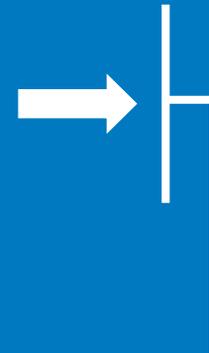
Wide variations in any or all of these parameters have negligible effects on trajectories because disturbances from turbines are highly localized and effectively instantaneous

SCENARIOS

Scenario 1: In the rotor plane



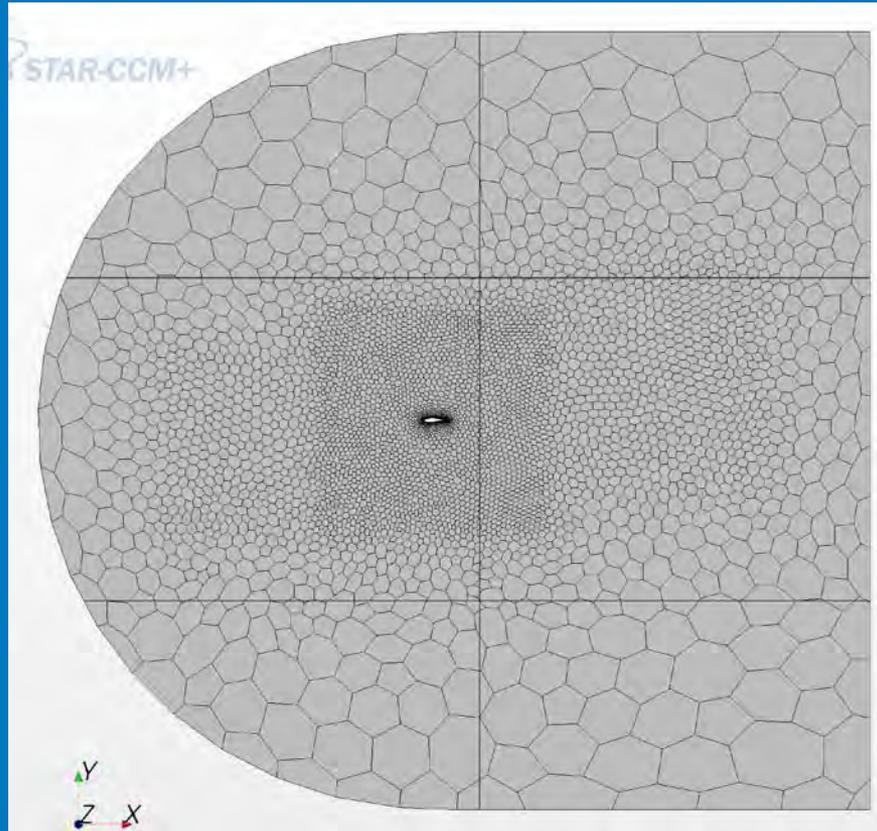
Scenario 2: Through the rotor plane



Scenario 3: Through the tip vortex



2D SIMULATION – MESH AND SETUP IN STAR CCM+

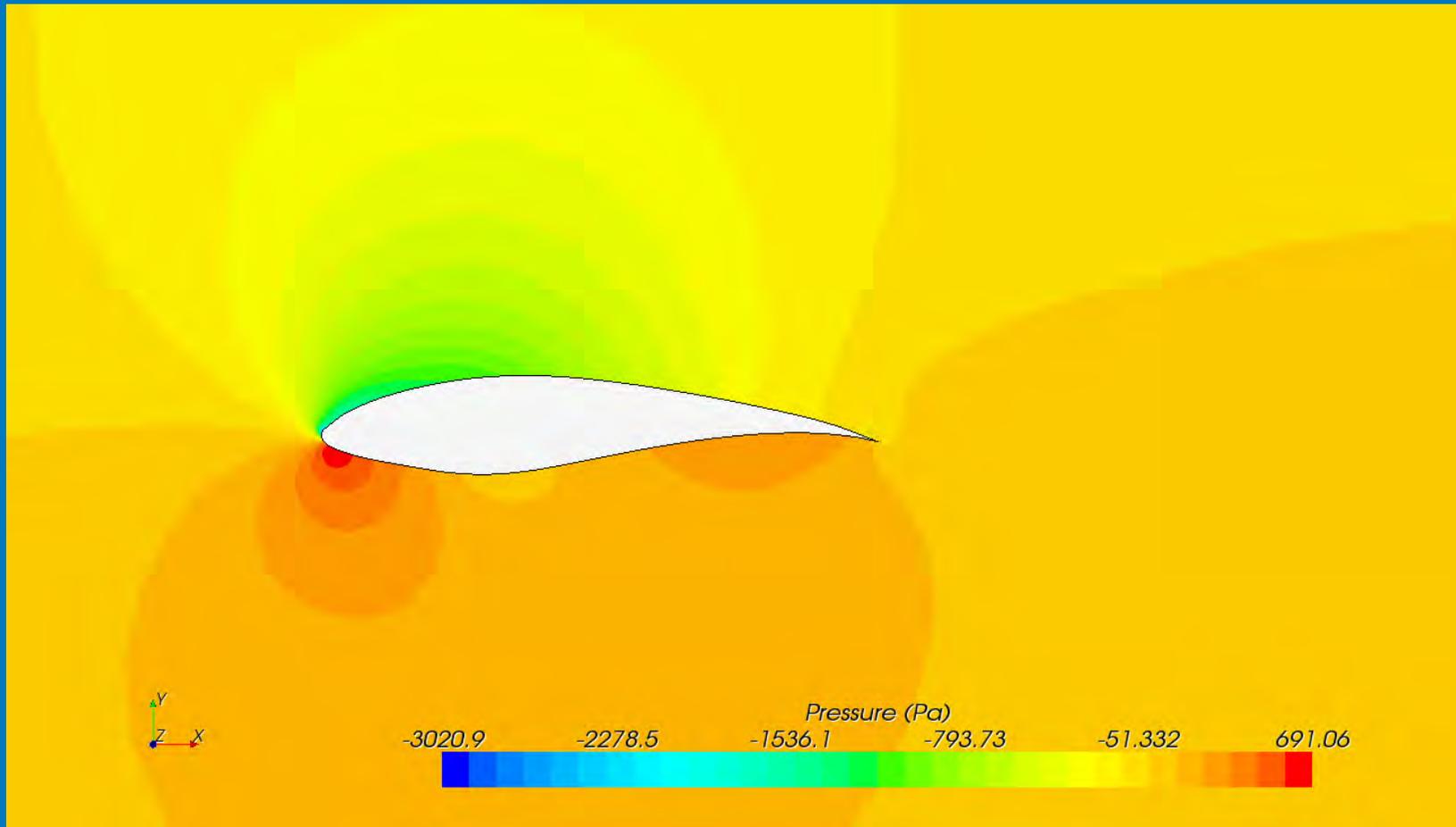


Inflow = 5 m/s, more bats die on low wind nights

Tip speed ratio = 7.55, which adds a rotational velocity component of 34 m/s

Chord = 1.1 m, represents 90% radius of 35.8 m blade

2D SIMULATION – PRESSURE FIELD IN STAR CCM+

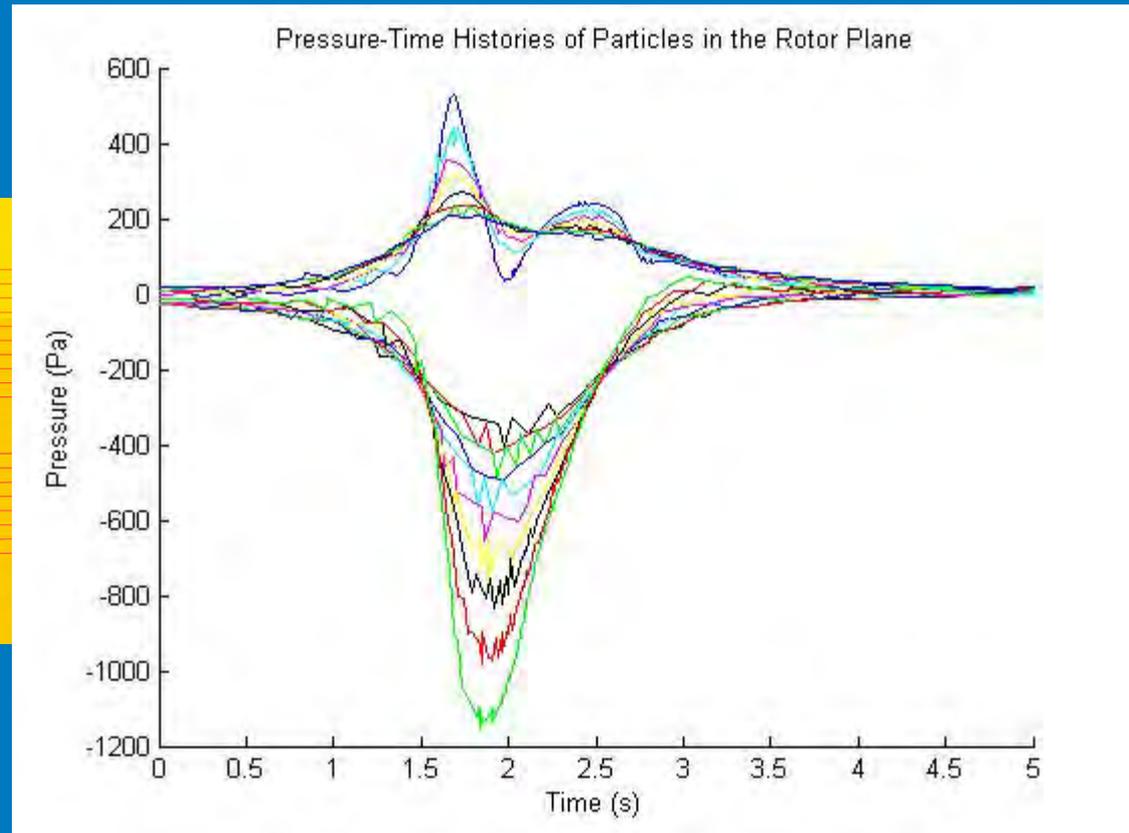
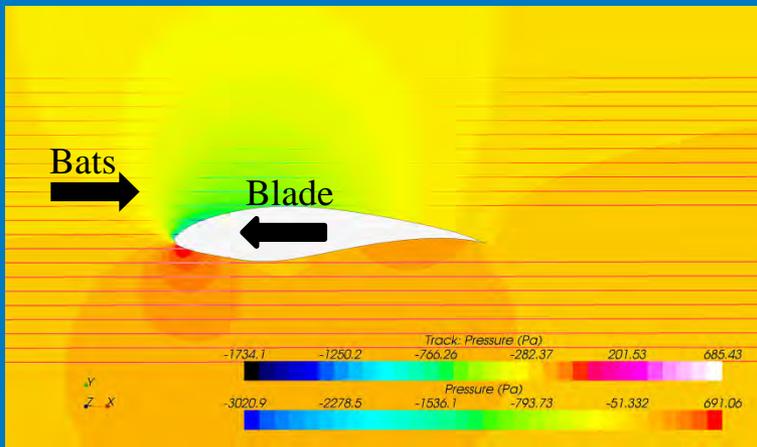


Residuals reduced by four orders of magnitude

Convergence tracked by lift and drag coefficients as well

2D SIMULATION – SCENARIO 1 WITH PARTICLE TRACKS

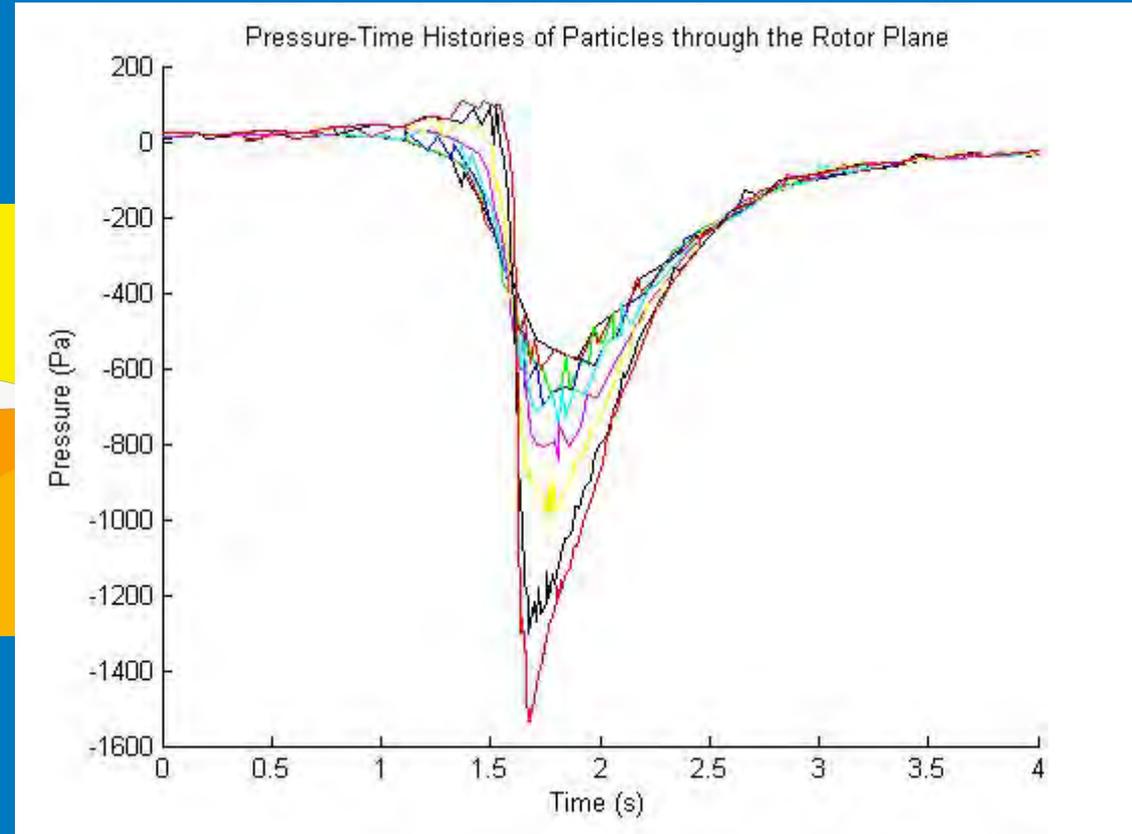
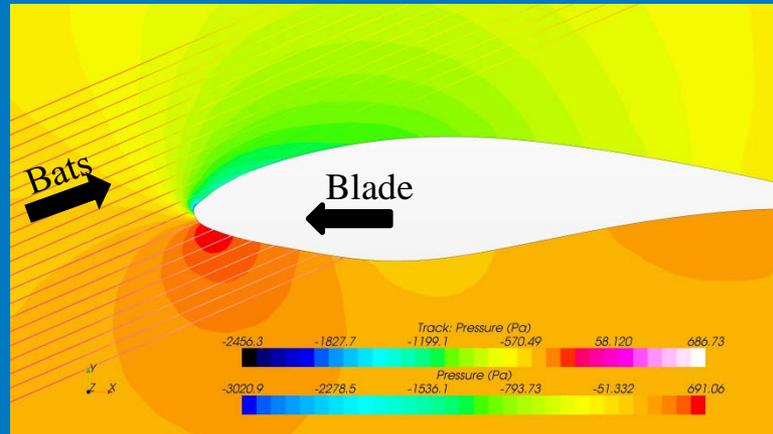
In the rotor plane:



Pressure changes without impact: 527 to -1147 Pa

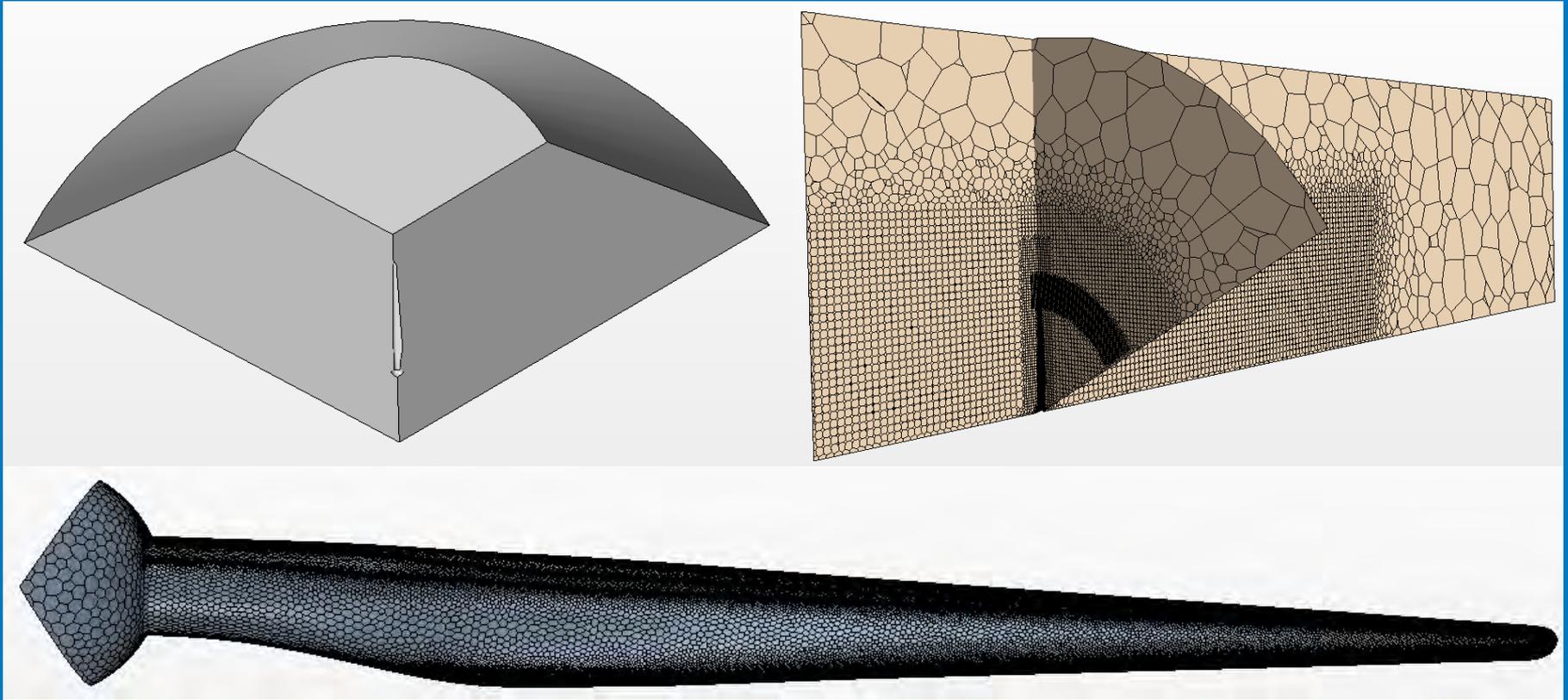
2D SIMULATION – SCENARIO 2 WITH PARTICLE TRACKS

Through the rotor plane:



Pressure changes without impact: 109 to -1536 Pa

3D SIMULATION – MESH AND SETUP

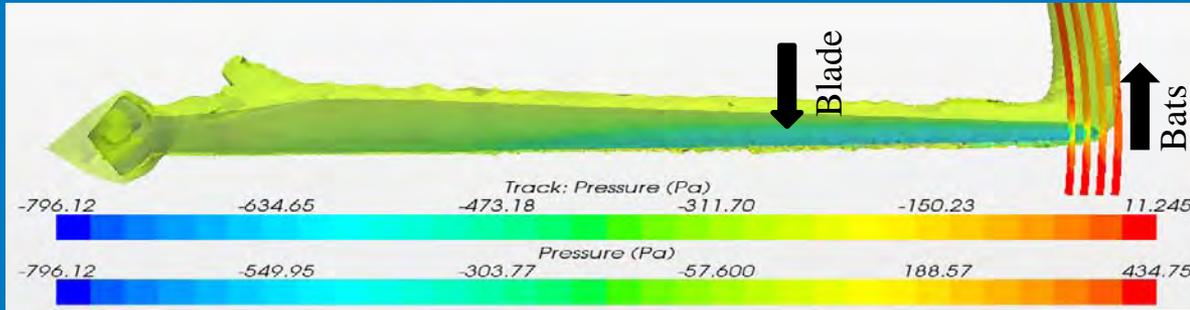


3D mesh uses 120 degree periodicity of three-bladed wind turbine

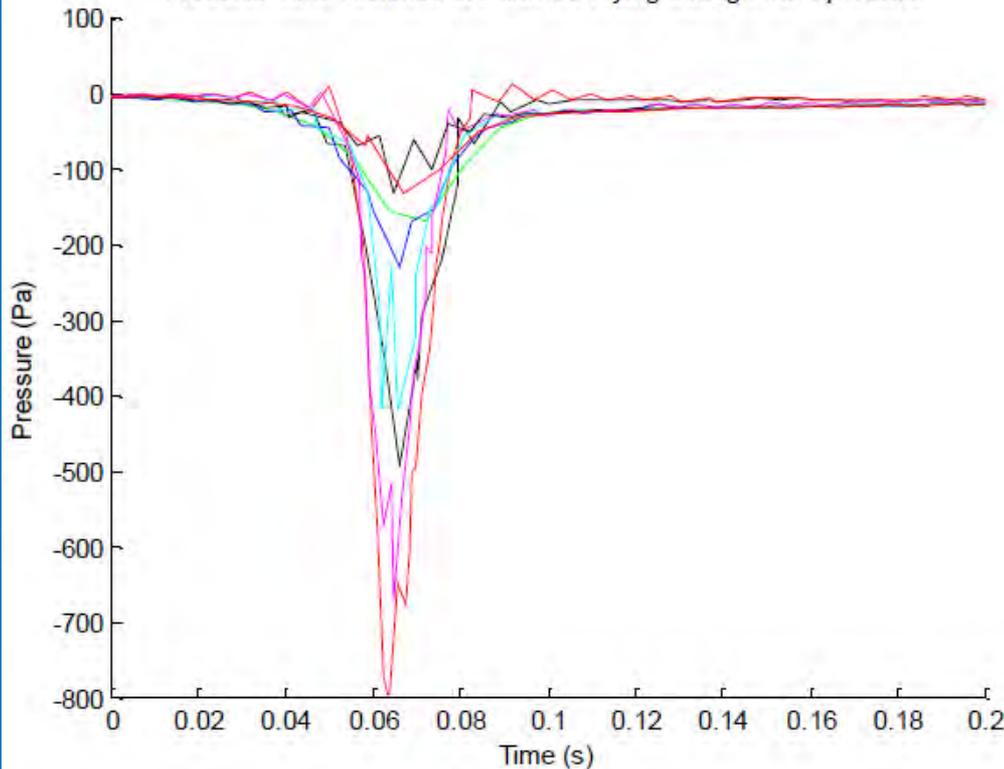
Conditions identical to 2D simulation, but uses rotating reference frame

3D SIMULATION – SCENARIO 3 WITH PARTICLE TRACKS

Through the tip vortex:



Pressure-Time Histories of Particles Flying through the Tip Vortex



Pressure changes without impact:
11 to -796 Pa

BOTH SIMULATIONS – SUMMARY OF RESULTS

Maximum Pressure Drops (kPa)

	In the rotor plane	Through the rotor plane	Through the tip vortex
2D Simulation	1.147	1.536	–
3D Simulation	0.957	0.853	0.796

Threshold for Mortality (kPa)

Overpressure (mice): 30

Underpressure (rats): 64

Underpressure (mice): -23 (using correlation)

CONCLUSIONS: ARE PRESSURE-TIME HISTORIES FATAL?

- Pressure changes determined in simulations are at least **one order of magnitude smaller than those required for death** in overpressure and underpressure studies
- Proximity to blades to experience pressure-time histories in simulations all but **guarantees getting hit by the blades**, regardless of possible barotrauma

Assuming bats' responses to pressure changes are similar to other mammals and comparisons to overpressure and underpressure are at least reasonable, then...

Death due barotrauma appears unlikely.

SUGGESTIONS FOR FUTURE WORK

- Clearly separate instances of impact trauma from barotrauma
 - Use stereoscopic video with a wide enough field of view or enough cameras to see where falling bats land around wind turbines in order to match carcasses to impact and barotrauma events in the video
 - Catch falling bats to eliminate impact with the ground as a variable
- Determine survivable pressure-time histories for bats
 - Perform underpressure studies with bats to determine lethal doses and mortality curves
 - Perform necropsies on underpressure subjects to clearly identify physical trauma typical of underpressure
 - Determine the roles of peak pressure, duration of peak pressure, and time to peak pressure in survivability
 - Correlate lethal doses to mass to extend applications to bat species of different mass

THANK YOU

