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Aerodynamic Tools and Aeroacoustics

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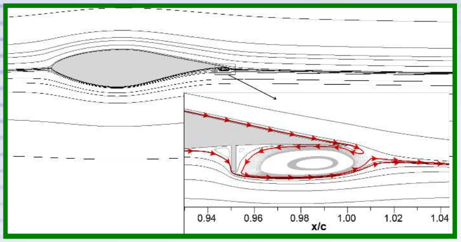
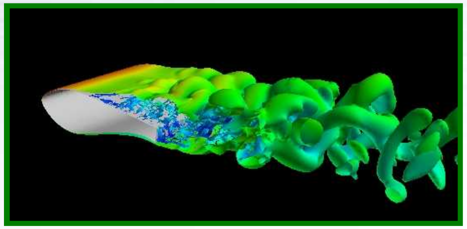
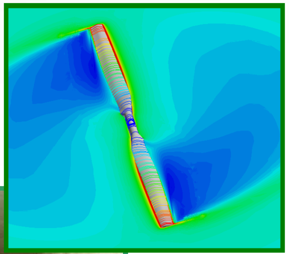
Aerodynamics & Aeroacoustics Activities

- Aerodynamic analysis capability to support SMART Rotor project.
- Advanced Aero-structural Designs
- Full 3D Rotor Aerodynamics
- Characterization of Wind Turbine Aerodynamic Noise





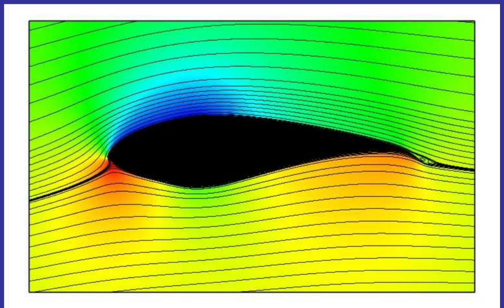


Active Aerodynamic Control

- **<u>Requirement</u>: Tool to generate airfoil performance data with/without active aerodynamic control, for input into aeroelastic system analysis.**
- **<u>Solution</u>: Automated tools to quickly generate Computational Fluid Dynamics (CFD) solutions over a large parameter space, leveraging Sandia's High Performance Computing resources.**

Thunderbird, Sandia's 53 TeraFlop Computing Cluster

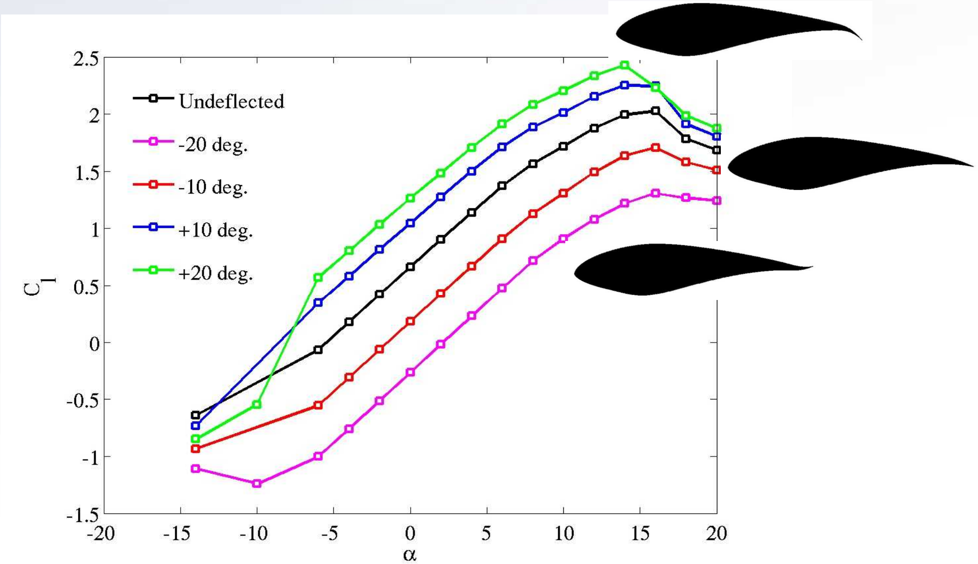
CFD Solution



<u>Example</u>: Aerodynamic Analysis of Morphed Airfoil Shapes

416 total CFD solutions generated

Lift vs. Angle of Attack for Morphed Airfoil Shapes



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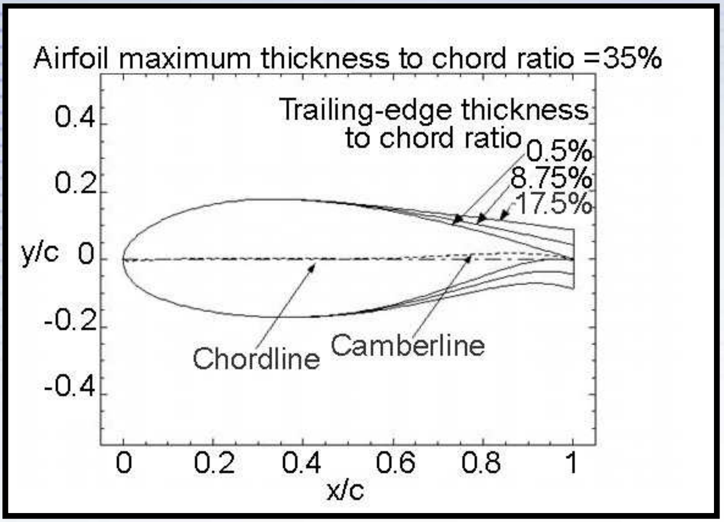
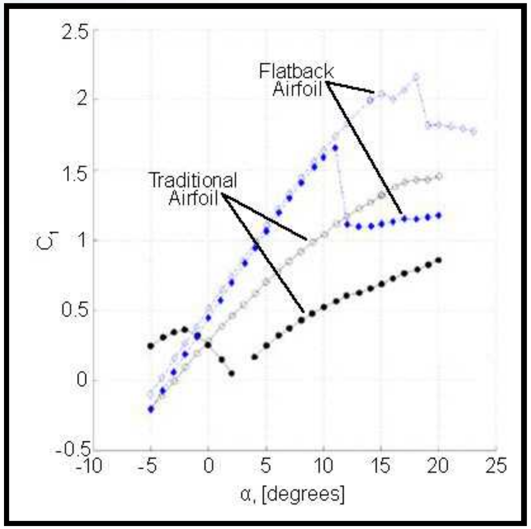
Advanced Aero-structural Designs

Flatback Airfoils



- Advantages
  - Structural benefit of larger sectional area for given chord and thickness.
  - Aerodynamic benefit of decreased sensitivity to blade soiling.
- Industry Concerns
  - Increased drag
  - Increased noise from trailing edge wake



Flatback Noise: Is it important?

- Flatbacks are used inboard where flow velocities are low
  - Noise intensity scales with velocity to the fifth or sixth power
- Vortex-shedding tone is at low frequencies, 50-250 Hz
  - Current noise standards emphasize A-weighted noise measurements
  - A-weighted noise emphasizes the middle of the human hearing range, and de-emphasizes high and low-frequency content

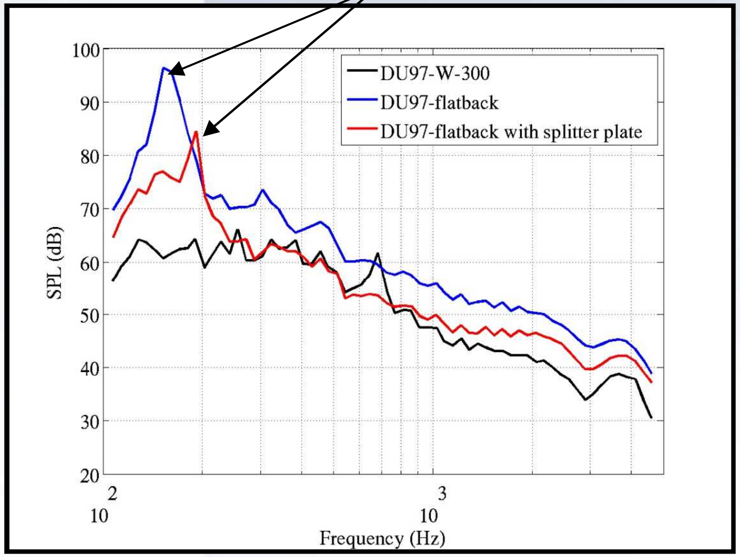
However…

- Low-frequency noise in the range 20-150 Hz is sometimes addressed by distinct community noise regulations
- Tonal noise is often perceived as more annoying than broadband noise; vortex-shedding can generate tones
- Low-frequency noise propagates efficiently

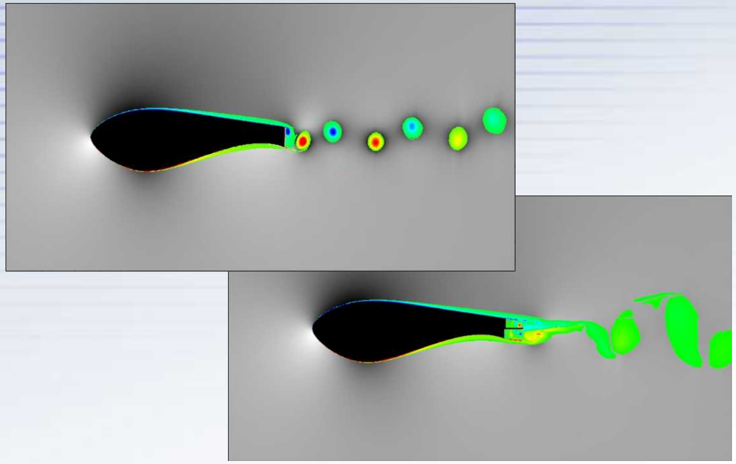
Flatback Airfoil Noise: Modeling and Testing

Virginia Tech Wind Tunnel Tests

Splitter plate treatment reduced noise from airfoil wake



CFD Simulations of the Flatback Wake, with/without splitter plate treatment

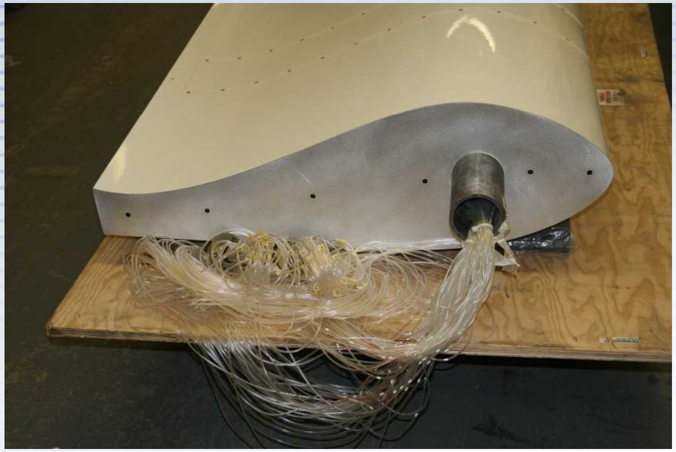


Proposed acoustic measurements of BSDS rotor with NREL microphone array (with Pat Moriarty, NREL)

Wind Tunnel Models

- **36-in chord**
- **30% thick airfoil**
- **Steel frame, fiberglass surface**
- **80 pressure taps per airfoil**
  - Pressure and suction surfaces
- **3 Model configurations**
  - 1.7% thick trailing edge (“sharp”)
  - 10% thick trailing edge (“flatback”)
  - Flatback with splitter plate
- **Profiles accurately measured**

Flatback Model



Flatback model with Splitter Plate

Instrumentation and Test Conditions

- **Instrumentation**
  - Surface pressures measured with scanivalve.
  - Wake pressures measured with traverse system.
  - Boundary layer velocity profiles measured with hot wire traverse system.
  - Boundary layer turbulence characteristics measured with hot wire.
- **Noise data obtained with 63 microphone phased array**
- **Test Conditions**
  - Clean surface
  - Tripped boundary layer
    - 0.5 mm thick zig-zag tape
  - Three Reynolds numbers (scaling of noise with velocity)
    - Re_c = 1.8, 2.4 & 3.2 X 10^6

Kevlar Wall

Model in Wind Tunnel

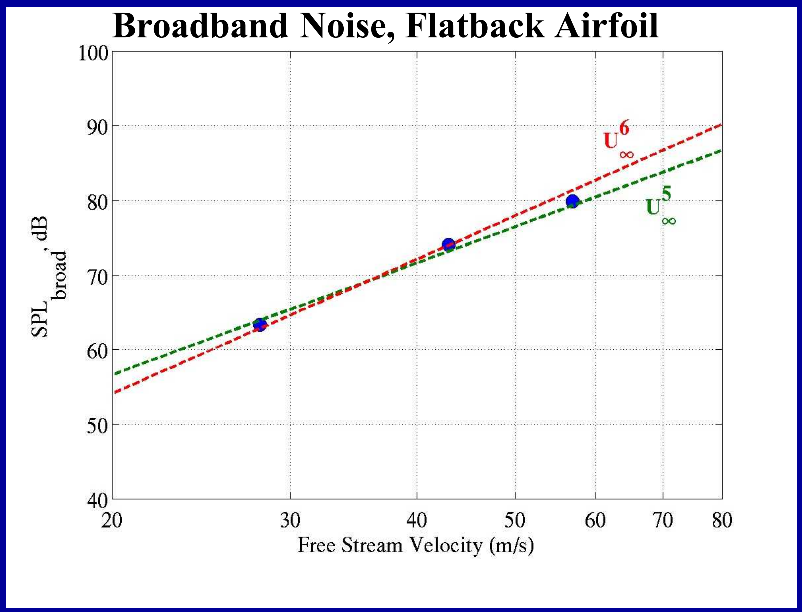
Phased Array

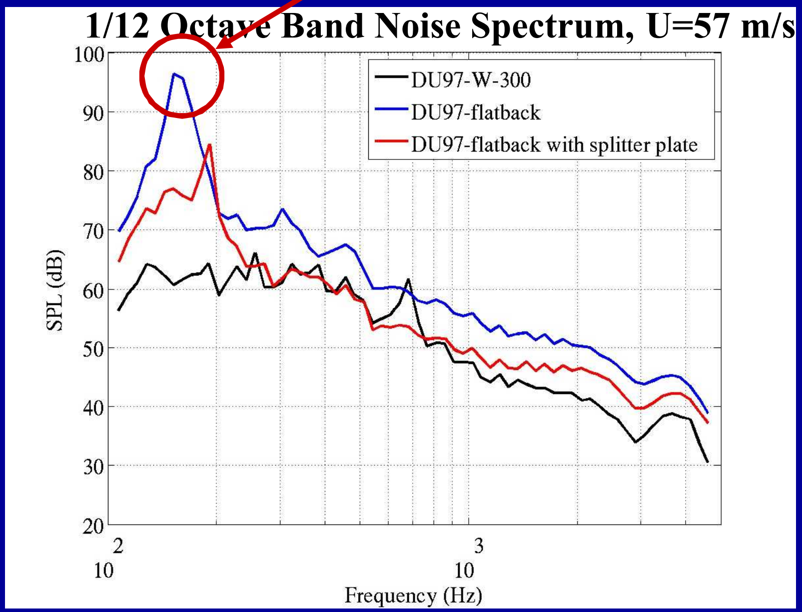
Preliminary Acoustic Results

- Broad-band trailing-edge noise scales with the expected power of free-stream velocity (U^6 for low velocities, U^5 for high velocities).
- A relatively loud vortex-shedding tone is generated by the flatback.
- Splitter plate reduces the vortex-shedding tone by at least 10 dB.

Vortex-shedding noise

angle of attack = 4 deg, free transition





*Uncertainty in measurements of low-frequency vortex-shedding noise amplitude to be addressed in follow-on testing.

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Computational Aeroacoustics

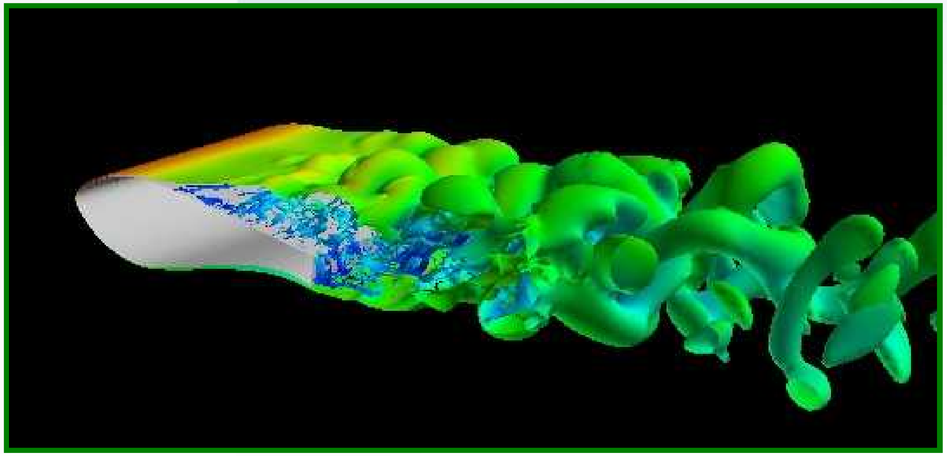
Flatback Airfoil Vortex Shedding Noise

(with Chris Stone, Computational Science & Engineering LLC)

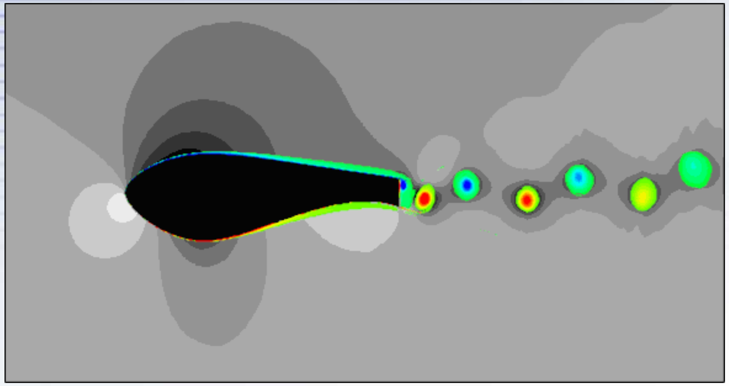
Approach

- Simulate the unsteady, turbulent flow responsible for generating noise using CFD
- Near-field solution is post-processed to generate far-field noise predictions

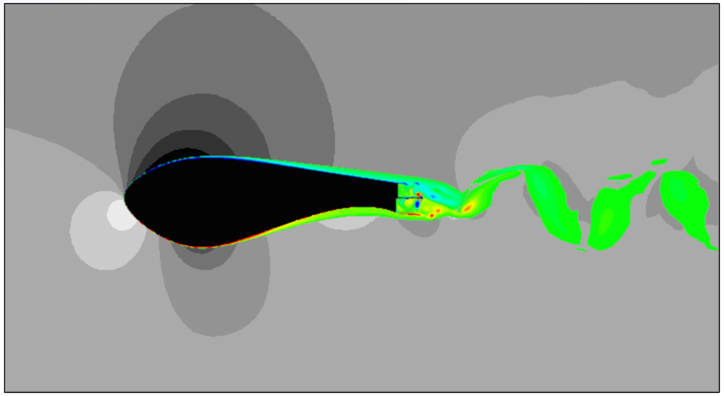
3D Simulation: DU97 Flatback



2D Simulation: DU97 Flatback without splitter plate



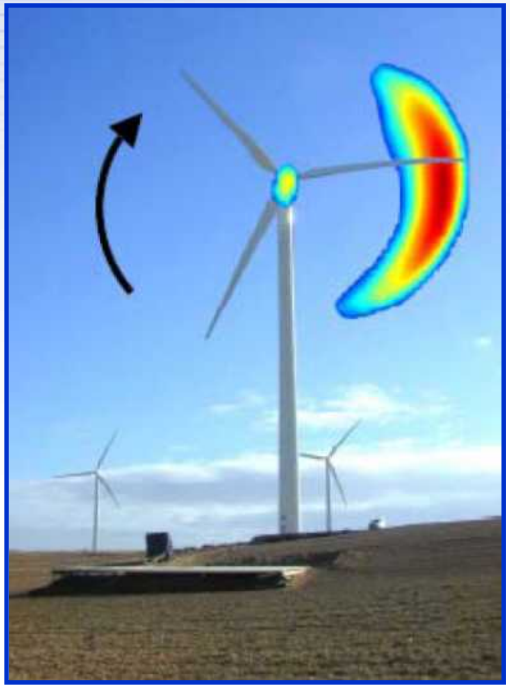
With splitter plate



Wind Turbine Trailing Edge Noise

- Dominant aerodynamic noise source of most upwind HAWTs is airfoil trailing edge noise emanating from near the blade tips.
- Trailing edge noise imposes a design restraint on blade tip speed.
- Higher tip speed allows for power generation at lower torque, decreasing component weight and cost and thus decreasing COE.
- New concepts must be evaluated for impact on noise, e.g. flatback airfoils and aerodynamic control actuators.

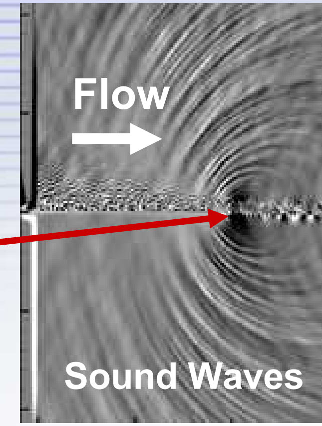
Noise map on a 850 KW turbine from the European SIROCCO project.



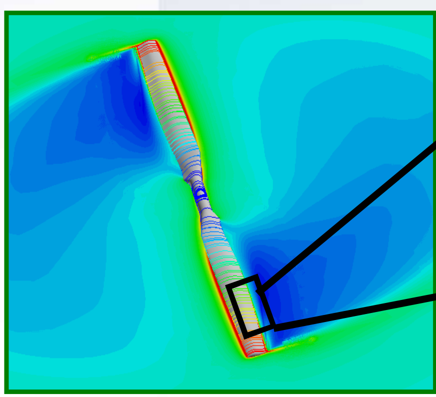
Trailing Edge Noise Prediction

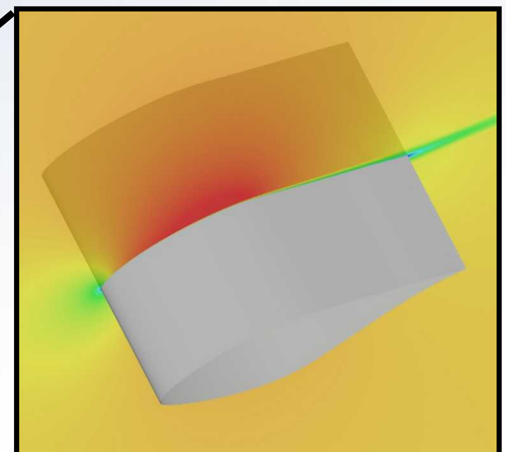
- **With Ken Brentner and Phil Morris of Penn State University**
- **Trailing edge noise is caused by scattering of the turbulent boundary layer at the trailing edge.**
- **Simulation tool is required to compute this scattering process.**

Simulation of a turbulent boundary layer interacting with a sharp edge to produce sound
Sandberg & Sandham, J. Fluid Mech., 2008.



Step 1.
Full Rotor Simulation





Step 2.
Isolate blade section for detailed turbulent boundary layer simulation

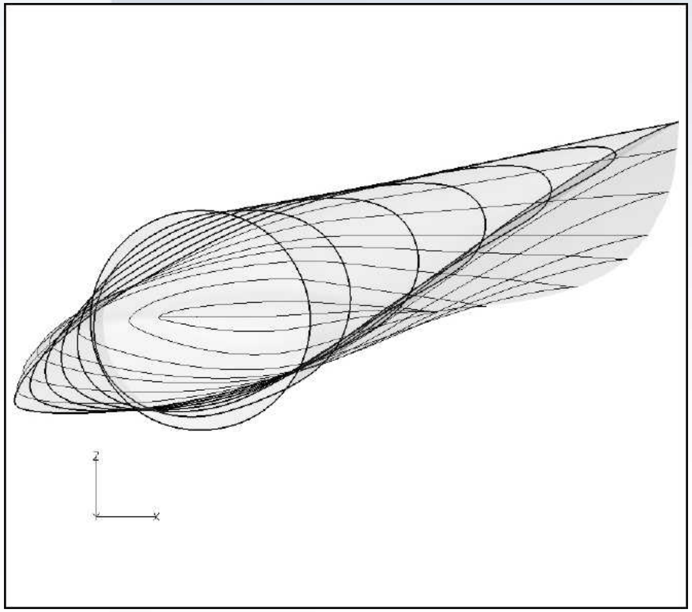
Full Rotor CFD

With Case Van Dam, UC-Davis

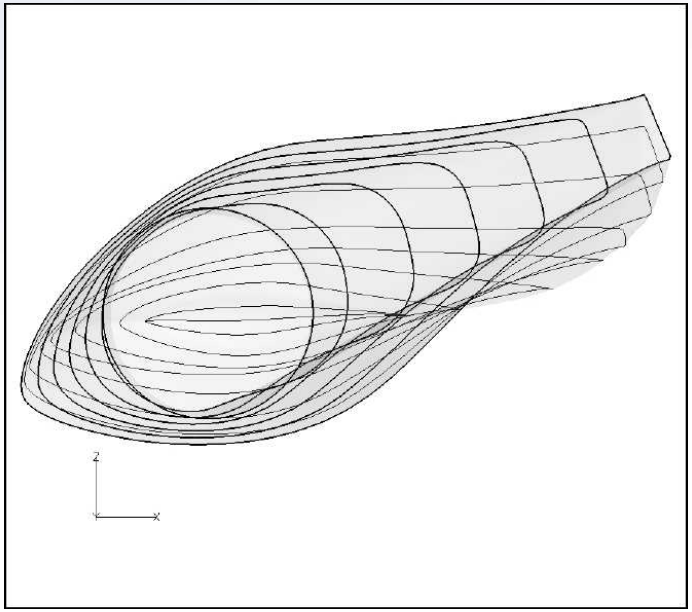
- **If we incorporate thick, high-drag, blunt trailing-edge airfoils in the root region of the rotor, will there be a penalty in rotor torque?**
- **Use CFD to study the effects of modifying the inboard region of the NREL Phase VI rotor using a thickened, blunt trailing edge section shapes on the performance and load characteristics of the rotor**

Blade Configurations (Tunnel View)

- **Constant:**
  - **Section shape r/R ≥ 0.45**
  - **Span (5.03 m)**
  - **Pitch angle (3.0 deg)**
  - **Twist distribution**
  - **Chord distribution**
  - **Blade sweep**



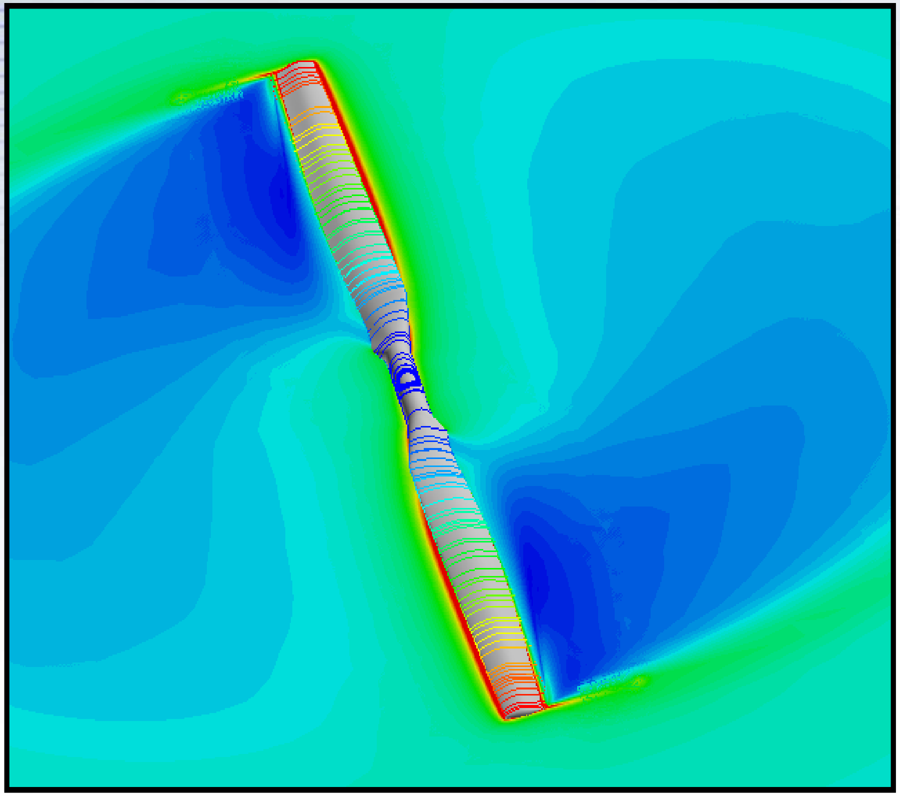
Baseline



Modified

Flow Solver

- OVERFLOW 2
- 3-D compressible Reynolds-averaged Navier-Stokes (RaNS) flow solver
- Developed by Buning et al. at NASA
- Steady and time-accurate solutions on structured block or Chimera overset grids
- Wide range of turbulence models available: Spalart-Allmaras model used in present study
- Capability to model moving geometries



NREL Phase VI rotor

Torque Comparisons

	Baseline		Modified
Wind Speed (m/s)	Experiment (N-m)	CFD (N-m)	CFD (N-m)
5	220-370	160	158
7	700-870	815	815
10	1210-1380	1750	1385

Conclusions: Rotor CFD Study

- Flow solver validated by comparing predictions for baseline rotor with benchmark wind tunnel results
- At attached flow conditions (5, 7 m/s) inboard blade modification does not affect rotor performance
- At stall onset (10 m/s) modified rotor generates less torque. Drop in torque caused by outboard flow separation triggered by changes in inboard loading