Aerodynamic and Aeroacoustic Properties of Flatback Airfoils

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Project Goal & Objectives
- Blade Program Background
  - BSDS
  - Flatbacks
- Wind Tunnel
- Models
- Test Matrix & Objectives
- Preliminary Results
- Future Work
- Summary

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Project Goal & Objectives

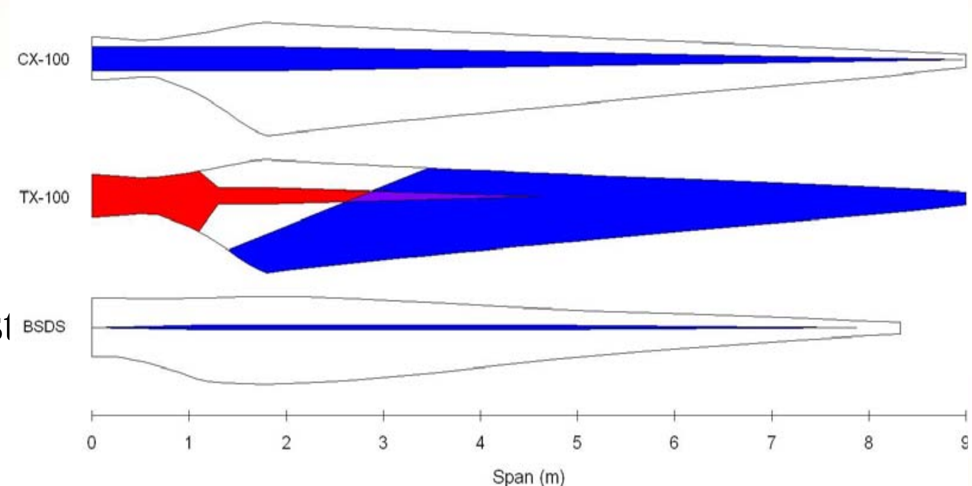
- **Goal:** Quantify the aerodynamic performance and aeroacoustic emission of a flatback airfoil relative to a conventional sharp trailing edge airfoil
- **Objectives:**
  - Dirctly measure performance of a flatback airfoil
    - aerodynamic
    - aeroacoustic
  - Directly compare to performance of a conventional airfoil
  - Evaluate effect of simple trailing edge treatment
- **Challenges:**
  - Large separation on blunt trailing edge
  - Highly turbulent/highly 3-D flow

Blade Research at Sandia National Labs

- **SNL initiated a blade research program in 2002 to investigate the use of carbon fiber and other advanced structural concepts in wind turbine blades**
- **Objective: build stronger, lighter blades**
- **Three 9 m blade designs have been produced**
  - **CX-100 (Carbon eXperimental 100 kW)**
  - **TX-100 (Twist-Bend coupled eXperimental 100 kW)**
  - **BSDS (Blade System Design Study)**
- **Laboratory and field tests have been conducted to evaluate the designs and to validate modeling tools**

Applications of Blade Innovations

- **Prototype Sub-scale (9 meters) Blades Manufactured**
  - **CX-100**
    - Carbon spar cap
    - Glass skin and shear web
  - **TX-100**
    - Carbon triax in skin for bend-twist
    - Constant thickness glass spar cap
  - **BSDS**
    - Flatback airfoils
    - Constant thickness carbon spar cap
    - High performance airfoils
    - Large scale architecture
    - Highly efficient structural design
    - Result of system design approach

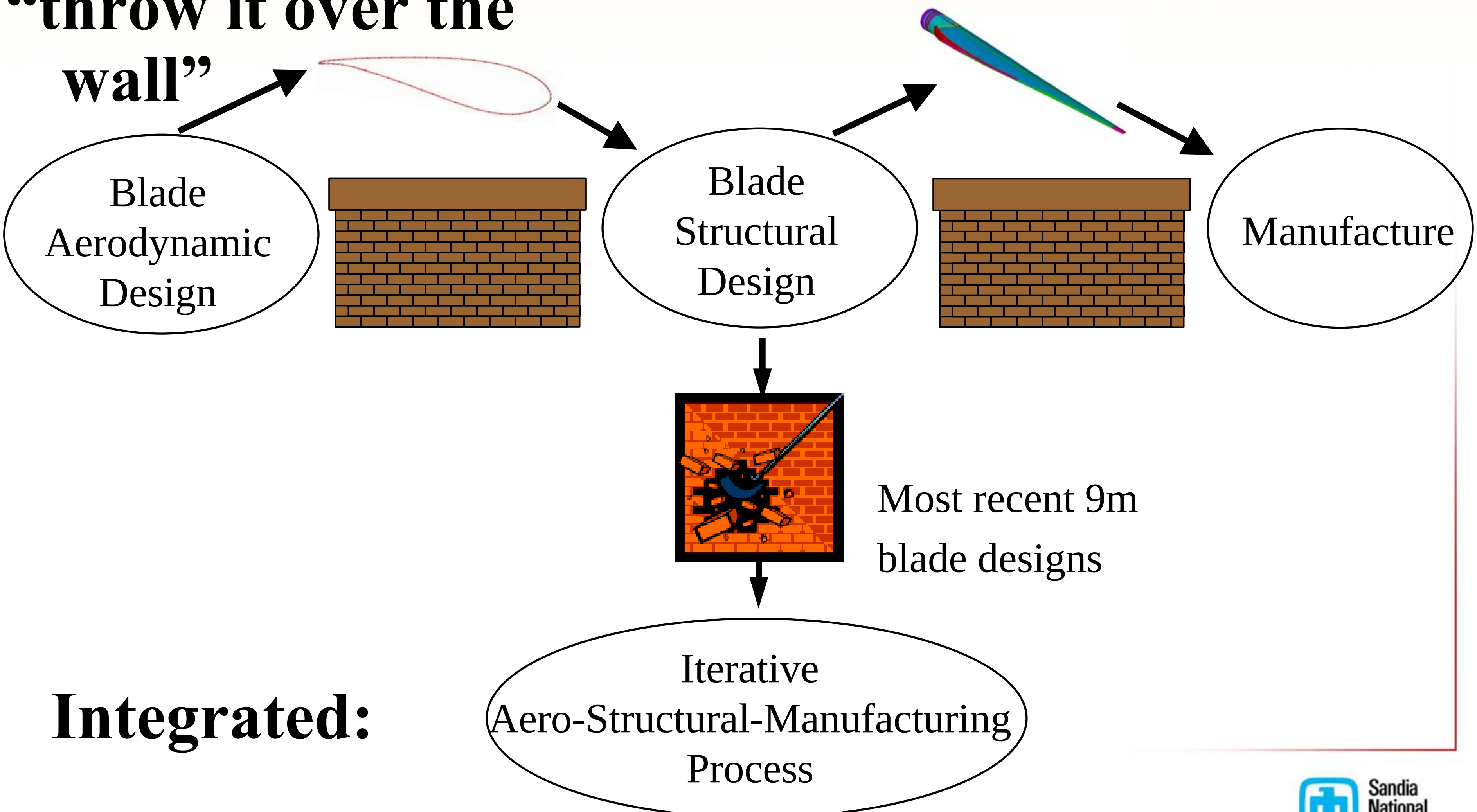


Aerodynamic

Manufacturing ← **Structural**

New Design Approach

Traditional:
“throw it over the wall”



Integrated:

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Blade Structural Comparison

Property	ERS-100	CX-100	TX-100	BSDS
Weight (lb)	426	383	361	289
% of Design Load at Failure	110%	105%	197%	310%
Root Failure Moment (kN-m)	122.8	117.0	121.4	203.9
Max. Carbon Tensile Strain at Failure(%)	NA	0.31%	0.59%	0.73%
Max. Carbon Compressive Strain at Failure(%)	NA	0.30%	0.73%	0.87%
Maximum Tip Displacement (m)	1.43	1.05	1.80	2.79

Integrated aero/structural design process resulted in lighter, less expensive, stronger blade

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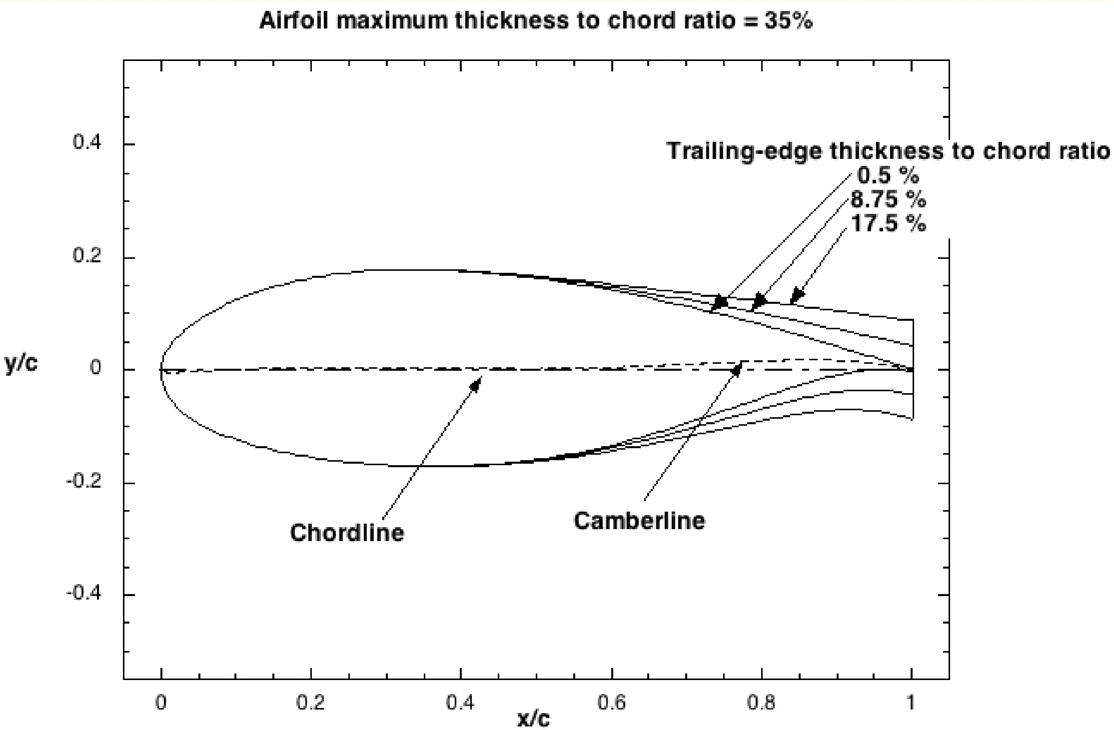
Flatback Airfoils

- **Flatback airfoils are created by the symmetric addition of thickness about the camber line**
- **Different from truncated airfoils which “chop” off the trailing edge and thus lose camber**
- **This is one solution for increasing thickness. Others, such as thick airfoil families, exist.**

Creation of Flatback Airfoils

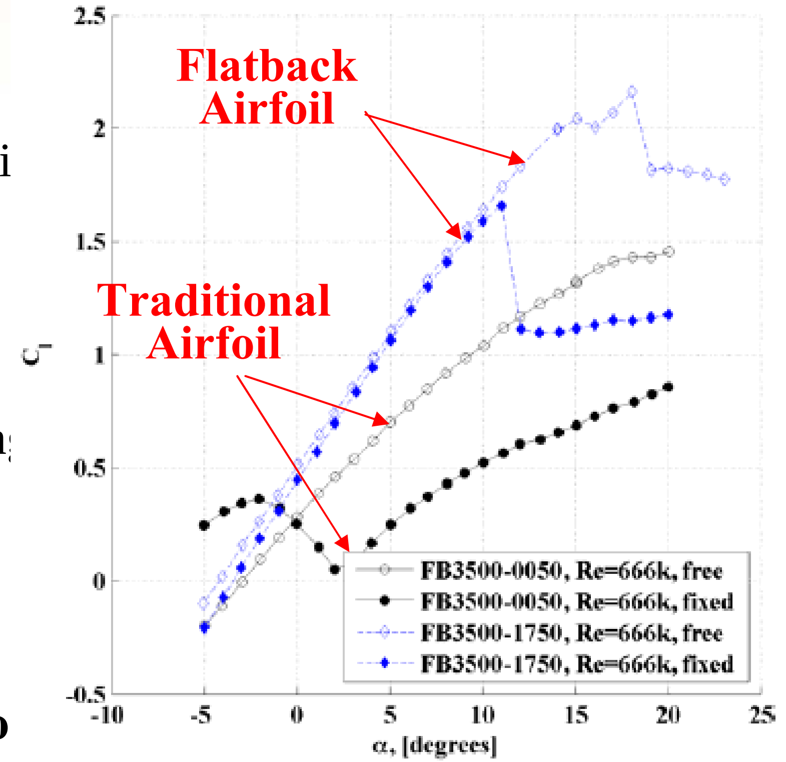


***Study of flatback airfoils performed in collaboration with UC Davis**

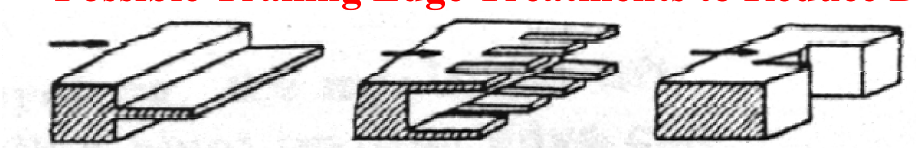
Flatback Airfoils

- **Advantages**
  - **Structural:**
    - Increased sectional area
    - Increased sectional moment of inerti
    - Shorter chord length
  - **Aerodynamic:**
    - Increased maximum lift coefficient
    - Reduced sensitivity to surface soilin
- **Disadvantages**
  - **Increased drag**
  - **Unknown and complex 3D base flow**
  - **Greater aeroacoustic (noise) generatio**

Experimental Data



Possible Trailing Edge Treatments to Reduce Drag



Source: Tanner (1973)

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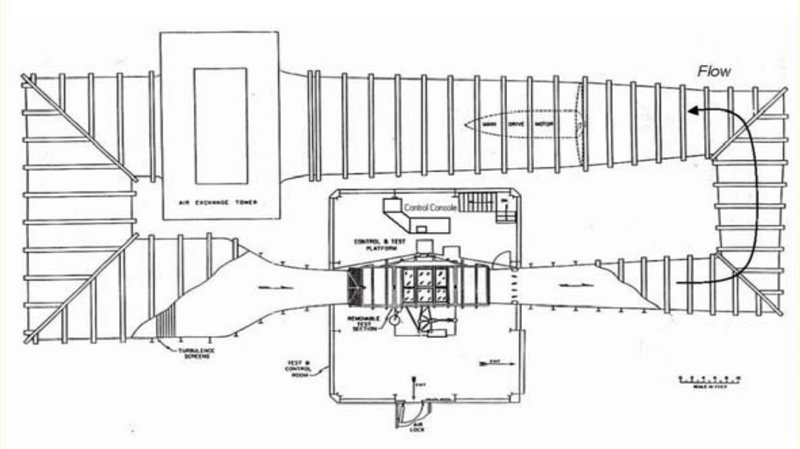
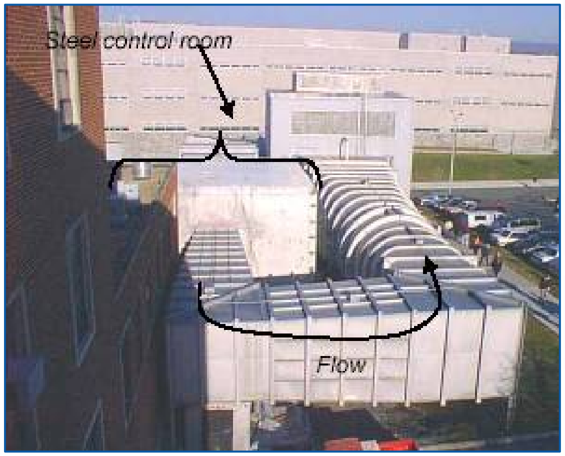
Virginia Tech Stability Wind Tunnel

- **Continuous flow**
- **6 ft X 6 ft test section**
- **170 mph maximum velocity**
- **Modified for aeroacoustic testing**
- **Kevlar windows in test section**
  - **Confine flow/transmit sound**
- **Extensive efforts to quiet tunnel**

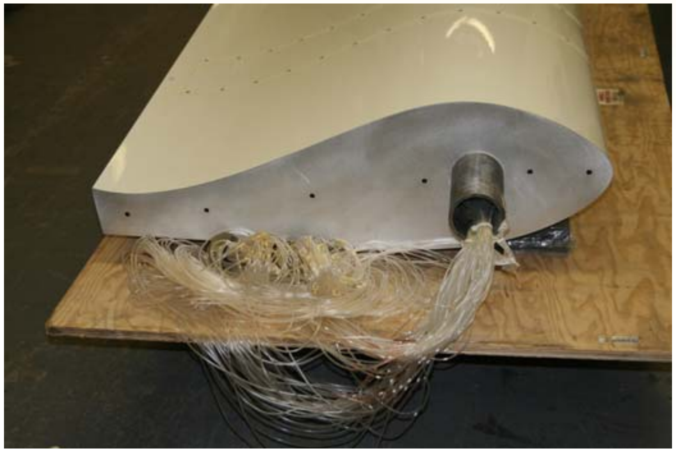




Wind Tunnel Models

- **36-in chord**
- **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**
- **Accuracy of profiles not yet established**

Flatback Model



Flatback model with Splitter Plate

Data Acquisition

- **Model mounted vertically in test section**
- **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 (specta) measured with hot wire.

- **Noise data obtained with 63 microphone phased array**

Kevlar Wall

Model in Wind Tunnel

Phased Array

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Measurement Conditions

- Define aerodynamic performance
  - C_d min
  - C_l/C_d max
  - C_l max
- Measure noise generation
- Clean surface
- Tripped boundary layer
  - 0.5 mm thick zig-zag tape
- Three Reynolds numbers (scaling of noise with velocity)

Measurements Obtained in Sandia Test

DU97-W-300 Airfoil							
Configuration			Measurements				
Effective Angle of Attack	Boundary Layer Trip	Chord Reynolds Number	Phased Array Microphones	Model Pressure Distribution	Wake Pressures	TE Hot-wire Bounday Layer Profile	TE Hot-wire Spectra
4	None	$1.6x10^6$					
4	None	$2.4x10^6$	X	X			
4	None	$3.2x10^6$	X	X	X	X	X
8	None	$1.6x10^6$	X	X	X	X	X
8	None	$2.4x10^6$	X	X			
8	None	$3.2x10^6$	X	X	X	X	X
12	None	$1.6x10^6$					
12	None	$3.2x10^6$	X	X		X	X
4	Tripped	$1.6x10^6$					
4	Tripped	$3.2x10^6$	X				
8	Tripped	$1.6x10^6$	X			X	X
8	Tripped	$2.4x10^6$	X	X			
8	Tripped	$3.2x10^6$	X	X		X	X

Measurement Matrix for Sharp Airfoil

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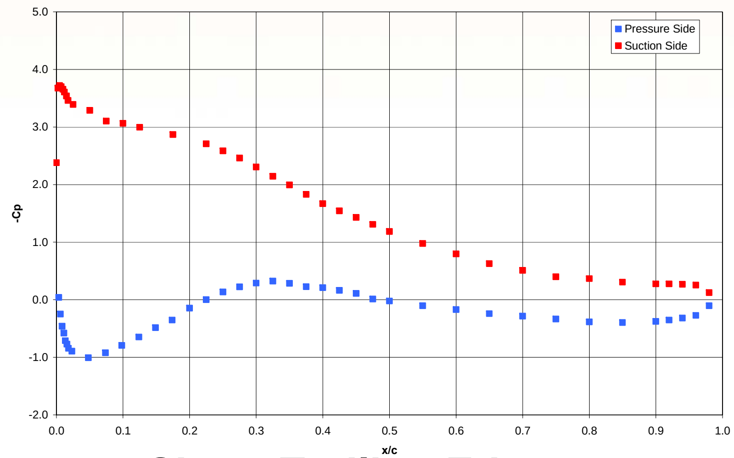
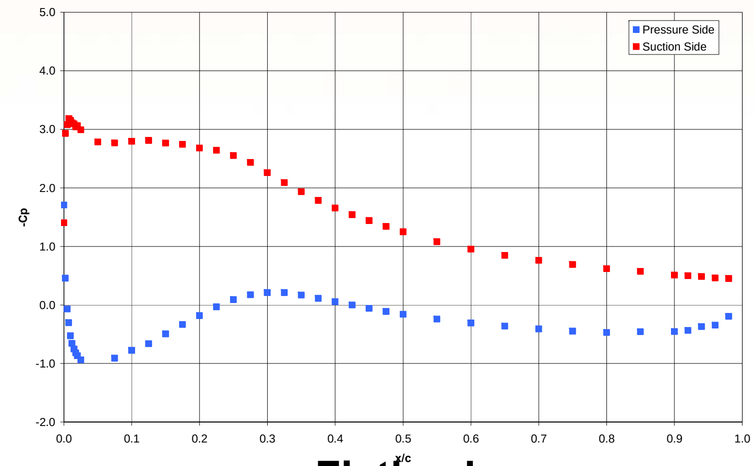
Preliminary Surface Pressure Results

α = 12°, no boundary layer trip



Sharp Trailing Edge

α = 10°, boundary layer trip



Flatback

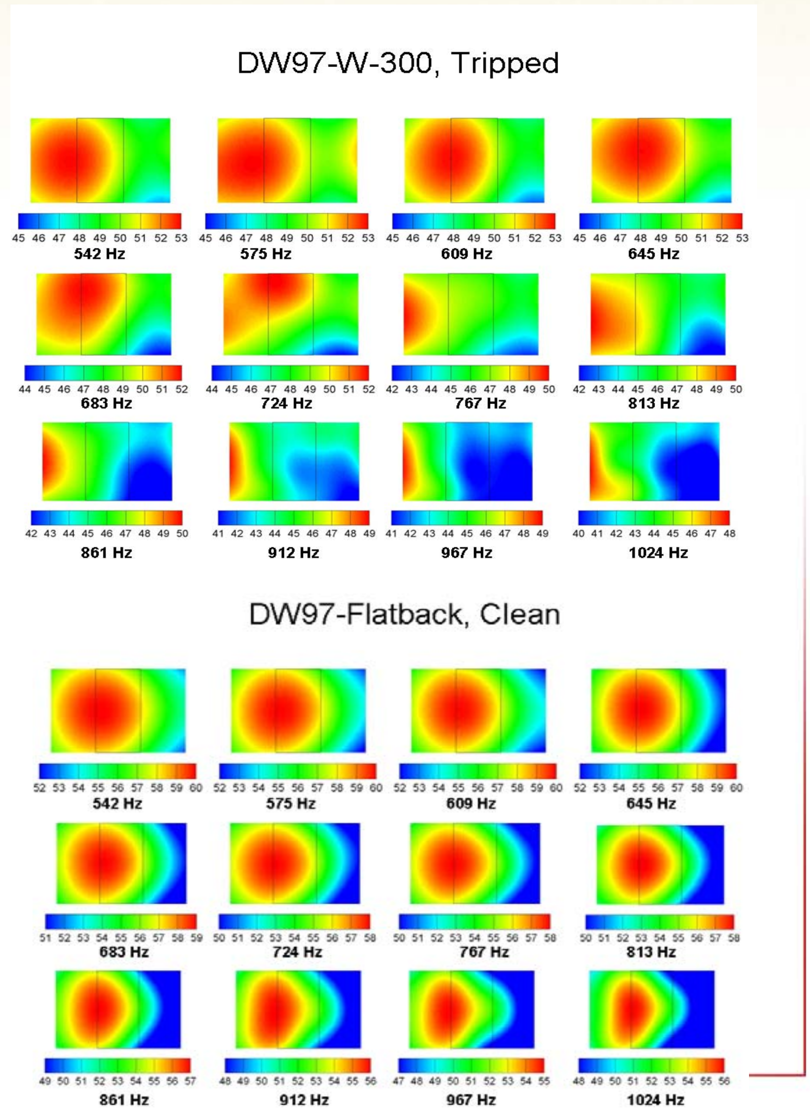
- **Reynolds number = 3.2 X 10^6**
- **Pressure recovery for flatback occurs aft of trailing edge**

Beam Forming Data Reduction

- All microphones sampled simultaneously at 25,600 Hz
- Data split into blocks of 8192 samples
- FFT performed on each block to determine spectral content
- Microphone spacing and delay times required for sound to reach each microphone permits identification of noise sources

Preliminary Beam Forming Results

- Flow is from right to left
- LE and TE shown by vertical lines
- Highest noise level always in red
- Note changes in SPL levels for flatback
- Highest noise levels are at trailing edge



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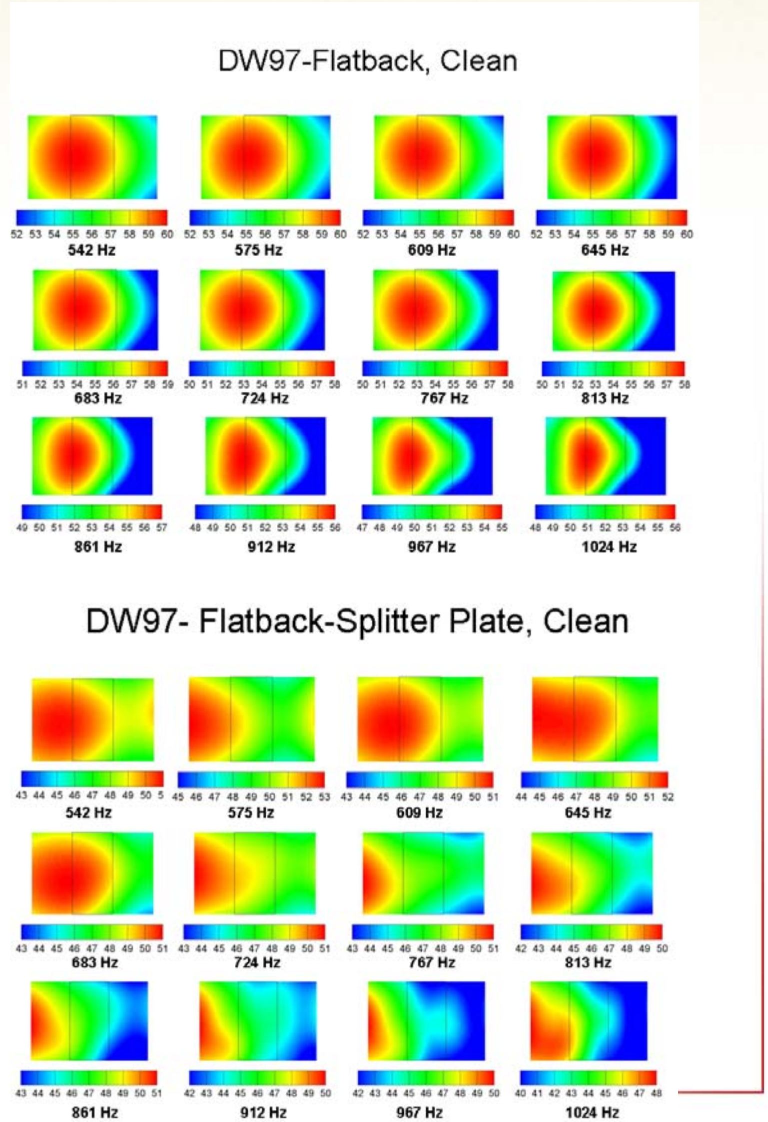
Preliminary Beam Forming Results

- **Flow is from right to left**
- **LE and TE shown by vertical lines**
- **Highest noise level always in red**
- **Note drop in SPL levels for splitter plate**
- **Highest noise levels are still at trailing edge, but not as intense**



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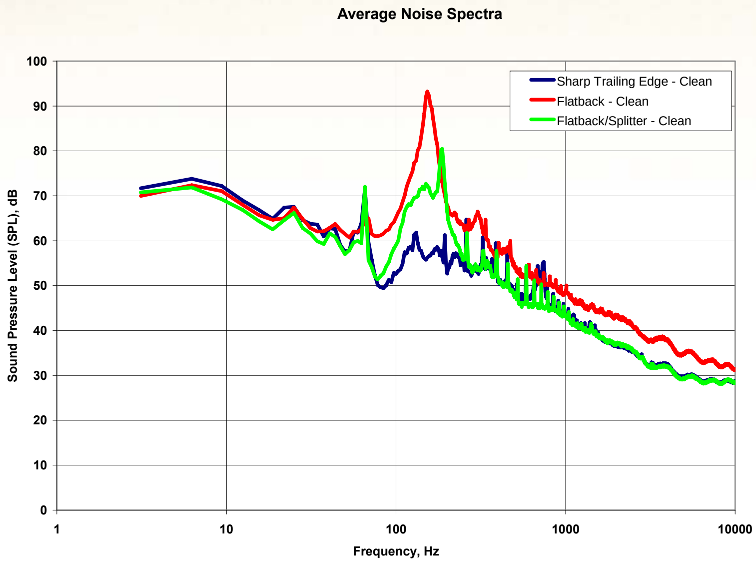
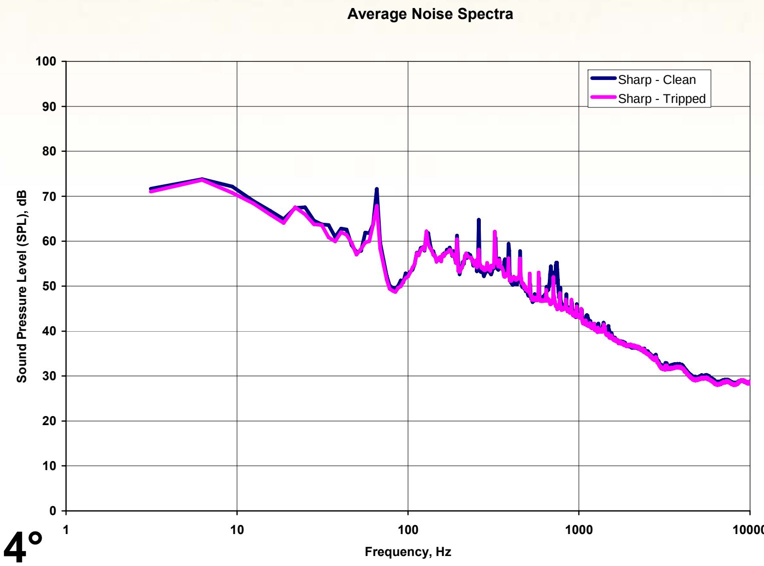
Preliminary Noise Spectra





α = 4°

- Integrated spectra (average of 100 calculations) from single microphone
- Background tunnel noise still included
- Extraneous noise spikes still included

Airfoil	Sound Level
DU97-W-300	74
DU97 Flatback	90
Flatback w/ Splitter	79

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Future Work

- Complete data validation and reduction
- Clean up noise data
- Compare experimental aerodynamic performance with CFD models and reconcile differences
- Use hot wire velocity and spectral data as initial conditions for computational aeroacoustic analysis
- Extend trailing edge bluntness noise generation correlation of Brooks, et al from 1% thick to 10% thick trailing edge
- Compare noise generated by blade with flatback sections to that generated by blade with only conventional sections
- Test other trailing edge treatments with noise reduction focus

Summary

- **SNL Blade Research effort resulted in design innovations**
  - **Flatback airfoil**
  - **Structurally efficient**
  - **Reduced weight**
- **Flatback airfoils raise concerns**
  - **Aerodynamic performance**
  - **Noise generation**
- **Direct measurement shows**
  - **Flatback noise is much higher than sharp TE noise (90 dB vs 74 dB)**
  - **Splitter plate drops noise significantly (down to 79 dB)**
- **Only preliminary data is available at this time.**
- **Much additional data reduction & validation work remains.**

Thank you

Questions??

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