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Aerodynamic and Aeroacoustic Properties of a Flatback Airfoil

(Will it Rumble or Whisper?)

Dale E. Berg & Matthew Barone

Wind Energy Technology Dept.

Sandia National Laboratories

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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

- Test Goals & Objectives
- Blade Research Background
  - BSDS
  - Flatback airfoils
- Wind Tunnel
- Models
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- Aerodynamic Results
- Aeroacoustic Results
- Future Work
- Summary

Test Goals & Objectives

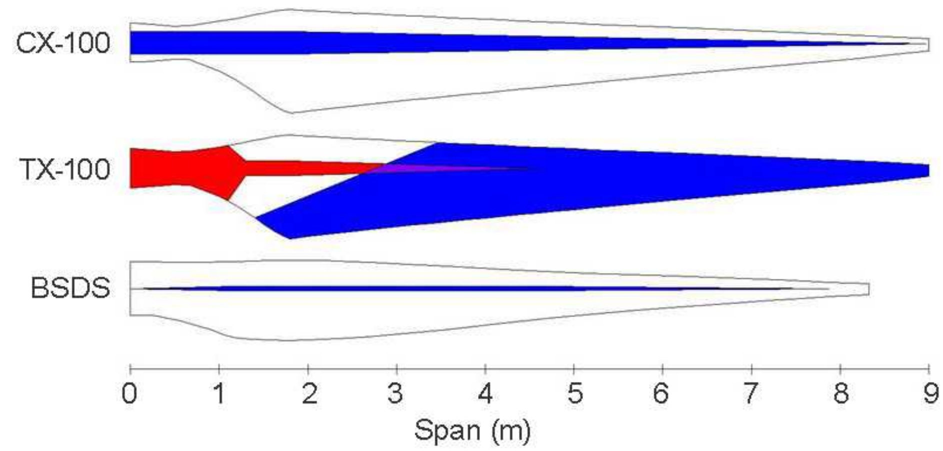
- **Goals:** Quantify the aerodynamic performance and noise generation of a flatback airfoil relative to a conventional sharp trailing edge airfoil
- **Objectives:**
  - Directly measure performance of a flatback airfoil
    - aerodynamic
    - aeroacoustic
  - Compare to measured performance of a conventional 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 iterative system design approach



Aerodynamic → **Structural** → **Manufacturing** → **Aerodynamic**

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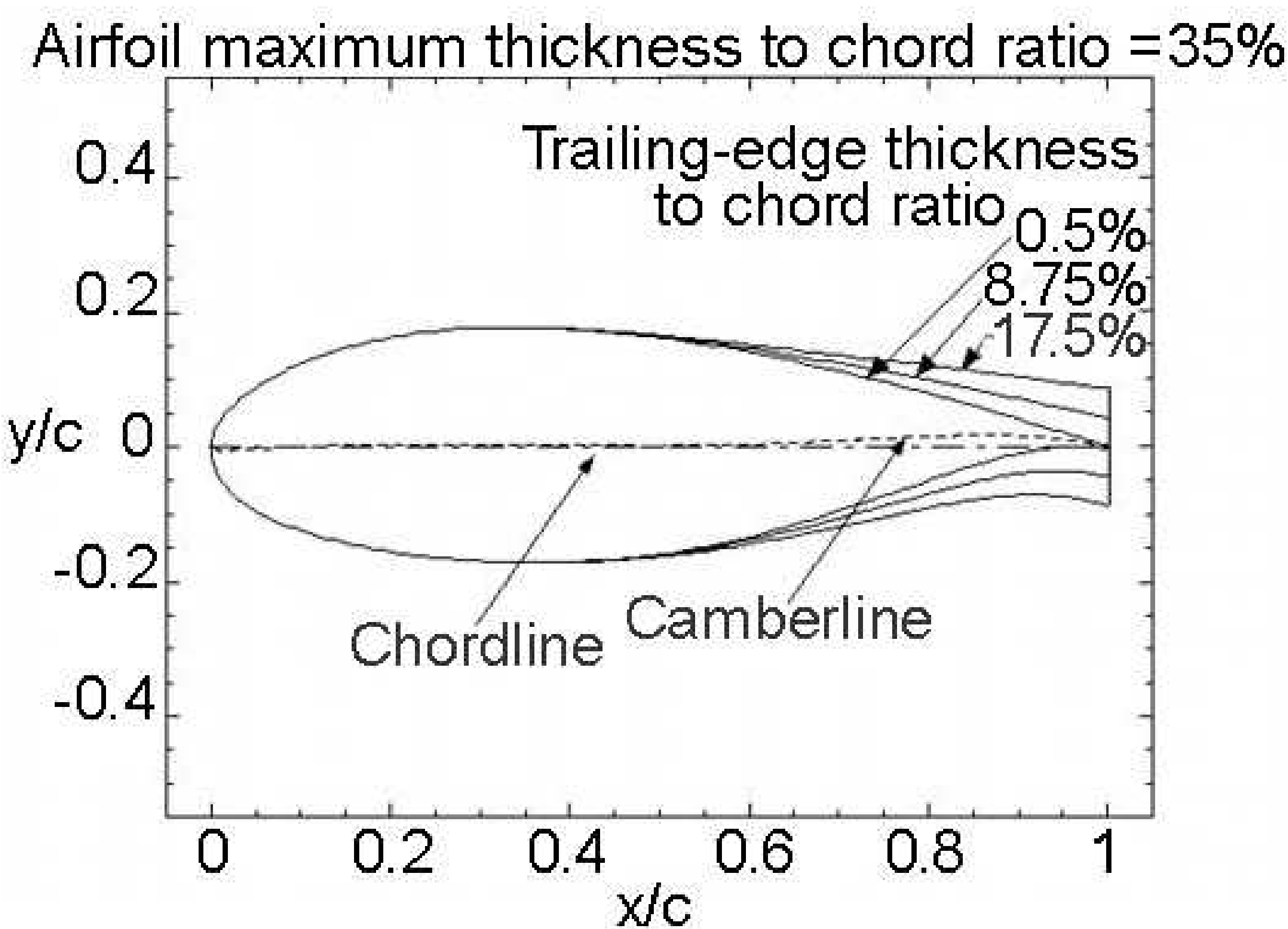
Blade Structural Comparison

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

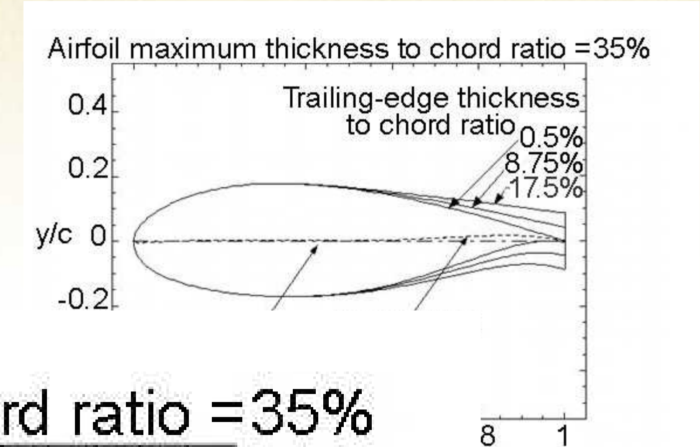
Integrated aero/structural design process resulted in lighter, less expensive, stronger blade

Flatback Airfoils

- **Flatback airfoils are created by the symmetric addition of thickness about**
-
-



Creation of Flatback Airfoils



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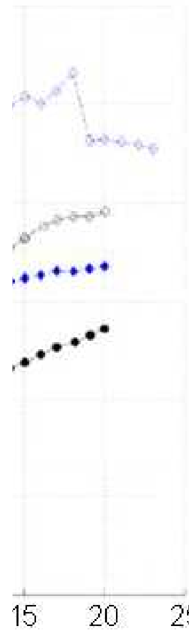

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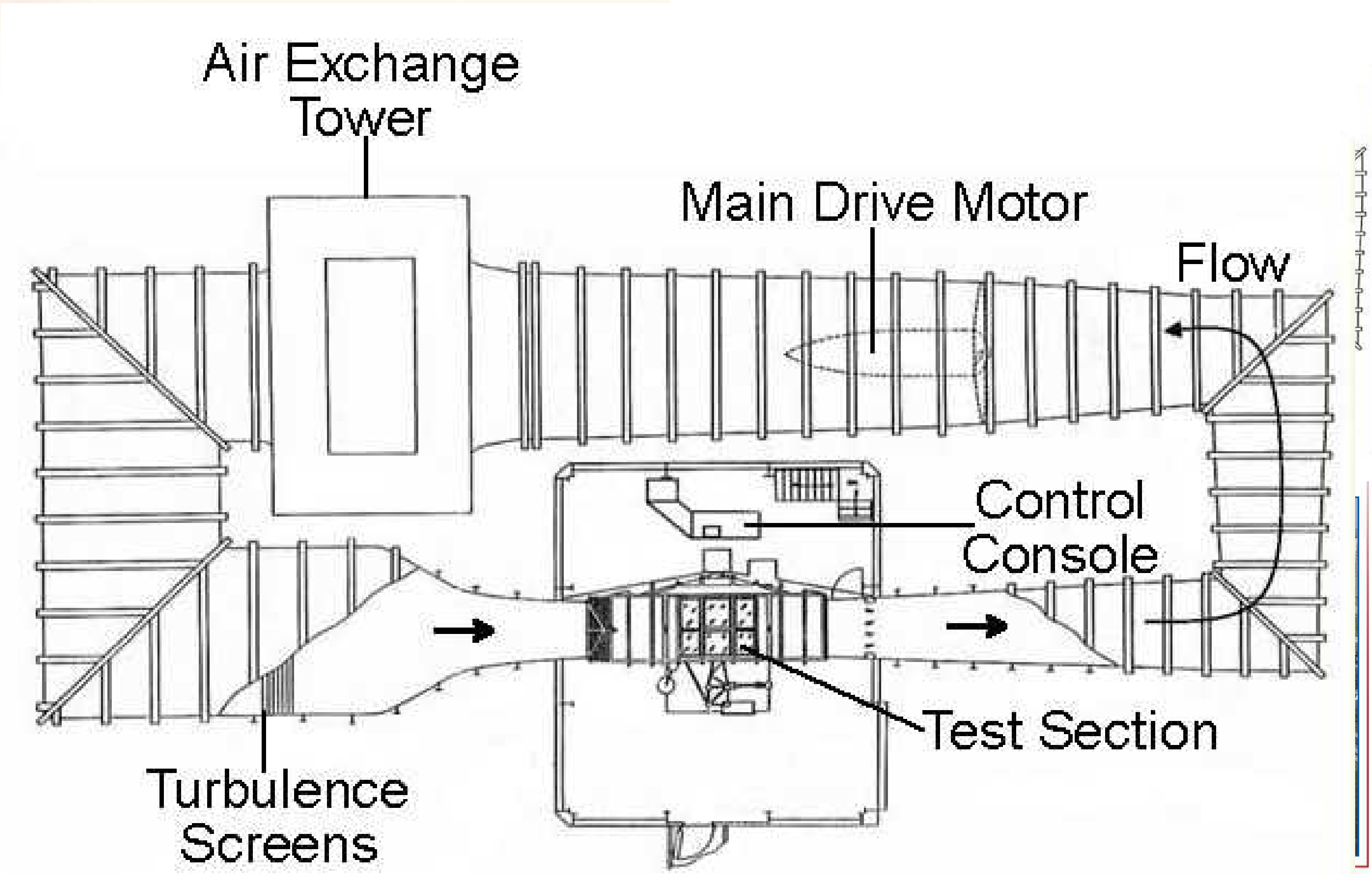
Why Perform Wind Tunnel Tests?

- **Why develop flatbacks?**
  - **TU Delft has developed thick airfoils for root sections**
  - **Others have tried truncating airfoils**
  - **All are very sensitive to leading edge soiling**
    - major loss of lift
- **Why perform this test?**
  - **Aerodynamic tests to date have been at low Re_c**
  - **Directly compare TU Delft airfoil and flatback version of that airfoil**
  - **No experimental data on flatback noise generation exits**
  - **Trailing edge noise correlation of Brooks et al (1989) based only on "sharp" trailing edge airfoils**

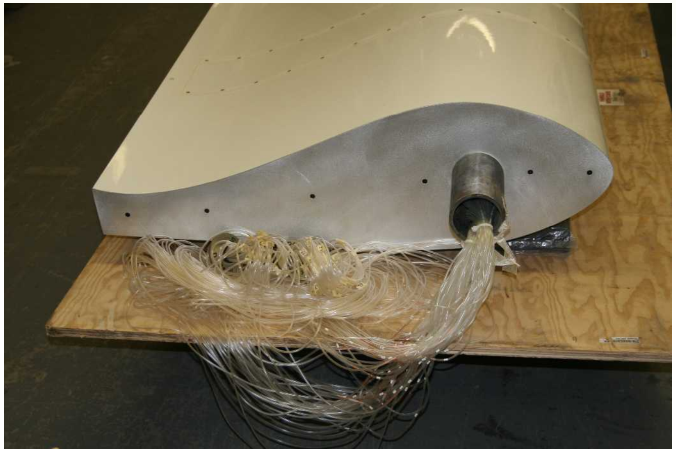
Virginia Tech Stability Wind Tunnel



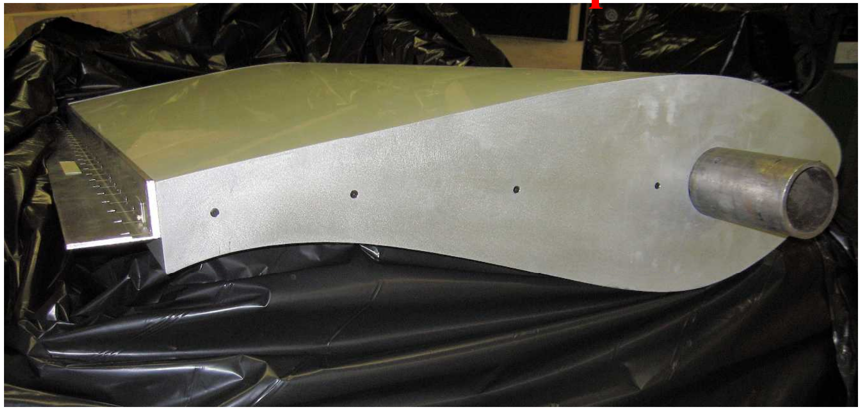
Wind Tunnel Models

- **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**
- **Profiles accurately measured**

Flatback Model



Flatback model with Splitter Plate



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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 (specta) 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)**
    - $Re_c = 1.8, 2.4 \& 3.2 \times 10^6$

Kevlar Wall

Model in Wind Tunnel

Phased Array

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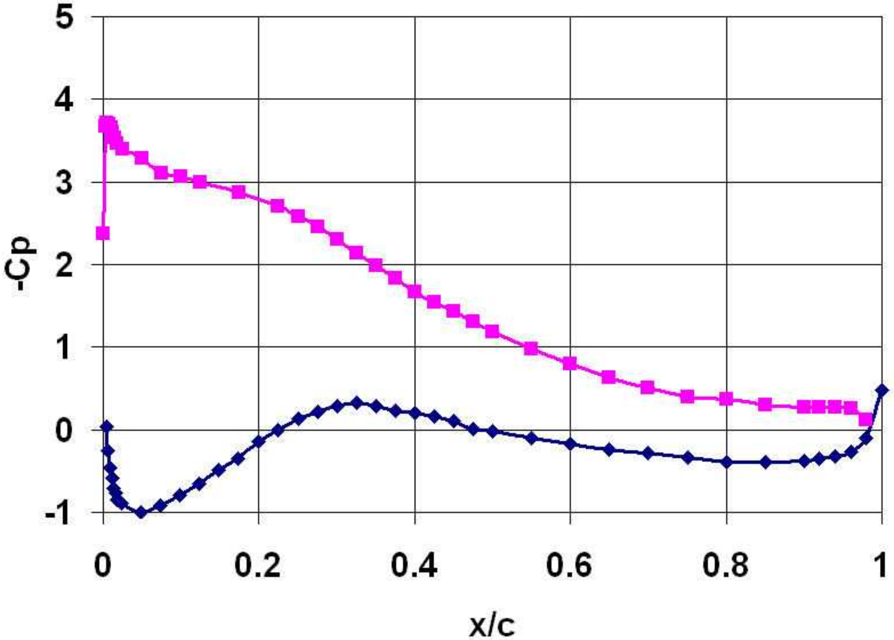
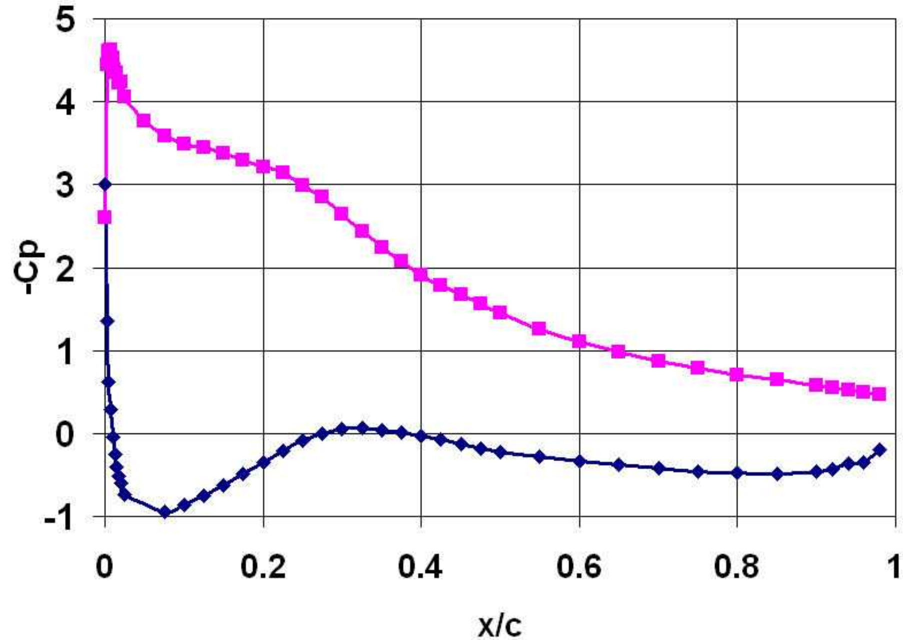
Typical Surface Pressure Results



Sharp Trailing Edge

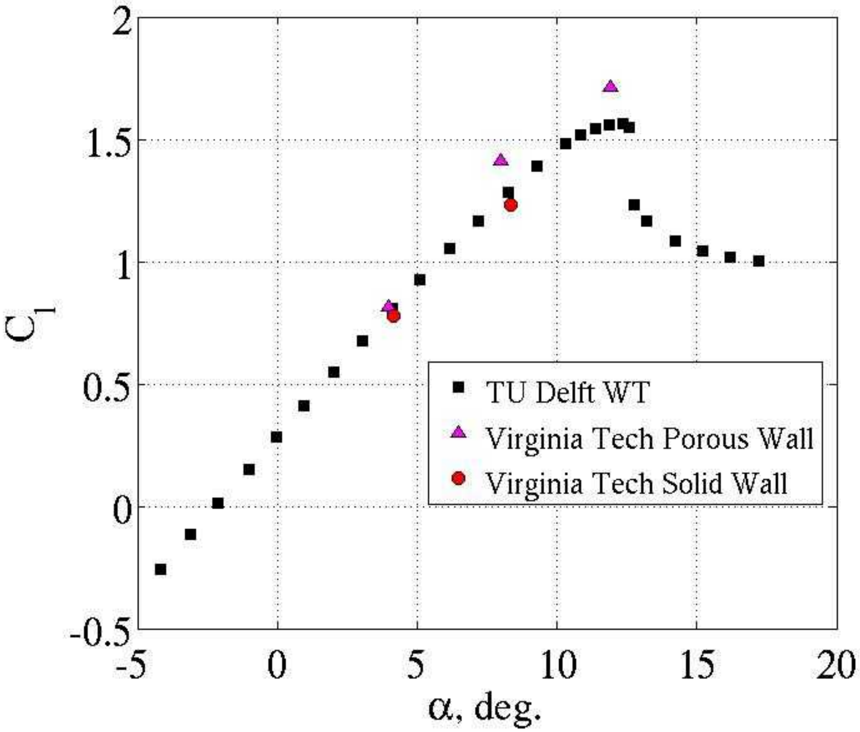


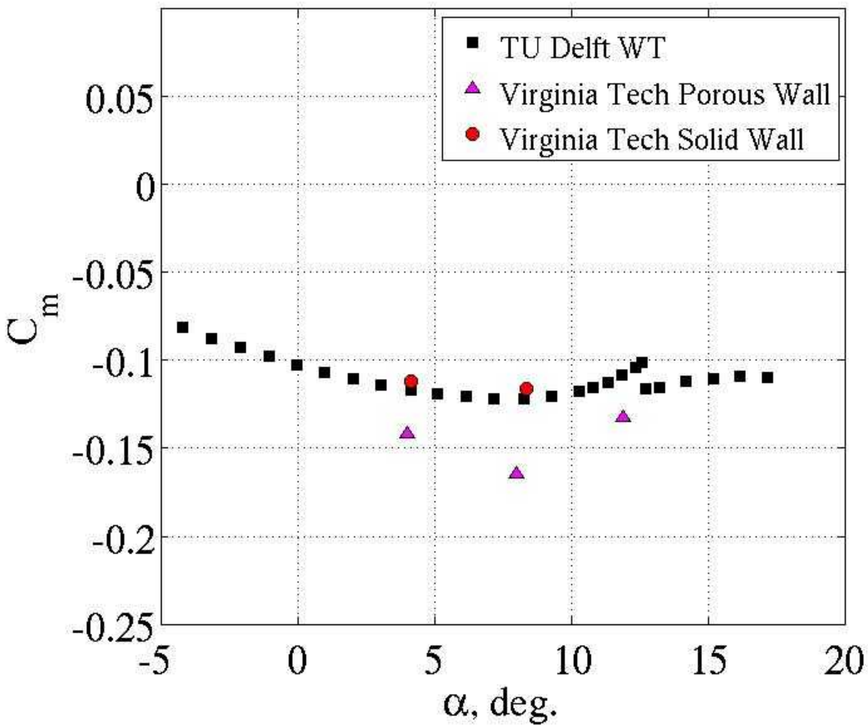
Flatback

- Reynolds number = 3.2 X 10^6, $\alpha = 15°$
- Pressure recovery for flatback occurs aft of trailing edge

Sharp Airfoil Data with Solid Wall Agrees Well with TU Delft Data

DU97-W-300, $Re_c = 3x10^6$, WT Wall Corrections Applied



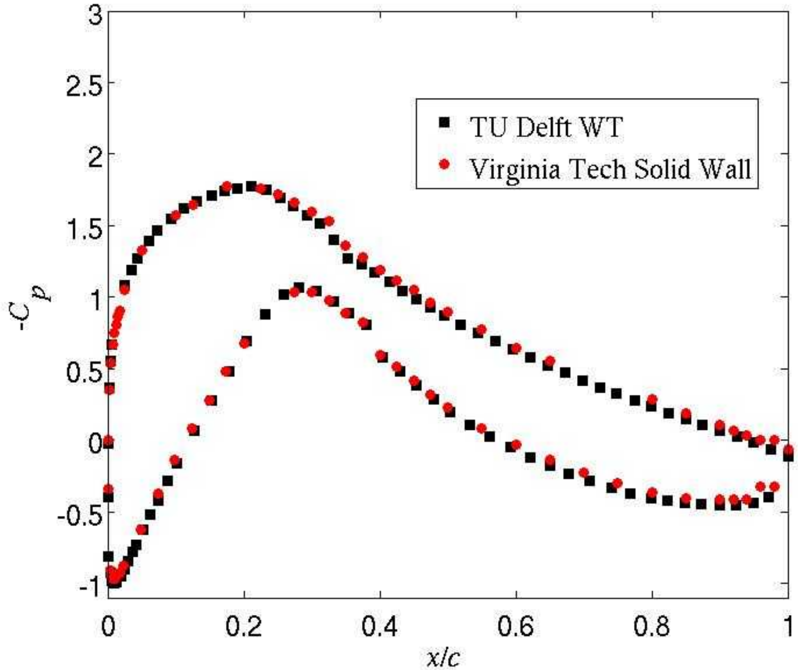


Porous wall blockage correction not yet fully resolved

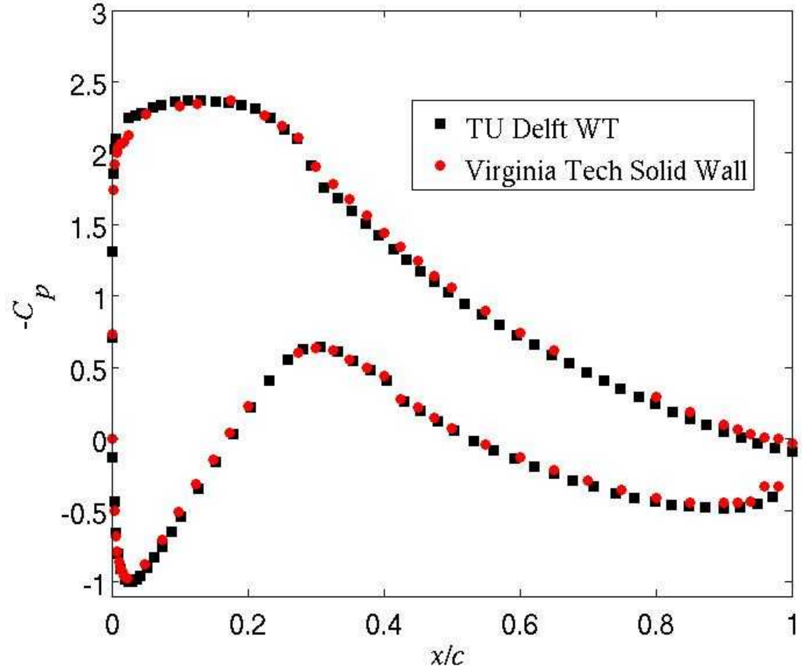
Solid Wall Pressure Distributions Agree Well with Delft Data

DU97-W-300 C_p Distributions, $Re_c = 3x10^6$

α = 4 deg.



α = 8 deg.



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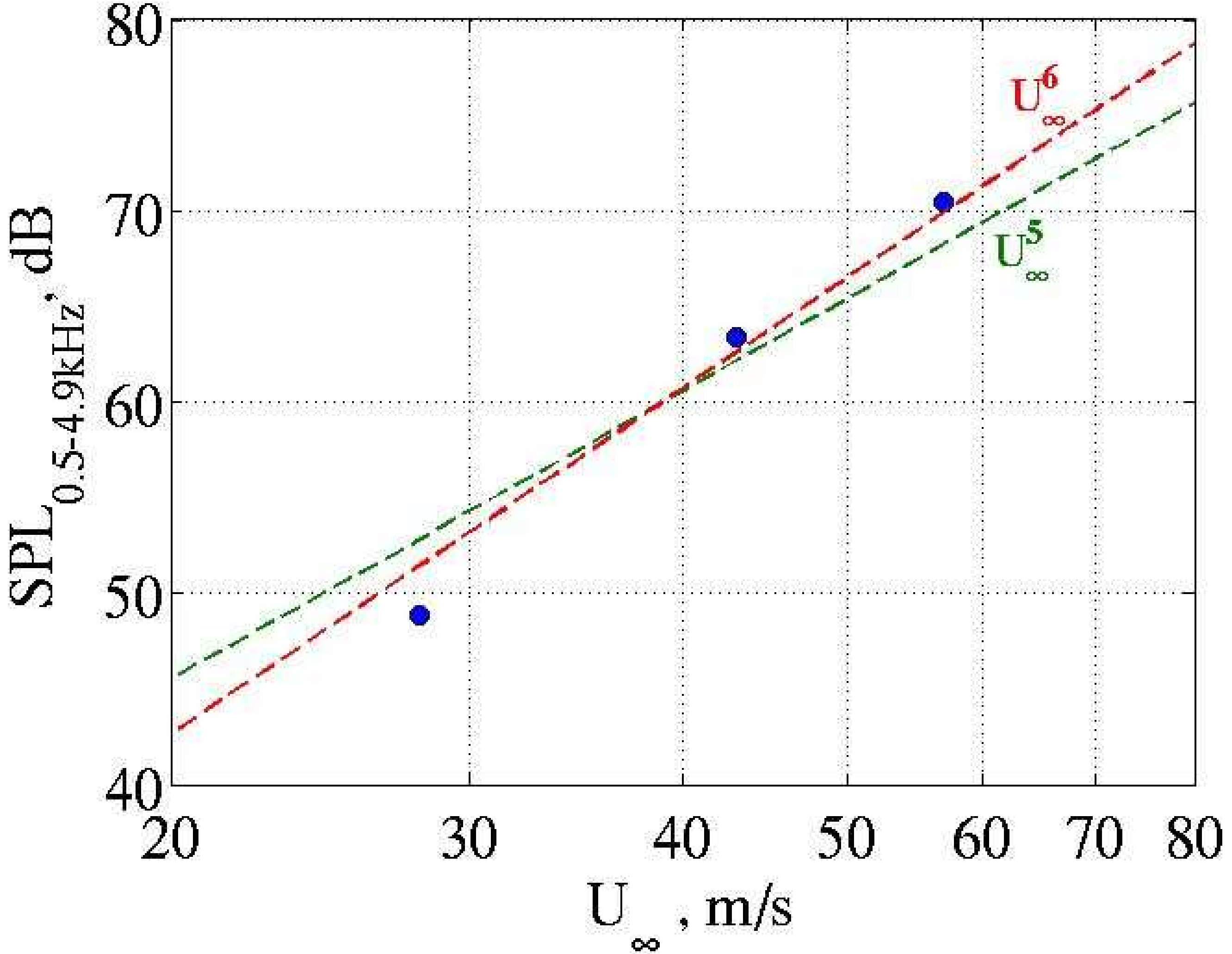
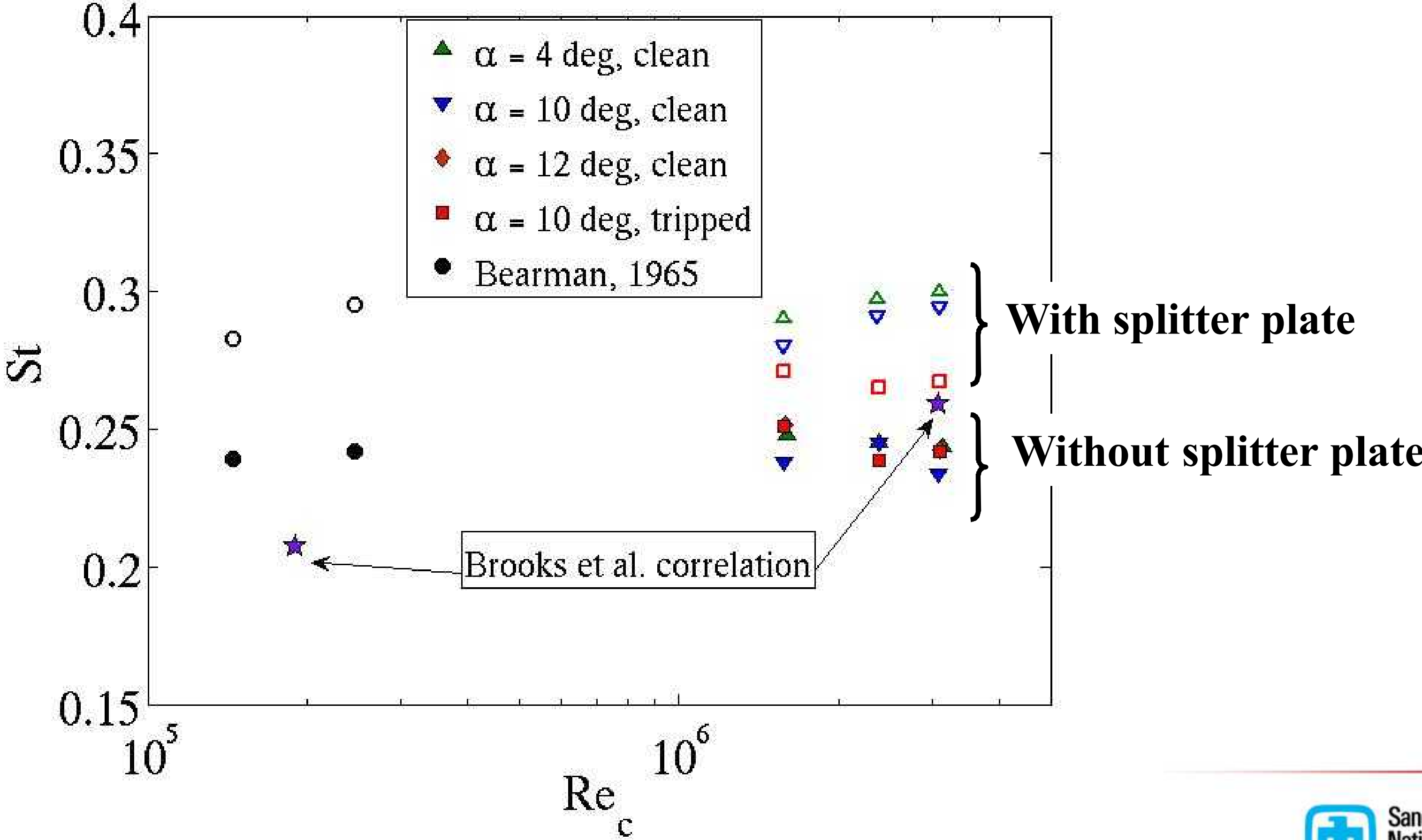
Sound Intensity Scales with Velocity

Broadband SPL for f>500 Hz: Clean Flatback Airfoil, α=4 deg



Splitter Plate Causes Increase in Strouhal Number

Flatback airfoil



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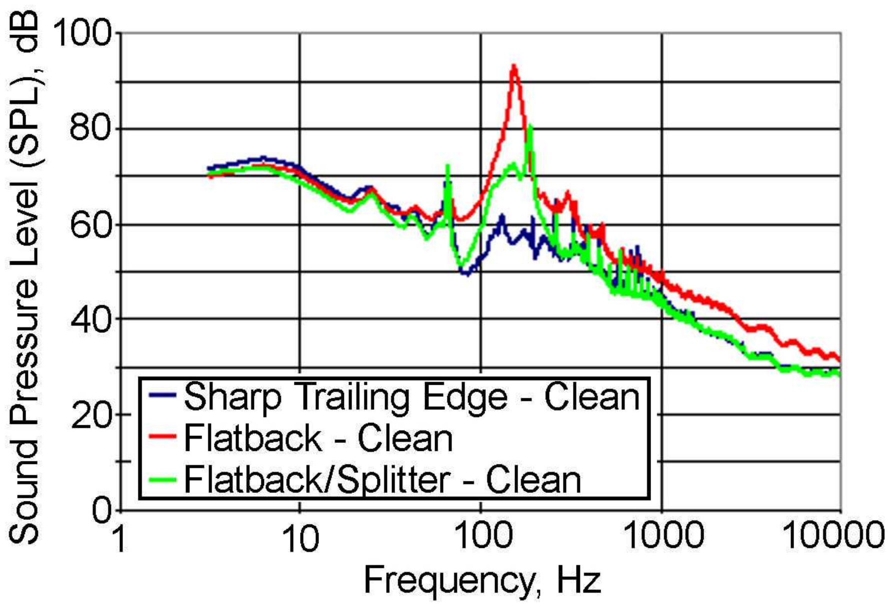
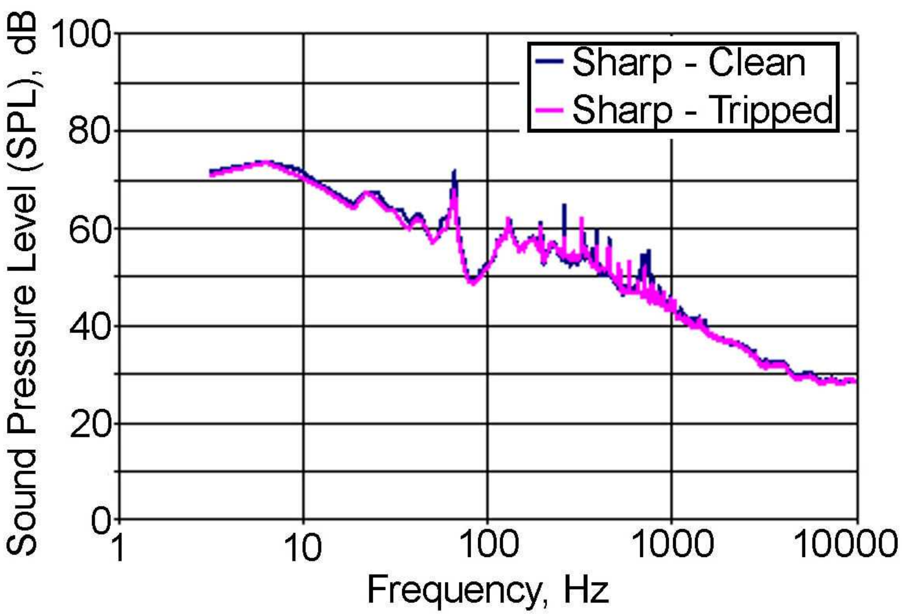
Integrated Noise Spectra





Natural transition **α = 4°** **Sharp trailing edge**

- **Integrated spectra (average of 100 calculations) from single microphone**
- **Sound amplified to make it audible**

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

Click to play sound files

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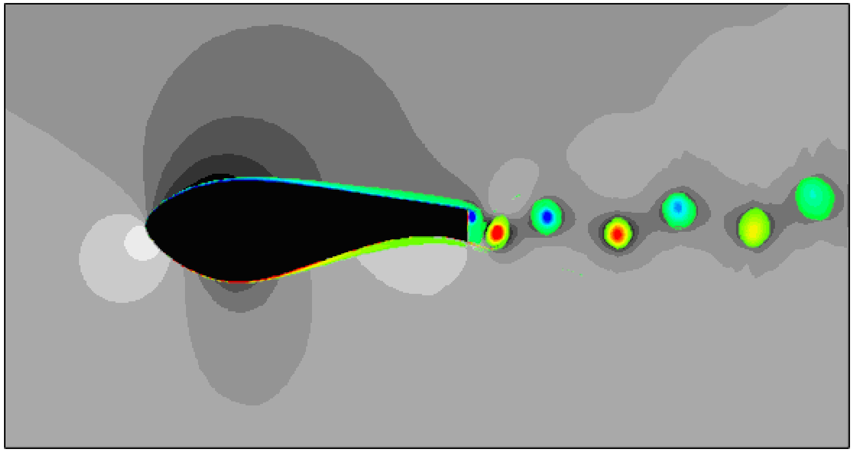
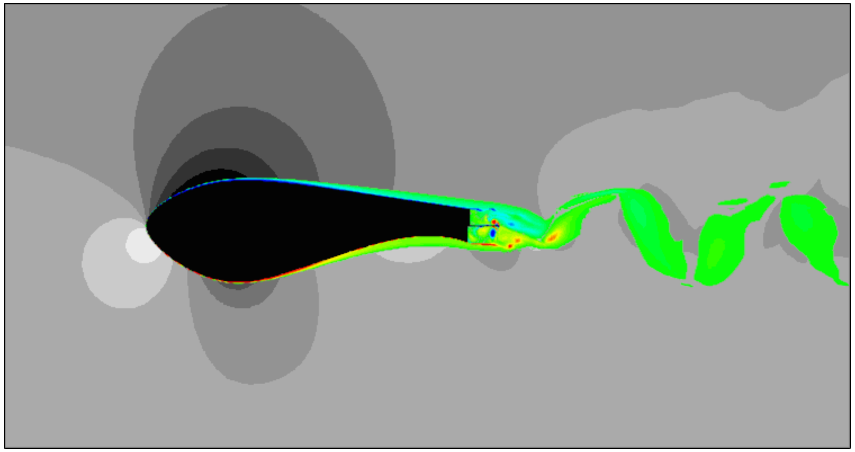
CFD Simulation



Flatback airfoil



Flatback airfoil with splitter plate

Splitter plate dramatically changes the flow

Click figure to play animation

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Future Work

- Determine noise damping characteristics of tunnel and correct noise measurements
- Complete correlation of noise measurements with those of Bearman (1965) and Brooks, Pope & Marcolini (1989)
- Establish wind tunnel blockage effects for porous wall & reduce flatback aerodynamic data
- Publish results as SAND report
- Test other trailing edge treatments with emphasis on noise reduction
- Compare flatback experimental aerodynamic performance with CFD model and reconcile differences
- Use hot wire velocity and spectral data as initial conditions for computational aeroacoustic analysis
- Use scaling and correlations to compare noise generated by blade with flatback sections to that generated by blade with only conventional sections

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)
- **Additional experimental work is planned**
- **Blockage effects for porous wall not yet determined**
- **Test results will be made available**

Thank you

Questions??

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