Aeroelastic Prediction Workshop

Overview of the Rectangular Supercritical Wing (RSW) Test Case

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NASA Langley Research Center

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Outline

- Test Case Selection Rationale
- RSW Description
  - Geometry and Construction
  - Features and Instrumentation
  - Known Deficiencies
- RSW Testing
  - Transonic Dynamics Tunnel (TDT)
  - Test Cases and Test Data
- Summary and RSW Bibliography

Overall Workshop Configuration Selection Strategy

- Aeroelastic prediction requires simulation with many independent variables spanning multiple disciplines
  - Must work to isolate independent variables and evaluate our ability to predict the processes defined by them
  - Coarse-grain independent variables:
    - Aerodynamics
    - Structural dynamics
    - Fluid / structural coupling
- Focus of 1st workshop: Prediction of unsteady aerodynamic pressures due to forced modal oscillations

AePW Definition of an "Excellent" Data Set

- Configuration that can be modeled without adding an unnecessary level of uncertainty to the analysis
- High-quality model definition
  - Well-documented geometry
  - Stiffness, mass, and inertia measurements
  - Structural dynamic properties:
    - Natural frequencies
    - Mode shapes
    - Generalized masses
- High-quality wind-tunnel measurements
  - Flow regime: subsonic, transonic, and supersonic
  - Extensive array of unsteady pressure measurements
  - Quantitative displacement measurements
  - Quantitative flow visualization measurements
  - Loads measurements
  - Quantitative definition of instability boundaries (LCO, flutter, divergence, buffet, etc.)

AePW-1 Case 1 Selection Rationale:
Rectangular Supercritical Wing (RSW)

- Cases chosen to focus on the steady and unsteady aerodynamics - C_p
- Mach 0.825 generates transonic conditions with a terminating shock; highest Mach number with forced transition
- Steady Data: Two static angles of attack chosen
  - $\alpha = 2.0^{\circ}$
    Generates a moderate-strength shock with some potential for shock-separated flow; corresponding forced oscillation data exists
  - $\alpha = 4.0^{\circ}$
    Generates strong shock with greater potential for shock-separated flow

- Unsteady Data: Two forced oscillation frequencies chosen to evaluate the ability of methods to distinguish frequency effects
  - Non-zero mean angle of attack introduces a wing loading bias for which code-to-code comparisons can be accomplished

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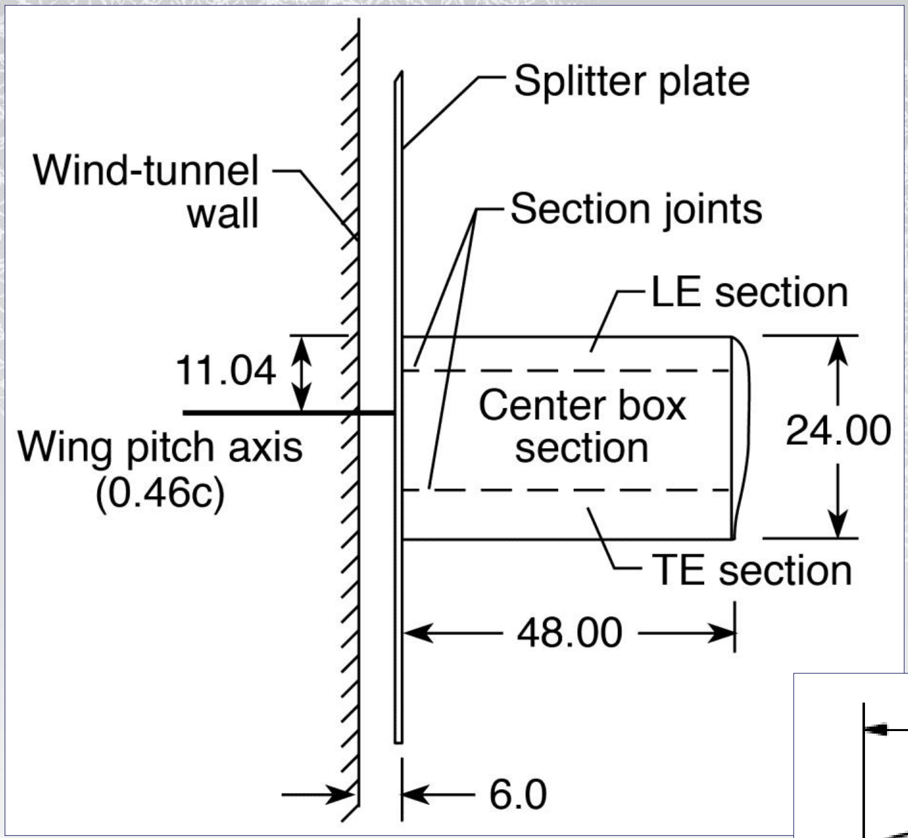
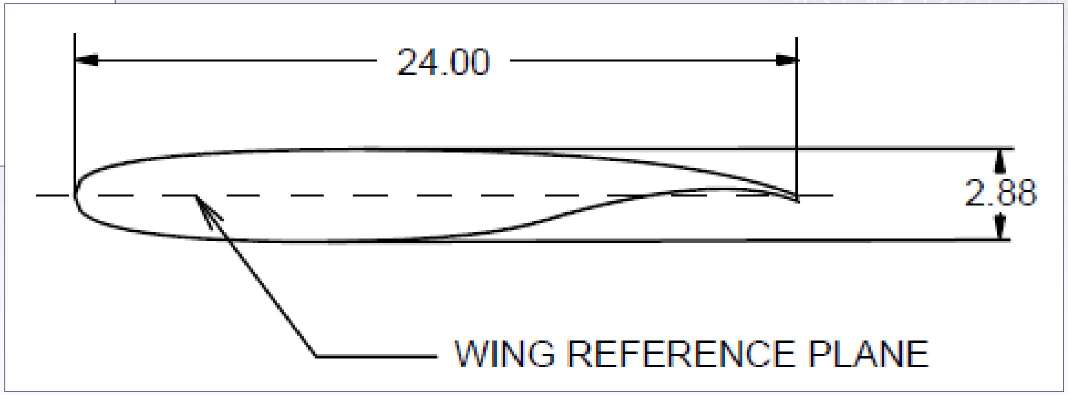
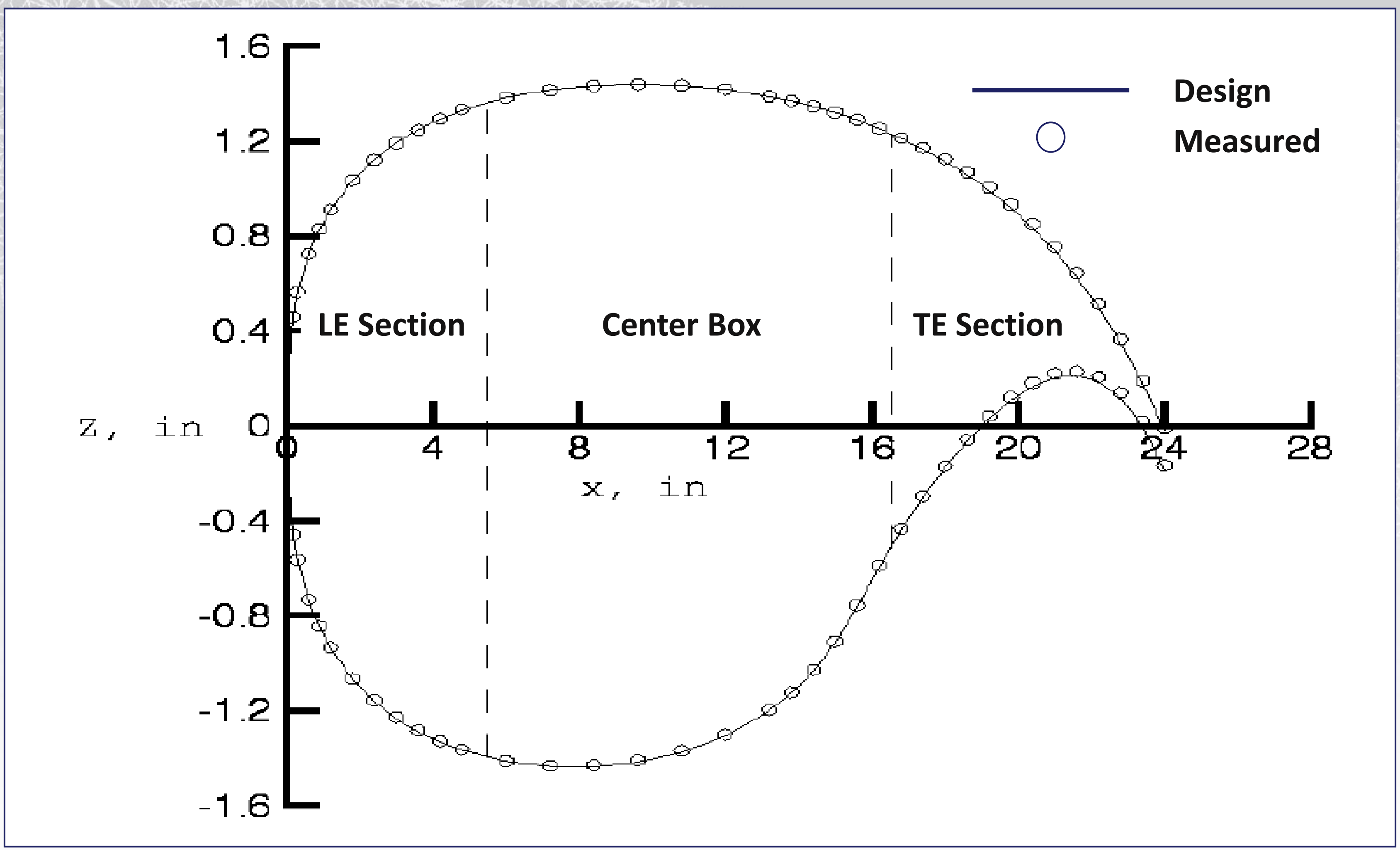
RSW Geometry and Construction



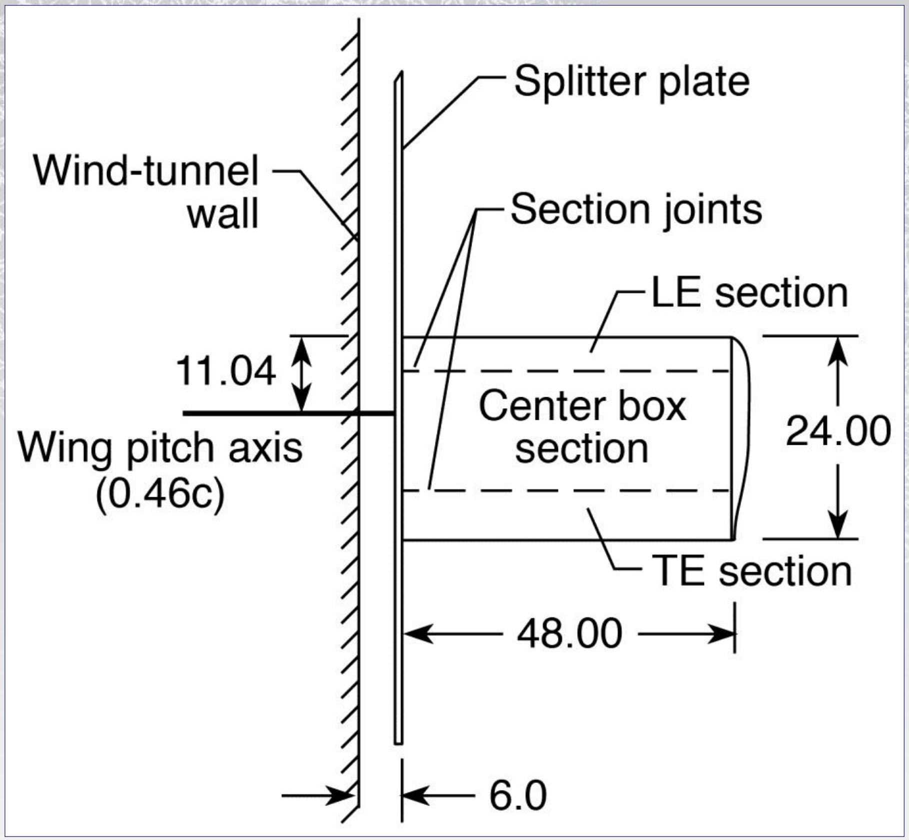
- Unswept, rectangular planform
- Panel aspect ratio = 2
- Tip of revolution
- Leading- and trailing-edge sections attach to center box at 23% and 69% chord
- Supercritical airfoil
  - 12% thick
  - No twist



Comparison of Design and Measured Coordinates
Span Station 38.932 in.



RSW Features



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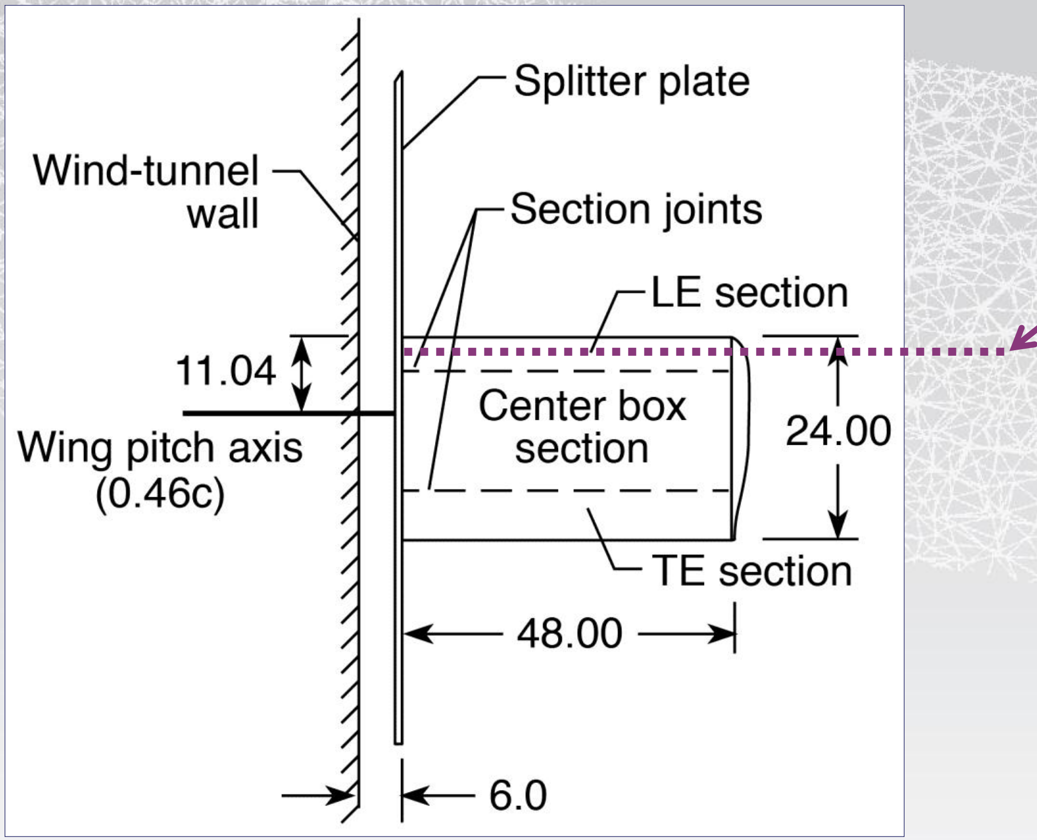
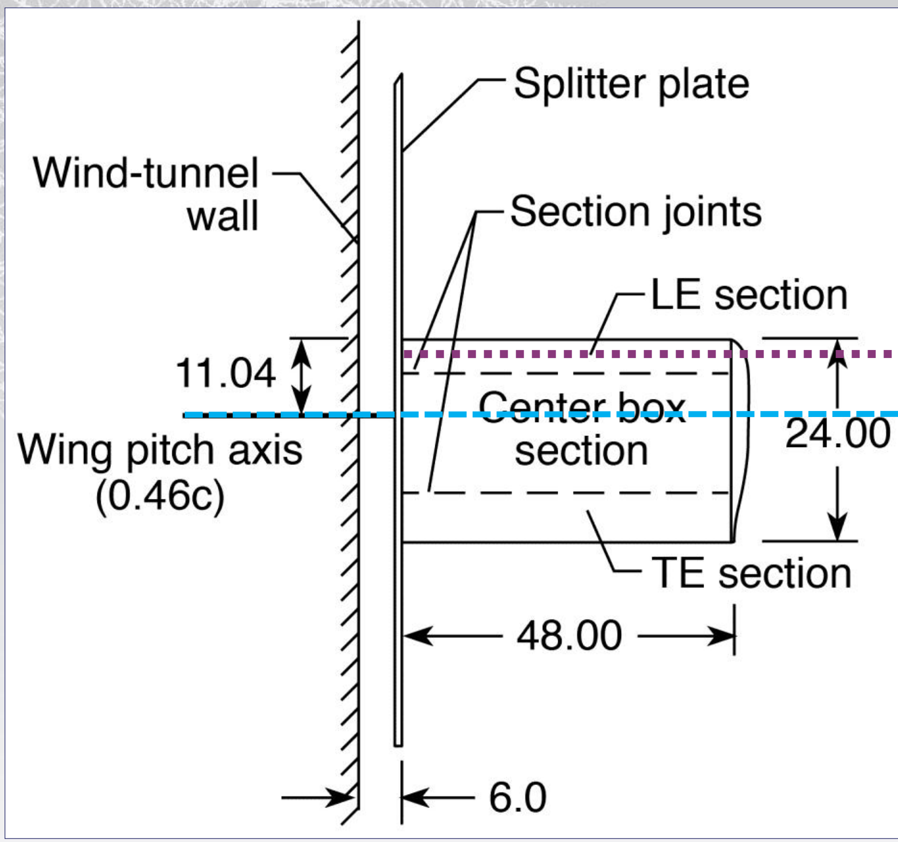


Transition Strip: 6% chord

RSW Features



Transition Strip:
6% chord

Forced Oscillation:
Pitching motion about 46% chord

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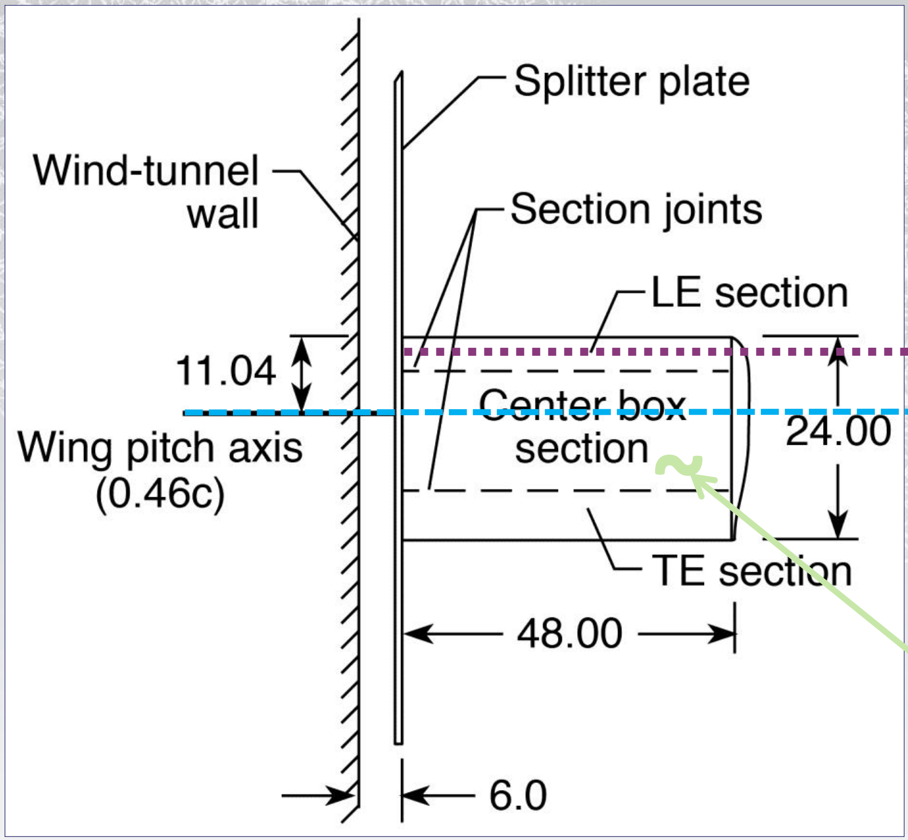

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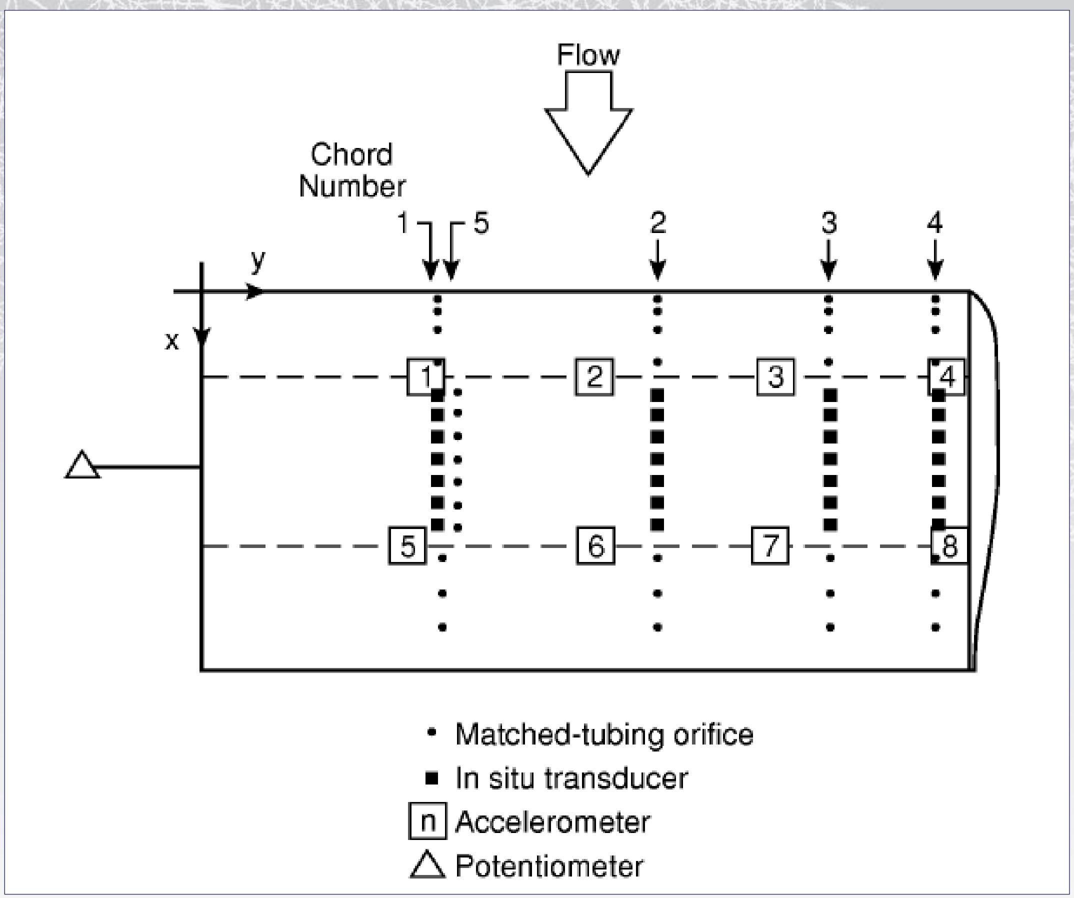
Structurally Stiff:
Lowest structural frequency of model and support system = 34.8 Hz

RSW Instrumentation Layout



Unsteady Pressure Transducers

- Kulites
- 4 full chords (1, 2, 3, 4)
  30.9, 58.8, 80.9, and 95.1 % span
- 29 pressure per chord
  14 upper, 14 lower, 1 leading edge
- Center section: in situ
- LE & TE sections: matched tubing

Accelerometers

- 4 along 23% chord
- 4 along 69% chord

Potentiometer

- 1 on pitch axis (46% chord)

Known Deficiencies with RSW Test

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- Splitter plate
  - Small size
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    - 6” off of tunnel wall
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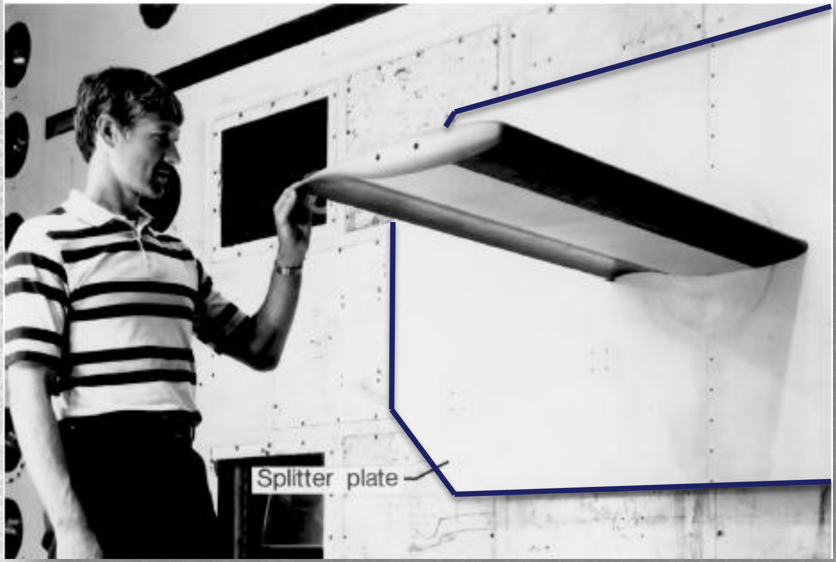

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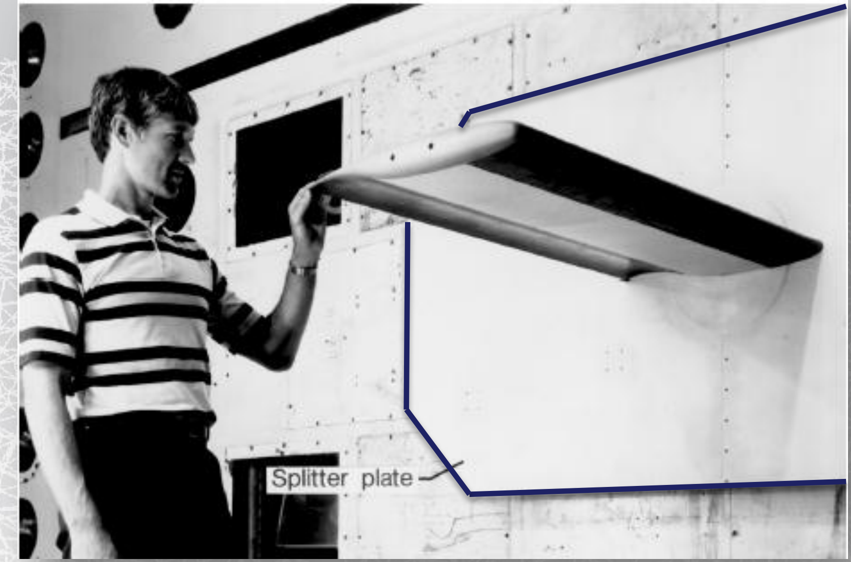

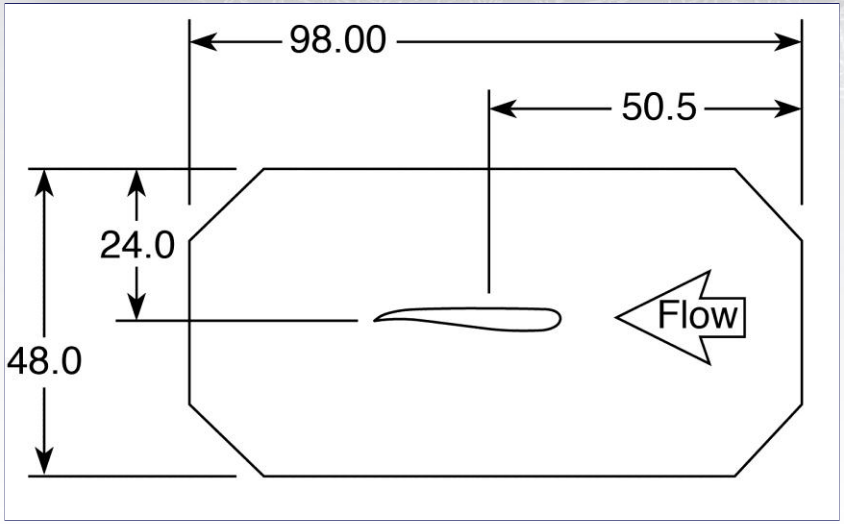

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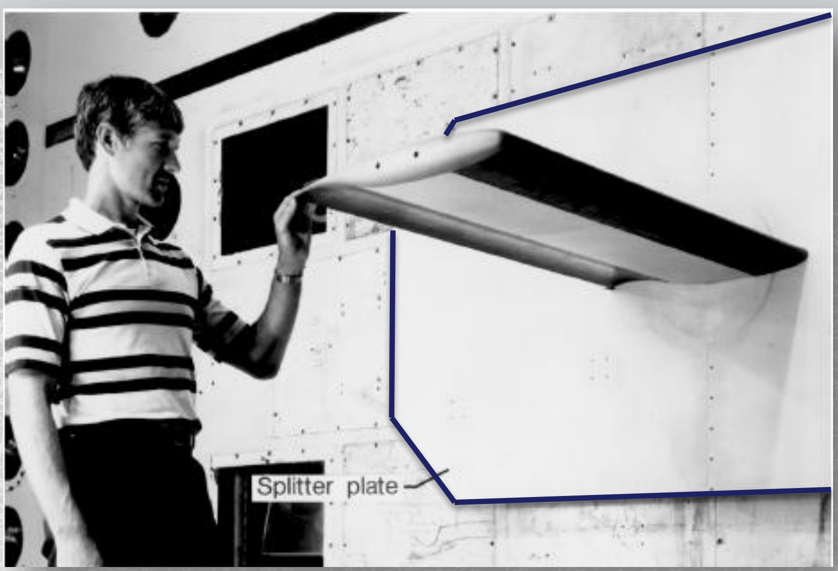

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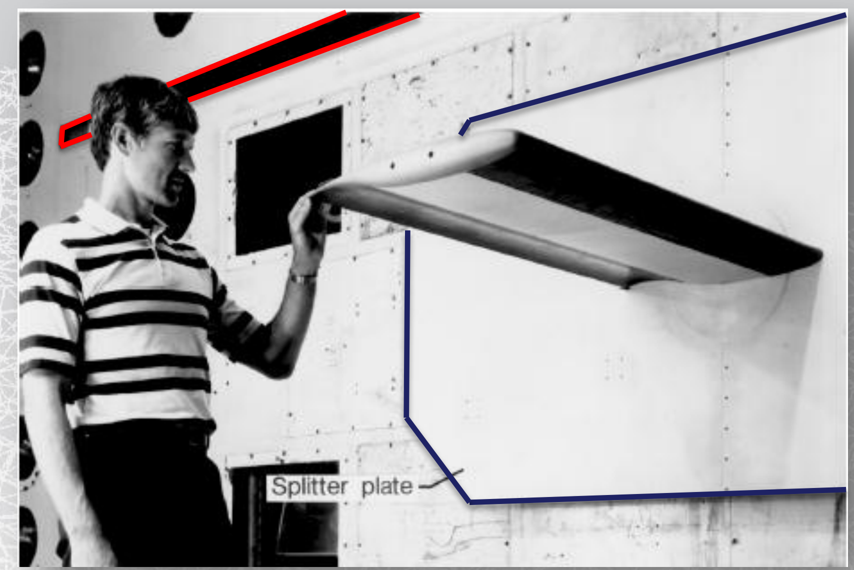

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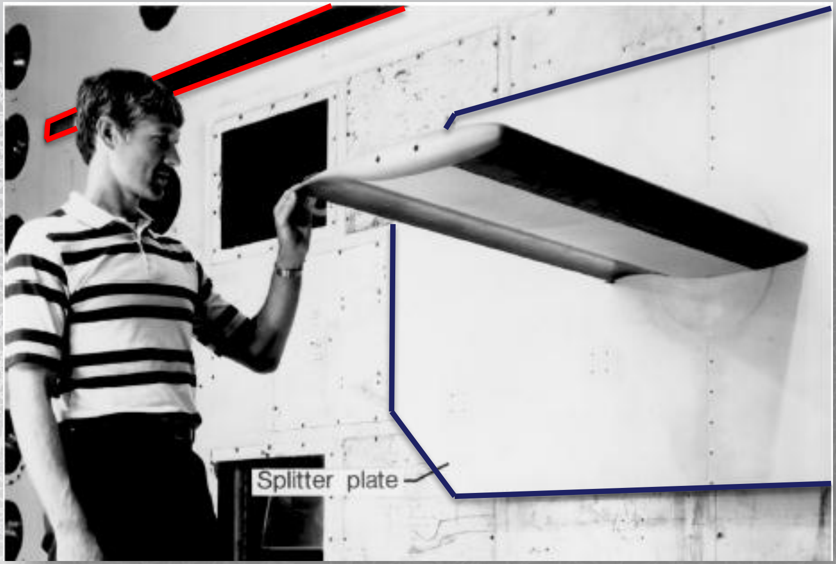

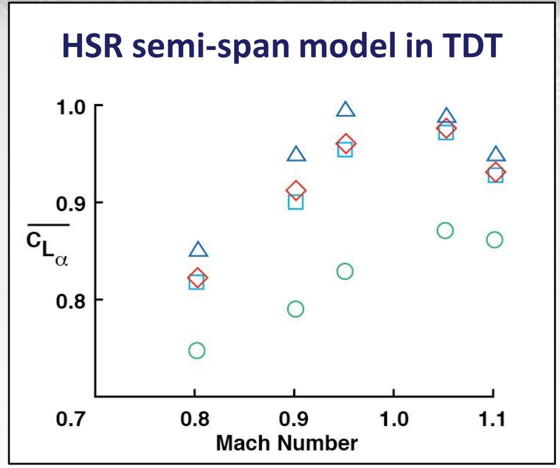

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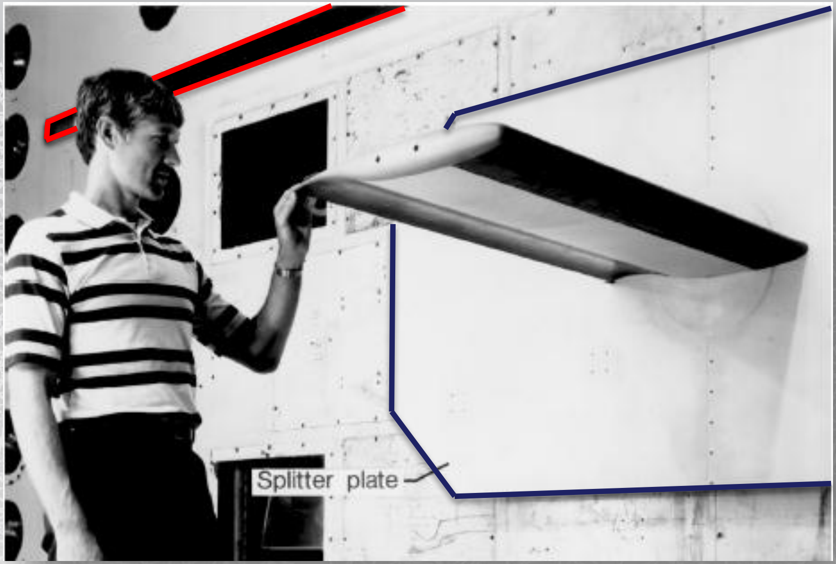

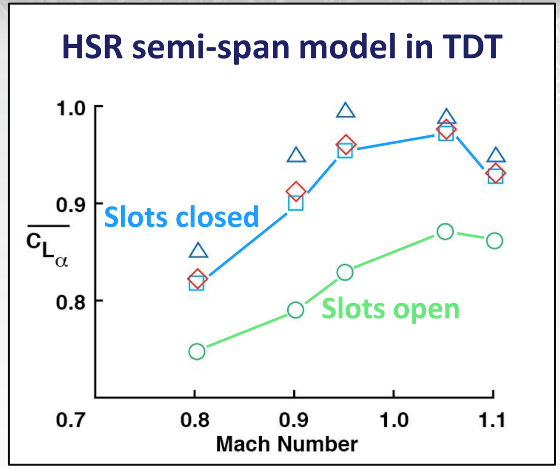

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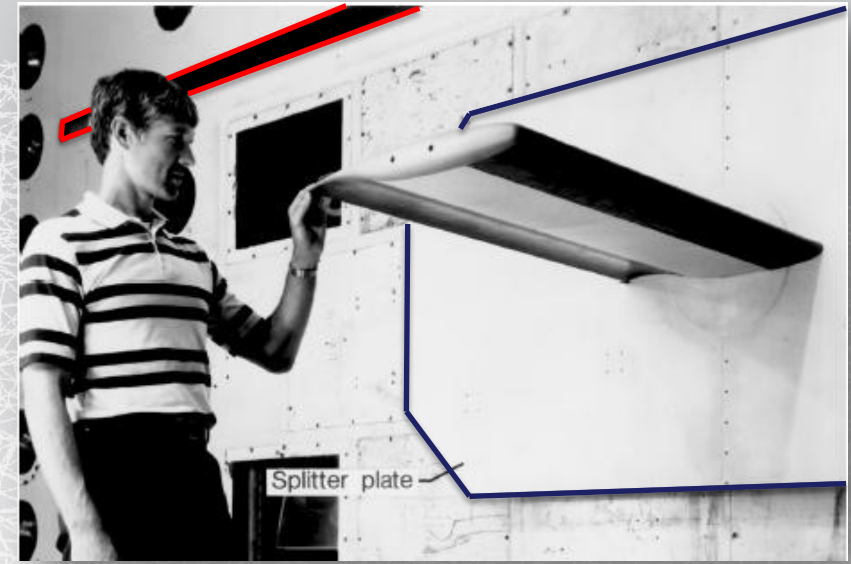
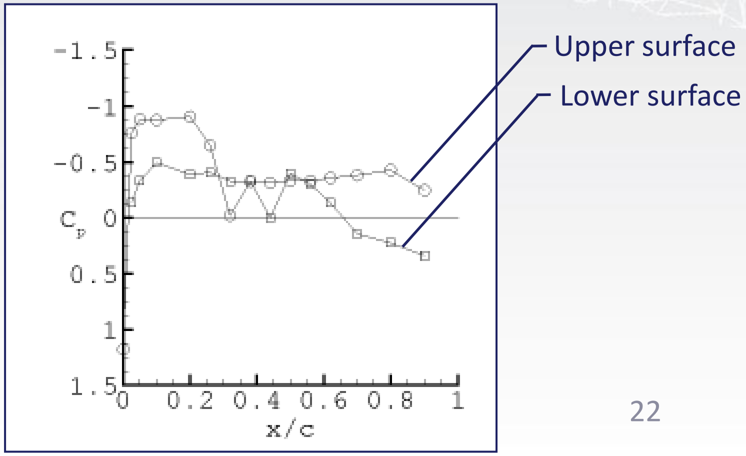


M = 0.825, $\alpha = 2^0$, $\eta = 0.809$



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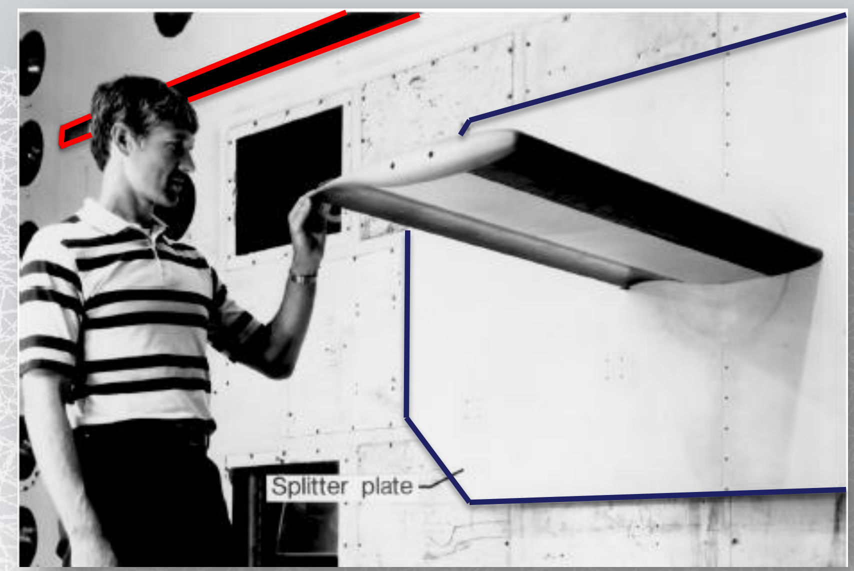

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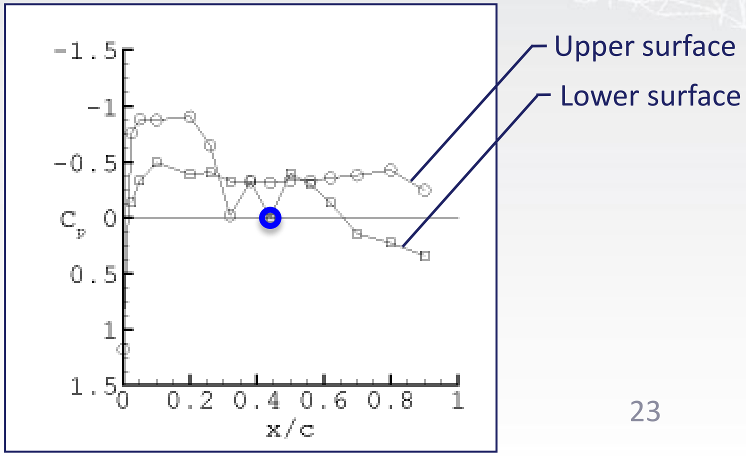

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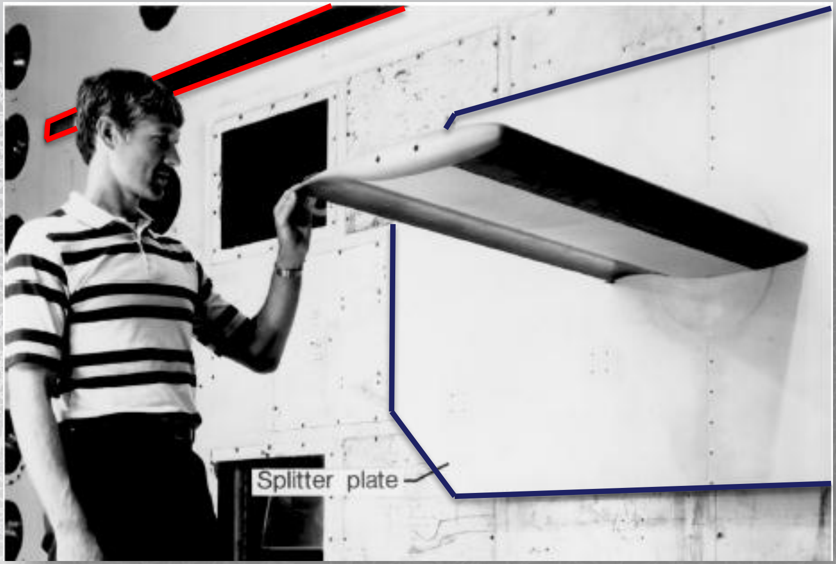

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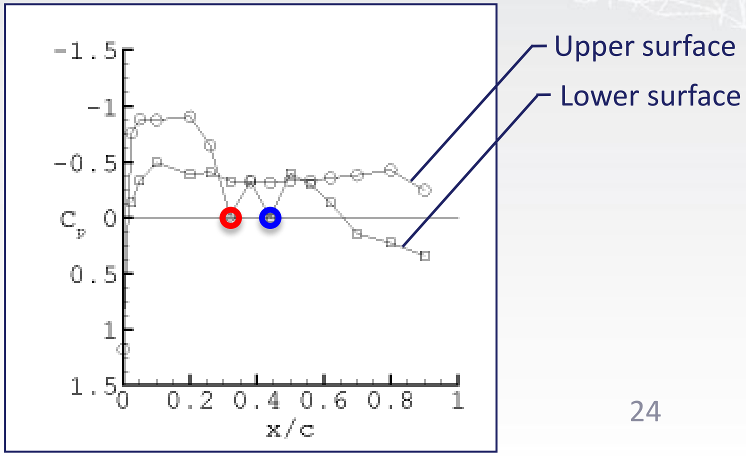
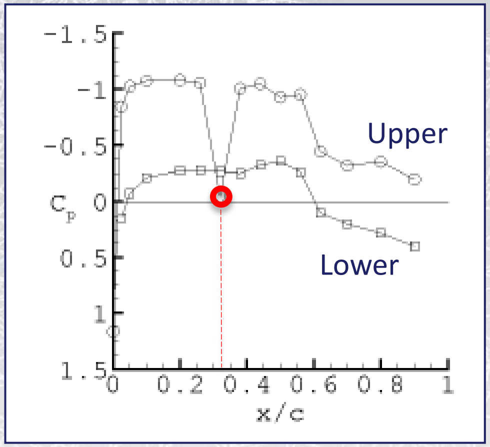


Bad Data Assessment

Upper-Surface Transducers at 32% Chord

- The upper-surface sensors at the 32% chord location are shown to have significantly reduced magnitude response for data sets that include the transition strips.
- The reduced responses are not thought to be altered due to the presence of the transition strip in the flowfield. If it were a physical alteration of the flow field due to the transition strip, there would be more significant changes in the pressure responses between the leading edge and the 32% chord location.
- For unsteady conditions, the phases of these sensors indicate that they are measuring the pressure changes still, but not at the proper response levels.
- The upper-surface sensors at the 32% chord location will not be used for comparison with computational results.

$M = 0.825$, $\alpha = 4^0$, $\eta = 0.309$



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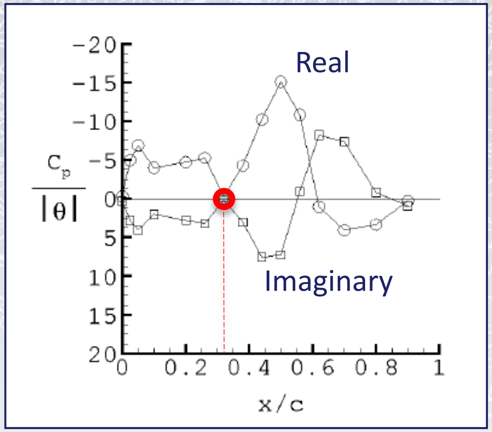

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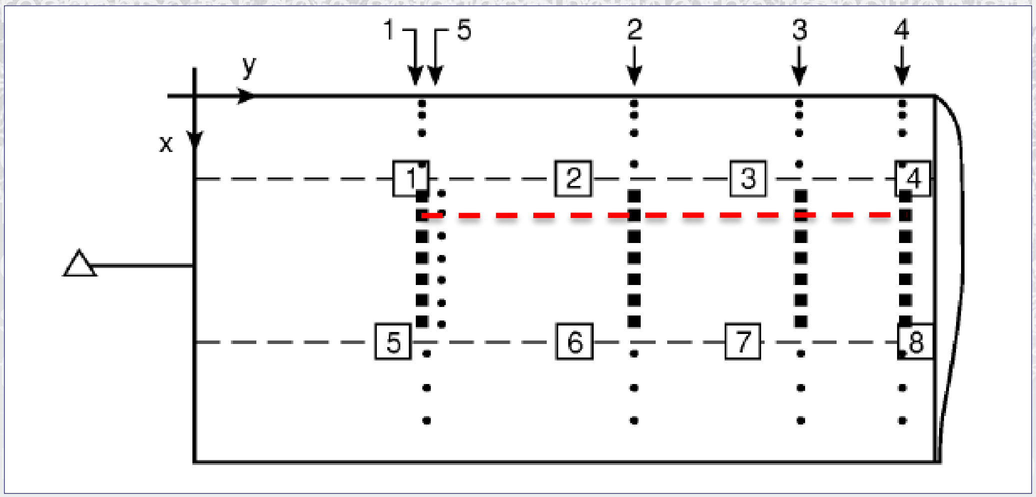

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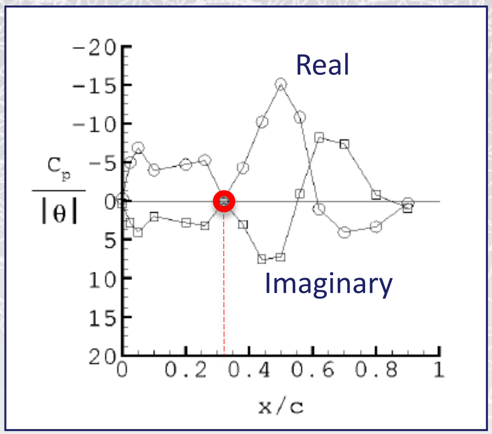

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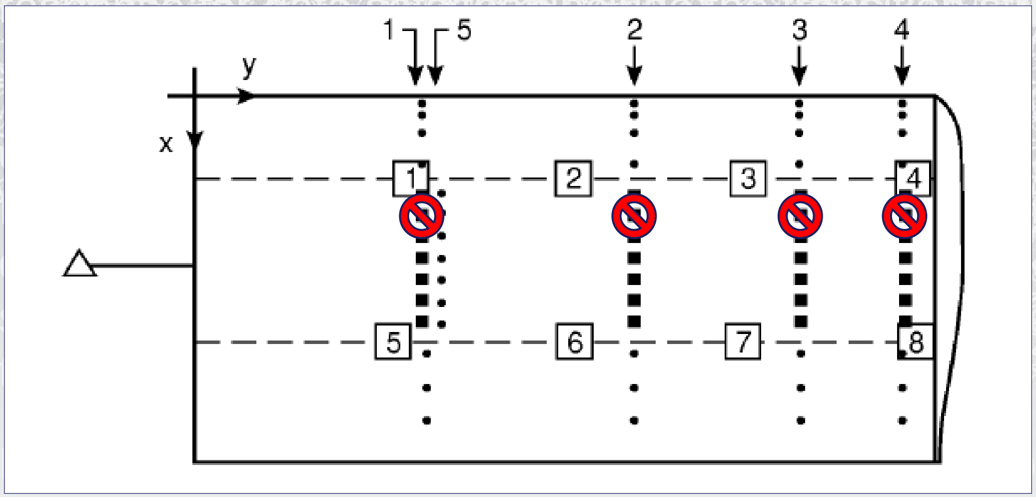

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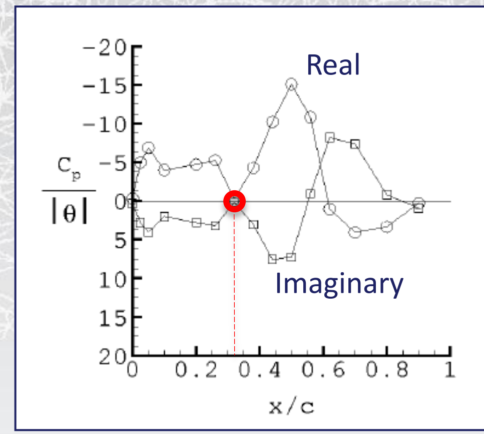

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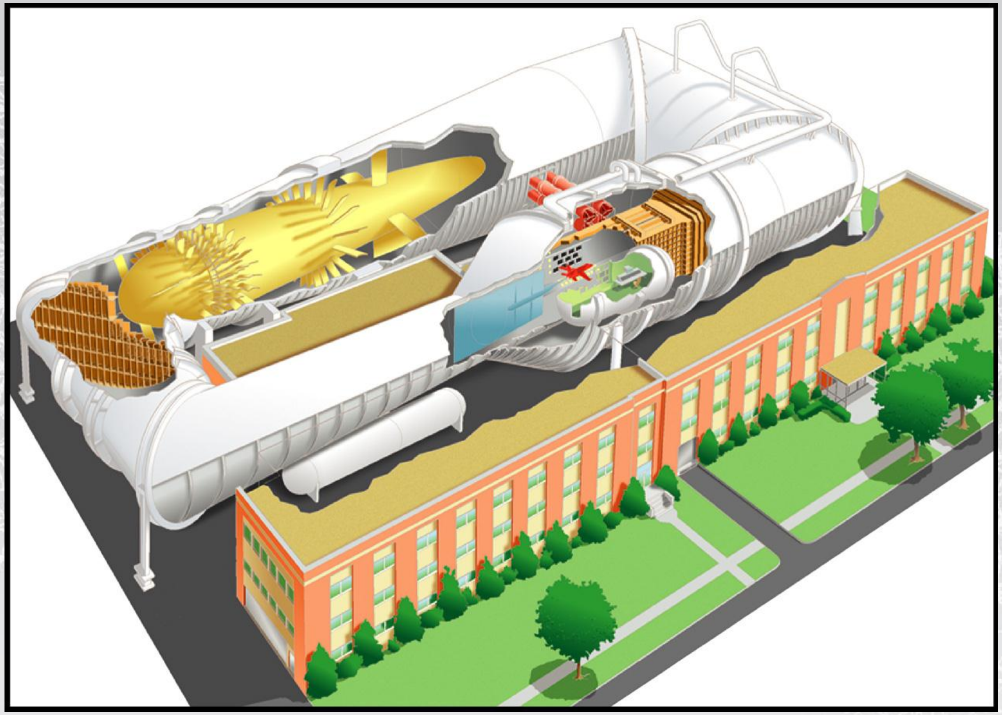
Langley Transonic Dynamics Tunnel (TDT)



- Closed-circuit, continuous-flow wind-tunnel
- Air or R-134a heavy-gas test medium
- Mach numbers up to 1.2
- Total pressures from near vacuum to 1 atmosphere
- Dynamic pressures up to 550 psf in R-134a
- Model and facility protection systems

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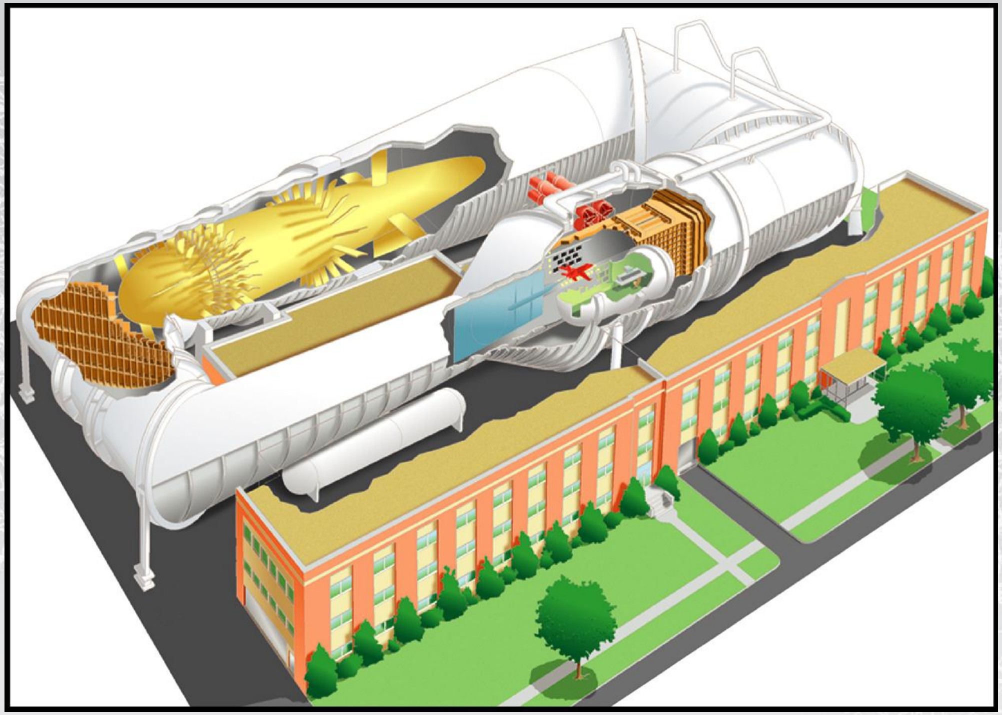

R-12 (Freon)
for RSW in 1982

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RSW Test Cases

- **Conditions common to all cases:**
  - **Mach number = 0.825**
  - **R-12 heavy gas test medium**
  - **Reynolds number = 4 million (based on chord)**

- **Steady Cases**
  - $\alpha = 2^0$
  - $\alpha = 4^0$
  - **Quantity of interest: mean C_p**

- **Dynamic Cases (forced oscillations)**
  - $\alpha = 2^0$, $\theta = 1^0$, f = 10 Hz, k = 0.15
  - $\alpha = 2^0$, $\theta = 1^0$, f = 20 Hz, k = 0.30
  - **Quantities of interest: real and imaginary of C_p / θ**
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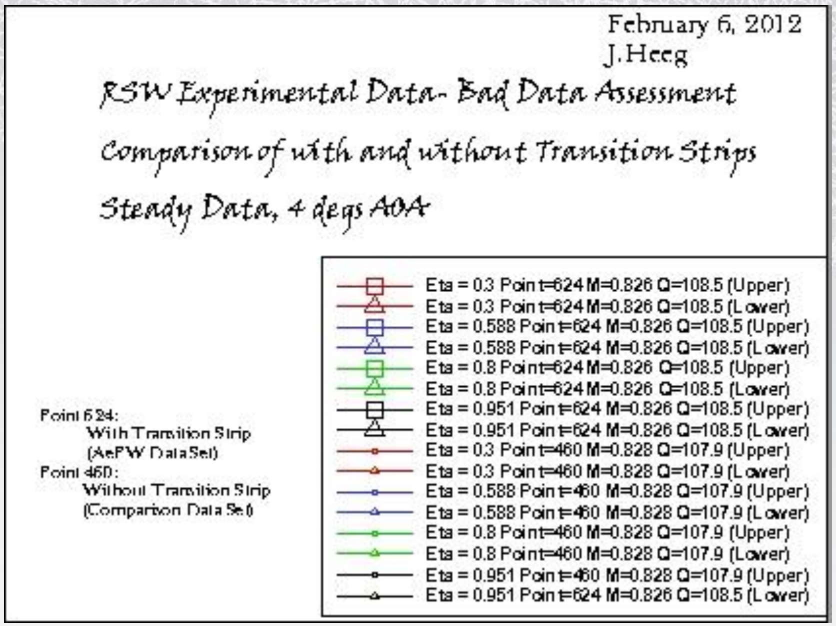
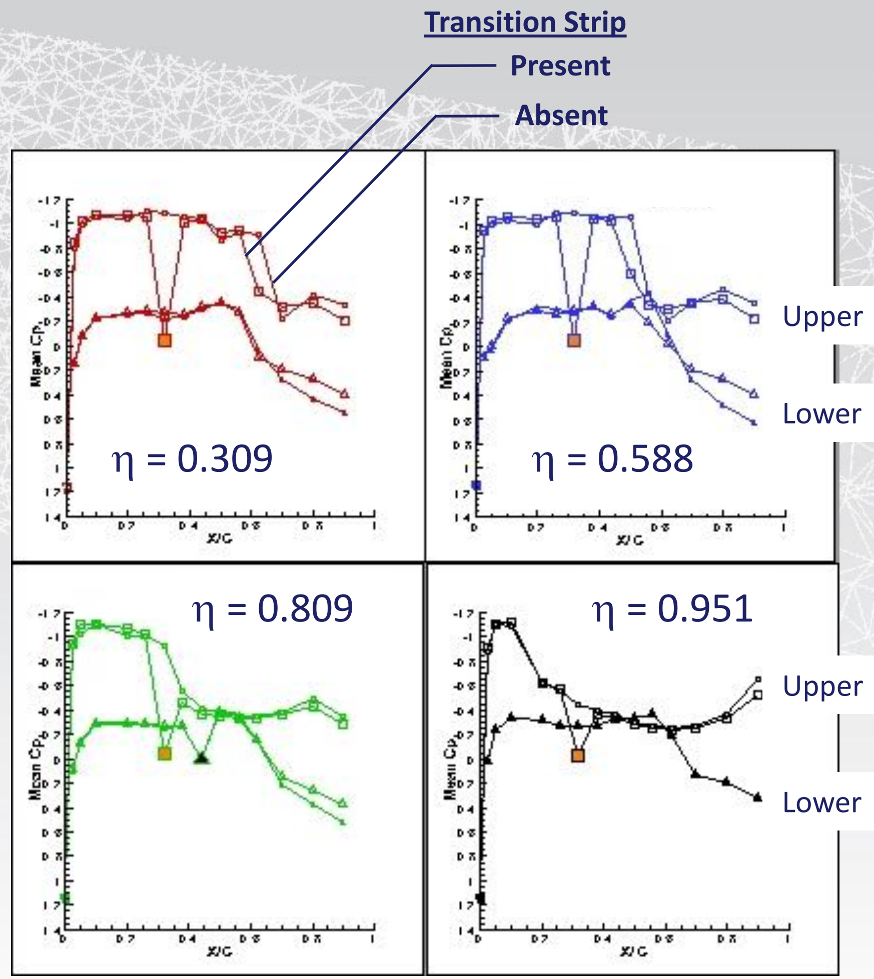
Example of RSW Steady Data

C_p vs. x/c

Mach number = 0.825

$\alpha = 4^0$





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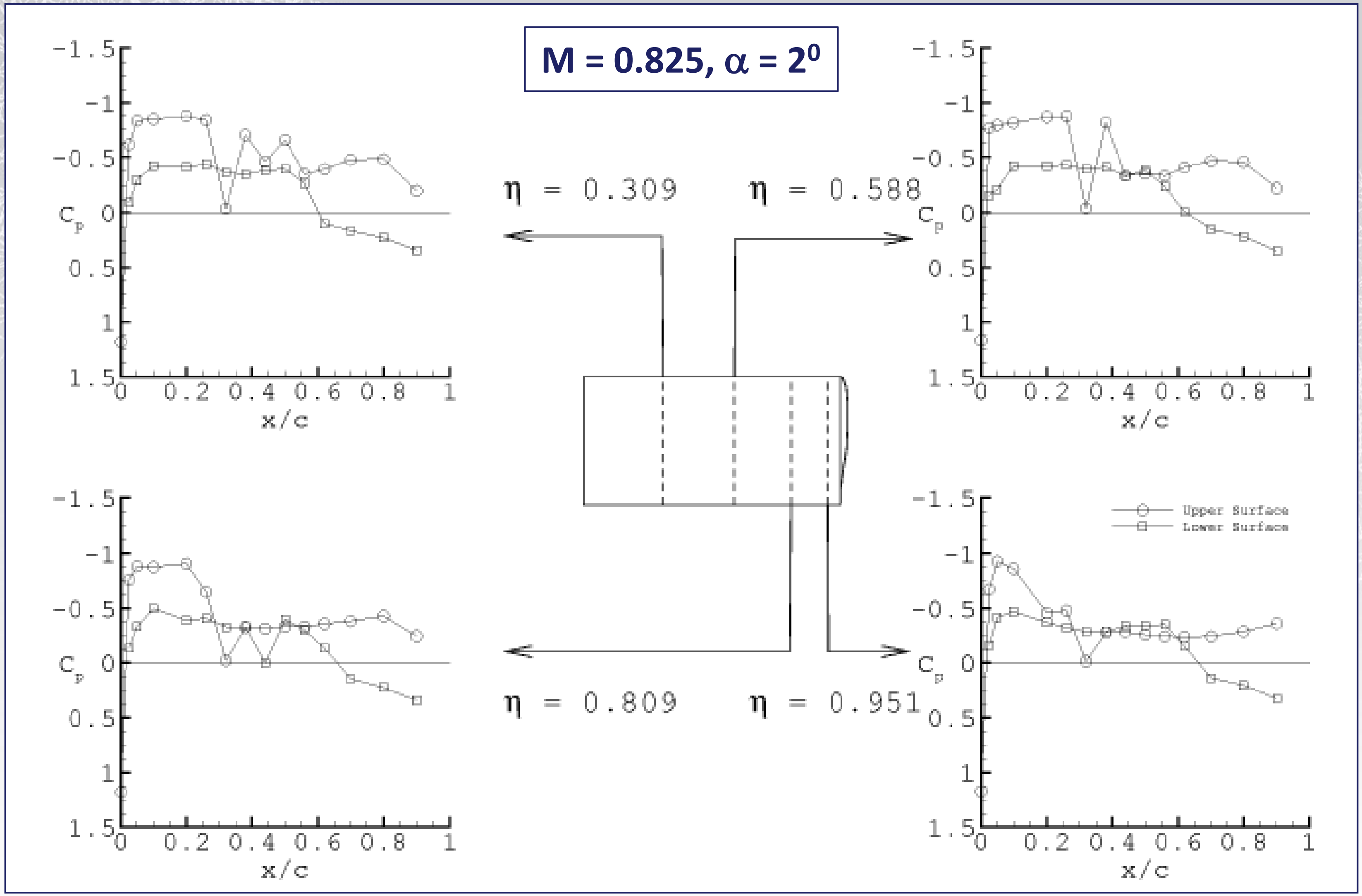

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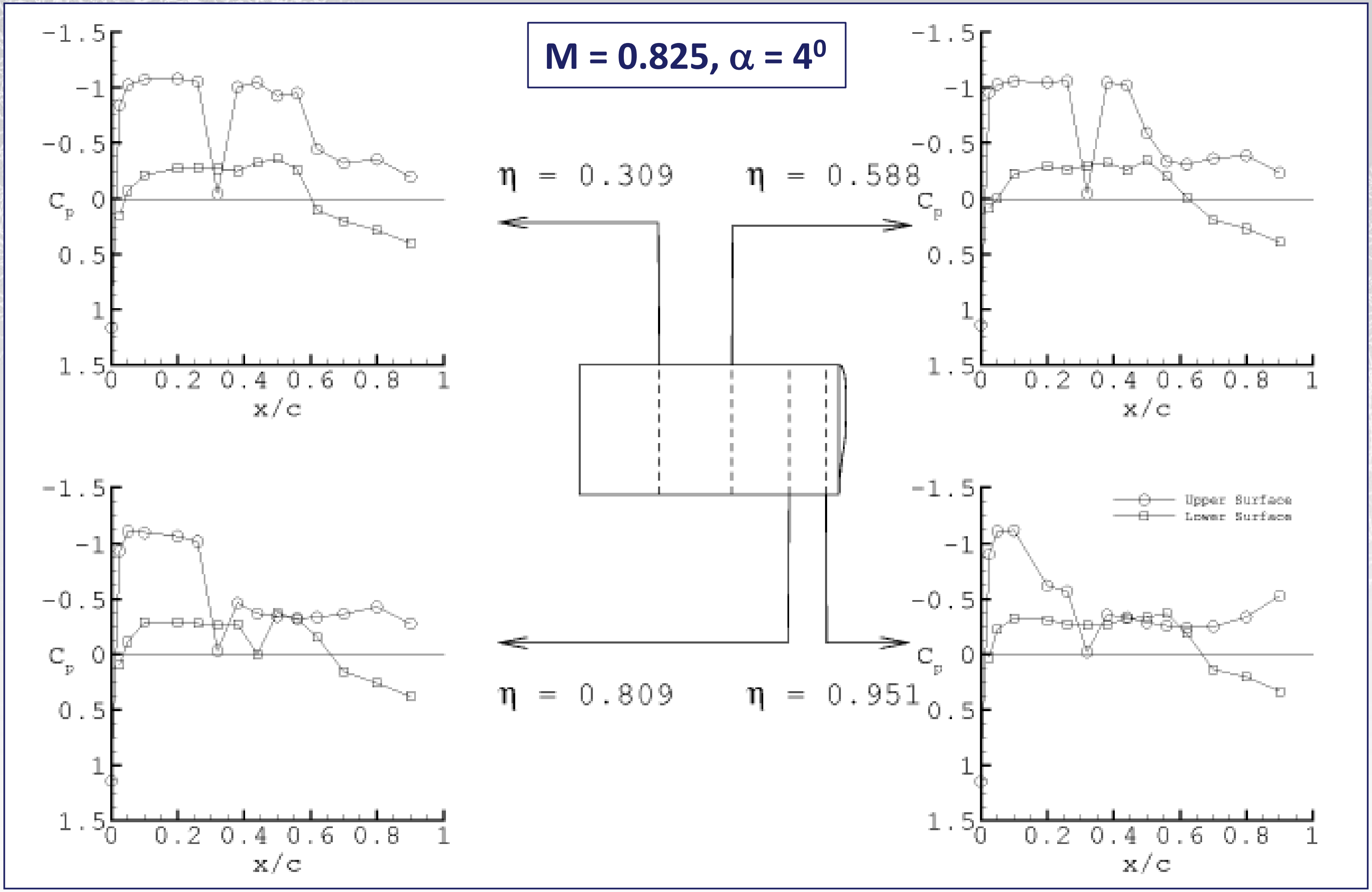

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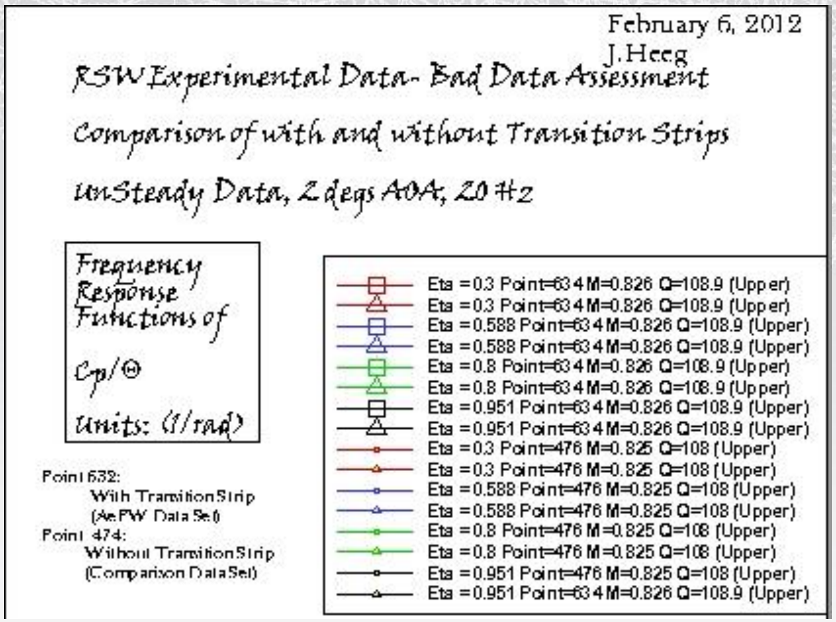
Example of RSW Unsteady Data

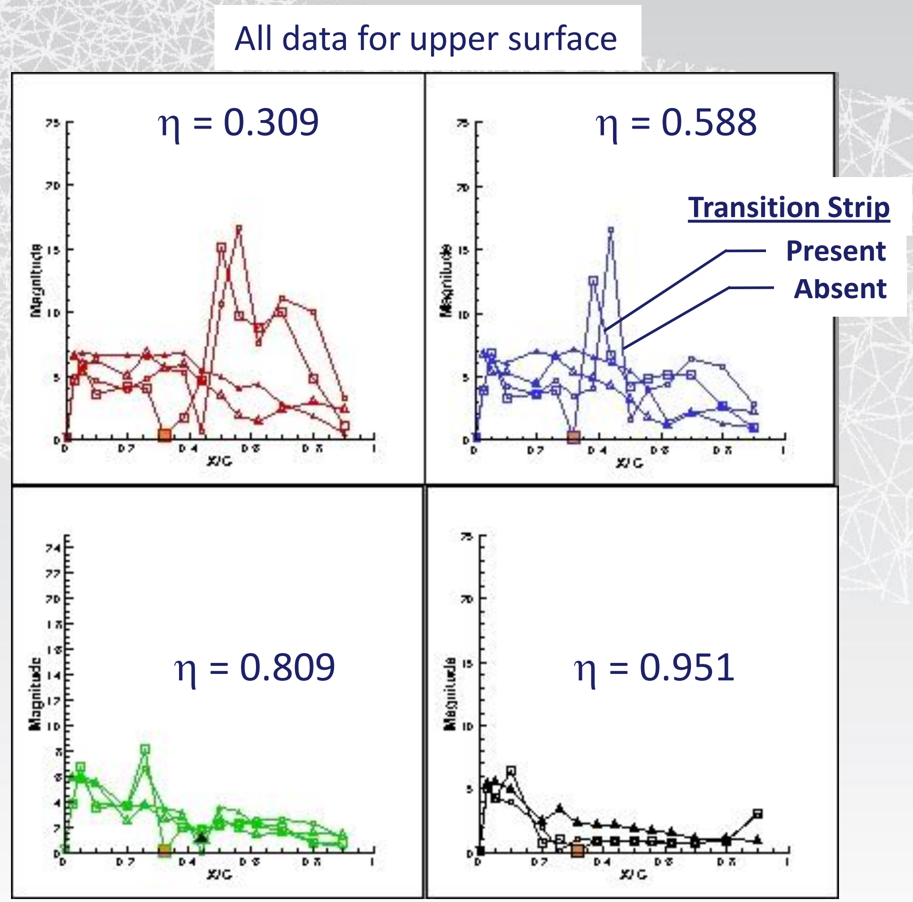
Magnitude of FRF of [C_p / θ] vs. x/c

Mach number = 0.825

$\alpha = 2^0$, $\theta = 1^0$

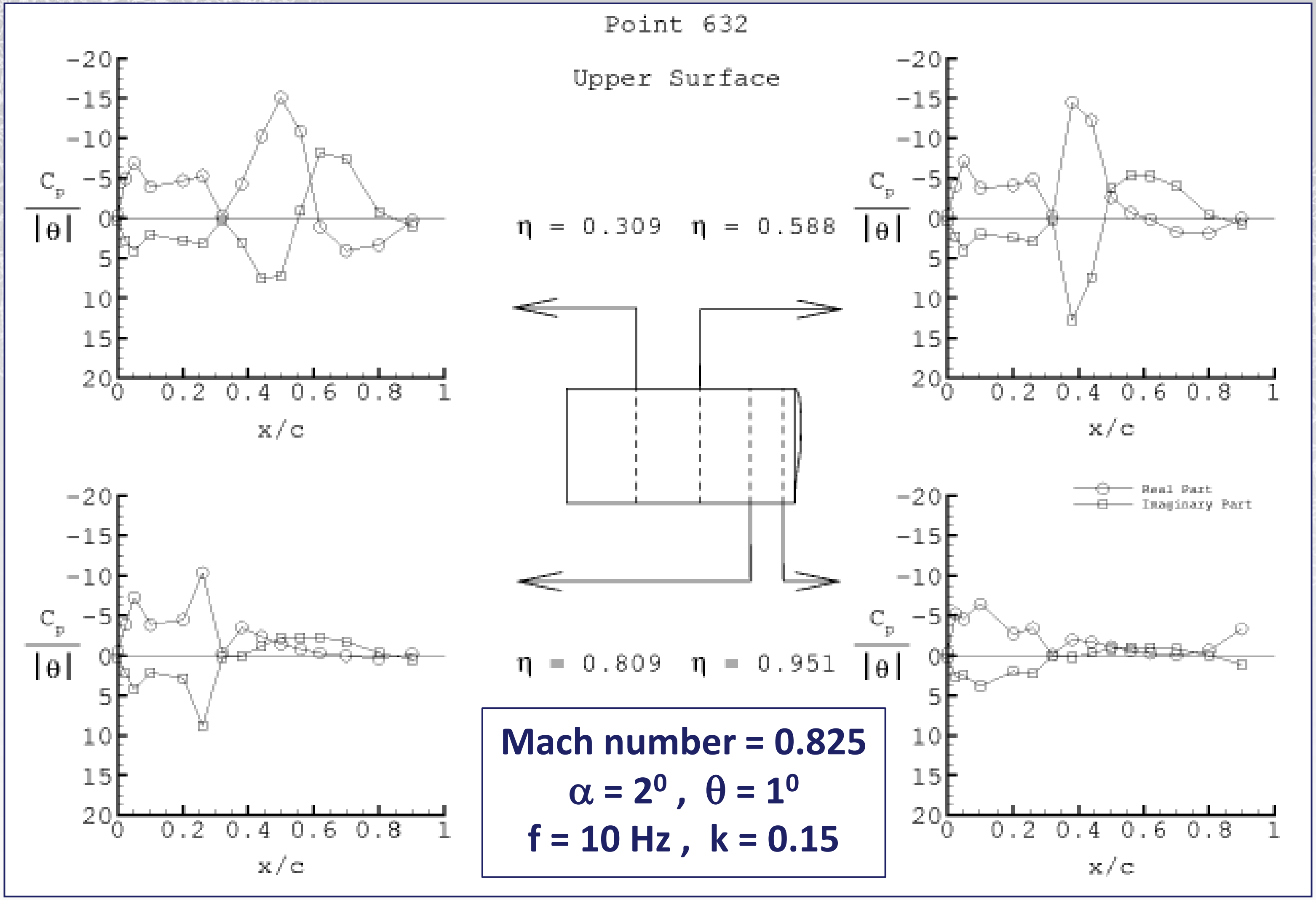
f = 20 Hz , k = 0.30





RSW Forced Oscillation Data

Real and Imaginary Parts of [C_p / θ] vs. x/c



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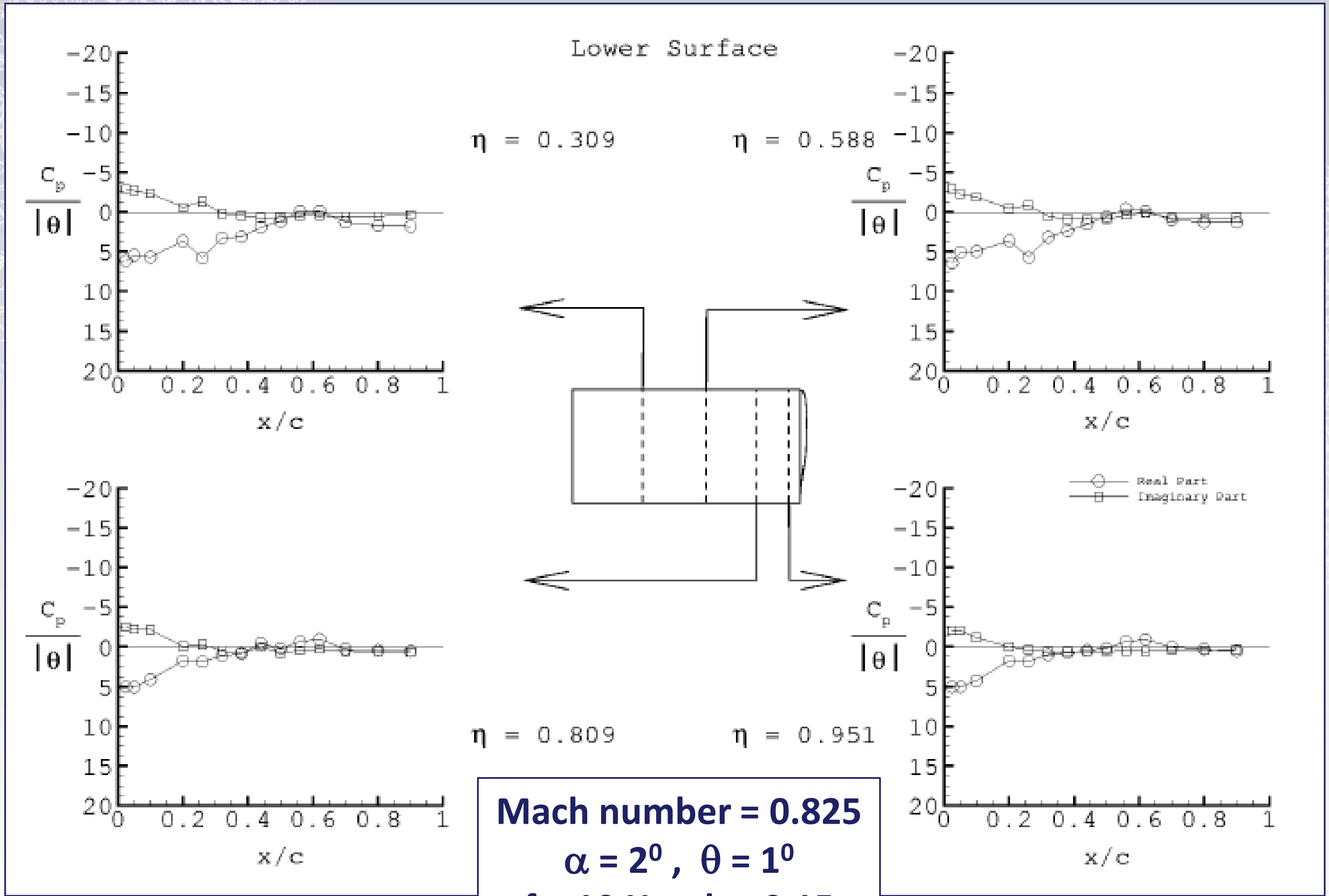

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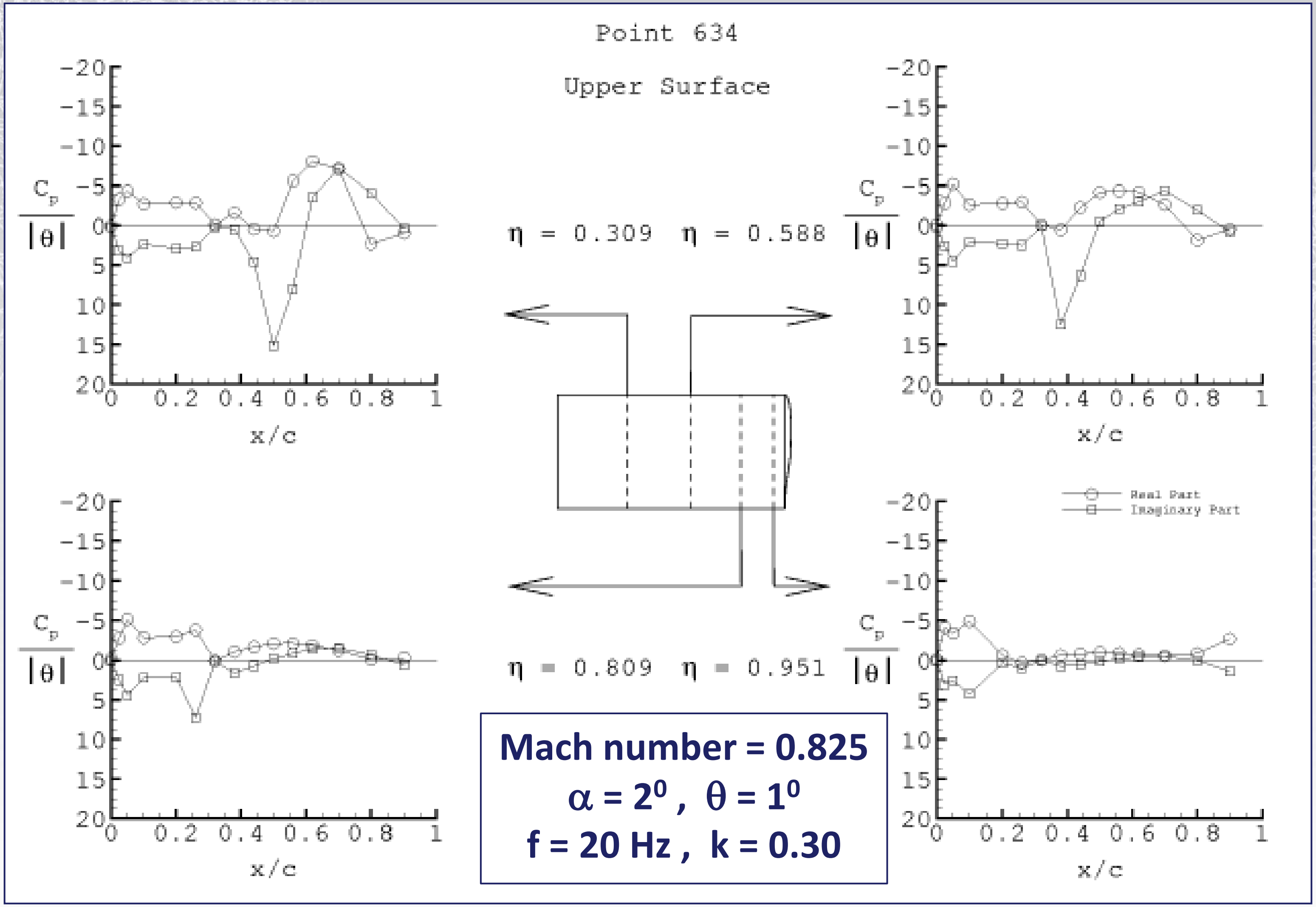

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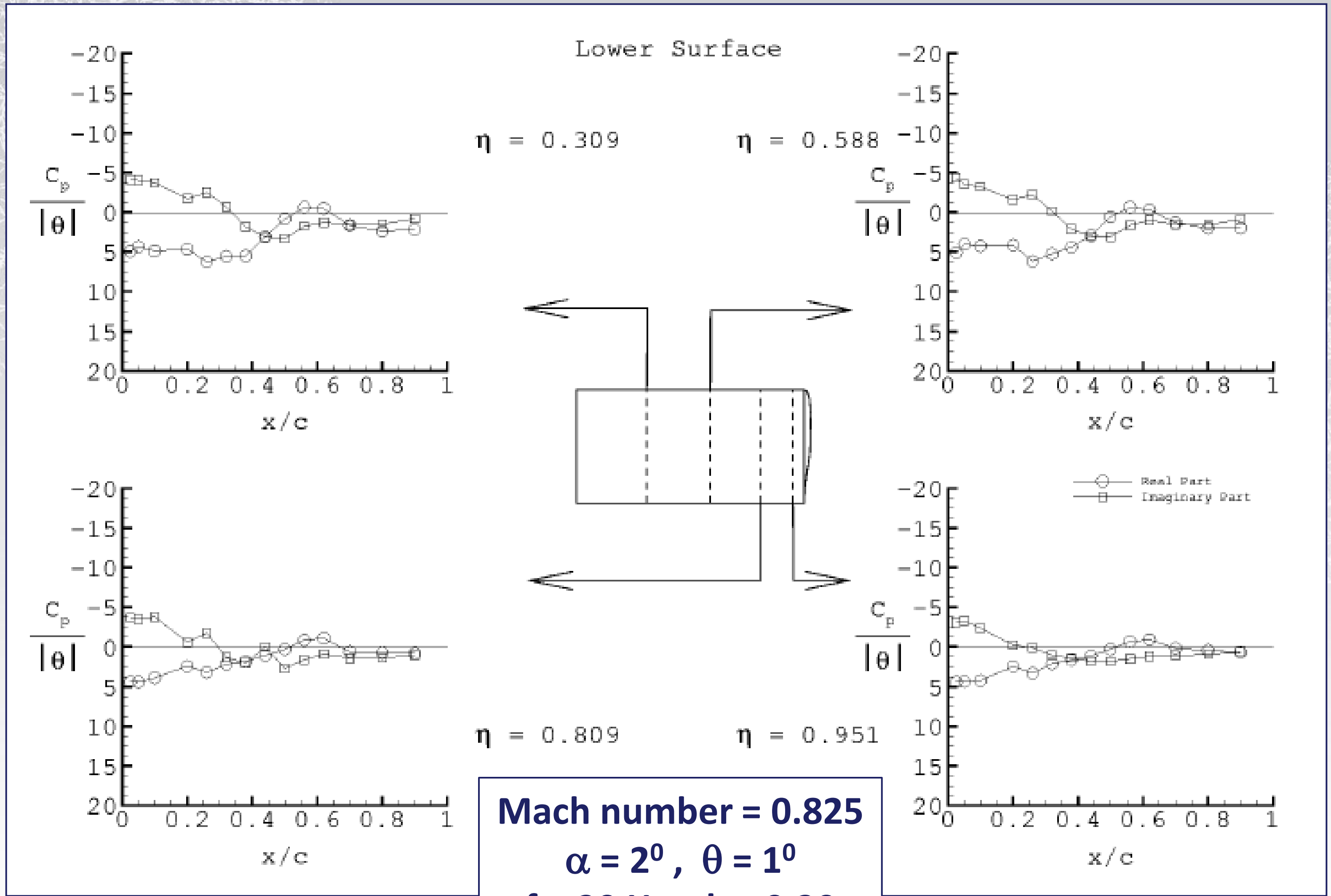

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$\alpha = 2^0$, $\theta = 1^0$
f = 20 Hz , k = 0.30

Outline

- Test Case Selection Rationale
- RSW Description
  - Geometry and Construction
  - Features and Instrumentation
  - Known Deficiencies
- RSW Testing
  - Transonic Dynamics Tunnel (TDT)
  - Test Cases and Test Data
- → **Summary and RSW Bibliography**

Summary

- RSW chosen because it has the attributes of an "Excellent" data set
  - High quality model definition
  - High quality wind-tunnel measurements
- RSW data set consistent with the focus of the 1st Aeroelastic Prediction Workshop
  - Unsteady aerodynamic pressures due to forced modal (for RSW, pitch) oscillations
    - Multiple oscillation frequencies
  - Transonic flow feature to challenge codes
    - Strong shock

RSW Bibliography

- Ricketts, Rodney H.; Sandford, Maynard C.; Seidel, David A.; and Watson, Judith J.: Transonic Pressure Distributions on a Rectangular Supercritical Wing Oscillating in Pitch. Presented at the 24th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics, and Materials Conference, May 2-4, 1983, Lake Tahoe, NV, AIAA Paper No. 83-0923. (Also available as NASA TM 84616, March, 1983.)

- Ricketts, Rodney H.; Watson, Judith J.; Sandford, Maynard C.; and Seidel, David A.: Geometrical and Structural Properties of a Rectangular Supercritical Wing Oscillated in Pitch for Measurement of Unsteady Transonic Pressure Distributions. NASA TM 85673, November, 1983.

- Ricketts, Rodney H.; Sandford, Maynard C.; Seidel, Watson, Judith J.; and David A.: Subsonic and Transonic Unsteady- and Steady-Pressure Measurements on a Rectangular Supercritical Wing Oscillating in Pitch. NASA TM 85765, August,1984.

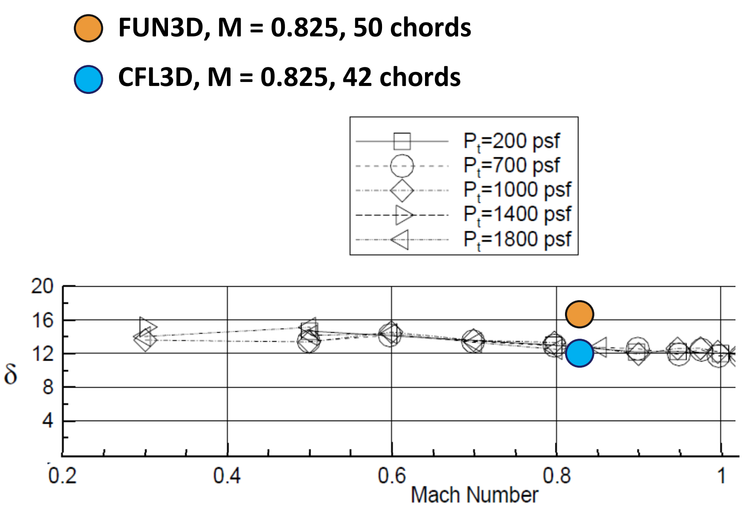
- Bennett, Robert M.; and Walker, Charlotte E.: Computational Test Cases for a Rectangular Supercritical Wing Undergoing Pitching Oscillations. NASA TM-1999-209130, April, 1999.

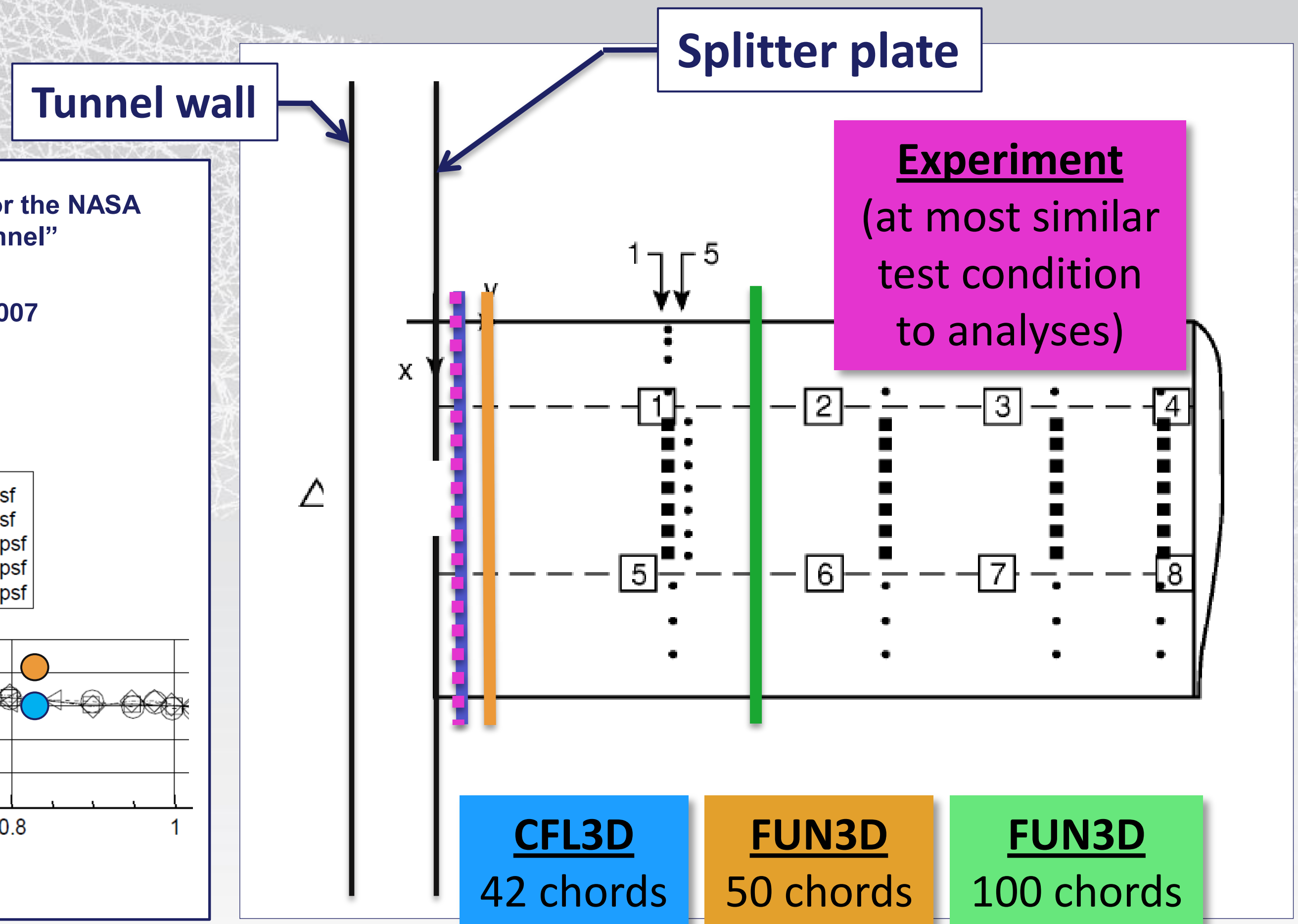
Extra Charts

Boundary Layer Comparisons

Analysis and Experiment

“Wall Boundary Layer Measurements for the NASA Langley Transonic Dynamics Tunnel”
by Wieseman and Bennett
NASA/TM-2007-214867, April, 2007



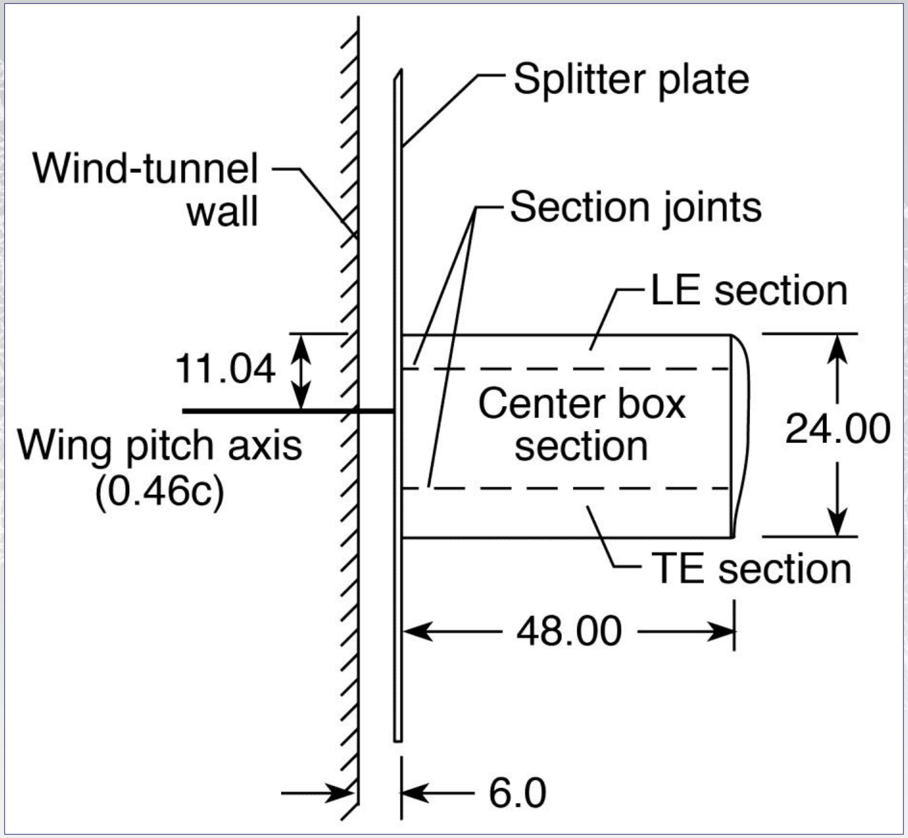


Review of the RSW Grid Development and Analysis Research by the AePW OC members: Story line

- Wall and splitter plate modeling investigated using **steady** analysis
  - Splitter plate models
    - None
    - Symmetry boundary condition
    - Viscous
  - Wall models
    - Symmetry boundary condition
    - Viscous
  - Wing size
    - Geometric model size
    - Extended wing span to duplicate placement within the test section
- Experimental data utilized to assess computational results:
  - Boundary layer thickness at model location
  - Steady pressure distributions
- Resulting recommended model
  - Reduce computational domain from 100 chords ahead of wing to 40 chords ahead of wing
  - Viscous model of wall
  - No splitter plate
  - Extended wing span

RSW Grids

- **Structured Grids**
  - Developed Using RSW Geometry Model A
  - ICEM CFD: structured hexahedral grids
  - Provided by Thorsten Hansen, ANSYS-Germany
- **Unstructured Grids**
  - Developed Using RSW Geometry Model D, with modified wall length ahead of wing
  - SolidMesh: unstructured grids with mixed and tetrahedral elements
  - Provided by Marilyn Smith, Georgia Institute of Technology



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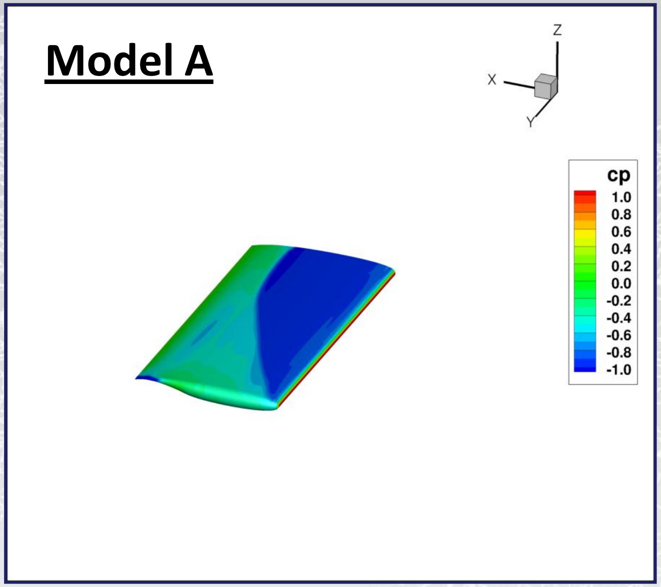

- No splitter plate
- Wing span = 48 inches

RSW Grids

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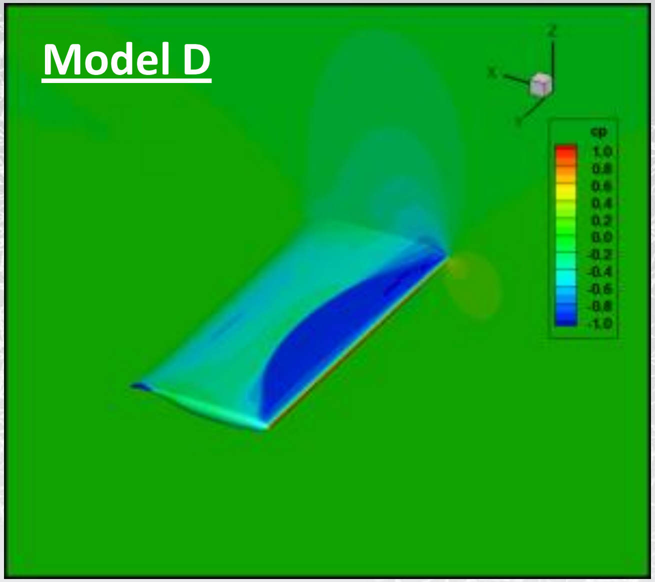

- No splitter plate
- Viscous tunnel wall*
- Wing span = 55 inches

* Viscous wall extends to 100 wing chords ahead of wing leading edge, intentionally disobeying the criterion specified in the gridding guidelines

RSW Grids

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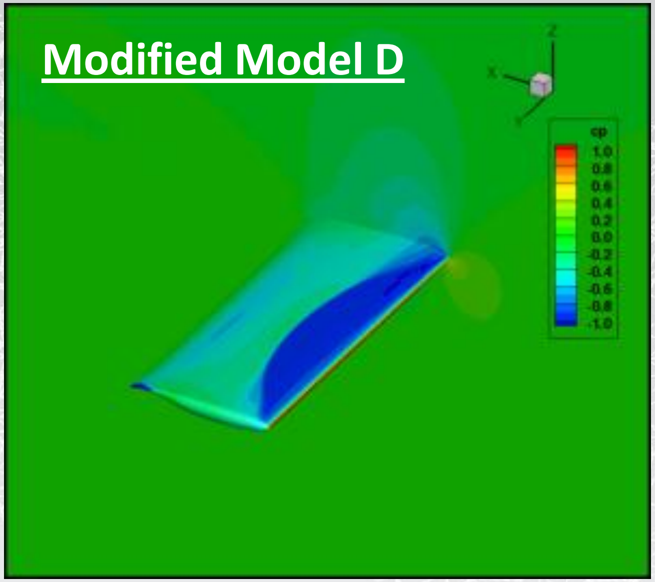
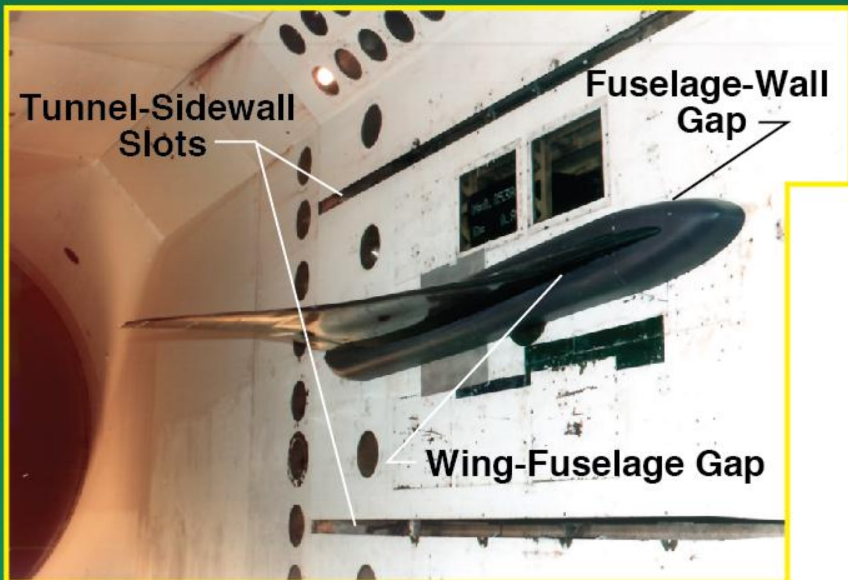


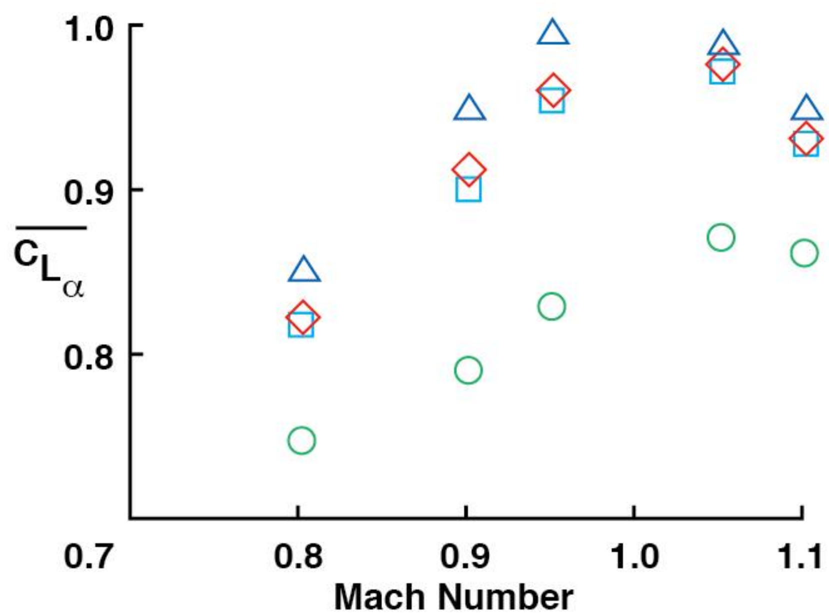
- No splitter plate
- Viscous tunnel wall*
- Wing span = 55 inches

* Viscous wall extends to 40 wing chords ahead of wing leading edge

MODEL GAP AND TUNNEL-SIDEWALL SLOT EFFECTS EVALUATED FOR HSR RIGID SEMISPAN MODEL IN THE TDT

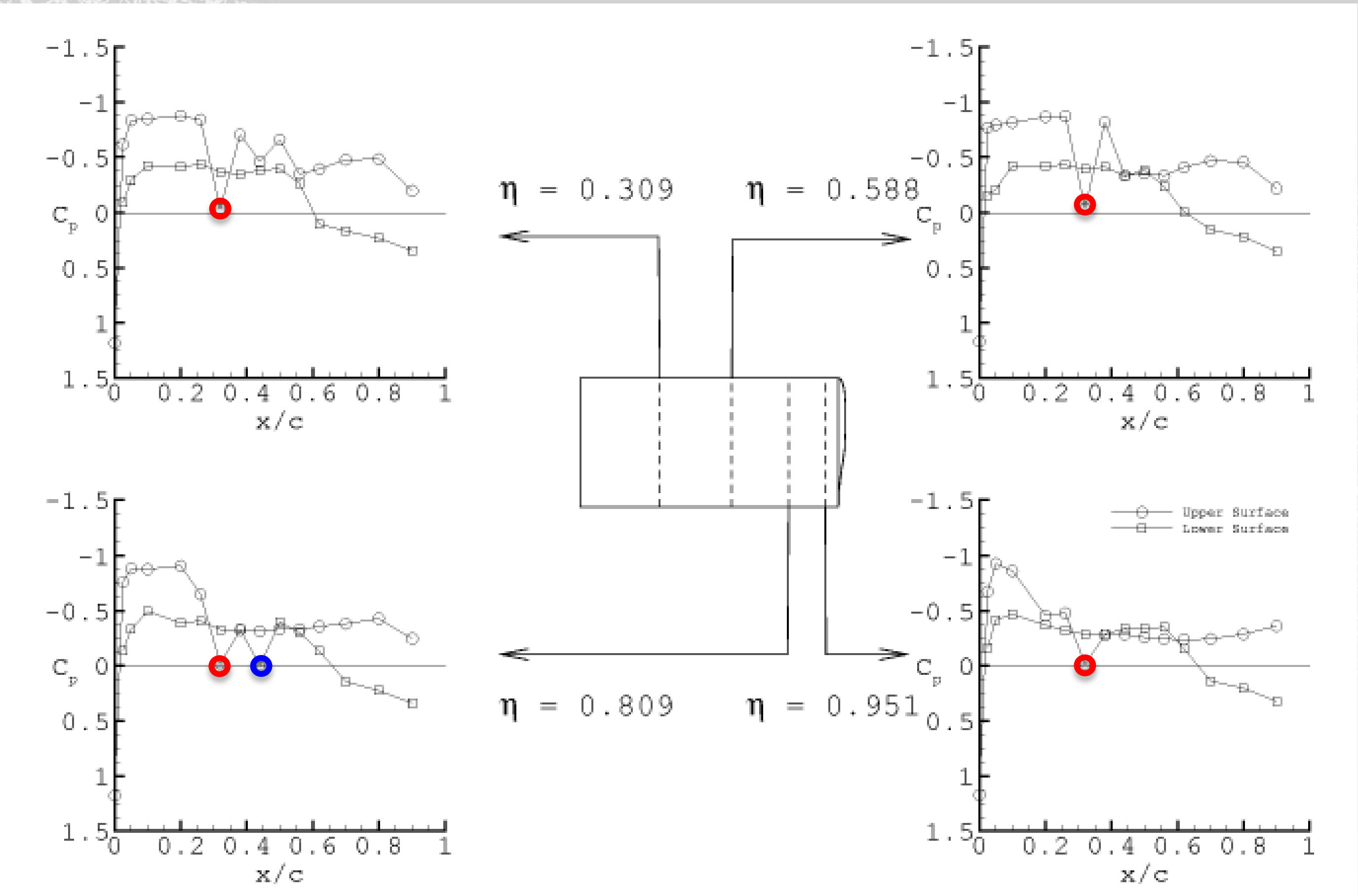


Effects of Slots and Gaps on Normalized Lift-Curve Slope



Configurations Tested

	Sidewall Slots Sealed	Wing-Fuselage Gaps Sealed	Fuselage-Wall Gap Sealed
○			
□	√		
◇	√	√	
△	√	√	√



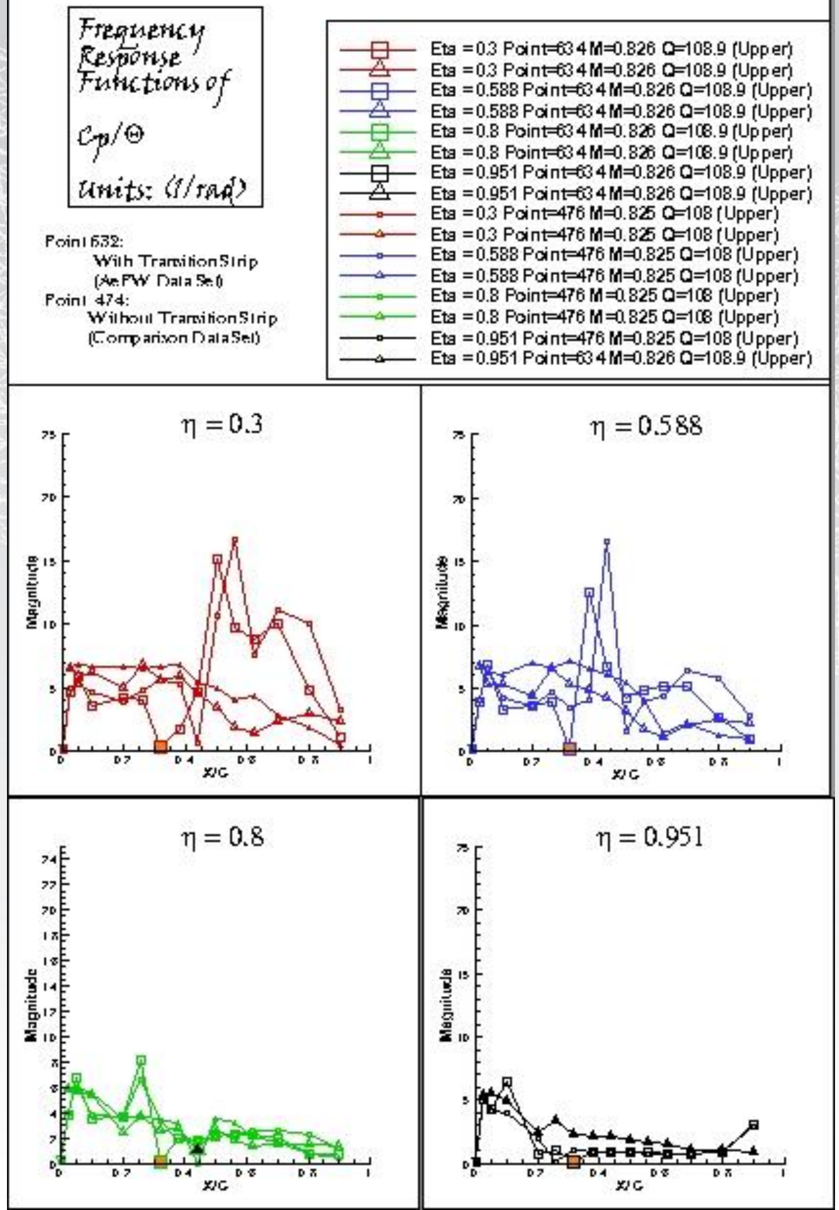
Point Number = 626 Mach Number = 0.825 Alphao = 2.00, deg.

February 6, 2012
J. Heeg

RSW Experimental Data- Bad Data Assessment

Comparison of with and without Transition Strips

unSteady Data, 2 degs AOA, 20 Hz



February 6, 2012
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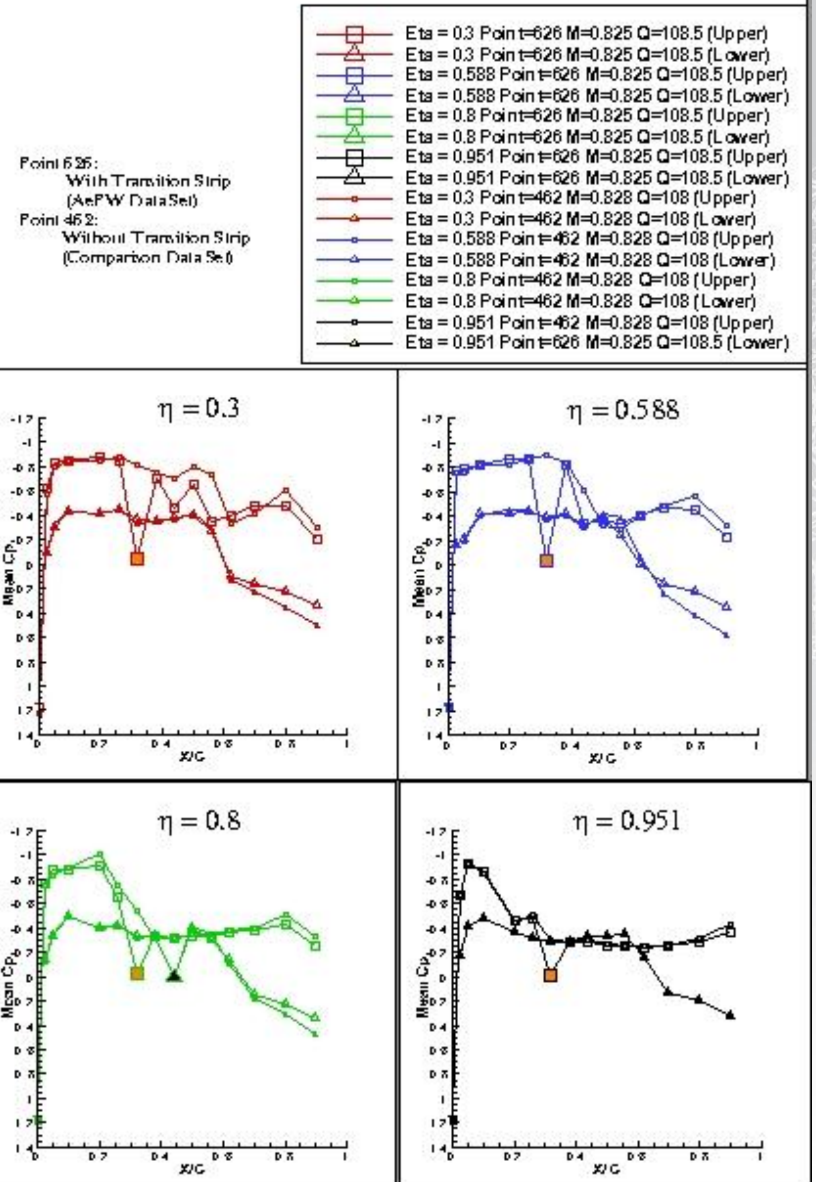
RSW Experimental Data- Bad Data Assessment

Comparison of with and without Transition Strips

Steady Data, 2 degs AOA



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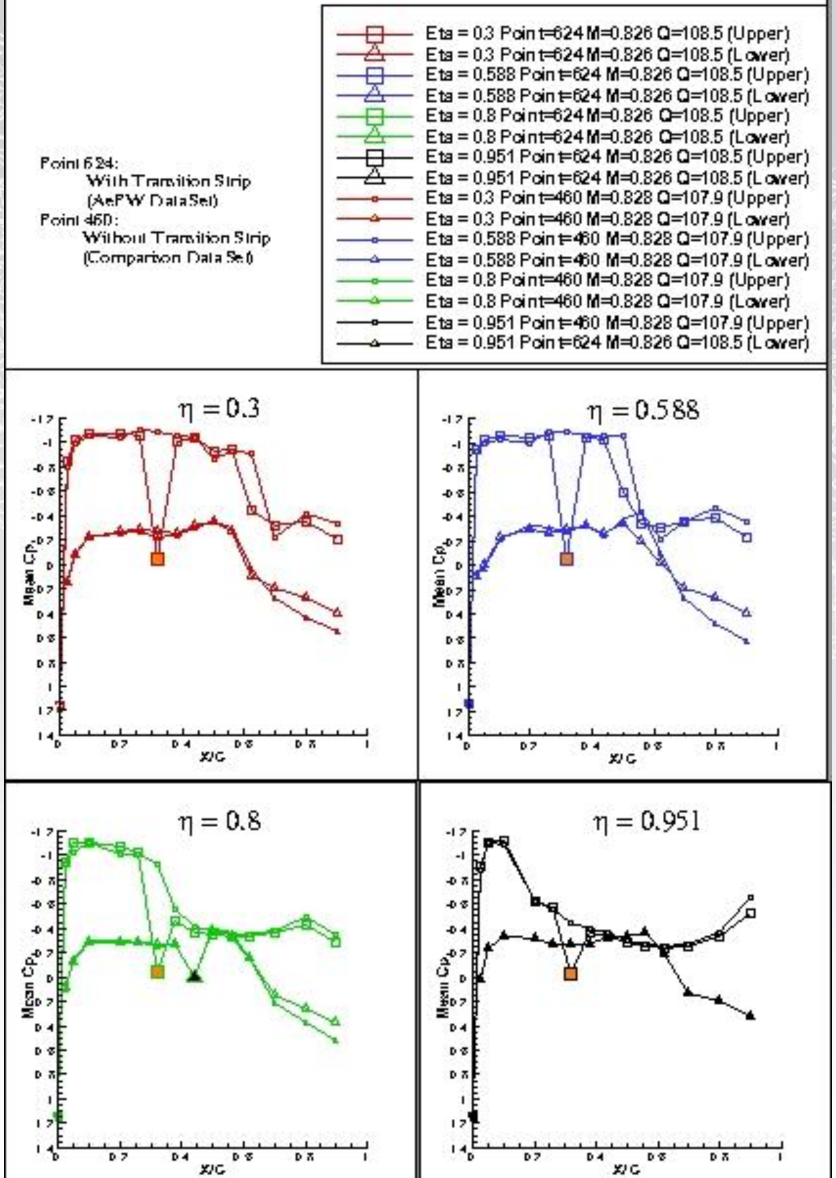
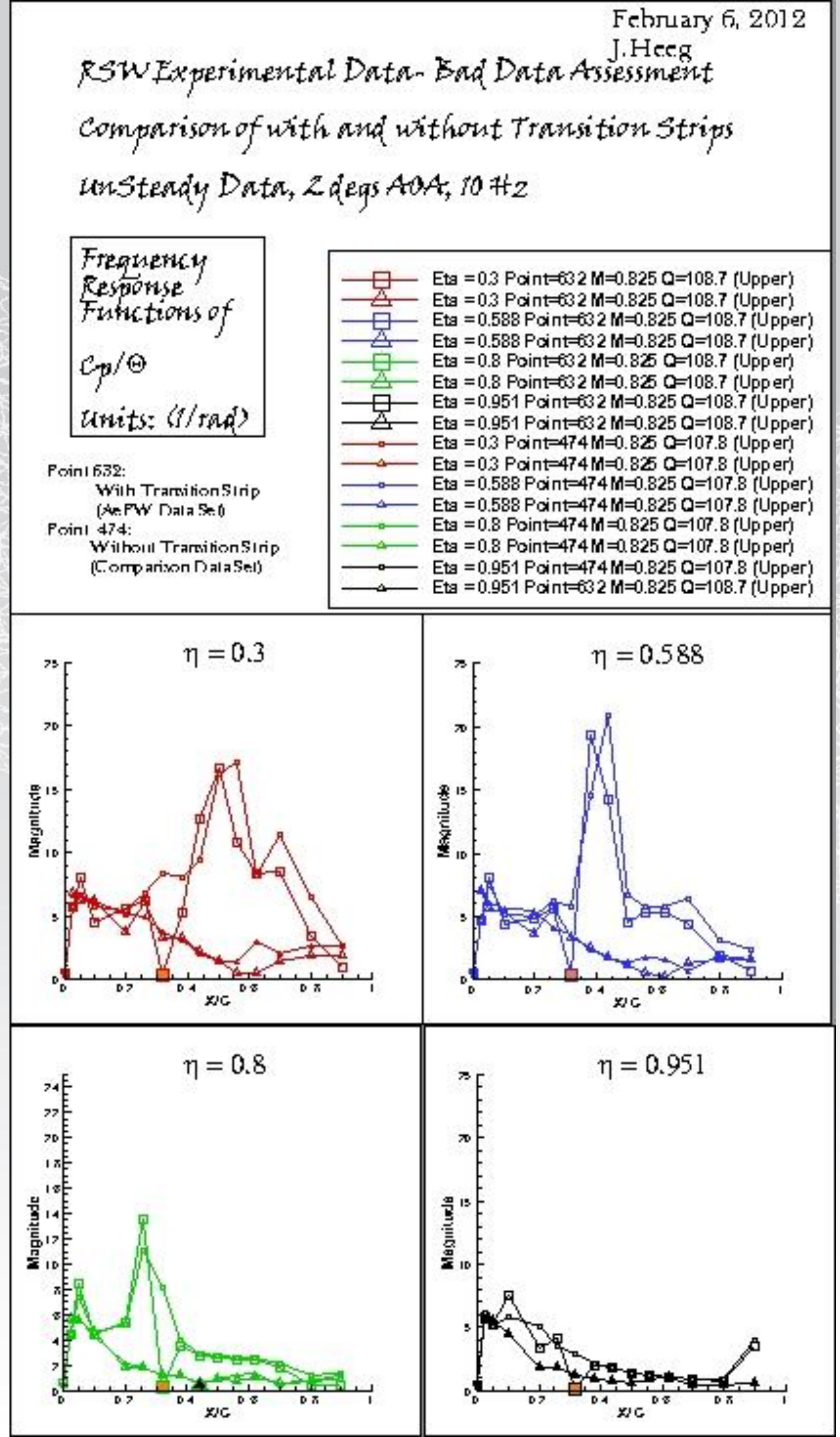
J. Heeg

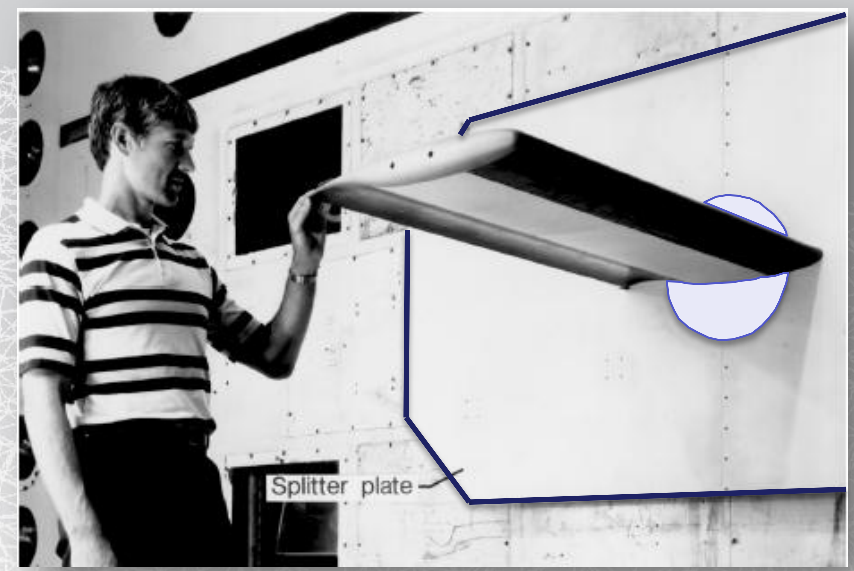
RSW Experimental Data- Bad Data Assessment

Comparison of with and without Transition Strips

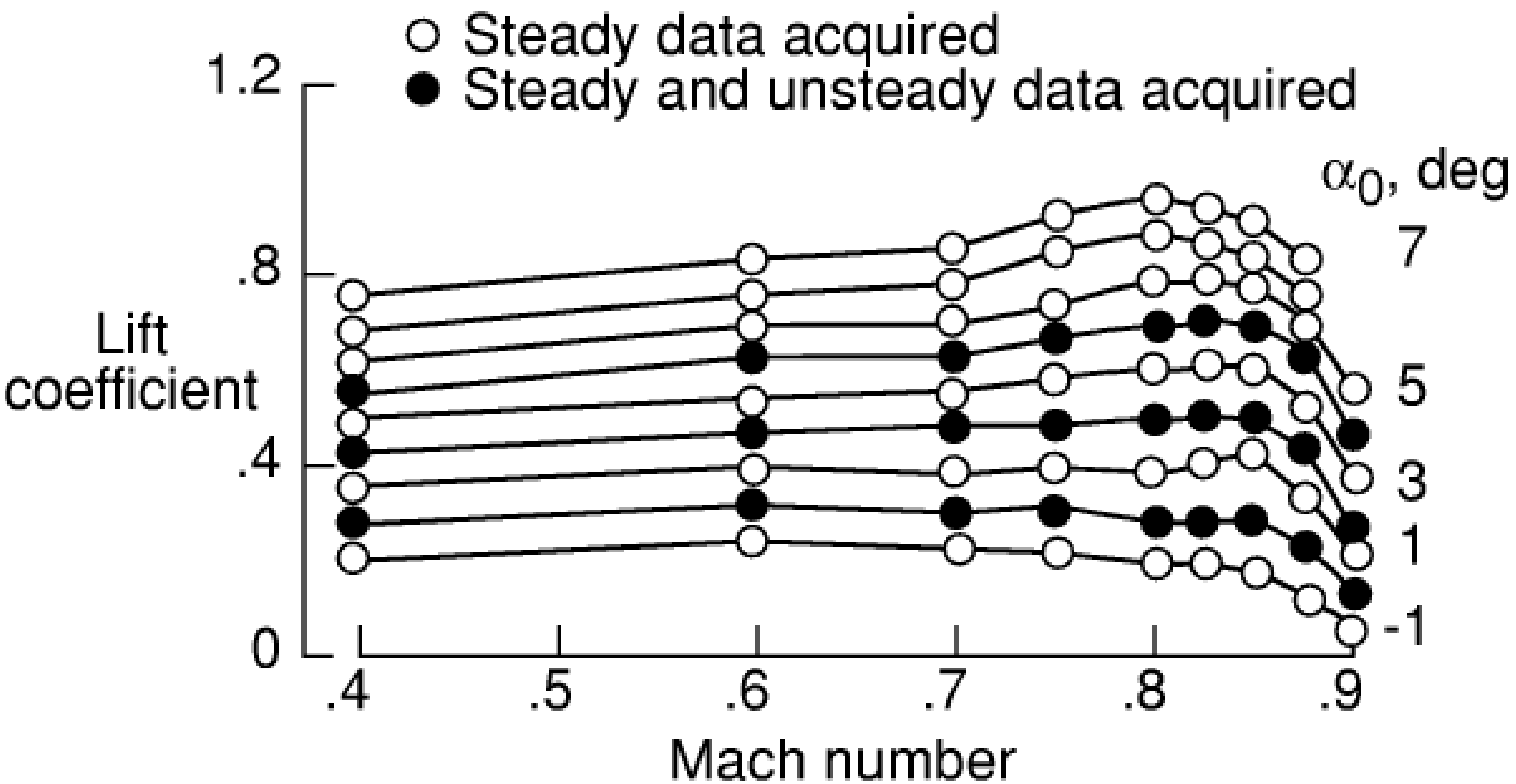
Steady Data, 4 degs AOA



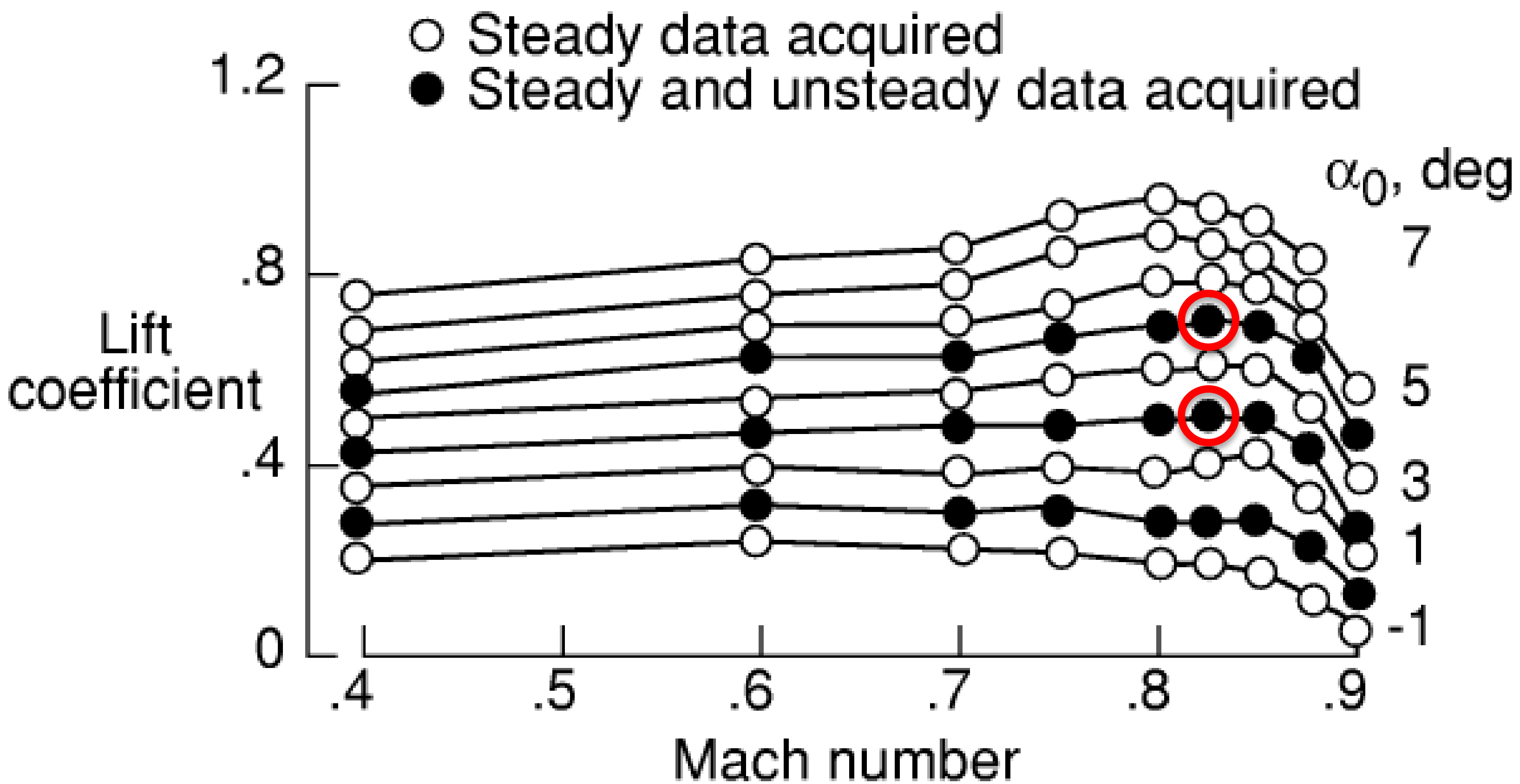

February 6, 2012
J.Heeg
RSW Experimental Data- Bad Data Assessment
Comparison of with and without Transition Strips
unSteady Data, 2 degs AOA, 10 Hz
Frequency Response Functions of
Cp/Θ
Units: (1/rad)
Point 632:
With Transition Strip
(AePW Data Set)
Point 474:
Without Transition Strip
(Comparison Data Set)
Eta =0.3 Point=632 M=0.825 Q=108.7 (Upper)
Eta =0.3 Point=632 M=0.825 Q=108.7 (Upper)
Eta =0.588 Point=632 M=0.825 Q=108.7 (Upper)
Eta =0.588 Point=632 M=0.825 Q=108.7 (Upper)
Eta =0.8 Point=632 M=0.825 Q=108.7 (Upper)
Eta =0.8 Point=632 M=0.825 Q=108.7 (Upper)
Eta =0.951 Point=632 M=0.825 Q=108.7 (Upper)
Eta =0.951 Point=632 M=0.825 Q=108.7 (Upper)
Eta =0.3 Point=474 M=0.825 Q=107.8 (Upper)
Eta =0.3 Point=474 M=0.825 Q=107.8 (Upper)
Eta =0.588 Point=474 M=0.825 Q=107.8 (Upper)
Eta =0.588 Point=474 M=0.825 Q=107.8 (Upper)
Eta =0.8 Point=474 M=0.825 Q=107.8 (Upper)
Eta =0.8 Point=474 M=0.825 Q=107.8 (Upper)
Eta =0.951 Point=474 M=0.825 Q=107.8 (Upper)
Eta =0.951 Point=632 M=0.825 Q=108.7 (Upper)
η = 0.3
η = 0.588
η = 0.8
η = 0.951
Magnitude
X/C

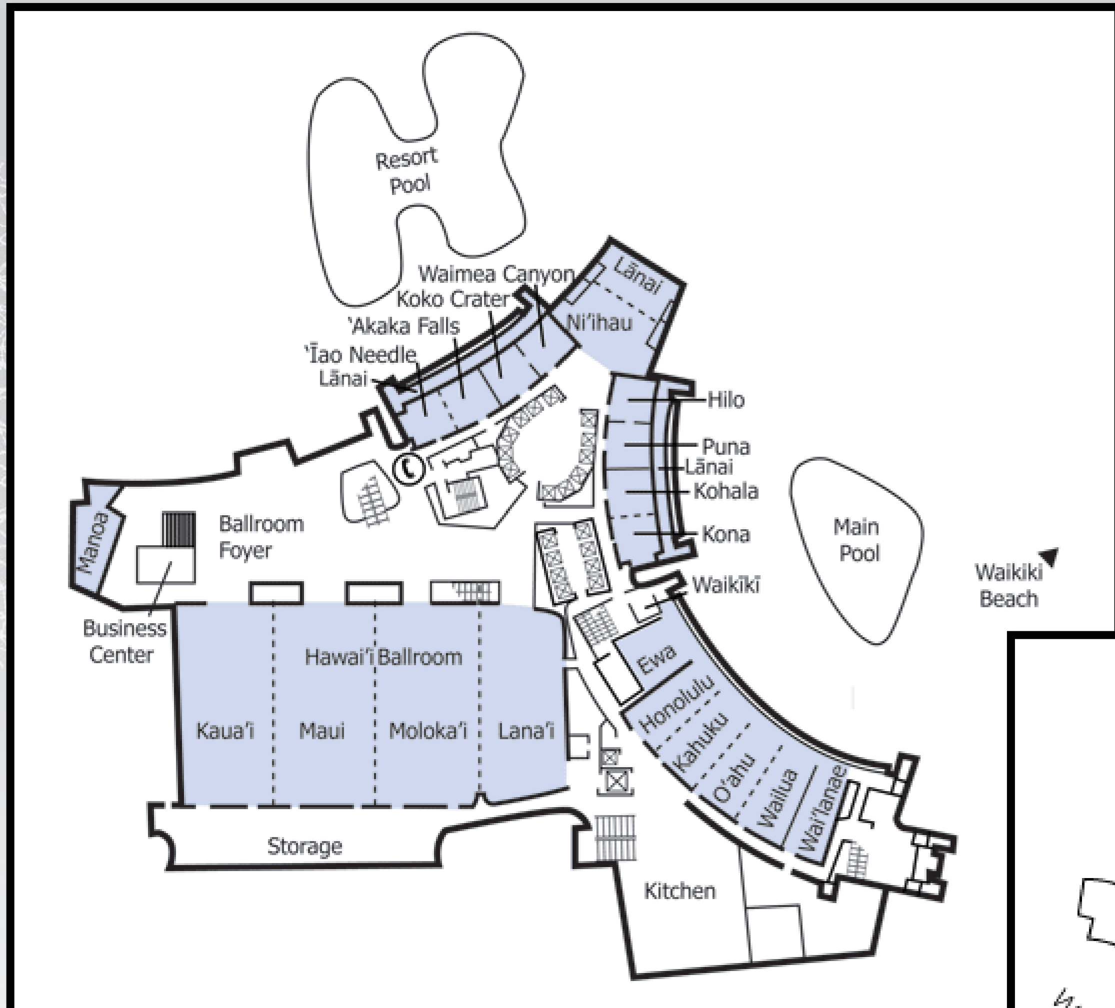

Splitter plate

Lift Coefficient vs. Mach Number

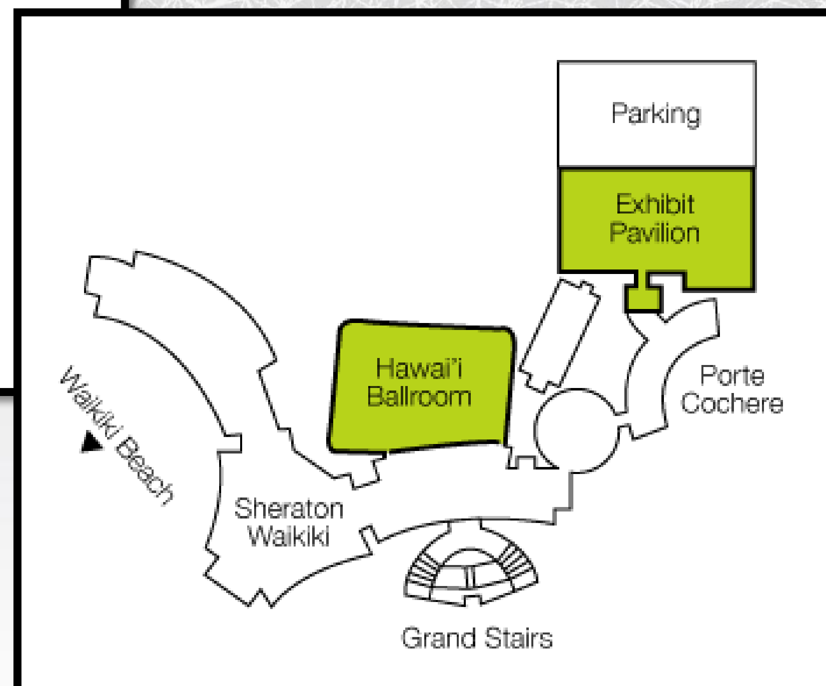


Lift Coefficient vs. Mach Number

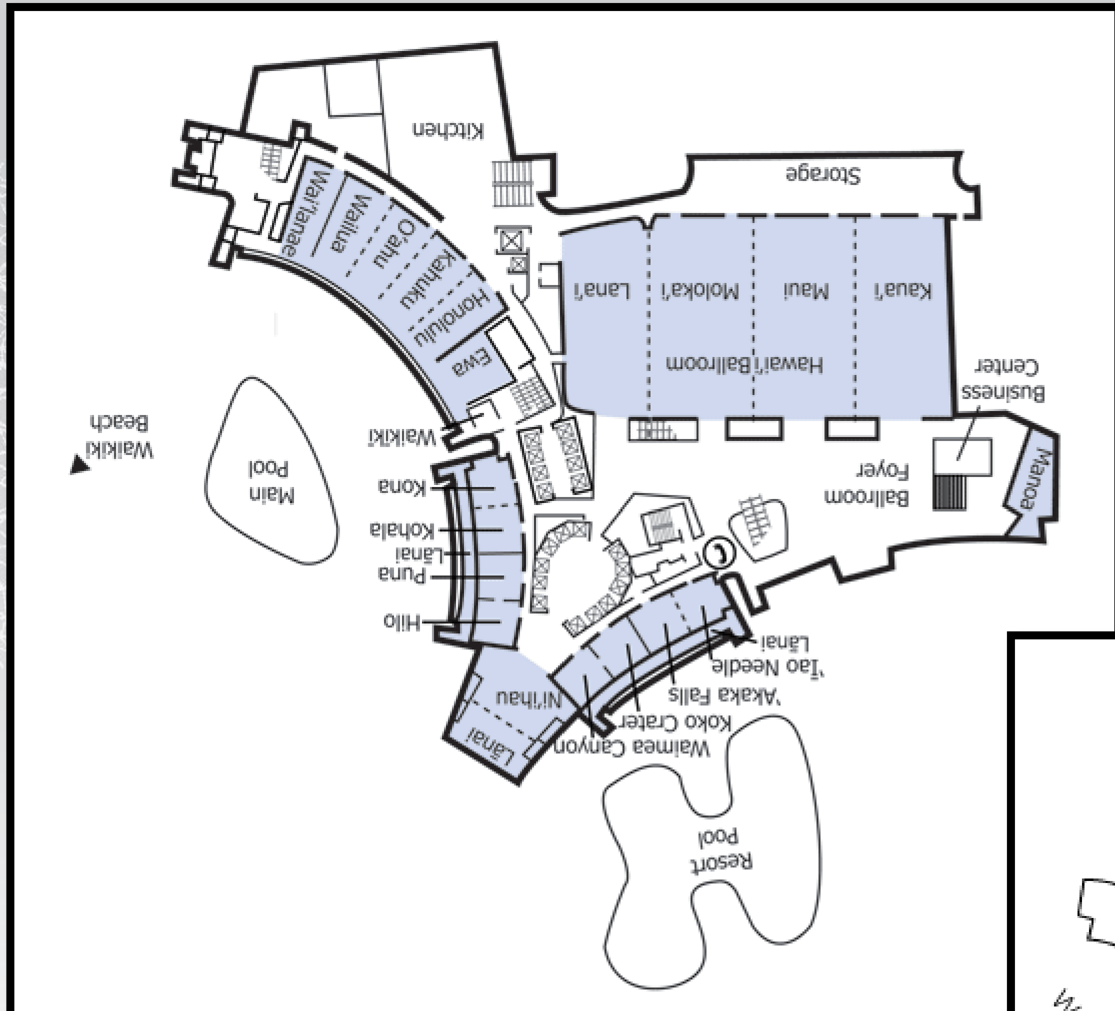




Resort Pool
Waimea Canyon
Koko Crater
'Akaka Falls
'Īao Needle
Lānai
Lānai
Ni'ihau
Hilo
Puna
Lānai
Kohala
Kona
Waikīkī
Main Pool
Waikiki Beach
Manoa
Ballroom Foyer
Business Center
Hawai'i Ballroom
Kaua'i
Maui
Moloka'i
Lana'i
Ewa
Honolulu
Kahuku
O'ahu
Wailua
Wai'lanae
Storage
Kitchen



Parking
Exhibit Pavilion
Hawai'i Ballroom
Porte Cochere
Waikiki Beach
Sheraton Waikiki
Grand Stairs



Kitchen
Storage
Wai'anae
Waialua
O'ahu
Kahuku
Honolulu
Ewa
Lana'i
Moloka'i
Maui
Kaua'i
Hawai'i Ballroom
Business Center
Ballroom Foyer
Manoa
Waikiki
Waikiki Beach
Main Pool
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'Iao Needle
Lanai
Resort Pool

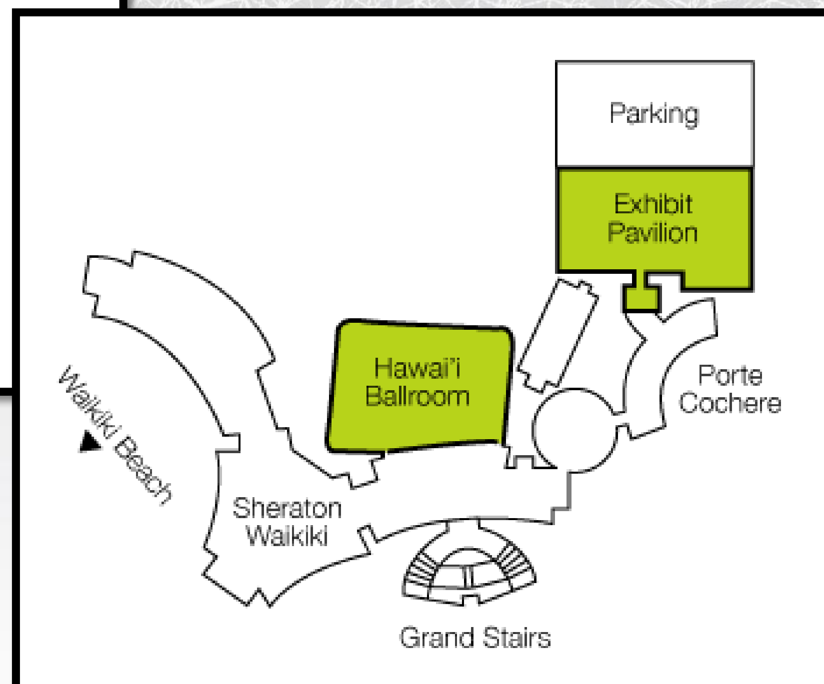

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Exhibit Pavilion
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Grand Stairs

Honolulu Weather

Updated: Apr 16, 2012, 12:53pm

Video: Your 60 second look ahead | TOR:CON Key to preparing Kansas

Today | Hourly | Tomorrow | Weekend | 5 day | 10 day | Monthly | Map

Detailed Forecast | Text Forecast

Today Apr 16	Tue 17	Wed 18	Thu 19	Fri 20	Sat 21	Sun 22	Mon 23	Tue 24	Wed 25
Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy	Partly Cloudy	Sunny	Mostly Sunny	Partly Cloudy
82°F High	82°	81°	80°	80°	80°	80°	80°	81°	80°
70° Low	70°	70°	70°	70°	70°	70°	71°	70°	70°

EXPAND GRAPH

◀ 5-Day Month ▶

Chance of:

Rain: 20%	Rain: 10%	Rain: 20%	Rain: 20%	Rain: 20%	Rain: 20%	Rain: 20%	Rain: 0%	Rain: 10%	Rain: 20%