Aeroelastic Prediction Workshop

Aeroelastic Prediction Workshop- Overview & Post Workshop Summary

Summarized by:

Jennifer Heeg, Dave Schuster, Pawel Chwalowski

AePW Website contains all presentations from the workshop:
https://c3.nasa.gov/dashlink/projects/47/
Direct link to workshop presentations:
https://c3.nasa.gov/dashlink/static/media/other/AePW_likeAB_main_v3.htm

Notes: These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results.
There are significant differences including normalization constants, definitions of FRF and sign conventions
These issues are being sorted out post-workshop. None of the results included should be interpreted without proper consideration of these issues. Corrections and rescalings etc will be performed prior to publication.
Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.

Tentative Schedule of Information Distribution

- AePW (April 21-22, 2012)
- LaRC Seminar (May 18, 2012)
- Aerospace Flutter & Dynamics Council (October 2012)
- ASM special session (January 2013): RSW focus
- SDM special session (April 2013): BSCW focus
- IFASD special session (June 2013): HIRENASD focus

Please consider these results showing proper regard for the willingness of the analysts and data reduction teams to share preliminary findings

- All of these results are preliminary
- We are still tracking down
  - Units
  - Normalization constants
  - Sign conventions
  - Reference points
  - FRF definitions
  - Implementation errors
- Re-analyses have not been performed

Contents

- Quick Summary
- Background material
- HIRENASD test case
- Benchmark supercritical wing test case, BSCW
- Rectangular supercritical wing test case, RSW

Organizing Committee Roster

Name	Affiliation
Bhatia, Kumar	Boeing Commercial Aircraft
Ballmann, Josef	Aachen University
Blades, Eric	ATA Engineering, Inc.
Boucke, Alexander	Aachen University
Chwalowski, Pawel	NASA
Dietz, Guido	European Transonic Windtunnel (ETW)
Dowell, Earl	Duke University
Florance, Jennifer	NASA
Hansen, Thorsten	ANSYS Germany GmbH
Heeg, Jennifer	NASA
Mani, Mori	Boeing Research & Technology
Mavriplis, Dimitri	University of Wyoming
Perry, Boyd	NASA
Ritter, Markus	Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Schuster, David	NASA
Smith, Marilyn	Georgia Institute of Technology
Taylor, Paul	Gulfstream Aerospace
Whiting, Brent	Boeing Research & Technology
Wieseman, Carol	NASA

Acknowledgments

Workshop sponsorship and organization

AIAA Structural Dynamics Technical Committee

AIAA Structural Dynamics Conference Team

Product managers

K.C Niedermeyr and Elizabeth Carter

Event planner Cathy Chenevey

NASA Engineering & Safety Center

Funding of NASA participation,
geometry generation & workshop organization

NASA Subsonic Fixed Wing Program

HIRENASD Research Project

Aachen University

HIRENASD Project Funding

German Research Foundation (DFG)

Grid Generation

Ansys, ATA, Georgia Tech, Technion University, ISCFDC, NASA

Workshop Contributors

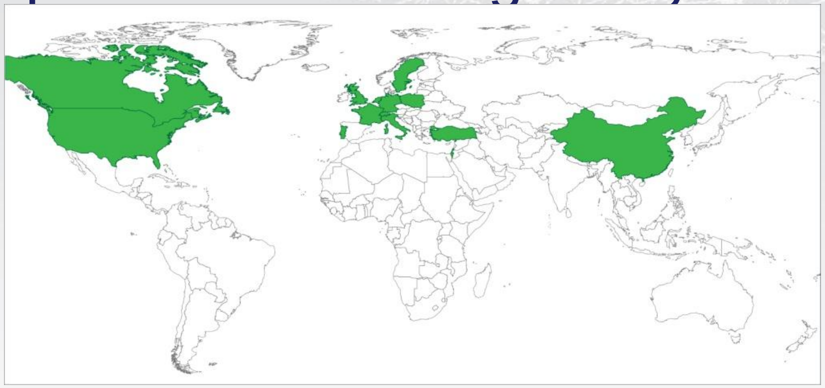
- 17 analysis teams providing data for workshop

Industry	University	Government
5	7	5

- 26 total analysis sets provided for workshop

RSW	BSCW	HIRENASD
6	6	14

- 10 nations represented among analysis teams



- 59 registered attendees

Updated April 23, 2012

RSW Data Submissions

Analyst	Organization
Pawel Chwalowski	NASA
Thorsten Hansen	ANSYS Germany GMBH
Dimitri Mavriplis	University of Wyoming
David Schuster	NASA
Daniel Steiling	RUAG Schweiz AG
Sebastian Timme	University of Liverpool

BSCW Data Submissions

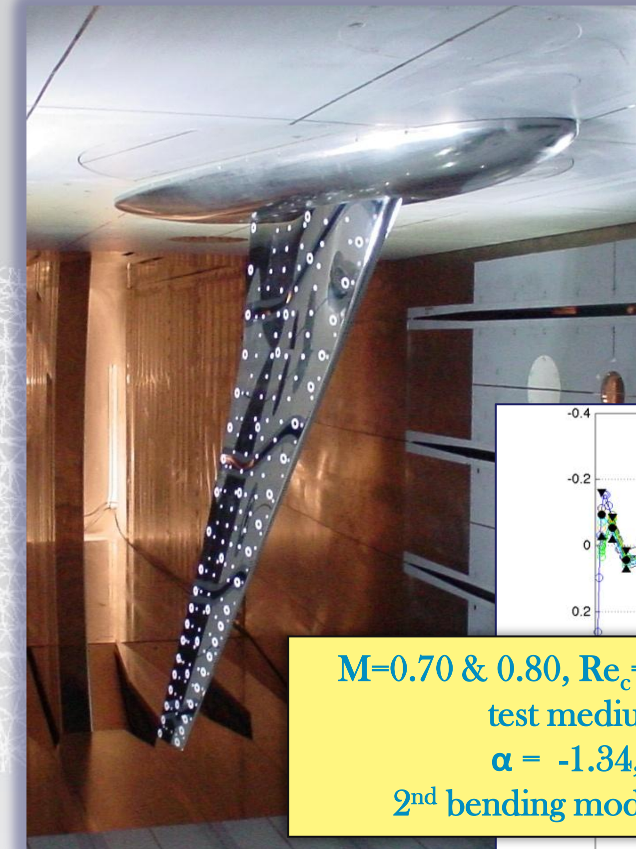
Analyst	Organization
Pawel Chwalowski	NASA
Thorsten Hansen	ANSYS Germany GMBH
Dimitri Mavriplis	University of Wyoming
David Schuster	NASA
Daniel Steiling	RUAG Schweiz AG
Marilyn Smith	Georgia Tech

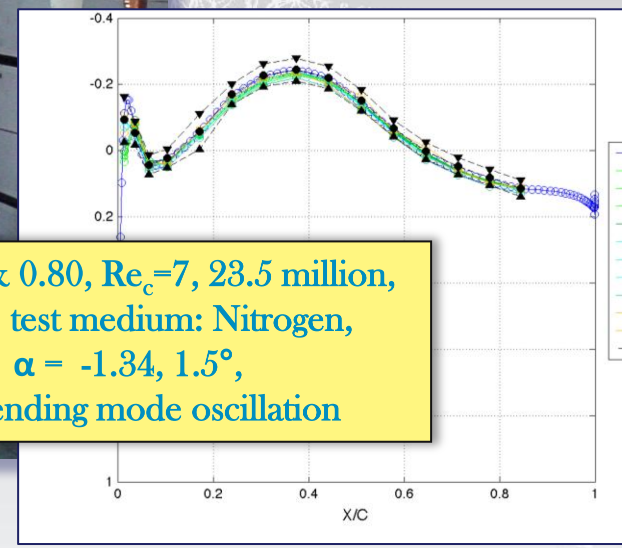
HIRENASD Analysis Presentations

Presenter or Analyst	Organization
Daniel Steiling	RUAG
Bart Eussen	NLR
Dimitri Mavriplis	University of Wyoming
Markus Ritter	DLR
Thorsten Hansen	Ansys
Mats Dalenbring	FOI
Pawel Chwalowski	NASA Langley
Jean Pierre Grisval	ONERA
Daniella Raveh	Technion University
Melike Nikbay & Z. Zhang	Istanbul TU/Zona
Sergio Ricci	Politecnico di Milano
Beerinder Singh & Jack Castro	CFD++/MSC Nastran
Alan Mueller & Sergey Zhelzov	CD Adapco
Larry Brace	Boeing

HIRENASD

- Chosen as a challenging test case, with aircraft-representative geometry & weak aeroelastic coupling
- Some preliminary assessments from AePW:
  - CFD solutions produce consistent results for the mid-span properties, both statically and dynamically; agreement with experiment is "not so bad"
  - Mach 0.7 case used as a benchmark- very benign and qualitatively good comparisons with experimental data
  - Neither solver type nor turbulence model appears to differentiate goodness of static solutions; influence on frequency response functions requires more evaluation





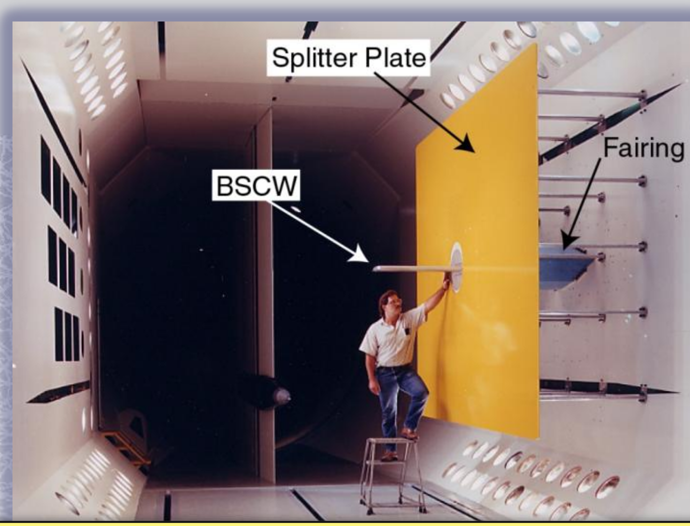
M=0.70 & 0.80, Re_c=7, 23.5 million,
test medium: Nitrogen,
α = -1.34, 1.5°,
2nd bending mode oscillation

<u>Likely plan of action:</u>

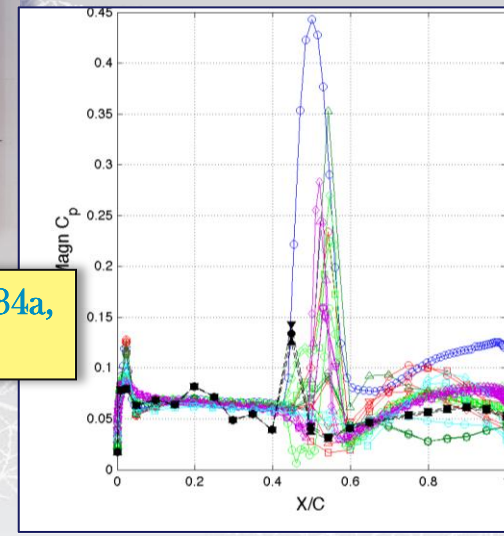
- Form technical working group of HIRENASD analysts
- Examine influence of static aeroelastic solution on oscillatory results
- Quantitative assessment of significant factors; identification of outliers and uncertainty bounds

Benchmark Supercritical Wing (BSCW)

- Chosen as a challenging test case, flow-wise, but simple geometry
  - Strong shock with suspected shock-induced separated flow
- Some preliminary assessments from AePW
  - Computational methods had difficulty producing converged solutions due to flow field complexity
  - Complex flow field also observed in experimental data; Largest magnitude of dynamic behavior appears to represent shock oscillations
  - CFD solutions vary widely, even for static solution;



M=0.85, Re_c=4.49 million, test medium: R-134a, α = 5°, θ = 1°, freq 1 & 10 Hz



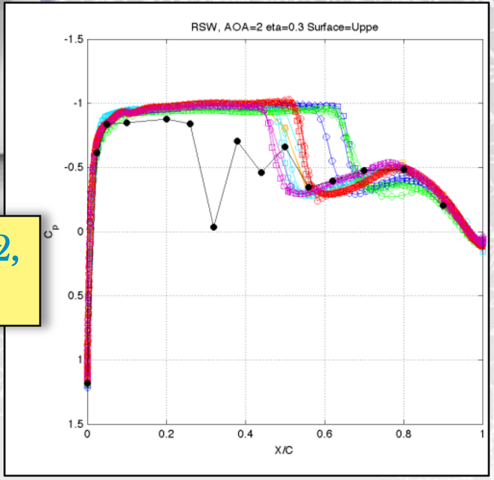
<u>Likely plan of action:</u>

- Form technical working group of BSCW analysts
- Extensive study of available experimental data; characterize different flow phenomena
- Benchmark against more benign cases- lower Mach number, lower angle of attack
- Analyze the static (unforced) problem using time-accurate evaluation methods
- Study of time convergence criteria

Rectangular Supercritical Wing (RSW)

- Chosen as the "slam dunk" test case
  - Pre-workshop assessment: Attached, fully turbulent flow; Moderate strength shock
- Some preliminary assessments from AePW:
  - Complications of modeling and computation due to splitter plate and model being enveloped in the boundary layer
  - CFD solutions vary widely, even for static solution; Not an accurate representation of the CFD state of the art

M=0.825, Re_c=4.0 million, test medium: R-12,
α = 2° & 4°, freq= 10 & 20 Hz



<u>Likely plan of action:</u>

- Form technical working group of RSW analysts
- Use configuration to focus on an analysis-only study
- Determine sources of variations from among modeling and analysis parameters and methods
- Determine relative significance of parameters

Please come see details of the workshop results

It's not too late to contribute as an analyst! Working groups now forming!

AePW Presentations Available on the website

- https://c3.nasa.gov/dashlink/projects/47

- Individual links for workshop presentation files:
  - Overviews, summary and comparison material:
    - https://c3.nasa.gov/dashlink/resources/568/
  - RSW analysts' presentations:
    - https://c3.nasa.gov/dashlink/resources/569/
  - BSCW analysts' presentations:
    - https://c3.nasa.gov/dashlink/resources/570/
  - HIRENASD analysts' presentations:
    - https://c3.nasa.gov/dashlink/resources/571/

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Aeroelastic Computational Benchmarking

- **Technical Challenge: Assess state-of-the-art methods & tools for the prediction and assessment of aeroelastic phenomena**

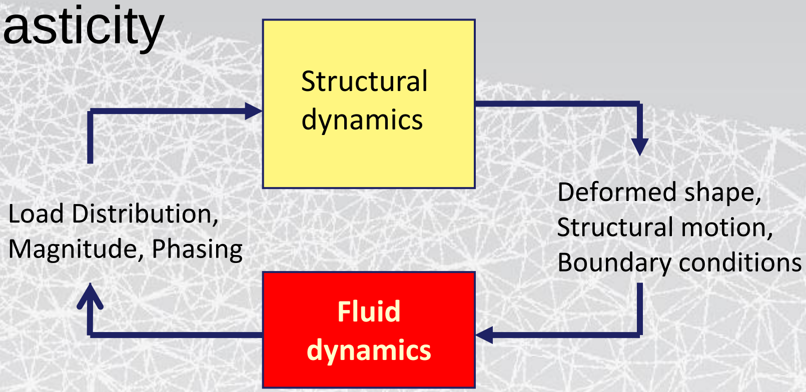
- **Fundamental hindrances to this challenge**
  - No comprehensive aeroelastic benchmarking validation standard exists
  - No sustained, successful effort to coordinate validation efforts
- **Approach**
  - Perform comparative computational studies on selected test cases
  - Identify errors & uncertainties in computational aeroelastic methods
  - Identify gaps in existing aeroelastic databases
  - Provide roadmap of path forward

Building block approach to validation

Aeroelastic prediction requires simulation with many independent variables spanning multiple disciplines

Utilizing the classical perspective in aeroelasticity

- Fluid dynamics
- Structural dynamics
- Fluid/structure coupling



Validation Objective of 1st Workshop

Unsteady aerodynamic pressures due to forced modal oscillations

Future Workshops

- Directed by results of this workshop
- Directed by big-picture assessment of needs & interests

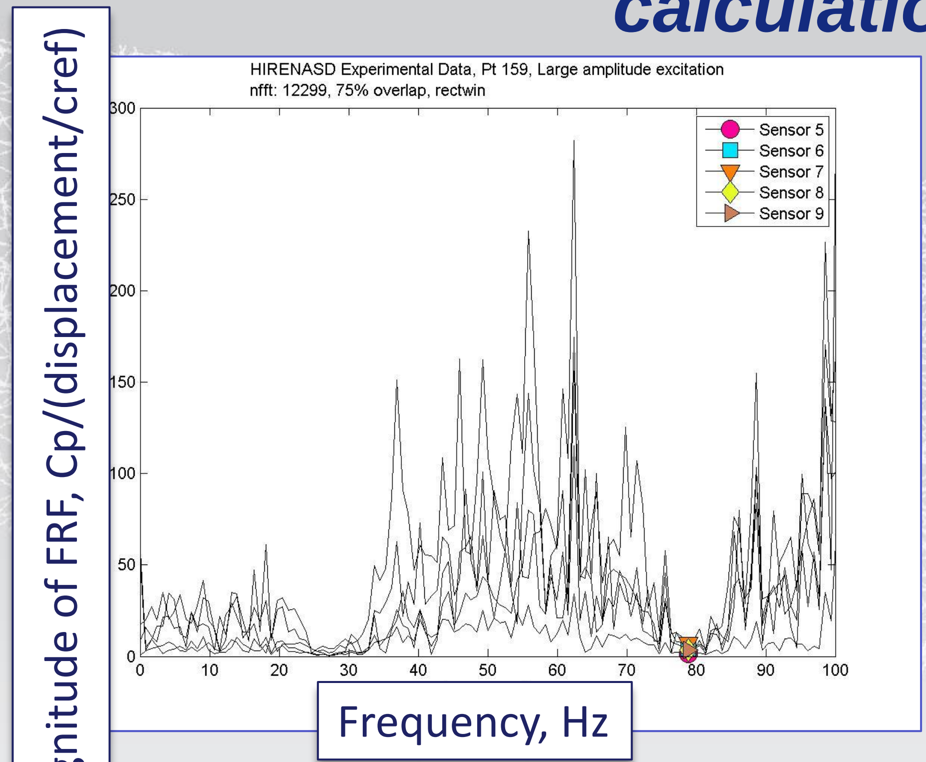
Configuration / Data Set Selection Compromises

- Configurations are not “aeroelasticky”
- Deflection data is sparse
- Expected flow phenomena does not encompass all possible applicable flows for aeroelastic configurations
- Results from workshop comparisons can not be directly translated to critical aeroelastic quantities
- Results of this workshop will only tell us how well we can predict the class of phenomena that we are looking at:
  - Forced transition
  - Shock-separated flow
  - Forced oscillations
  - Uncoupled and weakly coupled aerodynamics

Comparison Data Matrix

CONFIGURATION	REQUIRED CALCULATIONS			
	GRID CONVERGENCE STUDIES	TIME CONVERGENCE STUDIES	STEADY CALCULATIONS	DYNAMIC CALCULATIONS
Steady-Rigid Cases (RSW, BSCW)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M	n/a
Steady-Aeroelastic Cases (HIRENASD)	C_L, C_D, C_M vs. $N^{-2/3}$	n/a	• Mean C_p vs. x/c • Means of C_L, C_D, C_M • Vertical displacement vs. chord • Twist angle vs. span	n/a
Forced Oscillation Cases (all configurations)	• Magnitude and Phase of CL, CD, CM vs. $N^{-2/3}$ at excitation frequency	•Magnitude and Phase of C_L, C_D, C_M vs. dt at excitation frequency	n/a	• Magnitude and Phase of C_p vs. x/c at span stations corresponding to transducer locations • Magnitude and Phase of C_L, C_D, C_M at excitation frequency • Time histories of C_p's at a selected span station for two upper- and two lower-surface transducer locations

Frequency response functions (FRFs) calculation example



$$FRF(\omega) = \frac{CSD_{x,y}(\omega)}{PSD_x(\omega)} = \frac{FFT(y).*FFT(x)'}{FFT(x).*FFT(x)'}$$

Here,

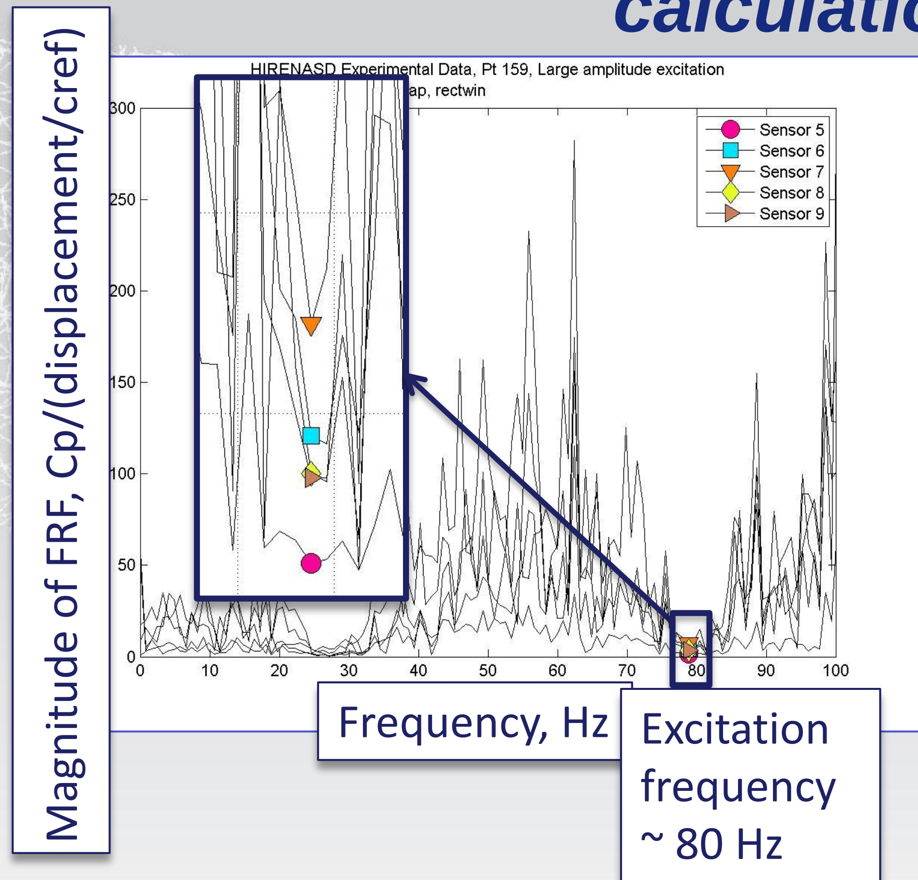
x = displacement

y = Cp

- **1 FRF for each pressure transducer**

Pressure / excitation:
At frequencies where there is no excitation, the calculation is dividing by 0'ish numbers, making the FRF a large amplitude noisy response

Frequency response functions (FRFs) calculation example



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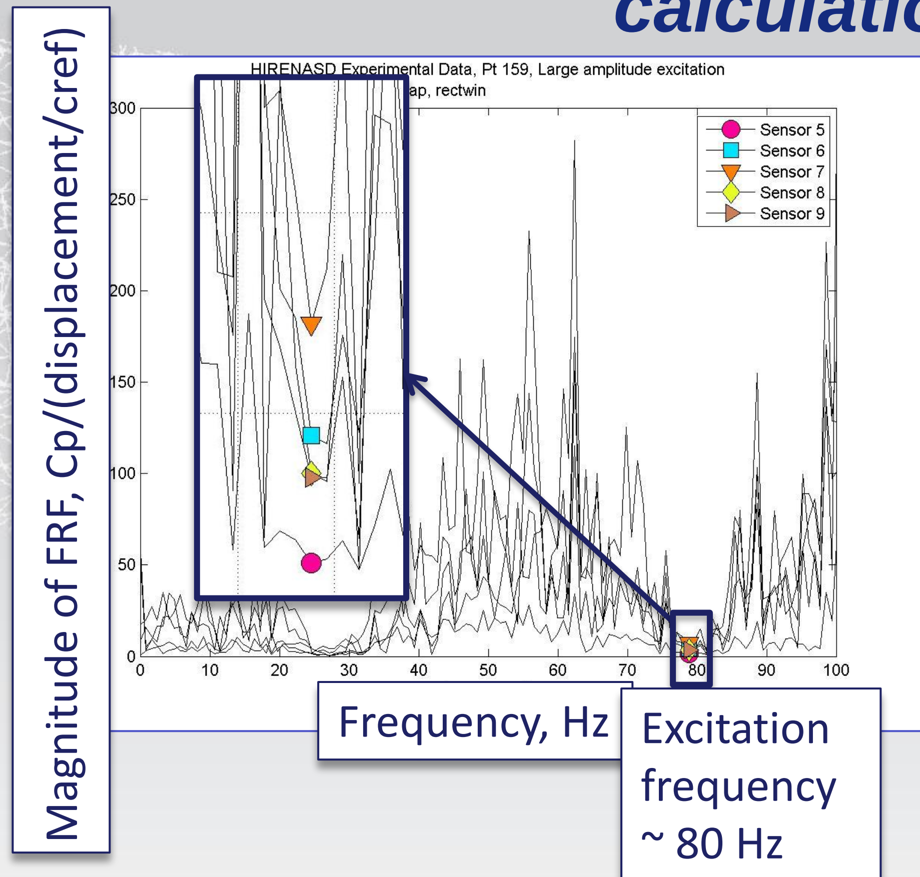

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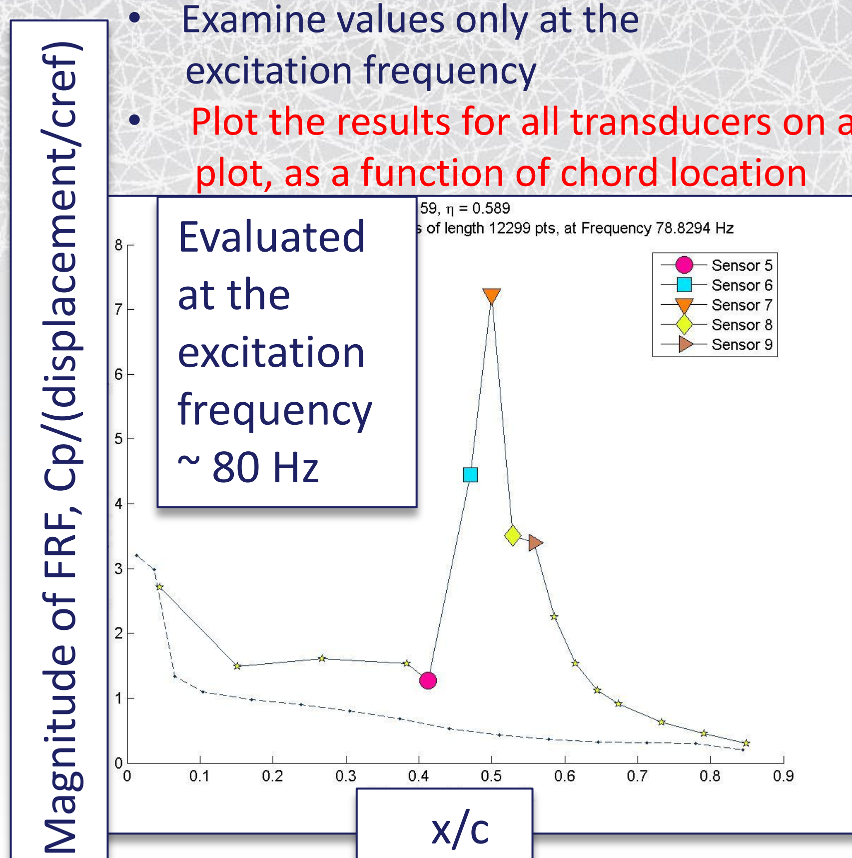
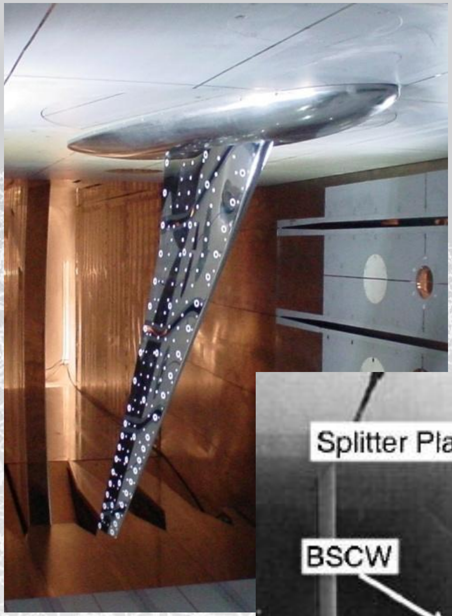
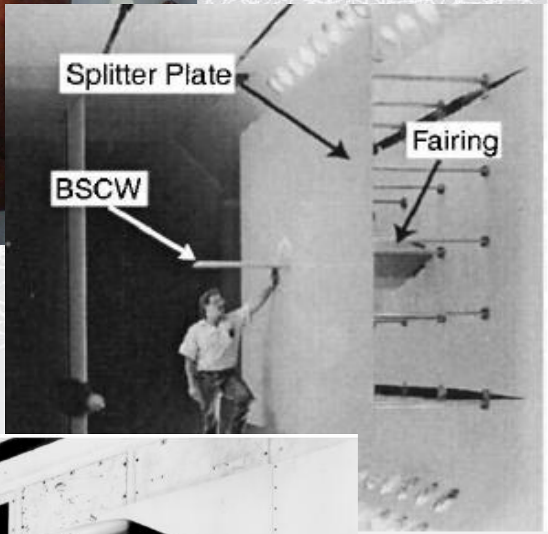
- 1 FRF for each pressure transducer
- Examine values only at the excitation frequency
- Plot the results for all transducers on a single plot, as a function of chord location



Configurations

- High Reynolds number Aero-Structural Dynamics Model (HIRENASD)
- Benchmark Supercritical Wing (BSCW)
- Rectangular Supercritical Wing (RSW)





Configurations

- **High Reynolds number Aero-Structural Dynamics Model (HIRENASD)**

- Benchmark Supercritical Wing (BSCW)

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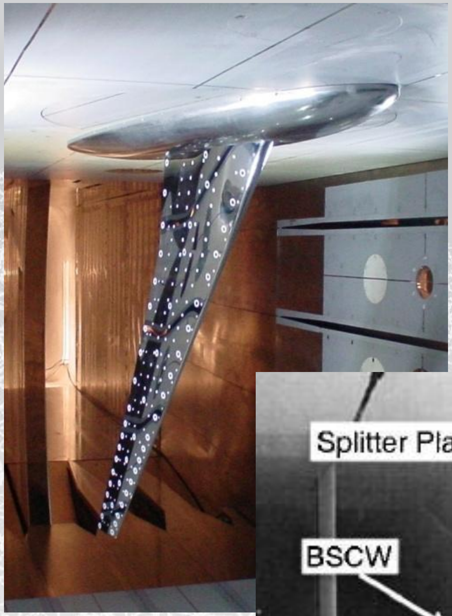
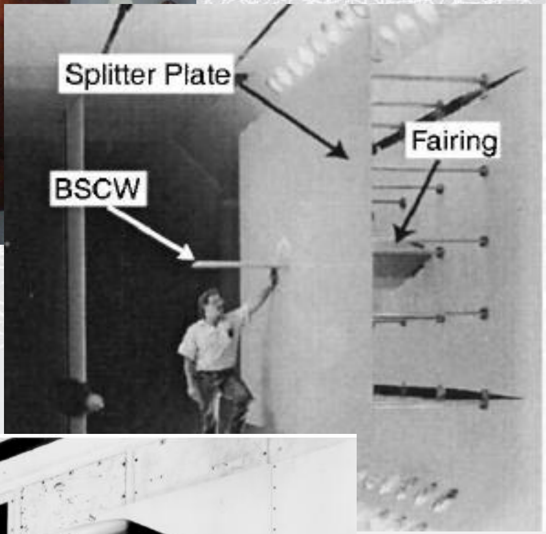
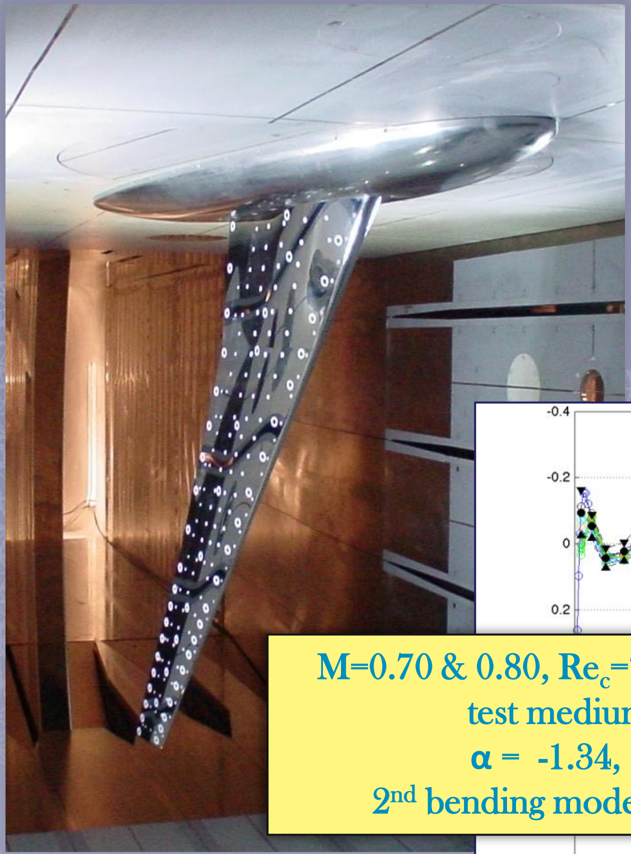
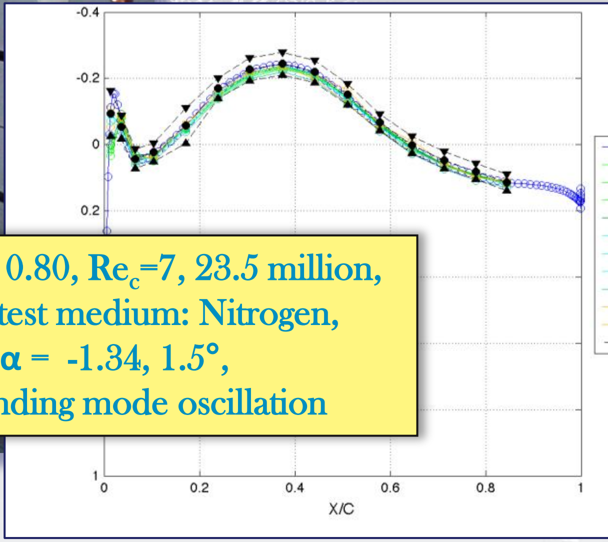




HIRENASD

- Chosen as a challenging test case, with aircraft-representative geometry & weak aeroelastic coupling





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test medium: Nitrogen,
α = -1.34, 1.5°,
2^{nd} bending mode oscillation

<u>Likely plan of action:</u>

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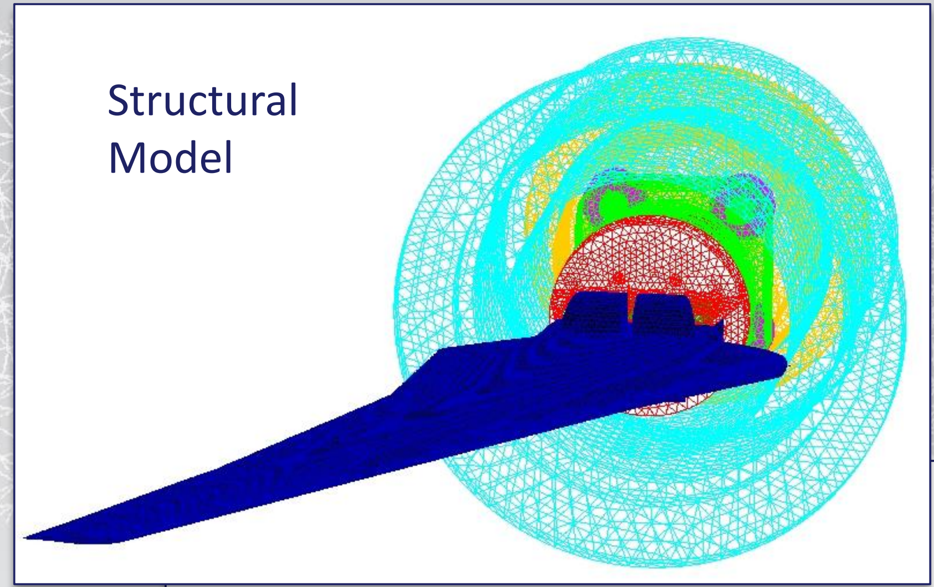
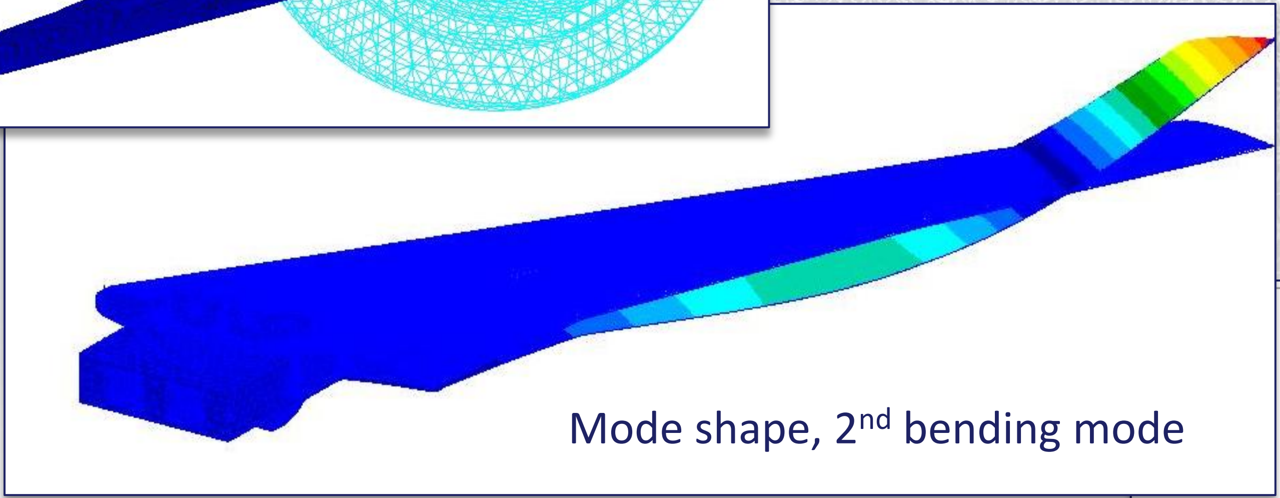
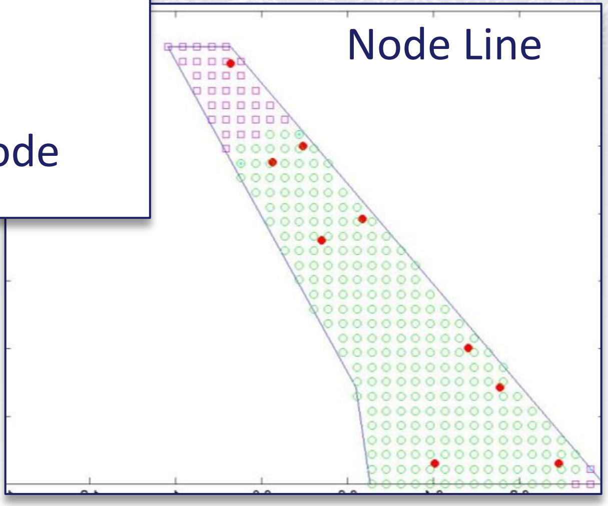
Structural Dynamic Model



The HIRENASD was excited at the 2^{nd} Bending mode frequency, ~80 Hz

Forces applied using piezoelectric stacks in the mounting hardware





	Summary of HIRENASD Entries					
Analyst	**A**	**B**	**C**	**D**	**E**	**F**
TURBULENCE MODEL	**kTNT**	**k-ω MSS**	**2 Eq. Realizable k-ε**	**SA**	**SA**	**SA, SST**
GRID TYPE	**Strmb**	**Str**	**Unstr**	**Str**	**Unstr**	**Str**

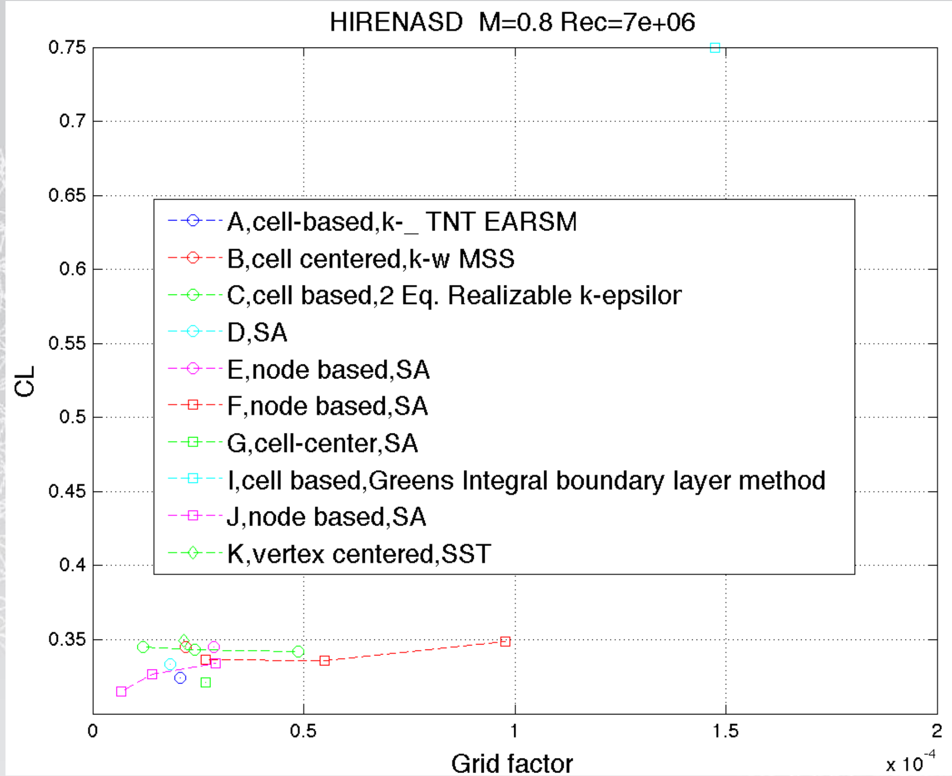
Analyst	**G**	**H**	**I**	**J**	**K**	
TURBULENCE MODEL	**SA**	**SA**	**Unknown**	**SA**	**SST**	
GRID TYPE	**Str**	**Unstr**	**Str**	**Unstr**	**Str**	

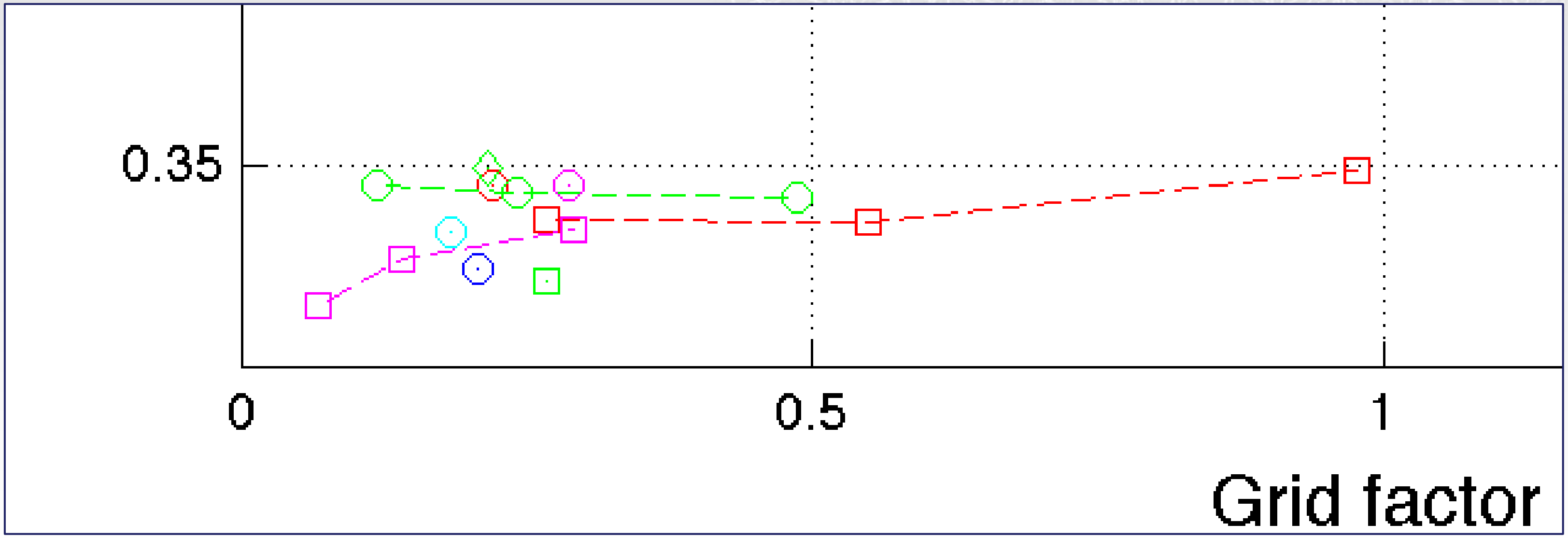
Str = Structured
Strmb = Structured multi-block
Unstr = Unstructured

Codes used:
Tau
Edge
elsA
ENFLOW
NSMV
CFD++ & NASTRAN
EZNSS
NSU3D
ZEUS
Fun3D
ANSYS CFX

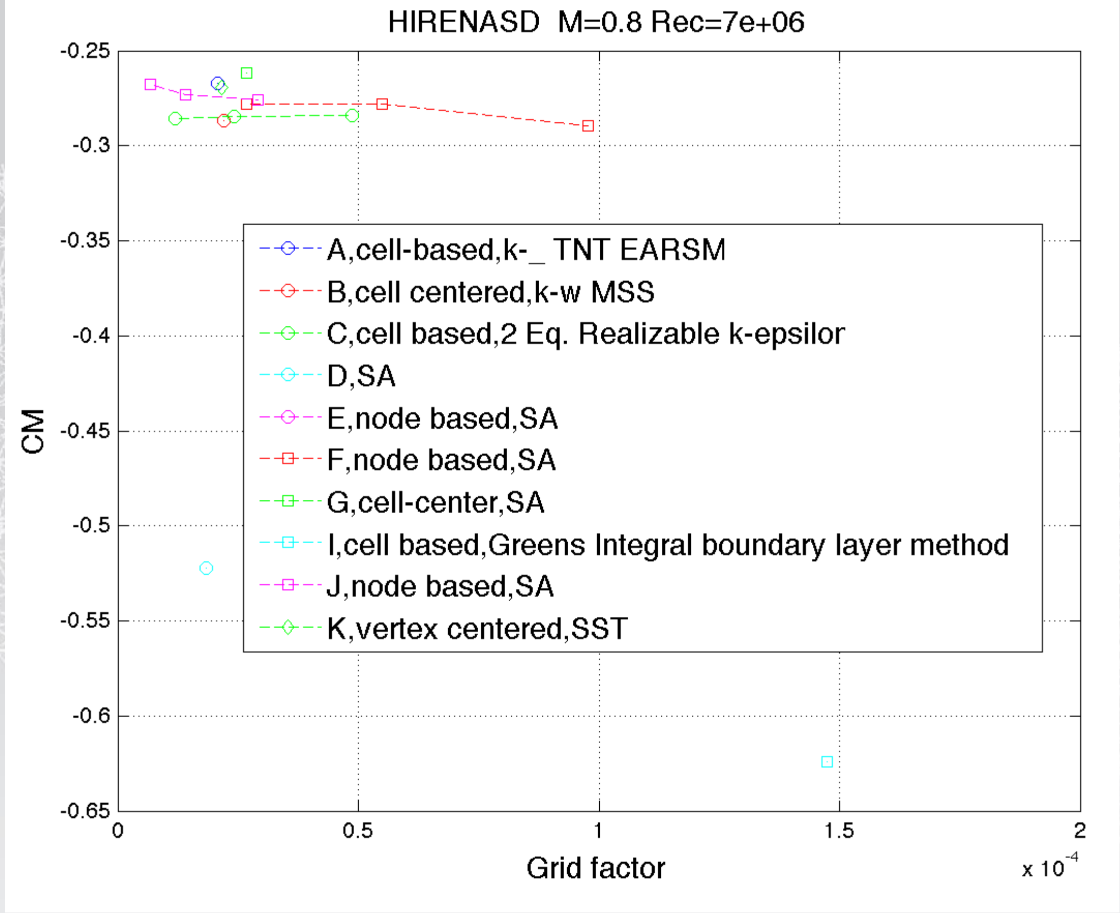
3 additional analysis teams showed results but have not yet provided information to the comparison database

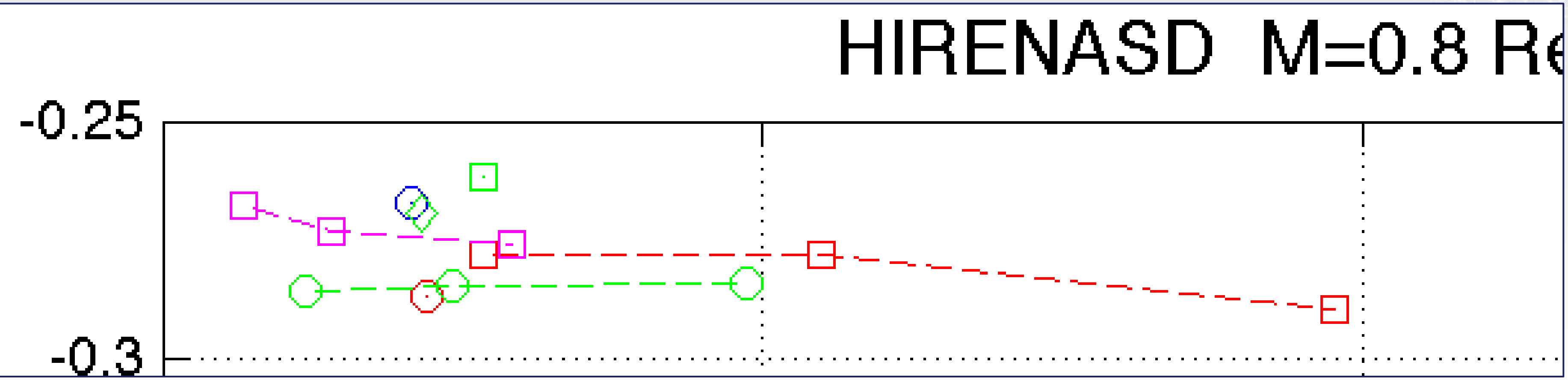
Spatial convergence, CL, steady





Spatial convergence, CM, steady





Upper surface, steady
Mach 0.8, Re 7M, α 1.5

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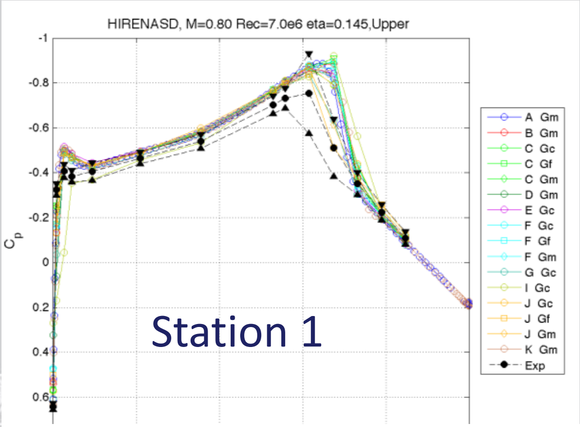

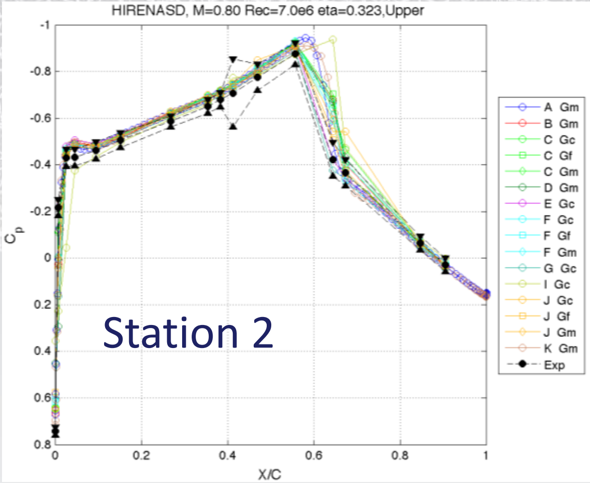

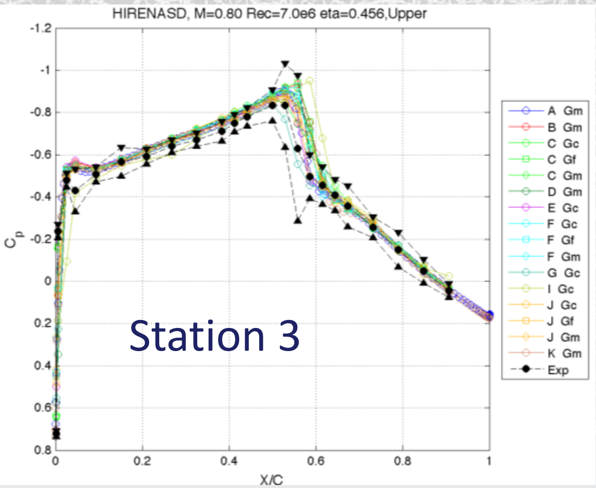

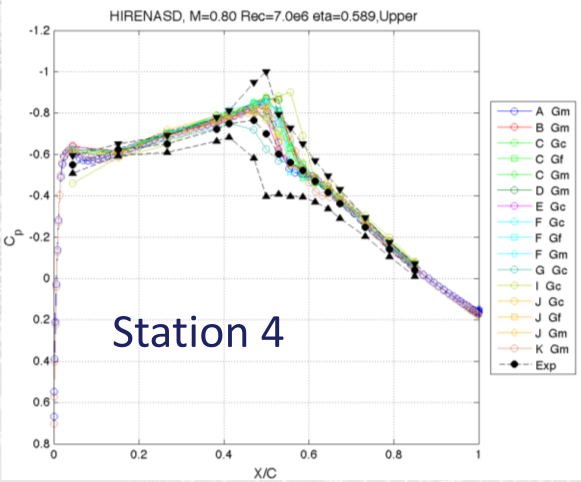

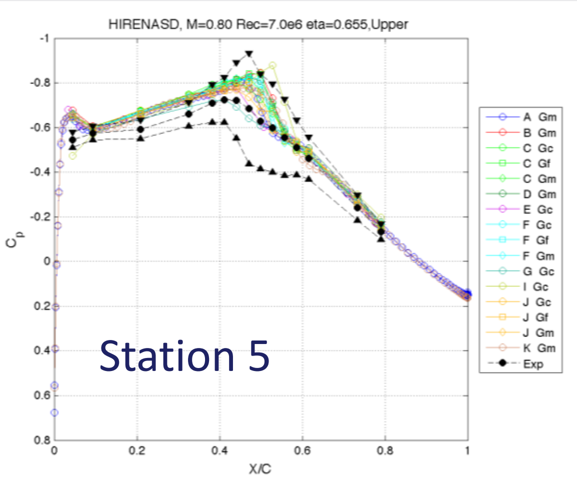

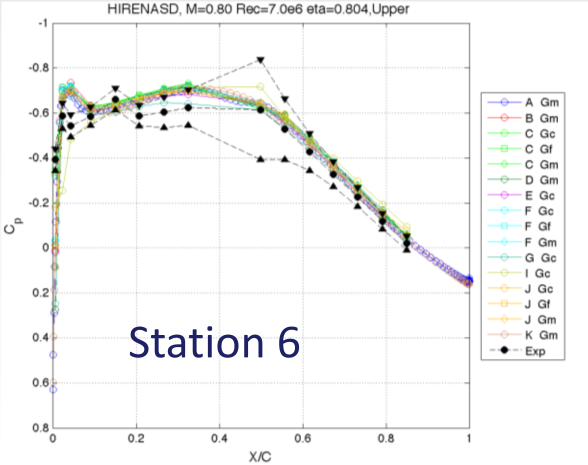

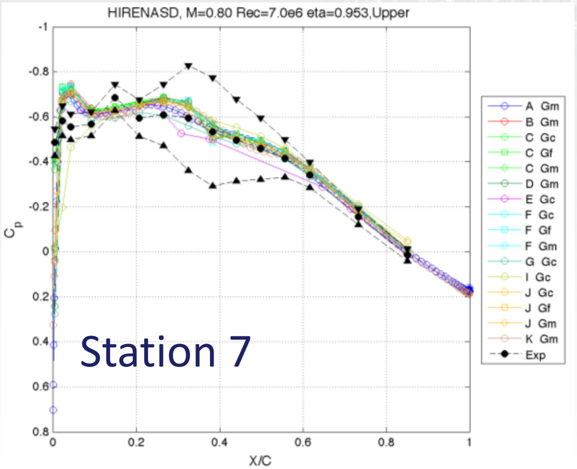

Unsteady comparison results, M 0.8, Re 7M Upper surface FRF Magnitude

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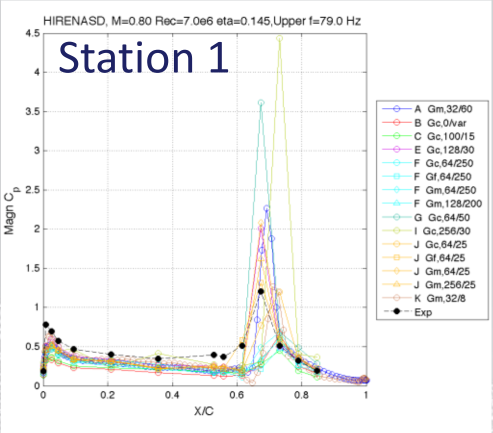

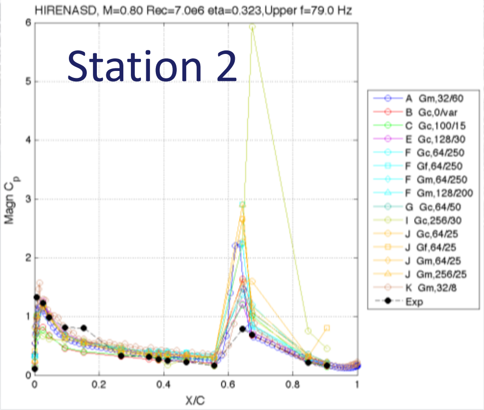

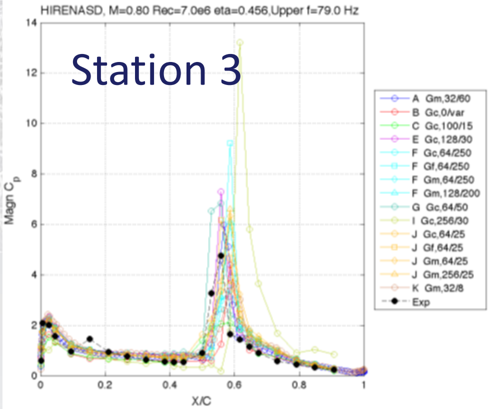

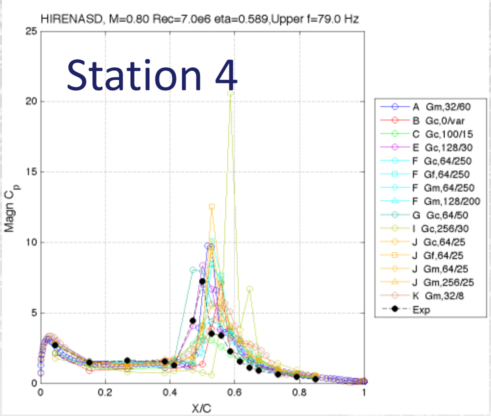

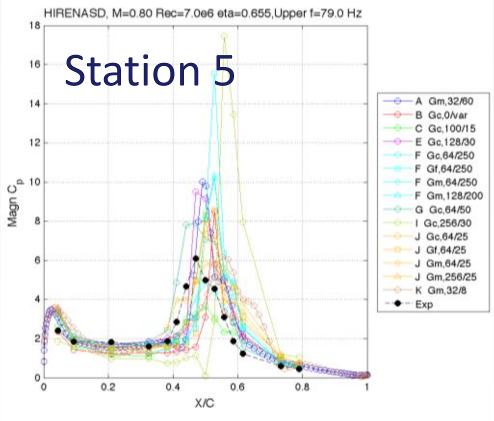

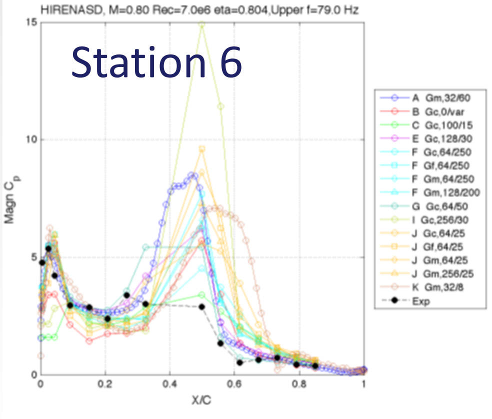

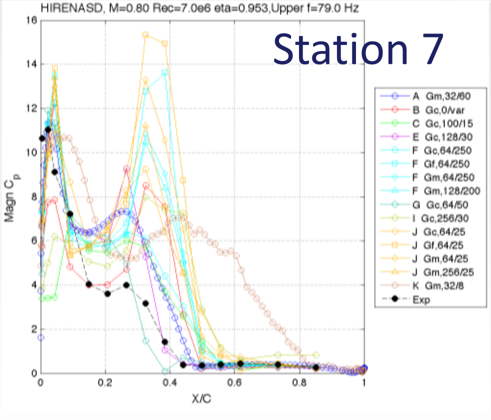

Lower surface, steady Mach 0.8, re 7M

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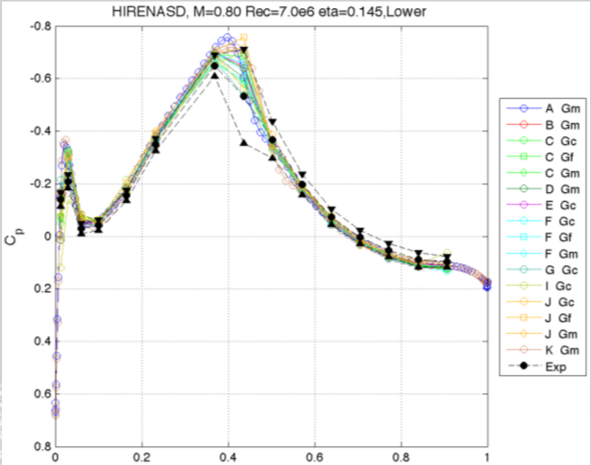
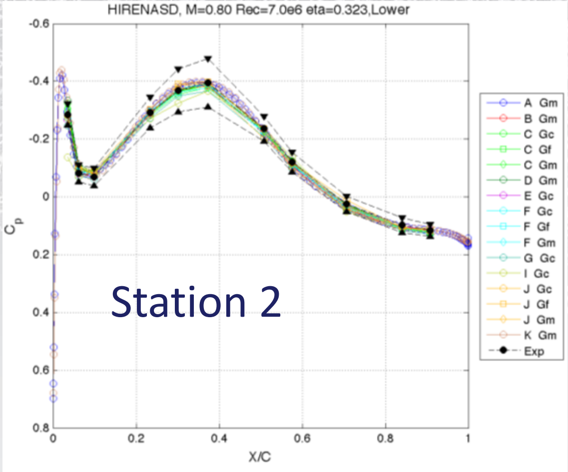
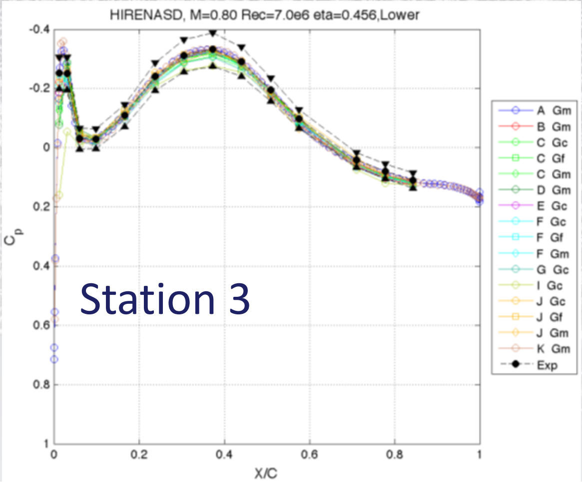
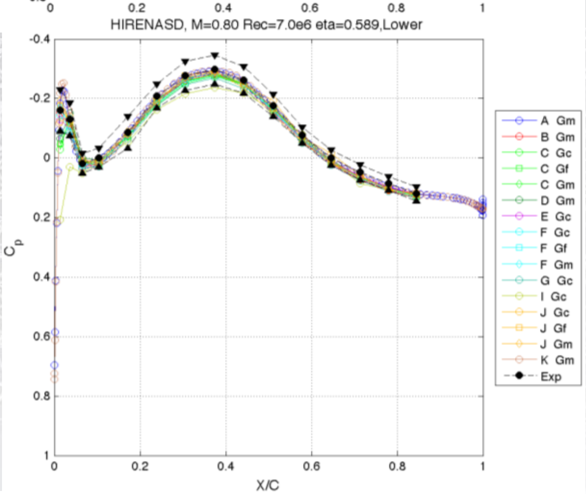
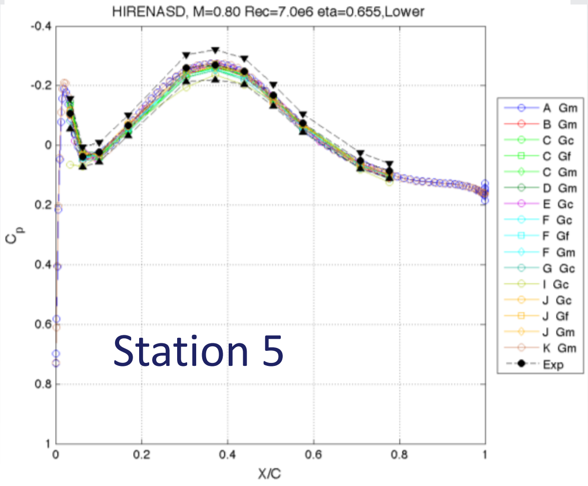
These issues are being sorted out post-workshop. None of the results included should be interpreted without proper consideration of these issues. Corrections and rescalings etc will be performed prior to publication.
Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.

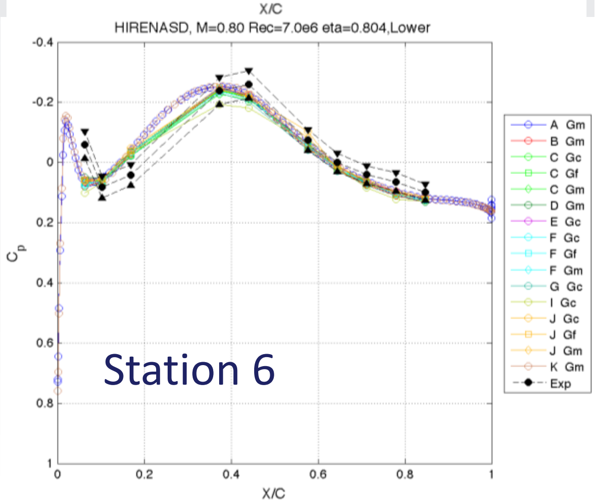


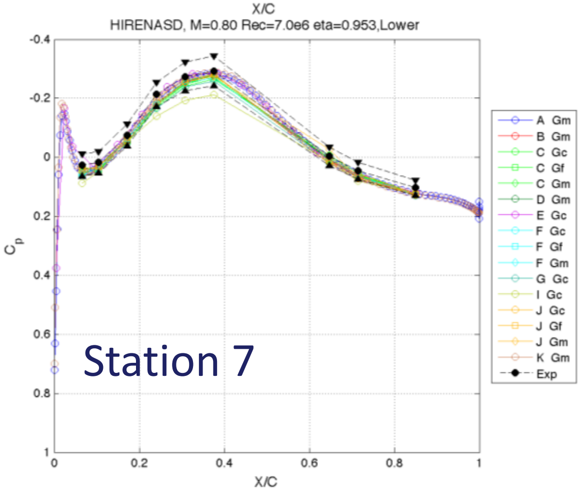




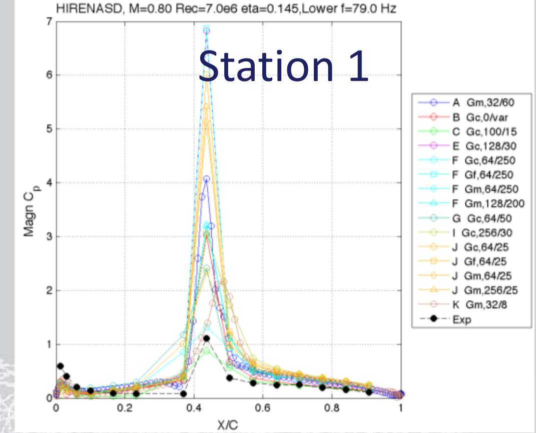








Unsteady comparison results, M 0.8, Re 7M Lower surface FRF Magnitude



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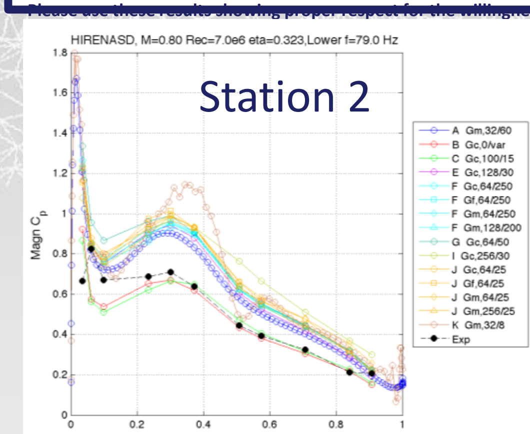
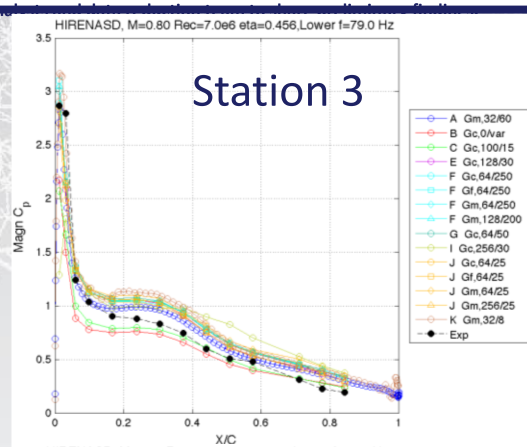
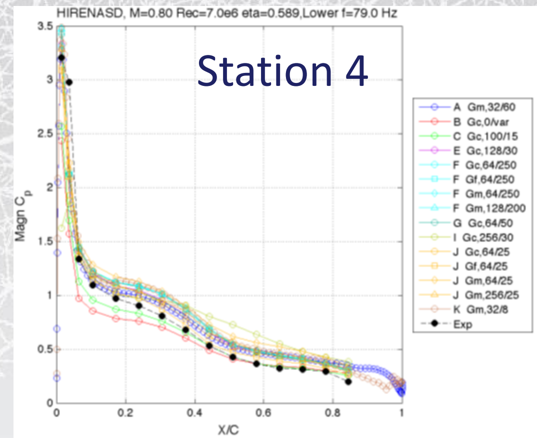
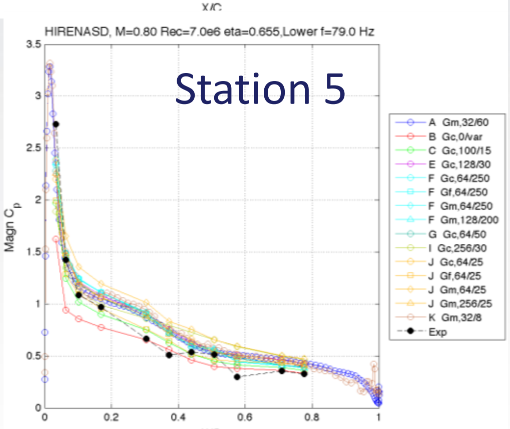
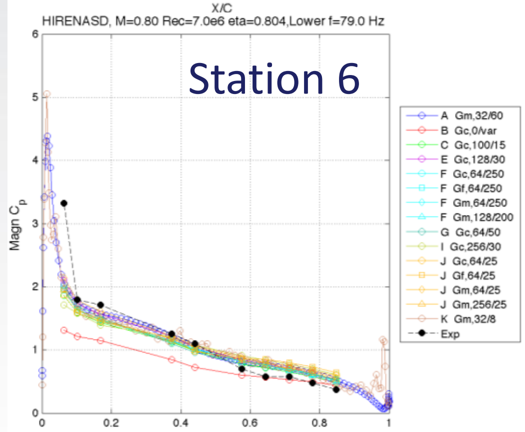
Please use these results showing proper respect for the willingness of the

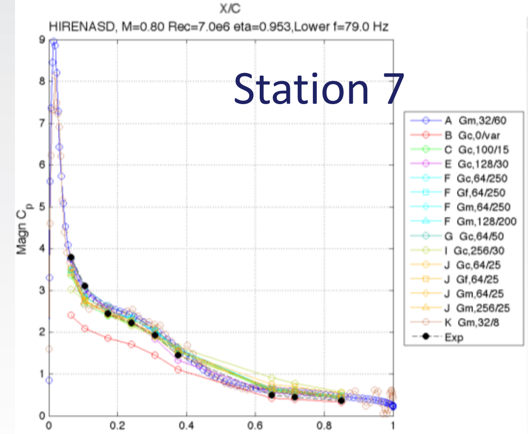




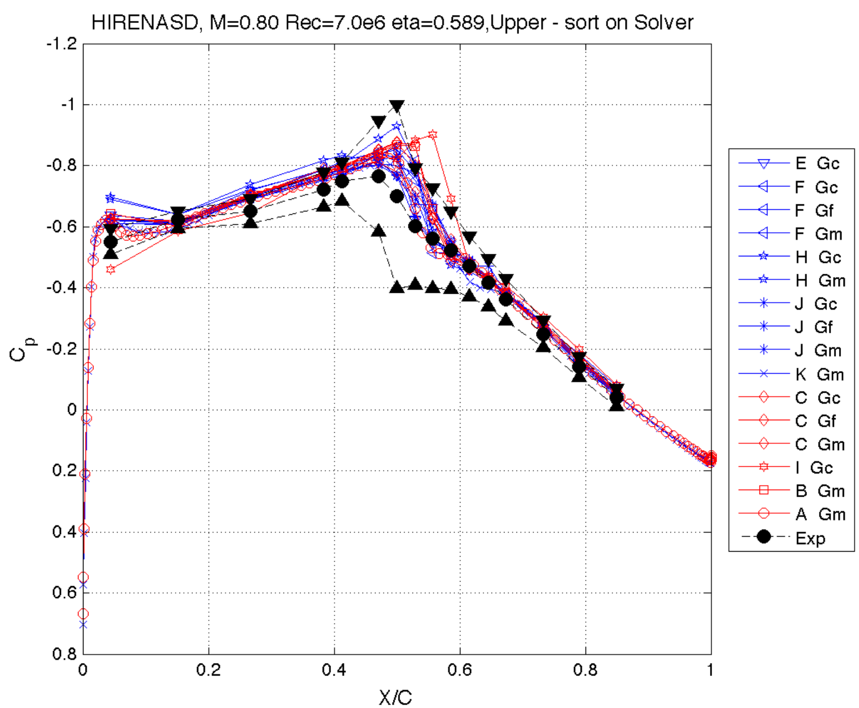


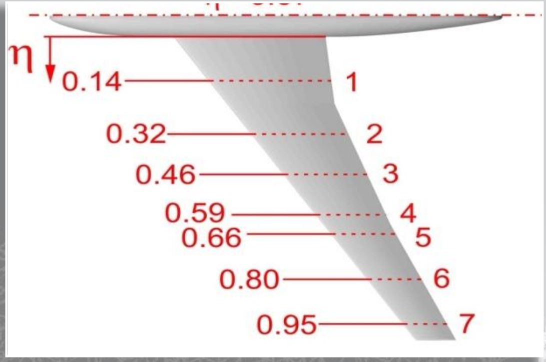






Sort by solver example, steady, M 0.8, 7M

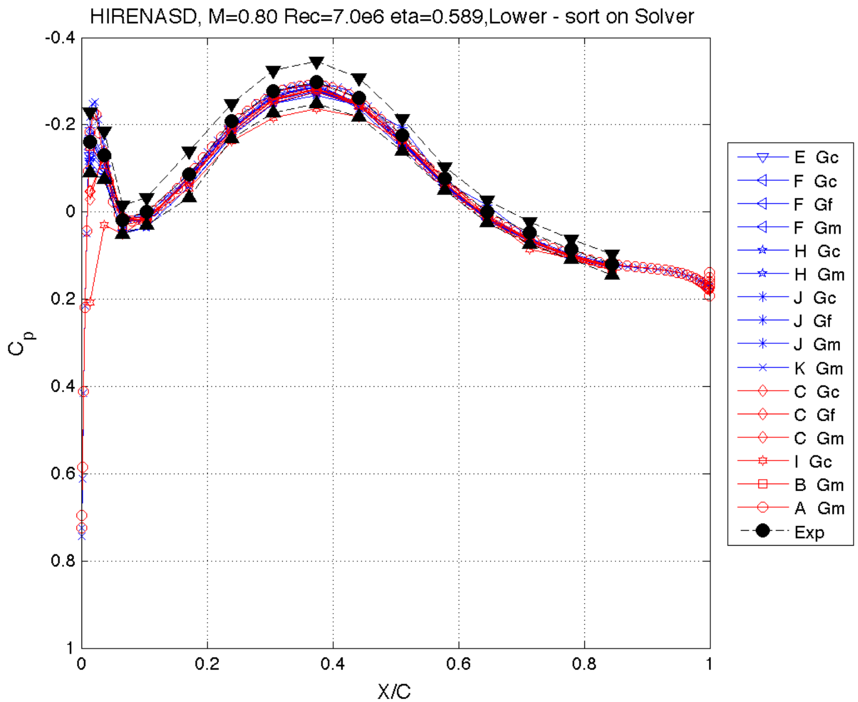




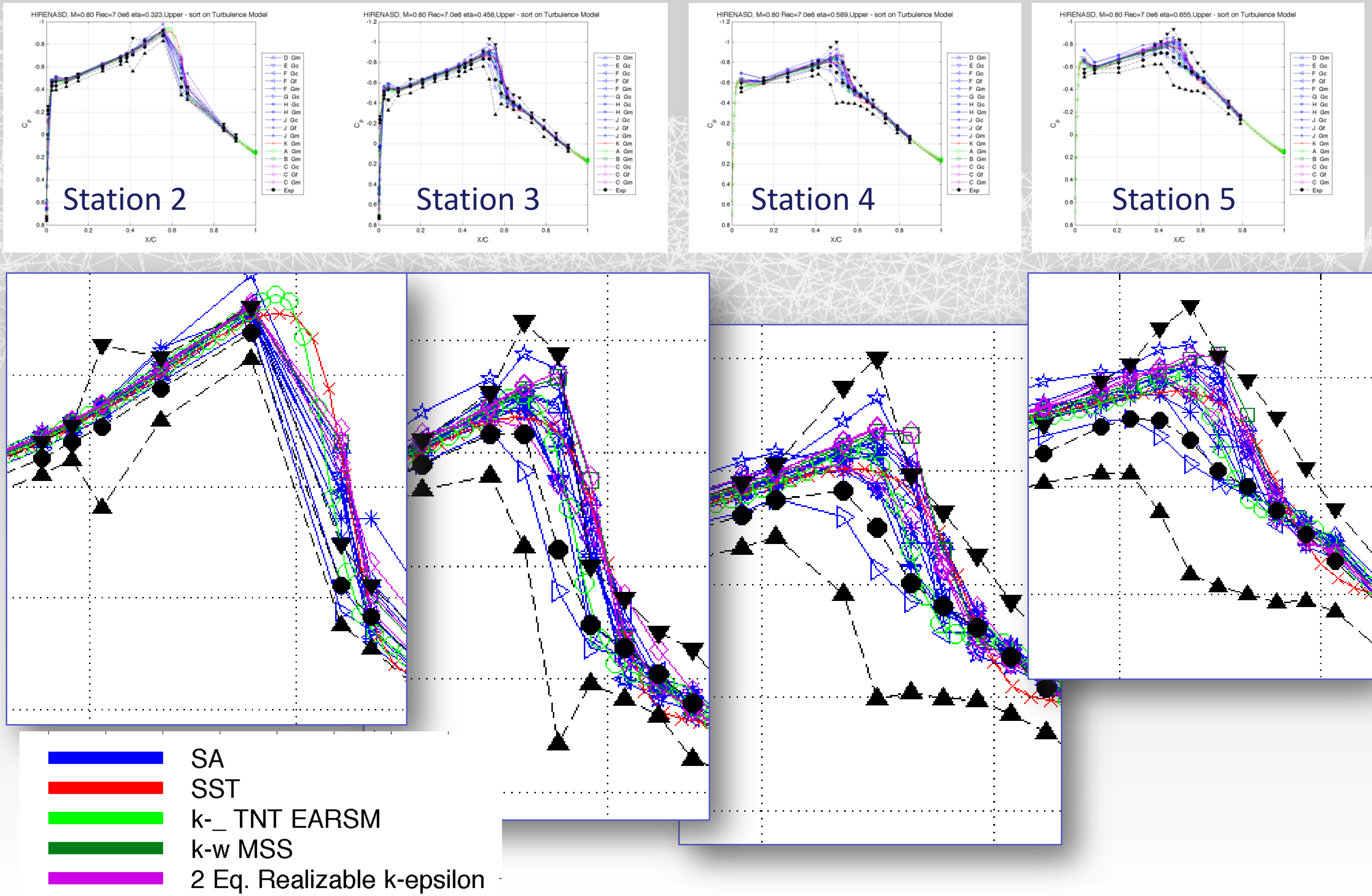
Station 4

node based

cell based

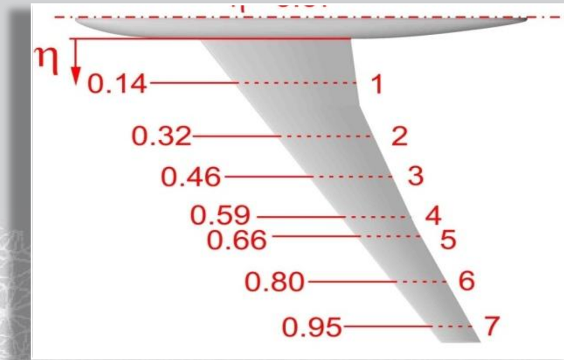


Sort by turbulence model example, steady, M 0.8, 7M



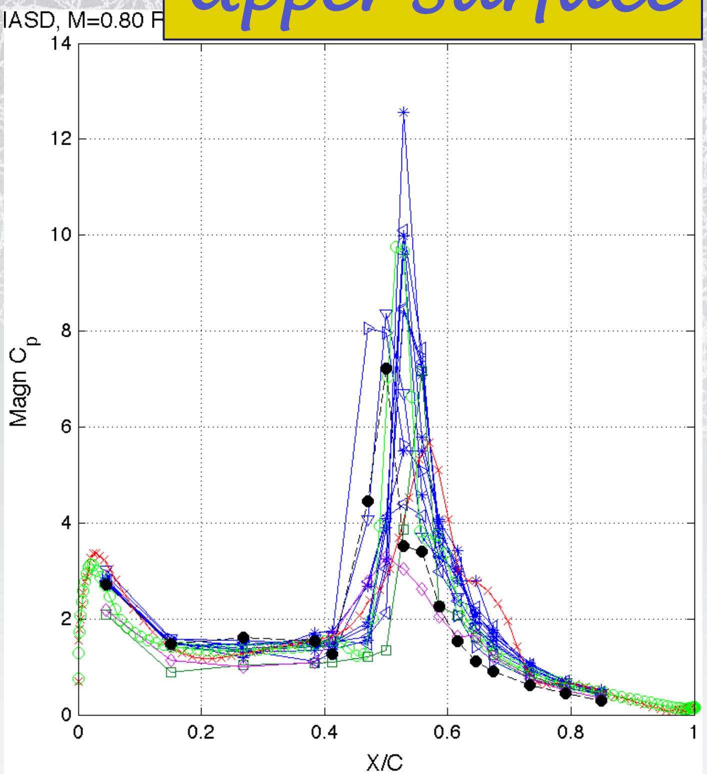
Sort by turbulence model, FRF Magnitude, M 0.8, 7M

There aren't enough results submitted with alternate turbulence models to draw meaningful conclusions

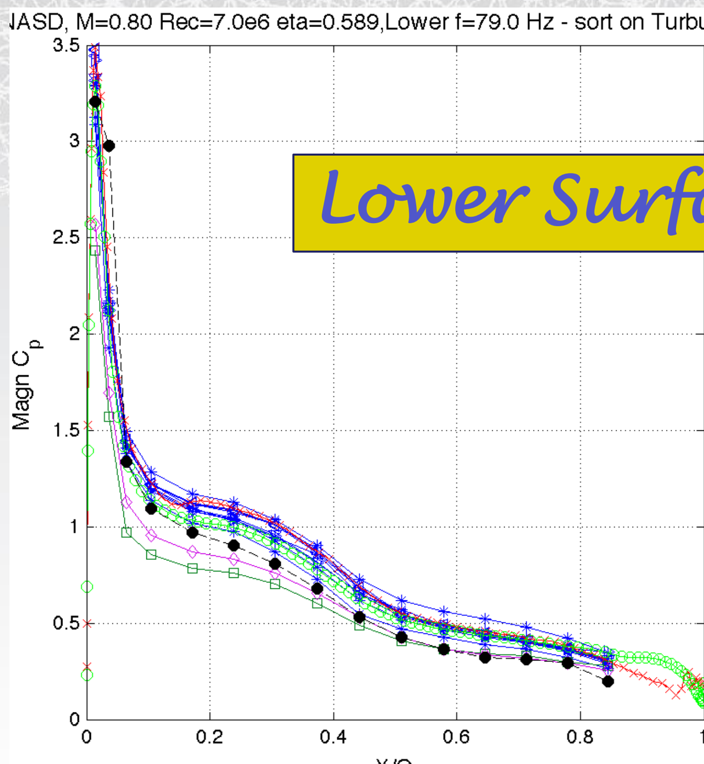


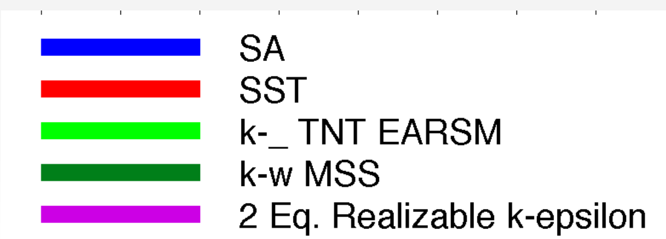
Station 4

Upper Surface

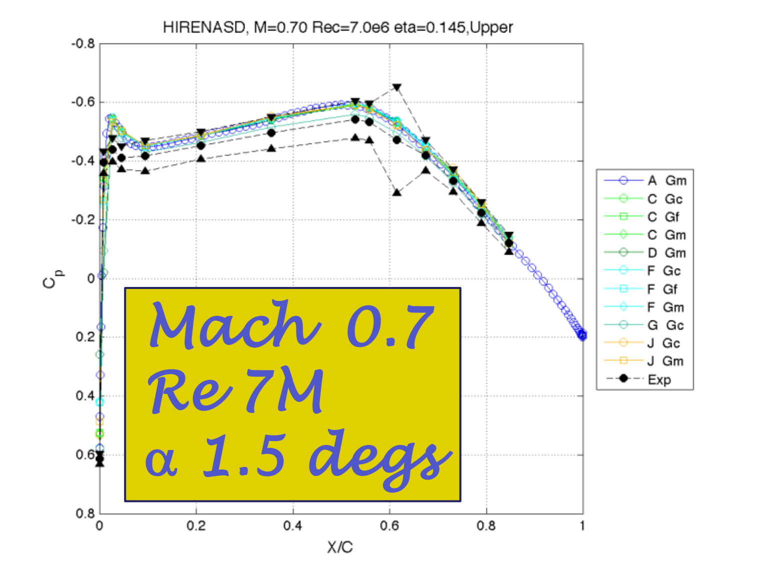


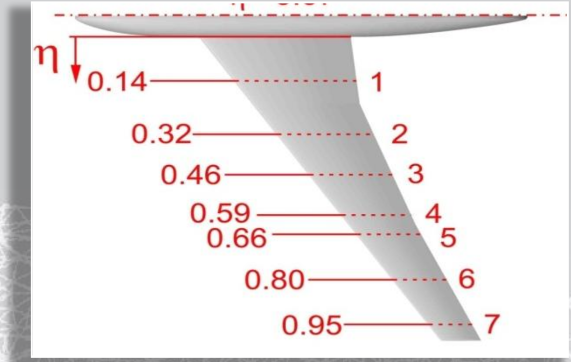
Lower Surface



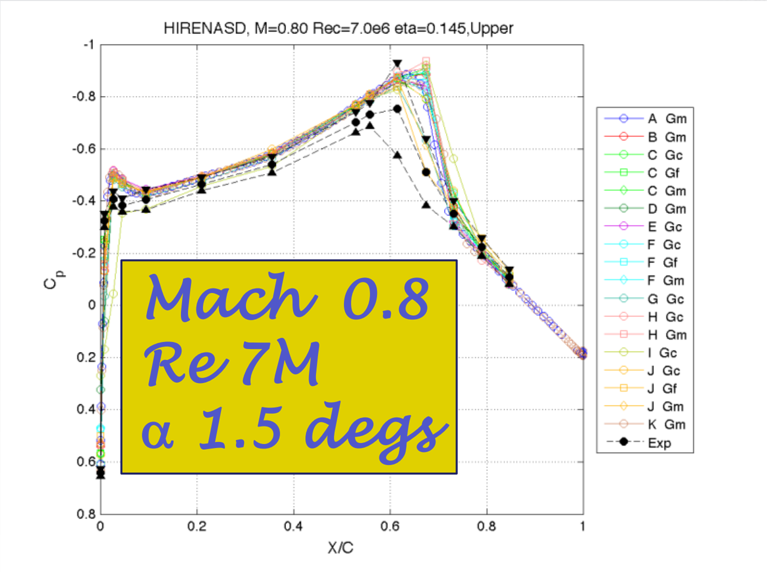


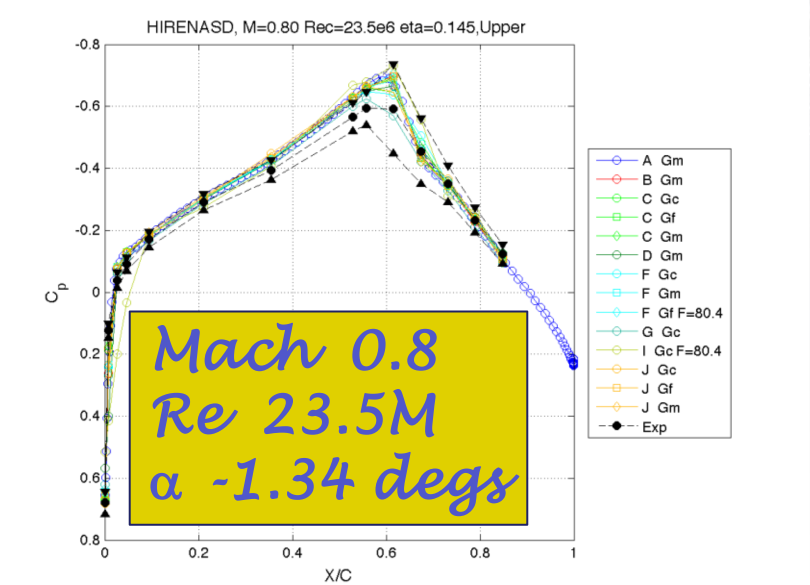
Static pressure distributions for all 3 analysis conditions: Inboard span station, upper surface





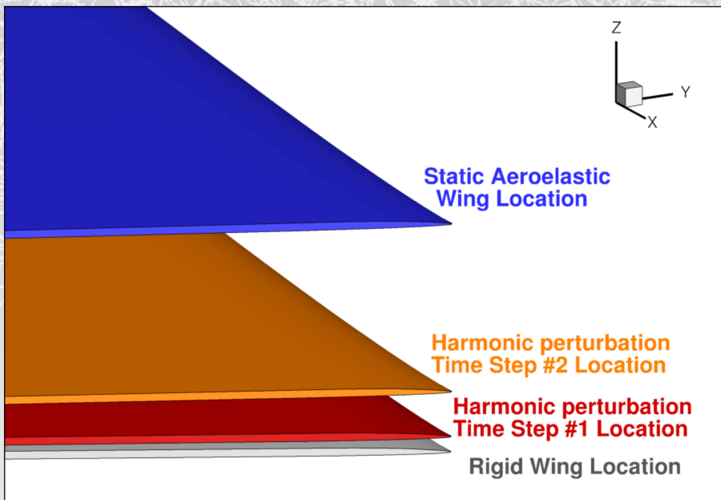
Station 1

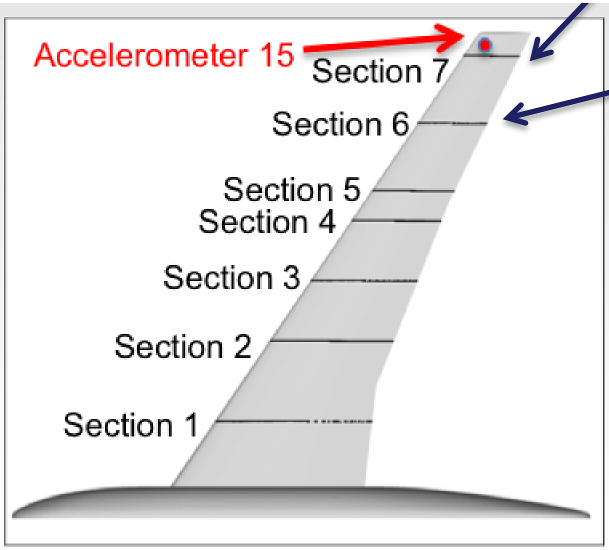


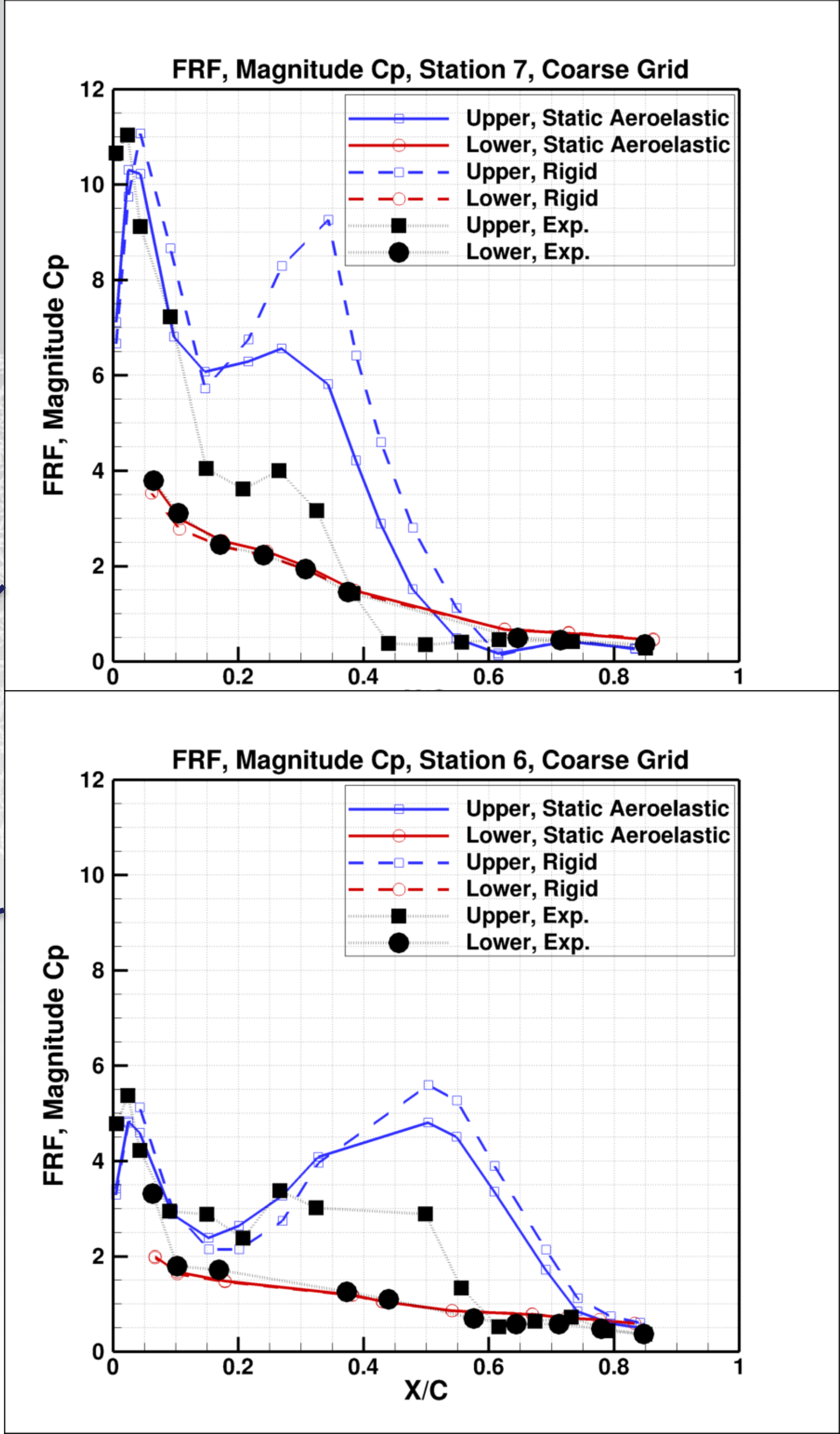


Influence of static aeroelasticity

Harmonic perturbation around correct initial geometry affects Cp and frequency response function near the wing tip







HIRENASD summary points

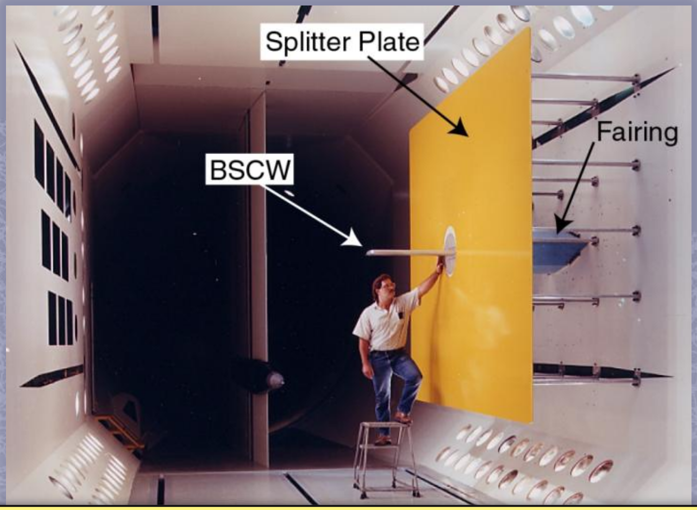
- Convergence results: Difficult to say anything at this point. Experimental comparison data & updates from analysts required
- CFD solutions produce consistent results for the mid-span properties, both statically and dynamically; agreement with experiment is “not so bad”
- Mach 0.7 case used as a benchmark- very benign and qualitatively good comparisons with experimental data
- Neither solver type nor turbulence model appears to differentiate goodness of static solutions; influence on frequency response functions requires more evaluation
- Wing tip region is poorly predicted
- Little attention has been paid to the leading edge suction peak or other behavior. Generally assumed that match would be poor; fully turbulent flow in modeling, forced transition in experimental data.

HIRENASD

Likely plan of action:

- Form technical working group of HIRENASD analysts
- Examine influence of static aeroelastic solution on oscillatory results
- Quantitative assessment of significant factors; identification of outliers and uncertainty bounds

Benchmark Supercritical Wing (BSCW)



M=0.85, Re_c=4.49 million, test medium: R-134a,
α = 5°, θ = 1°, freq 1 & 10 Hz

- Chosen as a challenging test case, flow-wise, but simple geometry
  - Strong shock with suspected shock-induced separated flow

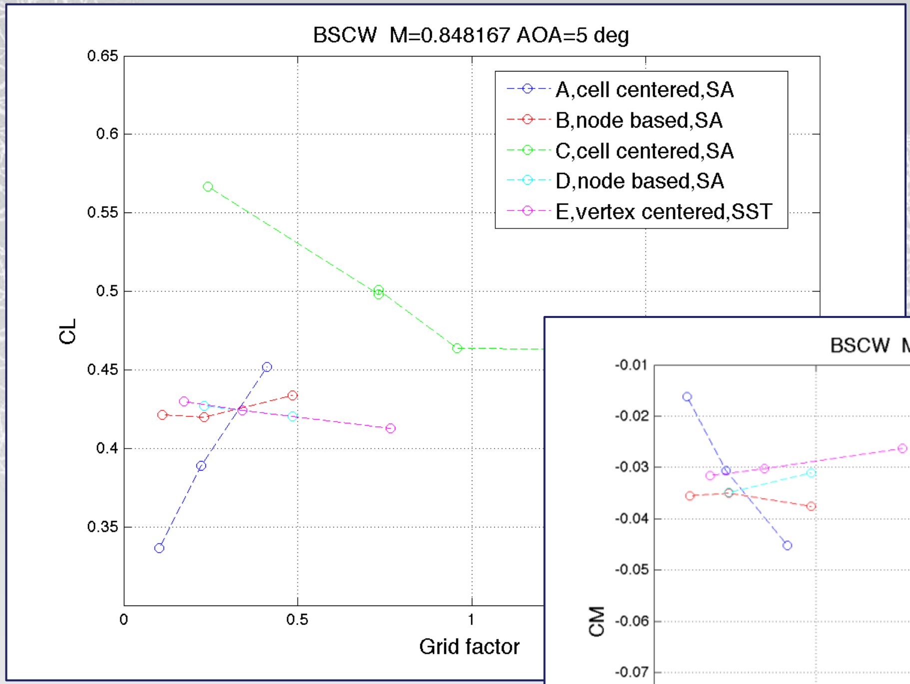
	Summary of Benchmark Supercritical Wing Entries					
Analyst	**A**	**B**	**C**	**D**	**E**	**F**
TURBULENCE MODEL	**SA**	**SA**	**SA**	**SA**	**SST**	**SST-kω**
GRID TYPE	**Str**	**Unstr**	**Str**	**Unstr**	**Str**	**Str**

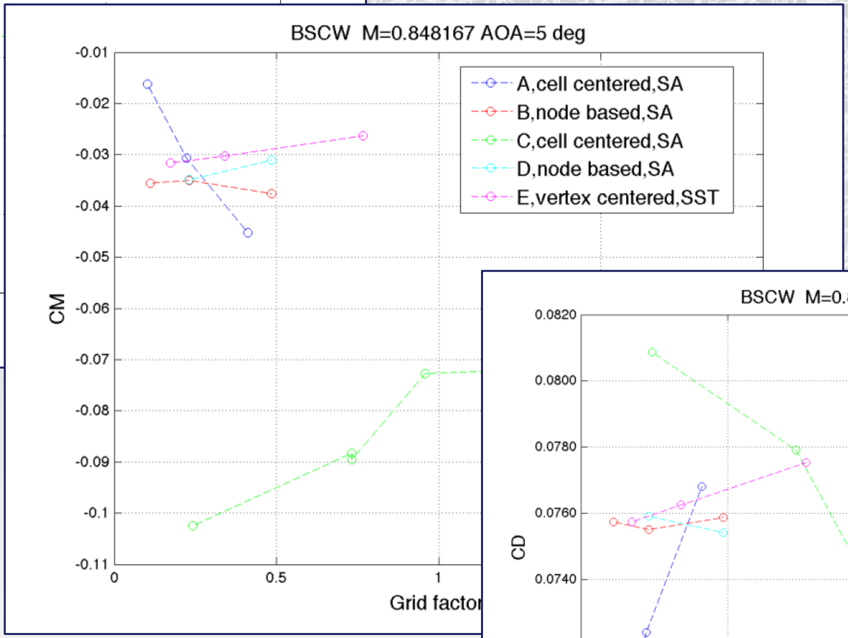
Str = Structured

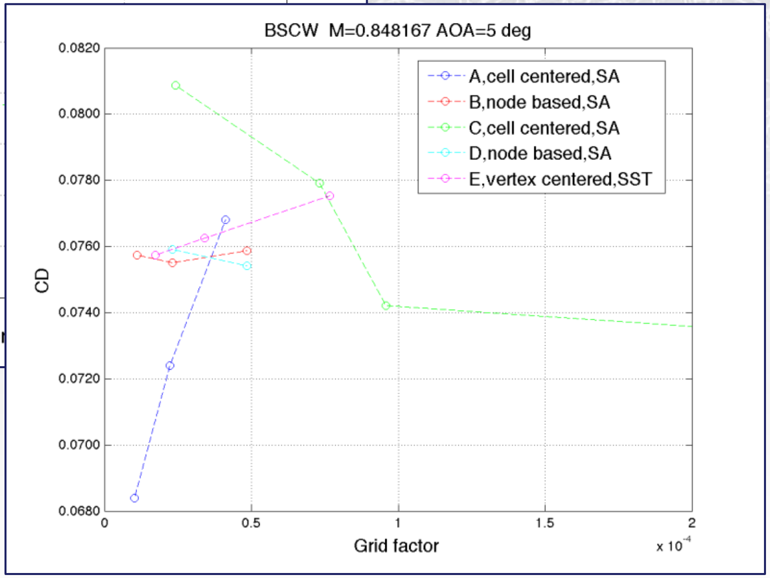
Unstr = Unstructured

Codes used:
FUN3D
CFL3D
Overflow 2.2c
NSMB
NSU3D
ANSYS CFX

BSCW Steady Grid Convergence

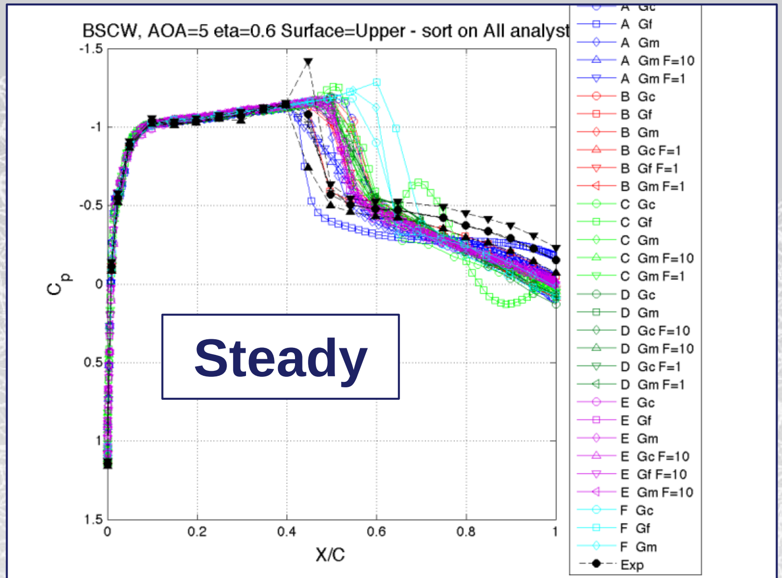




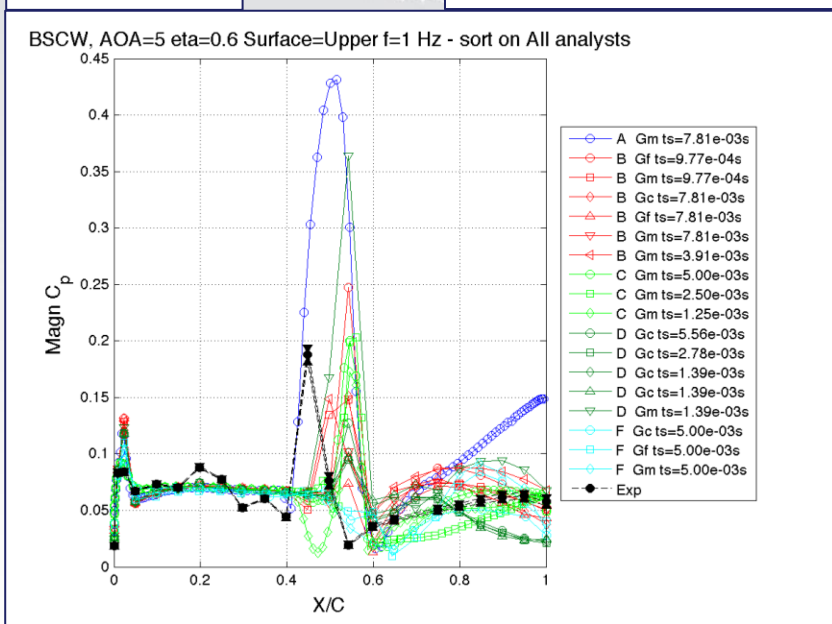


Comparison results, Upper surface

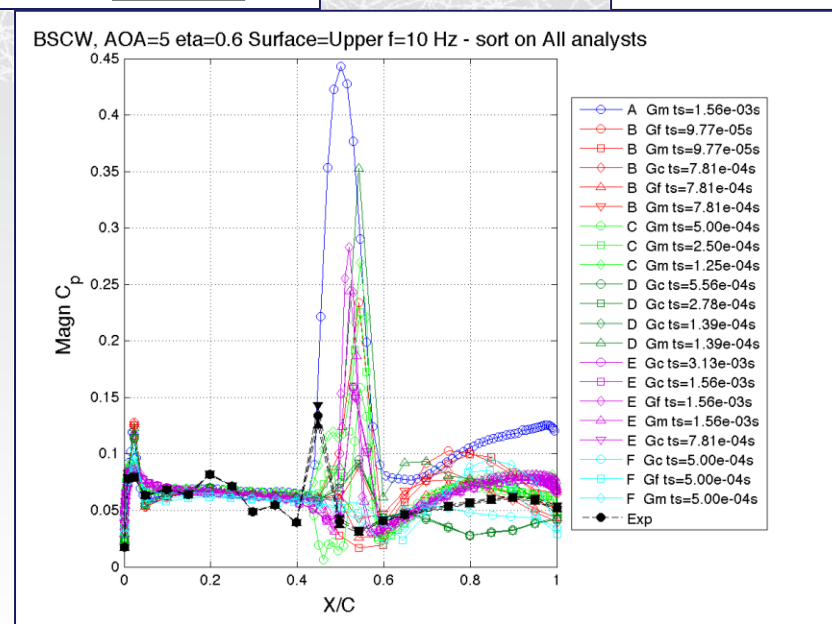
Steady



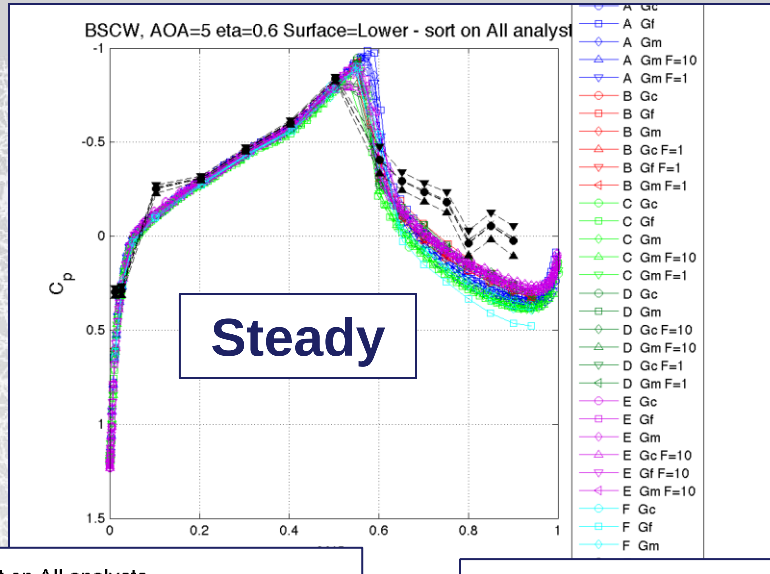
1 Hz



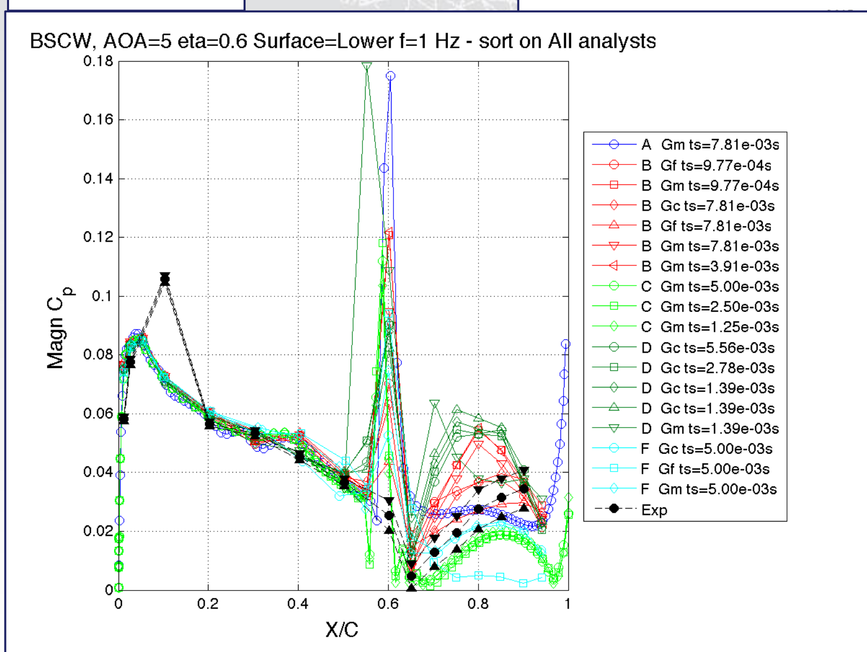
10 Hz



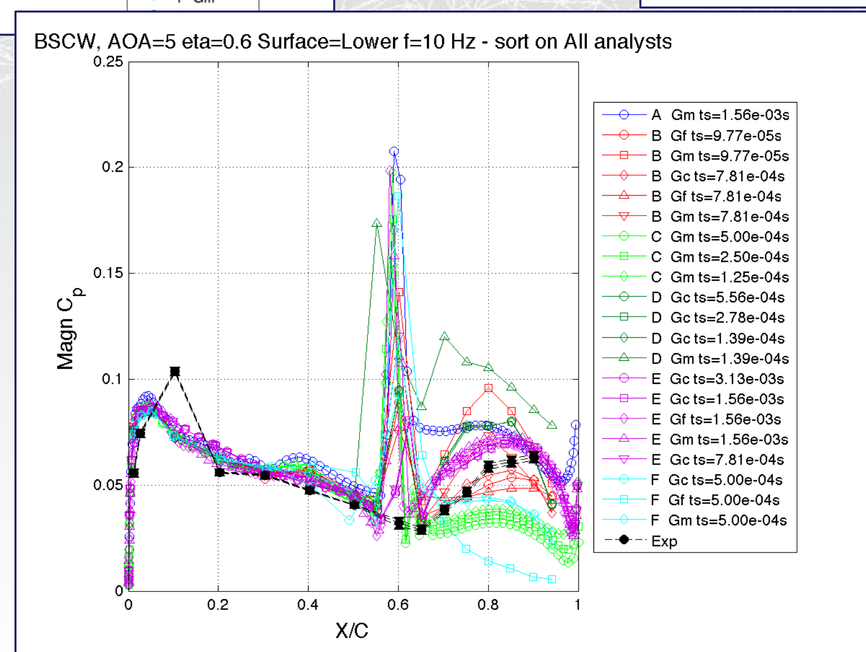
Comparison results, Lower surface



1 Hz



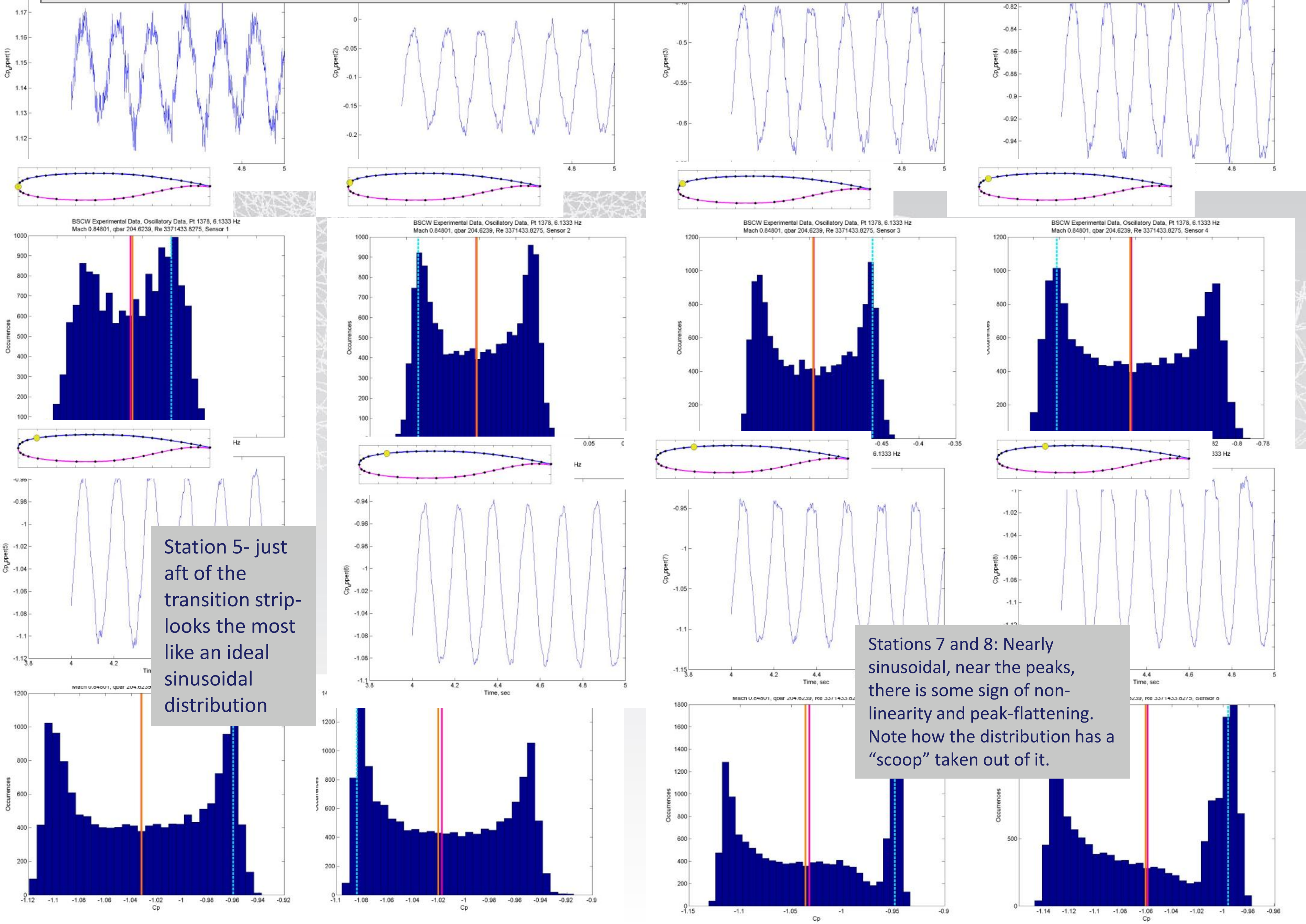
10 Hz



Some BSCW summary points, focused on computational results

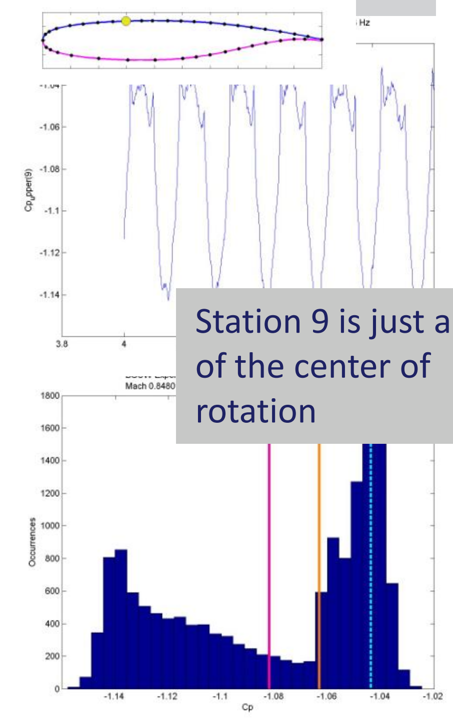
- Computational methods had difficulty producing converged solutions due to flow field complexity
- Complex flow field also observed in experimental data; Largest magnitude of dynamic behavior appears to represent shock oscillations
- CFD solutions vary widely, even for static solution
- The flow phenomena that appear to be present on the BSCW test case include
  - shock-induced separated flow
  - geometry-induced separated flow
  - shock oscillations even in the steady solution & unforced experiment
- Convergence wrt grid size has not been consistently demonstrated
- Static predictions of pressure distribution (Xducers are at 60% span):
  - Predictions of upper surface shock location vary by 25% of the chord
  - Predicted values of Cp ahead of shock are consistent among analyses and consistent with experimental data
  - If experimental data is taken as gospel, CFD solutions predict shock too far downstream
  - Aft of shock, the magnitude and distribution of the predictions vary and have a different distribution shape from the experimental data
  - Lower surface: aft of the shock predictions begin to fan out; disagree with the experimental data
- The analytical results tend to look more constant wrt frequency of excitation than experimental results
- Computational FRFs in the region of the shock and aft of the shock do not give consistent answers, nor do they match the experiment
- We have an insufficient number of data submitted to assign cause and effect relationships

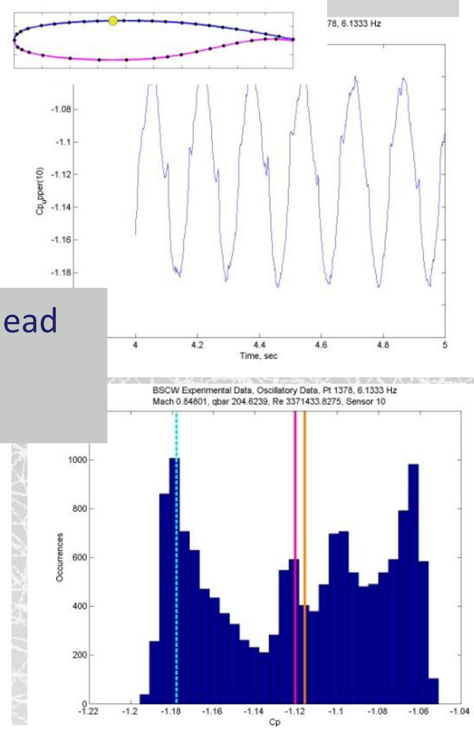
Time histories & histograms of Cp for each transducer



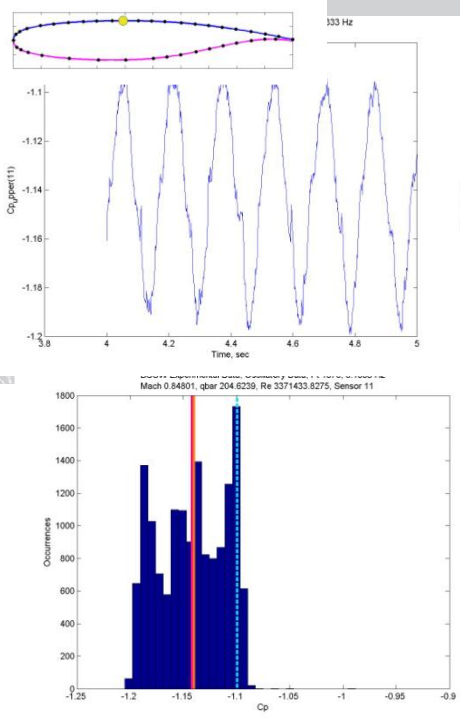
Station 5- just aft of the transition strip- looks the most like an ideal sinusoidal distribution

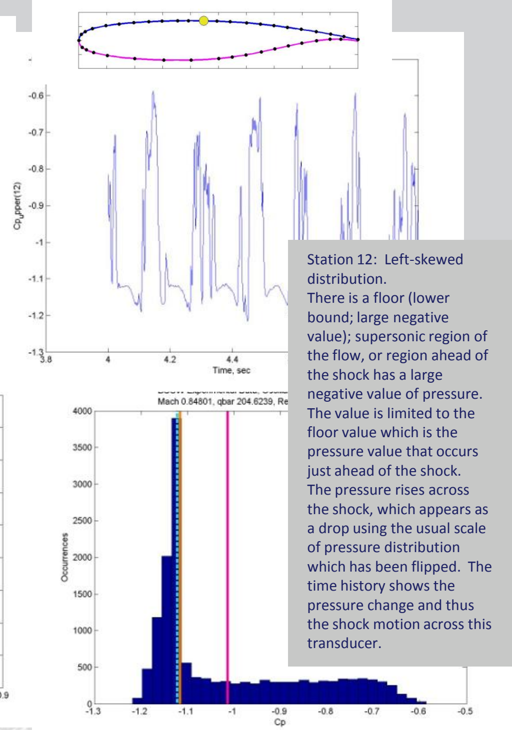
Stations 7 and 8: Nearly sinusoidal, near the peaks, there is some sign of non-linearity and peak-flattening. Note how the distribution has a "scoop" taken out of it.



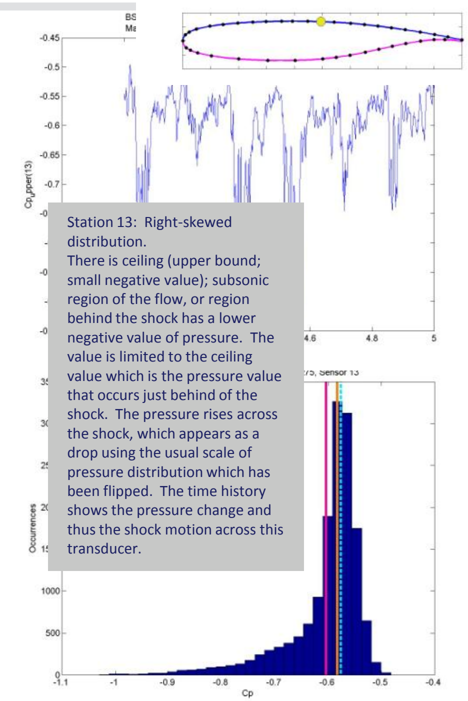


Station 9 is just ahead of the center of rotation

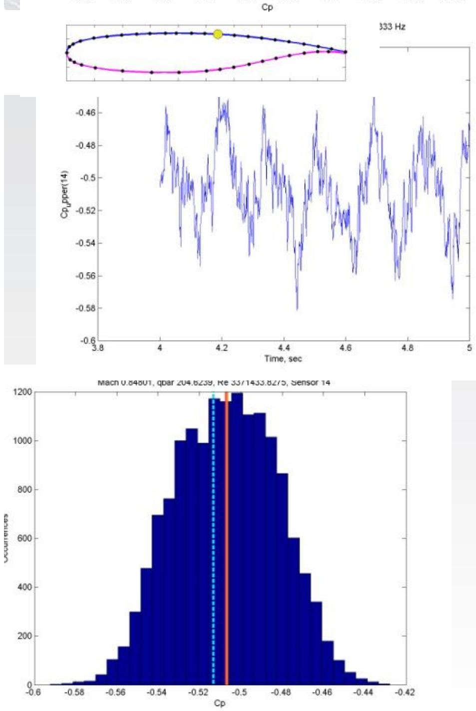


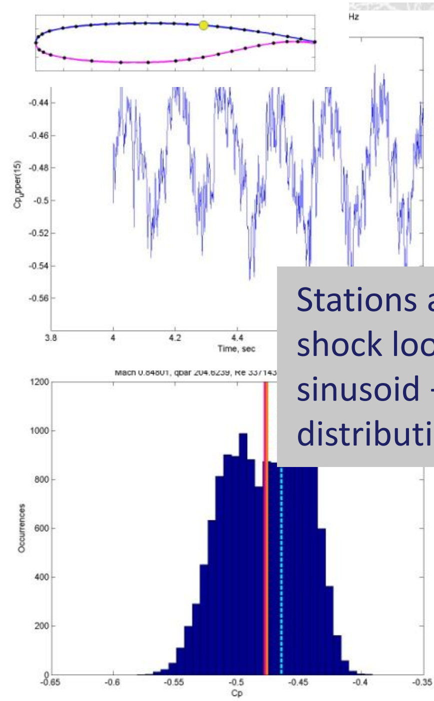


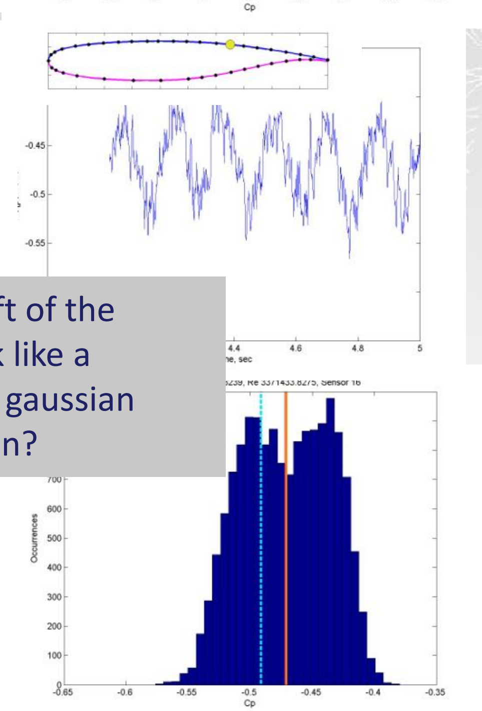
Station 12: Left-skewed distribution.
There is a floor (lower bound; large negative value); supersonic region of the flow, or region ahead of the shock has a large negative value of pressure. The value is limited to the floor value which is the pressure value that occurs just ahead of the shock. The pressure rises across the shock, which appears as a drop using the usual scale of pressure distribution which has been flipped. The time history shows the pressure change and thus the shock motion across this transducer.



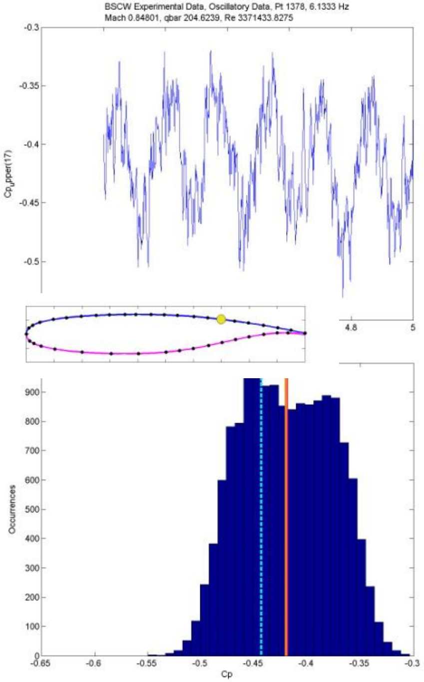
Station 13: Right-skewed distribution.
There is ceiling (upper bound; small negative value); subsonic region of the flow, or region behind the shock has a lower negative value of pressure. The value is limited to the ceiling value which is the pressure value that occurs just behind of the shock. The pressure rises across the shock, which appears as a drop using the usual scale of pressure distribution which has been flipped. The time history shows the pressure change and thus the shock motion across this transducer.

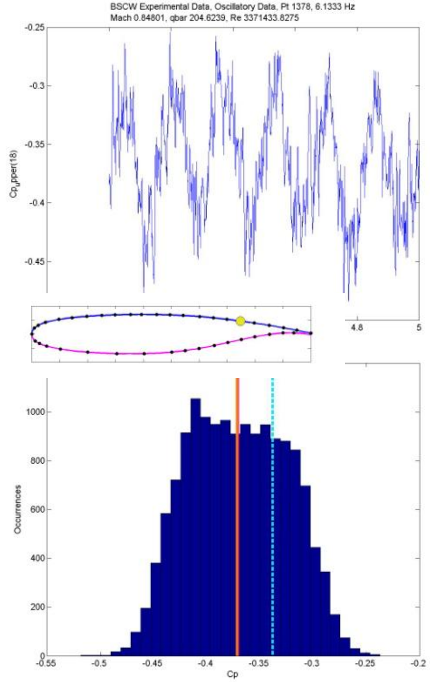


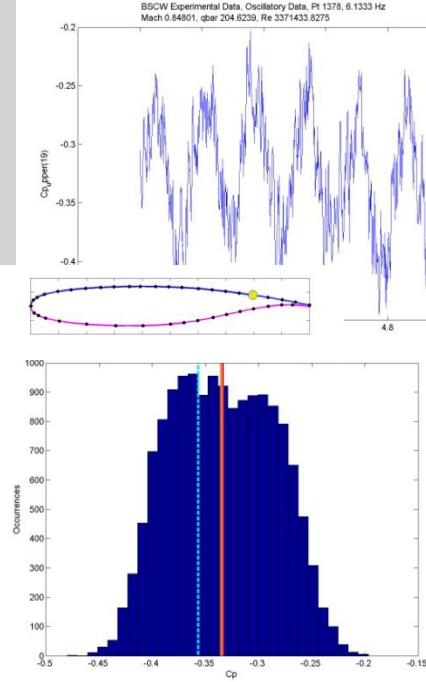


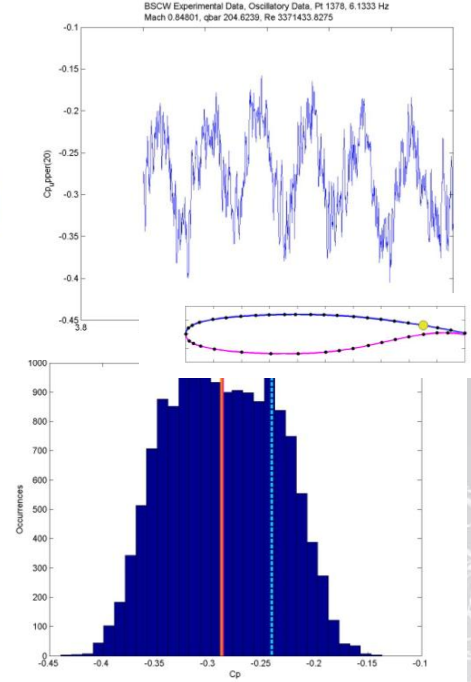


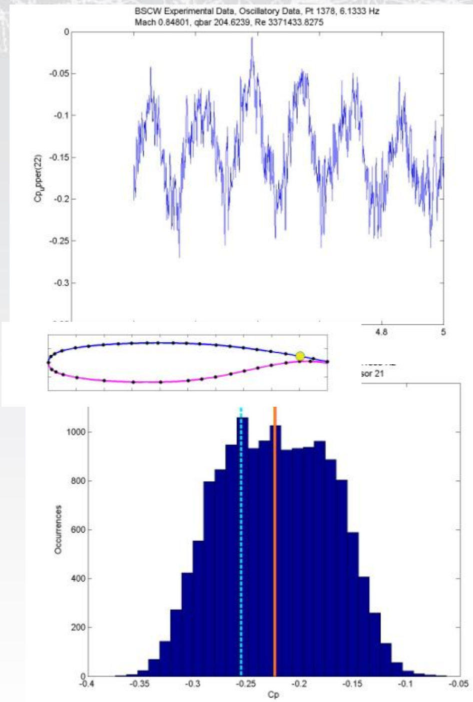
Stations aft of the shock look like a sinusoid + gaussian distribution?

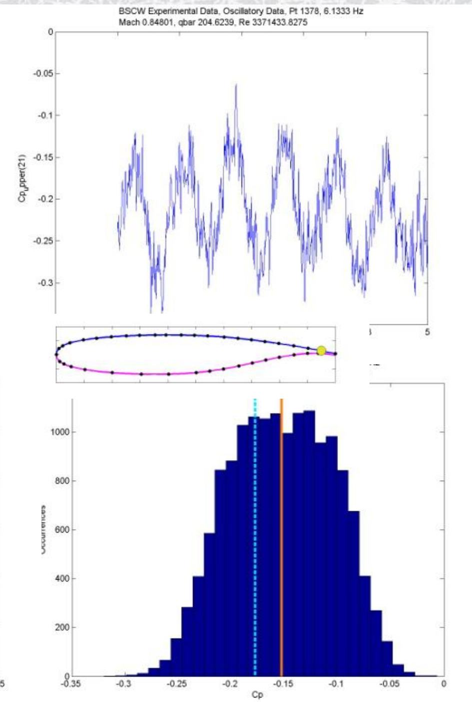

BSCW Experimental Data, Oscillatory Data, Pt 1378, 6.1333 Hz
Mach 0.84801, qbar 204.6239, Re 3371433.8275
Cp_upper(17)
Occurrences
Cp


BSCW Experimental Data, Oscillatory Data, Pt 1378, 6.1333 Hz
Mach 0.84801, qbar 204.6239, Re 3371433.8275
Cp_upper(18)
Occurrences
Cp

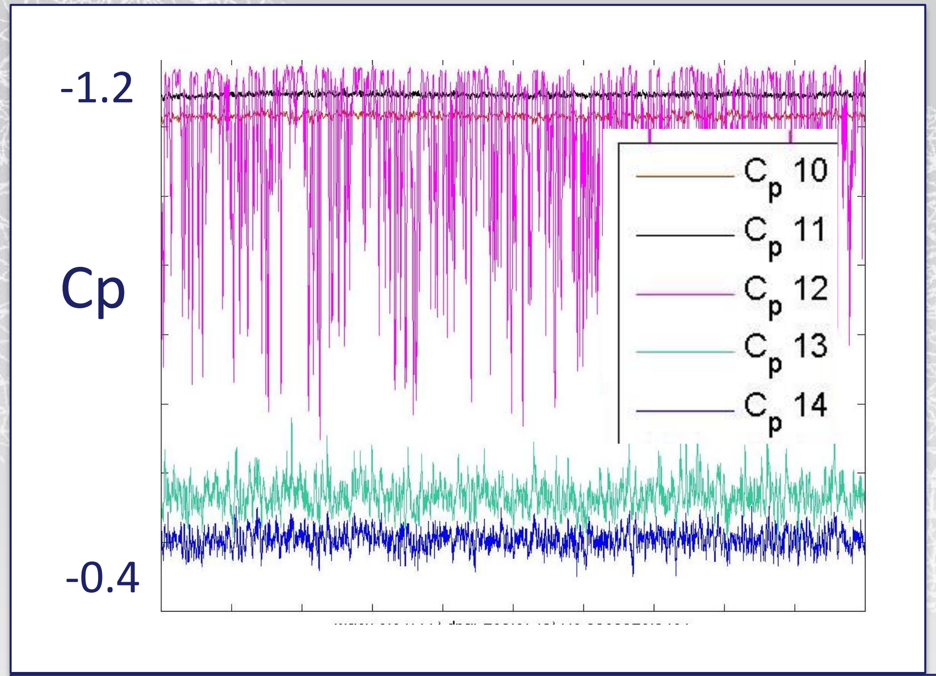

BSCW Experimental Data, Oscillatory Data, Pt 1378, 6.1333 Hz
Mach 0.84801, qbar 204.6239, Re 3371433.8275
Cp_upper(19)
Occurrences
Cp

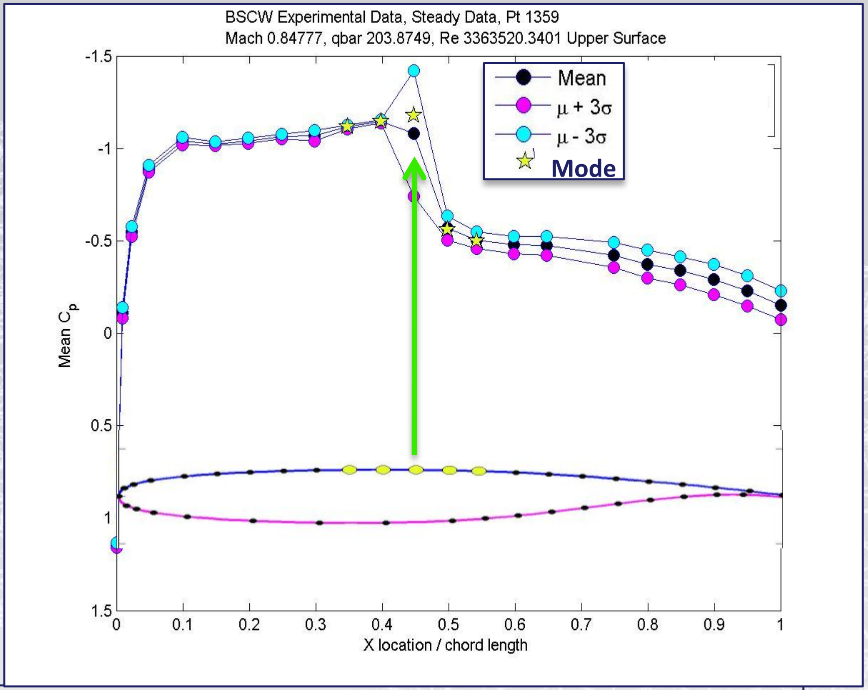

BSCW Experimental Data, Oscillatory Data, Pt 1378, 6.1333 Hz
Mach 0.84801, qbar 204.6239, Re 3371433.8275
Cp_upper(20)
Occurrences
Cp


BSCW Experimental Data, Oscillatory Data, Pt 1378, 6.1333 Hz
Mach 0.84801, qbar 204.6239, Re 3371433.8275
Cp_upper(22)
Occurrences
Cp


BSCW Experimental Data, Oscillatory Data, Pt 1378, 6.1333 Hz
Mach 0.84801, qbar 204.6239, Re 3371433.8275
Cp_upper(21)
Cp

BSCW Static Data:
Steady Shock Location





Location: just barely aft of upper surface transducer #12, x/c (12) = 0.448

(Note: x/c (13) = 0.498)

Upper surface pressure transducer 12: magenta data plot

- Pressure floor at -1.17, i.e. it is bounded by -1.17
- No well-defined, repeated ceiling value
- Not sinusoidal

Expected pressure change across the shock:

- large negative pressure ahead of the shock;
- reduced negative pressure aft of the shock

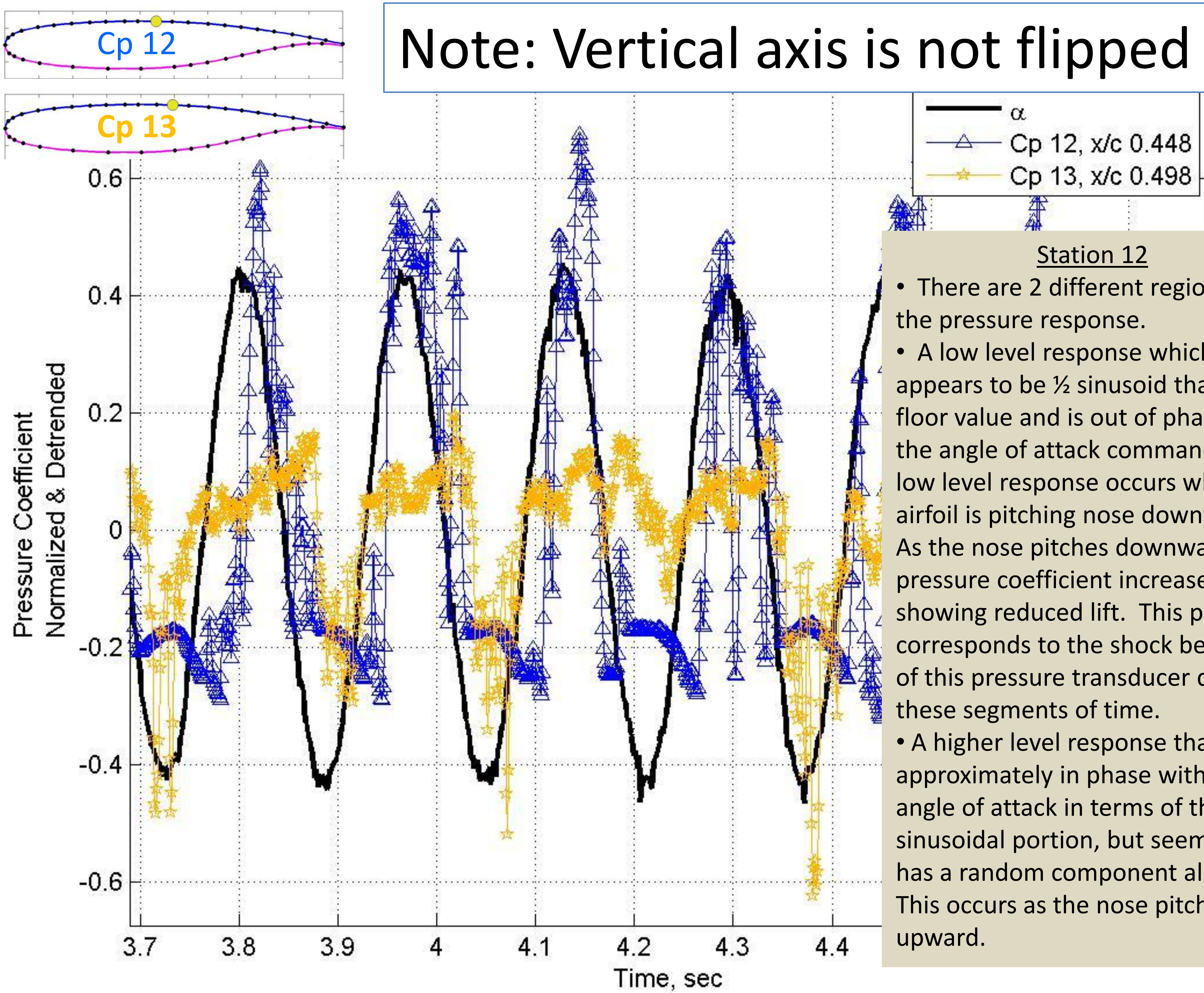
Actual shock location is suspected to be just aft of this transducer location: the value oscillates to a higher pressure (aft of shock) as the shock moves

Sensors towards leading edge (#10 and #11) have values near the minimum of #12

Sensors towards trailing edge (#13 and #14) have values beyond the maximum of #12

Simple interpretation: the sensor's preferred value reflects pressure ahead of shock, rather than aft of it.

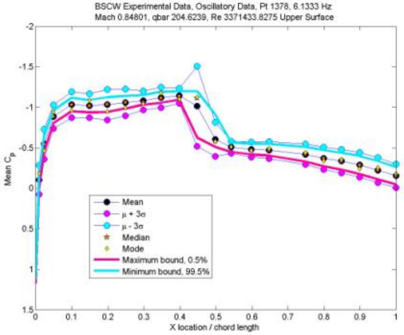
Note: Vertical axis is not flipped

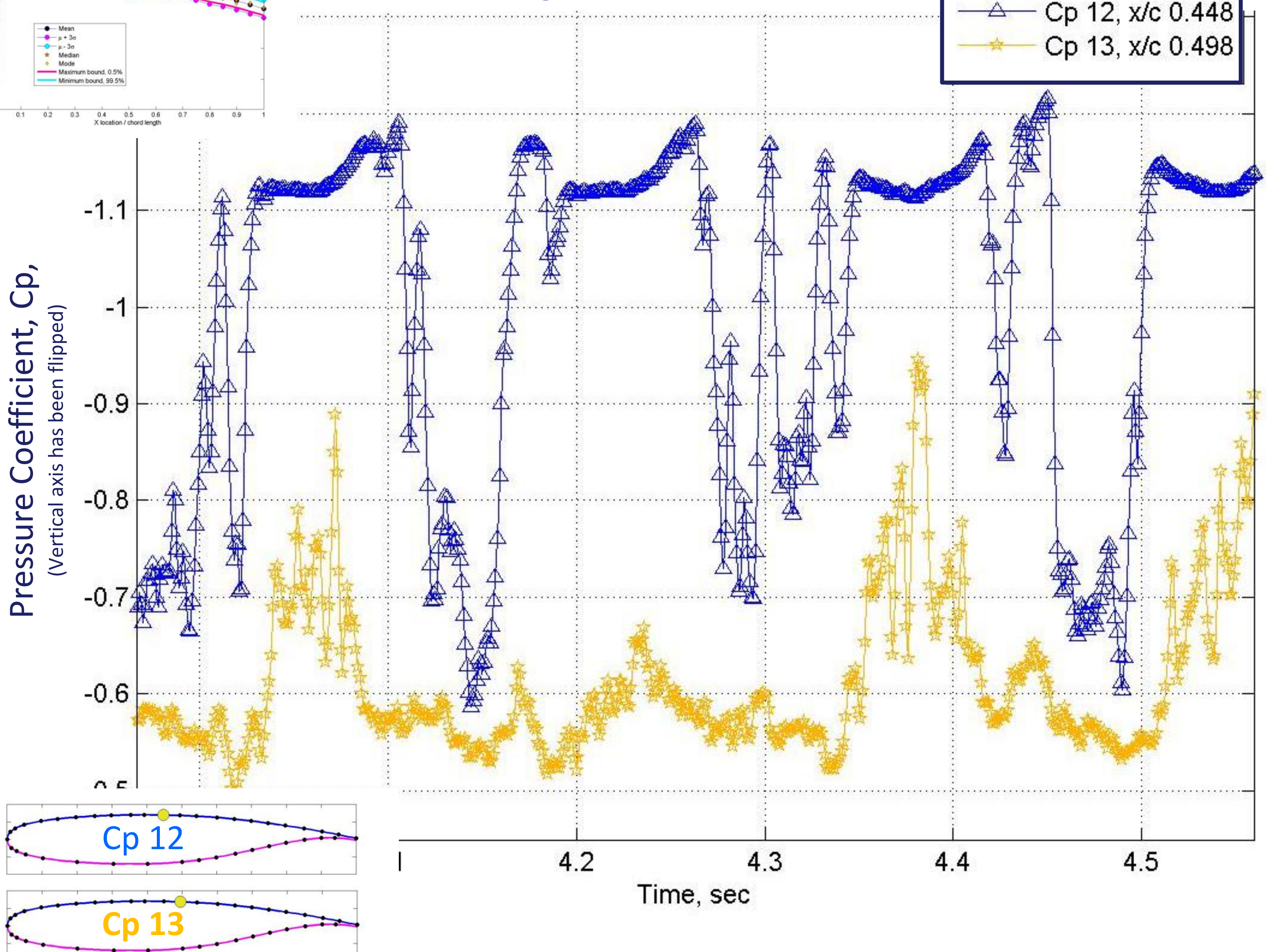


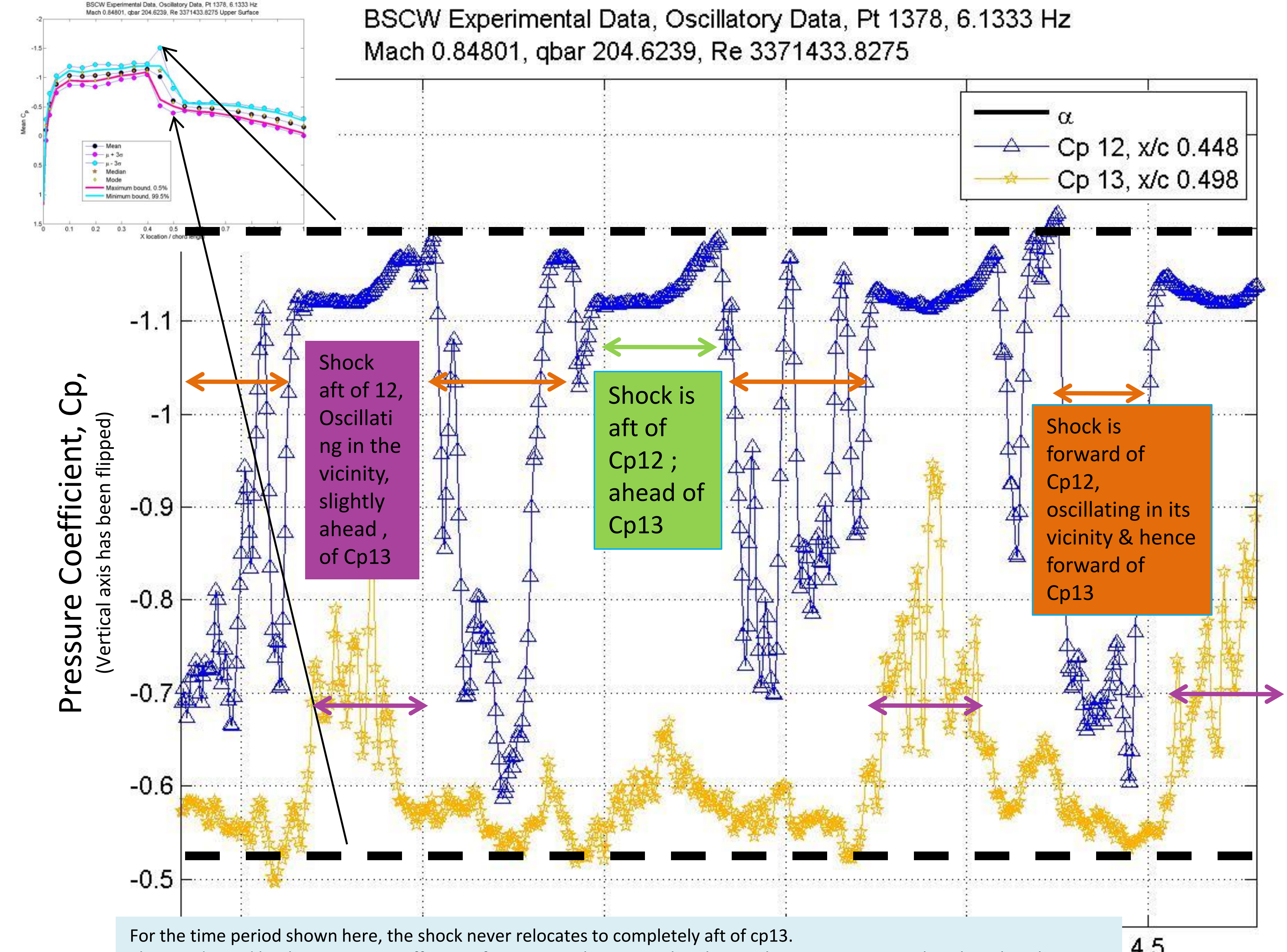
<u>Station 12</u>

- There are 2 different regions of the pressure response.
- A low level response which appears to be ½ sinusoid that hits a floor value and is out of phase with the angle of attack command. The low level response occurs when the airfoil is pitching nose downward. As the nose pitches downward, the pressure coefficient increases, showing reduced lift. This portion corresponds to the shock being aft of this pressure transducer during these segments of time.
- A higher level response that is approximately in phase with the angle of attack in terms of the sinusoidal portion, but seemingly has a random component also. This occurs as the nose pitches upward.

Pressure coefficient time history segment, in the vicinity of the shock motion







For the time period shown here, the shock never relocates to completely aft of cp13.
This is indicated by the pressure coefficient of cp13 never having a value that is a larger negative number than that shown at cp12.

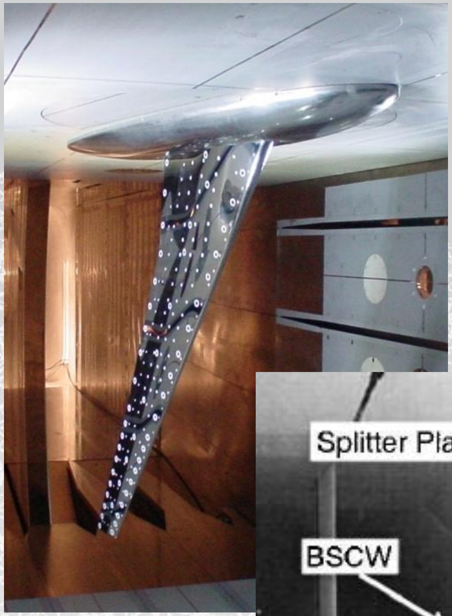
Some more BSCW summary points, focused on experimental data

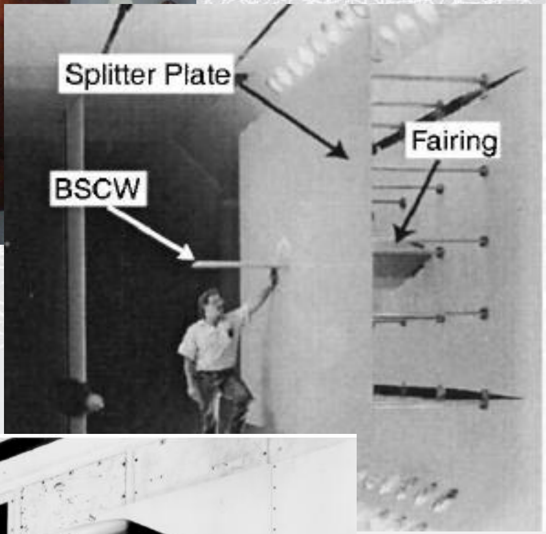
- Airfoil pitches nose upward, shock moves forward; airfoil pitches nose downward, shock moves aft **???**
  - Misinterpretation of the data?
  - We've found another sign convention issue or sign error?
  - Something interesting is going on?
- There are several regions on qualitatively different pressure behavior on the airfoil upper surface
  - Leading edge, ahead of transition (noisy sinusoidal data)
  - Between transition strip and shock (sinusoidal data)
  - Shock-traversing region (floor-limited, ceiling-limited fluctuations)
  - Aft of shock region (random + sinusoidal)

- The experimental data is not well-represented by mean values for the static data, particularly in the region of the shock oscillation
- The frequency response functions obtained at a single frequency do not necessarily represent the significant physics, particularly the oscillatory shock and the separated flow
- The experimental data needs to be more closely spaced; particularly in the region of the shock.
- The experimental frequency response functions do not have constant or monotonically increasing magnitude wrt oscillation frequency. The system has dynamics within the range of the frequencies investigated. (splitter plate vertical mode clearly contributes to this variation.)
- Methods being used to characterize the flow field:
  - Mean, max, min of non-forced-oscillation data ("steady" data)
  - Histograms and statistical quantities can possibly be useful in characterizing the different flow regions
  - Frequency response functions
  - Coherence (see separate document for details of coherence vs frequency as the chord location is varied- definite changes in behavior ahead of transition strip, ahead of the shock, in the shock motion region, aft of the shock)

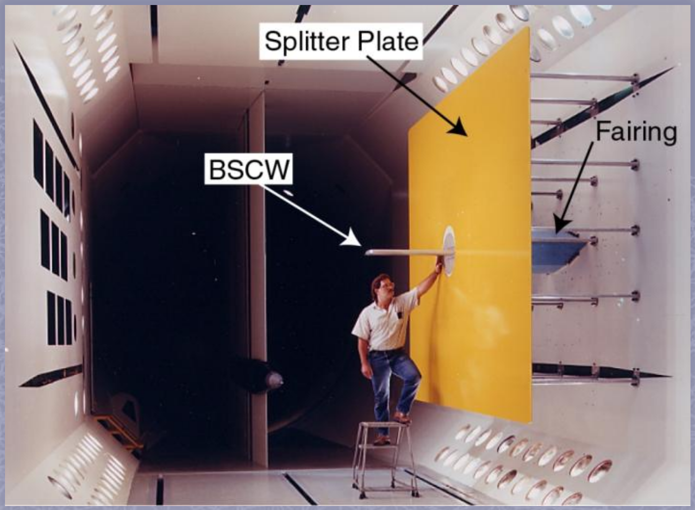
Configurations

- High Reynolds number Aero-Structural Dynamics Model (HIRENASD)
- **Benchmark Supercritical Wing (BSCW)**
- Rectangular Supercritical Wing (RSW)





Benchmark Supercritical Wing (BSCW)



Likely plan of action:

- Form technical working group of BSCW analysts
- Extensive study of available experimental data; characterize different flow phenomena
- Benchmark against more benign cases- lower Mach number, lower angle of attack
- Analyze the static (unforced) problem using time-accurate evaluation methods
- Study of time convergence criteria

Rectangular Supercritical Wing (RSW)

M=0.825, Re_c=4.0 million, test medium: R-12,
α = 2° & 4°, freq= 10 & 20 Hz

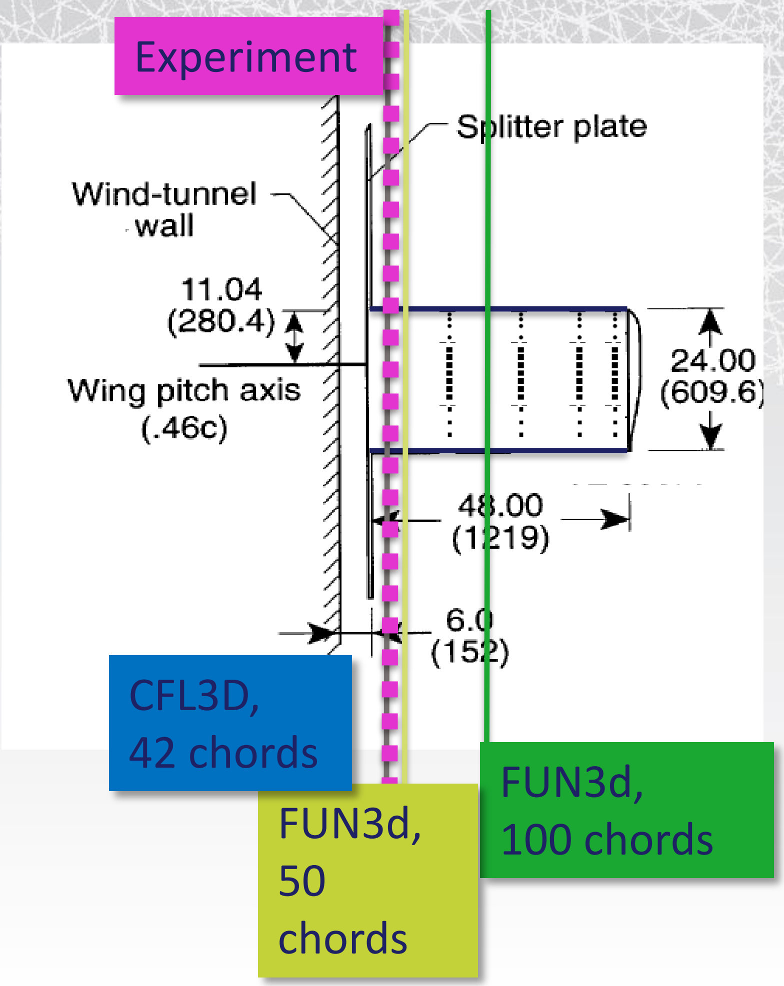
- Chosen as the "slam dunk" test case
  - Pre-workshop assessment: Attached, fully turbulent flow; Moderate strength shock

RSW

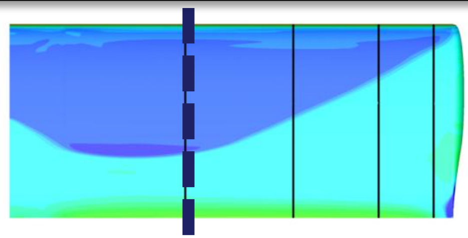
- The slam dunk test case, RSW, turned out to involve many issues, particularly associated with the model and splitter plate being engulfed in the boundary layer. The lift coefficient provides a good summary of the magnitude of the problem. The variation among the analytical results is pretty significant, in addition to the disagreement with the experimental results.

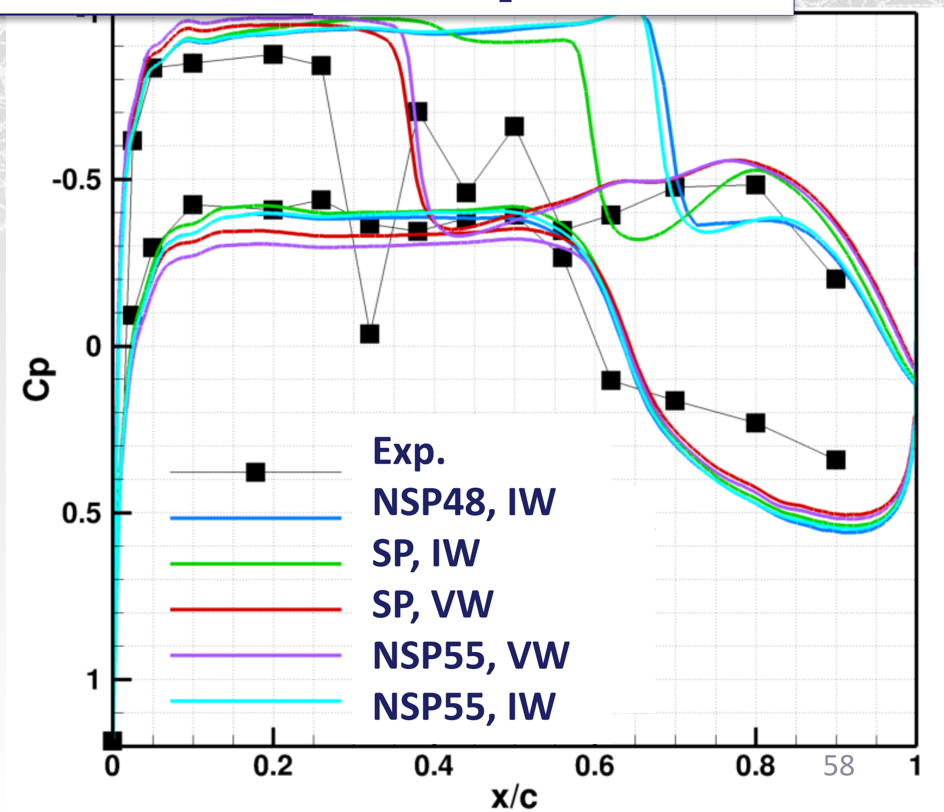
RSW Wall & Splitter Plate Investigation

- The boundary layer of the tunnel wall envelops the splitter plate and the inboard portion of the wing.
- The most important characteristic to capture appears to be proper positioning of the wing relative to the boundary layer profile
- Expedient solution was to adjust the inflow boundary location relative to the wing
- The splitter plate presence does not have a significant effect



Examining pressure station closest to the wall, η = 0.3





	Summary of Rectangular Supercritical Wing Entries					
Analyst	A	B	C	D	E	F
TURBULENCE MODEL	SA	SA	SA	SST	SA	SAE
GRID TYPE	Str	Unstr	Str	Str	Unstr	Blstr

Str = Structured

Blstr = Block structured

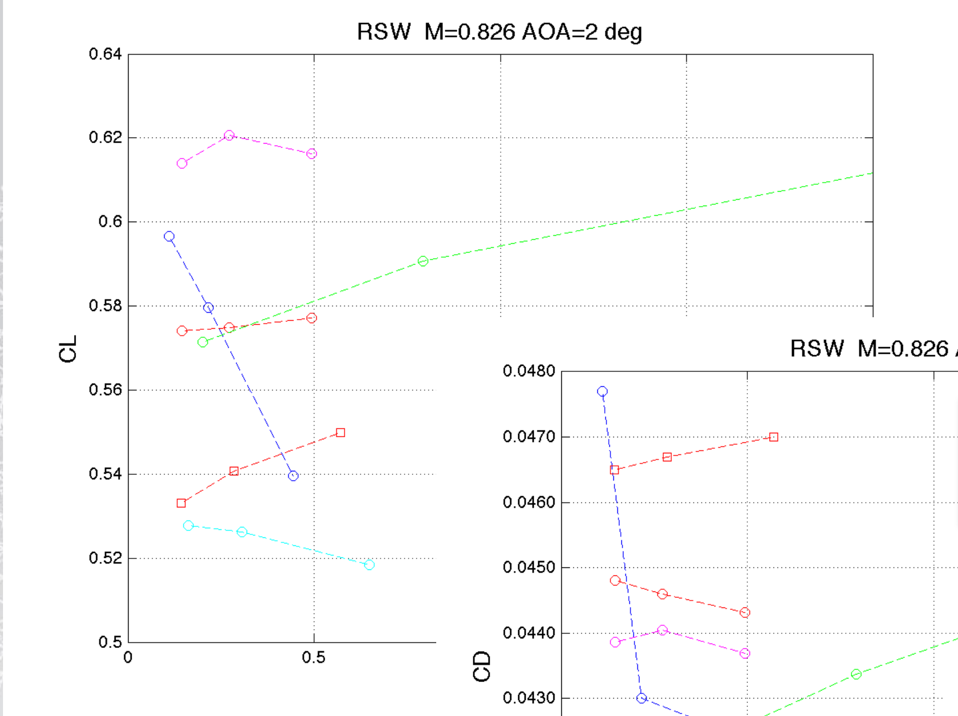
Unstr = Unstructured

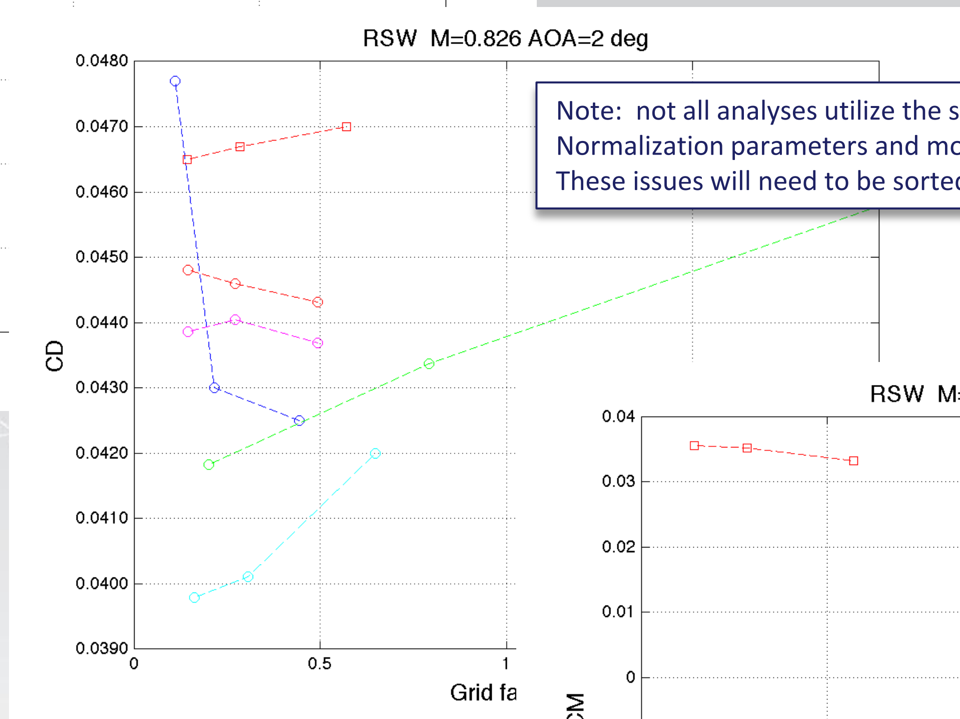
Codes used:

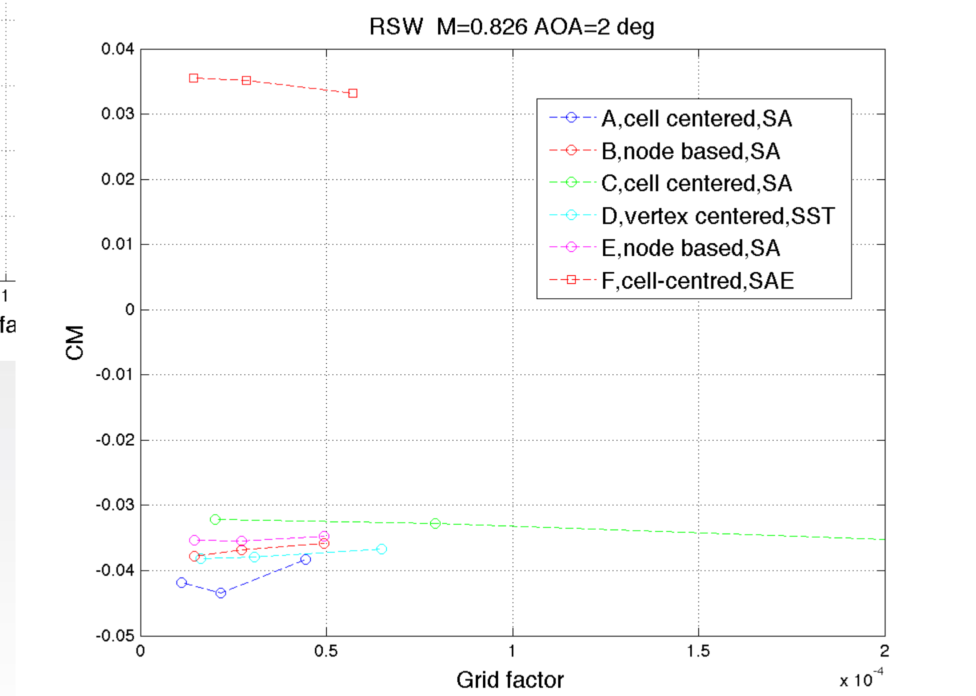
ANSYS CFX
NSMB
FUN3D
CFL3D
NSU3D
PMBv1.5

RSW Steady Results
α = 2 degs

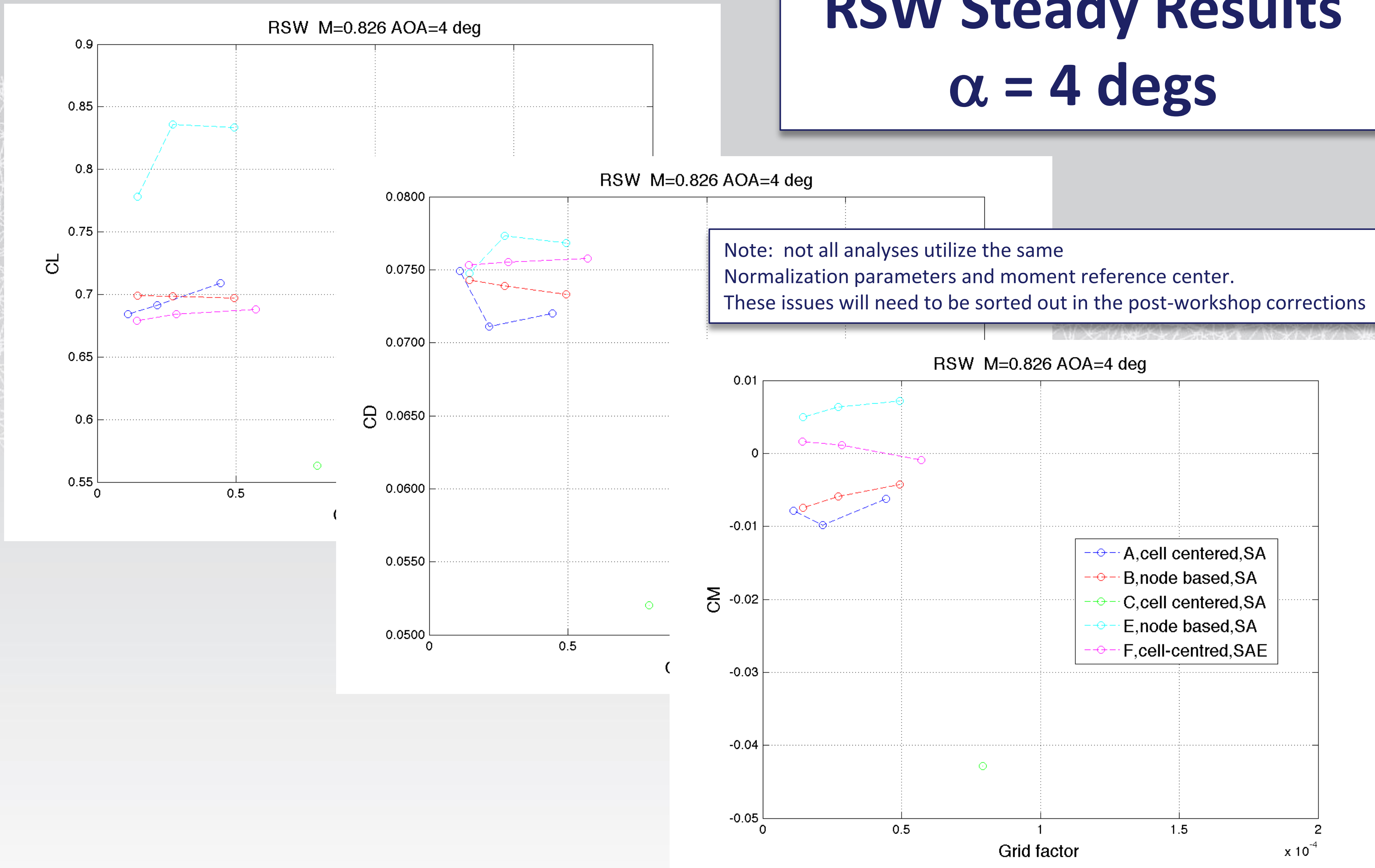
Note: not all analyses utilize the same
Normalization parameters and moment reference center.
These issues will need to be sorted out in the post-workshop corrections







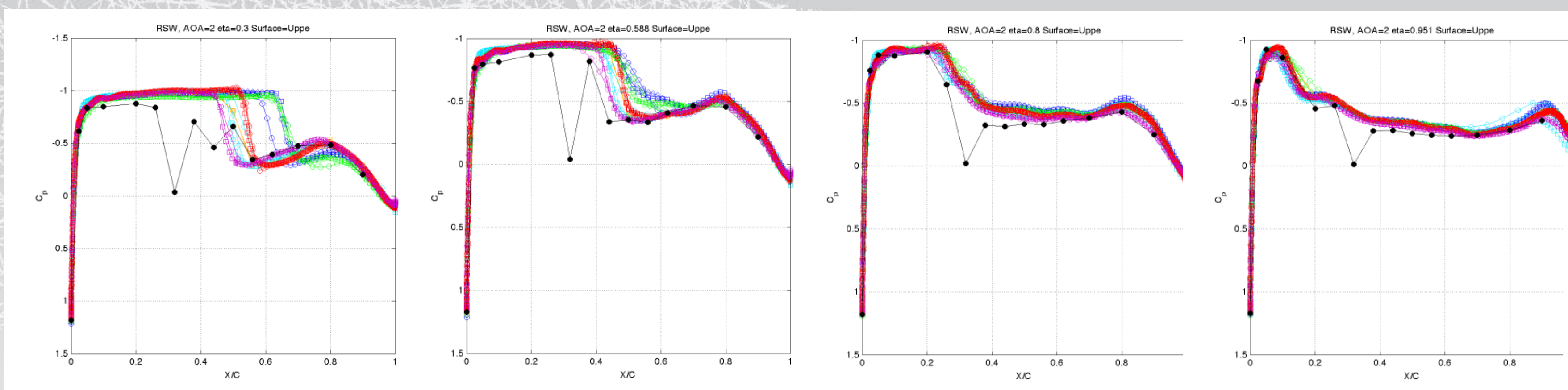
RSW Steady Results
α = 4 degs

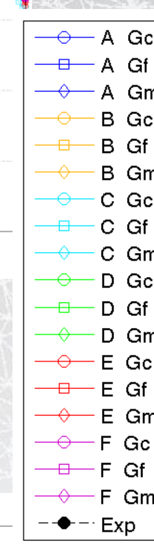


Note: not all analyses utilize the same
Normalization parameters and moment reference center.
These issues will need to be sorted out in the post-workshop corrections

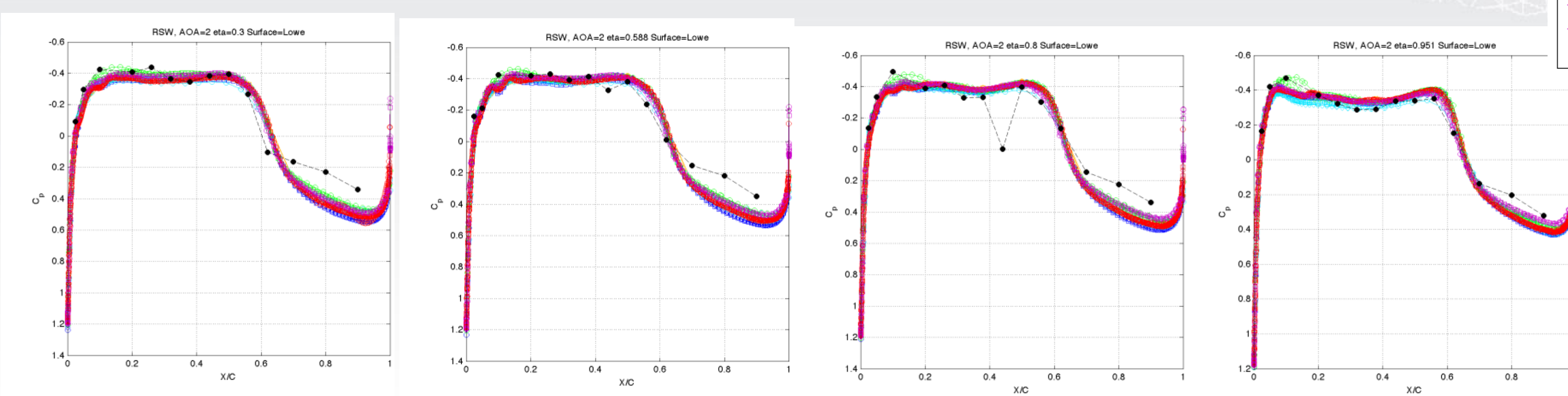
RSW, Mach 0.825, α = 2, Steady Cp distribution

Upper surface



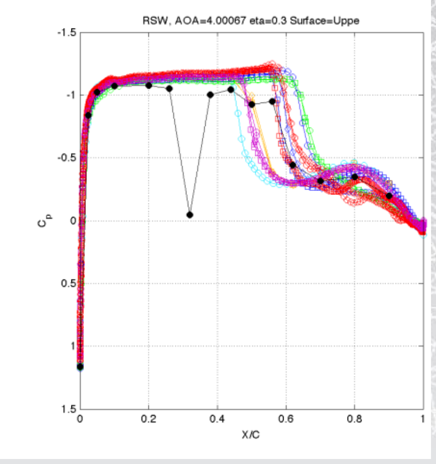


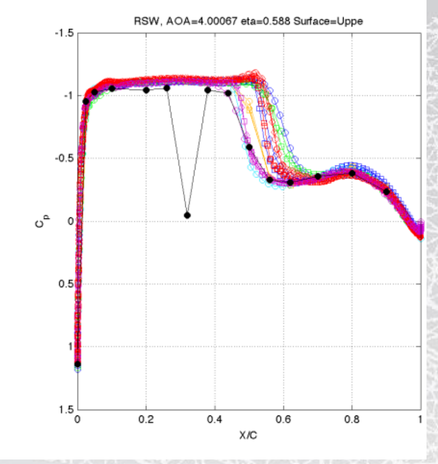
Lower surface

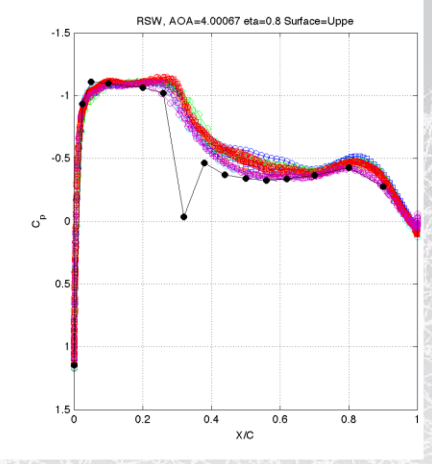


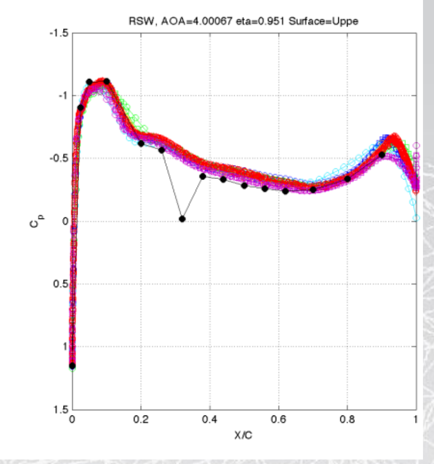
RSW, Mach 0.825, α = 4, Steady Cp distribution

Upper surface

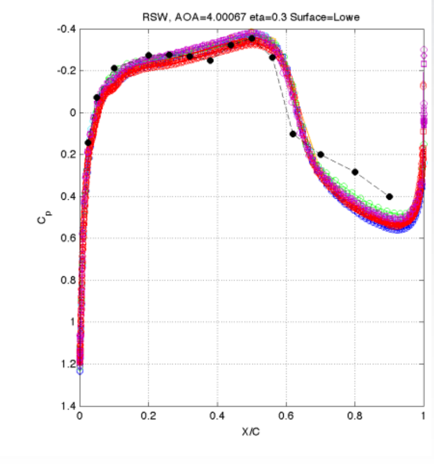


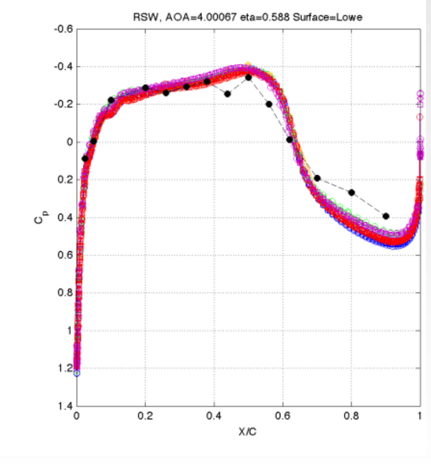


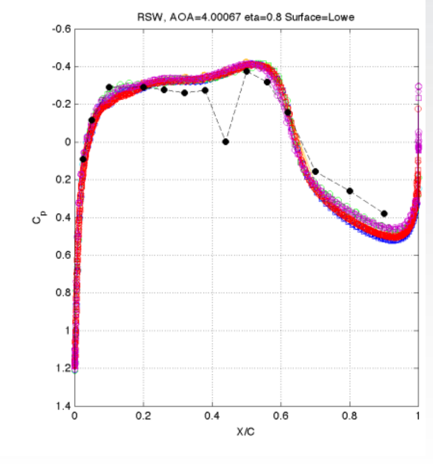


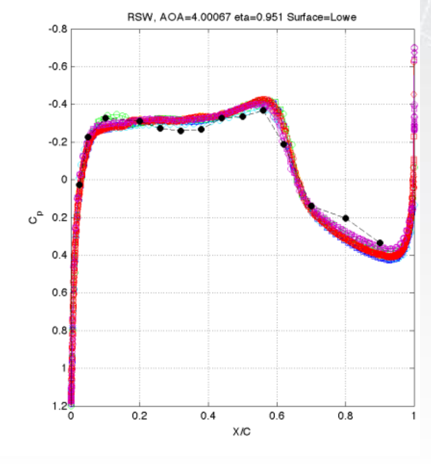


Lower surface







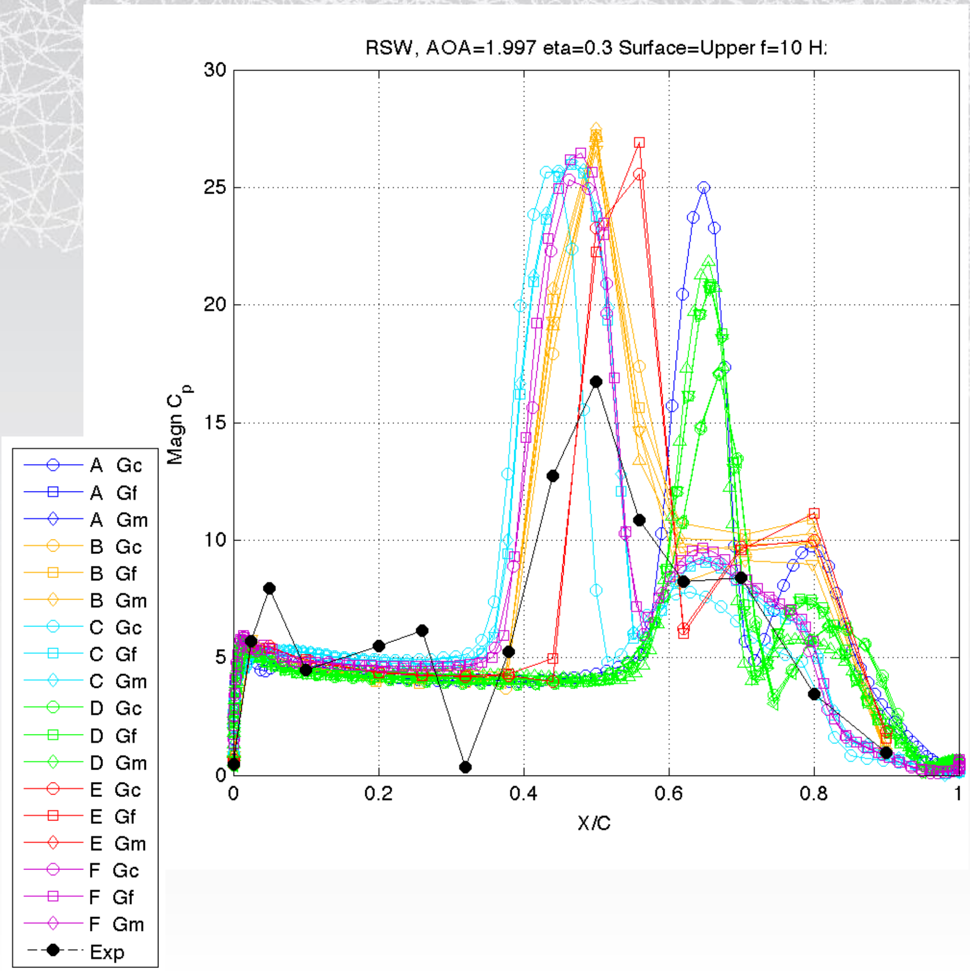


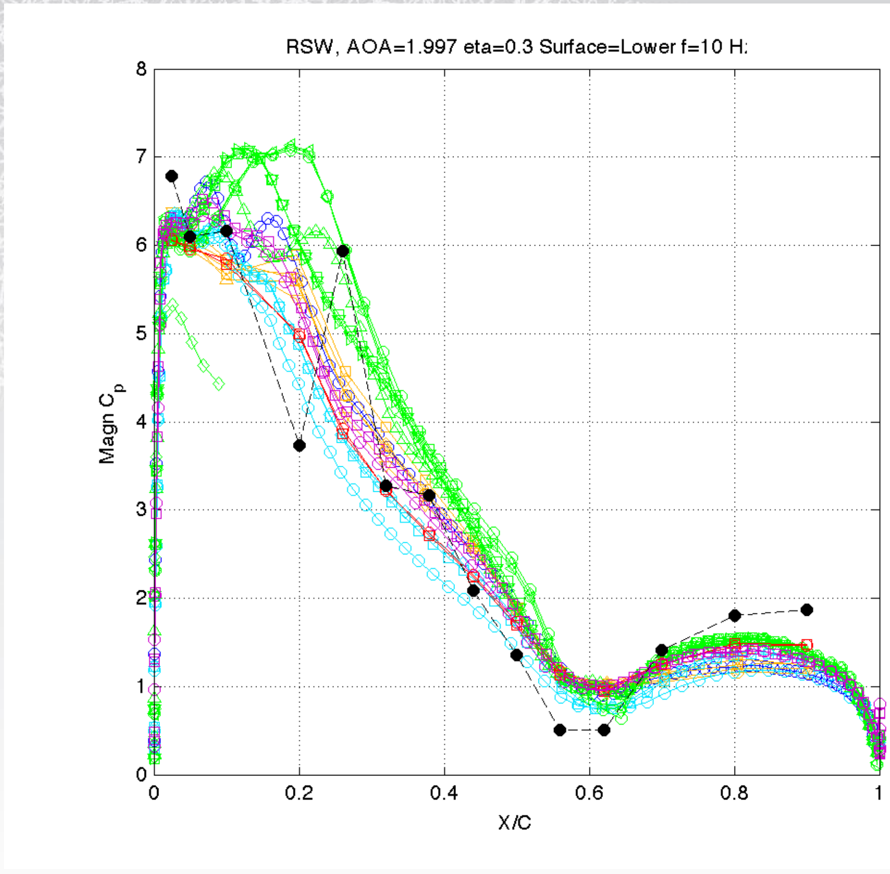
RSW, FRF Magnitude, 10 Hz Excitation

Inboard span station, η = 0.309

Upper

Lower

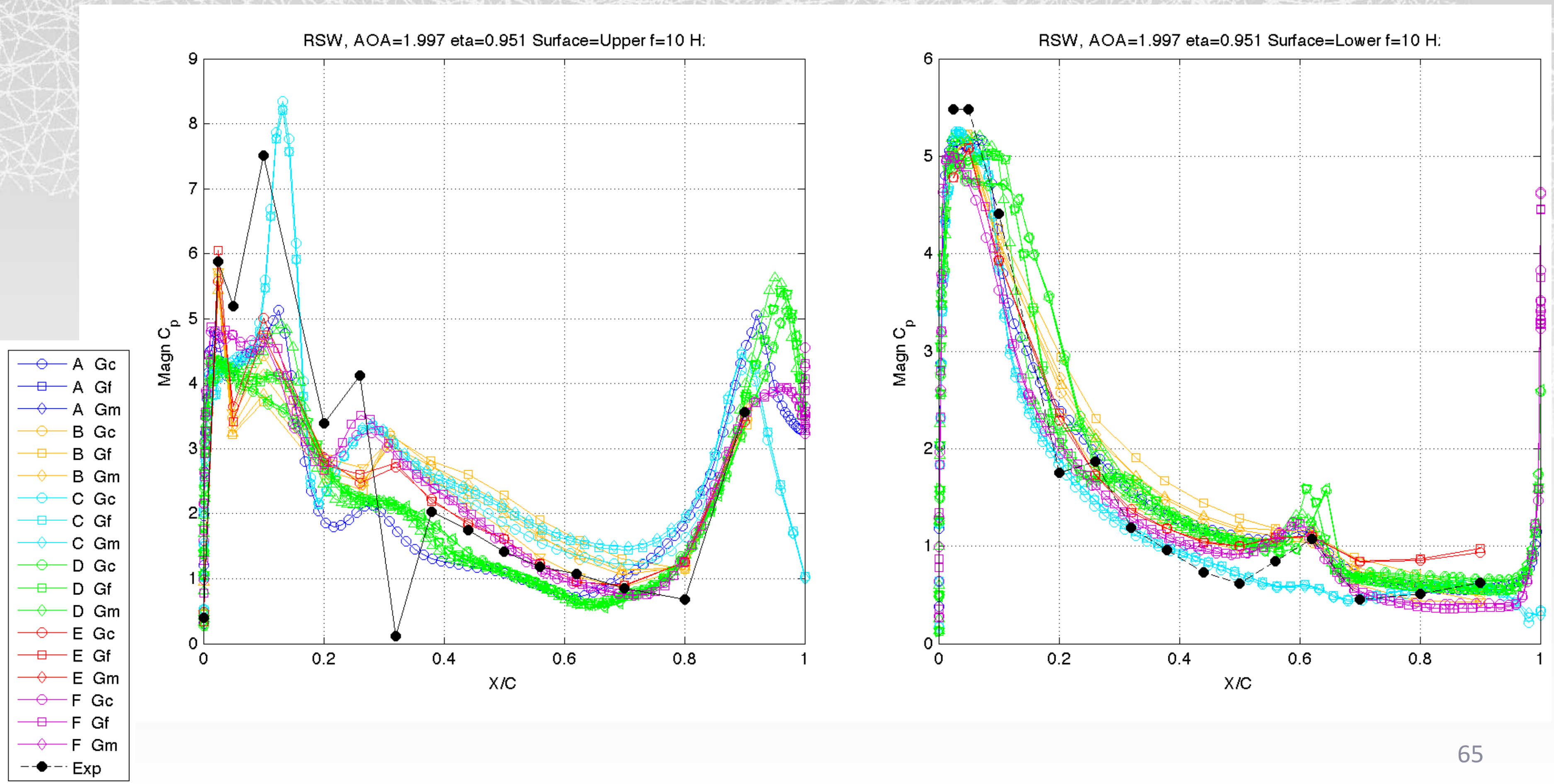




RSW, FRF Magnitude, 10 Hz Excitation

Outboard span station, η = 0.951

Upper **Lower**

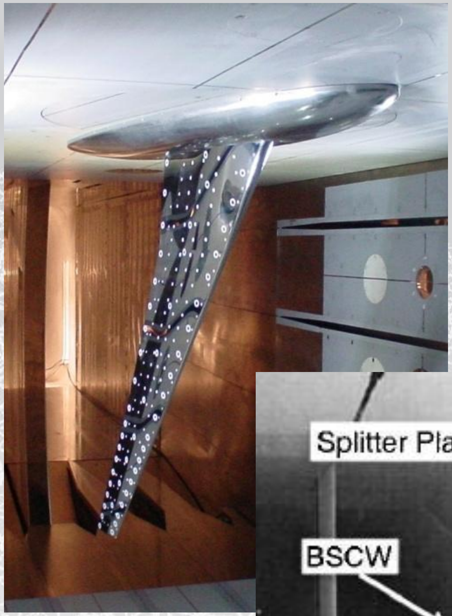


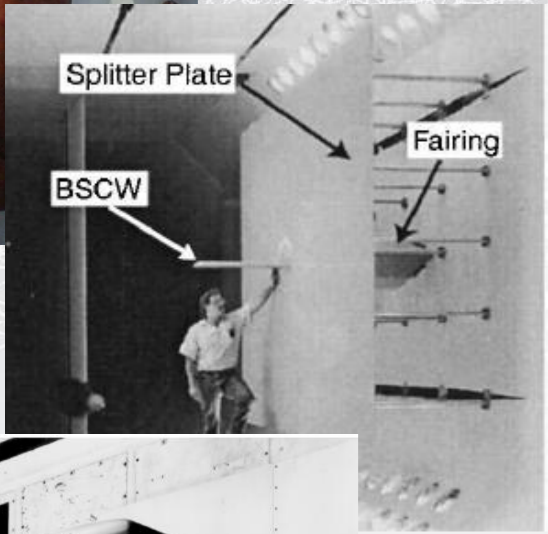
RSW Summary points

- CFD solutions vary widely, even for static solution; Not an accurate representation of the CFD state of the art
- Tunnel wall modeling assumptions have a significant impact on the static pressure distribution, unsteady behavior and integrated loads
- Different modeling and oscillation methods: what are the impacts of the different methods? Is this significant? Methods used:
  - Oscillating the entire computational
  - Oscillating one region of the grid relative to the rest of the domain
    - Boundary of fixed/oscillated on the splitter plate
    - Boundary of fixed/oscillated on the wing, near the root
- Definitions of converged solution seem to be subjective. (on the subiteration level, what defines converged?)

Configurations

- High Reynolds number Aero-Structural Dynamics Model (HIRENASD)
- Benchmark Supercritical Wing (BSCW)
- **Rectangular Supercritical Wing (RSW)**





Rectangular Supercritical Wing (RSW)

Likely plan of action:

- Form technical working group of RSW analysts
- Use configuration to focus on an analysis-only study
- Determine sources of variations from among modeling and analysis parameters and methods
- Determine relative significance of parameters

Some questions to consider

- What differentiates the analyses from each other?
- … from the experimental data?
- What is well-captured?
- What is not?
- How can we look at this data/other data to address what is not well-captured?
- What are the implications wrt aeroelastic analysis?
- What is common among the testcases?
- How can we process/treat the data differently to better capture the characteristics? … capture additional characteristics?

Thank you
&
Please come see details of the workshop results on the website

It's not too late to contribute as an analyst!
Working groups now forming!

- https://c3.nasa.gov/dashlink/projects/47

- Individual links for workshop presentation files:
  - Overviews, summary and comparison material:
    - https://c3.nasa.gov/dashlink/resources/568/
  - RSW analysts' presentations:
    - https://c3.nasa.gov/dashlink/resources/569/
  - BSCW analysts' presentations:
    - https://c3.nasa.gov/dashlink/resources/570/
  - HIRENASD analysts' presentations:
    - https://c3.nasa.gov/dashlink/resources/571/

Acknowledgements & Additional Materials

Gridding Acknowledgements

	Organization	Configuration	Software	Description
Marilyn Smith	Georgia Tech	RSW	SolidMesh	Unstructured
Thorsten Hansen	Ansys Germany	RSW, BSCW	ICEM CFD	Structured hexahedral
Pawel Chwalowski	NASA	RSW, BSCW, HIRENASD	VGRID	Unstructured mixed and tetrahedral
Eric Blades	ATA Engineering	BSCW	SolidMesh	Unstructured, node-based, mixed
Markus Ritter	DLR	HIRENASD	Centaur	Unstructured mixed
Daniella Raveh	Technion	HIRENASD		Overset structured

Thanks to Technical Working Group Leaders

Role:	RSW	BSCW	HIRENASD
Discussion Leader	Dave Schuster	Pawel Chwalowski	Markus Ritter & Dimitri Mavriplis
Technical Issue Recorder	Reik Thormann	Thorsten Hansen	

HIRENASD Project Partners

Aachen University:

Department of Mechanics

Institute for Lightweight Structures

Institute for Geometry and Applied Mathematics

Shock Wave Laboratory

Thanks to ...

- German Research Foundation (***DFG***) for funding ***HIRENASD***
- ***Airbus Industry*** for supporting the balance for dynamic force measurement
- ***DLR*** for advice concerning data acquisition and providing AMIS II
- ***ETW*** for providing windtunnel adaptations, for e.g. dynamic force measurement, and continuous advice during preparation of model and measuring equipment

AePW Analysis Parameters

Parameters		Units		Configuration				
		English	SI	RSW (English units)	BSCW (English units)	HIRENASD (SI units)	HIRENASD (SI units)	HIRENASD (SI units)
Mach number	M			0.826	0.848167	0.8005	0.8	0.7
Reynolds number (based on ref chord)	Re_c			4.01e+06	4.491e+06	6999999	23486600	6997830
Reynolds number per unit	Re/ unit	Re/ft	Re/m	2.0e+06	3.368e+06	2.032e+07	6.8176e+07	2.031e+07
Dynamic pressure	q	psf	Pa	108.65	204.1967	40055.4	88696.9	36177.3
Velocity	V	ft/s	m/s	413.73	468.9833	256.5	219.5	227.0
Speed of sound	a	ft/s	m/s	501.18	552.9333	320.3	274.8	324.3
Static temperature	Tstat	deg F	deg K	37.12	87.913	246.9	181.8	253.1
Density	r	slug/ft^3	kg/m^3	0.001270	0.001857	1.22	3.70	1.41
Ratio of specific heats	g			1.132	1.116233			
Dynamic viscosity	m	slug/ft-s		2.620e-07	2.59E-07			
Prandtl number	Pr			0.78	0.6738	0.72	0.72	0.72
Test medium				R-12	R-134a	Nitrogen	Nitrogen	Nitrogen
Total pressure	H	psf	Pa	410.48	757.31	136180	301915	146355
Static pressure	P	psf	Pa	280.76	512.12	89289	198115	105529
Purity	X	%			95			
Total temperature	T	deg F	deg K	60.00	109.5933	278.5	205.0	277.9

Reference quantities

		RSW	BSCW	HIRENASD
Reference chord	c_{ref}	24 inches	16 inches	0.3445 m
Model span	b	48 inches	32 inches	1.28571 m
Area	A	1152 in^2	512 in^2	0.3926 m^2
Moment reference point, relative to axis system defns	x	11.04 inches	4.8 inches	0.252 m
	y	0	0	-0.610 m
	z	0	0	0
Transfer function reference quantity		Pitch angle	Pitch angle	Vertical displacement (at x=0.87303m, y=1.24521m)