2nd AIAA Aeroelastic Prediction Workshop

Analysis Cases Defined, Data Comparison Overview

Jennifer Heeg & Carol Wieseman
NASA Langley Research Center

January 3, 2016

Many thanks to

Carol Wieseman, NASA, for processing:

- All of the spreadsheet data
- The ANSYS analysis team data files
- Most of the database plots that you are looking at

- Analysis Cases; Factors in choosing the cases
  - Benchmark Case
  - Availability of Experimental Data
  - Flow Physics
- Overview of Comparison Results Database
  - All data received by the data submittal deadline have been processed, along with format-preserving updates from those teams)
  - Data from 8 teams have been processed into the comparison data bases (FIFO processing)
  - There are 14 separate comparison data bases
  - All data submitted in the template spreadsheets has been incorporated into the databases

AePW-2 Analysis Cases

	Case 1	Case 2	Optional Case 3		
			A	B	C
Mach	0.7	0.74	0.85	.85	.85
Angle of attack	3	0	5	5	5
Dynamic Data Type	Forced oscillation	Flutter	Unforced Unsteady	Forced Oscillation	Flutter
Notes:	• Attached flow solution. • Oscillating Turn Table (OTT) exp data.	• Unknown flow state. • Pitch and Plunge Apparatus (PAPA) exp data.	• Separated flow effects. • Oscillating Turn Table (OTT) experimental data.	• Separated flow effects. • Oscillating Turn Table (OTT) experimental data.	• Separated flow effects on aeroelastic solution. • No experimental data for comparison.

14 Databases contain comparison data sets

Excitation	Steady or "Overdamped"	Time-accurate
None, Unforced	**1a** **2aR** **3aR**	3aU
Forced Pitch Oscillation		**1b** 3b
Aeroelastic, at common condition (qE = Experimental dynamic pressure)	2aSae_qE 3aSae_qE	**2c_qE** 3c_qE
Aeroelastic, at common condition (qF = Predicted flutter dynamic pressure; will be different for each analysis)	2aSae_qF 3aSae_qF	2c_qF 3c_qF

Team Name
FOI
EMBRAER
NASAEast
TECHNION
UMich
ZHAW
ANSYS
ATA
NRC
NLR
ITA
CDADAPCO
MILANO
RAFAEL
STRASBOURG

Data included in databases, 12/28/2015

Also includes Experimental Comparison Data

Analysis Parameters

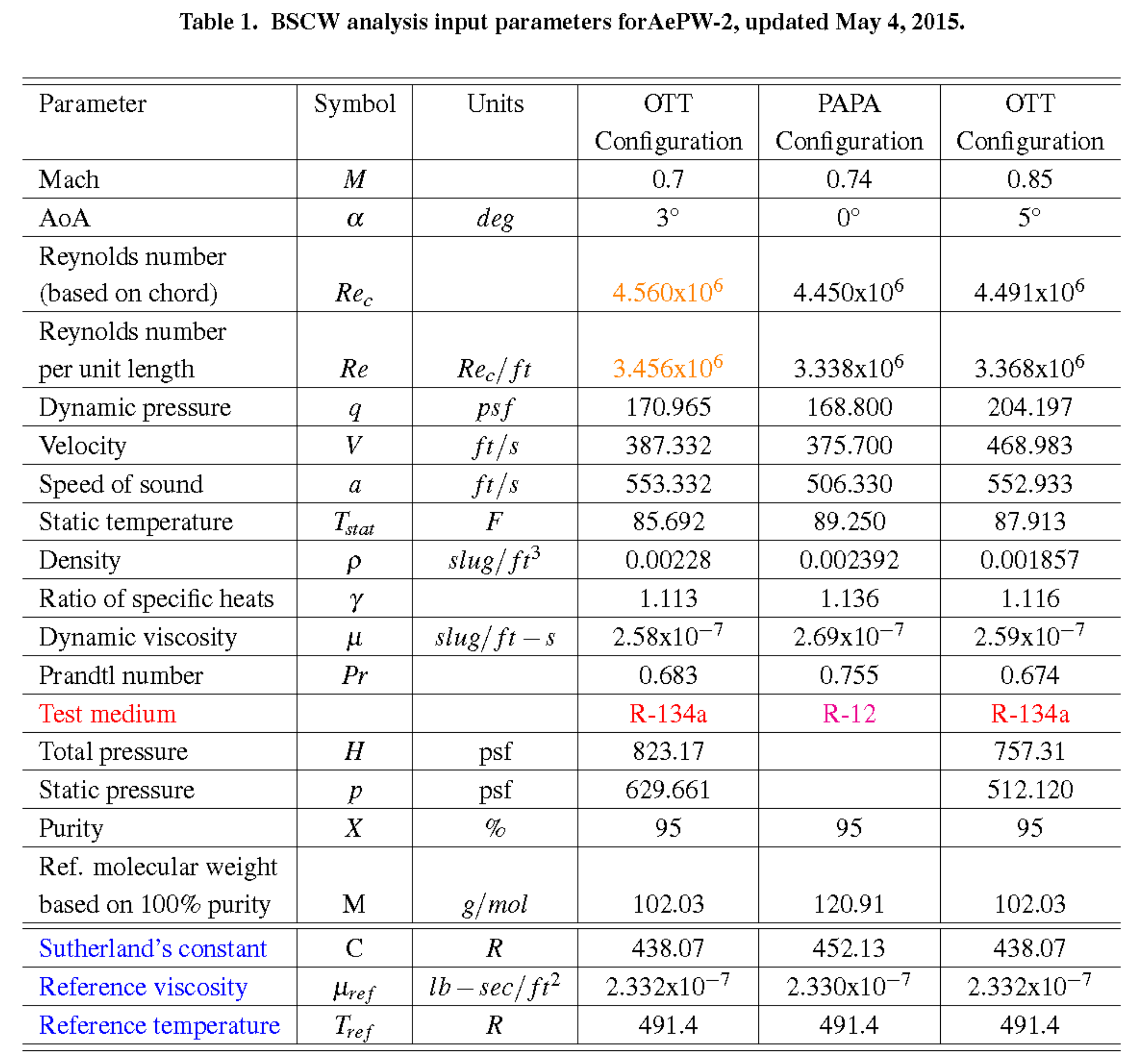
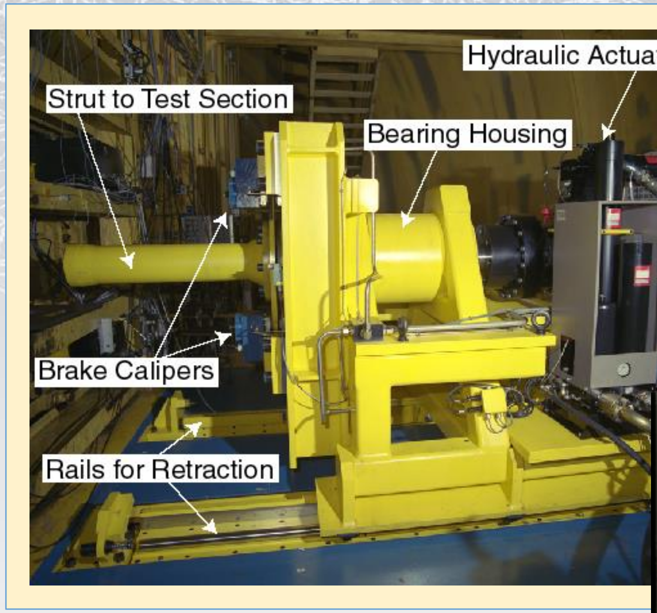


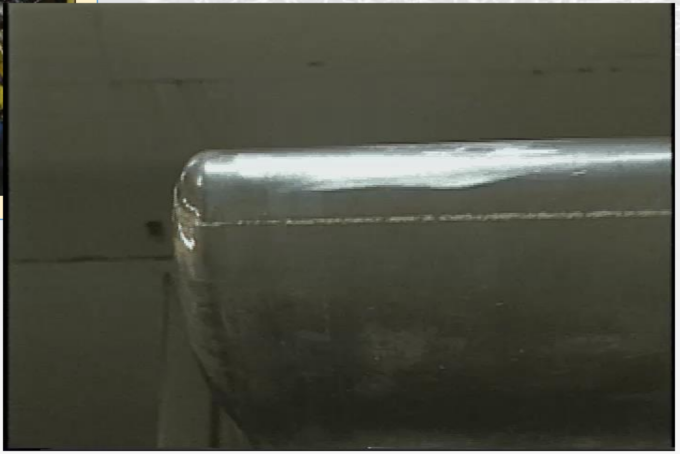
Table 1. BSCW analysis input parameters forAePW-2, updated May 4, 2015.

Parameter	Symbol	Units	OTT Configuration	PAPA Configuration	OTT Configuration
Mach	M		0.7	0.74	0.85
AoA	α	deg	3°	0°	5°
Reynolds number (based on chord)	Re_c		4.560x10^6	4.450x10^6	4.491x10^6
Reynolds number per unit length	Re	Re_c/ft	3.456x10^6	3.338x10^6	3.368x10^6
Dynamic pressure	q	psf	170.965	168.800	204.197
Velocity	V	ft/s	387.332	375.700	468.983
Speed of sound	a	ft/s	553.332	506.330	552.933
Static temperature	T_{stat}	F	85.692	89.250	87.913
Density	ρ	$slug/ft^3$	0.00228	0.002392	0.001857
Ratio of specific heats	γ		1.113	1.136	1.116
Dynamic viscosity	μ	$slug/ft-s$	2.58x10^{-7}	2.69x10^{-7}	2.59x10^{-7}
Prandtl number	Pr		0.683	0.755	0.674
Test medium			R-134a	R-12	R-134a
Total pressure	H	psf	823.17		757.31
Static pressure	p	psf	629.661		512.120
Purity	X	%	95	95	95
Ref. molecular weight based on 100% purity	M	g/mol	102.03	120.91	102.03
Sutherland's constant	C	R	438.07	452.13	438.07
Reference viscosity	μ_{ref}	$lb-sec/ft^2$	2.332x10^{-7}	2.330x10^{-7}	2.332x10^{-7}
Reference temperature	T_{ref}	R	491.4	491.4	491.4

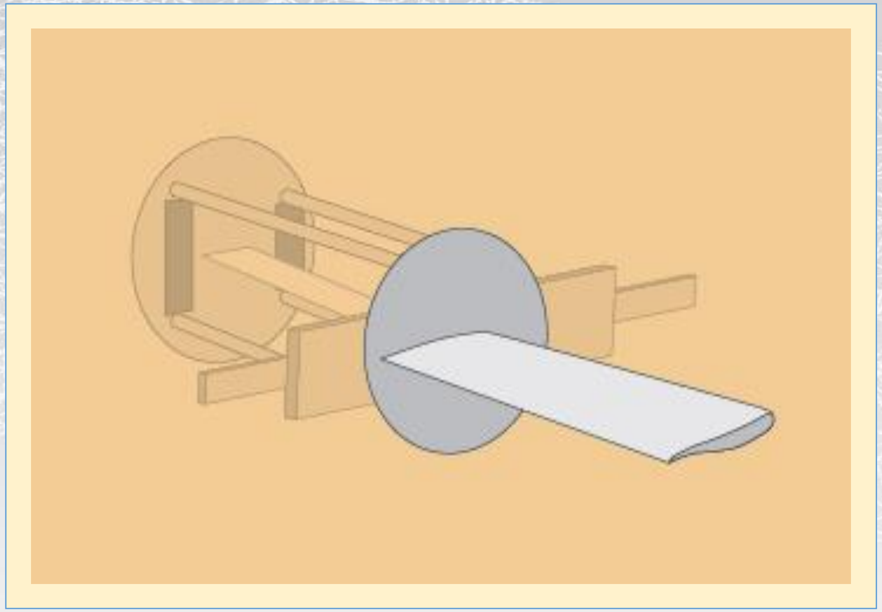
Two Experiments provide comparison data for AePW-2

TDT Test 548 (2000)
BSCW Testing on the Oscillating TurnTable (OTT)
for Forced Oscillation Cases





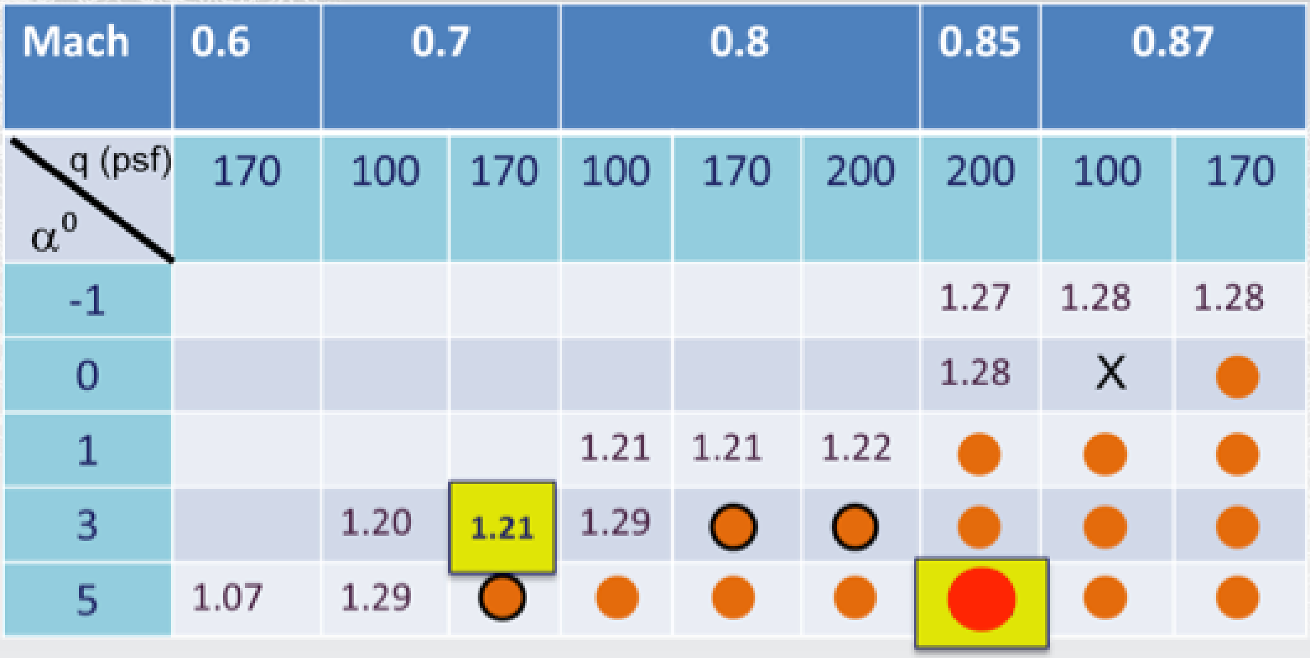
TDT Test 470 (1992)
BSCW Testing on the Pitch And Plunge
Apparatus (PAPA)
for Flutter Cases



	Case 1	Case 2		Optional Case 3	
			A	B	C
Mach	0.7	0.74	0.85	.85	.85
Angle of attack	3	0	5	5	5
Dynamic Data Type	Forced oscillation	Flutter	Unforced Unsteady	orced Oscillation	Flutter
Notes:	• Attached flow solution. • Oscillating Turn Table (OTT) exp data.	Unknown flow state. Pitch and Plunge Apparatus (PAPA) exp data.	• Separated flow effects. • Oscillating Turn Table (OTT) experimental data.	Separated flow effects. Oscillating Turn Table (OTT) experimental data.	• Separated flow effects on aeroelastic solution. • No experimental data for comparison.

	Case 1	Case 2	Optional Case 3		
			A	B	C
Mach	0.7	0.74	0.85	.85	.85
Angle of attack	3	0	5	5	5
Dynamic Data Type	Forced oscillation	Flutter	Unforced Unsteady	Forced Oscillation	Flutter
Notes:	• Attached flow solution. • Oscillating Turn Table (OTT) exp data.	• Unknown flow state. • Pitch and Plunge Apparatus (PAPA) exp data.	• Separated flow effects. • Oscillating Turn Table (OTT) experimental data.	• Separated flow effects. • Oscillating Turn Table (OTT) experimental data.	• Separated flow effects on aeroelastic solution. No experimental data for comparison.

Shock-induced separation assessment lead to AePW-2 case selection



Mach	0.6	0.7		0.8			0.85	0.87	
q (psf) / α⁰	170	100	170	100	170	200	200	100	170
-1							1.27	1.28	1.28
0							1.28	X	●
1				1.21	1.21	1.22	●	●	●
3		1.20	1.21	1.29	◉	◉	●	●	●
5	1.07	1.29	◉	●	●	●	●	●	●

● Shock-induced separation

◉ Shock-induced separation onset

X Data unavailable

Number value Sub-critical, maximum local Mach

🟥 AePW-1 case

🟨 AePW-2 case

Overview of Comparison Data

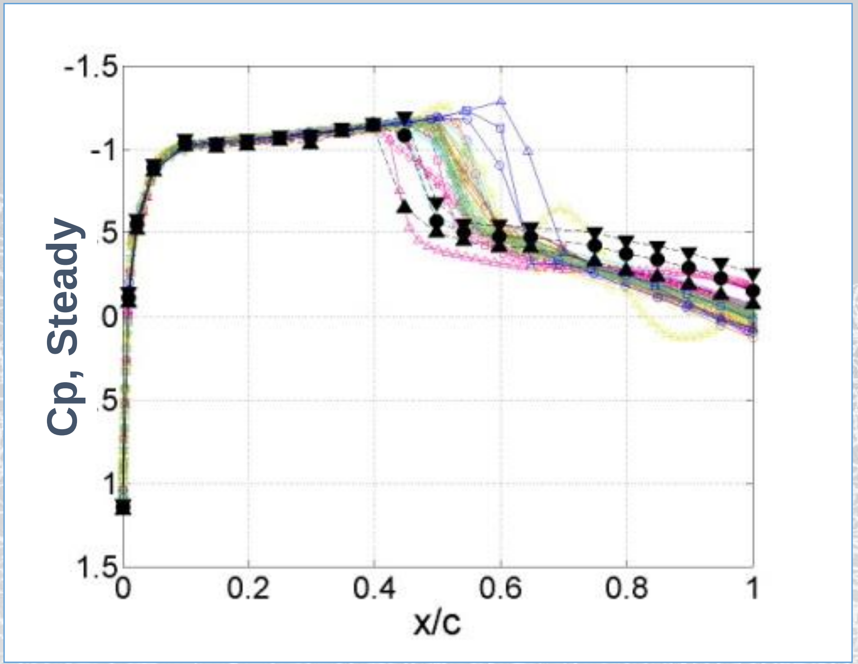
Important Note

These comparisons are utilizing the preliminary data, as submitted prior to the AePW.

These are workshop results, not publication results.

Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.

Results from AePW-1: BSCW Mach 0.85 5°



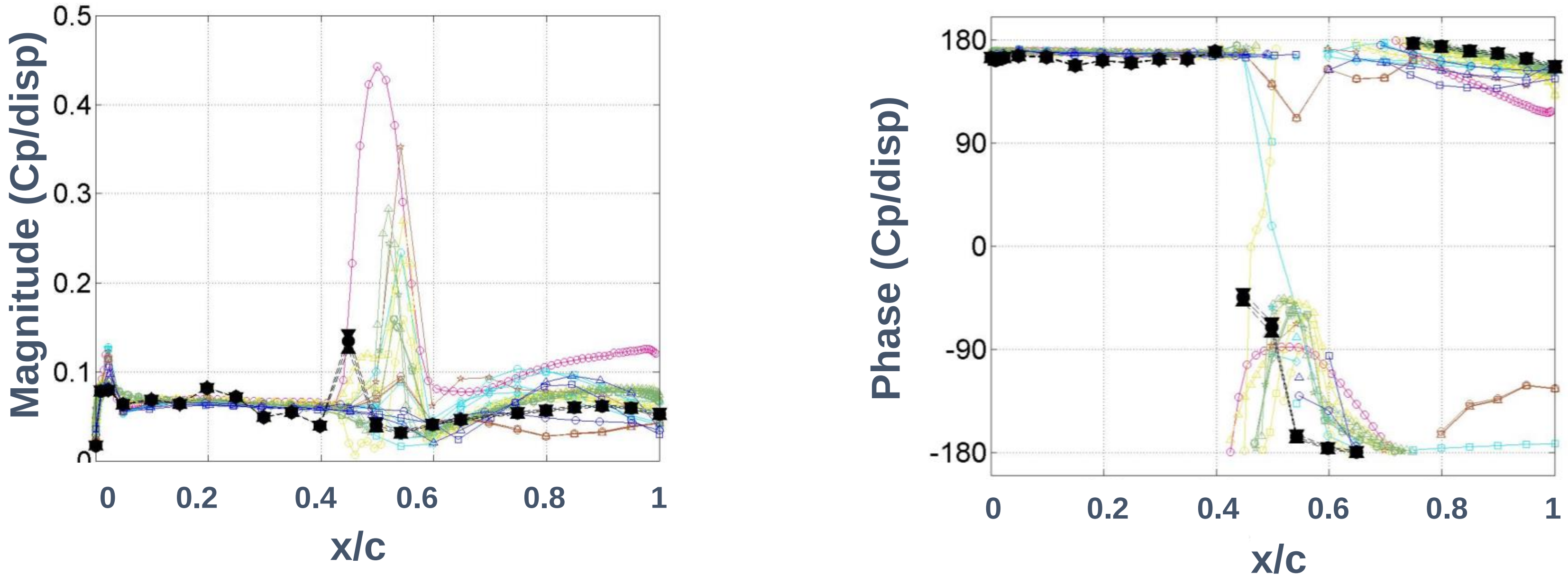
● Experimental data

▲ Bounds, ± 2 std

Colored lines with open symbols:

- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

Frequency Response Function at 10Hz

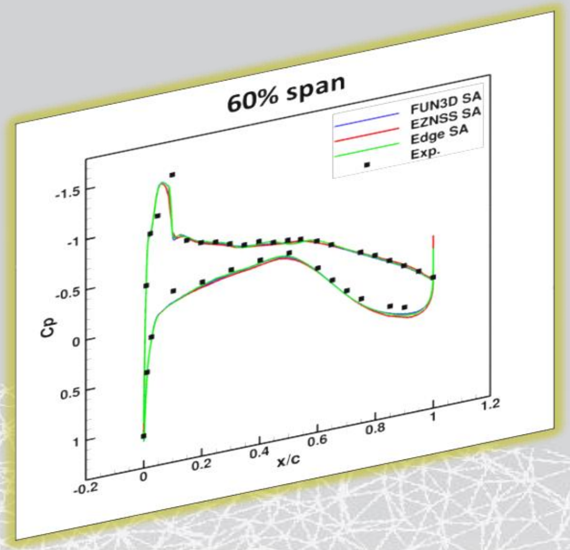


Critique:

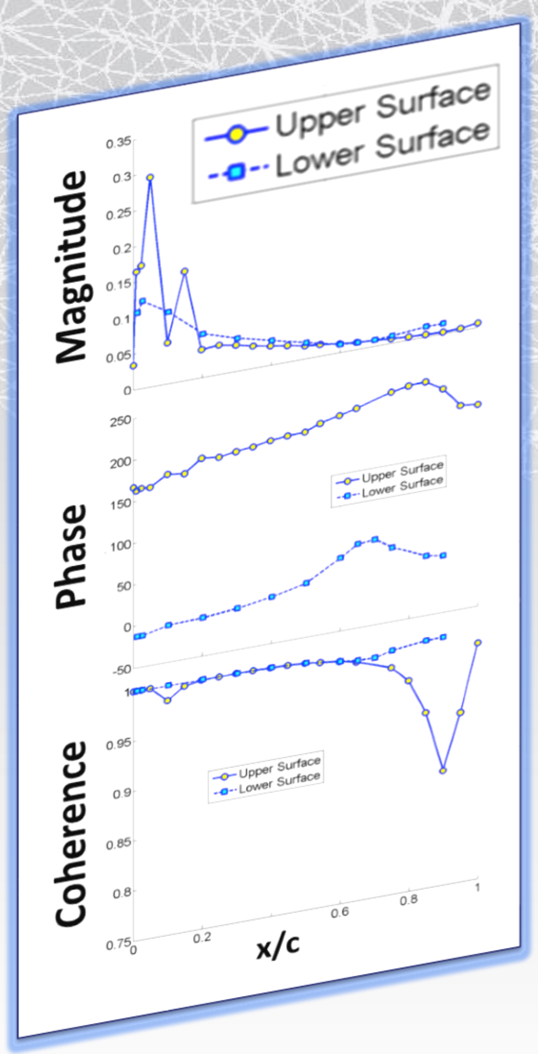
- Significant variation among computational results
- Inconsistent application of sign conventions led to uncertainty in phase angle definition
- No measure of the quality of the results; No coherence data
- Mean value characterization of experimental data artificially smears the shock (cants the pressure distribution, makes it less sharp than seen in instantaneous snapshots)
- Spacing of experimental data may lead to under-representing the magnitude peak

Primary data comparisons

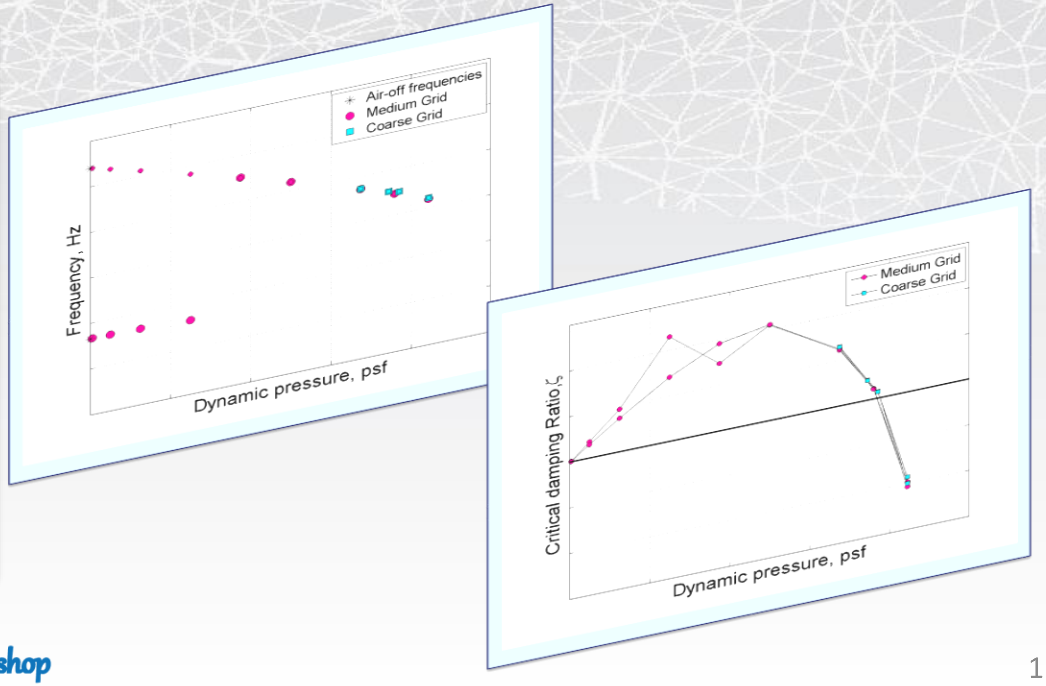
- Steady rigid pressure coefficient distributions: statistics of the results



- Frequency response functions: C_p/θ
  - At forced oscillation
  - At flutter condition, frequency
  - At prescribed, experimental condition



- Flutter conditions
  - Dynamic pressure at flutter onset
  - Frequency at flutter onset
  - Damping, frequency and static aeroelastic deformation at common analysis condition



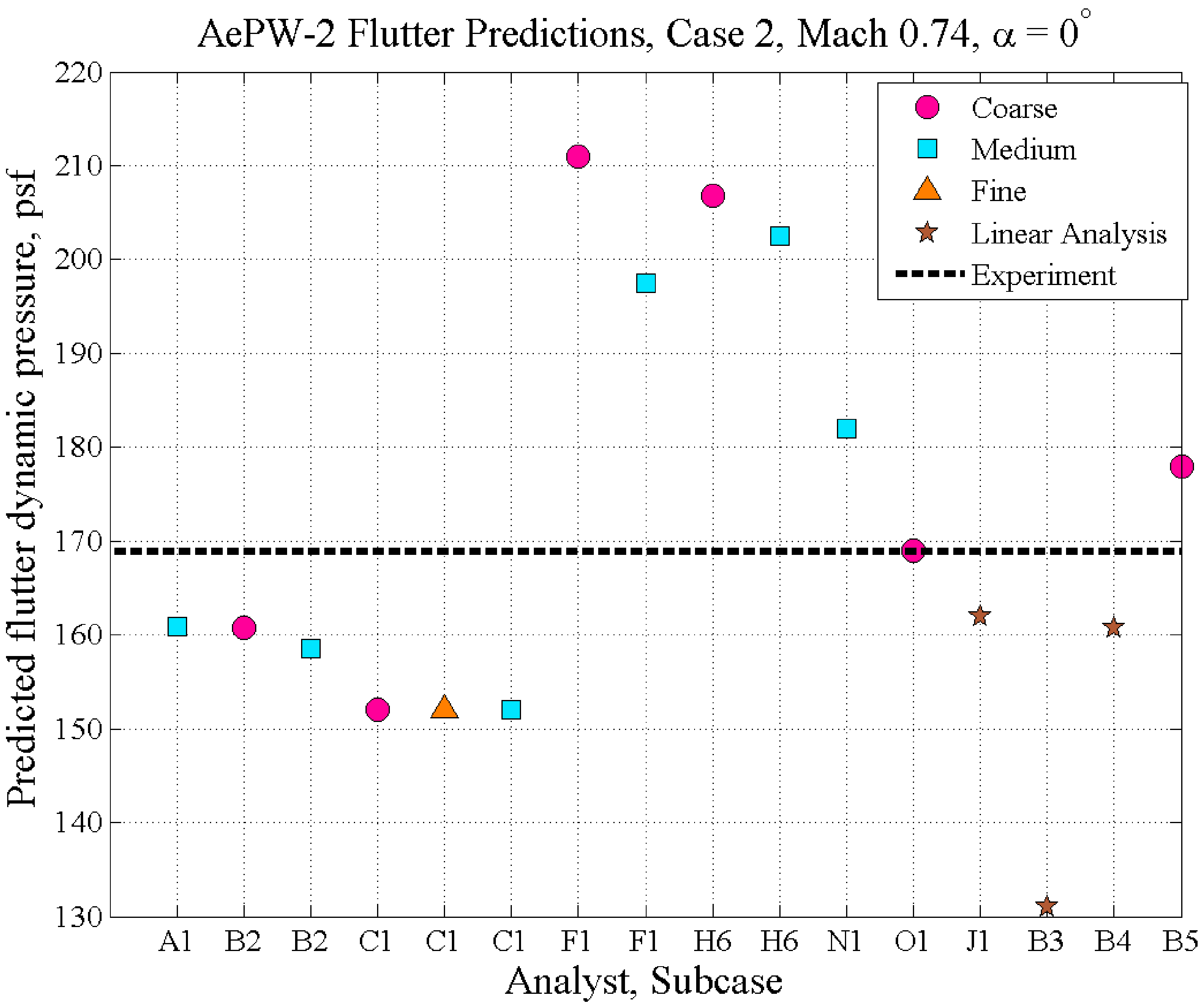
Guide to reading file names Steady Results

- Case_U/L_S1/2_SortBy
- U/L: Upper or Lower surface is designated by a single letter
- S1 / 2: Station 1 (60% span); Station 2 (95% span)
- SortedBy: string designating how the data is grouped on the plot
  - Groupings have different colors and symbols
  - Options currently plotted are Sorted By:
    - Analyst (specified by analysis team letter)
    - Plots are in directories named for other Sort options, but in the current versions they are not correctly designating the different sort parameters
      - Turbulence model
      - Grid Resolution
      - Flux Limiter
      - Grid Type (structured, unstructured, multiblock)
      - Software Name
- Currently only Mean Values of Cp are plotted (i.e. none of the other statistics have plots generated, although they are in the database files)

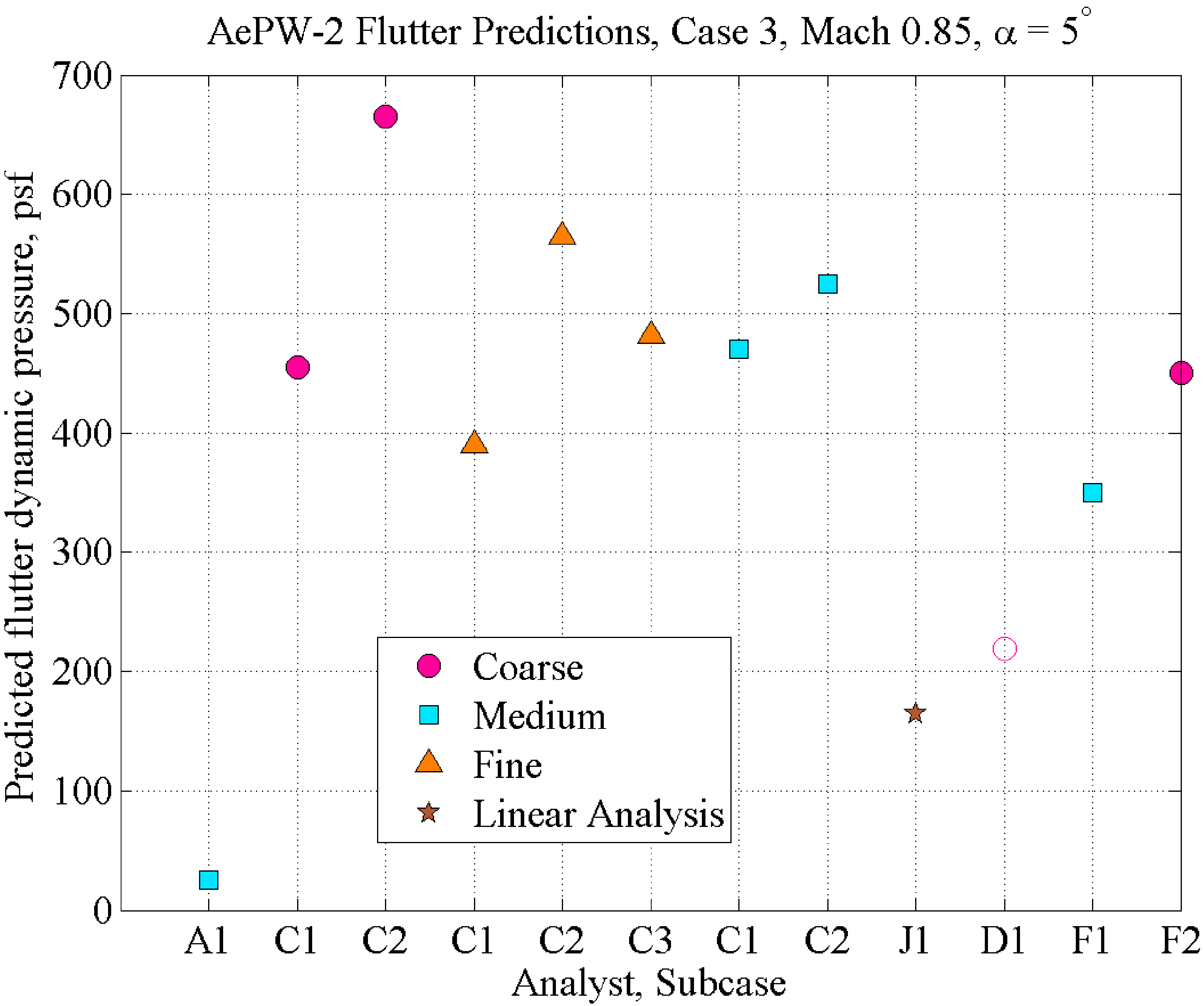
Guide to reading file names
Frequency Response Function Plots

- Case_U/L_C/M/P_S1/2_SortBy
- U/L: Upper or Lower surface is designated by a single letter
- C/M/P: Coherence, Magnitude or Phase, designated by a single letter
- S1 / 2: Station 1 (60% span); Station 2 (95% span)
- SortedBy: string designating how the data is grouped on the plot
  - Groupings have different colors and symbols
  - Options currently plotted are Sorted By:
    - Analyst (specified by analysis team letter)
    - Plots are in directories named for other Sort options, but in the current versions they are not correctly designating the different sort parameters
      - Turbulence model
      - Grid Resolution
      - Flux Limiter
      - Grid Type (structured, unstructured, multiblock)
      - Software Name

Case 2 Flutter Dynamic pressure



Case 3 Flutter Dynamic pressure



Spatial convergence

Coming Soon

Show CL, CM, CD
as functions of Coarse, Medium and Fine Grids for the 3 analysis conditions
Show sectional coefficients if sufficient data sets.

Temporal convergence

Show some unsteady quantity, such as CL/theta, CM/theta CD/theta as functions of time step size for the 3 analysis conditions

Show sectional coefficients if sufficient data sets.

Show flutter condition as a function of time step size.

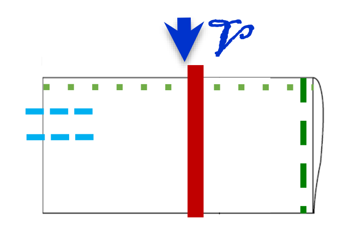
Coming Soon

Steady case results

● Experimental data
▲ Experiment bounds

Colored lines with open symbols:

- Each analysis team shown by a separate color
- Each grid size shown by a different symbol



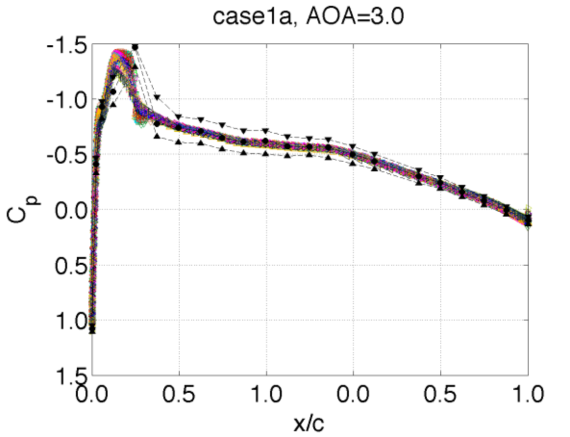
60% span

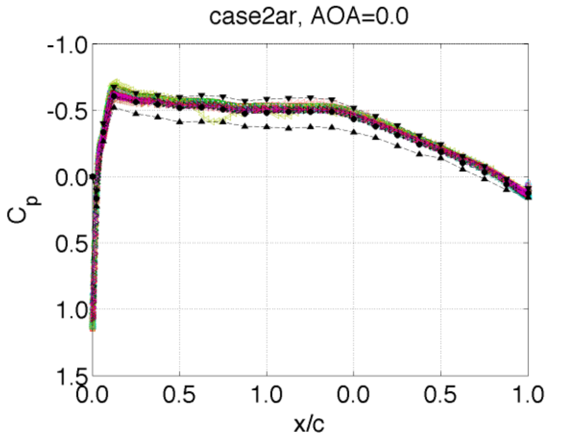
Case 1a
Mach 0.7, α = 3°

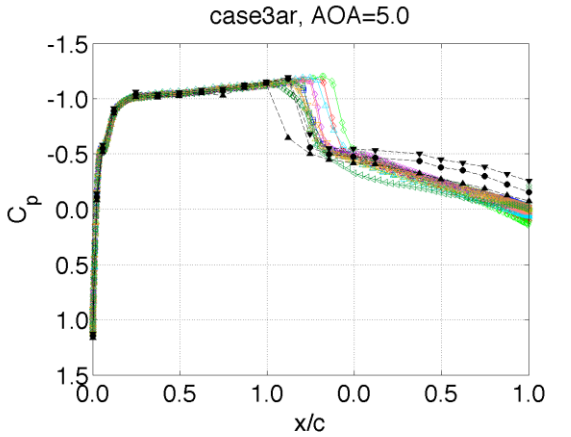
Case 2a
Mach 0.74, α = 0°

Case 3a
Mach 0.85, α = 5°

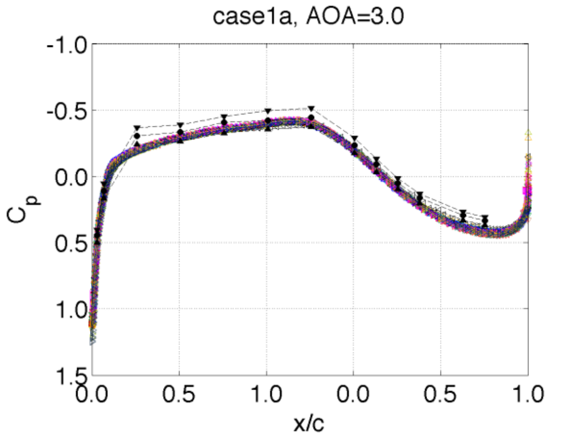
Upper Surface

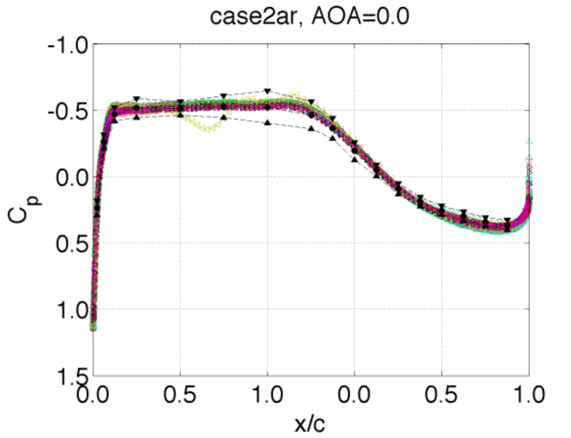

case1a, AOA=3.0

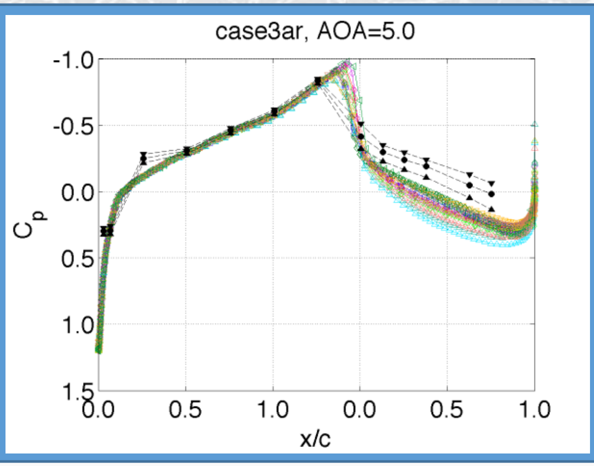

case2ar, AOA=0.0


case3ar, AOA=5.0

Lower Surface


case1a, AOA=3.0


case2ar, AOA=0.0


case3ar, AOA=5.0

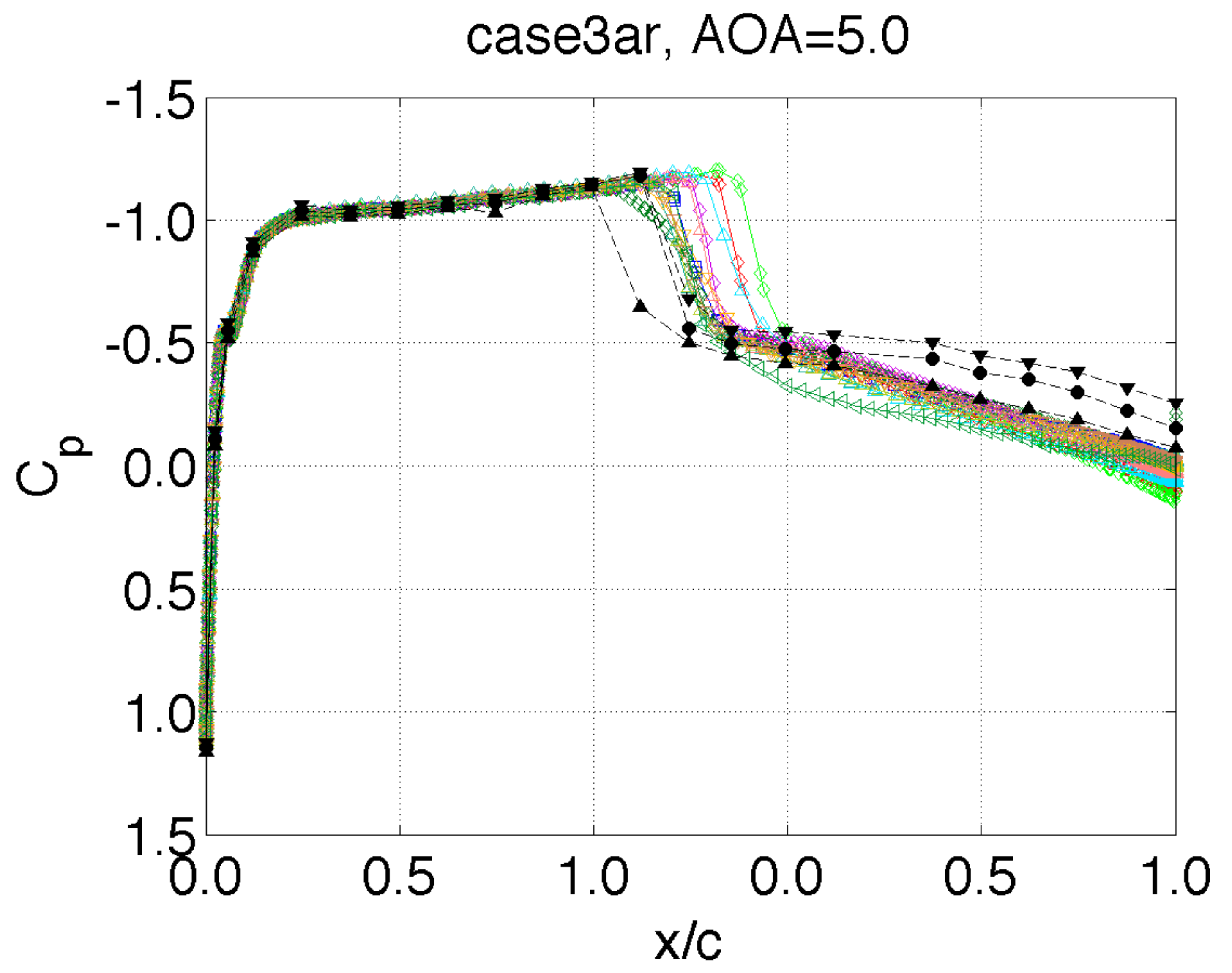
These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**

Steady case results

- ● Experimental data
- ▲ Experiment bounds

Colored lines with open symbols:

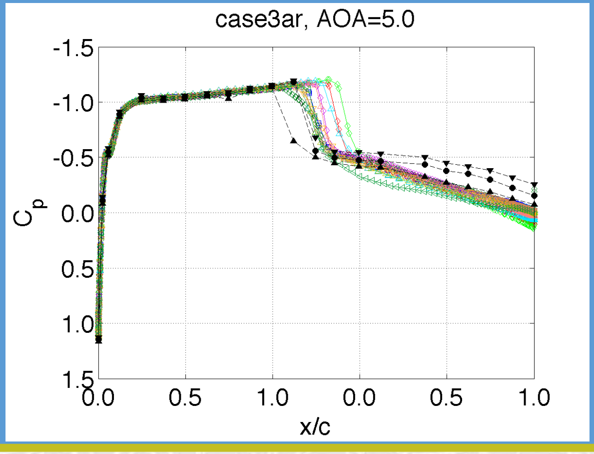
- Each analysis team shown by a separate color
- Each grid size shown by a different symbol



0°

Case 3a

Mach 0.85, α = 5°



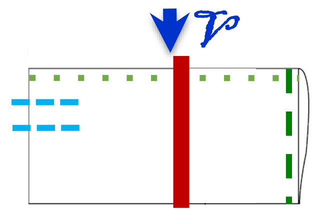
orkshop results, not publication results. **Please use**

team to share preliminary findings.

Steady case results

● Experimental data
▲ Experiment bounds

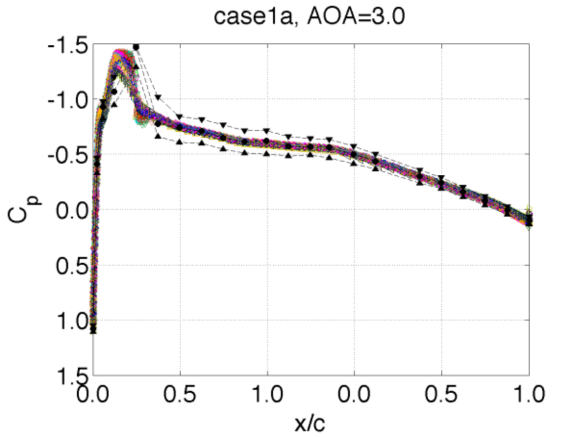
Colored lines with open symbols:
- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

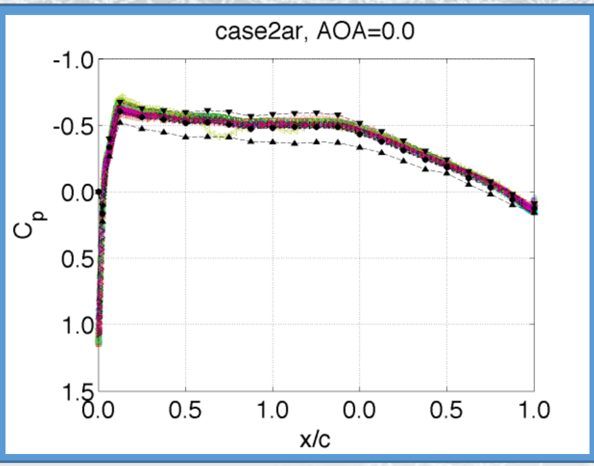


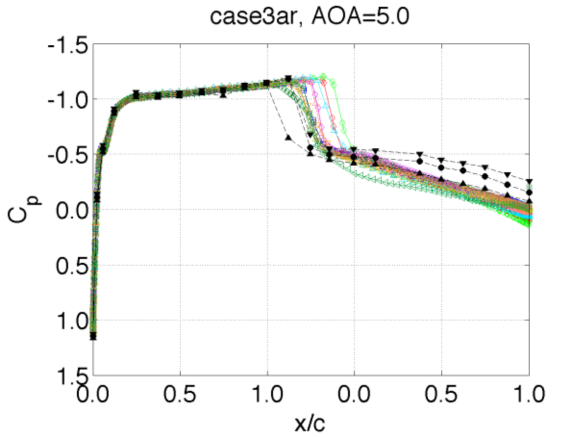
60% span

Case 1a Mach 0.7, α = 3°	Case 2a Mach 0.74, α = 0°	Case 3a Mach 0.85, α = 5°

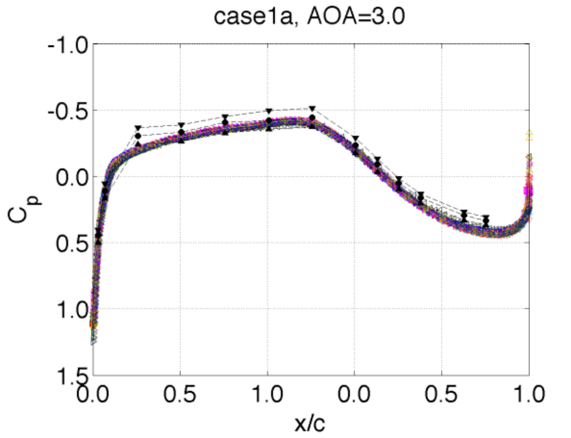
Upper Surface

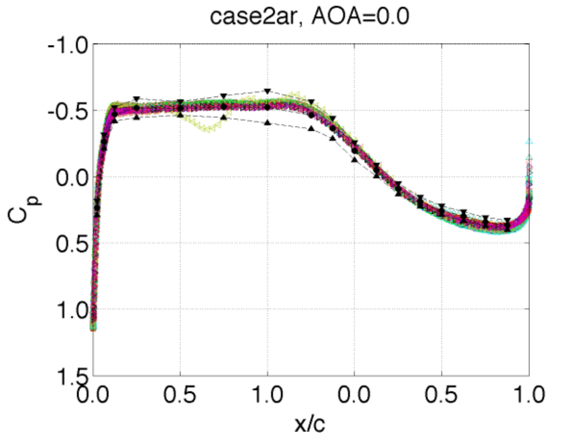


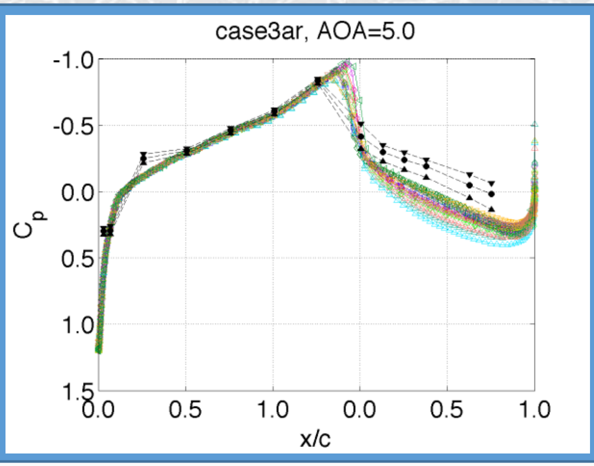




Lower Surface







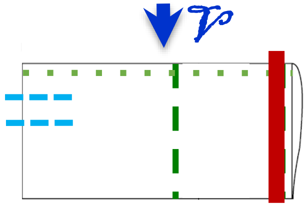
These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**

Steady case results

● Experimental data
▲ Experiment bounds

Colored lines with open symbols:

- Each analysis team shown by a separate color
- Each grid size shown by a different symbol



95% span

Case 1a
Mach 0.7, α = 3°

Case 2a
Mach 0.74, α = 0°

Case 3a
Mach 0.85, α = 5°

Upper Surface

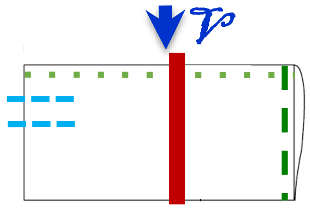
Lower Surface

To be done, post-workshop

These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**

Template

Case 2c_qE
Mach 0.74, α = 0°



60% span

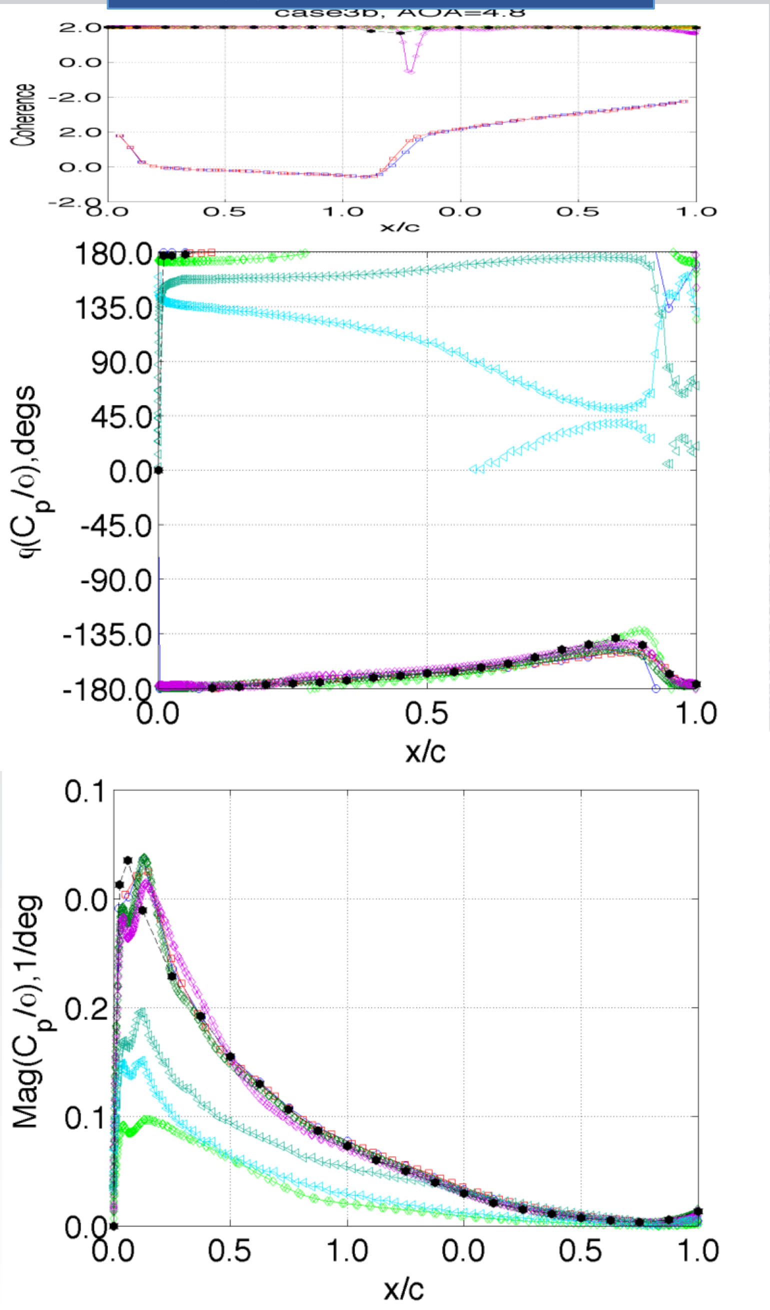
- ● Experimental data
- ▲ Experiment bounds

Colored lines with open symbols:

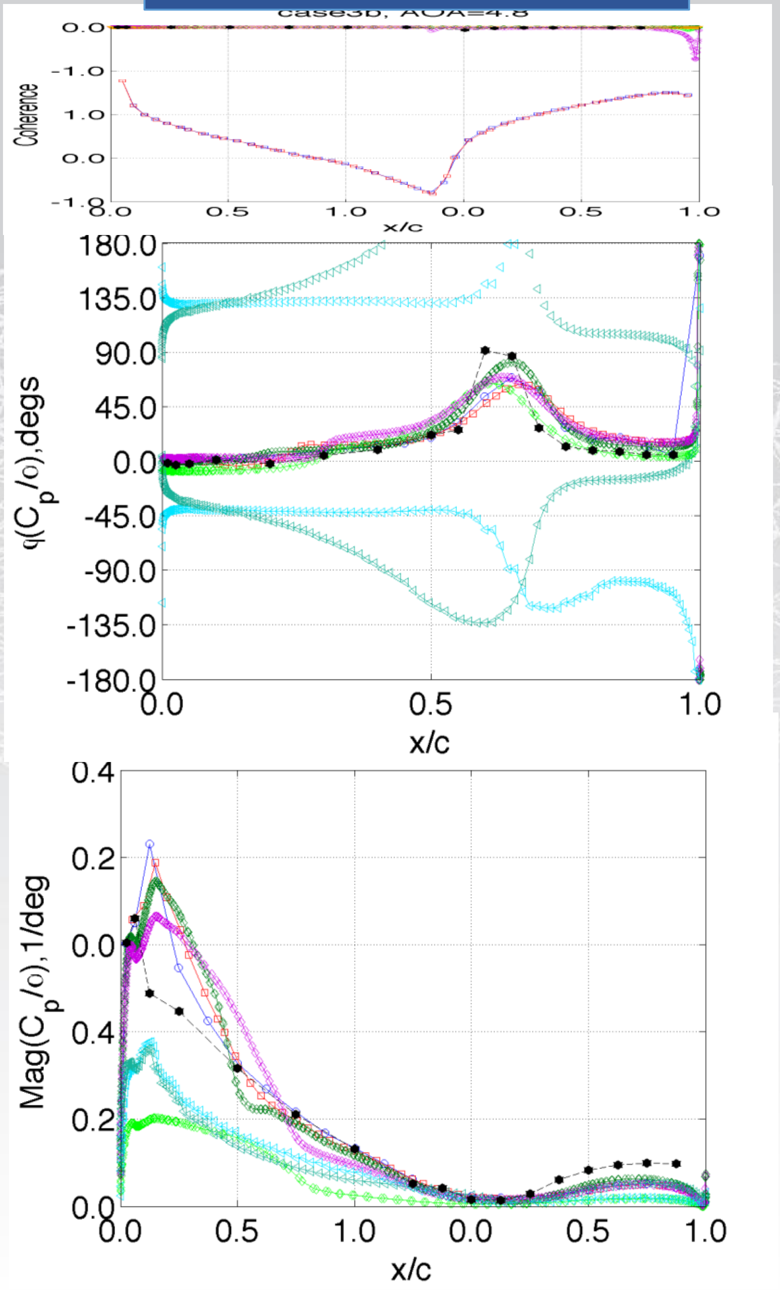
- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**

Upper Surface

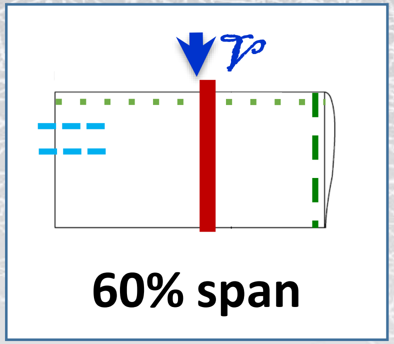


Lower Surface



Forced oscillation

Case 1b
Mach 0.7, α = 3°



60% span

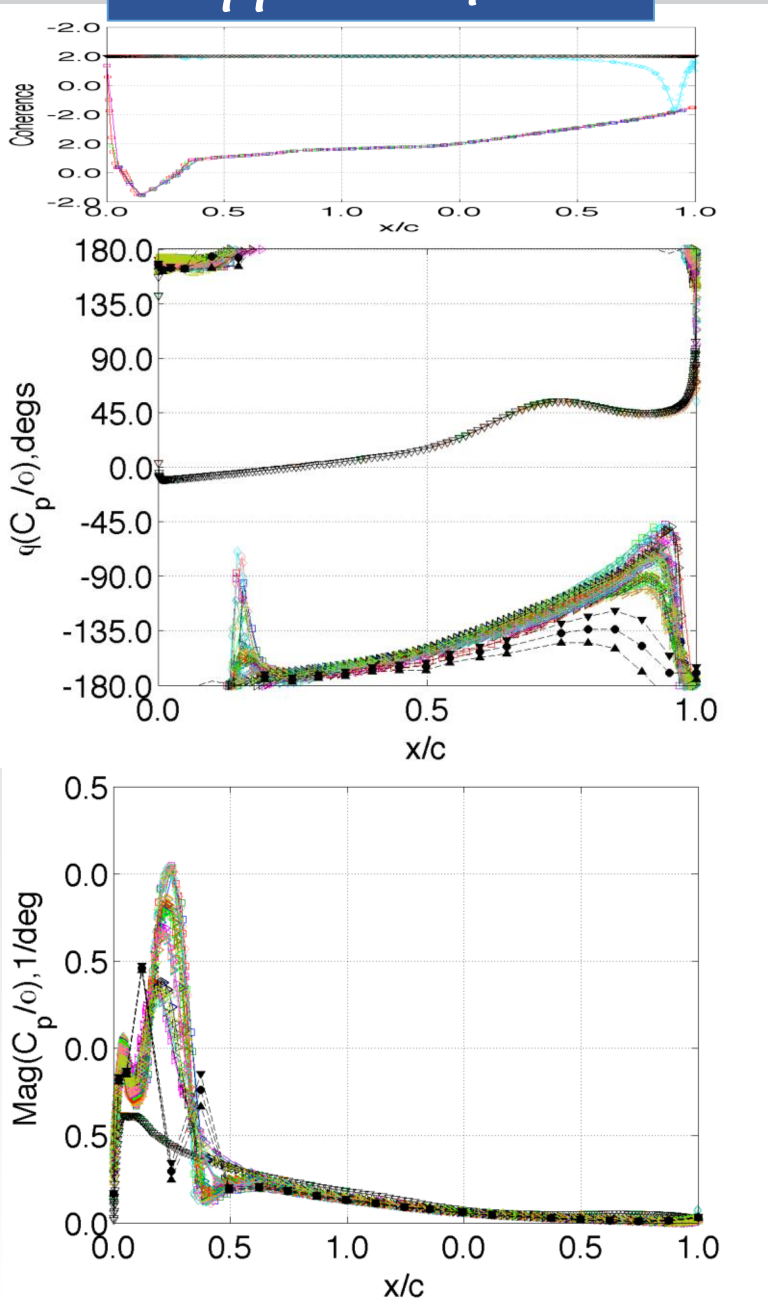
● Experimental data
▲ Experiment bounds

Colored lines with open symbols:

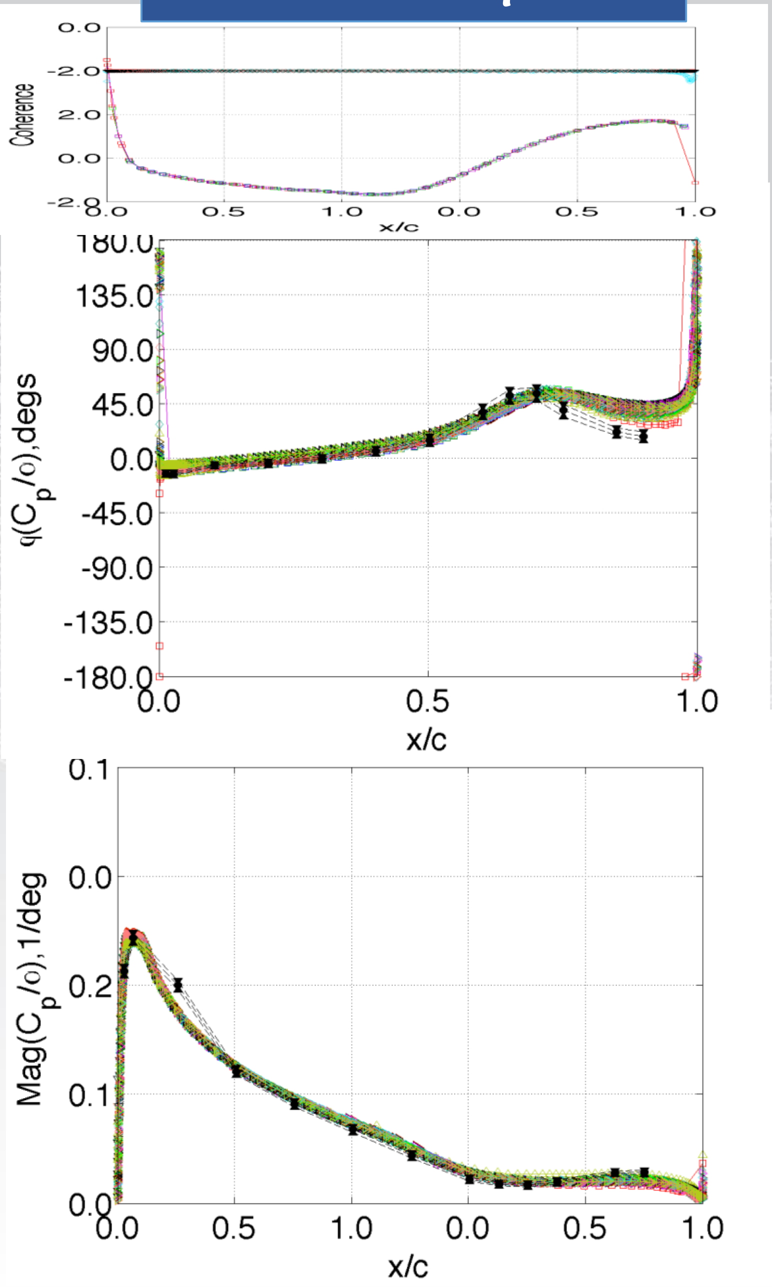
- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**

Upper Surface

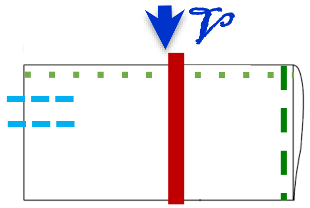


Lower Surface



Forced oscillation

Case 3b
Mach 0.85, α = 5°



60% span

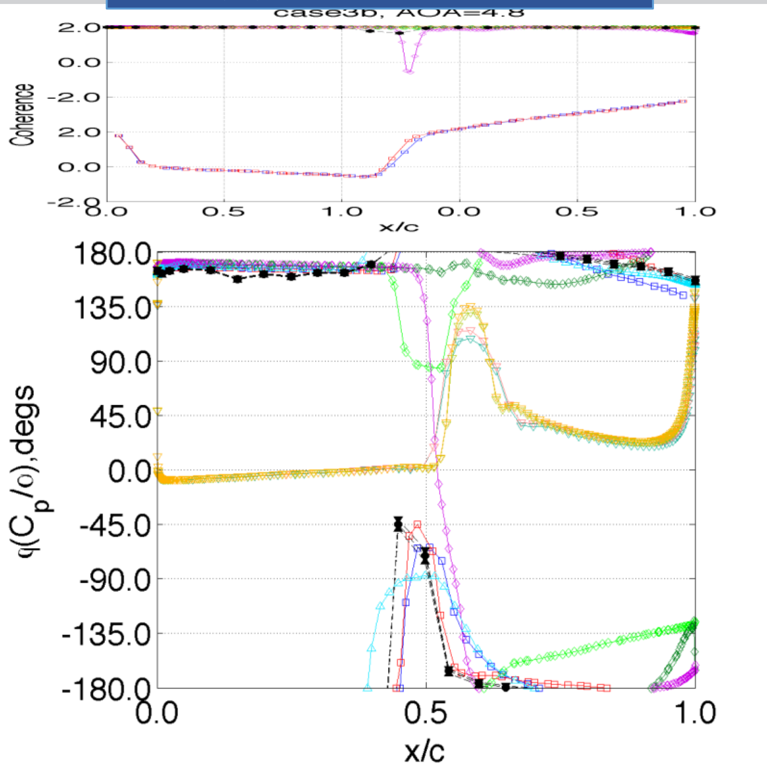
- ● Experimental data
- ▲ Experiment bounds

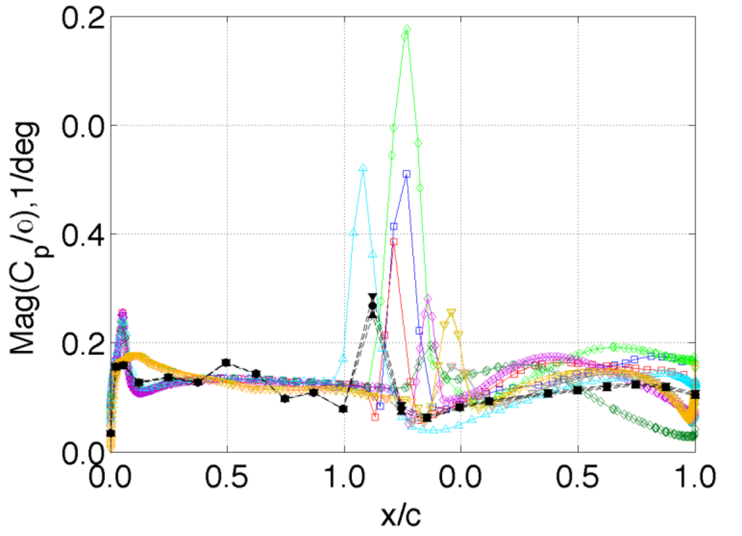
Colored lines with open symbols:

- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

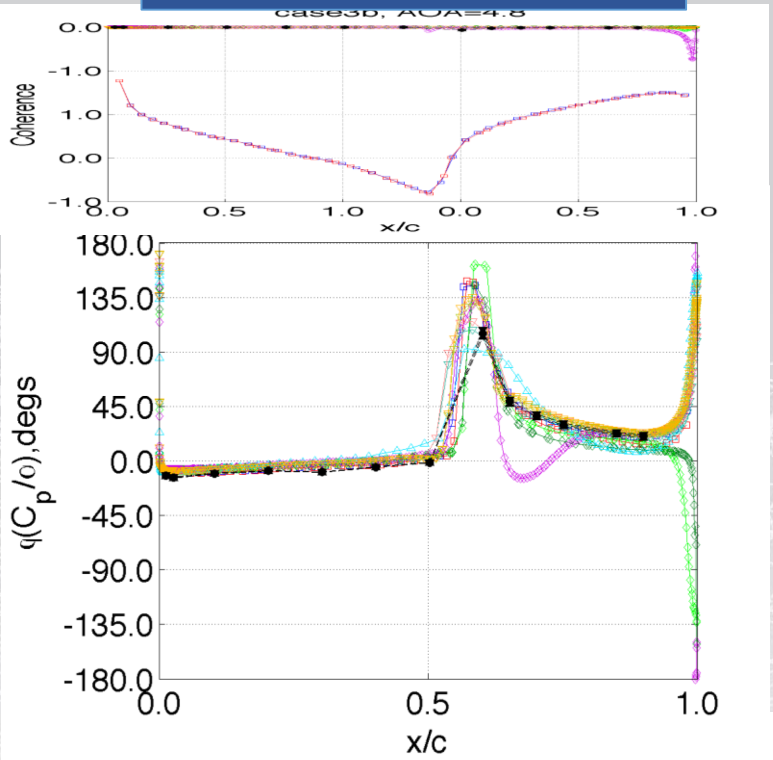
These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**

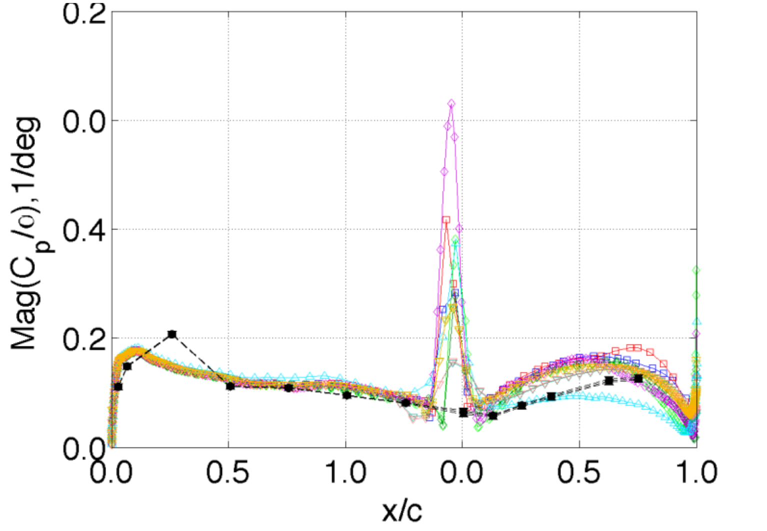
Upper Surface





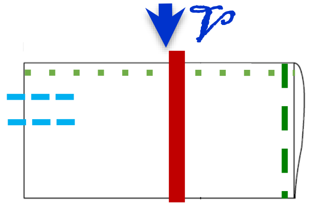
Lower Surface





Flutter analysis FRFs

Case 2c_qE, 169 psf
Mach 0.74, α = 0°



60% span

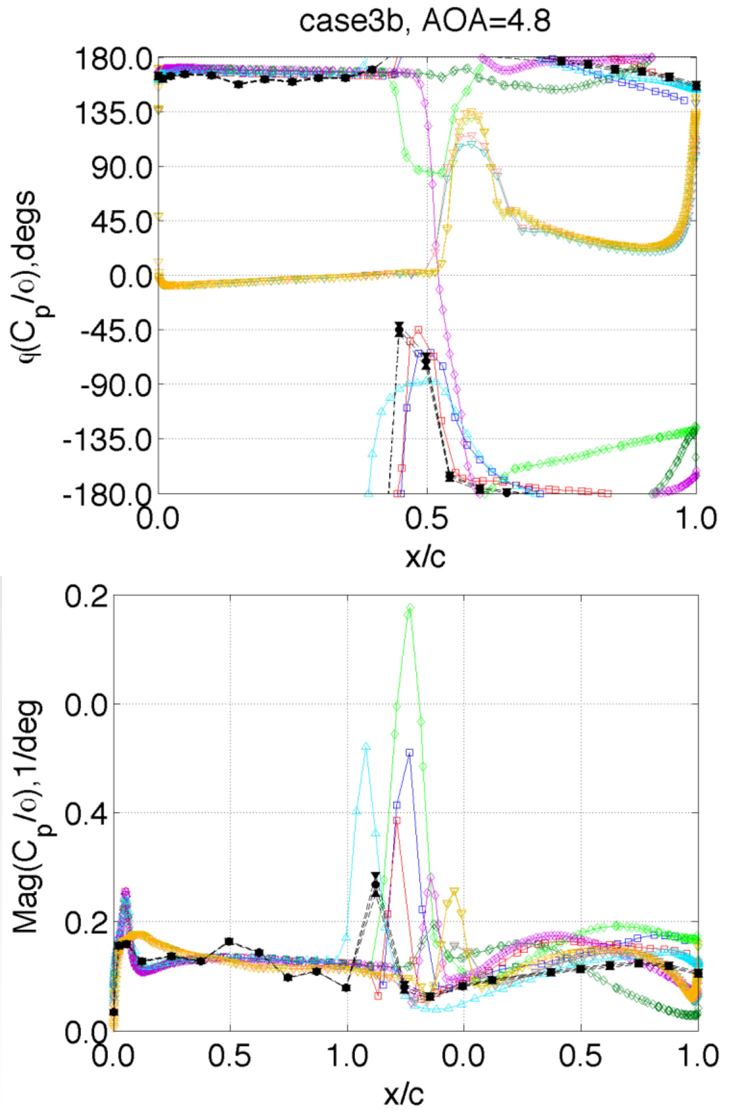
- ● Experimental data
- ▲ Experiment bounds

Colored lines with open symbols:

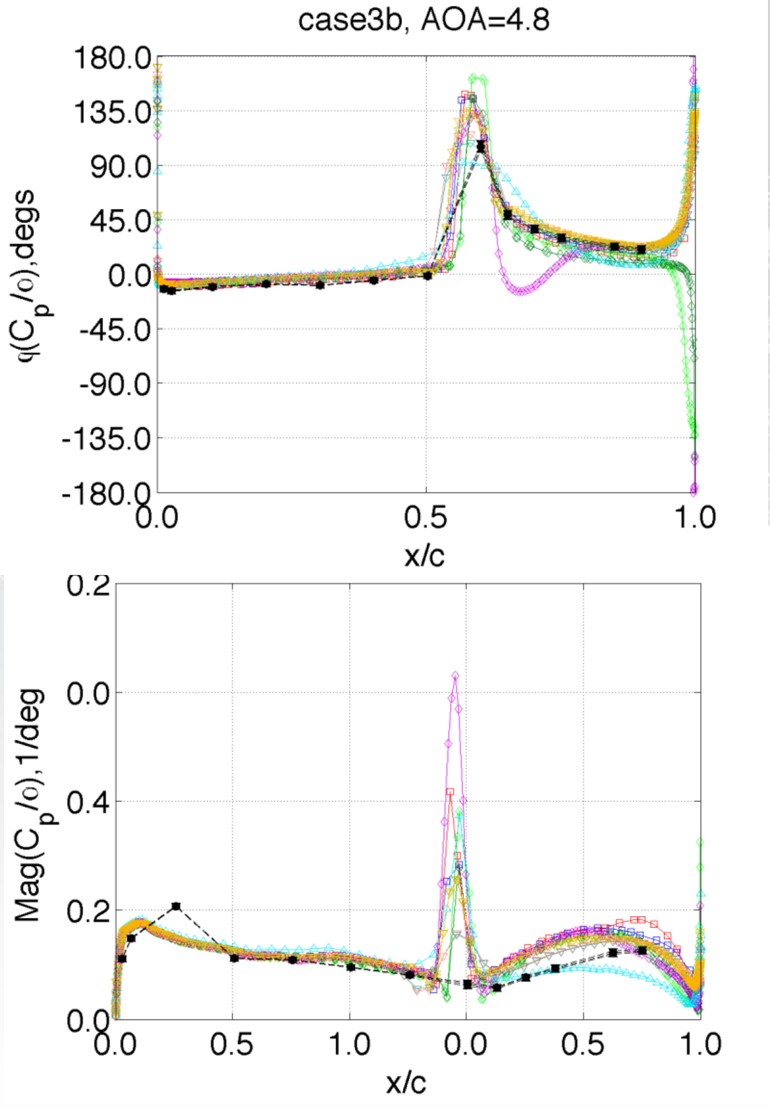
- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**

Upper Surface

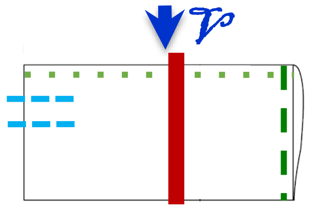


Lower Surface



Flutter analysis FRFs

Case 2c_qF
Mach 0.74, α = 0°



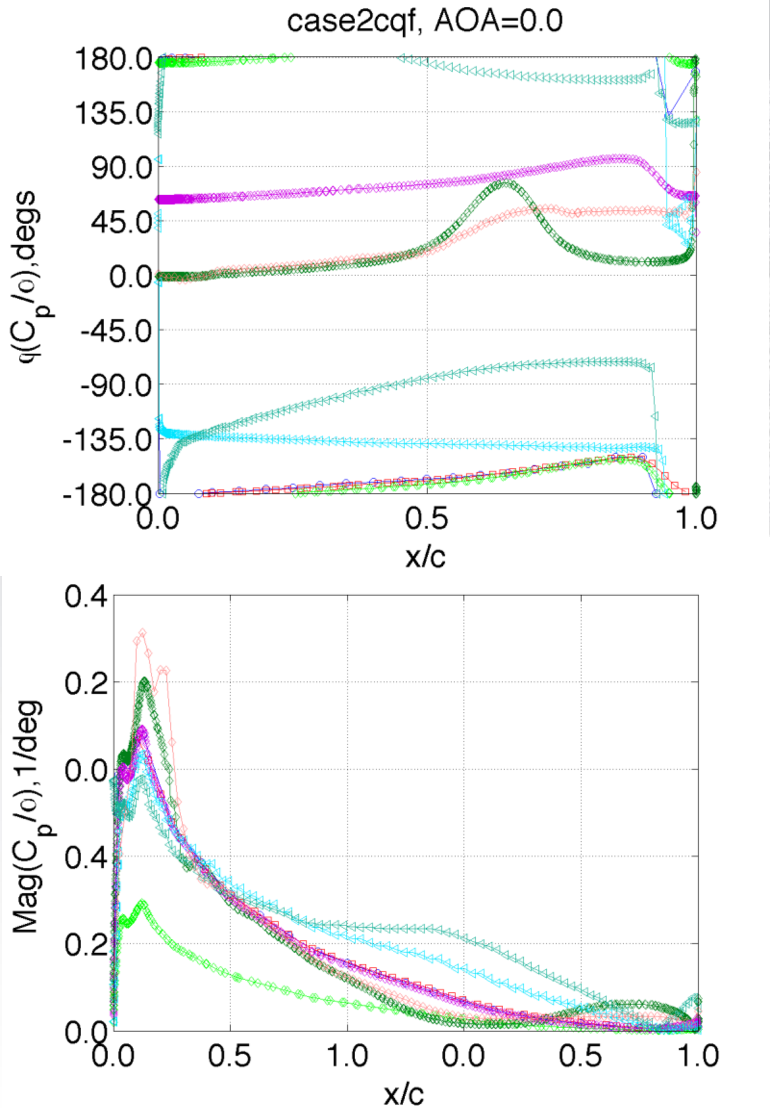
60% span

- ● Experimental data
- ▲ Experiment bounds

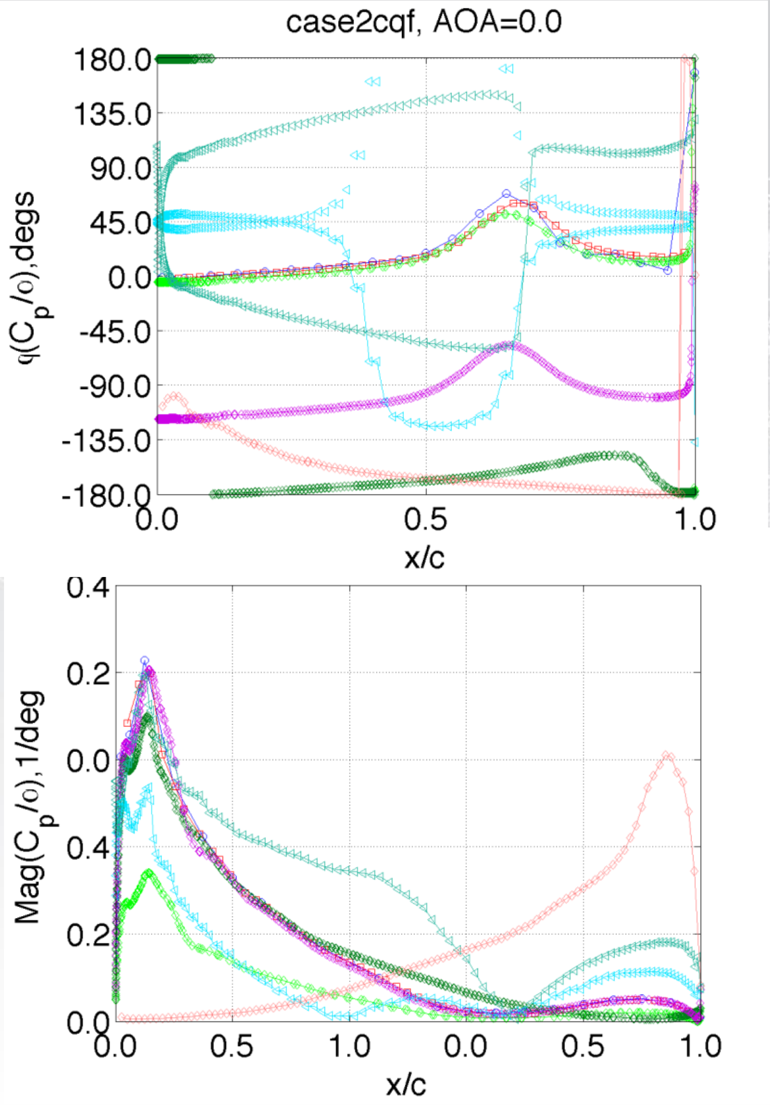
Colored lines with open symbols:

- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

Upper Surface



Lower Surface



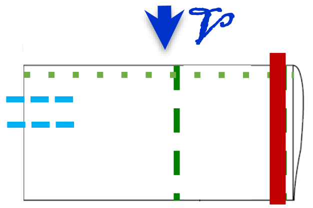
These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**

Flutter analysis FRFs

Upper Surface

Lower Surface

Case 2c_qF
Mach 0.74, α = 0°



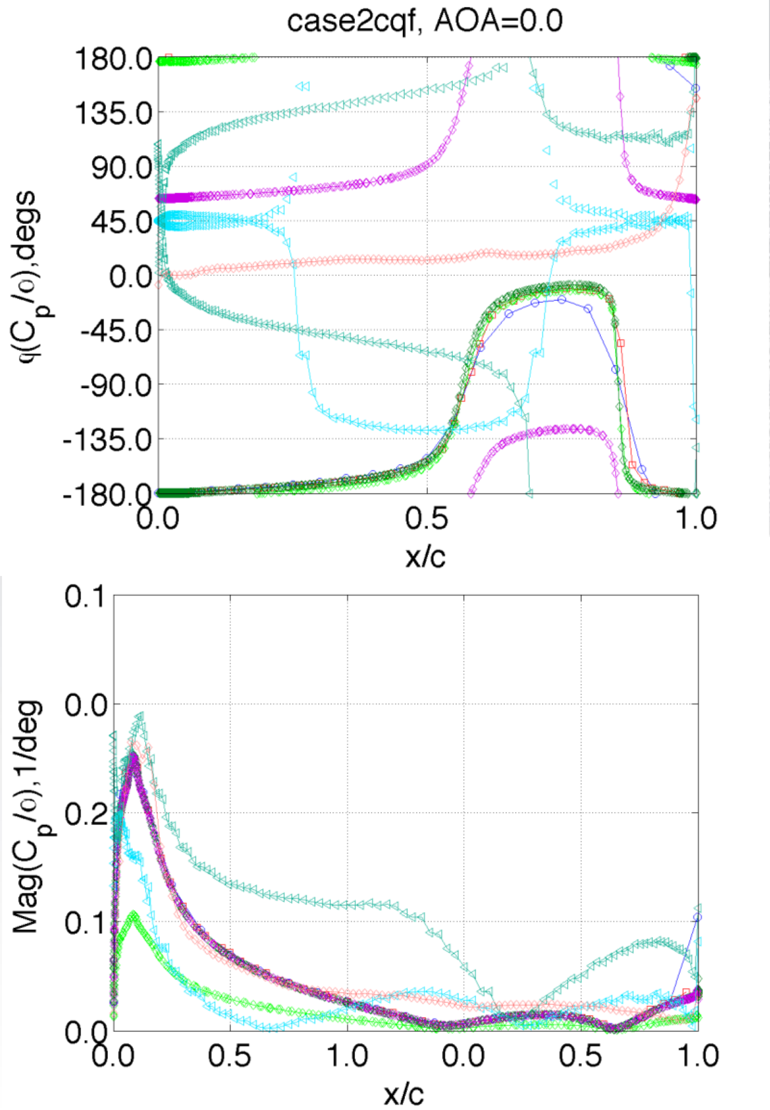
95% span

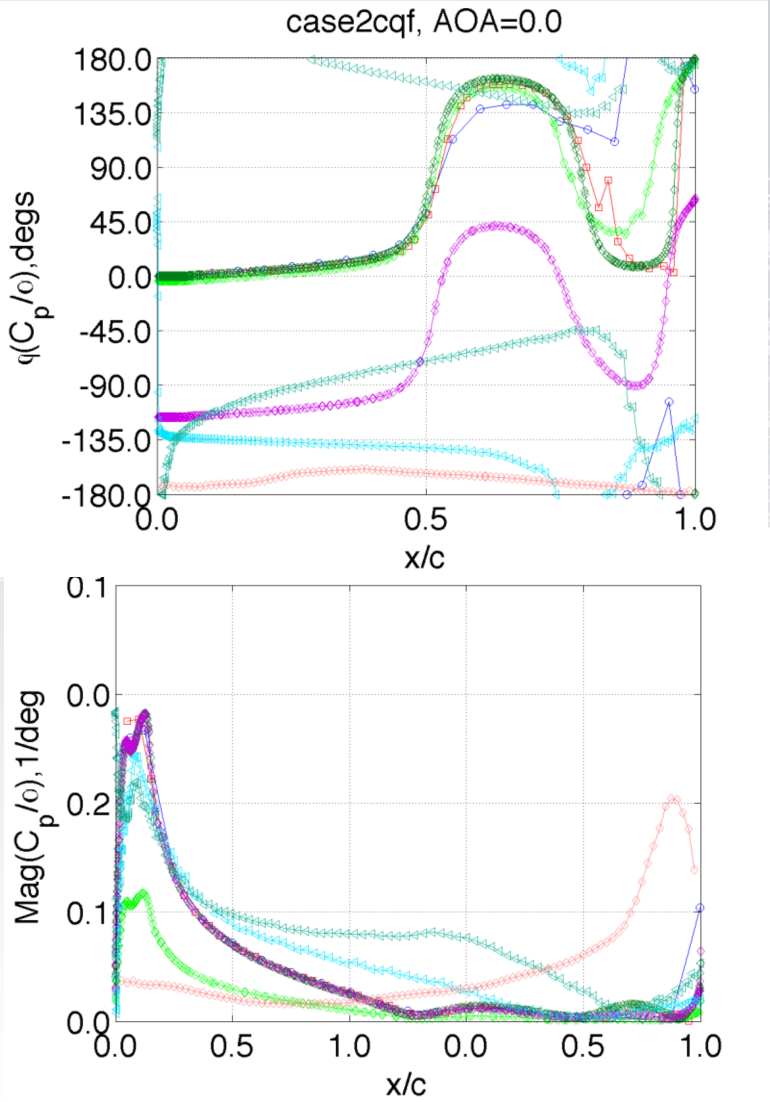
● Experimental data
▲ Experiment bounds

Colored lines with open symbols:

- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

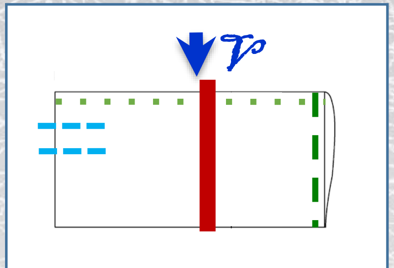
These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**





Flutter analysis FRFs

Case 3c_qE, 204 psf
Mach 0.85, α = 5°



60% span

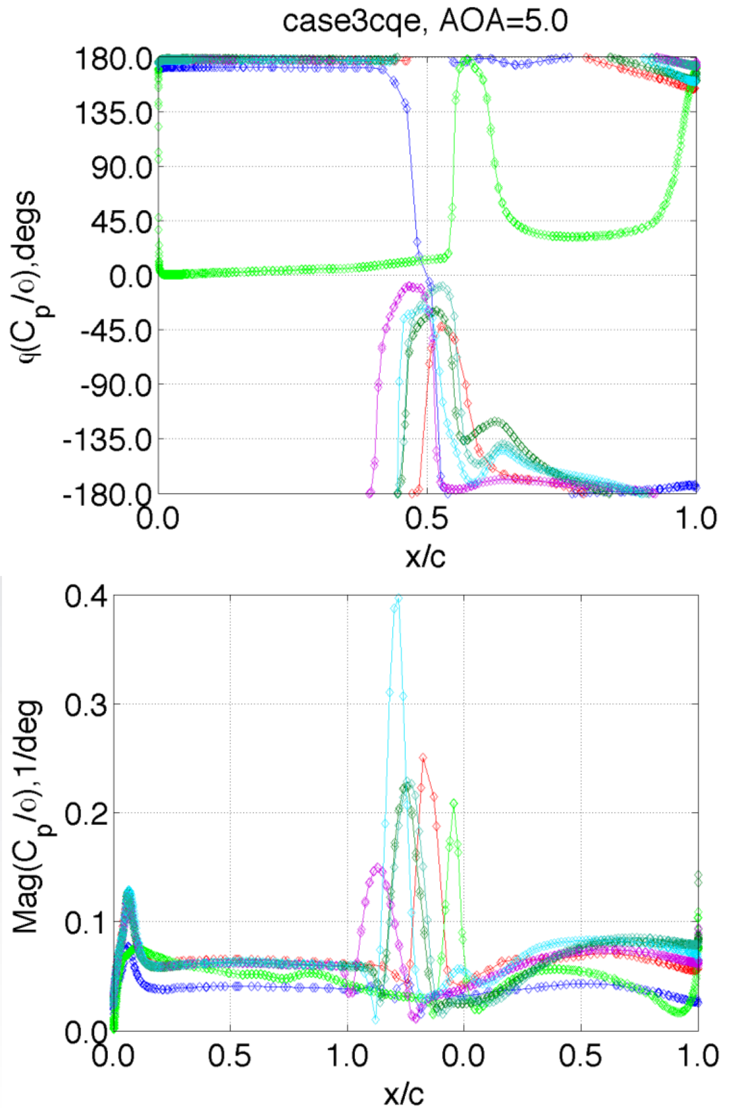
- ● Experimental data
- ▲ Experiment bounds

Colored lines with open symbols:

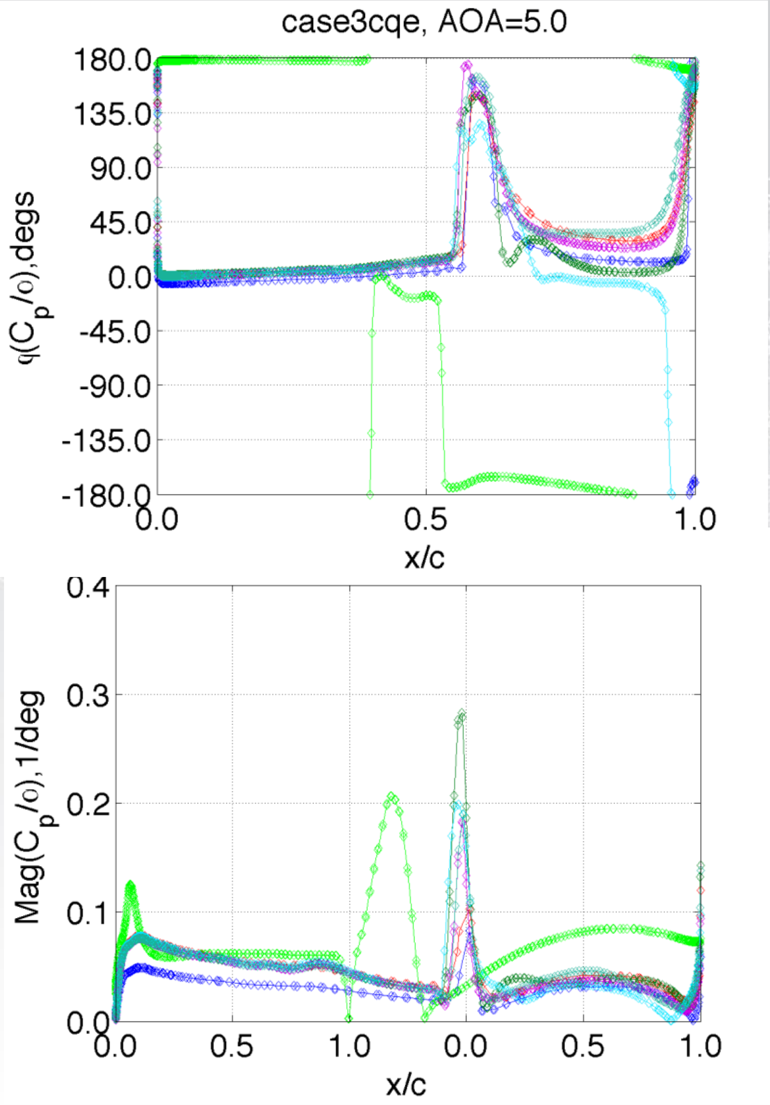
- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**

Upper Surface



Lower Surface

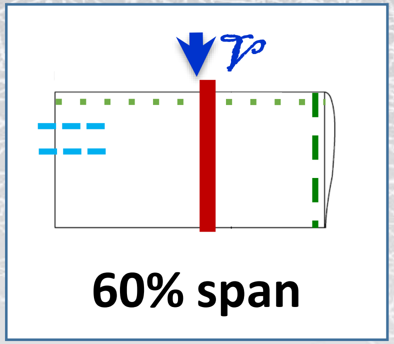


Flutter analysis FRFs

Upper Surface

Lower Surface

Case 3c_qF
Mach 0.85, α = 5°

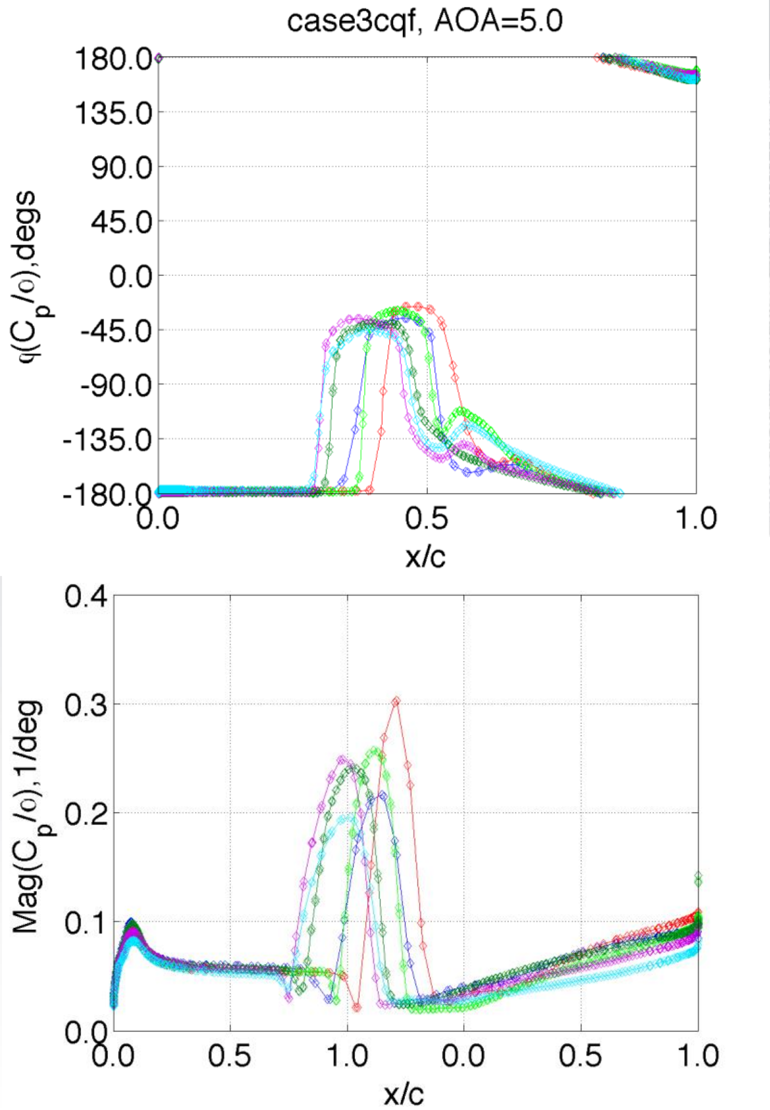


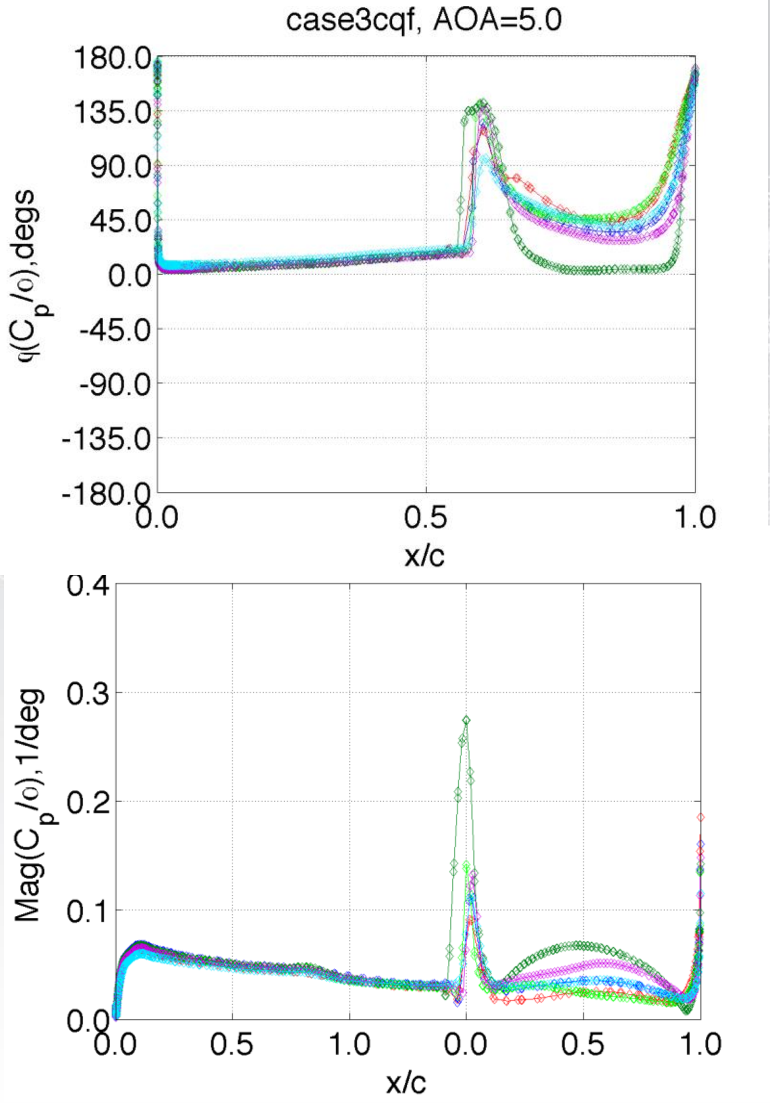
● Experimental data
▲ Experiment bounds

Colored lines with open symbols:

- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

These comparisons are utilizing the preliminary data, as submitted prior to the AePW. These are workshop results, not publication results. **Please use these results showing proper respect for the willingness of the analysts and data reduction team to share preliminary findings.**



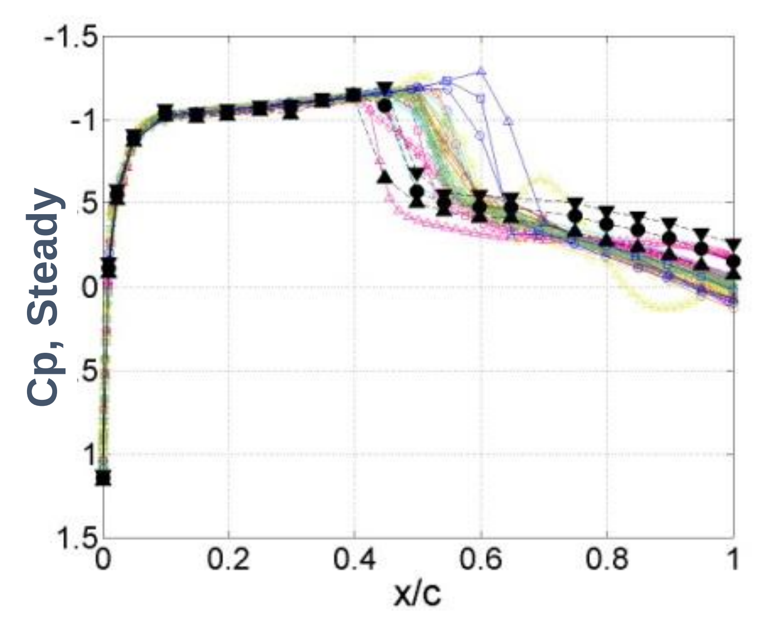


Sort by Turbulence Model

Considerations in data processing & interpretation computing FRFs

- Representing the average distributions
  - Statistic (mean, mode, median)
  - Unsteady effects
- Computing FRFs
  - Frequency to process for non-flutter dynamic aeroelastic points
  - Time history subset selection
    - Initial transient elimination
    - Large displacement solution elimination?
  - Fourier analysis parameters
    - Block size determination
    - Number of periodograms
  - Using the coherence information is important

Results from AePW-1:
BSCW Forced Oscillation Mach 0.85 5°



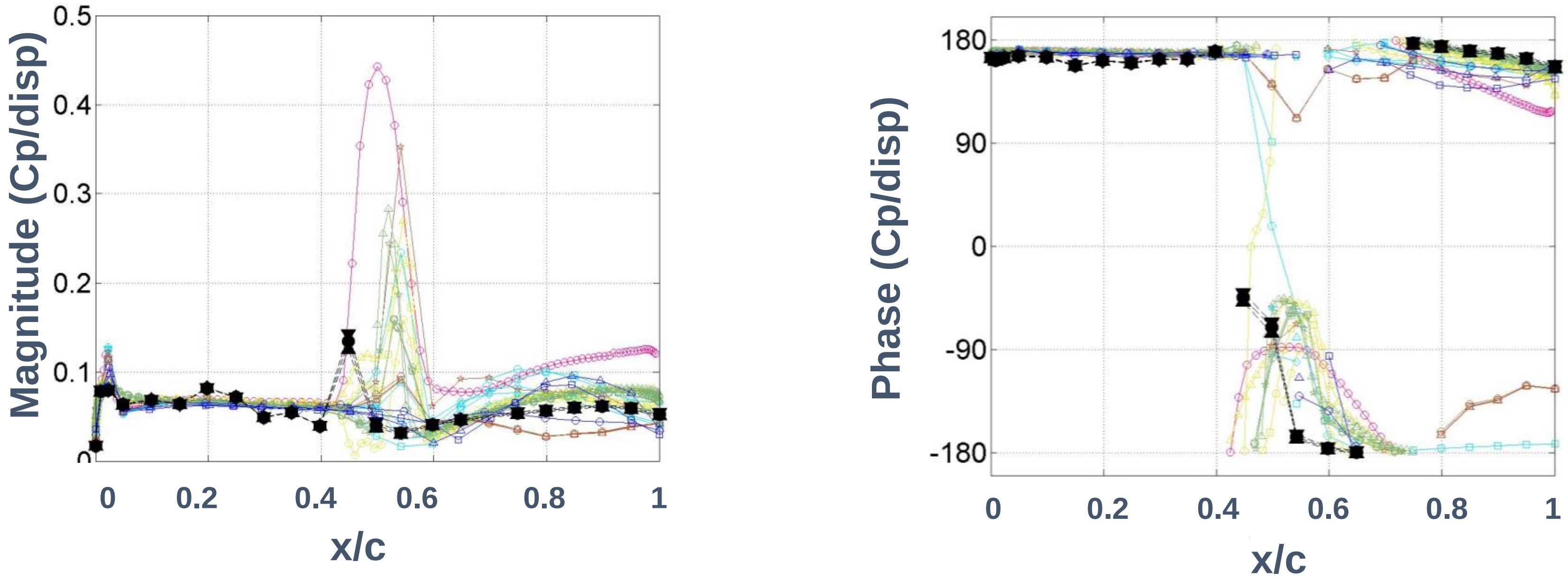
● Experimental data

▲ Bounds, ± 2 std

Colored lines with open symbols:

- Each analysis team shown by a separate color
- Each grid size shown by a different symbol

Frequency Response Function at 10Hz



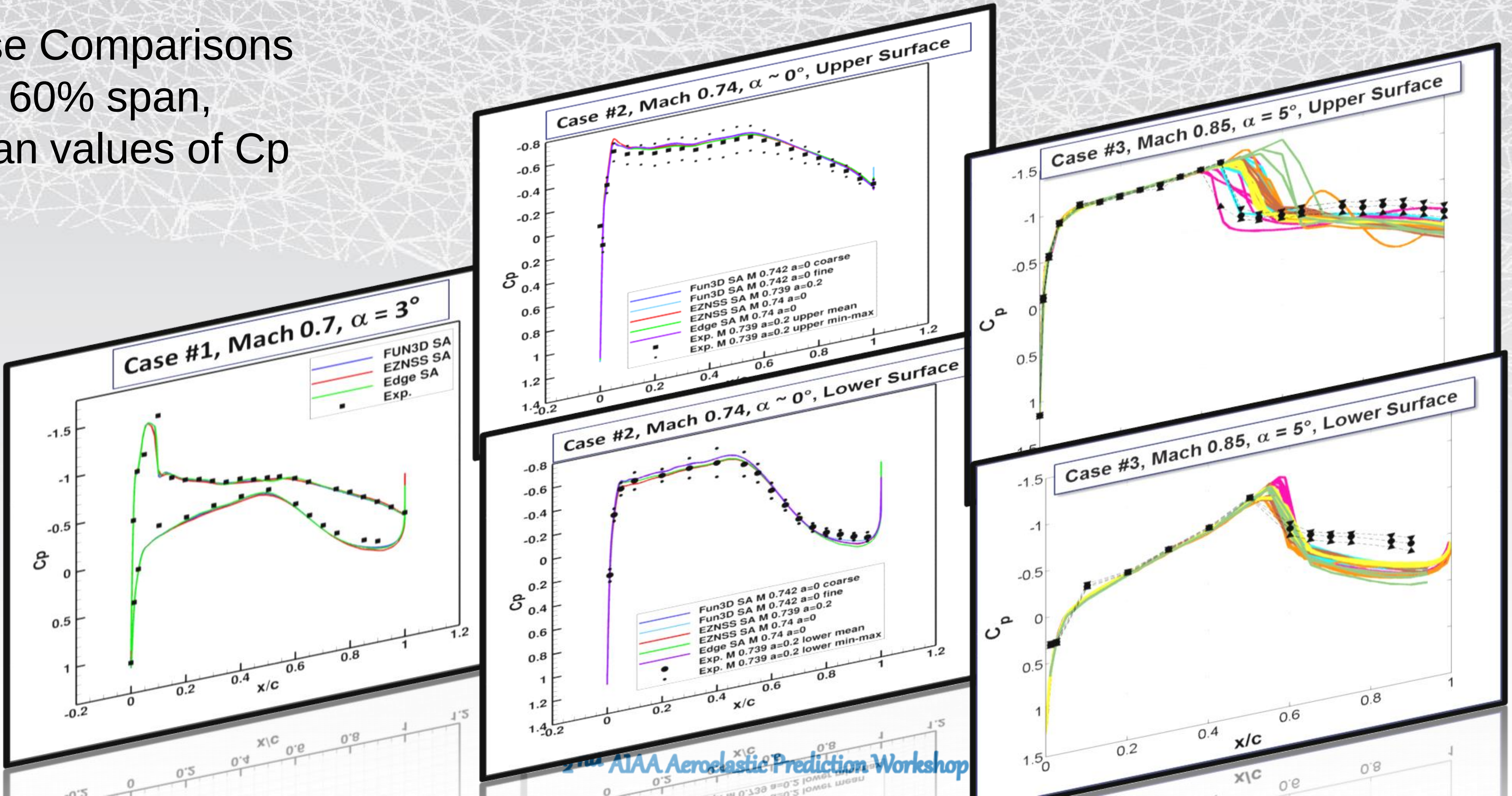
Steady Rigid Pressure Distributions

For the primary forced oscillation case, Case #1, disagreements with experimental data limited to the peak of the upper surface shock.

For the primary flutter case, Case #2, shows a well-matched rigid pressure distribution without much variation among the computational results.

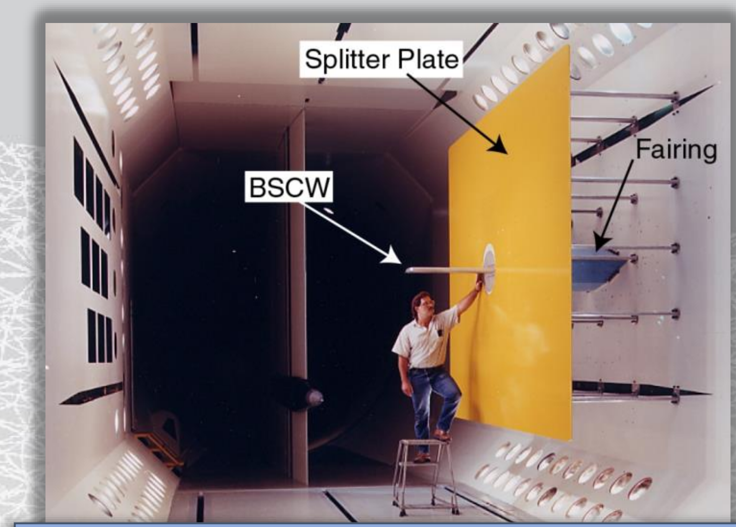
The complexity of the Case #3 is indicated by the variation among the computational results & difference from the experimental data →Shock location, shock strength, aft loading especially on lower surface.

Case Comparisons
60% span,
Mean values of Cp



From AePW-1 Data Comparisons

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**

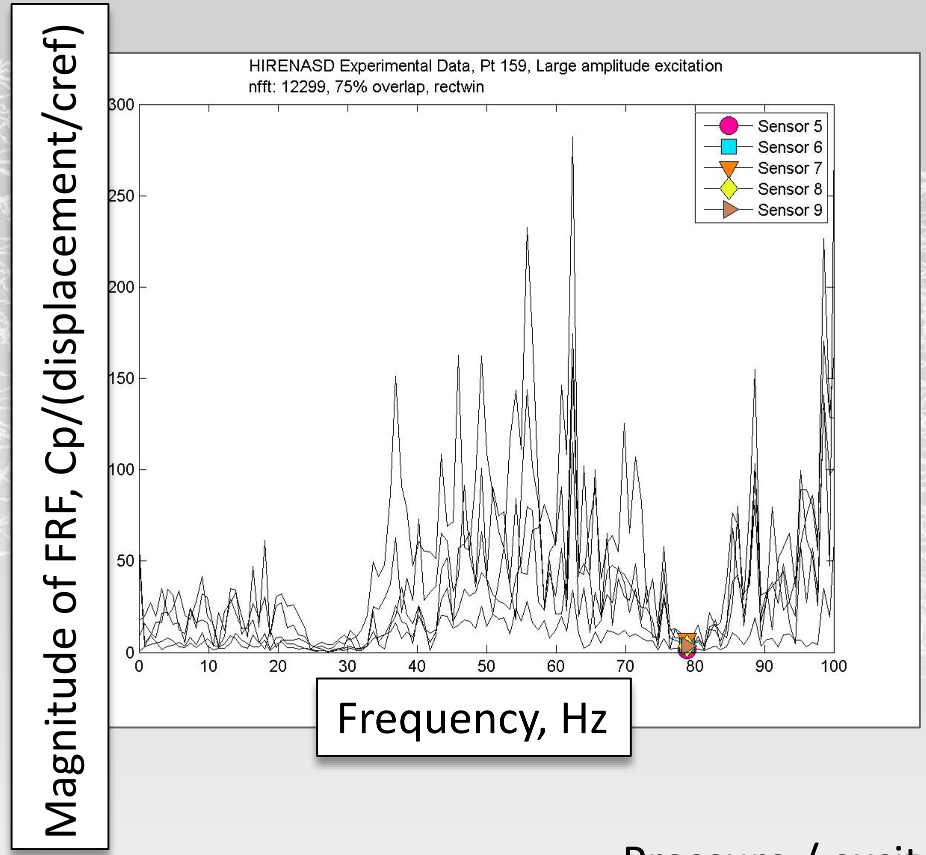
Str = Structured

Unstr = Unstructured

Codes used:

- **FUN3D**
- **CFL3D**
- **Overflow 2.2c**
- **NSMB**
- **NSU3D**
- **ANSYS CFX**

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,

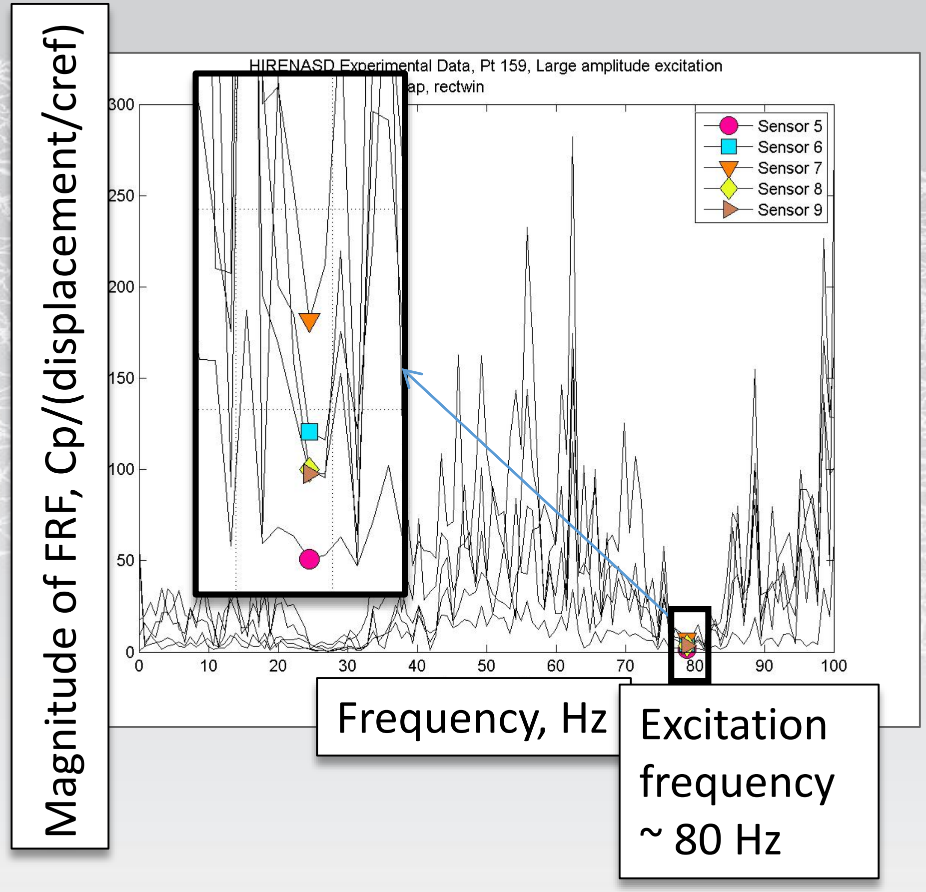
x = displacement
y = Cp

- **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

From AePW-1, using HIRENASD data for the example

Frequency response functions (FRFs) calculation example



Excitation frequency ~ 80 Hz

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

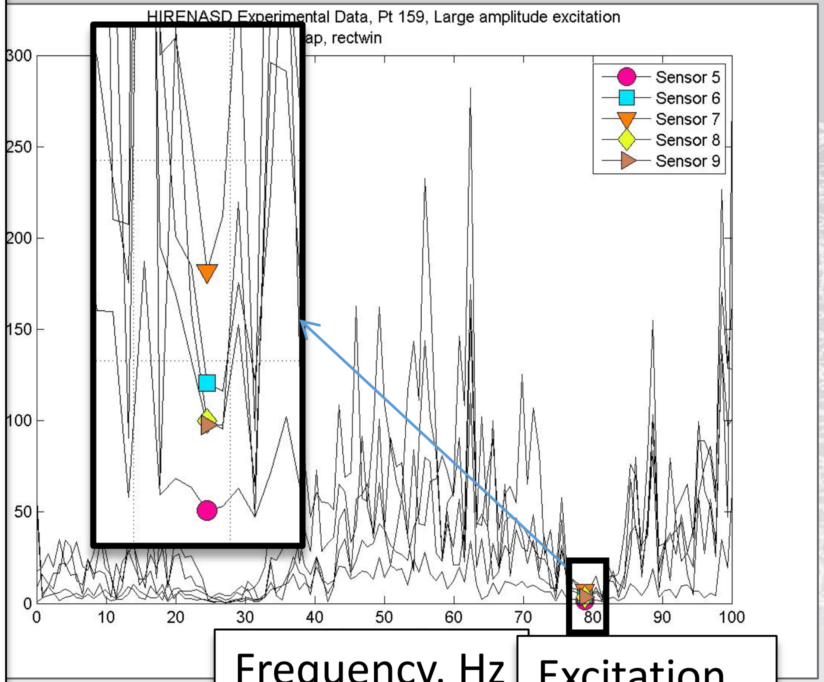
Here,

x = displacement
y = Cp

- 1 FRF for each pressure transducer
- Examine values only at the excitation frequency

From AePW-1, using HIRENASD data for the example

Frequency response functions (FRFs) calculation example



Magnitude of FRF, Cp/(displacement/cref)

Frequency, Hz

Excitation frequency ~ 80 Hz

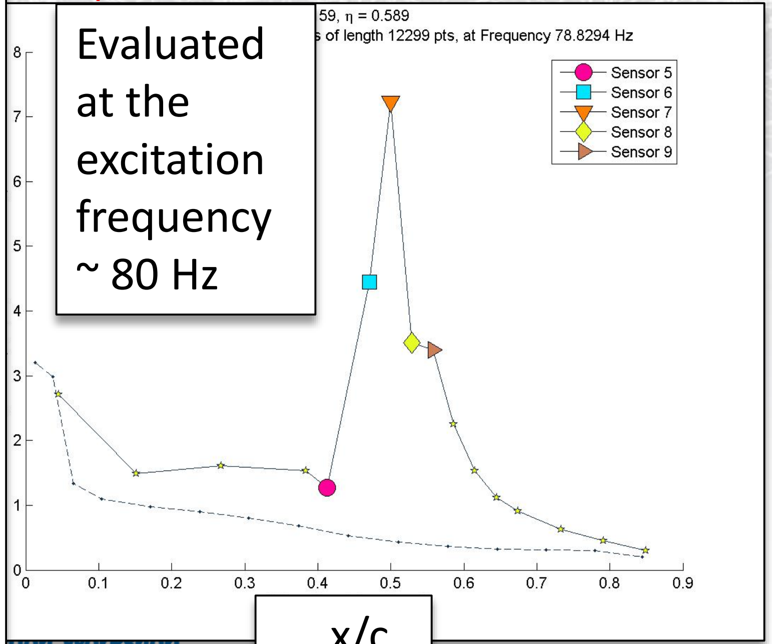
$$FRF(\omega)=\frac{CSD_{x,y}(\omega)}{PSD_x(\omega)}=\frac{FFT(y).*FFT(x)'}{FFT(x).*FFT(x)'}$$

Here,

x = displacement

y = Cp

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



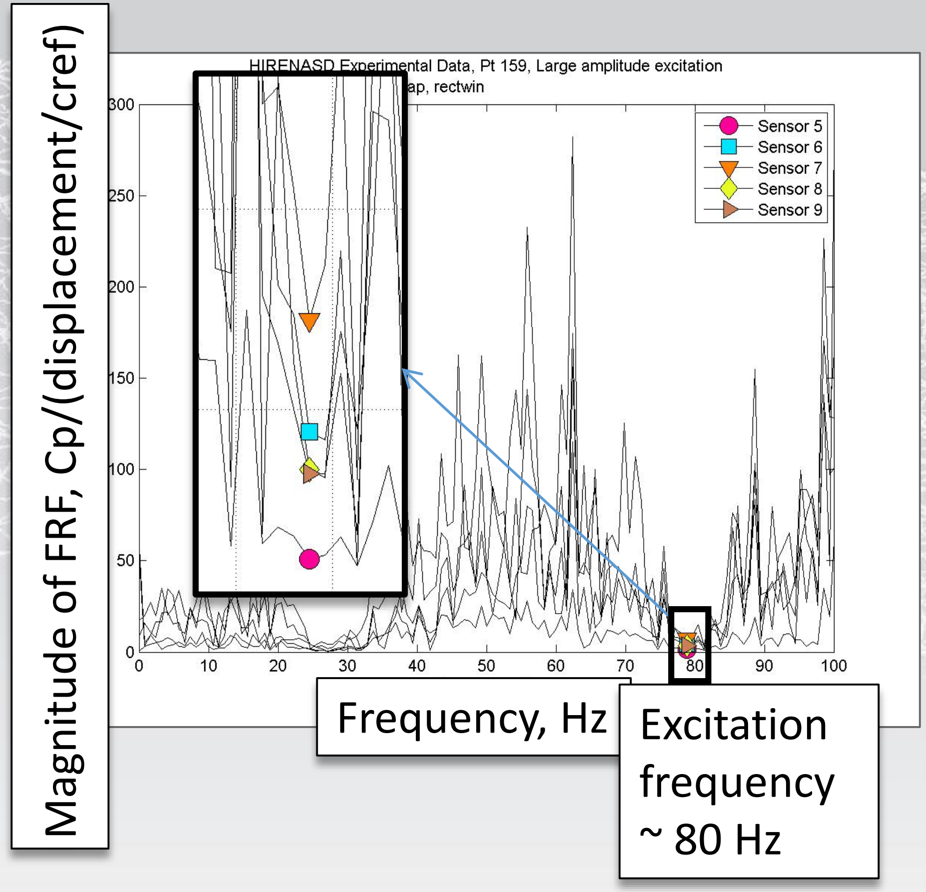
Magnitude of FRF, Cp/(displacement/cref)

Evaluated at the excitation frequency ~ 80 Hz

x/c

From AePW-1, using HIRENASD data for the example

Frequency response functions (FRFs) calculation example



Magnitude of FRF, Cp/(displacement/cref)

Frequency, Hz

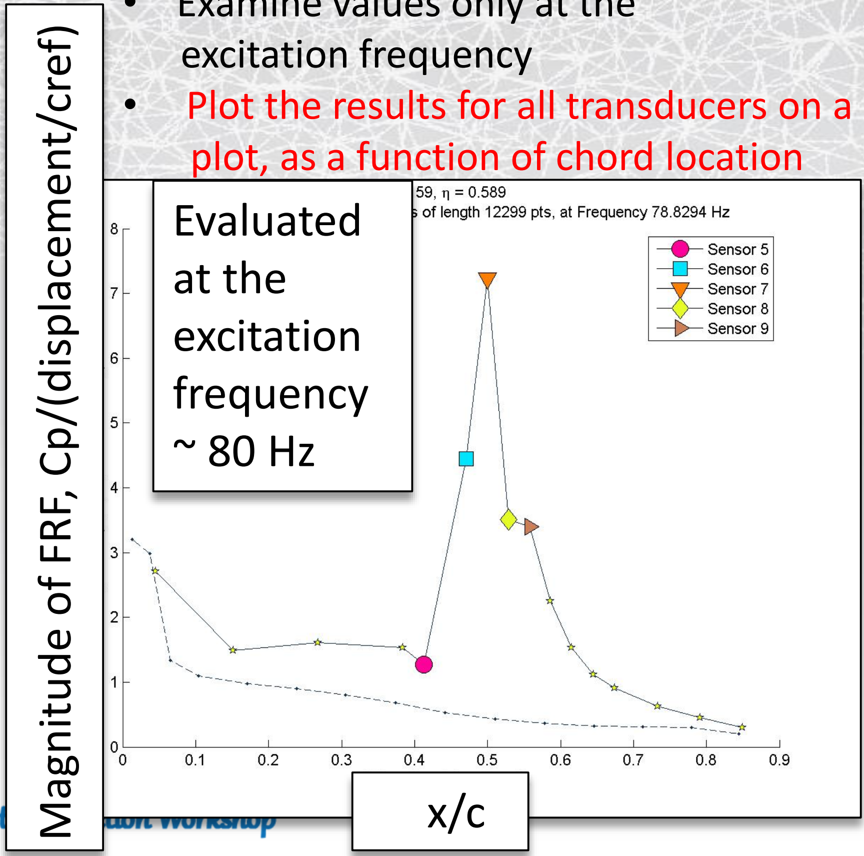
Excitation frequency ~ 80 Hz

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

Here,

x = displacement
y = Cp

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



Magnitude of FRF, Cp/(displacement/cref)

Evaluated at the excitation frequency ~ 80 Hz

x/c

From AePW-1, using HIRENASD data for the example

Uncertainty of FRFs (S4T DataGirl Paper)

- These methods were developed by various references using an assumption of Gaussian-distributed random data, rather than sinusoidal data. The methods were also developed based on non-overlapping segments (i.e. independent data records.).   Other methods were examined but not utilized in this report (see references below for these other methods)
- Douce, J.L, and Balmer, L, “Statistics of frequency response estimates,” IEE Proceedings, Vol 137, Pt D, No 5, September 1990.

- Fornies-Marquina, J.M., Letosa, J. Garcia-Gracia, M, and Artacho, J.M, “Error propagation for the transformation of time domain into frequency domain,” IEEE Transactions on Magnetics, Vol 33, No 2, March 1997.

- Douce, J.L., Widanage, W.D, and Godfrey, K.R., “Errors in frequency response estimates using overlapping blocks with random inputs,” 15th IFAC Symposium on system identification, Saint-Malo, France, July 6-8, 2009.

Nomenclature for FRF Uncertainty slides

- **f = frequency variable, (Hz)**
- **n = number of segments, ensembles, in a Fourier coefficient calculation**
- **$nfft$ = Fourier analysis block size, (samples)**
- **$samp$ = sample rate (samples/sec)**
- **a = statistical significance level**
- **γ^2_{xy} = mean square coherence between an input, x, and an output, y**
- **σ = standard deviation**
- **ω = frequency variable, (radians)**
- **DFT = Discrete Fourier Transform**
- **FRF = Frequency Response Function**
- **G = Open loop plant frequency response function**
- **PSD = Power Spectral Density function**
- **P_{xx} = PSD of the input, x**
- **P_{yy} = PSD of the output, y**
- **^ = approximate quantity based on a data sample**

FRF uncertainty method #1

$$\hat{\sigma}(|\hat{G}(\omega)|) = \frac{\sqrt{1-\hat{\gamma}_{xy}^2(\omega)}}{|\hat{\gamma}_{xy}|\sqrt{2}}|\hat{G}(\omega)| \tag{4}$$

$$\hat{\sigma}(angle(\hat{G}(\omega)) = sin^{-1}\left(\frac{\sqrt{1-\hat{\gamma}_{xy}^2(\omega)}}{|\hat{\gamma}_{xy}|\sqrt{2}}\right) \tag{5}$$

Ref: Doebling, S.W., and Farrar, C.R., Estimation of statistical distributions for modal parameters identified from averaged frequency response function data, Los Alamos National Laboratory, LA-UR-00-41, July 2000.

The confidence intervals or standard deviations of the magnitude and phase of the FRFs can be estimated using the coherence and FRF estimates, which are generated using a given number of data sets. For the S^{4}T analysis case, each overlapped average segment is treated as a separate data set. The data analysis in the reference assumed that the influence of bias errors had been minimized, and the primary source of error was random error arising from unmeasured excitations. The magnitude and phase values at each given frequency were assumed to be Gaussian-distributed random variables.

Error bounds on the FRF estimates are calculated following the method given in the reference, using Eqs (4) and (5). Results produced from this method are denoted FRF Method 1. The upper and lower bounds on the magnitude and phase were calculated using 3σ limits.

FRF uncertainty method #2

A second method to assess the uncertainties of the FRF- denoted FRF Method 2- is applied, following the process outlined in Bendat & Piersol. This method accounts for random error in the measured FRF. Specified in the reference by eqn 6.146, and reproduced here in Eqns (6) and (7), a confidence interval with confidence 100*(1-α)% can be calculated. Equation (6) says that the difference between the estimated plant and the true plant is less than the bound given by (7). From (7), **the error in FRFs is dependent on the degrees of freedom and the coherence**. The uncertainty in the calculation decreases as the number of ensembles, n, used in the averaging for computing the spectral estimates increases or as the coherence increases towards 1.

The S^4T simulation data, with 105 seconds in the time history, with 8192 points in the analysis block size, with 95% overlap has 237 overlapped analysis segments. The associated value of the F-distribution, *F2,235,0.05*= 3.03392. Results from applying FRF Method 2 are shown in Figure 11. The uncertainty bounds are almost identical to those produced by FRF Method 1. There are small changes in the bounds near the zeros- valleys- of the FRFs.

$$\left|\hat{G}(f) - G(f)\right|^2 \leq \hat{r}(f)^2 \qquad (6)$$

$$\hat{r}(f) = \frac{2}{(n-2)} F_{2,n-2,\alpha}\left[1 - \hat{\gamma}^2_{xy}(f)\right]\frac{\hat{P}_{yy}}{\hat{P}_{xx}} \qquad (7)$$

As the number of emsembles increases, the coherence values will decrease. The confidence the coherence value, however, increases with the number of ensembles.

Bendat, J.S., and Piersol, A.G., “Random data: Analysis and measurement procedures,” John Wiley & Sons, Inc, New York, 1971.

Some advice from some experts

- As pointed out by Schoukens, Rolain and Pentelon *"Measuring a periodic signal over an integer number periods removes the leakage problem completely, and we strongly advise the reader to apply periodic excitation signals whenever it is possible."*

*(*Schoukens, J., Rolain, Y., and Pentelon, R, "Analysis of windowing/leakage effects in frequency response function measurements," Automatica 42 (2006) P 27-38.)

- Using a rectangular window has its drawbacks, and one of them is leakage when the frequencies are not exactly windowed by the time length. From Bendat & Piersol, 1980, *"… the large side lobes of (the the frequency domain representation of the window) allow leakage of power at frequencies well separated from the main lobe of the spectral window and may introduce significant anomalies in the estimated spectra, particularly when the data are sinusoidal…"* This has been demonstrated to be the case in the analysis of these multisine data sets.

(Bendat, J.S., and Piersol, A.G., "Engineering applications of correlation and spectral analysis," John Wiley & Sons, New York, 1980.)

Some things recommended for future work (by myself in the DataGirl paper)

- Apply expressions for uncertainties of the FRF and coherence based on sinusoidal assumptions rather than on Gaussian random data assumptions.
- In the cases where the assumption has been made that the segments are non-overlapping, apply and/or develop the expressions for overlapping segments.
- Apply these same general methods to analysis of short time records pertinent to unsteady computational fluid dynamic simulation results.
- Investigate harmonic distortion through simulation results and analytical methods
- Investigate methods for properly representing and combining sources of uncertainty