AePW-2 Website: https://AePW2.larc.nasa.gov

Plans & Example Results for the 2nd AIAA Aeroelastic Prediction Workshop

Jennifer Heeg, Pawel Chwalowski
NASA Langley Research Center

Dave Schuster
NASA Engineering & Safety Center

Daniella Raveh
Technion – Israel Institute of Technology

Adam Jirasek, Mats Dalenbring
Swedish Defense Research Agency, FOI

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AePW-2 KickOff Meeting

- **<u>Tonight</u>: Monday, January 5th, 2015**
- **1900-2100 hrs**
- **Room: Emerald 4**

<u>Agenda</u>

- Open discussion and comments
- Plans for AePW-2
- Locating what you need to participate in AePW-2
- Website tour & Walkthrough of aspects
- Preliminary results from 3 analysis teams already working towards AePW-2
- Comparison of current results (with Experimental data; with AePW-1 results where appropriate)
- Relevant lessons from AePW-1, including examination through the data
- Re-analyses after AePW-1; Things that we're learned
- Q&A
- Future directions presentations and discussions

Outline

- Aeroelastic Prediction
- AePW-2 Plans
- Example Results from OC members
- Concluding Remarks

The most popular questions asked about AePW

What are you trying to do?

How is this different from aerodynamic validation?

Why should I care? Why should I participate?

What are you trying to do?

- **Assess the goodness** of computational tools for predicting aeroelastic response, including flutter
- **Understand why** our tools don't always produce successful predictions
  - Which aspects of the physics are we falling short of predicting correctly?
  - What about our methods causes us to fall short of successful predictions?
- Establish **uncertainty bounds** for computational results
- Establish **best practices** for using tools
- Explicitly **illustrate the specific needs** for validation experimentation- i.e. why what we have isn't good enough

Aeroelastic computational benchmarking

- **Technical Challenge:**

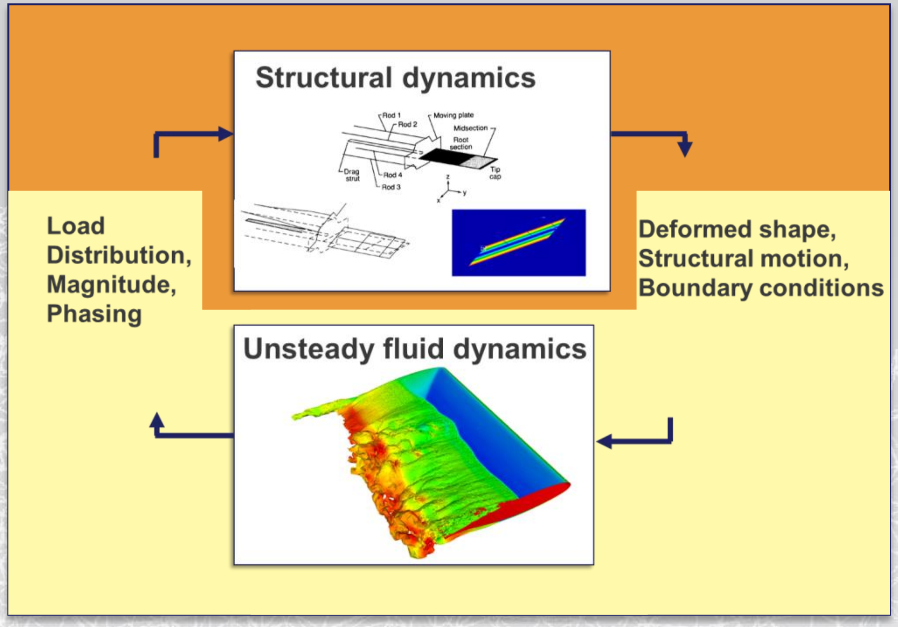
  Assess state-of-the-art methods & tools for the prediction and assessment of aeroelastic phenomena

- **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

AePW building block approach to validation

Utilizing the classical considerations in aeroelasticity

- Fluid dynamics
- Structural dynamics
- Fluid/structure coupling



AePW-1: Focused on Unsteady fluid dynamics

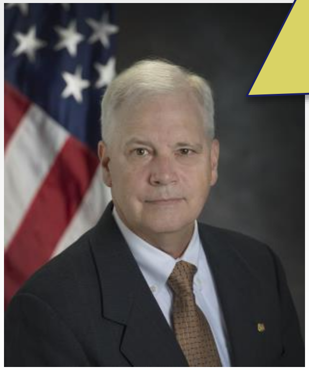
AePW-2: Extend focus to coupled aeroelastic simulations

How does validation of aeroelastic tools differ from validation of aerodynamic tools?

- Obvious (?) differences:
  - Coupling with structural dynamics
  - Unsteady effects matter
- More subtle differences:
  - Distribution of the pressures matters (integrated quantities such as lift and pitching moment tell you little regarding aeroelastic stability)
  - Phasings of the pressures relative to the displacements matter

Why should our organization participate? What do we get out of participating?

- Evaluation of your own methodologies and/or abilities to apply computational tools
- Experience of others brought to bear on examining your results in a critical thinking environment
- Inclusion of your results in determining best practices, uncertainty levels in predictions
- Identification of
  - Areas where your tools meet your required level of predictive and analytical capabilities
  - Benefits to be gained by added analytical complexity
  - Areas where you want to further refine your capabilities
- Detailed supporting information for
  - Advocacy within your organization
  - Advocacy to your customers
- Leveraging the work of others



Outline

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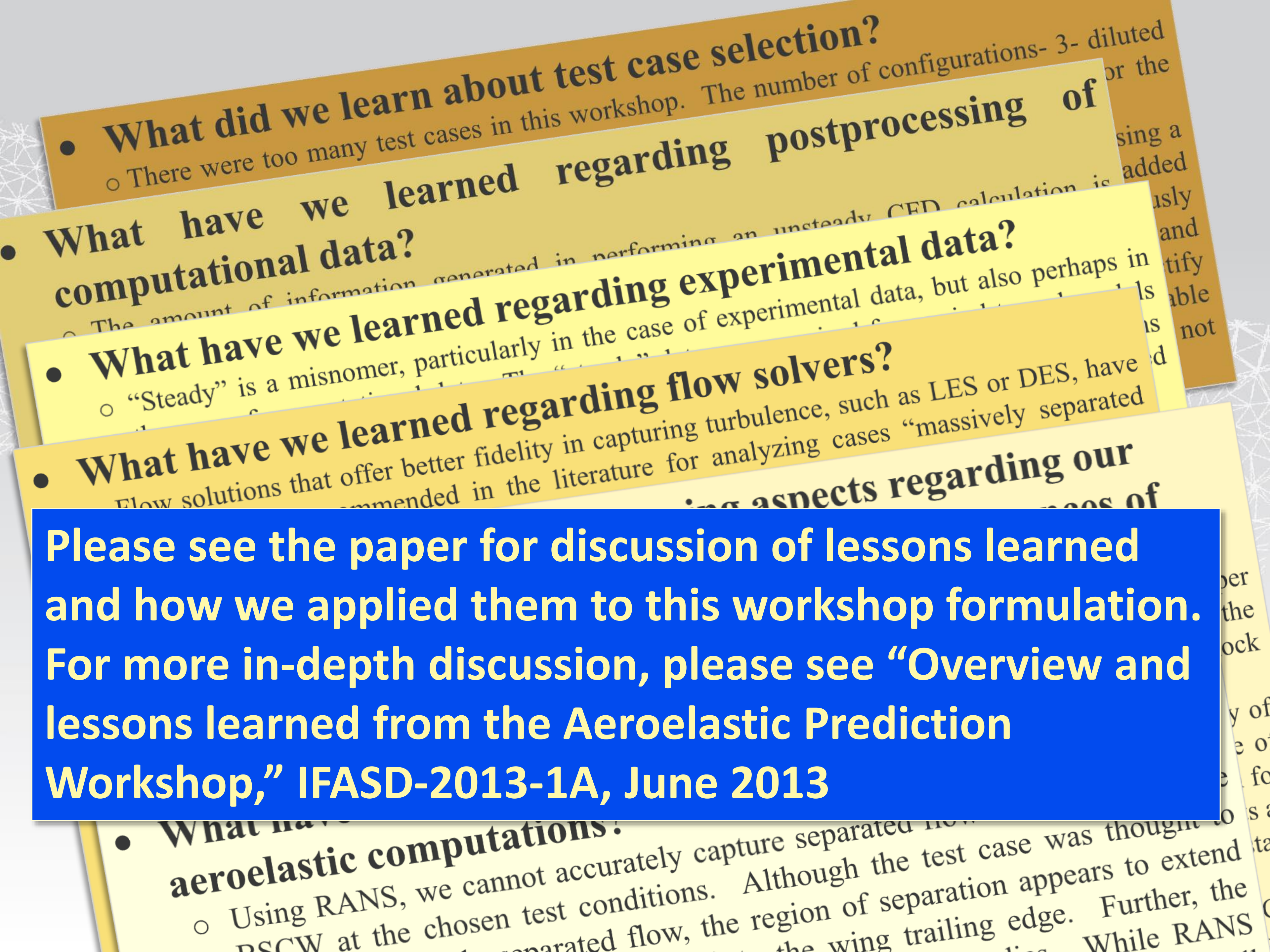
- AePW-2 Plans
- Example Results from OC members
- Concluding Remarks

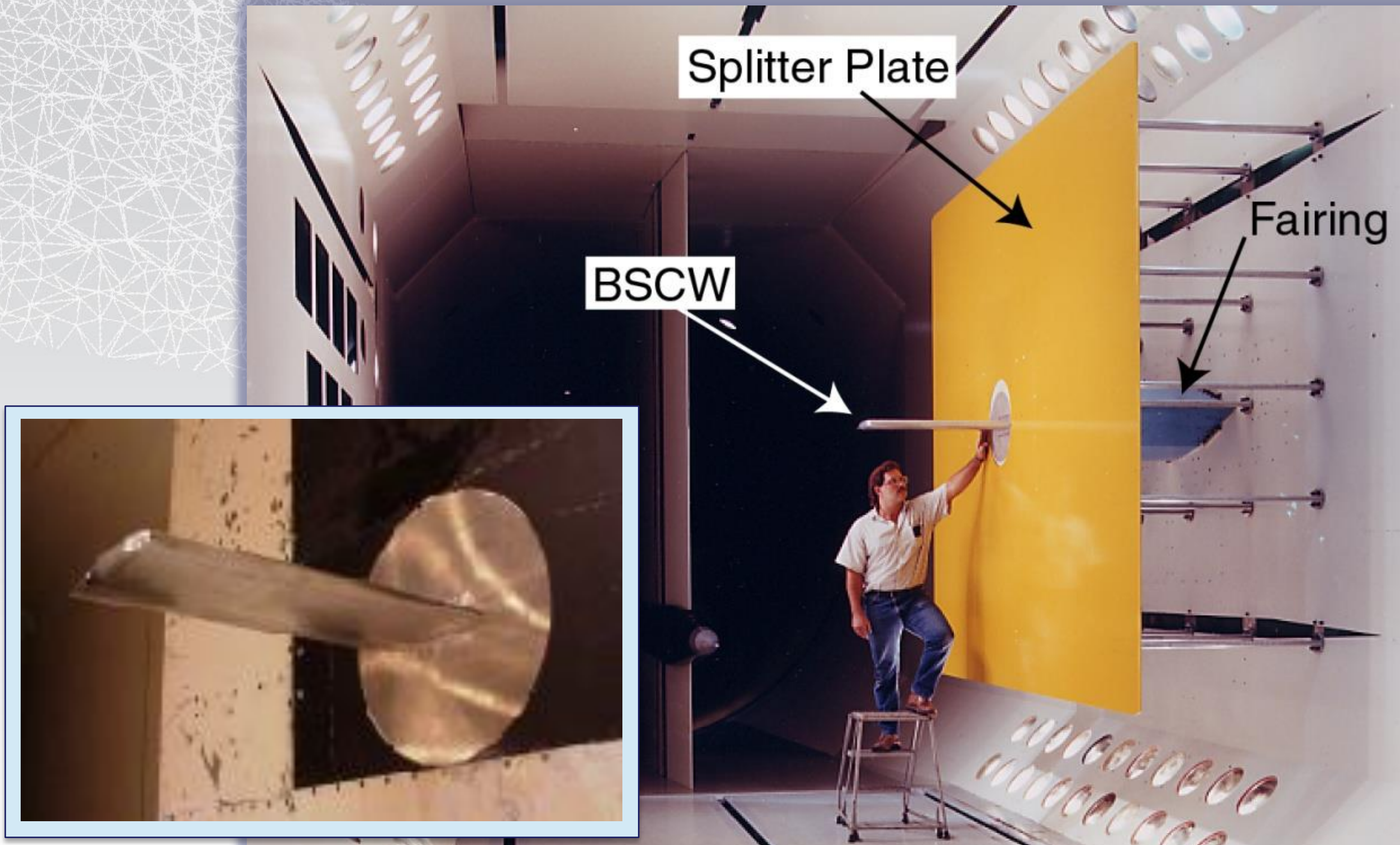


Please see the paper for discussion of lessons learned and how we applied them to this workshop formulation. For more in-depth discussion, please see "Overview and lessons learned from the Aeroelastic Prediction Workshop," IFASD-2013-1A, June 2013

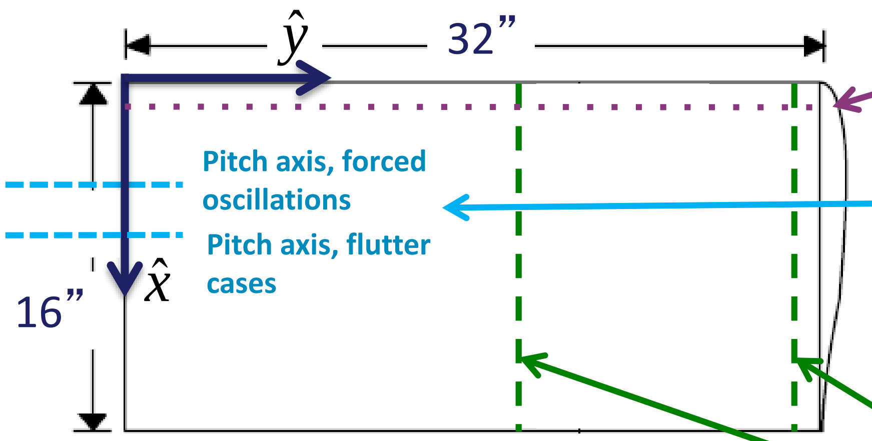
AePW-1: Applying the Lessons Learned

- One configuration only
- Benchmarking case: including a case that we have confidence can be "well-predicted"
- Comparison metrics:
  - Unsteady quantities for all cases
  - Integrated sectional forces and moments
  - Critical damping ratios and frequencies
  - Extended statistics: mean, std, mode, max, min
- Time histories from solutions requested because
  - nothing is steady
  - single person, single method of post-processing matters
  - there's always more to see- nonlinearities, off-nominal frequency content
- Results requested at more finely spaced points than experimental data
- Common grids suggested for analyses
- Various fidelity aerodynamic contributions encouraged
- Discussion telecons for analysis teams

Benchmark Supercritical Wing (BSCW)



BSCW test configurations



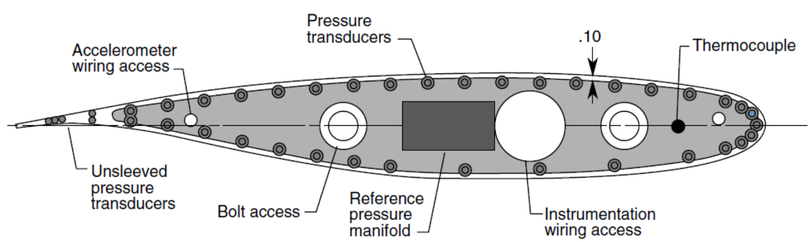
Model planform. Dimensions are in inches.

Transition Strip: 7.5% chord

Pitch Axis:
Forced Oscillation, (OTT Test): Pitching motion about 30% chord
Flutter, (PAPA Test): Pitching motion about 50% chord

Unsteady Pressure Measurements:
- 1 chord fully-populated at 60% span for both tests
- Outboard chord at 95% span populated for the PAPA test only (not for forced oscillation cases)

Airfoil section is SC(2)-0414



Cross-section at 60% span, showing the layout of the unsteady pressures.

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

Mach	0.6	0.7		0.8			0.85	0.87	
q (psf) / α^0	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

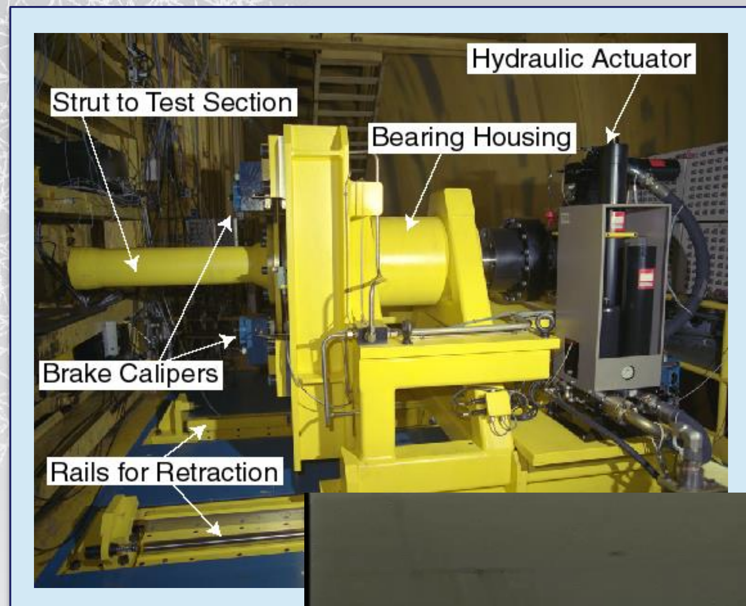
You are invited to participate in AePW-2

Extend focus to coupled aeroelastic simulations

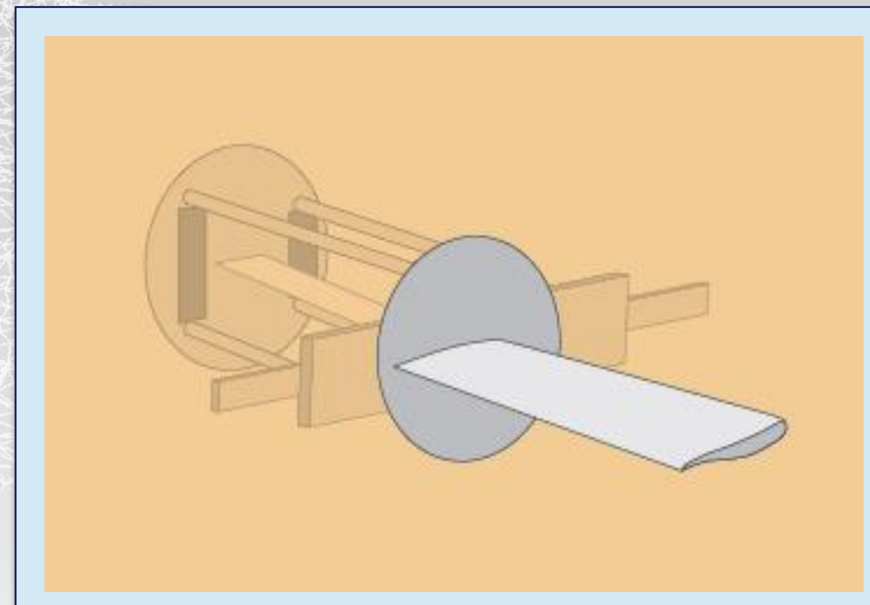
	Case 1	Case 2	Optional Case 3		
			A	B	C
Mach	0.7	0.74	0.85	0.85	0.85
Angle of attack	3	0	5	5	5
Dynamic Data Type	Forced Oscillation	Flutter	Unforced Unsteady	Forced Oscillation	Flutter
Notes:	• Attached flow solution • Oscillating Turn Table (OTT) exp data	• Unknown flow state • Pitch and Plunge Apparatus (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

Mount systems

Oscillating TurnTable (OTT)
for Forced Oscillation Cases



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	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.

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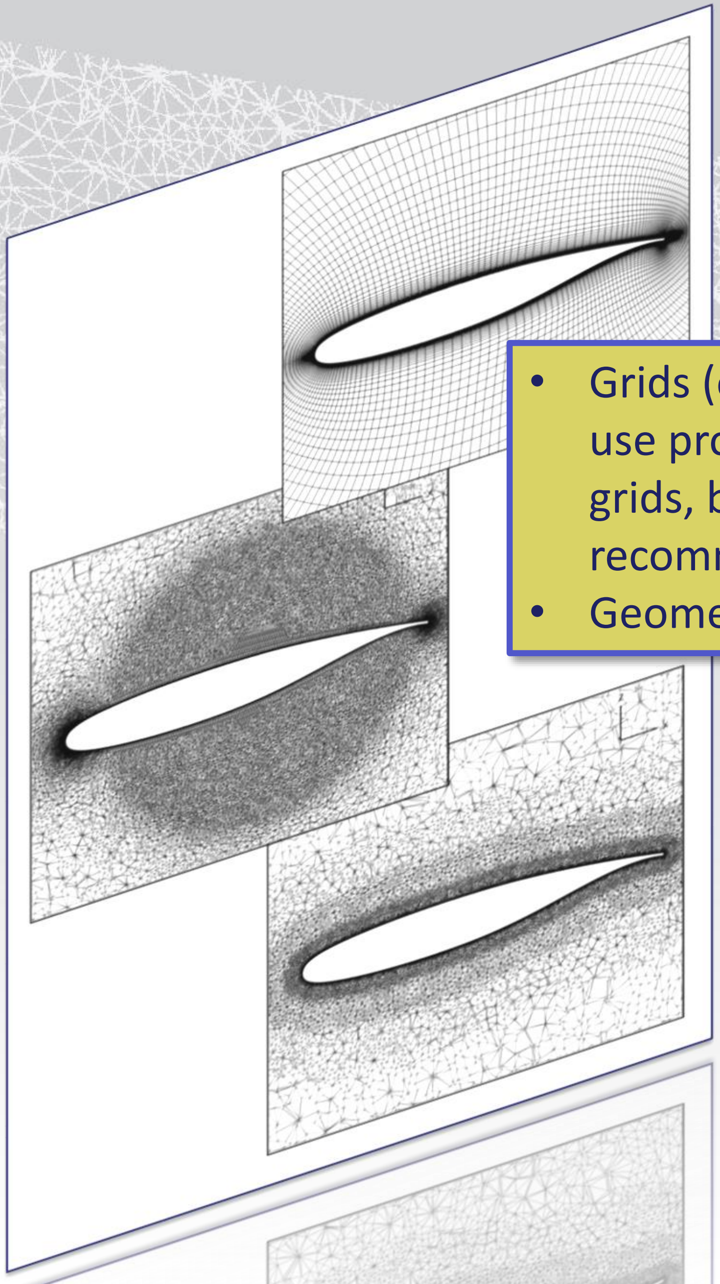
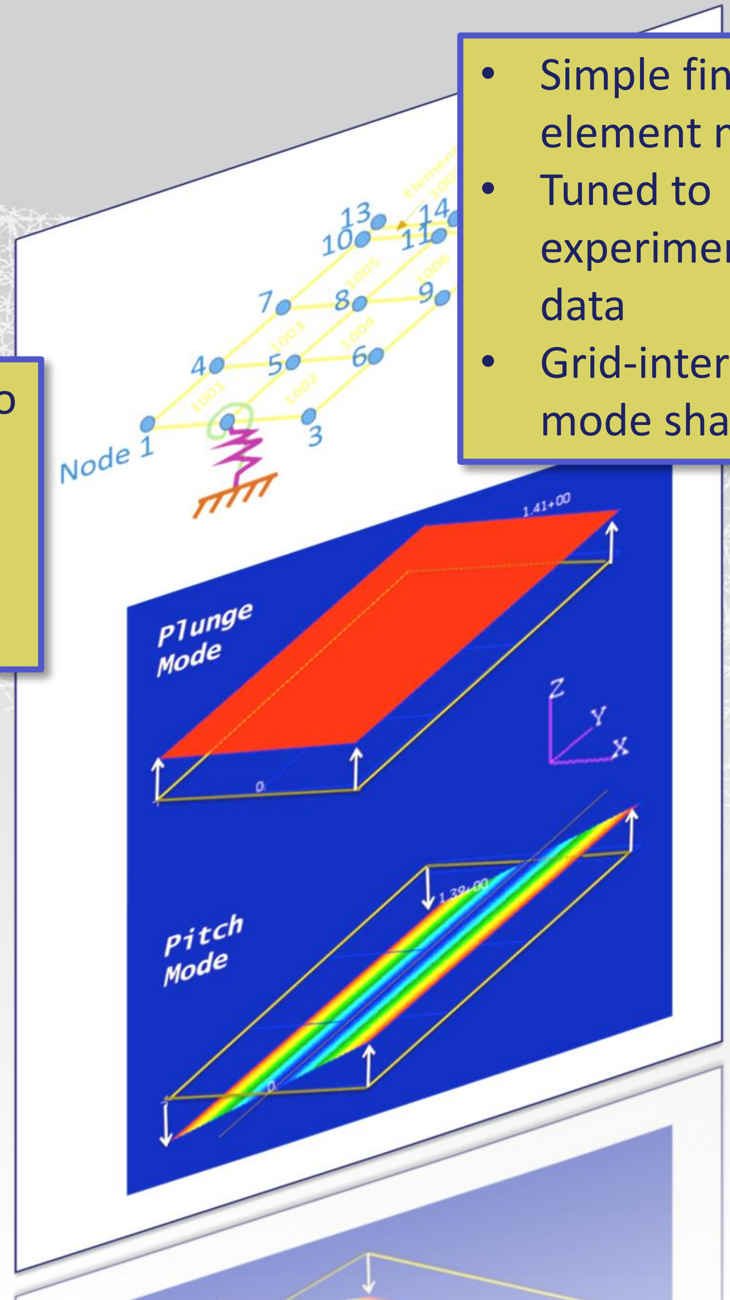
Computational information provided



- Grids (optional to use provided grids, but recommended)
- Geometry



- Simple finite element model
- Tuned to experimental data
- Grid-interpolated mode shapes

Overview of requested submittal data sets

- Steady rigid pressure coefficient distributions: statistics of the results
- Time histories
  - Angle of attack
  - Leading and trailing edge displacements
  - Pressure coefficients
  - Lift & pitching moment coefficients
  - Sectional lift & pitching moment coefficients
- Frequency response functions: C_p/θ
  - At forced oscillation or flutter frequency
  - Across 0-100 Hz
- Static aeroelastic pressure coefficient distributions: statistics of the results
- Flutter bounds

Outline

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Case #1: Attached flow Forced Oscillation case

	Case 1	Case 2	Optional Case 3		
			A	B	C
Mach	0.7	0.74	0.85	0.85	0.85
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

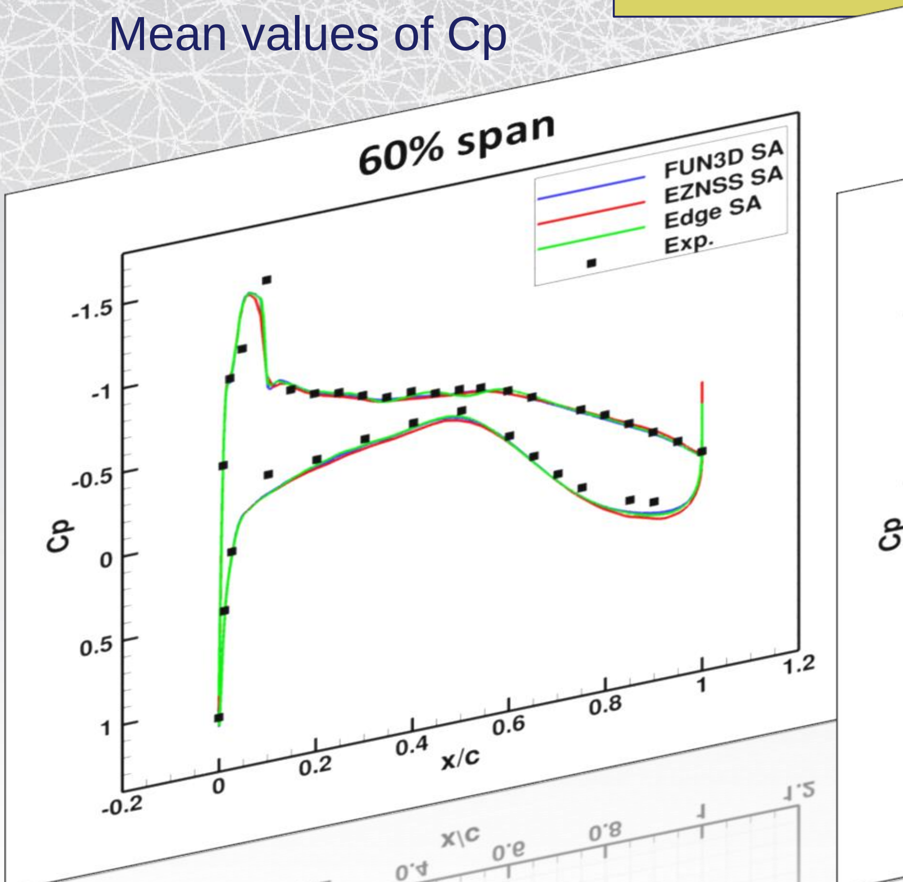
Steady rigid pressure distributions

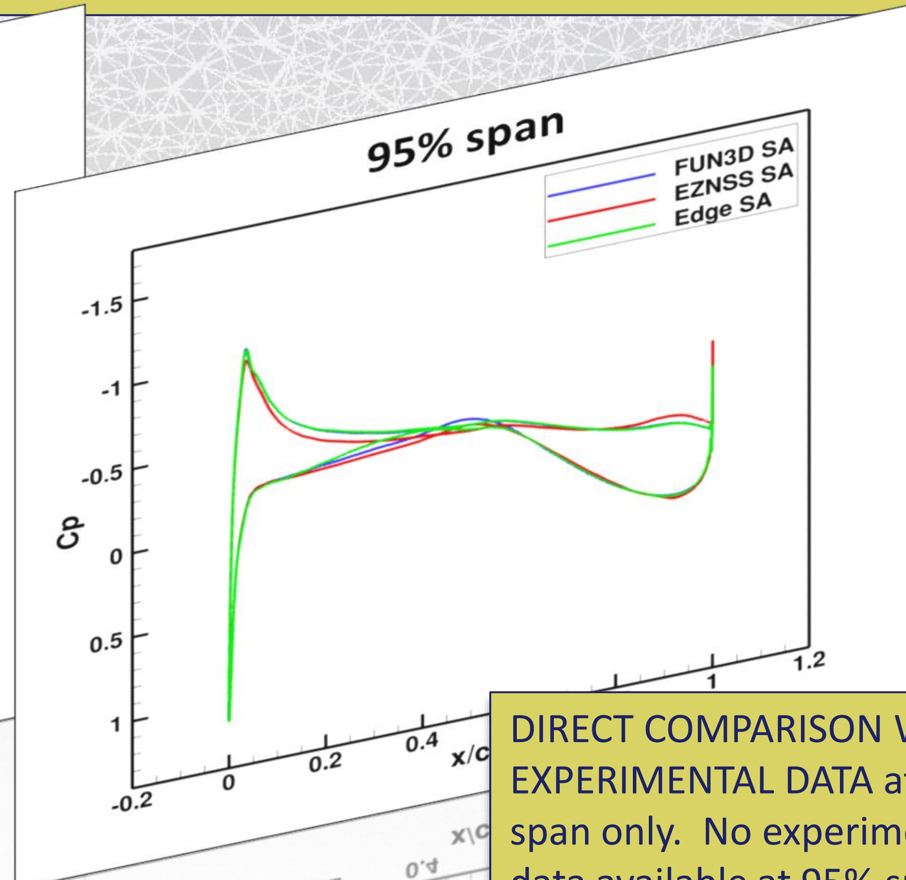
Example Results for Case #1
Mean values of Cp

These computational results agree much better with the experimental data than the case for AePW-1 (Case #3 for AePW-2)

Static pressure comparisons are a relatively easy and almost-for-free comparison enroute to the unsteady results comparisons

Results from 3 separate analysis codes are shown here. (Reynolds Averaged Navier Stokes simulations with Spalart-Allmaras turbulence models)



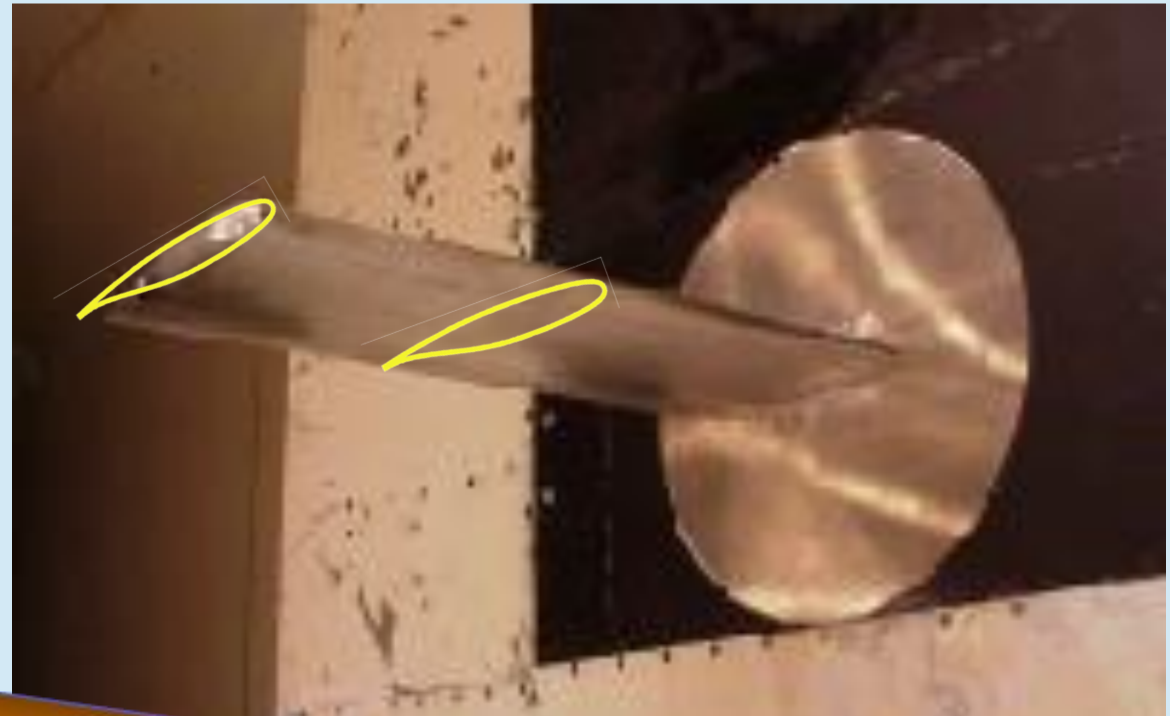


DIRECT COMPARISON WITH EXPERIMENTAL DATA at 60% span only. No experimental data available at 95% span.

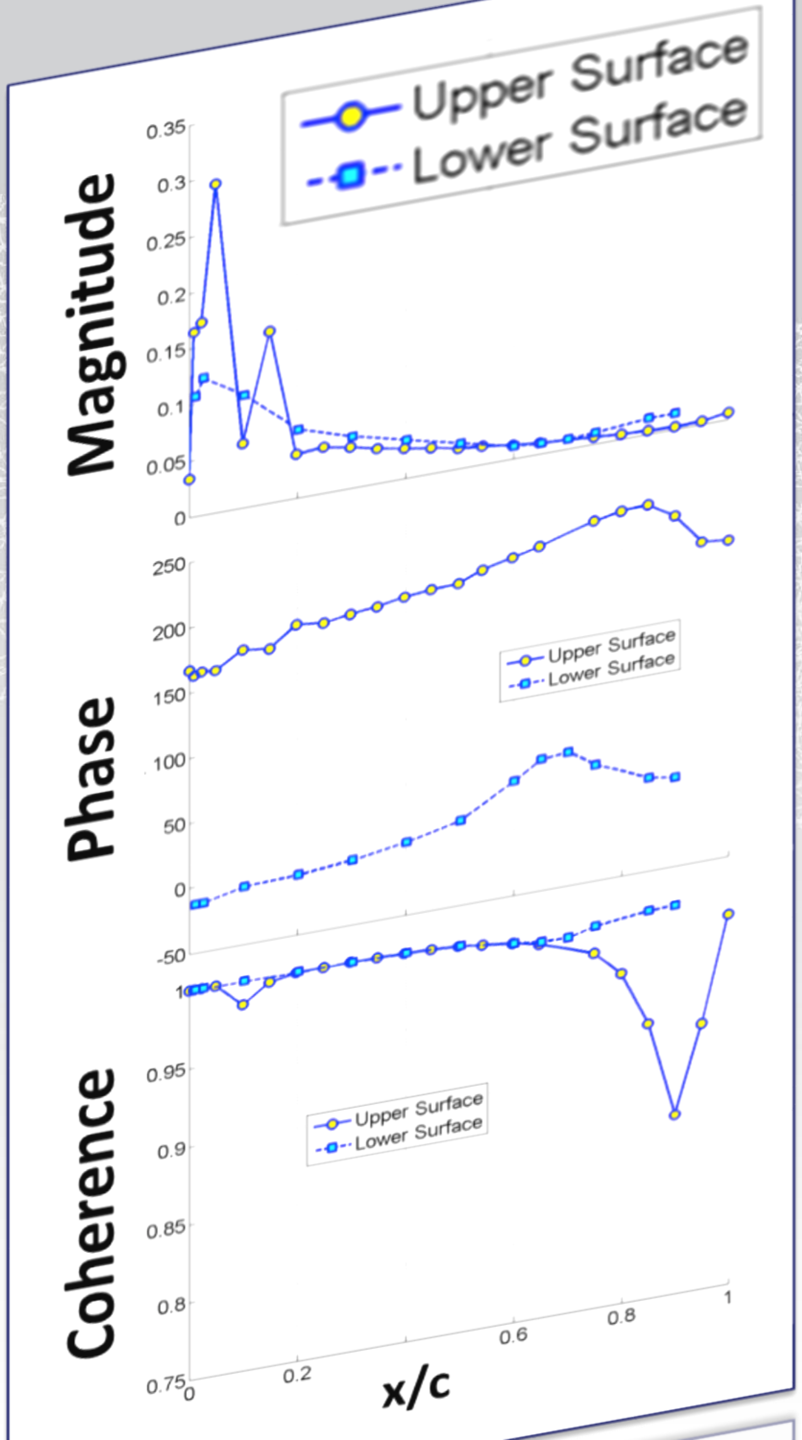
Forced Oscillation data and results are requested at the following locations & conditions

Forced Oscillation Con

- FRFs at excitation frequency
  - Experimental comparison d
  - FRFs as functions of chord
- Time history data
  - Angle of attack
  - Leading and trailing edge di
  - Pressure coefficients
  - Lift & pitching moment coeff
  - Sectional lift & pitching mon
- FRFs fr



At experiment dynamic pressure				
Span Station	60%		95%	
Surface	U	L	U	L



Case #1 Frequency Response Functions for Forced Oscillation C_p / α

- Forced oscillation at 10 Hz
- FRFs shown at 10 Hz, as functions of chord
- Shown here only for the experimental data
- Experimental data available only at 60% span

Case #2: Low Mach number Flutter Simulations

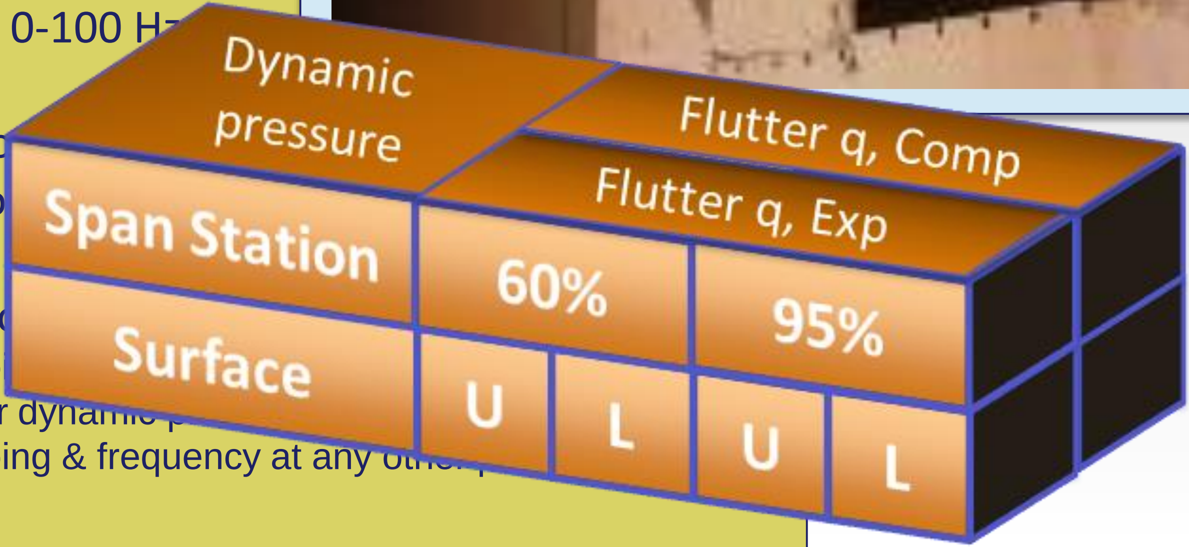
Extend focus to coupled aeroelastic simulations

	Case 1	Case 2	Optional Case 3		
			A	B	C
Mach	0.7	0.74	0.85	0.85	0.85
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

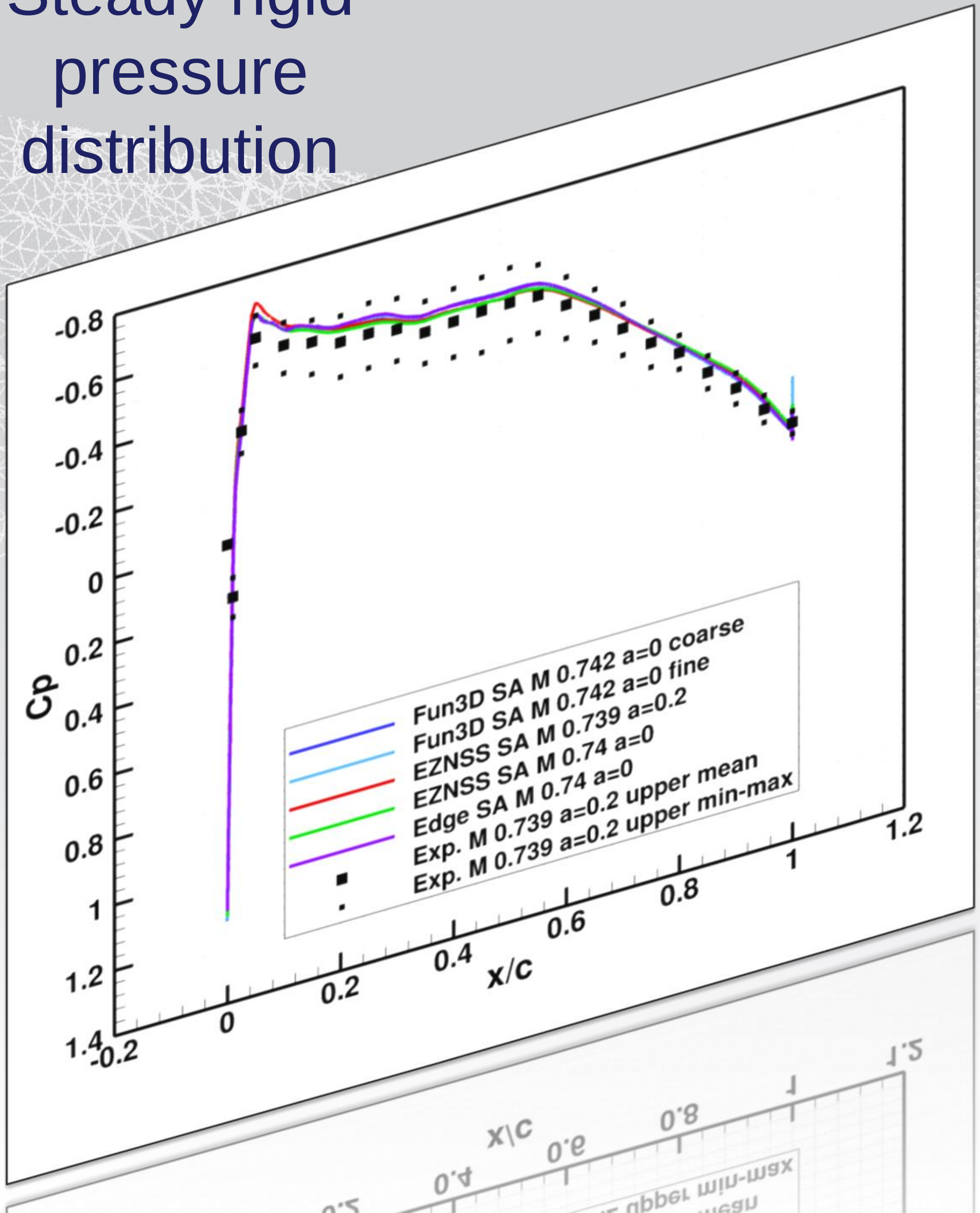
Flutter simulation data and results are requested at the following locations & conditions

Flutter Simulation C

- FRFs at flutter frequency:
  - Experimental compariso
  - FRFs as functions of ch
- Time history data
  - Angle of attack
  - Leading and trailing edg
  - Pressure coefficients
  - Lift & pitching moment c
  - Sectional lift & pitching m
- FRFs from 0-100 Hz
- Static aero distributio
- Flutter info
  - Dampi
  - Flutter dynamic p
  - Damping & frequency at any other p



Steady rigid pressure distribution



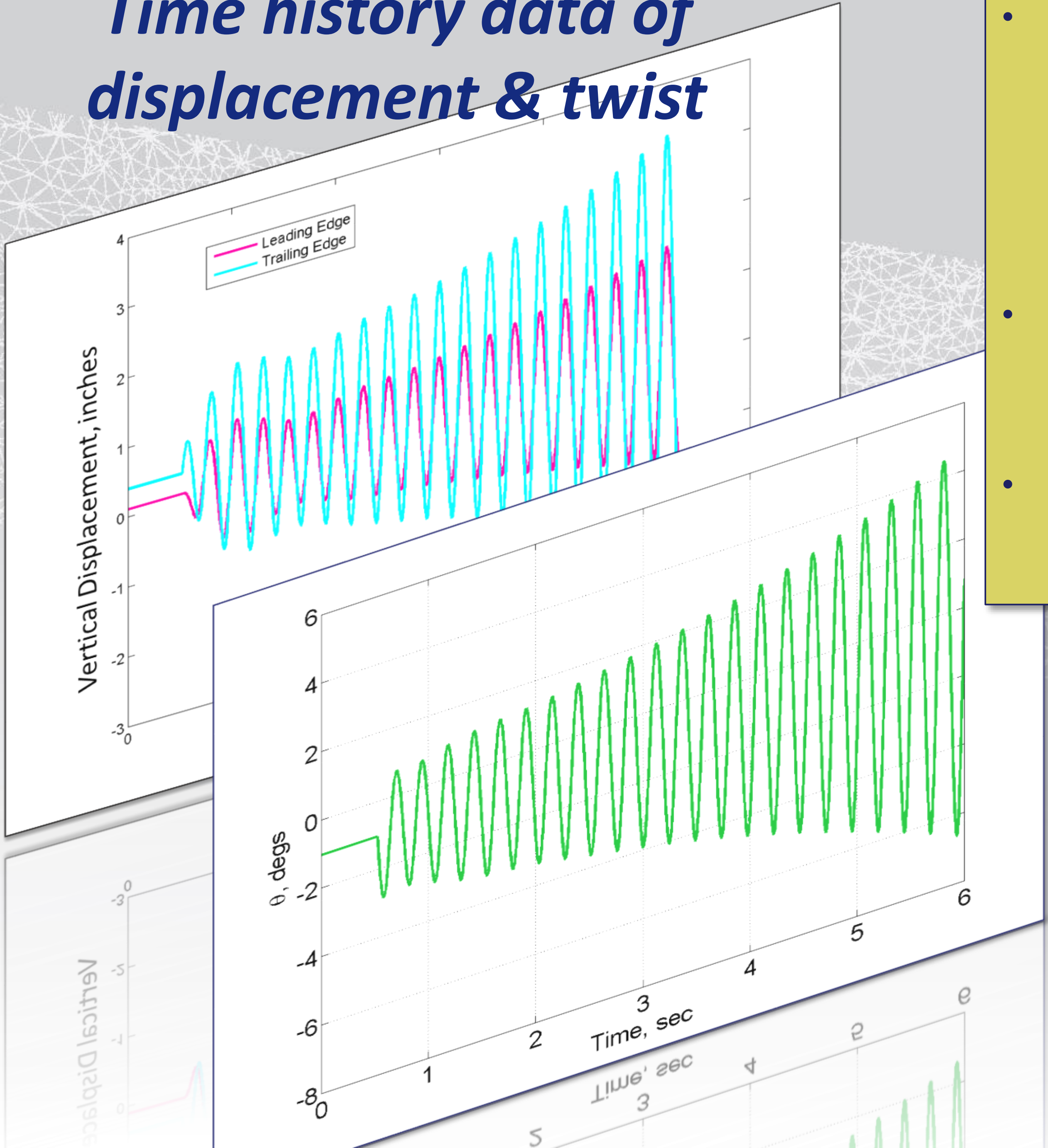
Example results for Case #2
Mean values of Cp
at 60% Span Station
Upper Surface

Results from 3 separate analysis codes are shown here.
(Reynolds Averaged Navier Stokes simulations with Spalart-Allmaras turbulence models)

Small perturbations on the angle of attack and Mach number were investigated. These perturbations are not part of the AePW-2 case matrix.

DIRECT COMPARISON WITH EXPERIMENTAL DATA

Time history data of displacement & twist

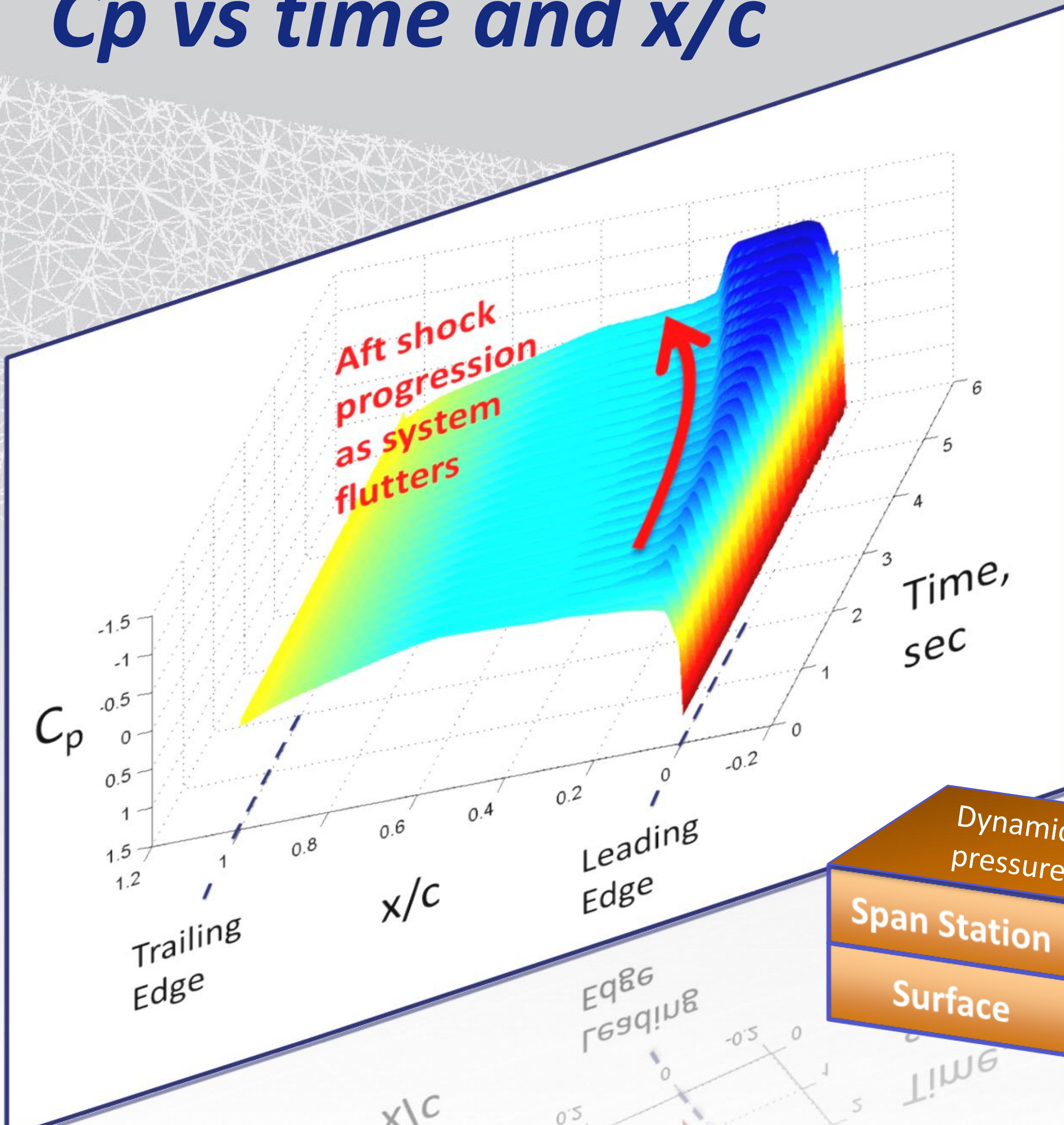


- These example results were calculated using
    - URANS + SA
    - Medium fidelity grid
    - Relatively coarse time step
    - 168.8 psf, the experimental flutter dynamic pressure
- The growing displacements and angles show that this solution predicts that flutter onset occurs at a lower dynamic pressure.
- The twist angle time history was analyzed to produce the damping and frequency results

This data is requested

- At the experimental flutter dynamic pressure
- At the computational flutter dynamic pressure
- At 95% span only
  (The wing itself is rigid, so span station will not matter)

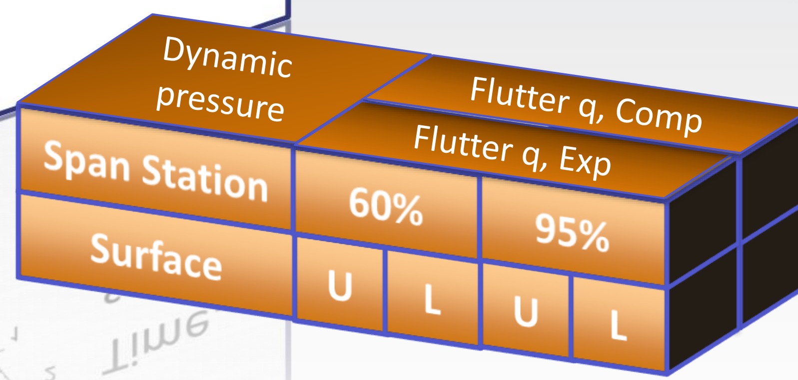
Cp vs time and x/c



The results shown here are at 60% span for the upper surface at the dynamic pressure of the experimental data set (168.8 psf)

Data sets are requested at

- 60% and 95% span
- Upper & lower surfaces
- Experimental flutter condition (168.8 psf) & Computational flutter condition as determined by each analysis team



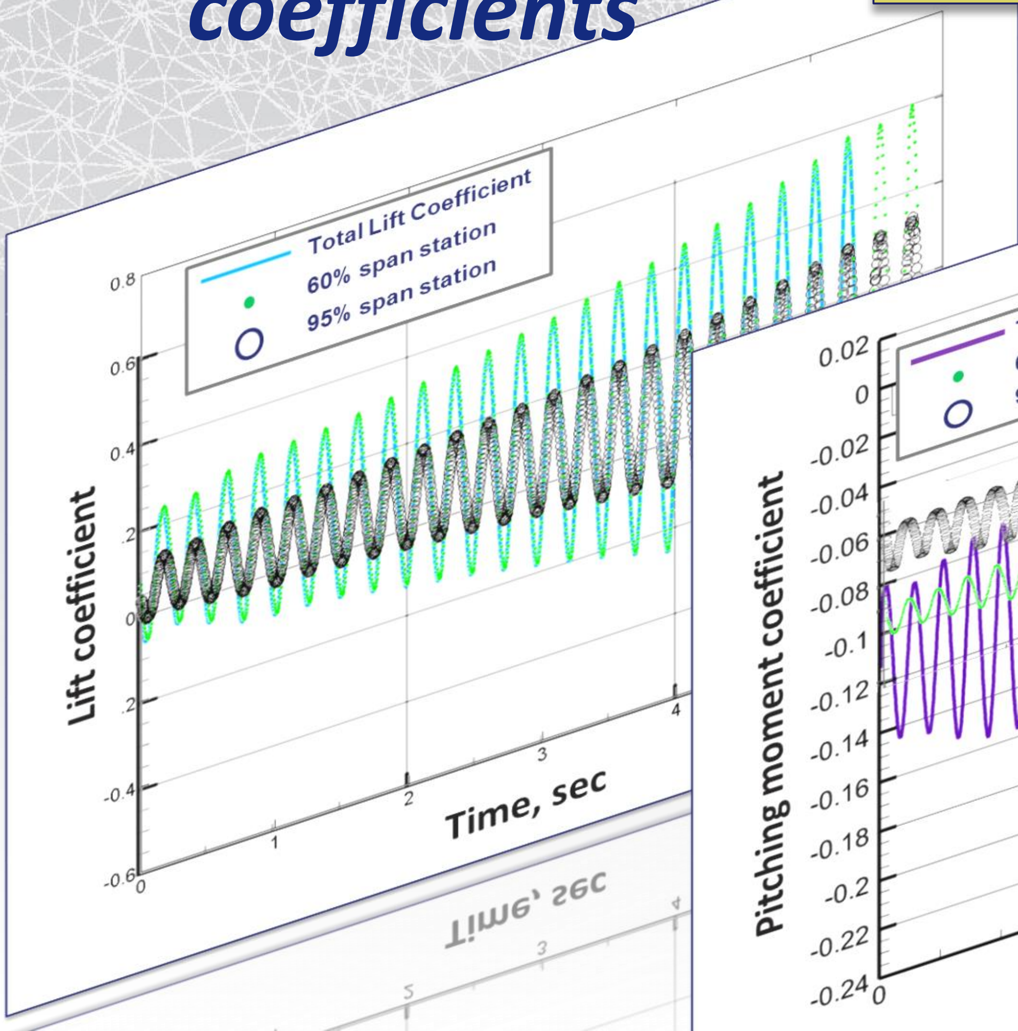
Time histories of Lift & Pitching moment coefficients

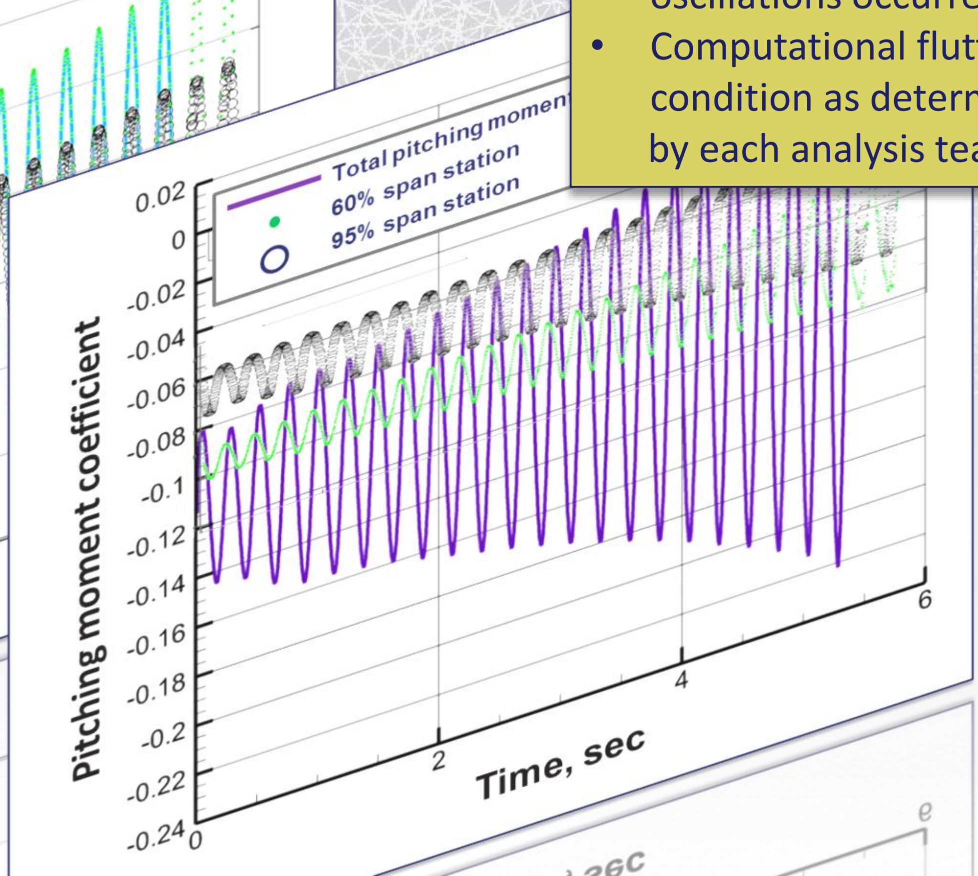
Quantities

- Total lift & pitching moment coefficients for the wing
- Sectional lift & pitching moment coefficients at
  - 60% span
  - 95% span

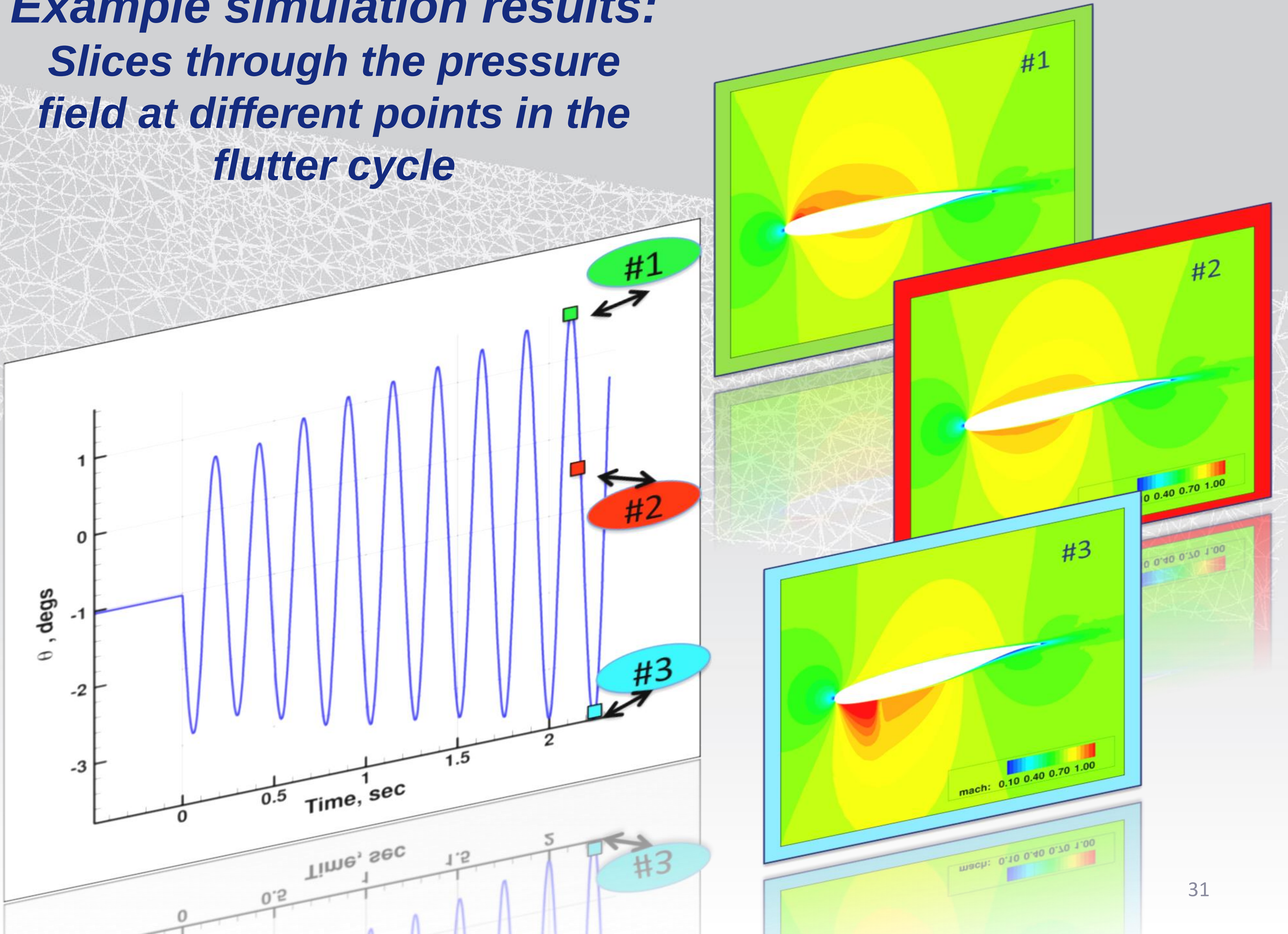
Dynamic pressures

- 168.8 psf: Experimental dynamic pressure where unstable aeroelastic oscillations occurred
- Computational flutter condition as determined by each analysis team



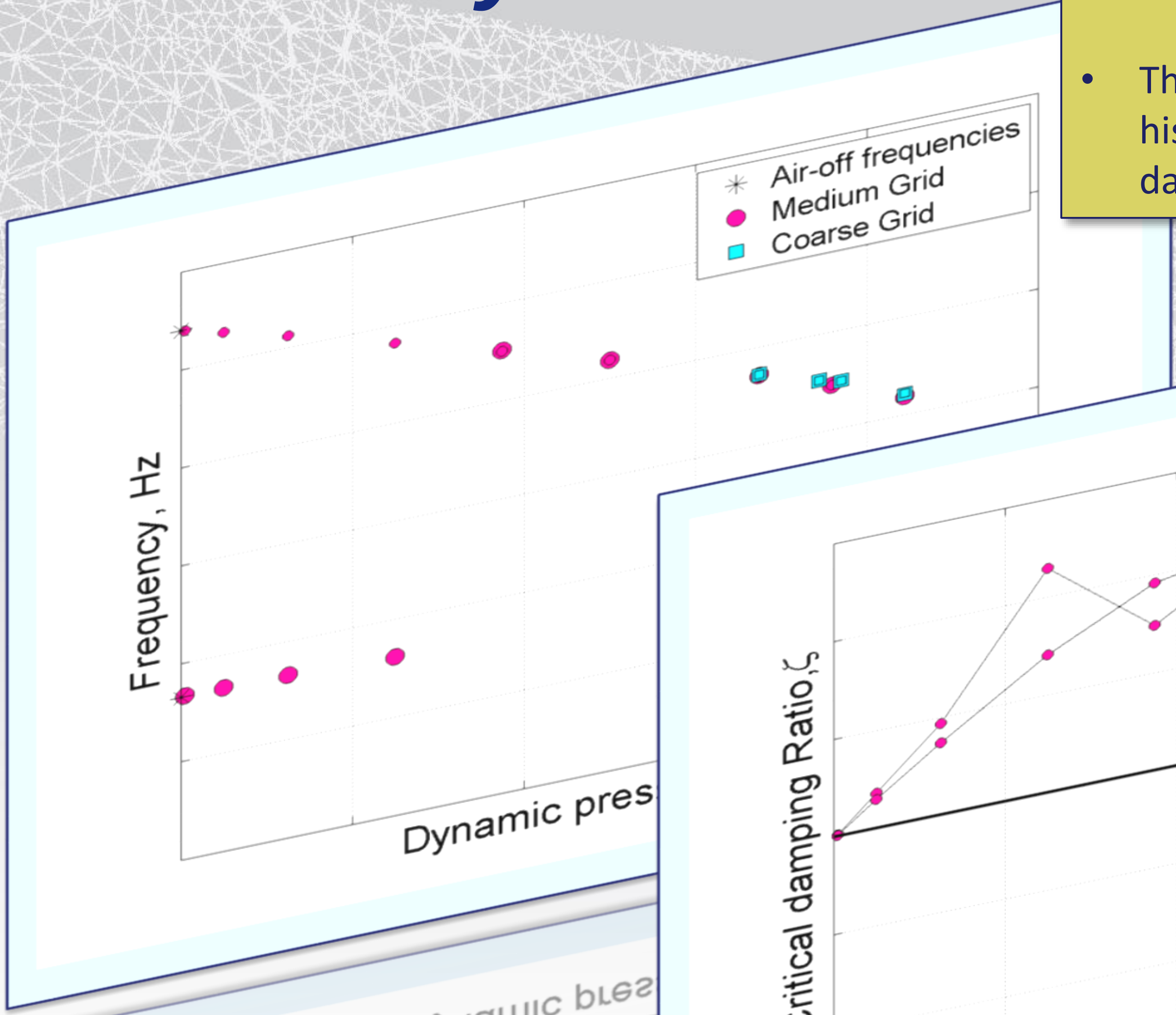


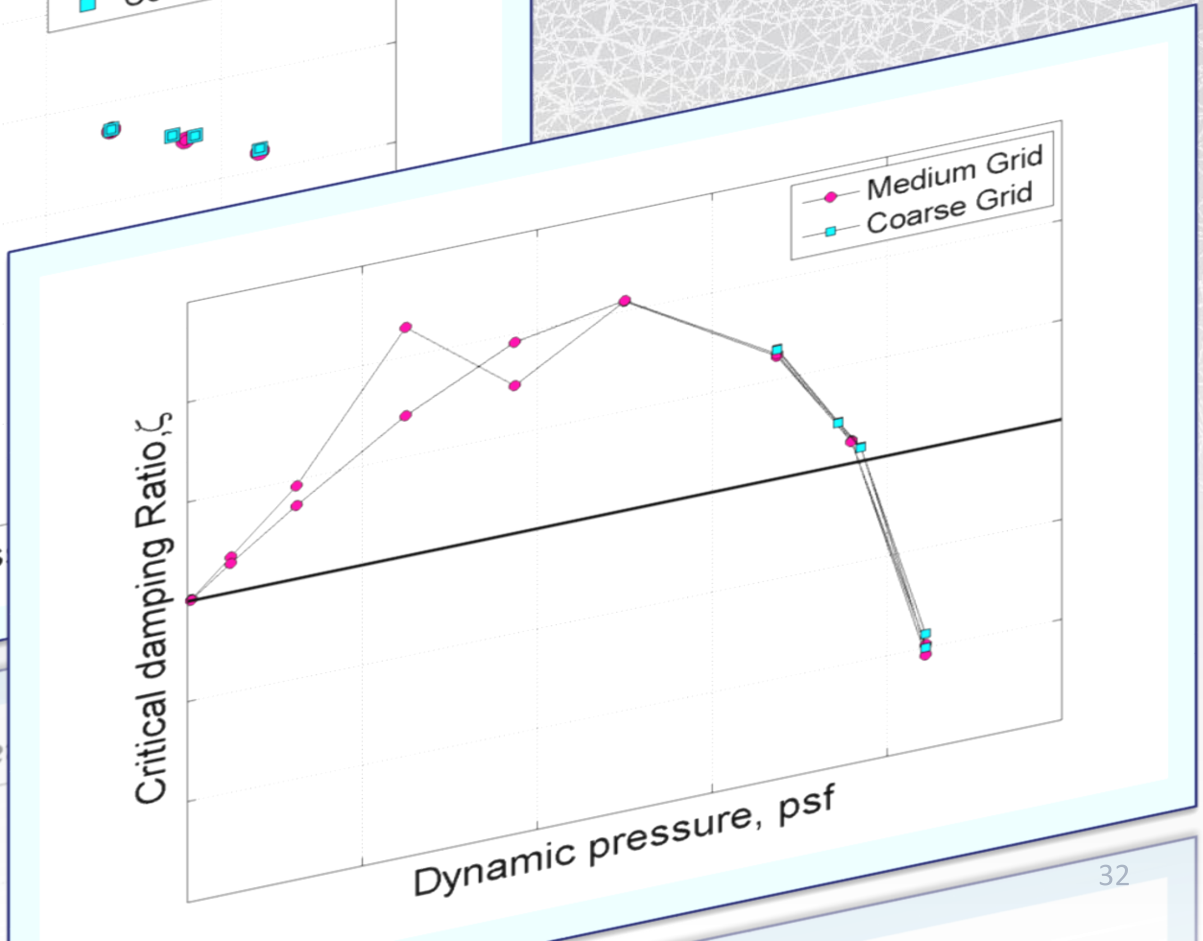
Example simulation results:
Slices through the pressure field at different points in the flutter cycle



Example Flutter summary results

- These example results were calculated using
  - URANS + SA
  - Medium fidelity grid
  - Relatively coarse time step
- The generalized displacement time histories were analyzed to produce the damping and frequency results





Optional analysis case: Mach 0.85

- Repeat of AePW-1 test case, in part
- Investigate unsteady separated flow modeling
- Utilize time-accurate methodology for unforced "steady" solution
- Utilize higher fidelity modeling and/or different turbulence modes
- Investigate solution convergence, especially temporal convergence

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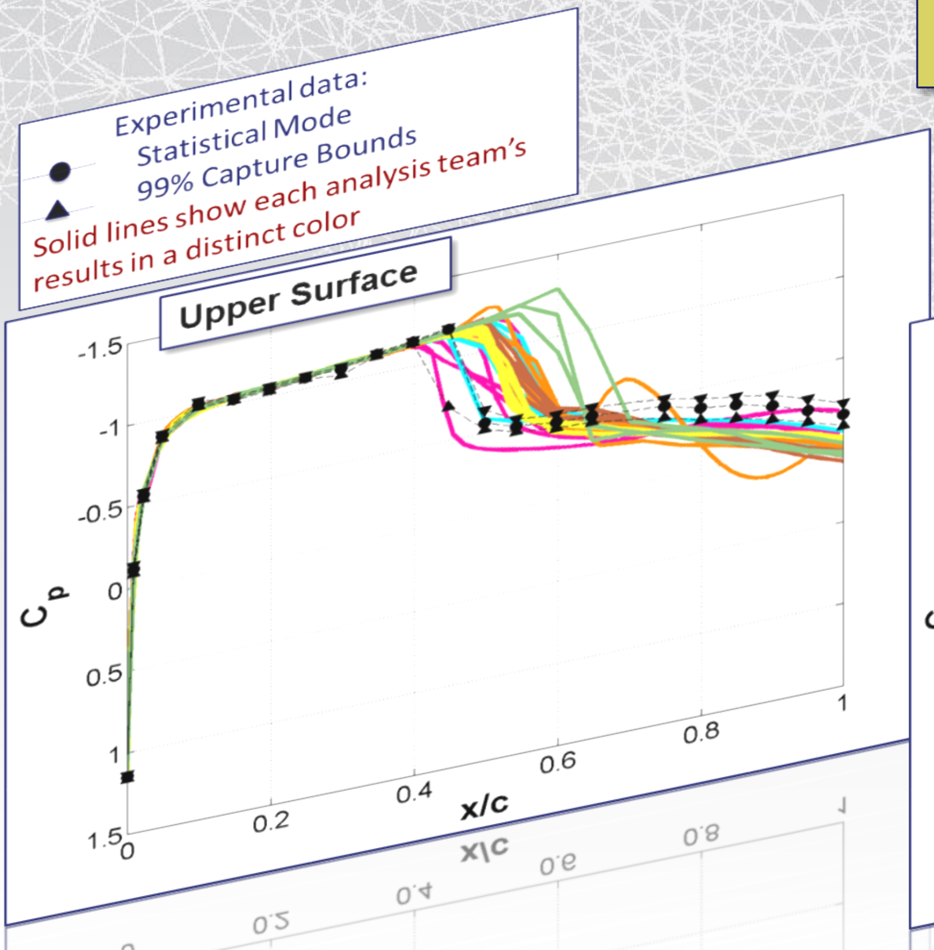
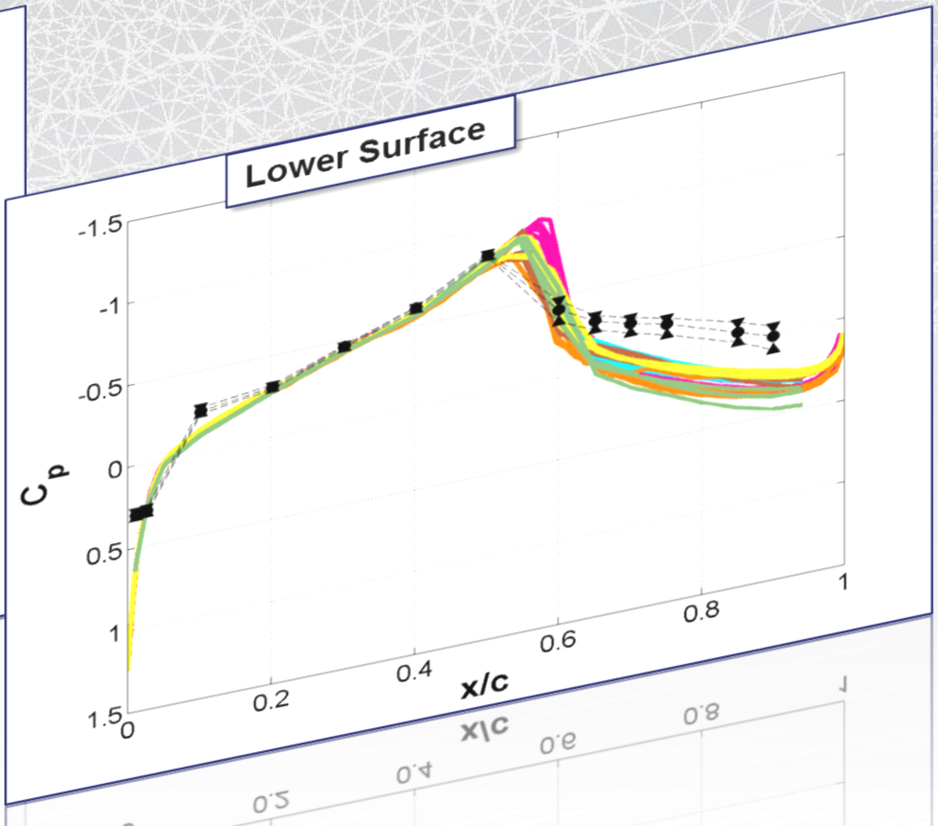
Case # 3A
(AePW-1 results)
Steady rigid pressure distributions
Mean value of C_p

<u>Predictions of upper surface shock location</u>
- Varied by > 20% of the chord
- Were aft of experimental data

<u>Lower surface aft-of-shock pressures</u>

Differed from experiment in
- Distribution
- Magnitude
- Sign



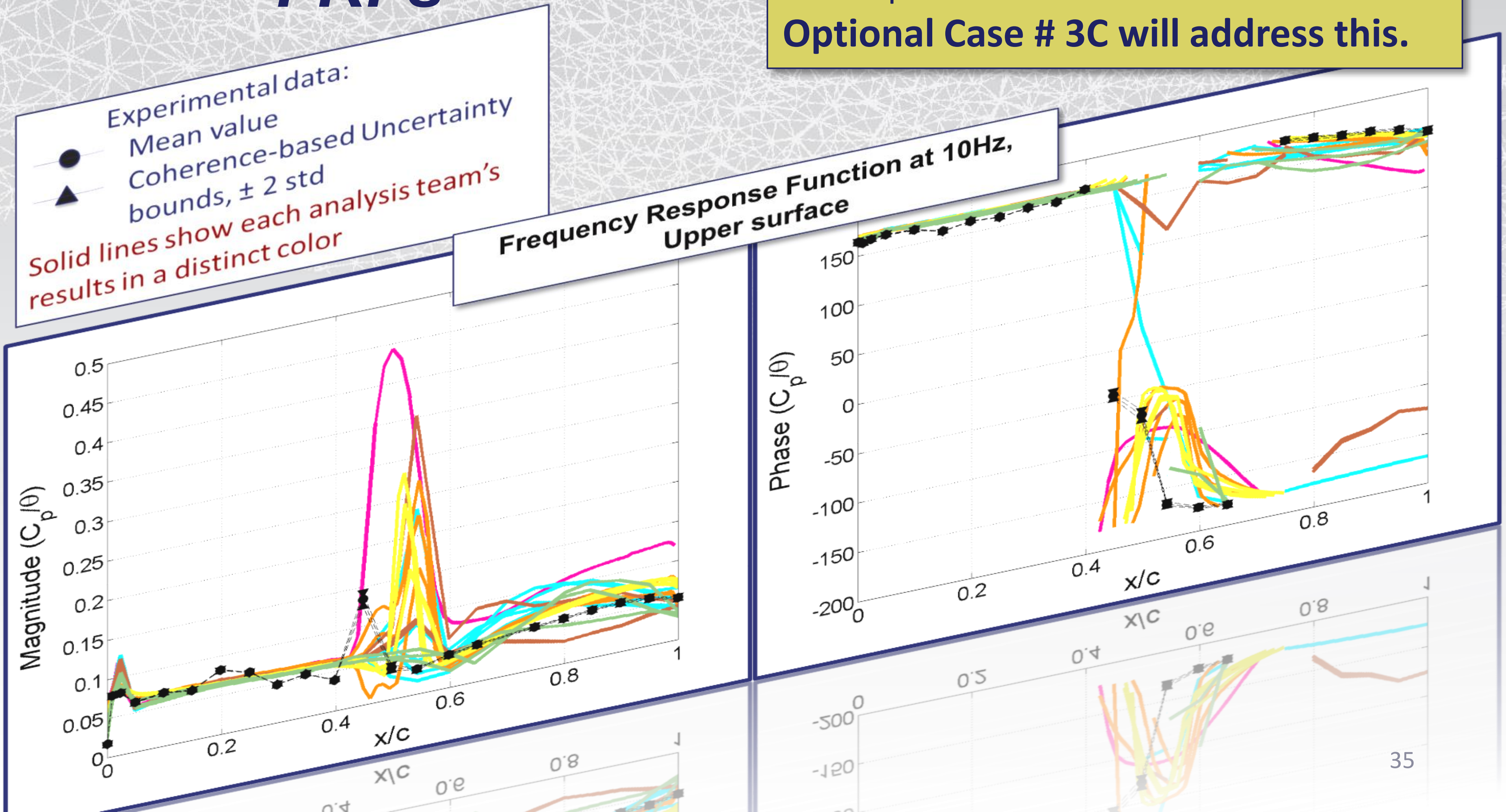


Case # 3B (AePW-1 results) Forced Oscillation FRFs

Variations & discrepancies in the unforced system predictions propagate through to the unsteady characteristics

Are these differences significant in the flutter prediction?

Optional Case # 3C will address this.



A glance of all of the cases: Rigid unforced system data

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Mach	0.7	0.74	0.85	0.85	0.85
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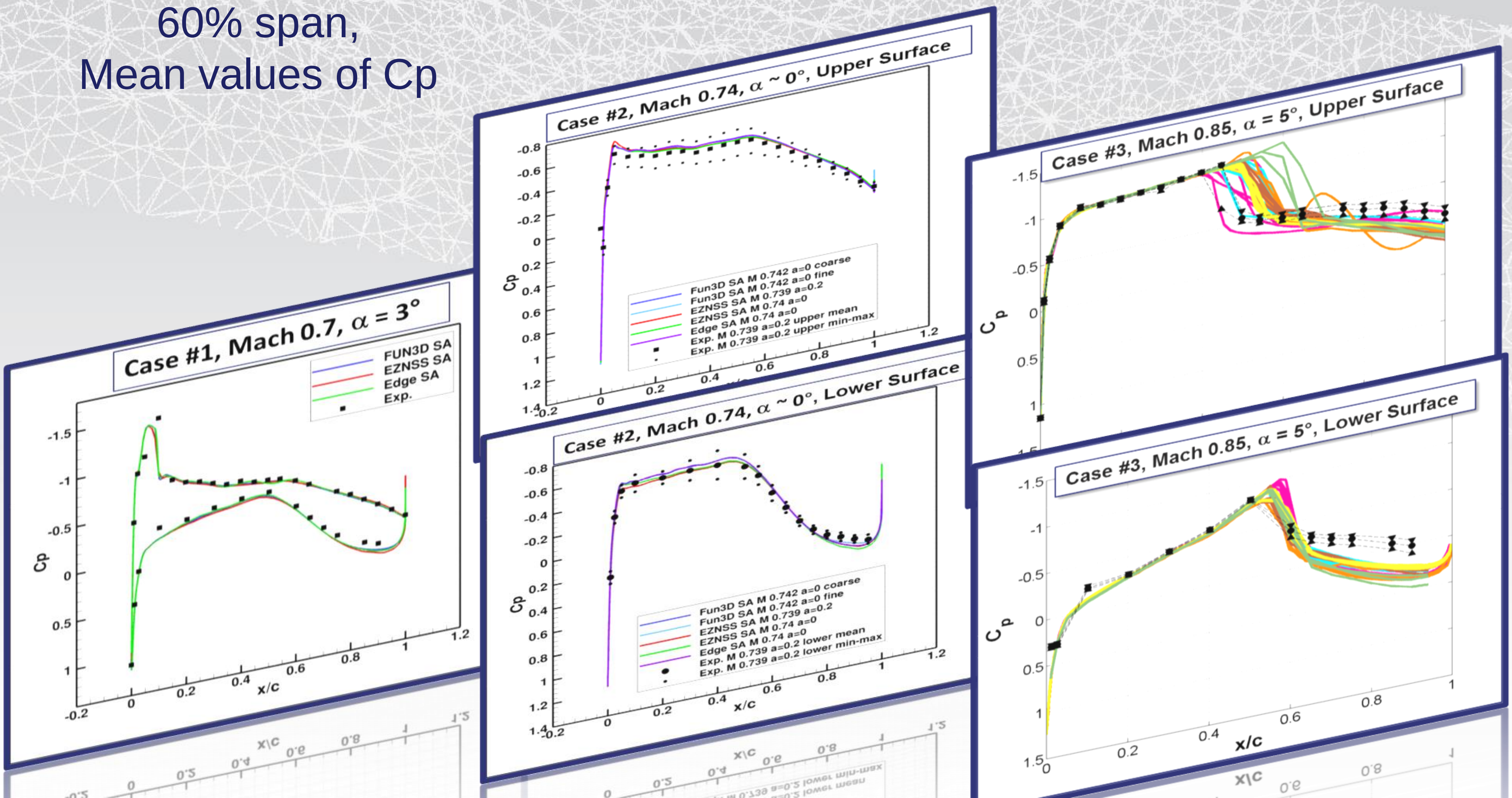
Steady rigid pressure distributions

Case comparisons
60% span,
Mean values of Cp

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.



AePW-2 Website: https://AePW2.larc.nasa.gov

Outline

- Aeroelastic Prediction
- AePW-2 Plans
- Example Results from OC members
- **Concluding Remarks**

We invite you to participate

Participation is unrestricted

Important Dates

- Kickoff Meeting: SciTech 2015
- Workshop: SciTech 2016
- Computational Results Submitted by Nov 15, 2015
- Computational Team Telecons: 1st Thursday of every calendar month 11 a.m. EST

AePW-2 KickOff Meeting

- **<u>Tonight</u>: Monday, January 5th, 2015**
- **1900-2100 hrs**
- **Room: Emerald 4**

<u>Agenda</u>

- Open discussion and comments
- Plans for AePW-2
- Locating what you need to participate in AePW-2
- Website tour & Walkthrough of aspects
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- Relevant lessons from AePW-1, including examination through the data
- Re-analyses after AePW-1; Things that we’re learned
- Q&A
- Future directions presentations and discussions

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Thank you

&

We look forward to working with you

The Aeroelastic Prediction Workshop is sponsored by the AIAA Structural Dynamics Technical Committee