2nd AIAA Aeroelastic Prediction Workshop

Welcome & Overview

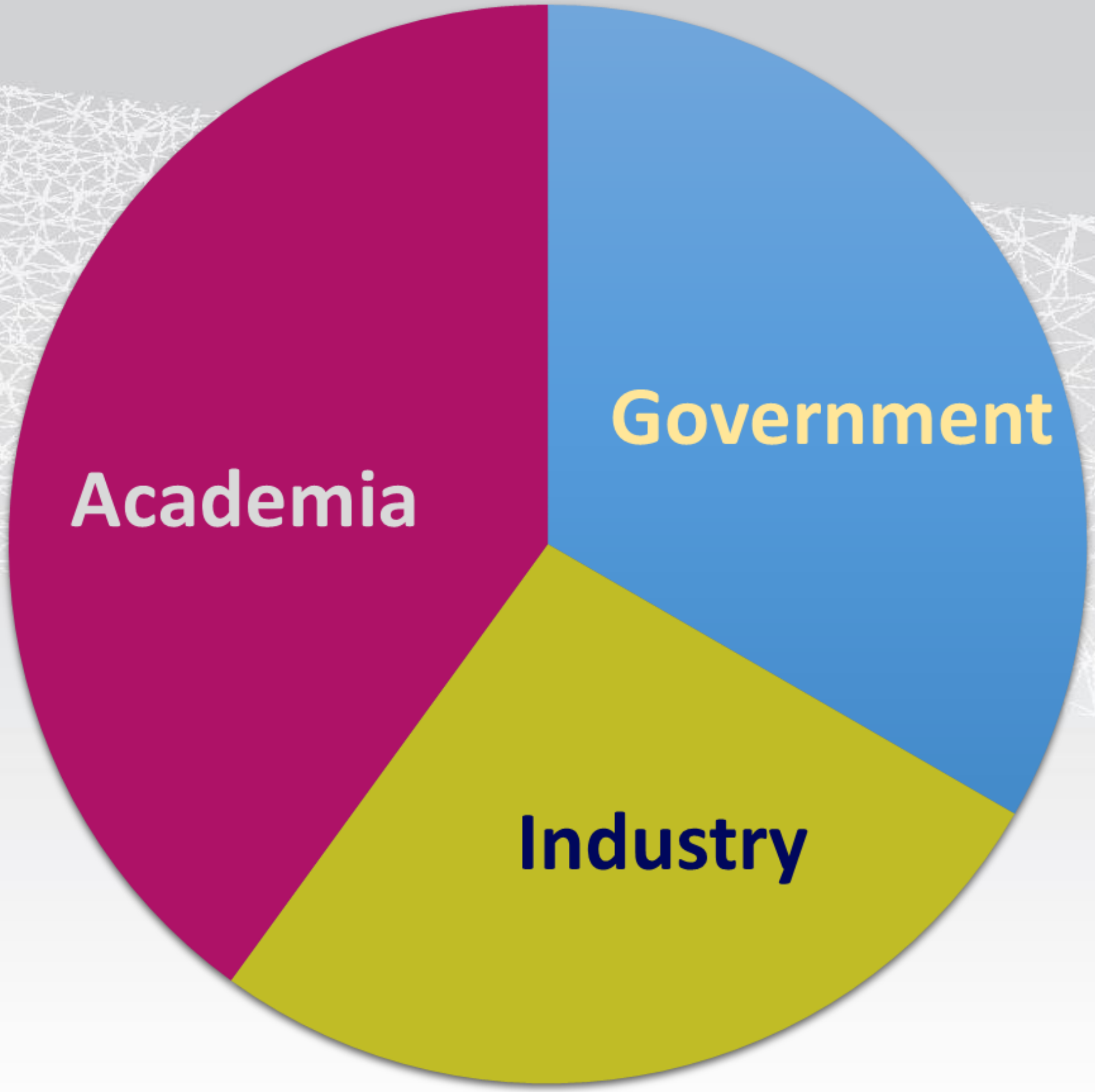
Jennifer Heeg
NASA Langley Research Center
January 2, 2016

Acknowledgements

- Megan Scheidt, AIAA, organizing and coordinating
- Joe Slater, Bruce Willis, Dale Pitt, Structural Dynamics TC, sponsorship, coordination, general support
- Organizing committee for doing preliminary analysis and preparations.
  - Pawel Chwalowski, NASA
  - Adam Jirasek, FOI
  - Daniella Raveh, Technion
  - Mats Dalenbring, FOI
  - Alessandro Scott, Pilatus
  - Jennifer Heeg, NASA
- Analysis team leaders and members
- Code development teams whose work we have utilized in performing these analyses

AePW-2
Analysis Teams

Adam Jirasek and Mats Dalenbring (FOI) Jan Navratil (Brno University of Technology, VUT, Czech Republic)
Yannick Hoarau and C.-K. Huang (ICUBE, Strasbourg University, France) A. Gehri and J. Vos (CFS Engineering, Lausanne, Switzerland)
Eric Blades (ATA Engineering)
Tomer Rokita (Aerodynamics department, RD&E Division, RAFAEL)
Balasubramanyam Sasanapuri and Krishna Zore (ANSYS India) Robin Steed (ANSYS Canada) Eric Bish (ANSYS Inc.)
Marcello Righi (Zurich University of Applied Sciences)
Daniella E. Raveh (Technion IIT) Yuval Levy and Yair Mor Yossef (Israeli CFD Center)
Guilherme Begnini Cleber Spode Aluísio V. Pantaleão Bruno Guaraldo Neto, Guilherme O. Marcório, Marcos H.J. Pedras Carlos Alberto Bones (Embraer)
Pawel Chwalowski and Jennifer Heeg (NASA Langley Research Center)
Eirikur Jonsson Charles A. Mader Joaquim R.R.A. Martins (University of Michigan)
Sergio Ricci and Andrea Mannarino (Department of Aerospace Science and Technology of Politecnico di Milano)
Patrick McGah Girish Bhandari Alan Mueller Durrell Rittenberg (CD-adapco)
Amin Fereidooni and Anant Grewal (NRC) Marcel Grzeszczyk (NRC, University of Toronto)
Bimo Pranata and Bart Eussen (NLR)
Eduardo Molena (ITA)



AePW-2 Analysis Codes Utilized

Linear	RANS, Uncoupled	Euler, Coupled	RANS, Coupled	Hybrid RANS/LES
• MSC NASTRAN	• SU2	• OpenFoam	• CFD++ • Aero • EZNSS • Edge • FUN3D • EZAir • Star_CCM+ • Loci/Chem • Fluent • CFX • SUMAD • ENFLOW • NSMB	• Edge • FUN3D • EZAir

Logistics

- Comparison Results
  - 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
  - There are 14 separate comparison data bases
- Good Ideas Capture Process
  - Discussions that we must table due to time and progress considerations
  - Noted and revisited in path forward discussion (on agenda: 1640-1700 Sunday)
- Agenda
  - Topics of common interest
  - Analysis team presentations of processes, results, lessons learned
  - Comparison data

Agenda, Saturday

Time	Title	Presenter	Organization, Affiliation	Team members
1500-1530	**Welcome, overview, logistics, agenda**	Jennifer Heeg	NASA	
1530-1600	**Fluid-structure coupling methods**	Mats Dalenbring	FOI	Adam Jirasek, FOI
1630-1700	**Turbulence modeling effects**	Yuval Levy	Israeli CFD Center	Daniella Raveh, Technion IIT
1700-1720	**Temporal effects**	Jennifer Heeg	NASA	
1720-1740	**Linear Analyses**	Guilherme Begnini	Embraer	Bimo Pranata, NLR
1740-1800	**Data Comparisons Overview:Open discussion of data comparisons**	Jennifer Heeg	NASA	

Agenda, Sunday

Time	Title	Presenter	Affiliation	Team members
0730-0800	**Open discussion of data comparisons**			
0800-0820	**Agenda, Logistics, Data Comparison Overview**	Jennifer Heeg	NASA	
0820-0840	**Recap of Workshop Day 1**	Cleber Spode	Embraer	
0840-0900	**BSCW Geometry and Grids**	Pawel Chwalowski	NASA	
0900-0920	**NSMB contribution to the AePW-2**	Yannick Hoarau	ICUBE, Strasbourg University, France	C.-K. Huang , ICUBE, Strasbourg University, A. Gehri and J. Vos , CFS Engineering, Lausanne, Switzerland
0920-0940	**CFD Simulations for the 2nd Aeroelastic Prediction Workshop using EZAIR**	Tomer Rokita	Aerodynamics department, RD&E Division, RAFAEL	
0940-1000	**ANSYS Simulation results for the 2nd AIAA Aeroelastic Prediction Workshop**	Balasubramanyam Sasanapuri	ANSYS India	Krishna Zore, ANSYS India Robin Steed, ANSYS Canada Eric Bish, ANSYS Inc.
1000-1020	**Coffee Break & Open discussion of comparison results**			
1020-1040	**Edge analysis results**	Mats Dalenbring	FOI	Adam Jirasek , FOI Jan Navratil, Brno University of Technology, VUT, Czech Republic
1040-1100	**Results obtained by ZHAW with Edge and SU2**	Marcello Righi	Zurich University of Applied Sciences	
1100-1120	**Simulations for the Second Aeroelastic Prediction Workshop Using the EZNSS Code**	Daniella E. Raveh	Technion - IIT	Yuval Levy , Israeli CFD Center Yair Mor Yossef, Israeli CFD Center
1120-1140	**CFD++ and Aero results**	Guilherme Begnini Cleber Spode	Embraer	Aluísio V. Pantaleão Bruno Guaraldo Neto, Guilherme O. Marcório, Marcos H.J. Pedras Carlos Alberto Bones
1140-1200	**FUN3D results**	Pawel Chwalowski	NASA	Jennifer Heeg

Agenda, Sunday, contd

Time	Title	Presenter	Organization, Affiliation	Team members
1200-1300	**Lunch**			
1300-1320	**SUMAD Unsteady Analysis of the Benchmark SuperCritical Wing for the Aeroelastic Prediction Workshop 2**	Eirikur Jonsson	University of Michigan	Charles A. Mader Joaquim R.R.A. Martins
1320-1340	**Loci/Chem analysis results**	Eric Blades	ATA Engineering	
1340-1400	**Flutter analysis with Euler-based solver in OpenFOAM**	Sergio Ricci	Department of Aerospace Science and Technology of Politecnico di Milano	Andrea Mannarino
1400-1420	**STAR-CCM+ Analysis Results**	Patrick McGah	CD-adapco	Girish Bhandari Alan Mueller Durrell Rittenberg
1420-1440	**Aeroelastic Prediction of the BSCW using an enhanced OpenFoam-based CFD Solver**	Amin Fereidooni	National Research Council Canada	Anant Grewal (NRC) Marcel Grzeszczyk (NRC, University of Toronto)
1440-1500	**Comparison results walk through and discussion**	Jennifer Heeg	NASA	
1500-1520	**Coffee Break & open discussion of comparison results**			
1520-1640	**Comparison Results Walk through and discussion, contd**	Jennifer Heeg	NASA	
1640-1700	**Path forward & good ideas recap**	Pam Sparks, Jennifer Heeg	NASA	

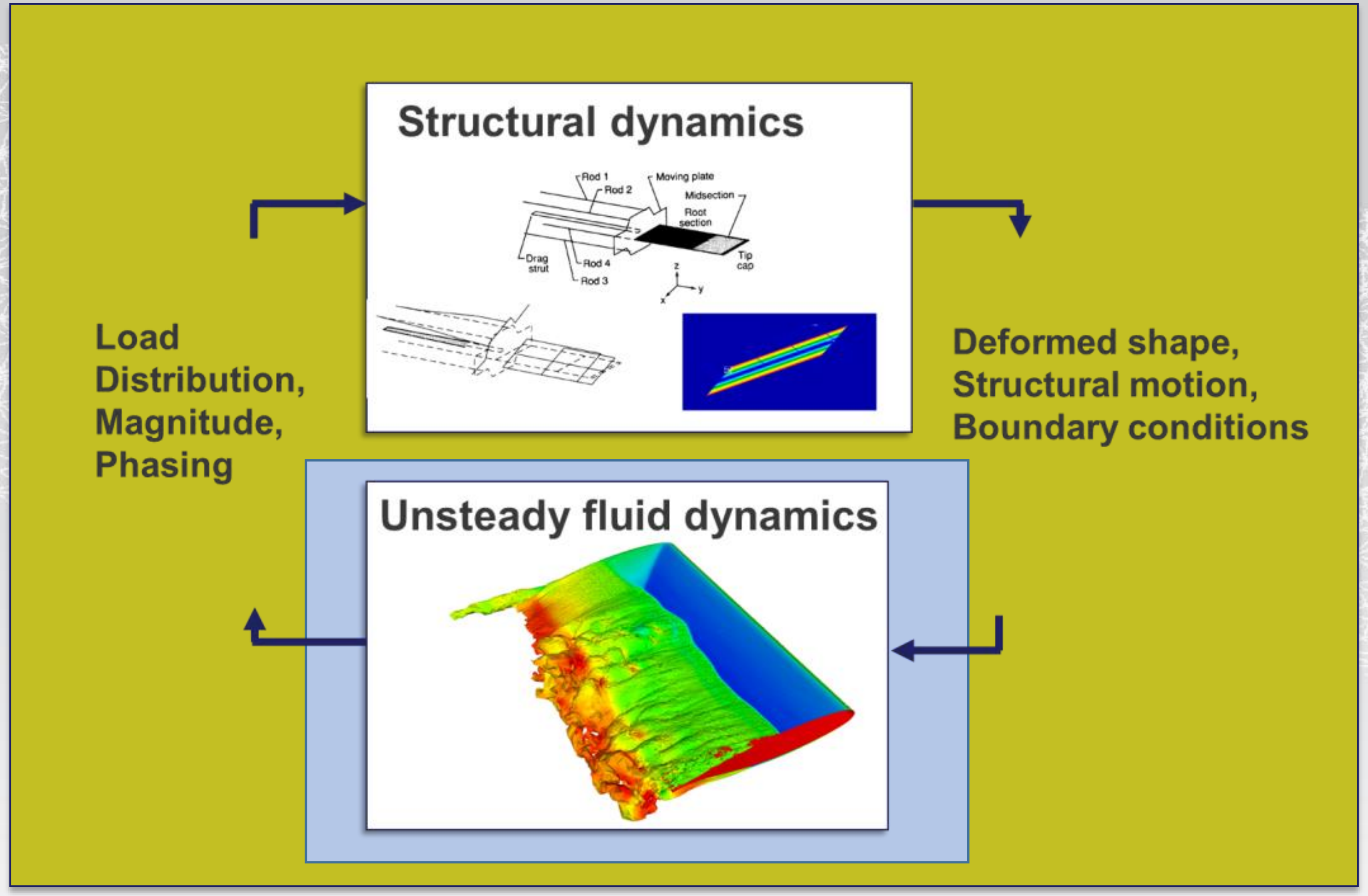
Objectives of the Aeroelastic Prediction Workshop

- **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
- Establish **community** for leveraging experiences and processes

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

- Coupling with structural dynamics
- Unsteady effects matter
- Distribution of the pressures matters (integrated quantities such as lift and pitching moment often tell you little regarding aeroelastic stability)
- Phasing of the pressures relative to the displacements matters

AePW Building block approach to validation



Structural dynamics

Load Distribution, Magnitude, Phasing

Deformed shape, Structural motion, Boundary conditions

Unsteady fluid dynamics

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

AePW-1 Configurations

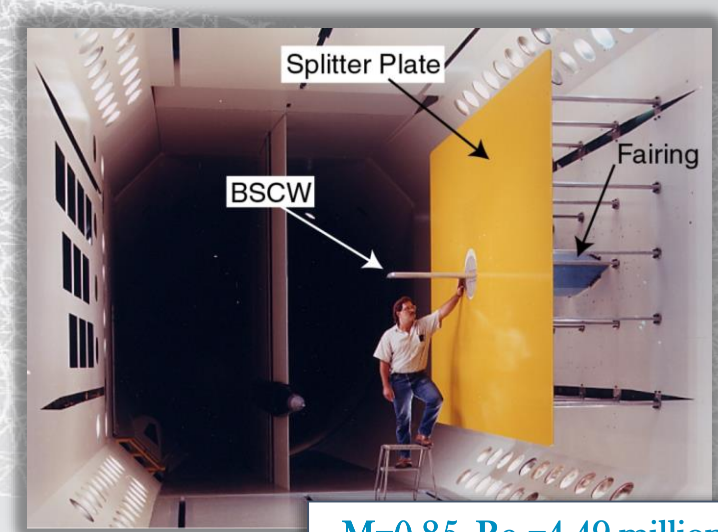
- High Reynolds number Aero-Structural Dynamics Model (HIRENASD)
- Benchmark Supercritical Wing (BSCW)
- Rectangular Supercritical Wing (RSW)

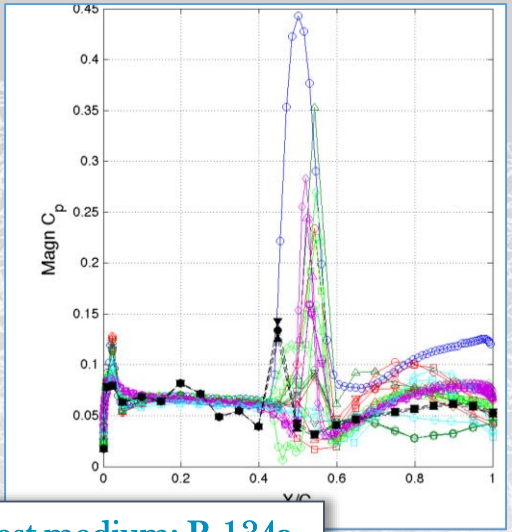
Applying the Lessons Learned; Formulating AePW-2

- **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

AePW-1 End of Workshop Summary of Benchmark Supercritical Wing (BSCW) Results

- 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;



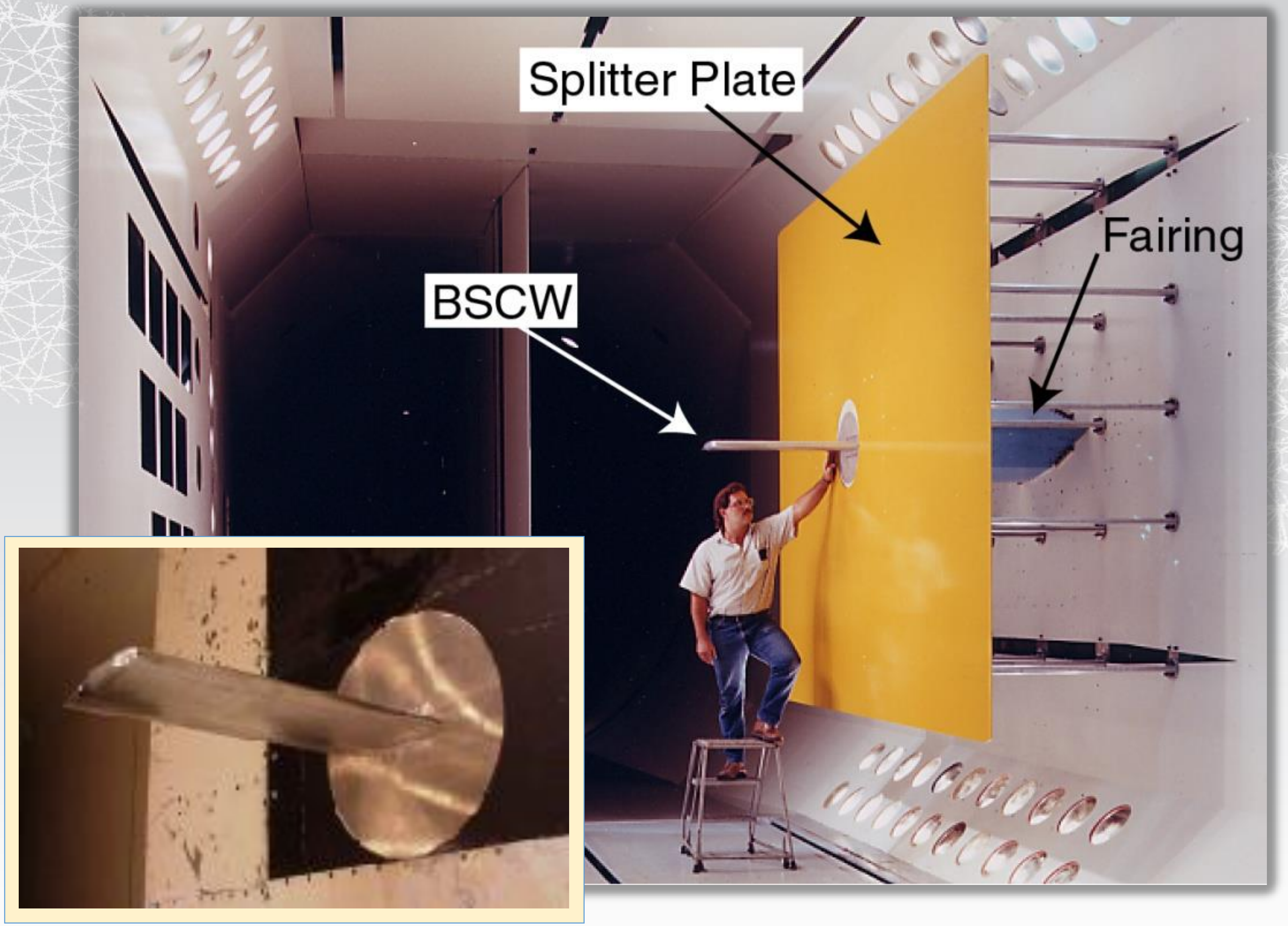


M=0.85, Re_c=4.49 million, test medium: R-134a,
α = 5°, θ = 1°, freq 1 & 10 Hz

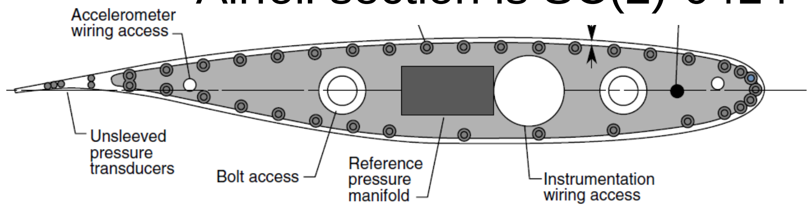
Likely plan of action:

- 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

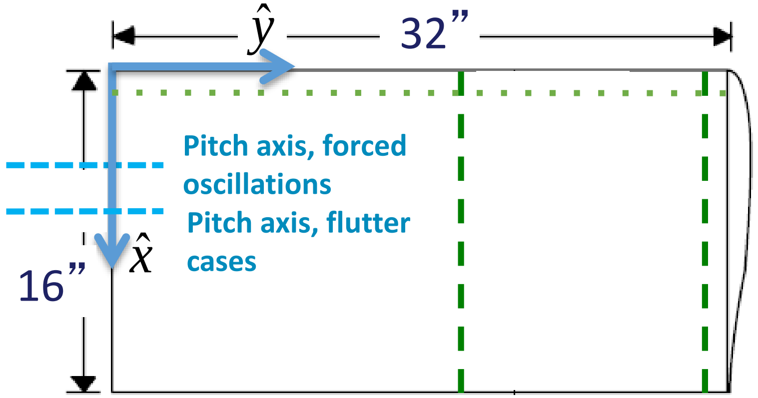
AePW-2 Configuration: Benchmark Supercritical Wing (BSCW)



Airfoil section is SC(2)-0414

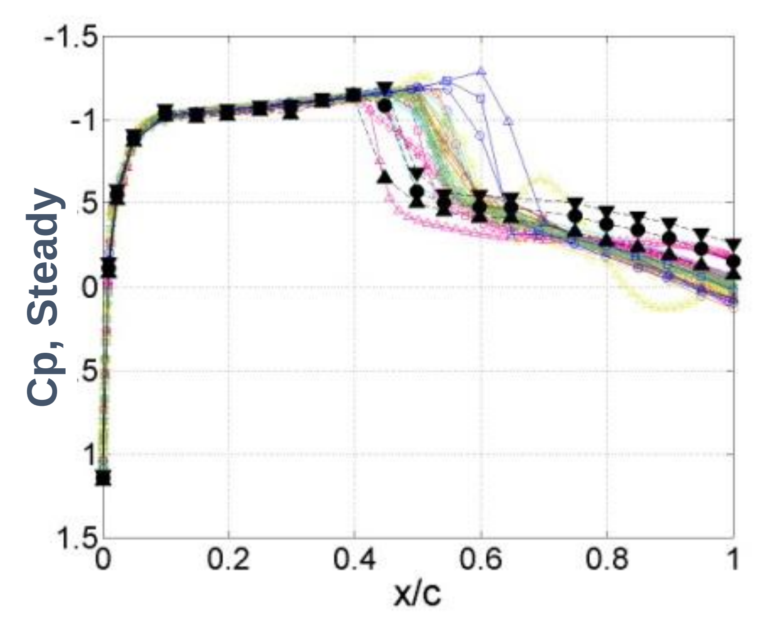


Cross-section at 60% span, showing the layout of the unsteady pressures.



Model planform. Dimensions are in inches.

Results from AePW-1: BSCW Mach 0.85 5°



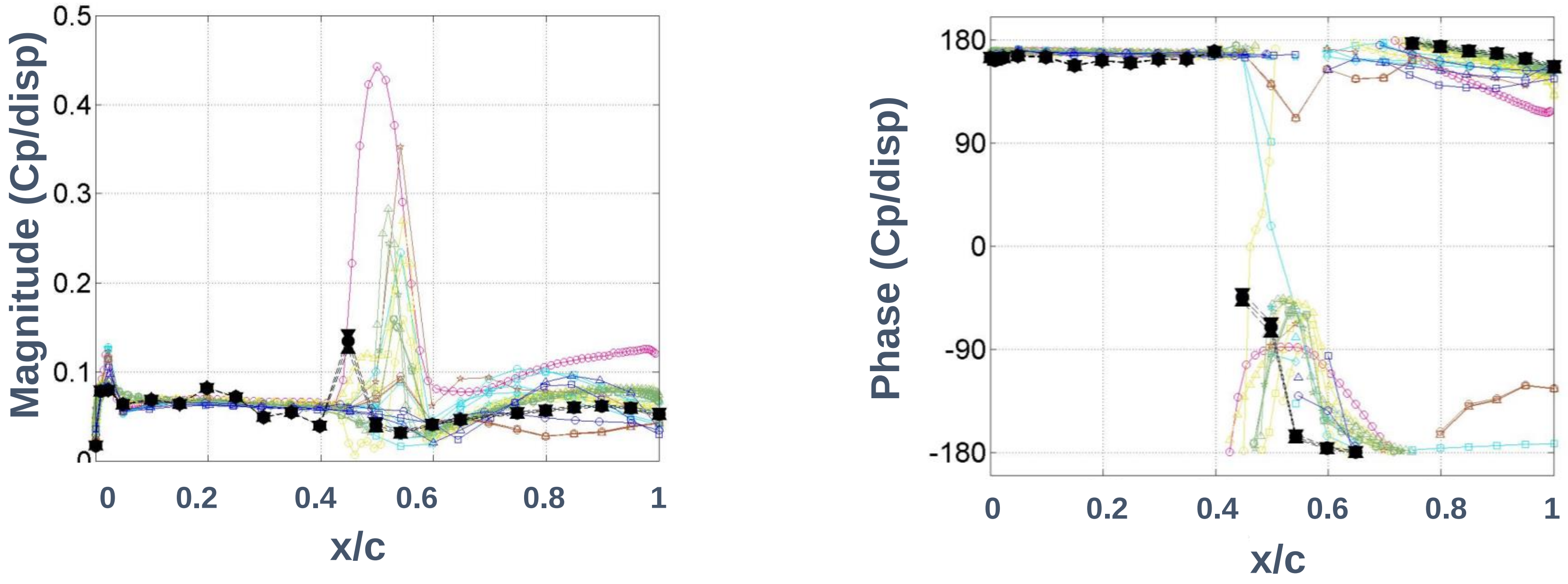
● Experimental data

▲ 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

Applying the Lessons Learned; Formulating AePW-2

- One configuration only
- **Benchmarking case: including a case that we have confidence can be “well-predicted”**
- Comparison metrics:
  - Unsteady quantities for all cases
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  - Extended statistics: mean, std, mode, max, min
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  - nothing is steady
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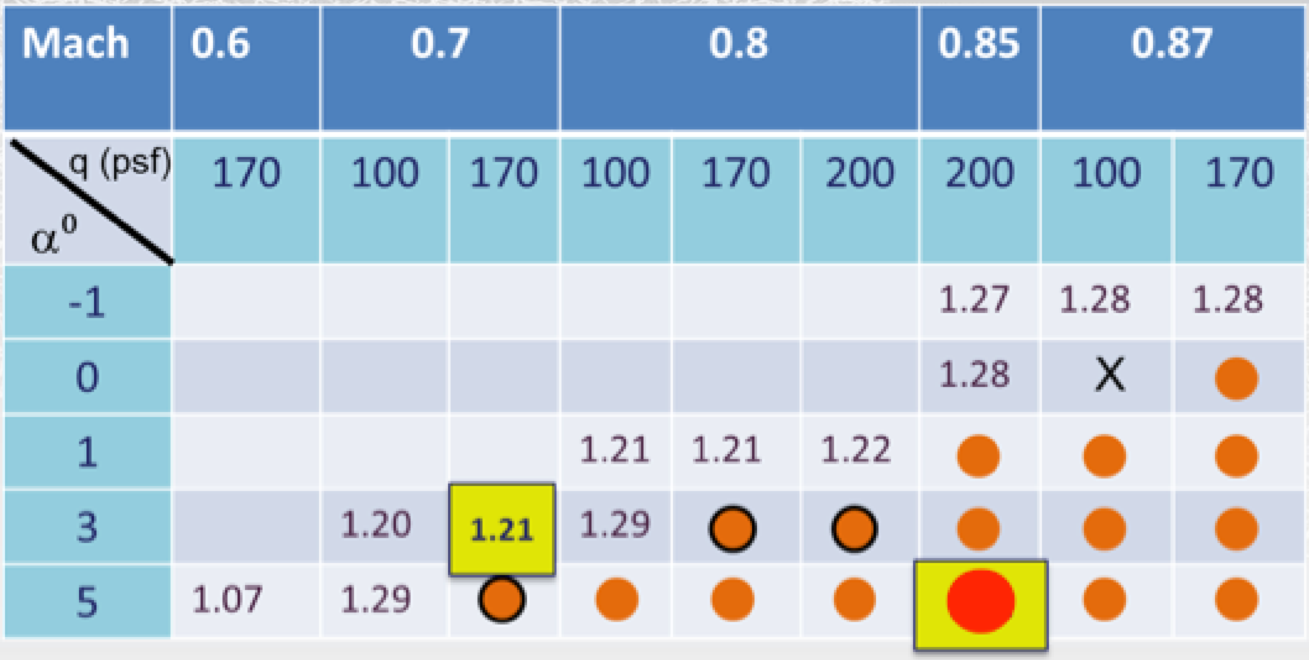
Shock-induced separation assessment of experimental data led to AePW-2 case selection



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

AePW-2 Analysis Cases

	Case 1	Case 2	Case 3
Mach	0.7	0.74	0.85
Angle of attack	3	0	5
Dynamic Data Type	• Forced oscillation	• Flutter	• Unforced Unsteady • Forced Oscillation • Flutter

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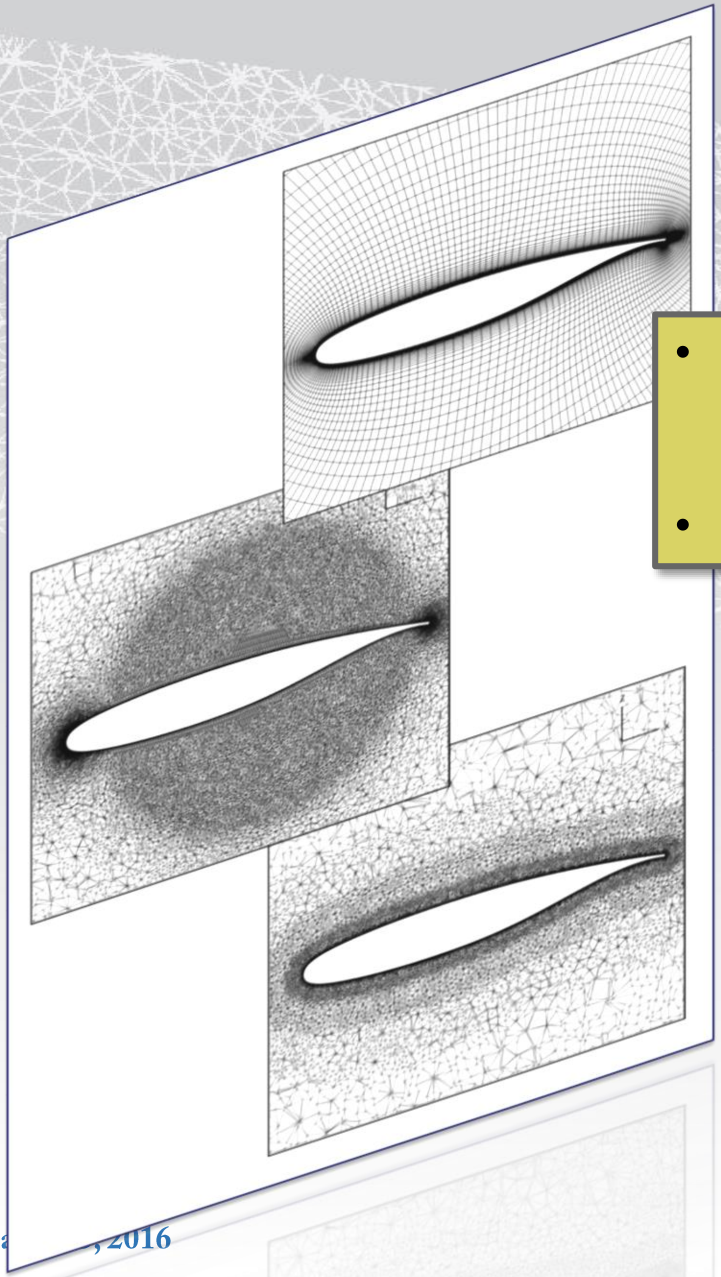
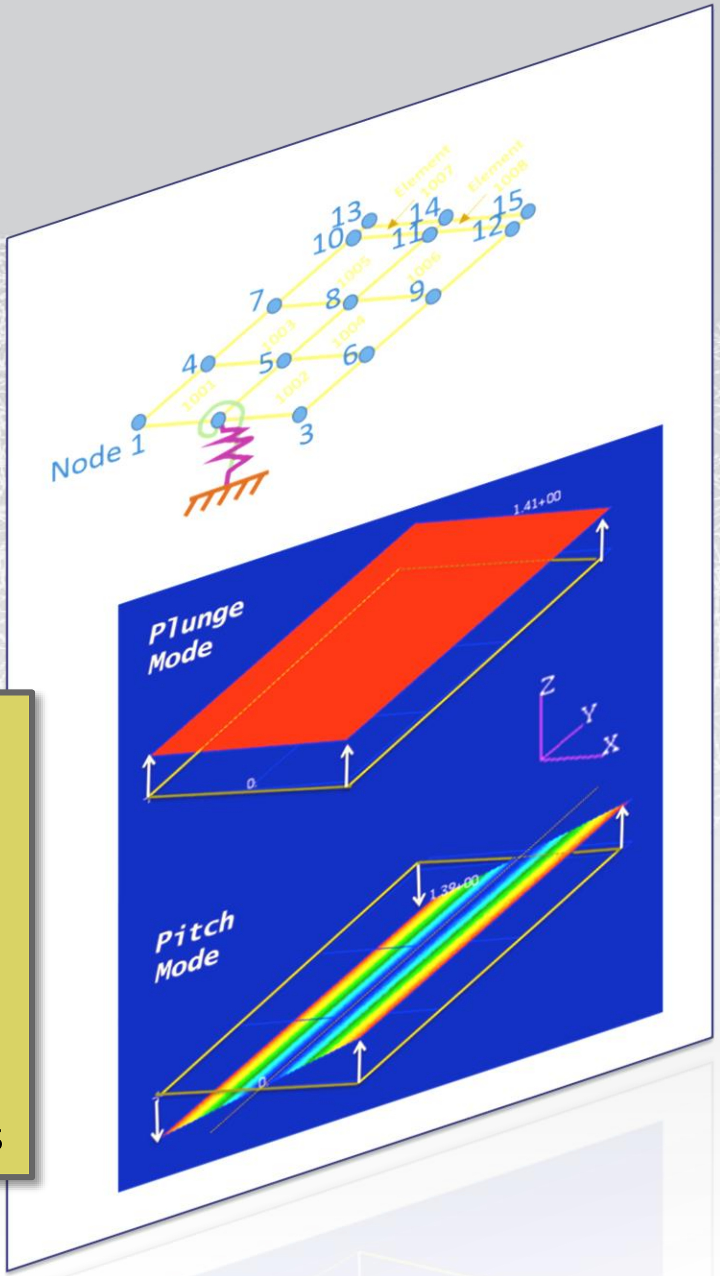
Computational Information Provided



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

- Simple finite element model
  - Plunge Mode
  - Pitch Mode
  - Governed by mount system stiffness & rigid wing mass properties
- Tuned to experimental data
- Grid-interpolated mode shapes



Applying the Lessons Learned; Formulating AePW-2

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- Common grids suggested for analyses
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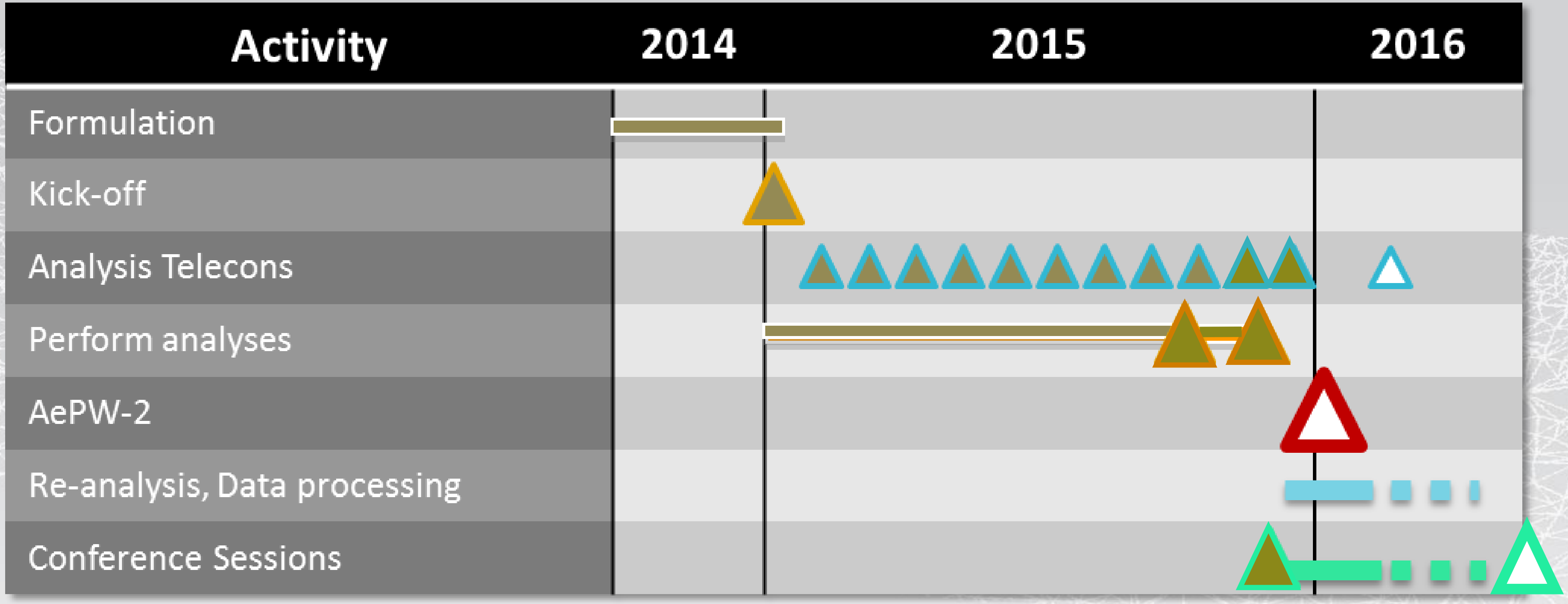
- **Discussion telecons for analysis teams ←←← Communication helps leverage the experiences and processes of others**

Aeroelastic Prediction Workshop Schedule



Key Dates:

- **Computational Team Telecons: 1st Thursday of every calendar month 11 a.m. EST**
- Deadline for Commitment to contribute analyses: **Oct 1, 2015**
- Computational Results Submitted by **Nov 15, 2015**
- Workshop: SciTech 2016: **Jan 2-3, 2016**
- SciTech Panel Discussion of Workshop: Jan 2016 at SciTech
- 2016 AIAA Aviation Conference Abstract Deadline ~ Nov 1, 2016 →→→→
- 2017 AIAA SciTech Conference Abstract Deadline ~ June 1, 2016

2016 Aviation Conference Manuscript Deadline: **10 May 2016**

Envisioned Workshop Process for Analysis Teams (May Telecon Discussion, 2015)

- Perform analyses
- Submit results
- Prepare informal presentations for workshop
- SciTech 2016
    - AePW-2
        - Present results
        - Results comparisons
        - Discussion of results
        - Path forward
    - Panel discussion
- Re-analyze
- Publish at special sessions of conferences (Aviation Conference Special Session Scheduled)
- Publish combined journal articles

Agenda, Saturday

Time	Title	Presenter	Organization, Affiliation	Team members
1500-1530	**Welcome, overview, logistics, agenda**	Jennifer Heeg	NASA	
1530-1600	**Fluid-structure coupling methods**	Mats Dalenbring	FOI	Adam Jirasek, FOI
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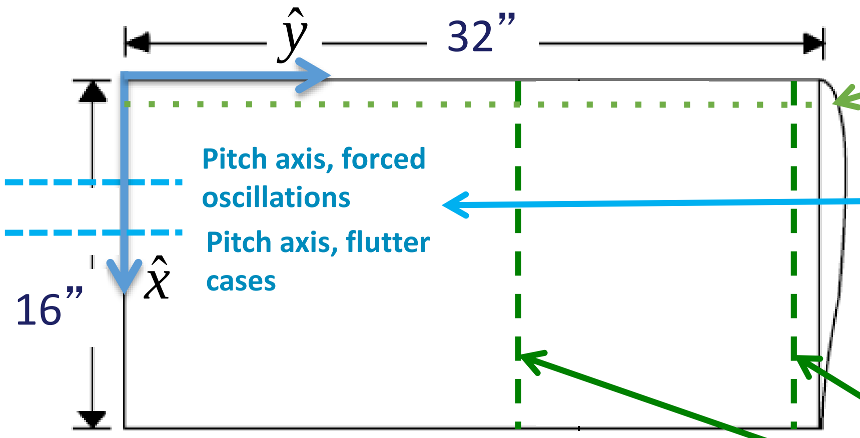
Additional Information

BSCW Test Configurations



Model planform. Dimensions are in inches.

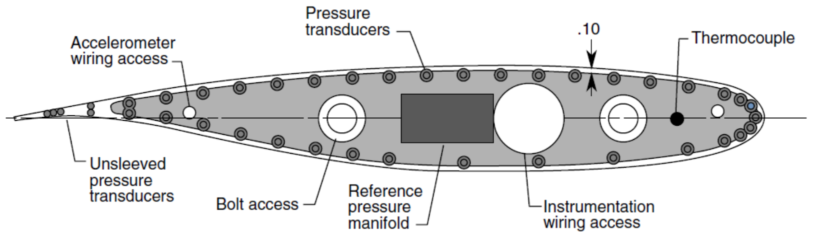
<u>Transition Strip</u>:
7.5% chord

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

<u>Unsteady Pressure Measurements</u>:

- 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.

Analysis Parameters

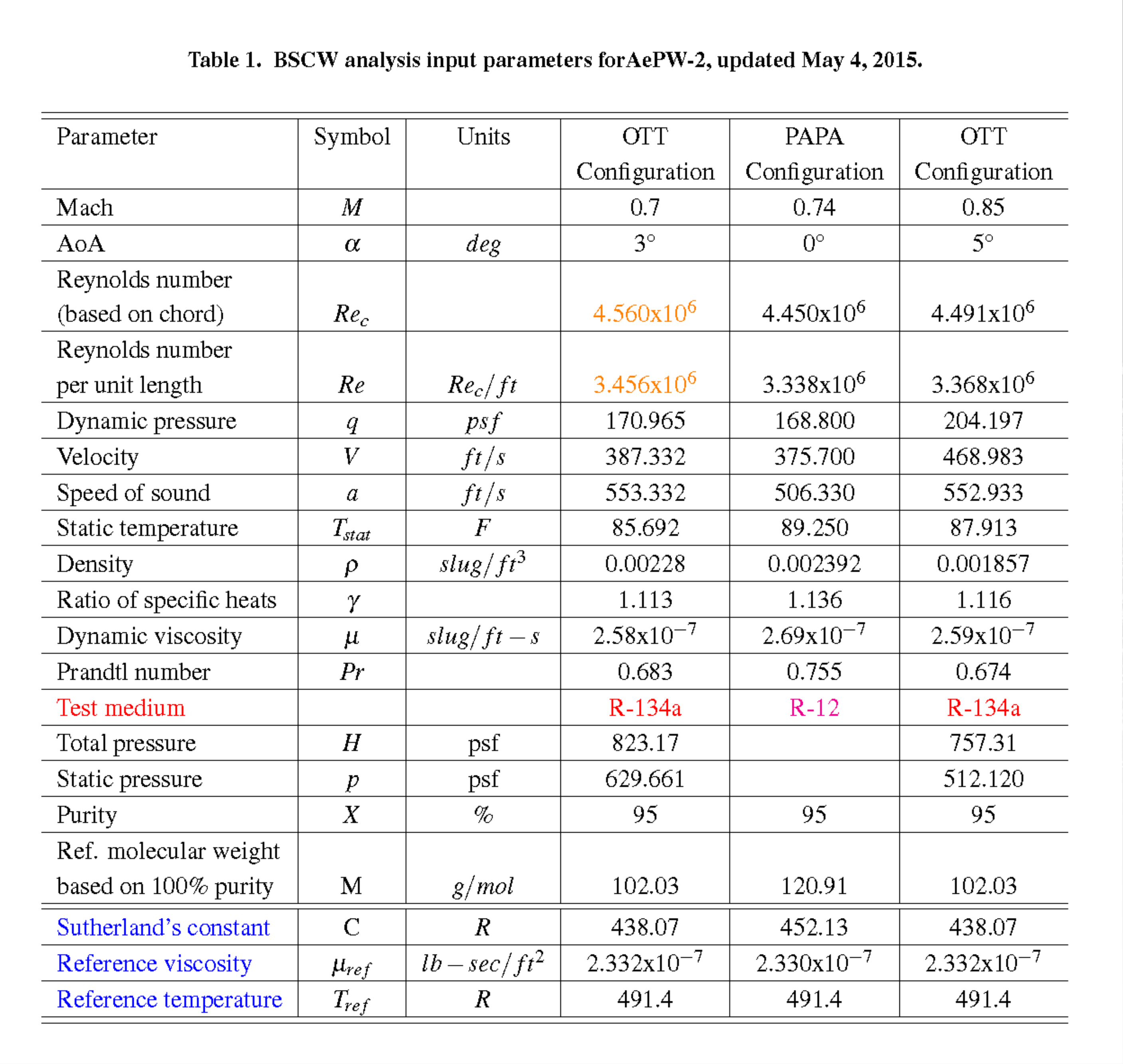


Table 1. BSCW analysis input parameters forAePW-2, updated May 4, 2015.

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

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.

Turbulence Models Employed

Name	**Spalart-Allmaras**	**Menter k-ω 2-eqn**	**Explicit Algebraic Stress k-ω 2-eqn**	**Turbulent Non-turbulent**	**Hybrid RANS/LES**
Abbreviation	SA	SST	EARSM	TNT	DDES
Analyst Designations Grouped	SA	k-ω/SST	k-ω EARSM	TNT	SA-DDES
		SST	W&J EARSM + std k-ω		X_LES
		SST Menter	EARSM		DDES
		k-ω			
		SST k-ω			