The 4th Aeroelastic Prediction Workshop
Welcome and Introduction

Bret Stanford

NASA Langley Research Center, Aeroelasticity Branch

June 6th, 2026

https://nescacademy.larc.nasa.gov/workshops/AePW4/public

AePW Goals and Motivation

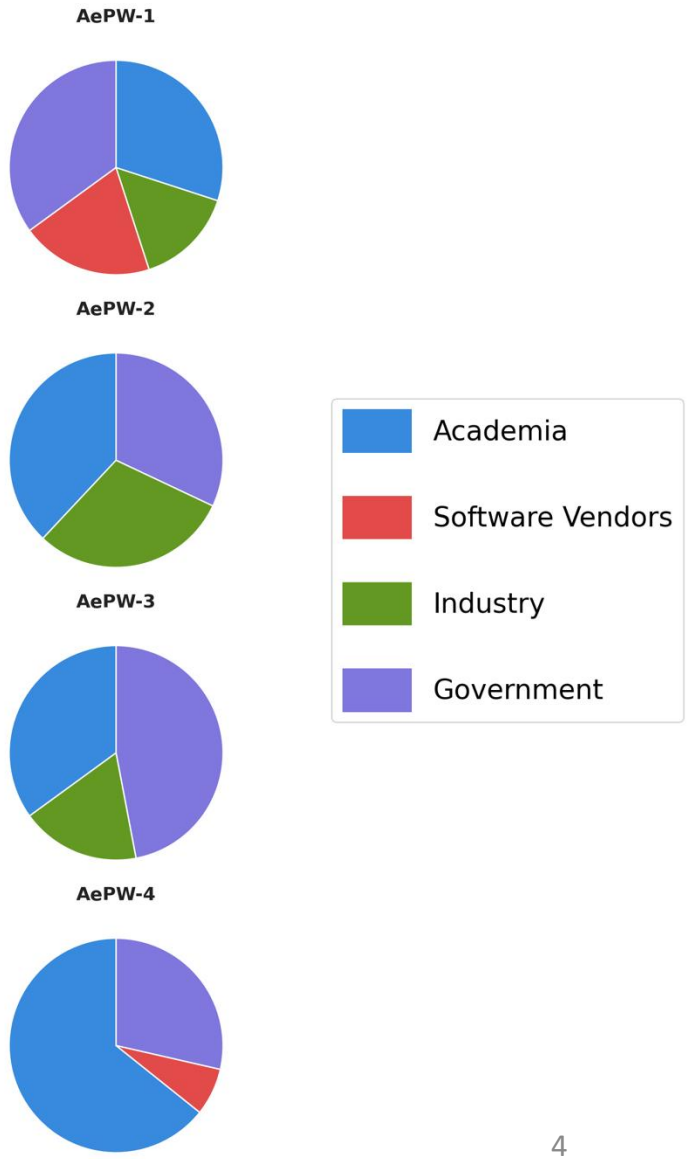
- An open and impartial forum to assess and evaluate the current state-of-the-art and state-of-the-practice in computational aeroelastic modeling
  - How effective are current solvers at predicting aeroelastic physics critical to aircraft analysis and design?
  - How can we understand the reasons for why our solvers may fail?
  - Can we establish best-practices for using aeroelastic solvers?
  - Can we establish uncertainty bounds for computational results?
  - Can we specify requirements on future validation experiments?
- What computational and experimental areas of research need further development?

Organizing Committee

- Kirk Brouwer, AFRL
- Carlos Cesnik, University of Michigan
- Pawel Chwalowski, NASA LaRC
- Adam Jirasek, USAFA
- Jeff Ouellette, NASA LaRC
- Rafael Palacios, Imperial College London
- Daniella Raveh, Technion
- Markus Ritter, DLR
- Walt Silva, NASA LaRC
- Bret Stanford, NASA LaRC

AePW History

- AePW-1 (Honolulu, 2012)
  - https://c3.ndc.nasa.gov/dashlink/static/media/other/AEPW.html
  - 17 analysis teams
  - 59 registered attendees
- AePW-2 (San Diego, 2016)
  - https://nescacademy.nasa.gov/workshops/AePW2/public/
  - 16 analysis teams
  - 47 registered attendees
- AePW-3 (National Harbor, 2023)
  - https://nescacademy.nasa.gov/workshops/AePW3/public/
  - 32 analysis teams
  - 70 registered attendees
- AePW-4 (San Diego, 2026)
  - https://nescacademy.larc.nasa.gov/workshops/AePW4/public
  - 14 analysis teams
  - 55 registered attendees (including DPW)

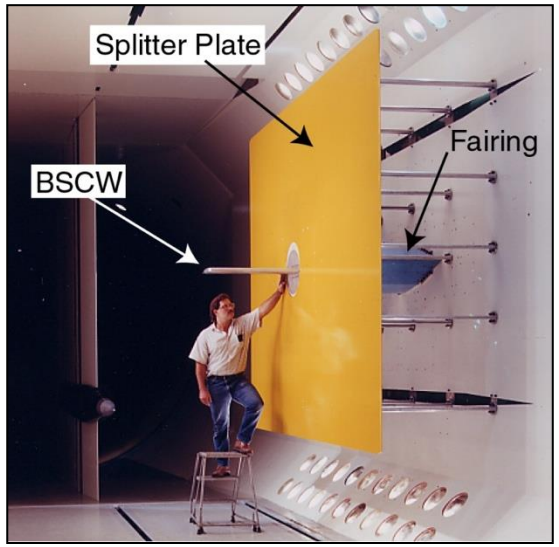


AePW-1

- Honolulu, 2012
- Led by Jennifer Heeg, NASA LaRC
- Focus on transonic unsteady aerodynamics, no aeroelasticity
- Three configurations under forced oscillation; unsteady pressure data

Rectangular Supercritical Wing (RSW)
Forced oscillation in pitch, Mach 0.82

photo credit: NASA

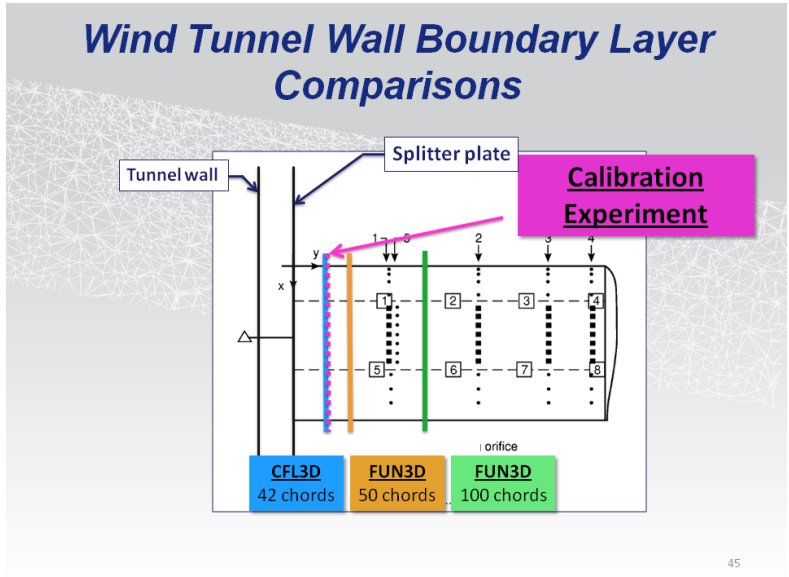


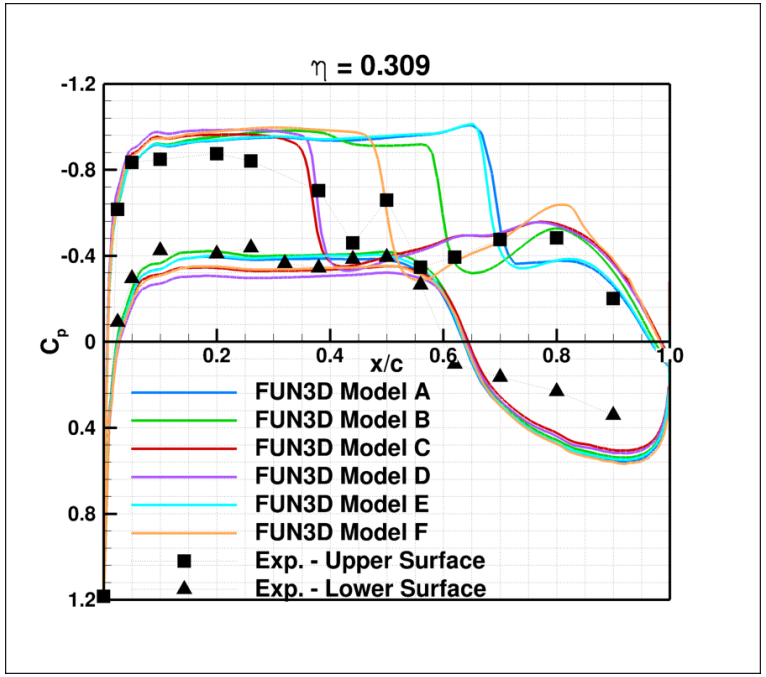
Benchmark Supercritical Wing (BSCW)
Forced oscillation in pitch, Mach 0.85

HIRENASD
Excitation in 2B, Mach 0.7, 0.8

AePW-1: Rectangular Supercritical Wing

- Part of the Benchmark Models Program (BMP) at the NASA LaRC Transonic Dynamics Tunnel (TDT) in the 1990s
- RSW was attached to a splitter plate, but the splitter plate was too close to the tunnel wall
- Flow over the wing was dominated by the tunnel boundary layer
- Not an effective benchmarking dataset, unless you were willing to model the splitter plate and the tunnel wall

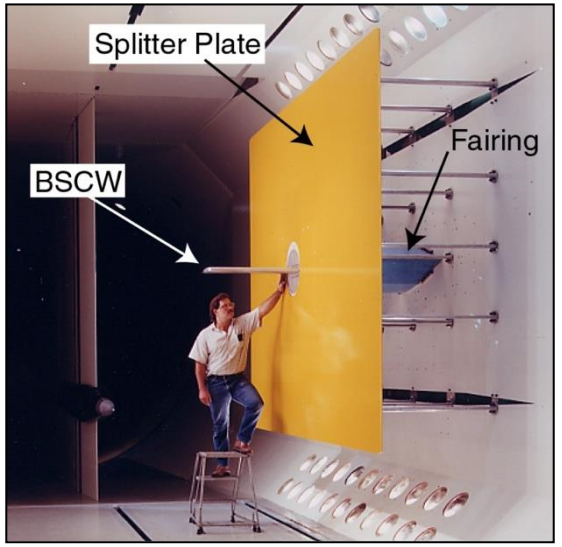


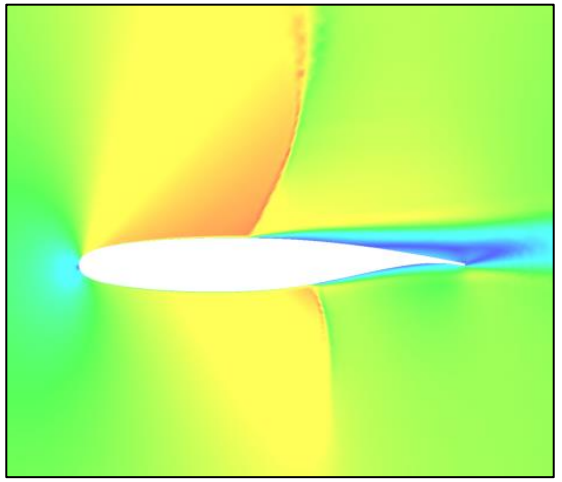


AePW-1: Benchmark Supercritical Wing

- Also part of NASAs BMP
- Attached to a splitter plate much further away from the tunnel wall
  - CFD simulations which treated the splitter plate as a symmetry plane were more reasonable
- There was massive flow separation for this Mach 0.85 condition, and the CFD solvers all struggled with this (as they still do)

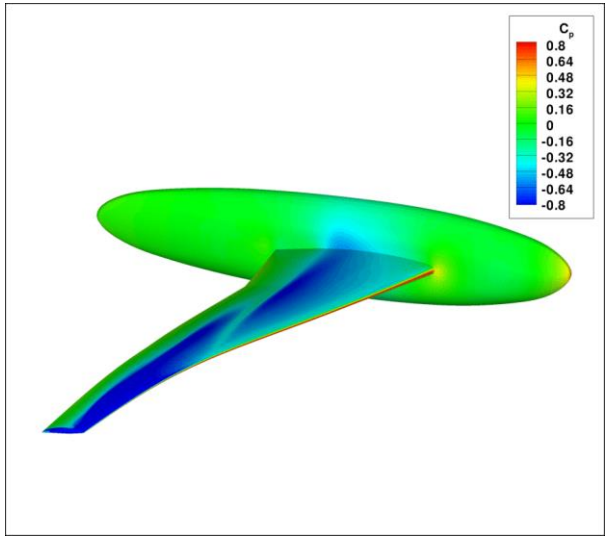
photo credit: NASA

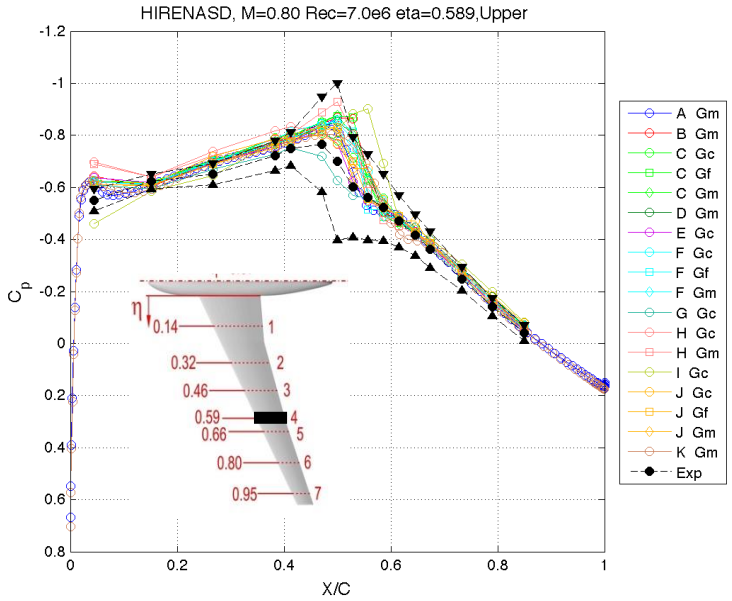




AePW-1: HIRENASD

- Tested in the European Transonic Wind Tunnel (ETW)
- Excited at the second bending mode frequency at Mach 0.7 and 0.8
- Despite the more complex geometry, this was considered to be the easiest of the three AePW-1 test cases
  - Generally good comparisons between different solvers, and with the test data





AePW-1 Conclusions

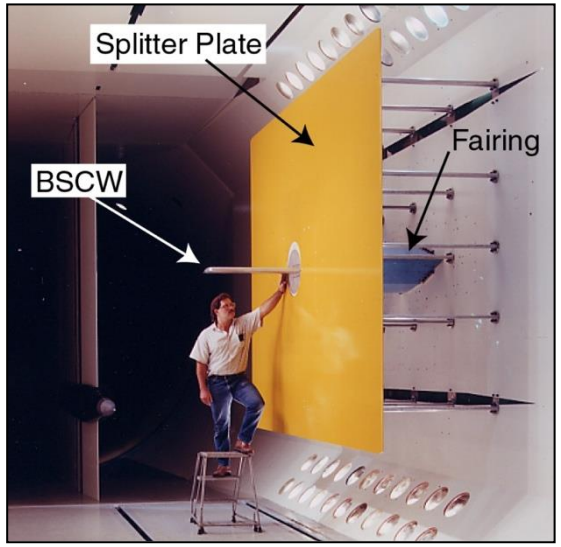
- https://c3.ndc.nasa.gov/dashlink/static/media/other/AEPW.html
- General consensus that there were too many test cases
  - Diluted the lessons-learned, and exhausted the participants
- Need for a relatively easy benchmarking case (stake in the sand) in addition to more challenging cases
- Need for LES and DES solvers over URANS, for massively separated flow
- Validation datasets should contain repeat data points, and small intentional variations in test conditions
  - Unsteady on- and off-body full-field flow measurements

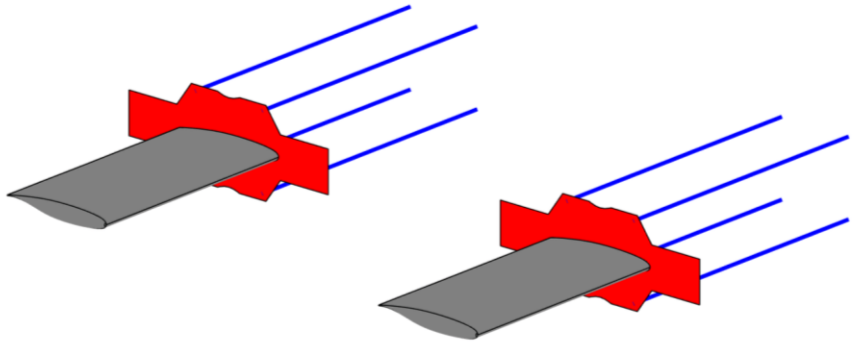
AePW-2

- San Diego, 2016
- Led by Jennifer Heeg, NASA LaRC
- Sole focus on the Benchmark Supercritical Wing, and introduction of some aeroelastic flutter cases
- BSCW structural dynamics is very simple: PAPA model

1. Mach 0.70, 3° AoA, forced oscillation
2. Mach 0.74, 0° AoA, flutter
3. Mach 0.85, 5° AoA
   - Rigid stationary model
   - Forced oscillation
   - Flutter (no experimental data at this condition)

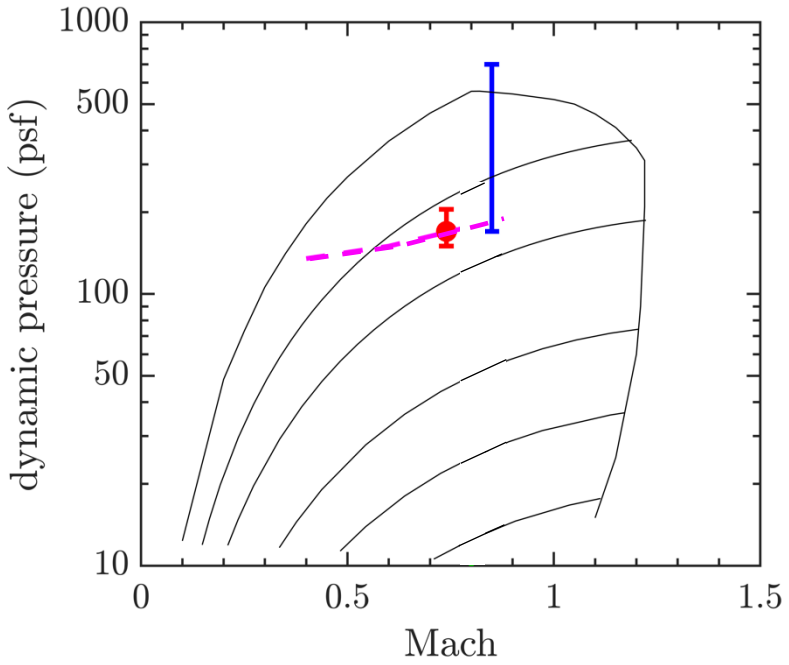
photo credit: NASA

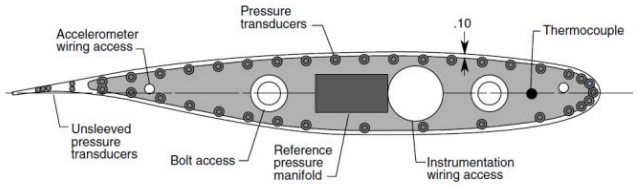


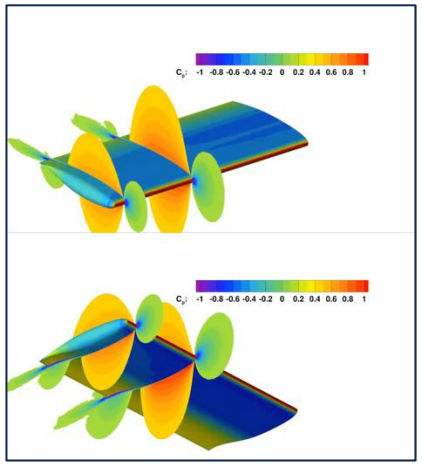


AePW-2 Flutter Results

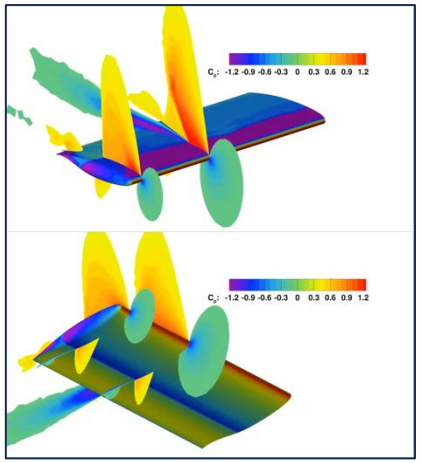
- The Mach 0.74 flutter point was well-predicted by all solvers
- At Mach 0.85, enormous code-to-code variations, and no experimental data to help guide the simulations







Mach 0.74, 0 ° AoA



Mach 0.85, 5 ° AoA

AePW-2 Conclusions

- https://nescacademy.nasa.gov/workshops/AePW2/public/

- Need for an easier case than Mach 0.85 / 5° AoA, but not as easy as Mach 0.74 / 0° AoA
- Far too little experimental data at each flutter point, from the 1990's BMP tests

- At this time (2016-2018), plans began to form at NASA for a re-test of the BSCW in the TDT, to provide more/better data for a notional AePW-3

AePW-3

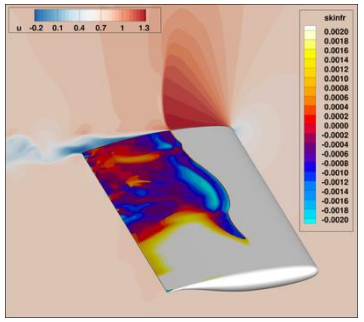
- National Harbor, 2023
  - Longer gap (7 years) between AePW-2 and AePW-3: COVID
  - Led by Pawel Chwalowski, NASA LaRC

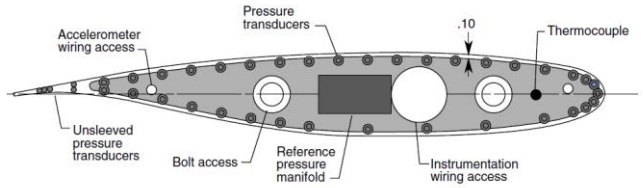
- Recognition that there is sufficient interest in BSCW and transonic flutter, to continue that work
- But recognition also that there are other key aeroelasticity challenges that are not addressed by BSCW, and would benefit from a workshop setting
- Decision to split AePW-3 into multiple diverse working groups

AePW-3 Working Groups

High Angle Working Group (HAWG)

- Led by Pawel Chwalowski (NASA)
- Continuation of AePW-2: focus on BSCW transonic flutter and buffet

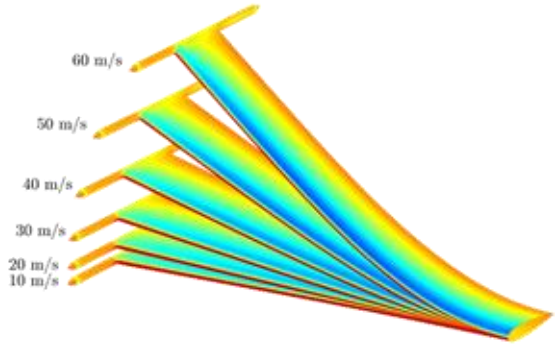




Large Deformation Working Group (LDWG)

- Led by Markus Ritter (DLR)
- Focus on large structural deflections of a subsonic high aspect ratio wing (Pazy wing, Technion)

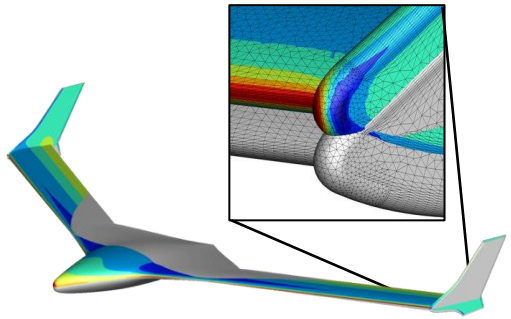
photo credit: Technion



Flight Test Working Group (FTWG)

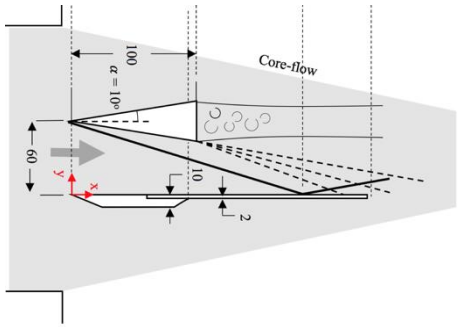
- Led by Jeff Ouellette (NASA)
- Focus on body freedom flutter mechanisms of the X-56A

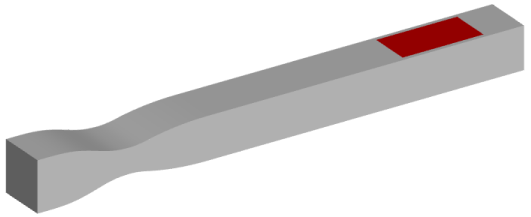
photo credit: NASA



High Speed Working Group (HSWG)

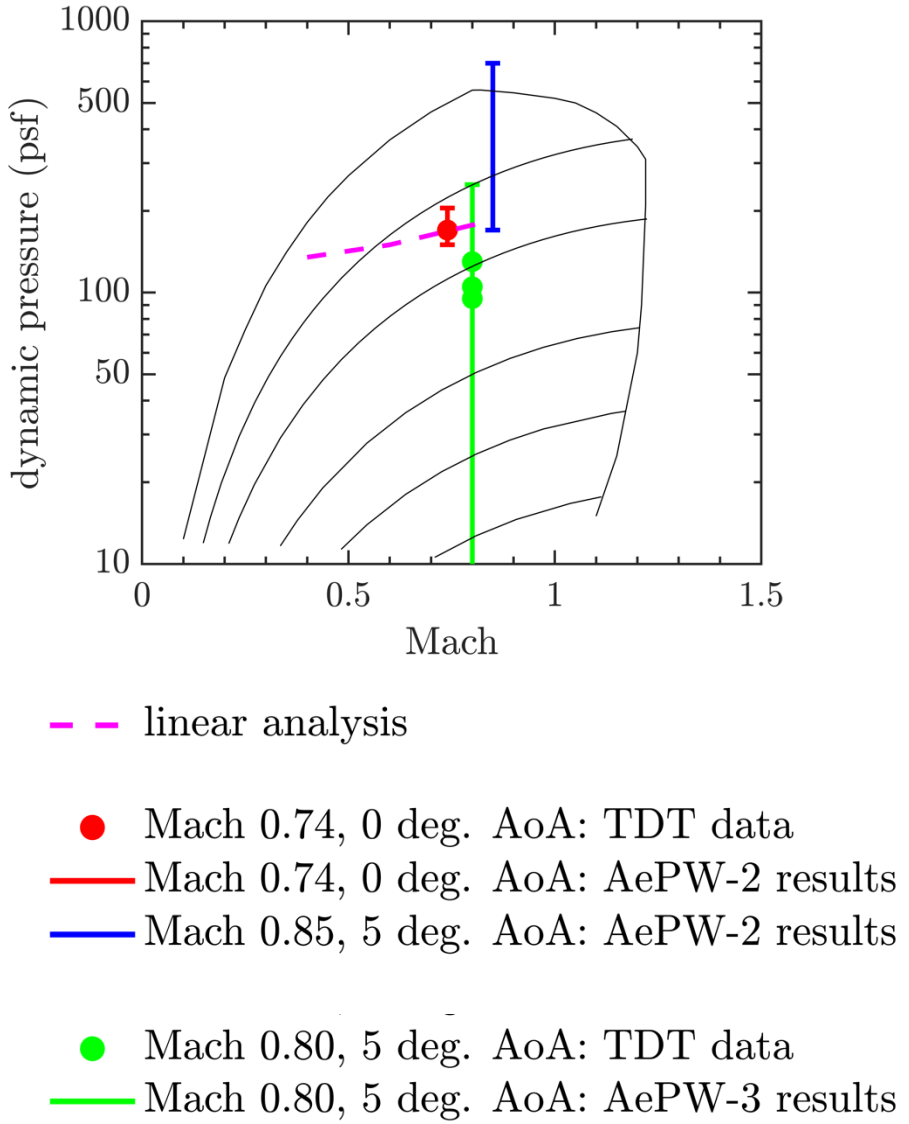
- Led by Eric Blades (ATA)
- Focus on supersonic and hypersonic FSI: RC19 test case (AFRL), and the HyMax test case (UNSW)





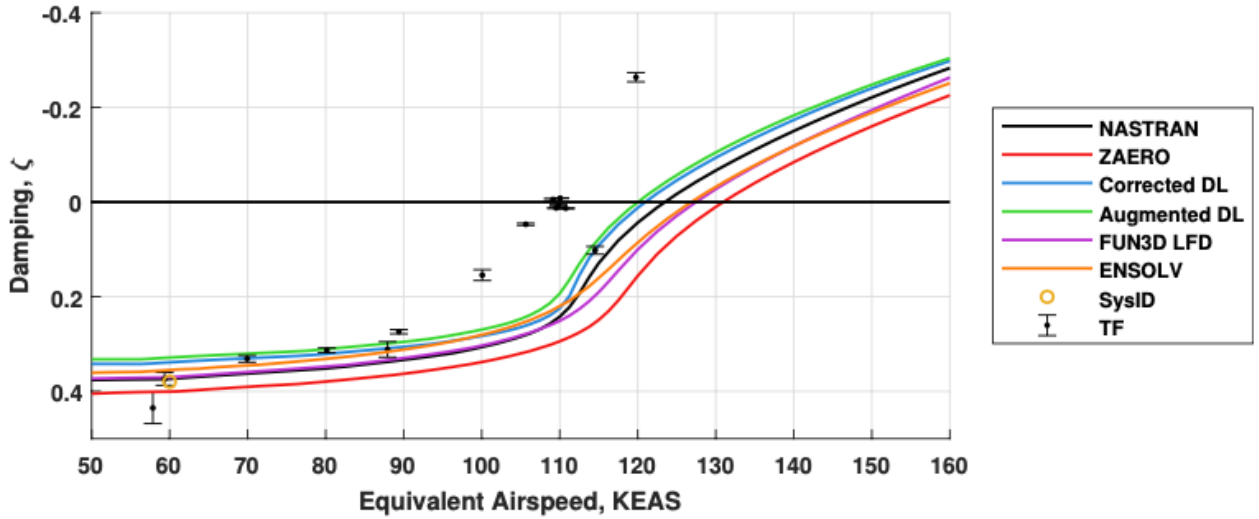
High Angle Working Group (HAWG)

- New BSCW data did not materialize in time for AePW-3
- Focus on an easier case (but not too easy) than AePW-2, and also one with experimental data from 1990's BMP
  - Mach 0.8 / 5° AoA
  - Still a large computational spread, though not as large as AePW-2
  - Some computational predictions predicted a flutter-Q of 0
- **AIAA Paper 2024-0417 and 2024-0418**
- Consensus to continue HAWG for AePW-4, with the hope that new BSCW data will be available
  - Which did not come true, again



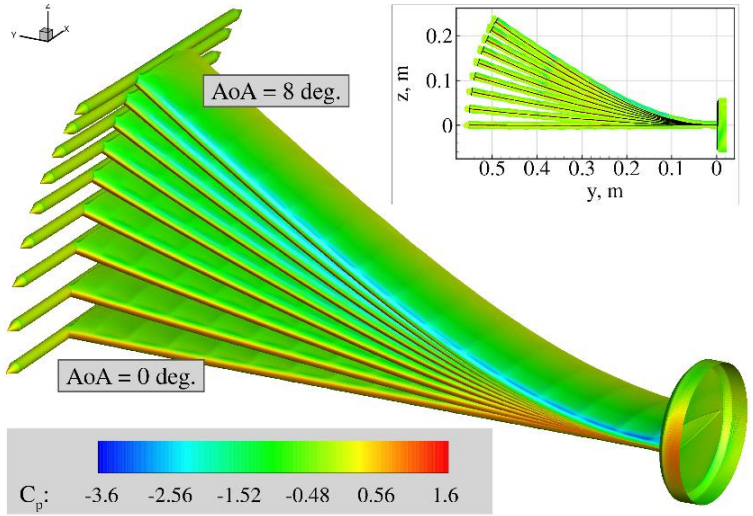
Flight Test Working Group (FTWG)

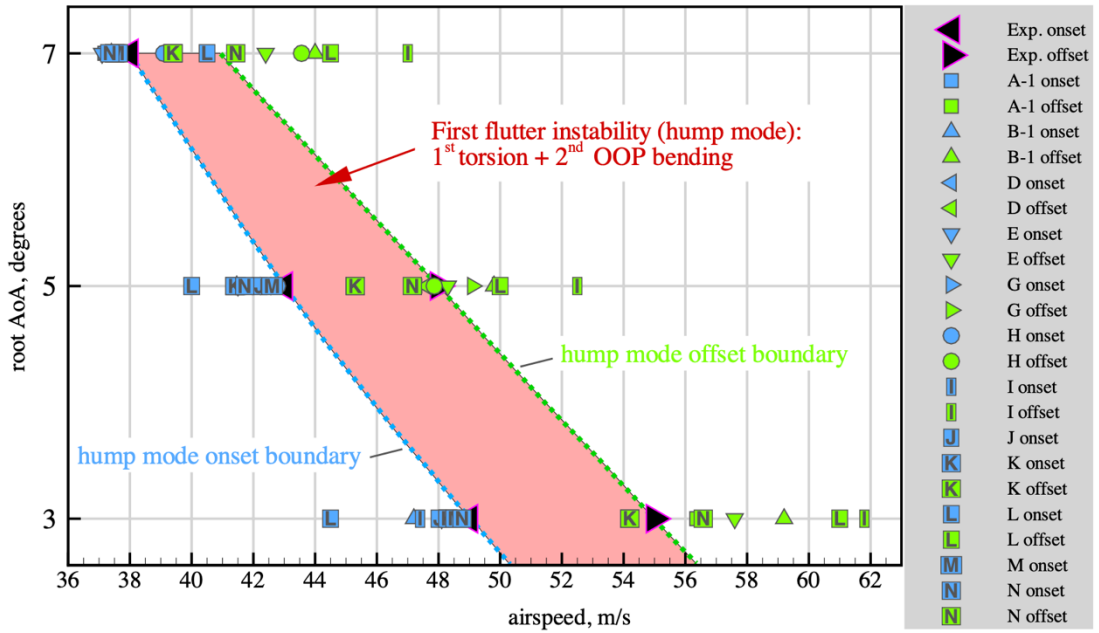
- Code-to-code comparisons via GAFs, aerodynamic work/energy, and root-locus plots for 4 different fuel states
- Reasonable agreement with test data, though flutter speed is over-predicted
- **AIAA Paper 2024-0415**
- Consensus not to continue FTWG for AePW-4, due to lack of interest/participation



Large Deformation Working Group (LDWG)

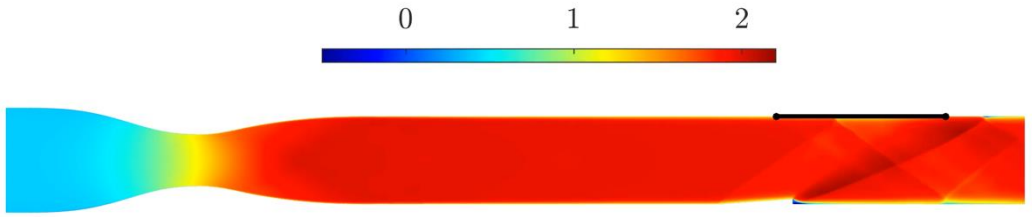
- Pazy wing: AoA-dependent hump-mode flutter boundary driven by geometric nonlinearities
- Aerodynamics are mostly linear: CFD can be used, but not required
- Reasonable agreement between the participants' results and the experimental data
- This WG was the most popular of the four AePW-3 WGs
- **AIAA Paper 2024-0419**
- Consensus to continue this WG in the future, but will not have a formal presence at AePW-4
- Leadership change from Markus Ritter (DLR) to Rafa Palacios (Imperial)



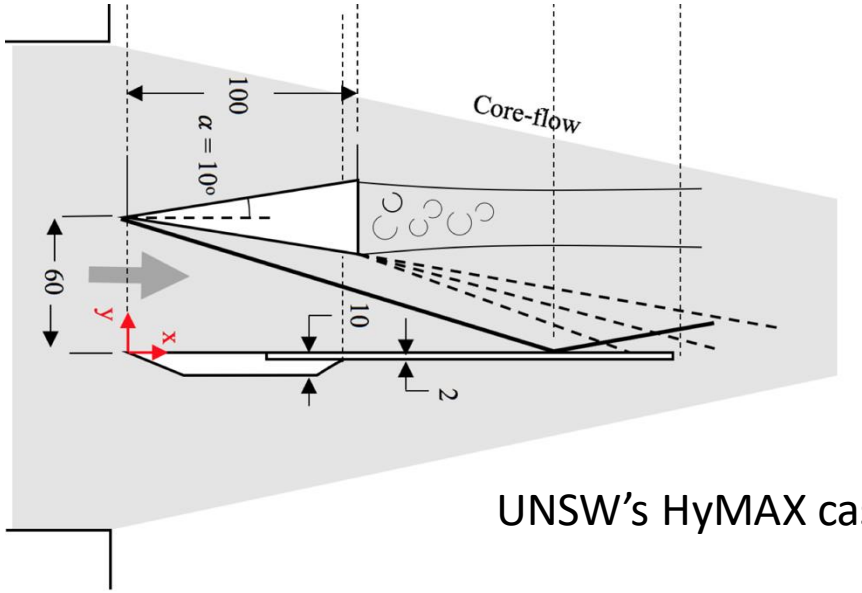


High Speed Working Group (HSWG)

- RC-19: Mach-2 flow through a wind tunnel with a nonlinear flexible panel
  - Different panel temperatures, cavity pressures, and wedge angles lead to different responses (LCO, chaos)
  - This is a very challenging problem which is very sensitive to the various inputs
- HyMAX: Mach-6 flow over a flexible plate, with shock impingement
  - 2 deg. wedge (laminar), 10 deg. wedge (transitional), oscillating wedge (reach case)
  - Linear structural response
- This WG did not have a formal workshop presence at AePW-3
  - Mini-workshop at SciTech 2024
  - Formal workshop presence at AePW-4
- Leadership change from Eric Blades (ATA) to Kirk Brouwer (AFRL)



AFRL's RC-19 test case



UNSW's HyMAX case

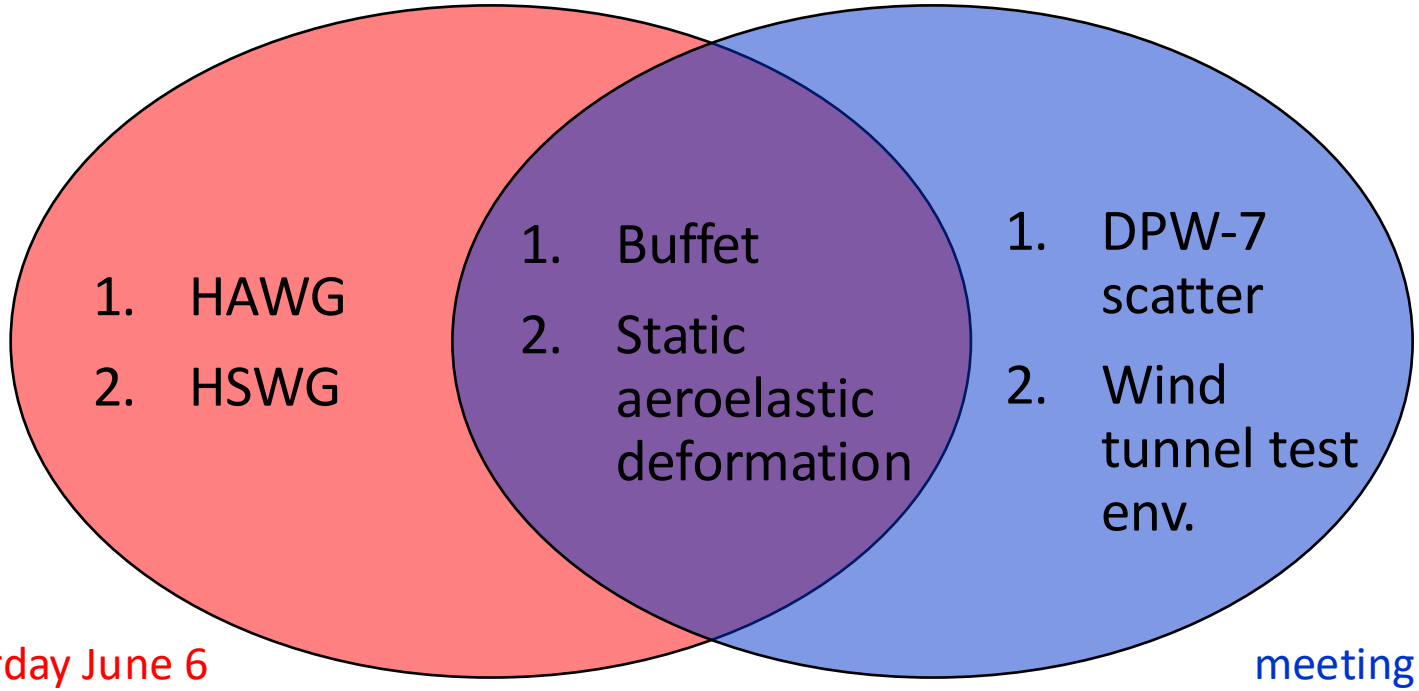
AePW-4

- High Speed Working Group (HSWG)
  - Led by Kirk
  - Five groups submitted results
- High Angle Working Group (HAWG)
  - Led by Pawel
  - Nine groups submitted results

- Kickoff held at AIAA SciTech 2024
- Tagups for both WGs (and LDWG) held nearly every month between then and now
  - https://nescacademy.larc.nasa.gov/workshops/AePW4/public

- We also have two joint working groups with the Drag Prediction Workshop Community (DPW)
  - DPW leadership is interested in incorporating new physics: aeroelasticity, unsteady flows
  - AePW can benefit from DPW's expertise in industry-relevant geometries, drag-centric workflows

AePW-4 / DPW-8 Venn Diagram



meeting Saturday June 6

meeting Saturday June 6

meeting Sunday June 7

Joint Working Groups

- Static Deformation Working Group
  - Leads: Ben Rider (Boeing), Stefan Keye (DLR), Garrett McHugh (NASA)
  - Consider static aeroelastic deformations of a sting-mounted Common Research Model (CRM) tested in the NASA NTF
  - This had previously been used as an optional test case in DPW-5, but very few participants considered it
  - Challenges for the AePW community: drag-centric computations, wing/body configuration

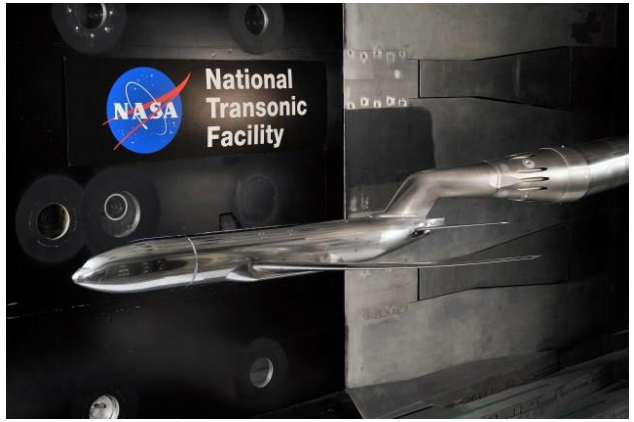
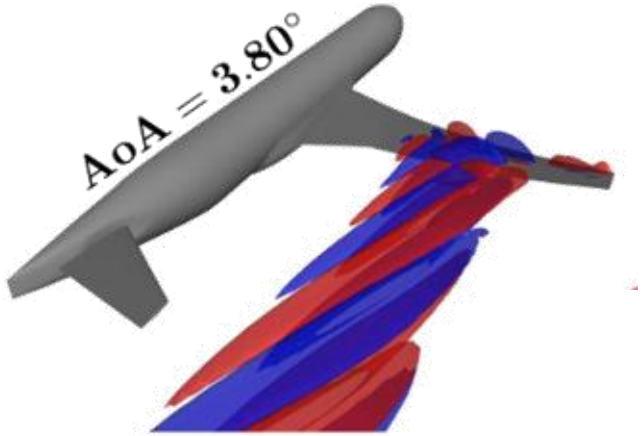


photo credit: NASA

- Buffet Working Group
  - Leads: Brent Pomeroy (NASA), Andrea Sansica (JAXA), Daniella Raveh (Technion), Hadar Ben-Gida (Technion)
  - Consider 2D and 3D transonic shock buffet over rigid and flexible models
  - Extension of buffet work done for HAWG in AePW-3



Sansica and Hashimoto, AIAA J, 2023

Agenda for Today (June 6)

start time	end time	speaker	org	attendance	subject
9:00 AM	9:30 AM	Bret Stanford	NASA	in-person	Welcome, AePW introduction/overview/history, agenda
Session 1: High Speed Working Group (HSWG)					
9:30 AM	9:45 AM	Kirk Brouwer	AFRL	in-person	HSWG introduction
9:45 AM	10:00 AM	Luisa Piccolo Serafim	Duke / G. Tech	virtual	HSWG results
10:00 AM	10:15 AM	Bret Stanford	NASA	in-person	HSWG results
10:15 AM	10:30 AM	break			
10:30 AM	10:45 AM	Kirk Brouwer	AFRL	in-person	HSWG results
10:45 AM	11:00 AM	Rodrigo Auza Guitierrez	Cadence	virtual	HSWG results
11:00 AM	11:45 AM	Kirk Brouwer	AFRL	in-person	HSWG summary and discussion
11:45 AM	1:15 PM	Lunch (on your own)			
Session 2: High Angle Working Group (HAWG)					
1:15 PM	1:30 PM	Pawel Chwalowski	NASA	in-person	HAWG introduction
1:30 PM	1:45 PM	Ron Efrati	Technion	virtual	HAWG results
1:45 PM	2:00 PM	Michael Candon	RMIT	in-person	HAWG results
2:00 PM	2:15 PM	Marcello Righi	ZHAW/ETH Zurich	virtual	HAWG results
2:15 PM	2:30 PM	Pawel Chwalowski	NASA	in-person	HAWG results
2:30 PM	2:45 PM	Marcel Sunano	Sao Paulo State U.	virtual	HAWG results
2:45 PM	3:00 PM	break			
3:00 PM	3:15 PM	Ryoya Kikuchi	Hokkaido U.	in person	HAWG results
3:15 PM	3:30 PM	Hang Yu	Stanford	in person	HAWG results
3:30 PM	4:00 PM	Pawel Chwalowski, Kevin Jacobson	NASA	in-person	HAWG summary and discussion
Session 3					
4:00 PM	4:15 PM	Bret Stanford	NASA	in-person	Large Deformation Working Group (LDWG) summary
4:15 PM	5:00 PM	All			Future AePW Directions

Agenda for Tomorrow (June 7)

- AePW-4 has two joint working groups with DPW-8

    1. Static Deformation Working Group
    2. Buffet Working Group

- We will combine with the DPW community tomorrow, to present these two working groups

WG Participant Presentations

- Each presentation is scheduled for 15 minutes
  - Plan for a 10-12 minute talk + 3-5 minutes of Q&A
- The WG leaders (Kirk, Pawel) will give an overview of the test case, so no need for the other presentations to do that also
- We have a mix of virtual and in-person presentations
  - Virtual presentations are pre-recorded, with a live Q&A
- Kirk and Pawel will give a summary talk, with plots comparing the results from all WG participants
- A few participants will have their results in the summary talks, but are not presenting today

Downstream Publication Plan

- We will have a series of invited special sessions at SciTech 2027 for AePW-4 and DPW-8
- It is much better to sign up and withdraw, than to miss the window
- Preferred submission process:
  - Filler abstract due by June 20
  - Only need a tentative title and one author name, and this will start a submission with a control ID
  - Talk to Bret/Brent to request an extension
- If export control prevents you from submitting a blank abstract by June 20: talk with Bret/Brent

Your Title Here

Your Name,*
Your Organization

This paper is in support of the DPW-8/AePW-4 Special Session being organized by Brent Pomeroy and Bret Stanford

Questions?

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pawel.chwalowski@nasa.gov
kirk.brouwer.1@us.af.mil

Large Deformation Working Group

- LDWG was led by Markus Ritter (DLR) for AePW-3, and this was the most popular WG at that workshop
- Focus on large structural deflections of a subsonic high aspect ratio wing (Pazy Wing, Technion)
- Currently led by Rafa Palacios @ Imperial College
  - r.palacios@imperial.ac.uk
  - Monthly tagups will continue past Aviation 2026
  - Please ping Rafa to be included on those tagups, get access to his Sharepoint site, etc.

- Special session held at SciTech 2026
- No formal workshop presence here at AePW-4
  - Tentative plans for a mini-workshop at…SciTech 2027? Aviation 2027?

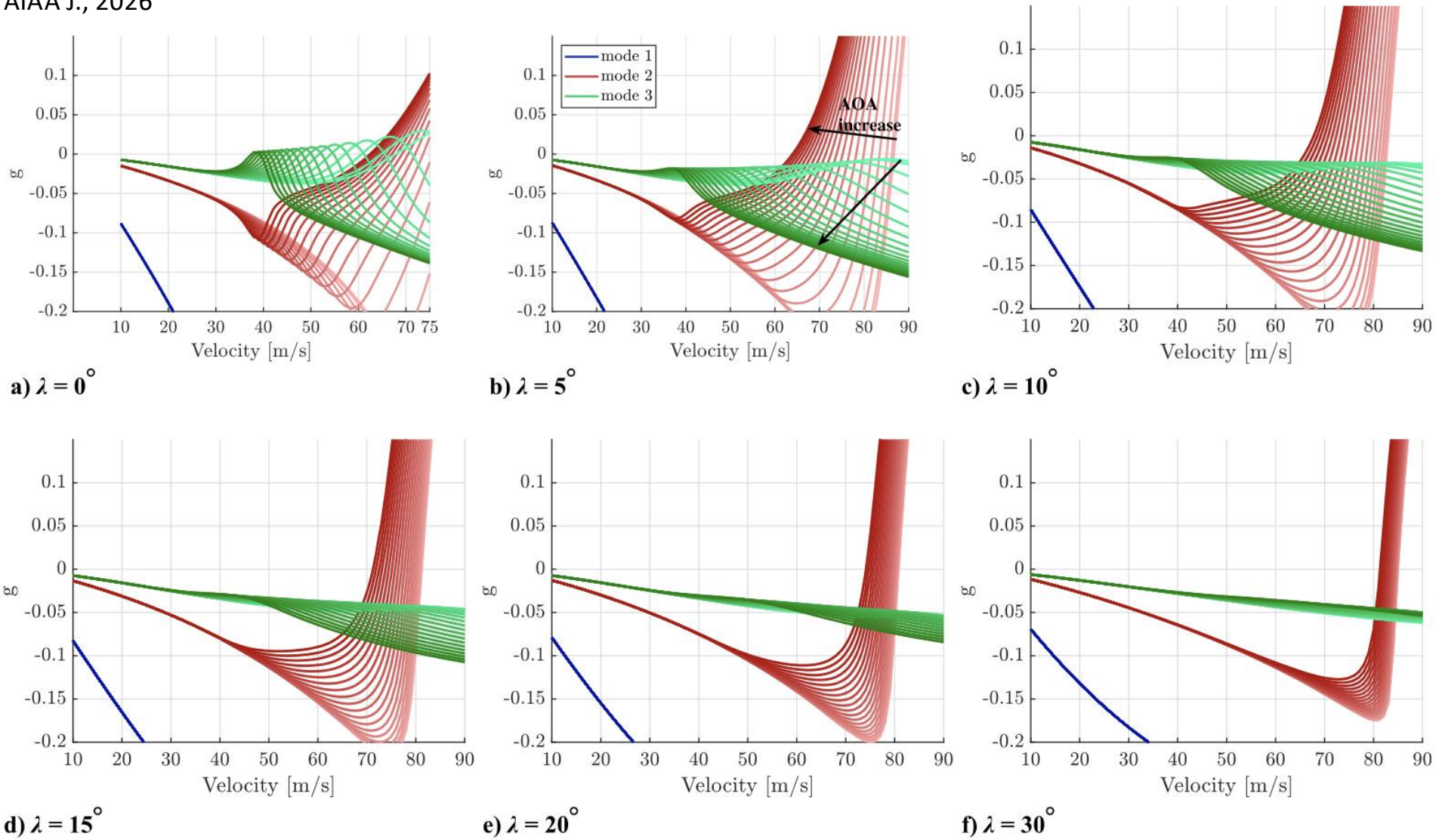
Swept Pazy Wing

- Consensus reached late last year to focus the latest iteration of this WG on the swept Pazy wings
- Experimental data, and preliminary computational predictions conducted at Technion, Sapienza University of Rome, ZHAW
- Fundamentally different mode shapes, static aeroelastic deformations, flutter mechanisms, and LCO, than observed for the unswept Pazy wing (AePW-3)

photo credit: Technion

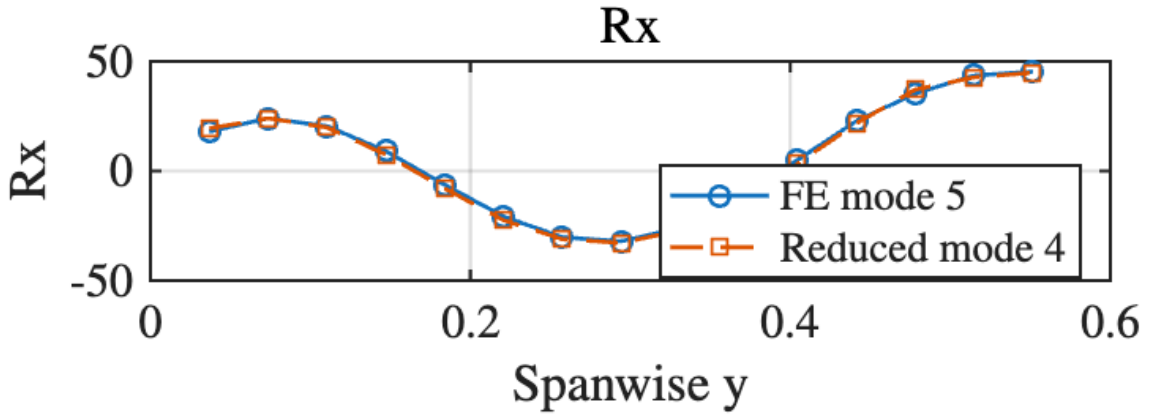
Computed Flutter Behavior

Revivo and Raveh, AIAA J., 2026



Equivalent Beam Model

- A few LDWG participants have coupled their aerodynamic tools to a full finite element model of the Pazy wing (either straight or swept), but most require an equivalent beam model
- In April 2026, Daniella created an equivalent beam model for the 10° swept Pazy model, in Nastran
- This model has been vetted by a few others in the LDWG, and will be released to the wider group in the next month or so



Questions?

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Future AePW Directions

- What is working, and what is not working?
- Our participation numbers are trending a little down relative to AePW-1 and AePW-2
  - And trending strongly down relative to AePW-3, though there was a bump there from the introduction of the four working groups
  - IFASD is next week in Germany, so that hasn't helped
- Industry participation has dropped across all four AePW's, and is currently at 0
- The collaboration with DPW: has this worked? Do we want to do this again?
- Open discussion

Miscellaneous Thoughts

- Three enormous challenges for AePW are, and have always been:
  1. Computational cost of unsteady CFD-based aeroelastic predictions, particularly for fidelities above URANS
     - We are seeing greater use of ROMs, linearized methods (LFD), accelerated computing platforms (GPU)
     - Presumably AI/ML will continue to make an impact for unsteady CFD
  2. Lack of validation experiments
     - High cost and complexity of these wind tunnel tests, particularly at larger facilities
     - Validation datasets should contain repeat data points, and small intentional variations in test conditions
  3. Convincing people to participate
     - Too-few results, and it can be difficult to draw any conclusions regarding computational best-practices

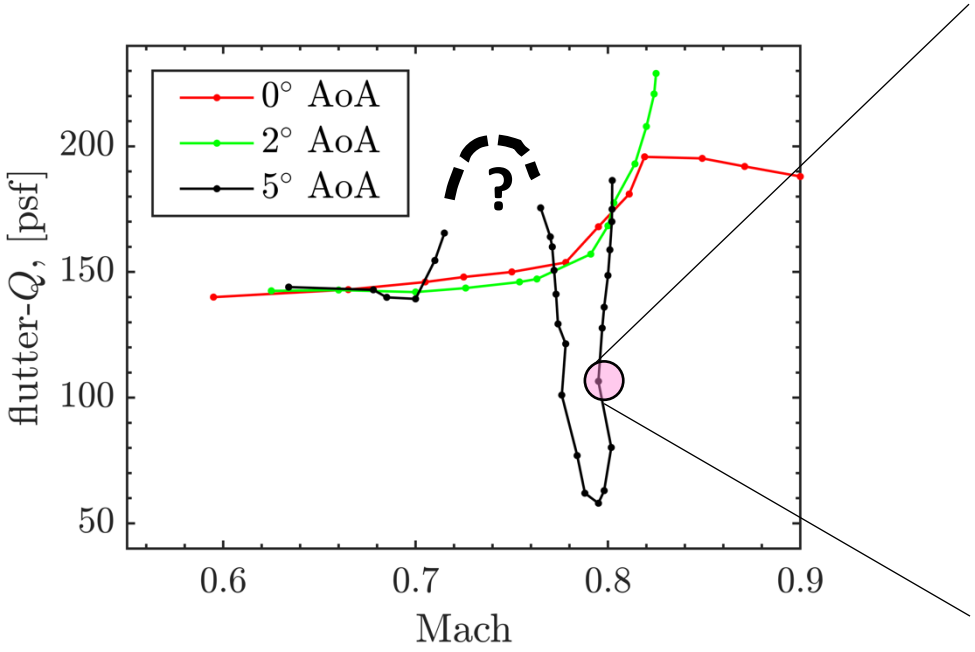
Future of the Working Groups

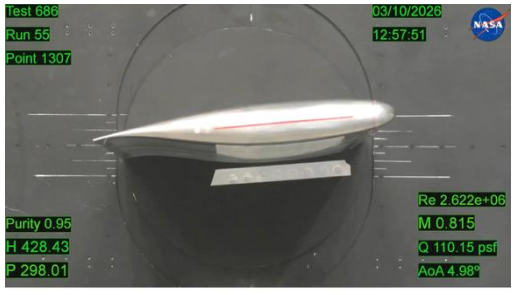
- High Speed Working Group
  - This community may benefit from the development of single-discipline unit-test cases
  - Stronger collaboration with the AIAA High Speed FSI Discussion Group?
  - Additional ideas / thoughts / comments from Kirk, for future directions?

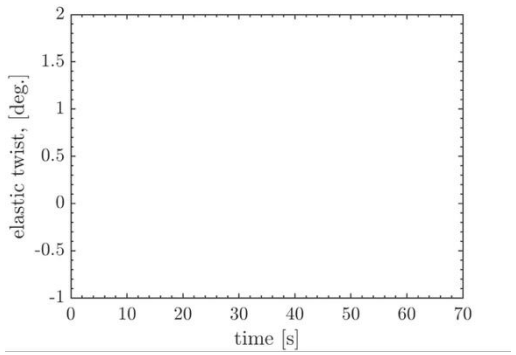
- Large Deformation Working Group
  - This group will continue on under the direction of Rafa Palacios
  - An equivalent beam model was recently created for this group, and we expect this to lead to a large increase in WG participant computations
  - Tentative plans for a mini-workshop at…SciTech 2027? Aviation 2027?

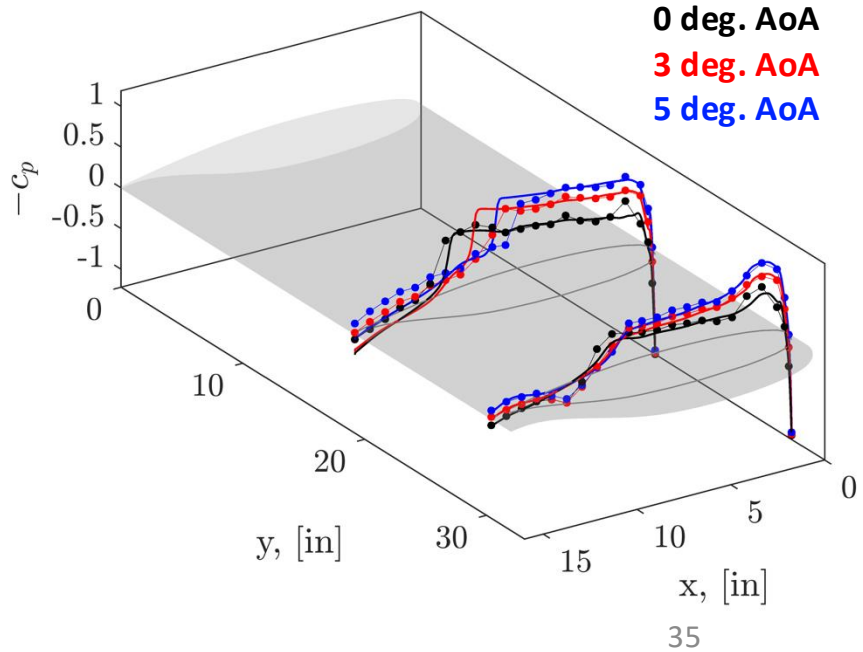
The Future of HAWG

- We (finally) have retested BSCW, and have new data
  - This is data we were hoping to have for both AePW-3 and AePW-4
- TDT entry January-March 2026
  - A second entry in June/July 2026 will repeat some of the first entry, with optical methods for full-field on- and off-body flow measurements
- Is there enough interest/momentum in the AePW community to continue with this BSCW topic for another cycle?

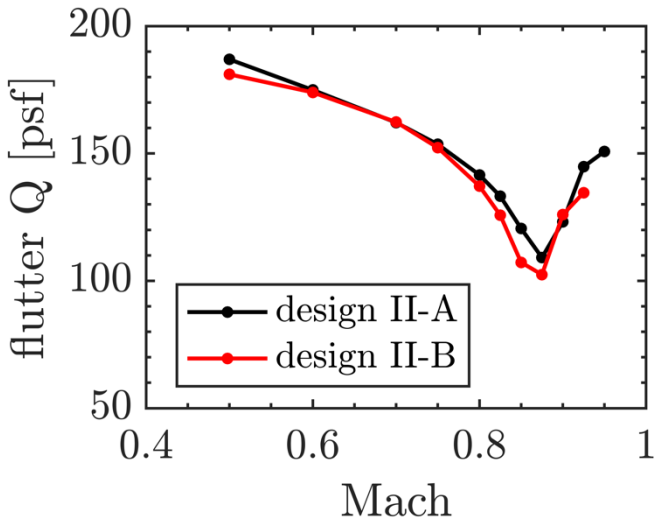


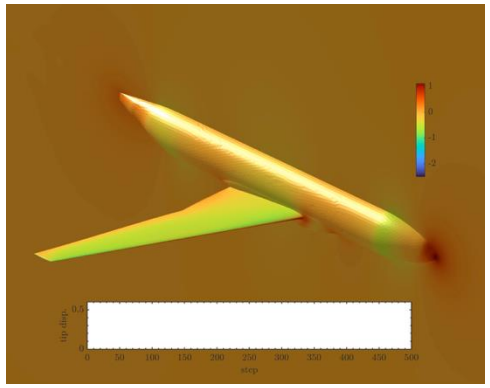




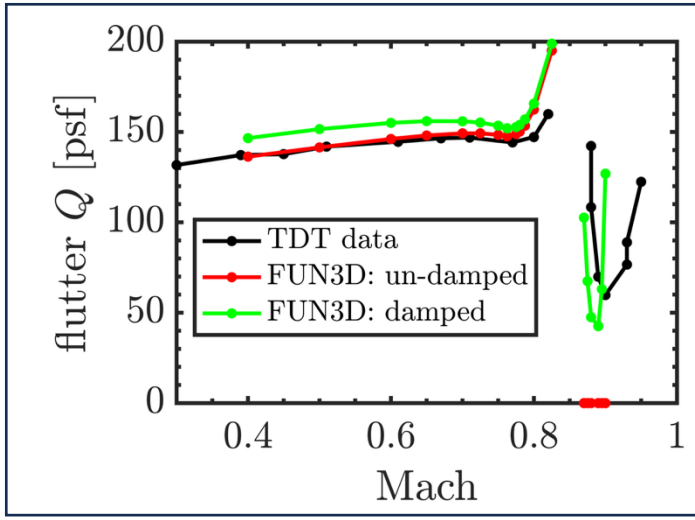


Other Flutter Configurations?





Aeroelastic CRM



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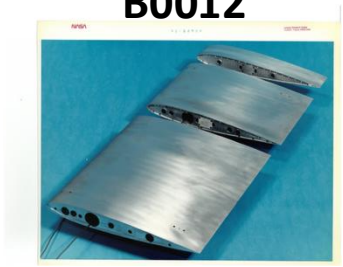

photo credit: NASA

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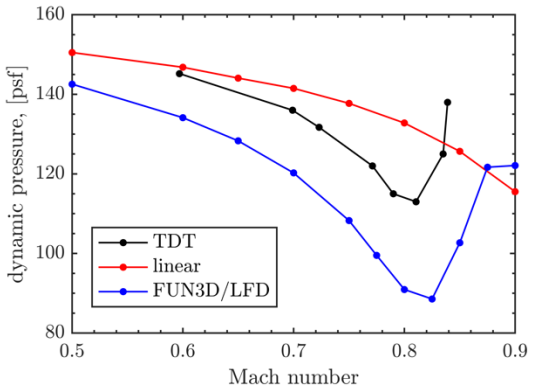
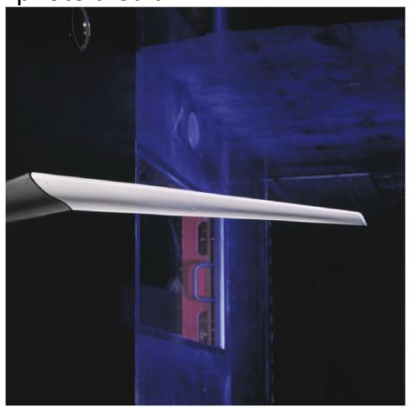
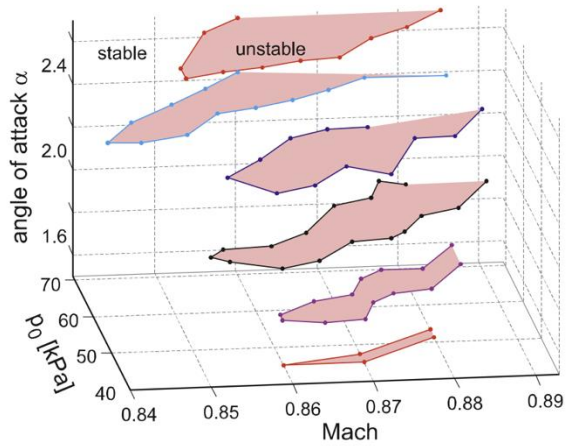


photo credit: DLR





Aerostabil: Schewe and Mai, JFS, 2019

Control Surfaces

- BACT wing (Benchmark Active Controls Technology)
  - Yet another benchmark model tested in the TDT in the 1990's
  - Relatively few CFD comparisons since then
- In theory there is a ton of BACT data (rigid/flexible mounts, different control surface combinations, ASE, etc.)…
  - …but the exact condition and fidelity of the dataset is uncertain

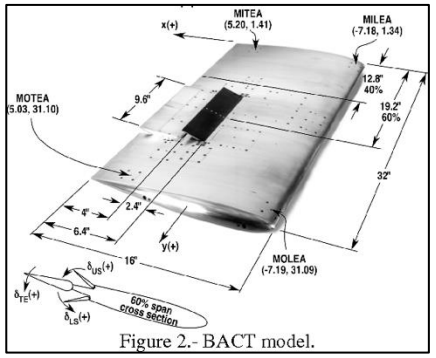
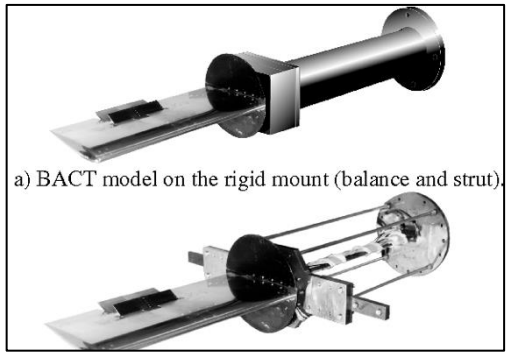
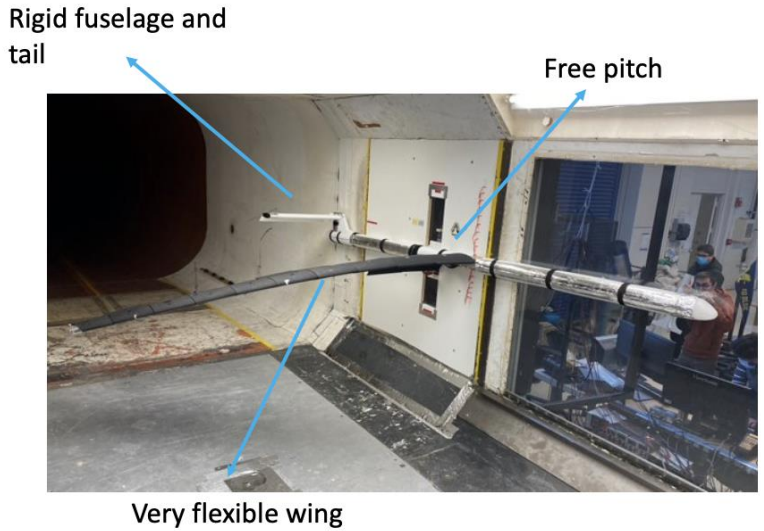


Figure 2.- BACT model.


a) BACT model on the rigid mount (balance and strut).

BACT

- Michigan's EASE configuration: semi-span, high-aspect-ratio model on a PAPA support
  - There is a build-up of physics, culminating in ASE load alleviation



EASE configuration: courtesy U. Michigan

Future Collaborations with other Workshops

- AePW has struggled with industry participation, but the joint working groups with DPW (Sunday) do better in this metric
  - Presumably, the more-realistic configuration (CRM) plays a role here?
  - There have not been as many AePW-centric participants in those joint WGs, as hoped for
- Collaboration with the High Lift Prediction Workshop (HLPW)?
- Should we better align ourselves with Grand Challenge problems that may come from the CFD-2030 community?
  - **APA-30/CFD2030-05: CFD 2030 Grand Challenge Workshop Scoping and Development**
  - **Wed. Jun 10, 3:30 – 5:30**

Open Discussion

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