High Angle Working Group Summary

AIAA Drag Prediction Workshop 8 / Aeroelastic Prediction Workshop 4
June 7th, 2026

Pawel Chwalowski
Pawel.Chwalowski@nasa.gov

Kevin Jacobson
Kevin.e.jacobson@nasa.gov

AePW-4 High-Angle Working Group Results

- Preliminary Results
- If you see that something is not processed correctly, please let us know.

	Organization	POC	Case 1	Case 2	Case 3	Participation/ presentation
1	NASA	Pawel Chwalowski	x	x	x	In person
2	Duke	Jeff Thomas			x	Not presenting
3	ZHAW/ETH Zurich	Marcello Righi	x		x	Virtual
4	University of Liverpool	Daniel Nash	x			Not presenting
5	Technion	Daniella Raveh	x		x	Virtual
6	Hokkaido University	Ryoya Kikuchi	x	x	x	In person
8	RMIT	Michael Candon	x			In person
9	Stanford	Hang Yu	x	x		In person
10	São Paulo State University - UNESP	Marcel R. Sunano			x	Virtual

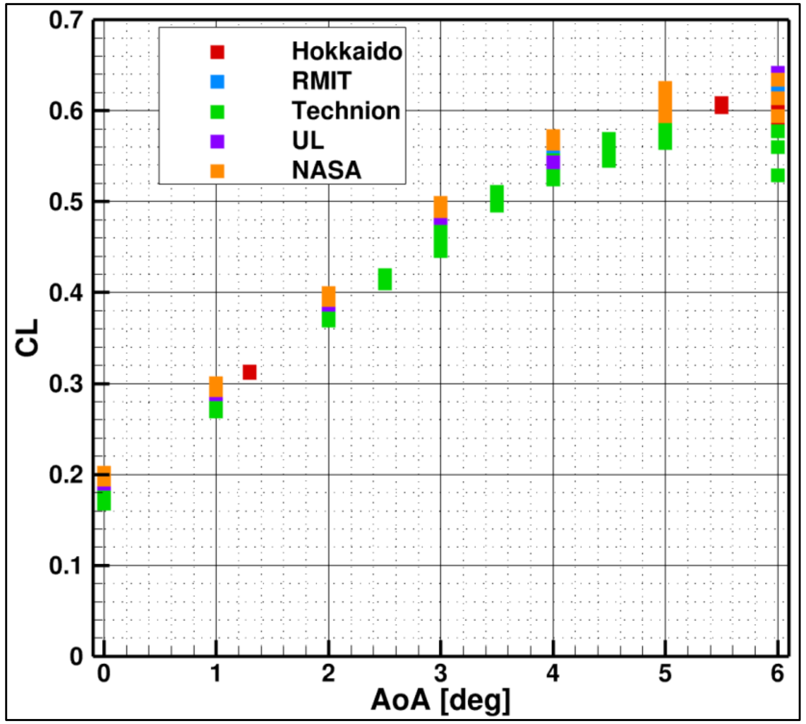
AePW-4 High-Angle Working Group Results

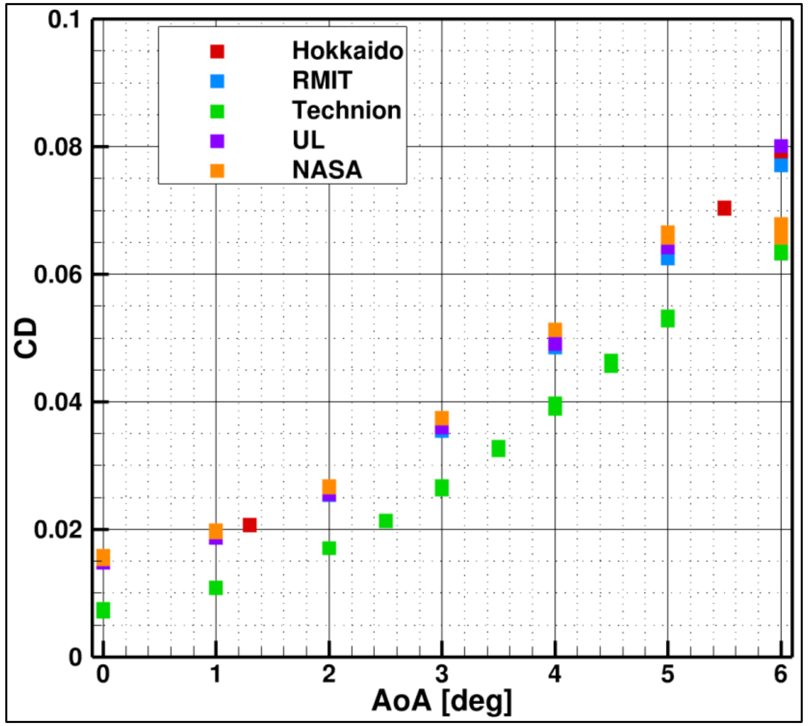
Data Preparation

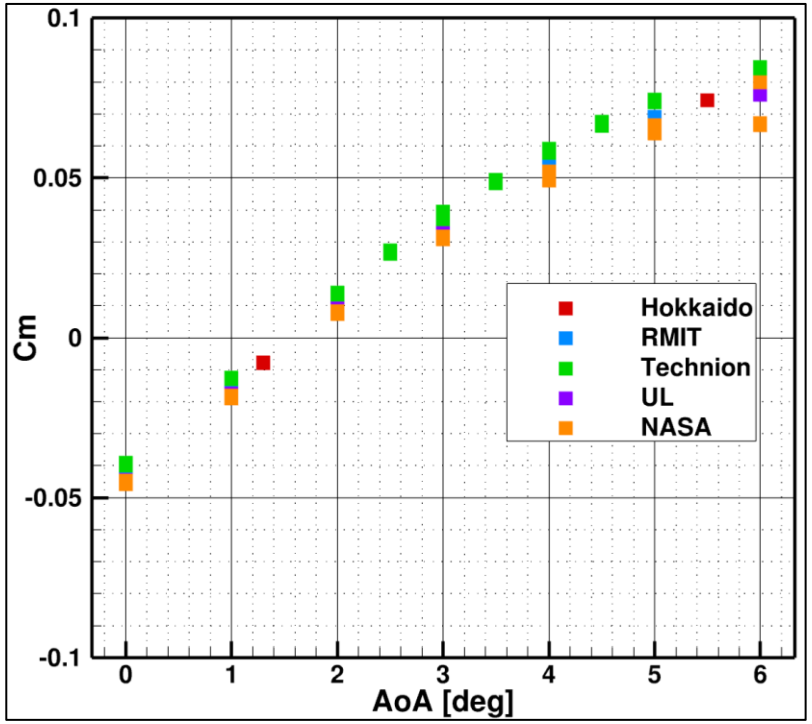
- Data preparation
  - Steady rigid: CL, CD, and Cm coefficients (moment reference point: mid chord) at ALL mesh resolutions.
  - Surface Cp in Tecplot format: I will extract Cp vs. x/c at 60% and 95% wingspan (2D and 3D).
  - Or, please extract Cp vs. x/c at 60% and 95% wingspan (2D and 3D).
- Time domain solvers
  - Temporal history of generalized displacement/velocity at ALL Qs at ALL mesh resolutions
    - Columns: (time | mode1 displacement | mode1 velocity | mode2 displacement | mode2 velocity)
    - File name request: {Team}_Dataset{#}_Case{#}_Mach{#}_AoA{#}_Q{#}_{Mesh}_Dt{# in seconds}.dat
      - + Example: NASA_Dataset1_Case1_Mach0.80_AoA5.0_Q169_Coarse_Dt0.0001.dat
      - + Teams provide 'Dataset' information as a table (perturbation size/type, turbulence model, limiter settings, etc.)
  - If you are computing static aeroelastic pitch angle, please provide a table with these angles and extract Cp vs. x/c at 60% and 95% wingspan (2D (?) and 3D) at all Qs.
  - Table with YOUR flutter dynamic pressure and flutter frequency prediction at Mach and AoA
- Frequency domain solvers: flutter dynamic pressure and frequency at Mach and AoA
- If you are using your own grids, please send them to Pawel
- **Data submission deadline is May 29.**

AePW-4 High-Angle Working Group Results
Steady-Rigid Aerodynamic Coefficients

- Case1: 3D wing flutter prediction at Mach 0.80 and angle-of-attack sweep: 0° – 6°



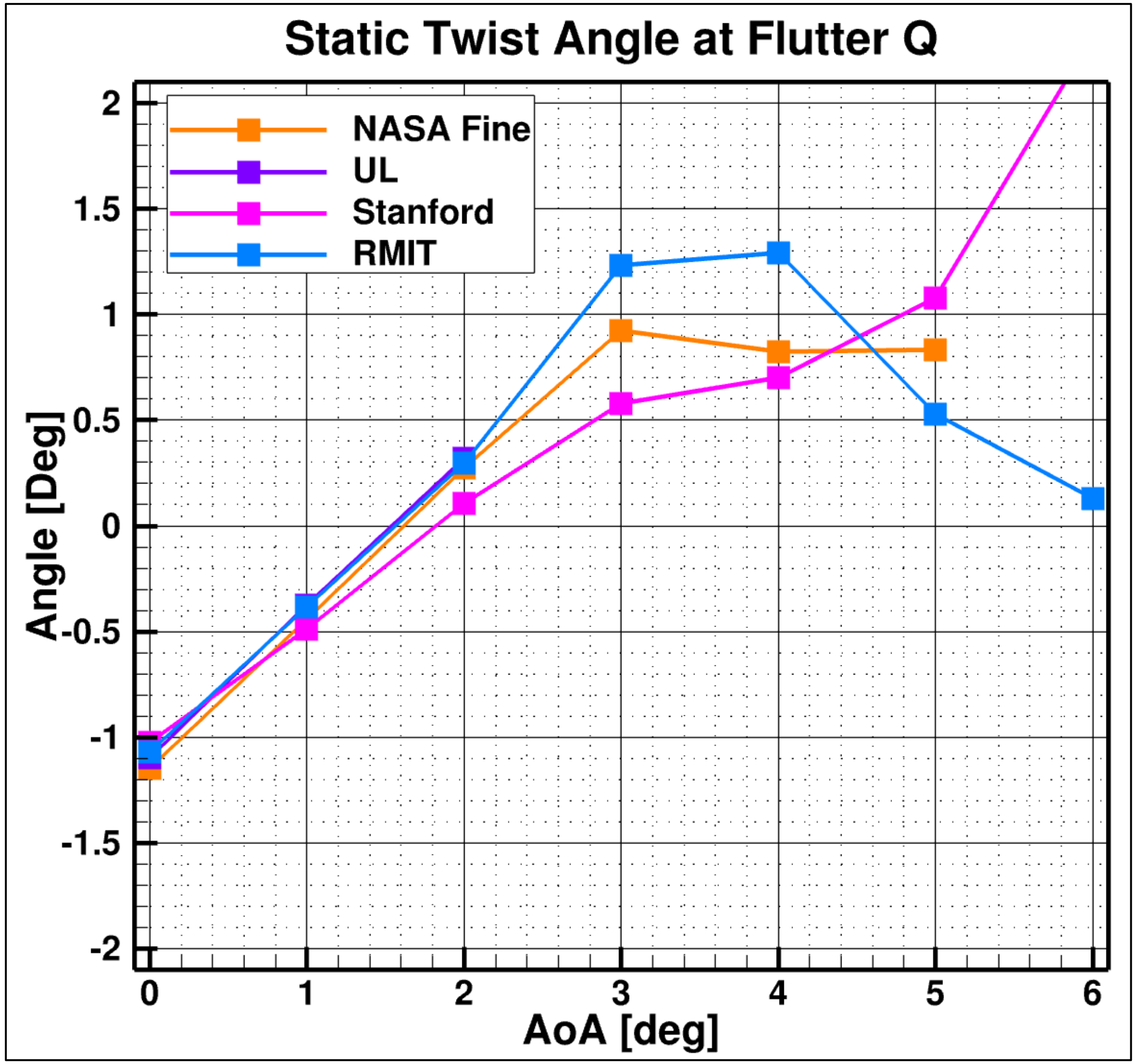




AePW-4 High-Angle Working Group Results

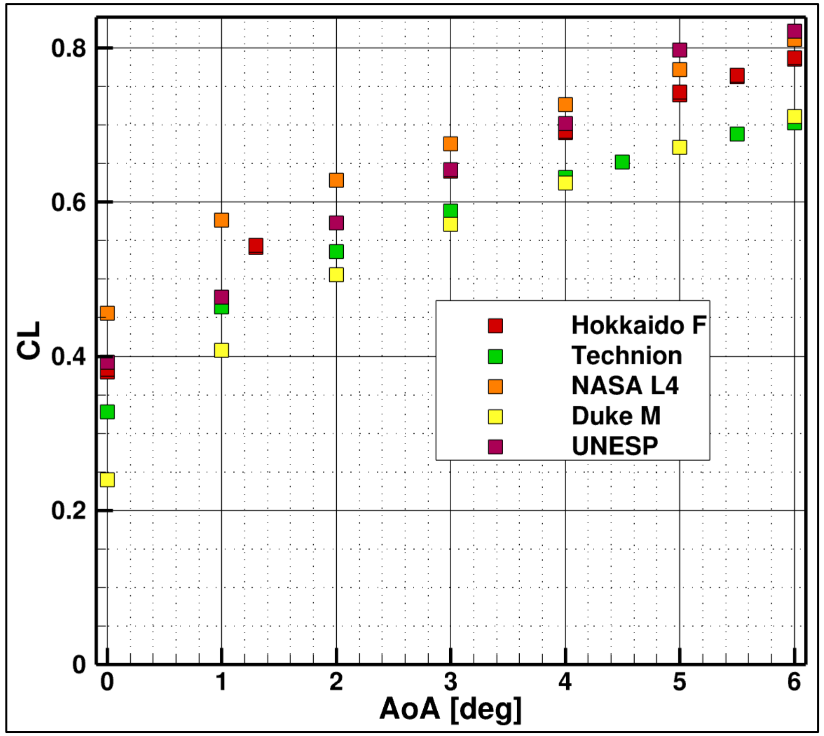
Static Twist Angle

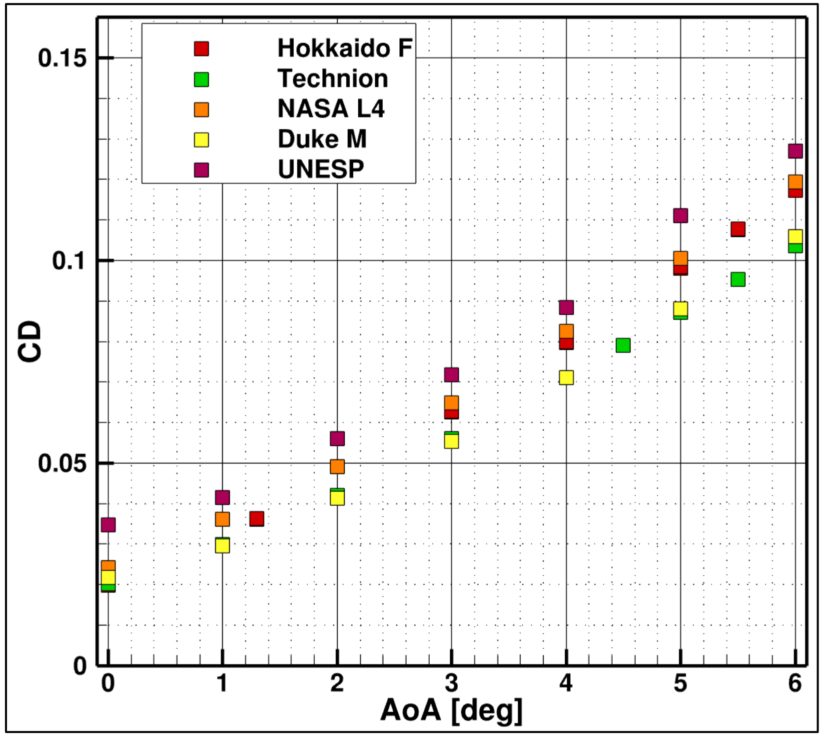
- Case1: 3D wing flutter prediction at Mach 0.80 and angle-of-attack sweep: 0° – 6°

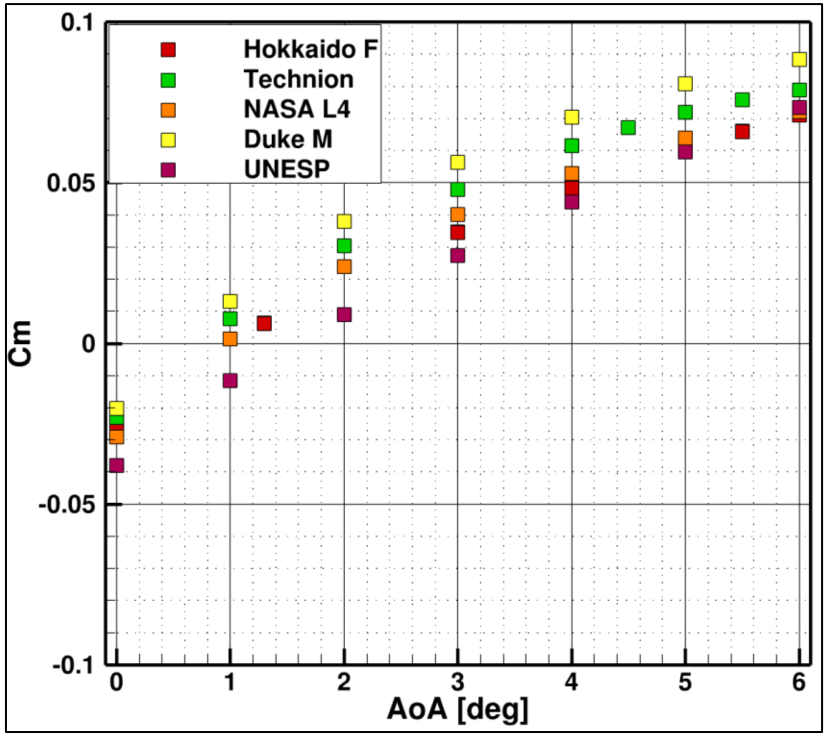


AePW-4 High-Angle Working Group Results
Steady-Rigid Aerodynamic Coefficients

- Case3: 3D wing flutter prediction at Mach 0.80 and angle-of-attack sweep: 0° – 6°



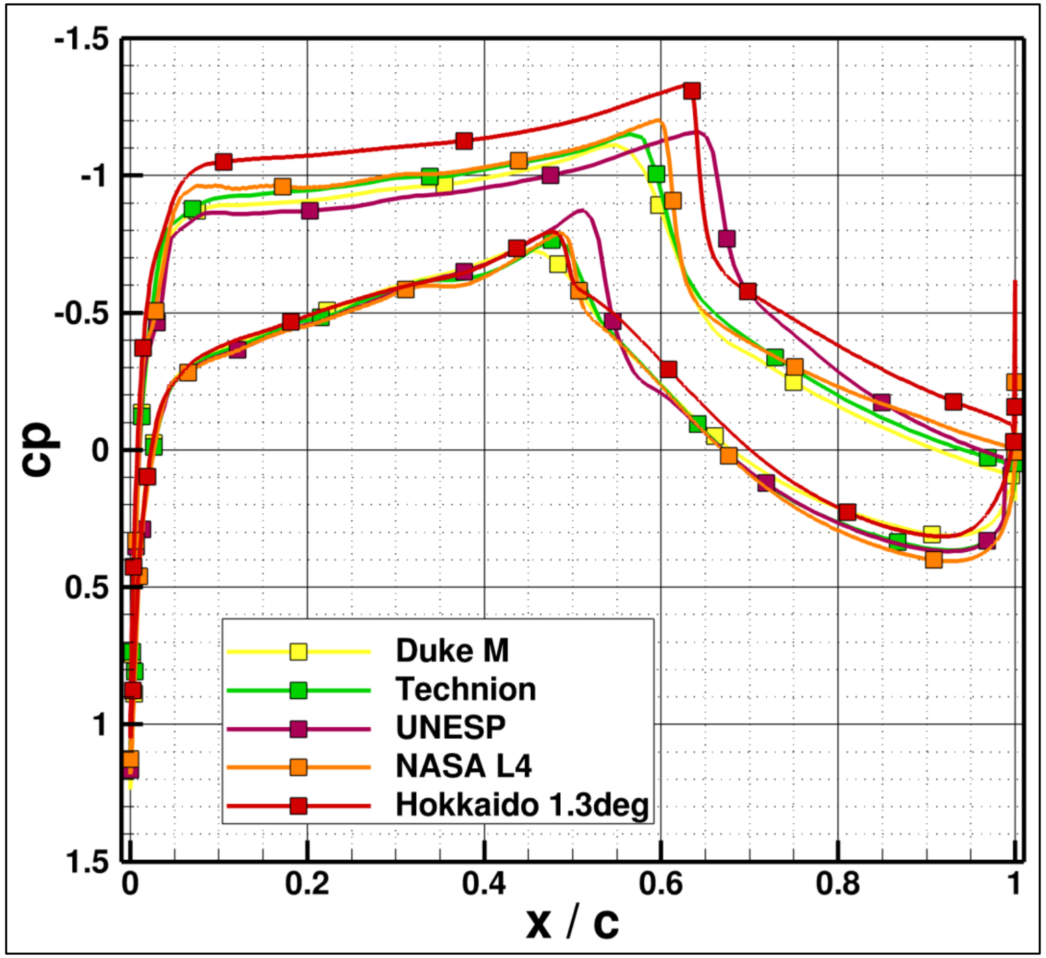




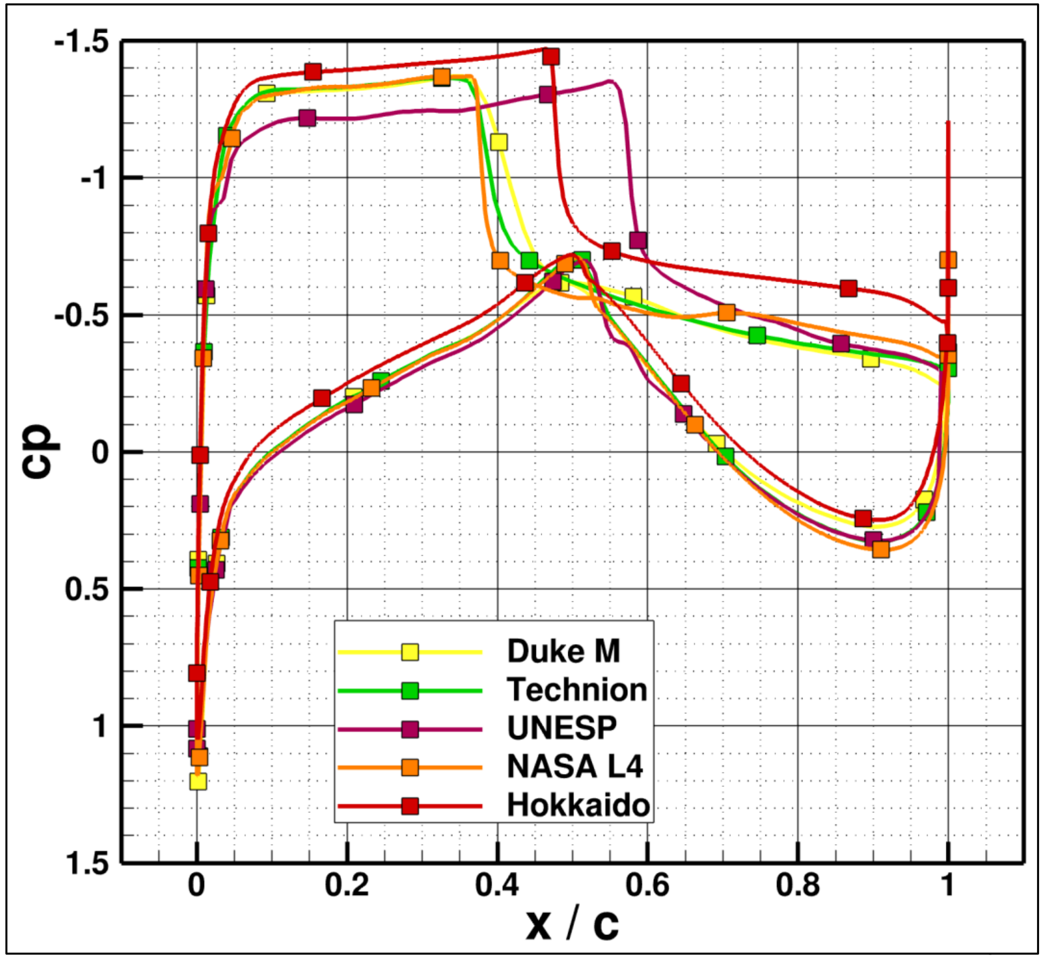
AePW-4 High-Angle Working Group Results
Steady-Rigid Pressure coefficient

- Case3: 3D wing flutter prediction at Mach 0.80 and angle-of-attack sweep: 0° – 6°

AoA = 1 deg



AoA = 5 deg



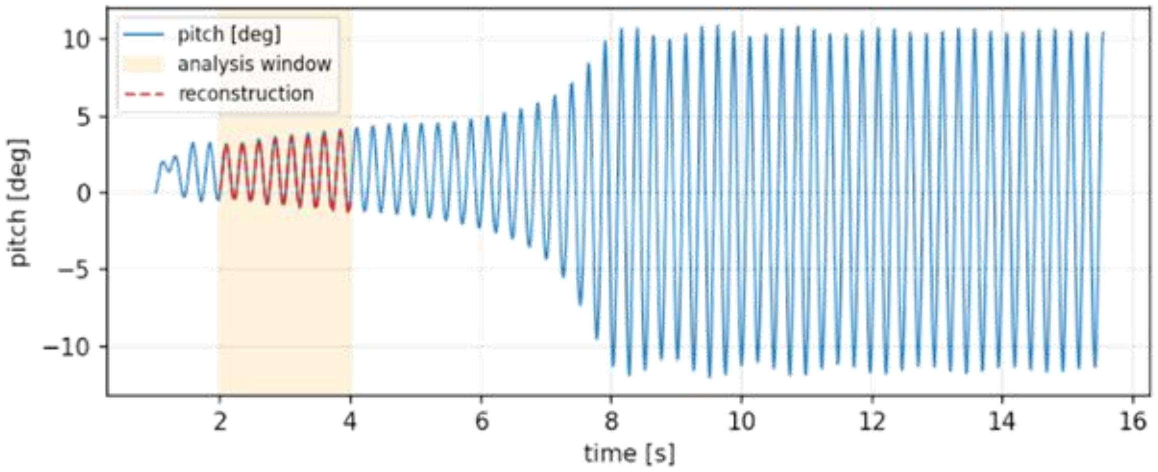
Flutter Data Processing – Matrix Pencil Method

- Matrix Pencil method to fit a Prony series to each signal
  - Prony series = a sum of damped sinusoids

$$z_n = \sum_{k=1}^{M} c_k e^{s_k n} + w(n)$$

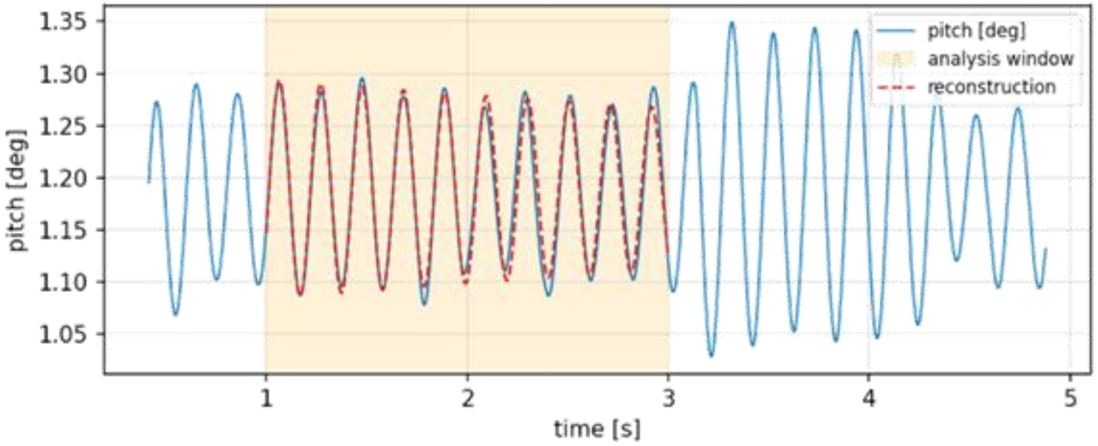
Noise term

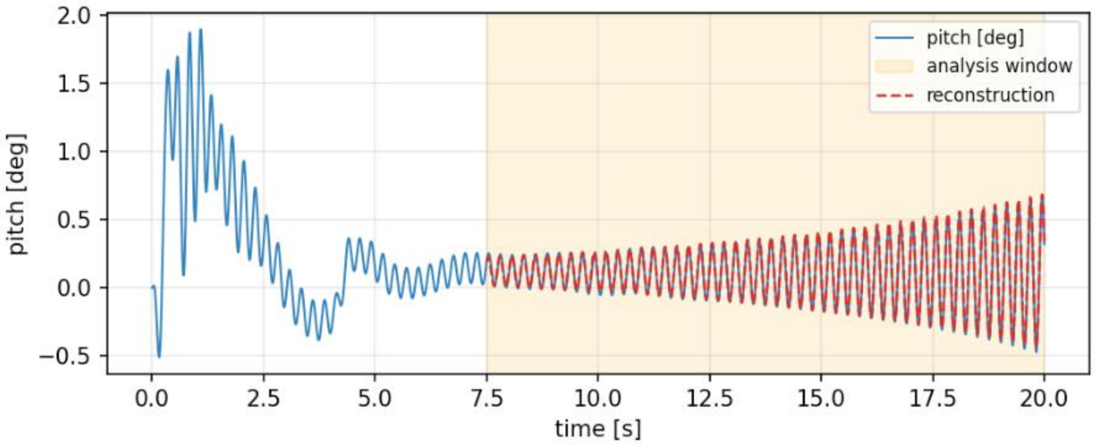
  - Plots to come show the minimum damping (most unstable) component of the Prony series reconstruction of the pitch angle
- Manual tuning of the Matrix Pencil required
  - Number of prony series components to keep (filter out noise)
  - Time window

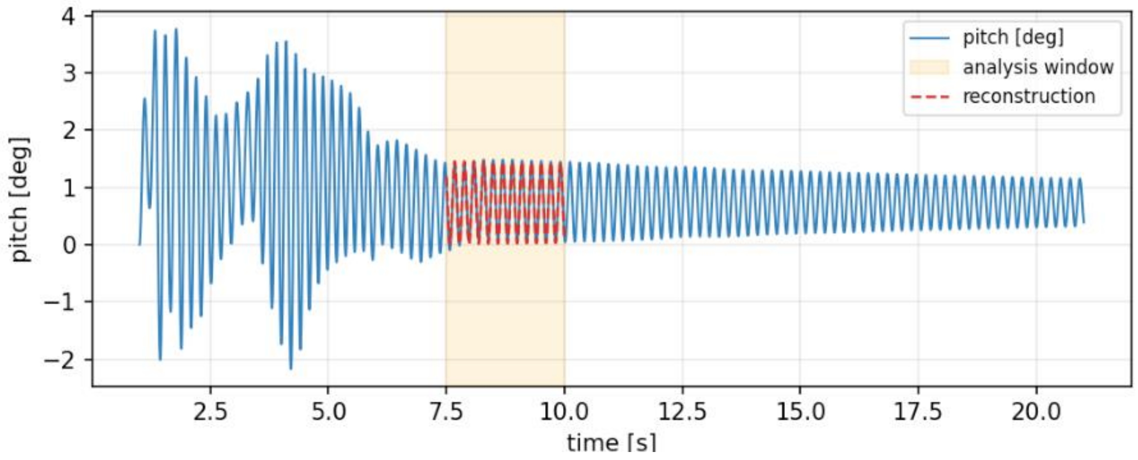


Data Presented Here is Preliminary!

- Prony series = linear assumption
  - Applied to nonlinear response in some cases
- Separated flows - some signals could have different damping values depending on the window selected
- We will send reports to each participant and iterate on the processing before the final SciTech paper





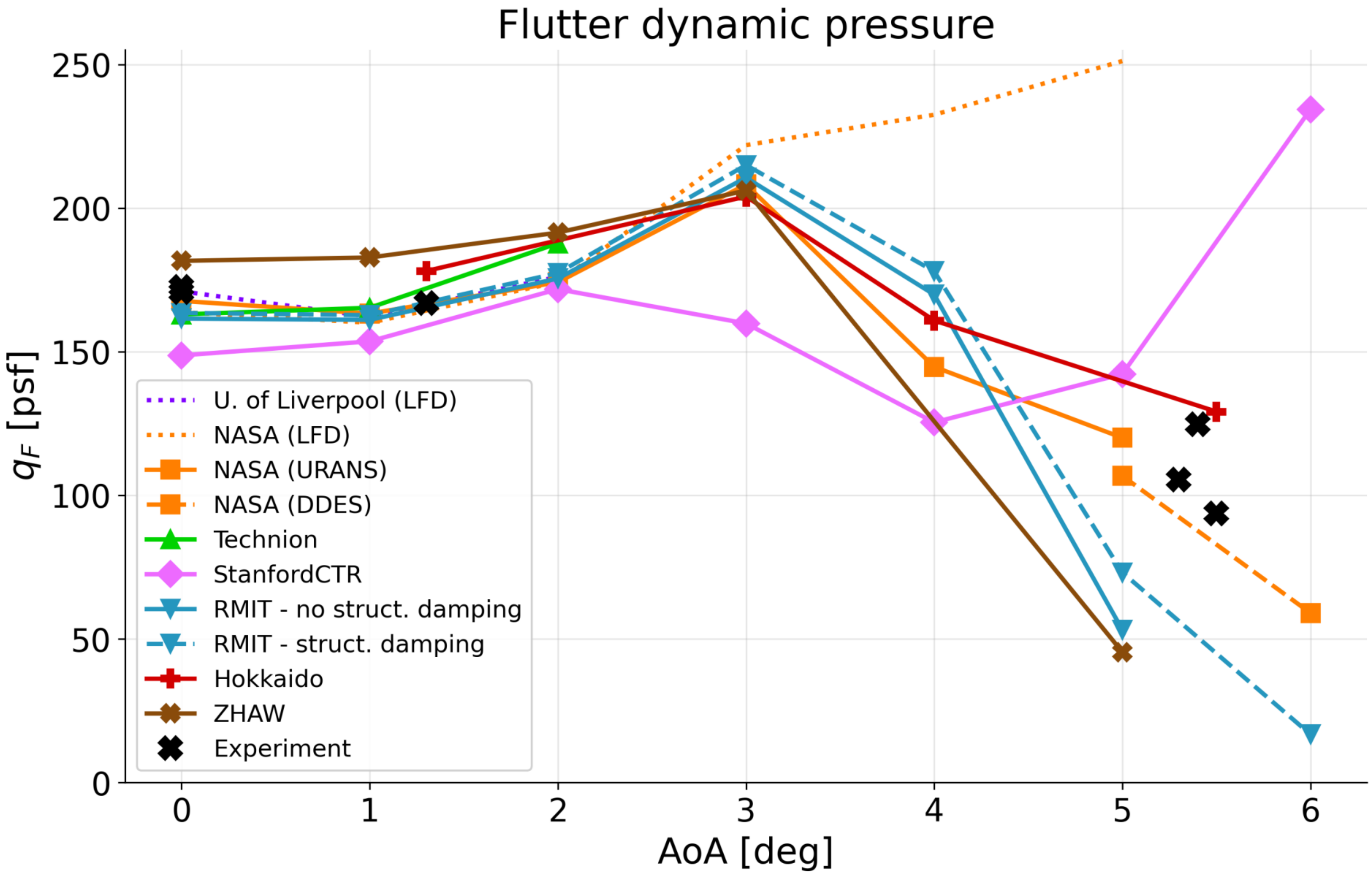


Plotted data

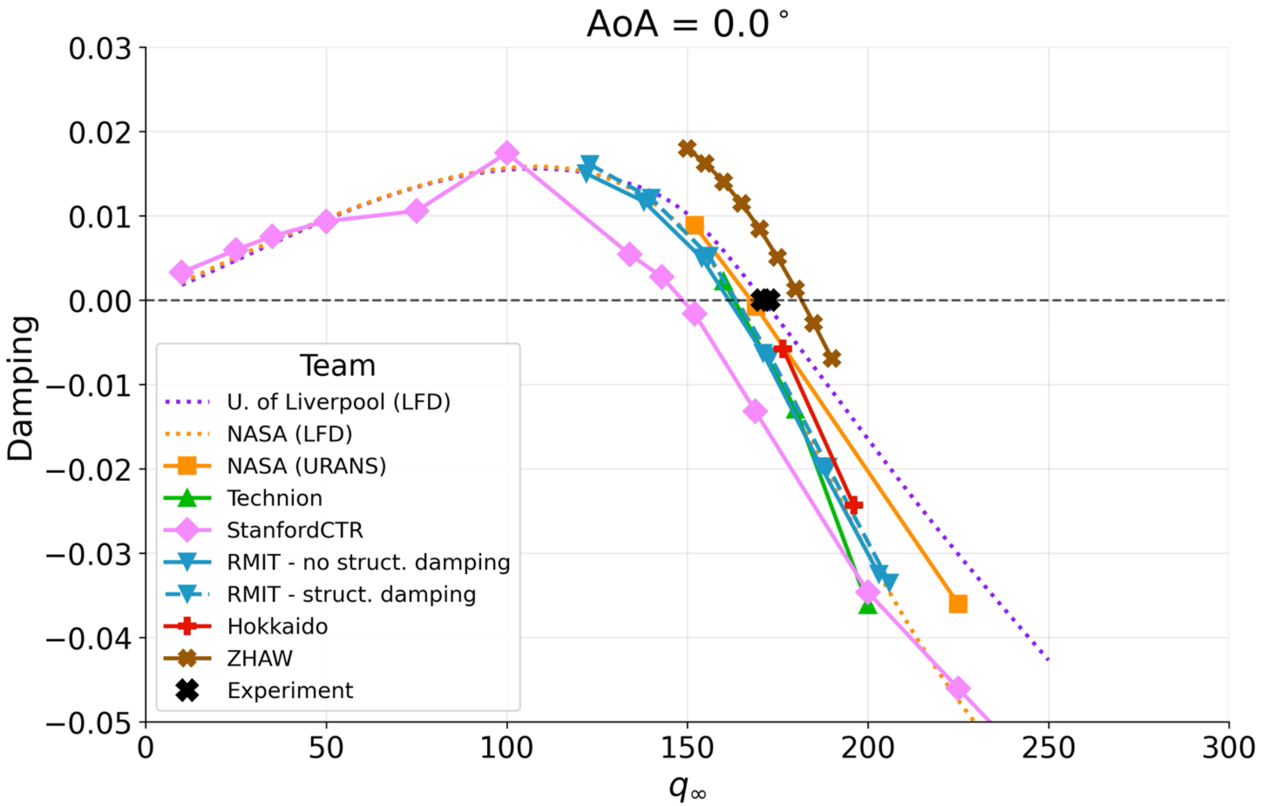
- Not all data sets shown (1-2 per participant)
  - Tried to select dataset from each participant with the most data points
- Damping ratio: positive = stable, negative = unstable

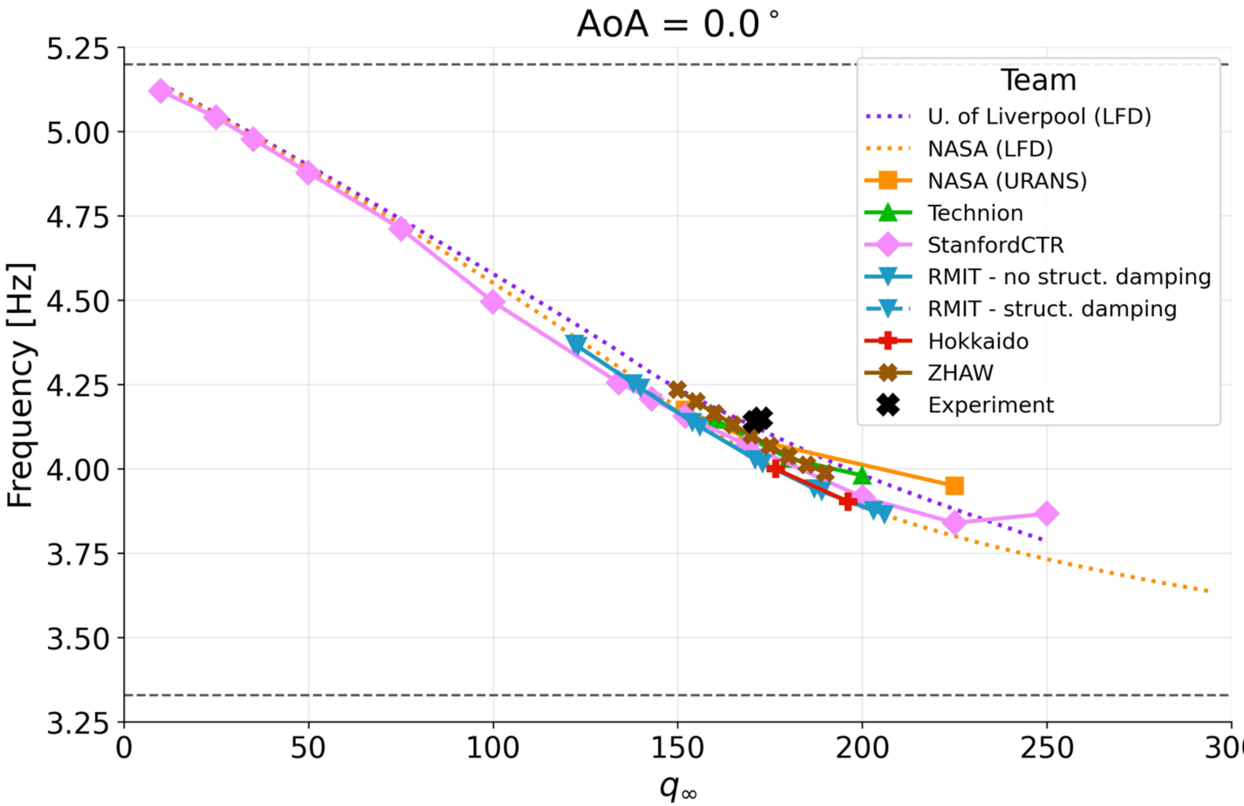
Team	Case 1	Case 2	Case 3	Color on plots	Notes
NASA	✓	✓	✓		URANS (SA), LFD (SA), DDES
Technion	✓		✓		URANS (SST)
Stanford CTR	✓	✓			WMLES
RMIT	✓				URANS (SST)
Hokkaido	✓	✓	✓		URANS (SA)
ZHAW	✓		✓		ROM (based on URANS)
Liverpool	✓				LFD (SA)
Duke			✓		Harmonic Balance (SA)
UNESP			✓		URANS (SST)
Total	**7**	**3**	**6**		

Case 1: Flutter Boundary



Case 1: Angle of Attack Sweep

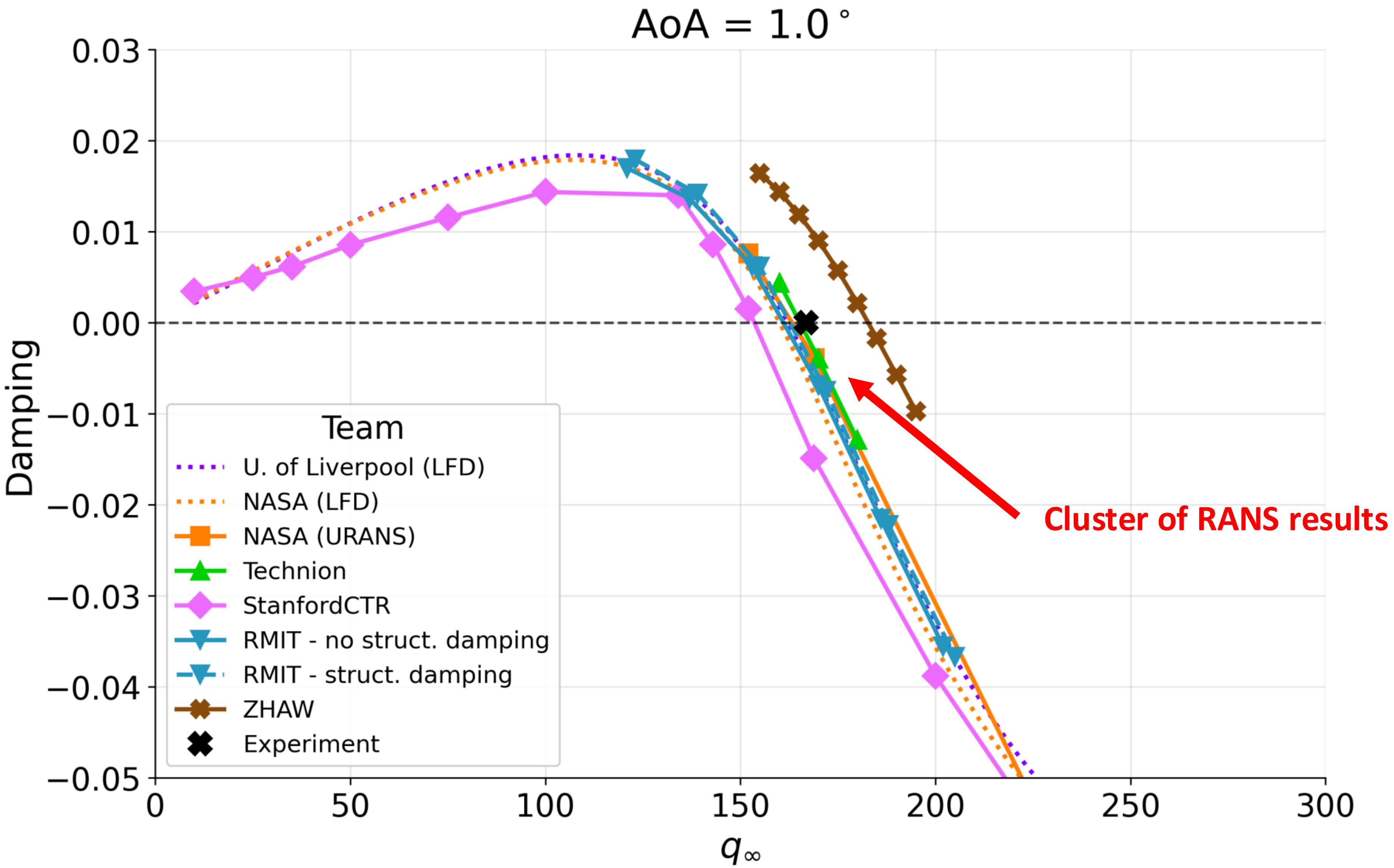




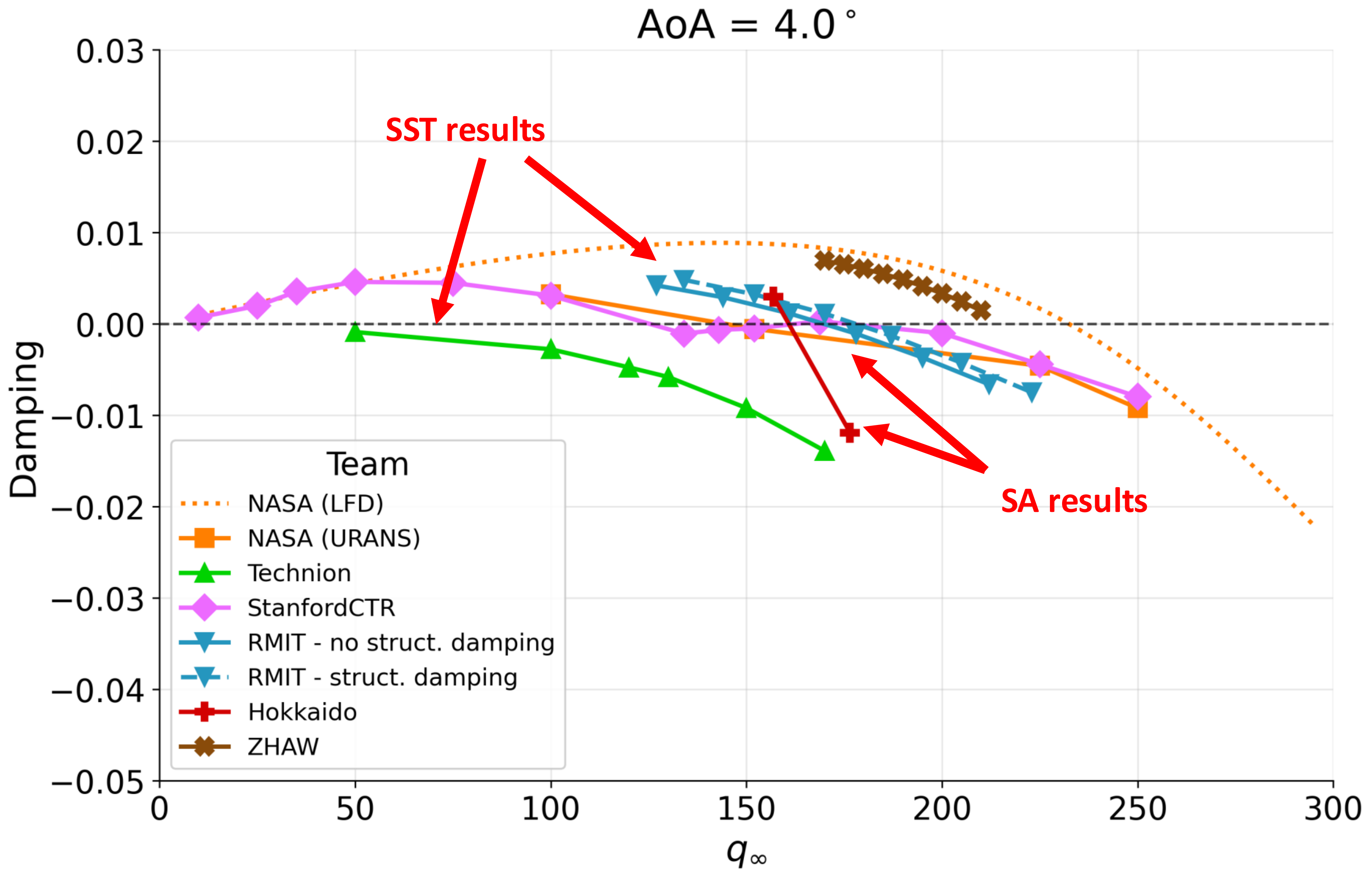
Case 1: Initial Observations

1. All participants showing softening of the flutter mechanism with increasing AoA
   - Reduction in damping vs q slope
2. All participants showing shift to pitch-dominate flutter mechanism with increasing AoA
3. At lower AoA, the URANS results have relatively good agreement regardless of turbulence model (SA vs SST)
4. The shift to lower flutter q with increasing AoA not consistent within a URANS turbulence model, i.e., SA or SST (note: potentially using different modifications for the model)
5. We need more scale-resolving data before we can definitively draw conclusions
   - The WMLES results shows softening of the flutter, but flutter q does not drop like others
   - DDES data has flutter q similar to the URANS but have limited data

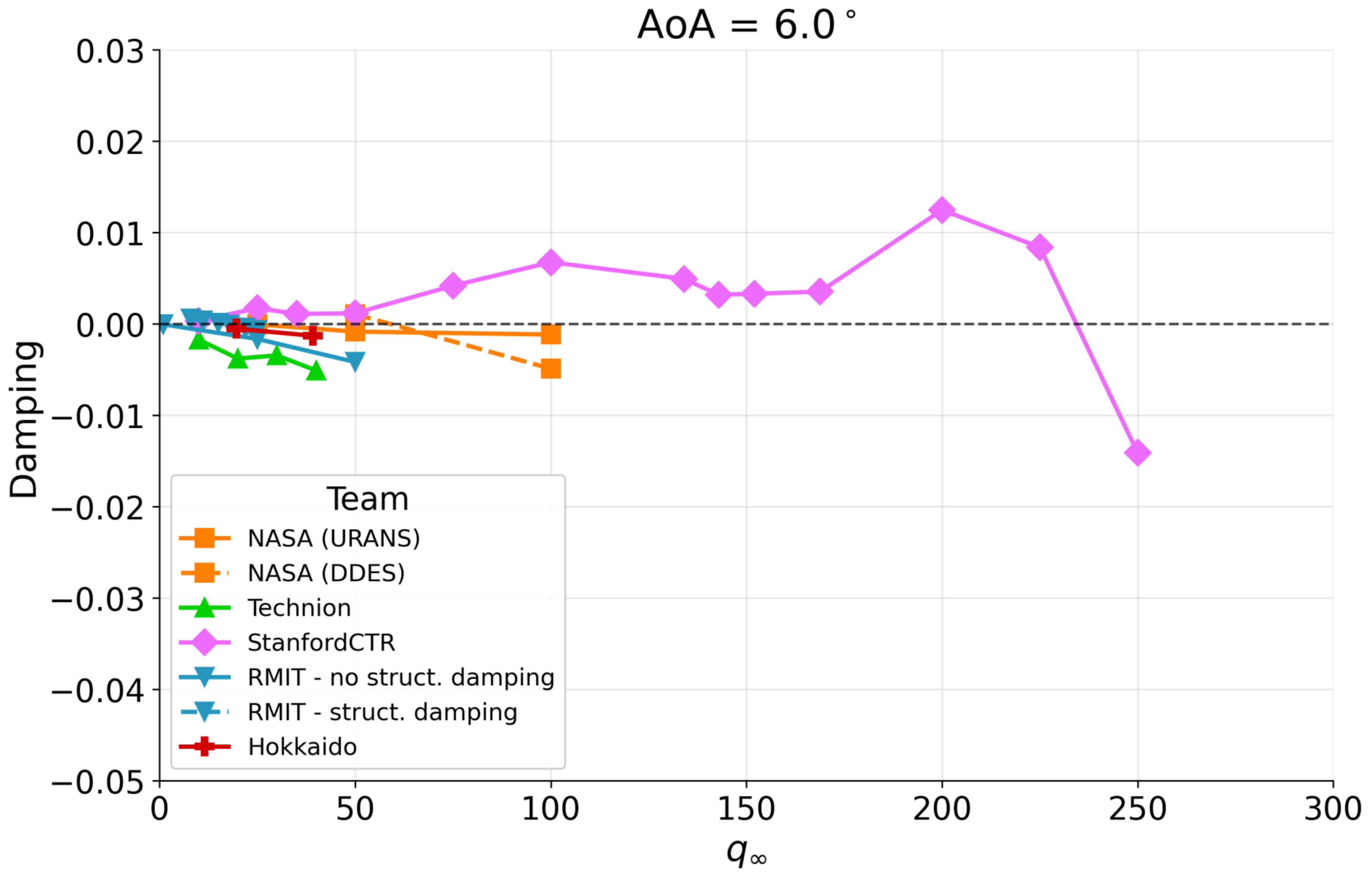
Case 1: Damping vs q, AoA = 1.0°



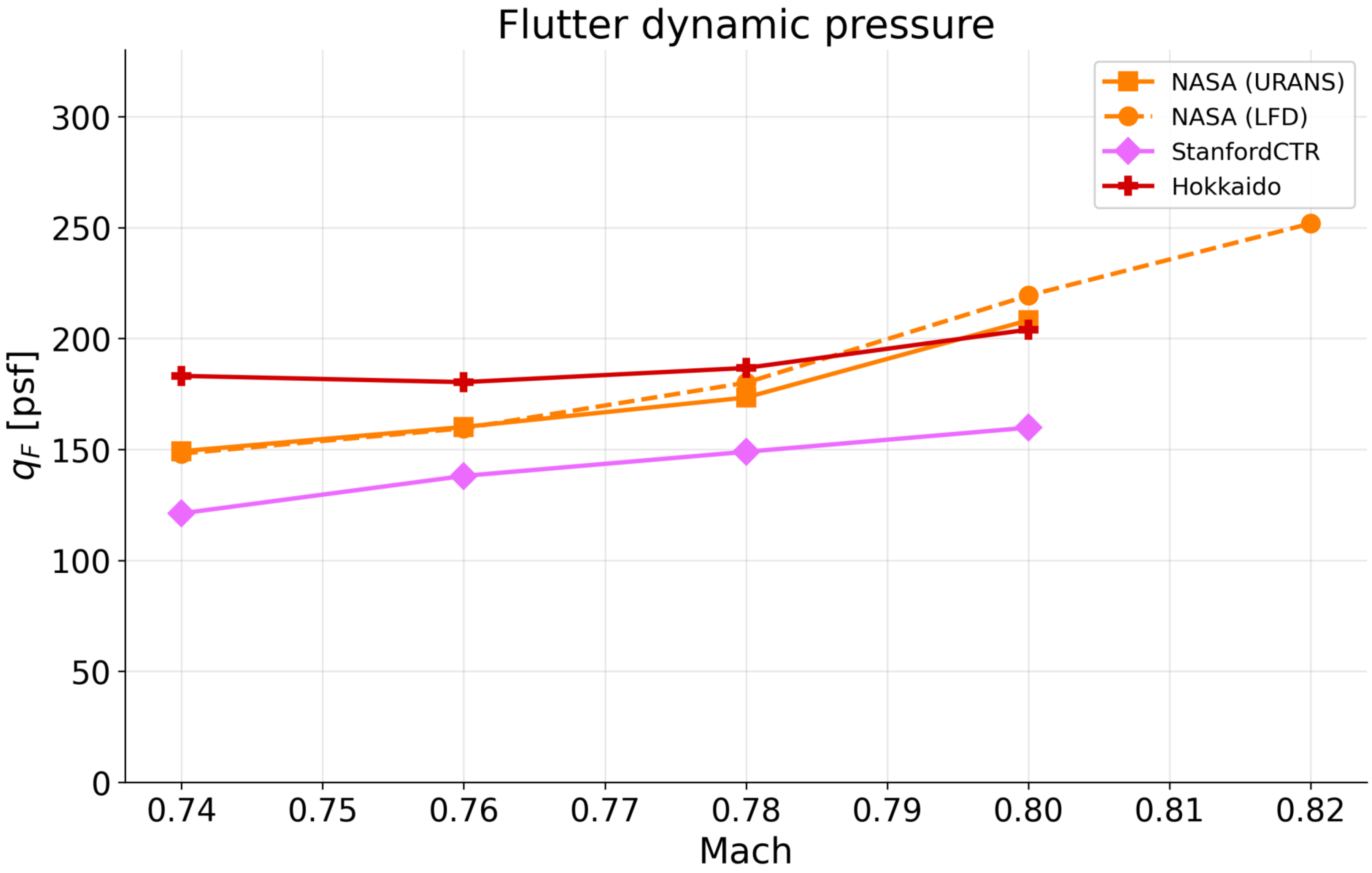
Case 1: Damping vs q, AoA = 4.0°



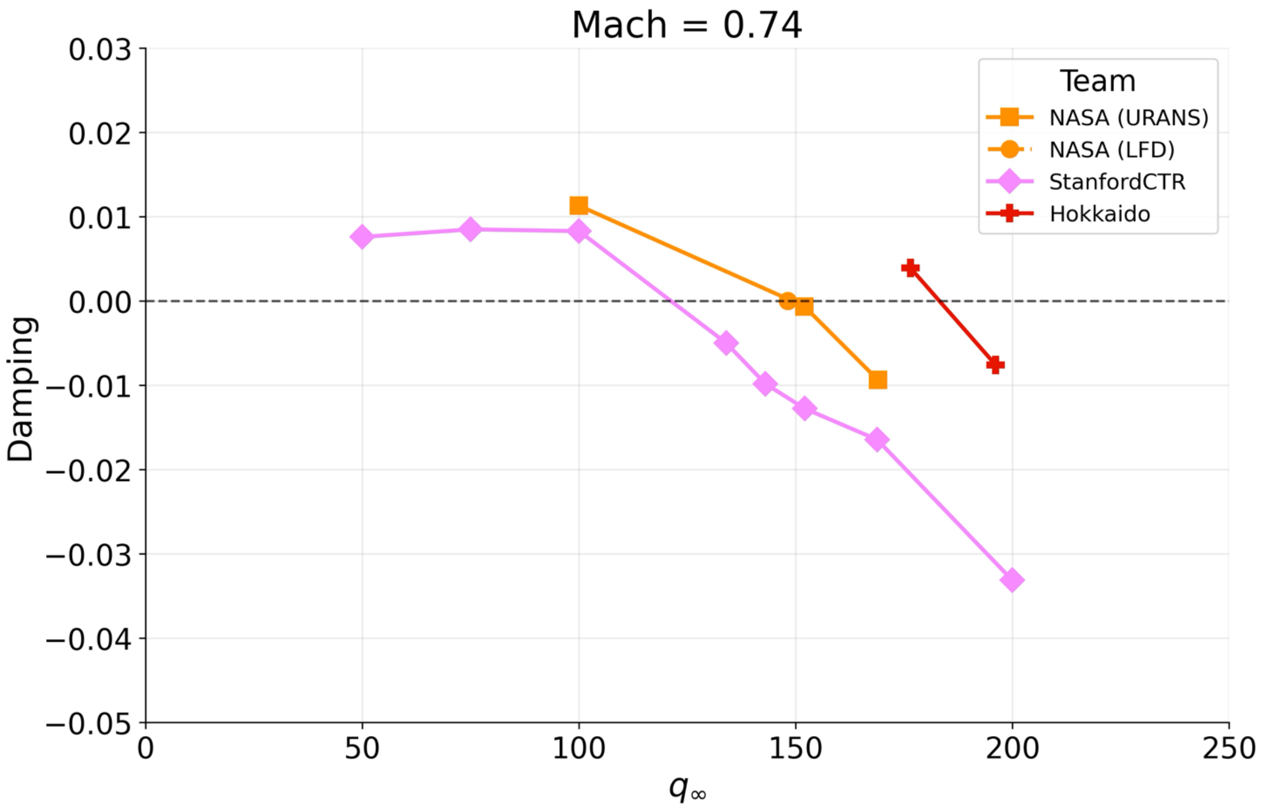
Case 1: Damping vs q, AoA = 6.0°

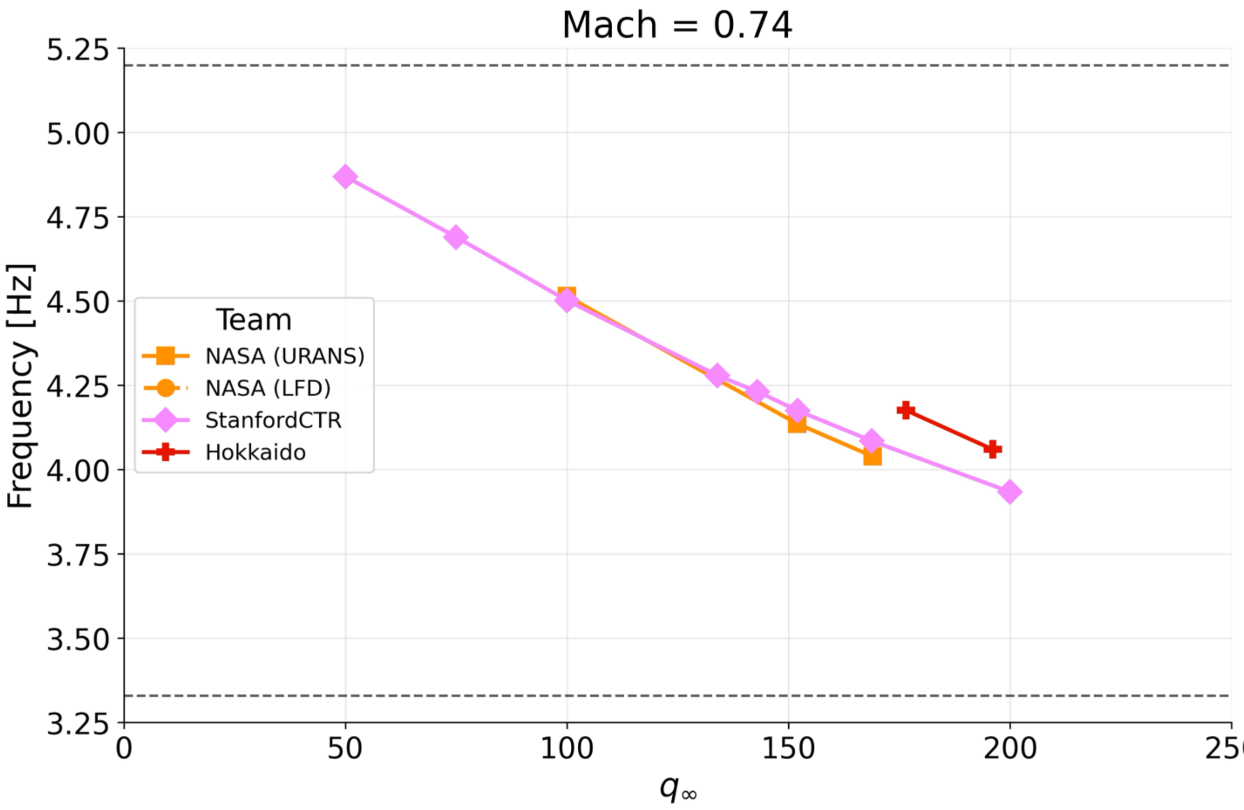


Case 2: Flutter Boundary



Case 2: Mach Sweep

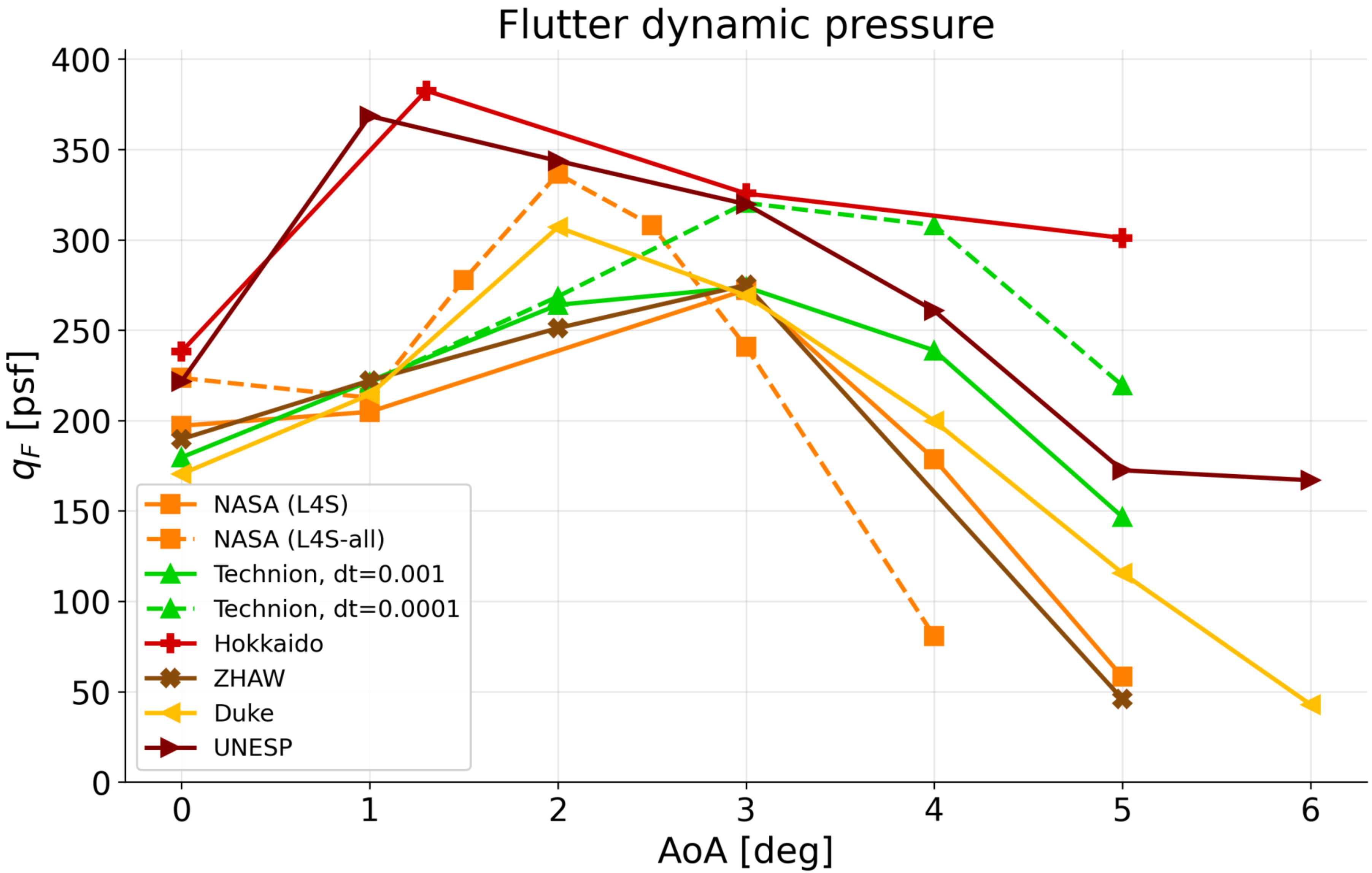




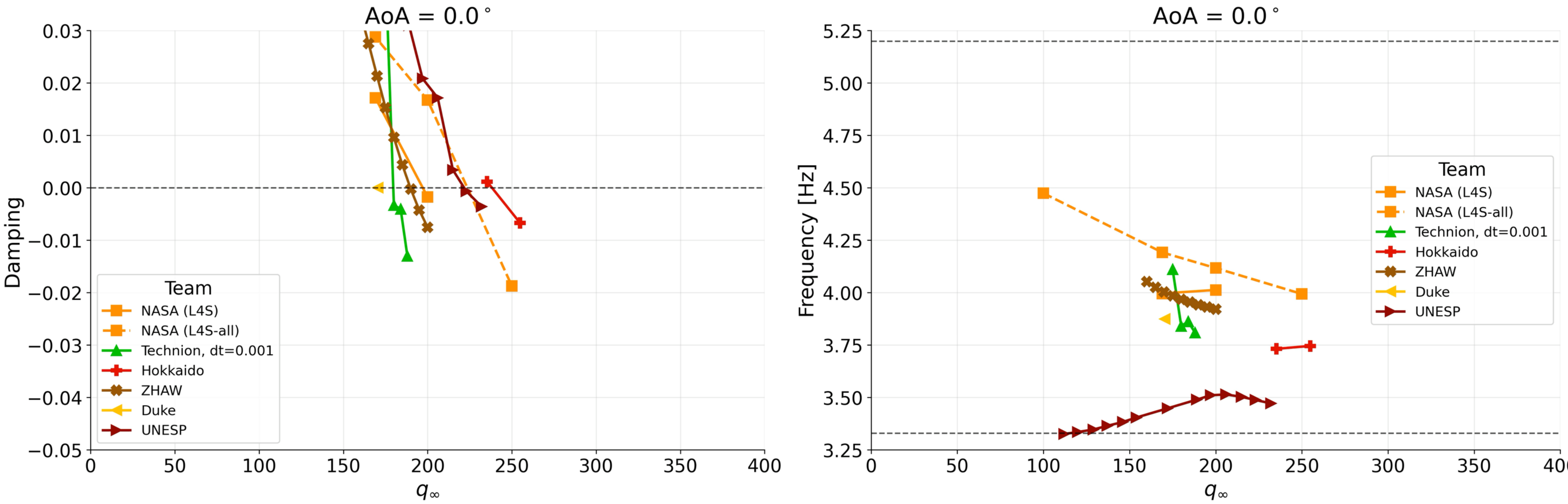
Case 2: Initial Observations

1. Stanford CTR (WMLES) and Hokkaido (URANS) show same flutter boundary shape but offset by ~100 psf
2. Frequency plots show Stanford CTR and NASA (URANS) shifting to pitch-dominate flutter mode with increasing Mach number. Hokkaido has fairly consistent flutter frequency

Case 3: Flutter Boundary



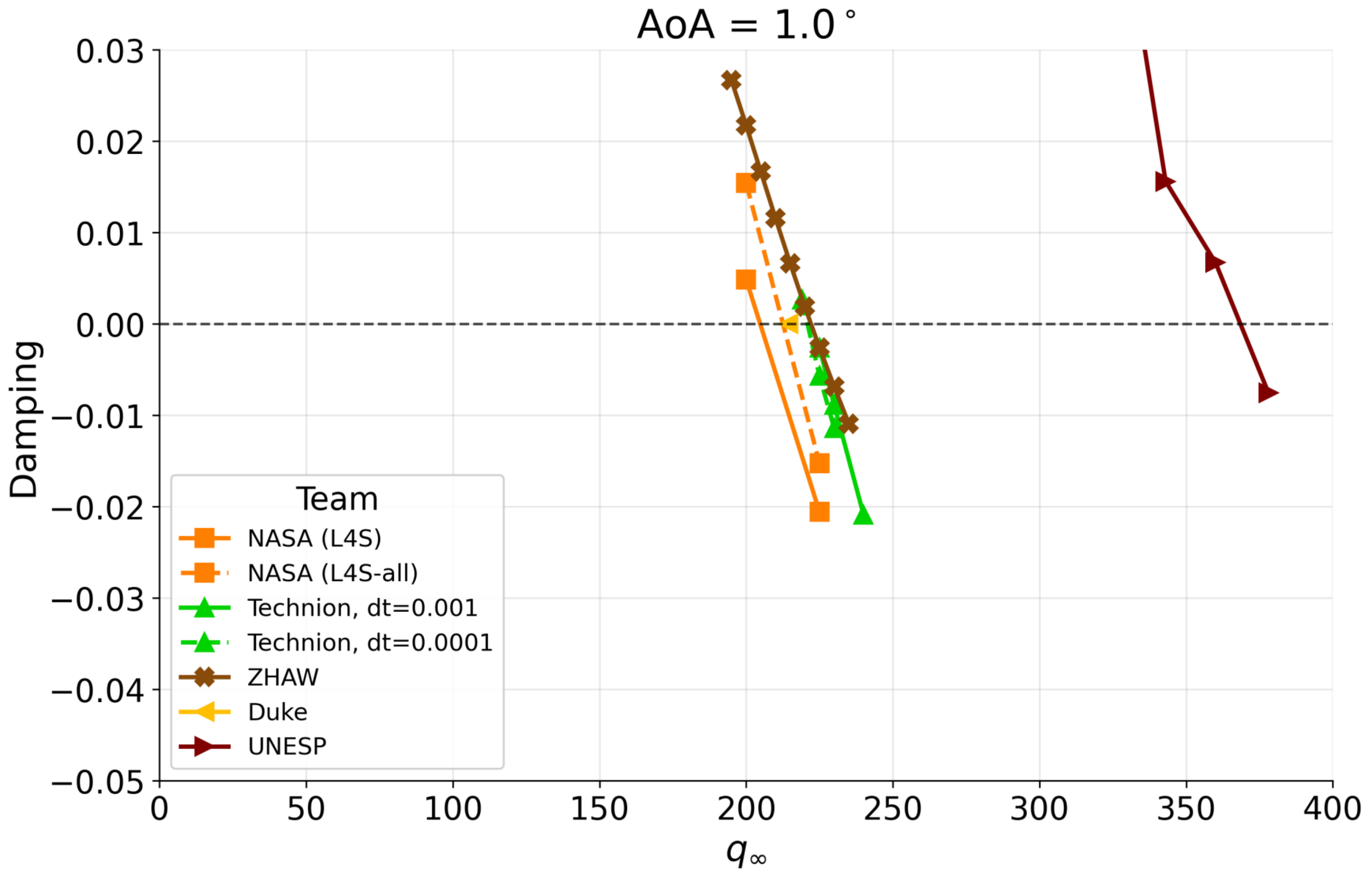
Case 3: Angle of Attack Sweep



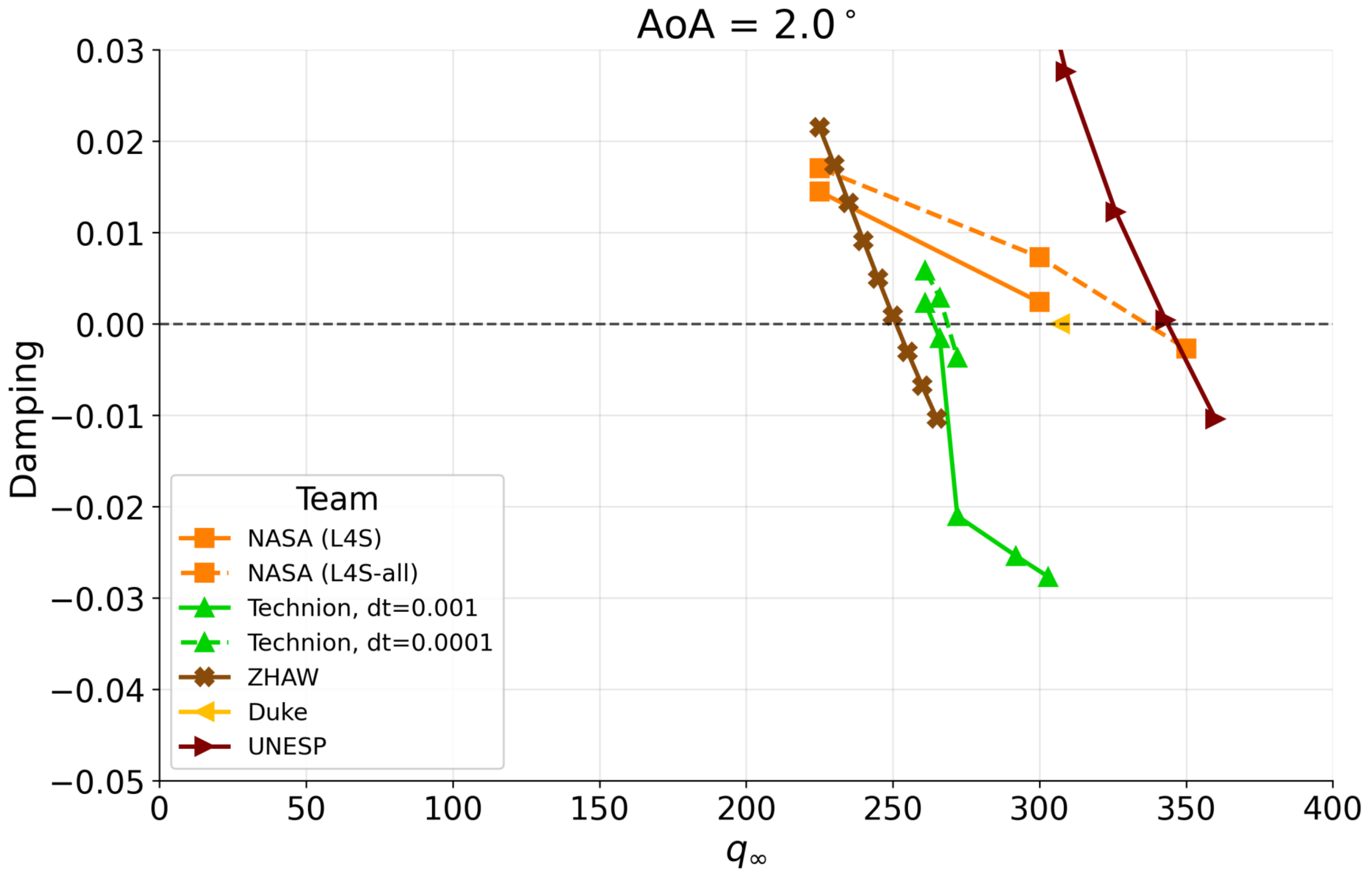
Case 3: Initial Observations

1. We went to 2D thinking it would make things easier and faster to run (give us ability to lower discretization errors)
   - Ended up with the least agreement of the 3 cases
2. Some clustering (4 of 6 participants) of flutter q at AoA=1.0°
3. NASA showing softer flutter crossing at 2° and 3° whereas others wait until 4° and 5° degrees
4. Technion case 3 is the only one with temporal resolution study
   - Shows time step sensitivity once the flow separates

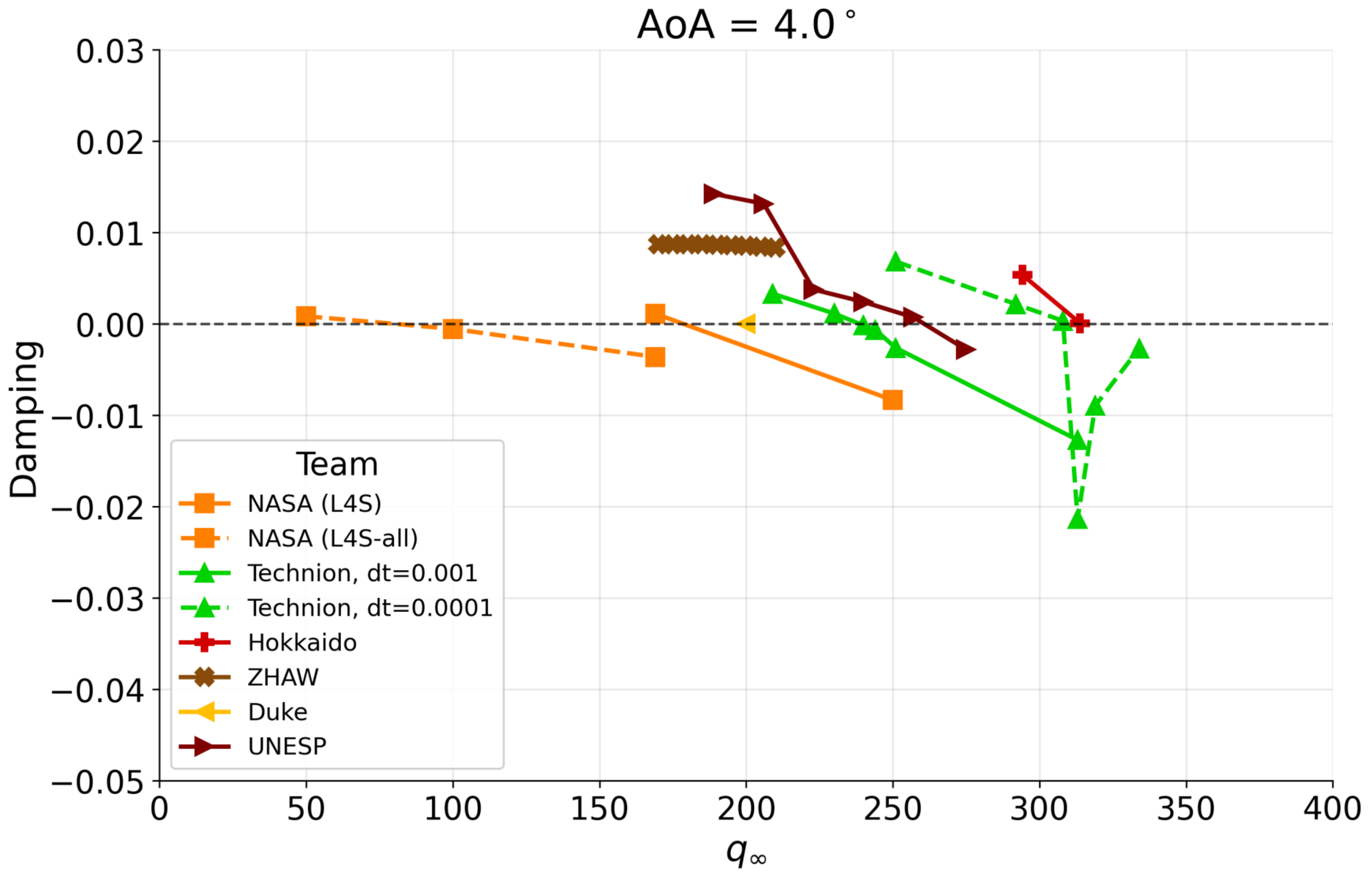
Case 3: Damping vs q, AoA = 1.0°



Case 3: Damping vs q, AoA = 2.0°

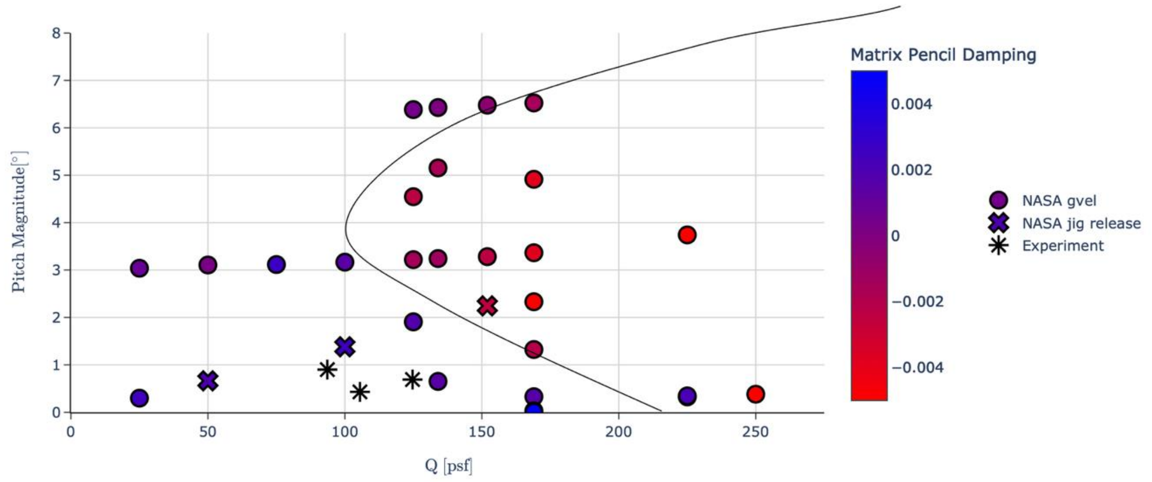


Case 3: Damping vs q, AoA = 4.0°



Data Processing TODOs

1. Look for connections in static and dynamic data/observations
   - Can static twist angle or shock position explain some of the differences we see in flutter results?
2. Look into amplitude effects (perturbation size)
   - In AePW 3, we observed a subcritical LCO at Mach 0.8, AoA=5°
3. Can we draw additional insight from metadata provided with results?
   - What flavor of turbulence model
   - Time step size
   - Subiteration convergence for implicit methods
   - Mesh resolution

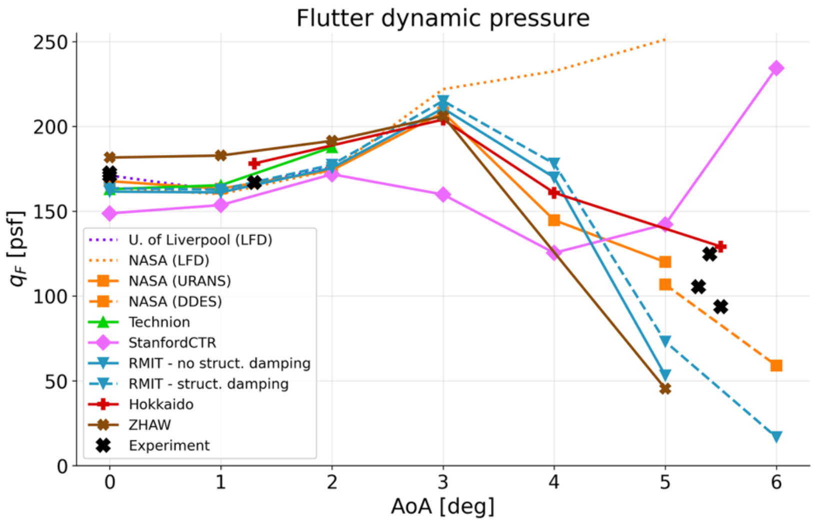


FUN3D LCO boundary – AePW 3

Flutter Conclusions

Case 1:

- Change in physics with increasing AoA correctly captured by all participants!
- Observe consist URANS prediction of hard flutter at transonic attached conditions (low angle of attack)
- Stall flutter at transonic separated conditions:
  - Everyone predicting pitch-dominated flutter with soft crossing
  - Where that soft flutter crossing occurs is inconsistent



Case 2:

- Difficult to draw conclusions about trends with 3 participants' data

Case 3:

- 2D flutter predictions for AoA sweep are less consistent than the 3D ones in Case 1
- Opportunity to learn more at a lower cost than the 3D cases
  - Potentially explore more scale-resolving methods here too