Dedicated to innovation in aerospace

Contribution to 2nd Aeroelastic Prediction Workshop

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NLR contributions, outline

1. Introduction
2. Linear flutter analysis
   - GAF computed using doublet-lattice lifting surface
   - GAF computed using CFD
3. AePW2 case 2
   - nonlinear time domain approach
4. Other AePW2 cases
   - case 1, steady and forced oscillation
   - case 3, steady and forced oscillation
5. Conclusions

Introduction

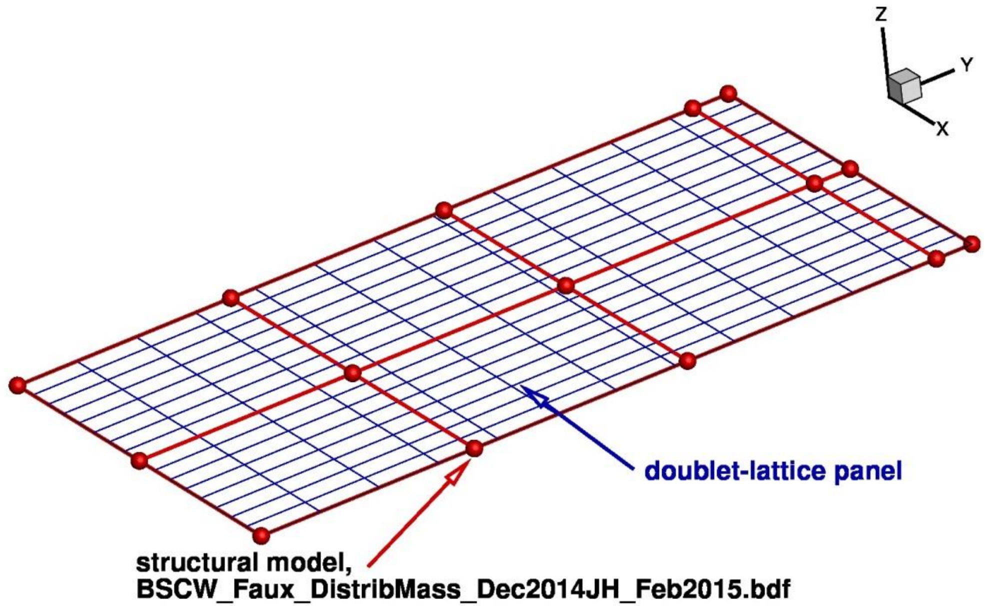
Why CFD for flutter prediction?

- currently doublet-lattice aerodynamics is the standard approach, robust and very efficient
- industrial applications include "correction", see e.g. presentation of Embraer
- use of CFD significantly increases (1) number of parameters, numerical and physical, and (2) effort: pre-, post-procs, CPU time

Most important expected contribution of CFD

- nonlinear dependency of flutter to flow state, e.g. transonic peculiarity
- strong nonlinearity, e.g. limit-cycle-oscillation beyond flutter boundary

Models for analyses based on doublet-lattice



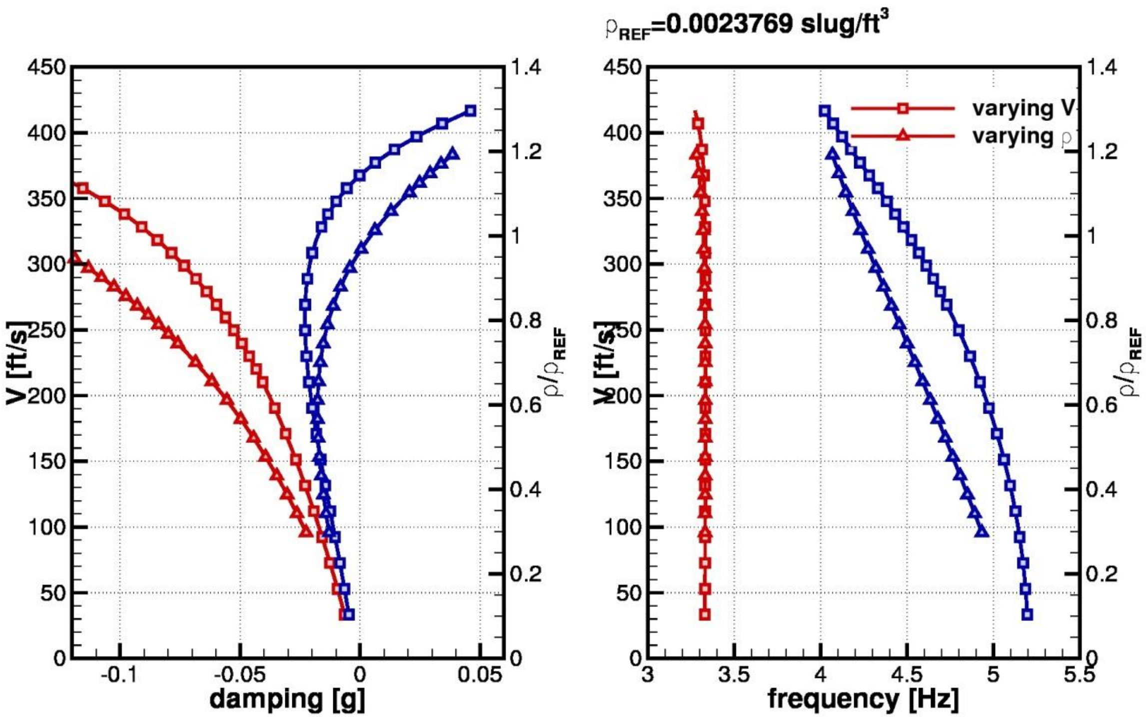
structural dynamics:

- NASTRAN FEM from AePW2 site
- critical damping ratio ζ_i=0.001 [NASA TM-4457]

aerodynamics

- doublet-lattice panel 16x12 panels
- not too fine at leading edge to avoid unrealistic suction peak

Linear flutter analysis

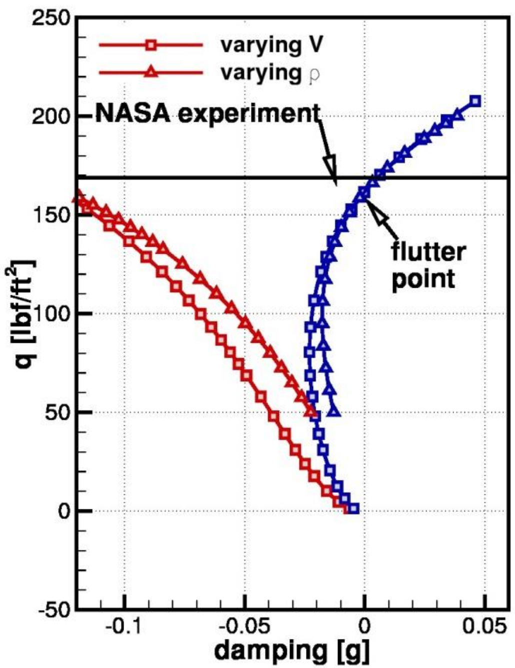


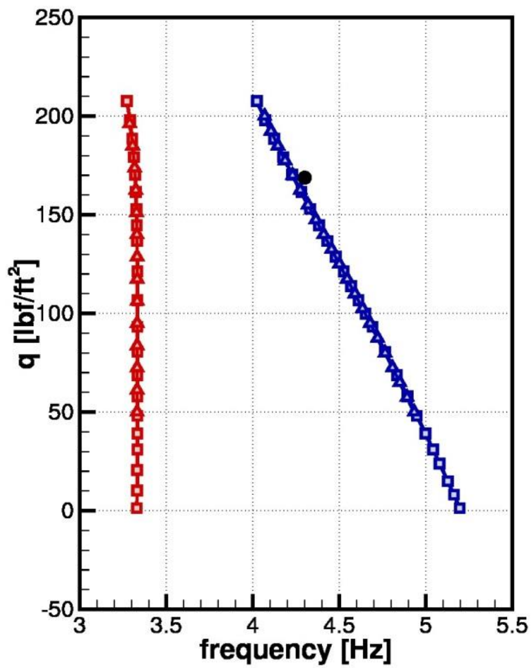
NASTRAN SEFLUTTR

- *pk*: constant density, varying velocity
- *pknl*: *varying* both density and velocity
- NASA experiment: constant velocity, varying density

- no-correction is applied

Comparison with experiment



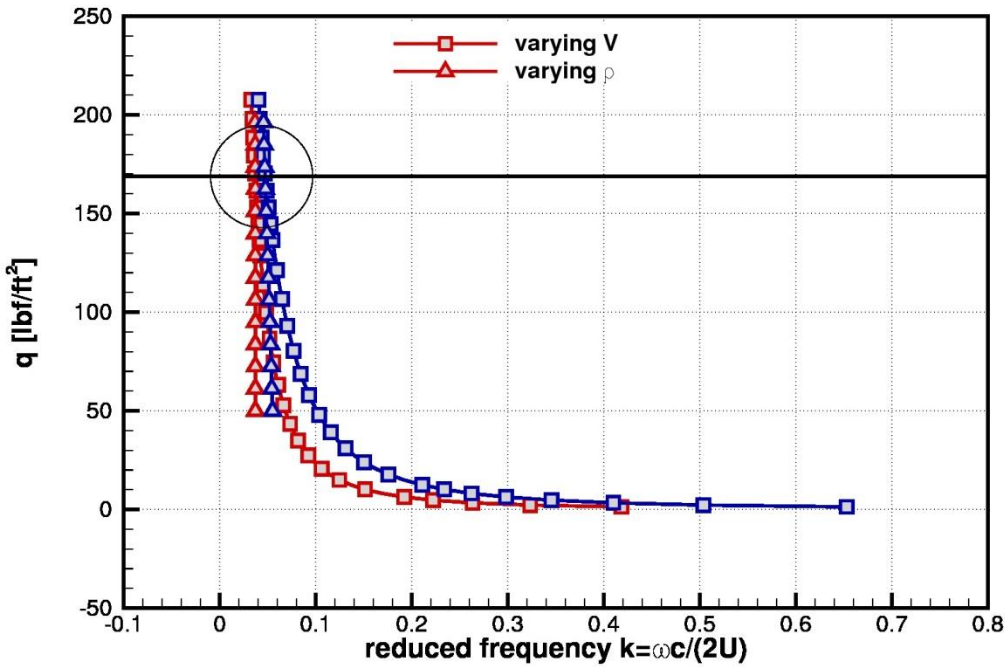


NASTRAN SEFLUTTR

- standard *pk* and *pknl* predict same flutter dynamic pressure *q*
- differences at *non-zero* damping due to harmonic (*k*) approxi-mation of GAF for complex root (*p*)

- reasonably close to experiment

Reduced-frequency of interest



NASTRAN SEFLUTTR

- at flutter point the reduced frequency is about 0.05-0.07
- this value is used to define time-step size for time-accurate computation using CFD

Flutter analyses involving CFD

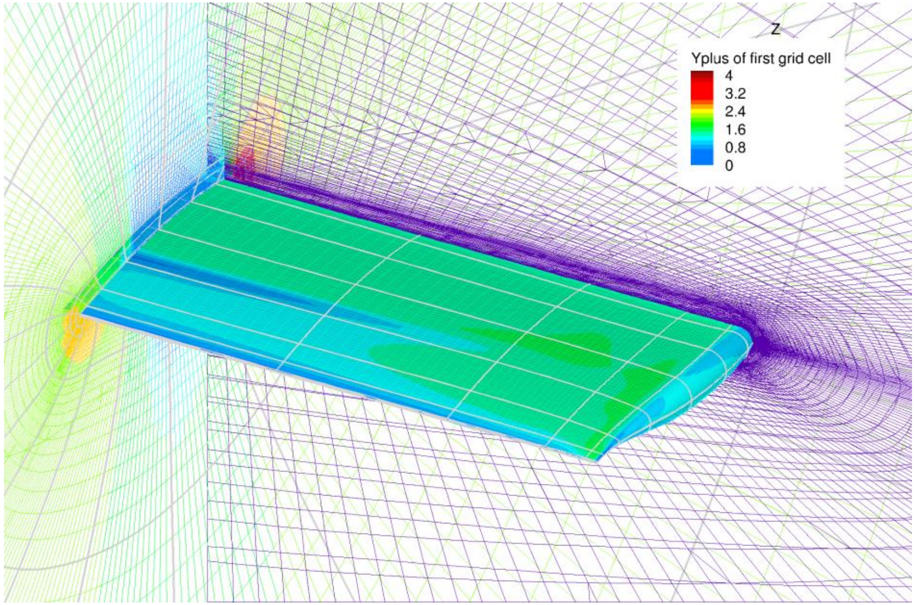
NLR in-house developed ENFLOW CFD system

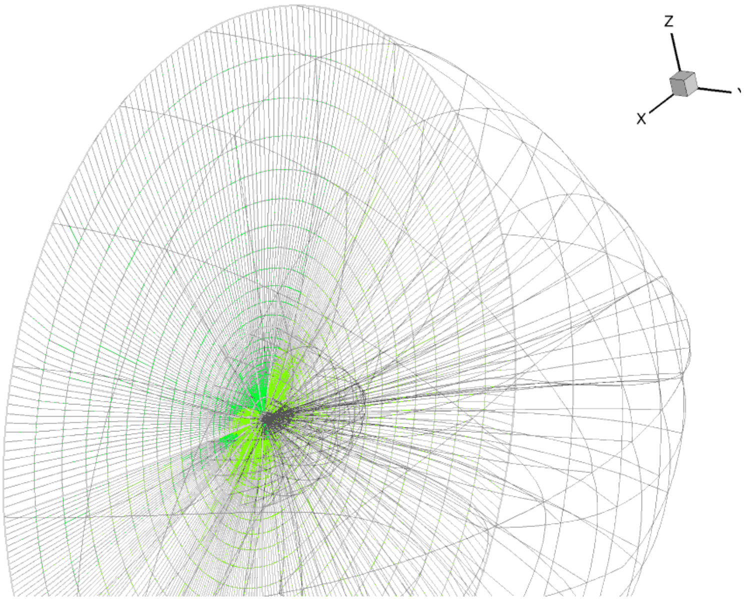
- structured multiblock, cell-centred finite volume method
- applicable for aerodynamic, aeroelastic and aero-acoustic analysis
- *k*-*ω* TNT, EARSM and SST (Menter) turbulence models
- implicit time integration, Δt determined by accuracy, not stability

Application for flutter analysis in AePW2

1. GAF computation based on harmonic motion for M=0.70, 0.74, 0.80, 0.82 about zero angle-of-attack
2. time-domain simulation with strong-coupling between CFD and structural model for AePW2 case 2 at M=0.74

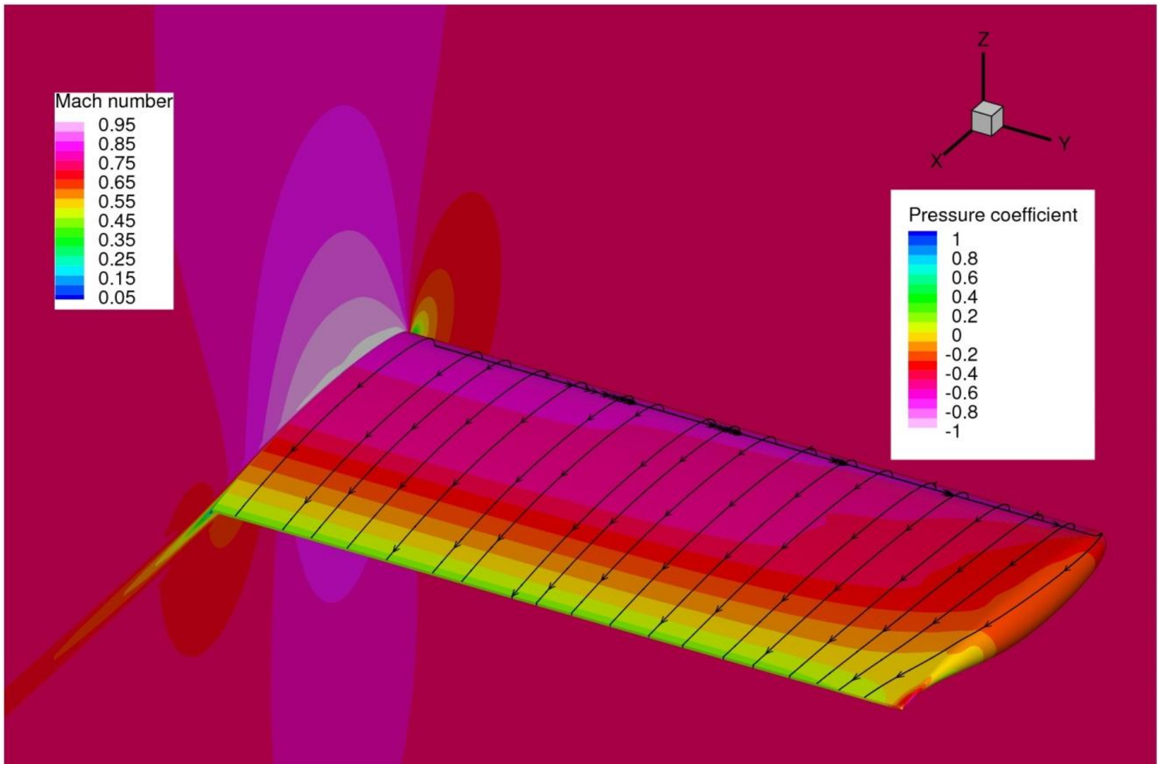
Grid for analyses based on CFD





original EZNSS CFD grid provided by Daniella Raveh of Technion, structured multiblock with OO topology.

Flow conditions

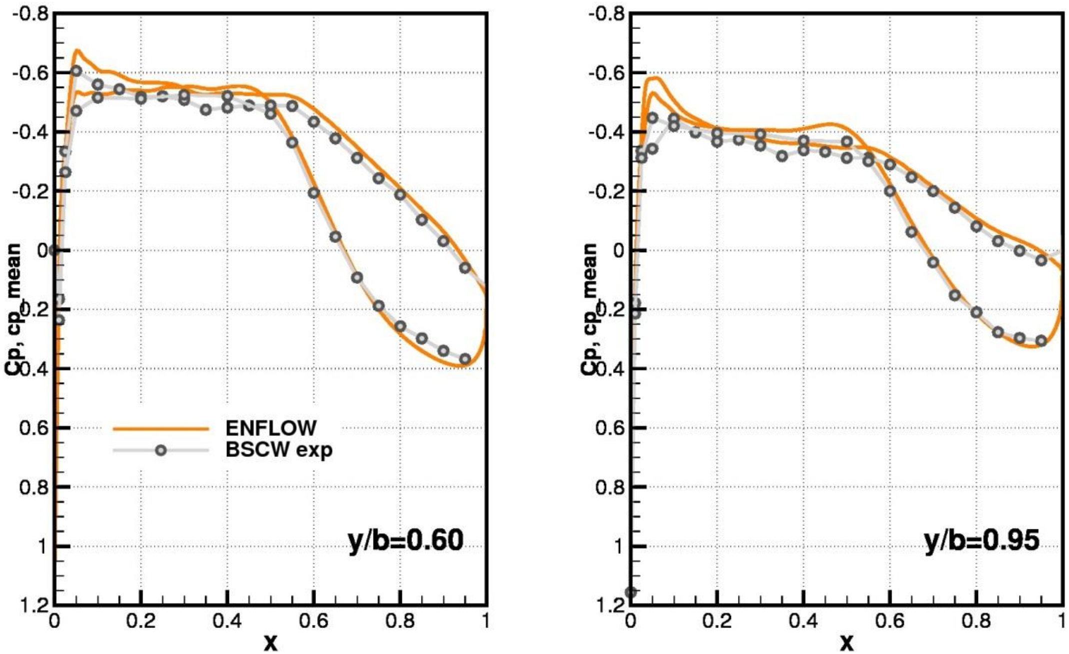


flow is attached for all cases considered

from weak shockwave on upper side at M=0.70

up to moderate shock-waves on upper as well as lower side at M=0.82

AePW2 case 2, steady Cp



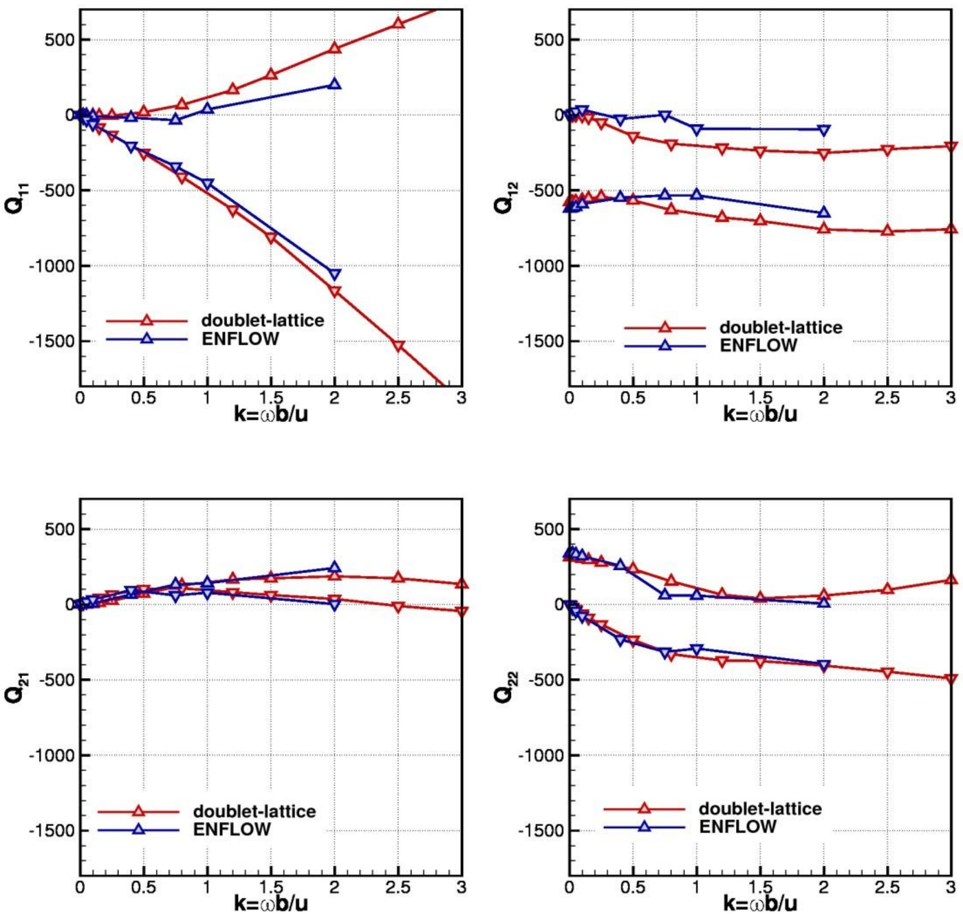
steady flow results at M=0.74, α=0 deg

differences to experiment close to LE, due to fully turbulent assumption

used as initial state for forced oscillation computations to obtain GAF

also as initial state for time-domain strongly-coupled simulation

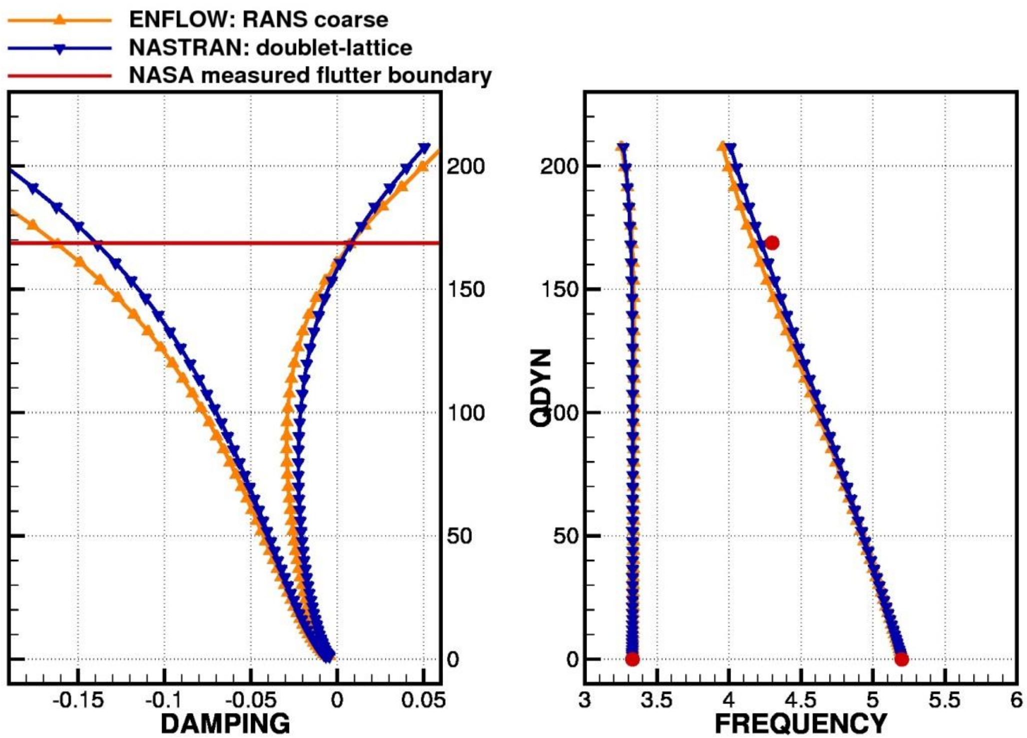
Comparison of GAF between DL and CFD



GAF for AePW2 case 2
M=0.74, AOA=0 deg

very similar results between DL and CFD especially at frequency range of interest

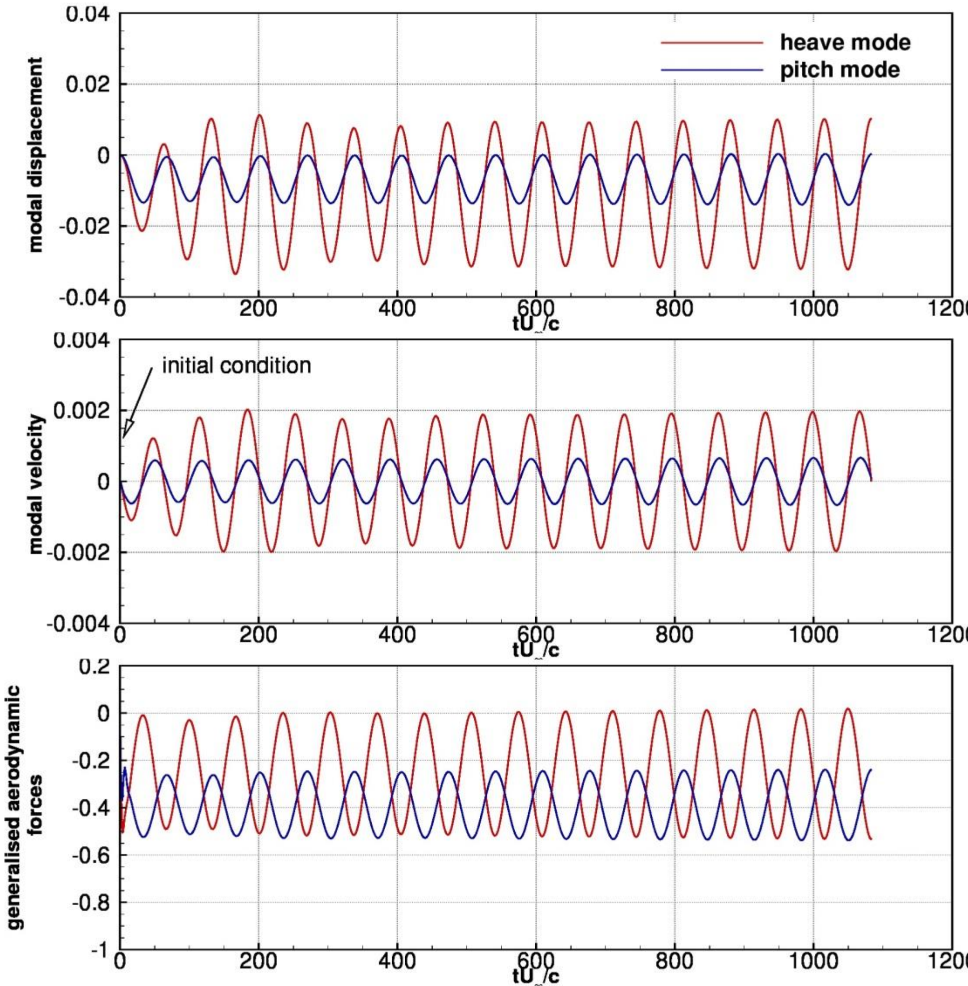
Flutter diagram DL and CFD GAF



GAF for AePW2 case 2
M=0.74, AOA=0 deg

as expected from similarity of GAF,
very similar results for flutter dynamic pressure

Time-domain FSI at exp flutter dynamic pressure

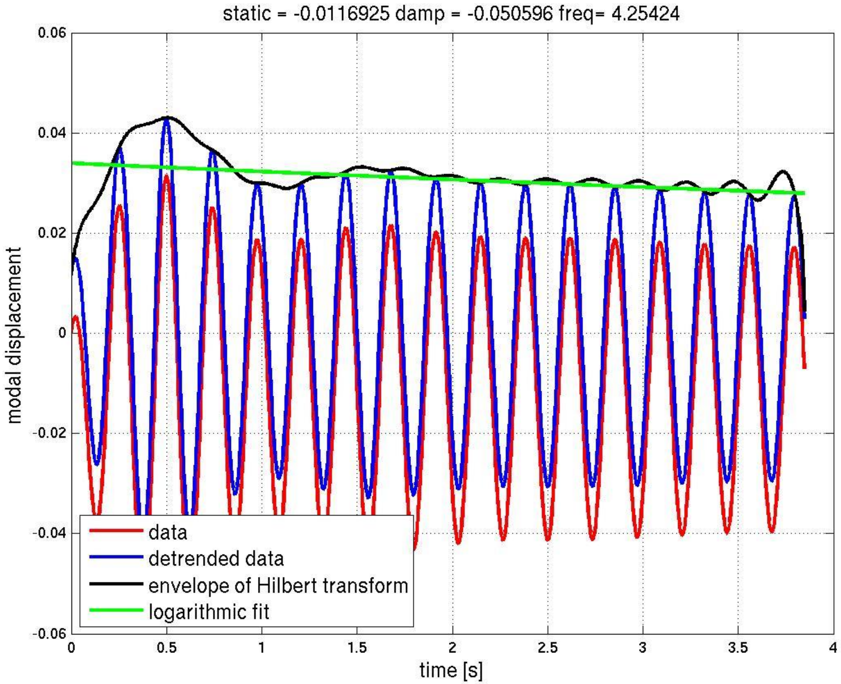


Simulation at experimental dynamic pressure

- case 2, M=0.74, q=168.8 psf, initial solution at α=0 deg
- no initial condition

- solution is slightly unstable, i.e. flutter boundary is lower than experiment

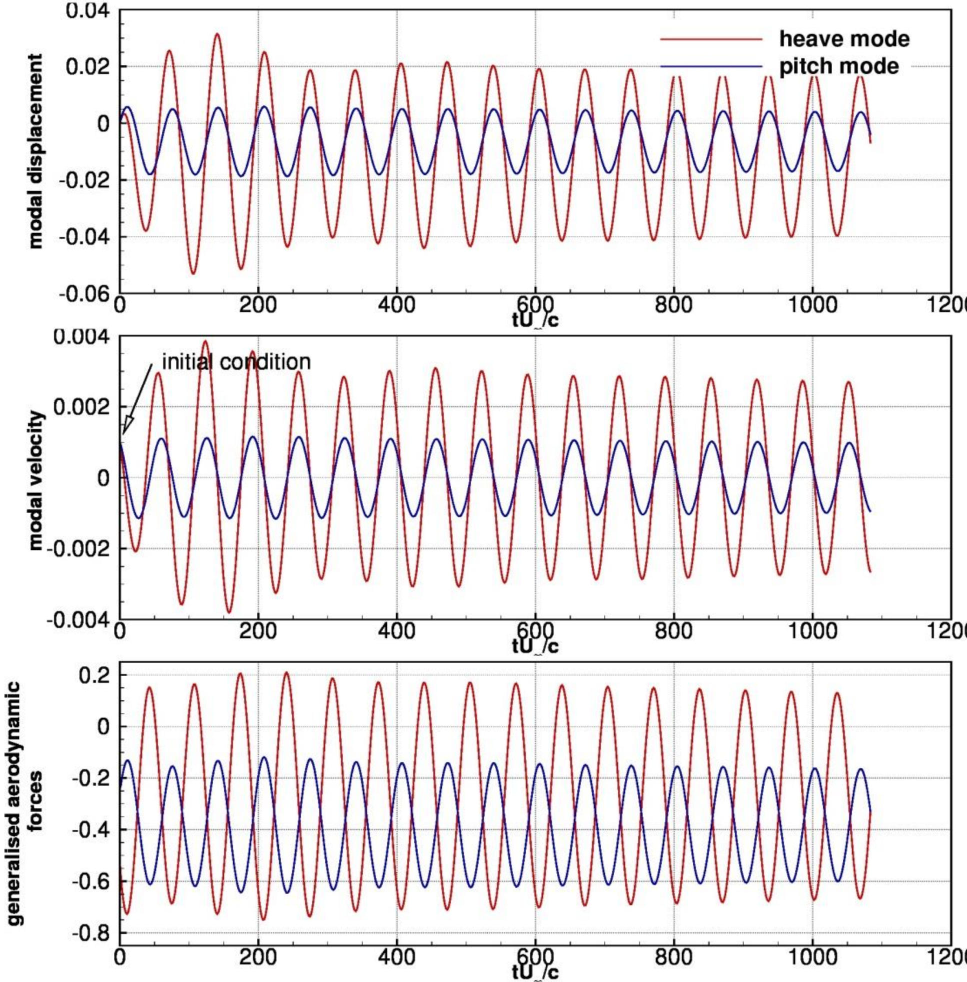
Method of identification



Simplified identification procedure:

- detrend the data → static solution
- apply Hilbert transform
- log fit the envelope → damping
- frequency obtained using zero crossing

Time-domain FSI at pk flutter dynamic pressure

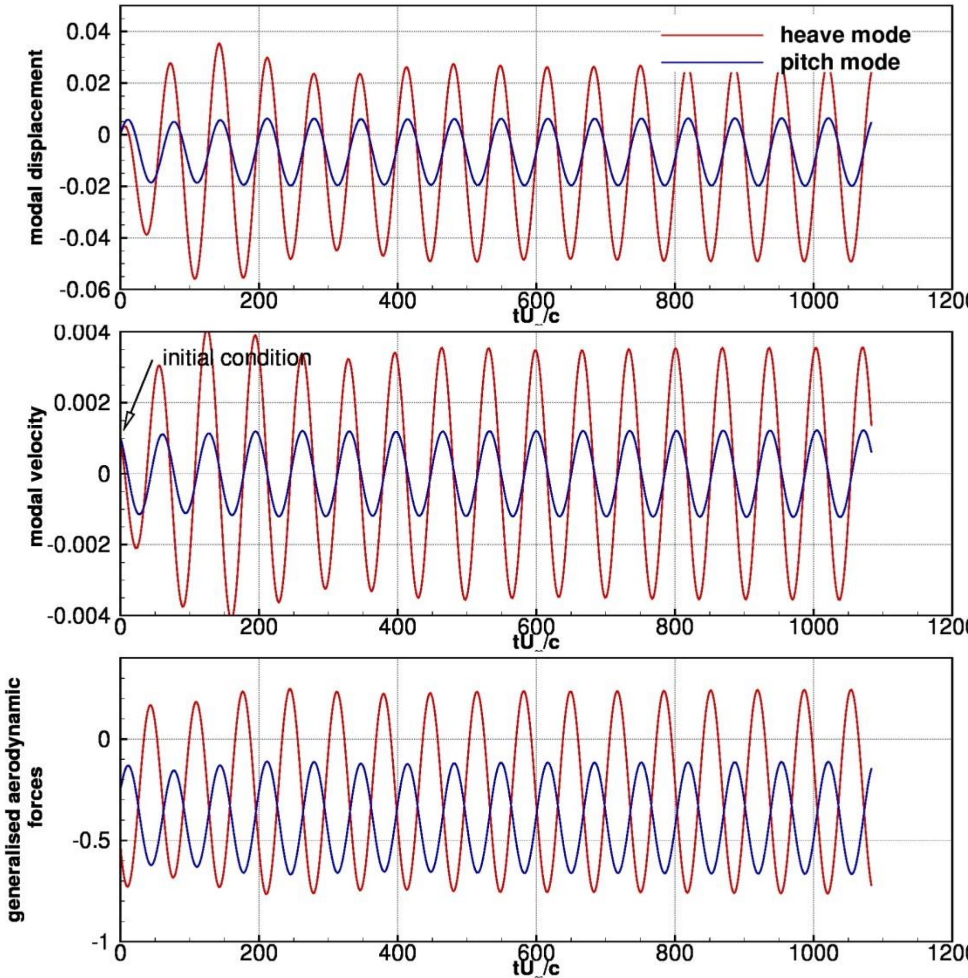


Simulation at linear (*pk*) flutter dynamic pressure

- case 2, M=0.74, q=158.6 psf, initial solution at α=0 deg
- modal velocity initial condition

- solution is stable, i.e. flutter boundary is higher than linear flutter boundary obtained using *pk*-method

Time-domain FSI at interpolated flutter dyn pressure

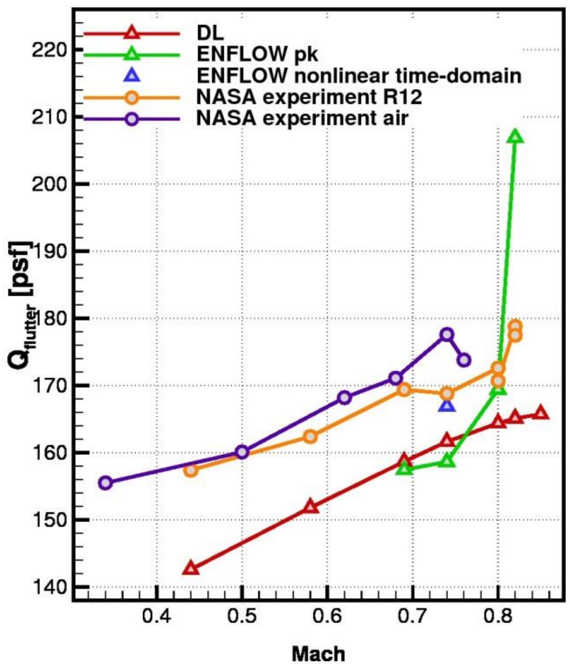


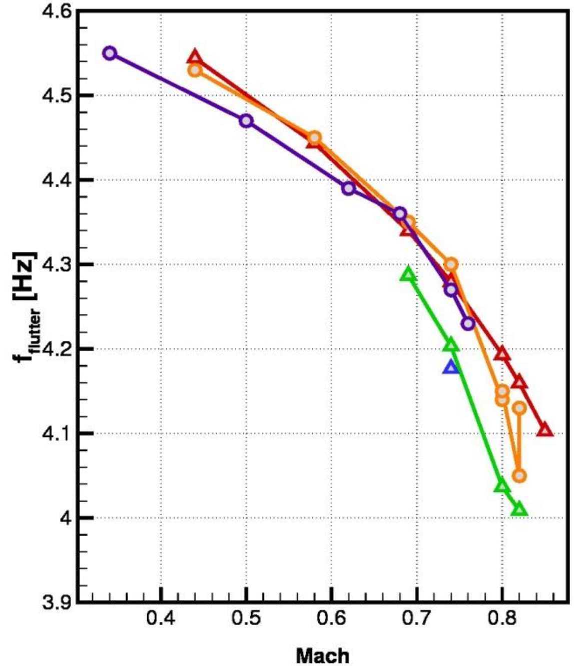
Simulation at interpolated flutter dynamic pressure

- case 2, M=0.74, q=166.9 psf, initial solution at α=0 deg
- modal velocity initial condition

- solution is neutrally stable,
- dynamic pressure is closer to experiment than linear flutter boundary

Summary of flutter dynamic pressures

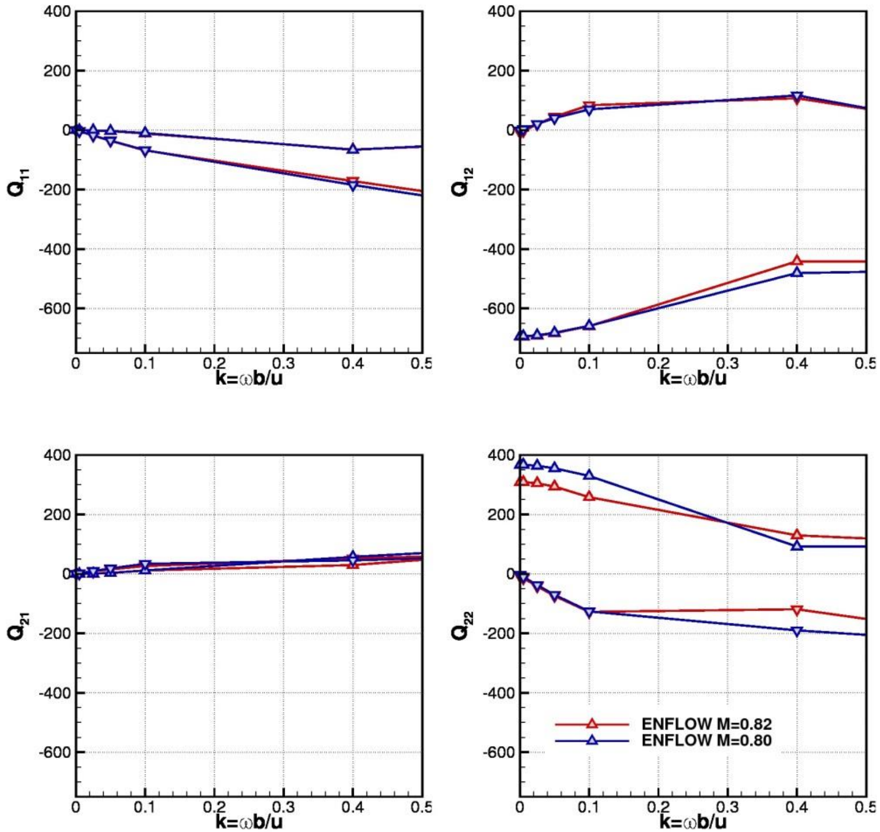


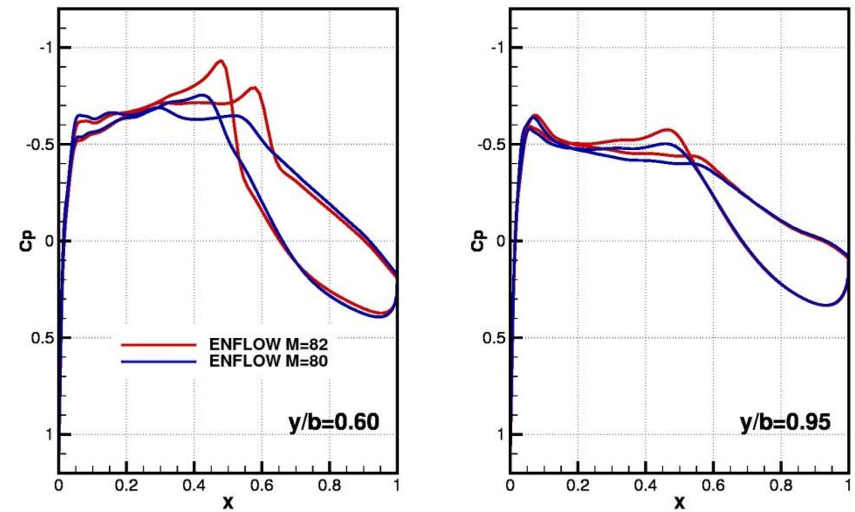


Remarks on predicted flutter boundary:

- DL results follow global trend but misses transonic peculiarity, i.e. dip and rise
- linear *pk* results with CFD capture the dip and rise but about 6% different from experiment
- nonlinear time domain result (case 2) is closer to experiment

Rise of flutter boundary at M=0.82

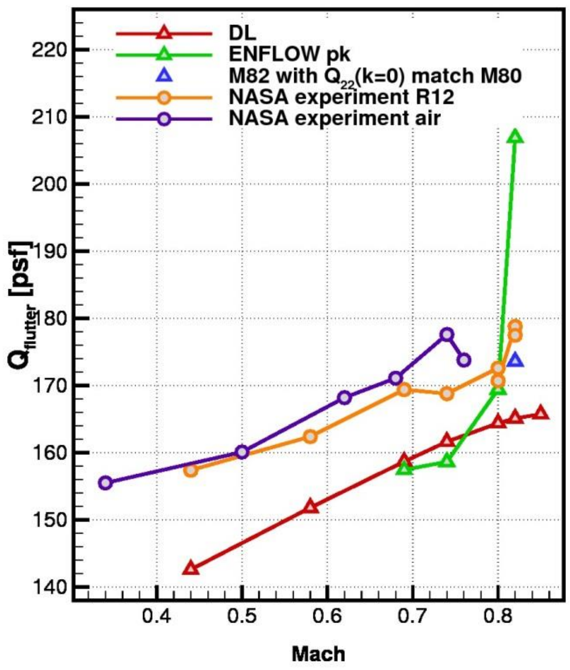


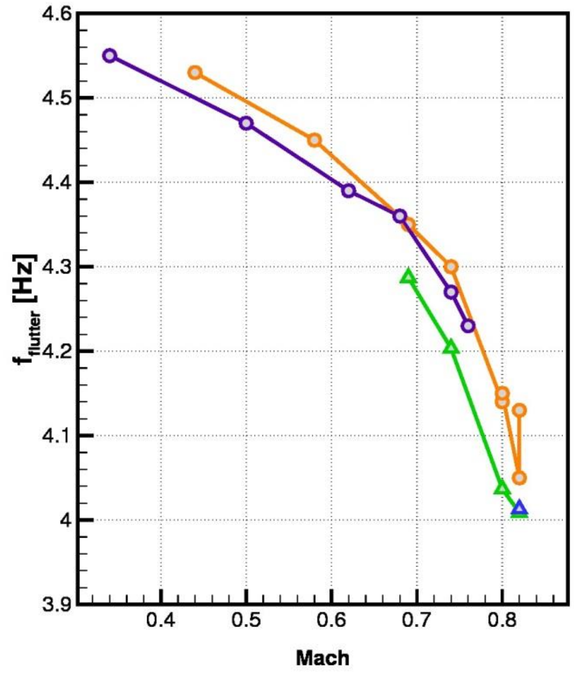


M=0.80 to M=0.82 leads to significantly higher flutter boundary

noticeable difference only in Q_{22} due to relatively strong shockwave at lower side; without flow separation

Rise of flutter boundary at M=0.82, concluded



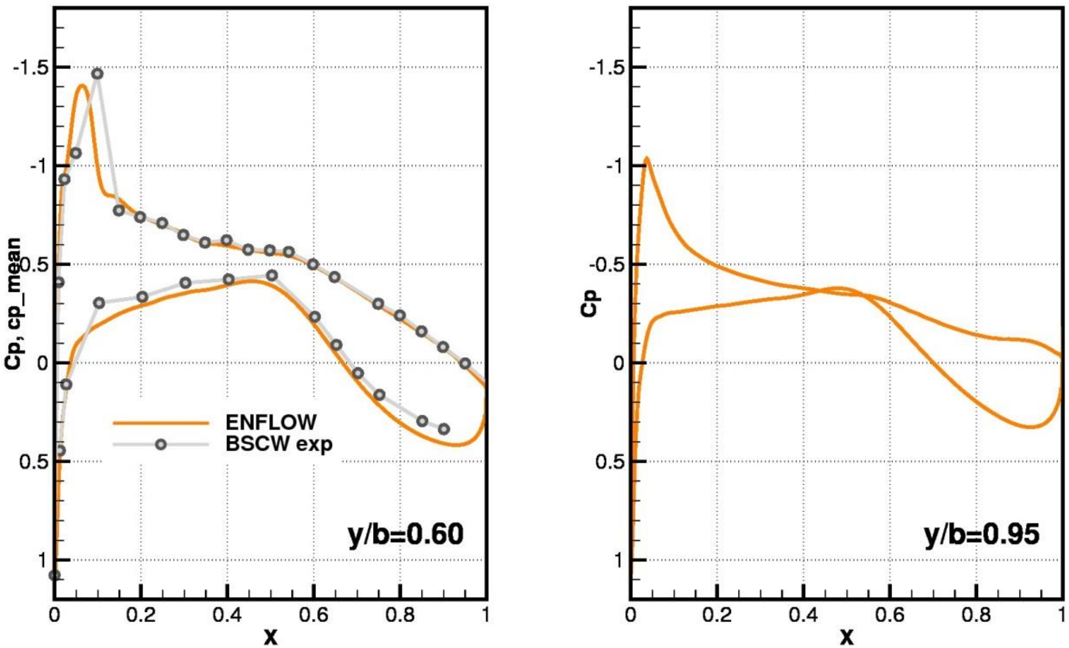


Simple check on Q_{22} contribution to flutter

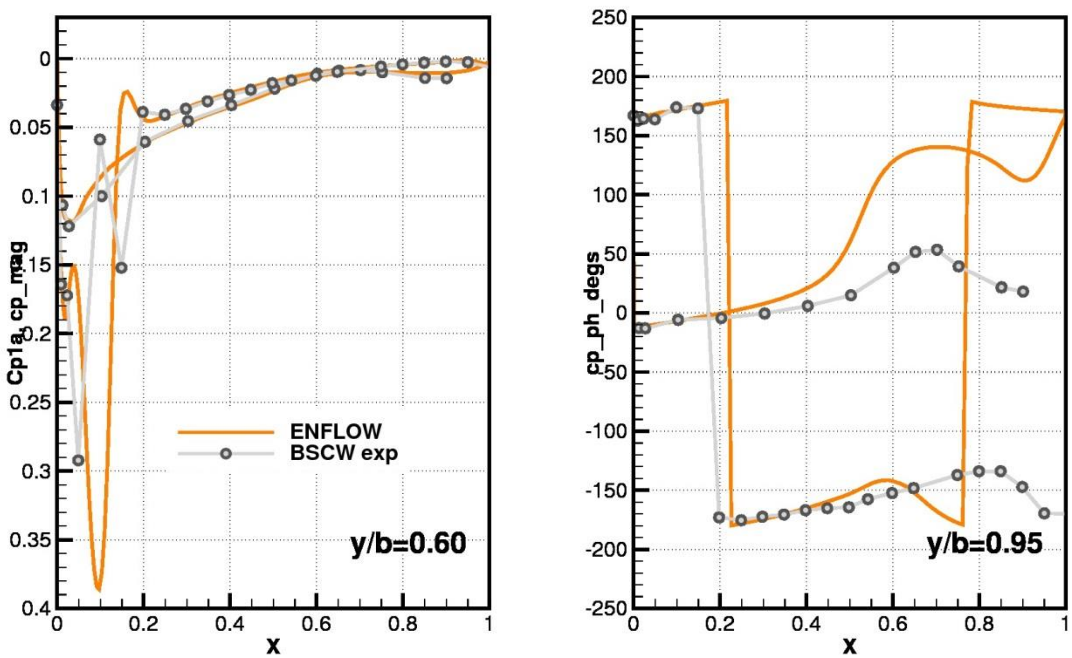
- modify Q_{22} of M=0.82 results to match Q_{22} of M=0.80 at *k=0*
- flutter boundary drops significantly

→ reduction of Q_{22} contributes to the rise of flutter boundary

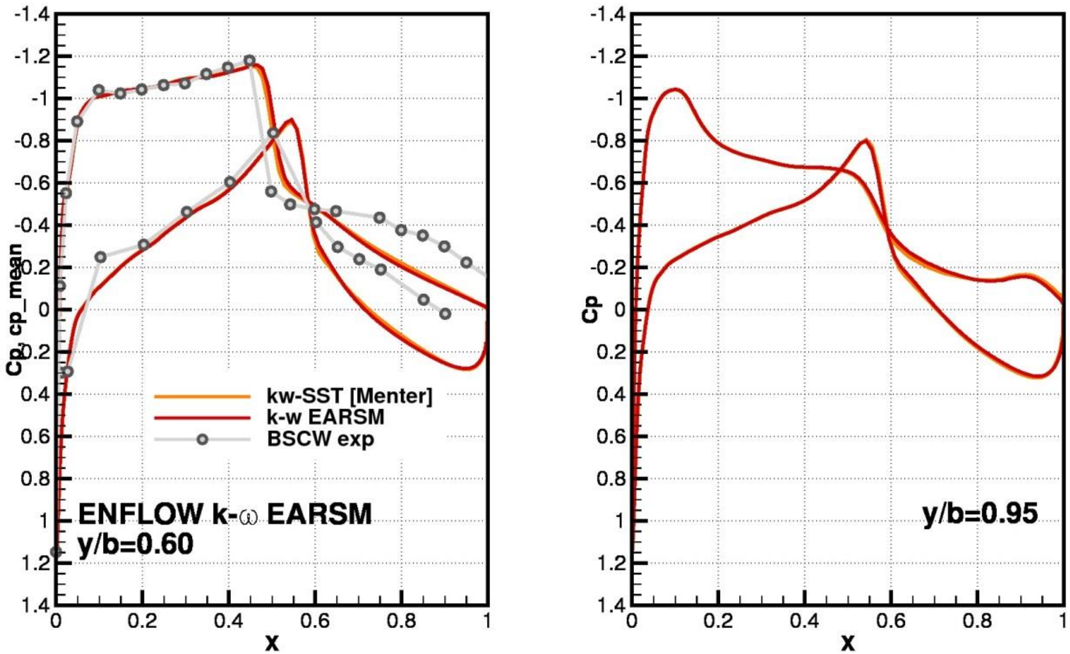
AePW2 case 1 results, steady



AePW2 case 1 results, forced oscillation



AePW2 case 2 results, steady



Conclusions

AePW2 case 2 represents transonic flutter problem without flow separation

- DL results can only capture *global trend*, misses transonic dip and rise
- linear flutter results with CFD GAF capture transonic flutter behaviour properly; however some quantitative differences compared to experiment: needs more parametric study, e.g. *effects of initial state, effects of amplitude of oscillation for obtaining GAF, etc*.
- nonlinear time-domain simulation give the best result compared to experiment