AePW 4 - HAWG

Preliminary Flutter Results for the BSCW at Mach 0.8 Using Nonlinear Aeroelastic ROMs

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What's next...

Australian Government
Defence

RMIT UNIVERSITY
Sir Lawrence Wackett Defence & Aerospace Centre

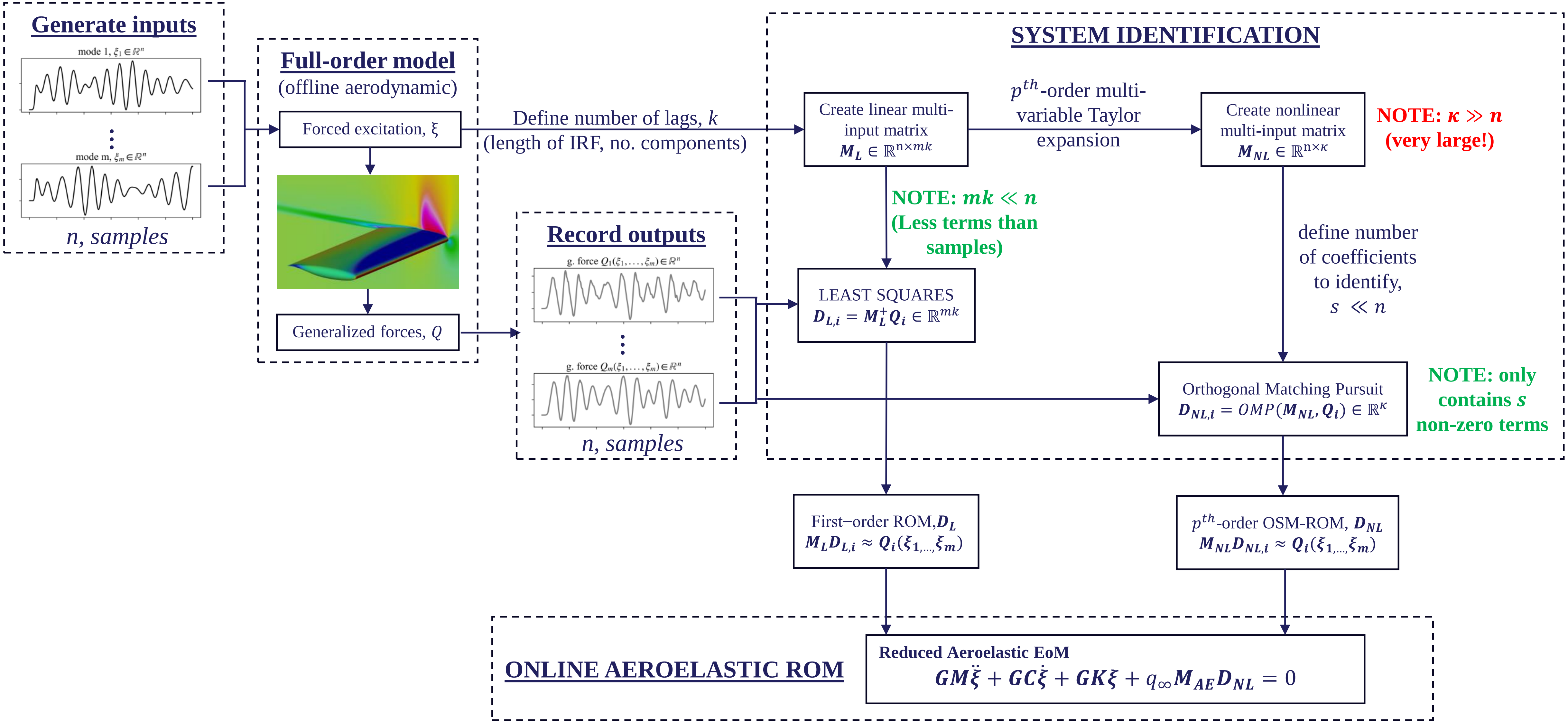
Polynomial Model Reduction

Method is based on sparse Volterra series:

1. Fitting approach (from smooth data), we are not identifying the kernels directly
2. Polynomial methods are plagued by the curse-of-dimensionality
   - The required amount of training data is directly proportional to the number of terms to be identified
   - The number of terms to be identified grows exponentially with the polynomial order AND the number of structural modes (in the order of tens/hundreds-of-thousands or millions)
3. This can be overcome by introducing sparsity, the problem is:
   - One can only make an educated guess as to which terms to retain
4. Sparsity promoting algorithms allow the sparsity patterns to be automatically optimized
   - Orthogonal matching pursuit is used in this work
   - The optimal ROMs in this work contain less than fifty of the tens/hundreds-of-thousands or millions of possible terms

Fundamental assumptions: nonlinear time-invariant (NLTI), memory fading, asymptotically stable, mildly nonlinear.

Identification of the Multi-Input ROM



Aeroelastic Models

Full-Order Aeroelastic Model (FOM)

Full-Order Unsteady Aerodynamics
- ANSYS Fluent 2023 R1
- Coupled pressure-based solver
- URANS (SST)
- Second-order temporal and spatial discretization
- Coarse grid 1.5M cells
- Medium grid 4.9M cells

+

Fluid-Structure Interaction
- In-house FSI solver (PyFSI)
- Modal coordinates
- Projection using ***Modal Projection and Force Reconstruction (MPR)*** method
- Newmark-beta time-integration
- Implicit and explicit coupling

Reduced-Order Aeroelastic Model

Nonlinear Unsteady Aerodynamic ROM
- Sparse Multi-Input Polynomials
- Trained using full-order unsteady aerodynamic model

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Fluid-Structure Interaction
- In-house FSI solver (PyFSI)
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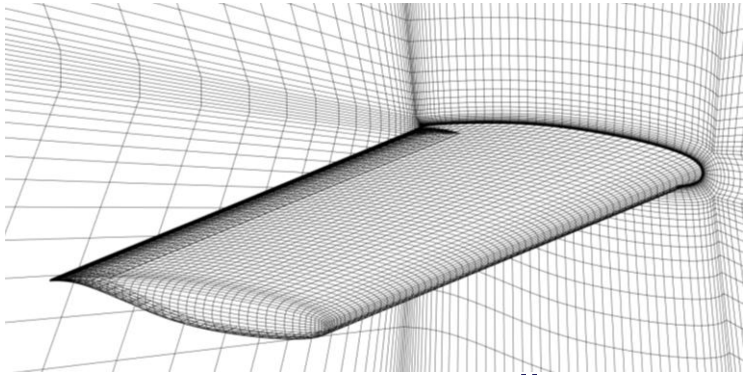
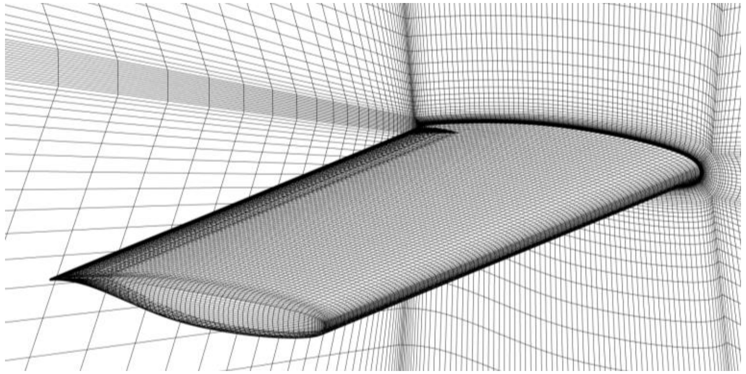


Coarse 1.5M cells



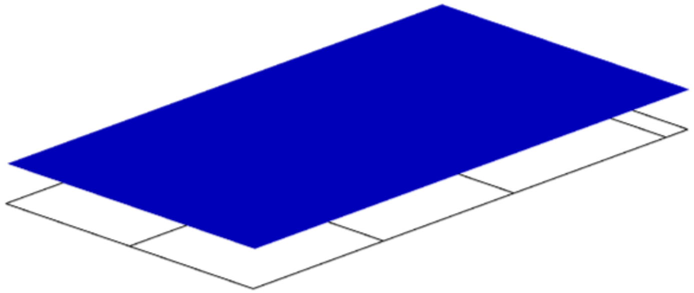
Medium 4.9M cells

** grids generated by ANSYS Germany

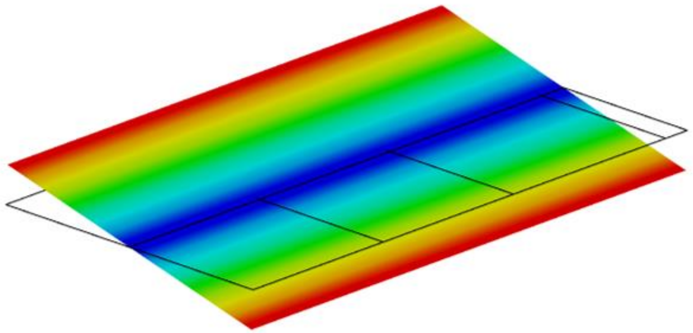
BSCW Test Cases

AePW 2 – Case 2 (Mach 0.74, AoA = 0 deg):
- FOM underpredicted experimental flutter speed by 1% (coarse, dt = 0.001 s with implicit fluid-structure coupling)
- First-order and second-order ROMs underpredicted flutter by 4% and 3.9% respectively (relative to FOM)
- Third-order ROM underpredicted flutter by 0.4% (relative to FOM)

AePW 4 - Mach 0.8, AoA = 2, 3, 5 deg: Results presented now
- R-134a
- Jig release (released from rigid steady-state solution)
- SST with Curvature Correction
- Coarse grid for verification of the ROM approach
- Medium grid to start comparing to FUN3D and experiment

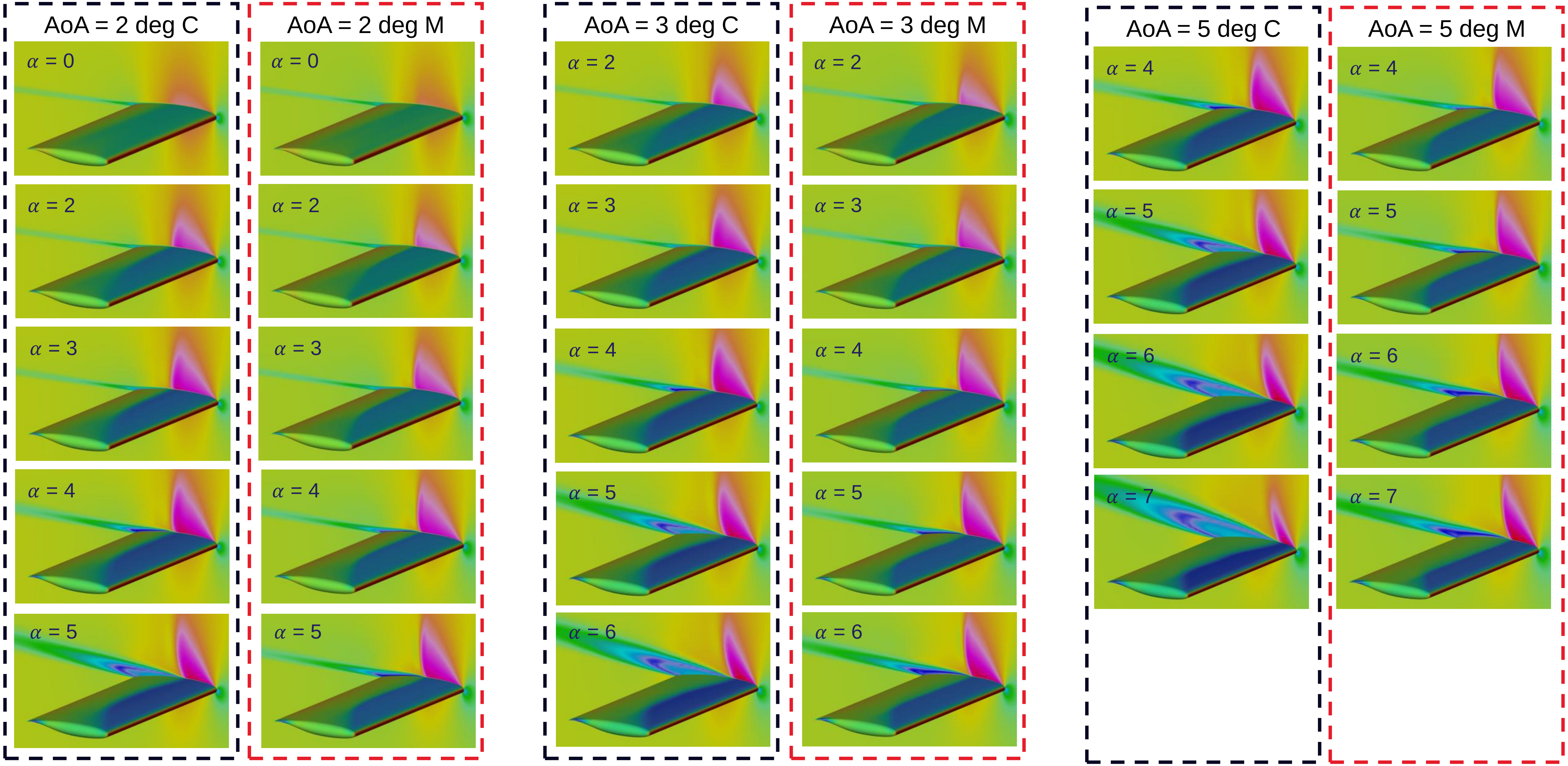


heave 3.33 Hz



pitch 5.2 Hz

BSCW Pitch Range in Training Signal

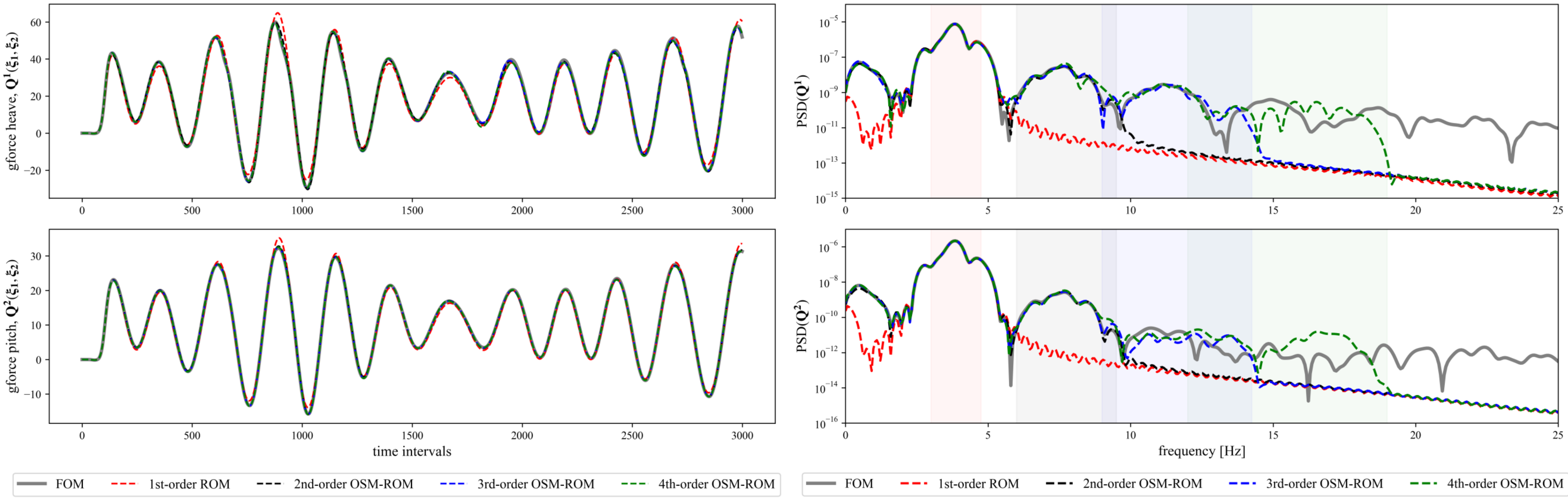


Coarse Mesh

ROM Verification

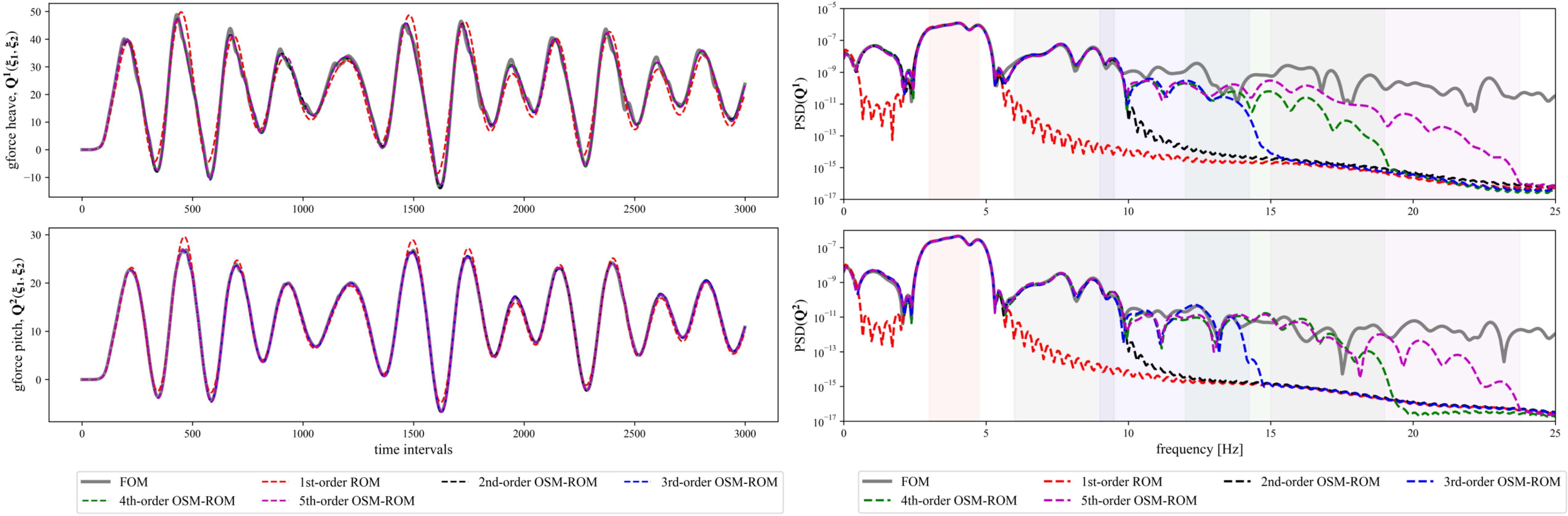
Training Data at Mach 0.8, AoA = 2 deg

- First half of data used for training second half for cross validation



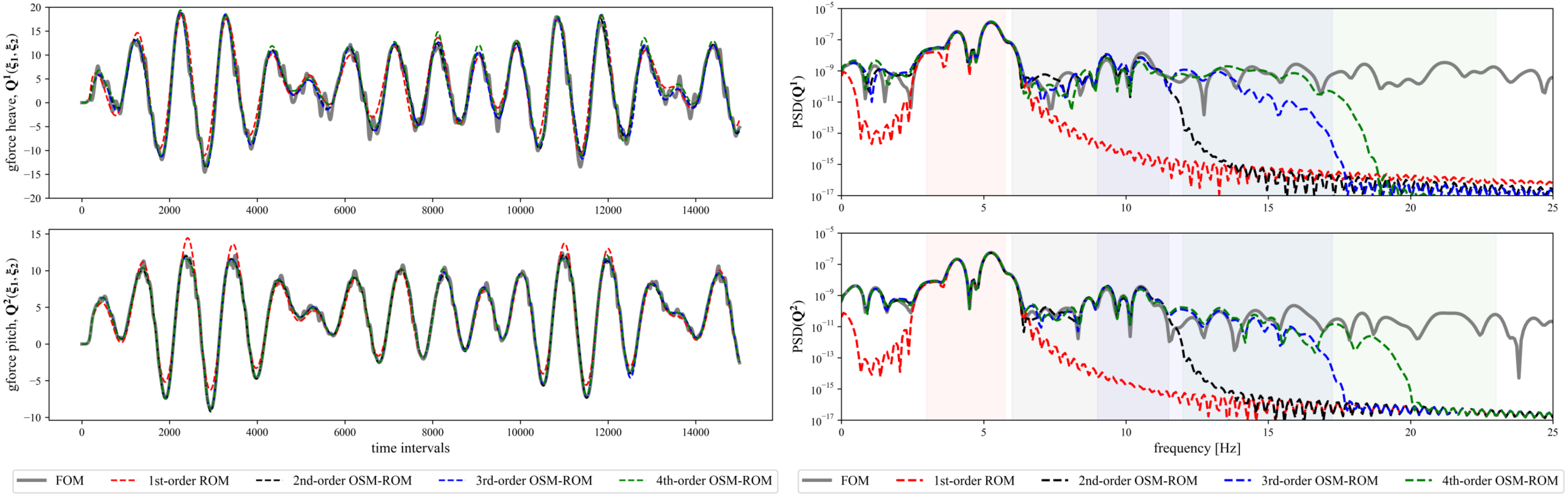
Training Data at Mach 0.8, AoA = 3 deg

- First half of data used for training second half for cross validation



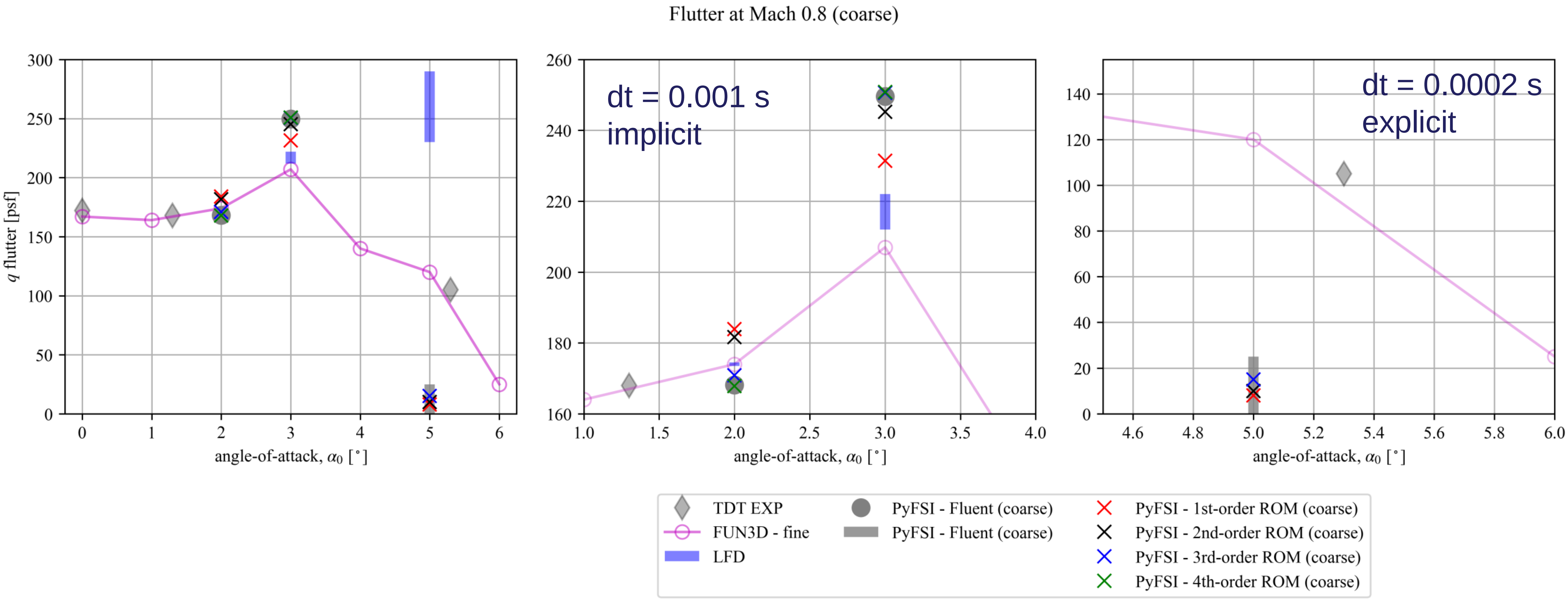
Training Data at Mach 0.8, AoA = 5 deg

- First half of data used for training second half for cross validation

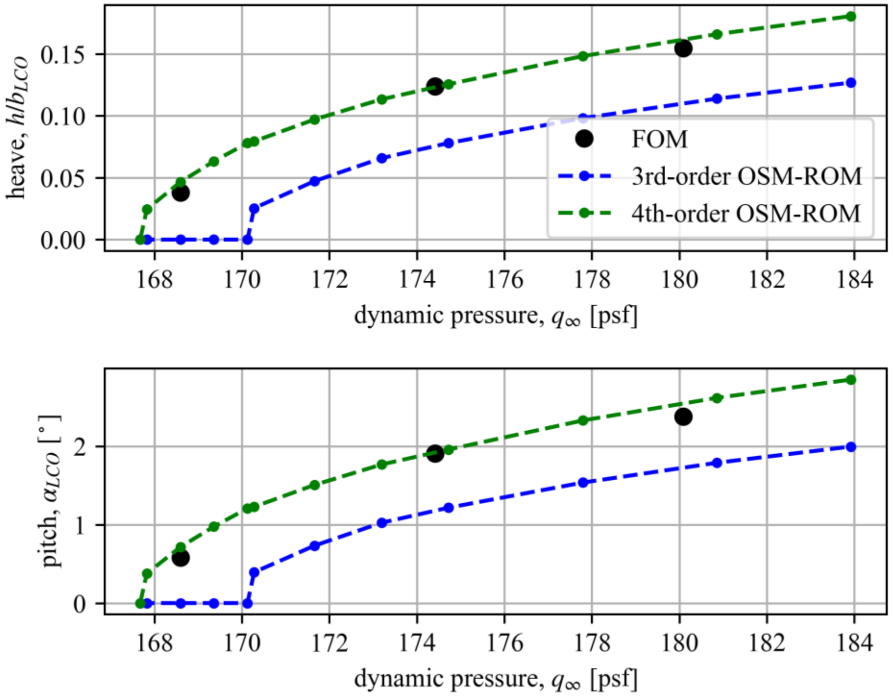


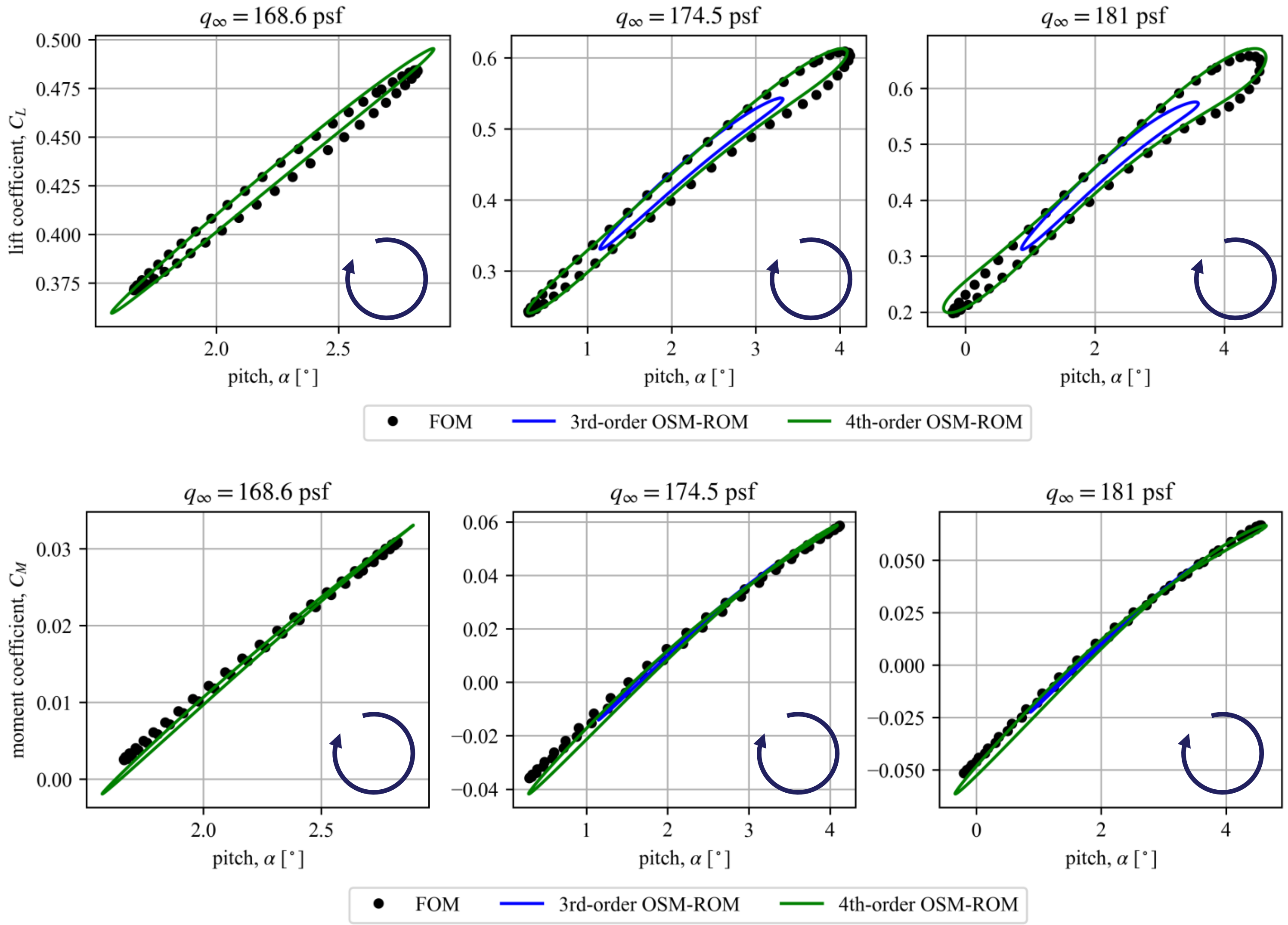
Flutter at Mach 0.8 (coarse)

- **Note: Our FOM is our truth model. Not attempting to match FUN3D or experiment (at this stage).**
- **Phenomenologically the FOM and ROM can model the different flutter modes**
- **AoA = 2, 3 deg: ROM can reproduce FOM very well (better FOM -> better ROM)**
- **AoA = 5 deg: Unclear how well ROM can reproduce FOM, looks promising!**

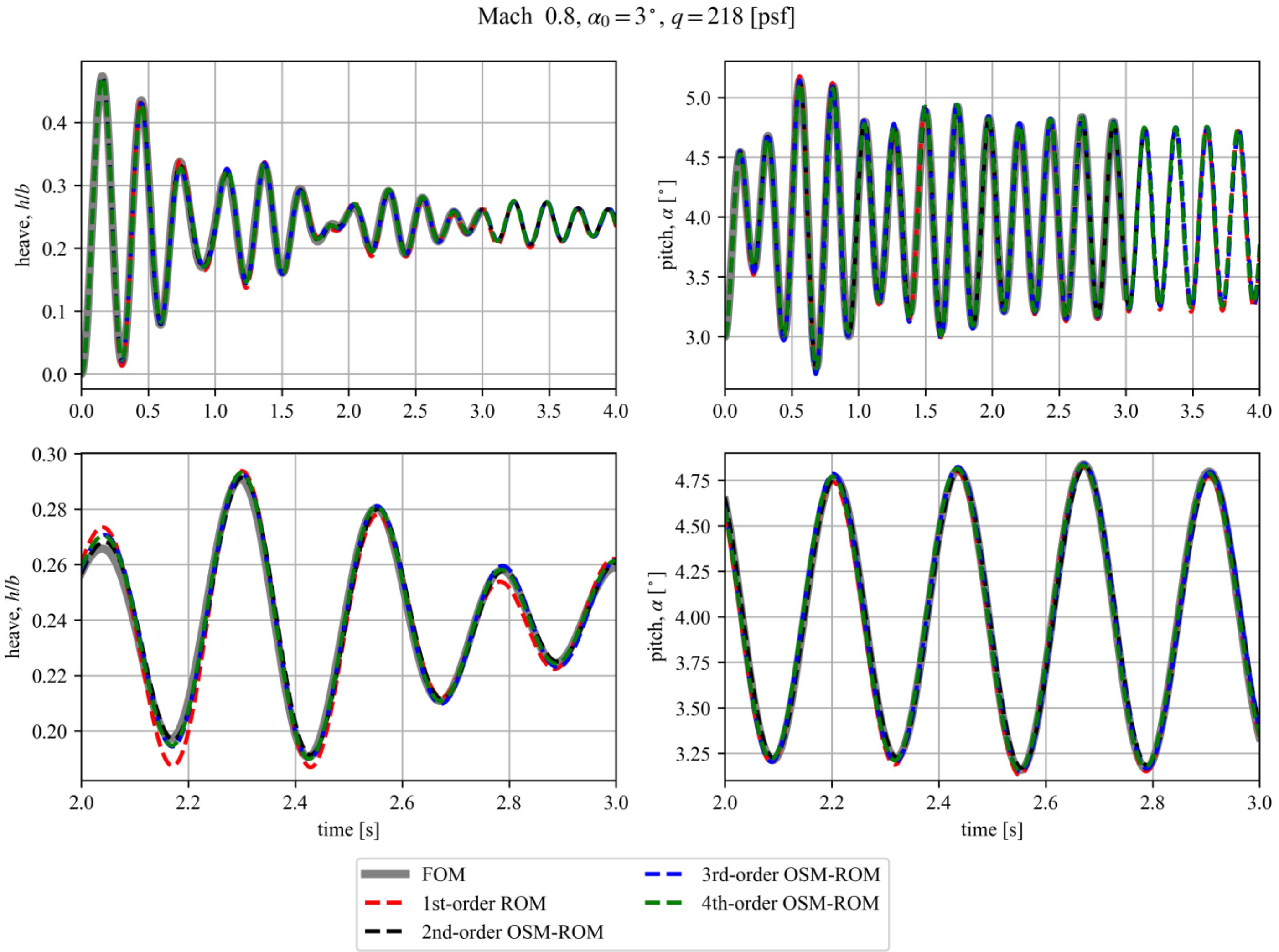


Verification at Mach 0.8, AoA = 2 deg

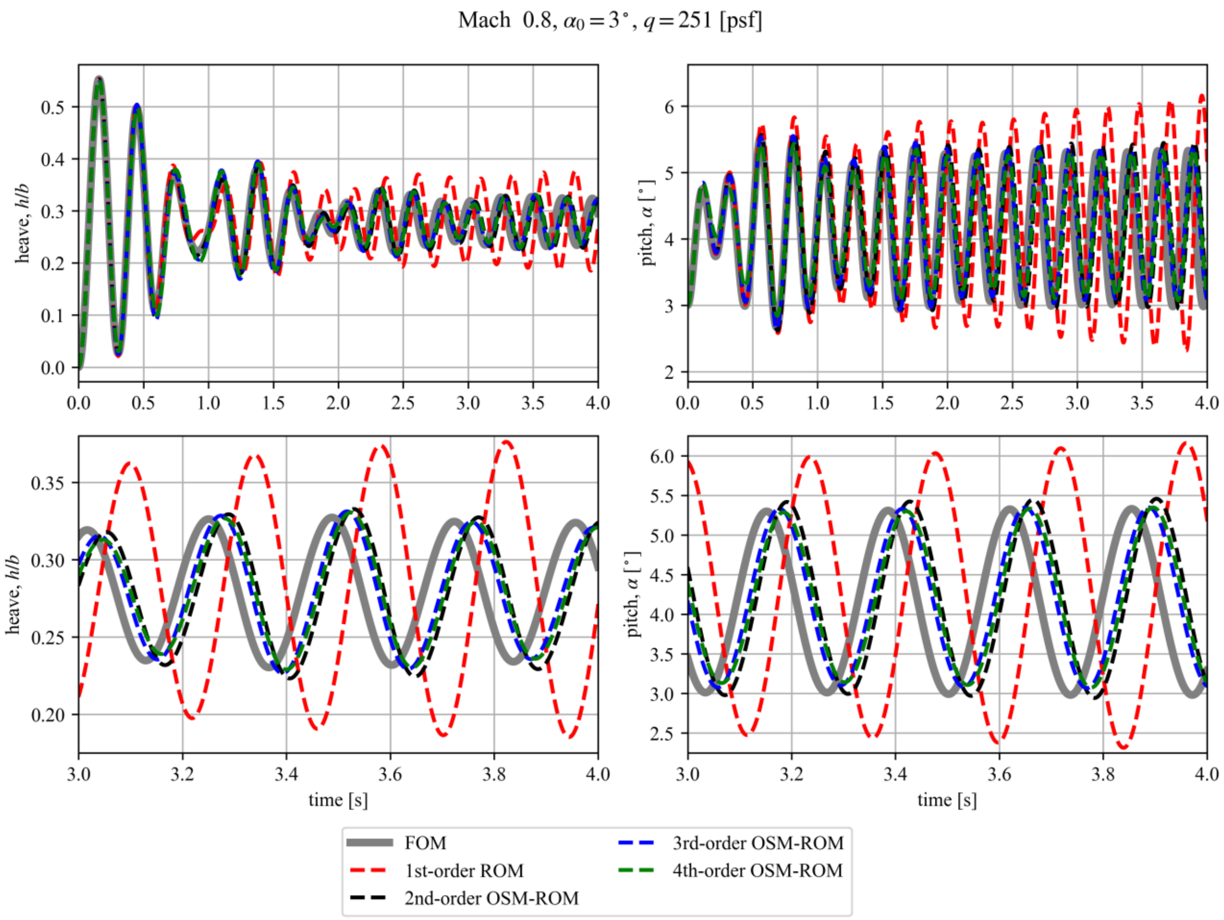


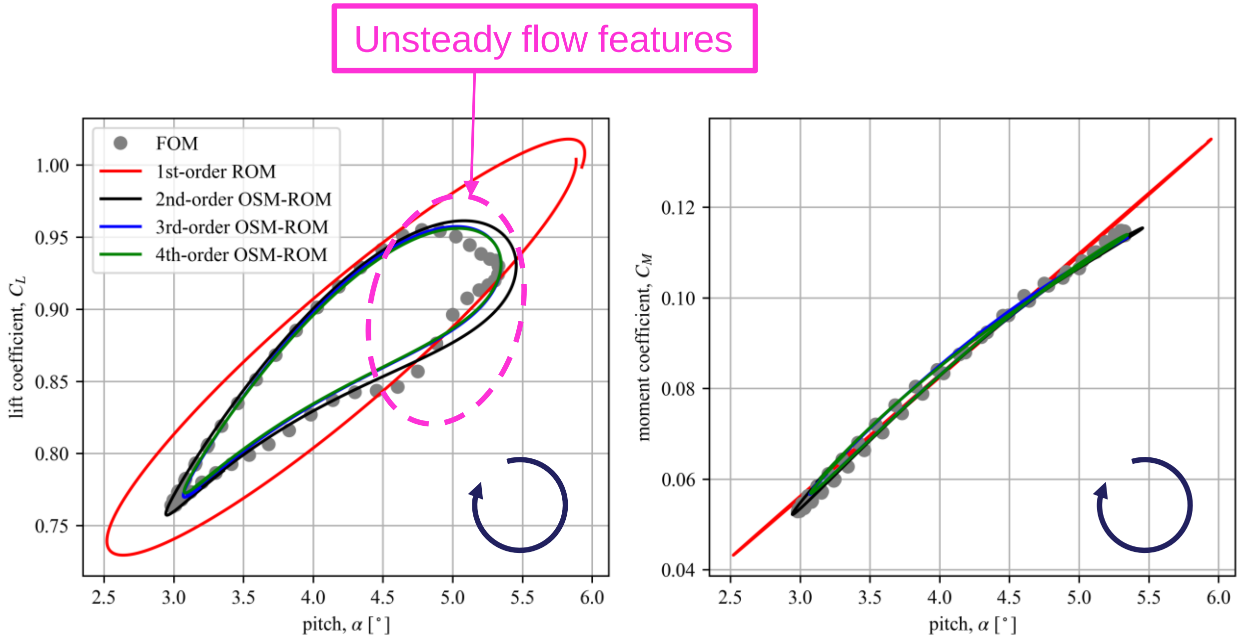


Verification at Mach 0.8, AoA = 3 deg (pre-flutter)

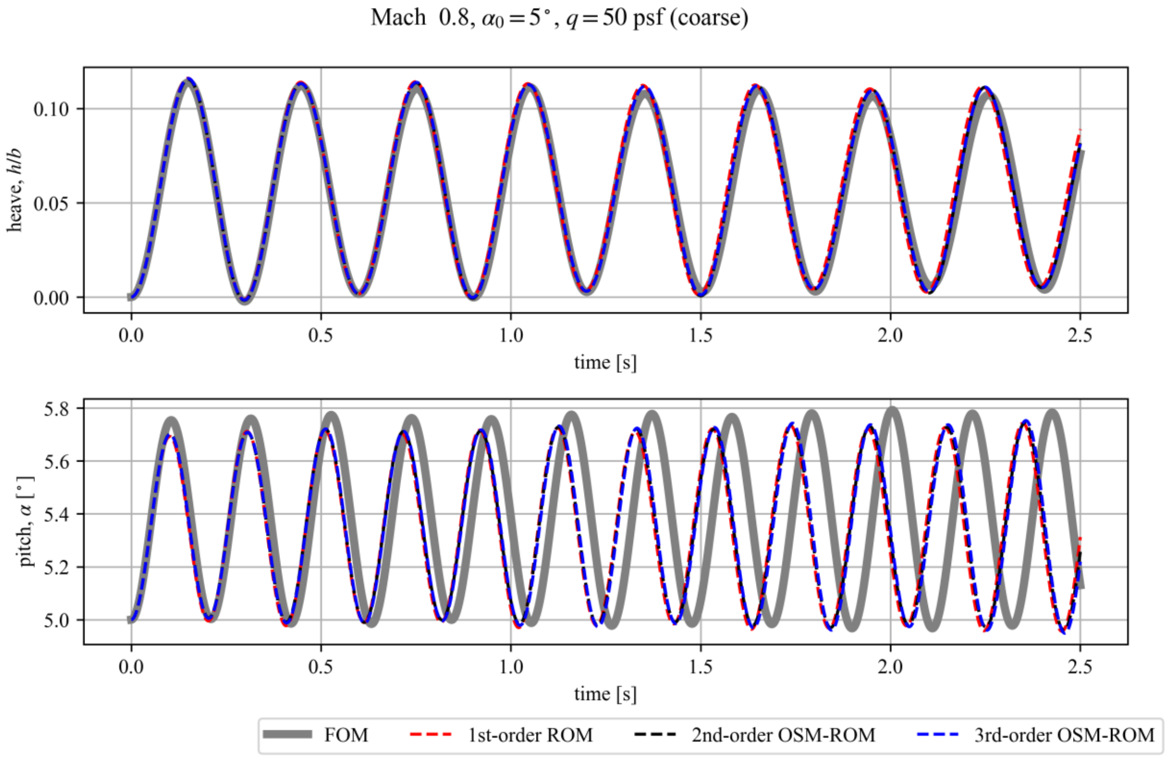


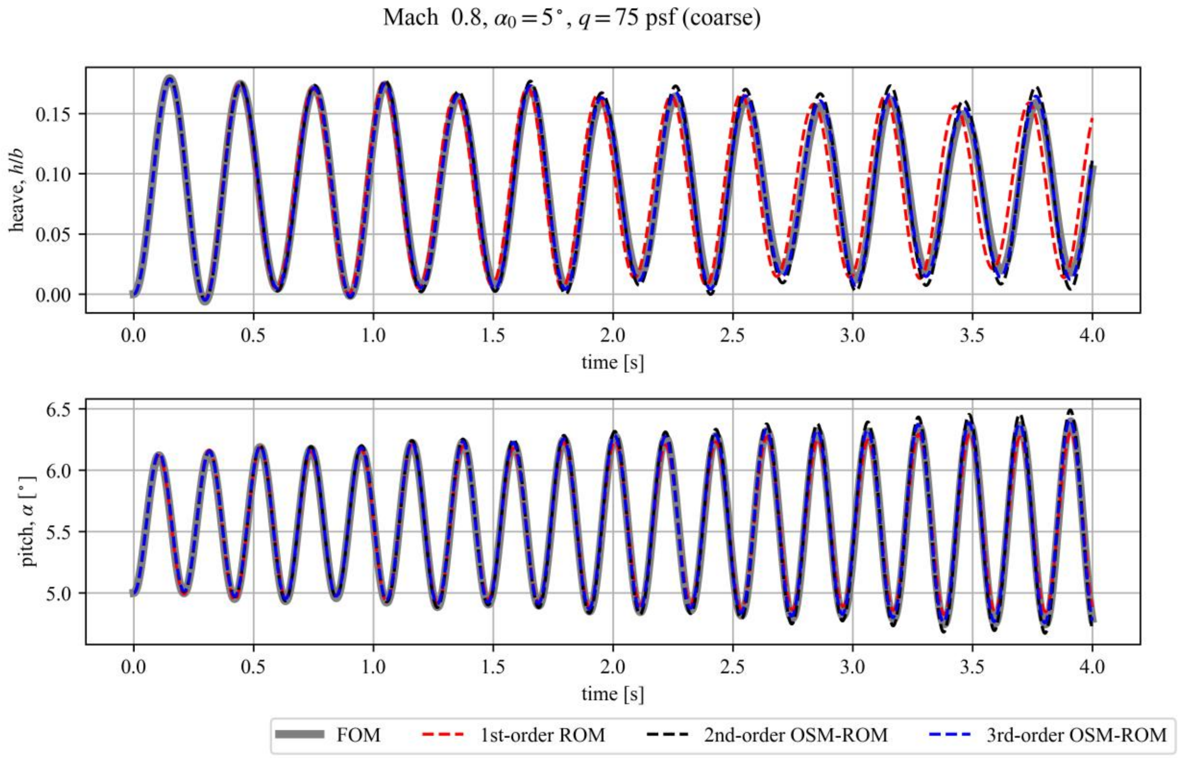
Verification at Mach 0.8, AoA = 3 deg (near-flutter)



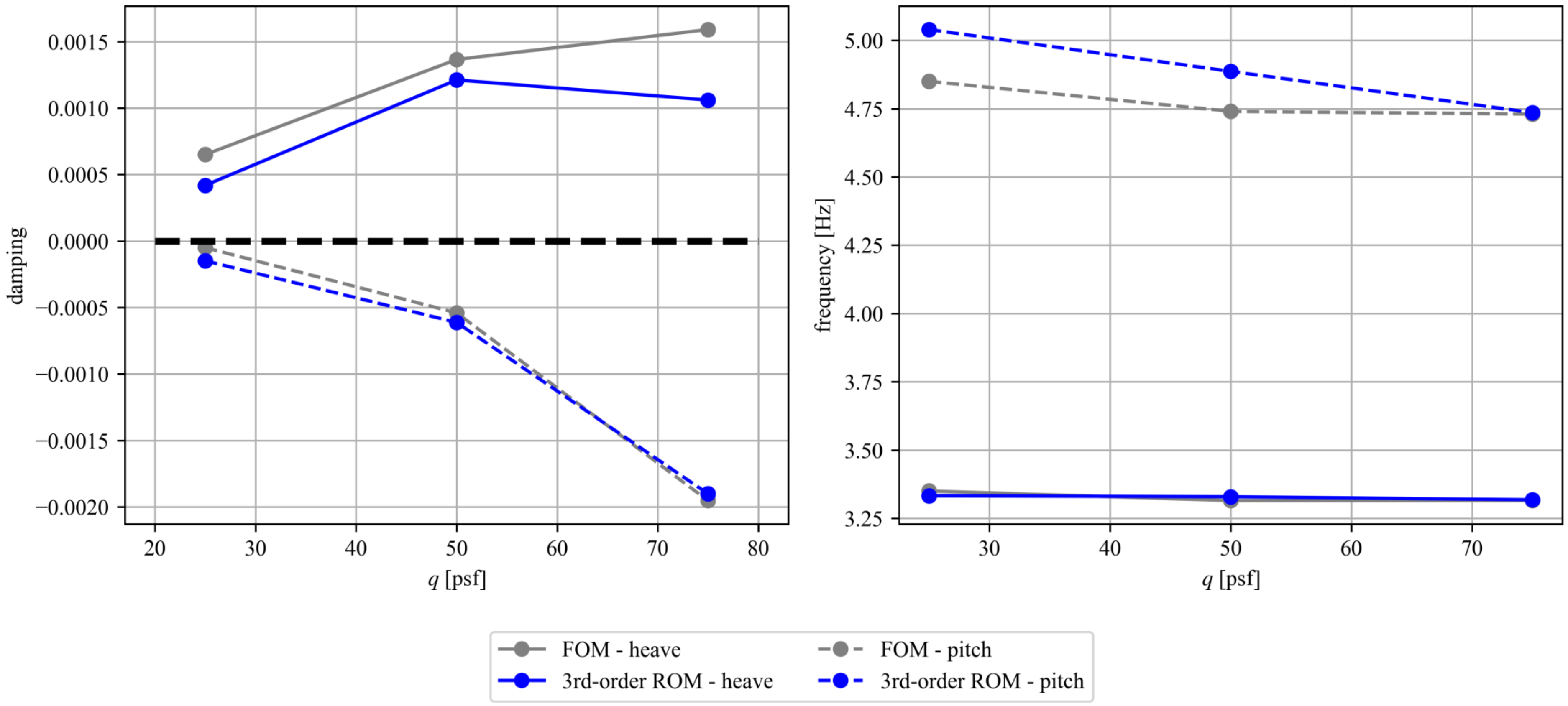


Verification at Mach 0.8, AoA = 5 deg





Verification at Mach 0.8, AoA = 5 deg

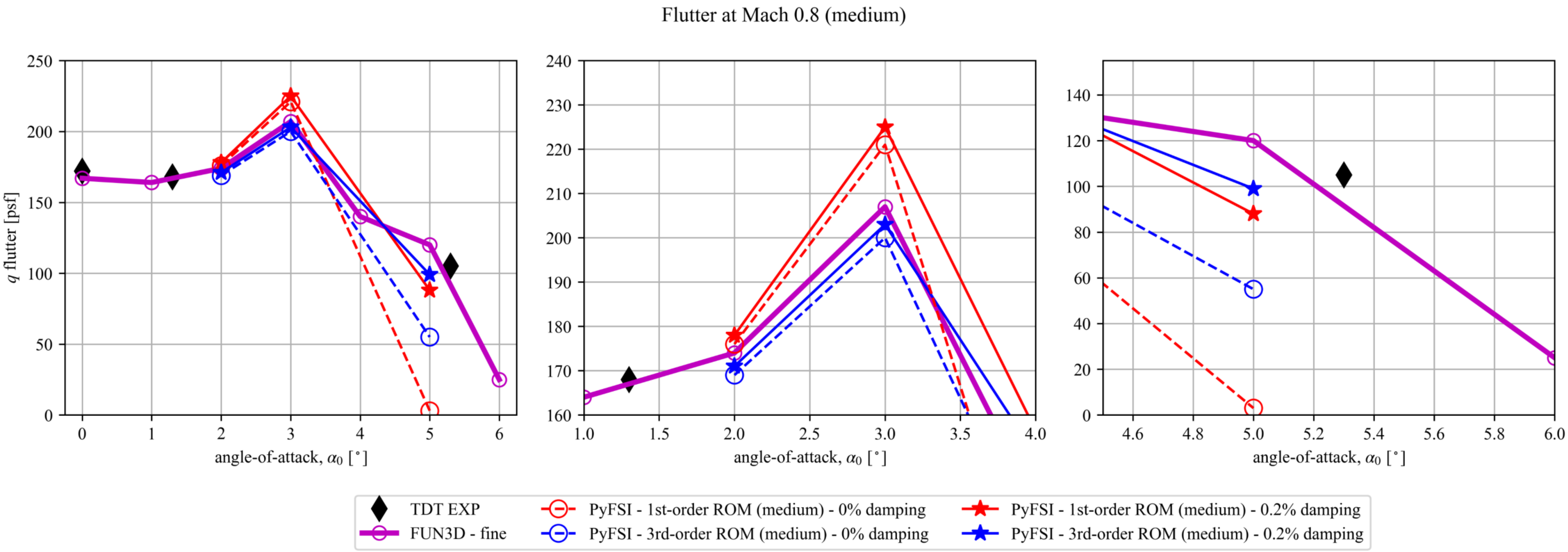


Medium Mesh

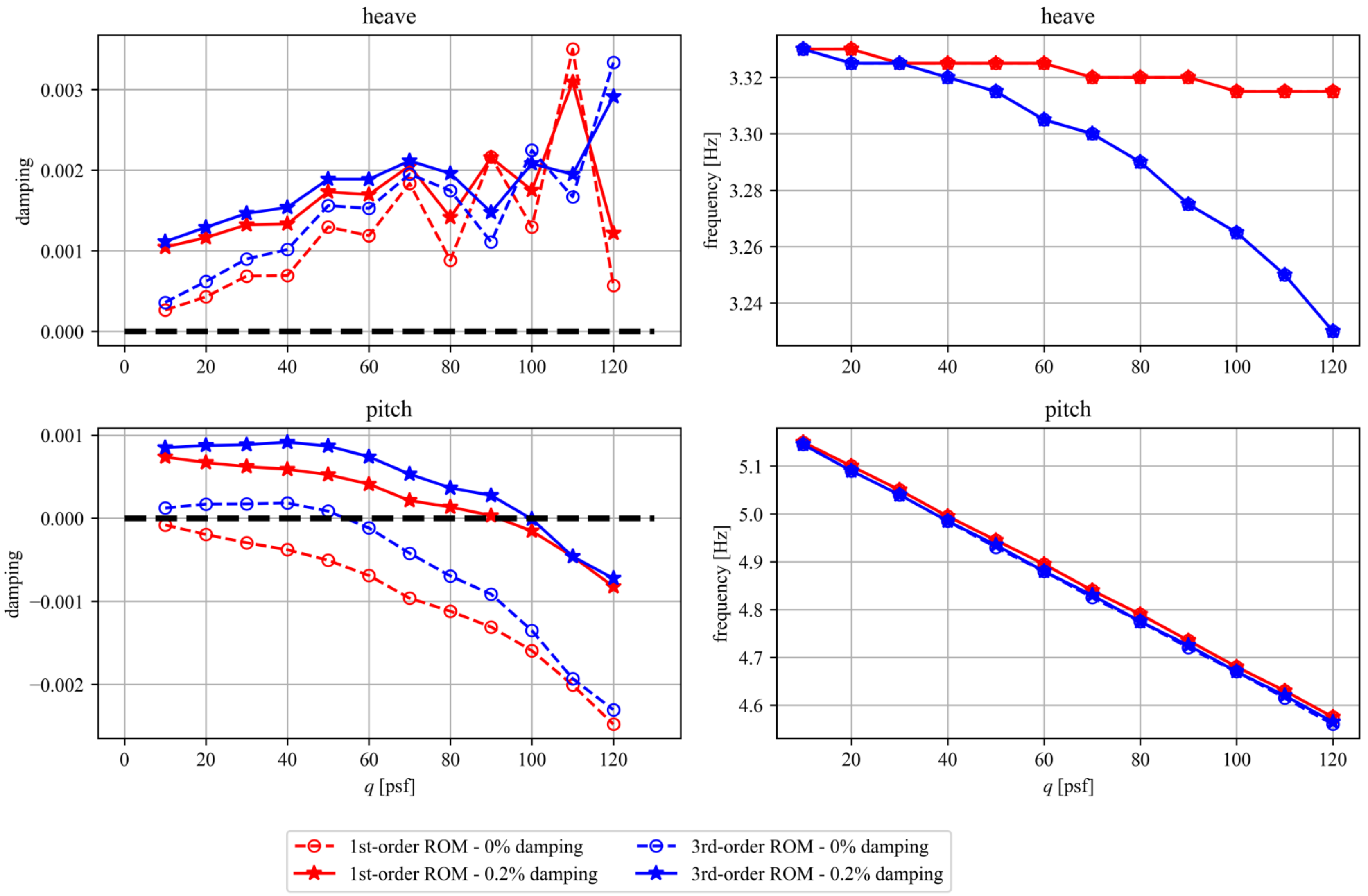
Comparison with Experiment / FUN3D fine

Flutter at Mach 0.8 (medium)

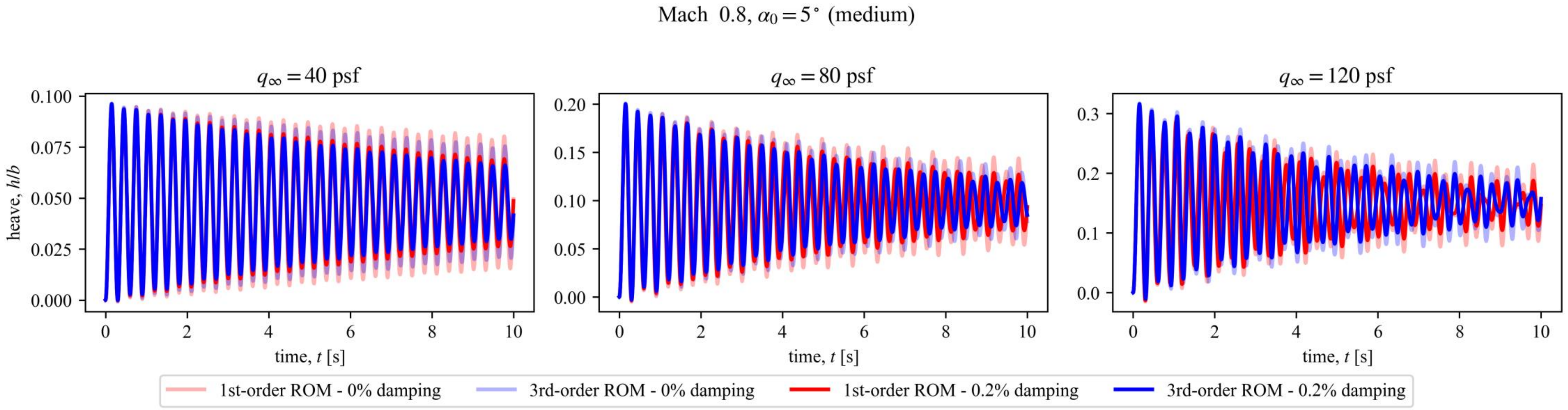
- All results using dt = 0.0002 s
- No FOM results for flutter yet using the medium mesh
- Quite confident that the ROM can reproduce the FOM from
- AoA = 2, 3 deg very good agreement with FUN3D
- AoA = 5 deg under prediction

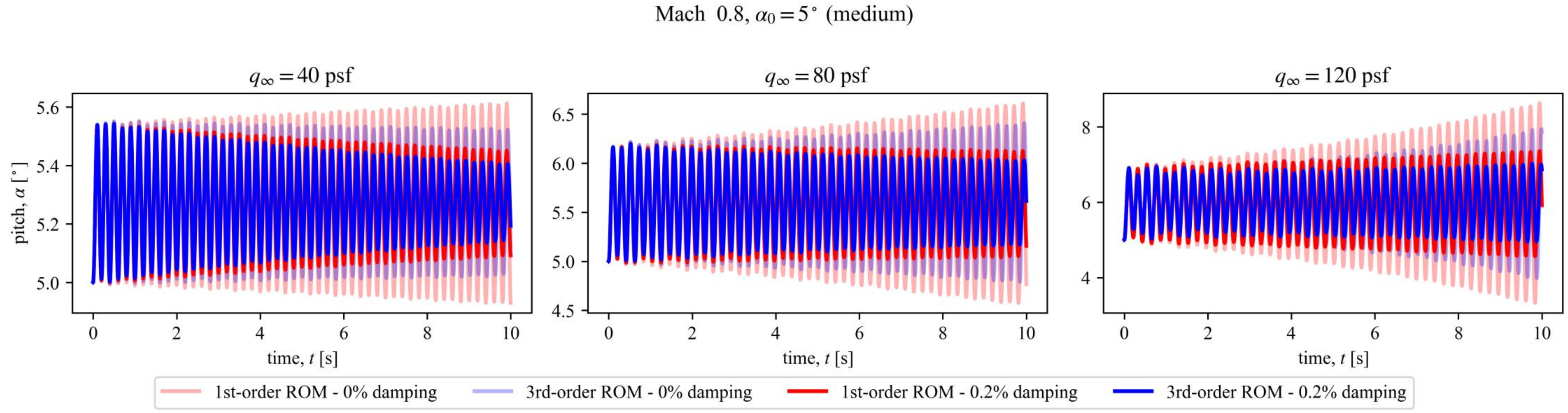


Stability at Mach 0.8, AoA = 5 deg



Time Response at Mach 0.8, AoA = 5 deg





Summary

- Nonlinear unsteady aerodynamic ROMs have been generated for BSCW at M = 0.8, AoA = 2, 3, 5 [deg]
- Aeroelastic simulation on coarse grid takes 3-4 days on 70 cores (20,000 time-steps)
- ROM runs in seconds / minutes on one core (offline cost of approximately 12-24 hrs on coarse grid 70 cores)
- The nonlinear ROM approach performs very well 2 deg and 3 deg.
  - As expected, performance is excellent for attached nonlinear flows.
  - Probably over-kill for flutter predictions < 3 deg.
  - Can capture supercritical LCO post-flutter at 2 deg with high accuracy.
  - At 3 deg the ROM performs well and smooths through some unsteadiness in the forces due to separation
  - 3rd Order ROM matches FUN3D very well when using the medium grid – 0.2% damping does not have much influence
- At 5 deg more work is needed.
  - Small amount of damping has a massive influence.
  - Think more about the initial perturbation.
  - Verification with medium grid is needed.