NASA LaRC Contribution to the AePW High Speed Working Group Test Case, RC-19

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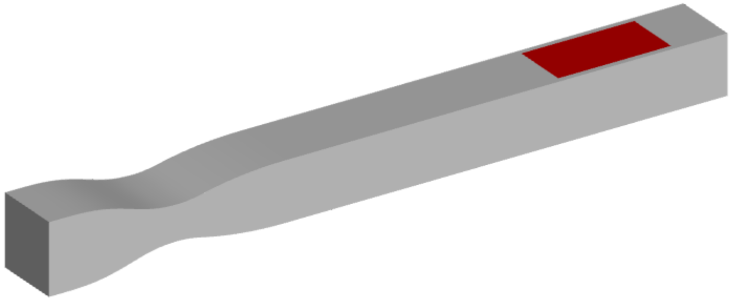
RC19 Test Case

- Mach 2 tunnel with a flexible panel on the ceiling
  - Three tuning knobs to control response:
    1. Panel temperature, ΔT
    2. Cavity pressure behind panel
    3. Wedge angle
  - Test case 1: ΔT ≈ 13 K, cavity pressure ≈ 50 kPa, wedge angle = 0 deg.
    - Should cause the panel to flutter, lead to a periodic LCO
  - Test case 2: ΔT ≈ 15 K, cavity pressure ≈ 52 kPa, wedge angle = 0 deg.
    - Should lead to chaotic panel vibrations
  - Test case 3: ΔT ≈ 13 K, cavity pressure ≈ 68 kPa, wedge angle = 4 deg.
    - Shock impingement on panel from wedge

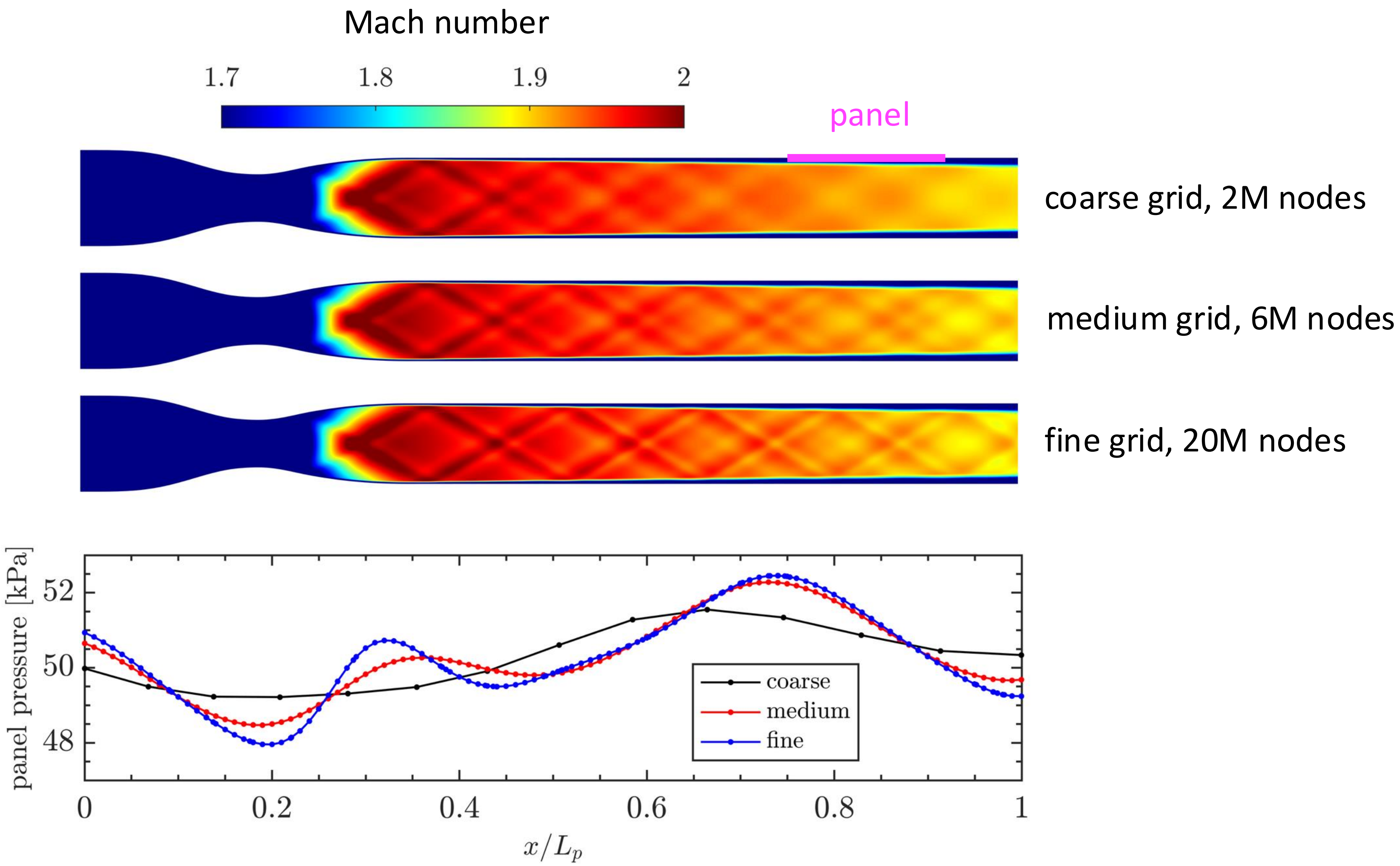
  - We have only attempted cases 1 and 3



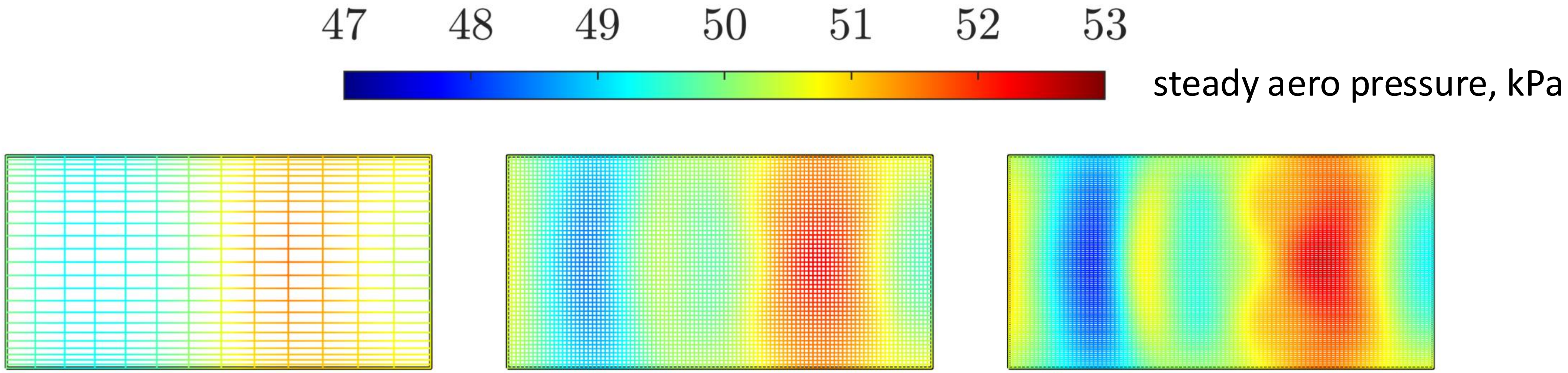
Solver

- Unsteady FSI coupling computed with FUNtoFEM
- https://github.com/smdogroup/funtofem
- Allows for time-domain coupling between NASA's FUN3D solver and an arbitrary finite element model, via python
  - FUN3D: unsteady RANS solver with SA
  - FEA: in-house nonlinear shell solver
  - Information transferred between FUN3D and FEA via MELD
- All FUN3D meshes have a surface y+ at the panel about equal to 0.4
  - For the case with the wedge, a y+ of 2 was needed to keep the flow solver from crashing

Steady Flow Fields, Rigid Panel



Steady Pressures on Rigid Panel



coarse grid, 2M nodes

medium grid, 6M nodes

fine grid, 20M nodes

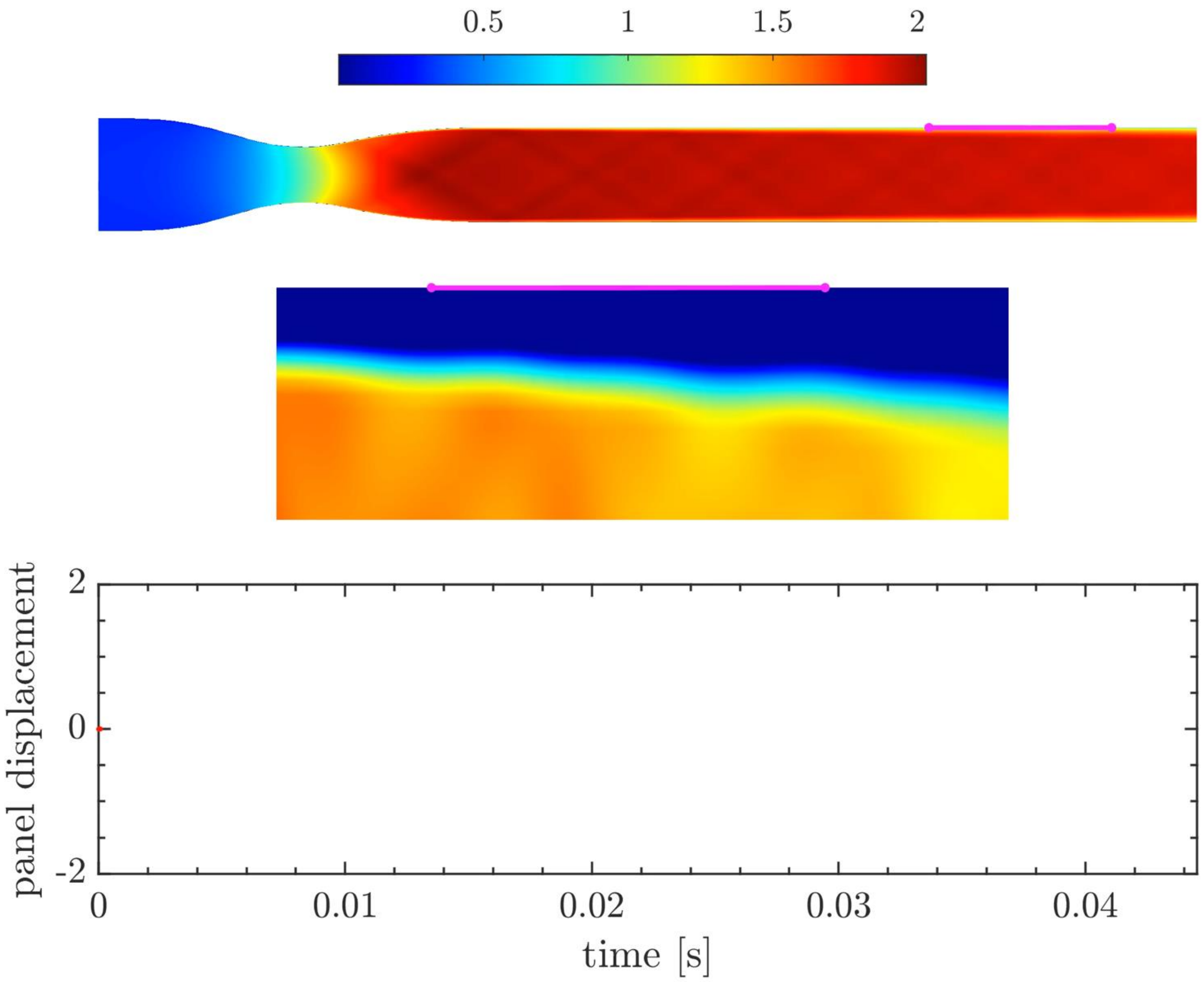
- If cavity pressure is 50 kPa, then mean steady Δp is nearly 0
  - Negative 2-3 kPa near LE, positive 2-3 kPa near TE

Boundary Layer Thickness

- Our computed boundary layer at the panel is ~13 mm thick
- The experimentally-measured boundary layer is closer to 9 mm thick

- A potential reason: we are modeling the entire setup (nozzle + test section) as turbulent
  - In reality, the flow will start out as laminar, and transition at some point in the nozzle (?)

Test Case 1 Results



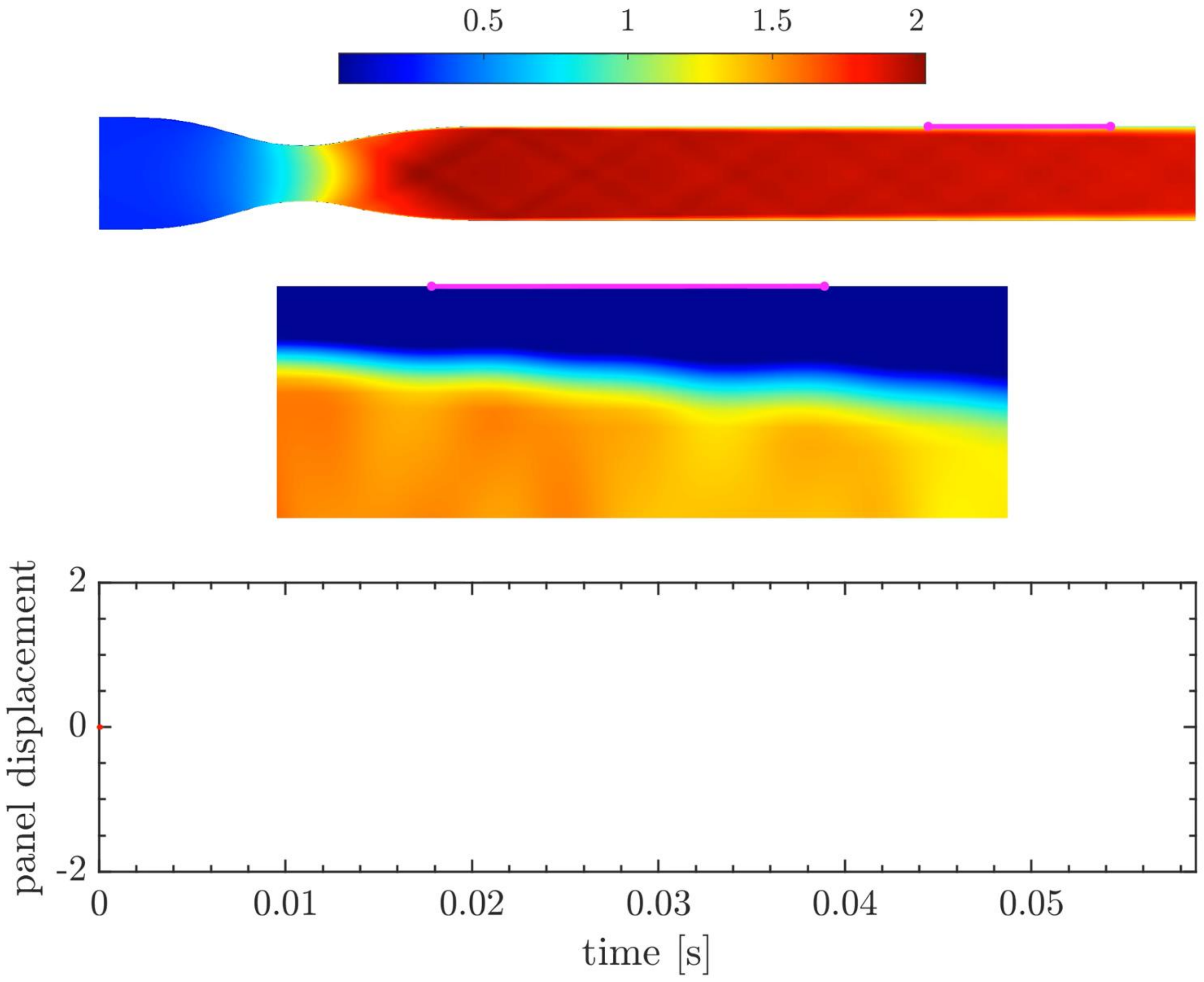
Test Case 1 Results

- Our numerical results show the panel settles into a deformed steady-state
  - The experiment shows a clean periodic LCO

- We are assuming that the in-plane supports on the panel are rigid
- We ran a linearized stability analysis for this case (FUN3D/LFD), and found that the system was very stable
  - The model will flutter if we remove the pre-load (i.e., make Δp everywhere on the panel exactly 0)
  - If we leave the pre-load, the model becomes less stable if we decrease the in-plane support stiffness, but still won’t flutter

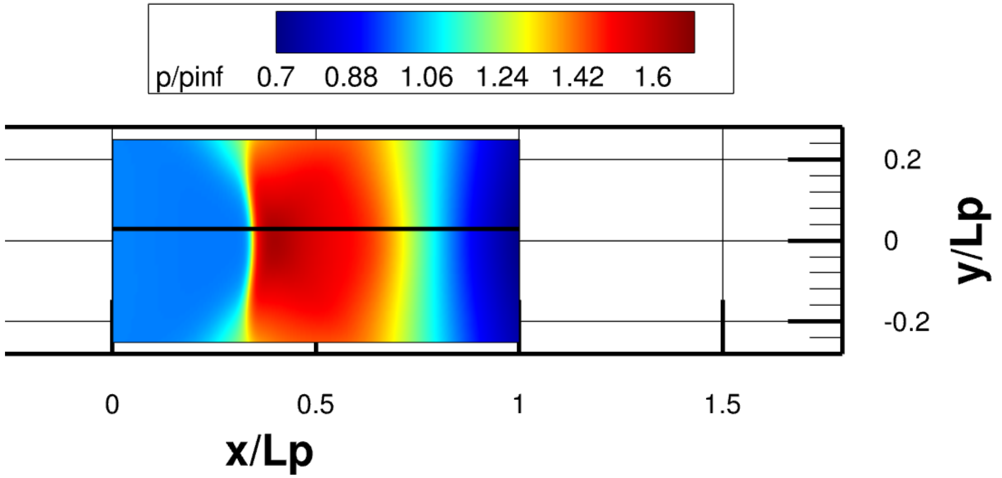
Panel LCO

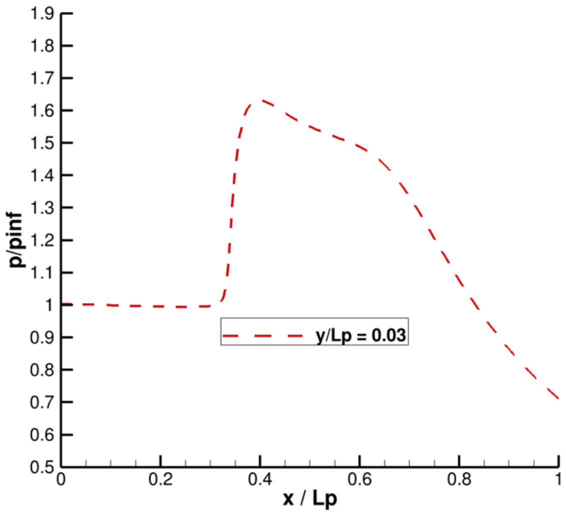
- Nonlinear results with 0 pre-load:
- Set the cavity pressure distribution equal-and-opposite to the initial aerodynamic pressures
- The only pressures on the panel are unsteady aerodynamic pressures



Test Case 3

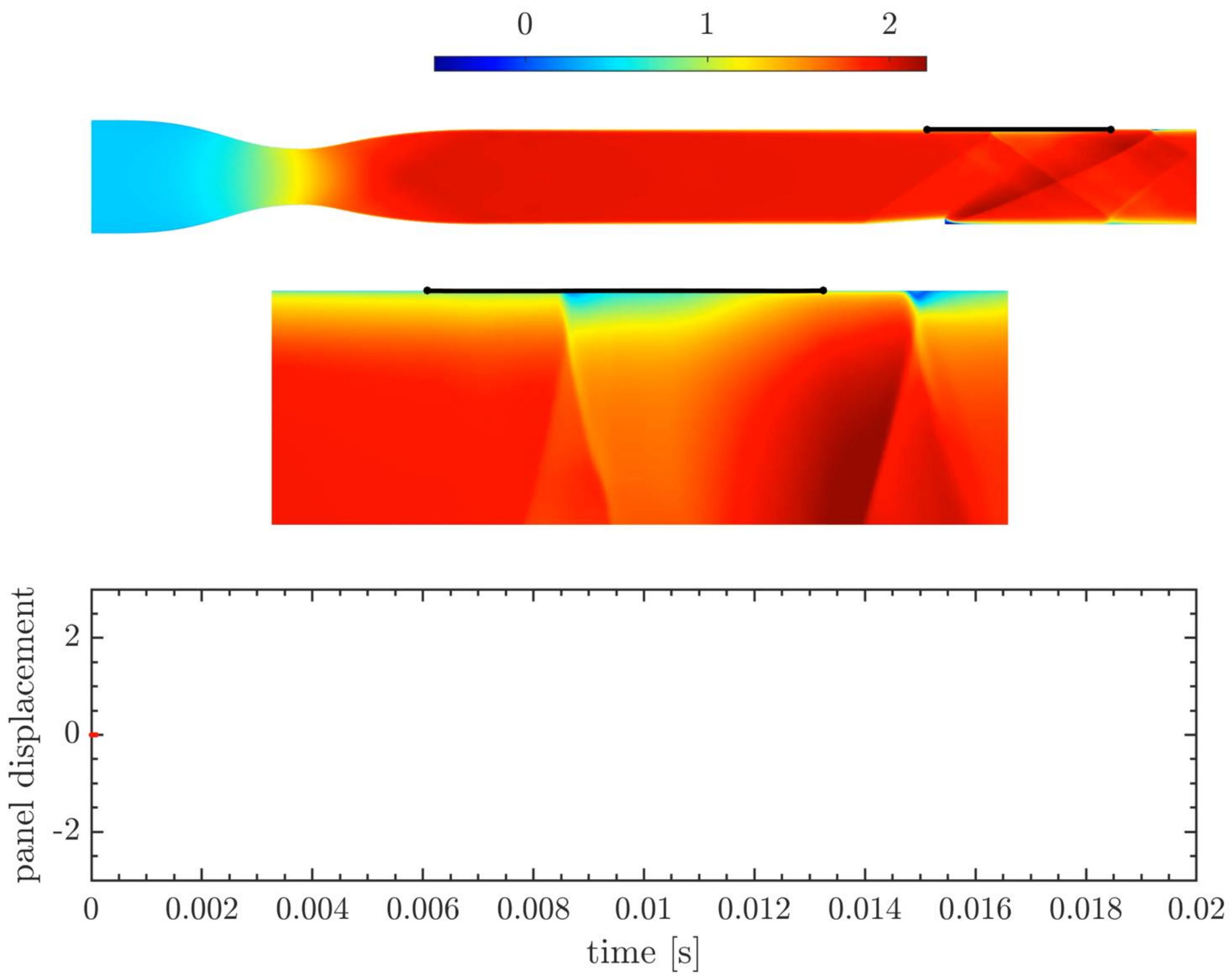
- Steady flows over the rigid panel, with a 4 deg. wedge angle, could be obtained with a surface y+ of 0.4



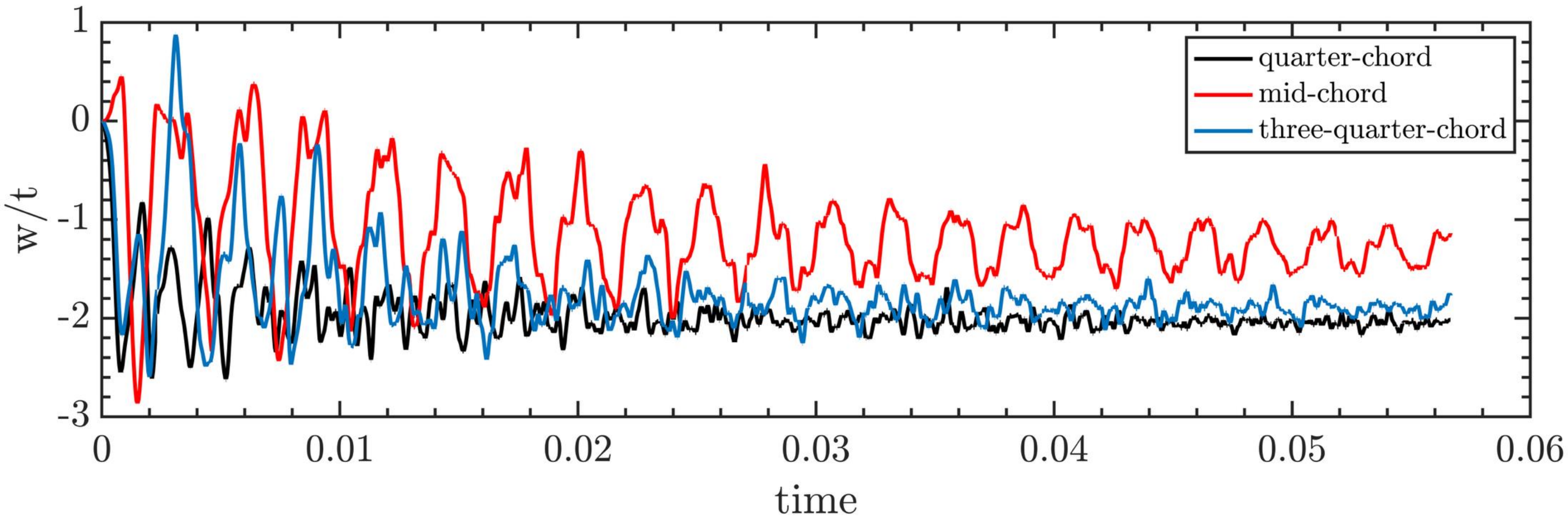


- But for unsteady flows over the deforming panel, this mesh would crash
  - A mesh with a higher y+ (2.0) does work, however

Test Case 3 Results



Test Case 3 Results



- Panel gradually settles into a W-shape
  - Panel mostly deforms downward, due to the high cavity pressure
  - But the mid-part of the panel inflects upward, a little, from the shock
- Like test case 1, this is the wrong answer:
  - Experimental results show a chaotic self-standing motion

Conclusions

- Test Case 1:
  - We think the pre-load on the panel is preventing flutter/LCO
  - The pre-load is driven by the diamond-shaped shock, and how we are modeling the nozzle
  - If we artificially remove the pre-load, we get a clean LCO result
- Test Case 3:
  - Here the pre-load is less subtle, due to the shock impingement
  - Our steady pressures compare well with the experiment, but still we cannot compute an LCO
  - We plan to run a linearized stability analysis for this case also, to help debug the issue

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