AePW-4

RC-19

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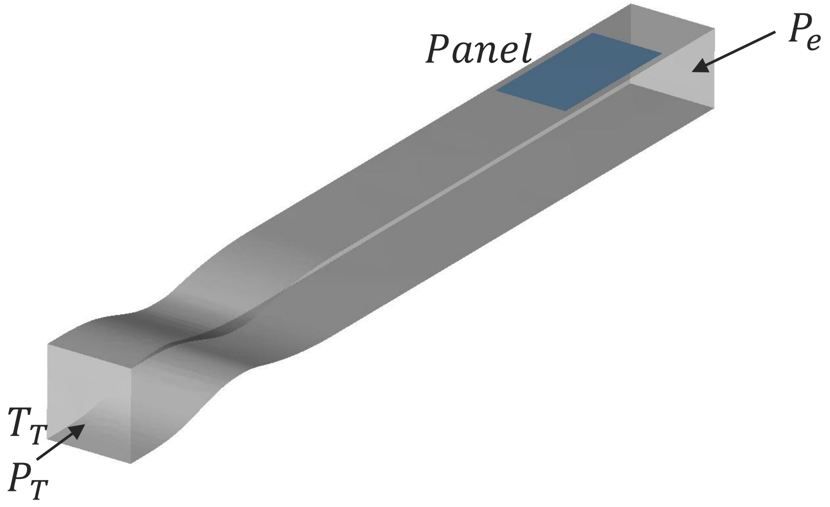
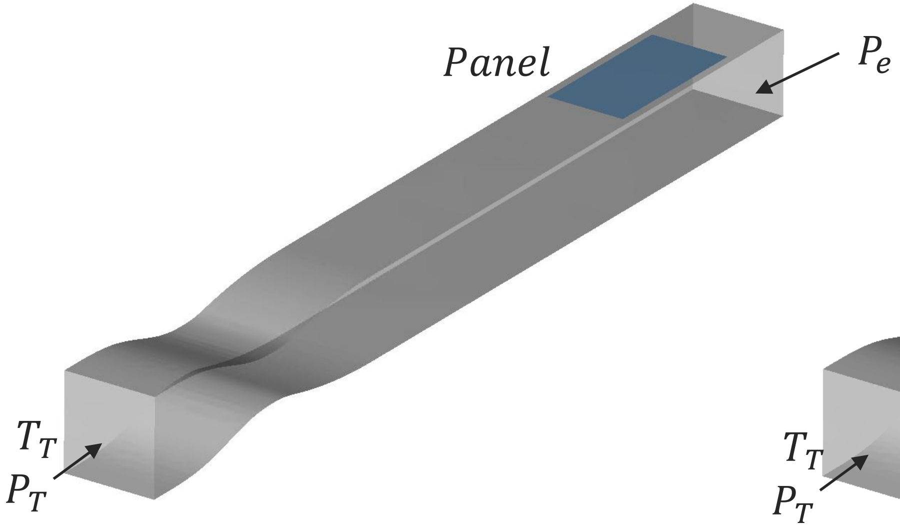
Simulated Cases

Case 1: NO SBLI Periodic



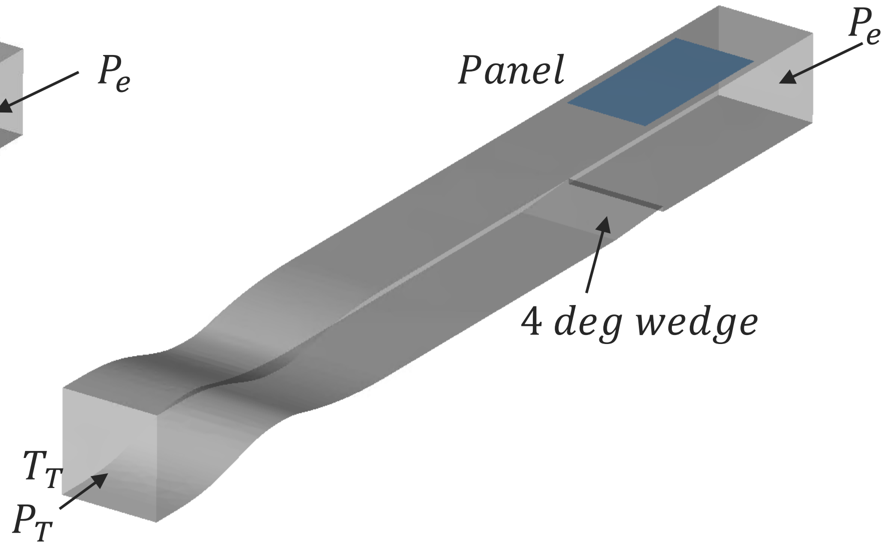
- P_cavity = 50.4kPa
- $\Delta T = 13K$
- These conditions should induce flutter and maintain periodic oscillation

Case 2: NO SBLI Chaotic



- P_cavity = 51.5kPa
- $\Delta T = 15K$
- These conditions should induce flutter and trigger chaotic oscillations

Case 3: SBLI – 4 deg. wedge



- P_cavity = 68.9kPa
- $\Delta T = 13K$
- These conditions should induce flutter and maintain periodic oscillations

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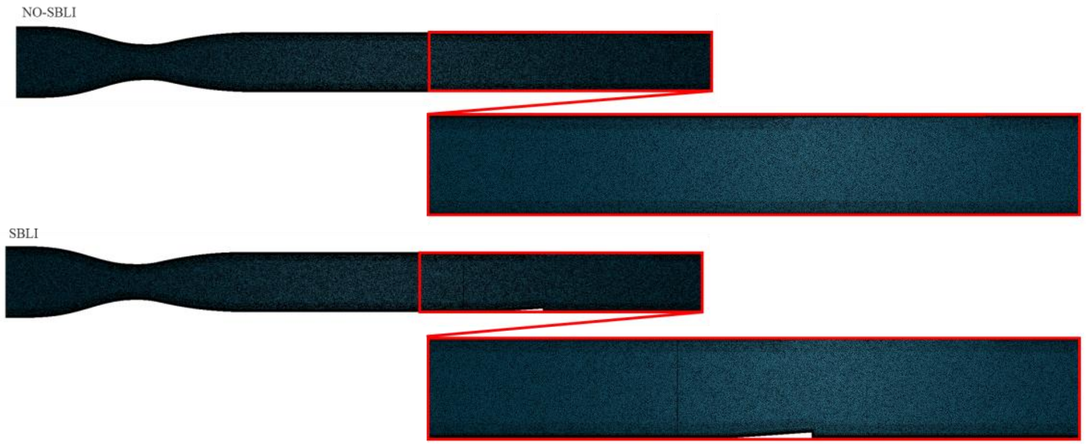
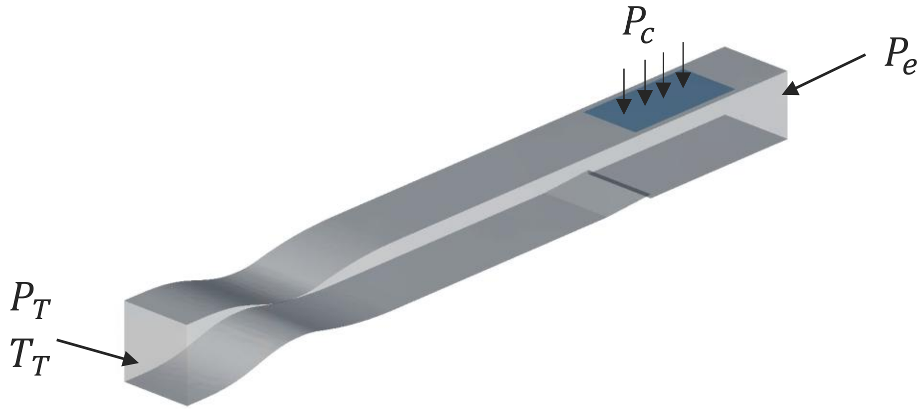
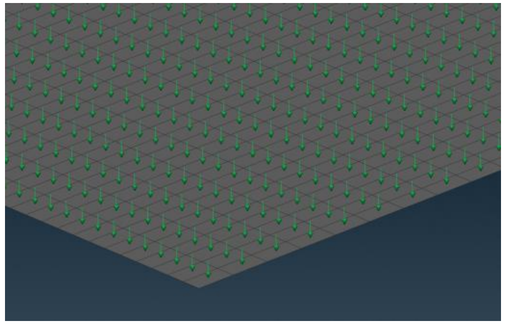
Solvers, meshes, and BC details:

- **CFD model: Cradle CFD scFLOW**
  - Polyhedral mesh with prism elements on walls
    - ~13-14million elements (medium mesh)
    - Average y+≈ 0.3
  - Inlet total pressure and temperature as provided by the workshop
  - RANS $\mathrm{k}-\omega$ SST turbulence model





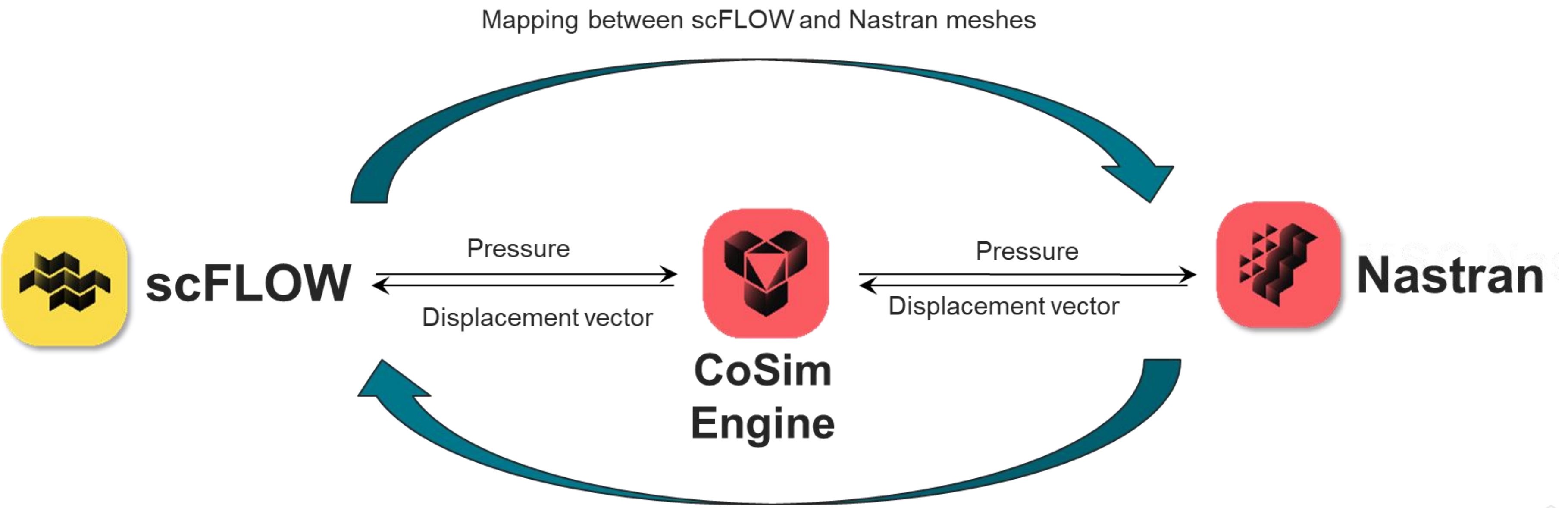
- **FEA model: Nastran**
  - SOL400 NLTRAN (Non-linear transient)
  - 10,000 QUAD4 elements (Shells)
  - Clamped edges
  - Cavity pressure applied to the top side as a constant and uniform load
  - Panel temperature applied as a constant and uniform value



Case	Inlet total pressure (kPa)	Inlet total temperature (K)	Cavity pressure (kPa)	$\Delta T(K)$
1 (NO-SBLI Periodic)	348	388	50.4	13
2 (NO-SBLI Chaotic)	347	387	51.5	15
3 (SBLI)	346	386	68.9	13

Aeroelastic simulation procedure

1. **Steady and rigid RANS**
   - Initialize the flow field, panel pressure, panel temperature
2. **Aeroelastic simulation**
   - Two-way coupled, one fluid-structure exchange per time step
   - Time step $\Delta \boldsymbol{t} = \mathbf{5.0E10^{-5}s}$ (both CFD and FEA solvers)→ resolve more than $10xf_{max}$ $(f_{max} = f_7 = 815Hz)$
   - Physical time $\boldsymbol{T} = \mathbf{0.5s}$ → sufficient to decay initial transients and resolve more than 20 cycles of the plate's fundamental frequency $f_1 = 241Hz$

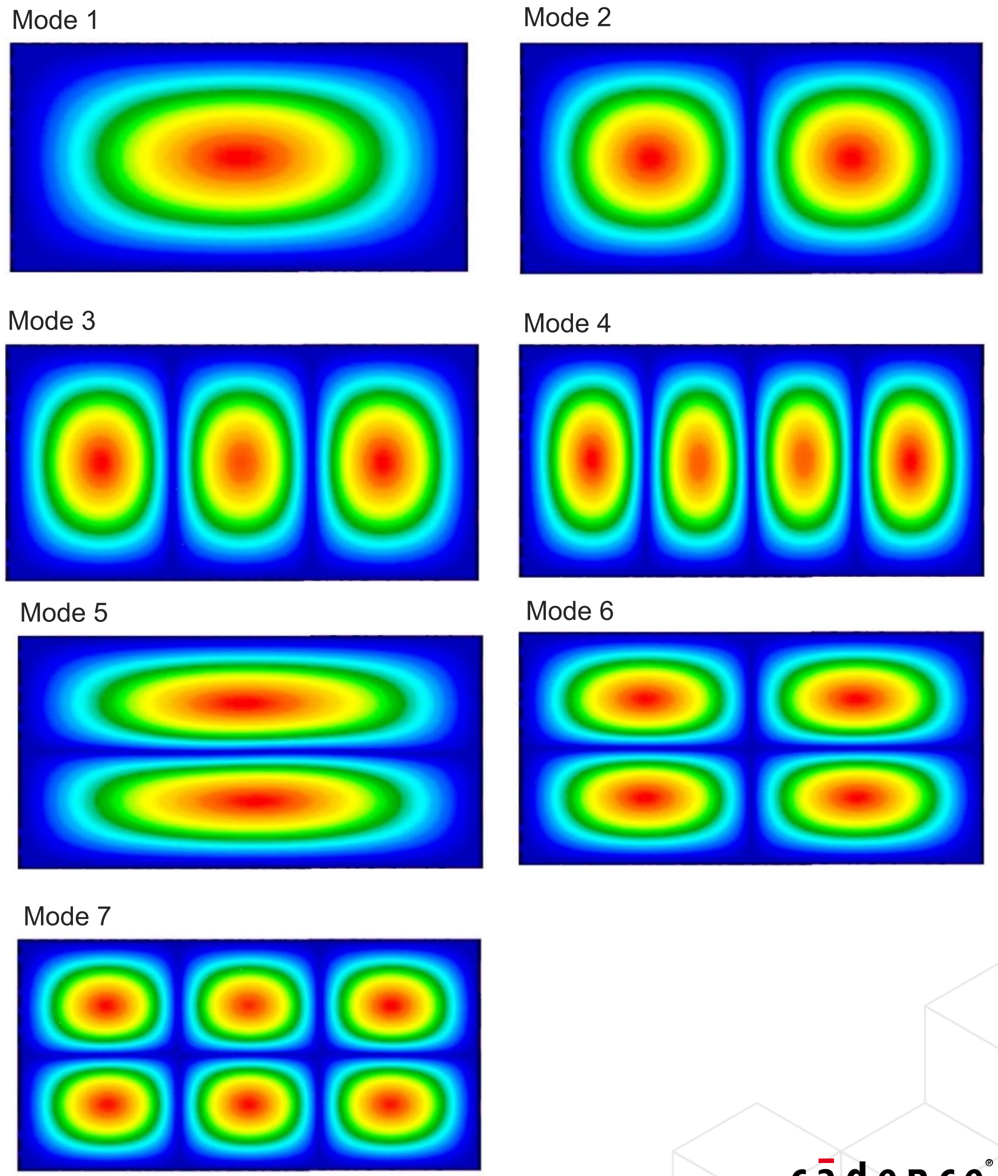


Free vibration analysis

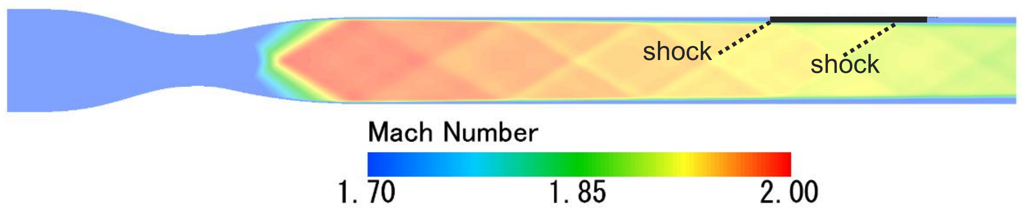
- Free vibration analysis of the plate was performed
- The free vibration frequencies are in good agreement with previous literature (Brower et al., 2021, Brower et al., 2023) and the reported experimental results from the workshop

Mode	$f_{Pre-test}(Hz)$	$f_{FEA}(Hz)$	**Diff. (%)**
(1,1)	242	241	0.41
(1,2)	302	312	3.31
(1,3)	418	438	4.78
(1,4)	593	620	4.55
(2,1)	618	627	1.46
(2,2)	679	696	2.50
(2,3)	771	815	5.71

FEA model

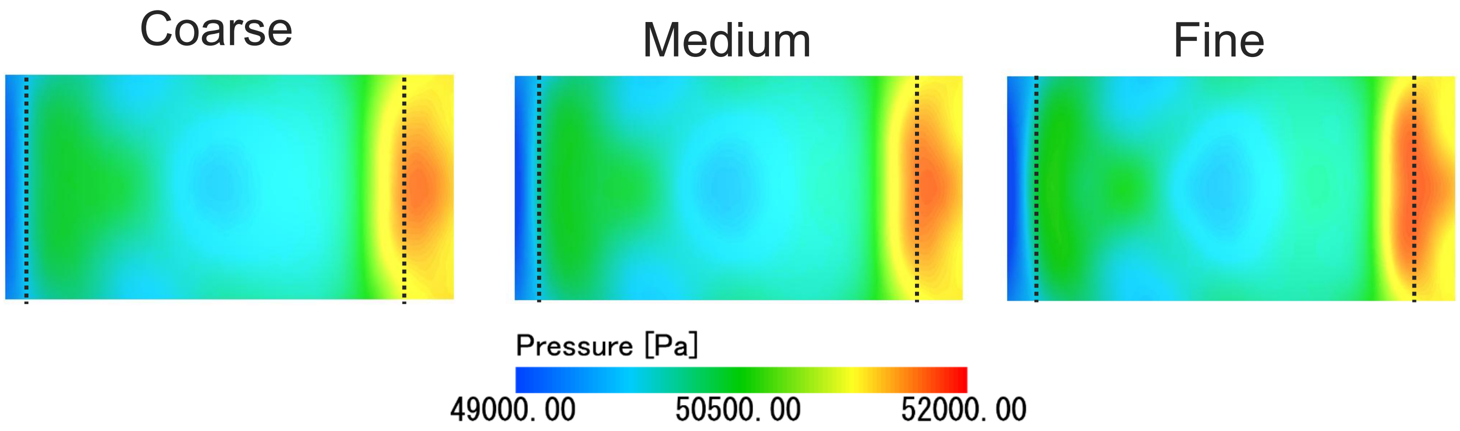


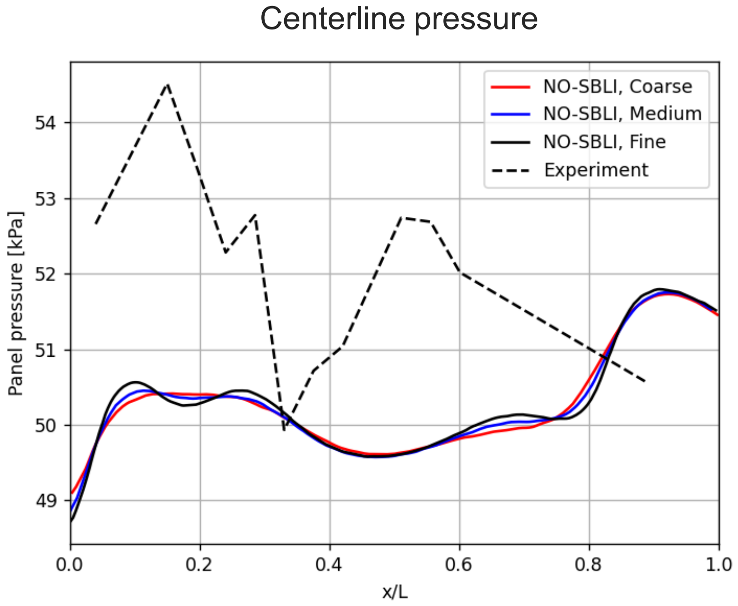
NO-SBLI mesh convergence study



Panel pressure

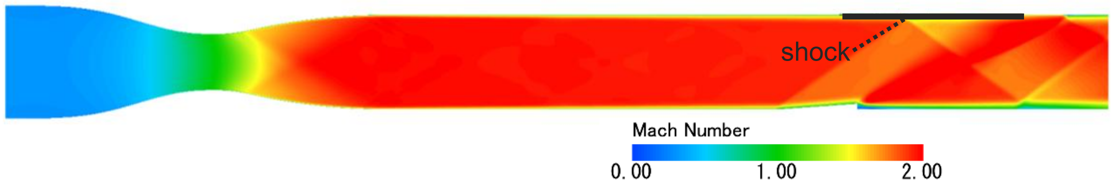
- Panel pressure is nearly identical across all meshes
- Two pressure peaks correspond to shock impingement locations
- Centerline profile shows systematic deviation from experiment
- This is likely due to shock-train accumulation effects (not mesh resolution)
- Unknown impact on aeroelastic response





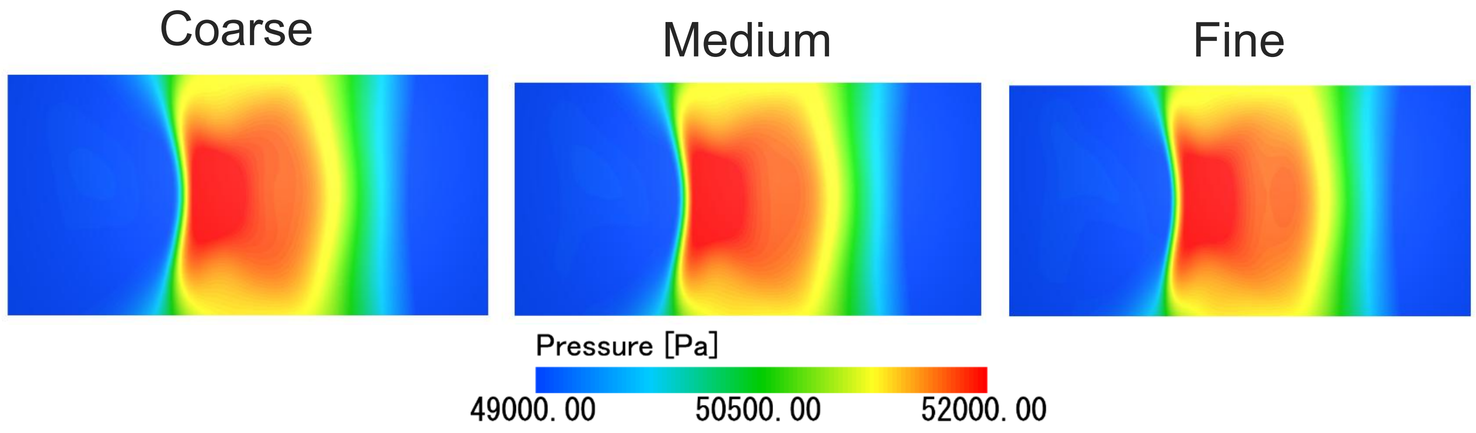
Mesh	Mesh count	Average panel pressure (kPa)
Coarse	7.29M	50.25
Medium	13.5M	50.25
Fine	27.1M	50.26

SBLI mesh convergence study

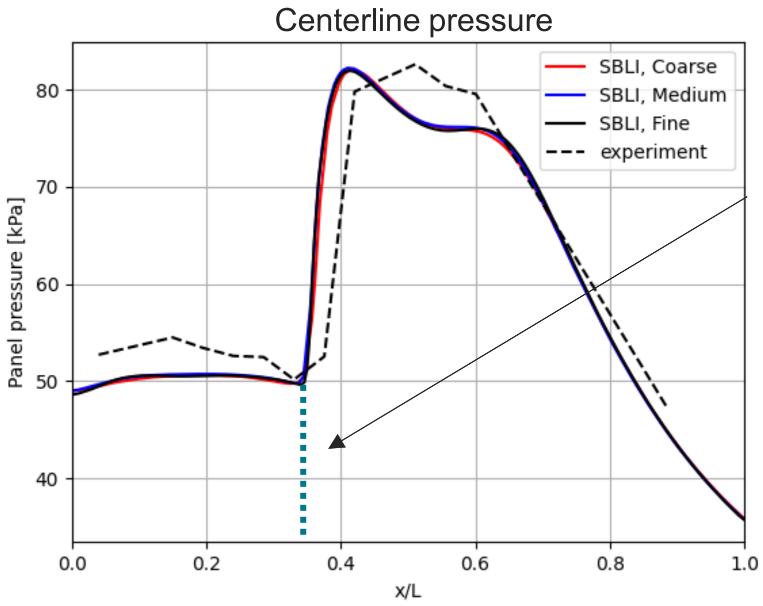


Panel pressure

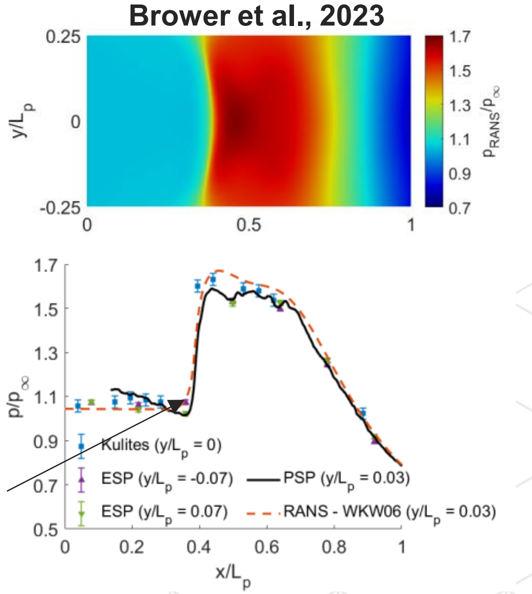
- The panel pressure for all meshes is effectively the same
- The shock impingement location remains unchanged
- Peak pressure level matches the experimental data well
- Overall pressure trends match prior work, but the shock induced pressure rise occurs upstream of the experimental location



Mesh	Mesh count	Average panel pressure (kPa)
Coarse	8.3M	58.69
Medium	14.0M	58.74
Fine	28.3M	58.83



Shock location at ~35% of the panel length



Shock location at ~40% of the panel length

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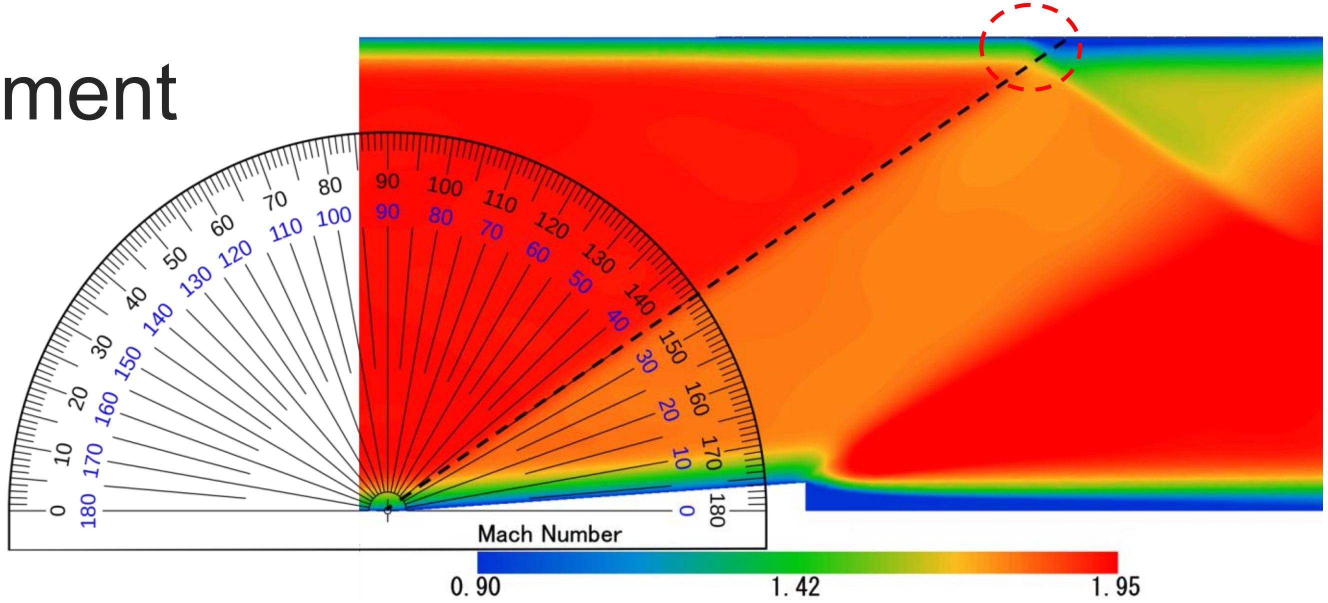
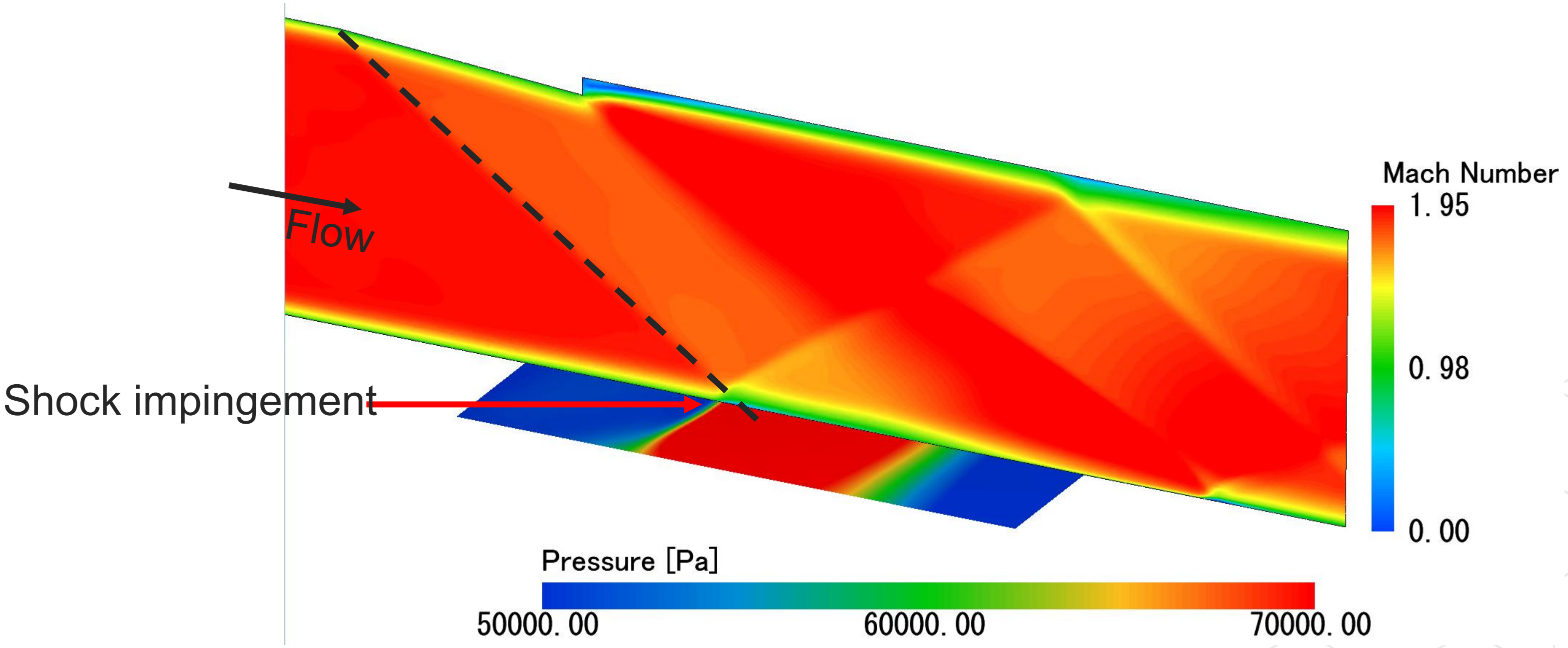
SBLI Shock Angle and Impingement Prediction

- Predicted shock angle (~35°) shows good agreement with experiment (35.7°)
- Simulated boundary layer is thicker than experiment
  - Shock interacts with the wall earlier
  - Upstream shift in impingement location
- Impact on aeroelastic response remains uncertain

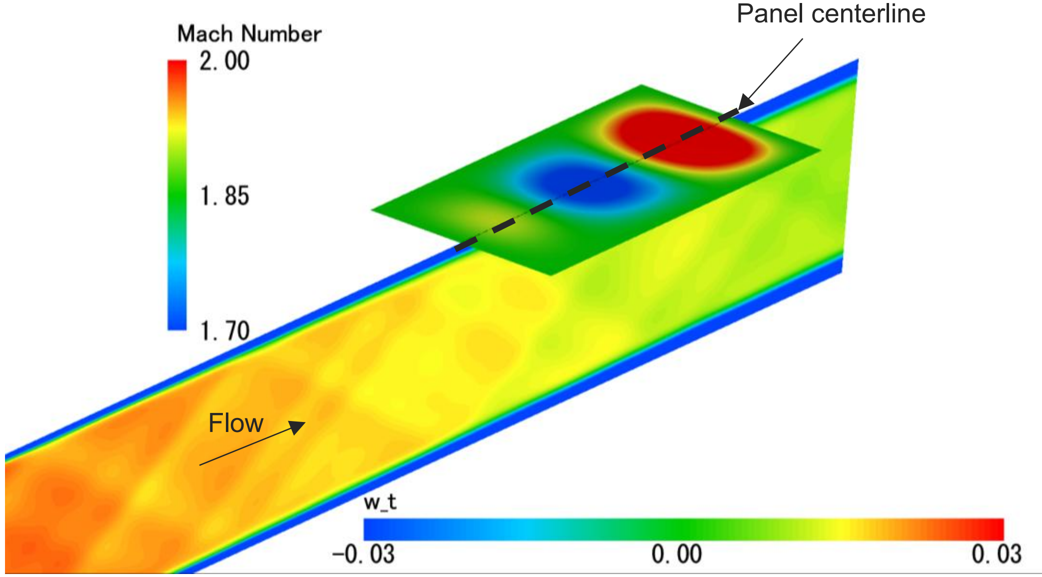


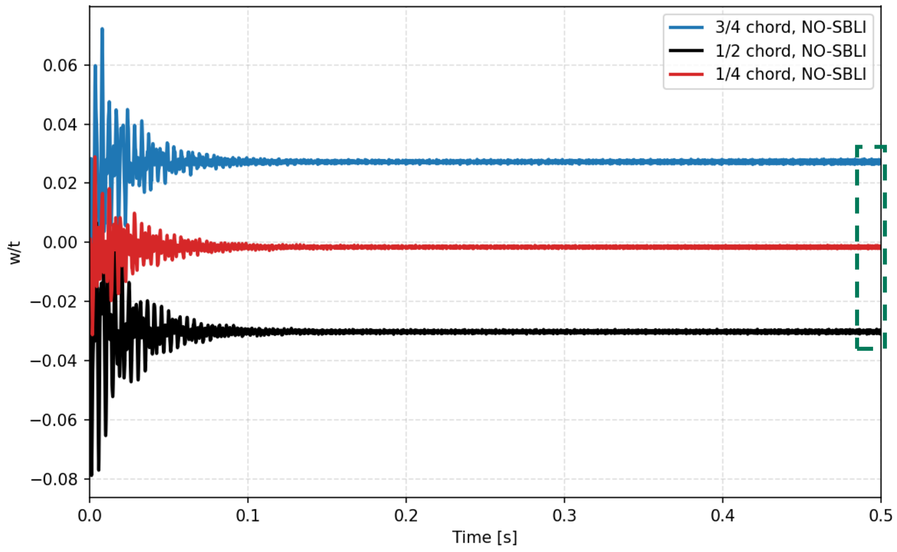


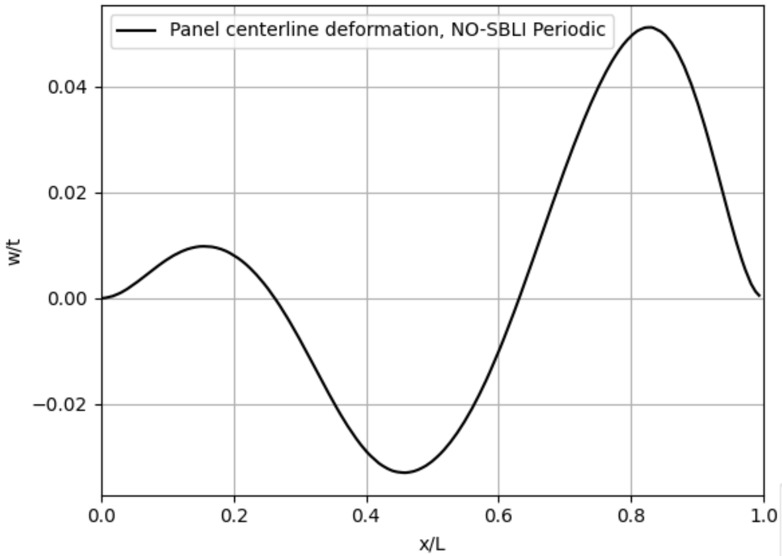
cadence

NO SBLI FSI - Periodic

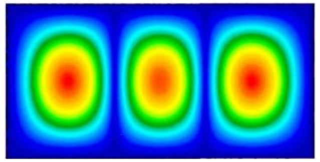
- These conditions should induce flutter and maintain periodic oscillation
- This response is triggered by the following cavity pressure and panel temperature
  - P_cavity = 50.4kPa
  - ΔT =13K
- Current results do not show a chaotic response. Instead, the deformation settles into a static deformation state
- Panel settles into mode 3 shape







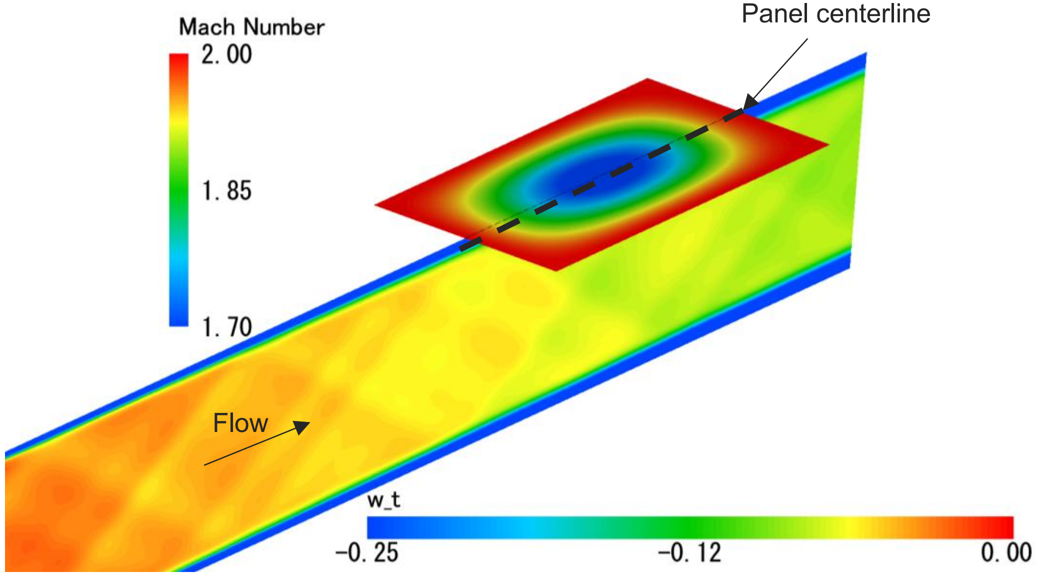
Mode 3

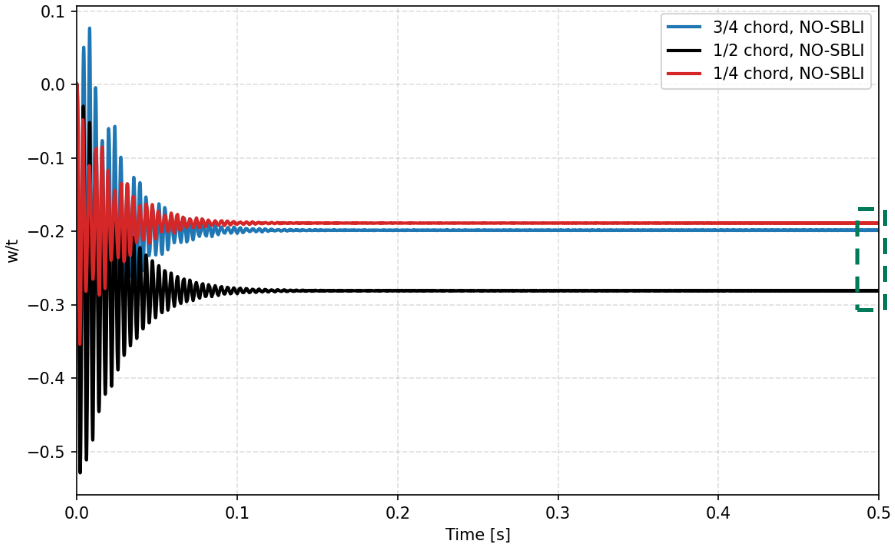


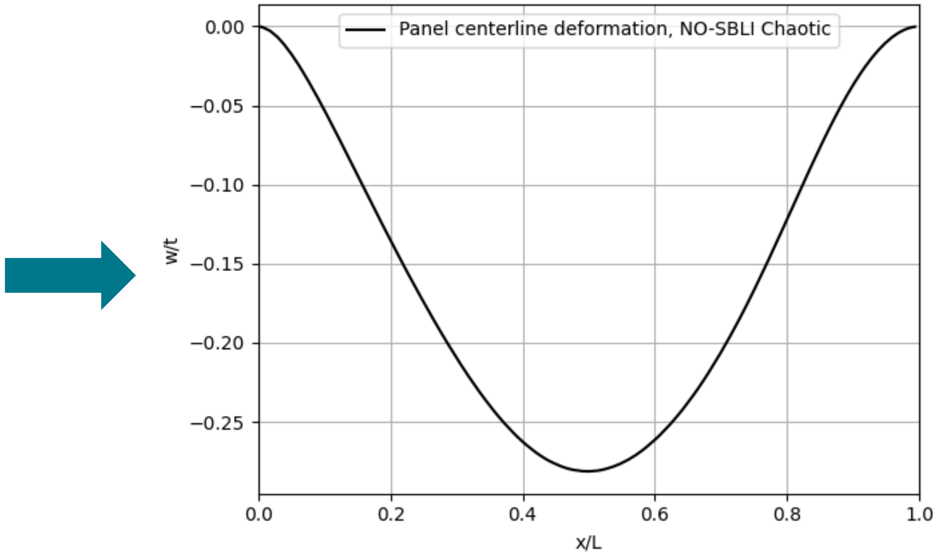
cadence

NO SBLI FSI - Chaotic

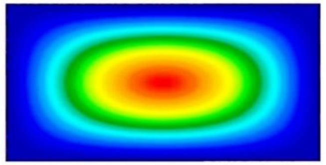
- This case refers to a chaotic panel response
- This response is triggered by varying the cavity pressure and panel temperature
  - P_cavity = 51.4kPa
  - $\Delta T = 15$K
- Current results do not show a chaotic response. Instead, the deformation settles into a static deformation state
- Panel settles into mode 1 shape







Mode 1



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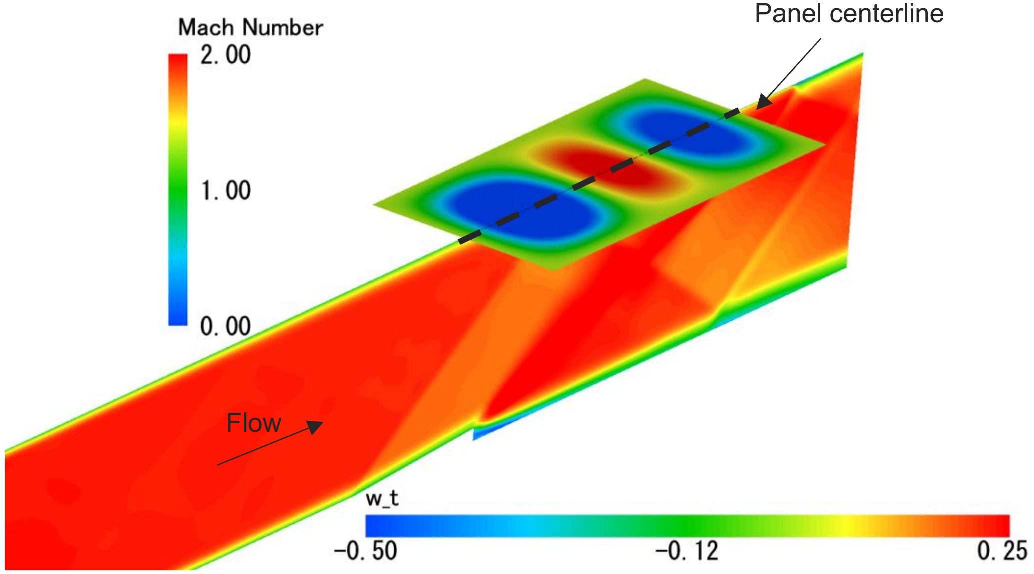
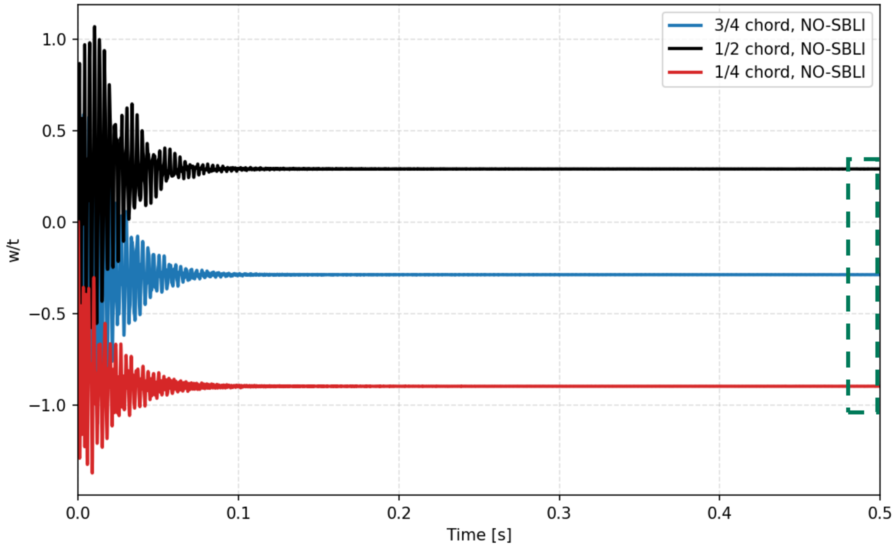
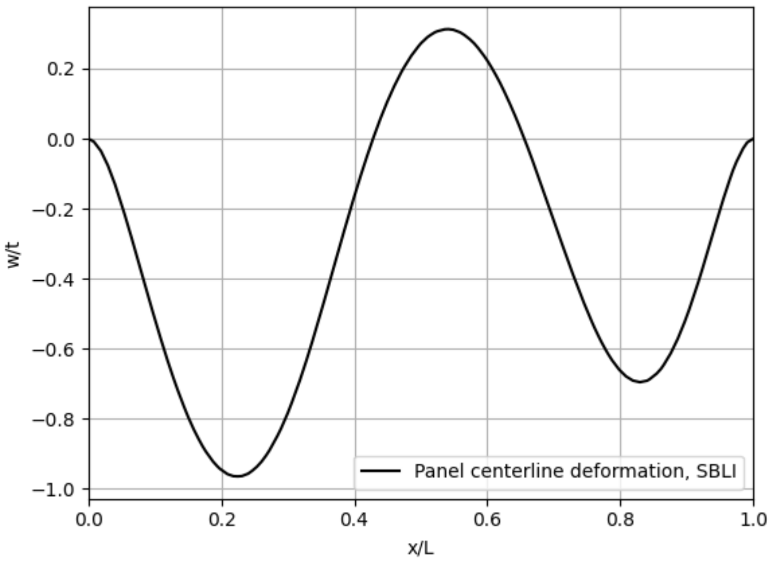
SBLI FSI

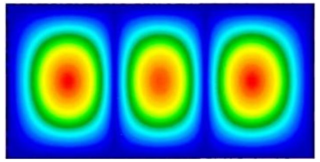
- This case expected to show a periodic flutter response
- This response is triggered by varying the cavity pressure and panel temperature
  - P_cavity = 68.9kPa
  - ΔT =13K
- Current results do not show flutter response. Instead, the deformation settles into a static deformation state
- Panel settles into mode 3 shape







Mode 3



Conclusions and next steps

- All cases (NO-SBLI and SBLI) did not exhibit the expected flutter, converging instead to a steady deformation state
- Mesh convergence studies indicate minimal sensitivity to grid resolution for pressure and boundary layer prediction
- Shock train structures in the nozzle introduce additional interactions, affecting BL growth and panel loading
- Lack of flutter likely due to combined effects of:
  - Constant and uniform cavity pressure
  - Constant and uniform thermal loading → does not generate sufficient pre-stress and must be revisited
  - Overpredicted panel stiffness / damping
- Next steps:
  - Refine structural model (stiffness, damping)
  - Improve thermal loading representation (non-uniform loading)
  - Evaluate test-section-only setup to remove nozzle-induced artifacts
  - Introduce dynamic cavity pressure modeling to capture feedback effects (Include the cavity in the CFD model)