Hypersonic Fluid-Structure Interactions on an inclined Clampled-Free-Campled-Free Compliant Panel

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Agenda

- Brief description of the CFCF FSI problem
- Methodology and assumptions
- Natural frequency correlation (FEM *vs* experiment)
- Thermal buckling analysis
- FSI response considering aerodynamic heating (for various ΔT)
  - $\alpha = 0^\circ$
  - $\alpha = 5^\circ$
  - $\alpha = 10^\circ$
- Future and ongoing studies

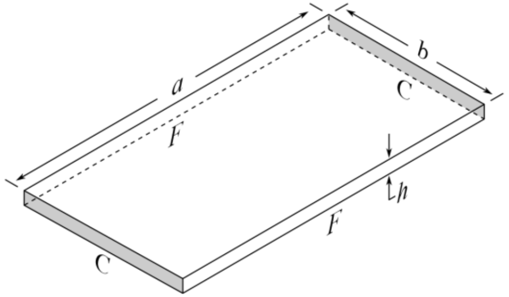
CFCF FSI case

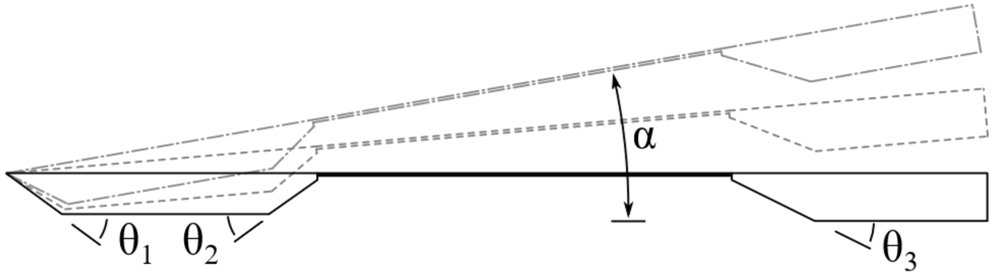
Without shock impingement

- TUSQ Mach 6 nozzle mean freestream conditions [1]:

Flow Parameter	Nominal Value
γ	1.4
M_∞	5.85
P_∞	747.1 Pa
T_∞	72.8 K
ρ_∞	0.0358 kg/m^3
Re_u	7.2505×10^6 / m

Table 1 TUSQ Mach 6 nozzle mean freestream conditions [10].





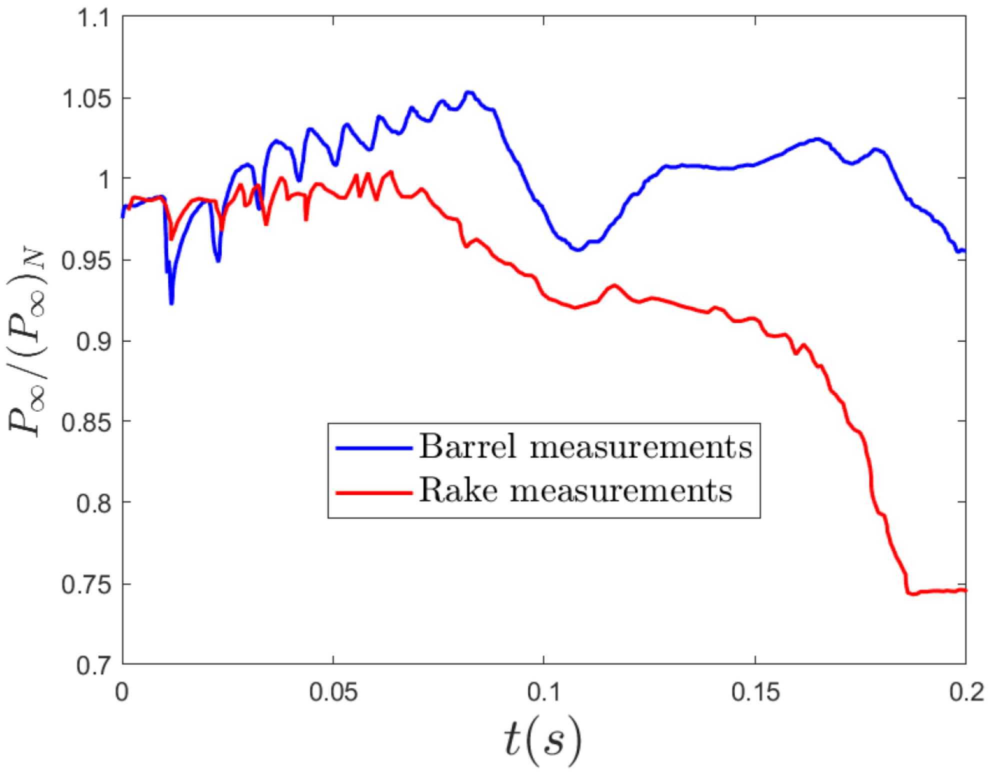
Geometry of the CFCF panel. Extracted from [2].

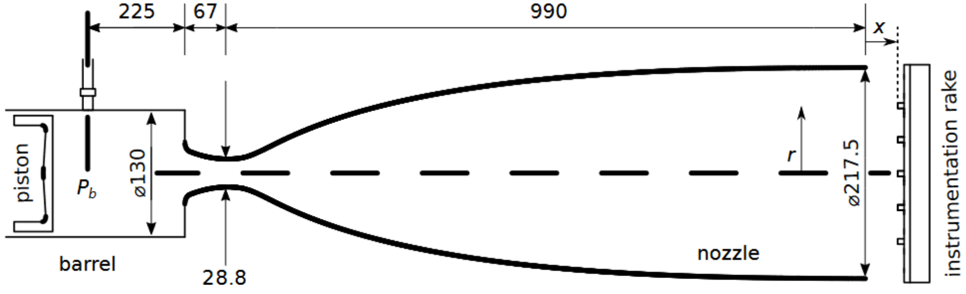
Geometric Property	Value
a	120 mm
b	60 mm
h	0.406mm and 0.813 mm
$\theta_1, \theta_2, \theta_3$	36.5°,35.5°, 26.6°
α	0°, 5°, 10°

[1] Vasconcelos, P. B. "**High-Speed Fluid-Structure Interactions on a Compliant Panel**," Ph.D. thesis, UNSW Sydney, 2023.

[2] Vasconcelos, P. B., McQuellin, L. P., Krishna, T., and Neely, A., "**Experimental study of hypersonic fluid-structure interactions on an inclined clamped-free-clamped-free compliant panel**," *ASCEND 2021*, 2021, p. 4232.

Wind tunnel pressure fluctuations

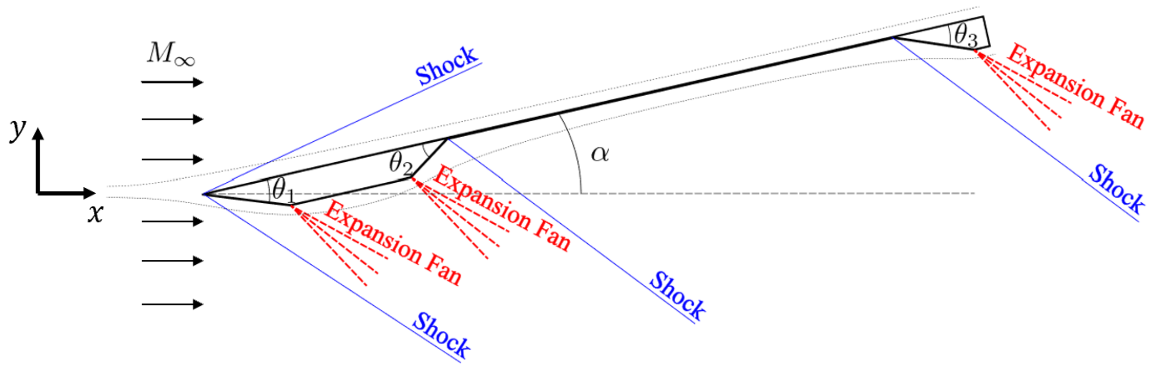




[3] Birch, B., Buttsworth, D., and Zander, F., "**Time-resolved stagnation temperature measurements in hypersonic flows using surface junction thermocouples**," *Experimental Thermal and Fluid Science*, Vol. 119, 2020, p. 110177.

Methodology and assumptions

- Aerodynamic model
  - Piston Theory
    - Inviscid and irrotational
    - Unable to model boundary layer, turbulence, and shocks
  - Shock-wave and expansion-wave relations from basic compressible flow
- Structural model
  - Mindlin Plate Theory combined with the Von Kármán nonlinear strain-displacement relations
- Aerodynamic heating
  - Lumped capacity model (only convection, disregard conduction)
  - Reference Temperature Method (Eckert)
  - Assuming laminar flow



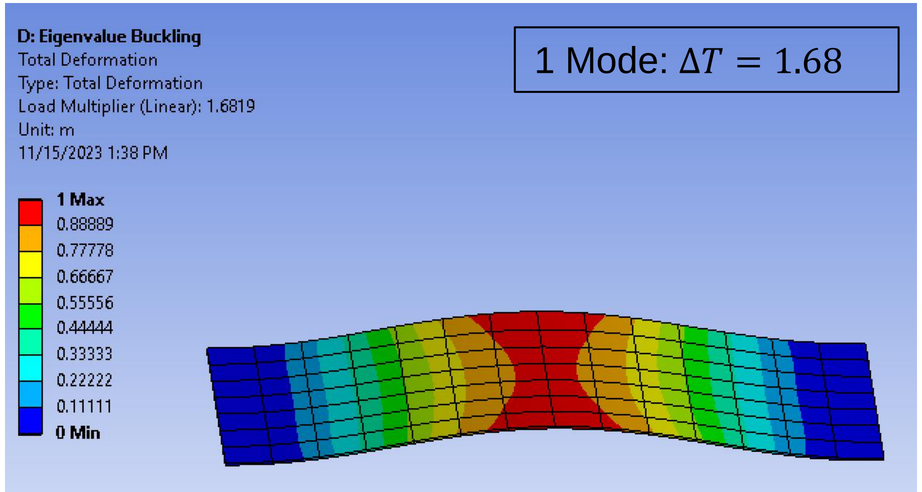
Natural frequencies of the panels

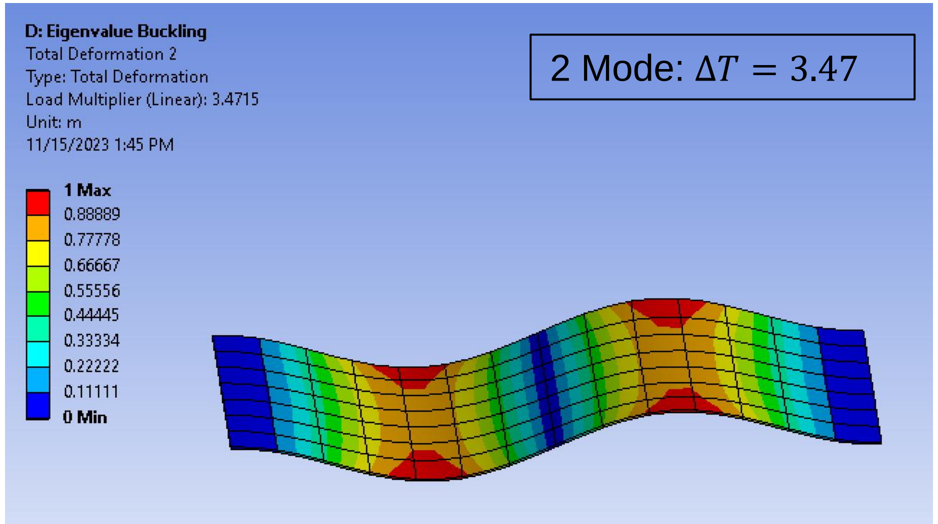
	Mode	Theory [10]	FEM [10]	Pre experiment	Post Experiment	Current FEM
h/a=0.0034	1^{st}	154	150	153	155	152.2
	2^{nd}	247	242	-	-	245.1
	3^{rd}	423	413	-	-	423.8
h/a = 0.0068	1^{st}	307	304	260	260	304.7
	2^{nd}	493	493	-	-	489.7
	3^{rd}	845	837	-	-	847.9

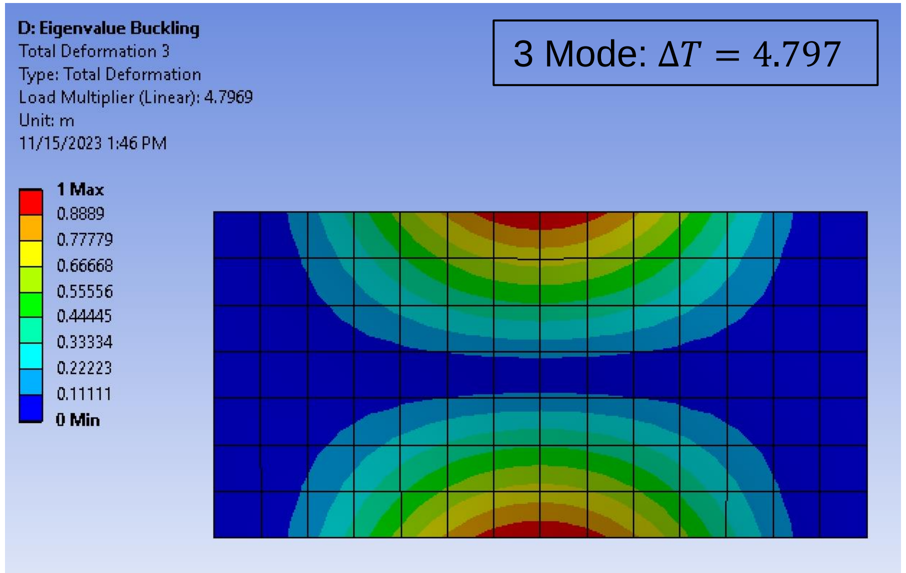
Table 3 Natural frequencies (in Hz) of the thinner and thicker panels. Comparison between the present model and [10].

Thermal buckling analysis

The thin ($h = 0.406mm$) panel will buckle for $\Delta T \geq 1.68$







$\alpha = 0^{\circ}$

$\alpha = 5^{\circ}$

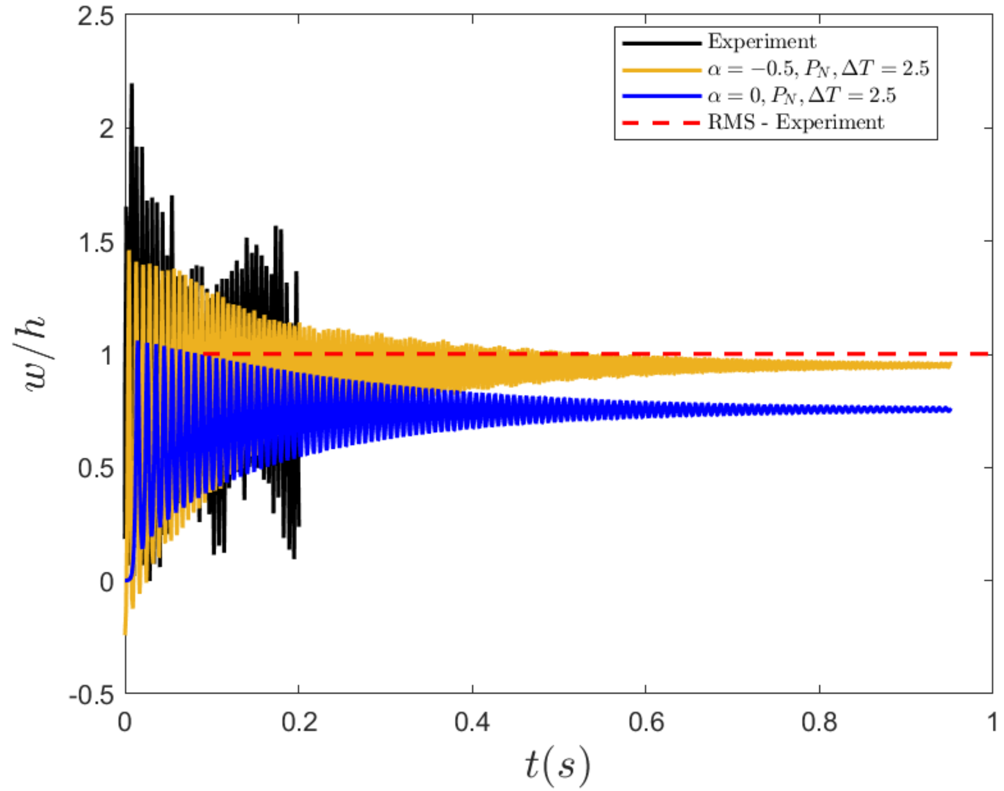
$\alpha = 10$

FSI response considering the aerodynamic heating

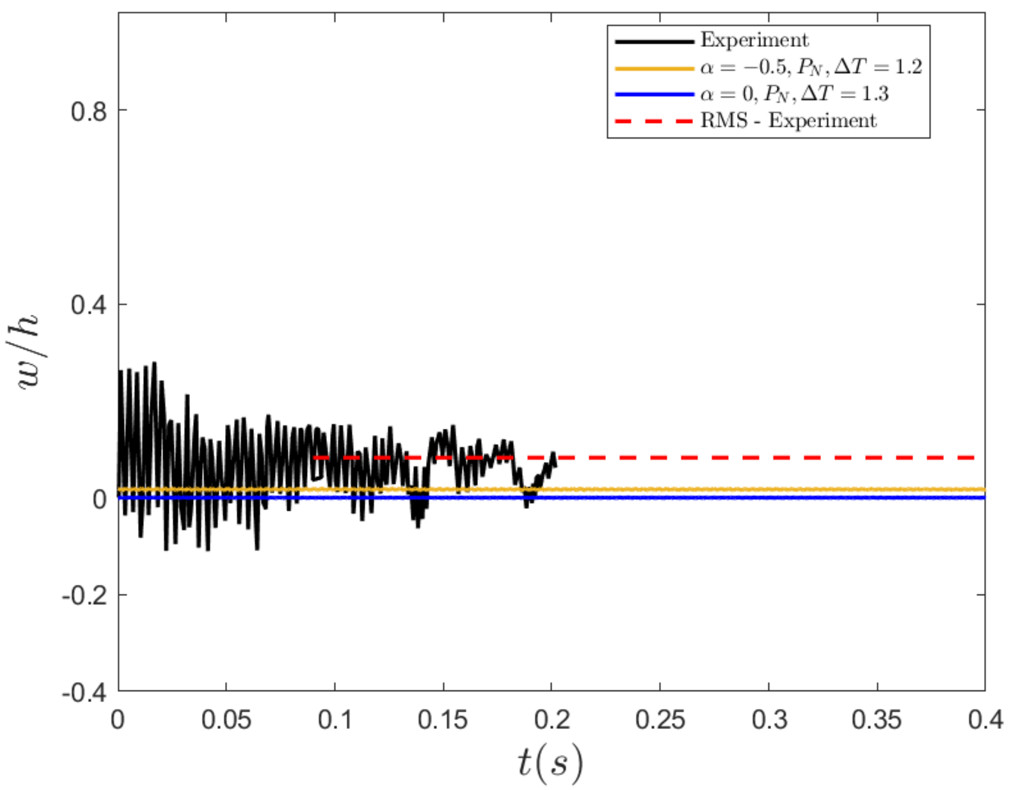
ΔT increase due to convection

	$h/a = 0.0034$	$h/a = 0.0068$
P_N	2.41	1.15
P_B	2.42	1.16
P_R	1.94	0.93

$h = 0.406mm$



$h = 0.813mm$



$\alpha = 0^{\circ}$

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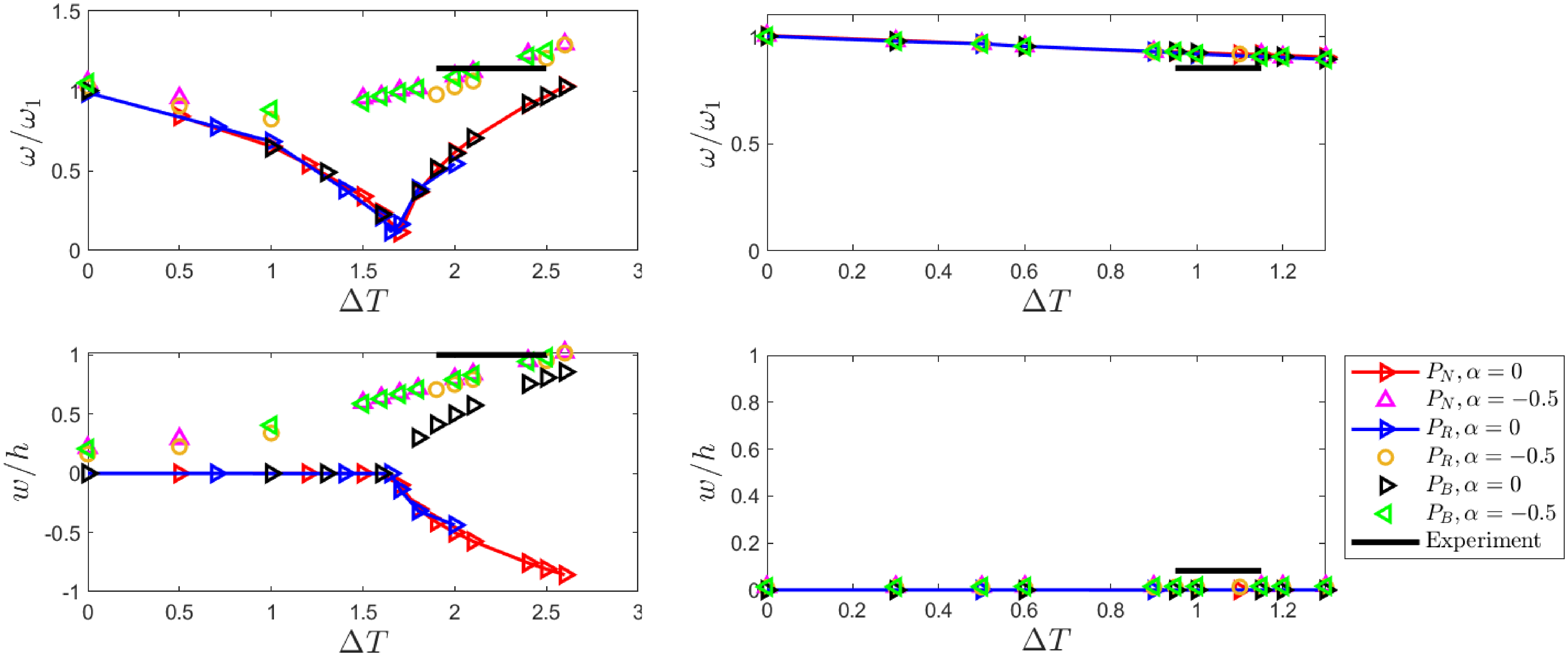
Frequency and displacement for various ΔT

$h = 0.406mm$ $h = 0.813mm$



ω_1 is the first natural frequency of the panel from the FEM simulation

$\alpha = 0^{\circ}$

$\alpha = 5^{\circ}$

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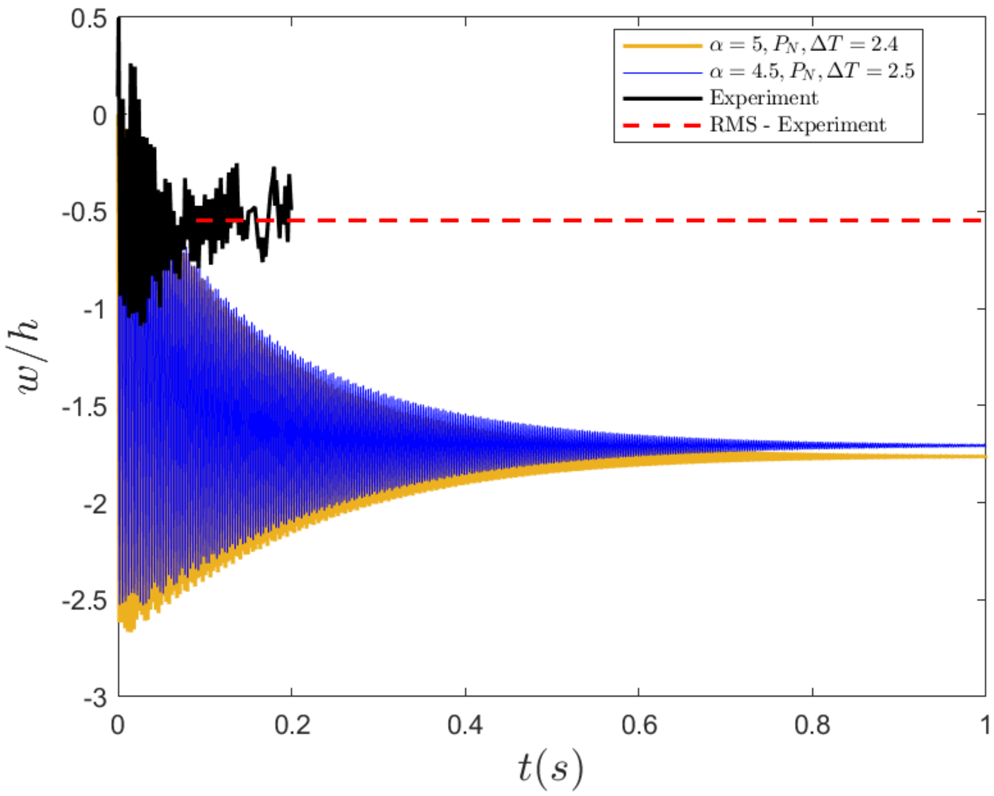

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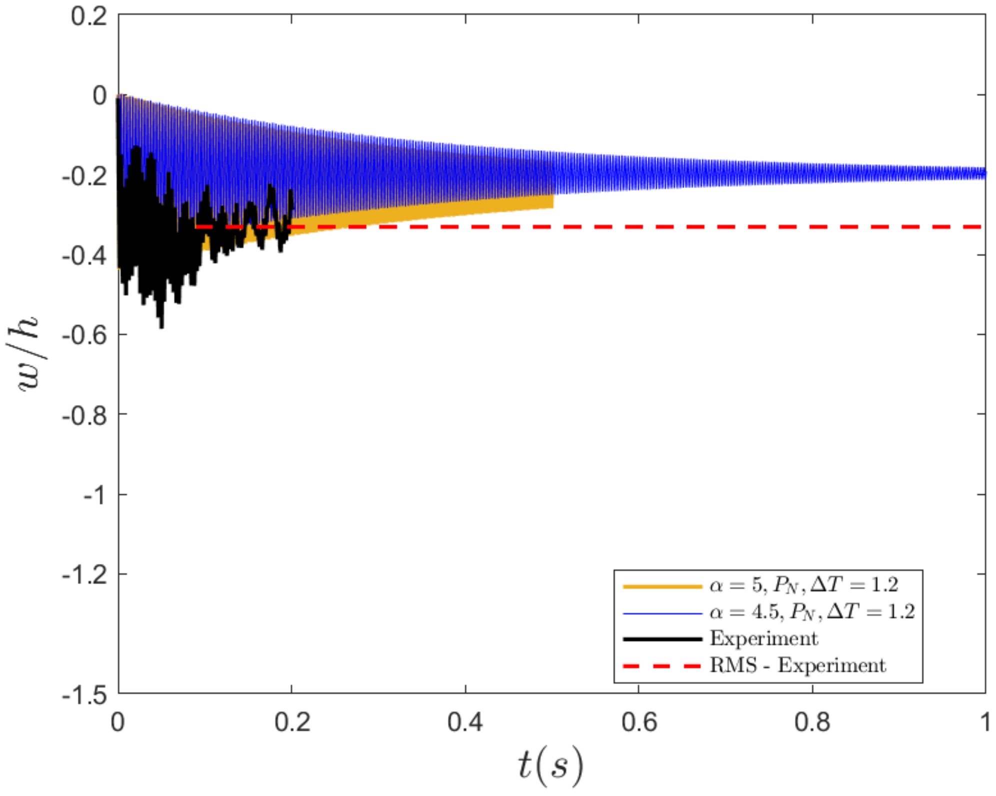

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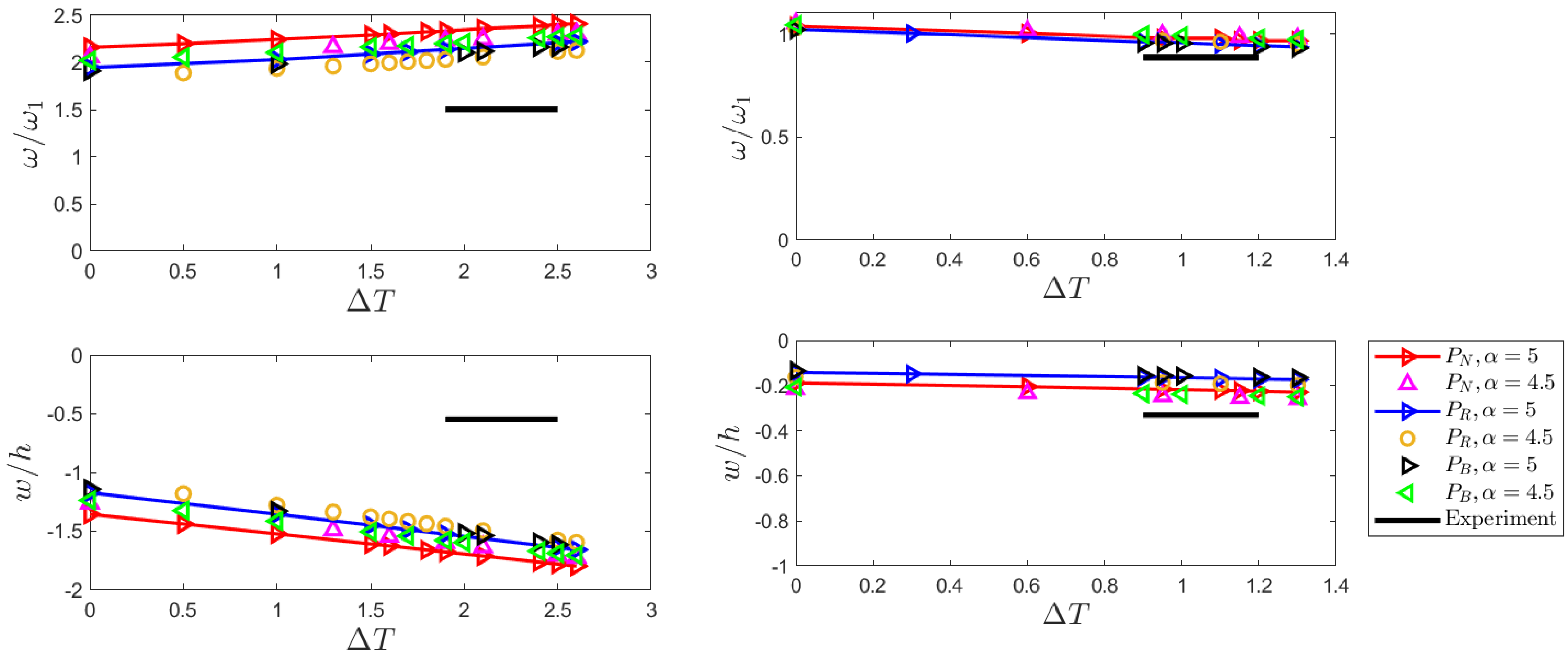

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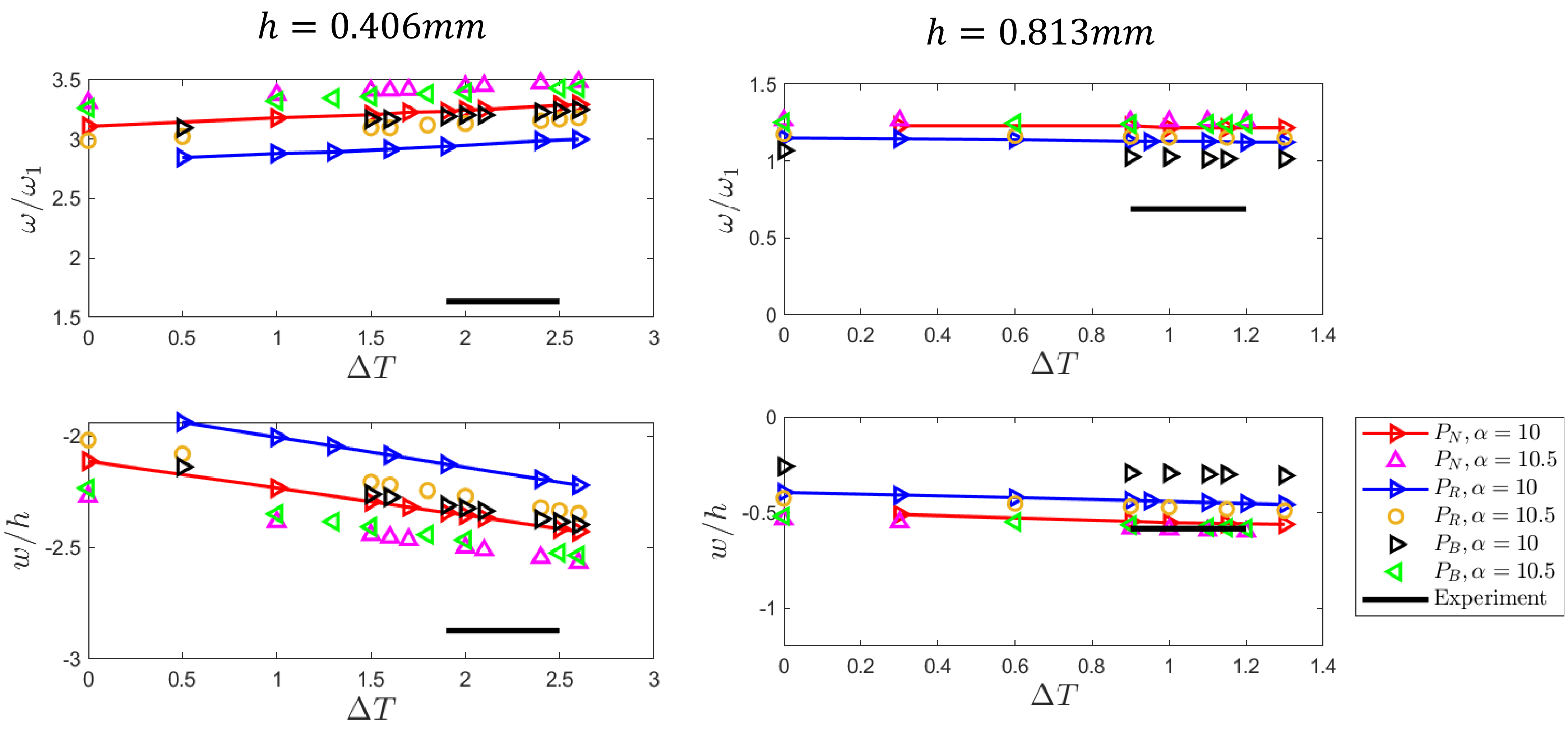
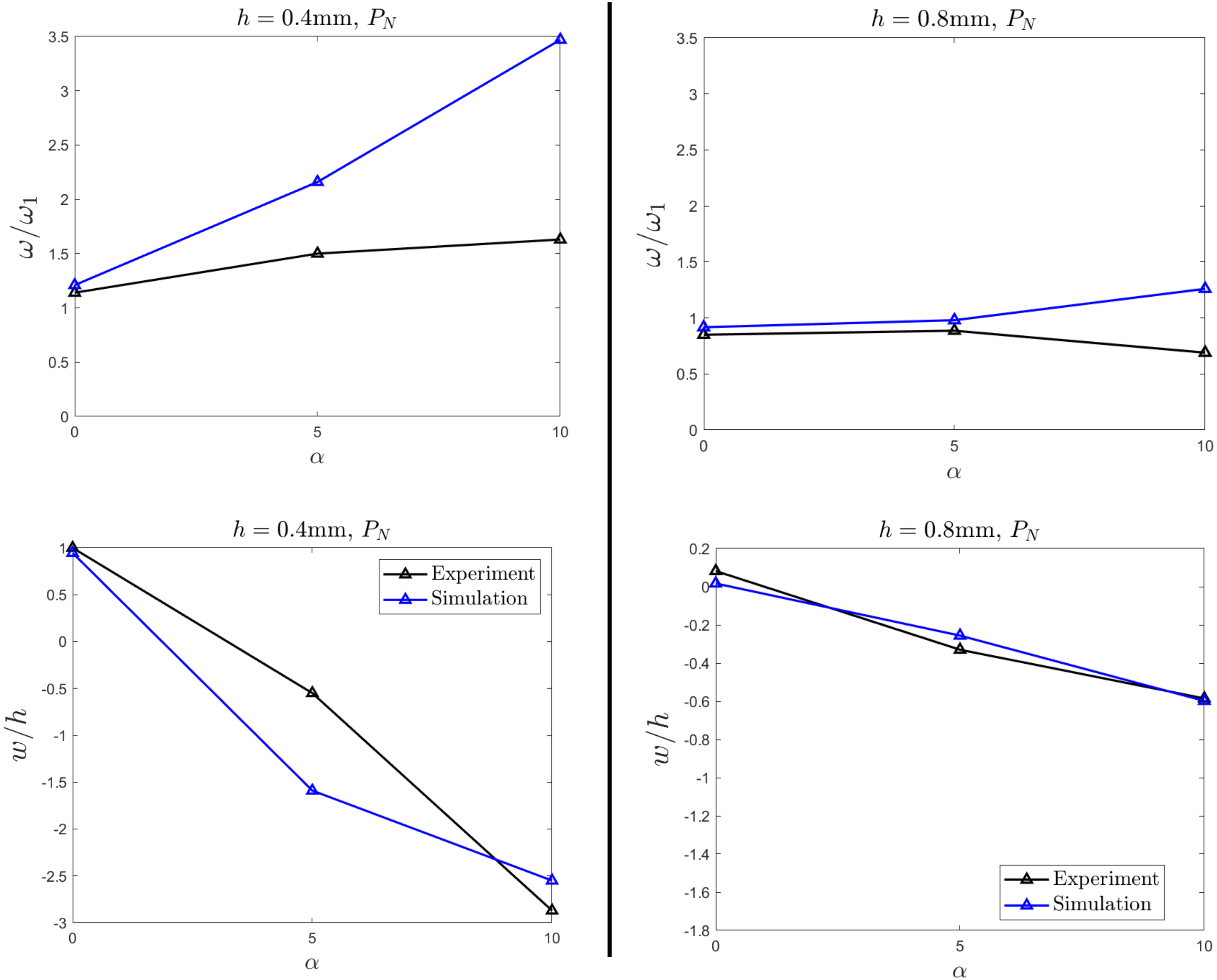
Frequency and displacement for various ΔT



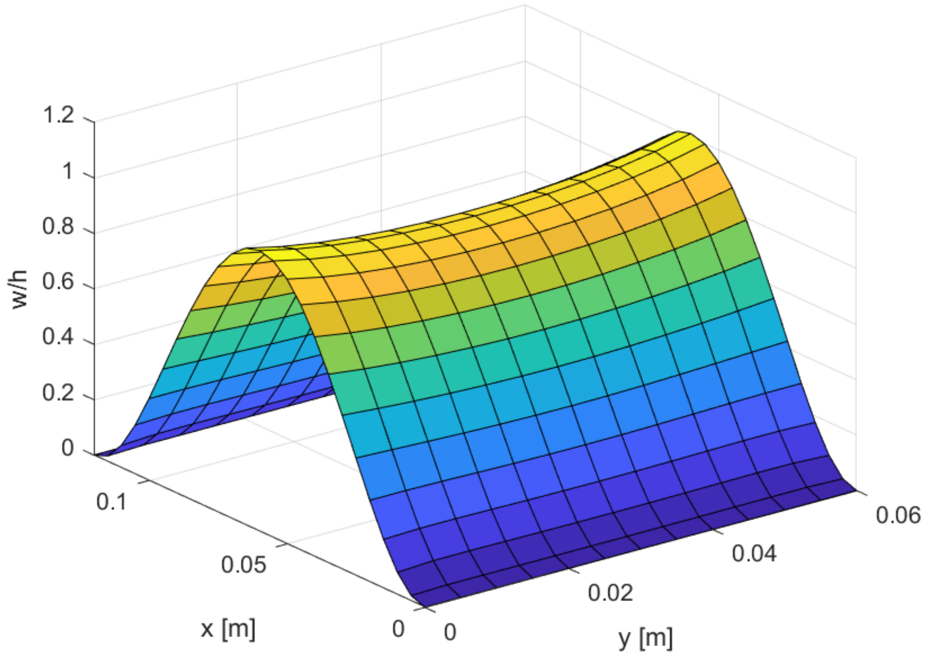
Summary (trends)



RSM values of the experiment and $\Delta T \sim 2.4$ *and* 1.2 for the thin and thick panel simulations, respectively.

Experimental data needed for correlation with computational simulations

- Pressure field
- Displacement field of the panel
  - One point is not sufficient to correlate the oscillation pattern
- Temperature distribution
  - Capture temperature increase due to convection
- Identification of the transition point
  - Where the flow transitions from laminar to turbulent



Static displacements due to static uniform load

Future and ongoing studies

Ongoing:

CFD simulations to capture the shocks, boundary layer and flow separation

- Code validation for hypersonics – comparison with DNS and experimental data (shock impingement case)
- 2D analysis for the CFCF rigid panel to characterize the flow behavior and aerodynamic heating

Future:

Aerodynamic model

Reduced Order Model (ROM) based on CFD data

Start with Euler solutions

NS solution

Maybe few LES simulations for comparison

Structural model

Mindlin Plate Theory combined with the Von Kármán nonlinear strain-displacement relations

Aerodynamic heating

POD?

Falkiewicz, Nathan J., and Carlos ES Cesnik. "Proper orthogonal decomposition for reduced-order thermal solution in hypersonic aerothermoelastic simulations." *AIAA journal* 49.5 (2011): 994-1009

THANK YOU!

Questions or suggestions?