RC-19 COMPLIANT PANEL ANALYSIS

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Aeroelasticity
LAB

GOALS

- Develop computational aerothermoelasticity simulation capabilities
  - Implement nonlinear structural model (Freydin and Dowell, 2021)
  - PT / NS CFD-based aerodynamics
- Verification through simulation of LCO conditions

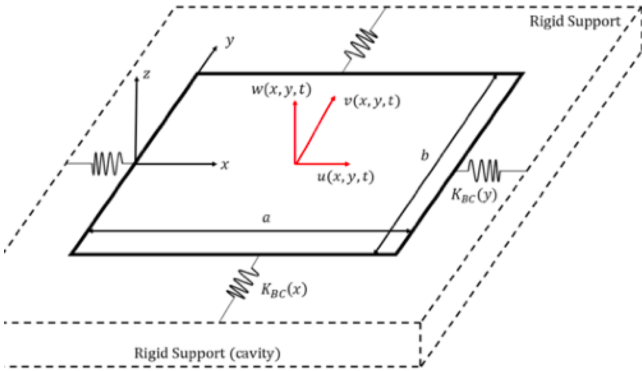
ATE MODEL - FREYDIN AND DOWELL 2021

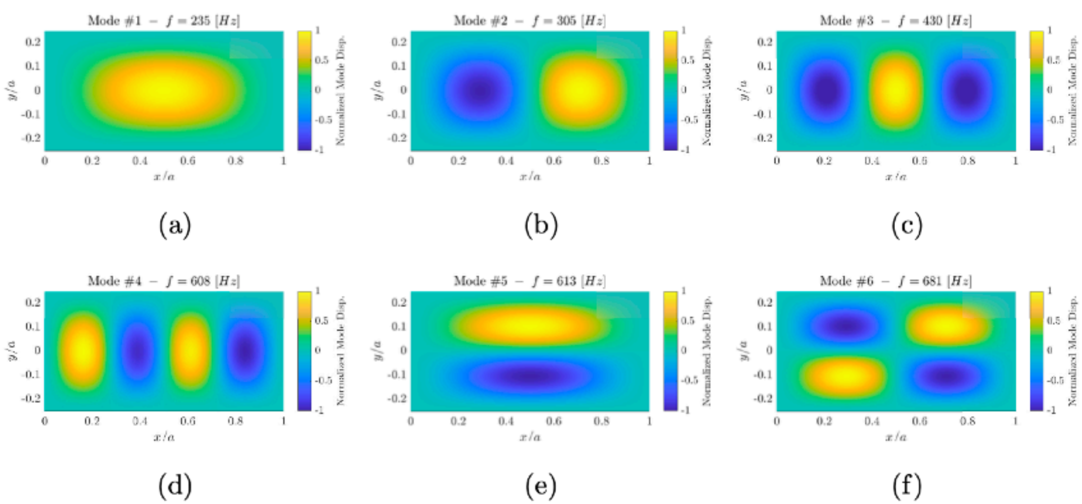
- Modal expansion

$$w = \sum_{i}^{N_w} w_i(t)\psi_i^w(x,y)$$

$$u = u_R(t)\psi_R^u(x,y) + \sum_{i}^{N_u} u_i(t)\psi_i^u(x,y)$$

$$v = v_R(t)\psi_R^v(x,y) + \sum_{i}^{N_v} v_i(t)\psi_i^v(x,y)$$





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ATE MODEL - FREYDIN AND DOWELL 2021

$$M_{nk}\ddot{w}_k + \bar{C}_{nk}\dot{w}_k + \left(G^{(1)}_{nk} - G^{Th}_{nk}\right) w_k$$

$$+ D^{(1)}_{nkrs} w_k w_r w_s + u_r E^{(1)}_{nkr} w_k + v_r F^{(1)}_{nkr} w_k = Q_n$$

$$M^u_{nk}\ddot{u}_k + (A_{nk} + K^u_{nk})\, u_k + C_{nk} v_k = -E_{ikn} w_i w_k + A^{Th}_n$$

$$M^v_{nk}\ddot{v}_k + (B_{nk} + K^v_{nk})\, v_k + C_{in} u_i = -F_{ikn} w_i w_k + B^{Th}_n$$

$$M^u_{Rk}\ddot{u}_k + M^v_{Rk}\ddot{v}_k + (A_{RK} + K^u_{Rk} + C_k R)\, u_k +$$

$$(B_{RK} + K^v_{Rk} + C_{Rk})\, v_k = -\left(E_{ikR} + F_{ikR}\right) w_i w_k + A^{Th}_R + B^{Th}_R$$

ATE MODEL - FREYDIN AND DOWELL 2021

- Generalized force due to
  - PT - pressure variation on the panel due to the panel's motion

$$\Delta p_{PT} = p(x,y,t) - p_\infty = \gamma p_\infty \left(\frac{v_n}{a_\infty}\right) = \frac{\rho_\infty U_\infty}{M_\infty}\left(\frac{\partial w}{\partial t} + U_\infty \frac{\partial w}{\partial x}\right)$$

$$\Delta p_{PT} = \frac{\rho_\infty U_\infty}{M_\infty}\left[\sum_k^{N_w} \frac{\partial w_k(t)}{\partial t}\psi_k^w(x,y) + U_\infty \sum_k^{N_w} w_k(t)\frac{\partial \psi_k^w(x,y)}{\partial x}\right]$$

  - Static pressure difference. Independent of the panel's motion

$$\Delta p_s(x,y) = p_s(x,y) - p_c$$

$$Q_n = \underbrace{A_{\dot{w}_{nk}}\dot{w}_k(t) + A_{w_{nk}} w_k(t)}_{Q_n^{PT}} + \underbrace{\left[\iint \Delta p_s(x,y)\psi_n^w(x,y)dxdy\right]}_{Q_n^s}$$

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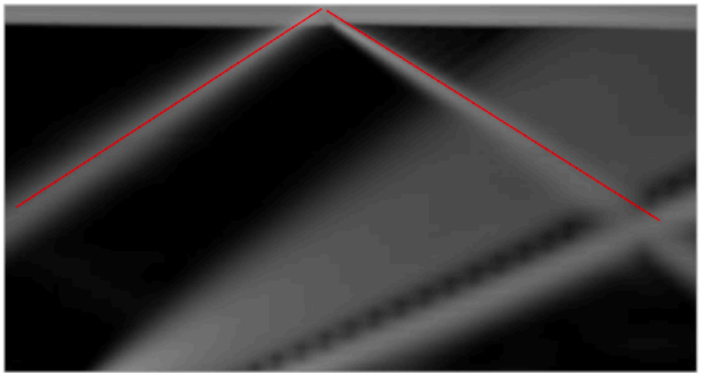
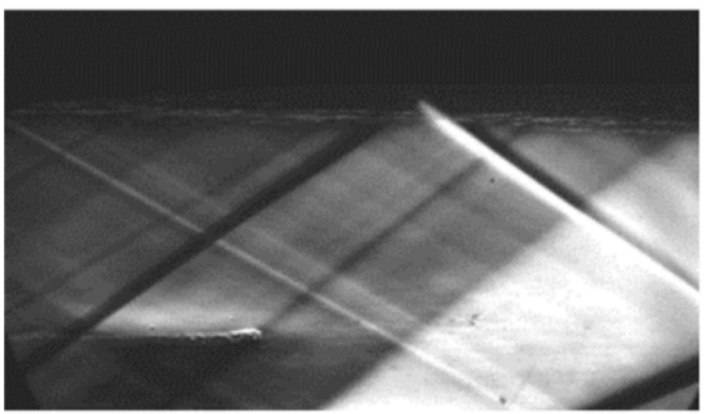
RIGID SIMULATION (CFD)

- Simulations at 0, 4, and 12 degrees shock-generator (wedge) angle
- Compared results to experimental (Schlieren images) and computational data (Brouwer et al. 2021) available
- Explored:
  - Mesh resolution
  - Turbulence modeling

FLOW AT 4 AND 12 DEG. SHOCK GENERATOR CASES

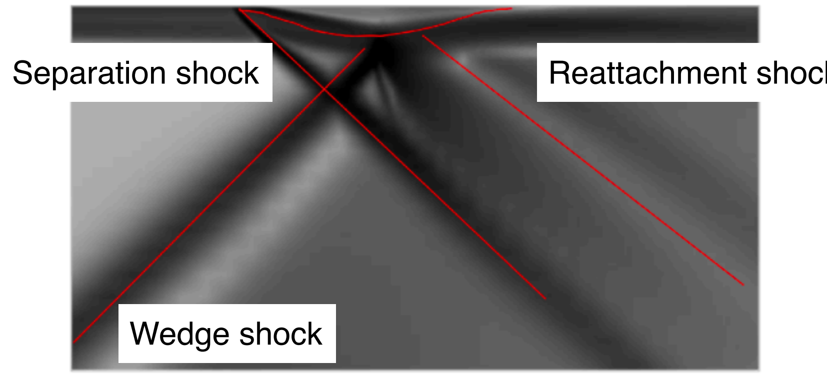


(a) Numerical

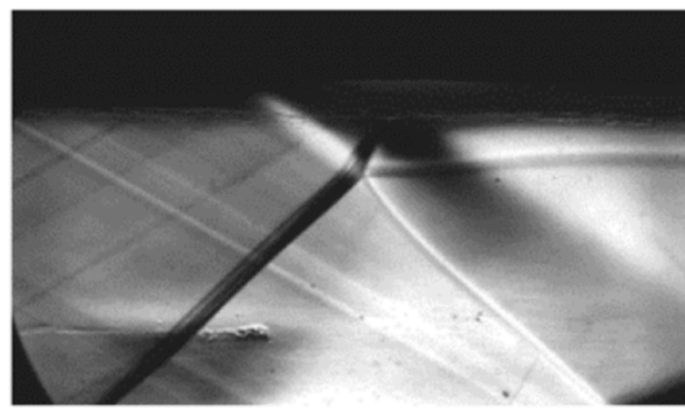


(b) Experimental (adapted from Brouwer et al. [2])

4 deg.



(a) Numerical

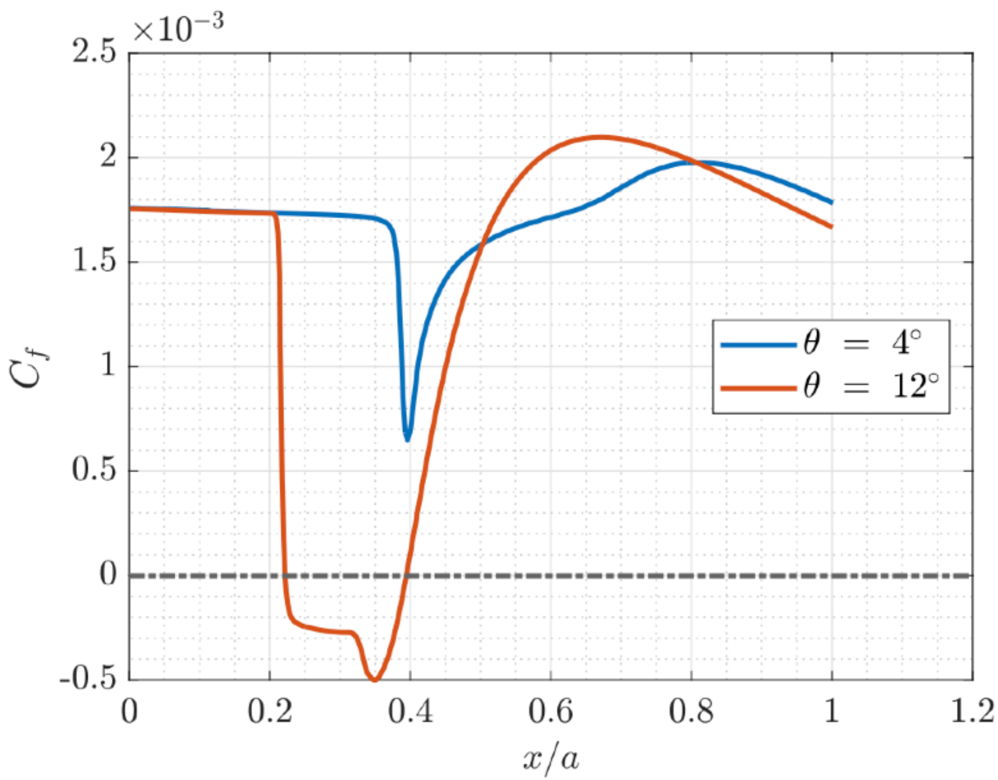


(b) Experimental (adapted from Brouwer et al. [2])

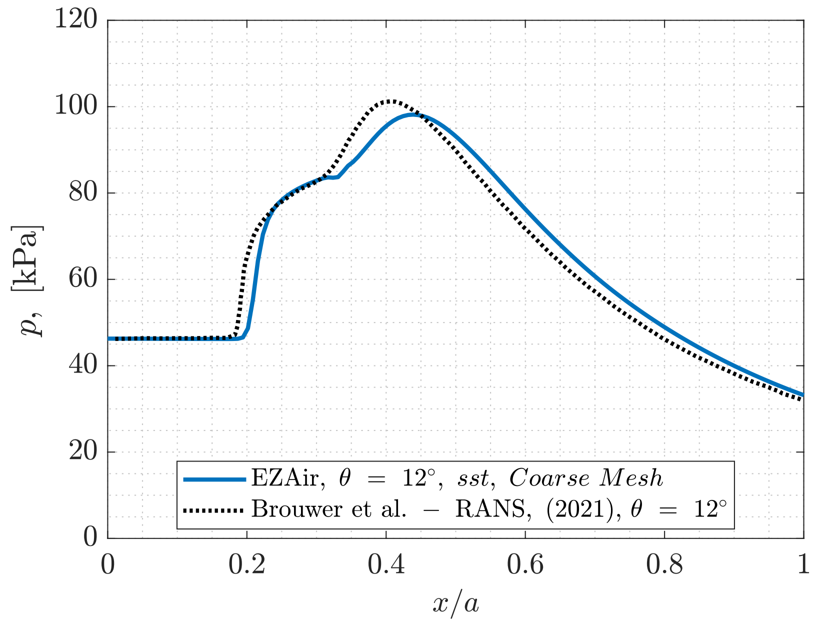
12 deg.

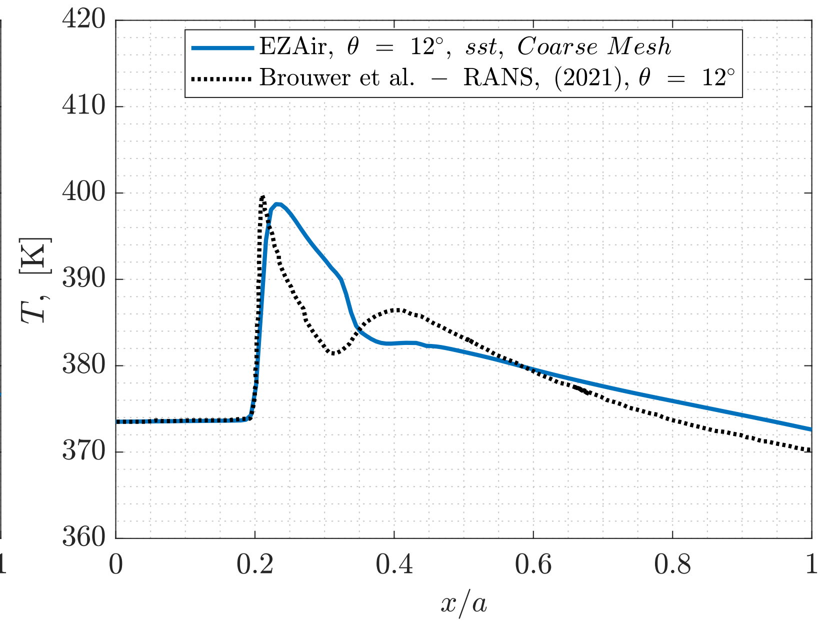
FLOW AT 4 AND 12 DEG. SHOCK GENERATOR - FRICTION COEFF.

- Shock location and separation extent similar to Brouwer et al. 2020



VALIDATION, 12 DEG WEDGE





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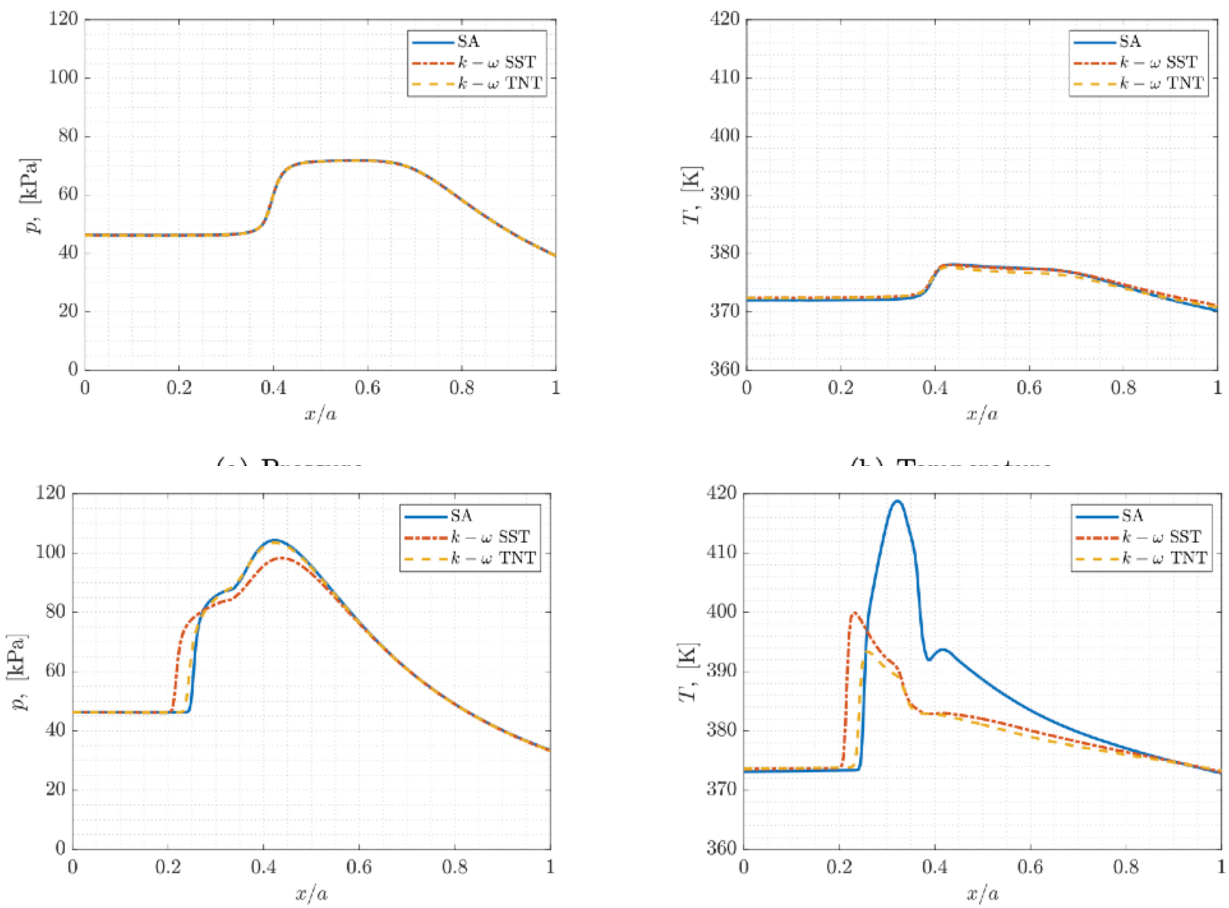
TURBULENCE MODEL

4 deg.

12 deg.



(a) Pressure

(b) Temperature

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AEROELASTIC SIMULATION

- Matlab simulation of the nonlinear plate model with PT aerodynamics
- For 0 deg shock-generator angle, investigate the effects of
  - Temperature (constant temp. difference between the panel and frame)
  - Pressure difference (constant static pressure difference between the pressurized cavity and the exposed panel surface)
  - BC stiffness parameter

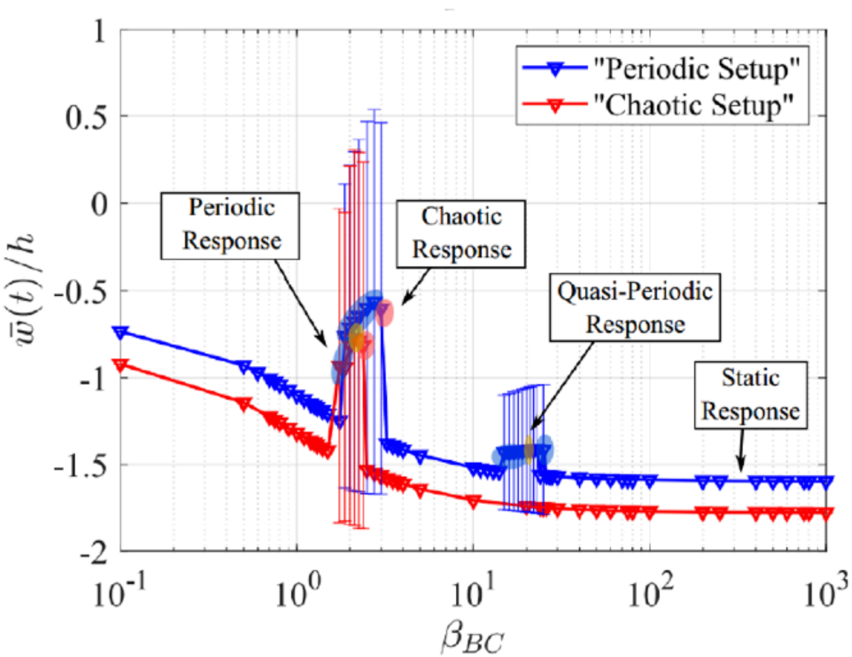
Designation	Δp_s [kPa]	ΔT [K]
Setup A ("Periodic")	- 3.91	12.8
Setup B ("Chaotic")	- 5.01	14.7

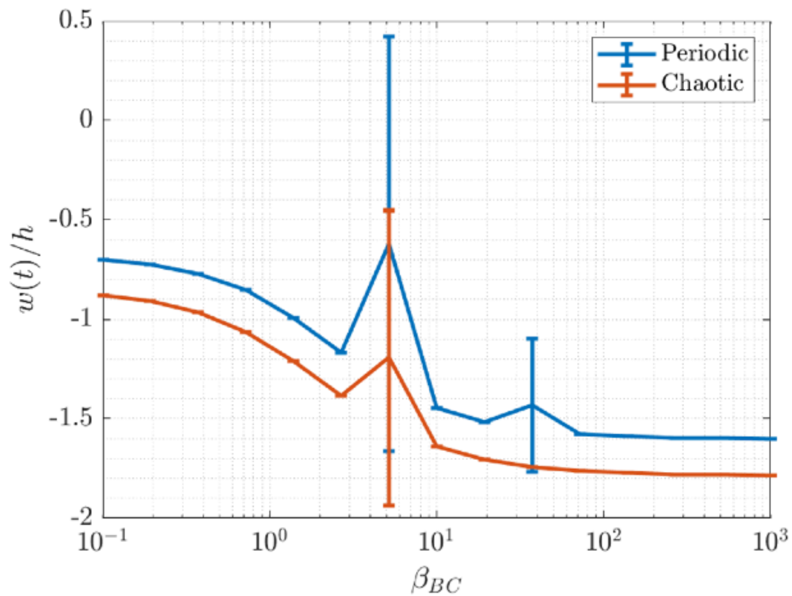
VALIDATION - SERAFIM ET AL. 2023

β_{BC} effect

1. No structural damping added
2. No modes calibration

Periodic Parameters		Chaotic Parameters	
Δp (kPa)	3.91	Δp (kPa)	5.01
ΔT (K)	12.8	ΔT (K)	14.7





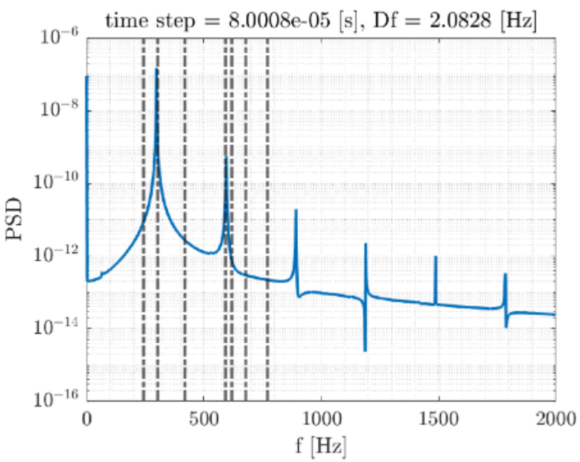
1. Trends captured well (given the sparse sampling of β_{BC})
2. Actual values (specifically, $\overline{w}$ for chaotic setup) are mis-predicted; could be result of damping, calibration, etc…

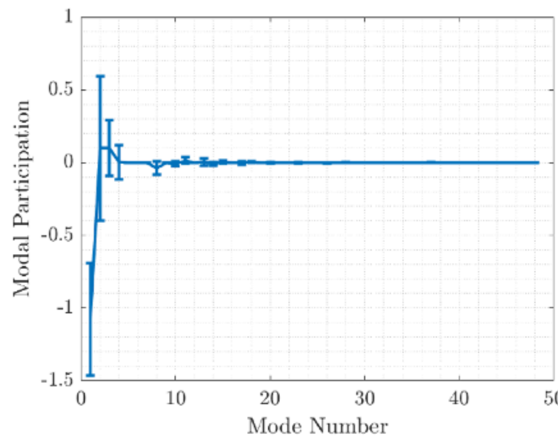
VALIDATION - MODAL RESPONSE

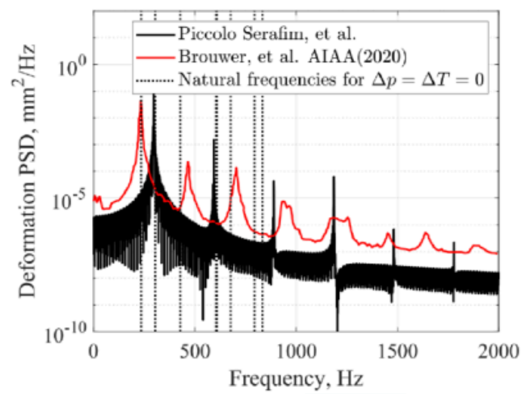
1. No structural damping added
2. No modes calibration

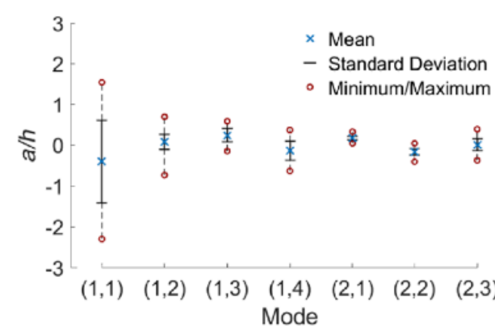
Periodic Parameters	
Δp (kPa)	3.91
ΔT (K)	12.8

"Periodic" setup, $\beta_{BC} = 4.5$









b) Large-amplitude periodic oscillations from Fig. 11 (c). p_c = 50.4 kPa, $\overline{\Delta p}$ = −3.91 kPa, ΔT = 12.8 K

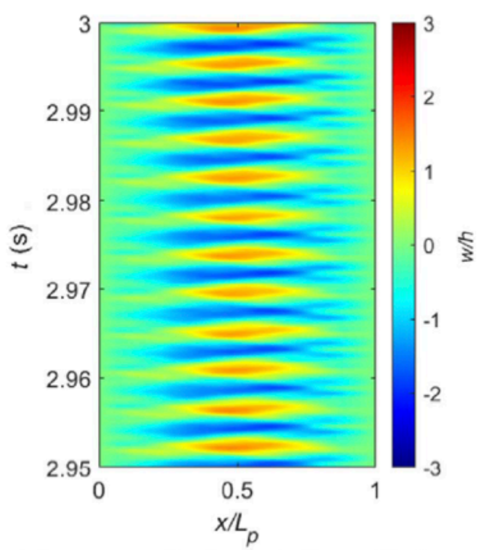
1. Response is mainly in the 2nd **mode (similar to Luisa's results)**, while Brouwer et al. show mostly the 1st mode
2. Dependence on IC's or β_{BC}

FREQUENCY CALIBRATION

1. No structural damping added

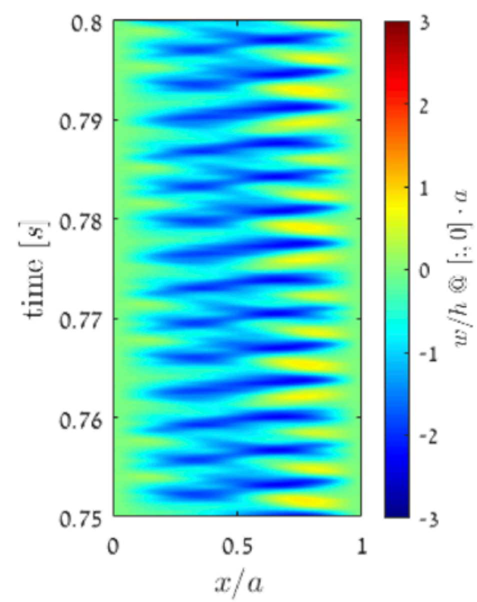
Periodic Parameters	
Δp (kPa)	3.91
ΔT (K)	12.8

"Periodic" setup, $\beta_{BC} = 4.5$

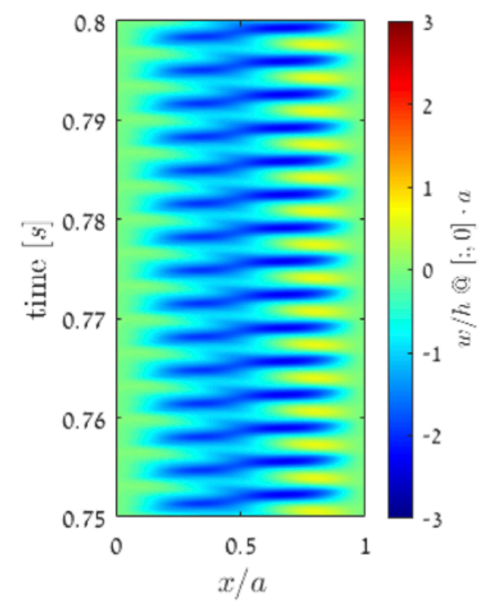


c) Large-amplitude periodic oscillations.
$y/L_p = 0.25, p_c = 50.4$ kPa, $\overline{\Delta p} = -3.91$ kPa, $\Delta T = 12.8$ K
$\theta = 0$ deg, $p_\infty = 44.1$ kPa, $Re_{L_p} = 7.50 \times 10^6$.

Brouwer et al.



With freq and damp calibration



W/O freq and damp calibration

1. 2nd mode visible in the computation
2. Amplitude is smaller (especially into the cavity), **mean is different**!
3. Maybe cavity effect? (Luisa showed it is minor…)

PRESSURE FROM CFD ANALYSIS

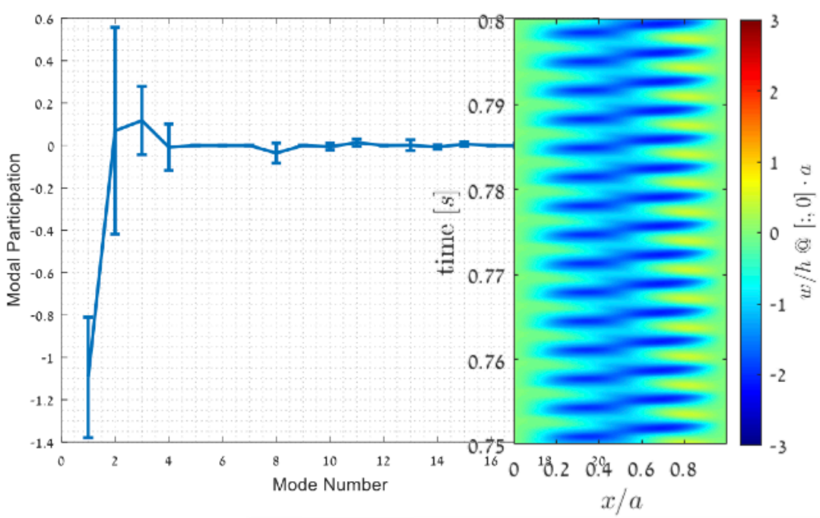
1. Considering the distribution, there is some effect, but the character of the response is similar (periodic with mostly 2nd mode contribution)

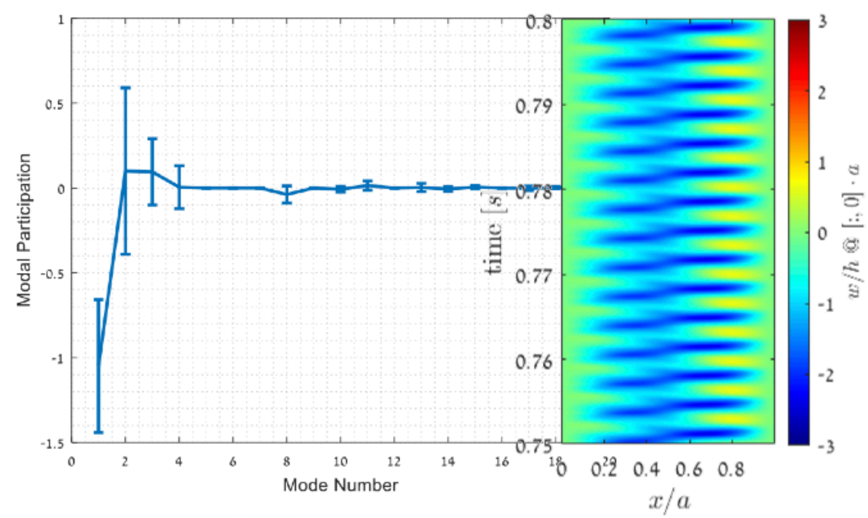
1. No structural damping added
2. No modes calibration

Periodic Parameters	
Δp (kPa)	3.91
ΔT (K)	12.8

"Periodic" setup, CFD-based Δp_s

Computation	$mean(\Delta p_s)$	$mean\left(\frac{w}{h}\right)$	$std\left(\frac{w}{h}\right)$
CFD-based Δp_s dist. (LEFT)	3.7123 kPa (~0.36 kPa std)	0.76323-	0.83154
CFD-based **mean** Δp_s dist. (RIGHT) (CONSTANT_DELTAS = 1)	3.7123 kPa (constant)	0.68189-	0.96475



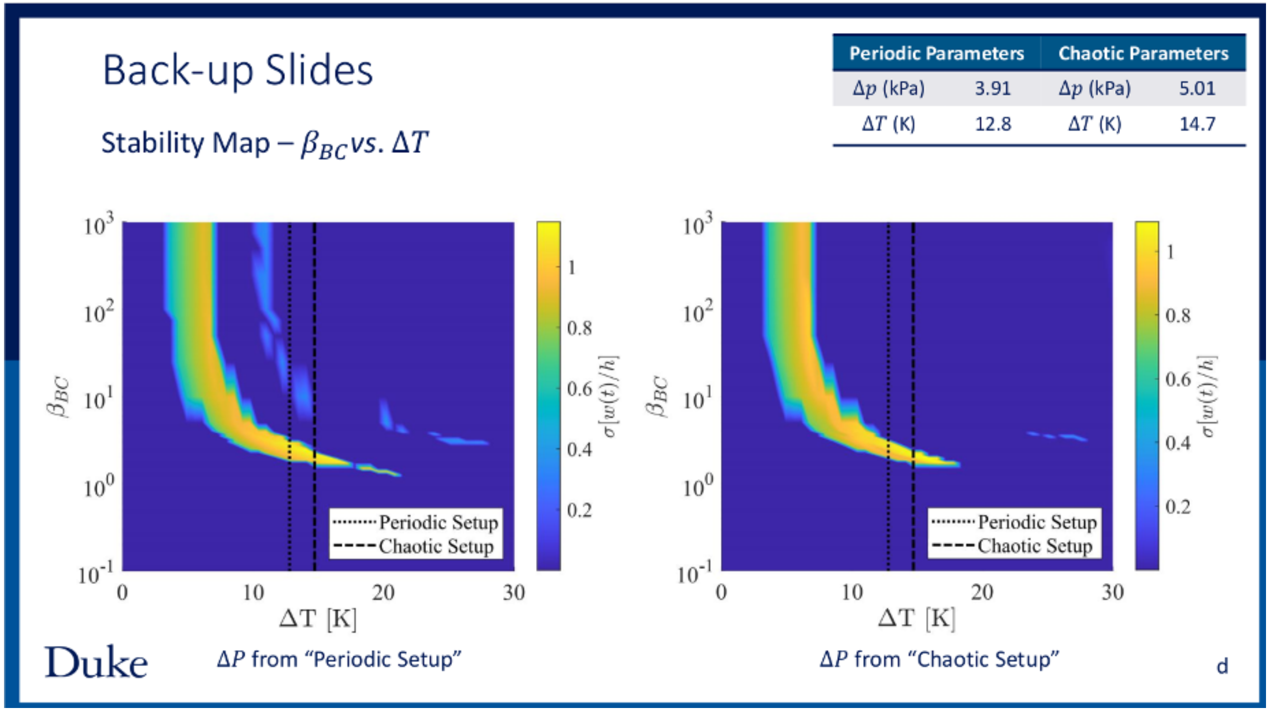


OTHER PARAMETERS

- Damping (0.05%)
- Frequency and damping calibration
- “Chaotic” setup

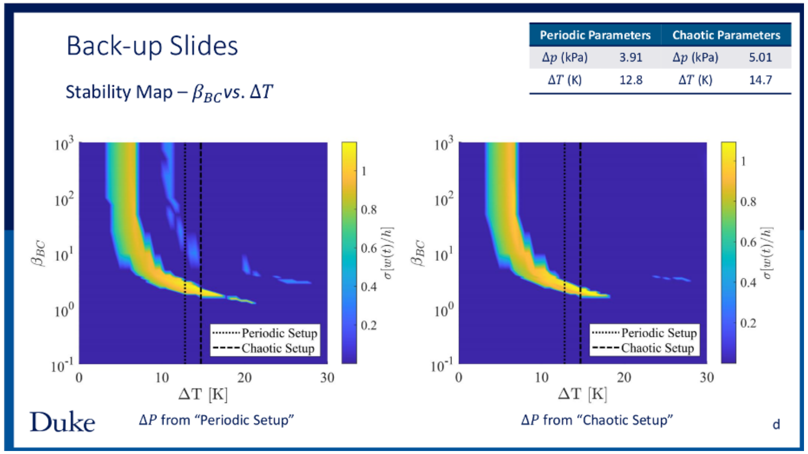
- All yielded amplified second mode responses

STABILITY MAP BY SERAPHIM ET AL.



- Large response at $\Delta T \approx 5$ and large β_{BC} values

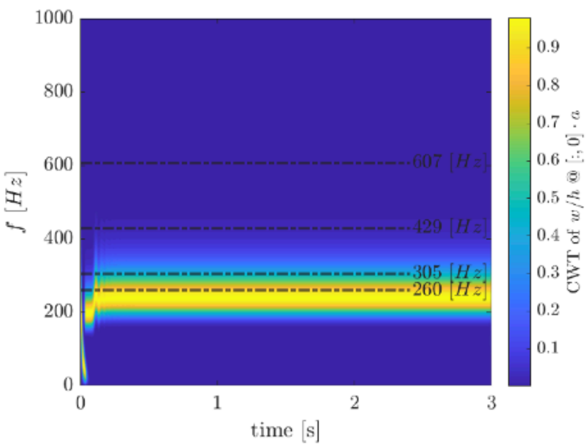
- Fix $\Delta T = 10$, $\beta_{BC} = 0.5 : 0.5 : 10$, $\Delta P = 0.01 KPa$
- Increasing β_{BC} -
  - Response magnitude increases (both STD and P2P)
  - First mode participation increases

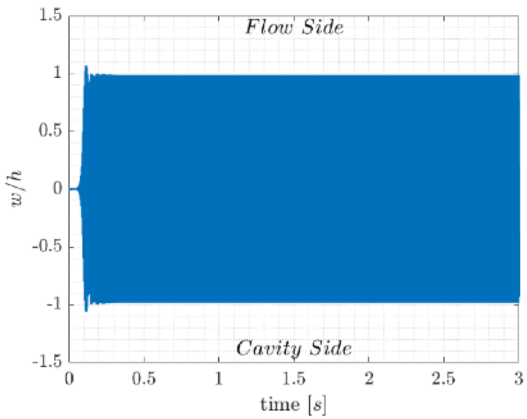


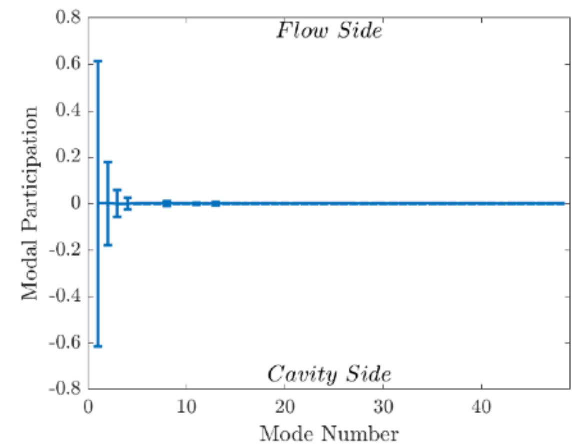
$\beta_{BC} = 8.5$

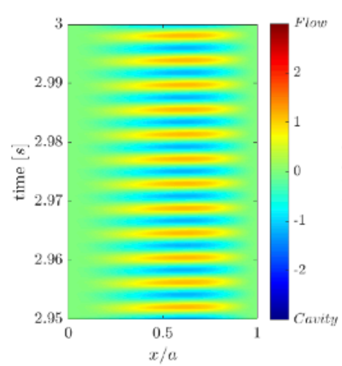
Data in results file 24.05.2023

Iteration	P_inf [kPa]	DT [K]	DPs [kPa]	beta_BC	zeta	CALIBRATE_STIFFNESS	CALIBRATE_DAMPING	std(w/h)	mean(w/h)	p2p(w/h)
17	48.398	5	1e-05	8.5	0	1	0	0.70444	0.0029573	1.9721





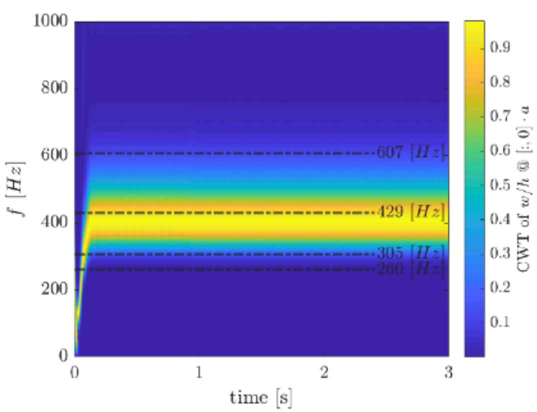


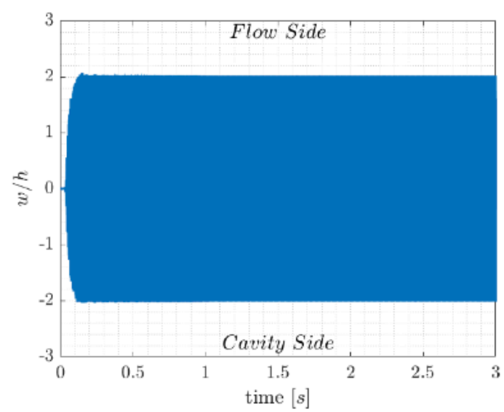


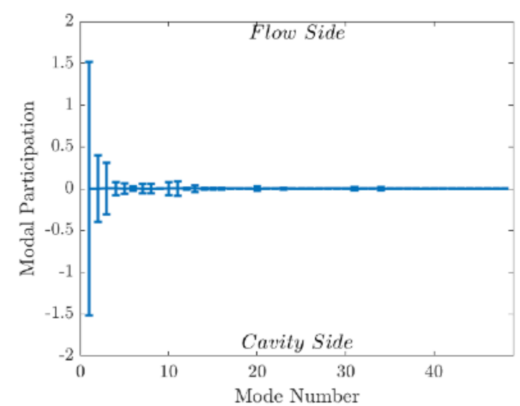
$\beta_{BC} = 1000$

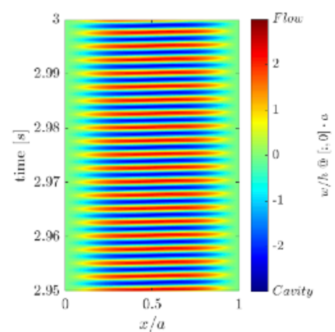
Data in results file:

Iteration	P_inf [kPa]	DT [K]	DPs [kPa]	beta_BC	zeta	CALIBRATE_STIFFNESS	CALIBRATE_DAMPING	std(w/h)	mean(w/h)	p2p(w/h)
1	48.398	5	1e-05	1000	0	1	0	1.4681	-0.0028277	4.0393









CURRENTLY

- Fix β_{BC} to a large value (~clamped panel) and study temperature and then pressure differential effects
- Assuming:
  - Test temp measurements inaccuracies?
  - Test temp measured at a single point might not be "mean temp"