AePW-3 – Third Aeroelastic Prediction Workshop

Coupled Numerical Simulation of Fluid-Structure Interaction

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German Aerospace Center (DLR)

Braunschweig, Germany

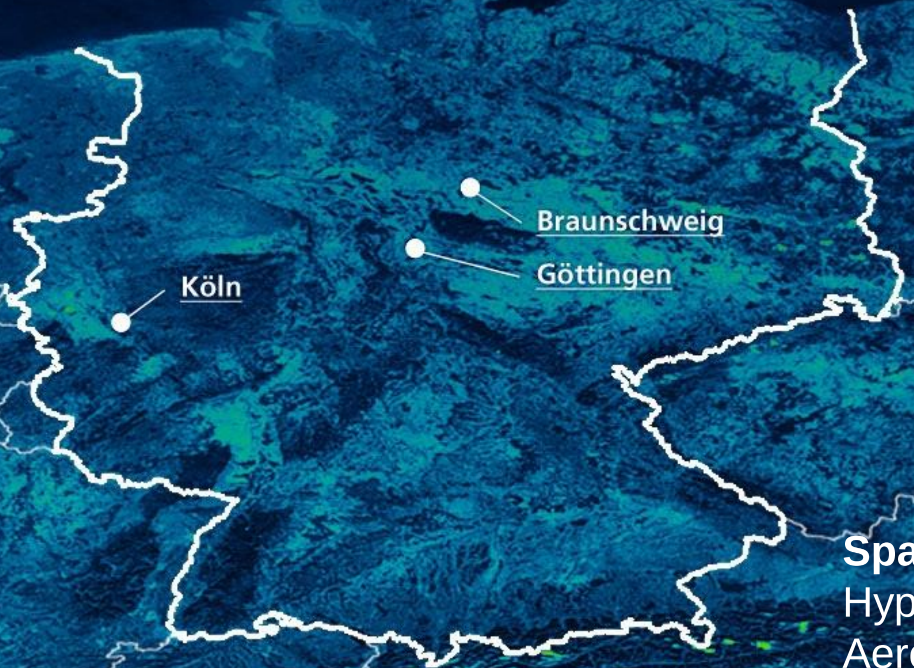
AePW-3 – Progress meeting

Online, 2024 June 27

Institute of Aerodynamics and Flow Technology
German Aerospace Center (DLR)

DLR – R&T Aeronautics, Space, Energy, Transport and Security
DLR – German Space Agency
DLR – Project Office

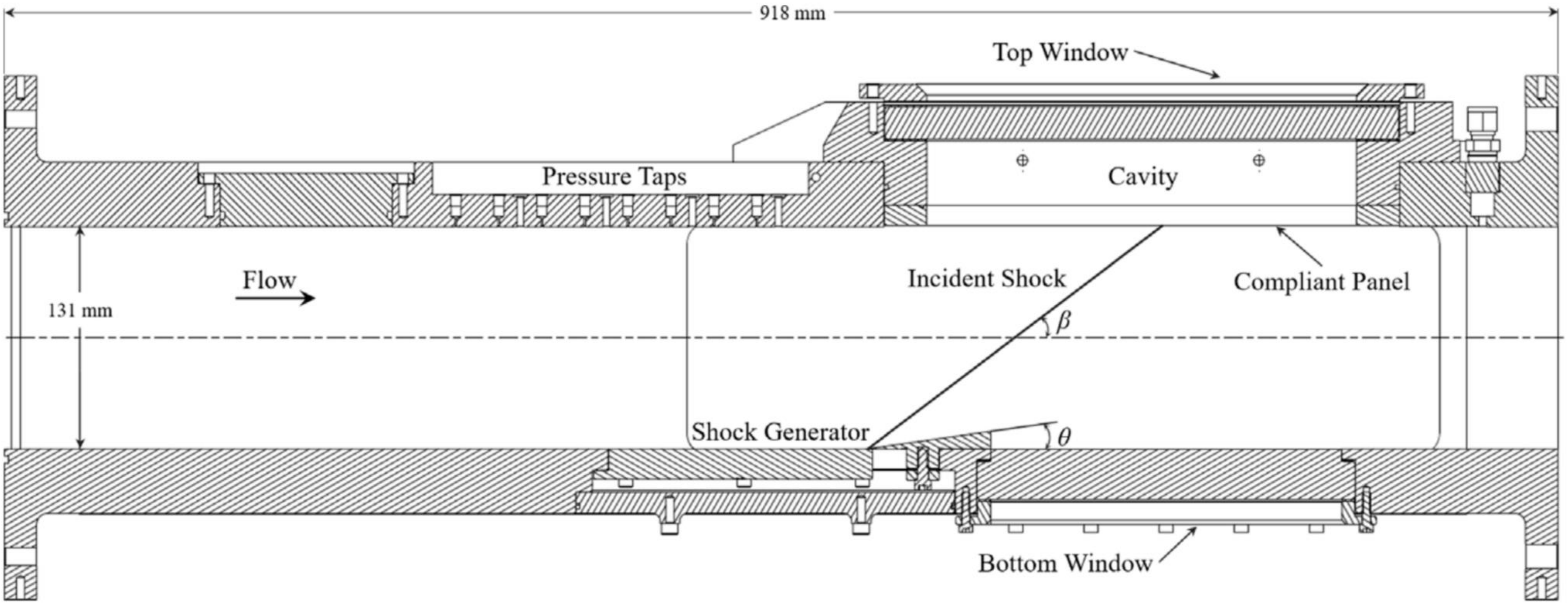
Institute	**DLR total**
3 sites	30 sites + 4 int. offices
~350 employees	~11.000 employees



Departments of the Institute
Experimental Methods
Ground Vehicles
Helicopters
High Speed Configurations
Spacecraft
Supersonic and Hypersonic Technologies
Technical Acoustics
Transport Aircraft
Wind Energy
Center for Computer Applications in AeroSpace Science and Engineering C²A²S²E

Spacecraft Department
Hypersonics
Aerothermodynamics
HEG Shock Tunnel
Rarefied Gas Dynamics
Satellite Thrusters (electric + chemical)
Numerics (DLR TAU-Code)

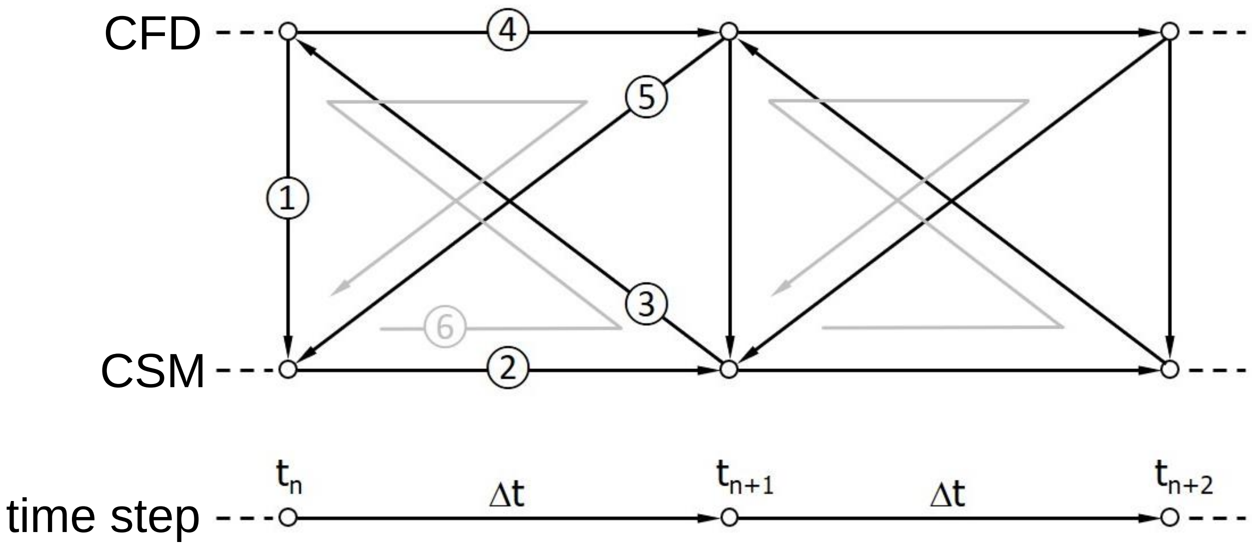
Task
ARFL RC-19 Test Cell[1] Dayton, Ohio



[1] K. B. Brouwer et al., J Fluids and Structures 108 (2022), https://doi.org/10.1016/j.jfluidsstructs.2021.103429

Coupling Scheme
CFD/CFM CFD/CSM

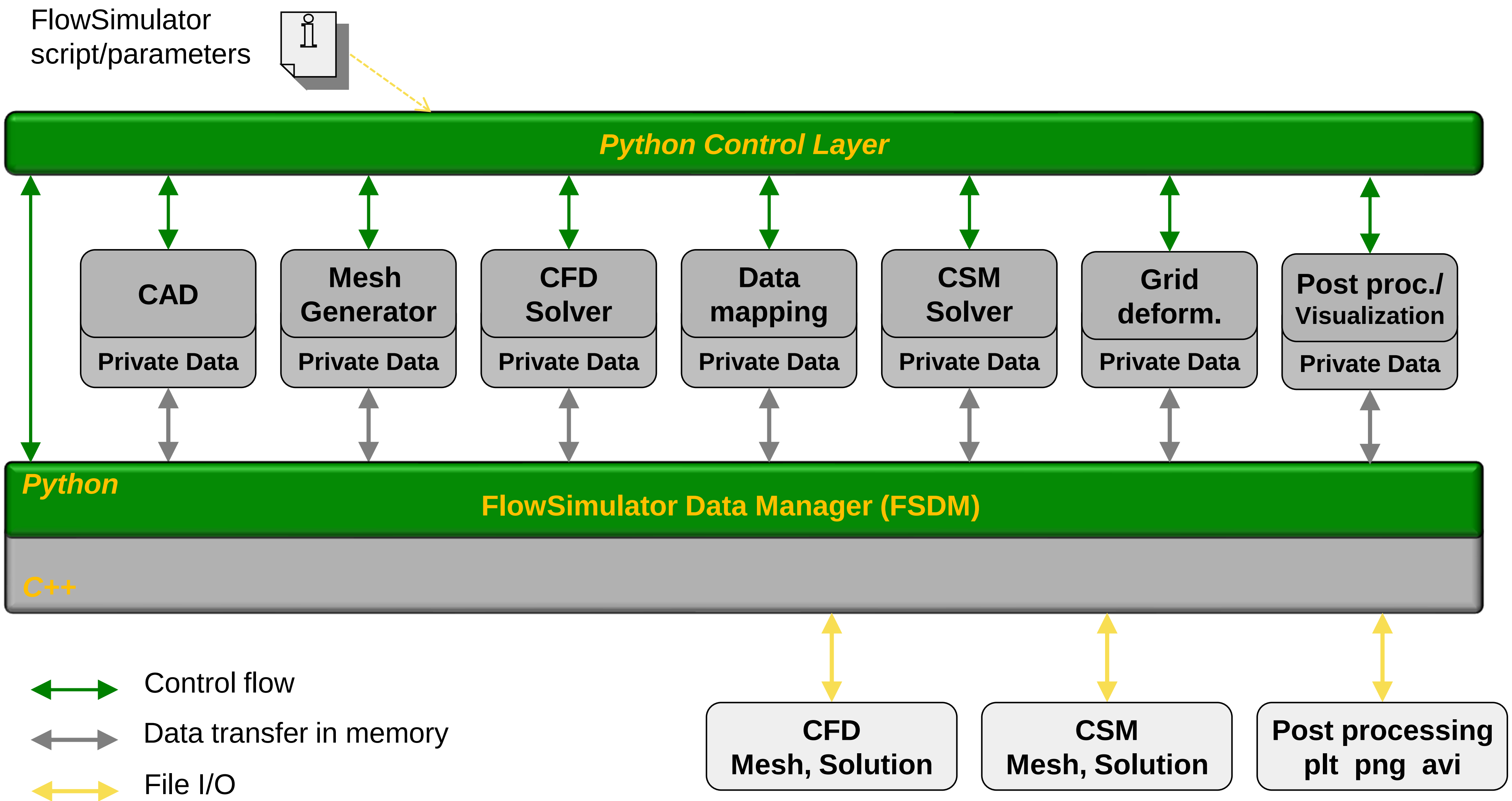
- CFD in-house solver DLR TAU-Code
- Flight dynamics solver, CFM (Reent 6D, 6-DoF TAU module solving Newton‘s second law and Euler equation)
- Structural mechanic solver, CSM (ANSYS, NASTRAN, B2000++pro)
- Partitioned approach with „strong coupling“



Coupled
Numerical
Fluid
Flight Mechanics
And
Structure
Simulations

①,③ and ⑤ exchange of coupling quantities
② computation of CSM time step
④ computation of CFD time step
⑥ repetition until convergence

FlowSimulator – Scheme FSI



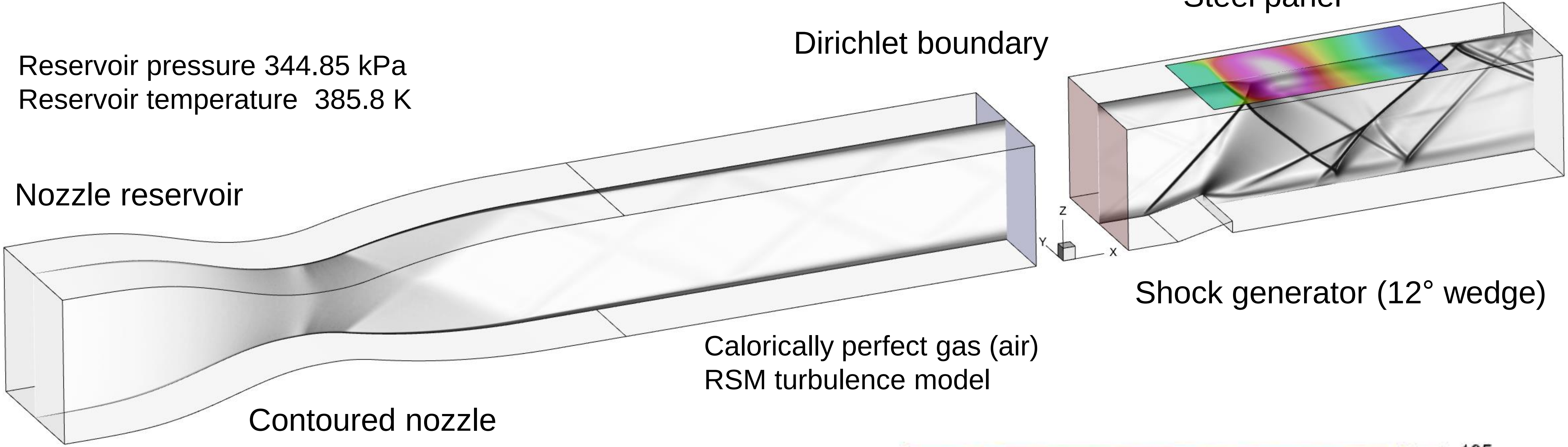
Computational Domain
Steady-state Initial Condition

Reservoir pressure 344.85 kPa
Reservoir temperature 385.8 K

Nozzle reservoir

Dirichlet boundary

Steel panel

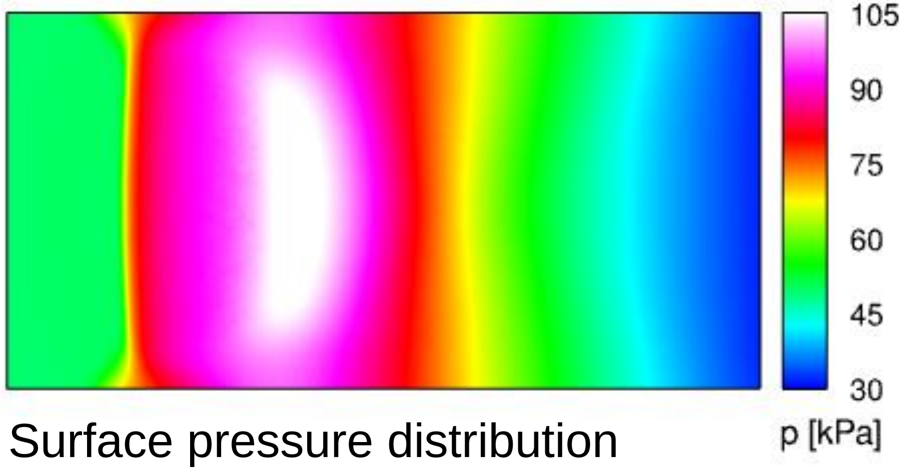


Shock generator (12° wedge)

Contoured nozzle

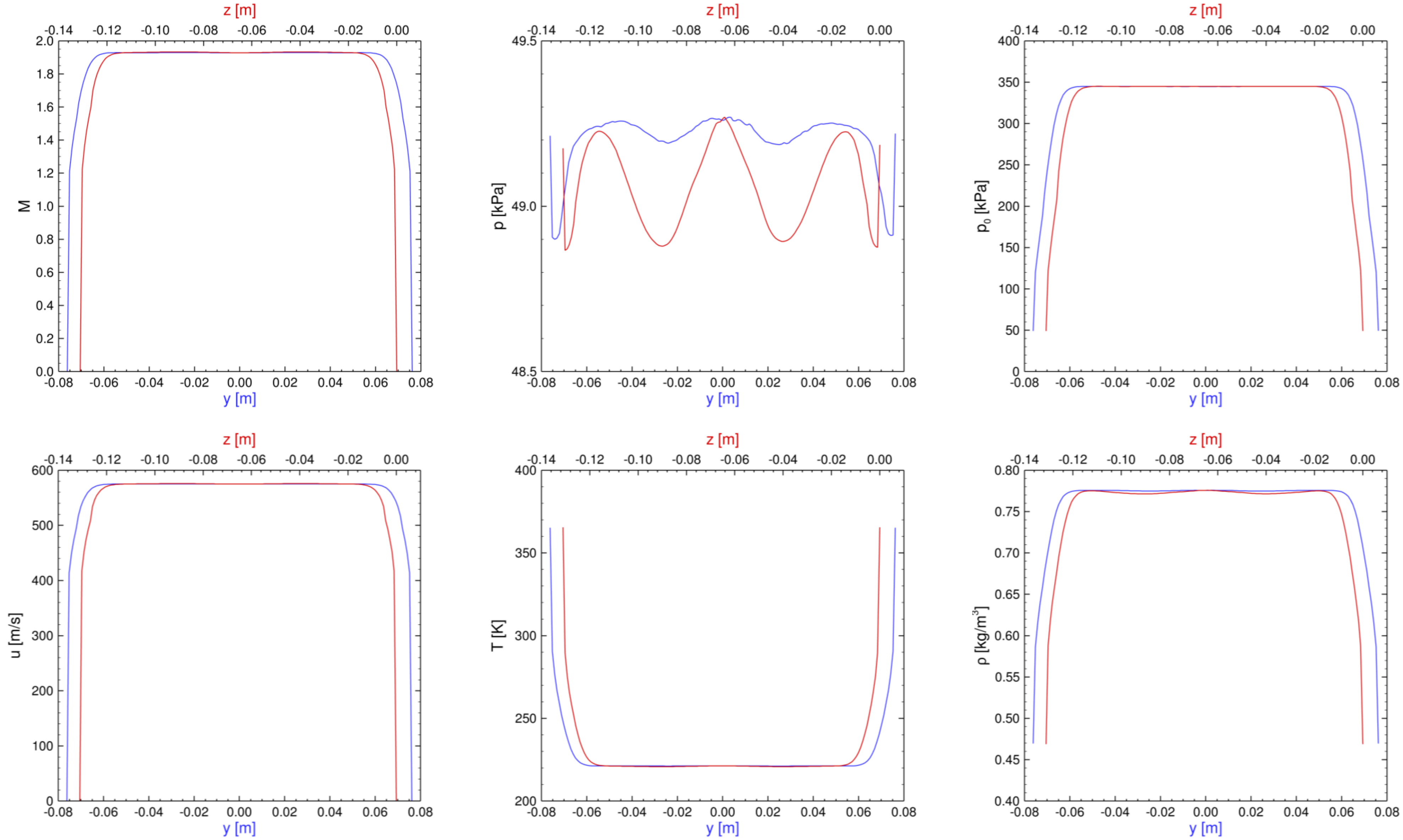
Calorically perfect gas (air)
RSM turbulence model

Panel size 253.9 x 127.0 x 0.635 mm
Material ASIS 4140 alloy
Density 7850 kg/m^3
Poisson’s ration 0.27
Young‘s modulus 2.08 Gpa
Thermal expansion coefficient 11.1 10^{-6} 1/K
Specific heat 460 J/(kg K)



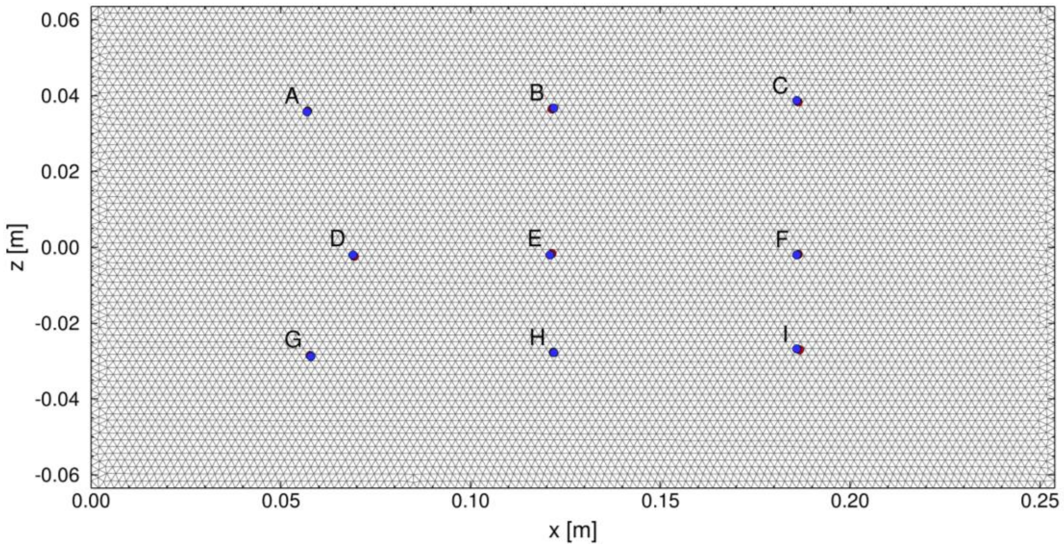
Surface pressure distribution

Inflow Profiles

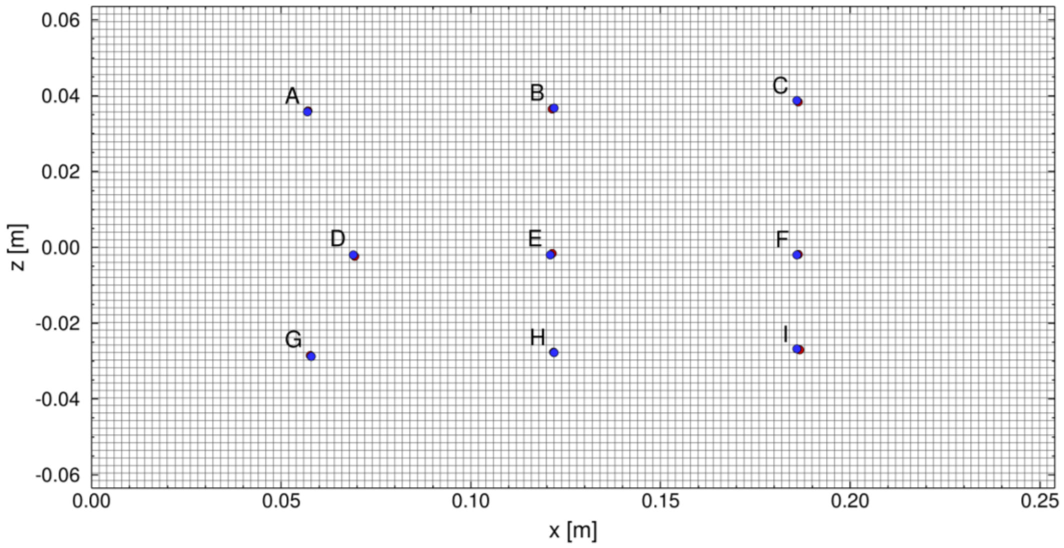


Panel Grid

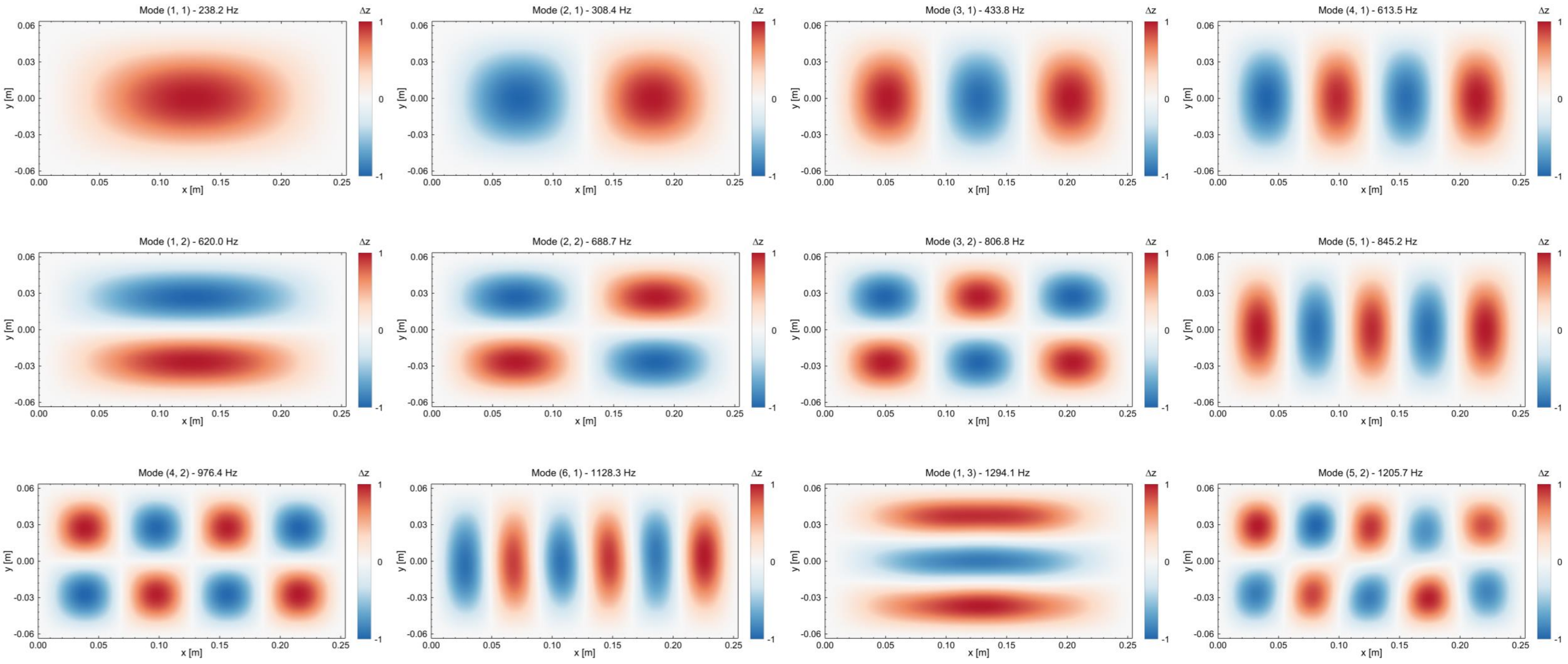
CFD grid



CSM grid

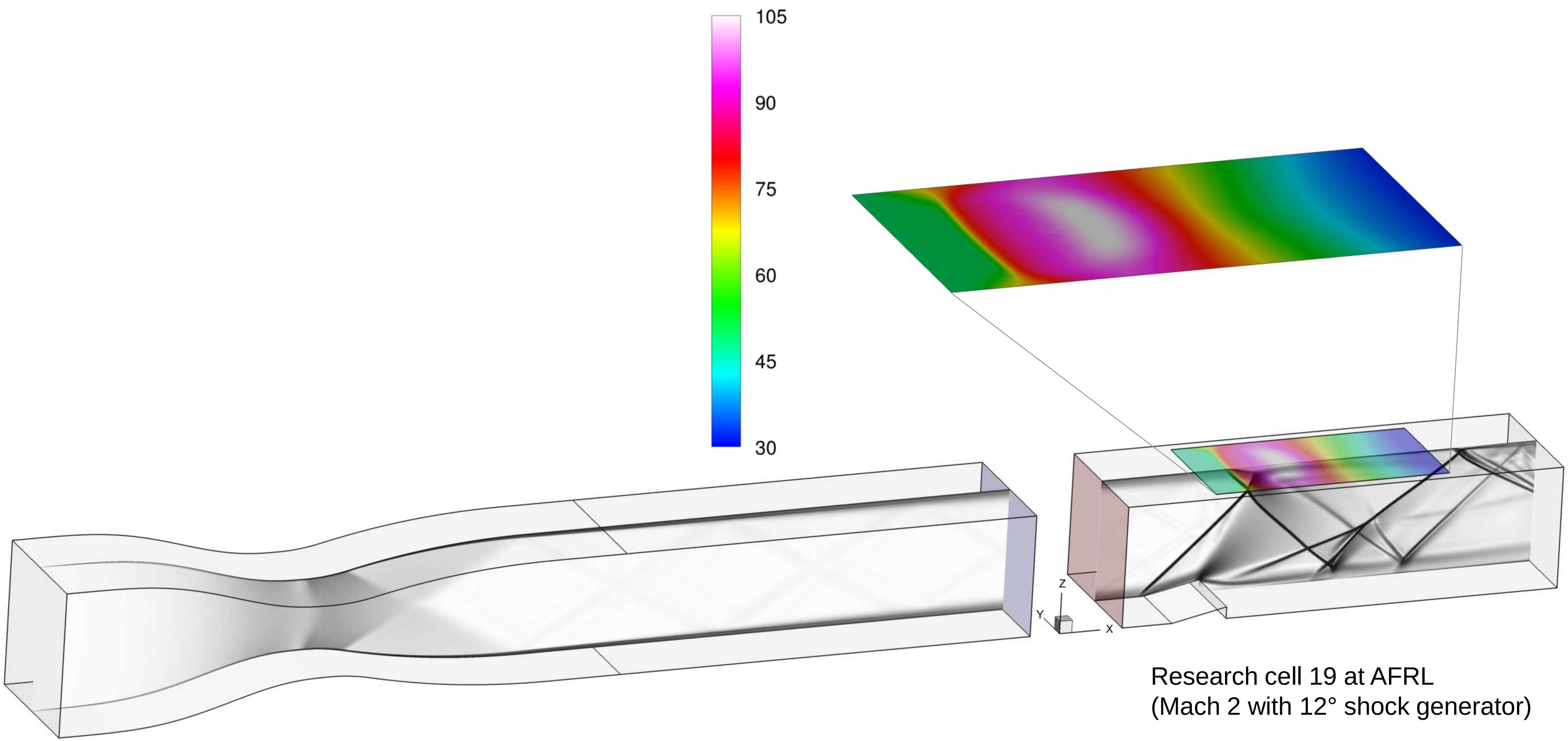


Modal Analysis
Natural Modal Frequencies ($\Delta T=0K$)



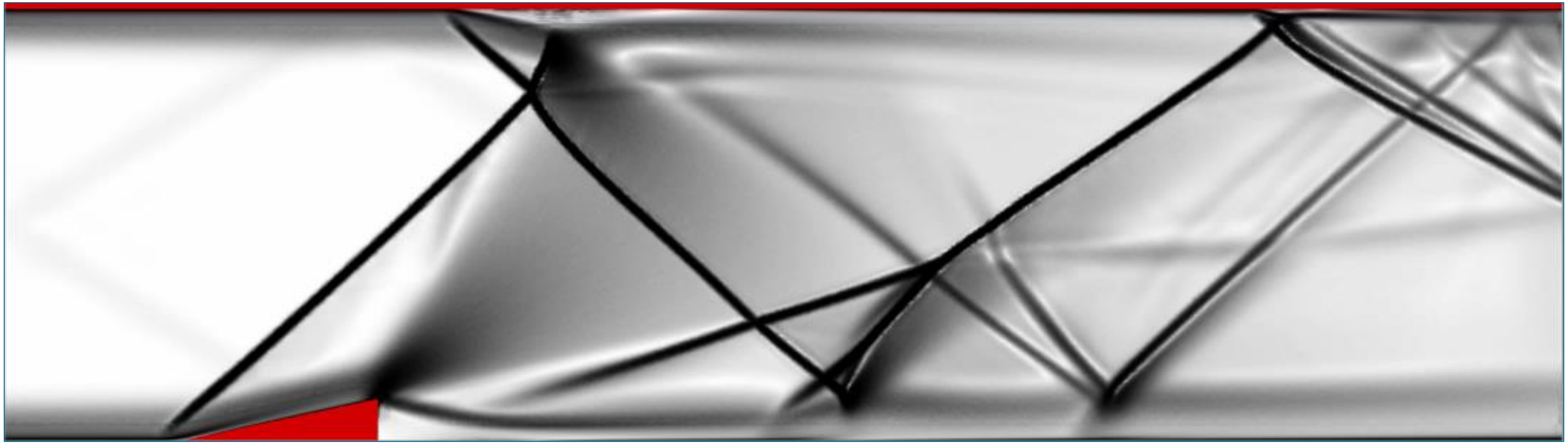
Flexible Panel Excited by Turbulent SBLI

Panel response (50x enlarged)

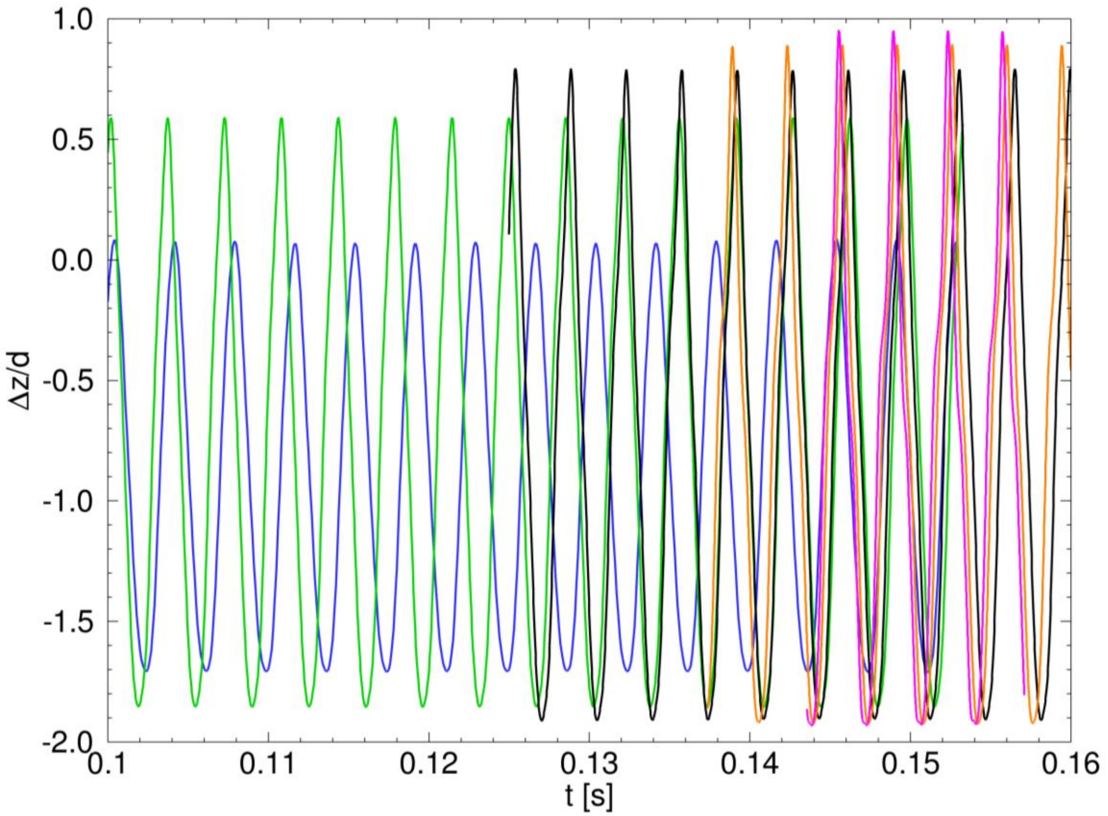


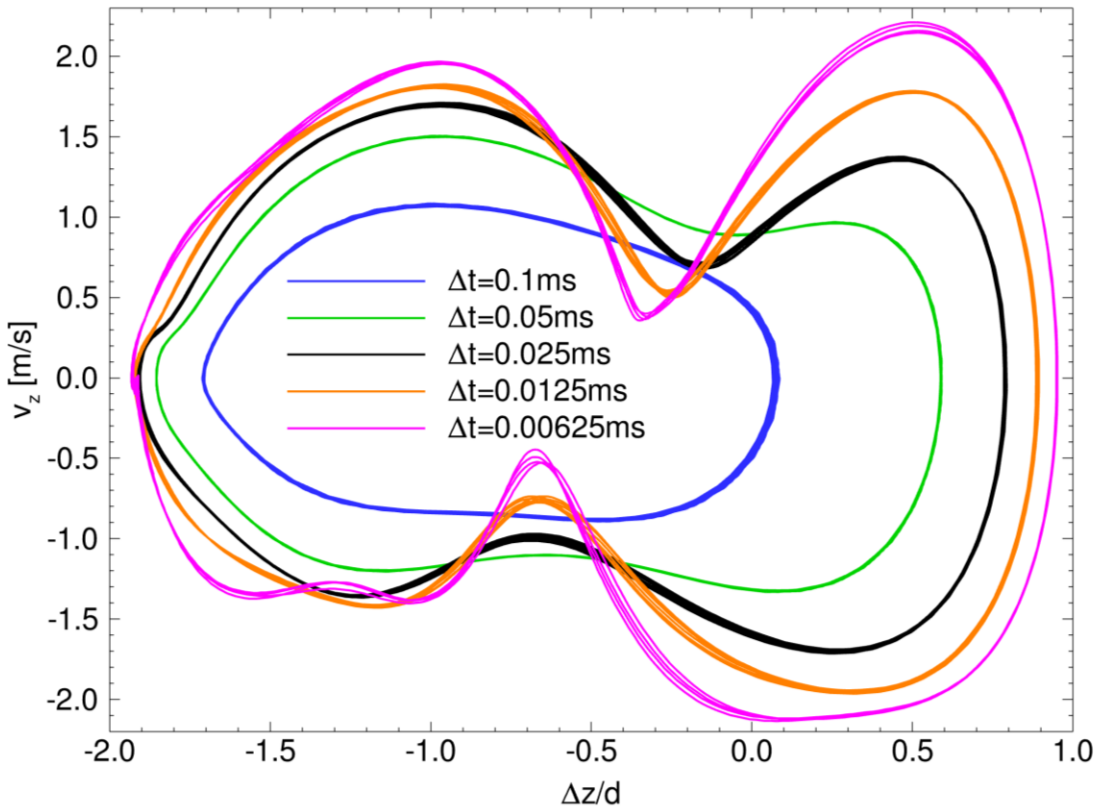
Research cell 19 at AFRL
(Mach 2 with 12° shock generator)

Flow field
Shadowgraph



RC-19 Limit Cycle (12° Shock Generator, ΔT=12K, p_c = 92.355kPa)
@point E x/L=0.5 y/L=0.25





without structural damping and variable cavity pressure

RC-19 Limit Cycle (12° Shock Generator, ΔT=12K, p_c = 92.355kPa)
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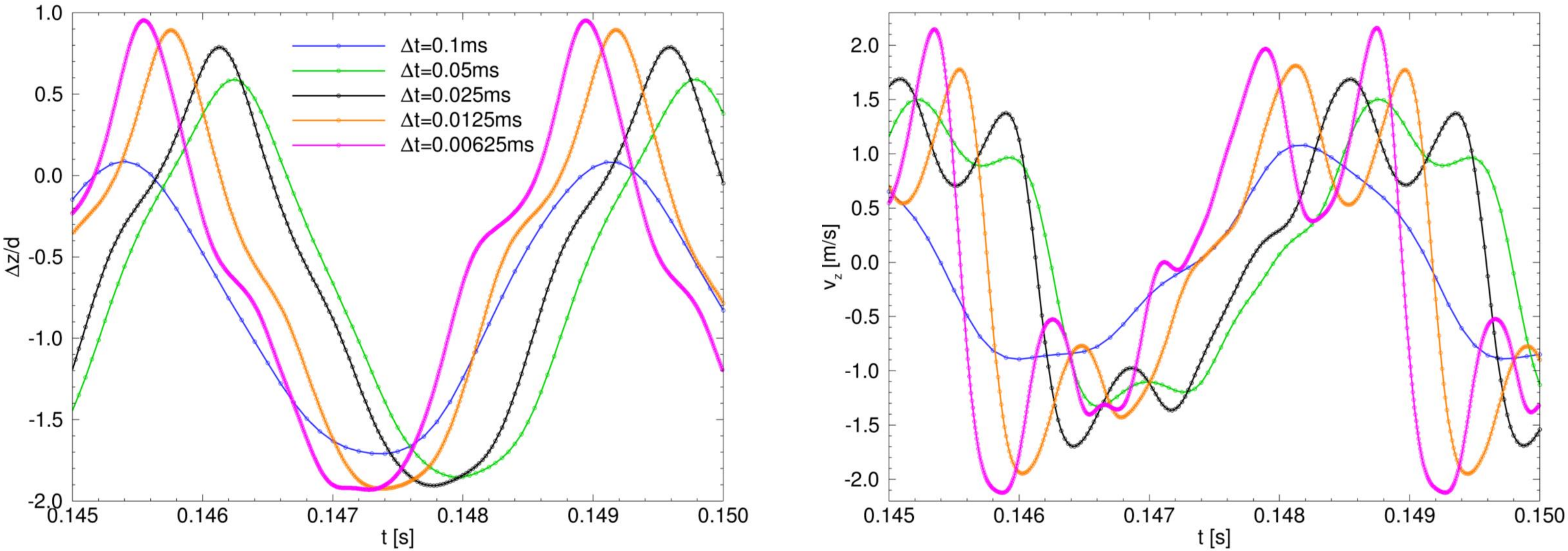

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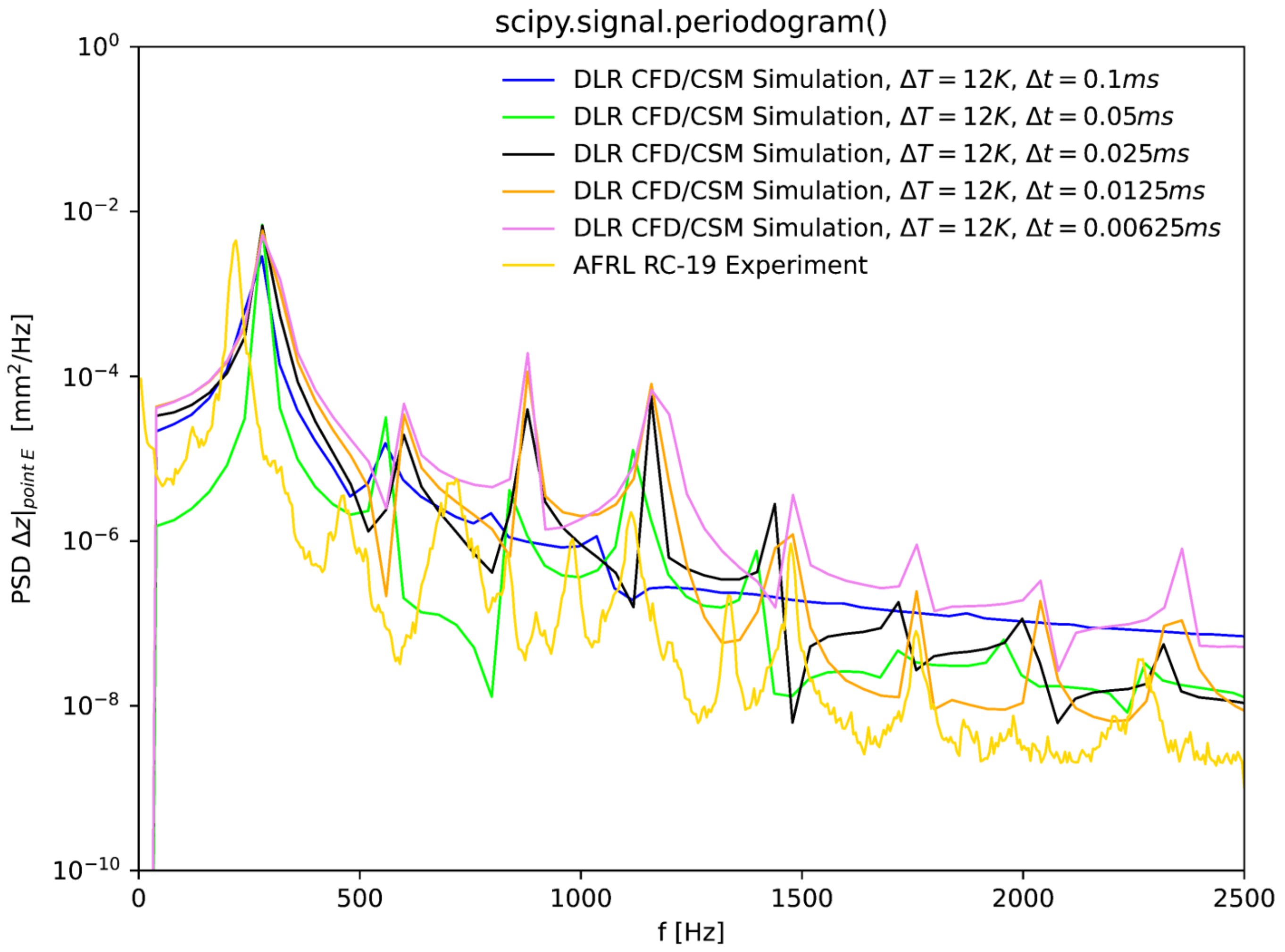


without structural damping and variable cavity pressure

Structural Damping and Cavity Pressure

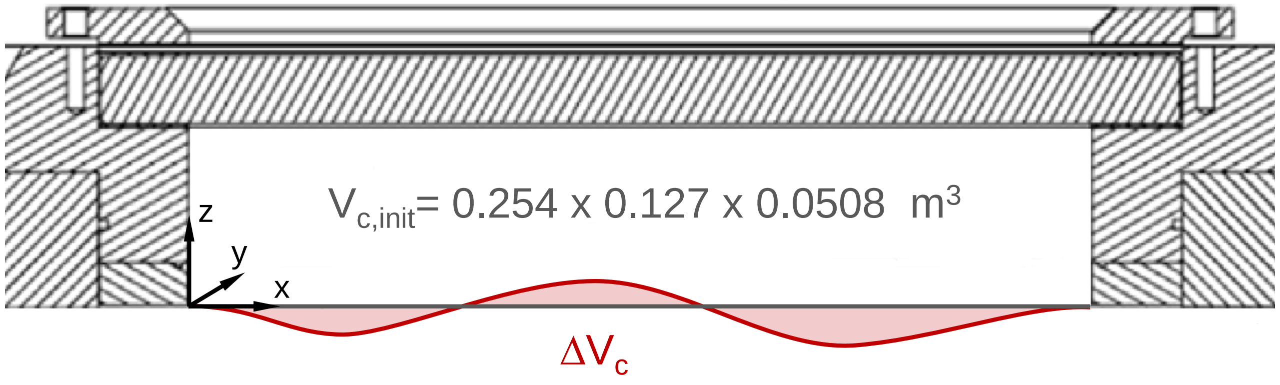
Rayleigh damping model

$$\mathsf{D}_{ij} = \alpha_d \, \mathsf{M}_{ij} + \beta_d \, \mathsf{K}_{ij} \qquad \alpha_d = 15, \;\; \beta_d = 8 \cdot 10^{-7}$$

Cavity pressure model

$$\Delta V_c(t) = \iint_{\text{panel}} z(t,x,y)\, dx\, dy$$

$$p_c(t) = \frac{p_{c,\text{init}}\, V_{c,\text{init}}}{V_{c,\text{init}} - \Delta V_c(t)}$$



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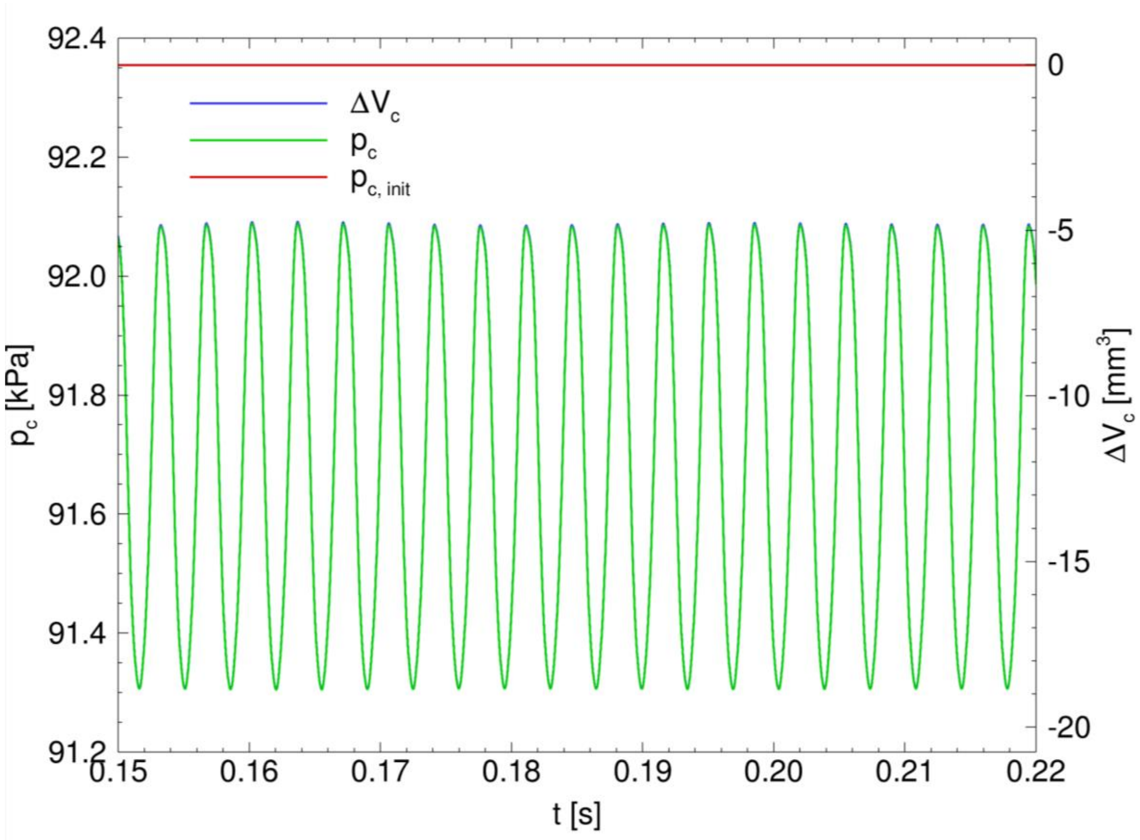

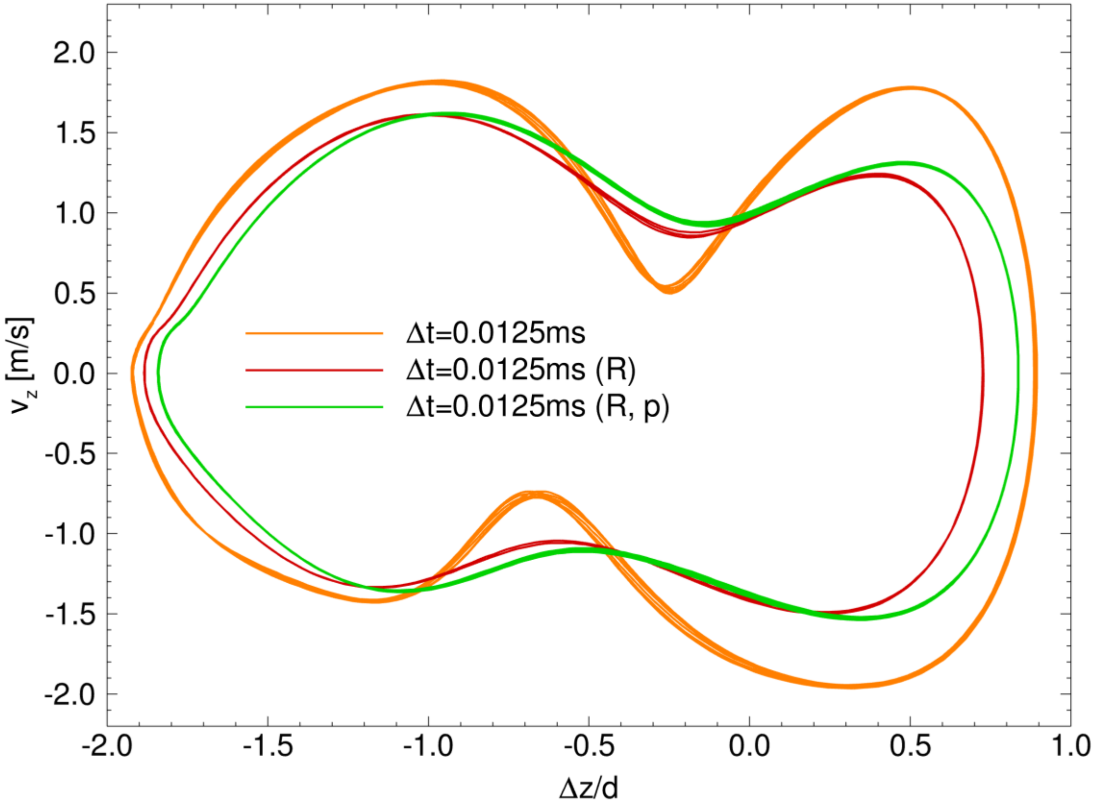

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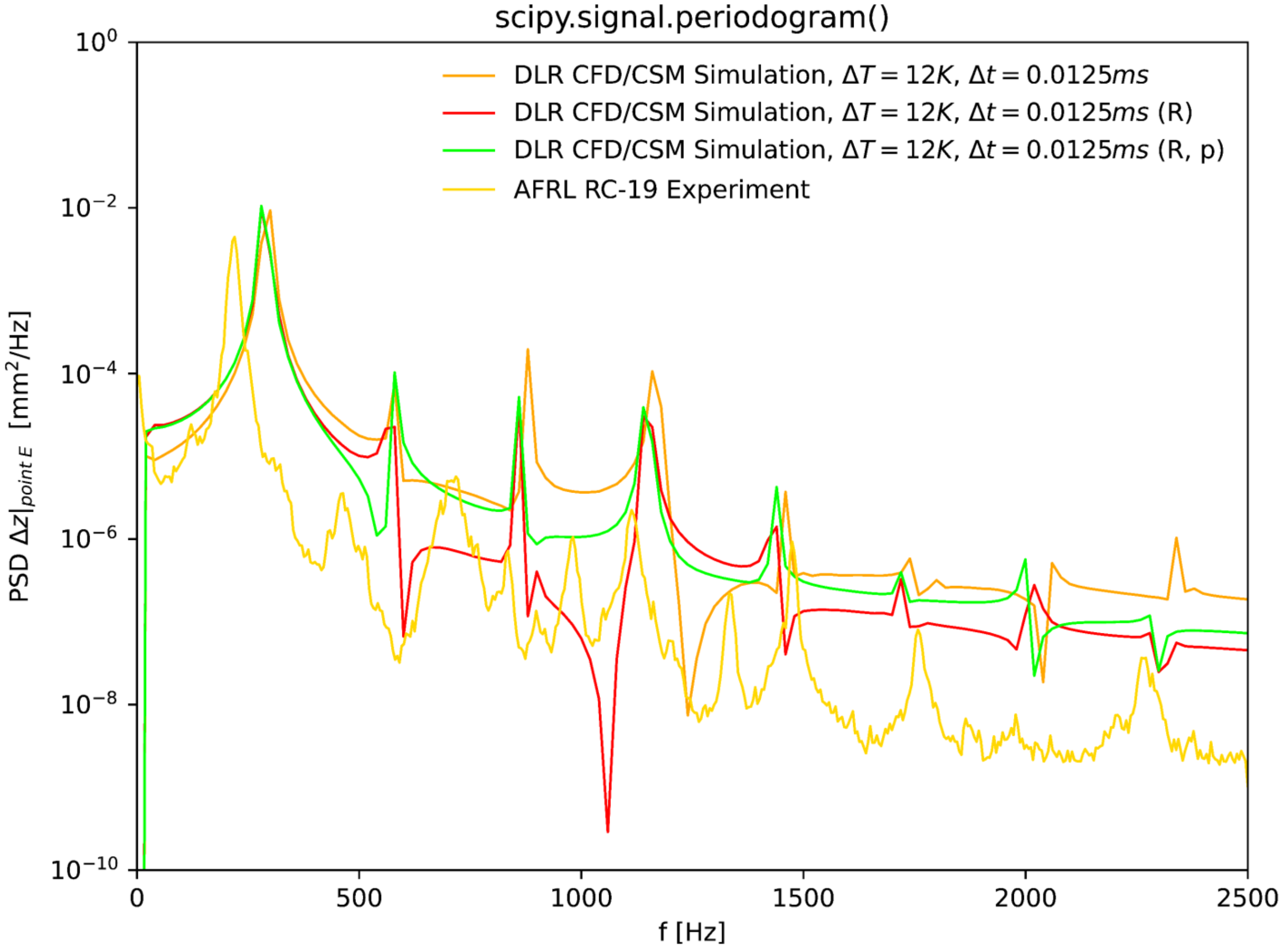
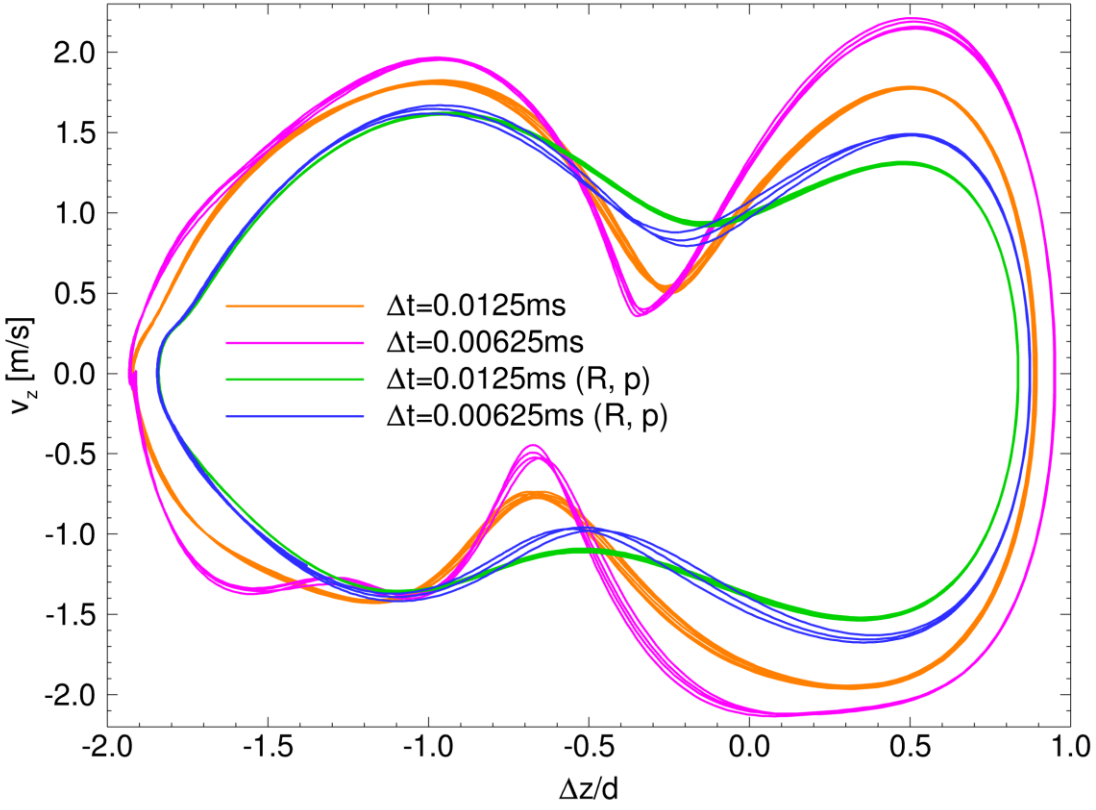
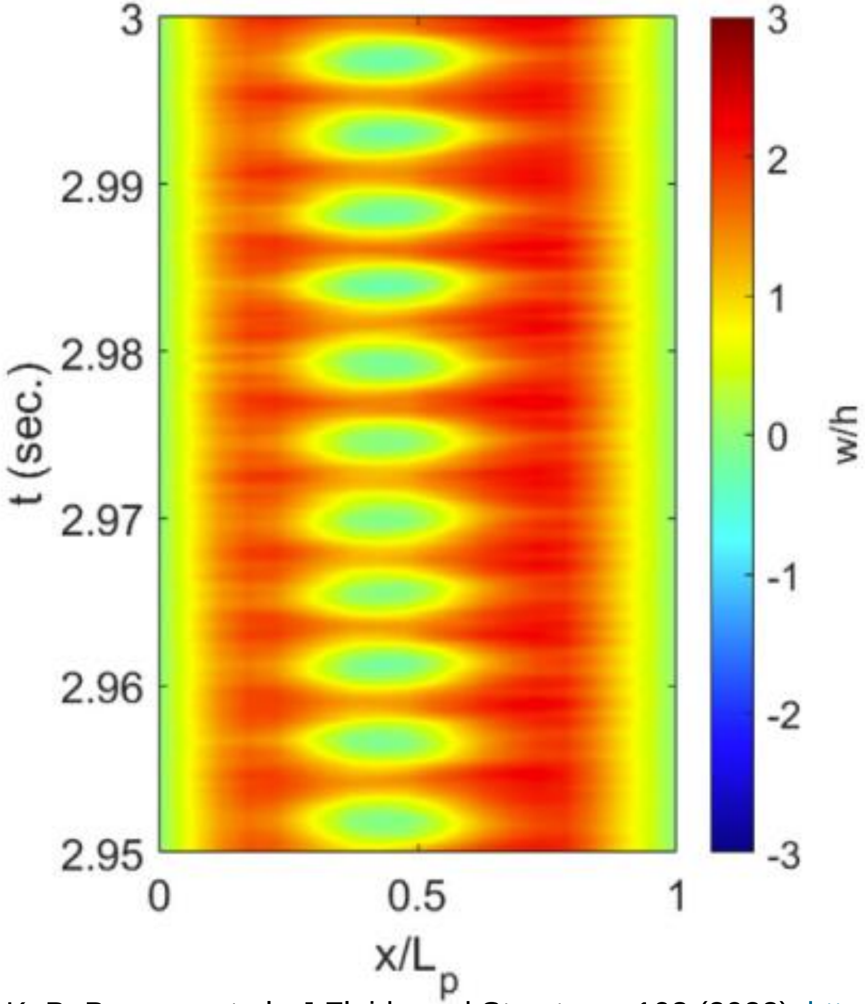


Rayleigh damping and cavity pressure

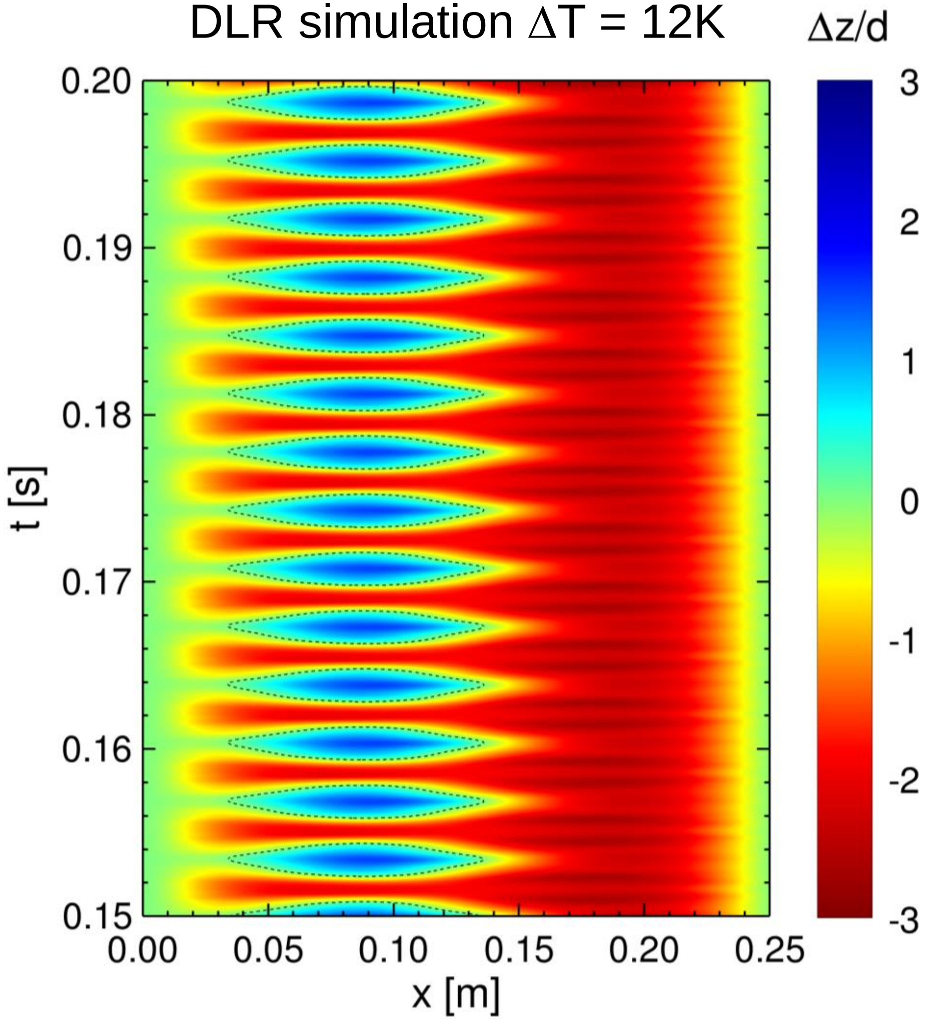


Time-history Plots
Comparison between Experiment and Simulation (Δt=0.0125ms)

AFRL RC-19 experiment[1]



DLR simulation ΔT = 12K



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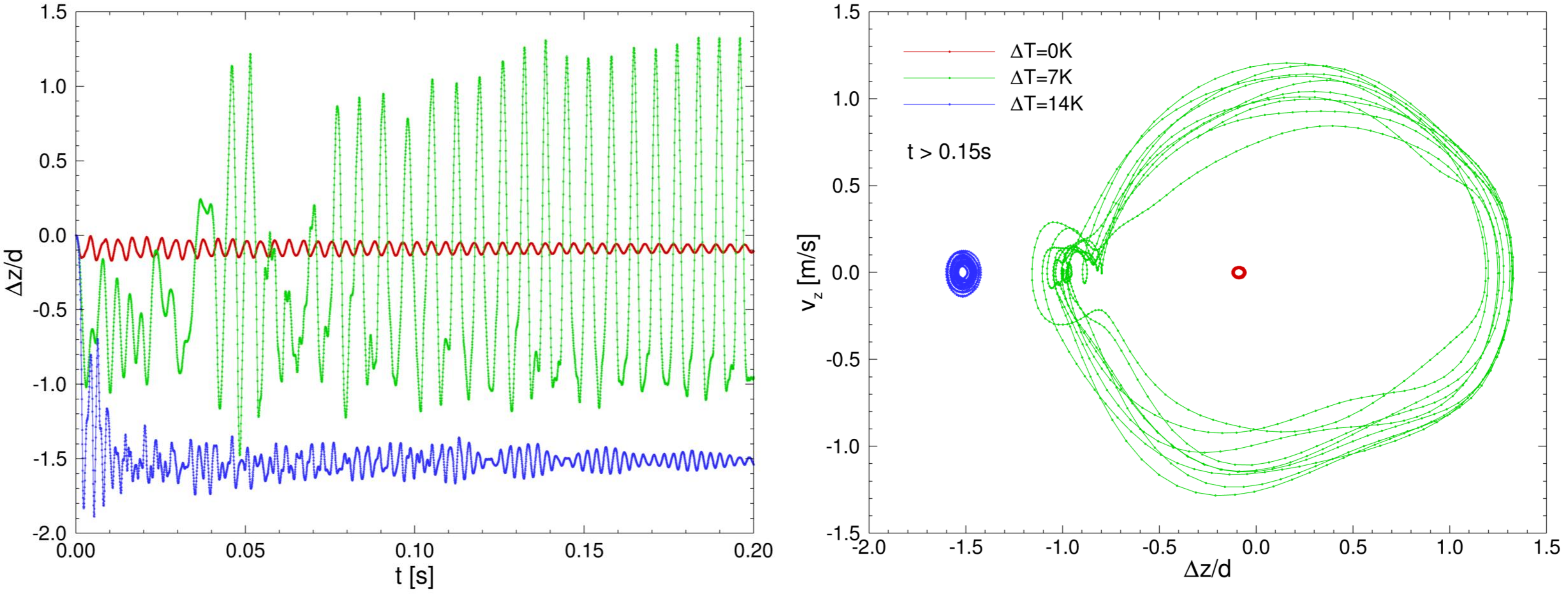
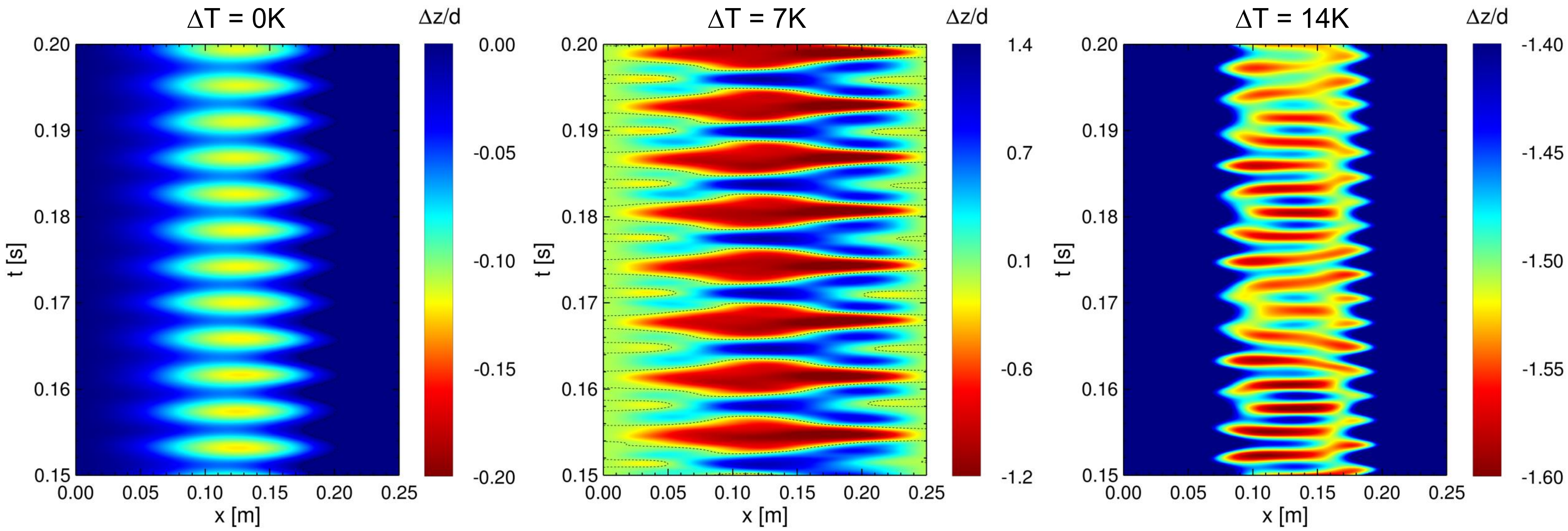
RC-19 Panel Limit Cycle, 0° Wedge (Δt = 0.05ms, p_c = 50.7235kPa)
@point E x/L=0.5 y/L=0.25



without structural damping and variable cavity pressure

RC-19 Panel Limit Cycle, 0° Wedge (Δt = 0.05ms, p_c = 50.7235kPa)
@centerline y/L=0.25



without structural damping and variable cavity pressure

Ongoing Work and Next Steps

- Simulaion of SeparatedSBLI ongoing
  - Cavity pressure influence

- Simulation of NoSBLI case (without wedge) periodic/chaotic transition (AePW3 test cases)

- CSM mesh possibly too fine (too many degrees of freedom) ?

- Analysis tools
  - Dynamic mode decomposition (DMD)
  - Spectral proper orthogonal decomposition (SPOD)
  - 0-1 chaos test
  - Lyapunov exponents