Recent high-speed aerodynamics work at Southampton

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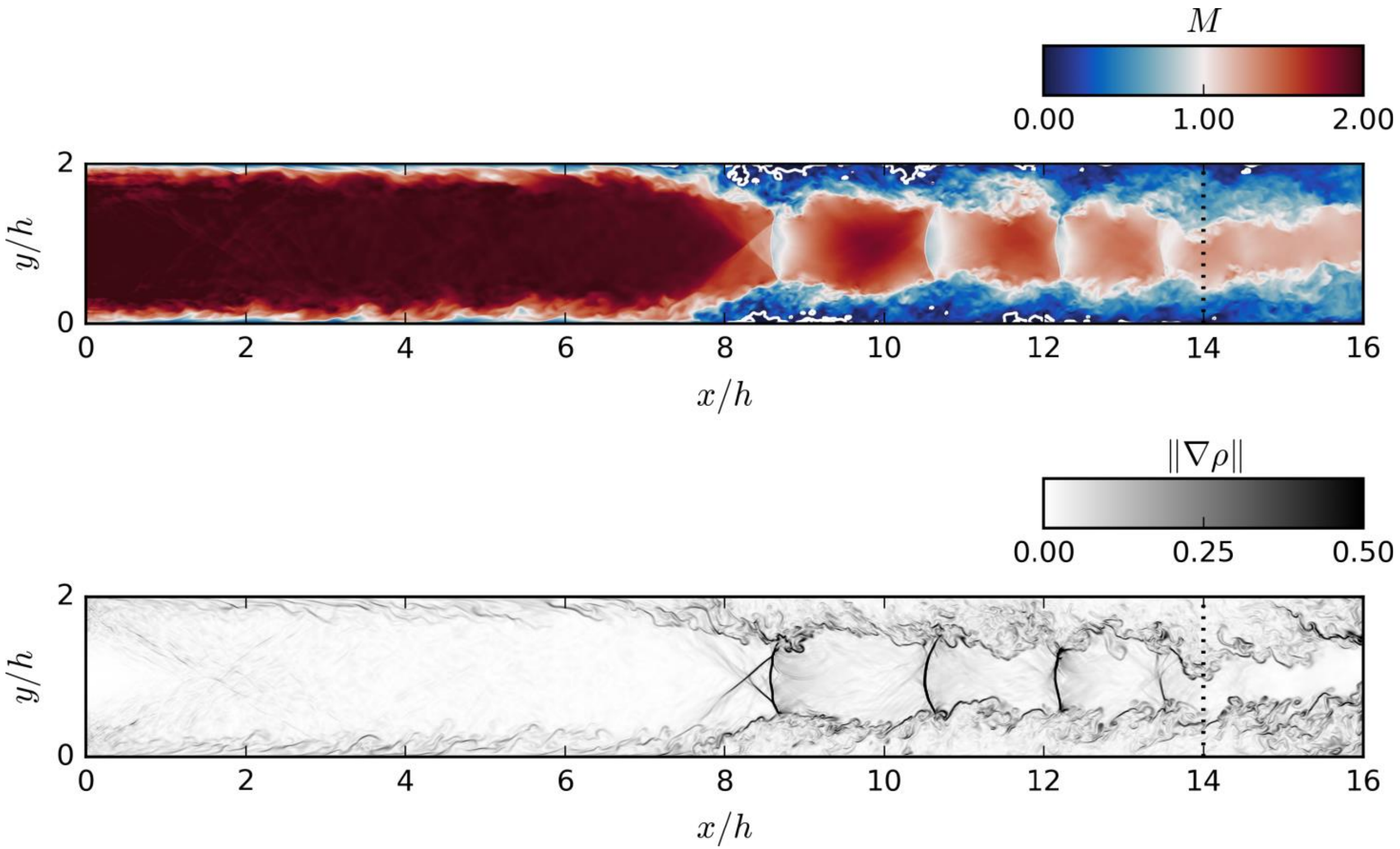
Some selected recent and ongoing work

- Transonic/supersonic
  - Shock-wave/boundary-layer interactions in ducts
  - Transonic buffet
  - Roughness
- Hypersonic
  - Transpiration cooling
  - Thermo-chemical nonequilibrium modelling
  - MHD Plasma

Shock train in duct, turbulent inflow

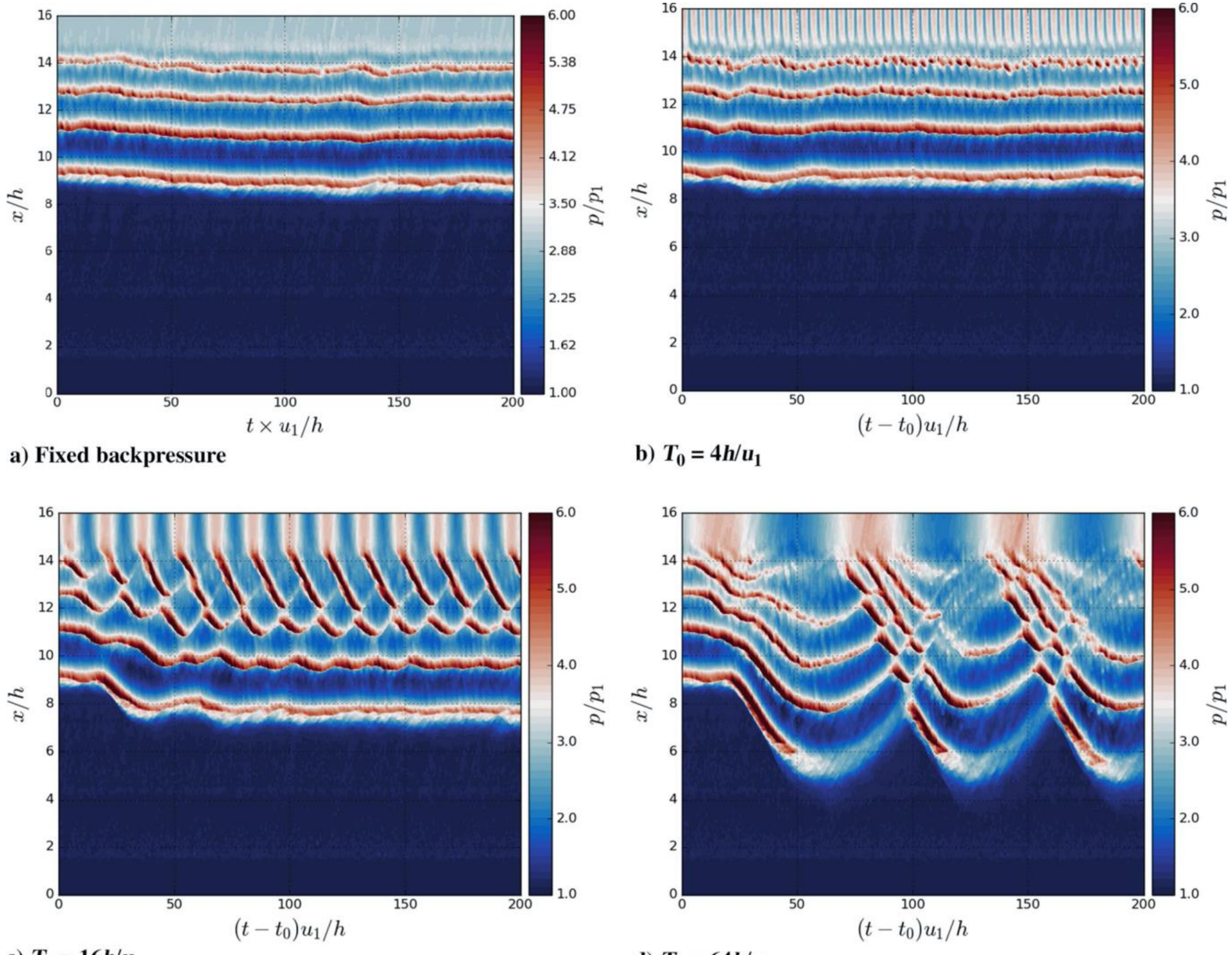
(Gillespie PhD 2021, AIAAJ 2022)

- M=2 inflow
- Imposed back pressure p_b/p_1=3
- Digital filter inflow
- Low-f unsteadiness present under leading shock (St_L=0.03)
- Studied response to coherent back pressure variations



Response to back pressure changes

- High and moderate frequency don't affect low-f response
- Strong response at low-f



a) Fixed backpressure

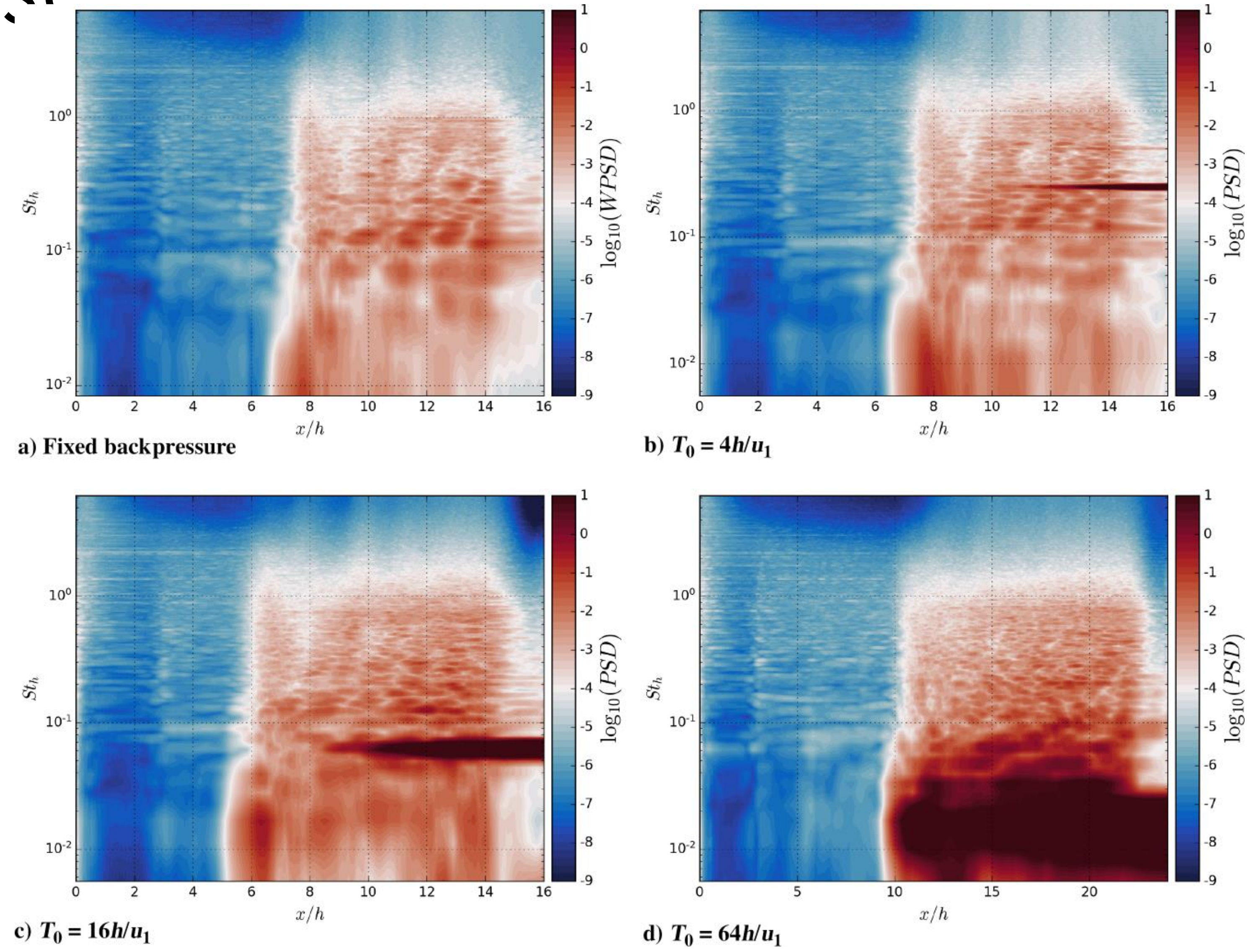
b) $T_0 = 4h/u_1$

c) $T_0 = 16h/u_1$

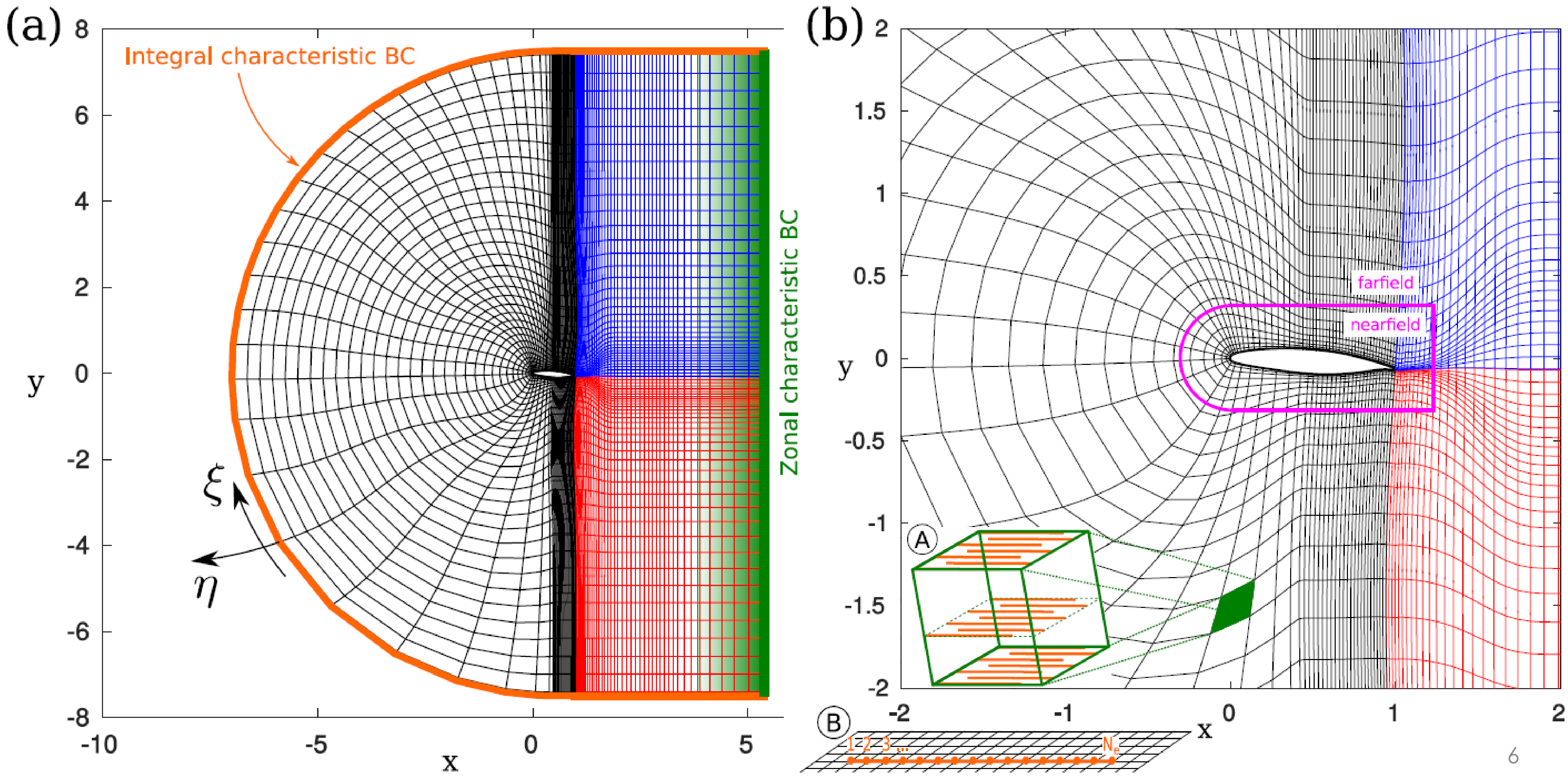
d) $T_0 = 64h/u_1$

PSD of response

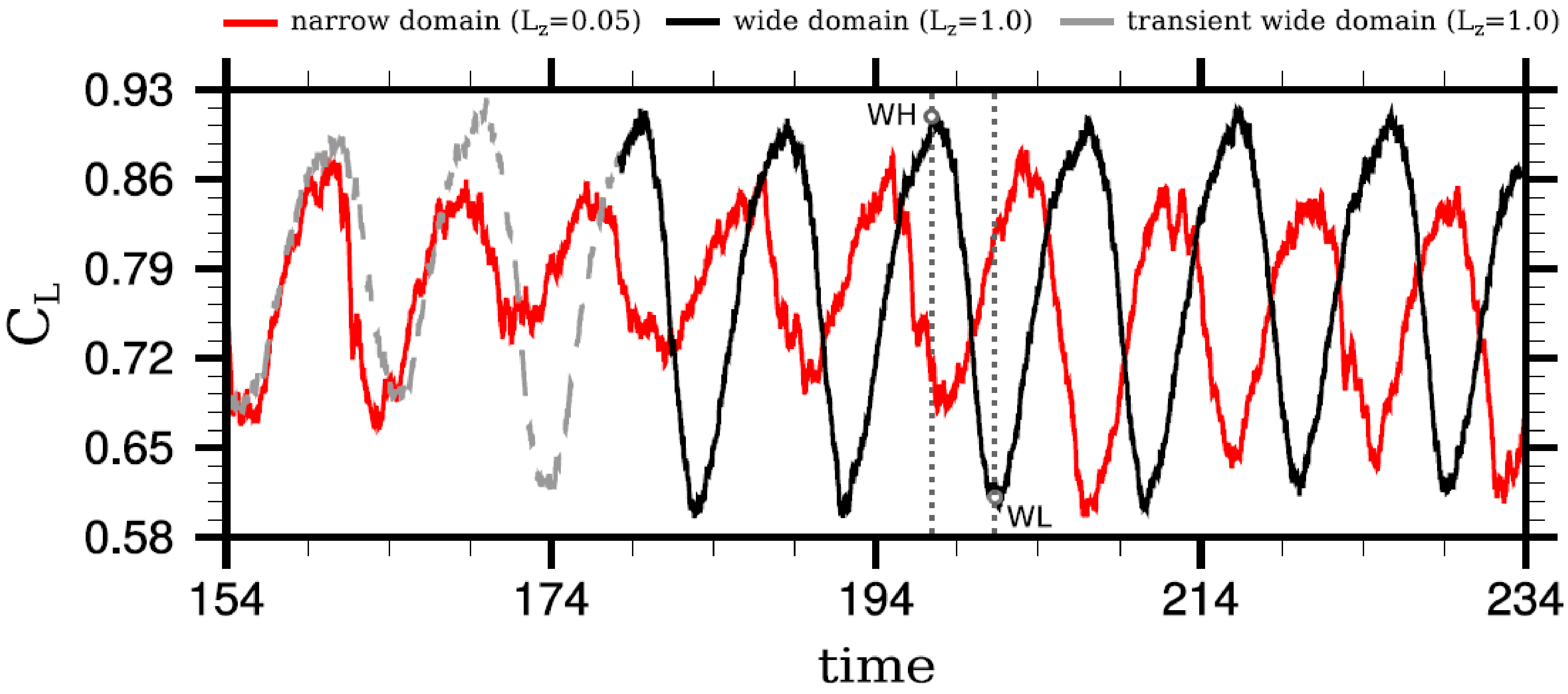
- Low-f mode present under leading shock foot
- Independent of back pressure forcing until frequencies match, then amplified



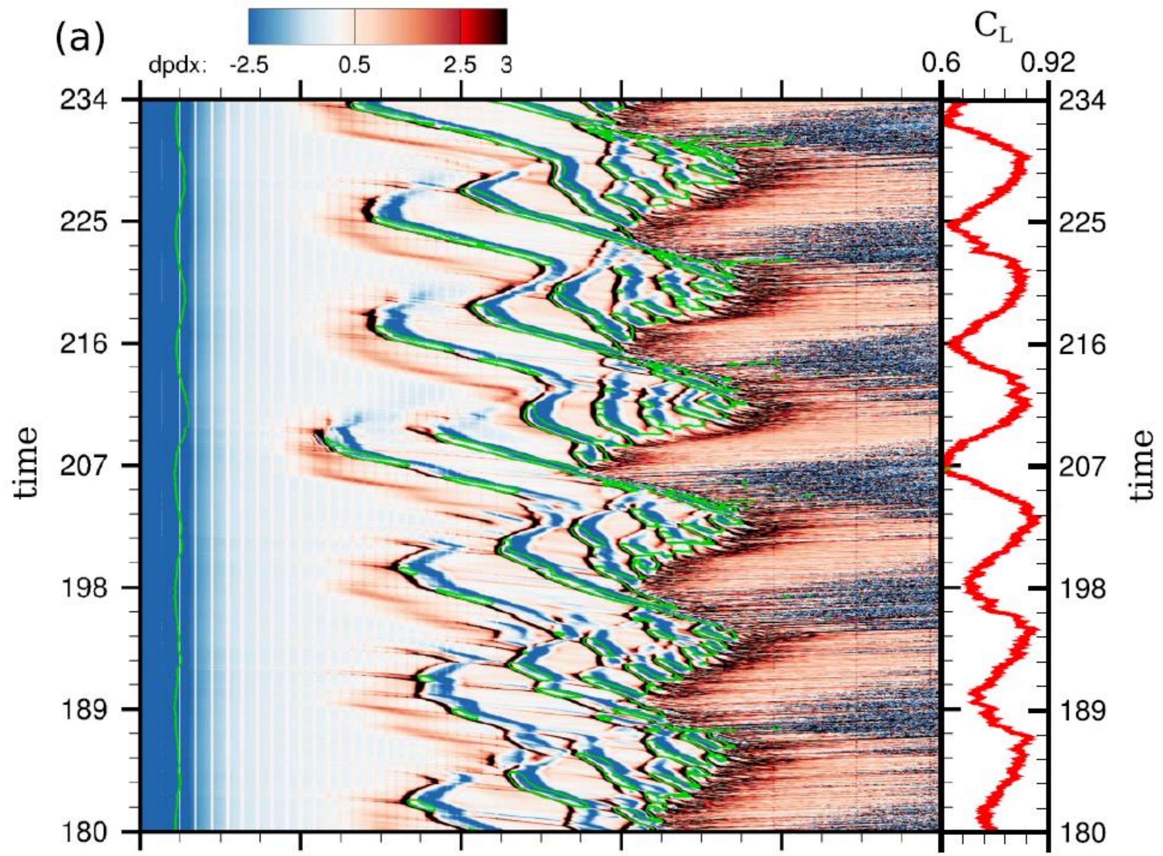
LES of transonic buffet (Zauner PRF 2020)



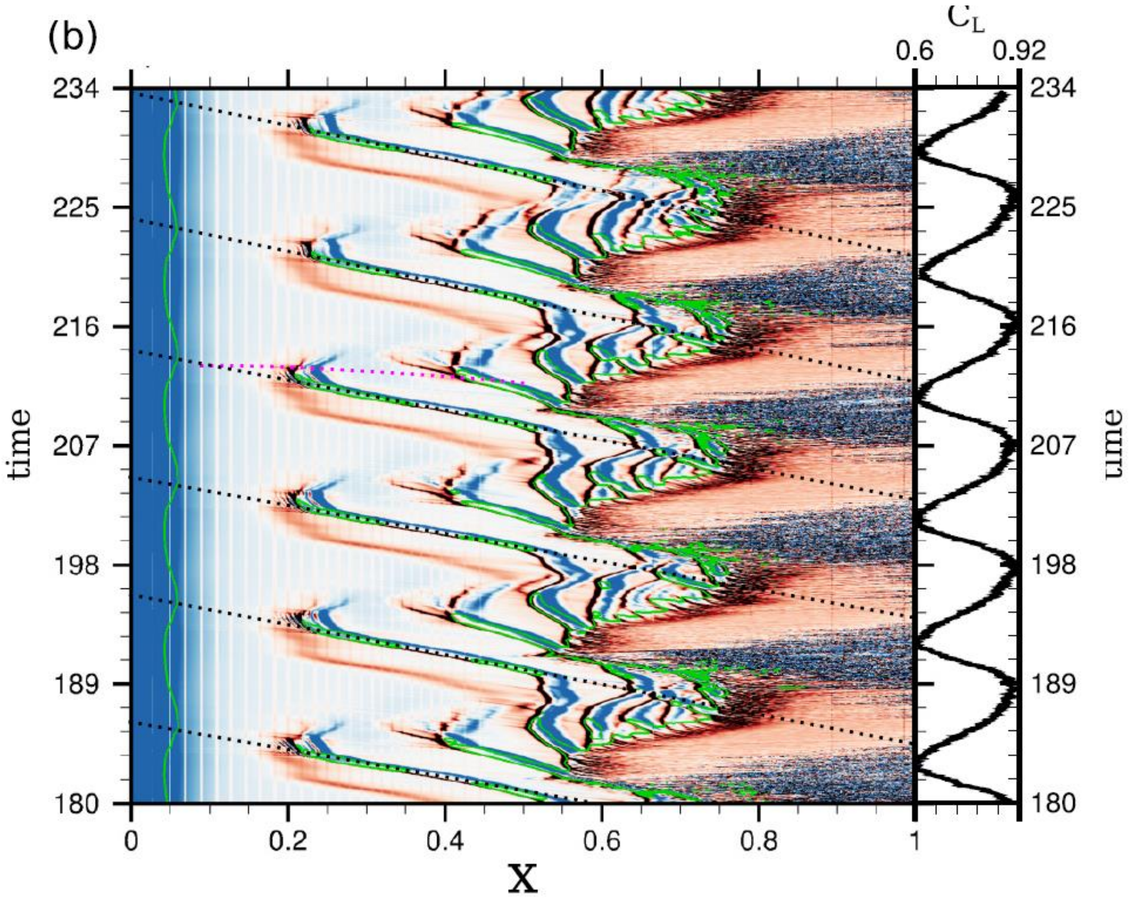
Lift variation with time during buffet



x-t diagrams



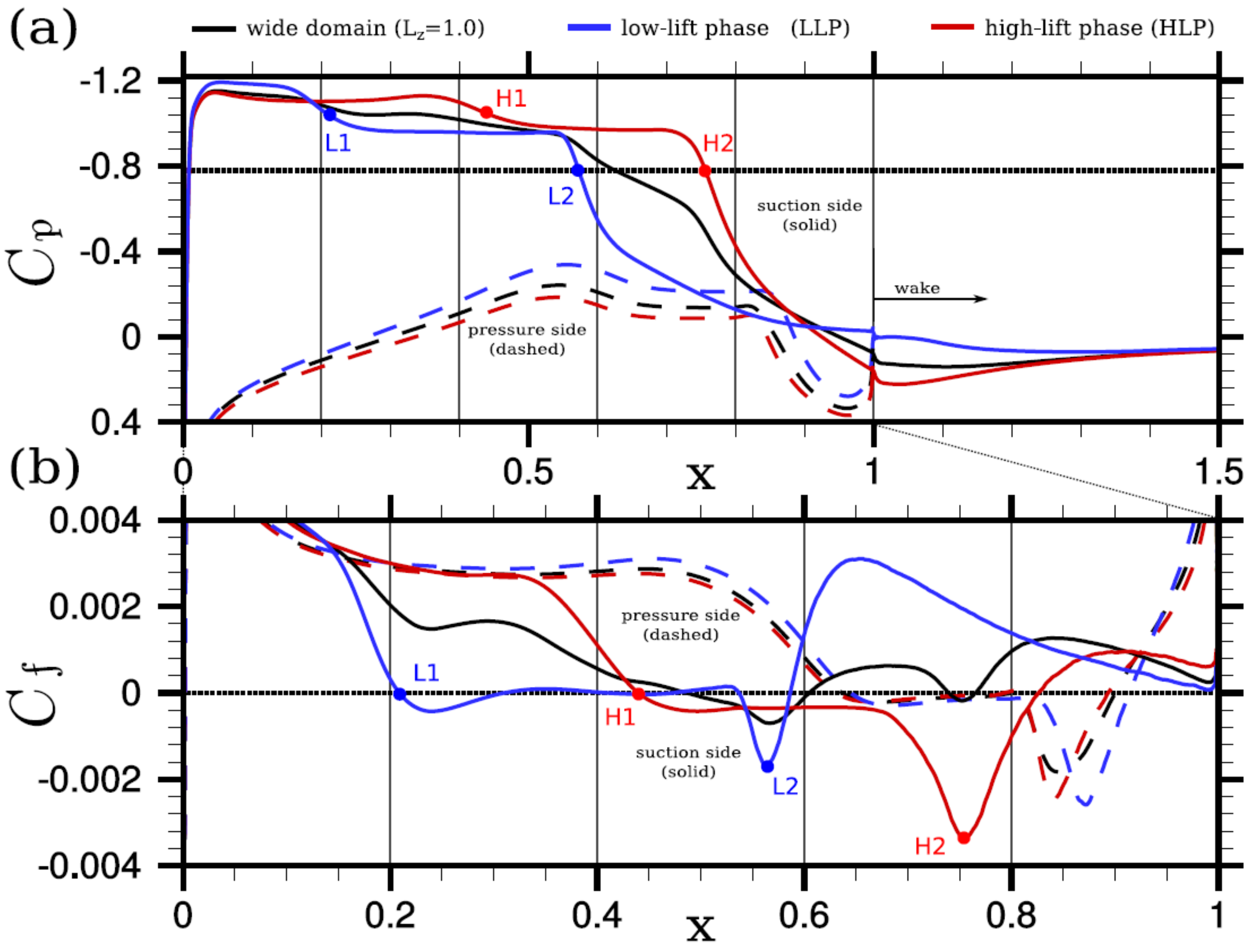
Narrow domain



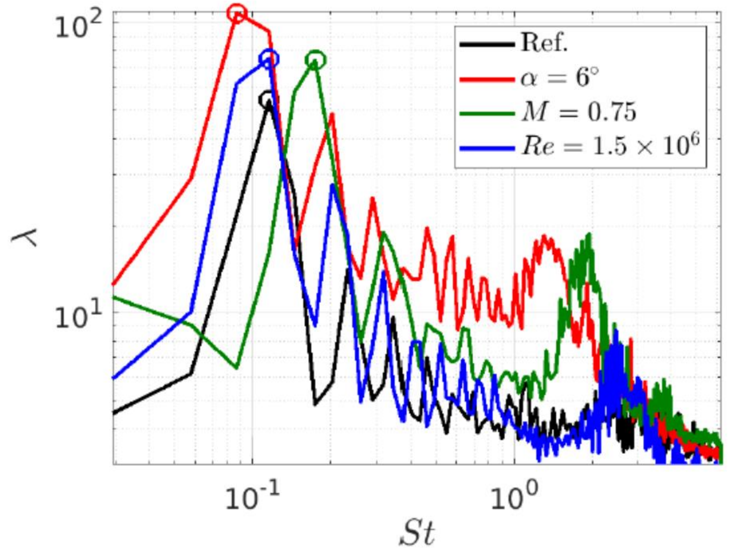
Wide domain

Sonic line in green

Pressure and skin friction



SPOD spectrum and reconstruction (buffet mode)



SPOD spectrum

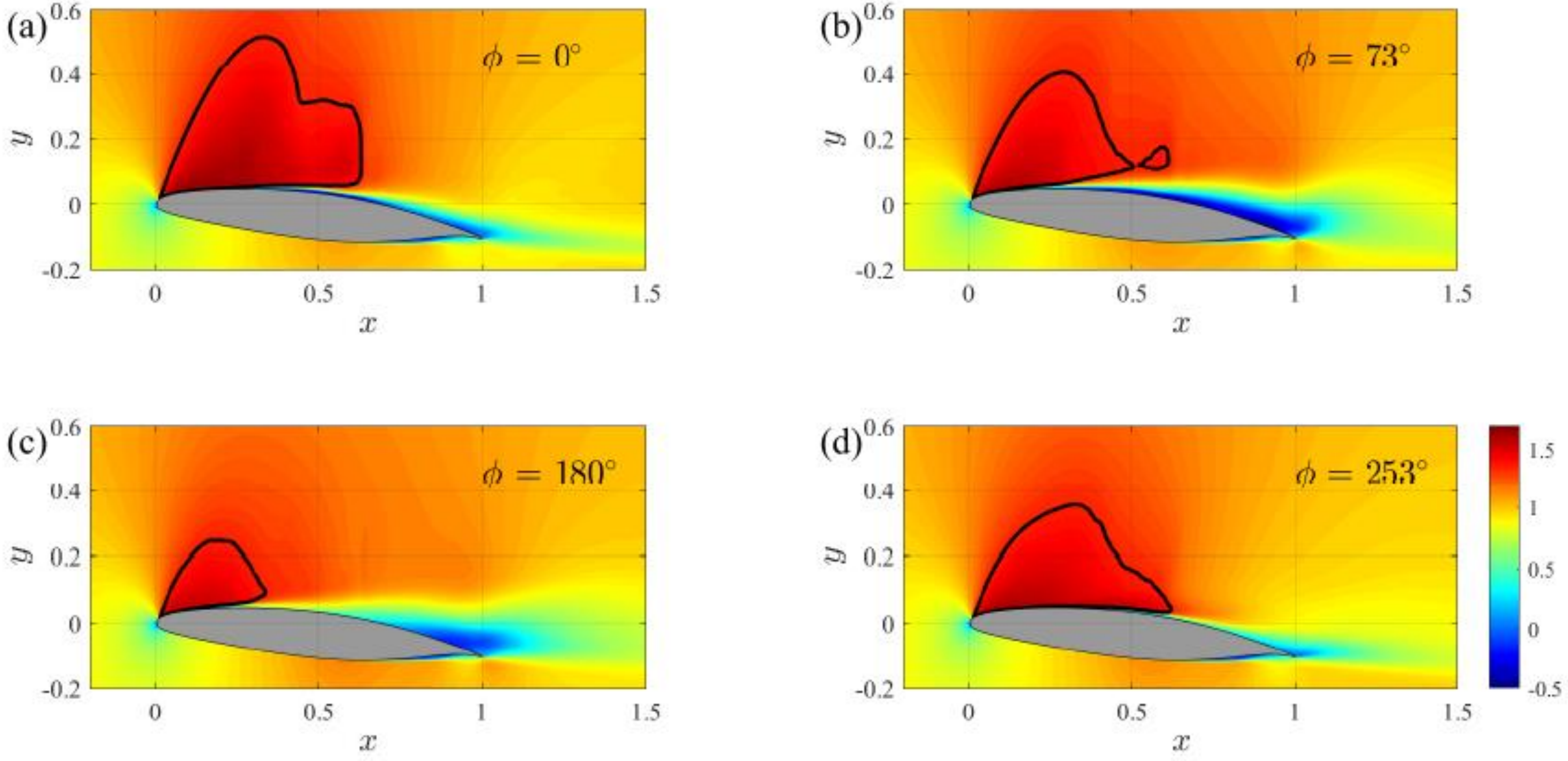


Figure 26: Reconstructed flow field based on the buffet mode for $\alpha = 6°$ shown using axial velocity contour at (a) high-lift, (b) low-skin-friction-drag, (c) low-lift, and (d) high-skin-friction-drag phases. The sonic line is highlighted using a black curve.

SPOD reconstruction (wake mode)

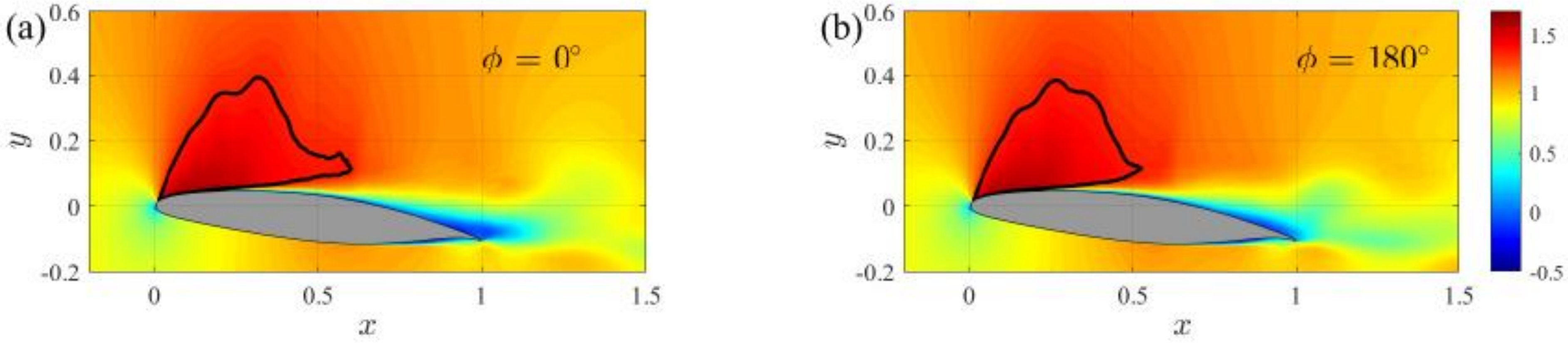
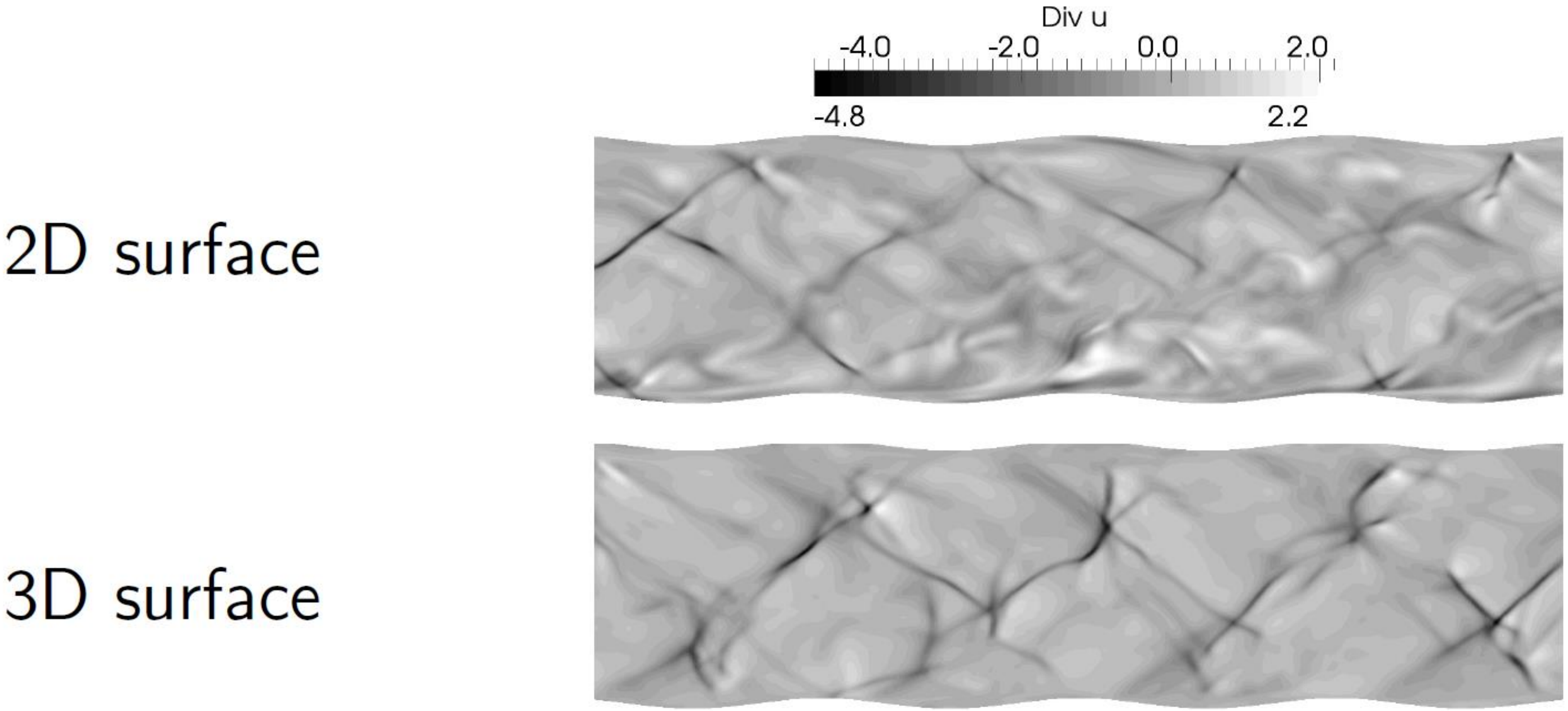


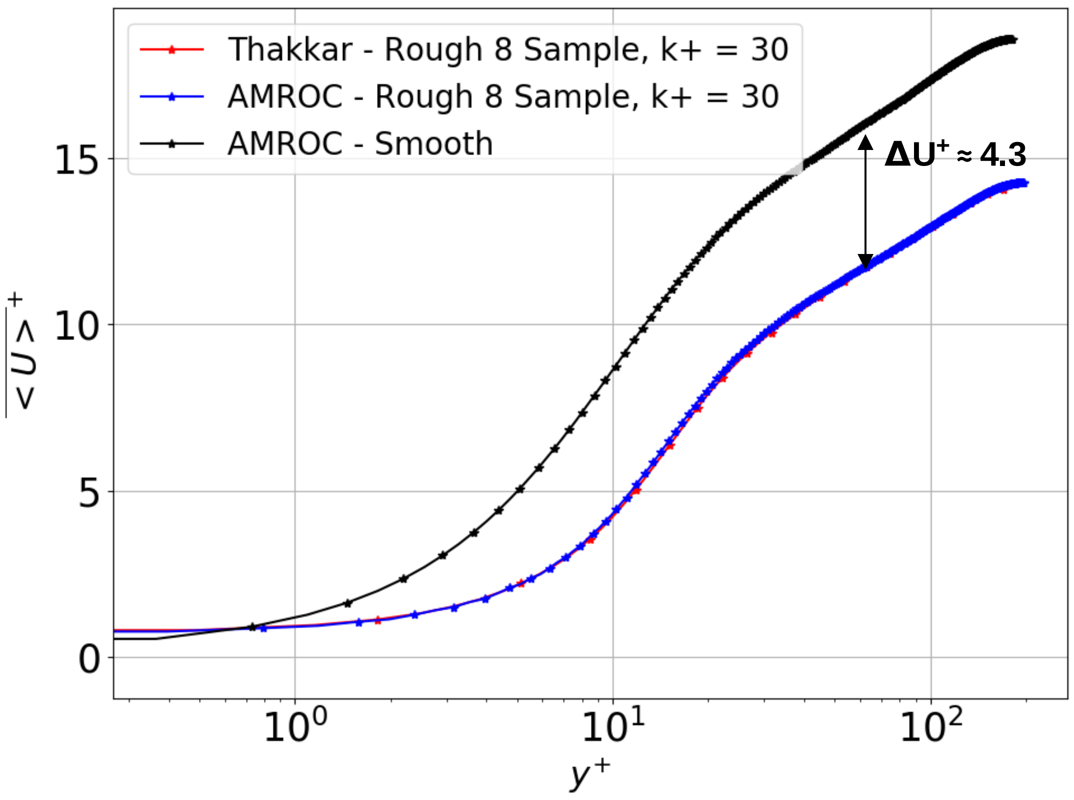
Figure 28: Reconstructed flow field based on the wake mode for $\alpha = 6°$ shown using axial velocity contour at (a) high- and (b) low-lift phases. The sonic line is highlighted using a black curve.

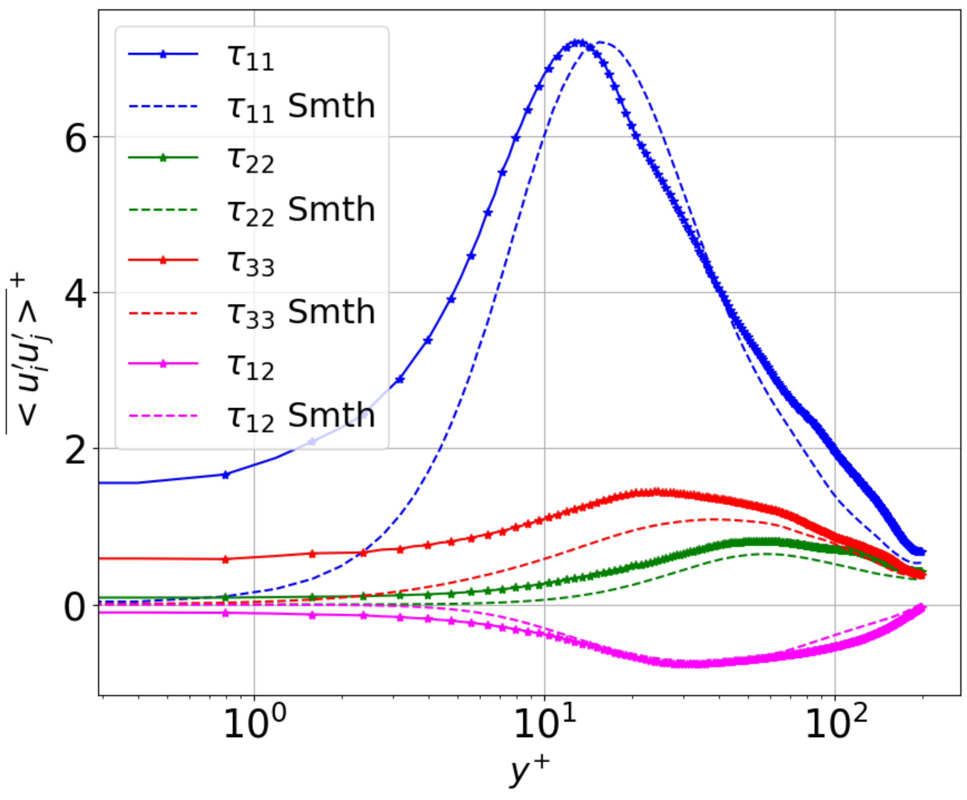
Compressible flow over wavy (Tyson) and rough (Tan) walls

Instantaneous $\nabla \cdot \mathbf{u}$ for 0.04 amplitude surfaces



Rough Channel Results – S8 at M_b = 0.1 and Re_b = 5790



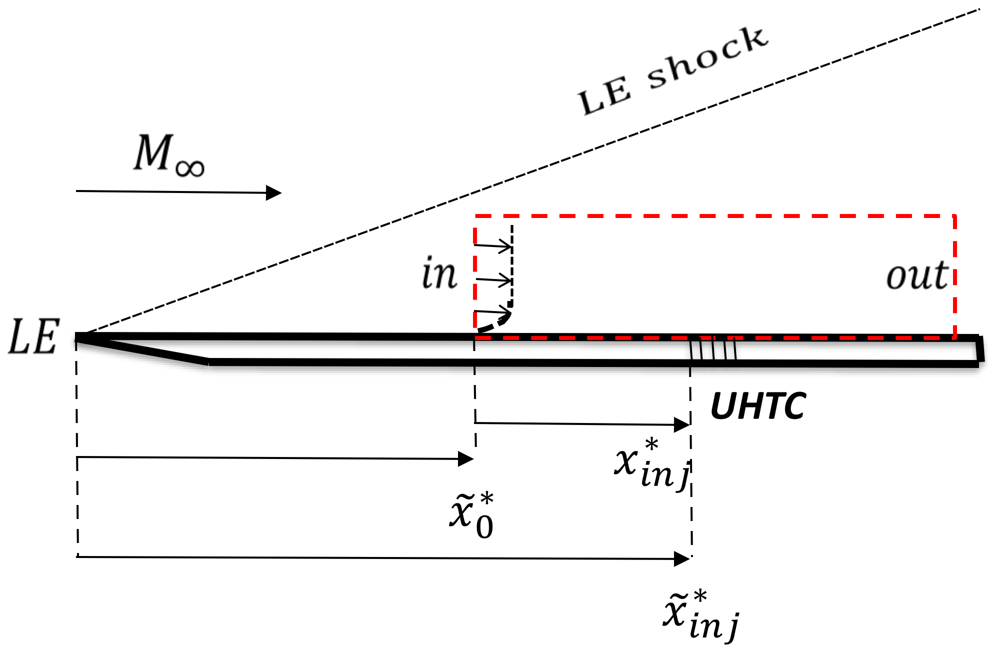


Numerical Set-up for transpiration cooling

Continuation of Adriano Cerminara's work

The set-up conditions:

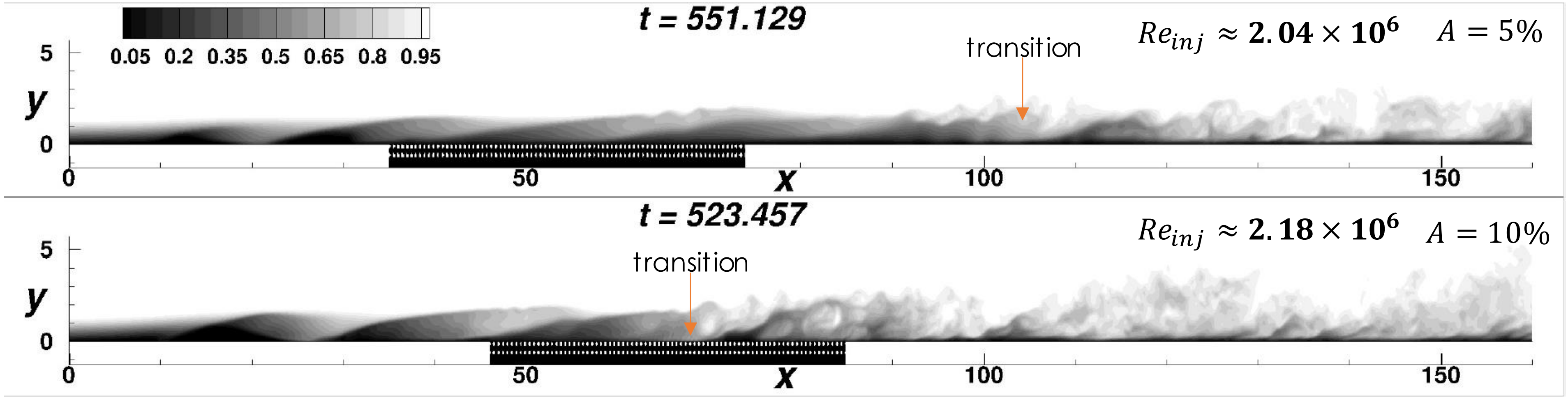
- $T^*_{0,\infty} = 460.0\ K$
- $T^*_{\infty} = 76.66\ K$
- $p^*_{0\infty} = 864\ kPa$
- $p^*_{\infty} = 1632.99\ kPa$
- $M_{\infty} = 5$
- $U_{\infty} = 877.5\ m/s$
- $\mu_{\infty}(T^*_{\infty}) = 5.2 * 10^{-6} \frac{Kg}{m\ s}$
- $\frac{Re}{m} = \frac{\rho_\infty U_\infty}{\mu_\infty} \sim 12.6 * 10^6$
- $Re_{\delta^*} = \frac{\rho_\infty U_\infty \delta^*}{\mu_\infty} \sim 12600\ ;\ \delta^* = 1mm$
- $\tilde{x}^*_0 = \ 127\ mm, \delta^* = 1mm$
- $Re_{inj} = 2.04 * 10^6$ (Experimental)
- $\tilde{x}^*_{inj} = \frac{Re_{inj}}{\frac{Re}{m}} = 162\ mm$
- $x^*_{inj} = \ 162 - 127 = 35\ mm$



Schematic of the computational domain for DNS with porous layer (UHTC experiments at Oxford, *Hermann et. al., 2018*)

Transition location

- The amplitude of excitation is selected such that the transition location for no blowing cases (as reported in the experiments **[1]**)
  1. is located after the porous sample for $Re_{inj} \approx \mathbf{2.04 \times 10^6}$
  2. is located over the porous sample for $Re_{inj} \approx \mathbf{2.18 \times 10^6}$

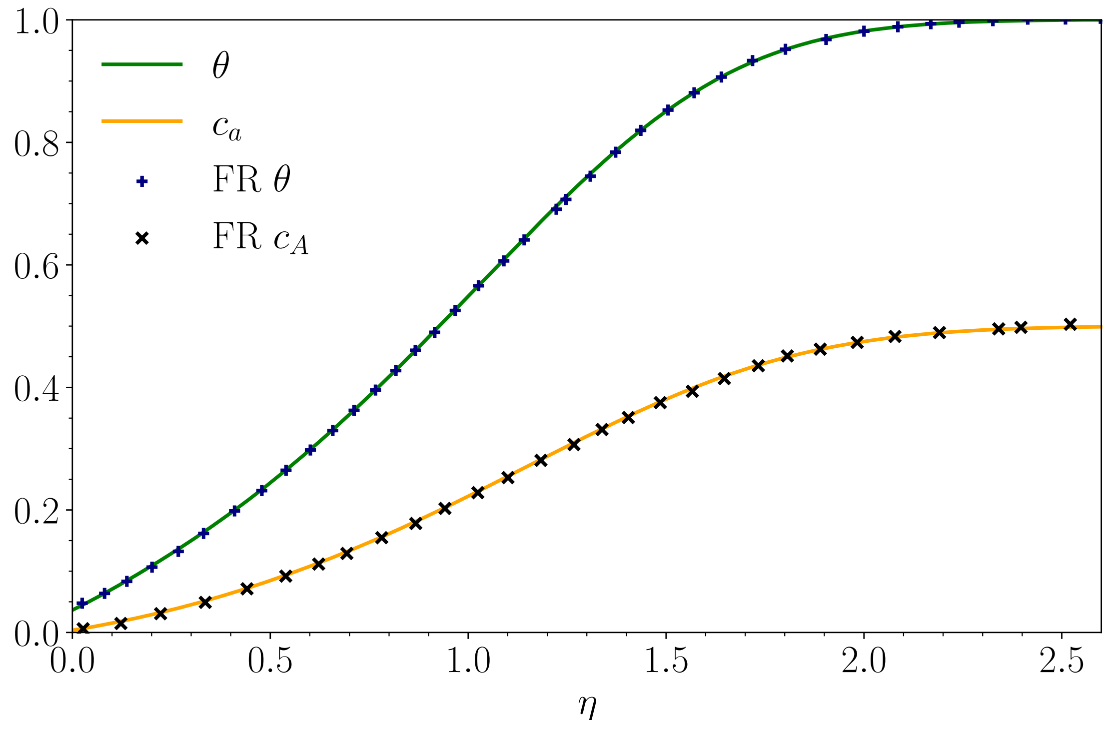


1. Hermann, T., Ifti, H. S., McGilvray, M., Doherty, L., and Geraets, R. P., 2018.Mixing characteristics in a hypersonic flow around a transpiration cooled flat-plate model, International Conference on High-Speed Vehicle Science and Technology, Moscow, Russia, 2018

Thermo-chemical non-equilibrium

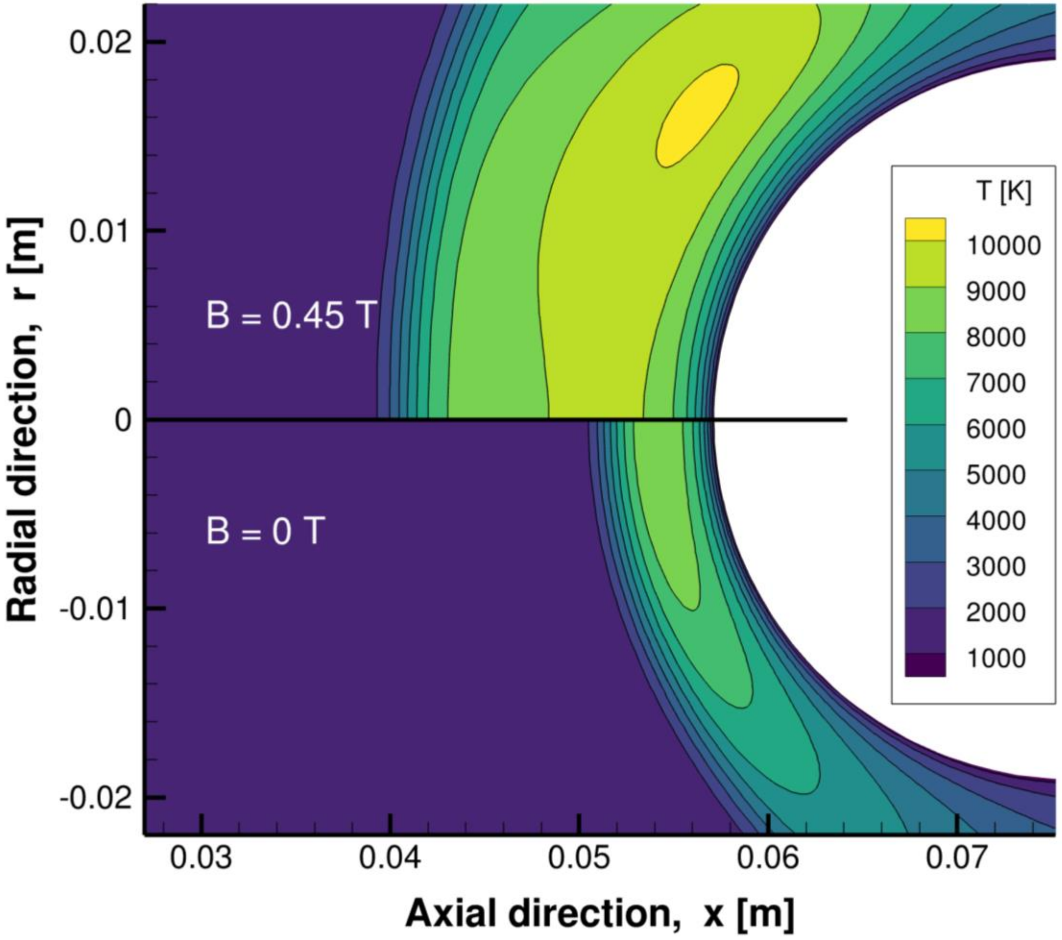
Teja Ala and Ali Musawi

- Target: DNS transition to turbulence with 5-species air model and vibrational non-equilibrium
- Start point: stagnation point flow (Fay-Riddell) and OpenSBLI implementation of non-equilibrium models



EU-MEEST project: radio blackout during entry

- M=4.75 Argon flow over hemisphere-cylinder with internal magnet
- 3 species Argon chemistry
- HANSA code
- Effect of magnetic field



Codes

- SBLI/OpenSBLI (Excalibur project ongoing)
  - current PhD and postdoc vacancies
- AMROC: adaptive meshing C++, 5-species air chemistry, thermal nonequilibrium (Clawpack hyperbolic solvers, Mutation++ thermodynamic data)
- HANSA: fully nonequilibrium, including ionisation