

High-Resolution 3D CFD Simulations of Wind Turbine Aerofoils with 3D Scanned Leading Edge Roughness

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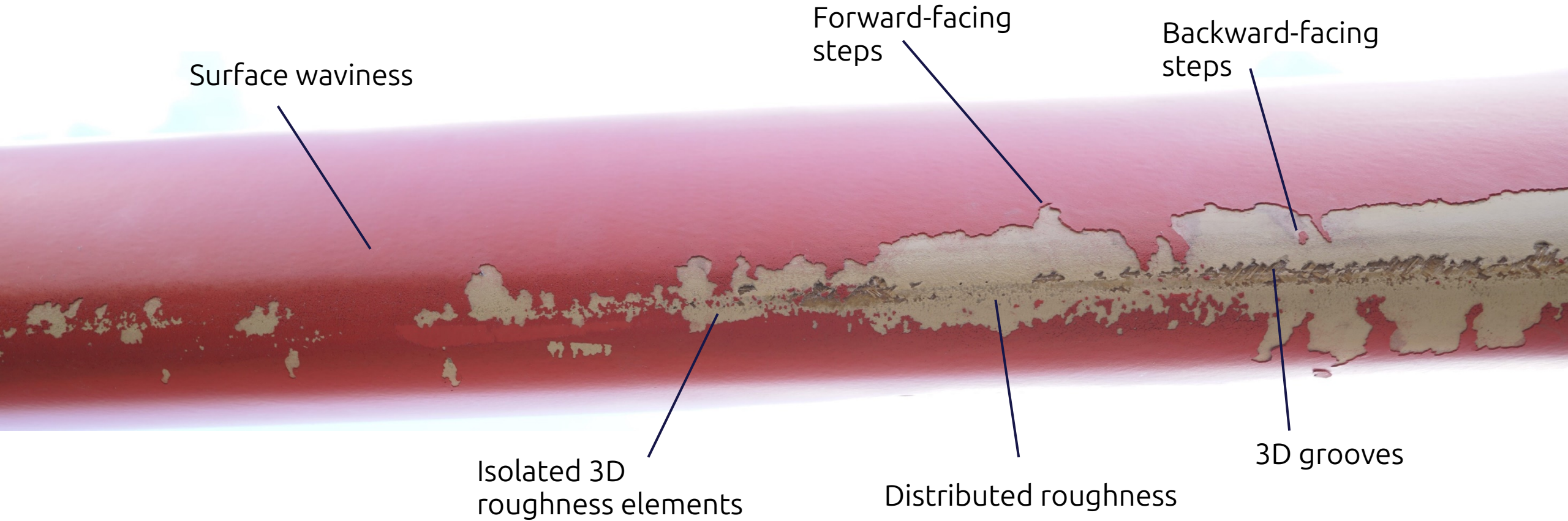
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Wind turbine blade leading edge roughness



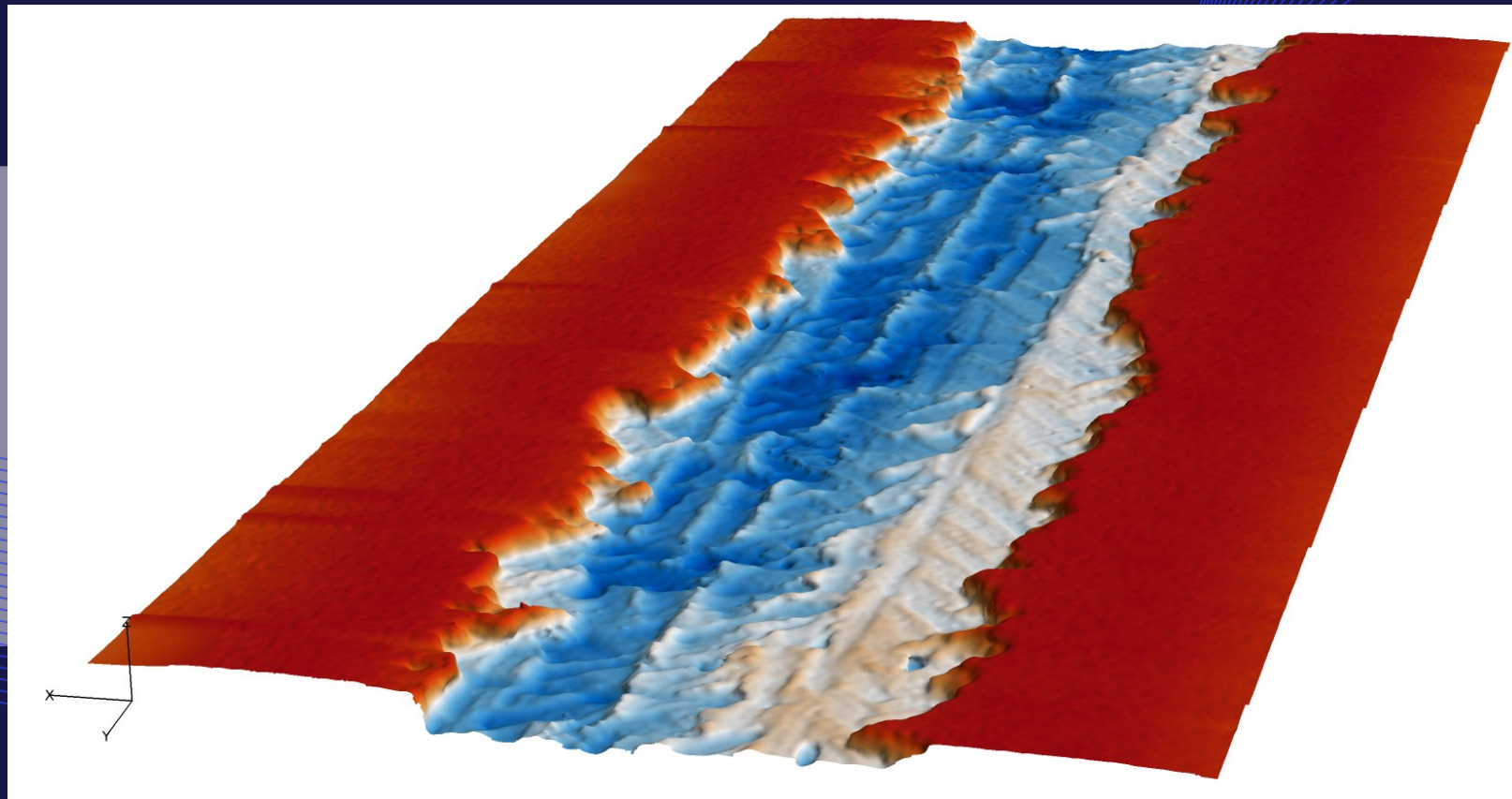
Wind turbine blade leading edge roughness



+ contamination (insects, pollen ..)

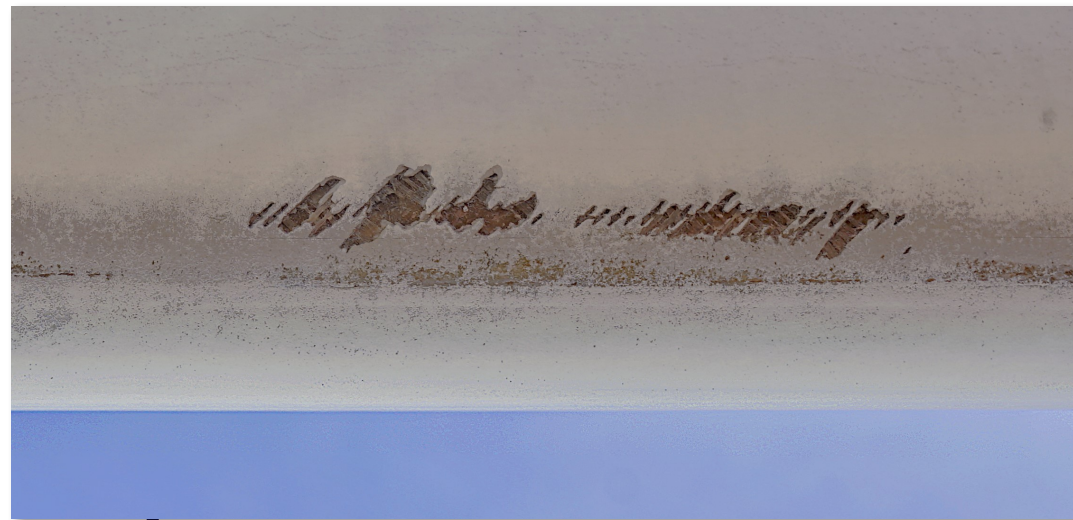


Digital LER



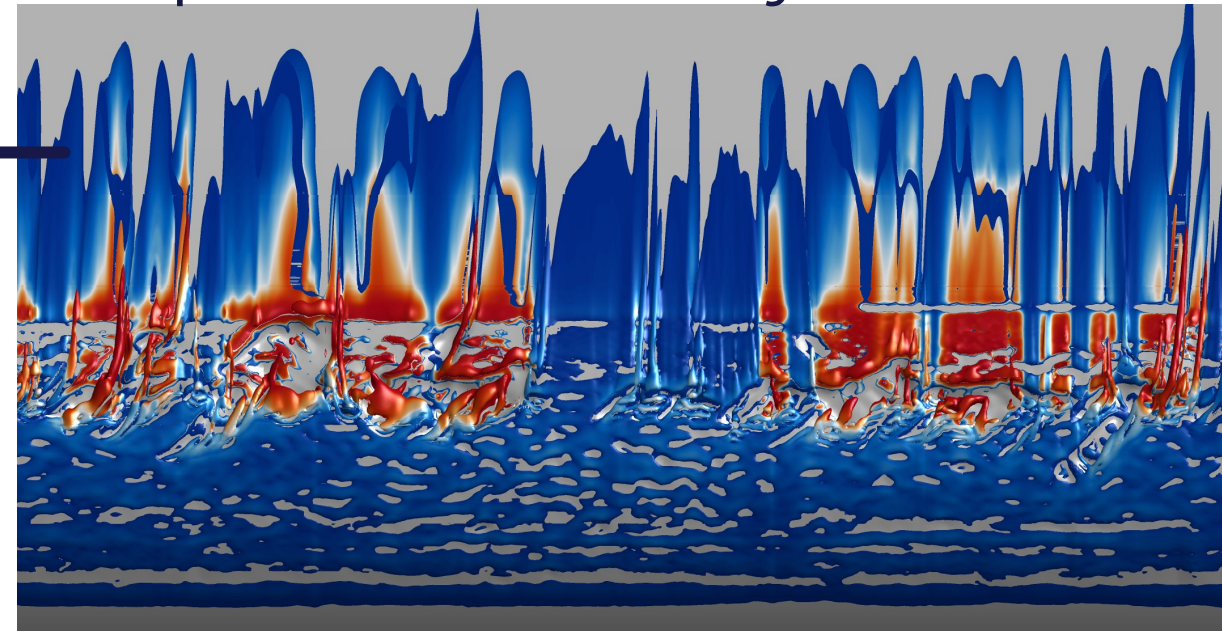
LERCat

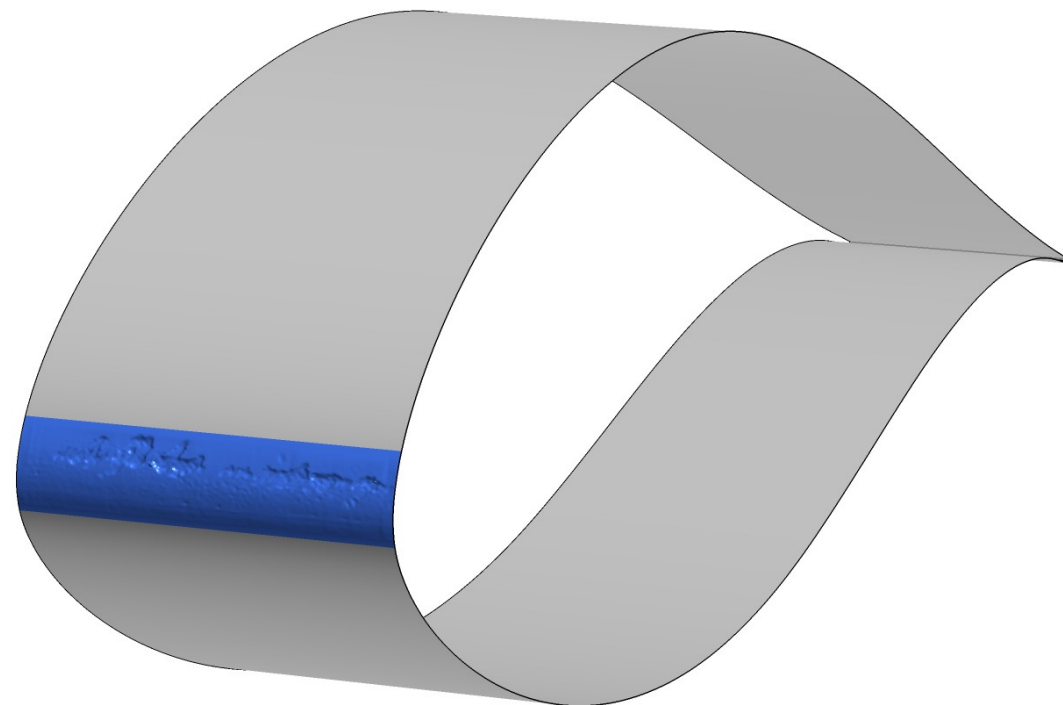
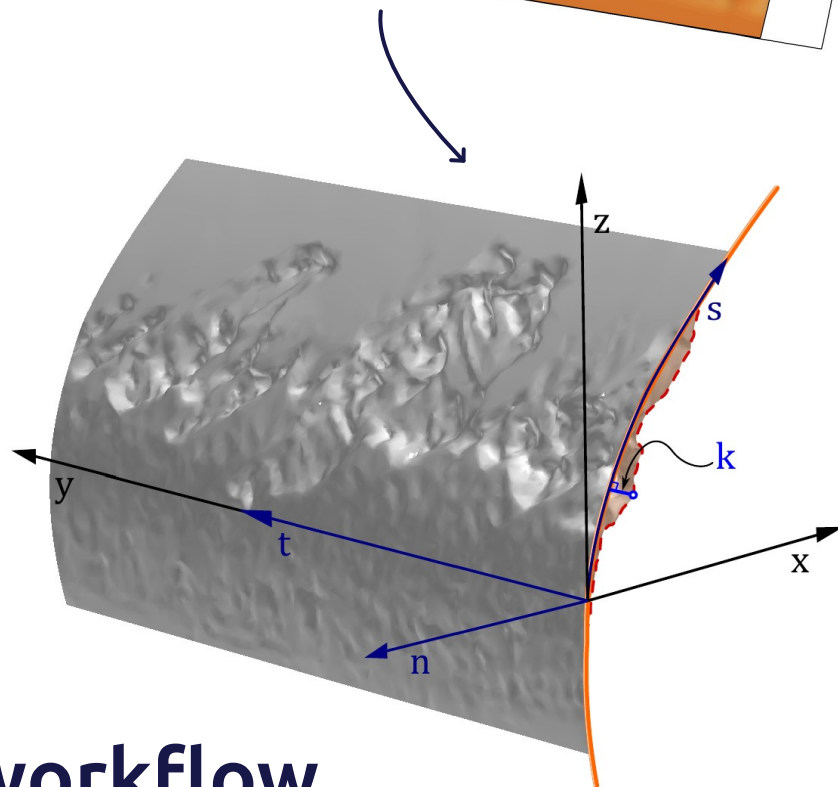
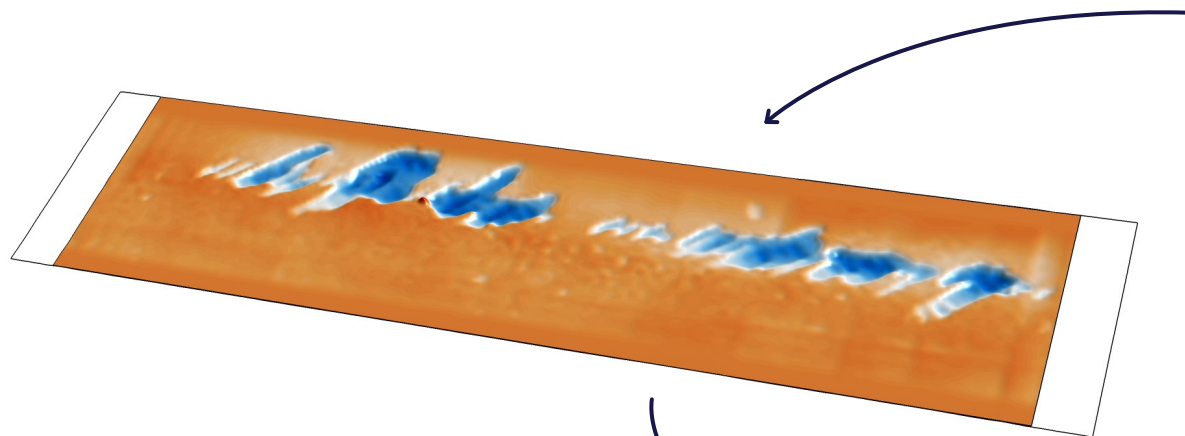
Aerodynamic assessment



Wind tunnel

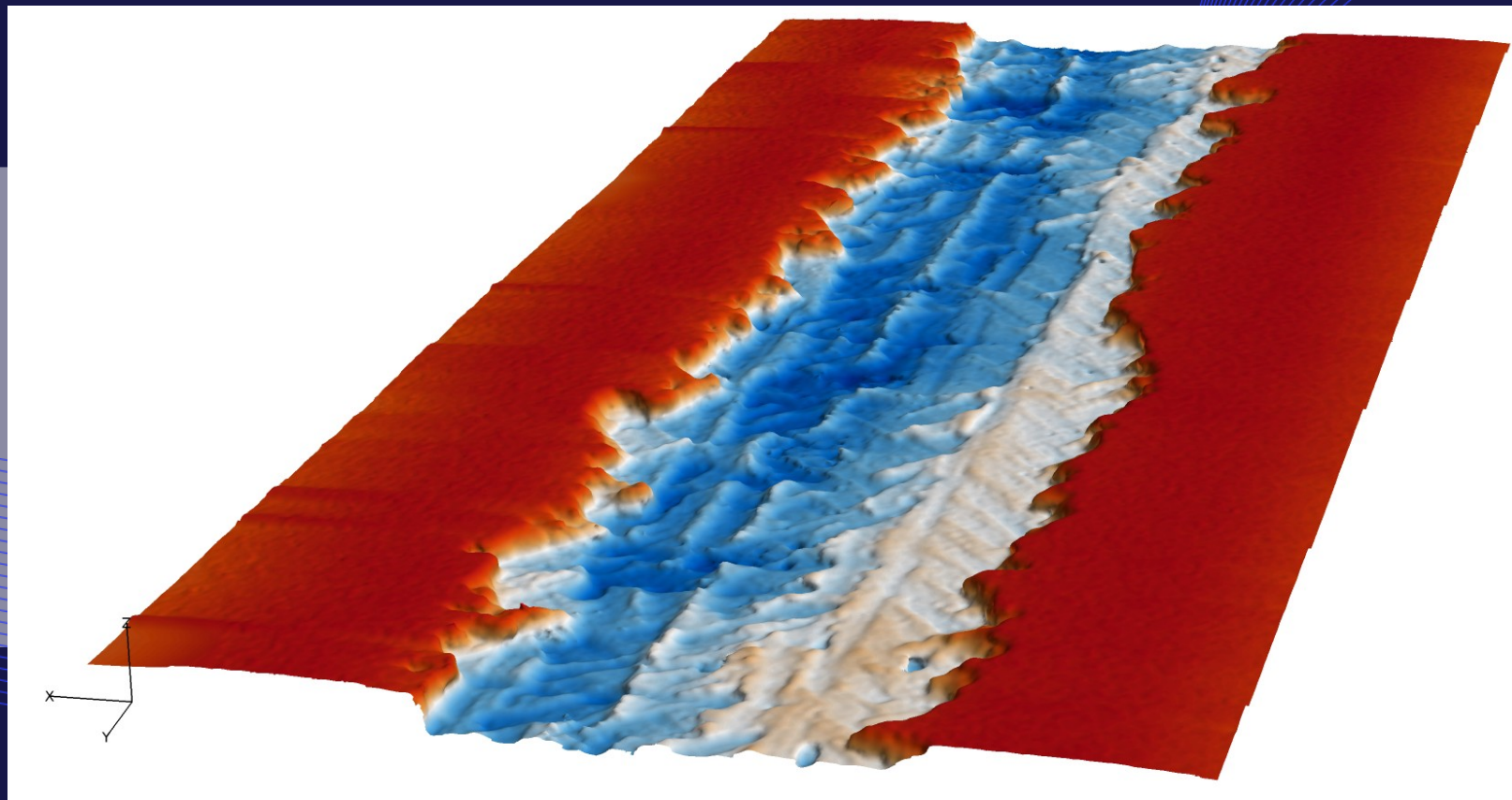
Computational Fluid Dynamics





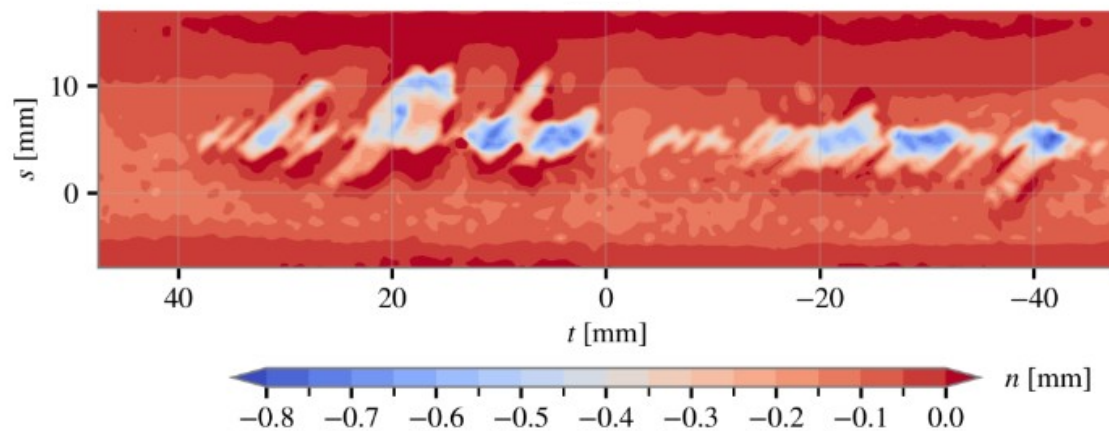
LERCat Digital LER workflow

LER Test Cases

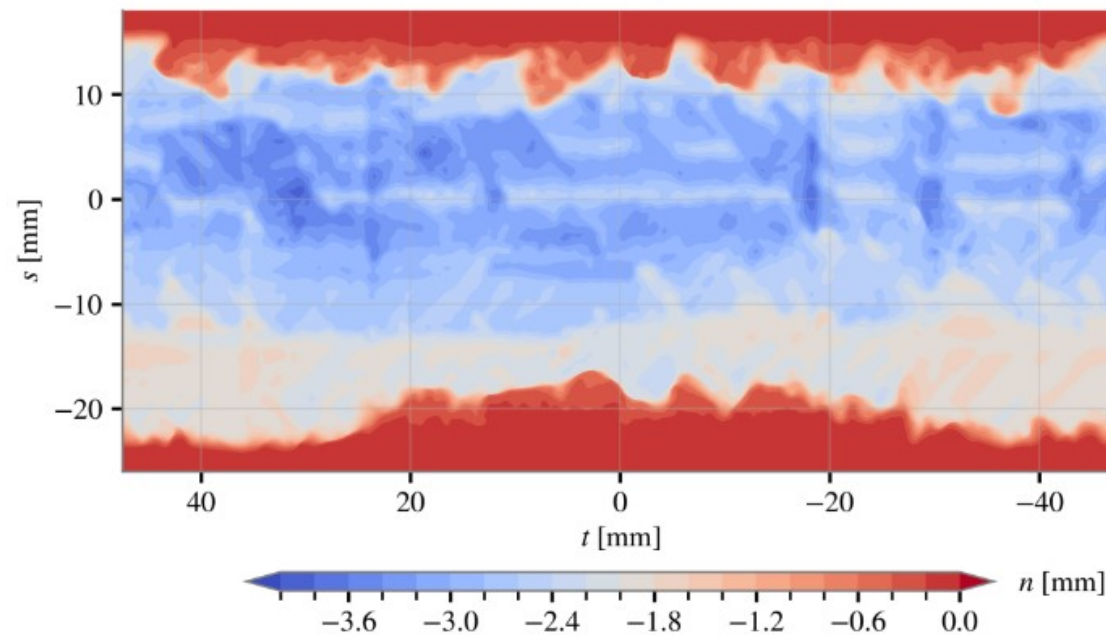


Erosion topographies

Mild erosion

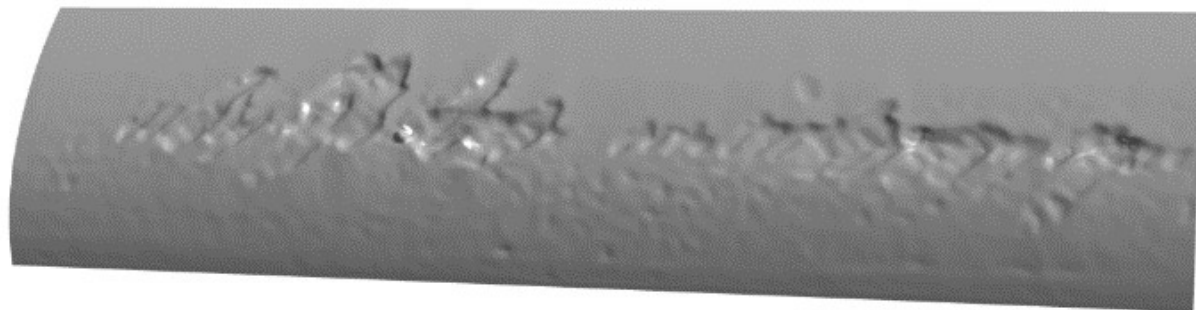
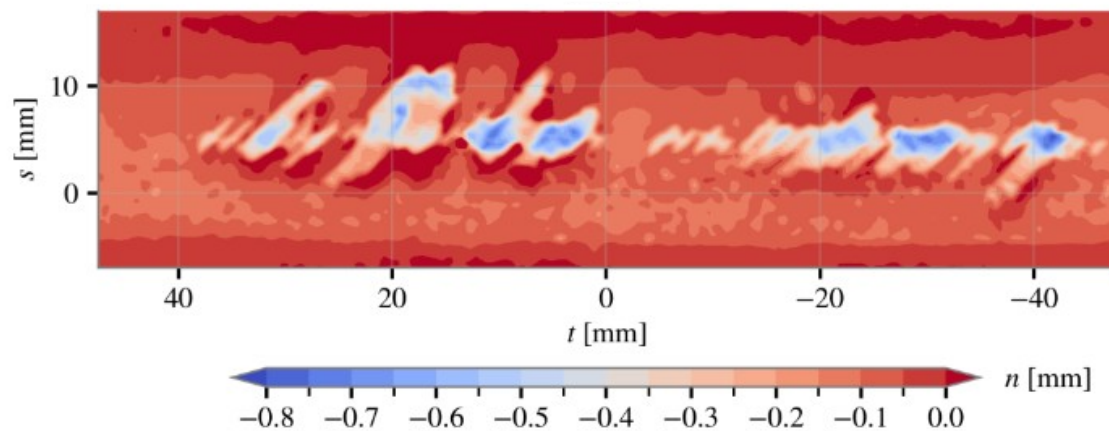


Severe erosion

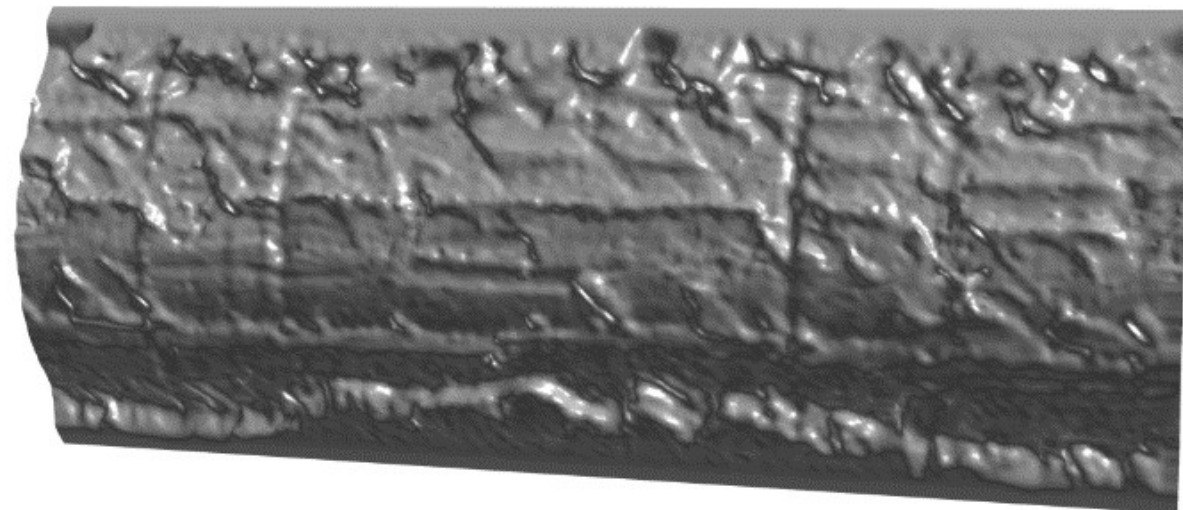
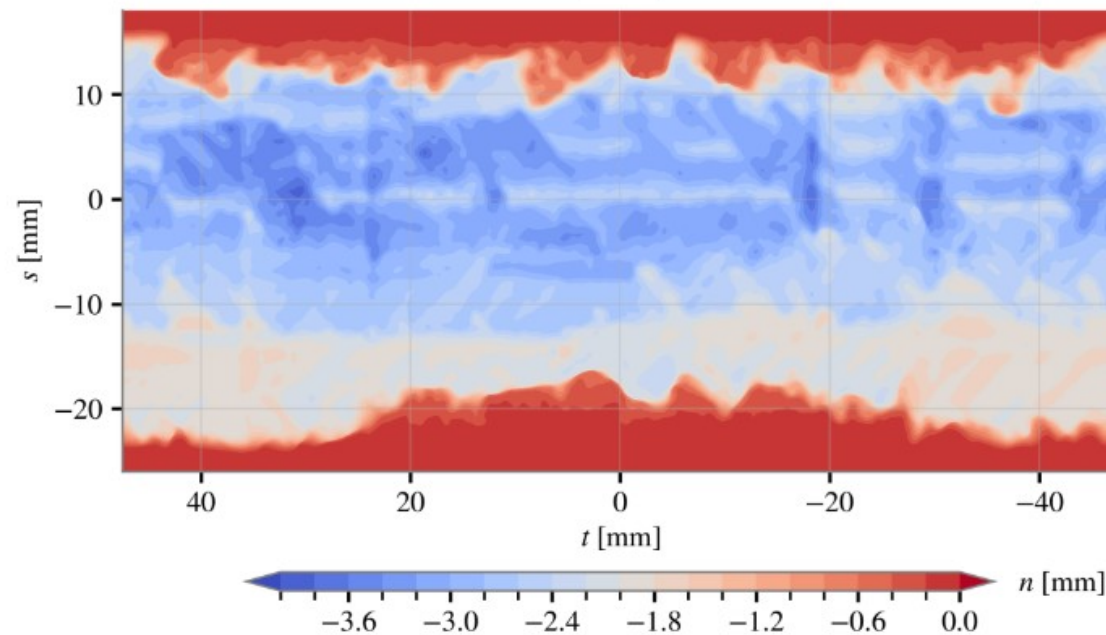


Erosion topographies

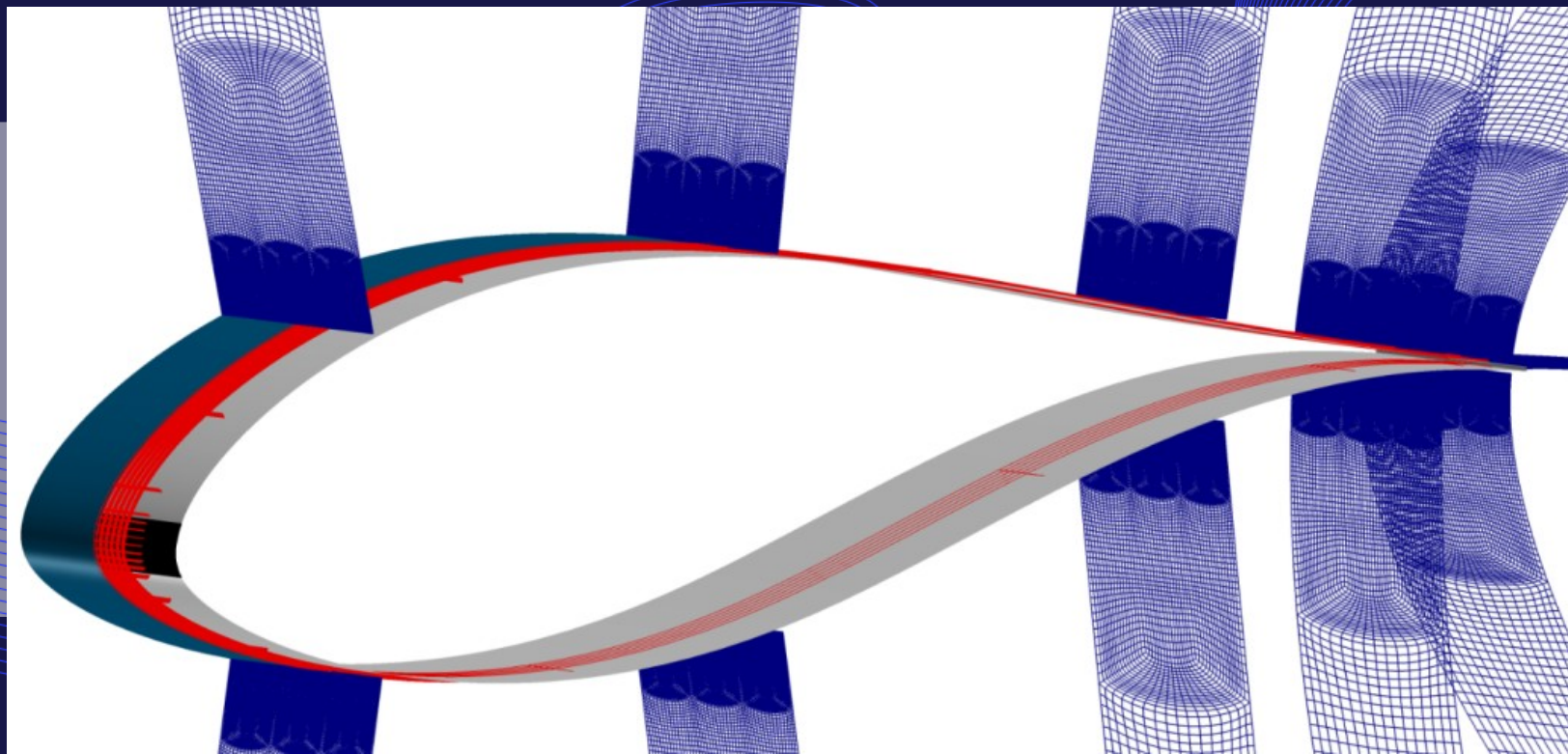
Mild erosion



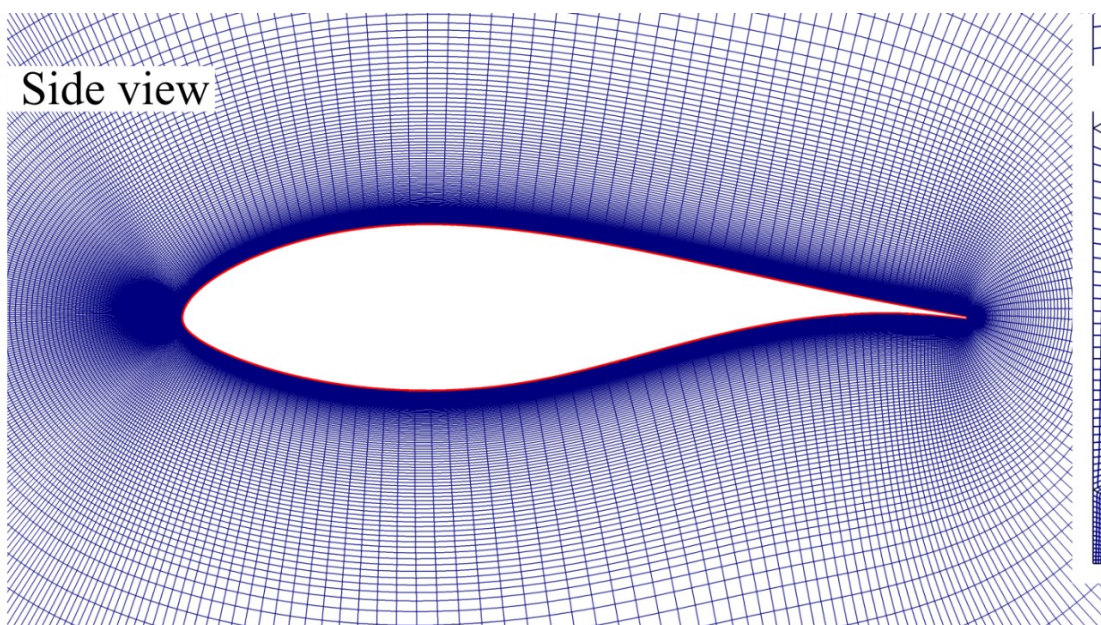
Severe erosion



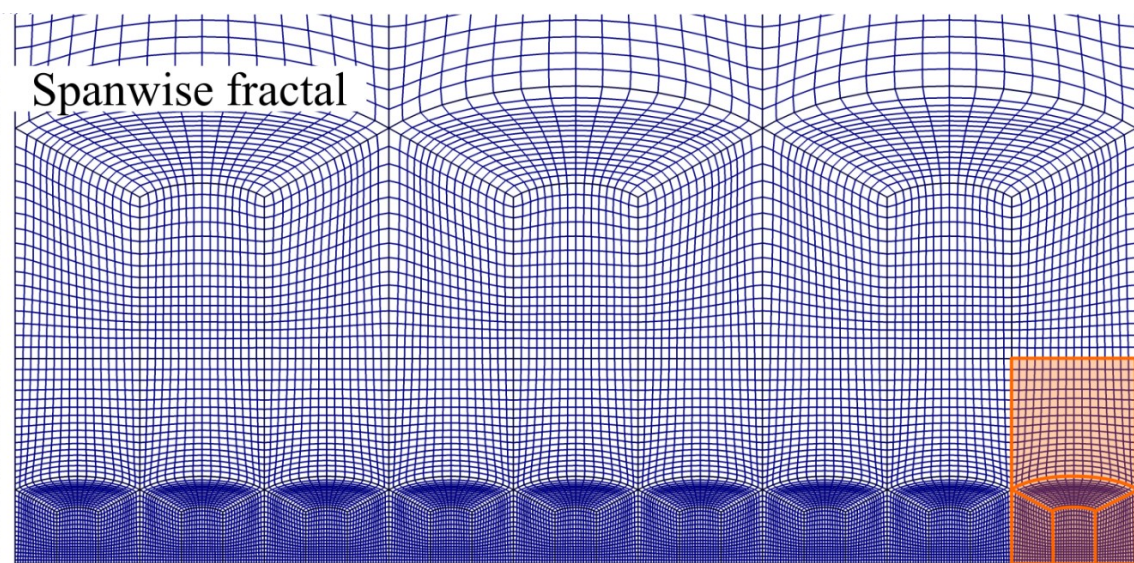
Computational Method



Side view



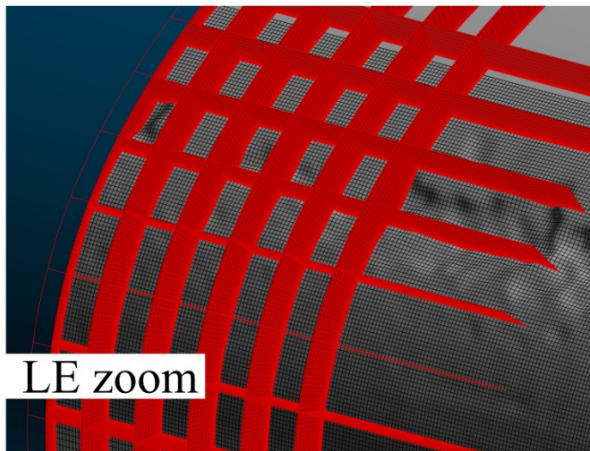
Spanwise fractal



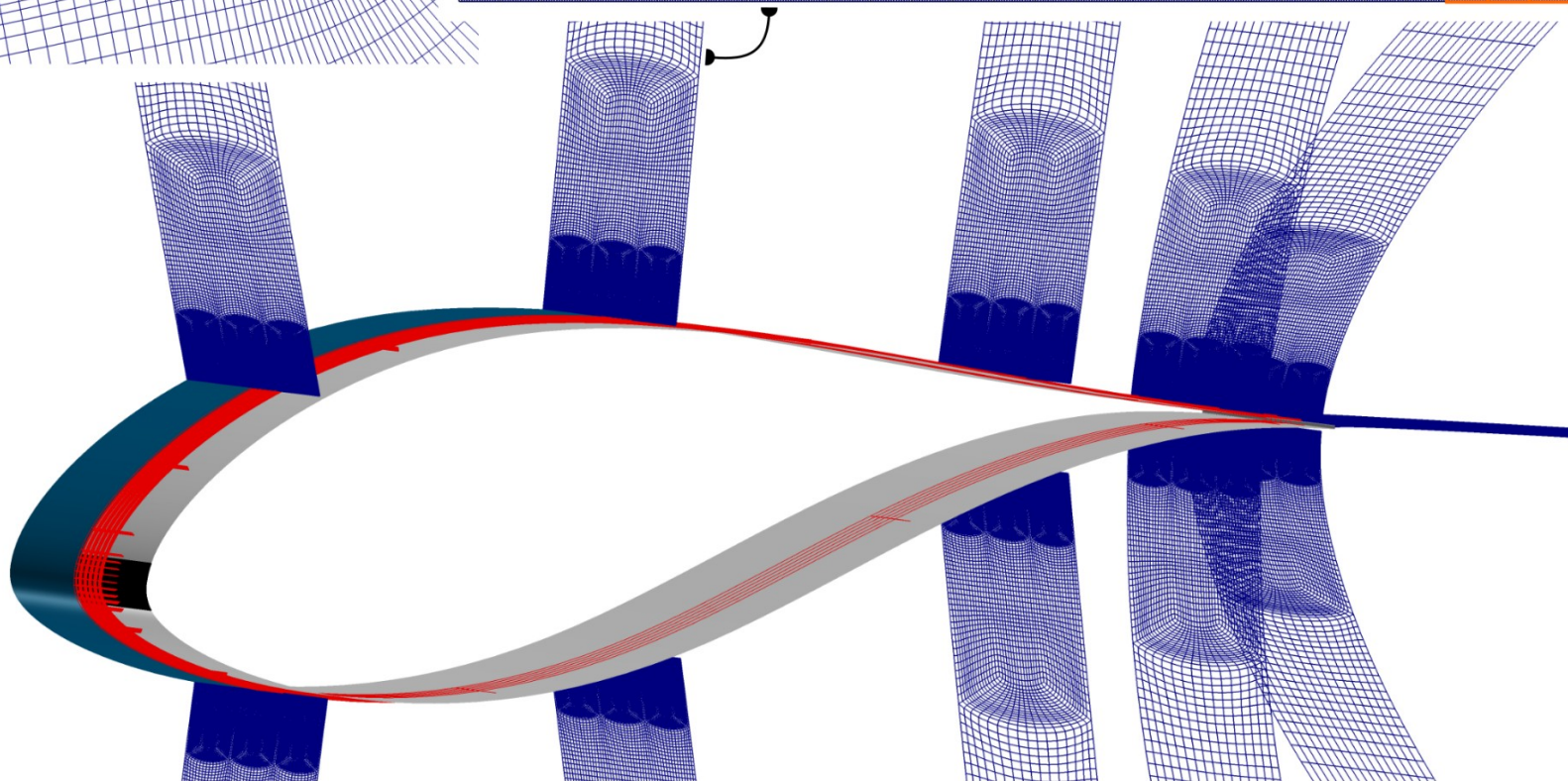
HypGrid2D + Fractal

HypGrid3D

HypGrid3D Target



LE zoom

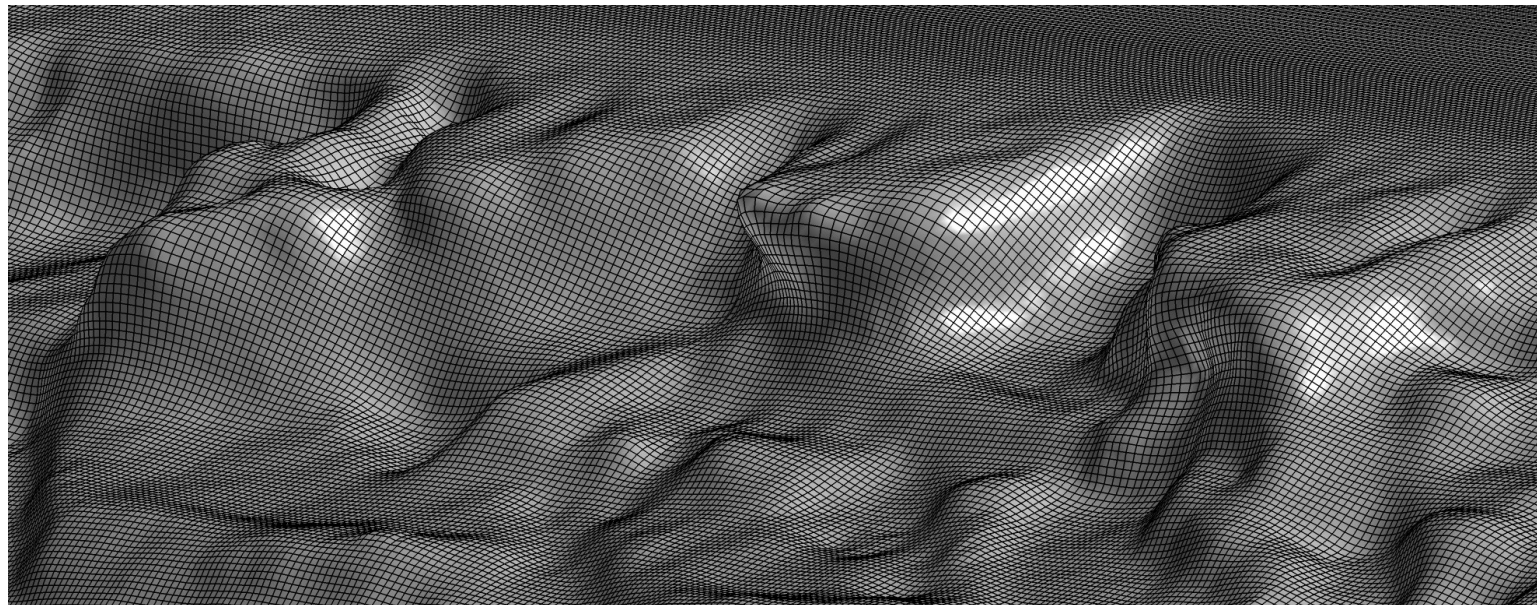


DTU Wind's EllipSys3D

- FV, structured, multiblock
- Incompressible
- SIMPLEC, QUICK schemes
- Steady-state RANS
 - k - ω SST (2003)
 - γ - $Re_{\theta t}$ transition model
 - Kato-Launder limiter
 - k , ω sustaining terms
 - BoostConv stabilisation

Simulations

- Python scripts using PyEllipSys + PyE2Dpolar
- $TI = 0.01\%$
- Chord-based $Re = [3.0e6, 6.0e6]$
- Reynolds number set through viscosity
- Inflow vector rotated with AoA



Mesh

Resolution

- 105 – 110 μm roughness resolution
- First normal cell height: $1e-6c$

Domain

- Hyperbolic mesh till $0.05c$
- Fractals at $1.10c$ and $1.15c$
- Spanwise extent $0.1c$
- O-mesh radius $45c$

Size

- Mild: 184 million (5616 blocks)
- Severe: 292 million (7020 blocks)

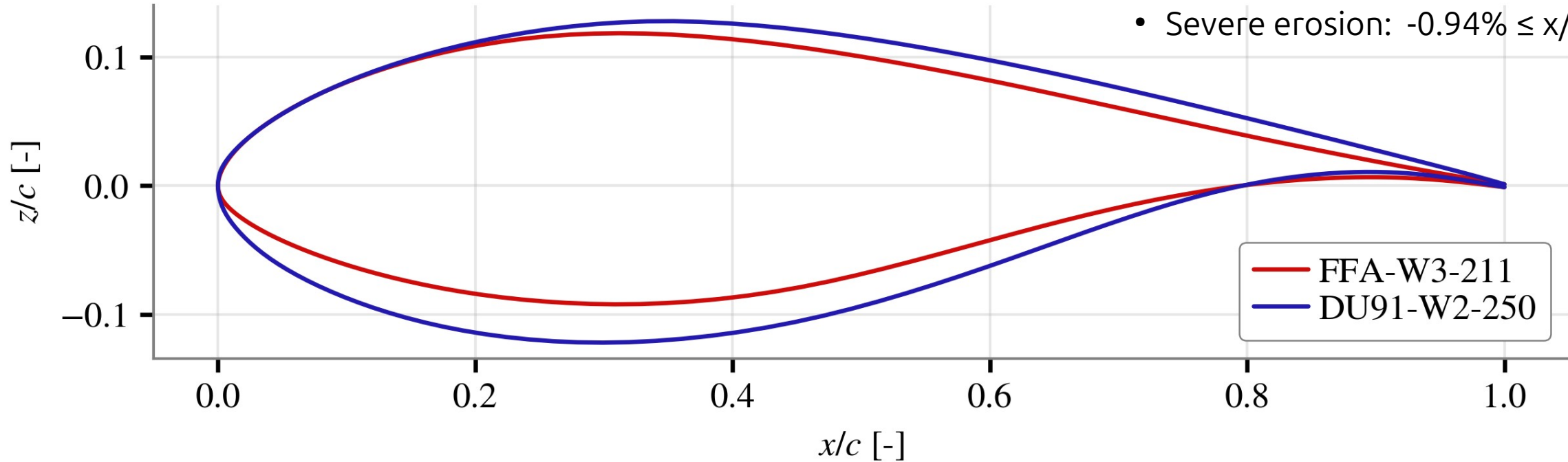
Open wind turbine aerofoils

FFA-W3-211

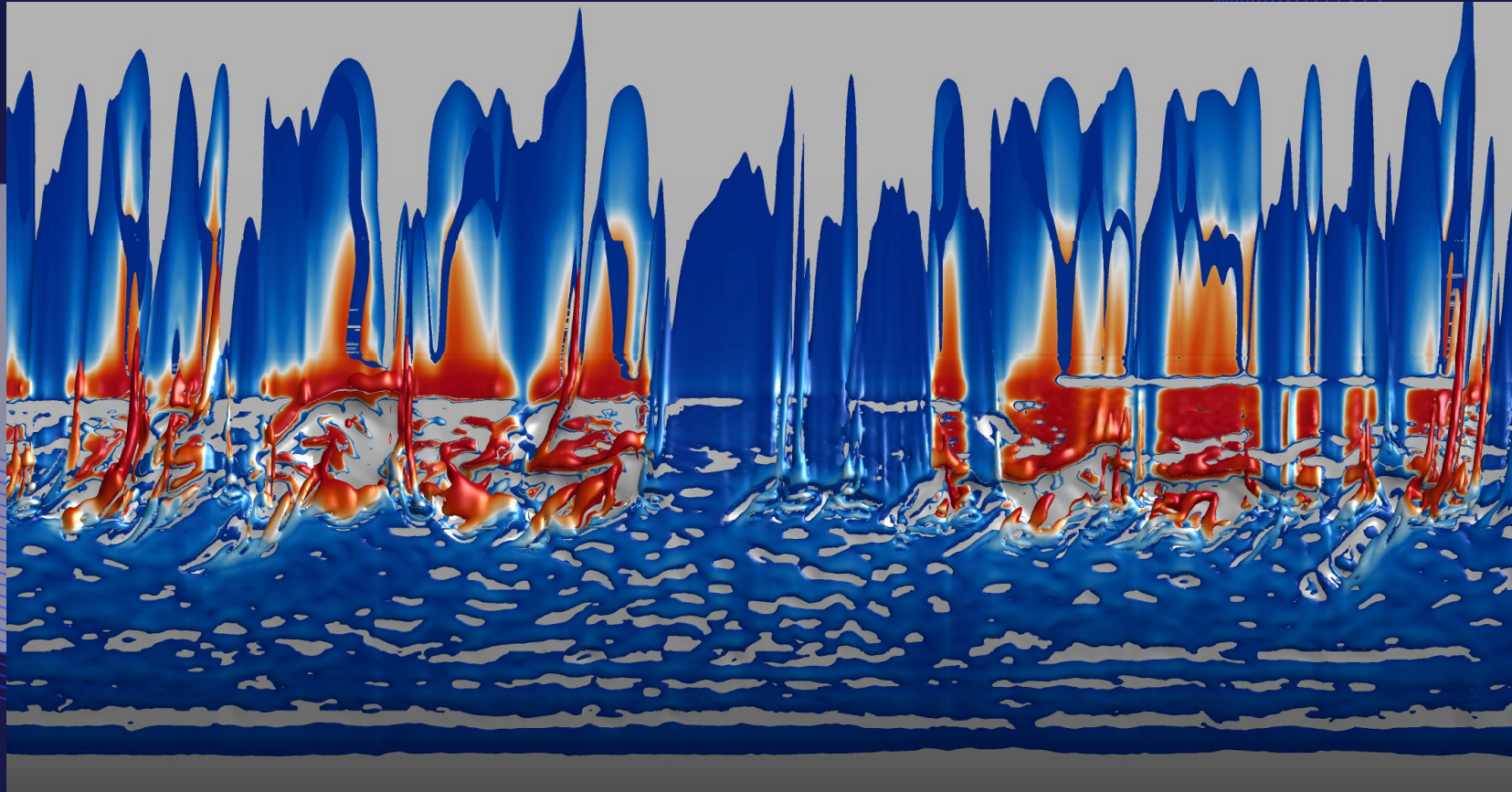
- 21% relative thickness
- Mild erosion: $-0.16\% \leq x/c \leq 0.61\%$
- Severe erosion: $-1.55\% \leq x/c \leq 0.67\%$

DU91-W2-250

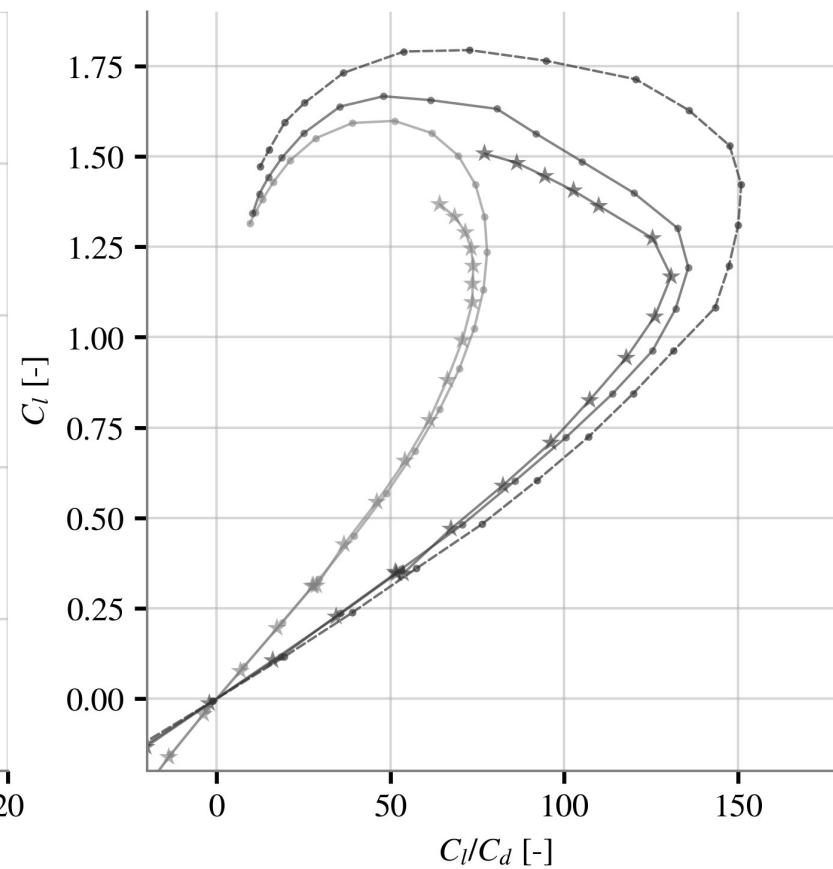
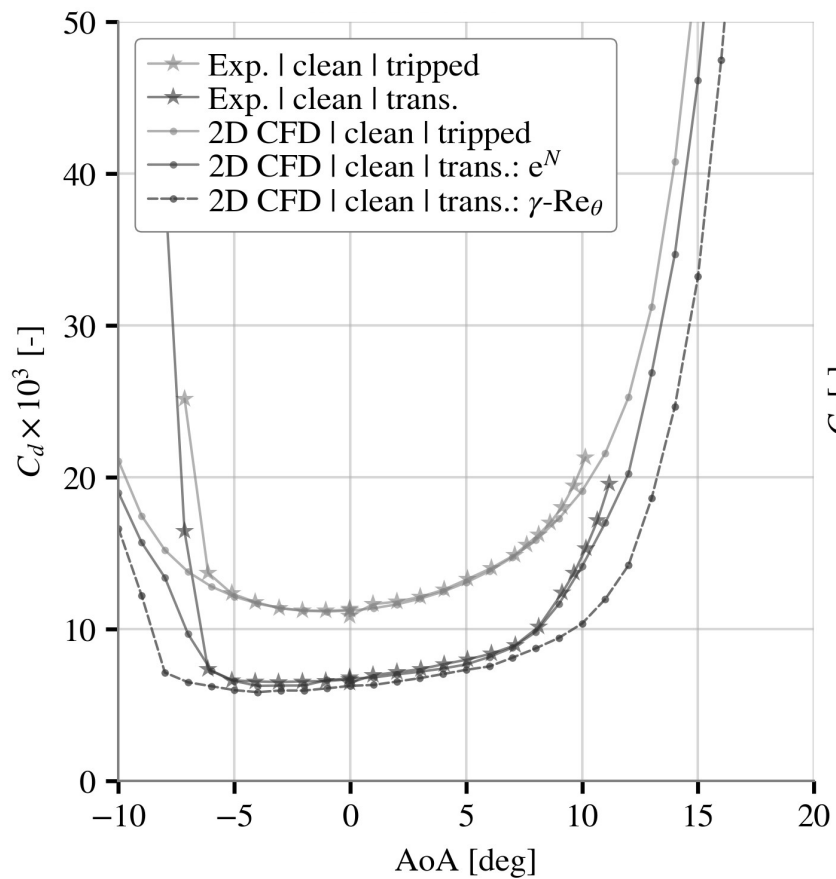
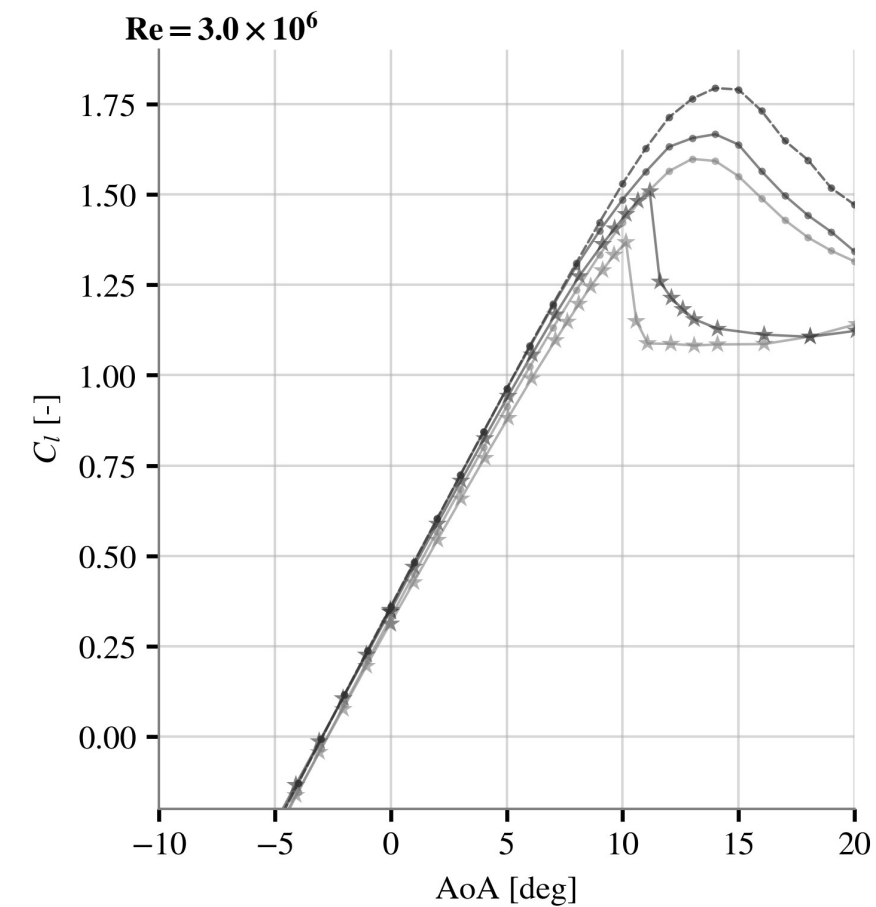
- 25% relative thickness
- Mild erosion: $-0.08\% \leq x/c \leq 0.52\%$
- Severe erosion: $-0.94\% \leq x/c \leq 0.58\%$



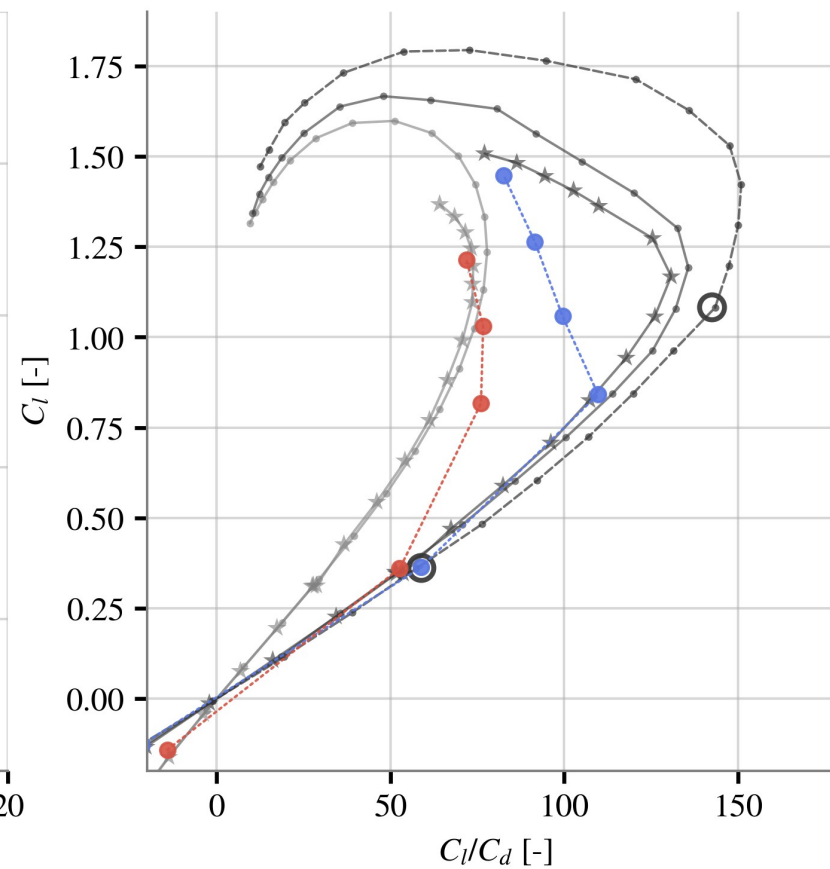
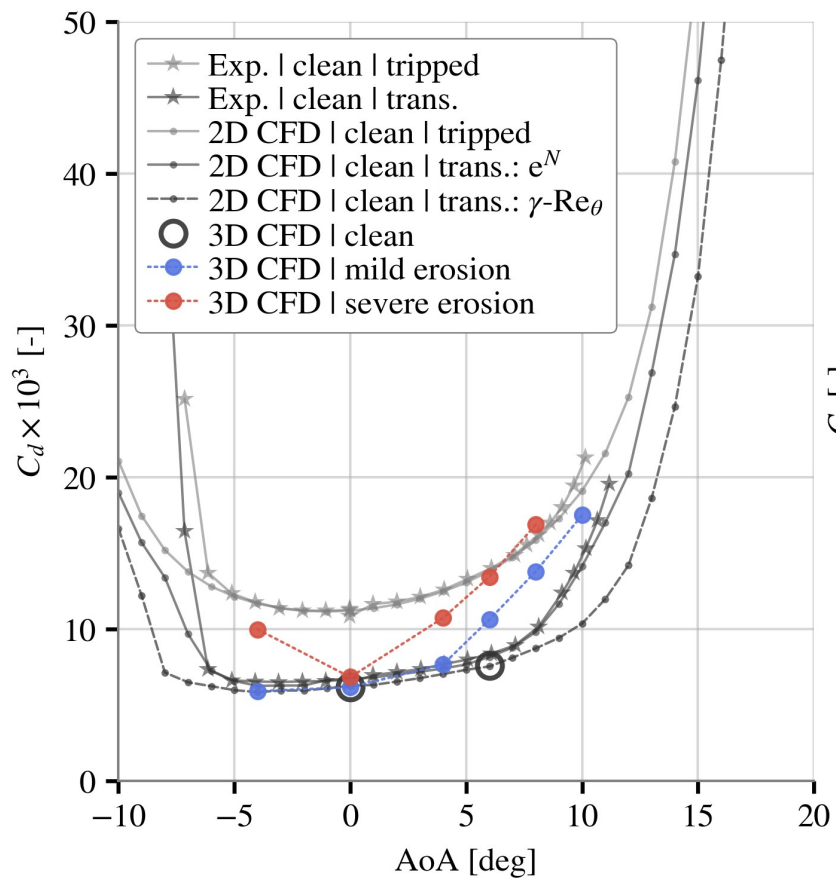
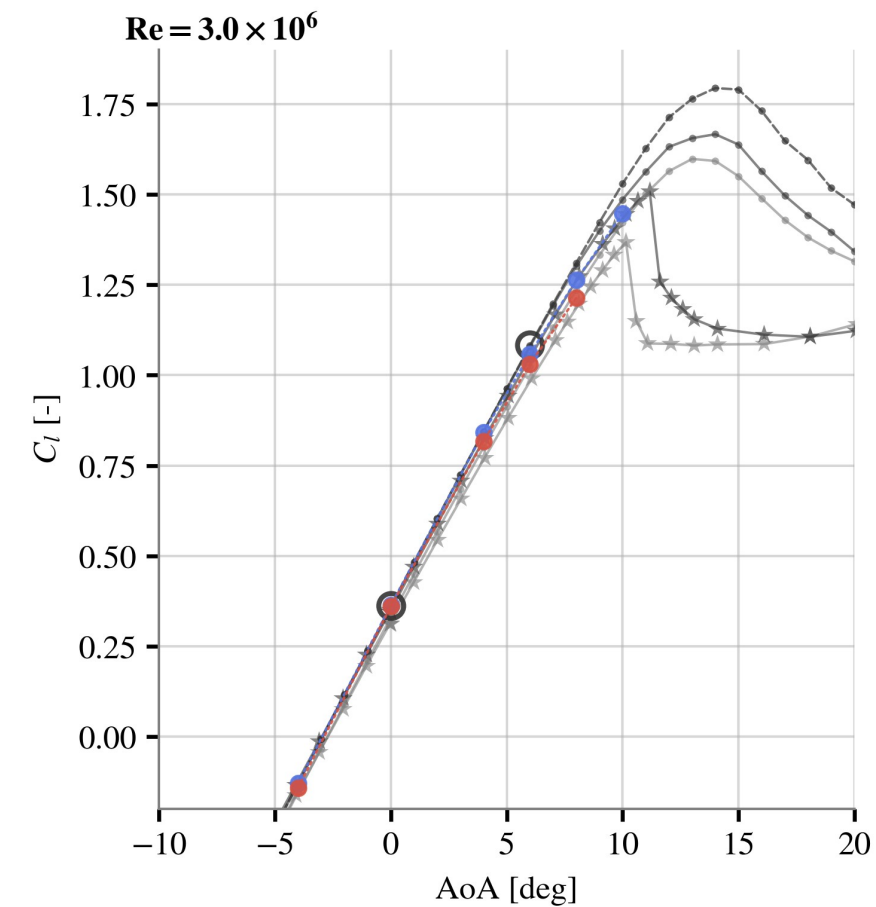
3D Simulations



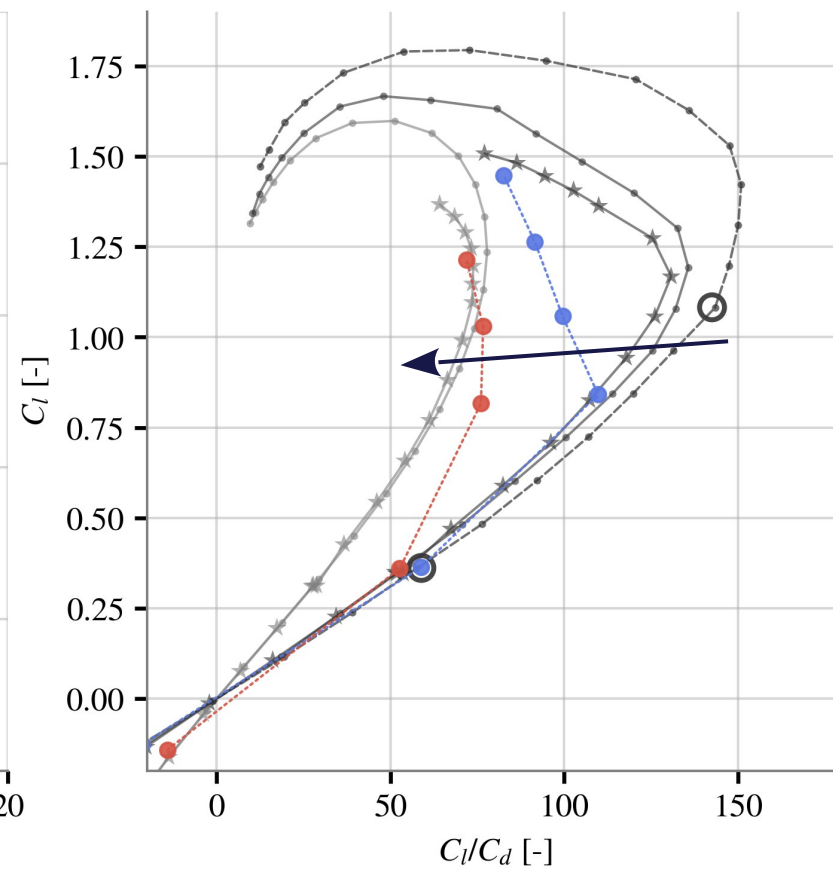
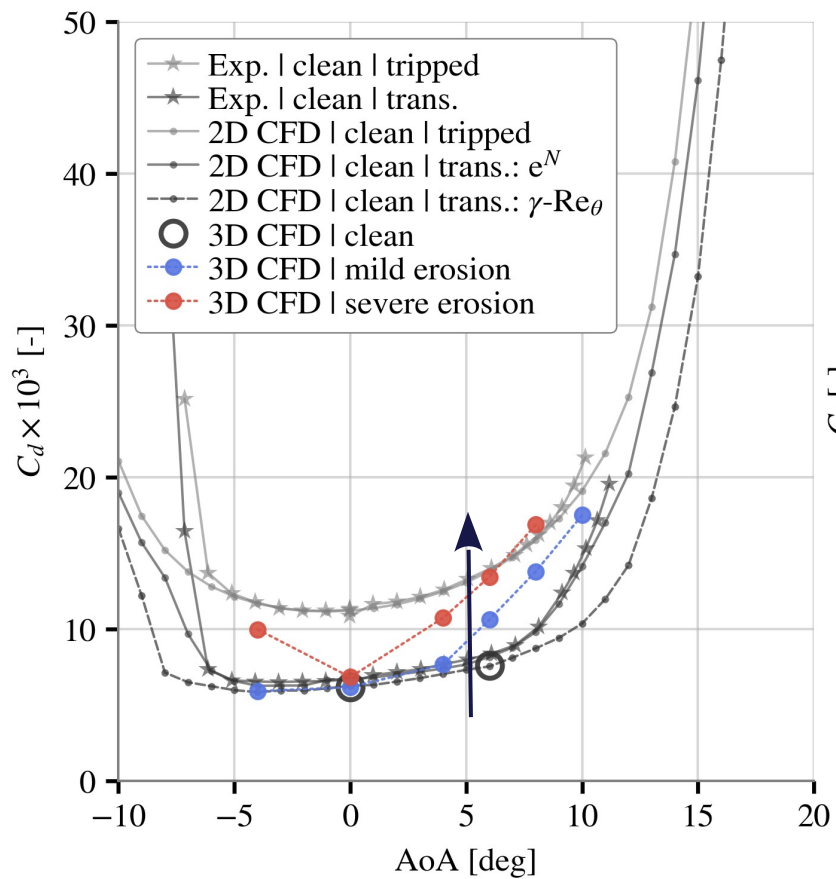
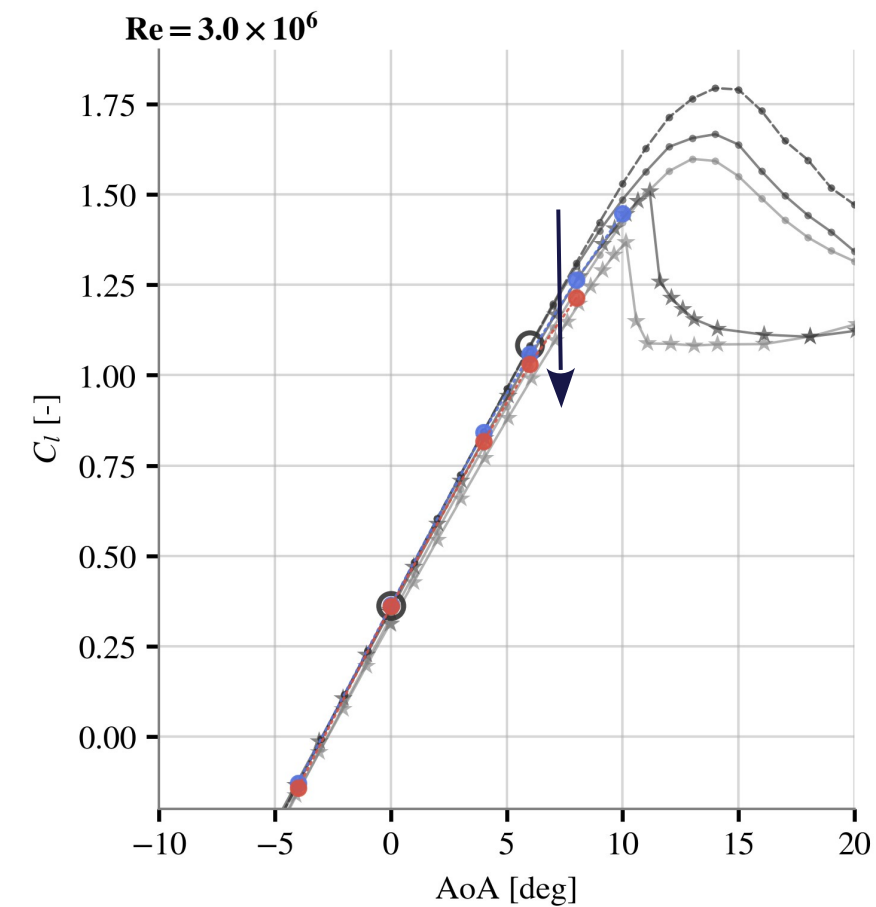
FFA-W2-211: 2D polars



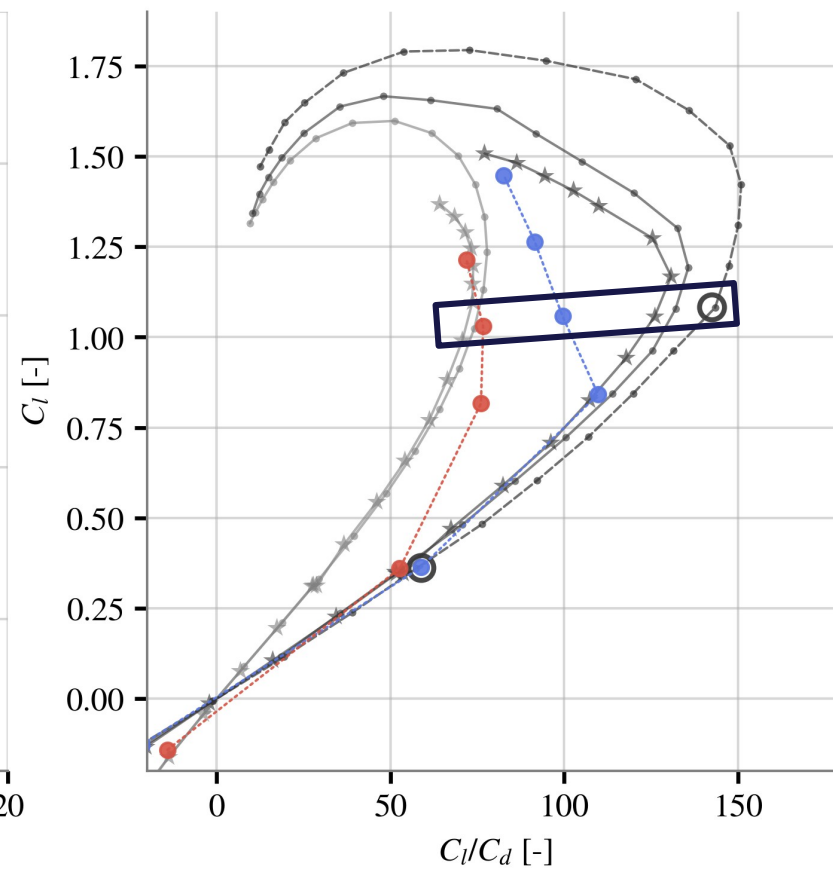
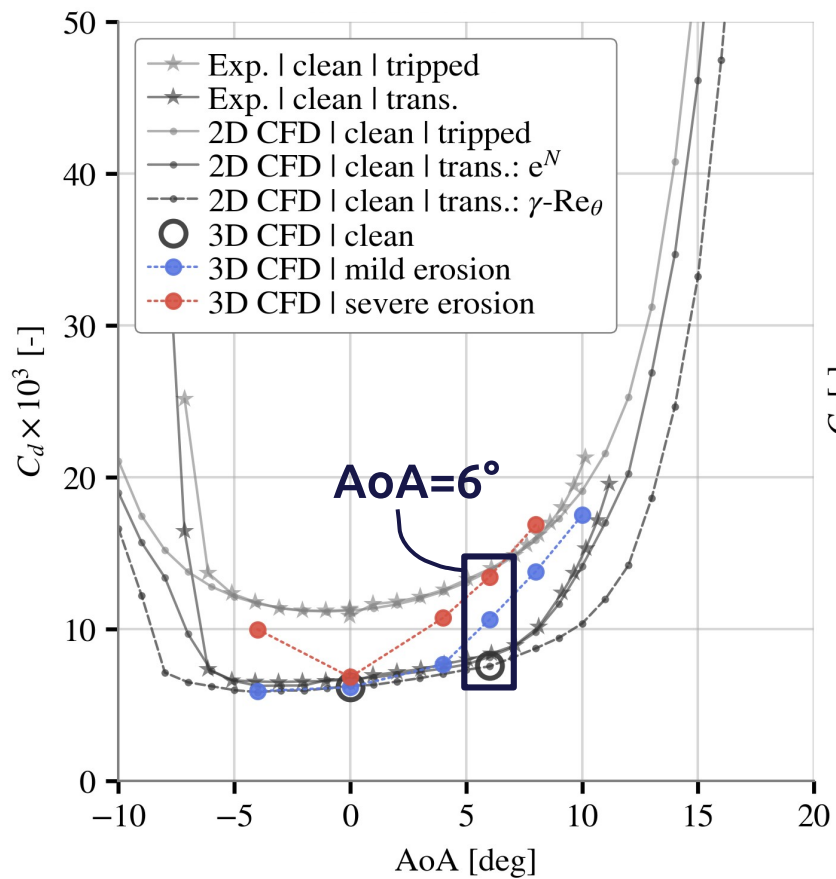
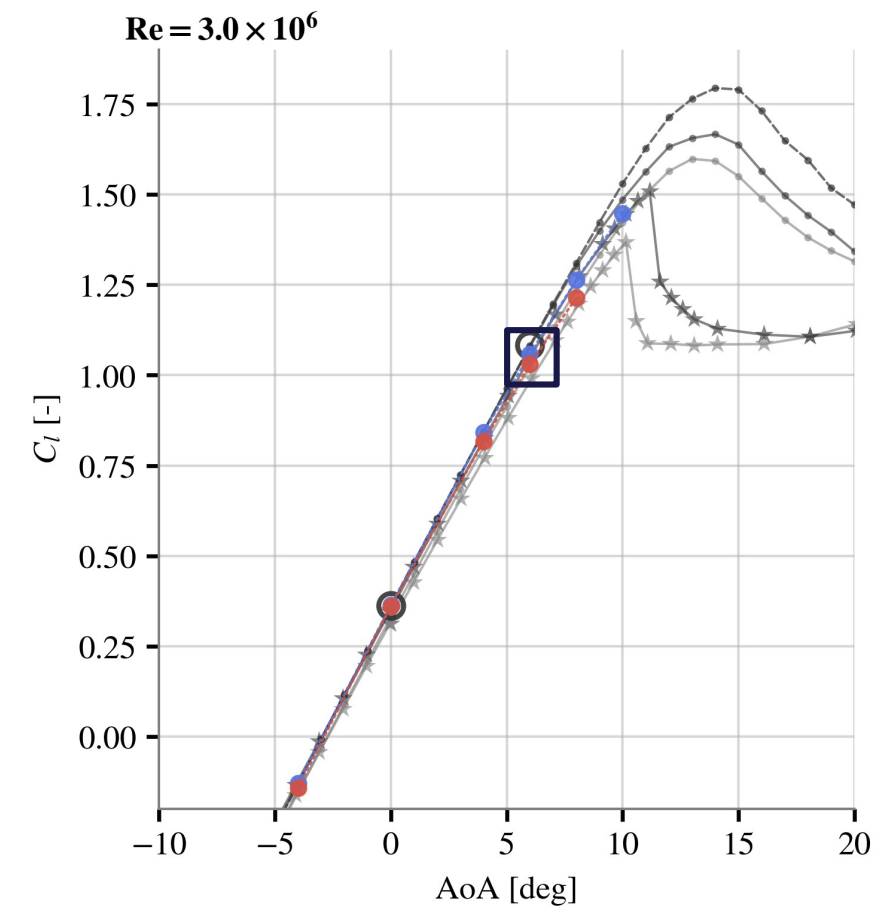
FFA-W2-211: 2D + 3D span-averaged



FFA-W2-211: 2D + 3D span-averaged

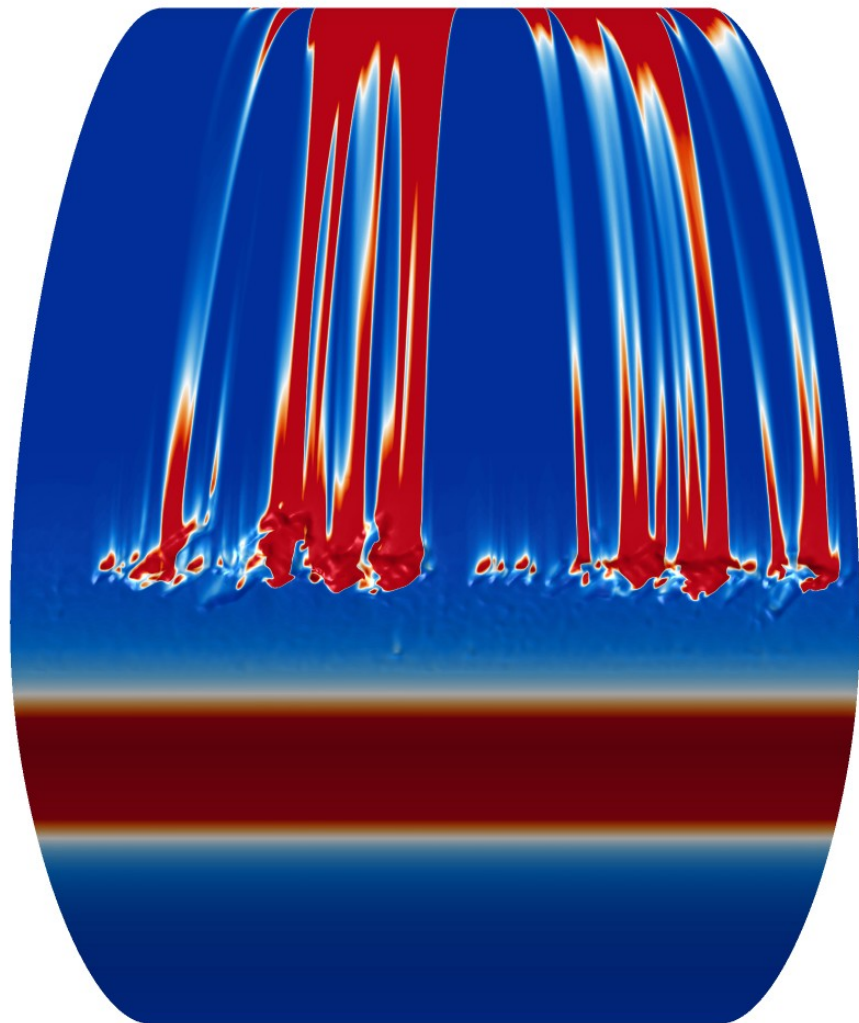


FFA-W2-211: 2D + 3D span-averaged

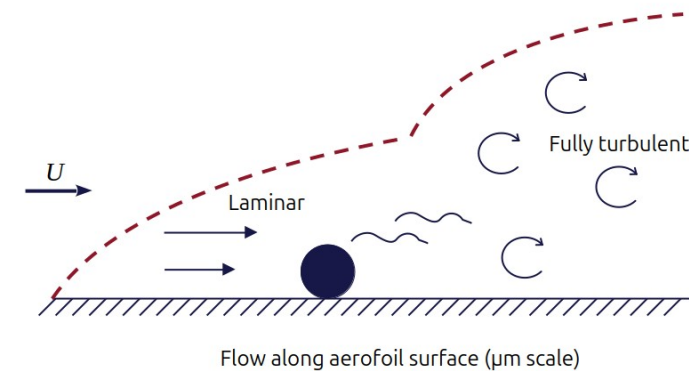
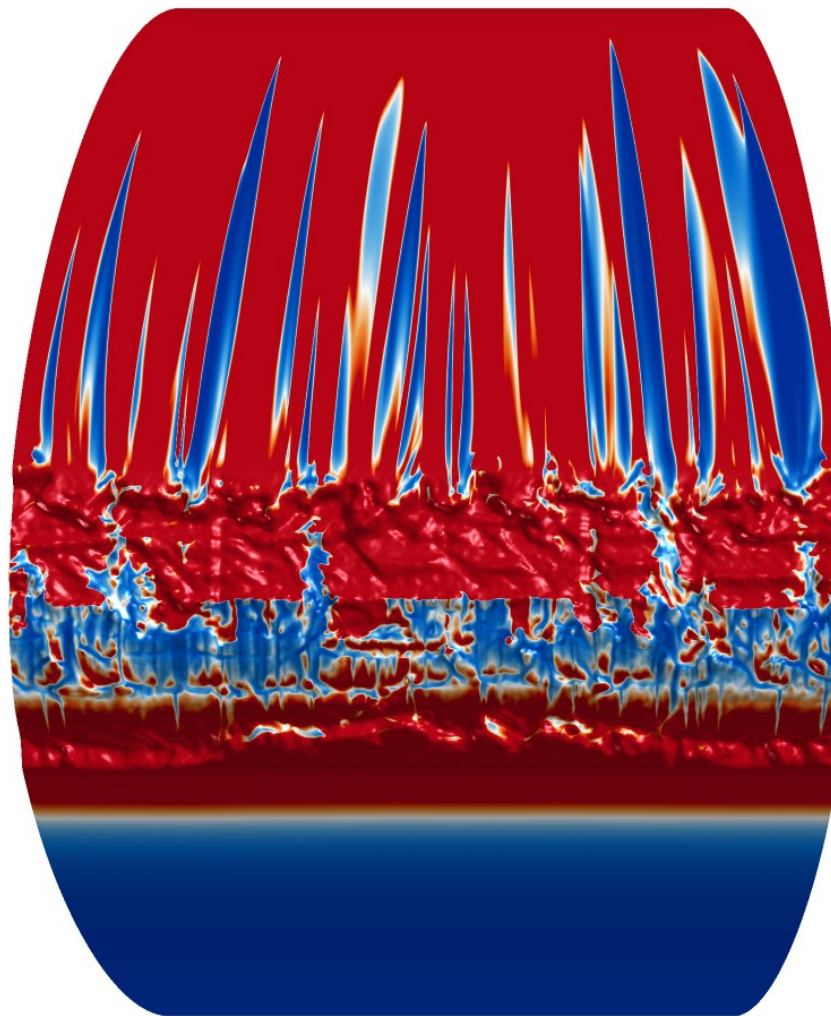


Transition behaviour

Mild erosion



Severe erosion



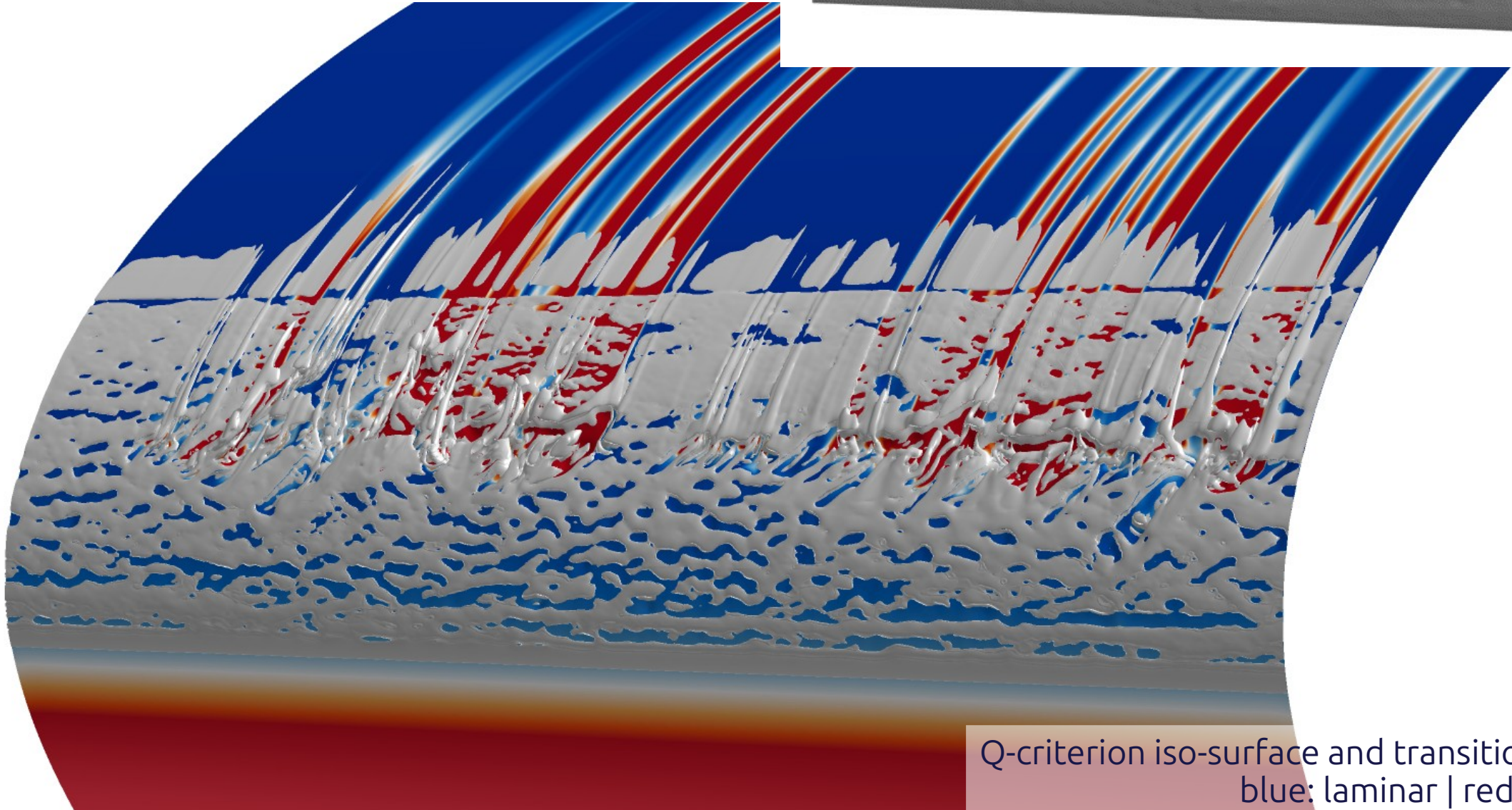
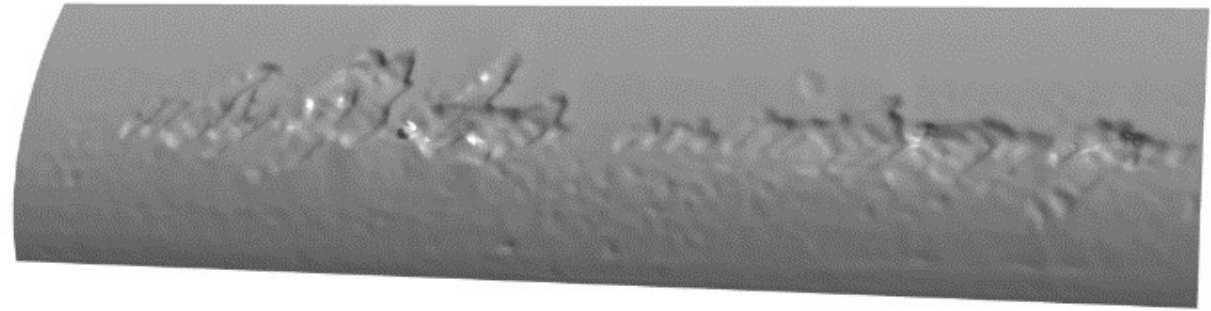
$Re=3 \text{ million} \mid AoA=6^\circ$

Frontal view of FFA
Transition indicator
blue: laminar | red: turbulent



Mild erosion

Re=3 million | AoA=6°

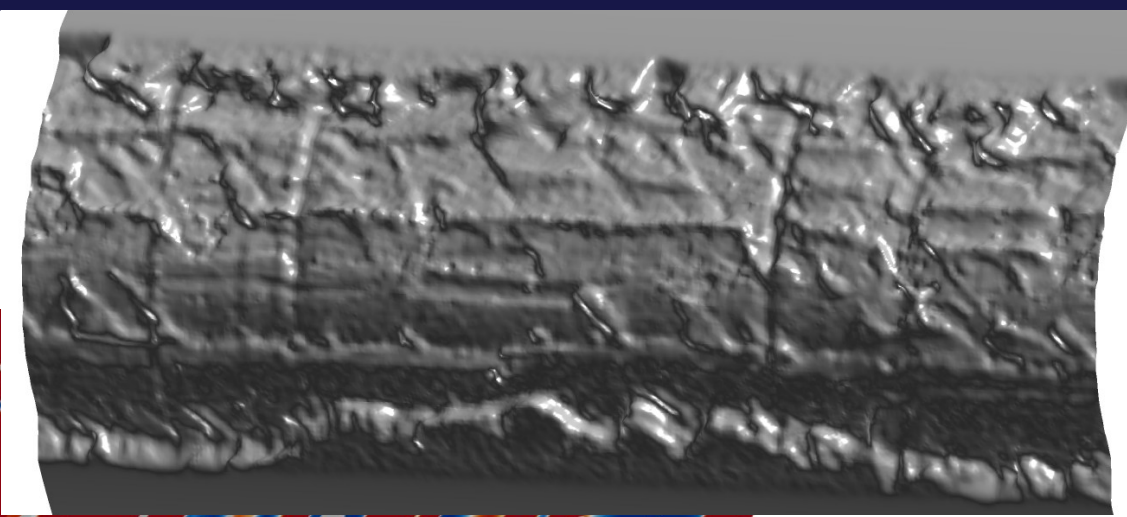
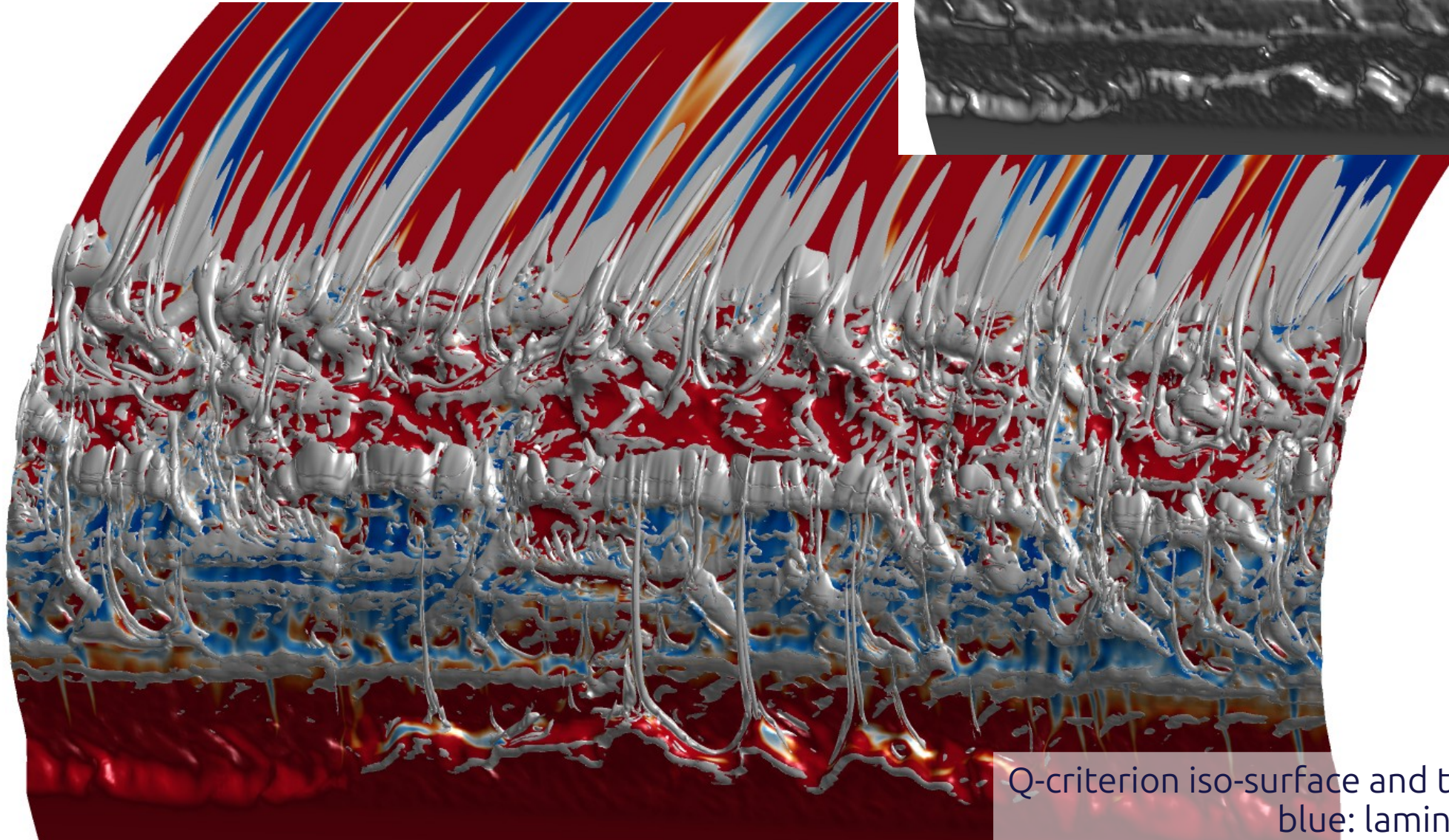


Q-criterion iso-surface and transition indicator
blue: laminar | red: turbulent



Severe erosion

Re=3 million | AoA=6°

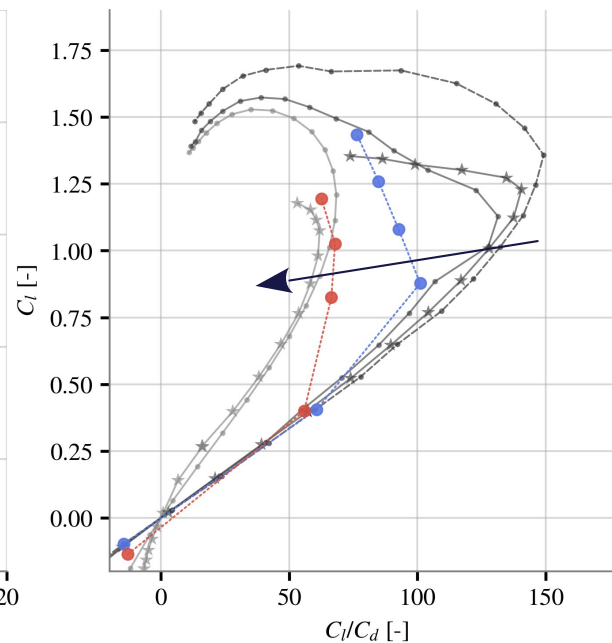
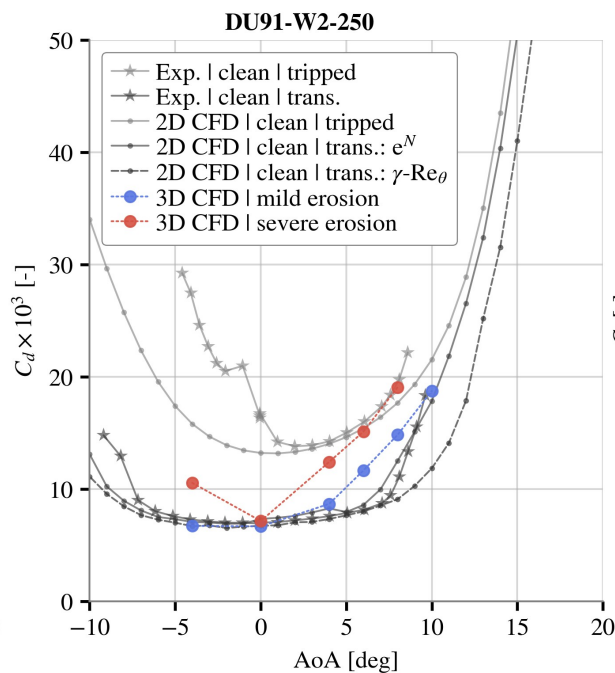
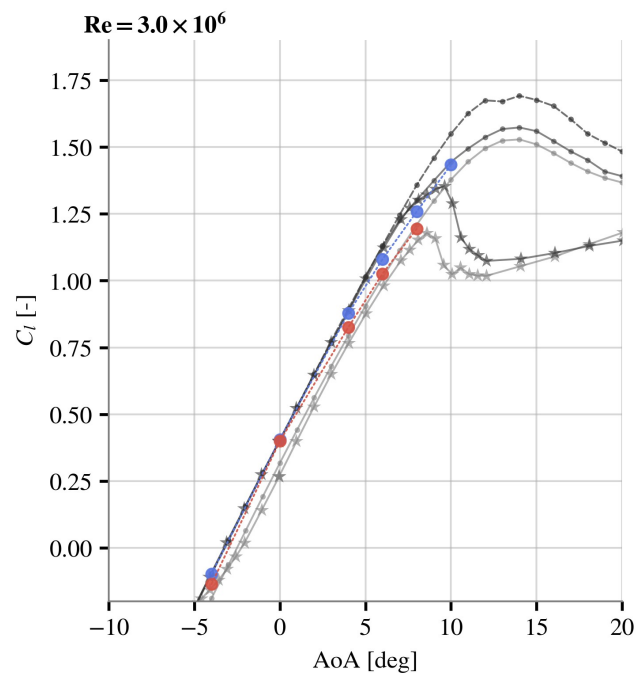
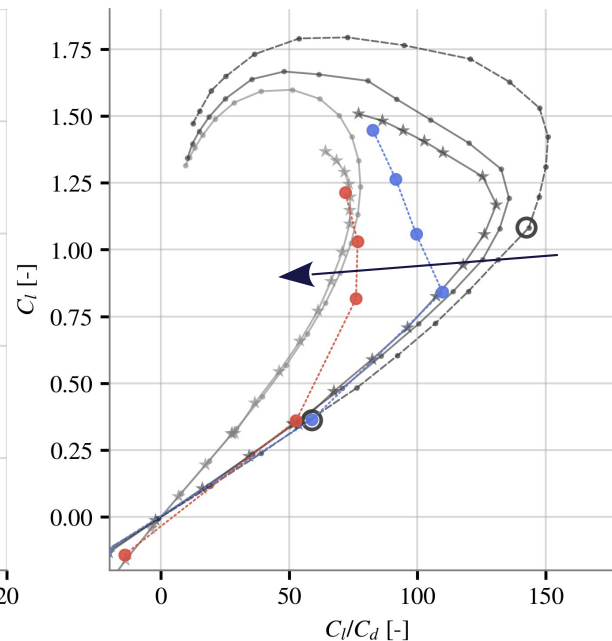
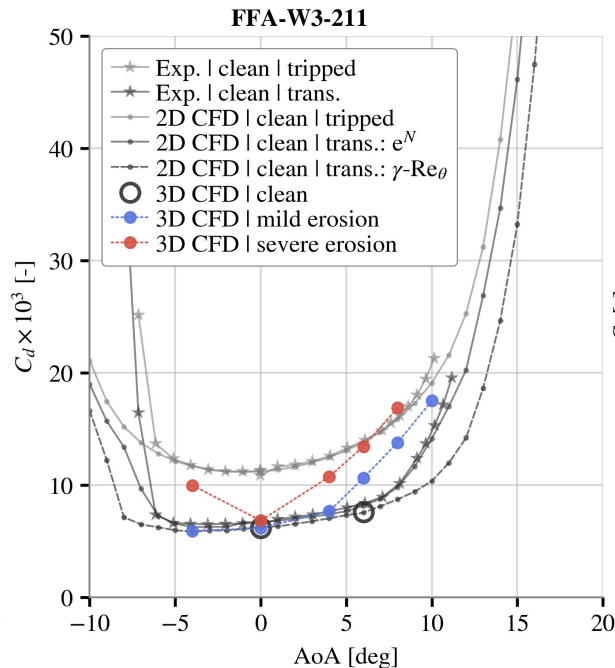
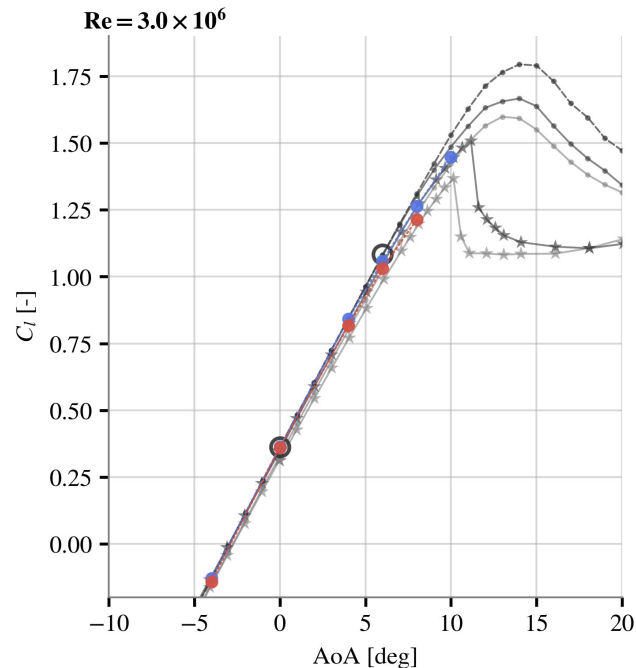


Q-criterion iso-surface and transition indicator
blue: laminar | red: turbulent

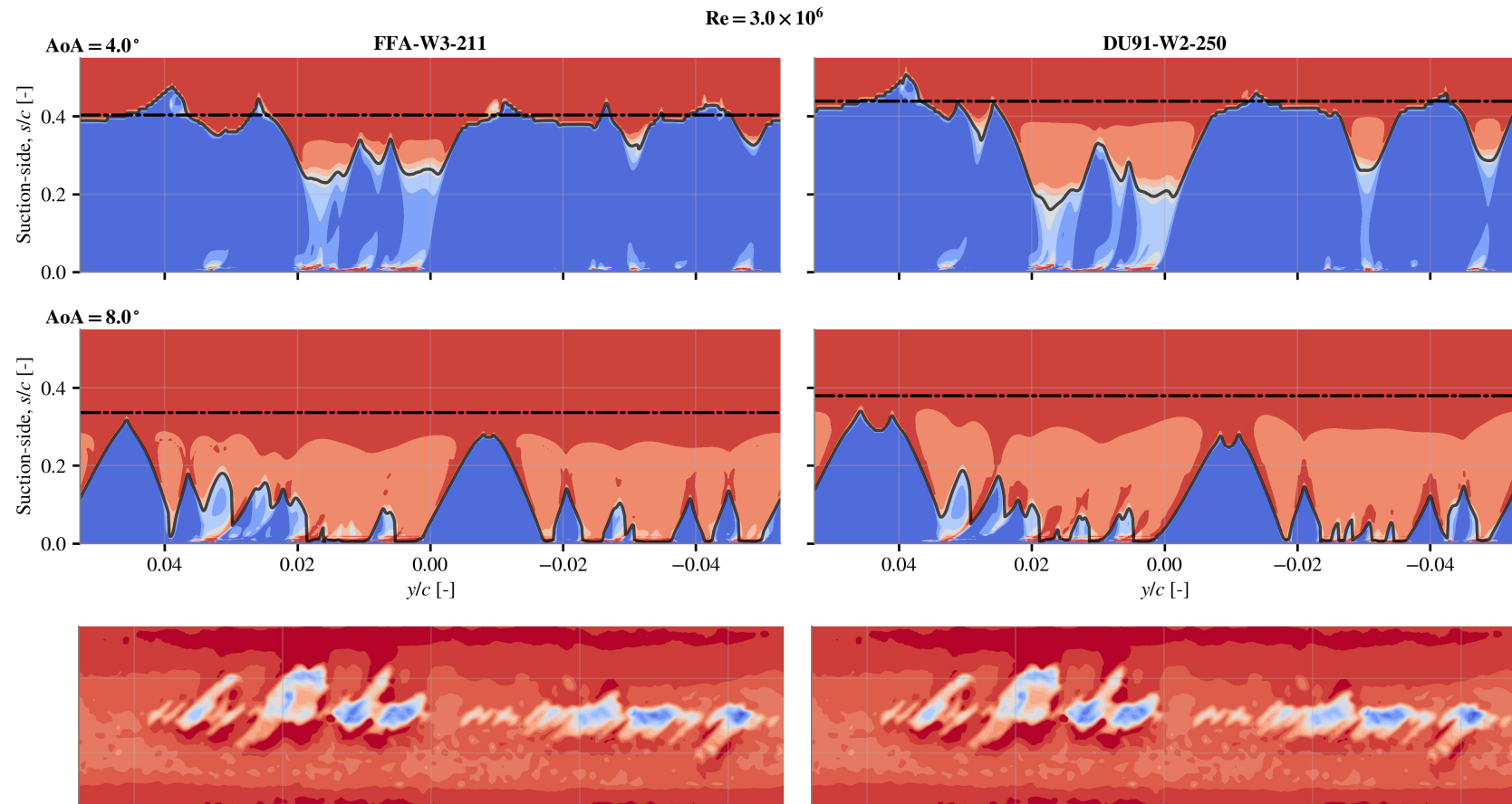
FFA-W2-211

VS

DU91-W2-250

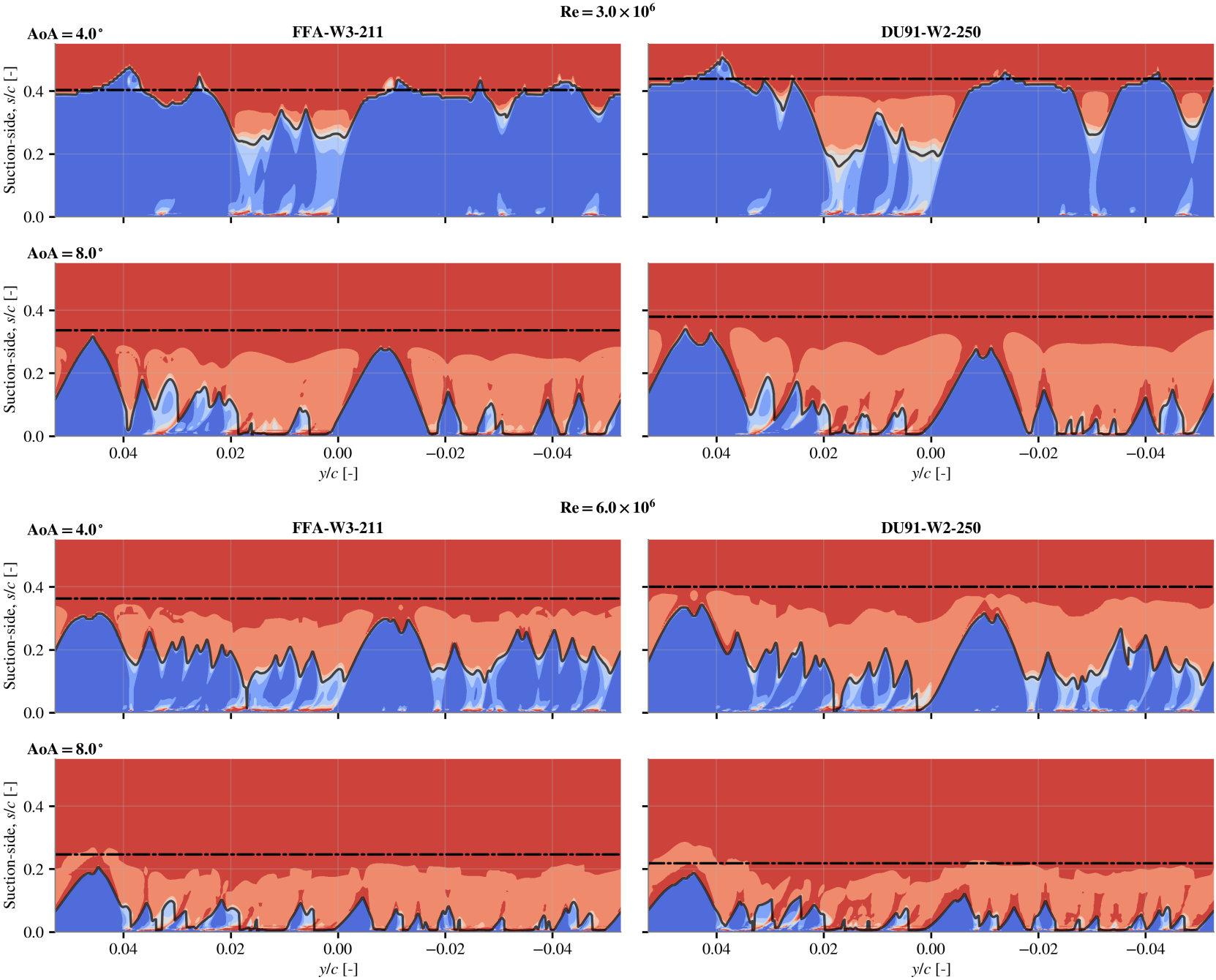


Suction-side transition behaviour with mild erosion



Suction-side transition behaviour with mild erosion

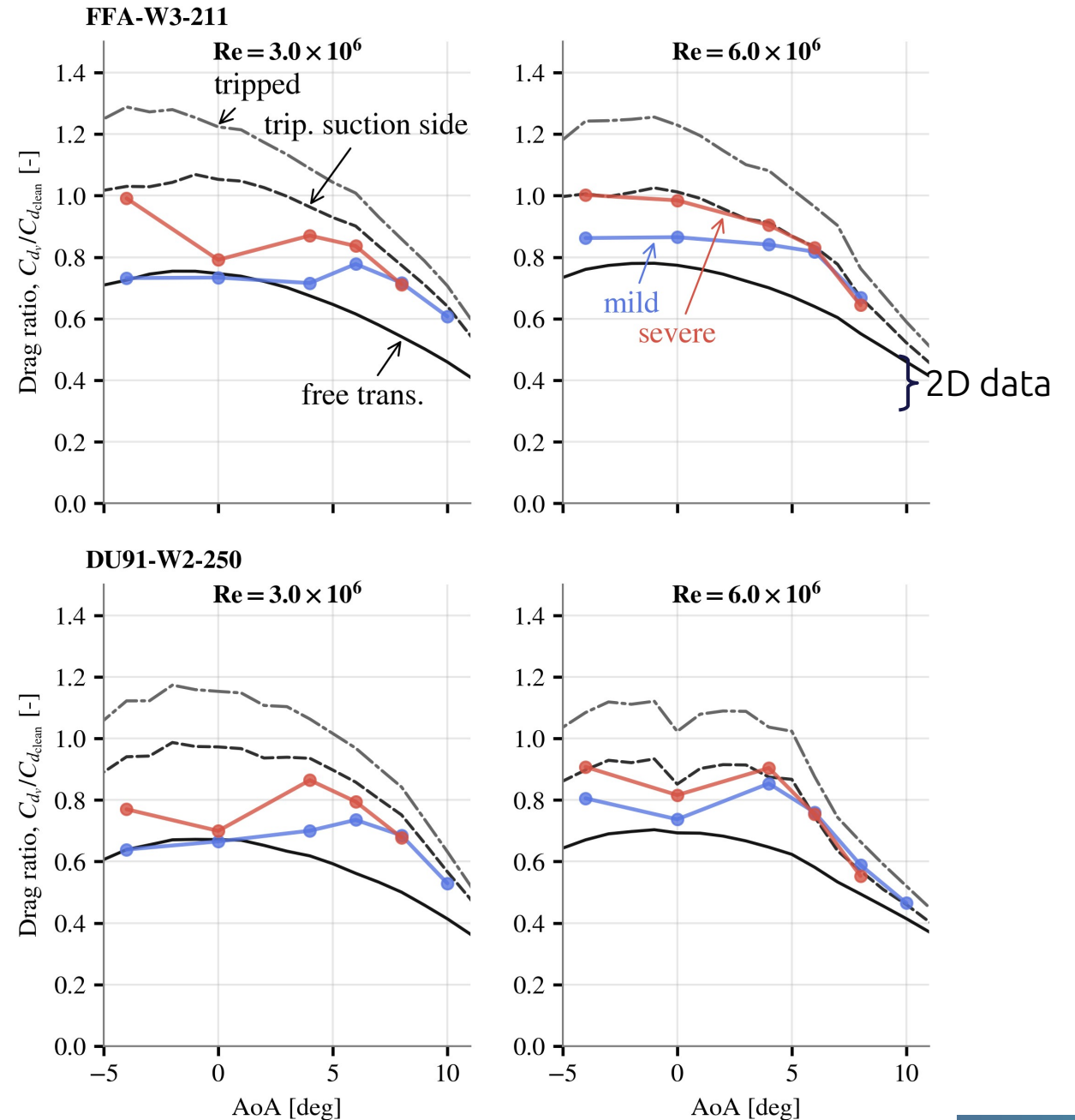
- Turbulent wedge angles between 12° to 28° , mean around 17°



Viscous drag

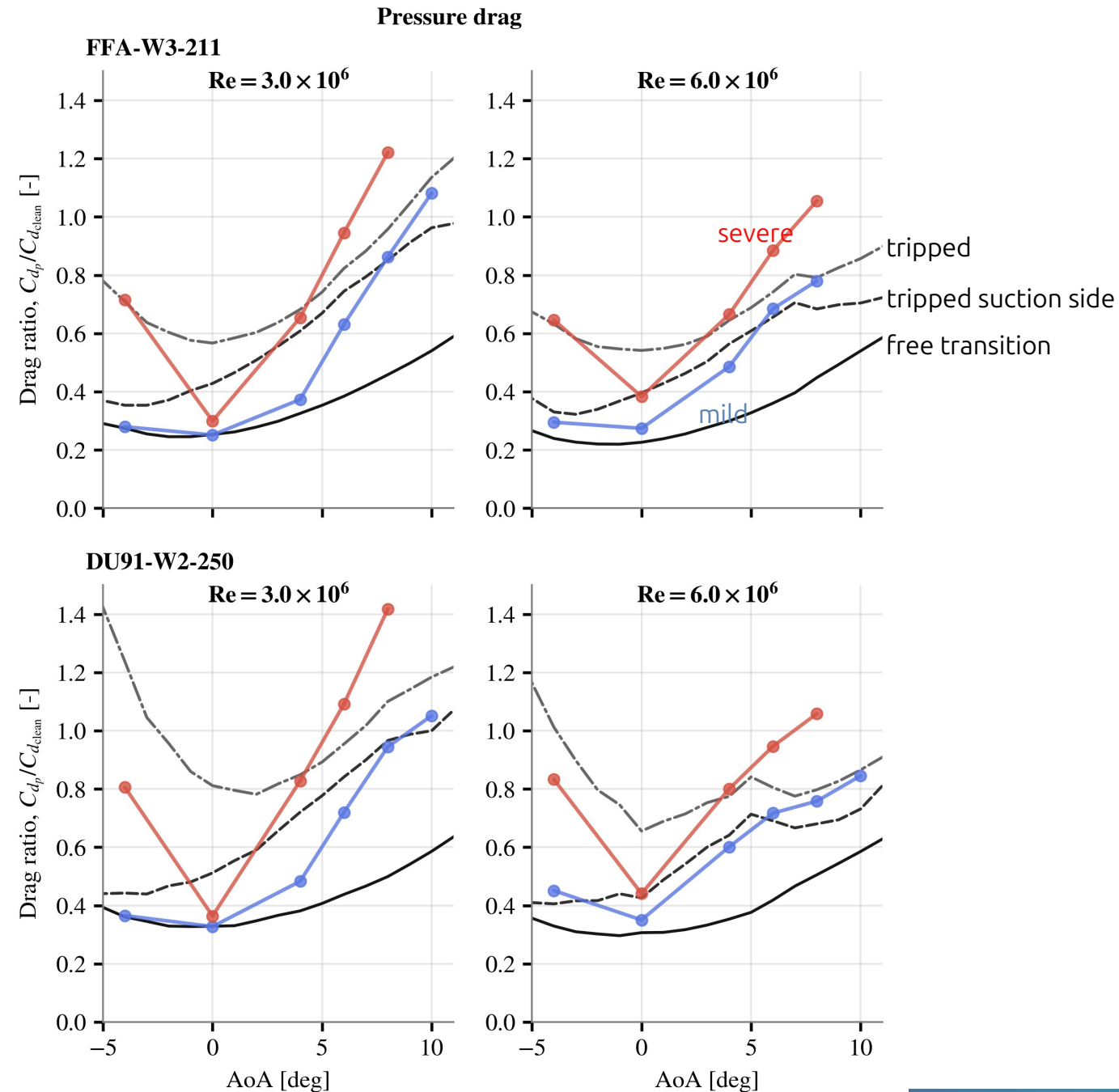
- Mild & severe erosion trigger transition on the suction side
- For mild only at larger AoAs and Reynolds number

Viscous drag

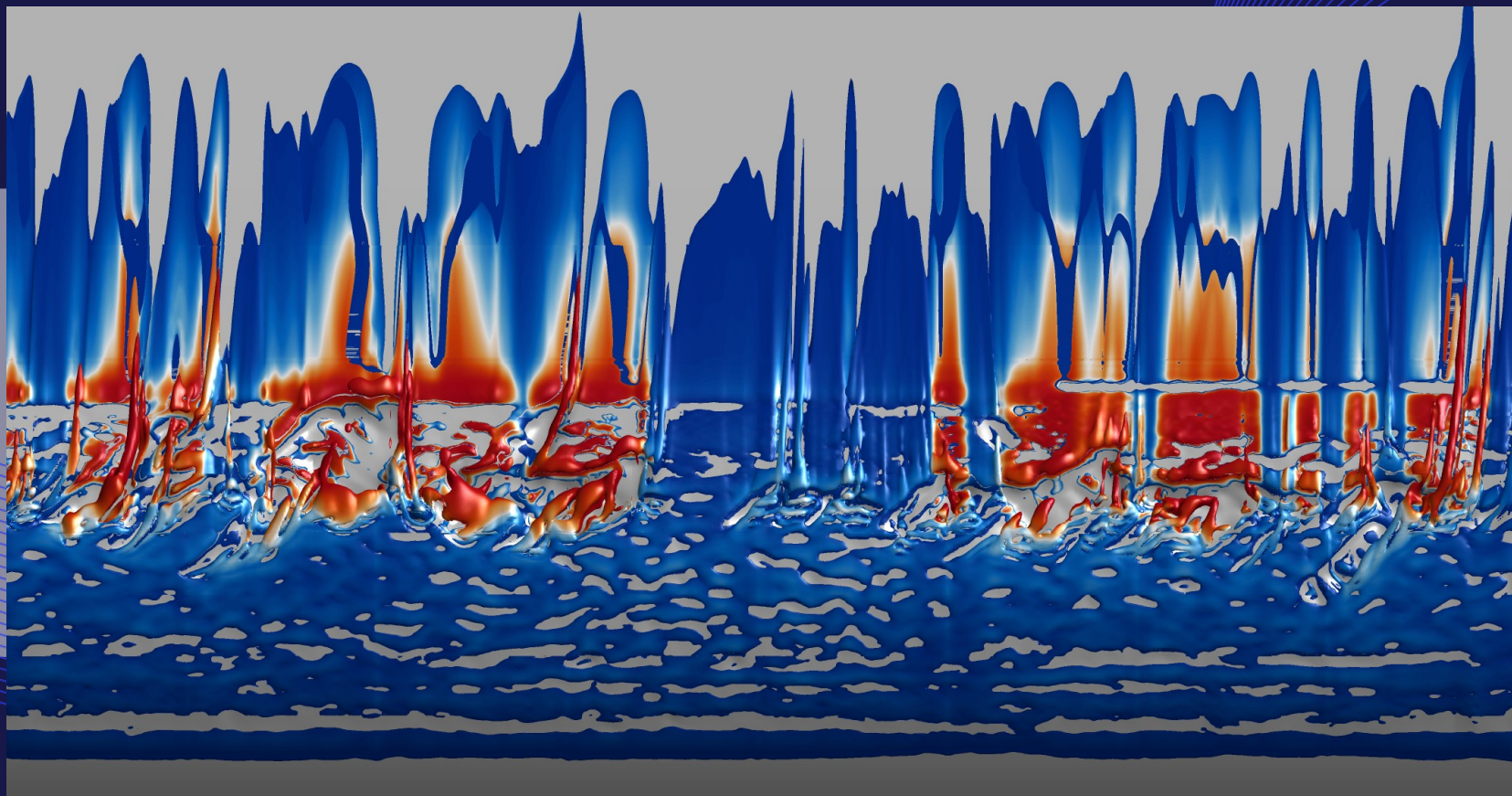


Pressure drag

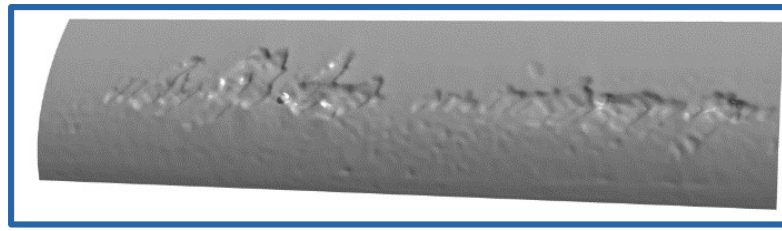
- Severe erosion behaves very differently, especially approaching stall
- Large forward-facing step reduces suction peak



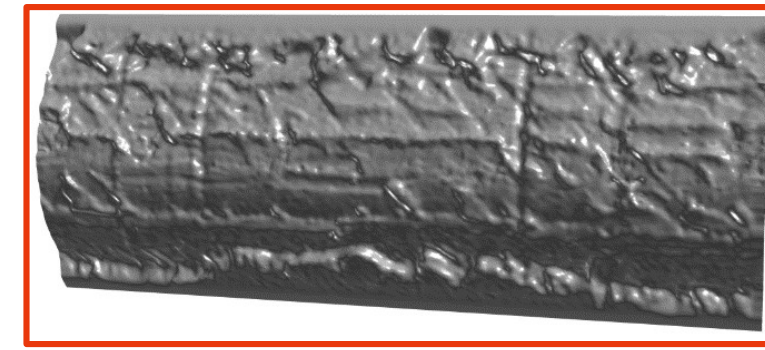
Summary



Summary



mild



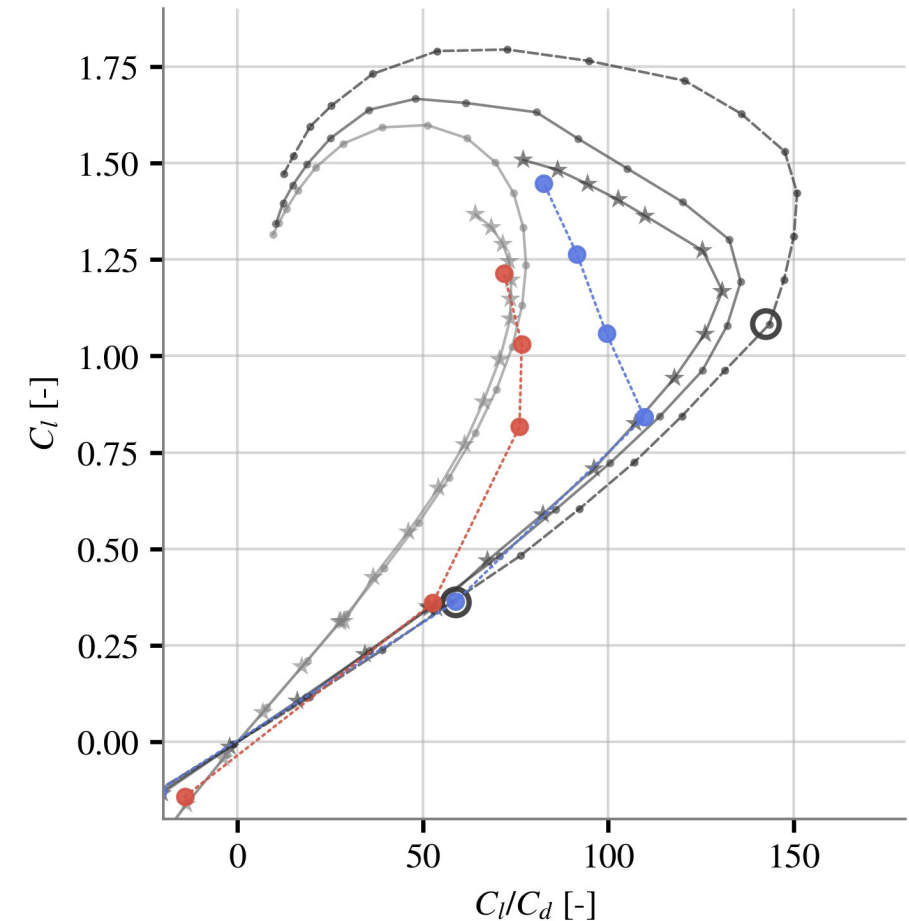
severe

Erosion effects

- Performed high resolution 3D RANS for two aerofoils with mild and severe erosion
- Mild erosion behaves like a suction side transition trigger
- Even small clean regions are triggered due to spanwise effects
- Severe erosion not only triggers transition but also increases pressure drag approaching stall
- Pressure side transition is not triggered

2D CFD as alternative? (in the paper)

- 2D simulations of erosion capture the spanwise-average behaviour as long as transition is triggered in 3D
- The spanwise variation is not matched

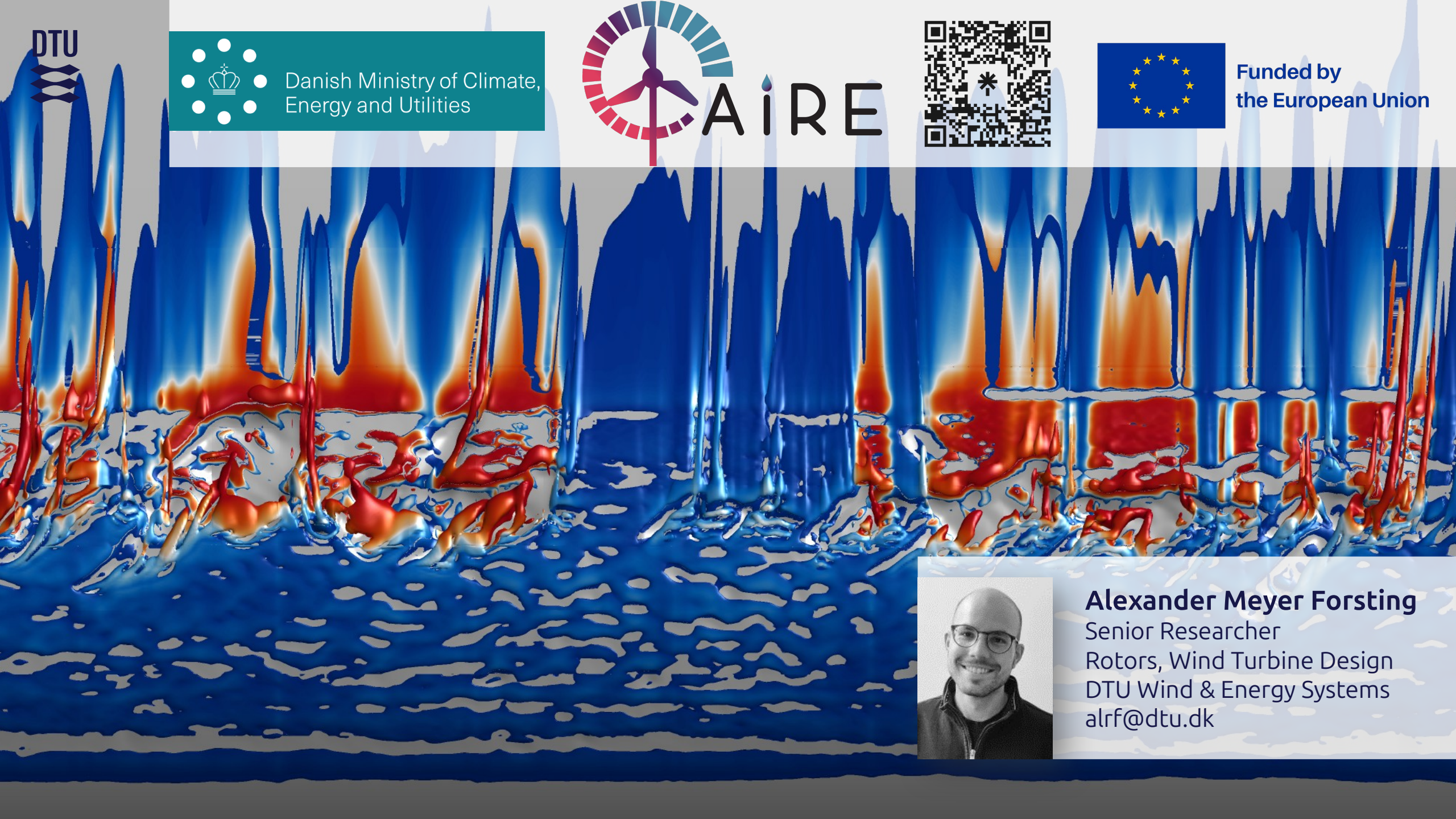




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