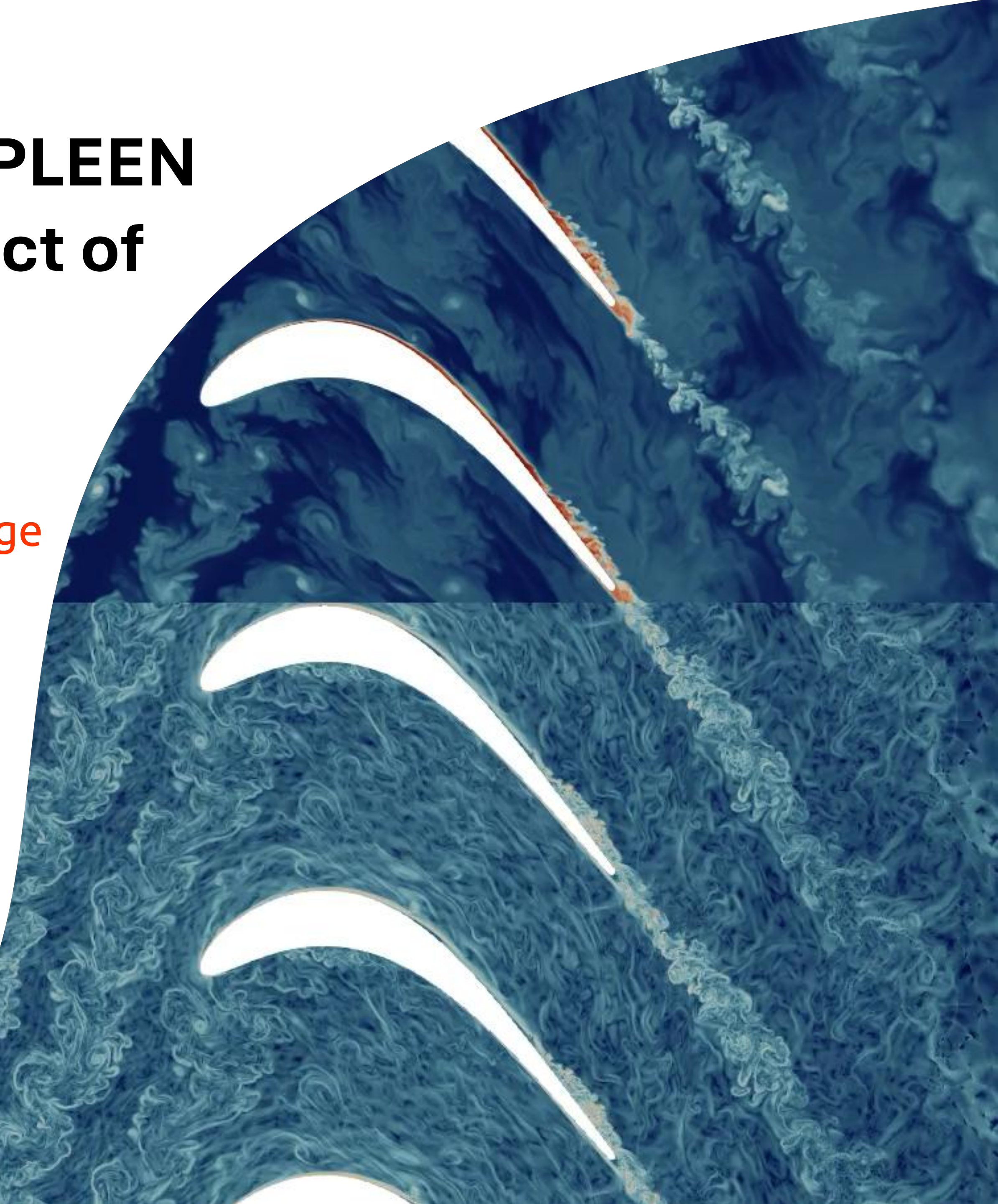
High-order simulation of the SPLEEN cascade wake generator: impact of the stabilisation method



The 15th ERCOFTAC workshop on Direct and Large Eddy Simulation

Authors: **A. R**euter, **M. B**orbouse, **M. T**hys, **A. B**ilocq, **D. H**enneaux, **K. H**illewaert

TU Delft
Delft, Netherlands
20th May 2026

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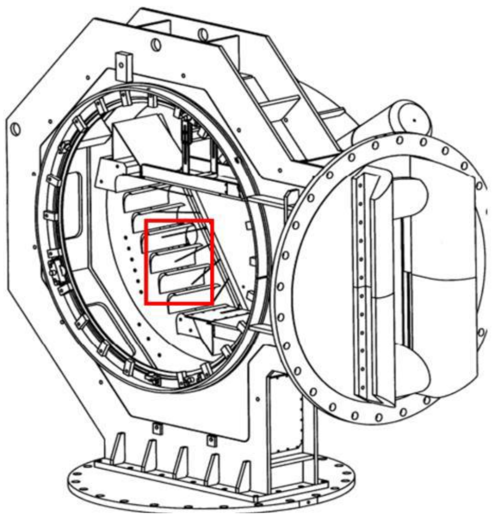
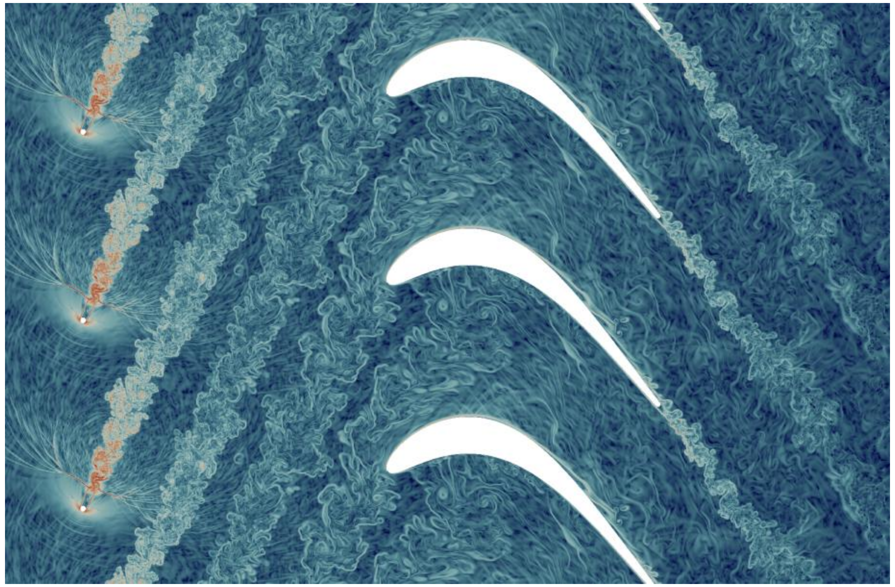
The next generation of low-pressure turbine

- High-speed low-pressure **turbine**, SPLEEN
- **Experimental** campaign, VKI
- **Numerical** campaign, ULiège + Cenaero:
  - Clean inlet, turbulent injection and **wake generator**



Lopes (2025), SPLEEN C1 cascade in S1 tunnel @ VKI



Thys et al. (2025) [1] courtesy ULiège and Cenaero

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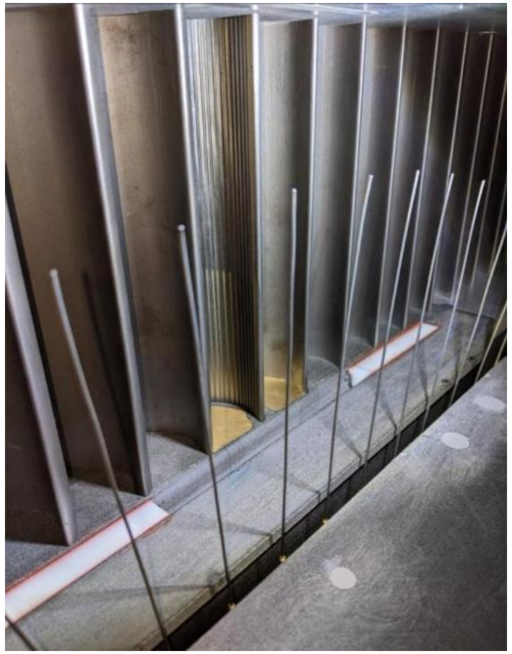
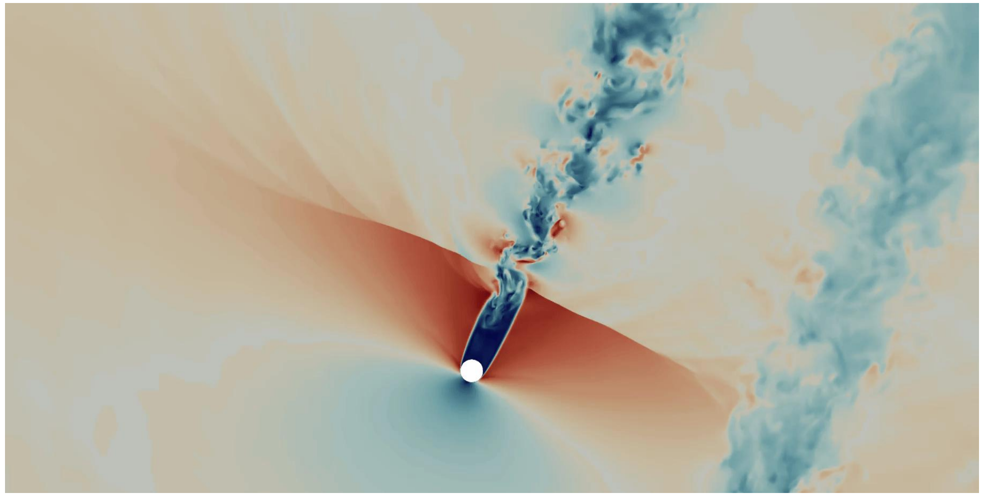
Wake generator
numerical reproduction

- Strong **shock** in the **wake**
- Intense flow **instability** during **transient** phase
- **Instability** even in **established** regimes

Challenge for discontinuous Galerkin method





Thys et al. (2025) [1]
courtesy ULiège and Cenaero

Need for stabilisation methods

Discontinuous Galerkin (DG):

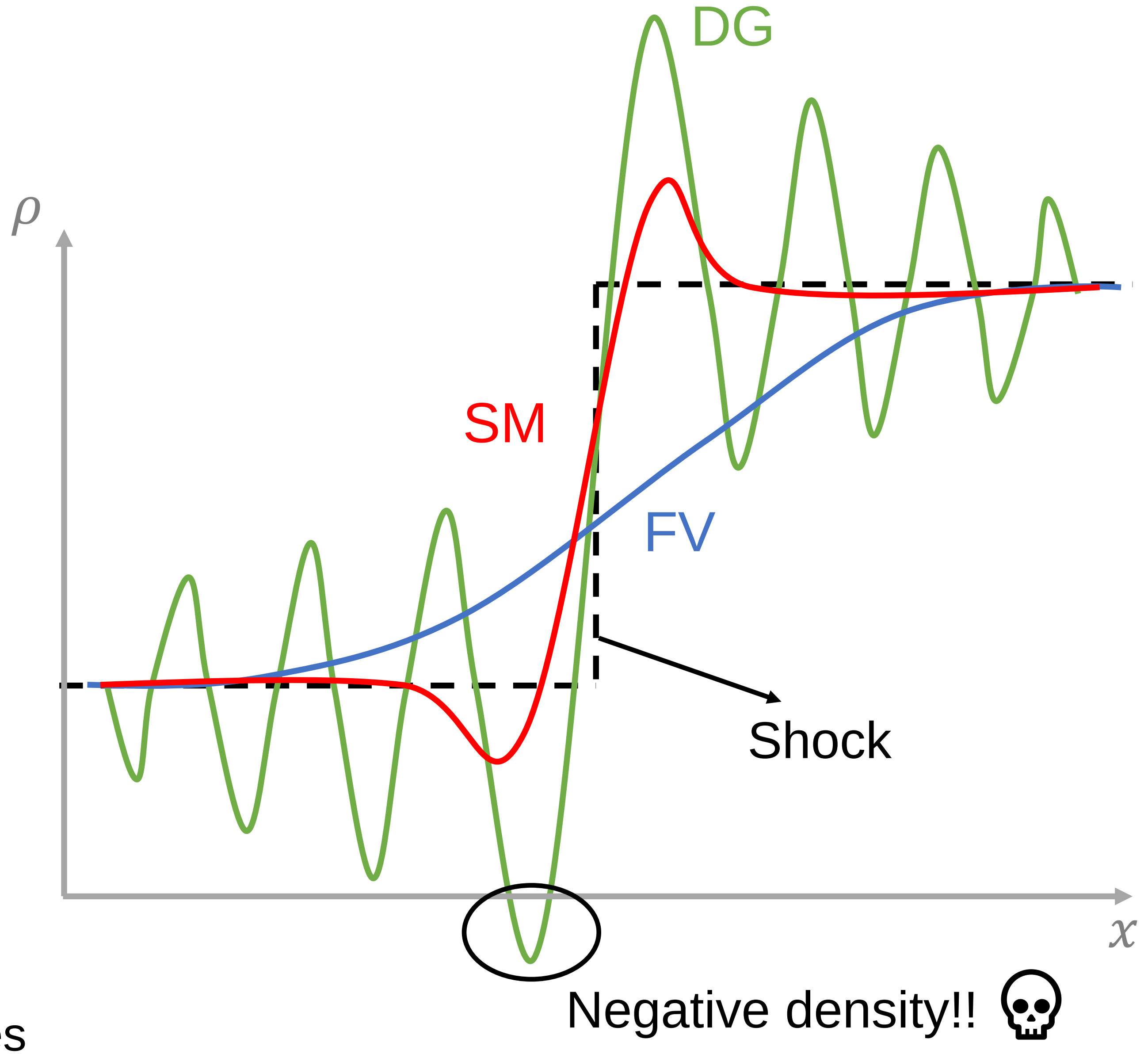
- **Gibbs** oscillations
- Stability **issues**

Finite volume (FV):

- **Monotonicity**
- **Low** shock **resolution**

Stabilisation methods (SM):

- **Decrease** oscillations
- Keep **shock-**capturing capabilities

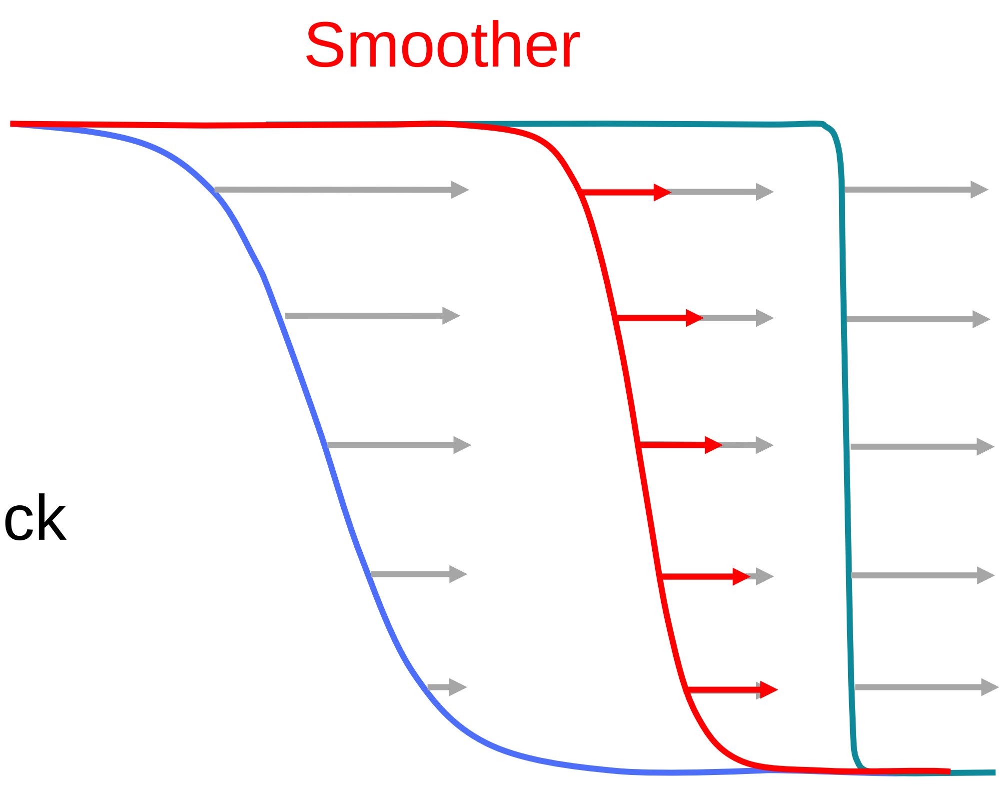


Artificial viscosity

- **Modifies** local governing **equations**:

$$\frac{\partial u}{\partial t} + \nabla \cdot f(u) = \nabla \cdot (d(u, \nabla u) + \alpha \mu_{AV} \nabla u)$$

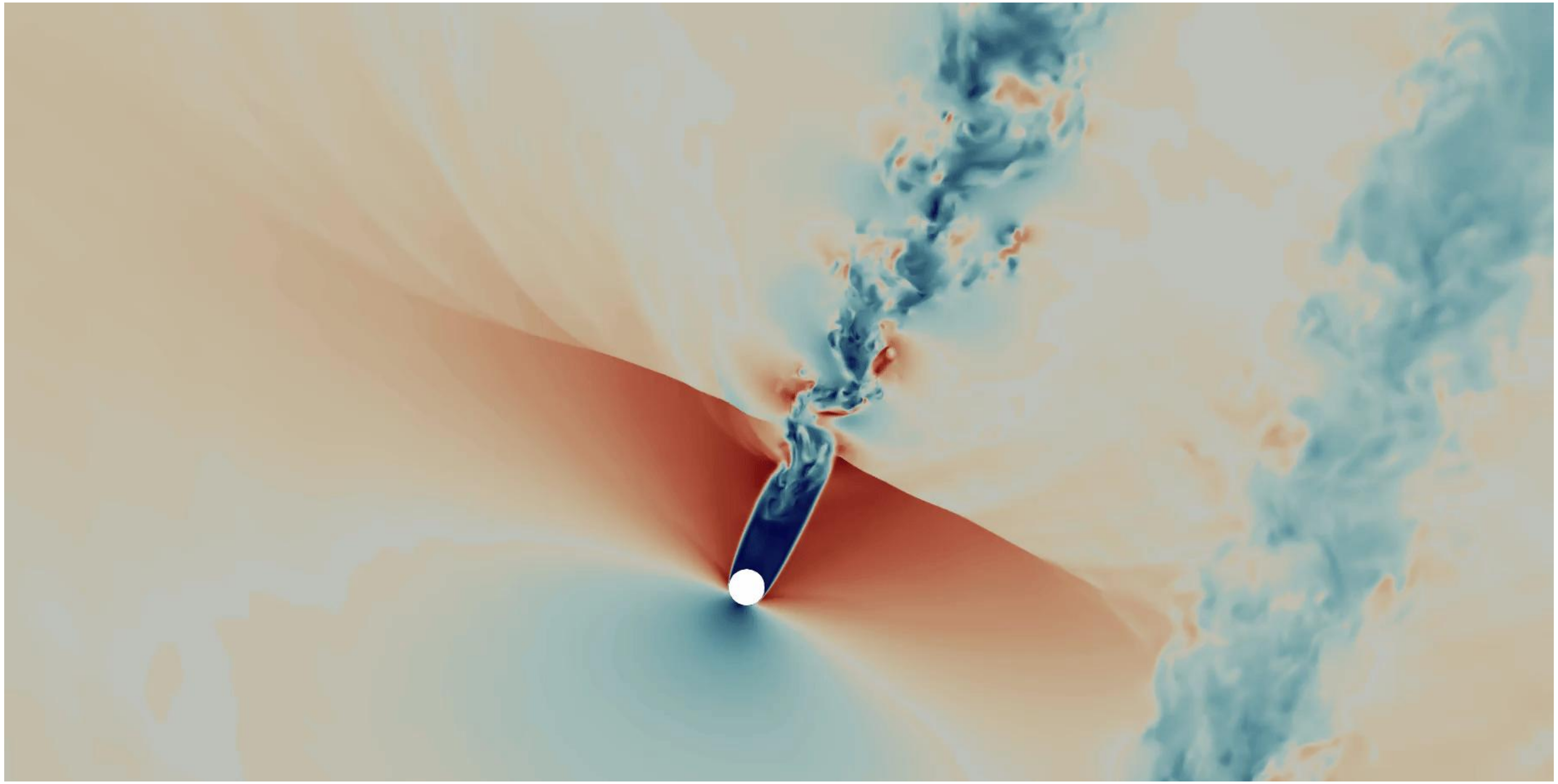
- Adds local **diffusion** that smooths out the shock
- **But changes** the resolved **physics**



A. E. Mattsson and W. J. Rider (2013) [2]

Artificial viscosity
Wake generator simulation

Mach number

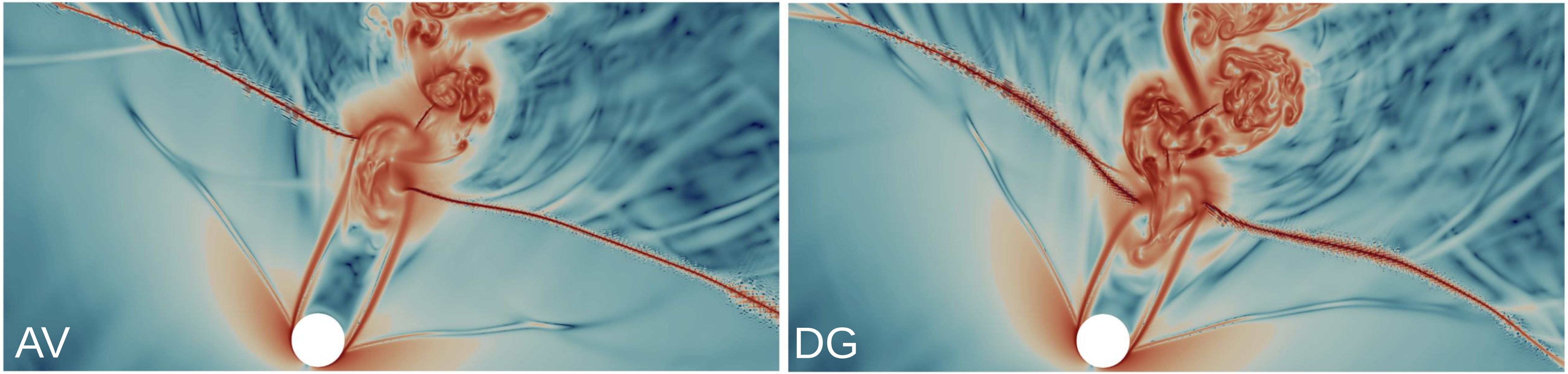


Thys et al. (2025) [1] courtesy ULiège and Cenaero

Artificial viscosity
Comparison with vanilla DG

- **Reduced** spurious **oscillations** with AV

Schlieren

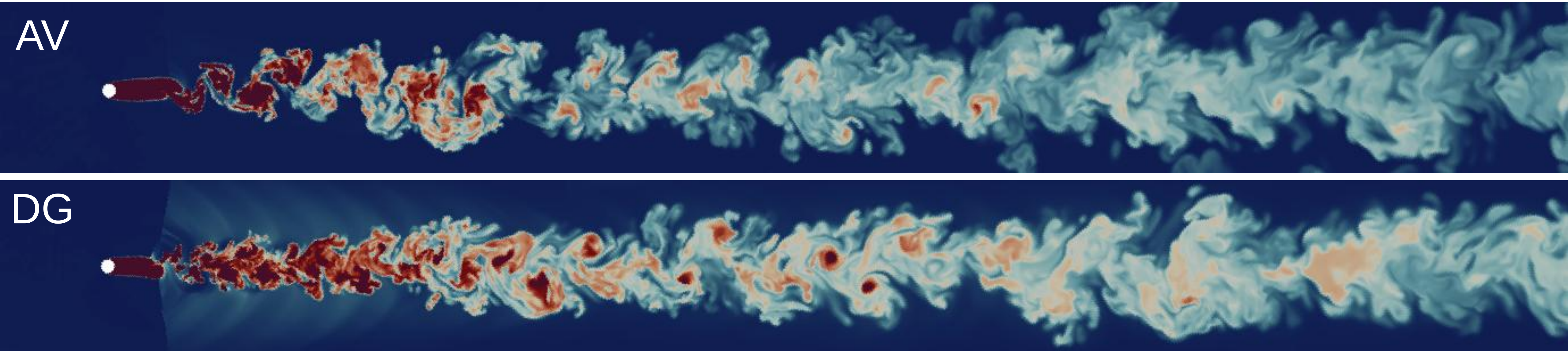


Thys et al. (2025) [1] courtesy ULiège and Cenaero

Artificial viscosity
Comparison with vanilla DG

- **Reduced** spurious **oscillations** with AV
- **Loss** of fine scale **eddies**, acoustic waves and weak shocks

Entropy



Thys et al. (2025) [1] courtesy ULiège and Cenaero

Entropy stable DG methods!

- **Stabilises** the simulation **without** adding **dissipation**
- **Enforces** a discrete analogue of 2nd **law** of thermodynamics
- **No increase** of mathematical **entropy**, $U = -\rho s$
- Still **non-physical** negative values can **appear**

Kelvin-Helmotz instability

Positivity preserving (PP)

- **Limiting** strategy: $\dot{u} = (1-\alpha)\dot{u}^{ESDG} + \alpha\dot{u}^{FV}$ with $\alpha \in [0;1]$
- Convex **combination** of **high** order ESDG and its **low** order counterpart
- Avoid **non-physical** negative values but **smooth** turbulent structures
- Several **methods** to compute α:
  - **Satisfy** certain norms or **inequalities** (MCL)
  - Use **sharp** sensor (Hennemann)
  - Computed a **priori** → easy **linearization**
  - Computed a **posteriori** → estimation next time step solution

Positivity preserving (PP)

Choice of α

- **Limiting** strategy: $\dot{u} = (1-\alpha)\dot{u}^{ESDG} + \alpha\dot{u}^{FV}$ with $\alpha \in [0;1]$
- Hennemann is **simple**, cheap and **works** well

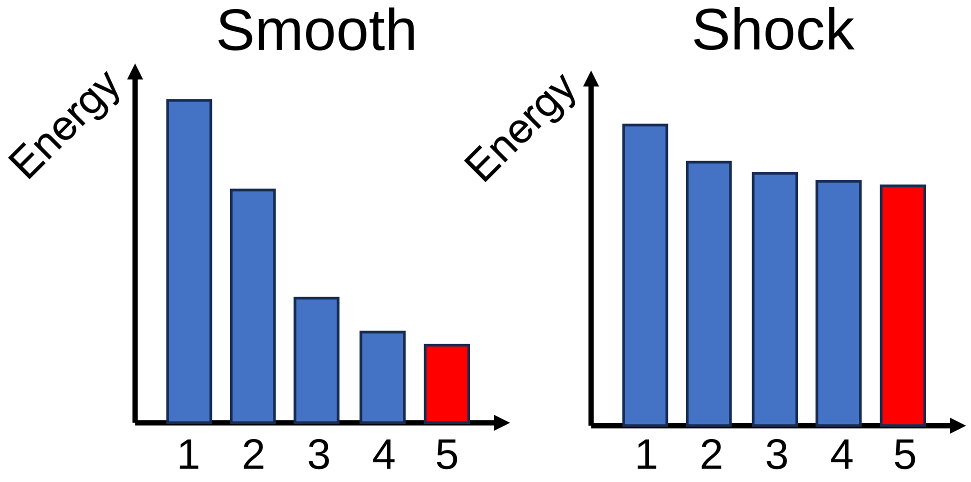
Hennemann sensor [3]

$$\alpha = \frac{1}{1+\exp(-s/T(\epsilon_K - T))}$$

Sharpness

Threshold

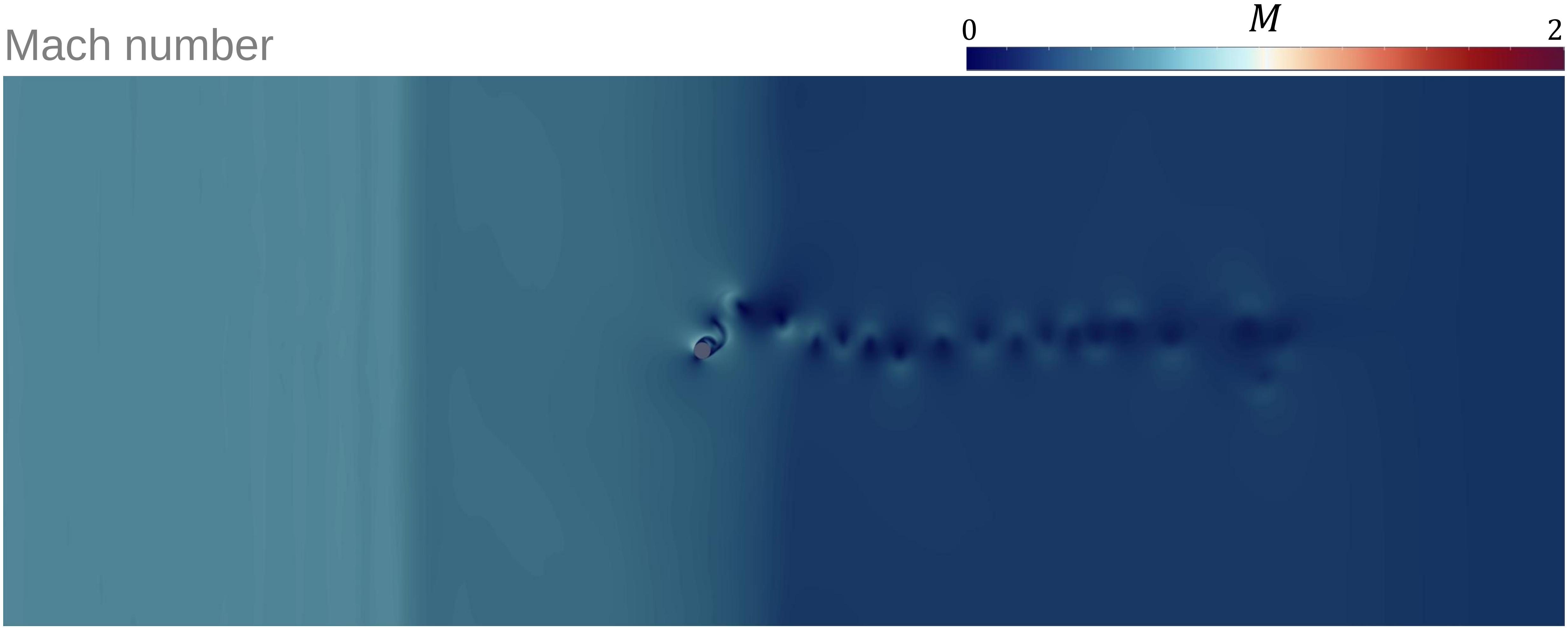
$$\epsilon_K = \frac{\text{Energy in p mode}}{\text{Total solution energy}}$$



Positivity preserving

Wake generator simulation

Mach number



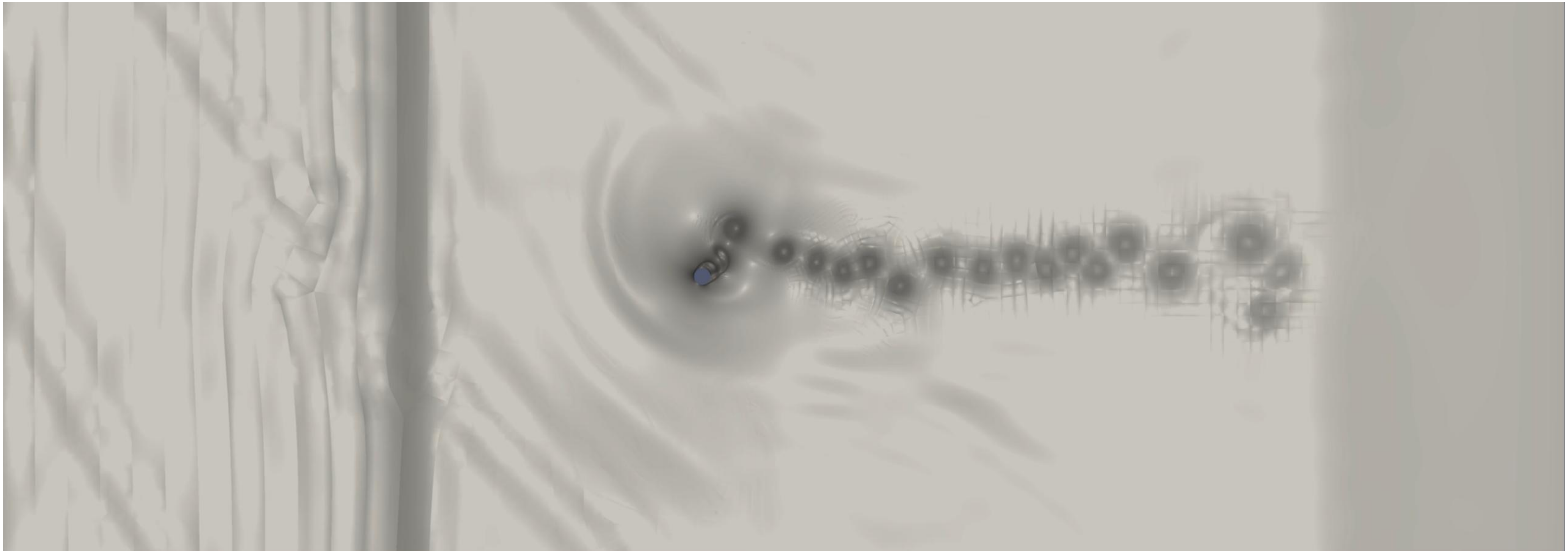
Positivity preserving

Wake generator simulation

Schlieren

$\nabla\rho/\rho$

1 $1{,}8e4$



Final objective
Stabilisation methods comparison

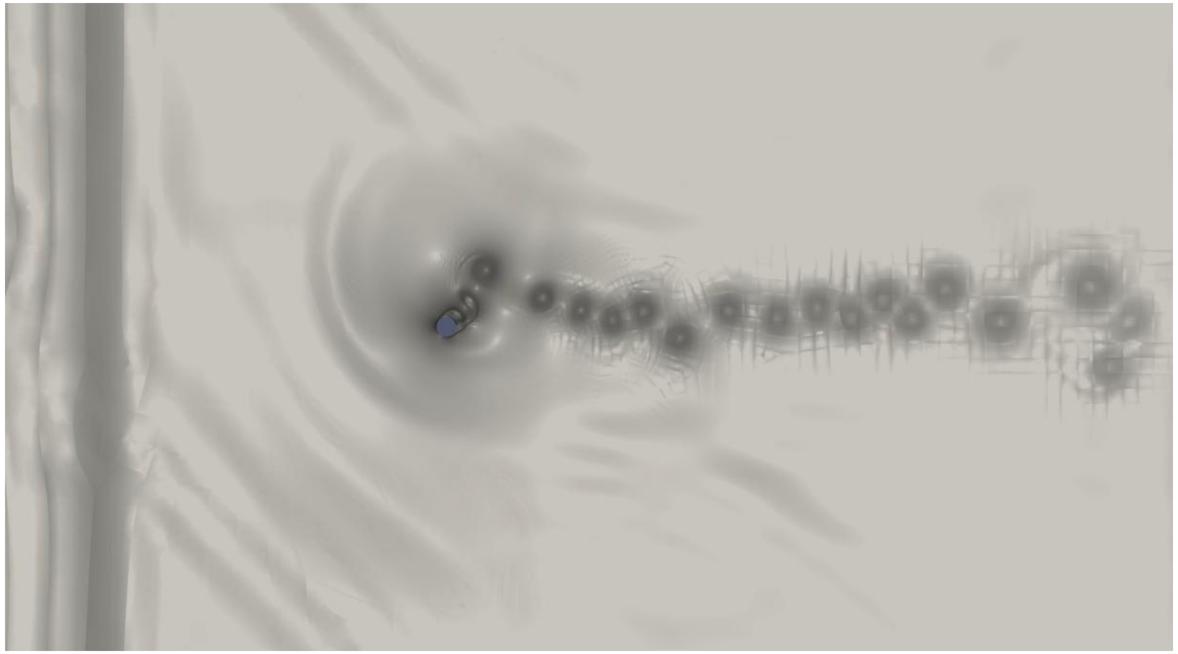
- **Parametric** study using 3 **Mach** numbers and 2 **Reynolds** numbers

- **Test** matrix for **each** stabilisation **method** (AV, ESDG, PP):

Reynolds	70k			120k		
Mach	0.7	0.9	0.95	0.7	0.9	0.95

- Compare **quantities** in the **wake**:
  - Kinetic energy **budget**
  - **Qualitative** comparison

Conclusion



Wake generator

(highly compressible flows)

↓

Strong shocks

↓

Stabilisation methods:

Artificial viscosity

- × Modifies the physics
- × Difficult to converge

Entropy stable

- ✓ Bounded entropy
- × Gibbs oscillations

Positivity preserving

- × Tends to smooth structure
- ✓ Click&Play ☺

Acknowledgment

The present research benefited from computational resources made available on Lucia, the Tier-1 supercomputer of the Walloon Region, infrastructure funded by the Walloon Region under the grant agreement n°1910247.

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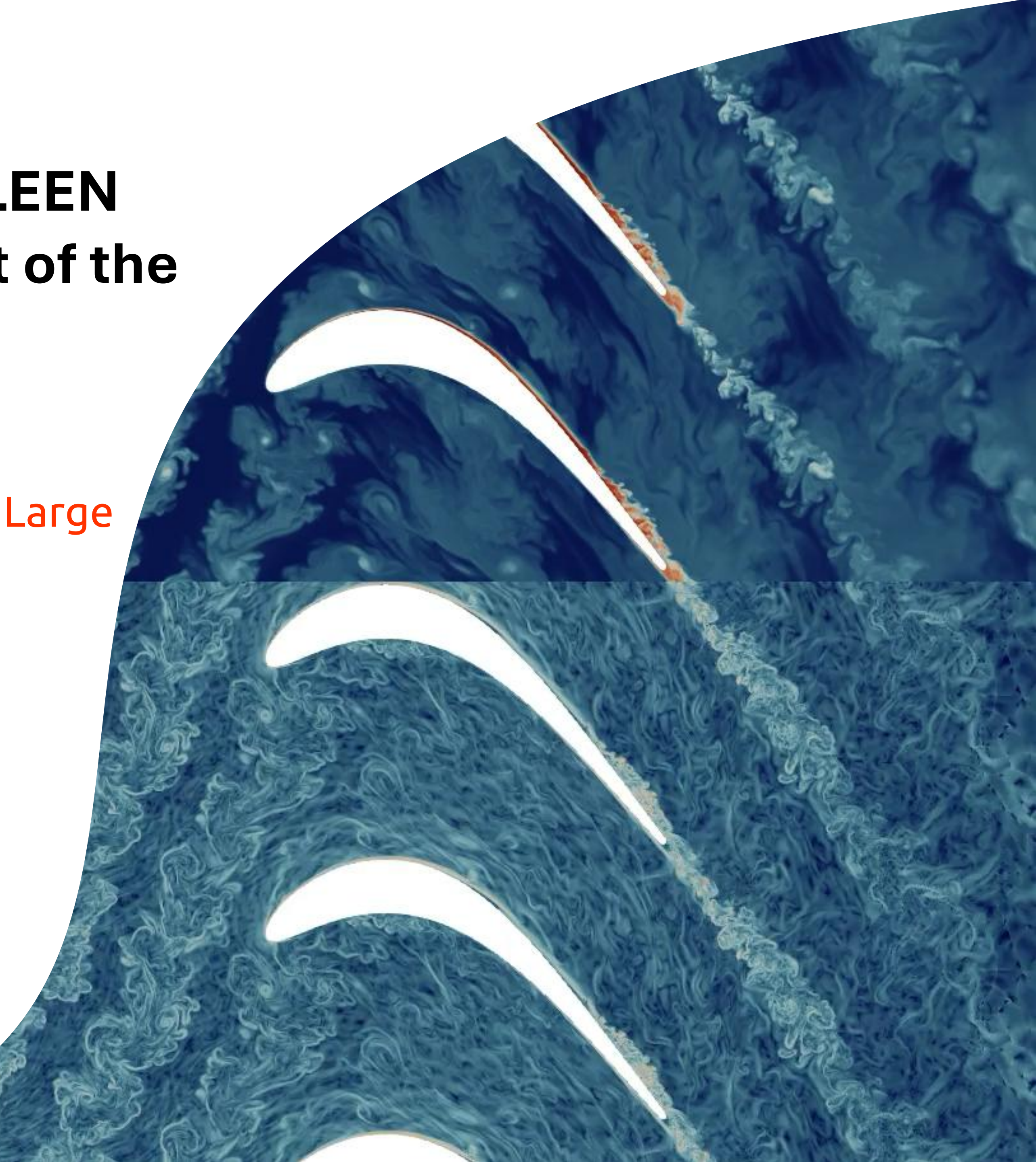

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[1] M. Thys, N. Deneffe, M. Borbouse, M. Boxho, M. Rasquin, S. Lavagnoli, G. Lopes and K. Hillewaert, “Simulation of Wake-Blade Interactions in a High-Speed Low-Pressure Turbine Cascade Using a High Order Discontinuous Galerkin Method”, finalist of the ERCOFTAC Milton van Dyke competition (2025), https://www.ercoftac.org/about/ercoftac-milton-van-dyke-competition/2025/

[2] A. E. Mattsson and W. J. Rider, “Artificial viscosity: Back to basics.,” Aug. 2013. [Online]. Available:https://www.osti.gov/biblio/1115027.

[3] Sebastian Hennemann et al. “A provably entropy stable subcell shock capturing approach for high order split form DG for the compressible Euler equations”. In: Journal of Computational Physics 426 (Feb. 2021), p. 109935. issn: 00219991. doi: 10.1016/j.jcp.2020.109935.