



Centre Tecnològic de Transferència de Calor
UNIVERSITAT POLITÈCNICA DE CATALUNYA



On the Combined Effect of Mesh Anisotropy and Scheme Accuracy in the Periodic Hills Case

J. Ruano¹, A. Oliva¹, A. Duben², A. Gorobets², F. X. Trias¹

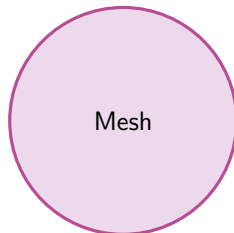
¹Heat and Mass Transfer Technological Center (CTTC), Technical University of Catalonia

²Keldysh Institute of Applied Mathematics (KIAM)



Selecting the CFD triad

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Selecting the CFD triad

Uniform,
non-uniform,
body fitted,
octree,
unstructured...

Mesh

Discretization
schemes

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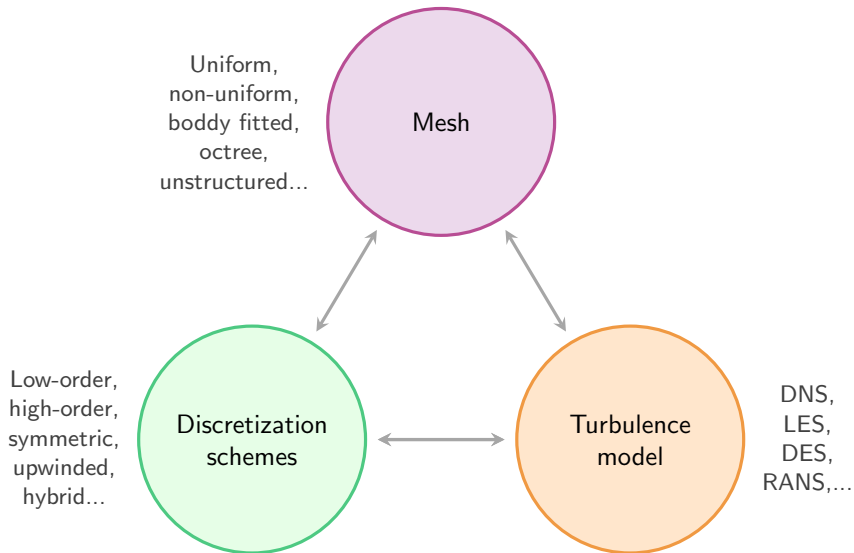
Mesh

Low-order,
high-order,
symmetric,
upwinded,
hybrid...

Discretization
schemes

Turbulence
model

Selecting the CFD triad



Meshes: Academy vs Industry

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Same goal, different approach

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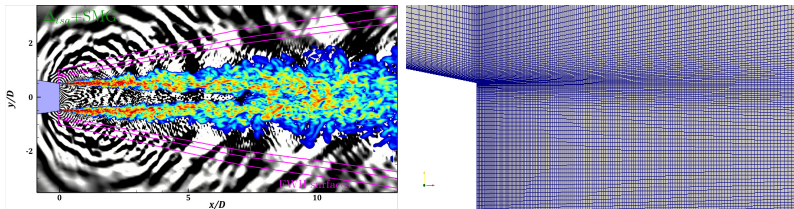
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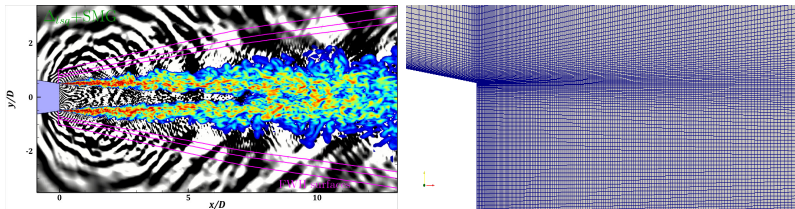
Instantaneous flow field in a jet plume ($Re_D = 1.1e6$, $Ma = 0.9$)¹.

¹A.P. Duben, J. Ruano, A.V. Gorobets, J. Rigola, and F.X. Trias. (2023). Evaluation of enhanced gray area mitigation approaches based on jet aeroacoustics. AIAA journal, 61(2), 612-625.

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Stretching ratio in streamwise direction 3%.

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Schemes: Low order vs high order

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Mesh' effect on scheme's accuracy

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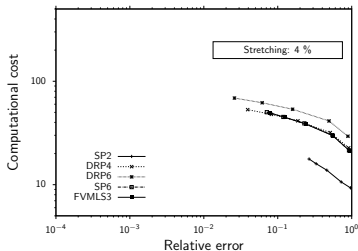
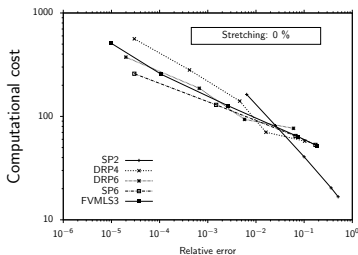
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Computational cost vs numerical error for uniform (left) and stretched (4%) (right) grid².

²J. Ruano, A.B. Vidal, J. Rigola, and F.X. Trias. (2022). A new general method to compute dispersion errors on Cartesian stretched meshes for both linear and non-linear operators. Computer Physics Communications, 271, 108192.

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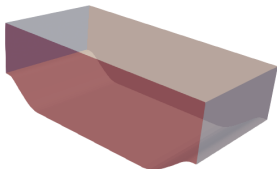
Research question #3:

- Can this problem be “cheap” ?
 - So we don't need excessive number of CV to have reliable results.

Selected problem

Lots of interesting things to analyse!

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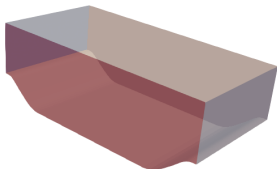


Periodic hill test case ($Re_H = 10595$)

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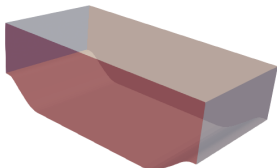


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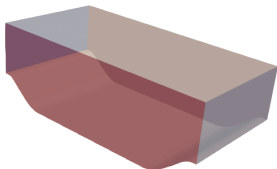
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Case	Turbulence model	Length scale
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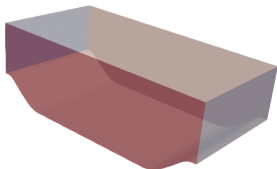
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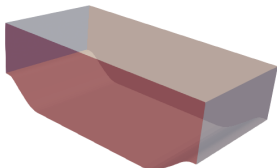
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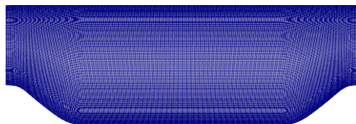
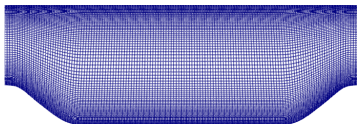
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3	WALE [Nicoud et. al., 2011]	Δ_{vol} [Deardorff 1970]

Mesh definition

Uniform meshes characteristics

Mesh characteristics	Coarse	Medium	Fine
$N_x \times N_y \times N_z$	140x110x100	210x165x150	280x220x200*
Total cell count	1.54M	5.2M	12.32M
$\Delta x/H$	0.064	0.043	0.032
$\Delta z/H$	0.045	0.03	0.0225
$\max(\Delta y/H)$	0.06	0.04	0.03
$\max(\Delta y/H)$ wall	0.0024	0.0016	0.0012
$\max(\Delta y/\Delta x, z)$	26.26	26.54	26.08

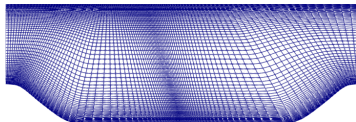
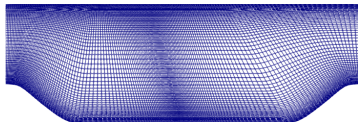
*M. Breuer, N. Peller, Ch. Rapp, M. Manhart (2009). Flow over periodic hills
– Numerical and experimental study in a wide range of Reynolds numbers.
Computer & Fluids, 38, 437-457.



Mesh definition

Computational meshes: non-Uniform

Mesh characteristics	Smooth	Medium	Agressive
$N_x \times N_y \times N_z$	167x110x140	138x110x140	110x110x140
Total cell count	2.6M	2.1M	1.7M
Stretching	5%	5-10%	10%
$\Delta x/H$ at detachment	0.015	0.015	0.015
$\Delta x/H$ at retachment	0.017	0.017	0.017
$\max(\Delta y)$	0.06	0.06	0.06
$\max(\Delta y)$ bottom wall	0.0024	0.0024	0.0024
$\max(\Delta y/\Delta x, z)$	180	344	295.7



Schemes effect: Two different numerical algorithms

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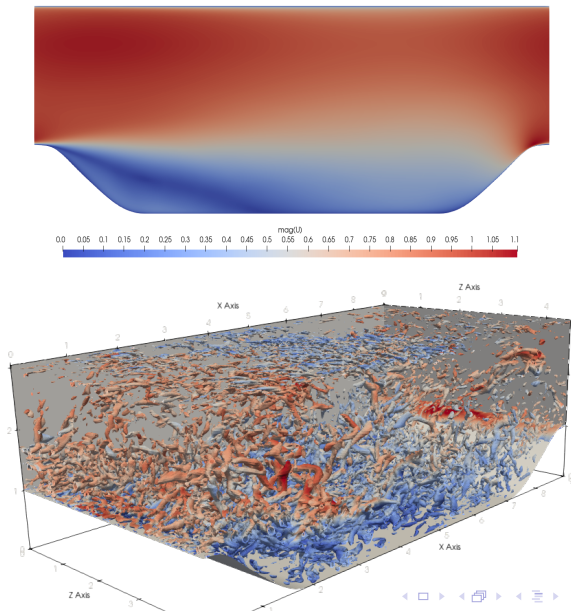
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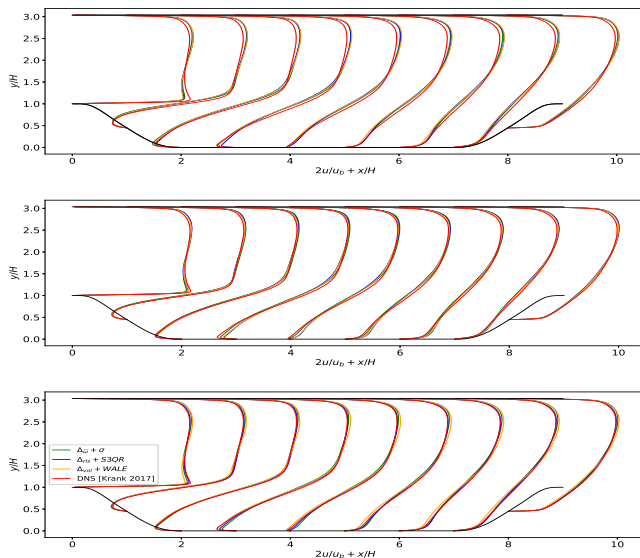
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Time integration	Implicit 2n order	Implicit 2n order

*On translationally symmetric meshes

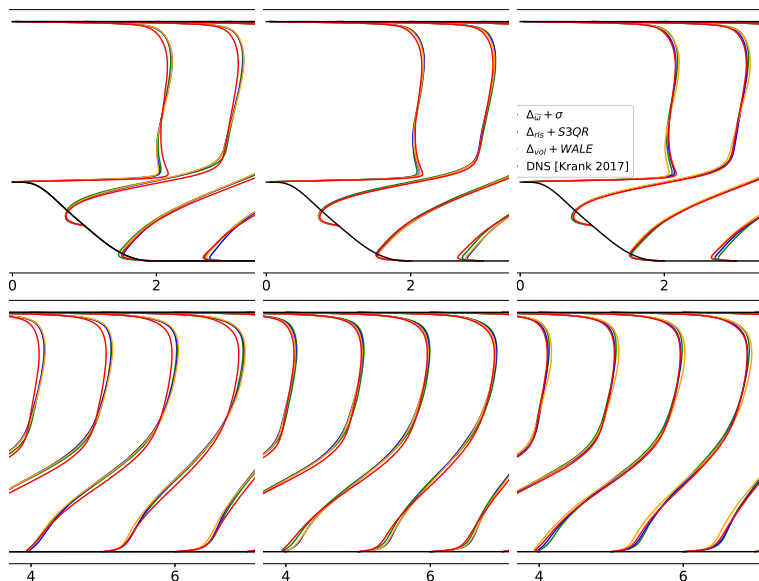
Nice Color Fluid Dynamics



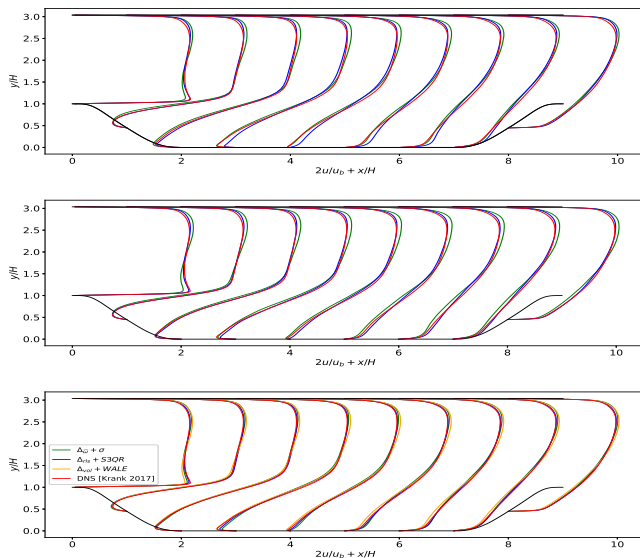
Mean velocity (uniform mesh) OpenFOAM



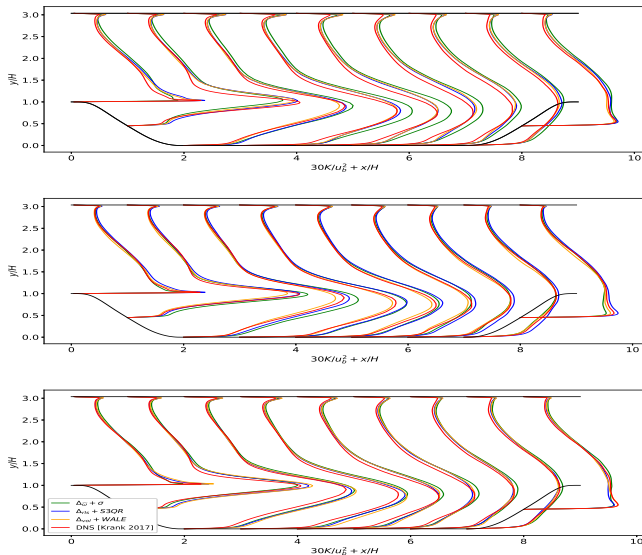
Mean velocity (uniform mesh, zoom) OpenFOAM



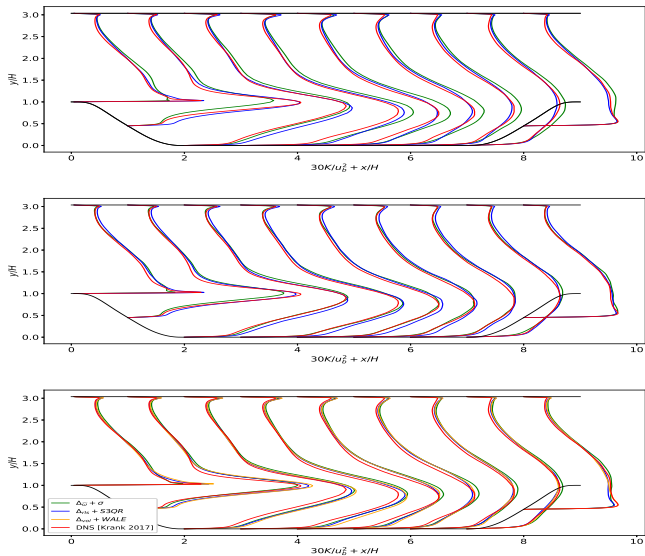
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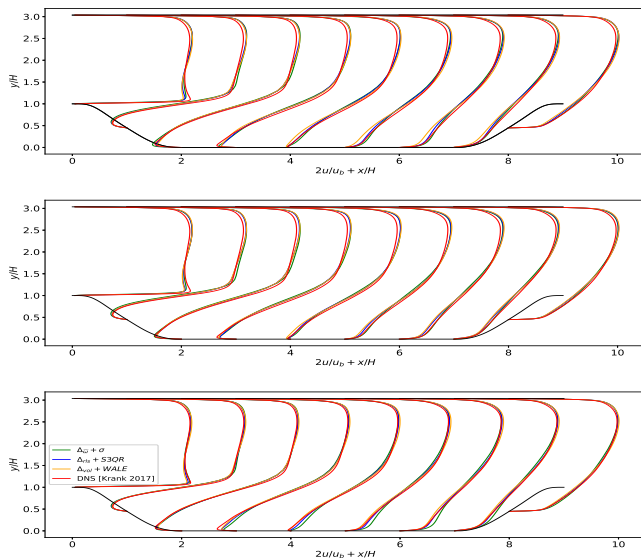
Mean kinetic energy (uniform mesh) OpenFOAM



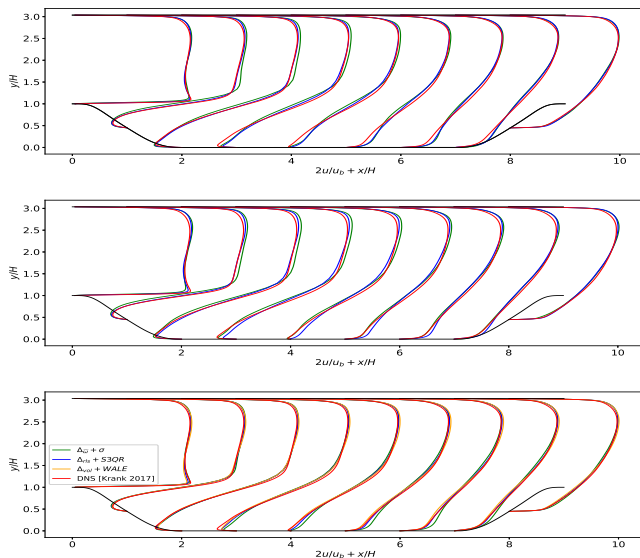
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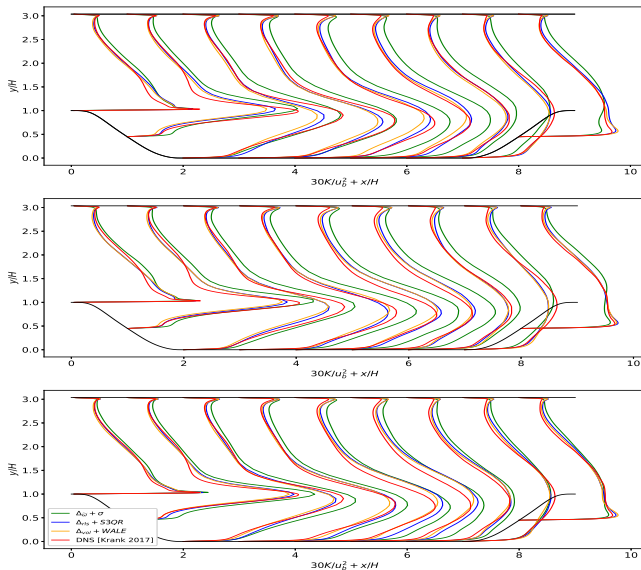
Mean velocity (non-uniform mesh) OpenFOAM



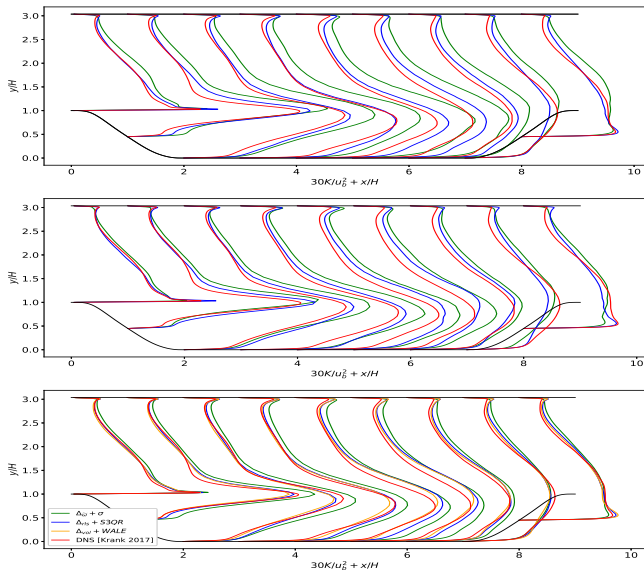
Mean velocity (non-uniform mesh) NOISEtte



Mean kinetic energy (non-uniform mesh) OpenFOAM



Mean kinetic energy (non-uniform mesh) NOISEtte



Concluding remarks

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For uniform meshing...

- Selected approaches provide good mesh convergence.
- WALE + Δ_{vol} has more mismatch near walls, improper velocity decay.
- Overpredicted kinetic energy ($< 5\%$) by all models in the recirculating zone.
- Selecting non-geometric Δ + proper invariant behavior model is recommended.

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For non-uniform meshing...

- Velocity profiles are slightly overpredicted in the upper part for all models; underprediction near detachment point.
- Overall, $\sigma + \tilde{\Delta}_\omega$ overpredicts kinetic energy.
- Increased stretchings lead to more inaccurate results.
- S3QR + $\tilde{\Delta}_{rls}$ seems to produce more accurate results near walls.

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Further (on-going) work

Non-controlled numerical diffusion

OpenFOAM is known to introduce additional numerical dissipation.

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- More elements to compare.

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Additional quantities to study

Detachment and reattachment points should be studied in detail.

- Initial measurements indicate good detachment point prediction.
- Retachment point seems to lie between DNS [Krank 2017] and experimental results [Rapp 2011].

Thanks for your attention