First Automotive CFD Prediction Workshop

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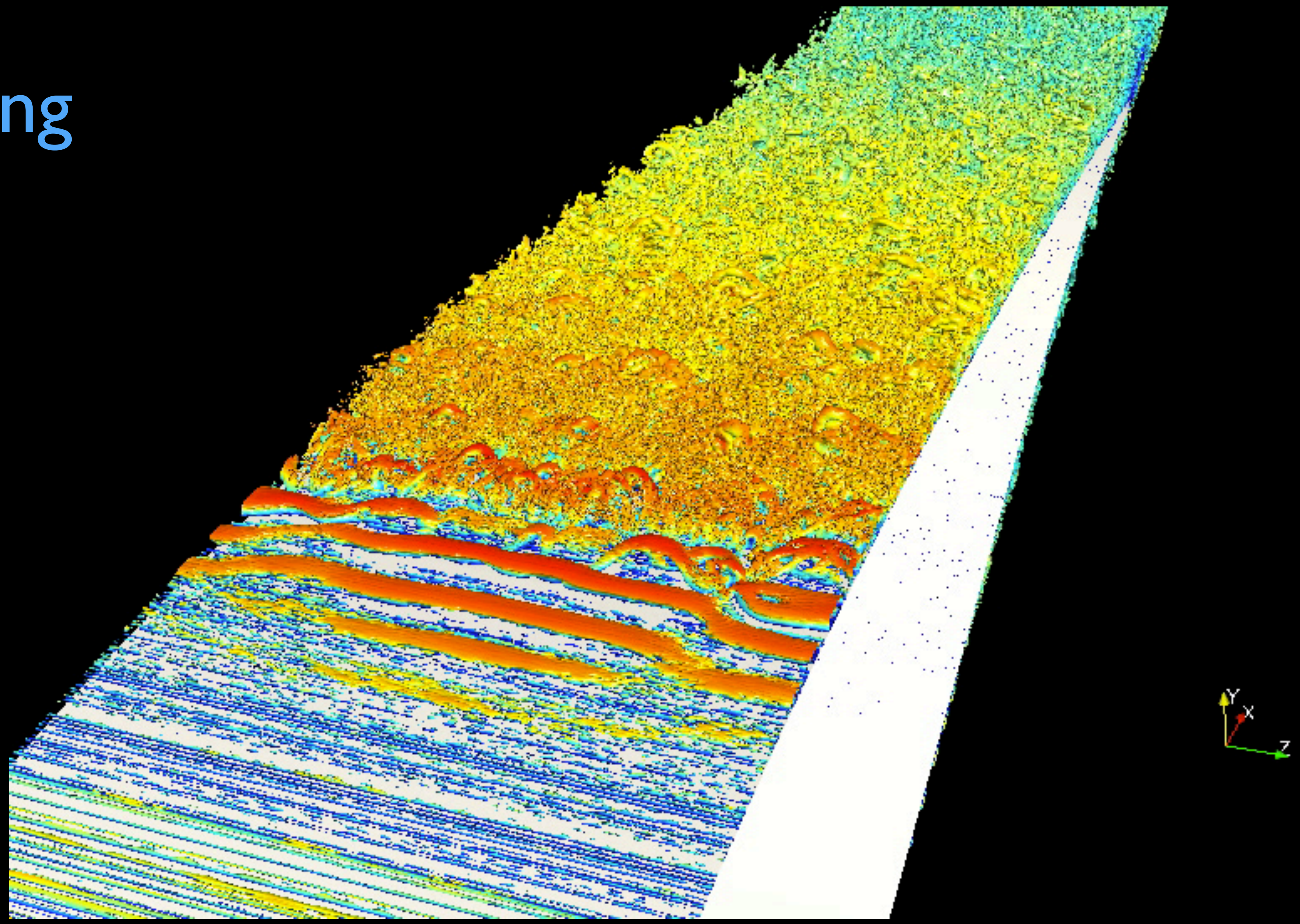
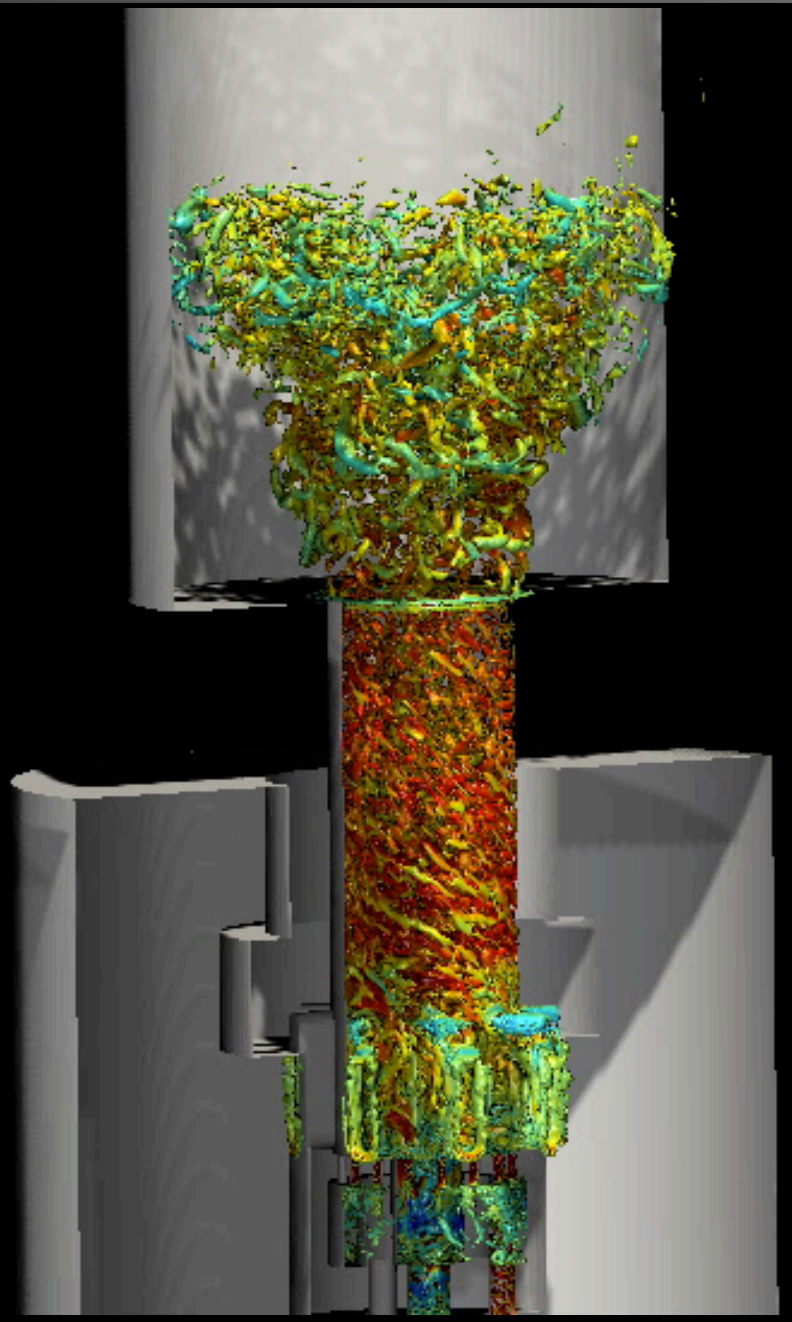
Motivation

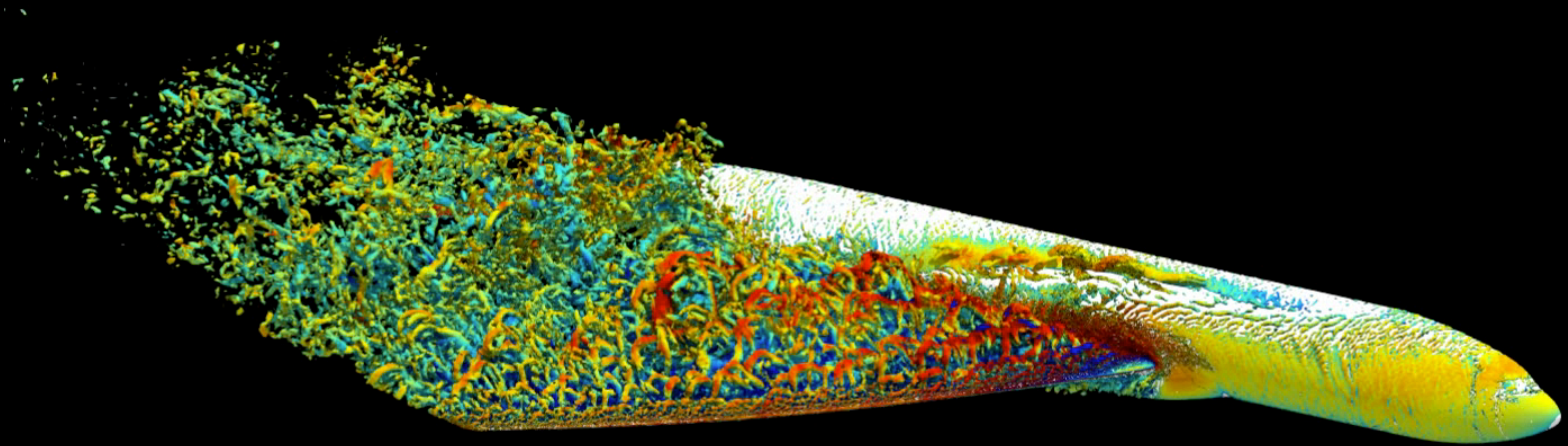
Turbulent flows still need turbulence modelling

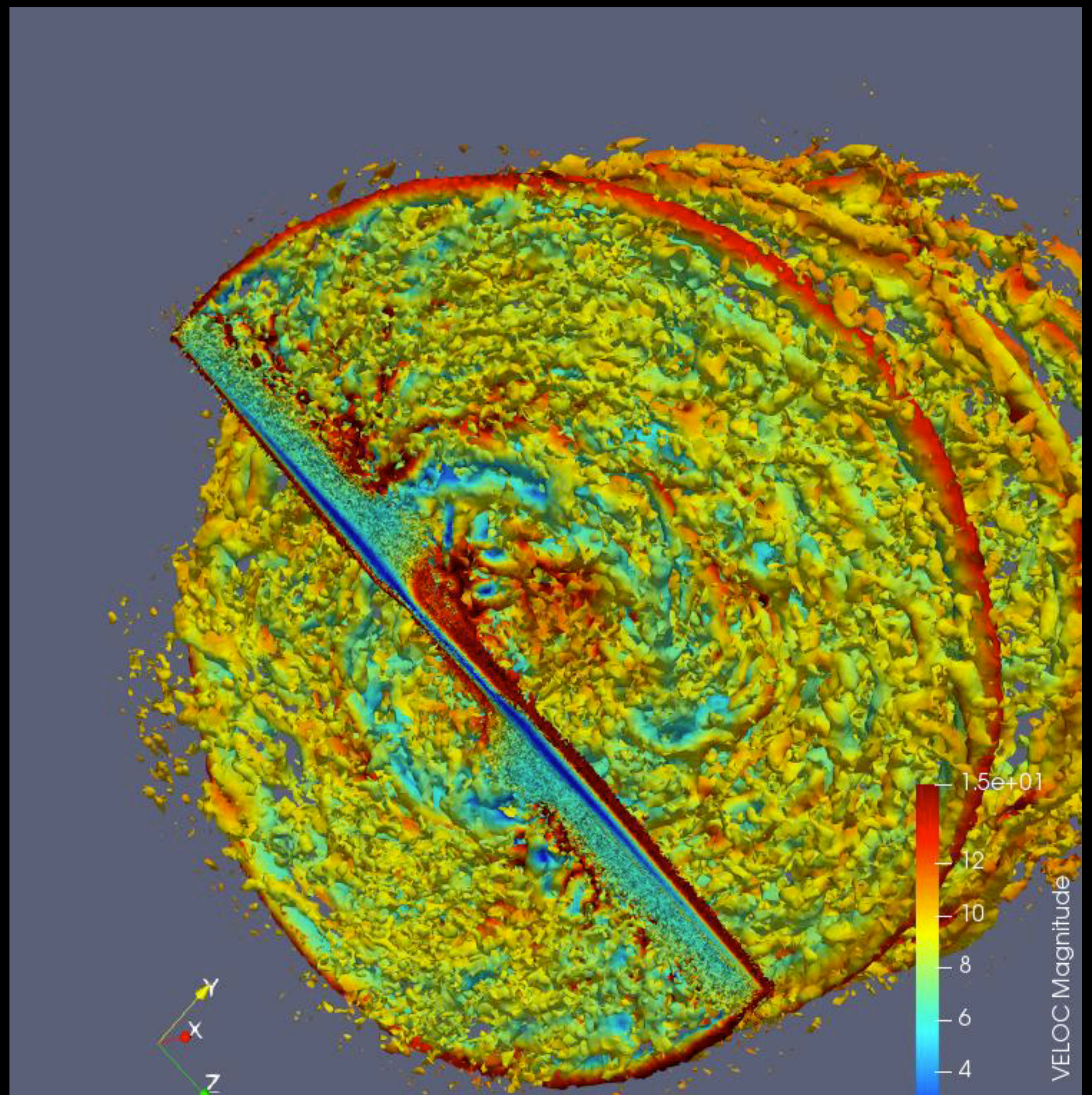
DNS, O(10B) elements, O(10^8) time steps

LES, O(100M) elements, O(10^6) time steps









Another Motivation

Collaboration with SEAT

EL PAÍS

SUSCRÍBETE

Simulación de la aerodinámica de un coche de Seat en el BSC. **JUAN BARBOSA**

Includes rotating wheels

Only 3PM

https://elpais.com/ccaa/2019/05/03/catalunya/1556896370_462478.html

Large eddy simulation models: challenges and bottlenecks

By spatially filtering the NS equations:

$$\frac{\partial \overline{u}_i}{\partial x_i} = 0$$

$$\frac{\partial \overline{u}_i}{\partial t} + \frac{\partial \overline{u}_i \overline{u}_j}{\partial x_j} - \nu \frac{\partial^2 \overline{u}_i}{\partial x_j \partial x_j} + \rho^{-1} \frac{\partial \overline{p}}{\partial x_i} - F_i = -\frac{\partial \mathcal{T}_{ij}}{\partial x_j}$$

$$\mathcal{T}_{ij} - \frac{1}{3}\mathcal{T}_{kk}\delta_{ij} = -2\nu_{sgs}\overline{S}_{ij}$$

$$\overline{S}_{ij} = \tfrac{1}{2}(g_{ij} + g_{ji}) \qquad g_{ij} = \partial \overline{u}_i / \partial x_j$$

Closure:

Smagorinsky

Dynamic Smagorinsky

Wall-Adapting Local Eddy-Viscosity (WALE) Model

Vreman

Variational Multi-Scale

…

Specific challenges:

Numerics interact with the LES model

Usually the mesh is the filter

Scales at the wall are case dependent

Numerical Model: Alya - LES

Alya: HPC Finite element code developed at BSC.

LES has recently undergone huge transformation.

FROM: VMS with implicit treatment of convective and diffusive terms.

TO: Galerkin with explicit (RK3) treatment of convective and diffusive terms.

EMA - Energy, momentum and angular momentum conserving convective term.

Stabilisation for the p-v interaction coming from Laplacian approximation in Fractional Step Method.

Physical based SGS modelling (Vreman in current work).

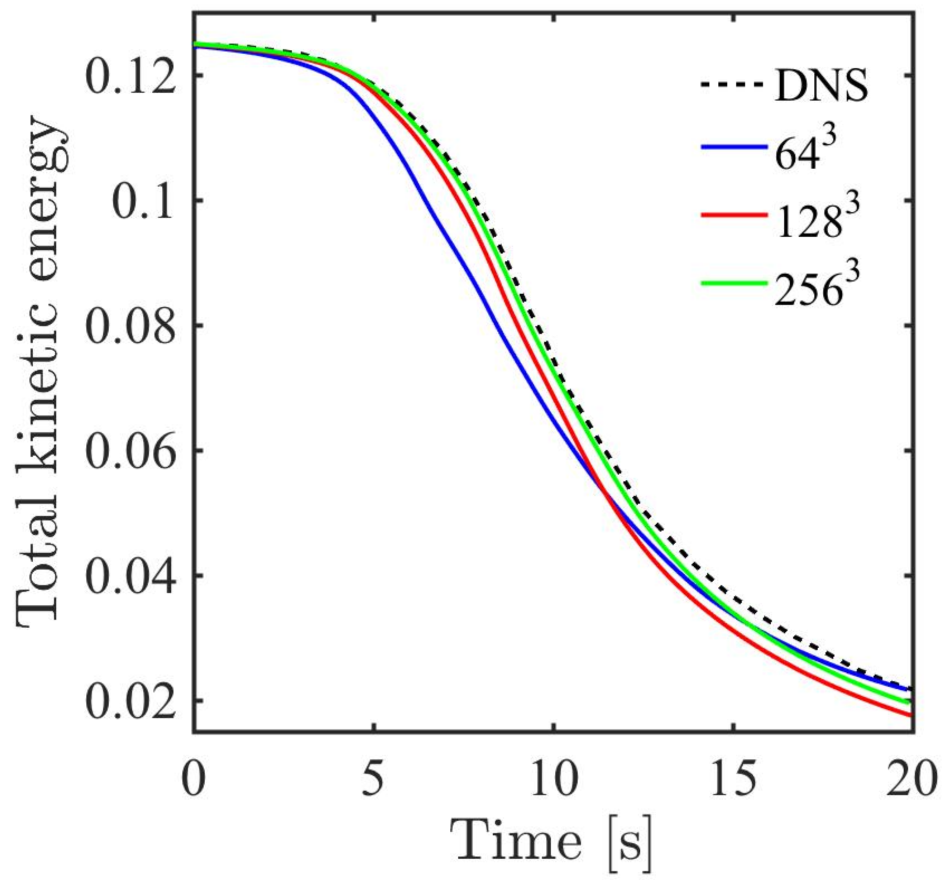
SIMPLE and no user defined numerical parameters.

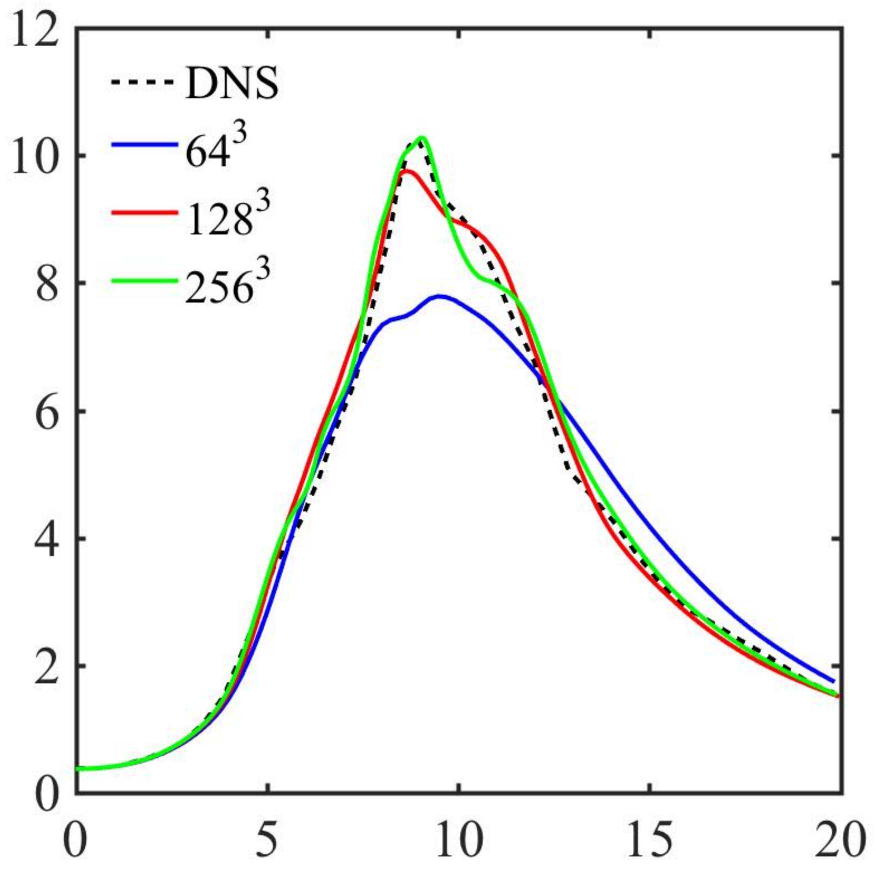
Lehmkuhl el al. A low-dissipation finite element scheme for scale resolving simulations of turbulent flows J. Comput. Phys., 308:51–65, 2019

Numerical Model: Alya - LES

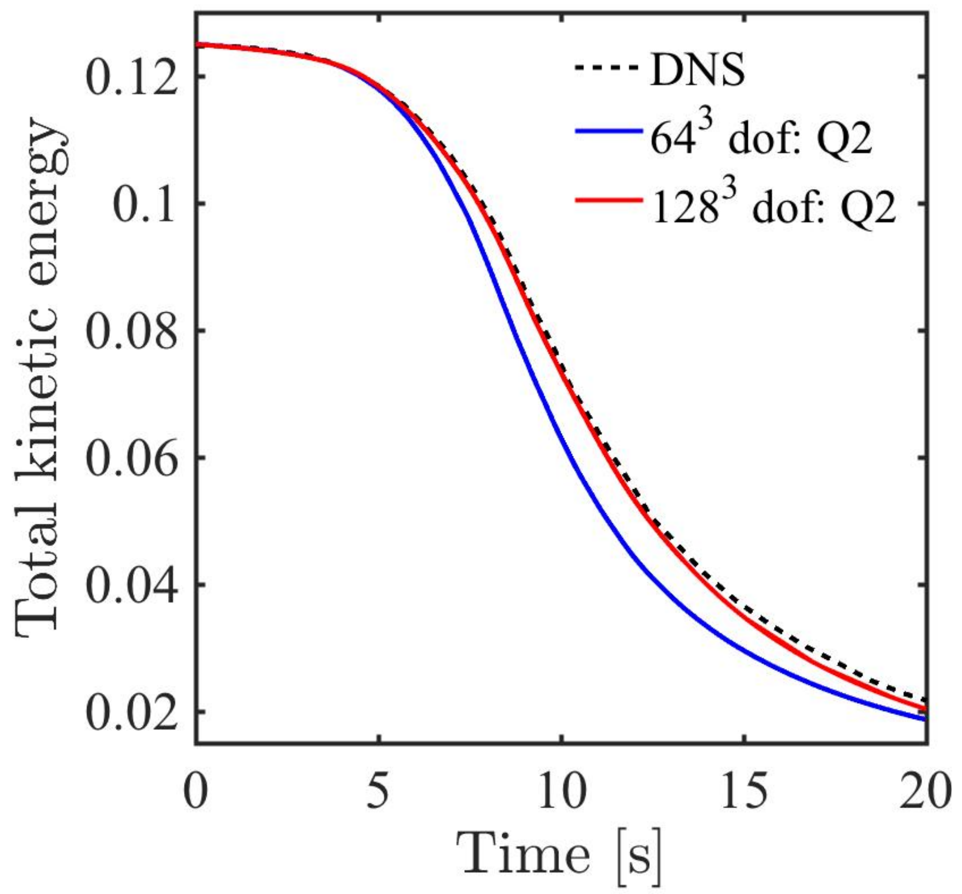
Test case: Taylor-Green vortex Re = 1600 *

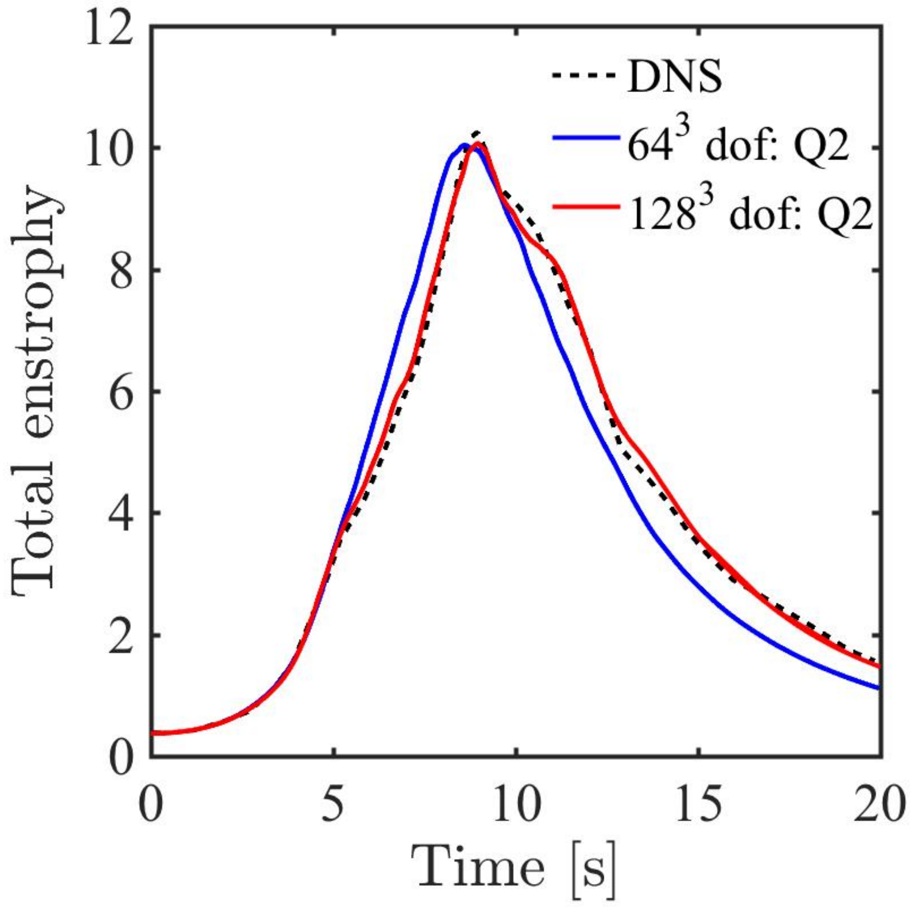
EMA approximation: Q1

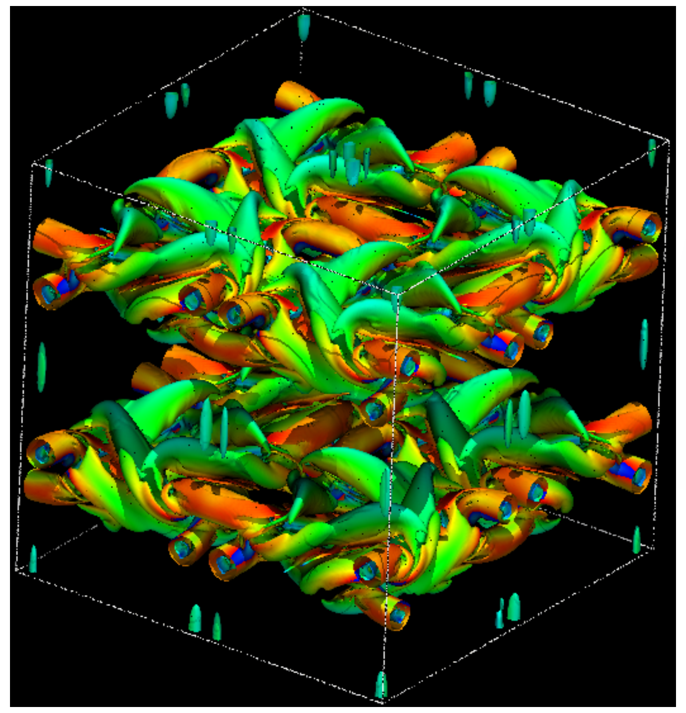




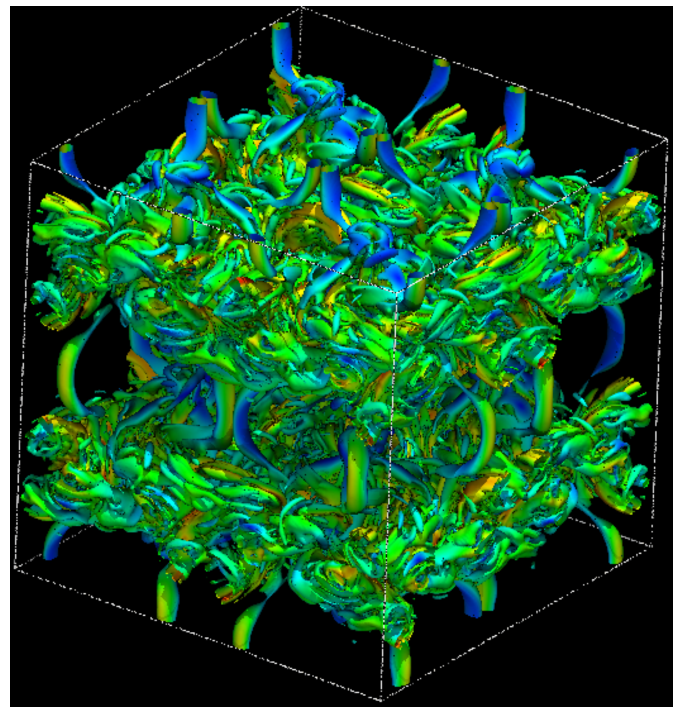
EMA approximation: Q2



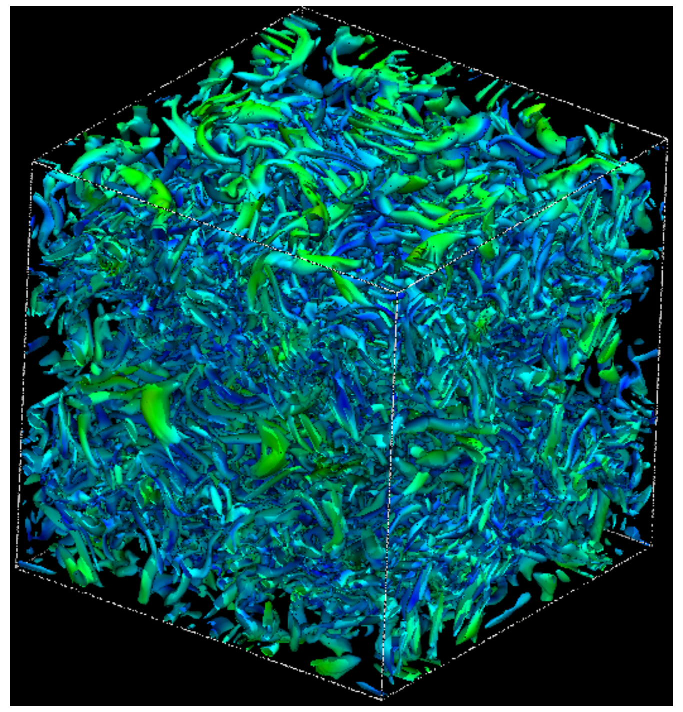




t = 5



t = 10

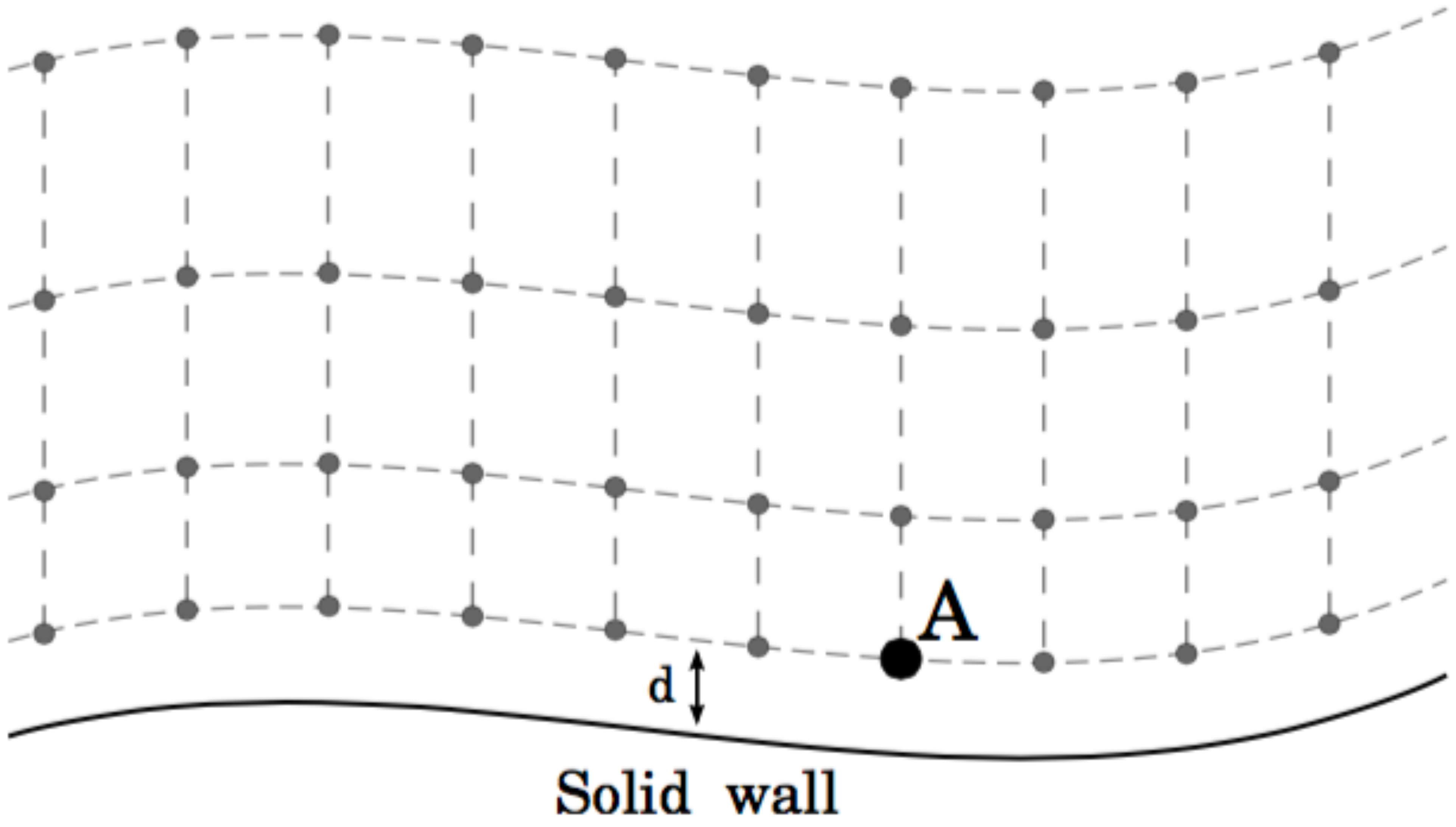


t = 20

A low-dissipation finite element scheme for scale resolving simulations of turbulent flows, Lehmkuhl et al. submitted to Journal of Computational Physics

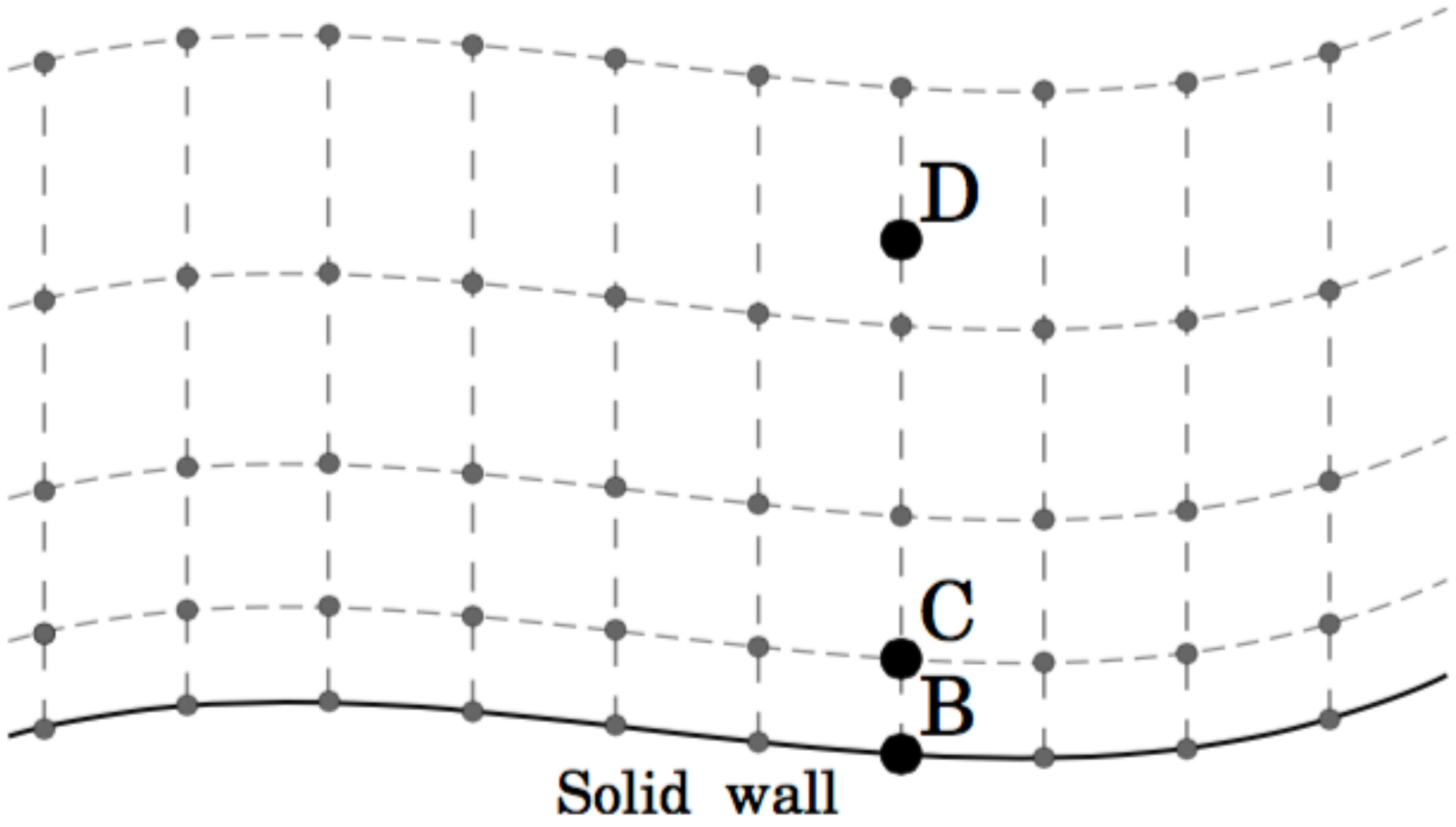
For reference see: Comparison between several approaches to simulate the Taylor-Green vortex case, Moulinec et al. PARCFD 2016

Huge improvements with new implementation for FE



Standard FE approach

D within the inner portion of the boundary layer

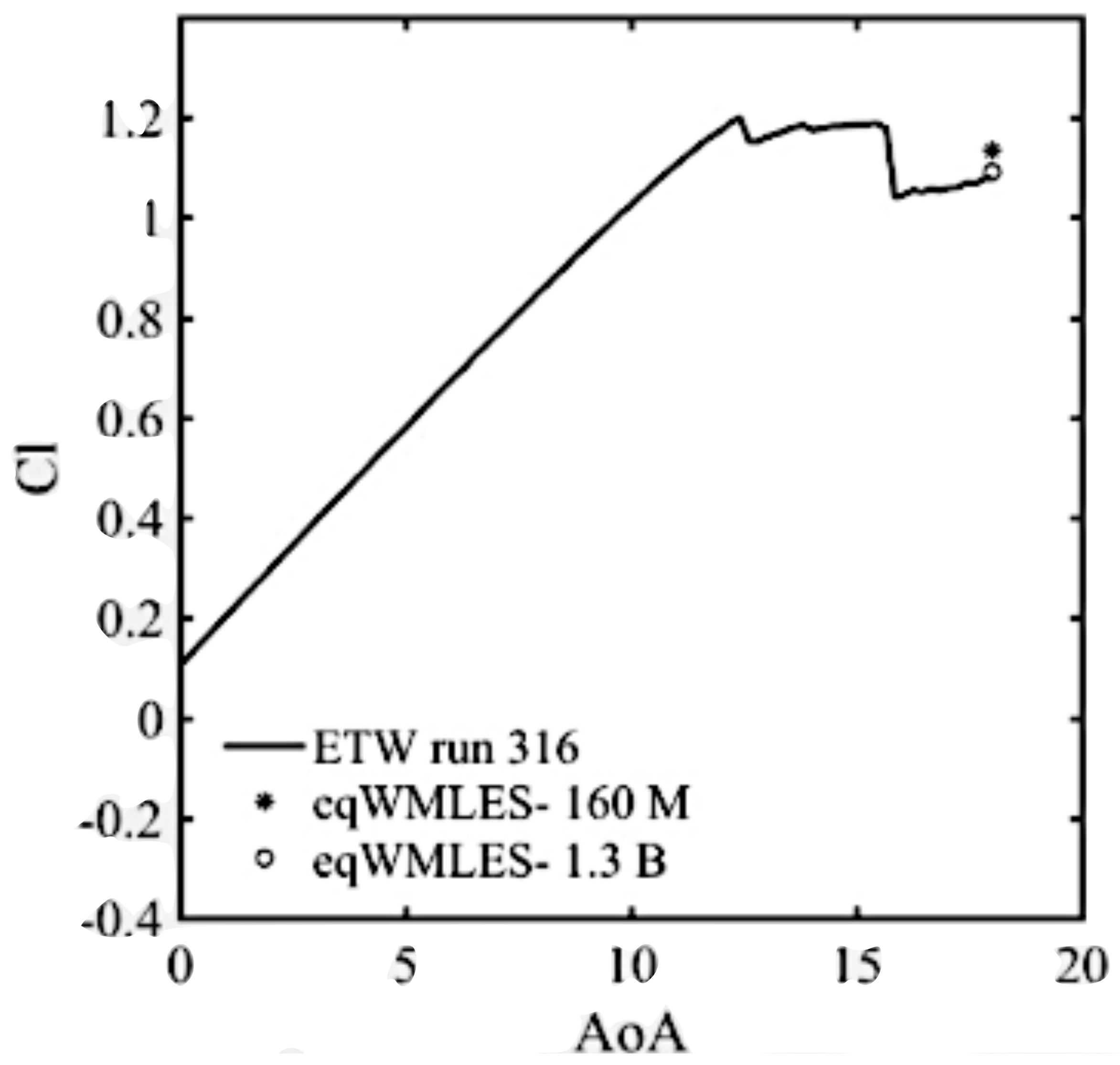


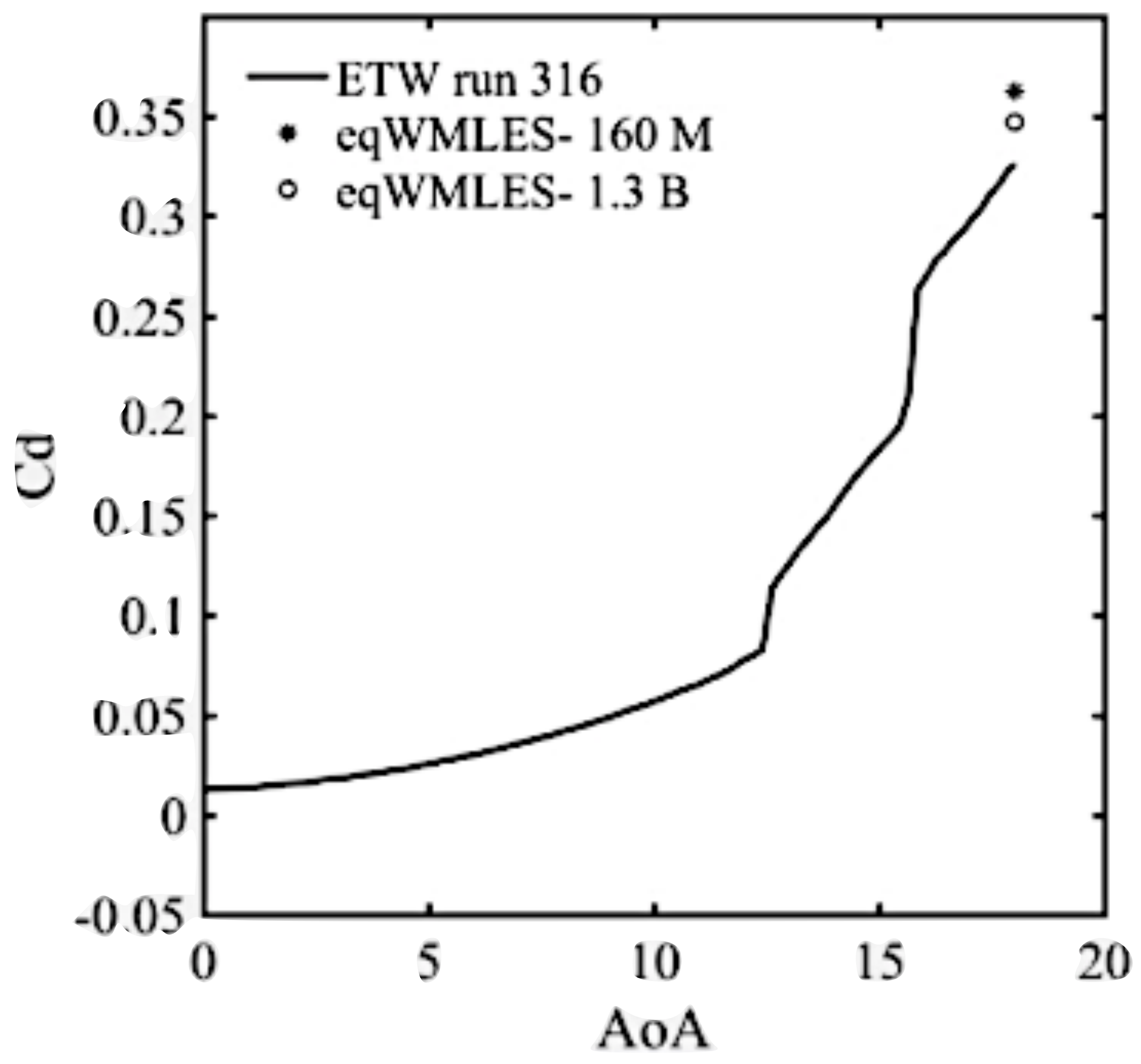
B-C Standard FD

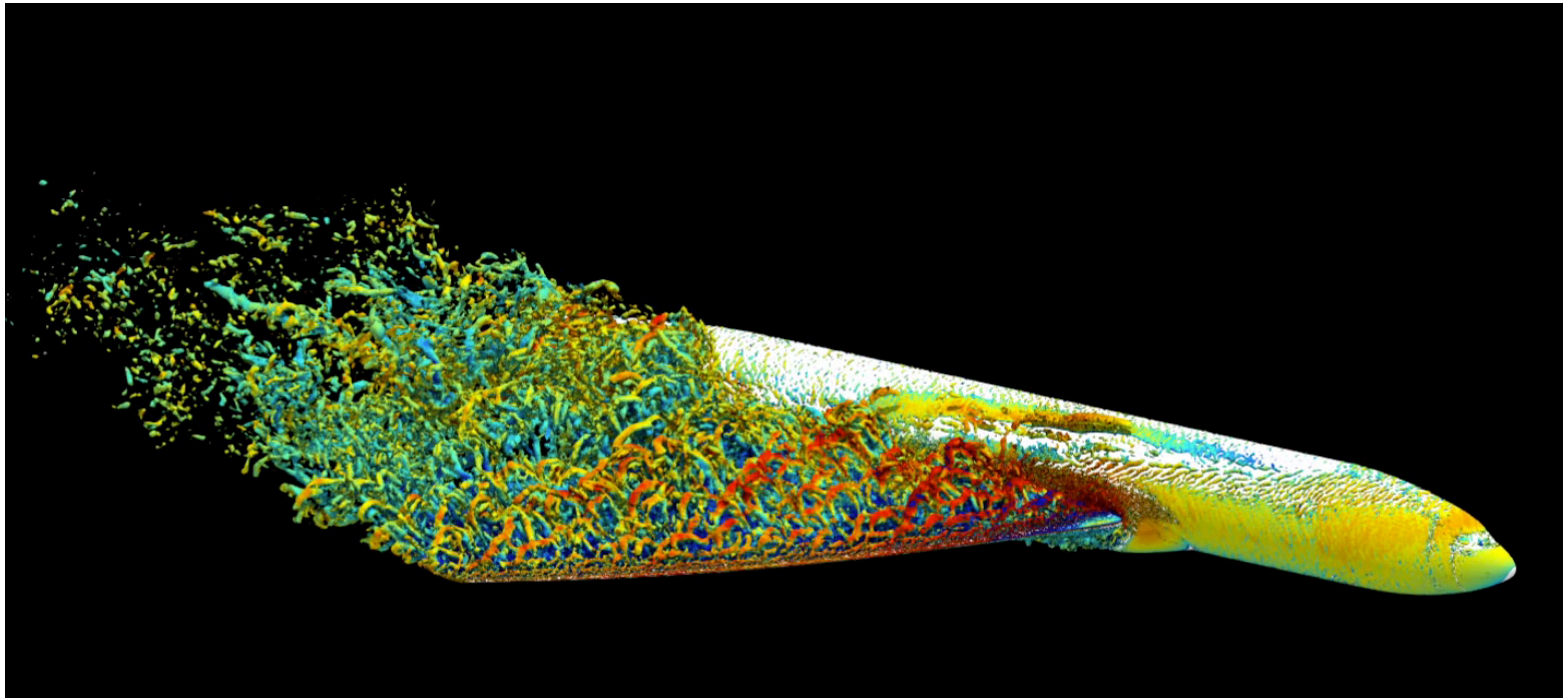
B-D Exchange location (Kawai & Larsson)

Wall-modelled large-eddy simulation in a finite element framework , Owen et al. IJNMF 2019

LES of flow over the NASA common research model (collaboration with CTR)





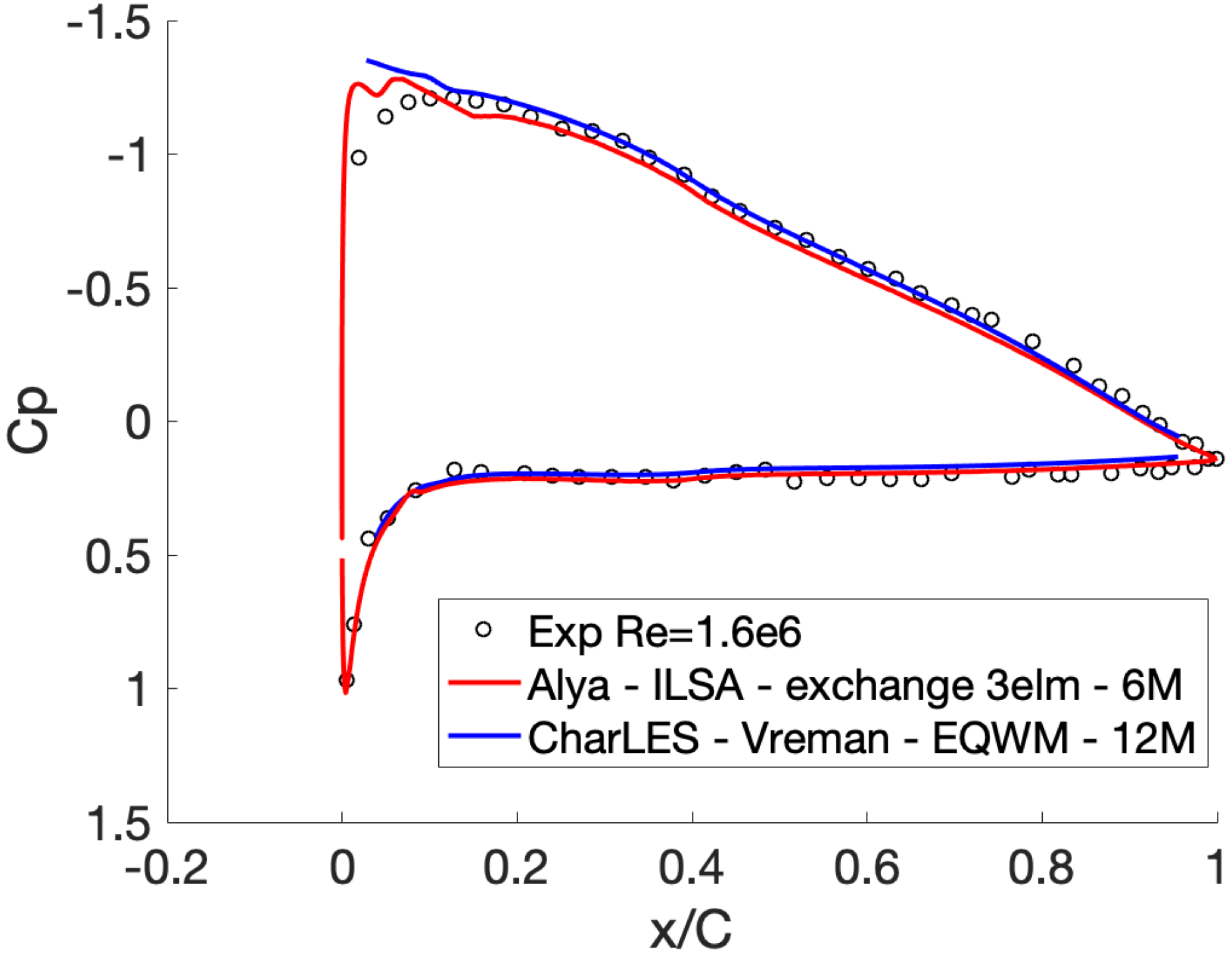


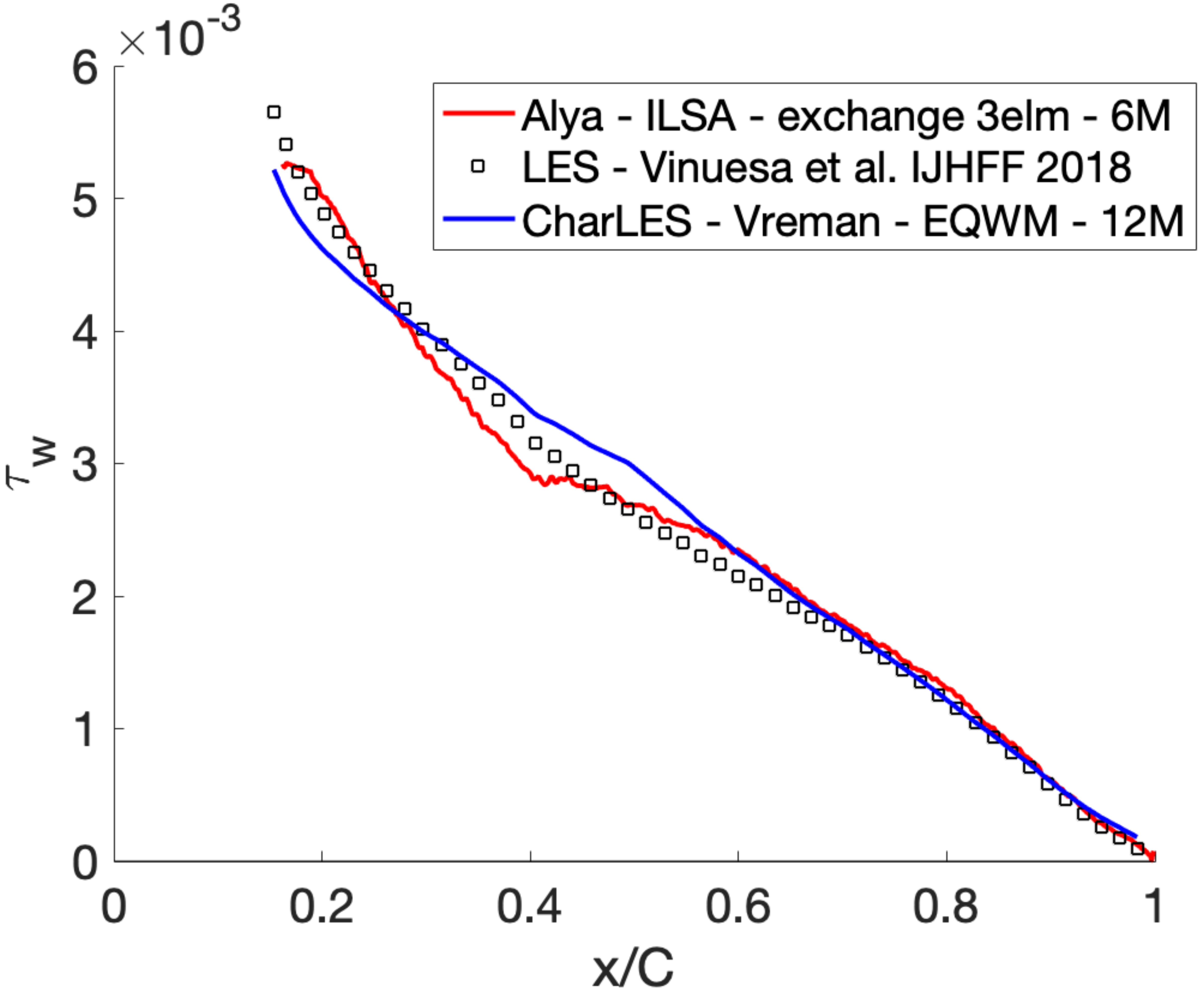
WMLES for stall regime
Re = 11M Ma = 0.2

Experiments coming from DLR
Mesh from O(150M) to O(1.5B)

Obtained results are the first large scale demonstration of the WMLES technology

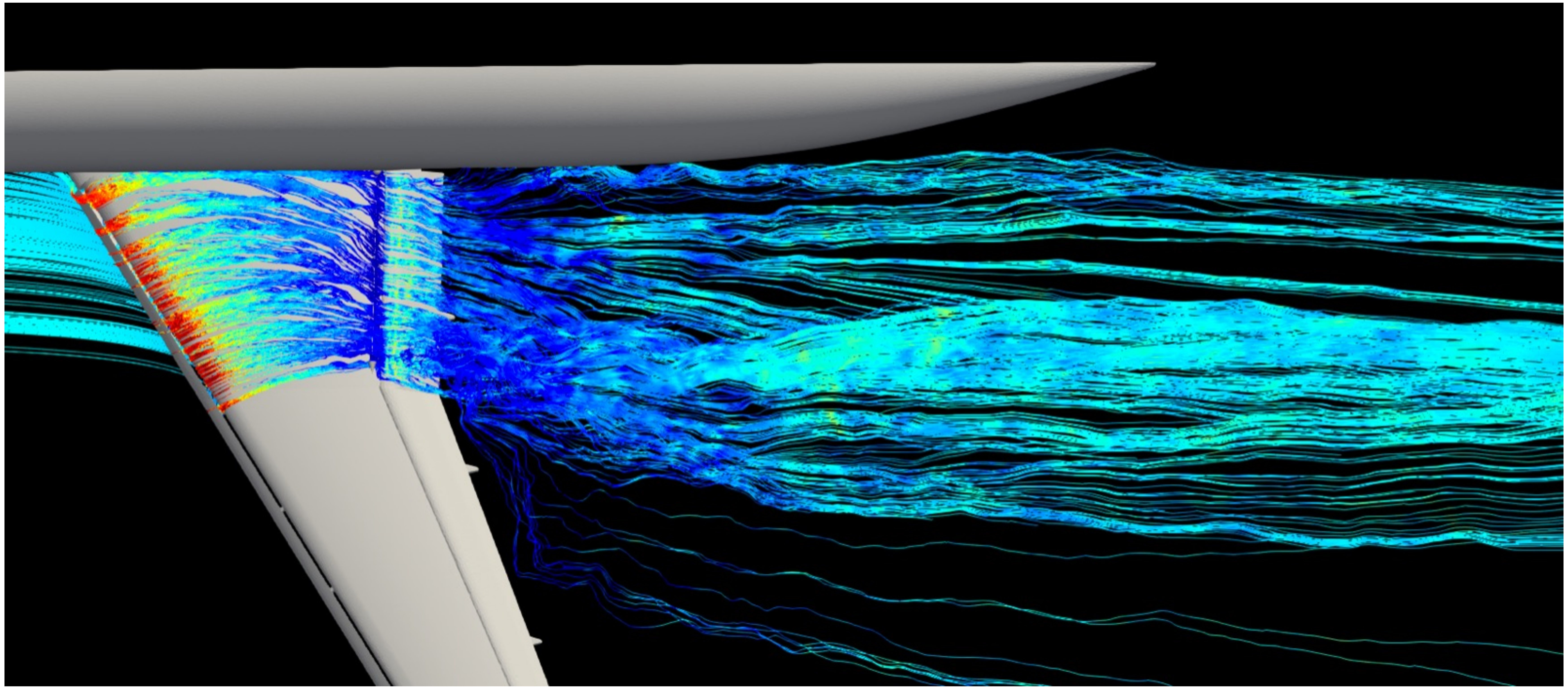
LES validation: NACA 4412, Re 1M, AoA = 5º





Testing Alya Toward Exascale

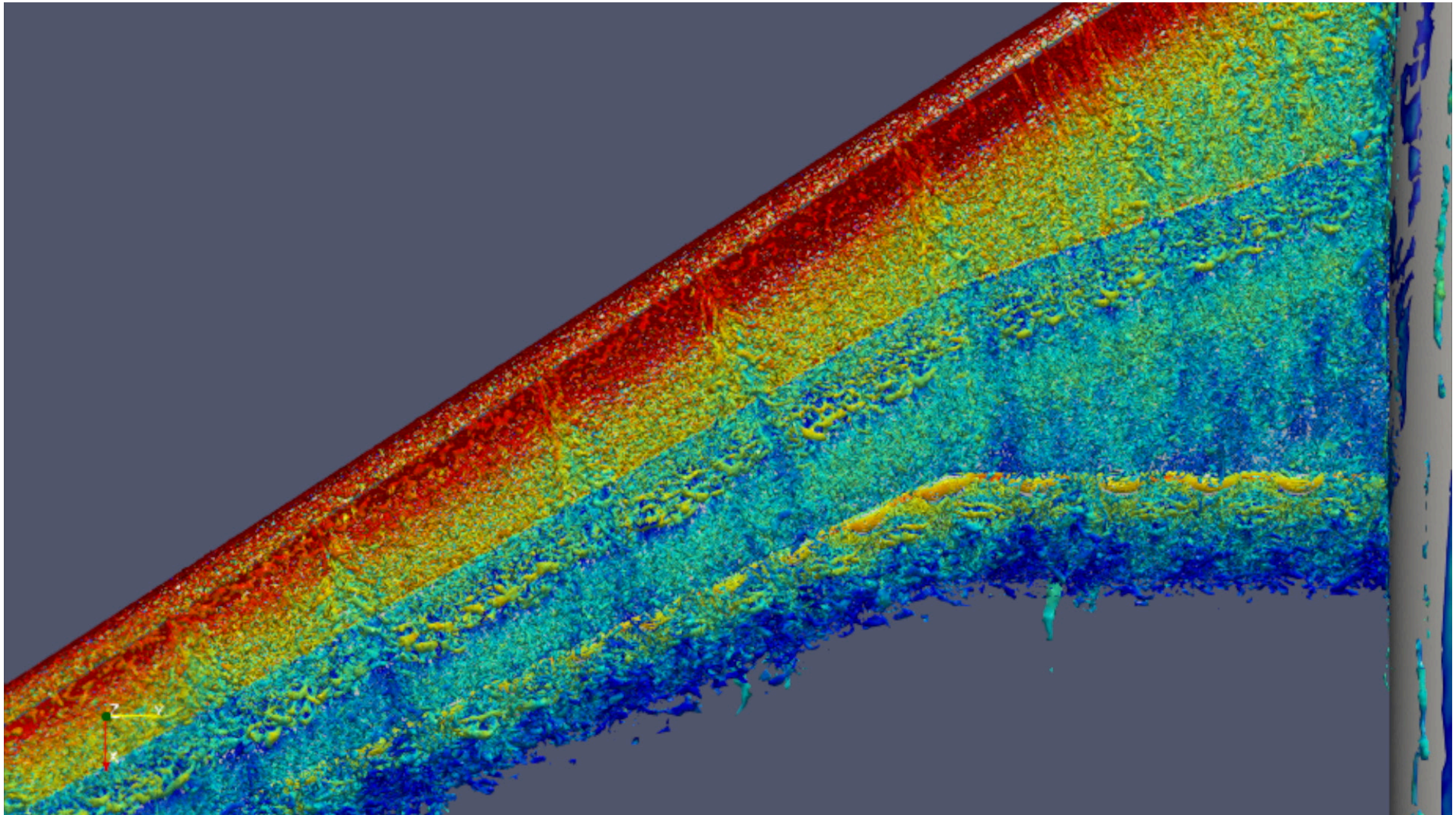
- NASA Common Research Model
- $2x10^9$ elements Large Eddy Simulation.
- Run for 24 hours on 2000 nodes (96k cores - 96k mpi processes).



Alya can also run on GPUs

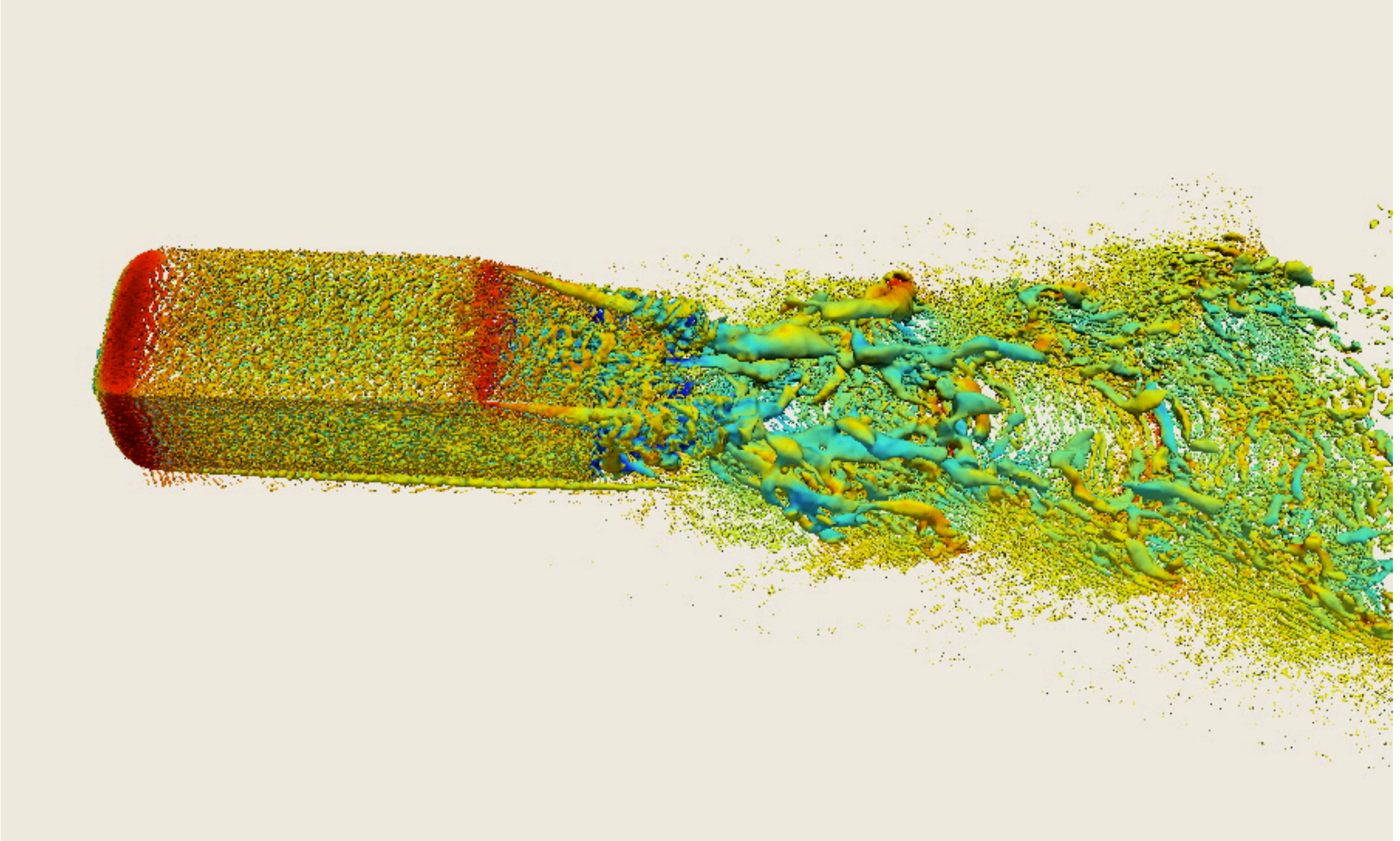
JAXA High-lift - ACTUATION

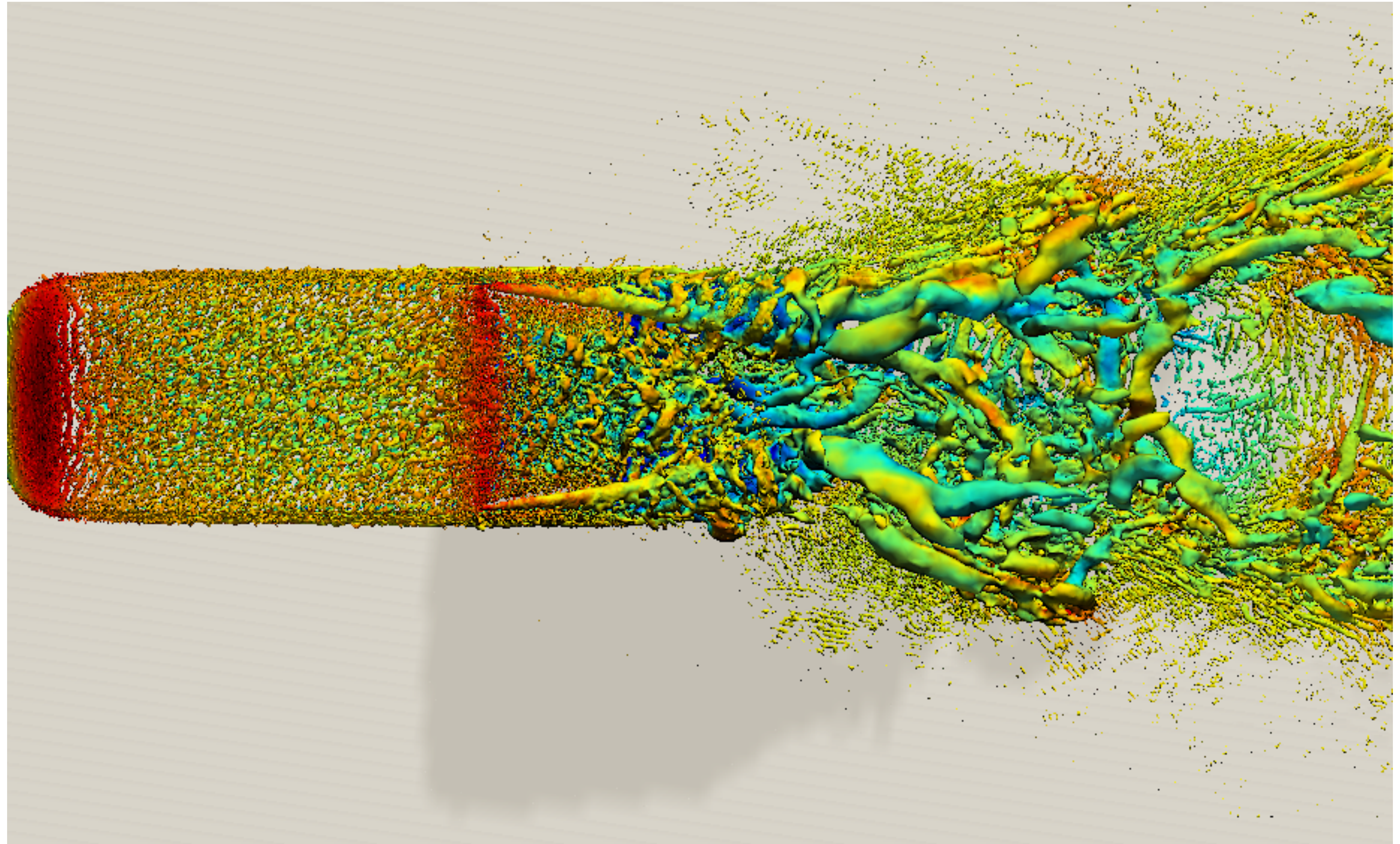
	C_L	C_D	C_L/C_D
Baseline	2.685	0.405	6.630
AFC10	**2.754(2.6%)**	0.391 (3.5%)	7.040 (6.2%)



$Re=1x10^6$ AoA = 21.51°

Better results than the ones published in literature for simplified car - Ahmed





	Cd (pressure)	Cd (total)	Cl	Cd_rms	Cl_rms
Ahmed (Exp)	**0,234**	**0,285**			
Krajnovic(LES)	0,292		0,344	0,005	0,018
Aljure (LES)	0,292	0,302	0,331		
EMAC	0,244	0,280	0,244	0,009	0,035
SKEW	0,242	0,279	0,248	0,006	0,032

Sliding mesh results on a real car

Sliding mesh results on a real car

SAE Mesh & Cpu Time

Refinements regions following those used in the workshop mesh but bigger first element size - 0.25 mm

11 Mnodes
53Melements
Tetrahedra, Pyramids, Pentas
ANSA

185k Timesteps
dt = 6.5e-6 - CFL 1.0
1.15 s - average last 0.2 s

1.7 s per time step in 20 MN4 nodes (960 cores)
Intel Xeon Platinum 8160

Drivaer Mesh & Cpu Time

Refinements regions following those used in the MEDIUM mesh but bigger first element size - 0.8 mm.

28 Mnodes
131Melements
Tetrahedra, Pyramids, Pentas
ANSA

500k Timesteps
dt = 2.5e-5 - CFL 1.0
12 TU - average last 2

0.9 s per time step in 50 MN4 nodes (2400 cores)
Intel Xeon Platinum 8160

Without sliding mesh

1TU = 40000 time steps = 10 CPU hours

Future work

- Test on finner meshes
- Optimise sliding mesh algorithm - currently 4 times slower than without it.
- Converge sliding mesh cases. Improve robustness.
- Continue optimising code - collaboration with George Hager

Thanks for your attention!

European Commission

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