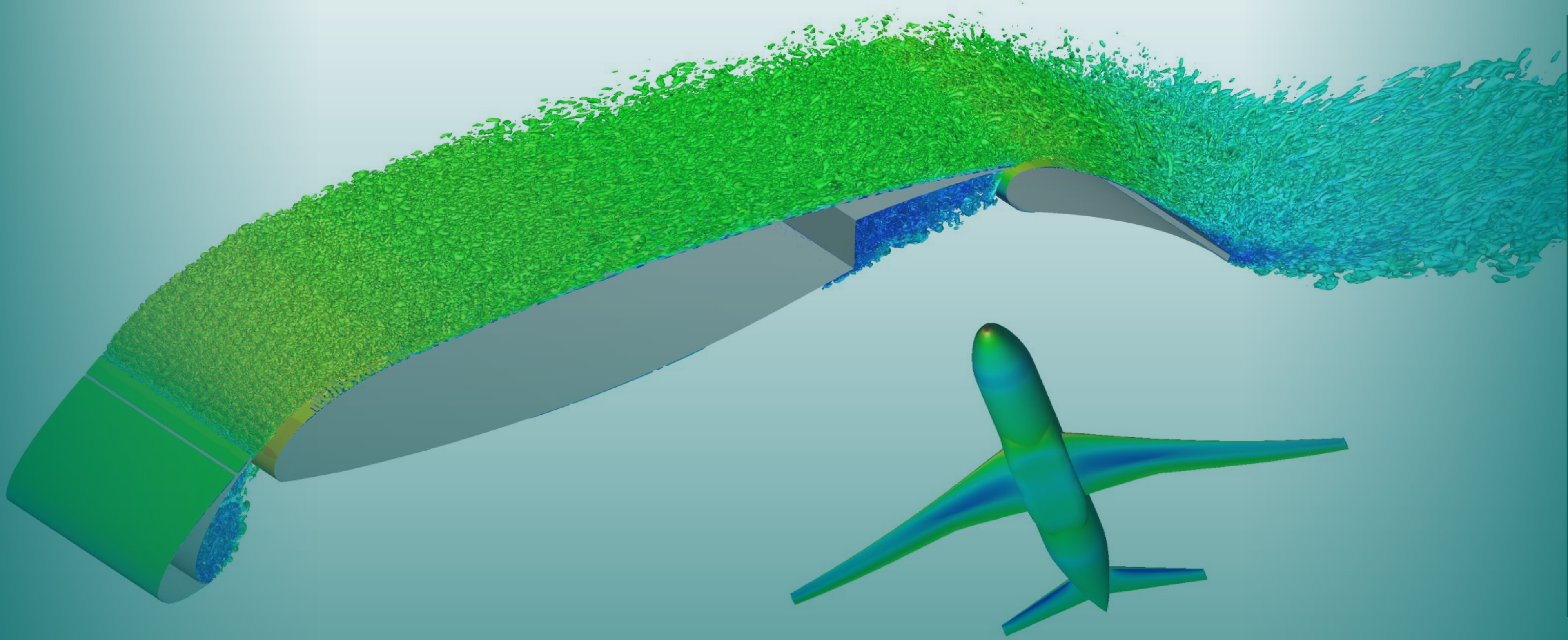
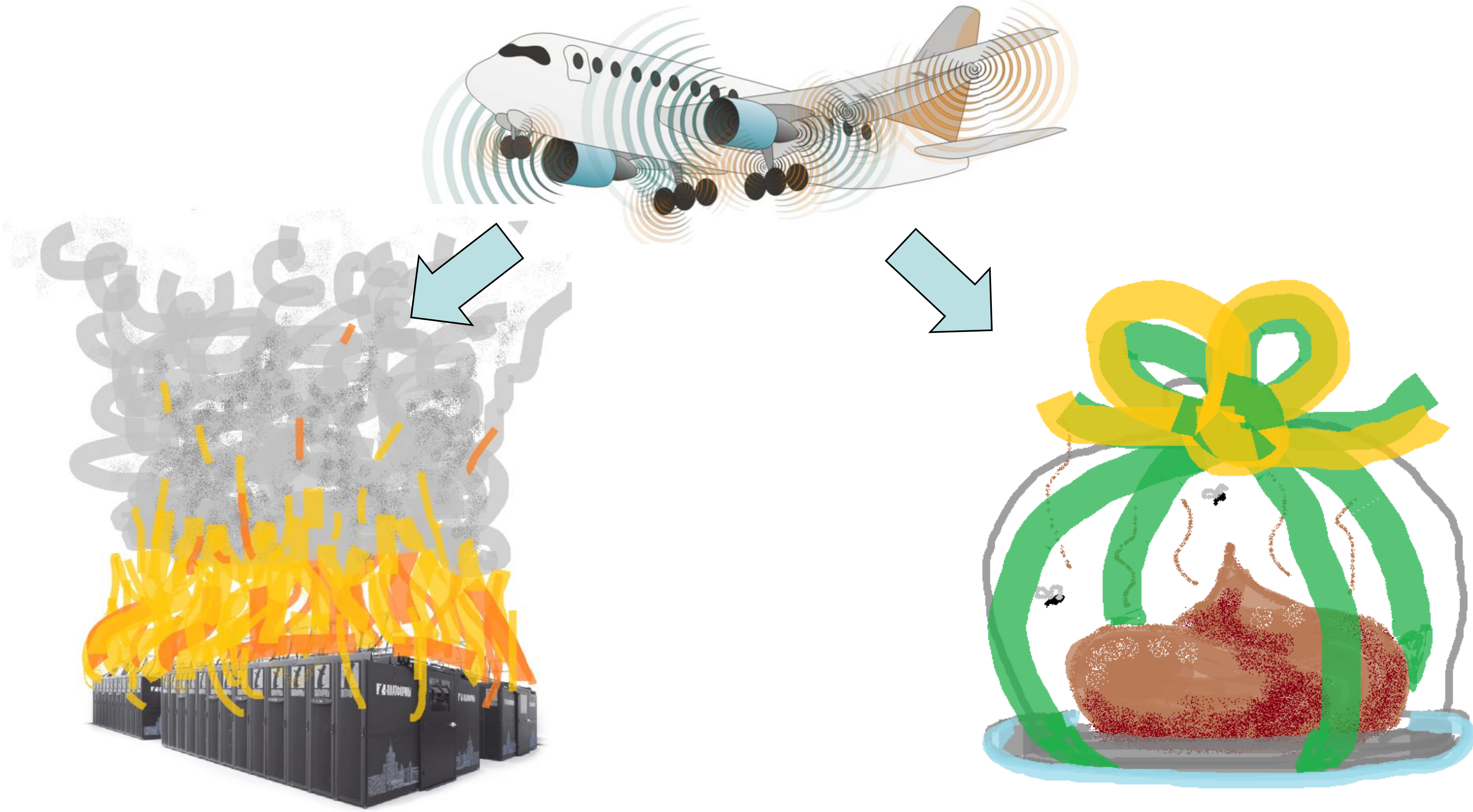
TOWARDS AFFORDABLE CAA SIMULATIONS OF AIRLINER'S WINGS WITH HIGH-LITF DEVICES



V. Bobkov, A. Gorobets, A. Duben, T. Kozubskaya, V. Tsvetkova

Vortex-resolving CAA simulations of aircrafts



Extra-massive burning out of CPU time
Simulation of an airplane
which costs like an airplane

Colorful Coarse Crap
Underresolved simulations
Generation of fancy
nonsense movies and images

Vortex-resolving CAA simulations of aircrafts

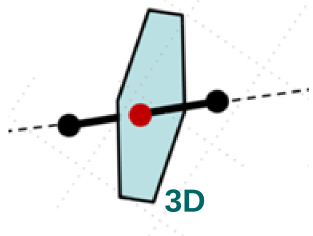
- **Cheap and accurate numerical methods**
  numerical schemes, turbulence models, …

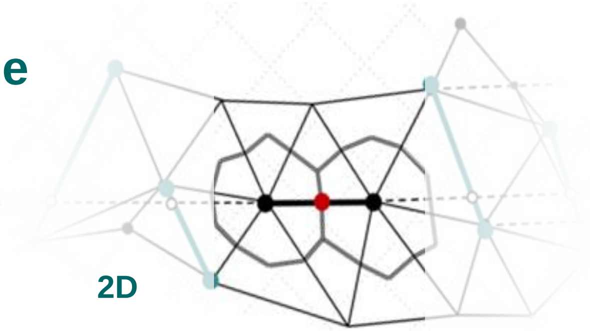
- **Efficient HPC implementations**
  scalable parallel algorithms, heterogeneous computing, …

- **Efficient simulation technology**
  mesh adaptation, acceleration of SSS, postprocessing, …

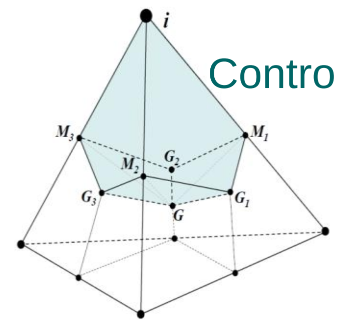
Cheap and accurate numerical methods: EBR schemes

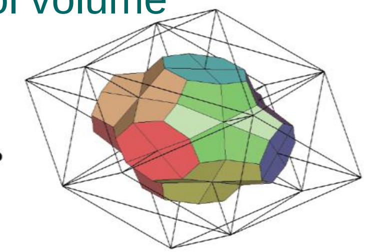
Basic low-order scheme

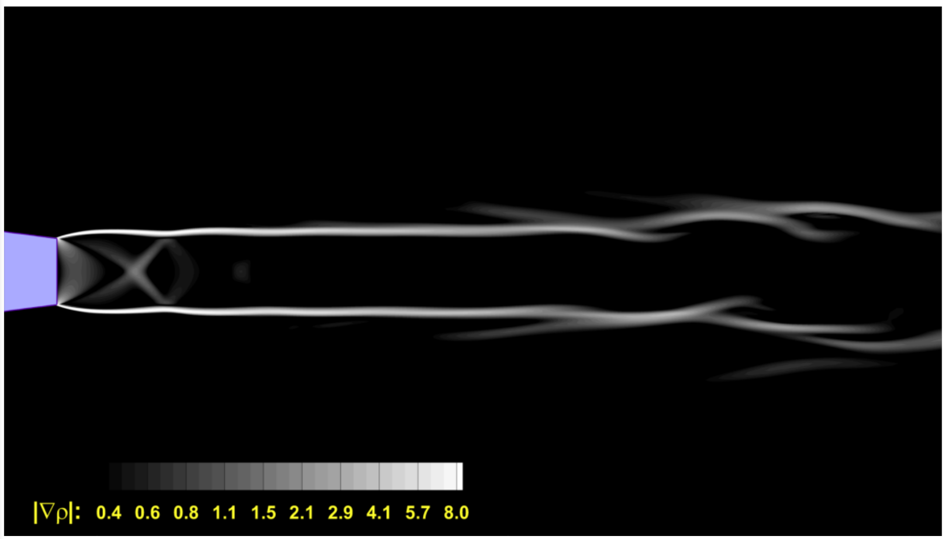


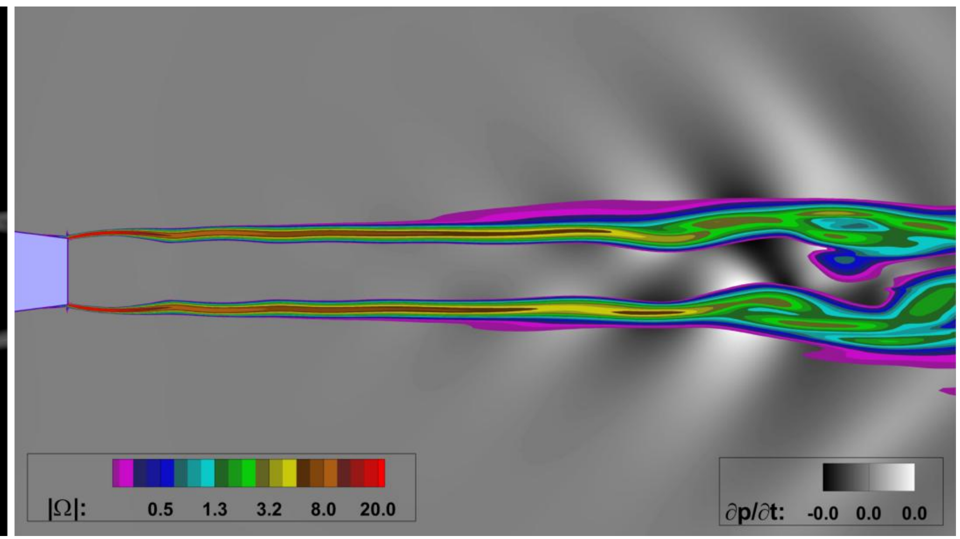


Control volume





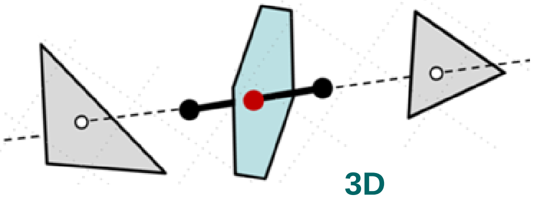


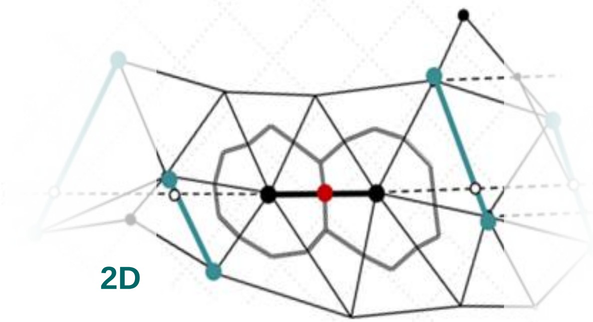


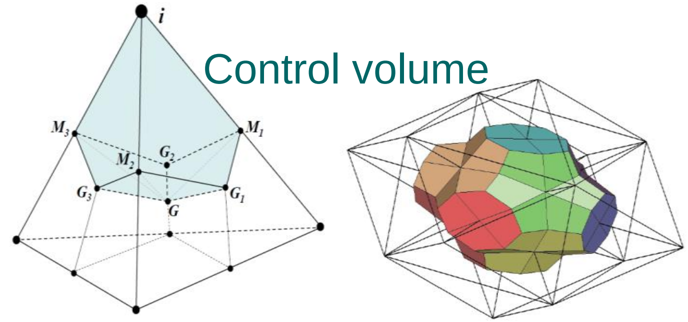
Bakhvalov, P.A. & Kozubskaya, T.K. Comput. Math. and Math. Phys. (2017) 57: 680.
https://www.doi.org/10.1134/S0965542517040030

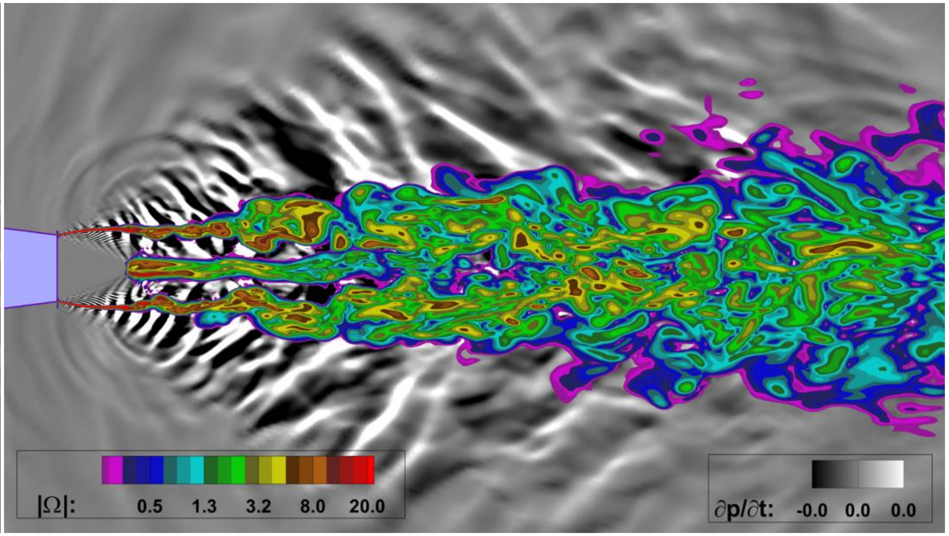
Cheap and accurate numerical methods: EBR schemes

EBR3-WENO scheme



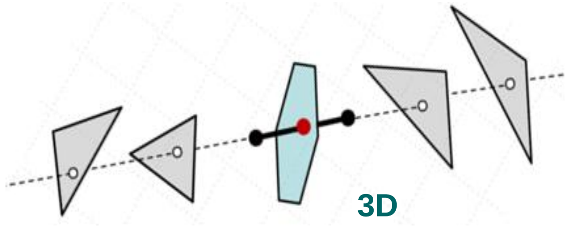


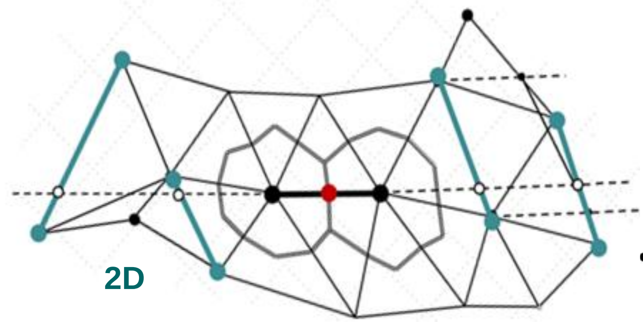




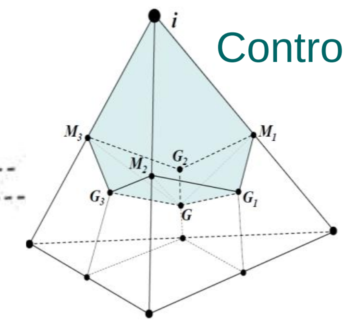
Bakhvalov, P.A. & Kozubskaya, T.K. Comput. Math. and Math. Phys. (2017) 57: 680.
https://www.doi.org/10.1134/S0965542517040030

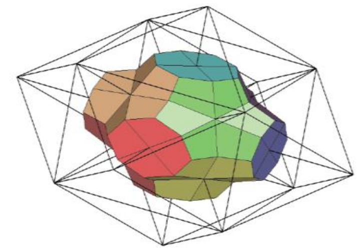
EBR5-HYB scheme

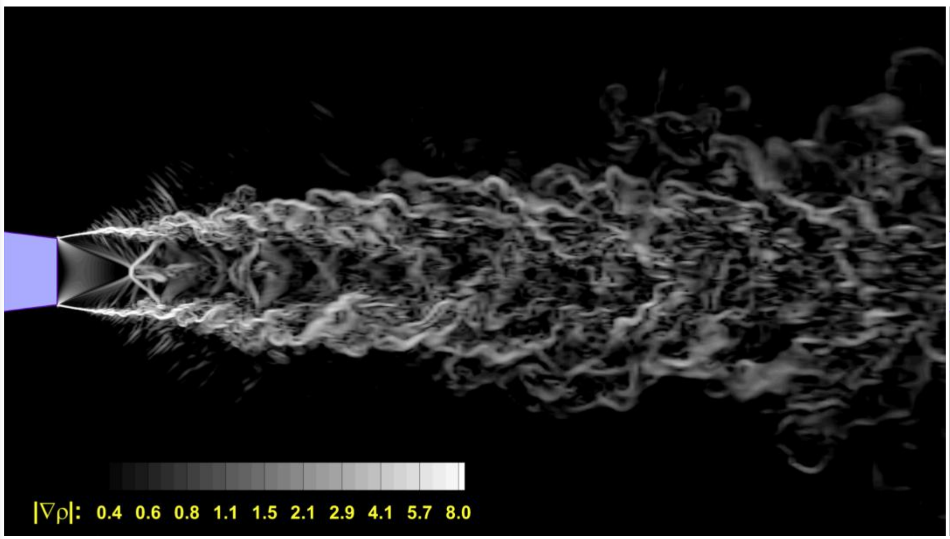


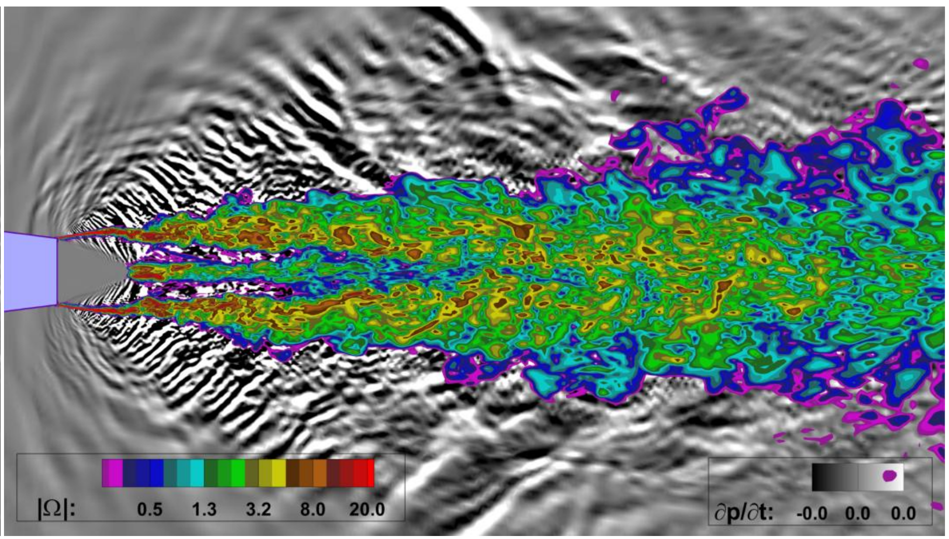


Control volume









Just +15% computing cost compared to low-order scheme

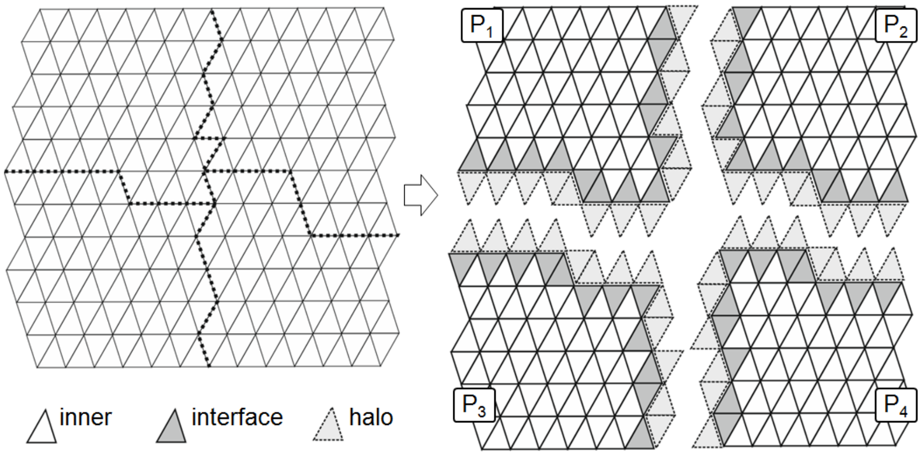
Up to **6-th order** of accuracy (on translationally invariant meshes)

Bakhvalov, P.A. & Kozubskaya, T.K. Comput. Math. and Math. Phys. (2017) 57: 680.
https://www.doi.org/10.1134/S0965542517040030

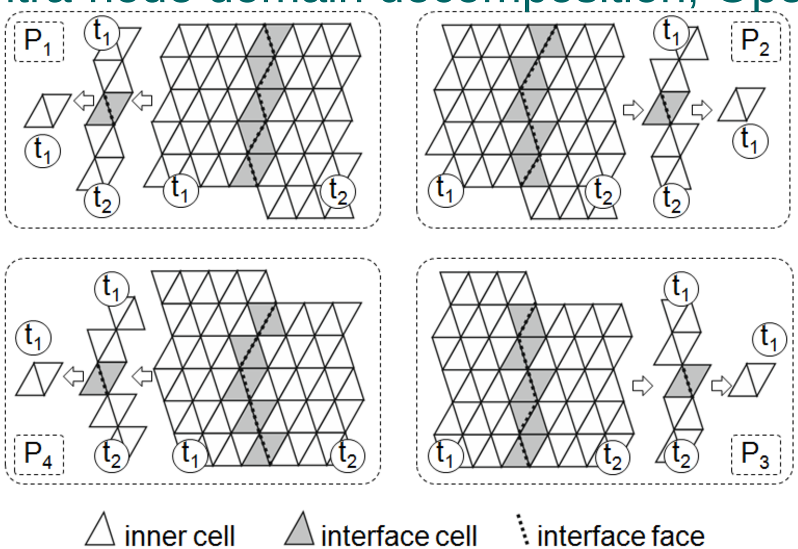
Efficient HPC implementations

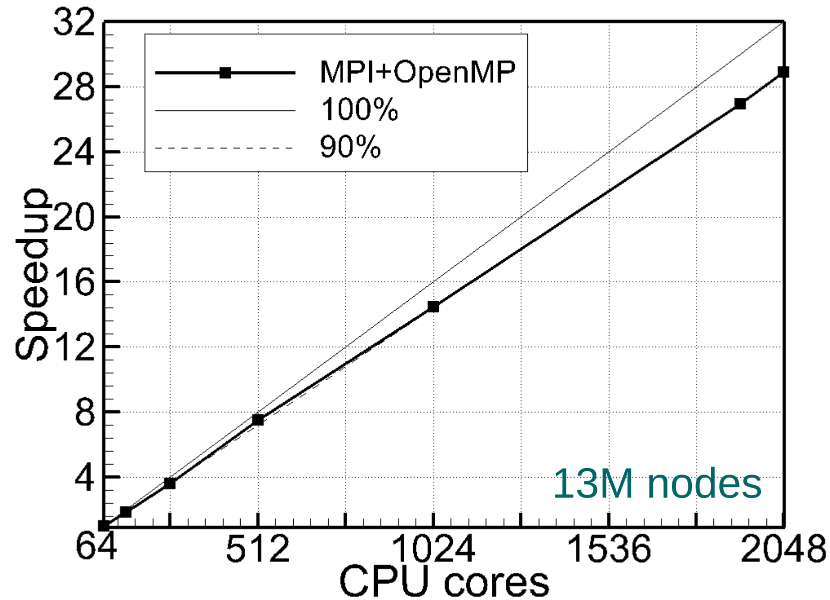
Multilevel MPI+OpenMP parallelization

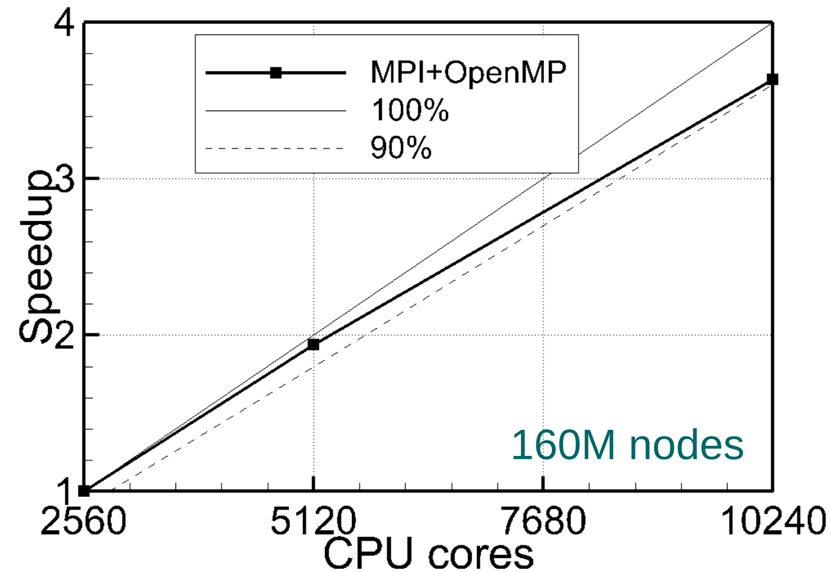
Upper level domain decomposition, MPI



Intra-node domain decomposition, OpenMP

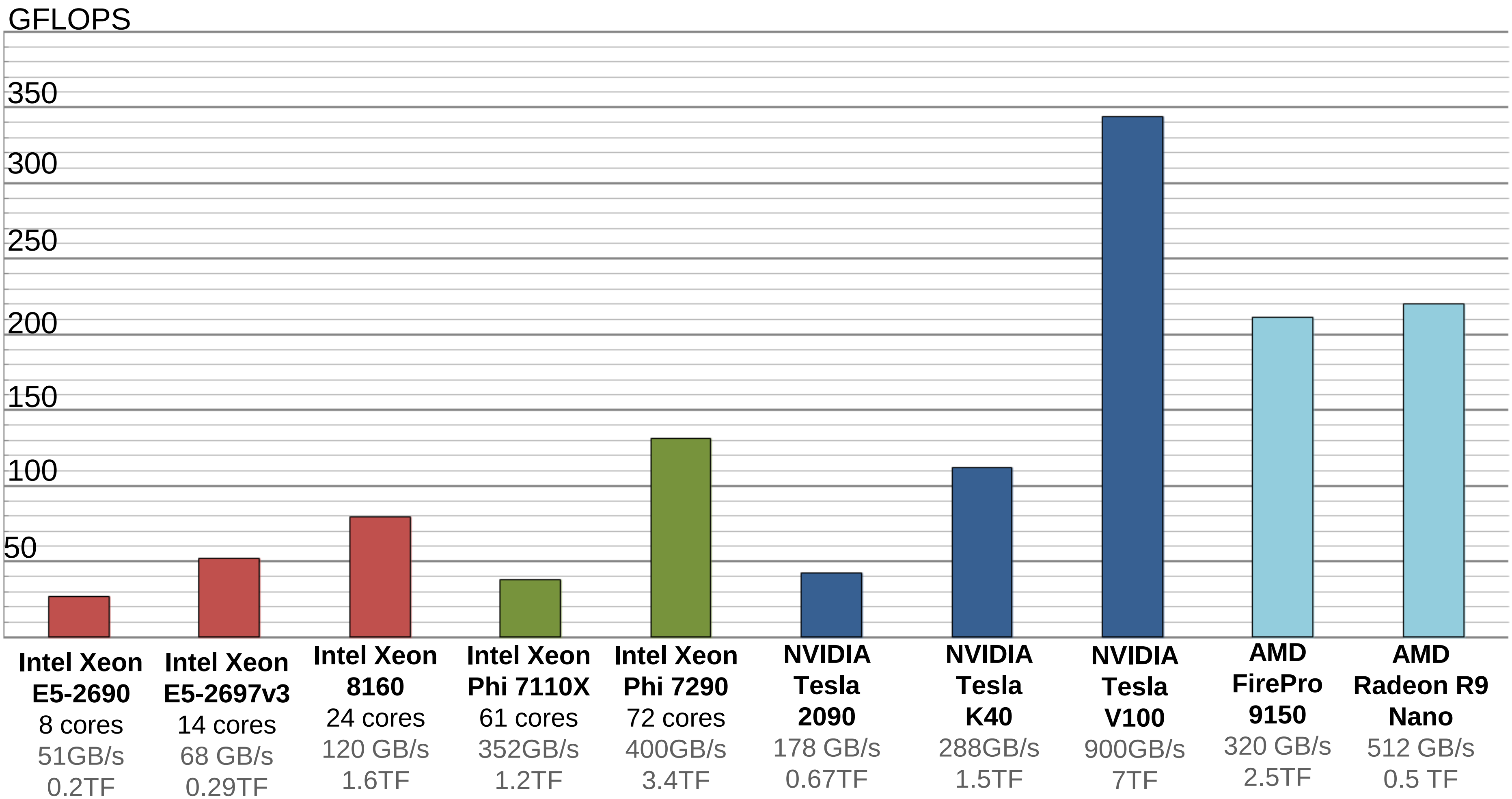






Gorobets, A. Parallel Algorithm of the NOISEtte Code for CFD and CAA Simulations. Lobachevskii J Math (2018) 39: 524. https://doi.org/10.1134/S1995080218040078

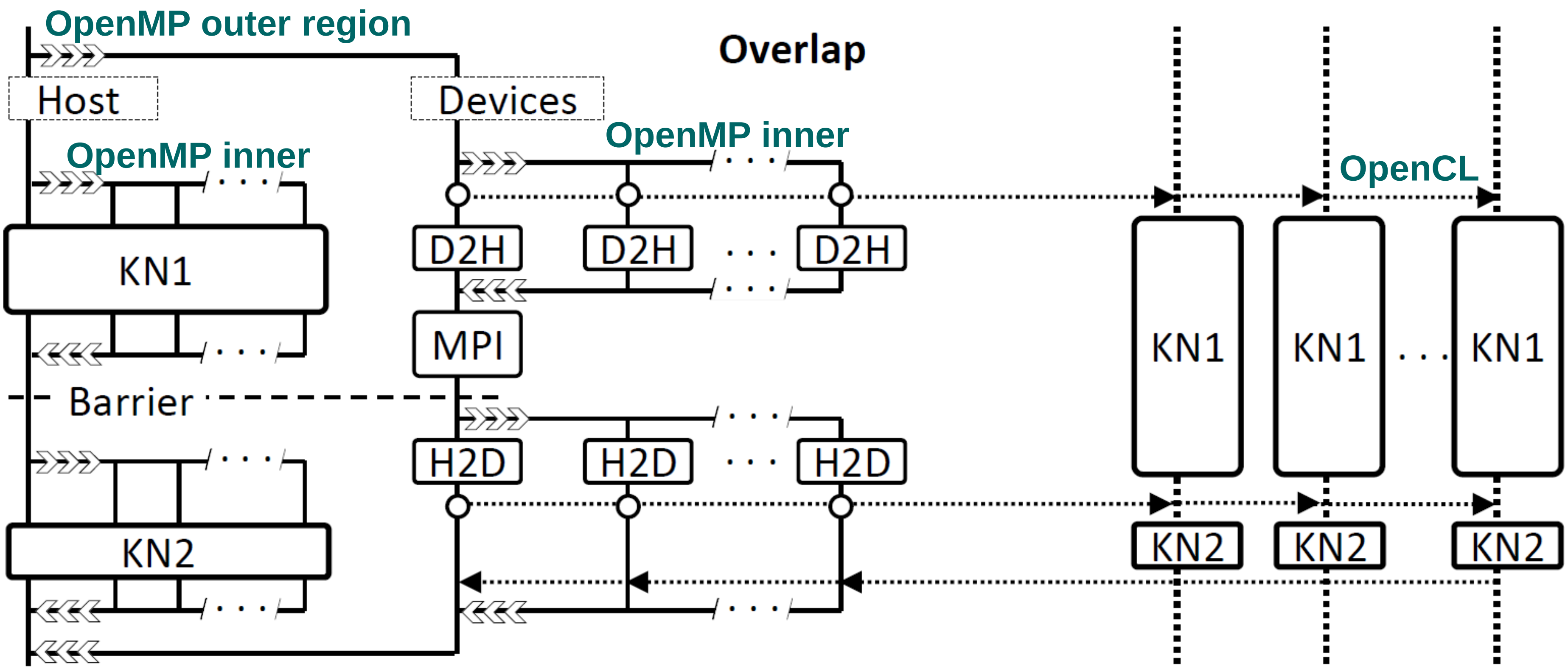
Portable OpenCL implementations



A.Gorobets, S.Soukov, P.Bogdanov. Multilevel parallelization for simulating turbulent flows on most kinds of hybrid supercomputers. Computers&Fluids. (2018) 173:171. https://doi.org/10.1016/j.compfluid.2018.03.011

Heterogeneous execution scheme

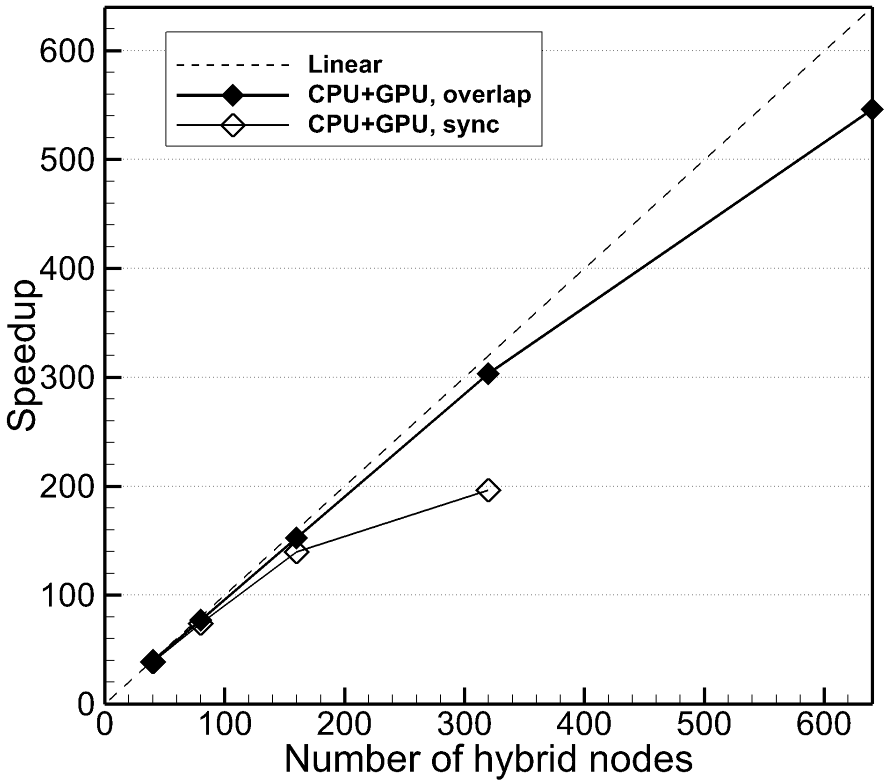
DMA, overlap, workload-balancing, autotuning

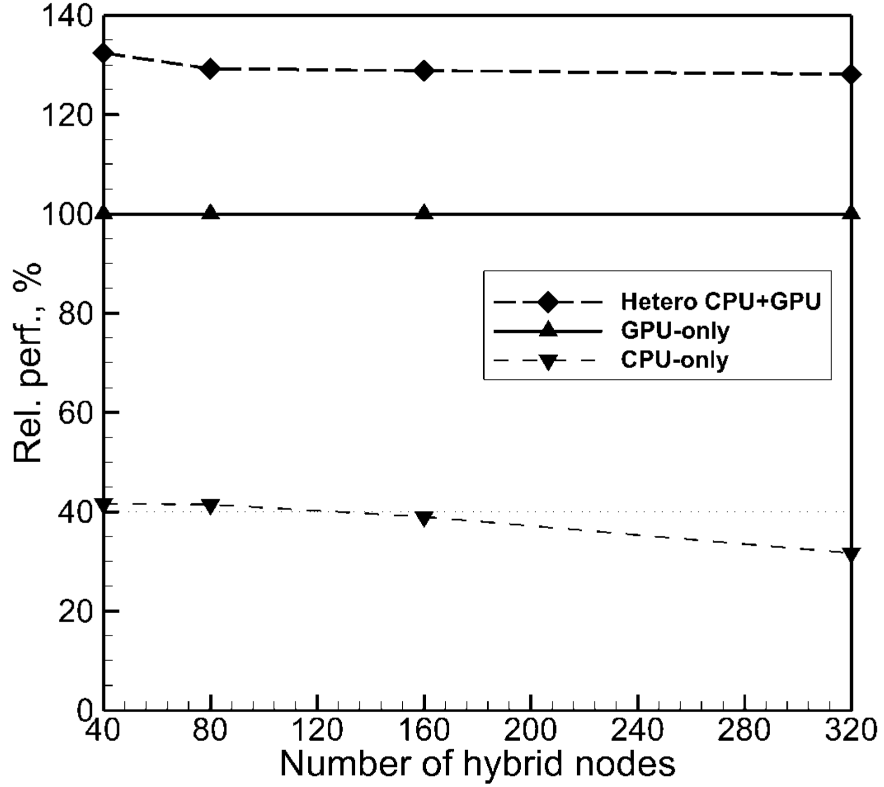


A.Gorobets, S.Soukov, P.Bogdanov. Multilevel parallelization for simulating turbulent flows on most kinds of hybrid supercomputers. Computers&Fluids. (2018) 173:171. https://doi.org/10.1016/j.compfluid.2018.03.011

Heterogeneous computing – MPI+OpenMP+OpenCL

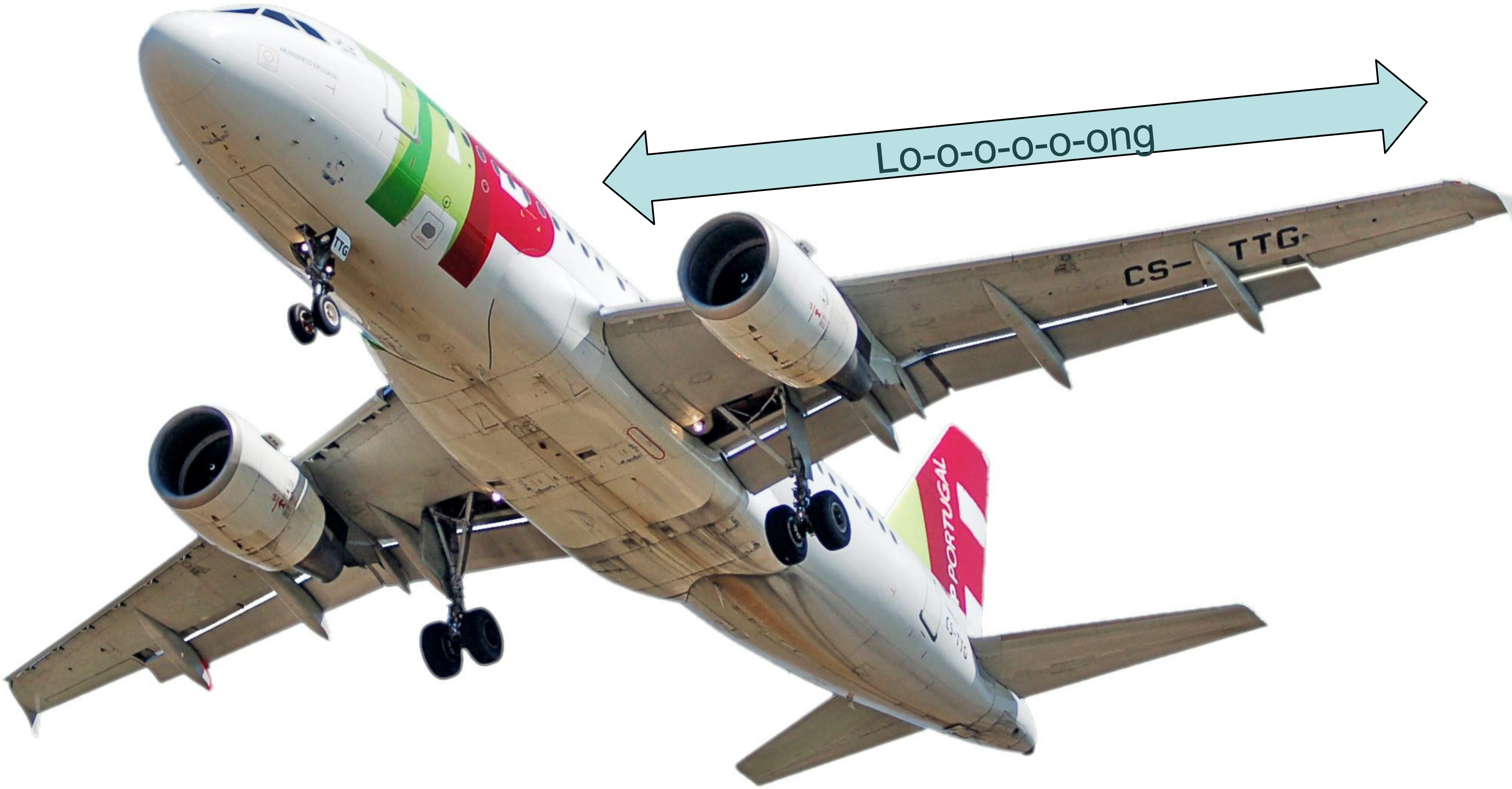
Lomonosov-2 nodes: 14c Xeon E5 v3 + K40M





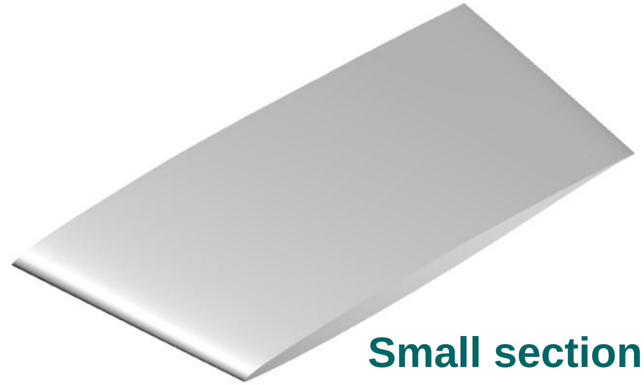
A.Gorobets, S.Soukov, P.Bogdanov. Multilevel parallelization for simulating turbulent flows on most kinds of hybrid supercomputers. Computers&Fluids. (2018) 173:171. https://doi.org/10.1016/j.compfluid.2018.03.011

Airframe noise prediction

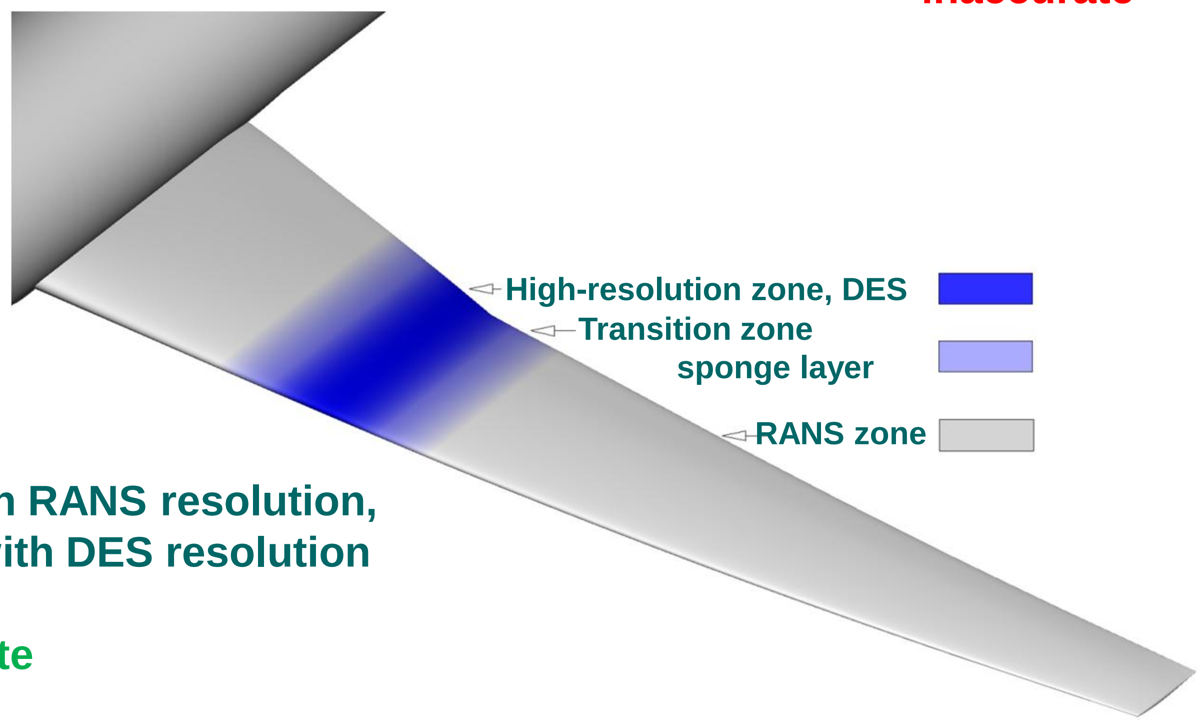


CAA simulation of a swept wing of an airliner

Whole-wing
with DES resolution
expensive
accurate

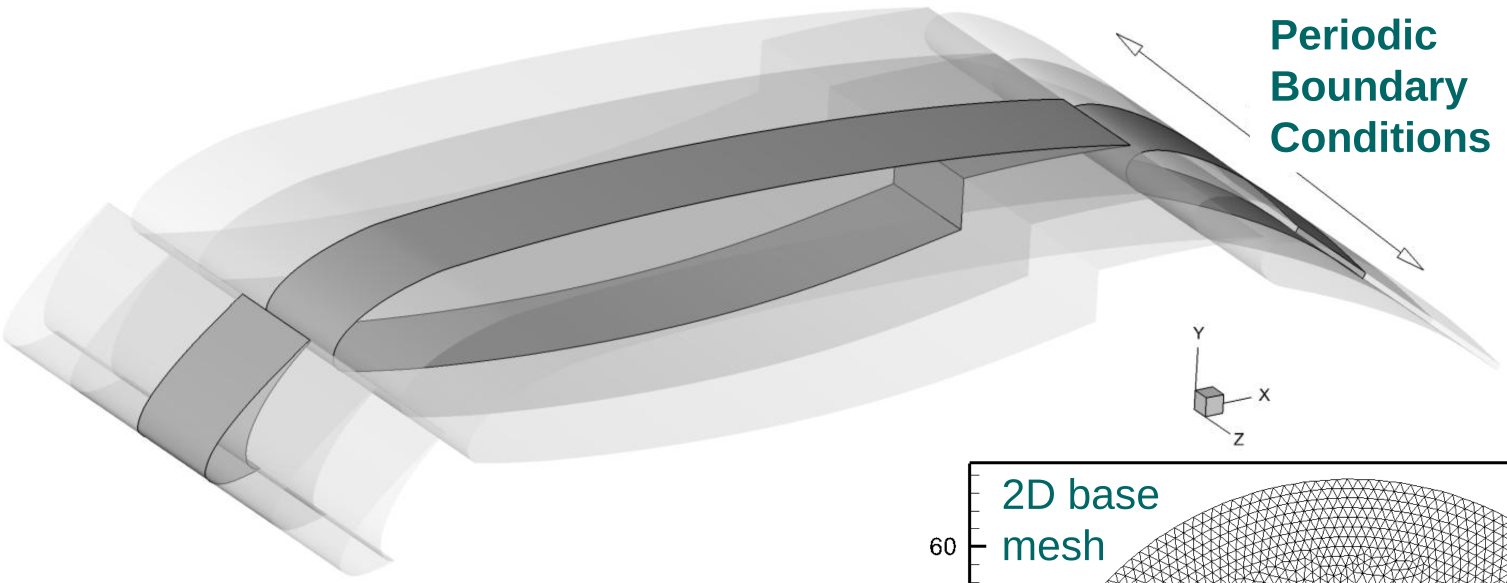


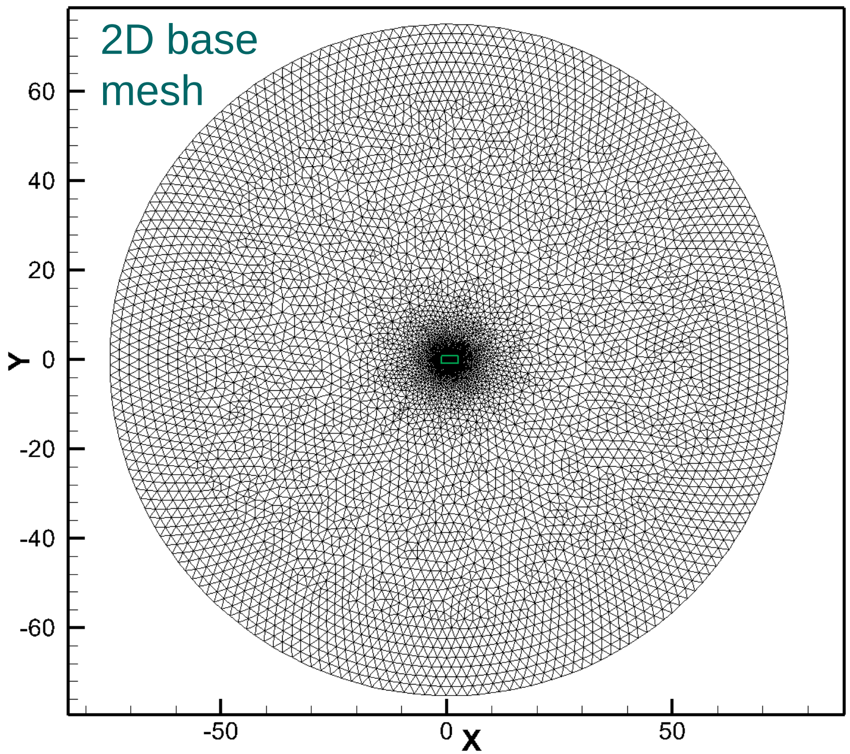
Small section
with DES resolution
cheap
inaccurate



Whole wing with RANS resolution,
Small section with DES resolution
cheap
not so inaccurate

30P30N model configuration, AOA 5.5°

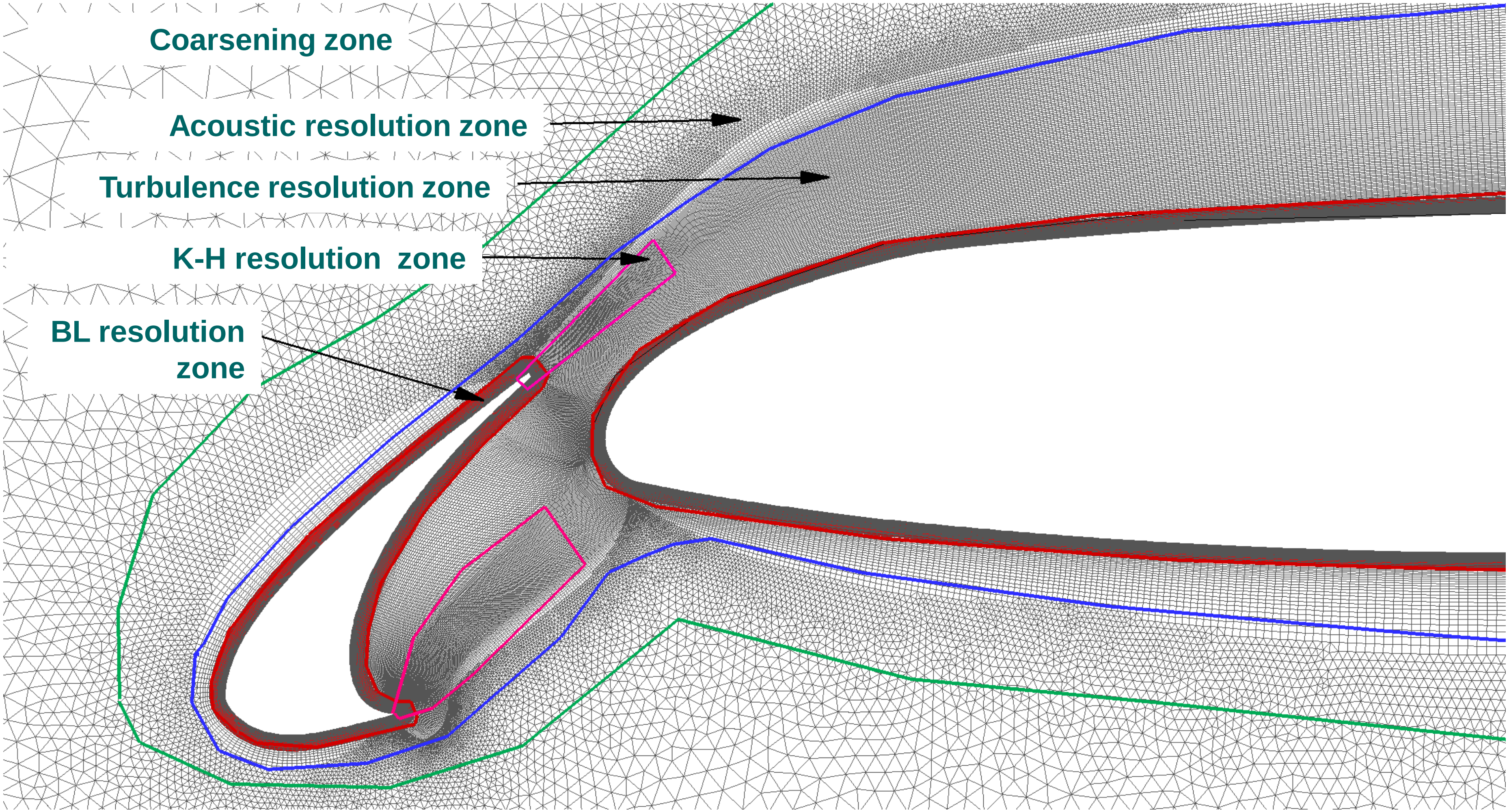




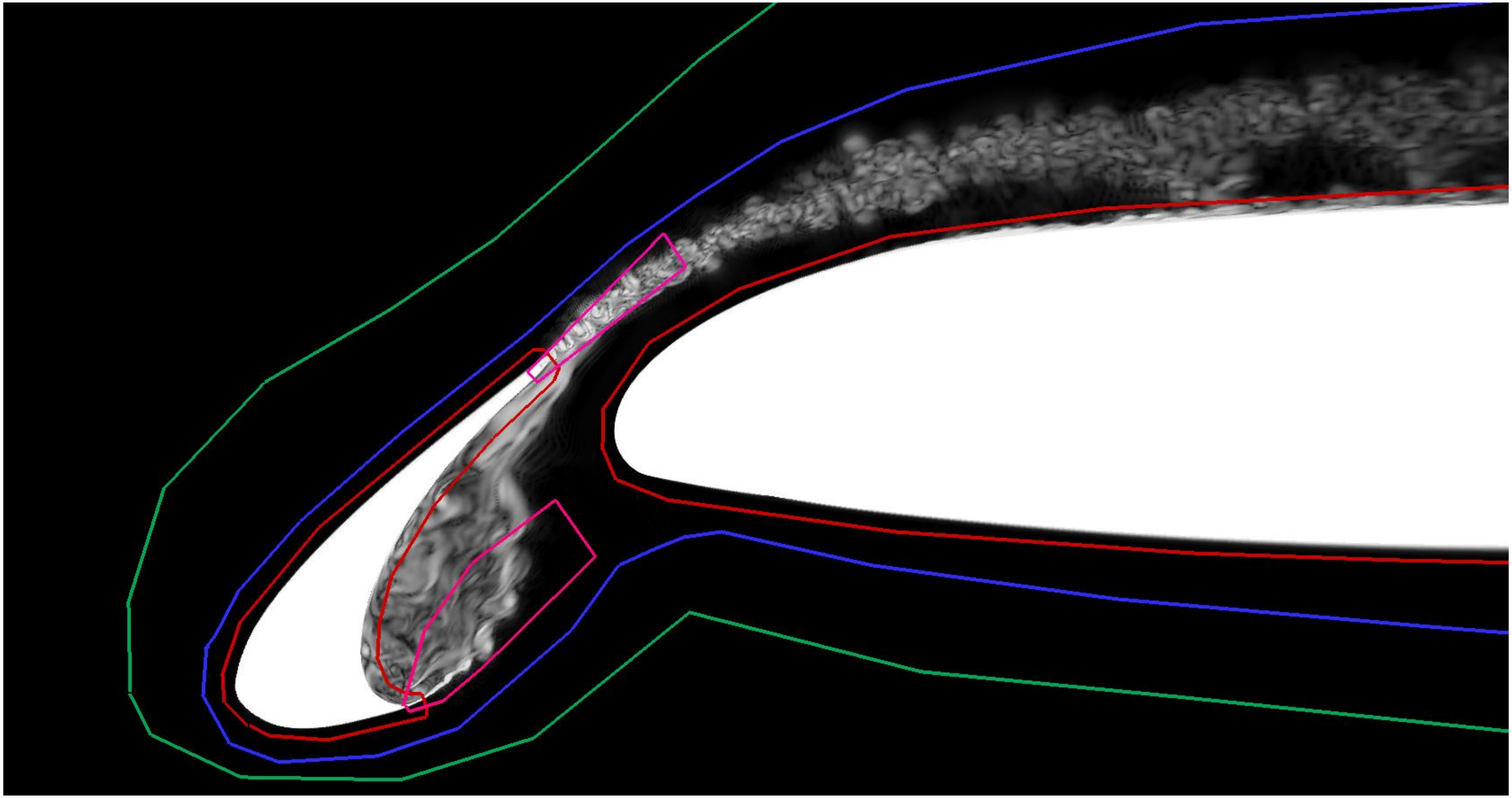
Model problem to study
mesh resolution,
time integration periods,
zonal approach

2D base mesh is extruded in the spanwise direction

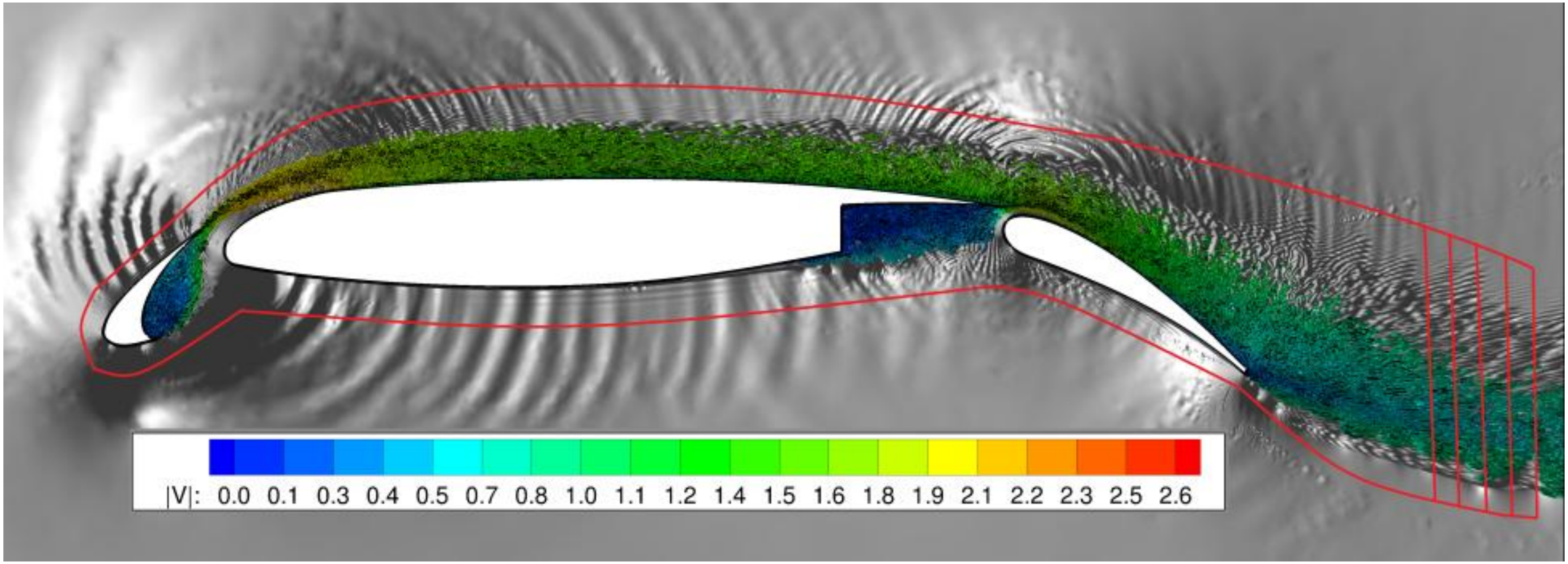
Resolution zones



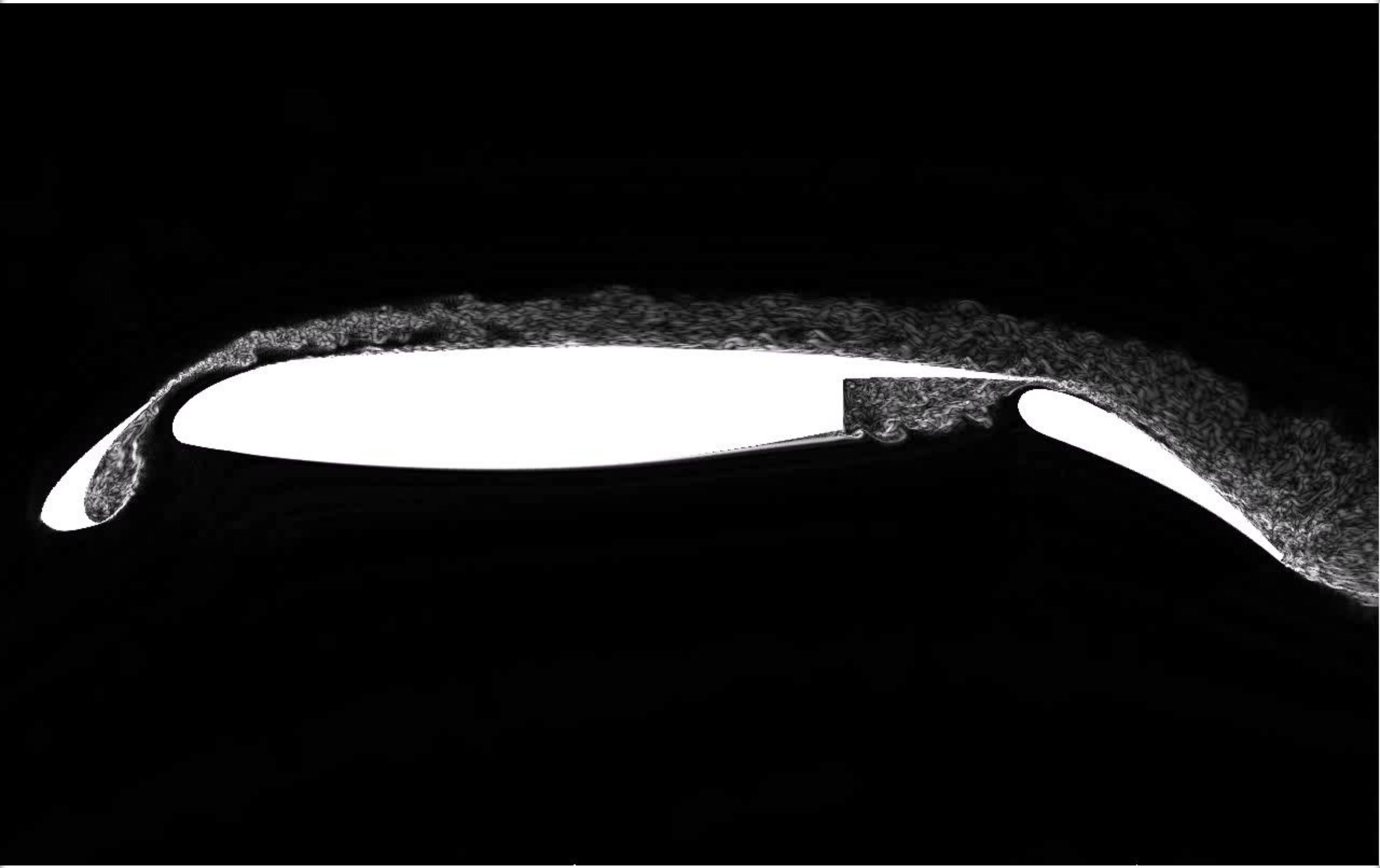
Instantaneous flow within zones



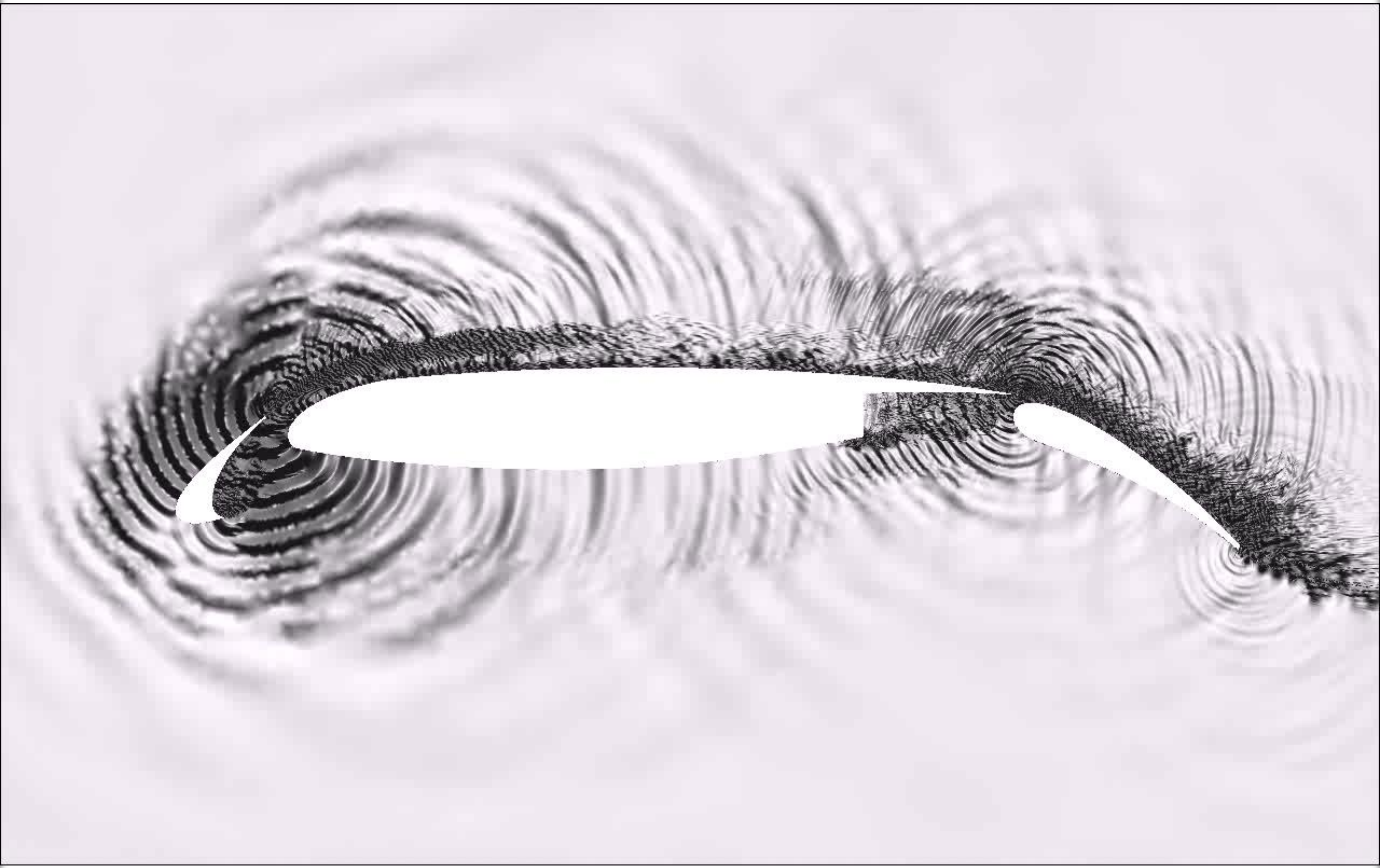
Permeable FW/H surface – as close as possible



Another nonsense animation

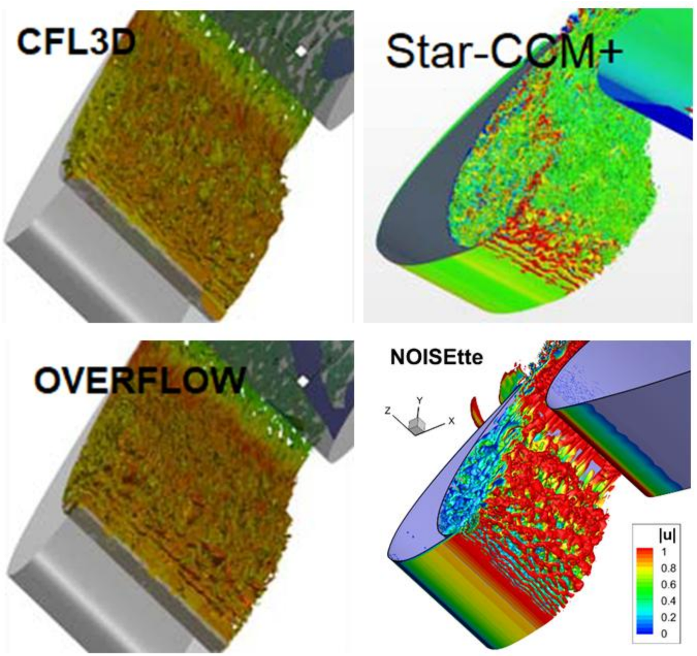


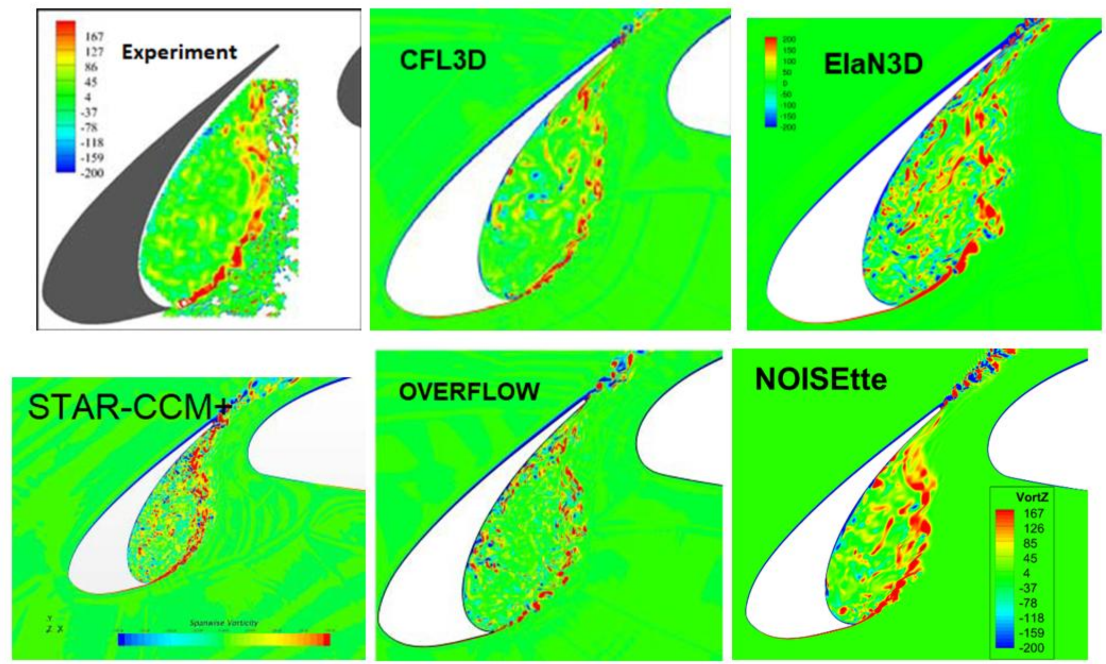
Another nonsense animation



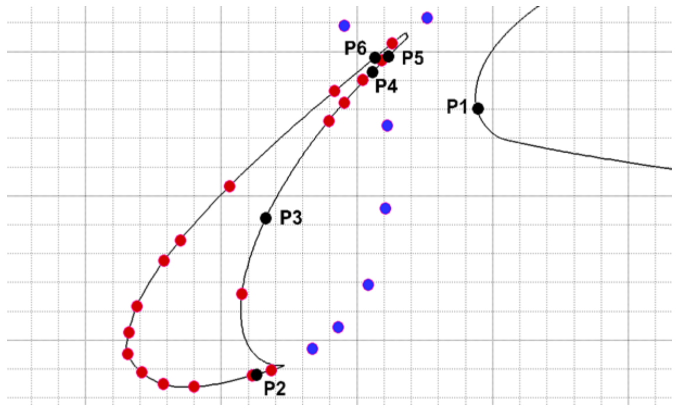
Instantaneous flow field

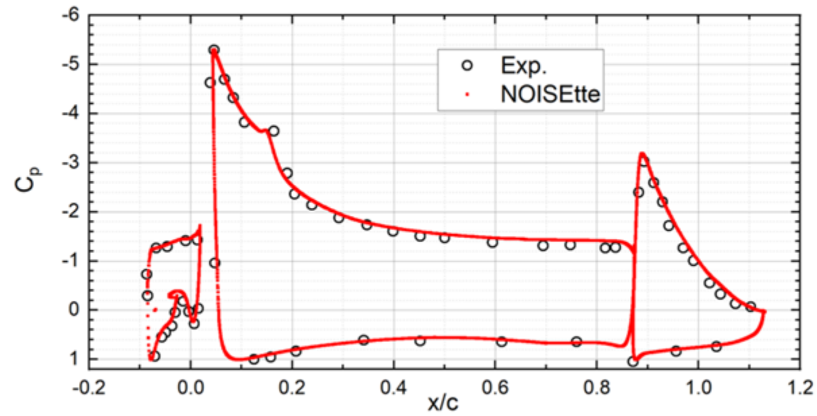
Code	Model	Mesh	N_c (millions)	L_z
CFL3D	DDES	Struct	73.2	$c/9$
ElaN3D	DDES	Struct	25	$c/30$
Star-CCM+	IDDES	Unstruct	73	$c/9$
OVERFLOW	DDES	Struct	73.2	$c/9$
NOISEtte	**IDDES**	**Unstruct**	**34**	**c/9**

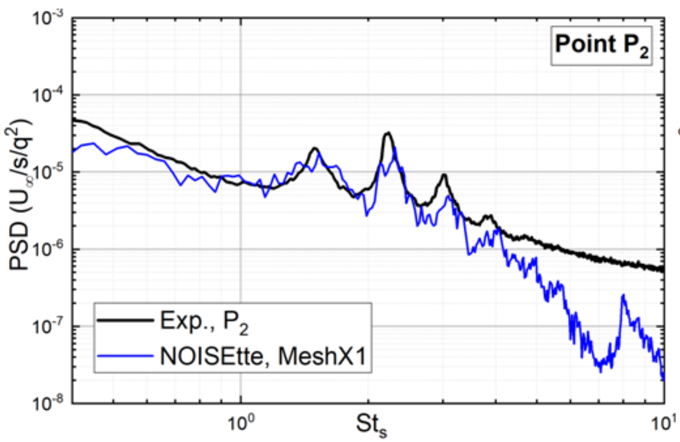


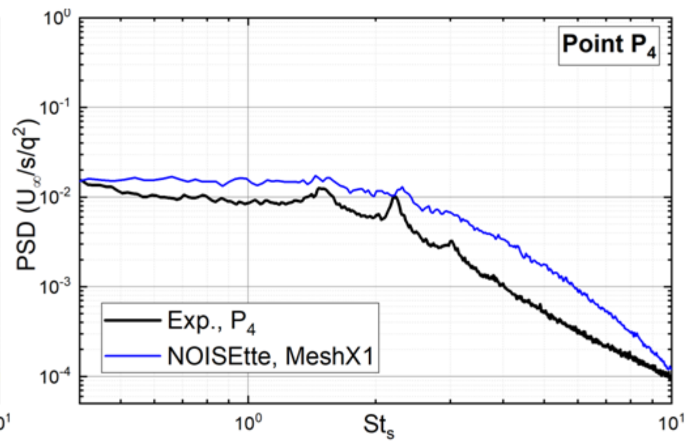


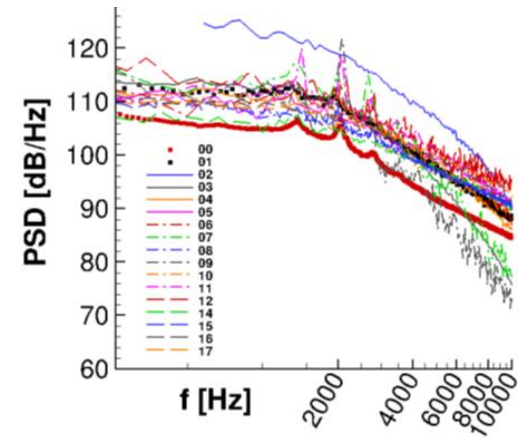
Spectra at surface

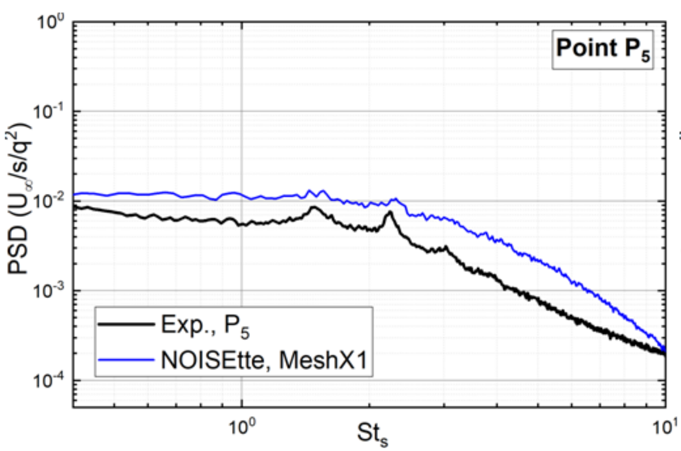


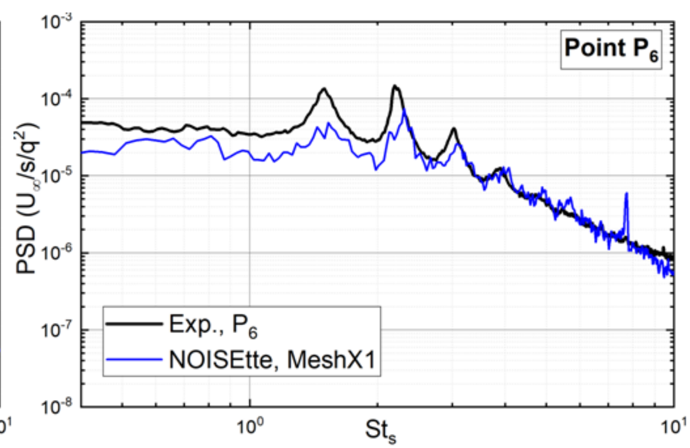


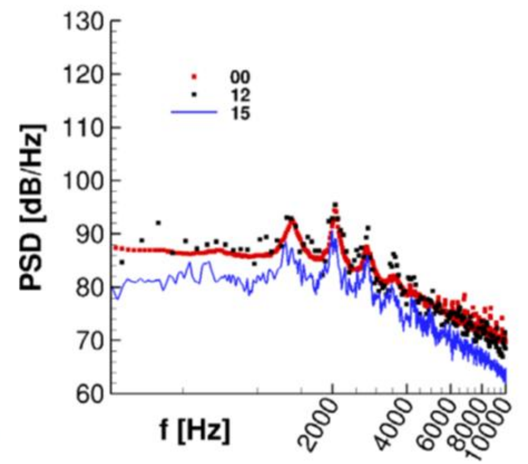




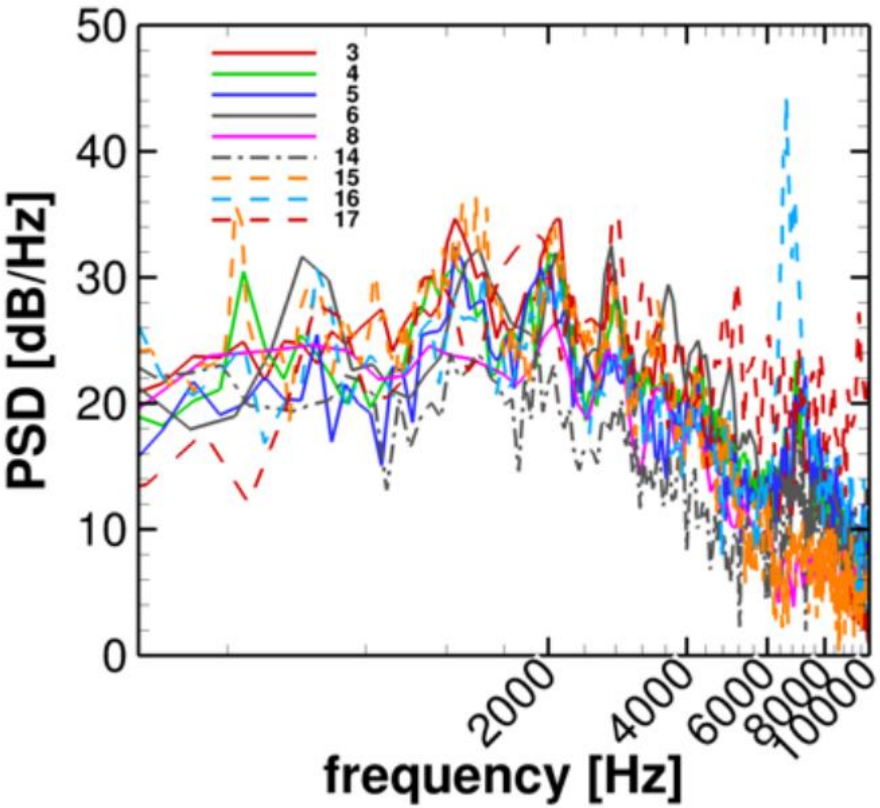




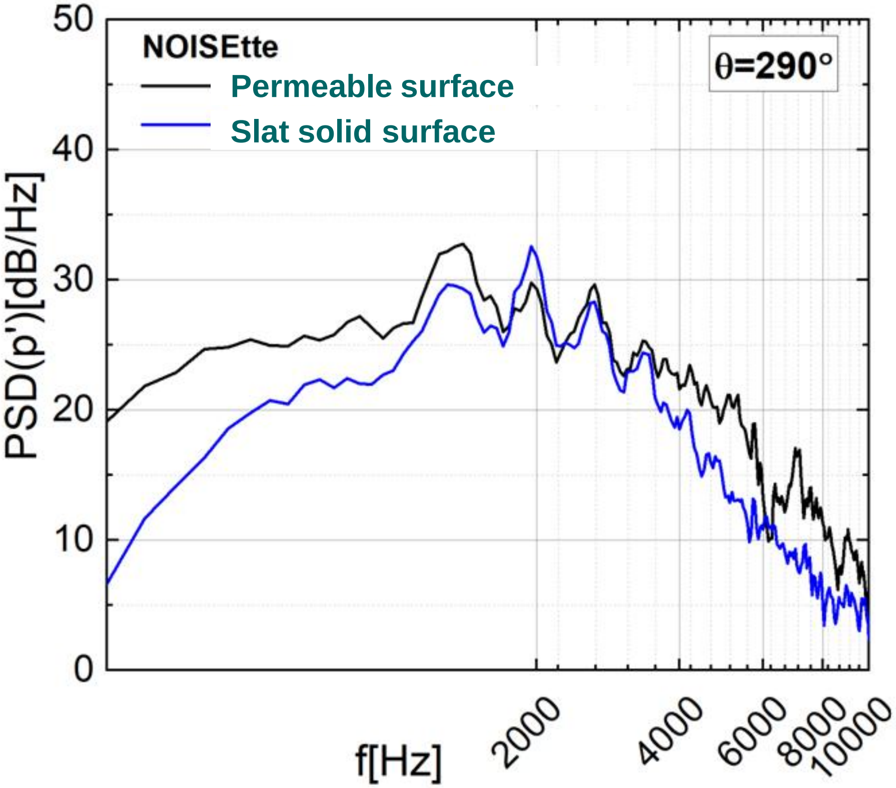




Far field

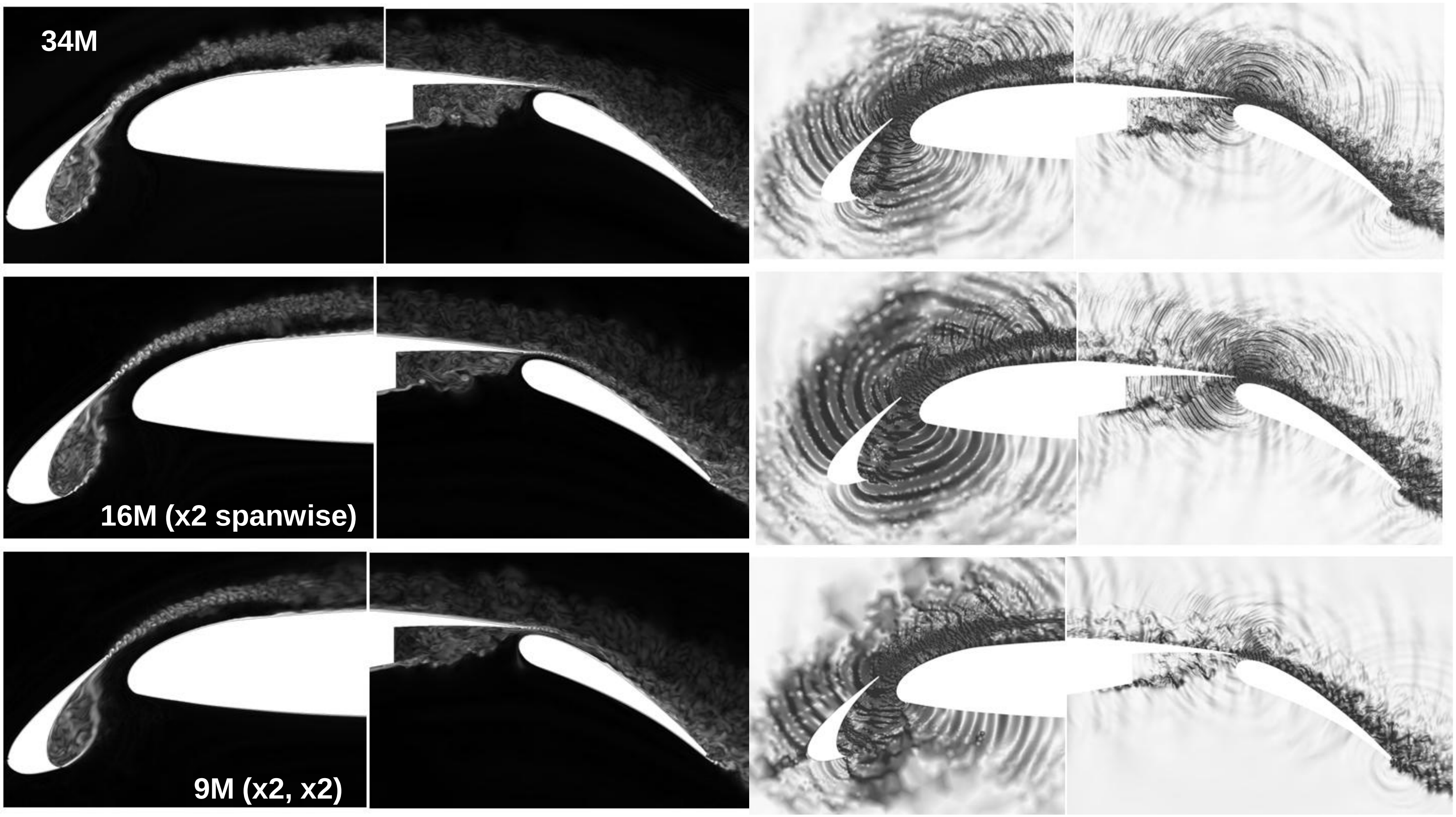


PSD [dB/Hz]
frequency [Hz]
3
4
5
6
8
14
15
16
17
50
40
30
20
10
0
2000
4000
6000
8000
10000



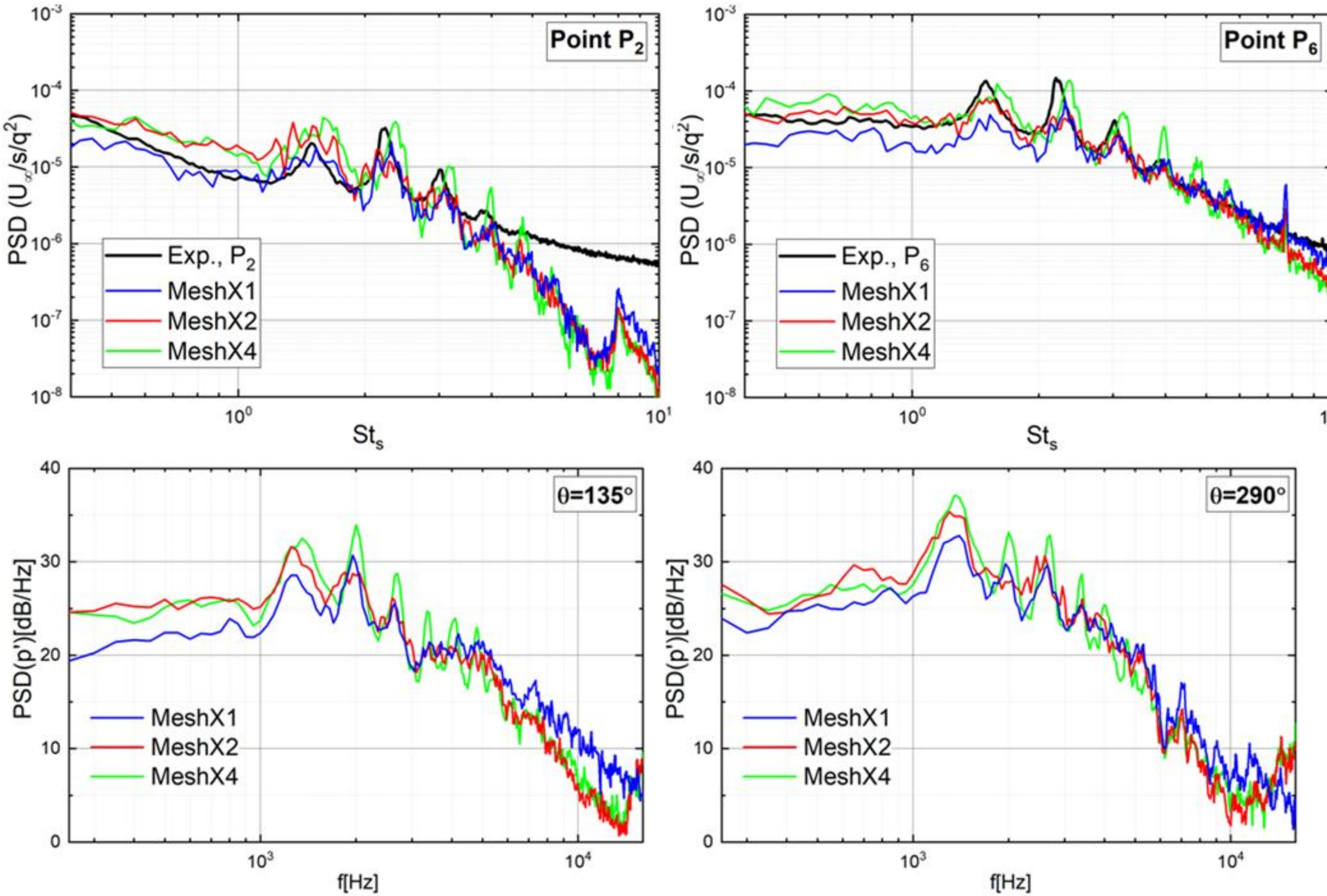
NOISEtte
Permeable surface
Slat solid surface
θ=290°
PSD(p')[dB/Hz]
f[Hz]
50
40
30
20
10
0
2000
4000
6000
8000
10000

Mesh coarsening – instantaneous fields

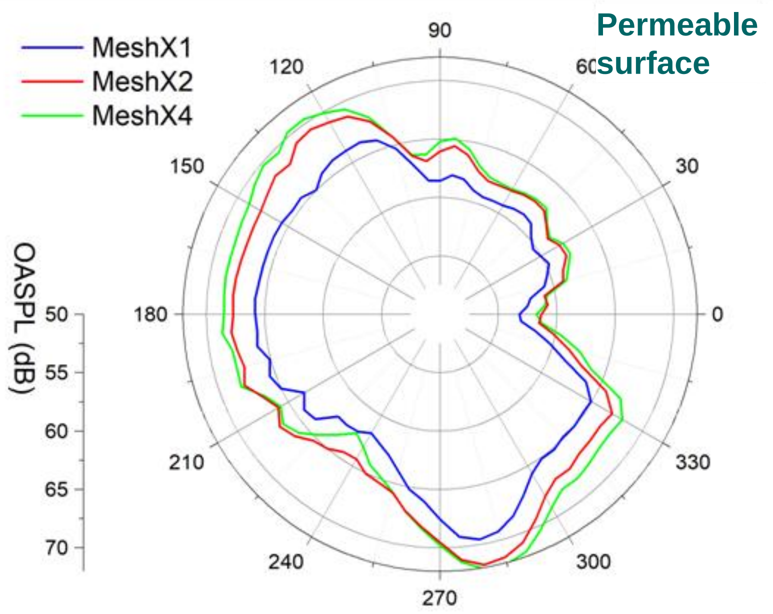


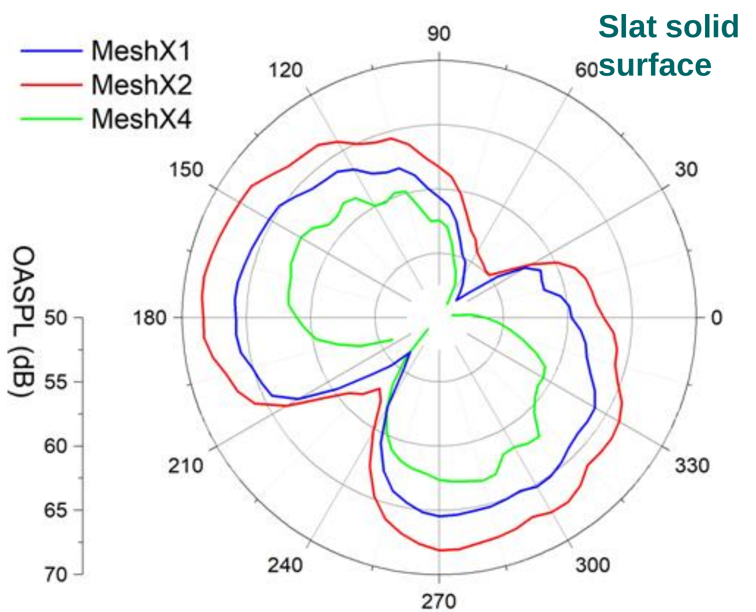
Mesh coarsening – instantaneous fields

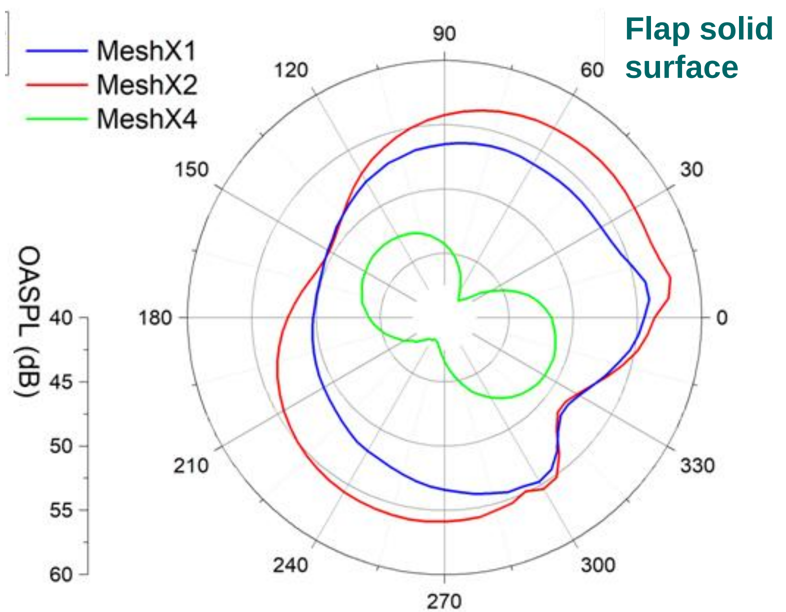
Mesh coarsening – spectra



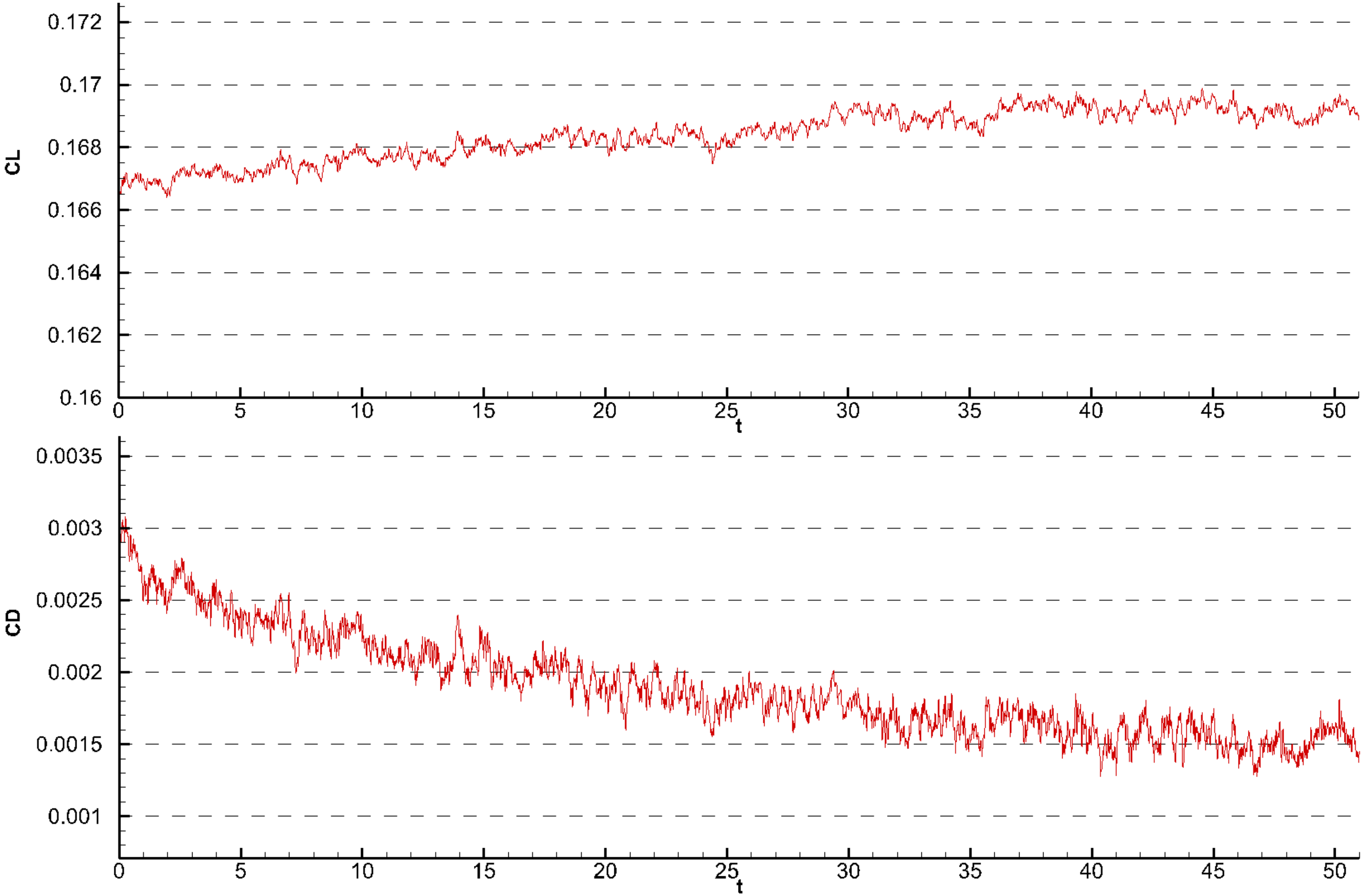
Mesh coarsening – far field



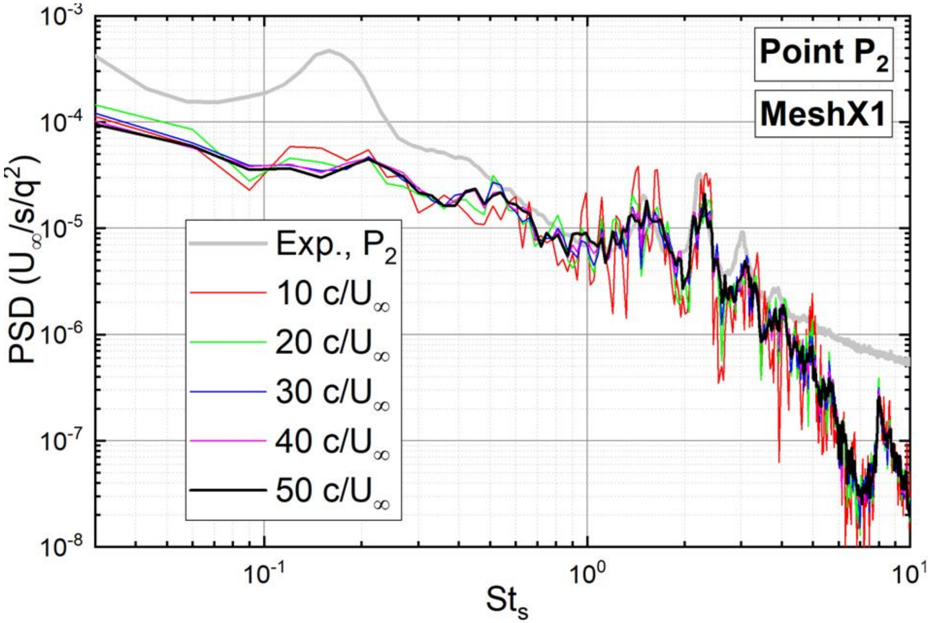


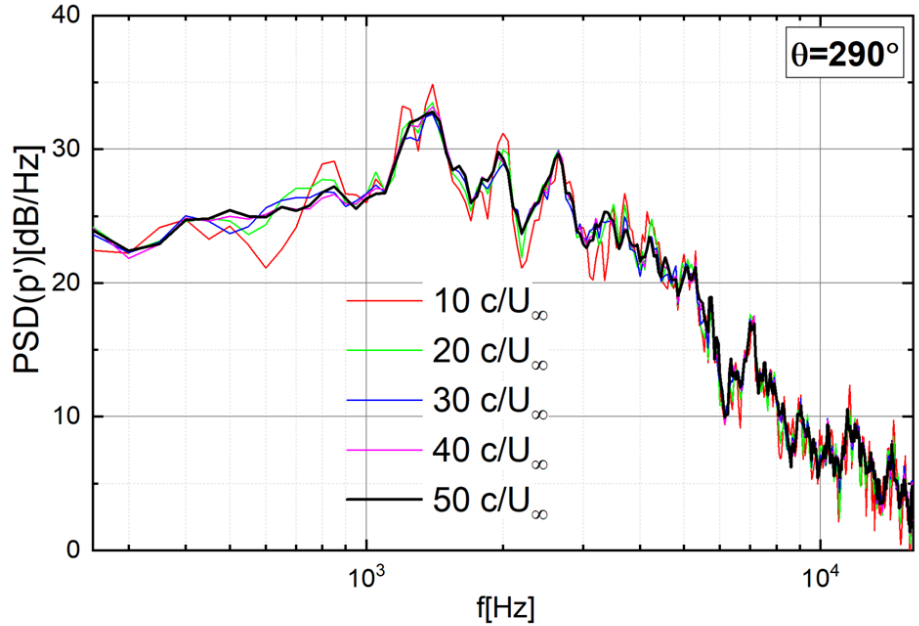


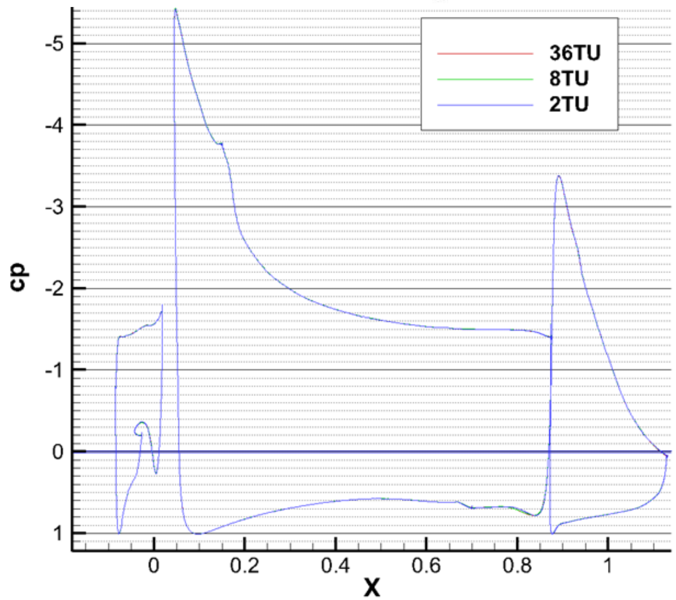
Reaching SSS from RANS solution

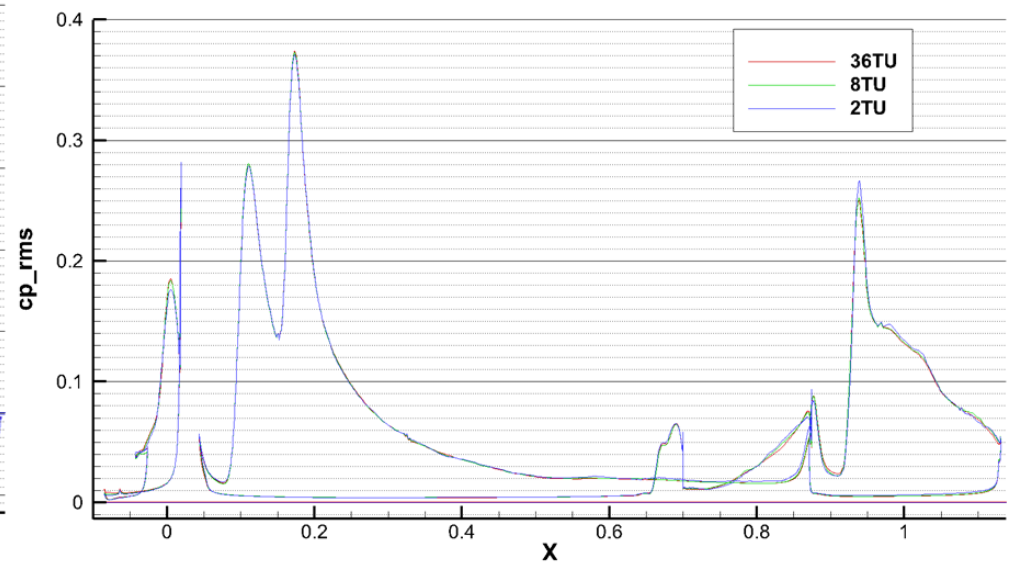


Convergence in time









Conclusion: estimation of CPU time

- **Reaching SSS: 30 TU**
- **Integration for average fields: <8 TU**
- **Integration for spectral data: 20 – 30 TU**
- **Overall time integration: >50 TU**

Reference: 1 TS with 35M mesh = 0.4 CPUh (dt=7E-5), 1 TU = 5.7K CPUh (Intel Xeon v3)

Whole wing simulation

X1 resolution = 1000M nodes, ~8M CPUh
X2 resolution = 600M nodes, ~5M CPUh
X4 resolution = 300M nodes, ~2M CPUh

Using wall functions can further save 10% of CPU time

Using SSS acceleration with refining meshes can save some 30% more

Reasonable whole-wing simulation can fit 4-5M CPUh

Simulation of wing segment: 200 – 300 K CPUh

Hybrid whole-wing RANS + segment of DES: 500 – 700 K CPUh