LaBS

Lattice Boltzmann Solver

LaBS: a CFD tool based on the Lattice Boltzmann method

E. Tannoury, D. Ricot, B. Gaston

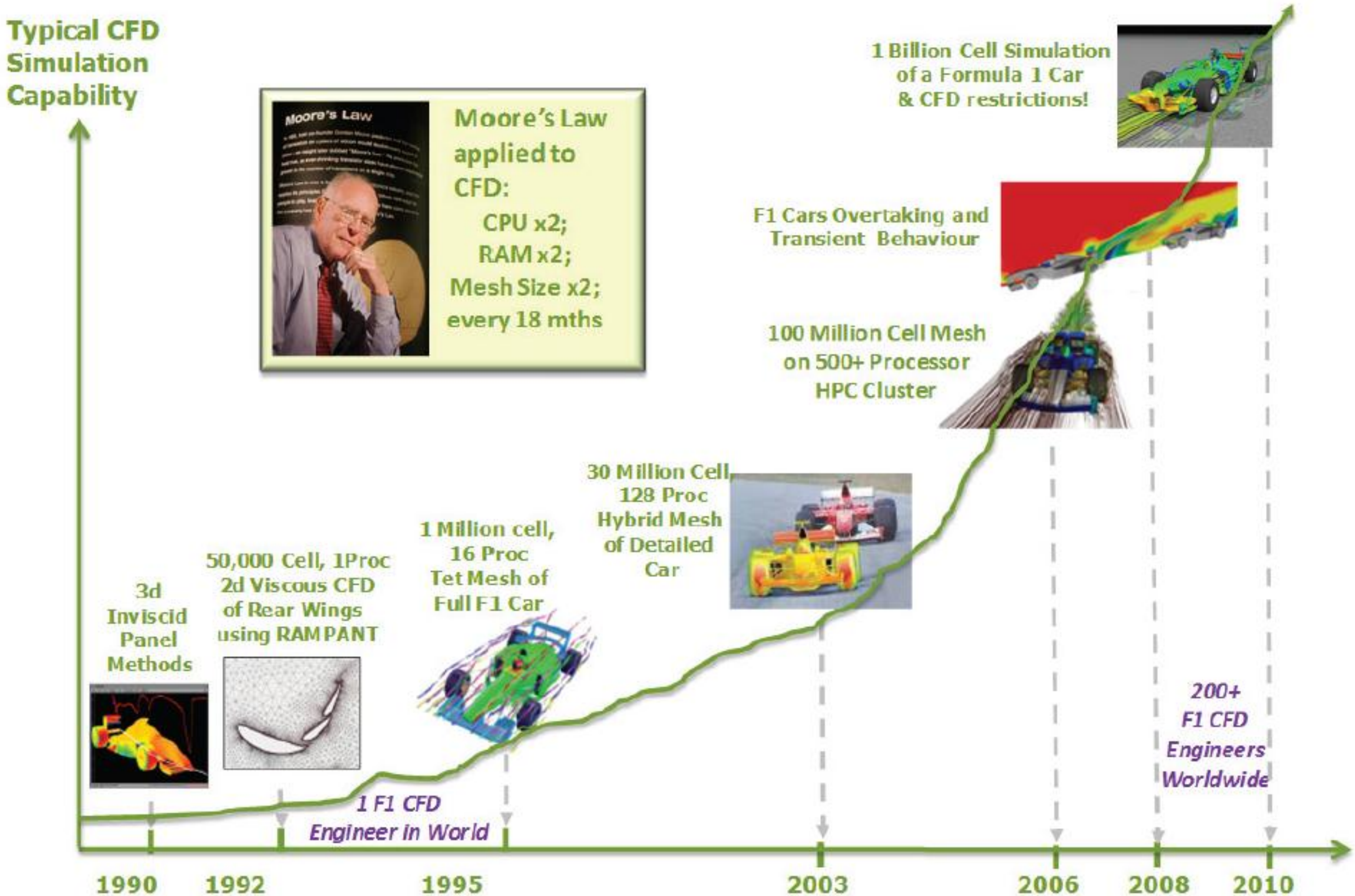
RENAULT

Impact of HPC on automotive engineering applications

Alain Prost, 1989

Lewis Hamilton, 2008

Impact of HPC on automotive engineering applications



Source: « Back to the future: trends in commercial CFD », K. Hanna, 2011.

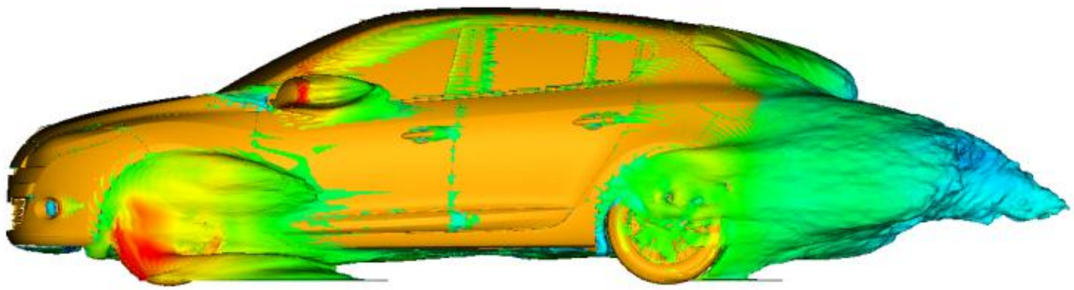
LaBS: external aerodynamics

Pre-processing:
≈ 2h engineering time

Solver:
≈ 48h/192 cores

Post-processing:
Automatic

	Exp.	LaBS	Delta
SC_x (m^2)	0,742	0,740	-0,27%



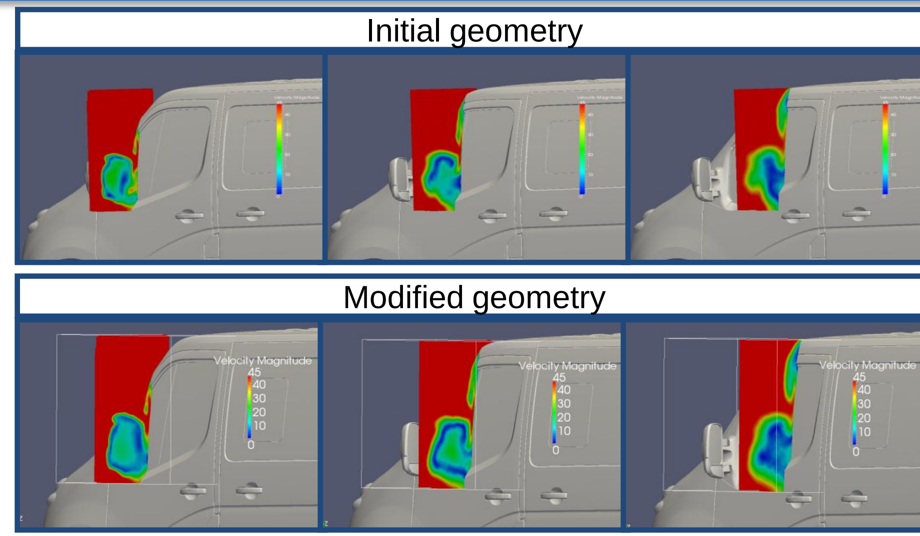
	Cost
Simulation	< 1 k€
Wind tunnel session	≥ 10 k€

Surface mesh:
186 surfaces, 2,3M Δ

Volume mesh:
88M cells
10 refinement levels

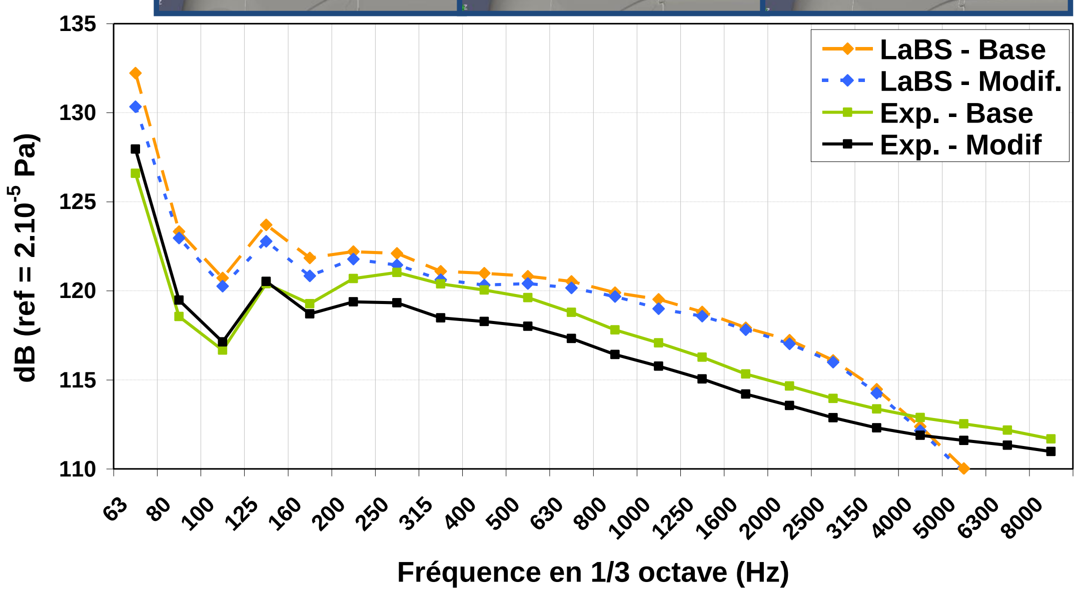
Simulated physical time:
1s
300 000 time-steps

LaBS: passenger comfort, aeroacoustics



- Wall pressure fluctuations due to the side-mirror (160 km/h)

- Quick iterations to determine:
  - Impact on aerodynamics?
  - Impact on noise generation?



LaBS, the R&D project

LaBS project

LaBS Consortium

Three industrial companies and two scientific laboratories, software's co-owner and developpers, leading, supporting and validating LaBS.

A collaborative project with strong partnerships

« LaBS Consortium » collaborates with partners whose scientific expertise enables building mathematical models and establishing simulation best-practices for several application domains.

<u>With the support of competitiveness clusters :</u>

<u>Financial support from FUI8 :</u>

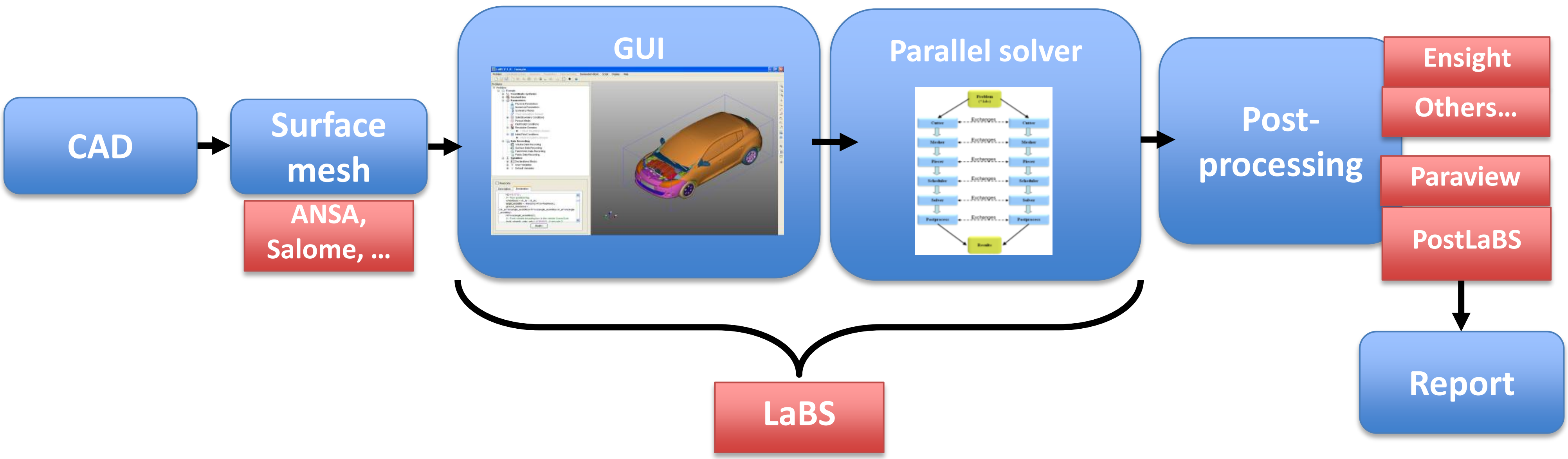
<u>Period :</u> 2009-2013

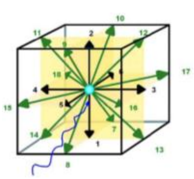
LaBS project in figures

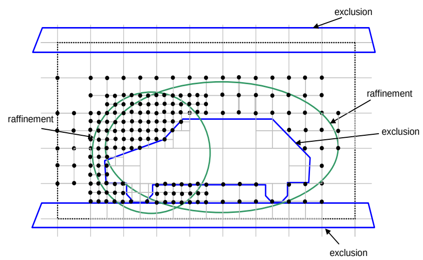
- **Budget (2009-2013):**
  - ✓ Total budget : 3,5 M Euros
  - ✓ incl. 1,8 M Euros grant
- **HPC :**
  - ✓ Several million core-hours used for testing and validation of the software (probably around 7 million hours) during 2009-2013
  - ✓ LaBS tested on a dozen servers, 64-1024 cores (CS, Renault, UPMC, OVH, Airbus, CEA/Curie,…)
  - ✓ At Renault: about 3 million core-hours used on 120 to 600 cores jobs.
- **Important scientific production :**
  - ✓ 18 papers in international peer-reviewed journal
  - ✓ 12 international conference papers
- **Project created 11 jobs (2013 status):**
  - ✓ 5 full position (CDI): CS (3 positions), Matelys (1 position) and Gantha (1 position)
  - ✓ The other 6 positions were fixed-term contracts in laboratories

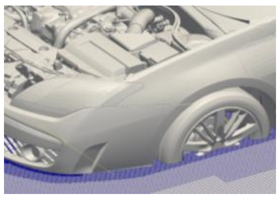
LaBS software and simulation workflow

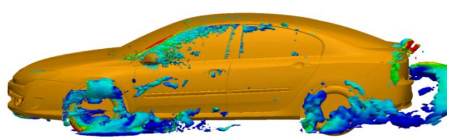
❑ Developed from scratch since 2009
- a GUI for simulation setup
- a parallel solver, including the volumetric mesher
- PostLaBS : a Paraview script suite for automatic post-processing (incl. signal processing)





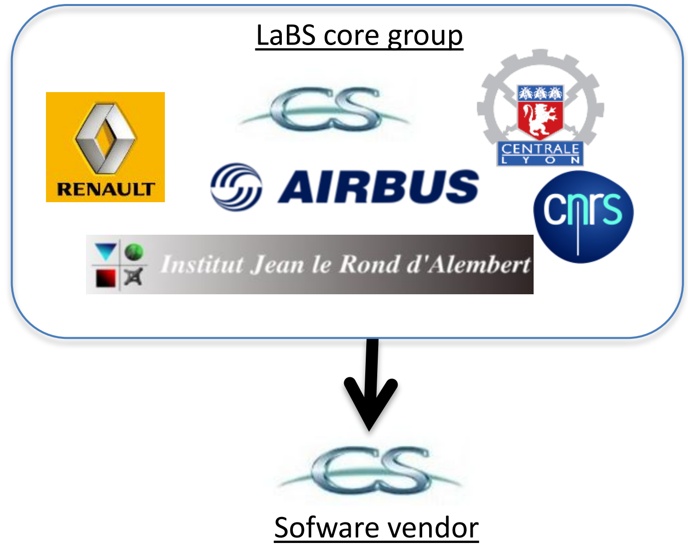


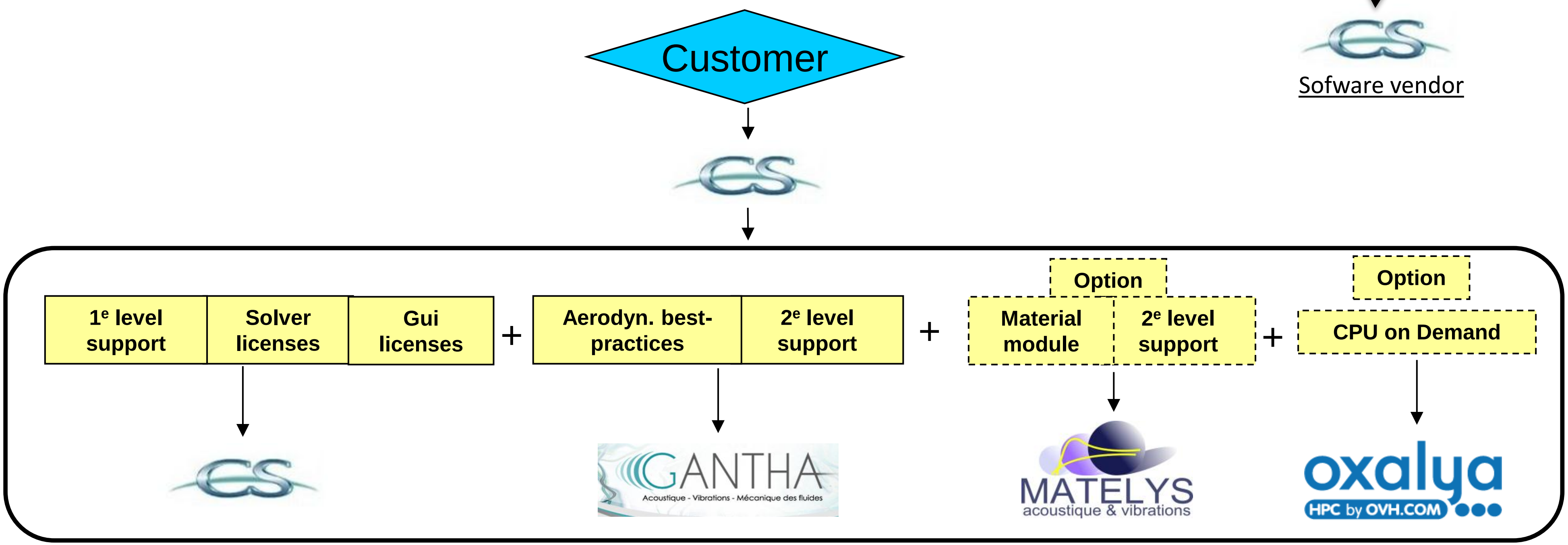




Sustainable development and commercial diffusion

- **LaBS commercial distribution**
  - ✓ Shared IP between 6 partners
  - ✓ Long-lasting relationship with own development activities and financial support
  - ✓ CS is the software vendor





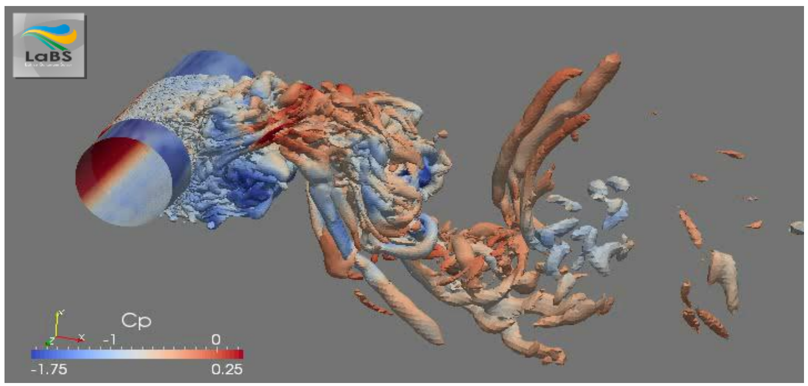
Turbulence modeling strategies : LES and Wall-modeled LES

- **shear-improved Smagorinsky model (SISM)** is a subgrid turbulence viscosity model adapted to inhomogeneous flows

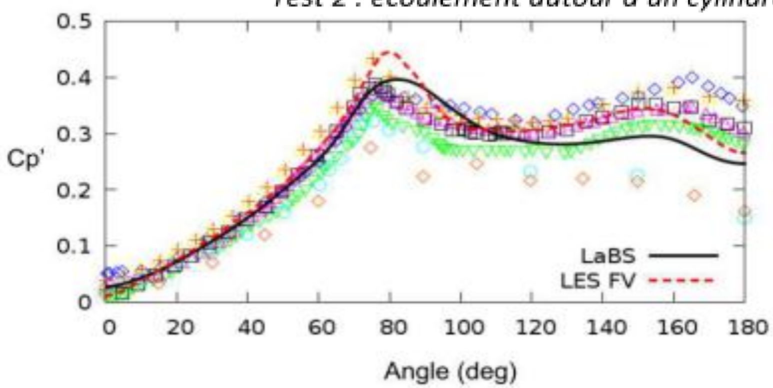
$$\nu_{\text{sgs}}(\mathbf{x}, \mathbf{t}) = (C_s \Delta x)^2 \left(|S(\mathbf{x}, t)| - \left| \widetilde{S}(\mathbf{x}, t) \right| \right)$$

  - *E. Leveque, F. Toschi, L. Shao and J.-P. Bertc ... dy Simulation of Wall-Bounded Turbulent Flows, Journal of Fluid Mechanics 2007, vol. 570, pp. 491-502*

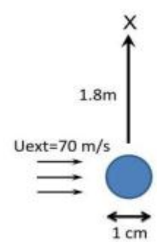
LES with SISM model
9 refinement levels
17 millions on mesh nodes
128 procs.

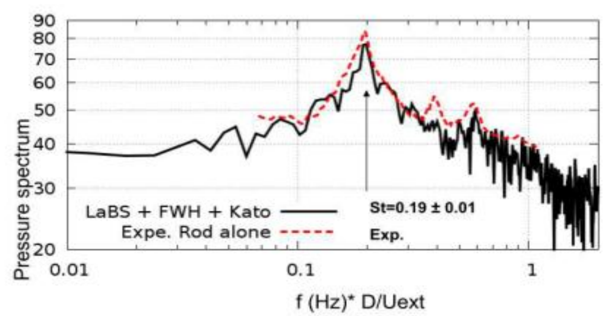


Test 2 : écoulement autour d'un cylindre dans le régime turbulent sous-critique à Re=47000



Symboles: données expérimentales Re=[32 000; 140 000]

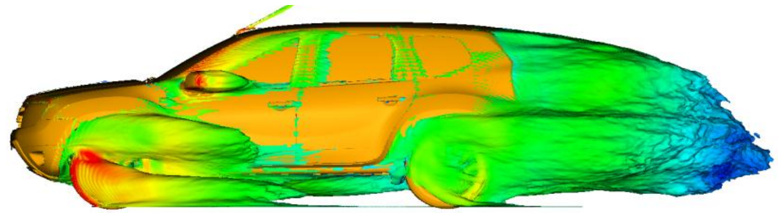




Le spectre de pression acoustique (en champ lointain) est bien prédit par la simulation avec le logiciel LaBS.

H Touil, D. Ricot, E; Lévêque, J. Comp. Phys. Vol 256, 1 January 2014

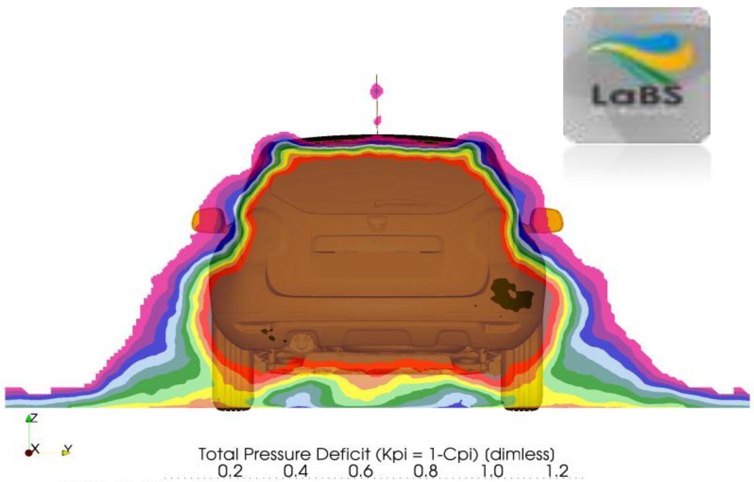
Duster

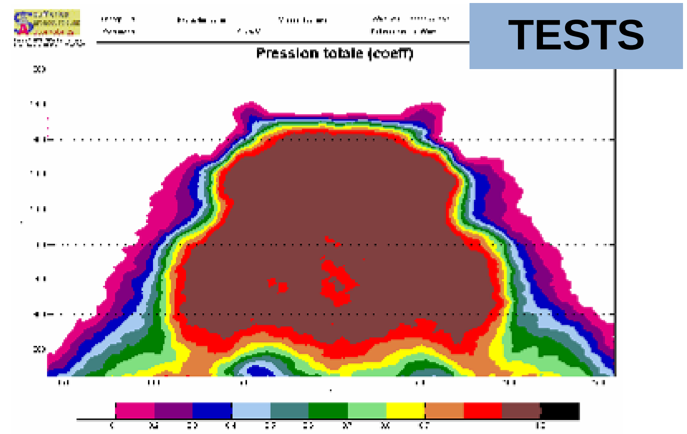


	SCx	Ecart
Tests in wind tunnel	1.016	
LaBS	1.010	-1%

DE-TDSM : H79_BASE_svn13012_R25G07C6

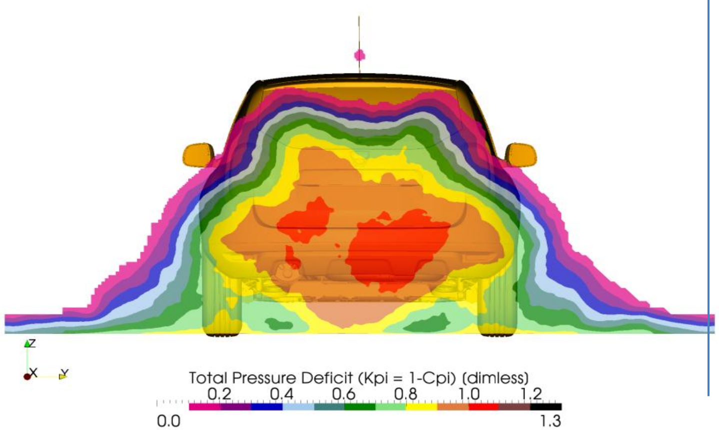
Plan X = culot + 50 mm

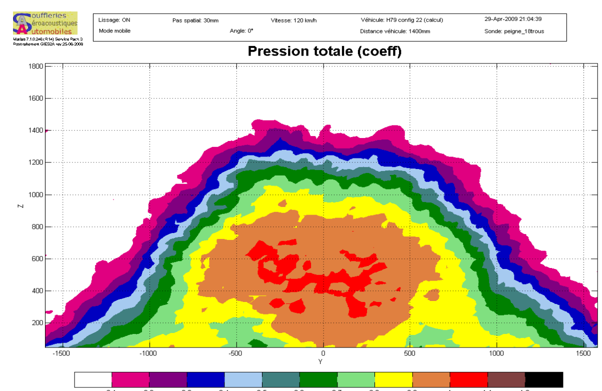




DE-TDSM : H79_BASE_svn13012_R25G07C6

Plan X = culot + 1400 mm

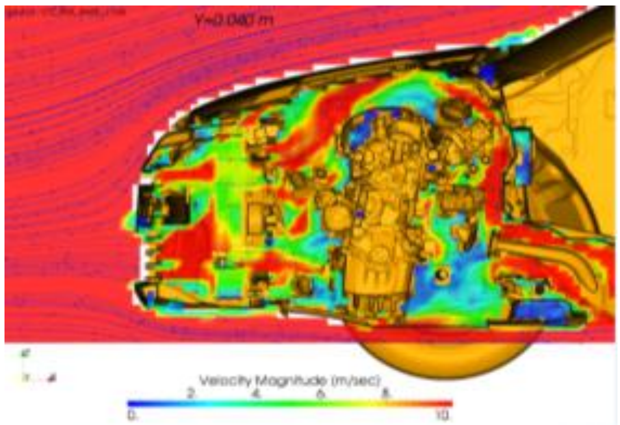




AERODYNAMIC VALIDATION : with porous media and rotating fan

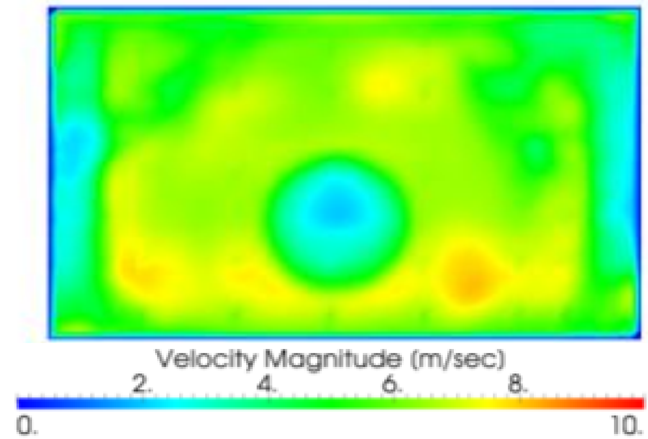
Mégane III

- **Fan OFF**
- **V = 165 km/h**

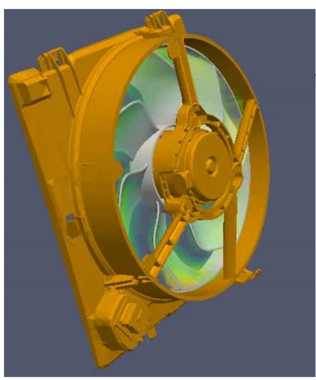


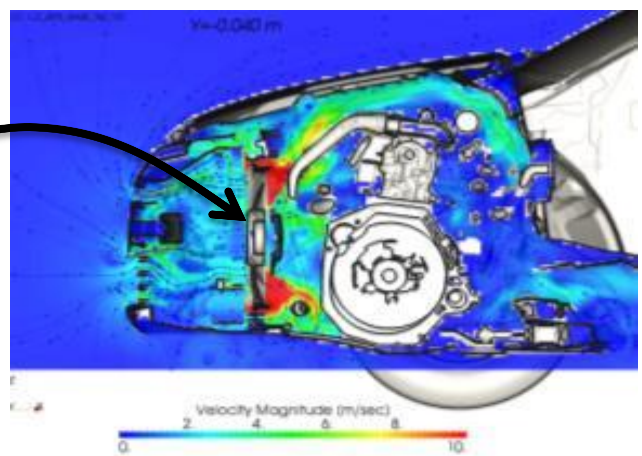
Mean Velocity (m/s) on radiator	LaBS **(m/s)**
V=165km/h	5.47
V=2km/h	1.51

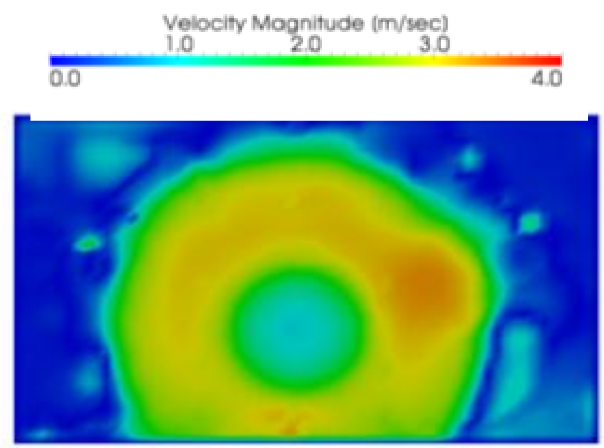
OK with Experimental results



- **Fan ON**
- **V = 2 km/h**

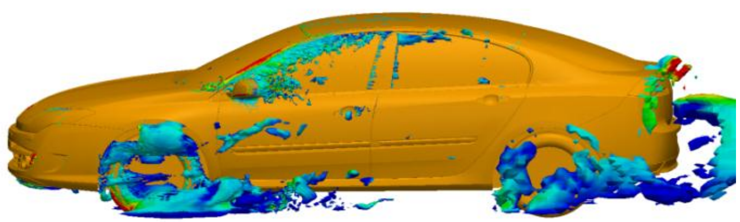


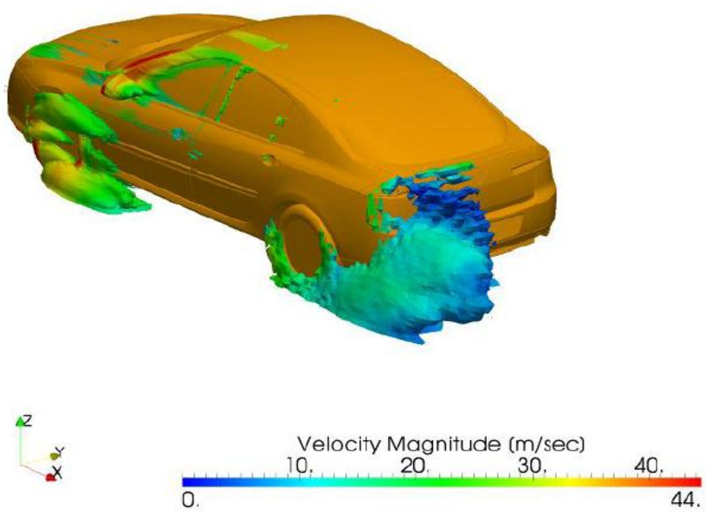




Wall pressure fluctuation

- Full scale vehicle simulation
- 10 levels of refinement, around 30 millions mesh nodes, 300 000 time-steps
- U0 = 44.4 m/s
- Wall Law LES (Approximate Deconvolution Model)





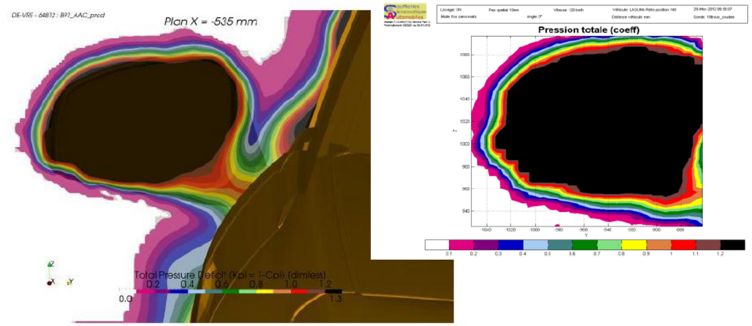


Figure 8 : déficit de la pression totale numérique à 70 mn

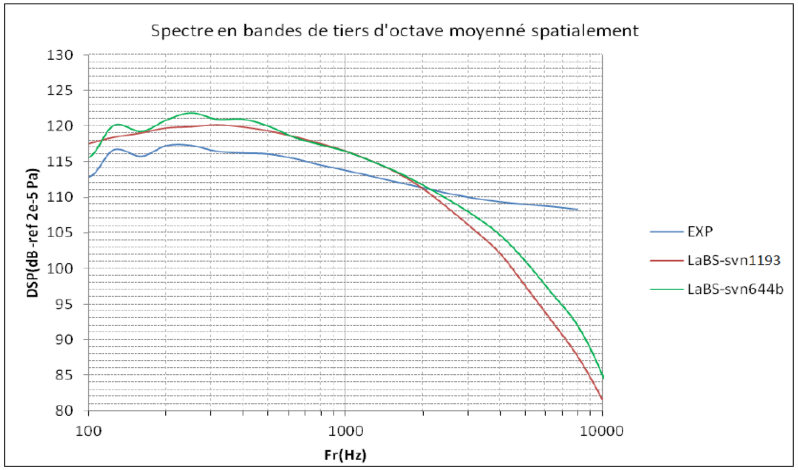
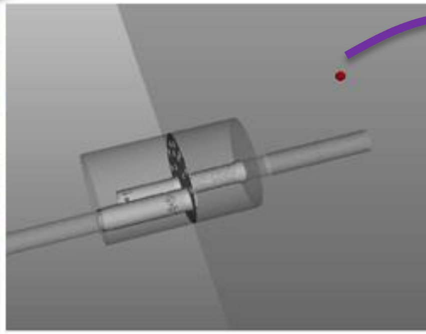


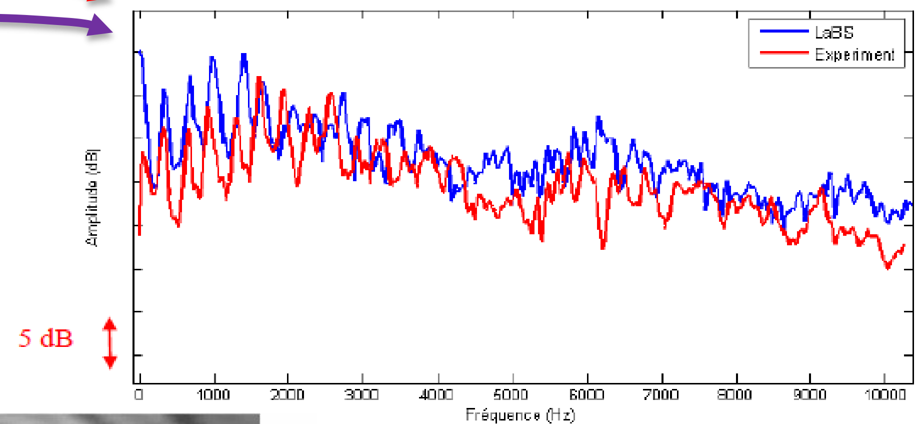
Figure 14 : spectres en tiers d'octave moyennés spatialement sur la vitre conducteur

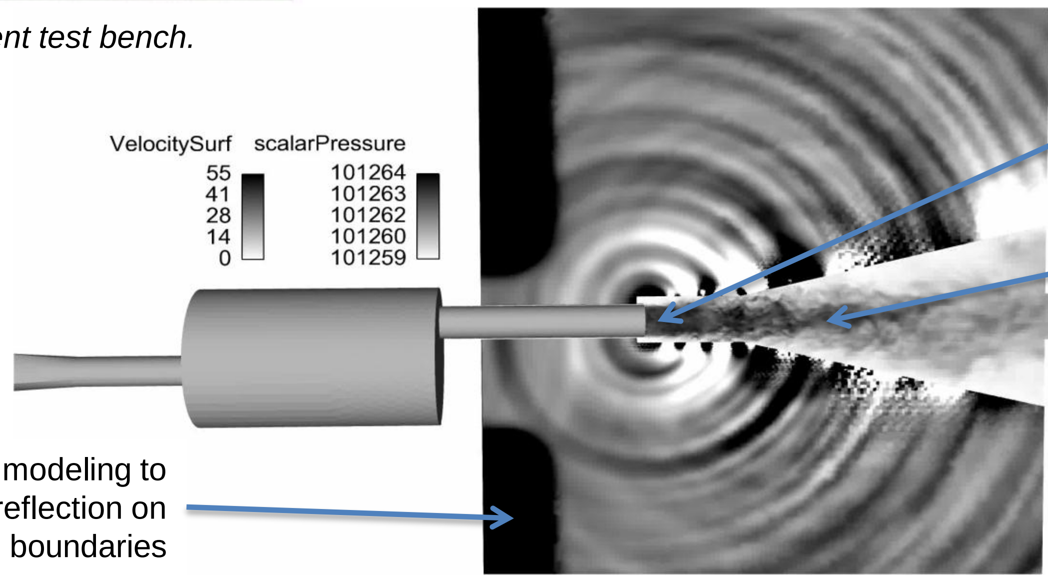
Aeroacoustic sources inside mufflers

Tailpipe measurement test bench.



Comparison expe/num of the power spectral density of the acoustic pressure field at the external reference probe.





physical noise coming from internal sources

spurious source region due to mesh size jump (fine to coarse)

Instantaneous velocity

Sponge zone modeling to avoid acoustic reflection on fluid domain boundaries

Instantaneous pressure

Concluding remarks

- New CFD solver based on Lattice Boltzmann method :
  - With strong scientific background and careful validation on each application fields
  - Collaborative development and validation

- Industrial CFD simulations can be done (isothermal) :
  - Robust workflow available (easy pre-processing, GUI, dedicated post-processing tools)
  - LES (with two models : SISM and ADM), WM-LES (Wall Model LES)
  - Run on standard HPC servers with hundred of cores for full scale industrial cases (O(100) millions nodes)

- At Renault LaBS is used for :
  - Wall pressure fluctuation simulations since Jan. 2013
  - Drag calculations and simulations of flow through heat exchangers with rotating fan since Jan. 2015

- Improvements are in progress for extended use at Renault (CLIMB project) :
  - HPC performance using new HPC architecture (GPU/Manycore)
  - More physics : thermal, acoustics
  - Better numerical schemes (example : some spurious noise can be created at refinement mesh interface)

LaBS

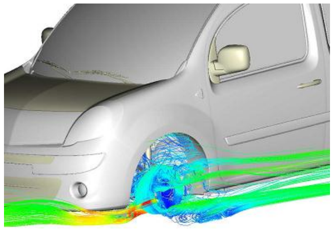
Lattice Boltzmann Solver

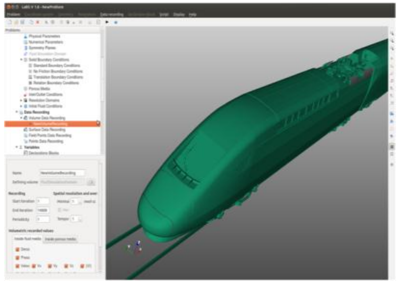
CLIMB

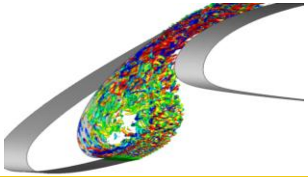
CLIMB : ComputationaL methods with Intensive Multiphysics Boltzmann solver

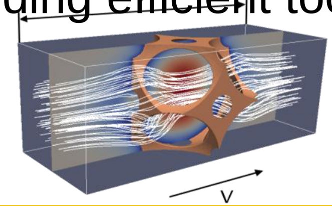
- Collaborative project : 15 partners

- Support of competitiveness clusters
- Financial support of DGE
- Aim :
  - Deploy and advance technology LBM on multi-physical aspects
  - Improve performances (optimizations & GPGPU/Many-core)
  - Reduce the overall time of simulation by providing efficient tools for pre- and post-processing



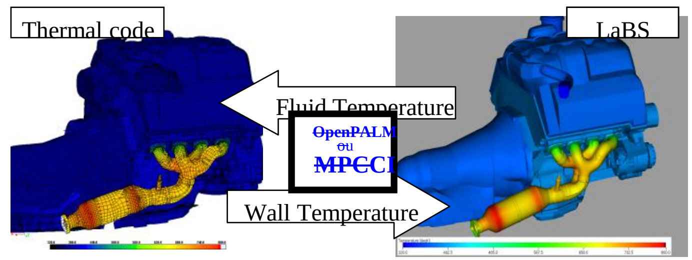






CLIMB: Physical models developments

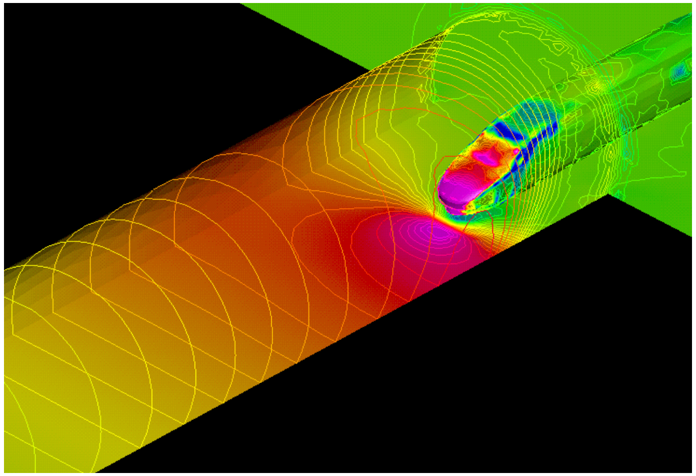
- Aerothermal transient co-simulation with fluid / structure
  - LBM Thermal models
  - Coupling with external thermal code

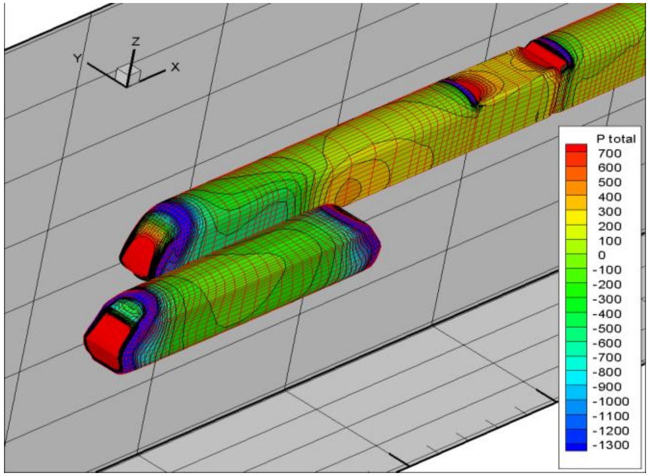


- Dispersion of pollutants in urban and confined environments

CLIMB: Physical models developments

- Advanced aerodynamics and aeroacoustics (aeroacoustic sources, high Mach, Translation)
  - Models for flow propagation with porous media
  - Models for high Mach numbers
  - Simulations with solids in translation
  - Industrial validation in aeronautics





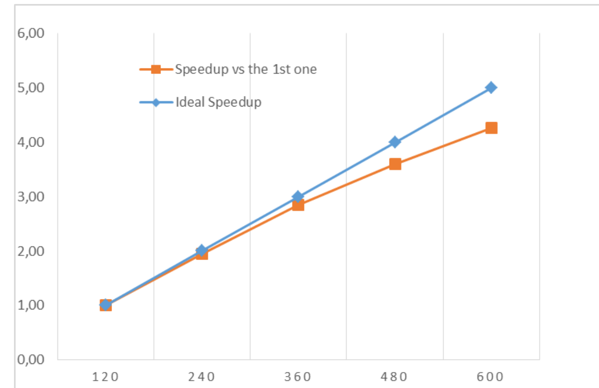
CLIMB: HPC Works

- ➔ All these works requires a HPC environment
  - Simulation domain around 1 billion of cells
  - Simulation on thousands cores
  - Outputs of hundreds gigabytes
- ➔ Users requires an industrial environment
  - Opitmization of pre/post-processing
  - Integration in some HPC systems

CLIMB: HPC Works

➔ code optimizations

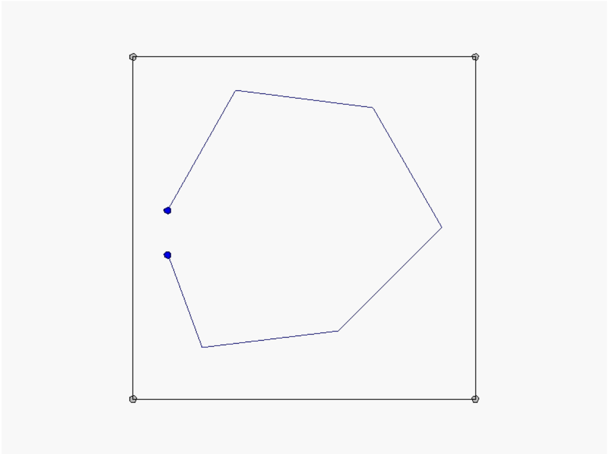
- Hybrid parallelism to increase the scalability
- Two levels of parallelism: distributed memory/shared memory
- High level : several parallel scheme using MPI allowed (point-to-point, collectives, non blocking, …)
- Low level : multiple targets
  - Vectorization (GPU-like)
  - Work stealing paradigm
  - I/O optimization

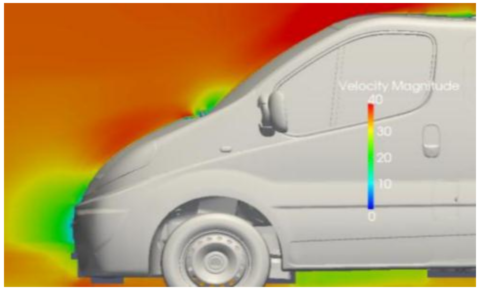


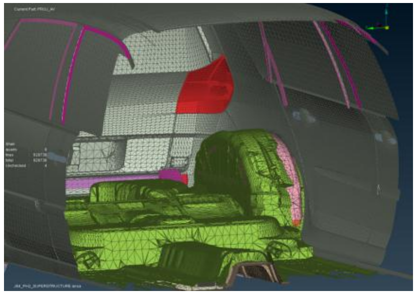
CLIMB: HPC Works

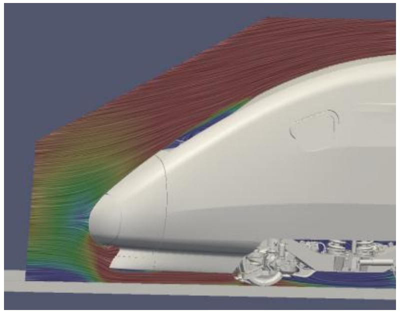
➔ Pre/post-processing optimizations

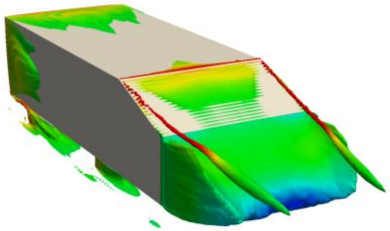
- Meshes from CAD without cleaning
- Outputs vizualization during the simulation
- Results analysis automated











Workflows HPC

→ Complex workflows in cloud environment

- Development of SaaS tools for generic workflows
- Business specific workflows with LaBS