LaBS: a CFD tool based on the Lattice Boltzmann method

E. Tannoury, D. Ricot, B. Gaston
Impact of HPC on automotive engineering applications

Alain Prost, 1989

Lewis Hamilton, 2008
Impact of HPC on automotive engineering applications

LaBS: external aerodynamics

Pre-processing:
≈ 2h engineering time

Solver:
≈ 48h/192 cores

Post-processing:
Automatic

Surface mesh:
186 surfaces, 2,3M Δ

Volume mesh:
88M cells
10 refinement levels

<table>
<thead>
<tr>
<th>$SC_x (m^2)$</th>
<th>Exp.</th>
<th>LaBS</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.742</td>
<td>0.740</td>
<td>-0.27%</td>
<td></td>
</tr>
</tbody>
</table>

Cost

<table>
<thead>
<tr>
<th></th>
<th>Simulation</th>
<th>Wind tunnel session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>&lt; 1 k€</td>
<td>≥ 10 k€</td>
</tr>
</tbody>
</table>

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 developers, 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.

With the support of competitiveness clusters:

Financial support from FUI8:

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

Sustainable development and commercial diffusion
shear-improved Smagorinsky model (SISM) is a subgrid turbulence viscosity model adapted to inhomogeneous flows

\[ \nu_{sgs}(x, t) = (C_s \Delta x)^2 \left( |S(x, t)| - |\tilde{S}(x, t)| \right) \]

- E. Leveque, F. Toschi, L. Shao and J.-P. Bert
  - Simulation of Wall-Bounded Turbulent Flows,
Duster

Tests in wind tunnel

<table>
<thead>
<tr>
<th>SCx</th>
<th>Ecart</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.016</td>
<td>-1%</td>
</tr>
</tbody>
</table>

LaBS

1.010

Plan X = culot + 50 mm

Total Pressure Deficit ($Kp = 1 - Cpi$) (dimensionless)

Plan X = culot + 1400 mm

Pressure totale (coeff)

Preassion totale (coeff)
AERODYNAMIC VALIDATION: with porous media and rotating fan

Mégane III

- Fan OFF
  - \( V = 165 \text{ km/h} \)
- Fan ON
  - \( V = 2 \text{ km/h} \)

<table>
<thead>
<tr>
<th>Mean Velocity (m/s) on radiator</th>
<th>LaBS (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V = 165 \text{ km/h} )</td>
<td>5.47</td>
</tr>
<tr>
<td>( V = 2 \text{ km/h} )</td>
<td>1.51</td>
</tr>
</tbody>
</table>

OK with Experimental results
Wall pressure fluctuation

- Full scale vehicle simulation
- 10 levels of refinement, around 30 millions mesh nodes, 300,000 time-steps
- $U_0 = 44.4 \text{ m/s}$
- Wall Law LES (Approximate Deconvolution Model)
Aeroacoustic sources inside mufflers

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

Tailpipe measurement test bench.

Sponge zone modeling to avoid acoustic reflection on fluid domain boundaries

Instantaneous velocity

Instantaneous pressure

physical noise coming from internal sources

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

5 dB
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)
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
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

- Optimization 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 visualization 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