Towards the full scale CFD modelling of the Mont-Blanc tunnel ventilation system

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Outline of the presentation

1. Aims of the present study
2. Numerical work
3. Feasibility study of the full scale simulation on PLX
4. Further work

Aims of the present study

Full scale 3D modeling for the analysis of the airflow in the Mont Blanc Tunnel ventilation system

- Collaboration among Department of Engineering Enzo Ferrari (DIEF) of the University of Modena and Reggio Emilia and the Gruppo Europeo di Interesse Economico del Traforo del Monte Bianco (GEIE-TMB) started in 2009, on the study and optimization of the Mont Blanc tunnel ventilation system.
- The research is carried out by both modeling and experiments, combined in an integrated approach for analysis of this class of problems.
- Experiments allowed to collect accurate in situ air velocity data for model development and validation, and for the verification of airflow control infrastructures.

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Numerical work

Critical aspects

- **Huge domain**: Length 11611 m, Height 6 m, Width 9 m
- **Ventilation elements**: Jet fans, Fresh air intake, Smoke extraction outlet
- complex modularity
- **Geometrical simplification**: No garage, no sidewalk, no road signal, equivalent wall roughness (tuned with experimental data), Jet fane modelled as hollow cylinders with ad-hoc Bcs
- **Meshing**: Near high-gradient zones: smoke extraction, jet fans, fresh air intake.
- Computation **challenging** and **expensive**

E. Agnani, D. Angeli, I. Spisso, P. Levoni, E. Stalio, G. S. Barozzi and M. Cipollone, Towards the full scale CFD modeling of the Mont-Blanc tunnel ventilation system, 31^{st} *UIT Heat Transfer Conference, Como, June* $25-27^{th}$, 2013

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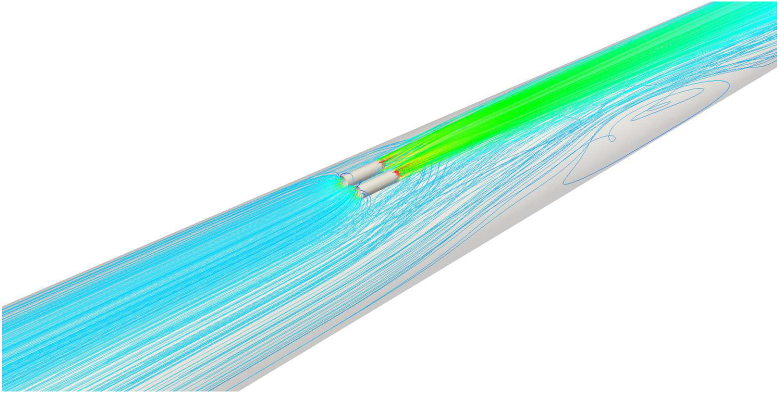
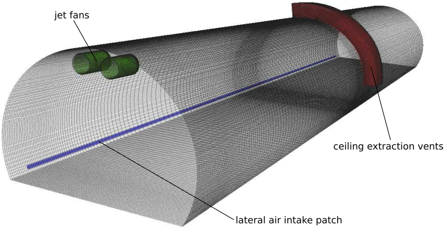
Feasibility study of the full scale simulation on PLX

- Installation
- Pre-processing
- Decomposition
- Computation
- Reconstruct and Post-processing



Installation

- tool chain used: `pyfoam/0.5.7`, `gnu/4.5.2`, `openfoam/2.1.1-gnu-4.7.2`, *swak4foam0.2.1*
- pyfoam, is a python library to control OpenFOAM-runs and manipulate OpenFOAM-data, is used to chain the script used.
- The boundary conditions used (groovyBC) requires the usage of a specific version of swak due to compatibility issue (local installation).



Pre-processing

- The full model is build up using 7 elementary blocks, generated using `snappyHexMesh`. Each block represents 50m linear of tunnel.
- The elementary blocks are assembled together using pyfoam with a LEGO technique using the attached scheme.
- The model assembly is a serial process, and it requires an increasing quantity of memory in the linking of a consecutive series of blocks.
- Final model assembly is around 155 M of cells. The fat node with 128 GB of RAM has been reserved for such operation. Usage of 91 GB of RAM, wall-time 3 hours.
- A finer mesh, with a number of cells around 200 M, requires the usage of the big1 node, equipped with 0.5 T of RAM.

SCHEMA_TUNNEL_STAMP

PM_start	PM_end	mesh_type	no.	base	Ax3	Ax2	Ax1	Bx3	Cx3	base_1	Ax3_1	pendenza	no. cells	block cells
0	300	base	3	3	0	0	0	0	0	0	0	2.40%	4924623	65.61E+06
300	700	Ax3	1	0	1	0	0	0	0	0	0		12150496	
700	900	base	2	2	0	0	0	0	0	0	0		3283082	
900	1300	Ax3	1	0	1	0	0	0	0	0	0		12150496	
1300	1600	base	3	3	0	0	0	0	0	0	0		4924623	
1600	1900	Ax2	1	0	0	1	0	0	0	0	0		8647511	
1900	2200	base	3	3	0	0	0	0	0	0	0		4924623	
2200	2500	Ax2	1	0	0	1	0	0	0	0	0		8647511	
2500	2700	base	2	2	0	0	0	0	0	0	0		3283082	
2700	2850	base_1	1	0	0	0	0	0	0	1	0		2669932	
2850	3200	Ax3_1	1	0	0	0	0	0	0	0	1	1.80%	11122105	64.97E+06
3200	3300	base	1	1	0	0	0	0	0	0	0		1641541	
3300	3700	Ax3	1	0	1	0	0	0	0	0	0		12150496	
3700	4500	base	8	8	0	0	0	0	0	0	0		13132328	
4500	4900	Ax3	1	0	1	0	0	0	0	0	0		12150496	
4900	5800	base	9	9	0	0	0	0	0	0	0		14773869	
5800	6900	base	11	11	0	0	0	0	0	0	0	-0.25%	18056951	63.60E+06
6900	7200	Bx3	1	0	0	0	0	1	0	0	0		10194744	
7200	7700	base	5	5	0	0	0	0	0	0	0		8207705	
7700	7900	Ax1	1	0	0	0	1	0	0	0	0		5144526	
7900	8200	base	3	3	0	0	0	0	0	0	0		4924623	
8200	8500	Cx3	1	0	0	0	0	0	1	0	0		10509570	
8500	8900	base	4	4	0	0	0	0	0	0	0		6566164	
8900	9400	base	5	5	0	0	0	0	0	0	0	-0.25%	8207705	66.35E+06
9400	9800	Ax3	1	0	1	0	0	0	0	0	0		12150496	
9800	10100	Bx3	1	0	0	0	0	1	0	0	0		10194744	
10100	10600	base	5	5	0	0	0	0	0	0	0		8207705	
10600	10900	Cx3	1	0	0	0	0	0	1	0	0		10509570	
10900	11100	base	2	2	0	0	0	0	0	0	0		3283082	
11100	11500	Ax3	1	0	1	0	0	0	0	0	0		12150496	
11500	11600	base	1	1	0	0	0	0	0	0	0		1641541	

Decomposition

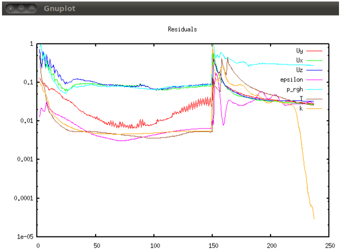
- The computational model has been decomposed along the y axis, using the `simple` method.
- A constant number of cells per processor is obtained, (between 0.5 M and 0.9 M cells per processor, using a number of procs between 144 and 264).

Computation

- All the ventilation elements have been tested separately with ad-hoc simulations.
- Runs have been done on the compute nodes of PLX clusters, that are 2 esa-cores Intel Xeon 2.40 GHz per node with 47 GB of memory available per node.
- The solver used is the `buoyantBoussinesqSimpleFoam`. The simulation has been done by switching-off the fans.
- Three runs has been done using 12, 16 and 22 nodes, that correspond to 144, 192 and 264 cores.
- Preliminary simulations with a lower number of nodes (8 nodes), failed after few iterations, probably given to an eccess of memory requested.

Computation

- Number of iteration is around 210, the residual are in the interval $[10^{-0}, 10^{-3}]$, as shown in the figure for Np=144.
- The memory occupancy (average) of the compute nodes is max with 12 nodes, and it is around 20 GB.

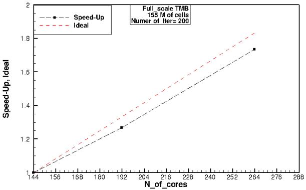


Scalability

- The scalability is satisfactory for the runs carried out.
- The Wall time, for 200 number of iterations, is between 14 and 8 hours, respectively with 12 and 22 node.
- The Cpu-hours for a single run is around 2,000.
- Cpu-hours = (number of cores $\times$ WallClock Time (sec.)) / 3600

n. of nodes	n. of cores	cells per processor	n. of it	WCT	Cpu-hours
12	144	0.9 M	210	50.812 s = 14.11 h	2.032
16	192	0.7 M	210	39.906 s = 11.09 h	2.128
22	264	0.5 M	210	29.126 s = 8.09 h	2.135

Table: Computational resources used for preliminary runs



Reconstruct and Post-processing

- The fluid-dynamics fields have been saved every 35 iterations, and they have been reconstructed using `reconstructPar`.
- Memory demanding operation. Example: with Np=144 procs, 110 GB of memory used, 11 hours of cpu-time, and 13 GB of data occupancy for each time-field.
- Remote Visualization using RCM of CINECA and ParaView. It is mandatory, at least, a node with 128 GB of memory or bigger. The mesh has been visualized inside CINECA with RCM.
- Loading time for the entire model, aroud 30 min. Simple manipulation operations have been performed.

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Further work

- Feasibility study of the full scale simulation of the Mont-Blanc tunnel on PLX has been conducted.
- Satisfactory results (preliminary).

From feasibility to $\Longrightarrow$ *Pre-production runs*

- Simulation with the fan switch-on.
  Increase of the computational cost is expected.
- Refined mesh more than 200 M of cells. Big1 node for pre and post-processing. Increase of the computational cost is expected.
- Runs with a greater number of final iterations $> 400 - 500$ (or 1,000 time iterations), to study the accuracy and behaviour of the residuals. Increase of the computational cost is expected.
- Evaluation of 5,000 cpu/hours per run, conservative (Budget of 50,000/ 100,000 cpu/hours for pre-production runs?).
- Optimization of the meshing process, creation of the whole mesh in parallel with `snappyHexMesh`?
- Strategy for data visualization?

Estimation of computational budget for Pre-prod runs

- Evaluation of (at least) 5,000 cpu/hours per run
- 20 runs $\Longrightarrow 5,000 \times 20 =$ **100,000** cpu-hours on PLX.
- test run on FERMI? minumum allocation resources 1024 cores,
- scaling factor between FERMI and PLX $\sim 3-4$.
- $8h\ WCT_{plx} \simeq 24h\ WCT_{fermi}$
- $cpuhours_{fermi} = 1,024 \times 24h = 24,576.$
- 20 runs $\Longrightarrow 24,576h \times 20 = 491,520 \simeq$ **500,000** cpu-hours on FERMI
- Optimization of the meshing process, creation of the whole mesh in parallel with `snappyHexMesh`?
- Strategy for data visualization?