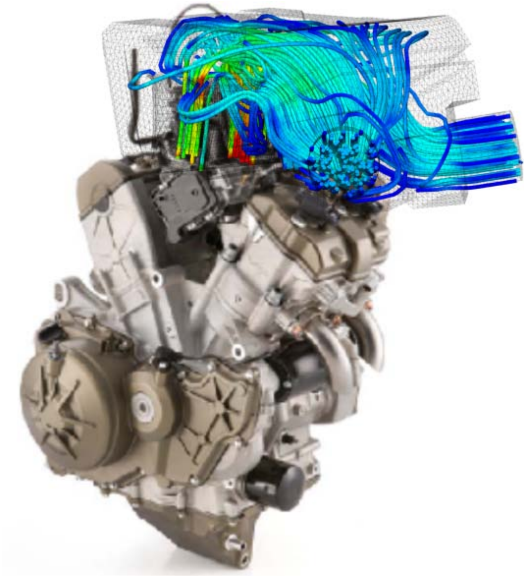
1D-3D THERMO – FLUID DYNAMIC SIMULATION OF A HIGH PERFORMANCE MOTORBIKE ENGINE



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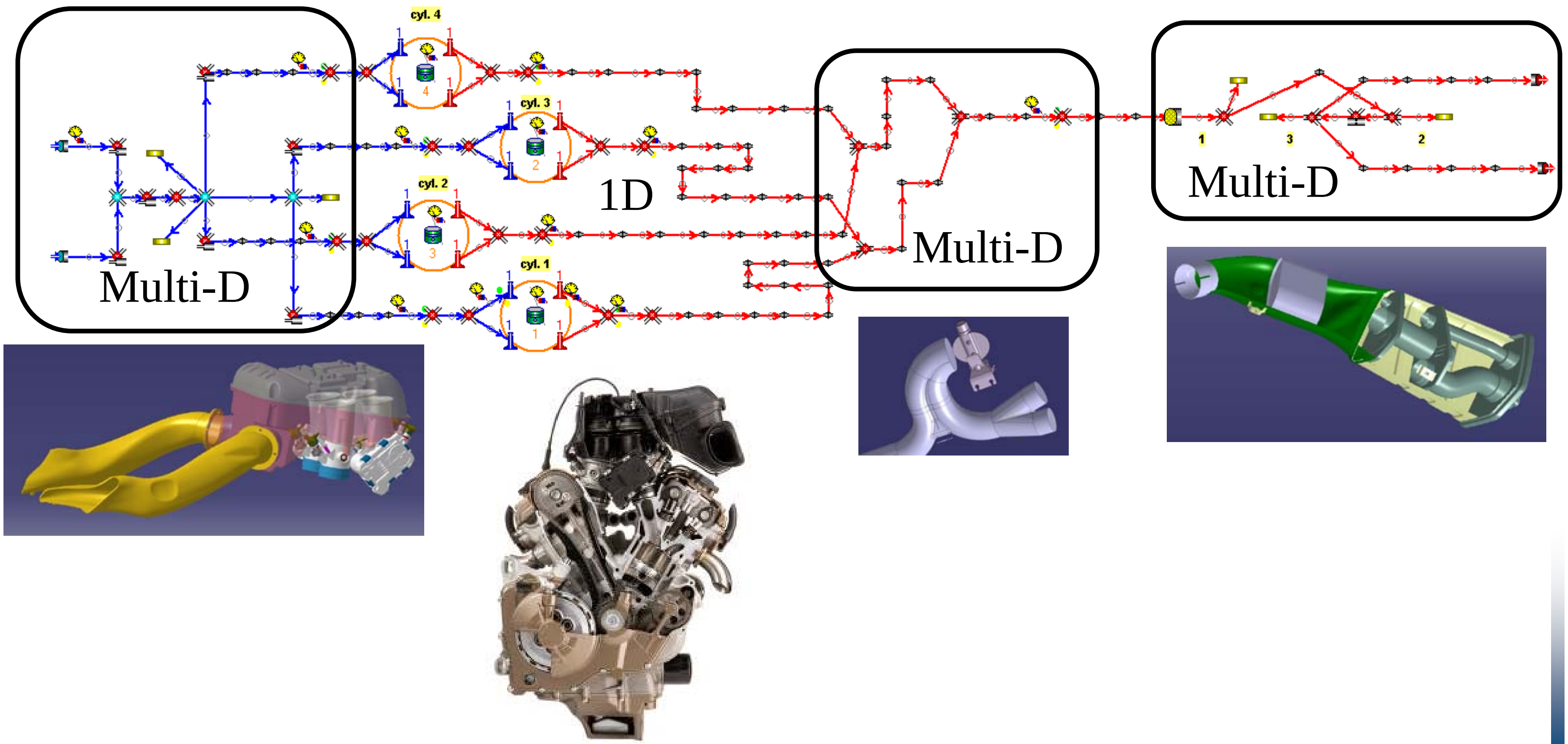
PIAGGIO & C.s.p.a. aprilia

Summary

- Introduction
- Engine characteristics
- Experimental apparatus
- Intake system analysis
- Exhaust system analysis
- Prediction of volumetric efficiency
- Conclusions
- Work in progress

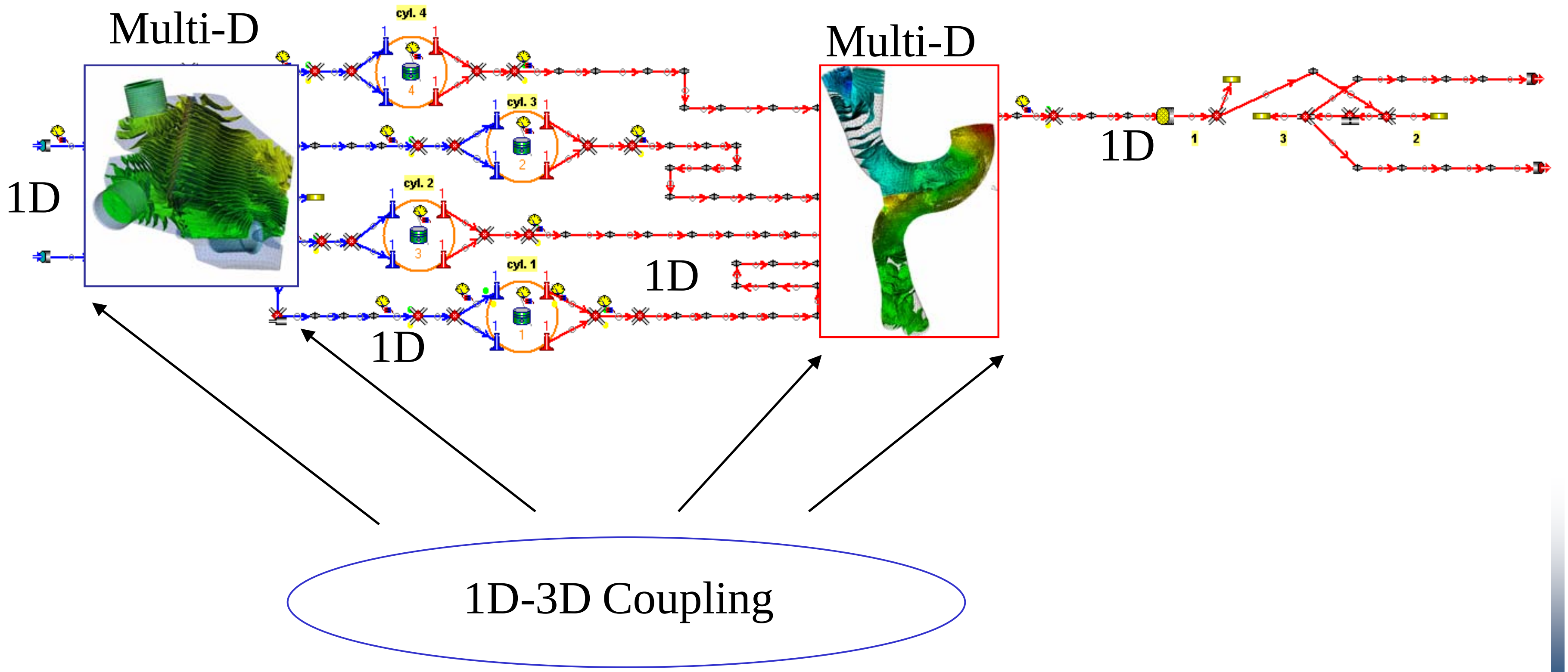
Introduction

- High performance engine: accurate optimization of all components
    - Reduction of fluid dynamics losses and optimization of dynamic effects
        - Improve volumetric efficiency



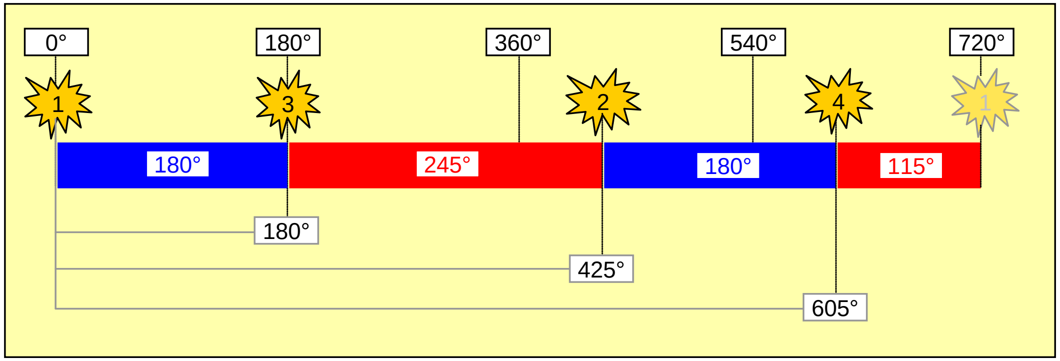
Introduction

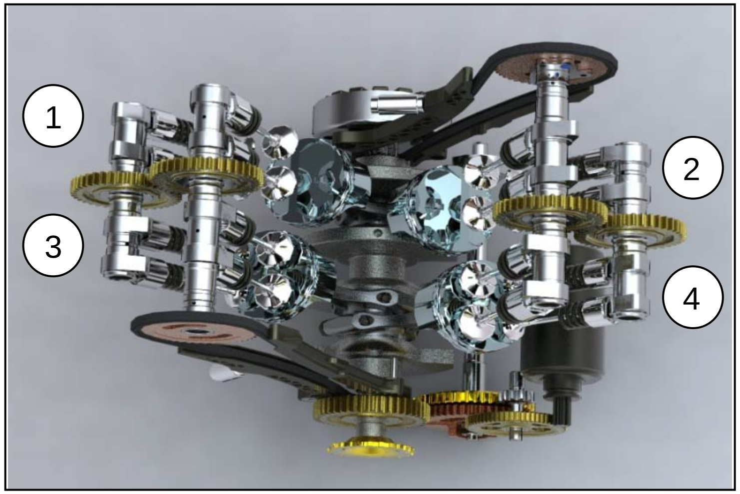
- 1D–3D simulation of intake and exhaust systems with multiple 3D domains (airbox and exhaust junction).



Engine characteristics

Firing Order





Engine type	Spark Ignition
Cylinder layout	V4 - 65°
Total displacement [dm^3]	0.9996
Bore [m]	0.078
Stroke [m]	0.0523
Compression ratio	13:1
Number of valves per cylinder	4
Air metering	Naturally aspirated
Injection system	PFI

Experimental Apparatus

- **Istantaneous pressure**
  - Piezo – resistive transducer Kulite ETL 173-190 (intake)
  - Piezo – resistive transducer Kulite EWCT-312 cooled (exhaust)
  - Piezo – electrical transducer Kistler 6052C (cylinder)

- **Crank angle position**
  - Optical encoder AVL 364, resolution: 0.5°

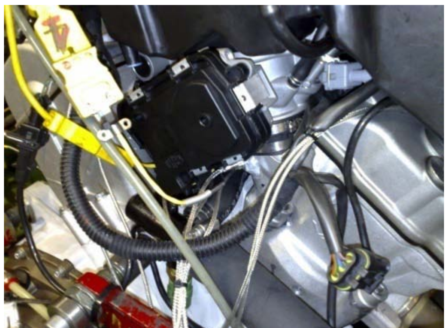
- **Fuel mass – flow**
  - Mass flow meter Micromotion ELITE CMF025

- **Equivalence ratio**
  - Linear Lambda sensor NTK 6312-W1

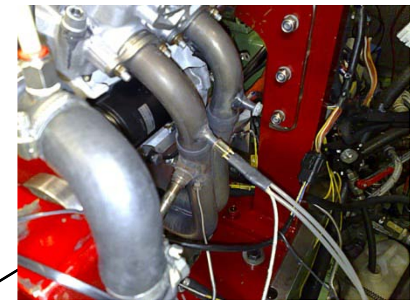
- **Data acquisition system**
  - AVL Indicom 1.6

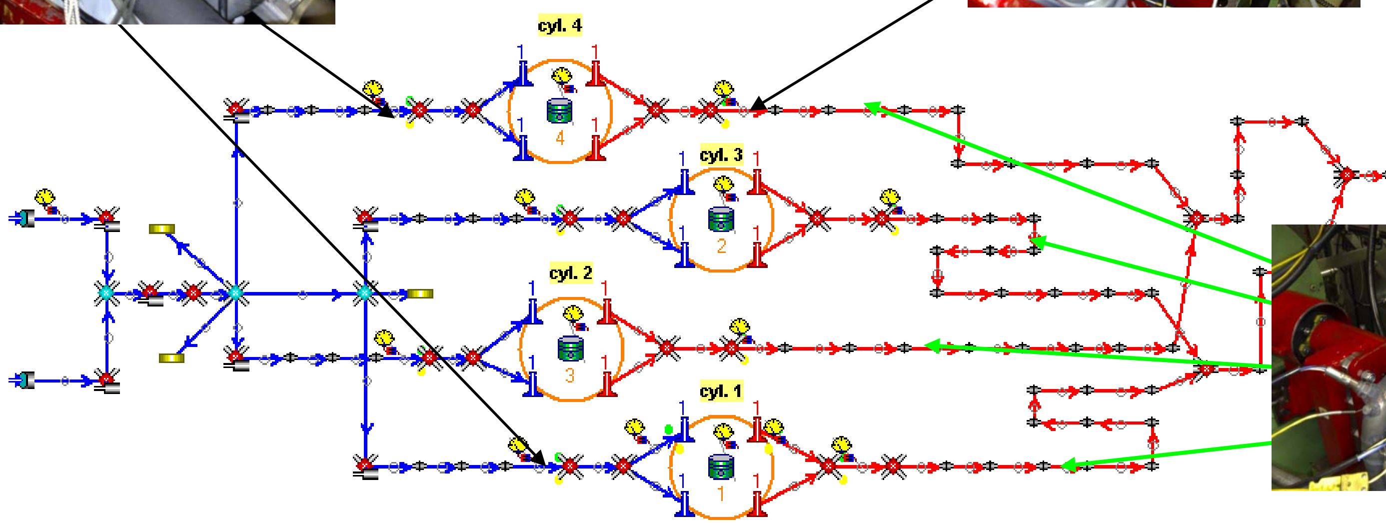
Experimental Apparatus

- Crank angle based cylinder and duct pressure traces
- Measure of fuel mass flow and equivalence ratio:
    - Calculation of Volumetric Efficiency



Intake pressure (downstream throttle):
Cylinder 1
Cylinder 4
Exhaust pressure:
Cylinder 4

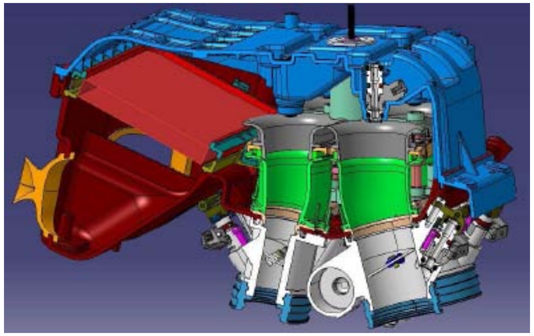




Equivalence ratio:
Cylinder 1
Cylinder 2
Cylinder 3
Cylinder 4

Intake system analysis

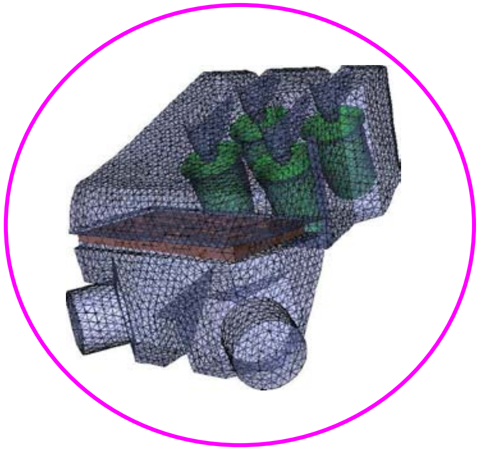
- Creation of 1D schematic and 3D mesh
- 1D and 3D model interfaces on boundary patches



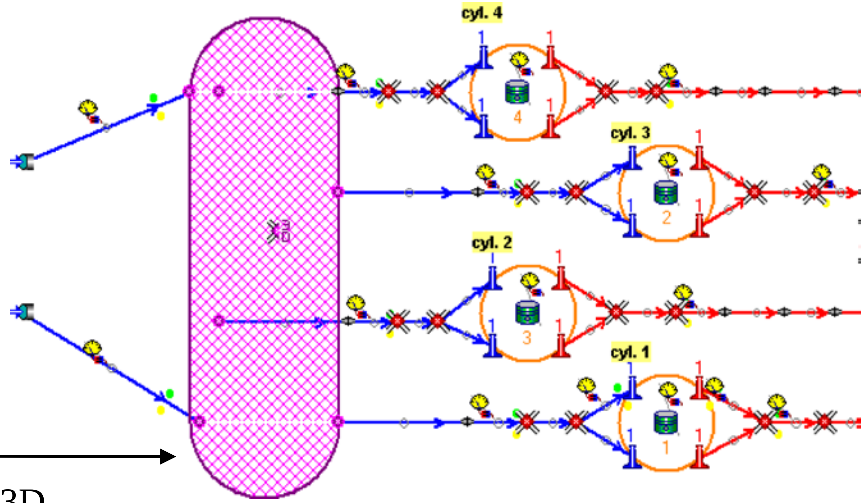
Engine intake system:

airbox, trumpets, throttle body and fuel injectors

Calculation domain from 3D CAD model



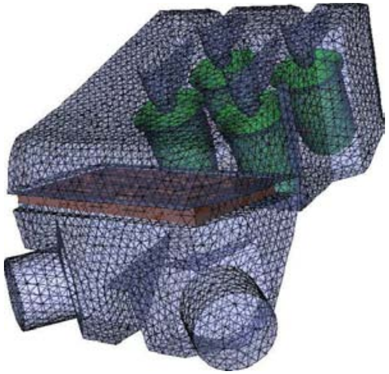
1D - 3D coupled model



Layout of 3D domain coupled with 1D model

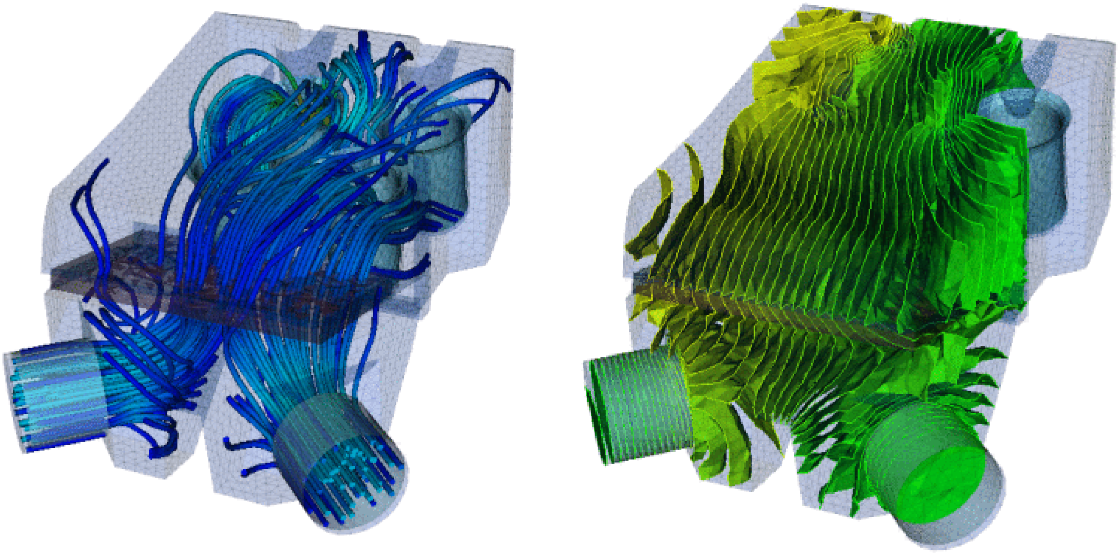
Intake system analysis

- Multi-D analysis



Airbox mesh: full tetrahedral grid of about 57500 cells (mean side dimension: 5 mm).

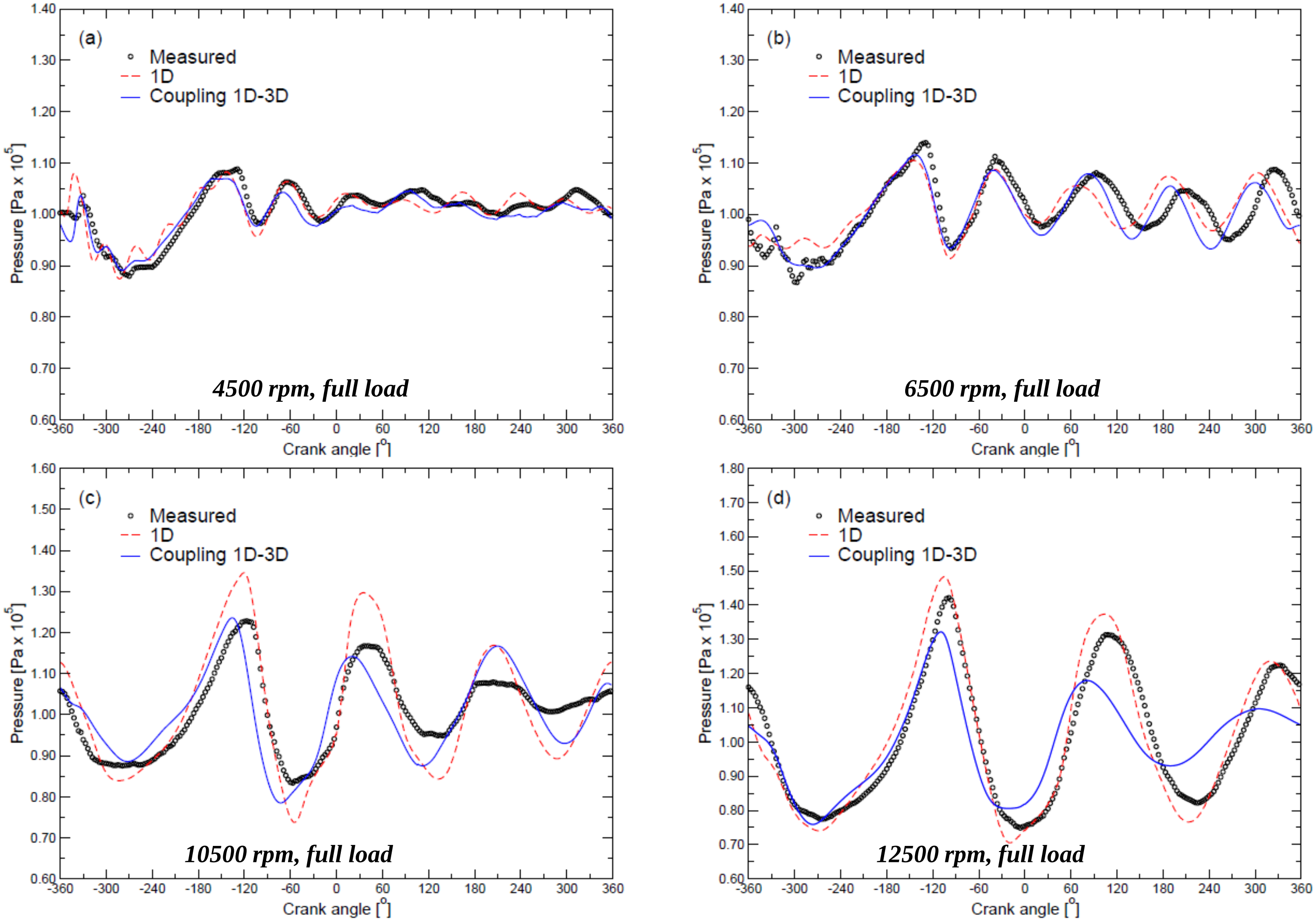
Air filter panel: airbox grid area of about 1700 cells.



Velocity and pressure fields at 12500 rpm

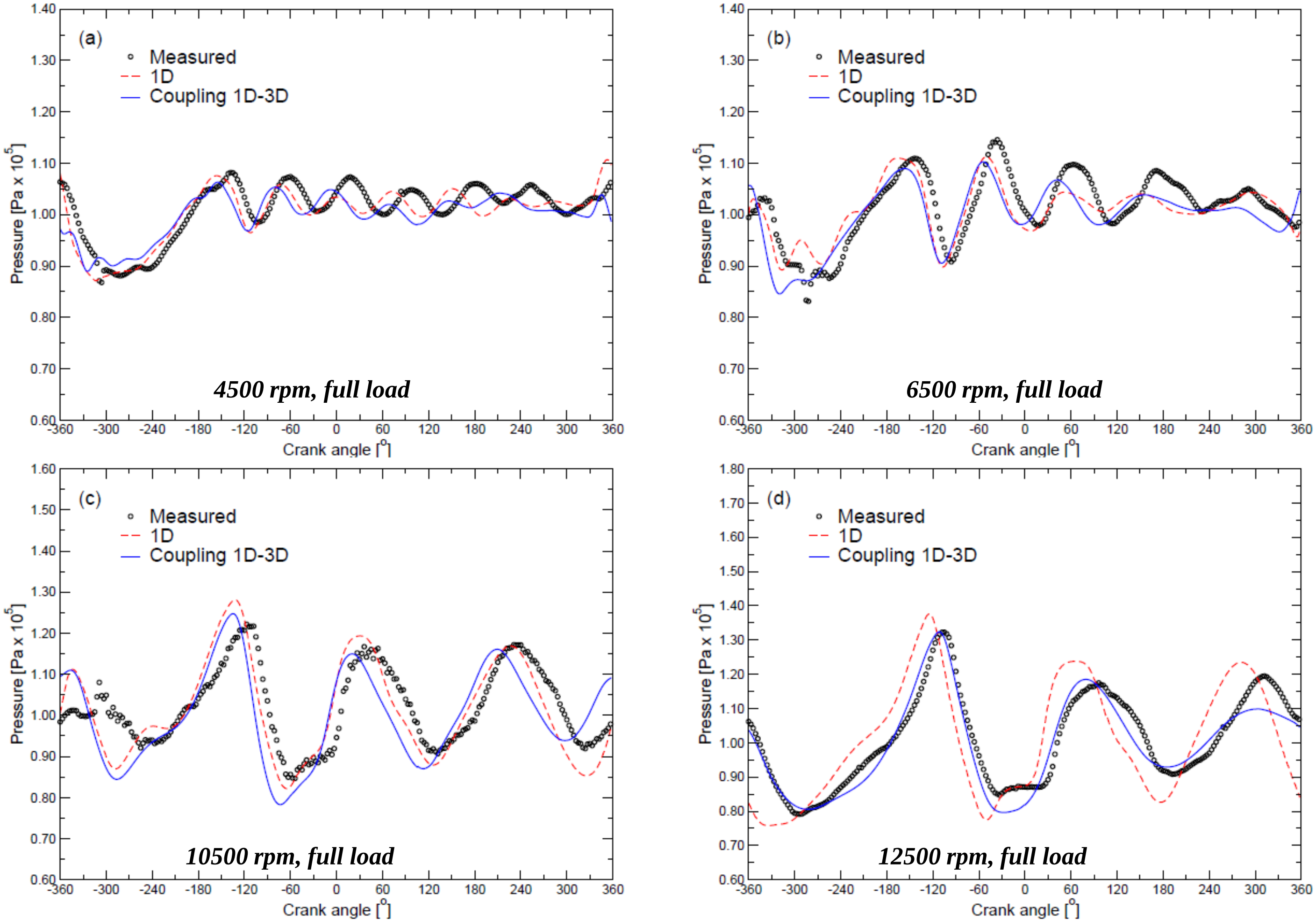
Intake system analysis

- Simulations results: duct pressure upstream cylinder 1



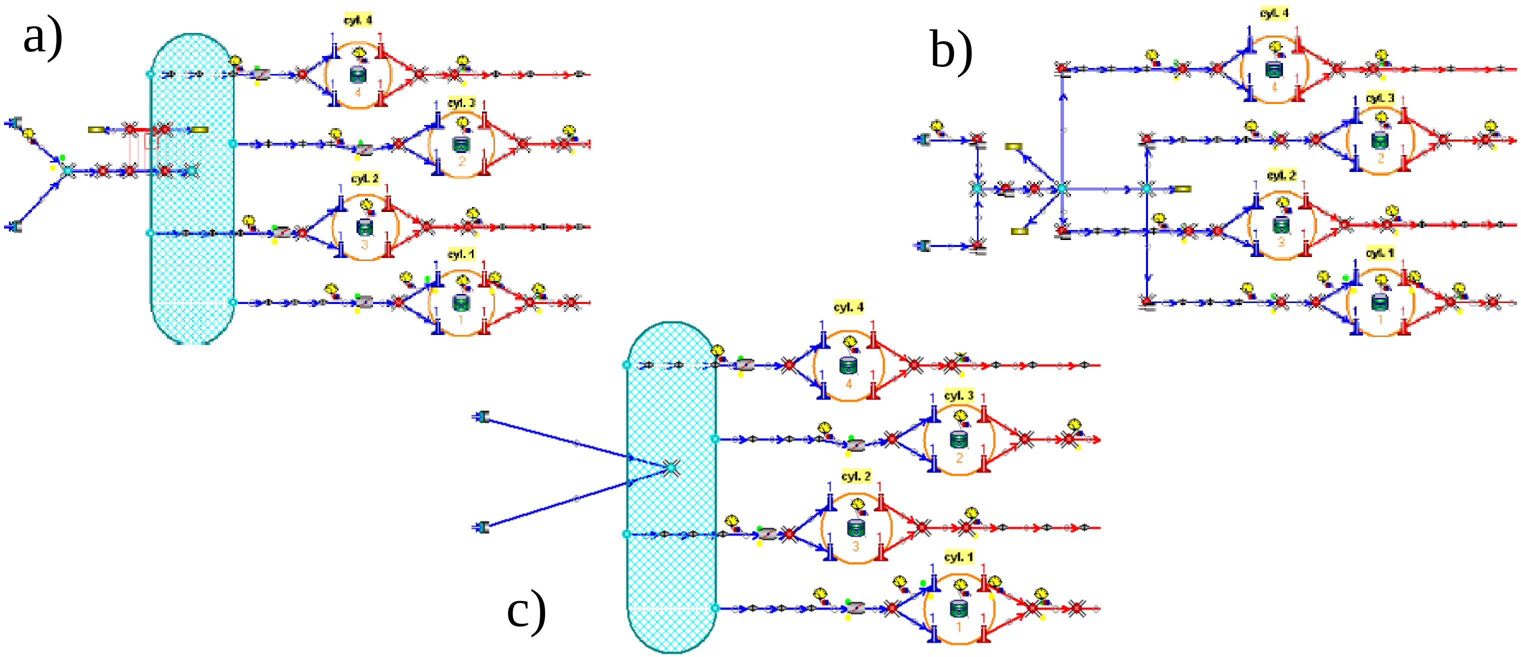
Intake system analysis

- Simulations results: duct pressure upstream cylinder 4

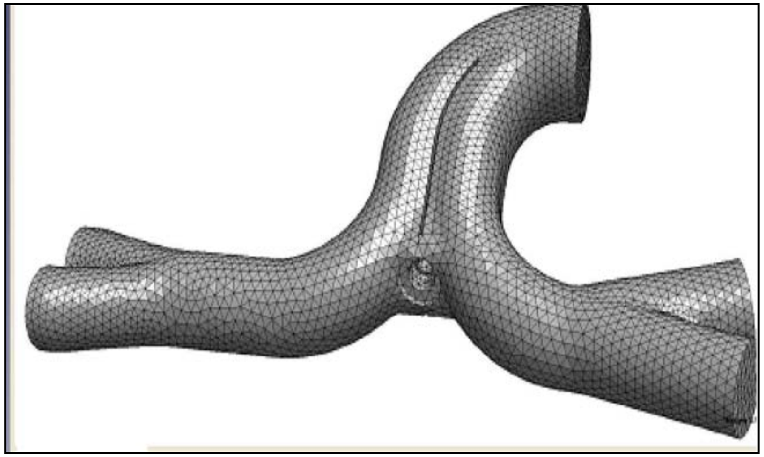


Intake system analysis

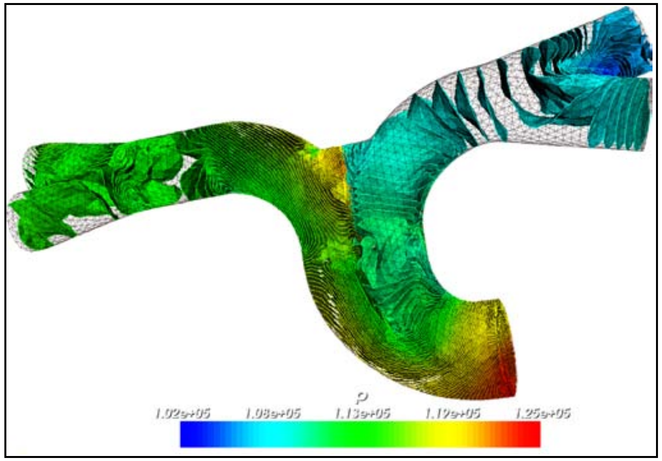
- 1D analysis
- Different modeling strategy
  - Prediction of fundamental resonances on principal axis:
    a) transverse resonances; b) longitudinal resonances; c) 0D volume with corrective lengths on intake ducts



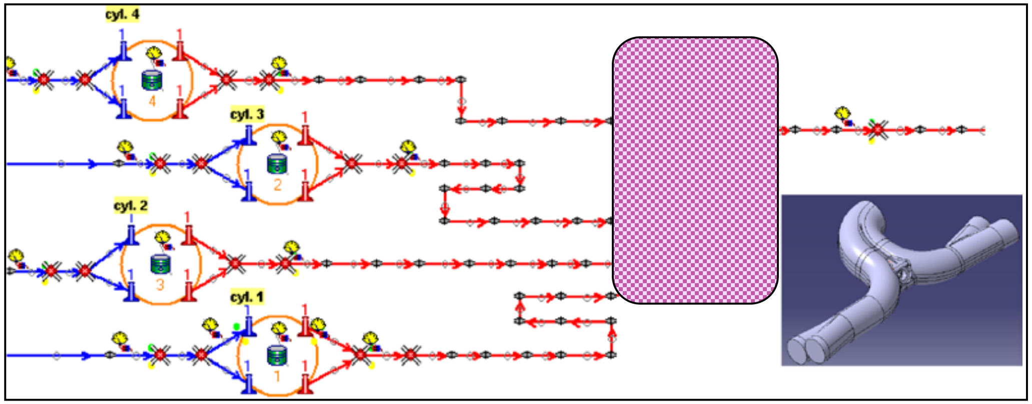
Exhaust system analysis



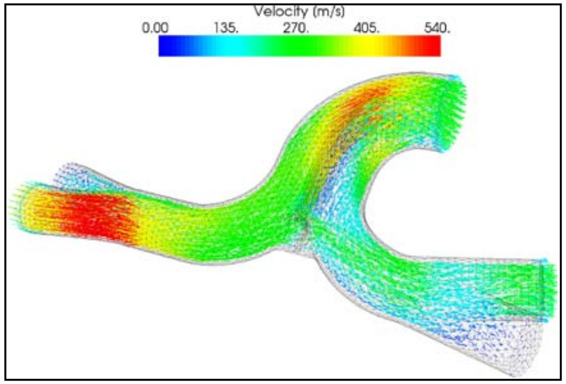
Exhaust junction mesh: full tetrahedral grid of about 36000 cells (mean side dimension: 5 mm)



Velocity and pressure fields at 12500 rpm

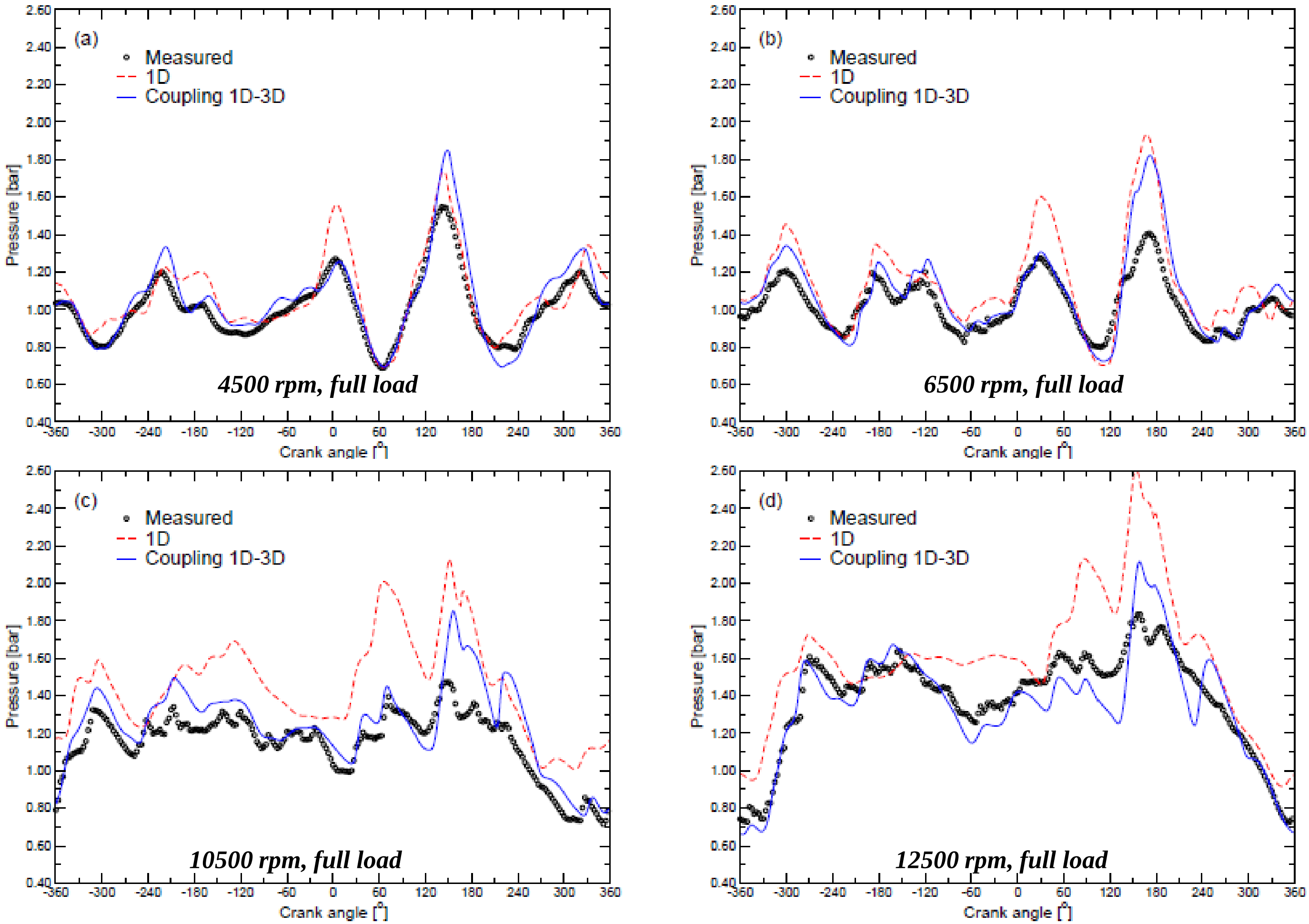


Exhaust 3D domain coupled with 1D model



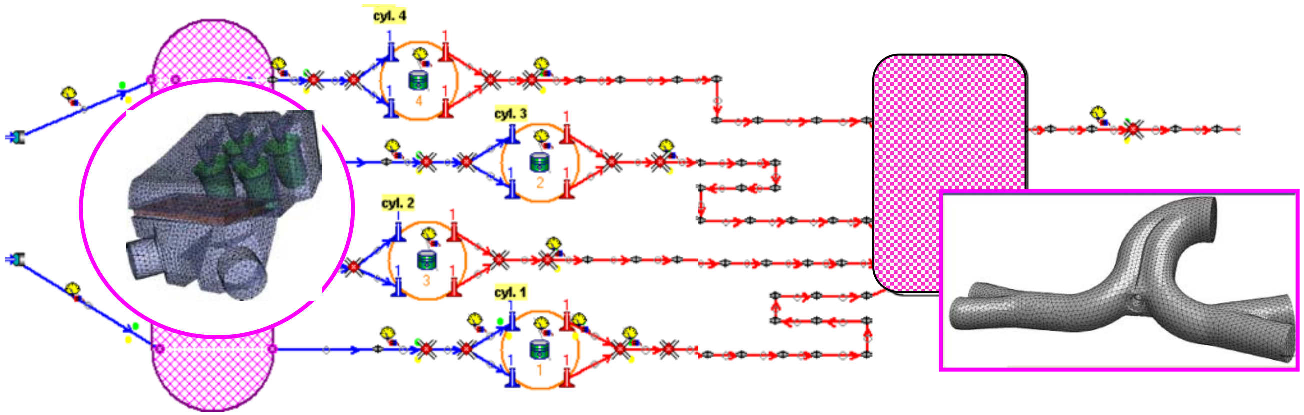
Exhaust system analysis

- Simulation results: duct pressure downstream cylinder 4



Prediction of volumetric efficiency

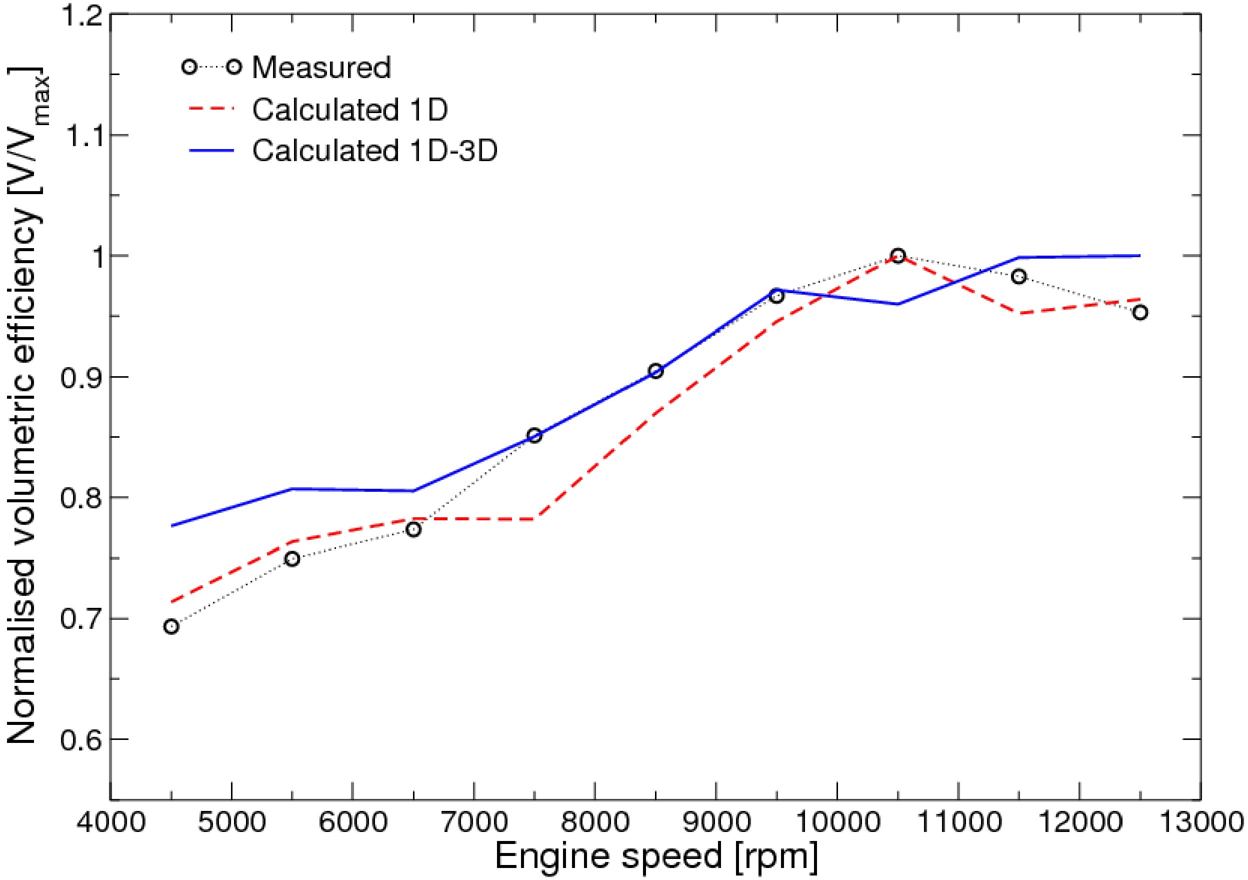
- 1D–3D simulation with both airbox and exhaust junction
- Coupling of multi-D domains
  - Engine revolution speed range:
    - (4500 ÷ 12500) rpm, step 1000 rpm
    - 5 ÷ 6 engine cycles for each engine revolution speed



- Calculation time: ~100 hours (~50 engine cycles) with AMD Athlon™ 64 X2 6000+ / 3 GHz CPU.

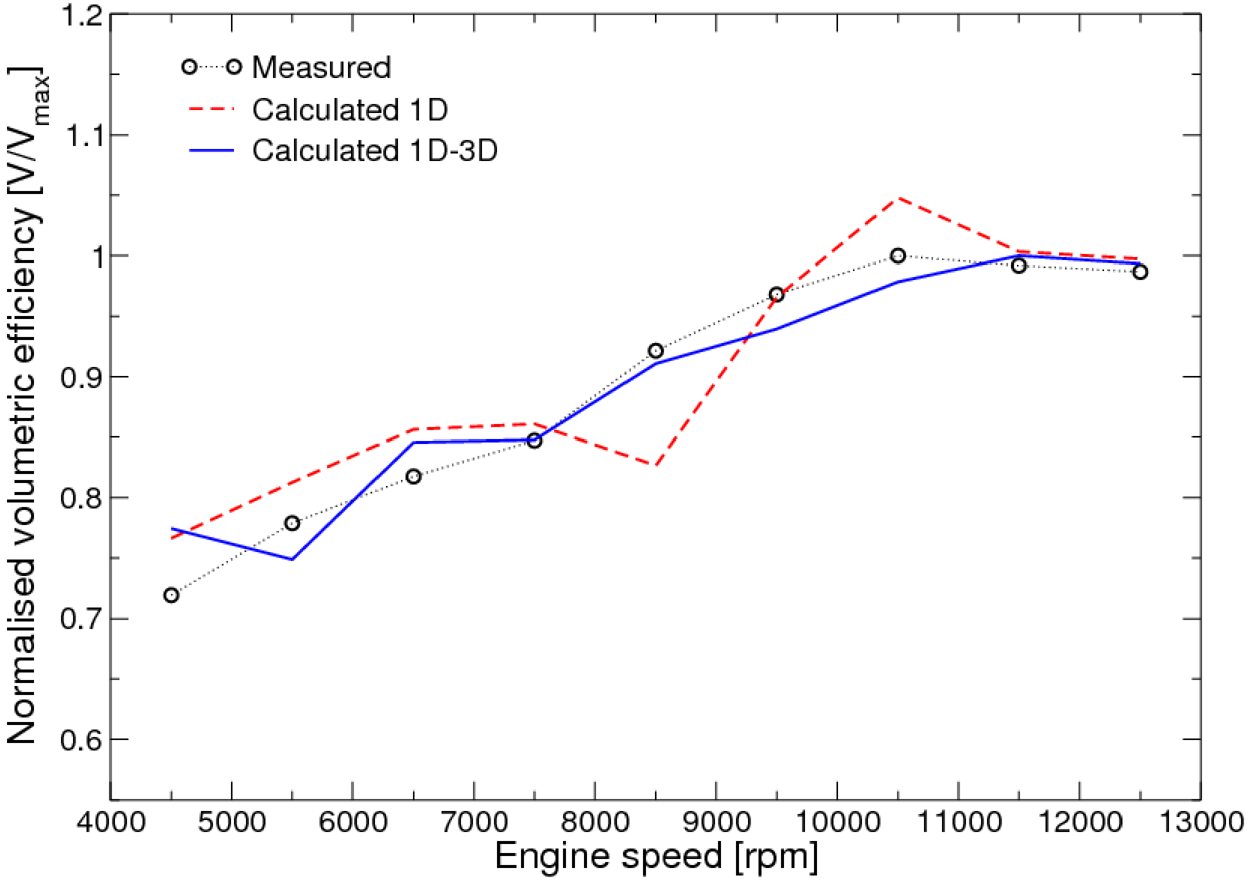
Distribution of cylinder volumetric efficiency

- Simulation results (full load): cylinder n.1



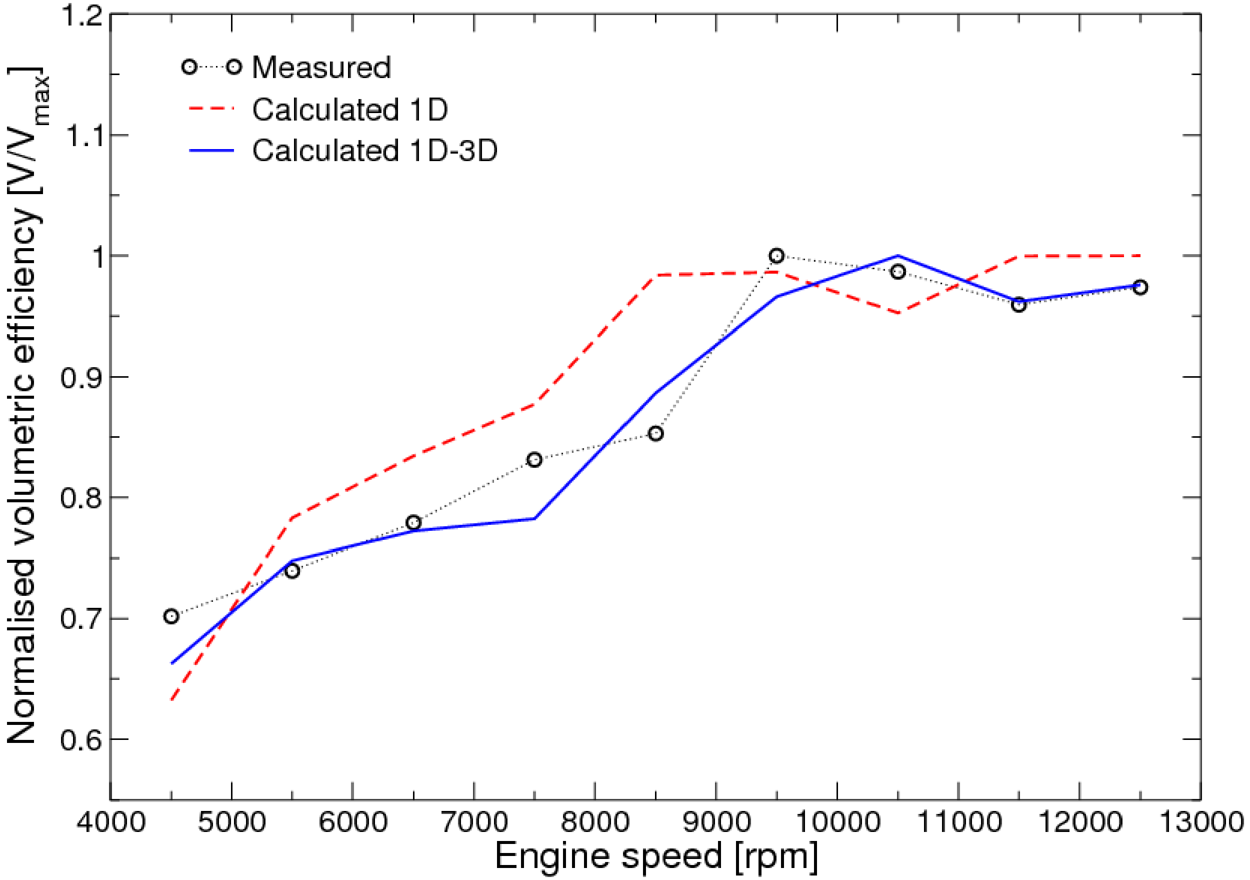
Distribution of cylinder volumetric efficiency

- Simulation results (full load): cylinder n.2



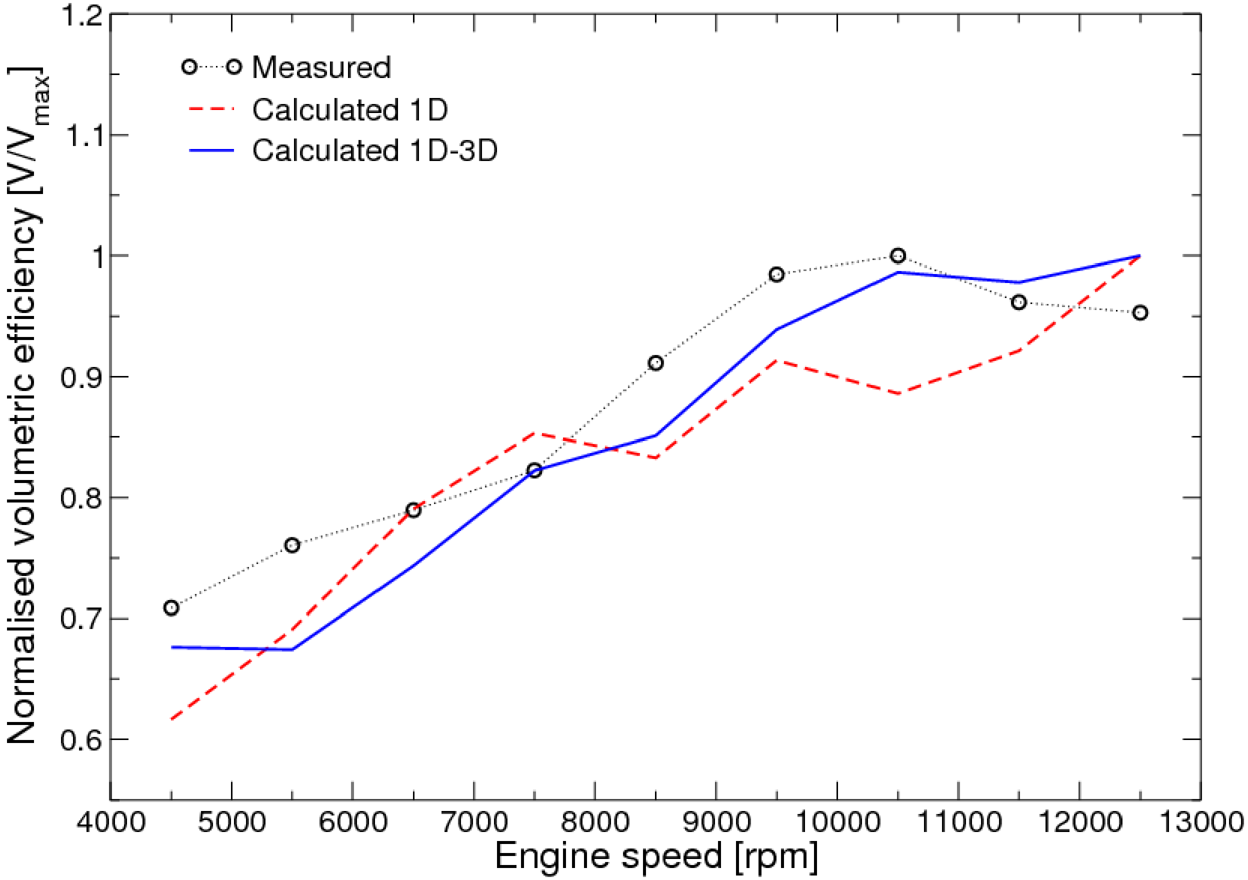
Distribution of cylinder volumetric efficiency

- Simulation results (full load): cylinder n.3



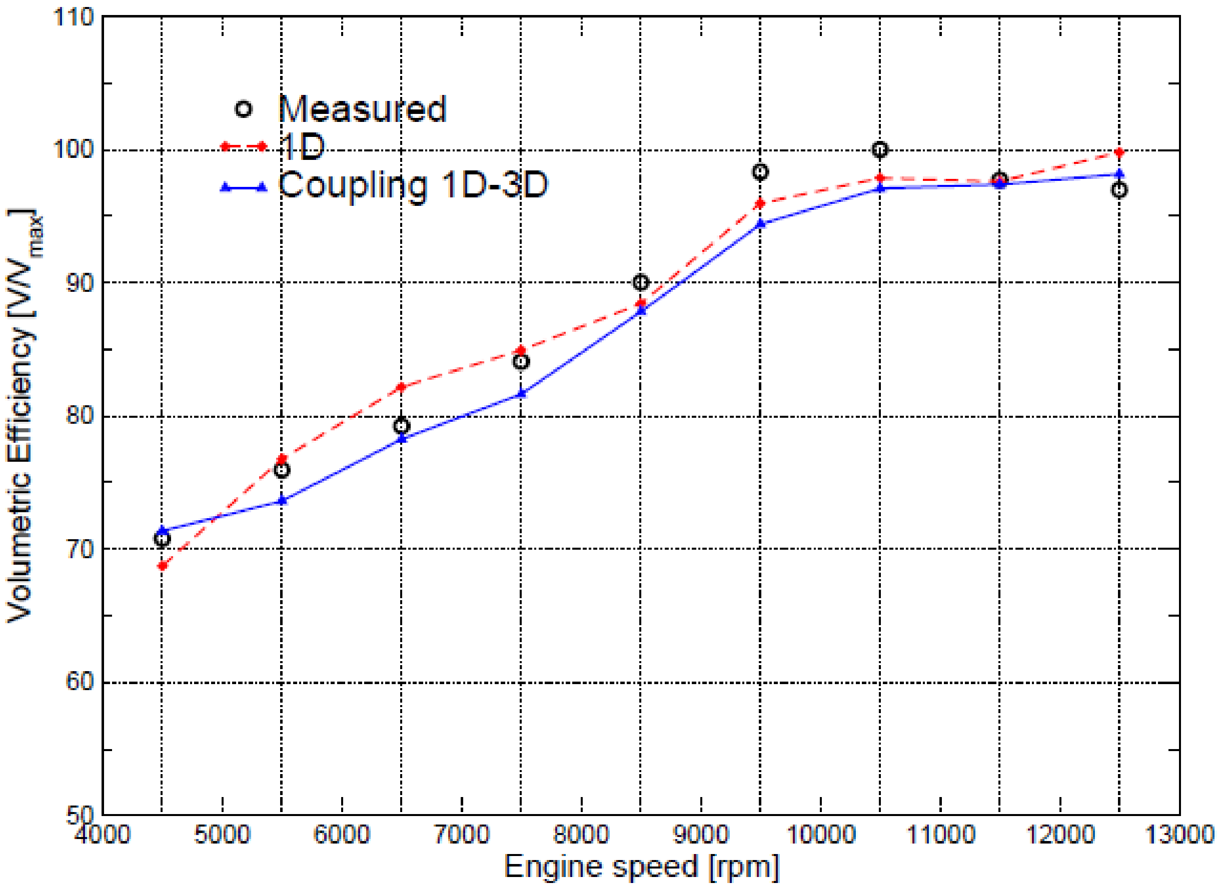
Distribution of cylinder volumetric efficiency

- Simulation results (full load): cylinder n.4



Prediction of volumetric efficiency

- Simulation results (full load): overall values



Conclusions

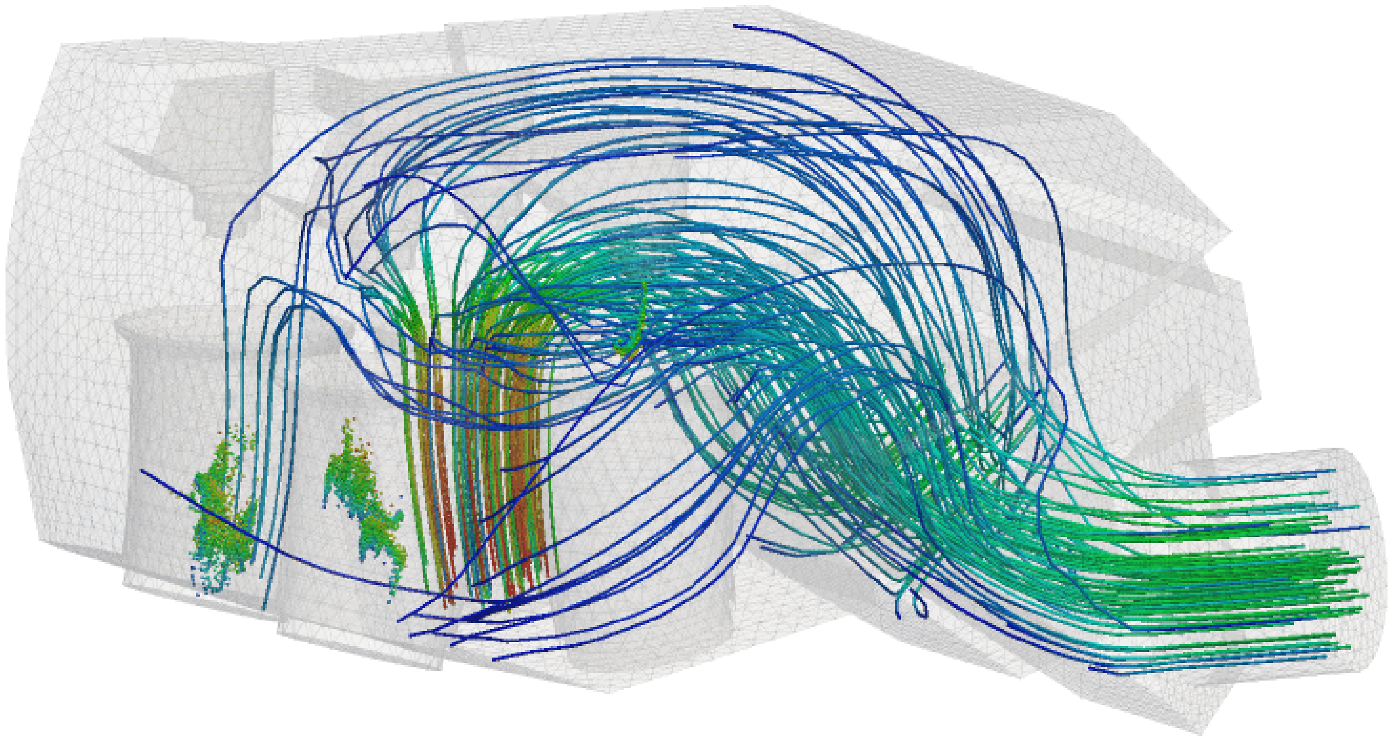
- Detailed fluidynamic analysis to better understand the phenomena in complex shape intake and exhaust systems of a high performance engine.

- Different approaches to reach this target: 1D analysis and 1D–multiD integrated analysis.

- Good results achieved with each approach in the prediction of fluid dynamic parameters of the engine
  - 1D: low CPU time and good prediction, but corrective lenghts are required
  - 1D-3D: high CPU time and very good prediction, independent from the geometrical complexity of the calculation domain.

Work in progress and future developments

- A new coupled solver to simulate spray evolution into the intake system, in order to predict the effect of the flow field on the mixture formation.



- A new solver is under development to take model the liquid film formation on the airbox walls

Thank you for your attention