UNIVERSITÀ DEGLI STUDI FIRENZE
DIEF
Dipartimento di Ingegneria Industriale
REASE
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Department of Industrial Engineering, University of Firenze, Firenze (Italy)

REASE group **R**eciprocating **E**ngines and **A**dvanced **S**ystems for **E**nergy

Modena, 25 maggio 2016 – Giornata Studio sui MCI

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Outline

- 2S LPDI Engine
  - Motivation & research aim
  - Approach & main results
- Turbo Speed Sensor for engine diagnostic
  - Experimental & numerical approach
  - Main results & next steps
- Acoustic analysis of Inlet & Exhaust Systems
  - Description of numerical and experimental approach

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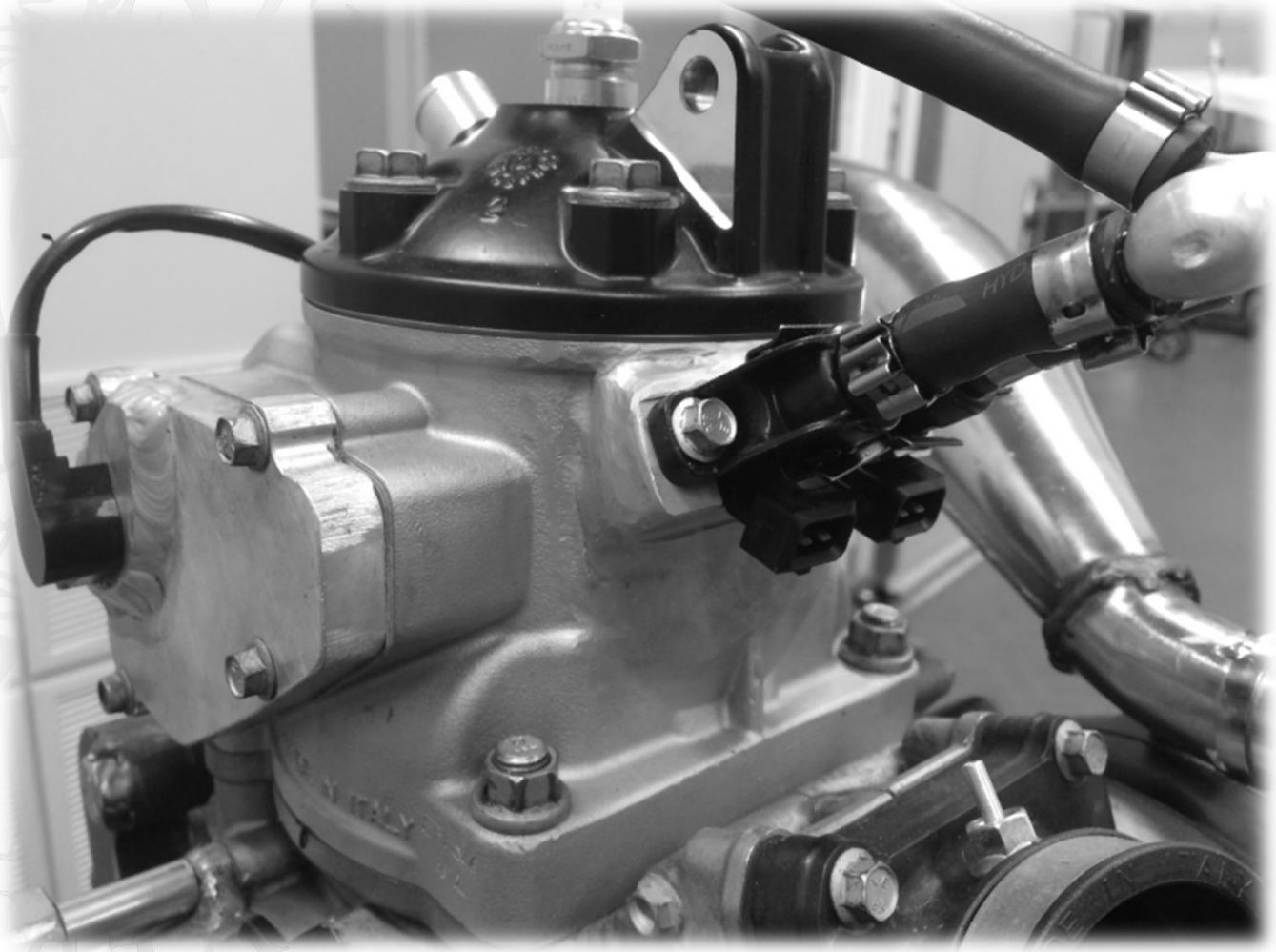
Development of new generation 2S engine



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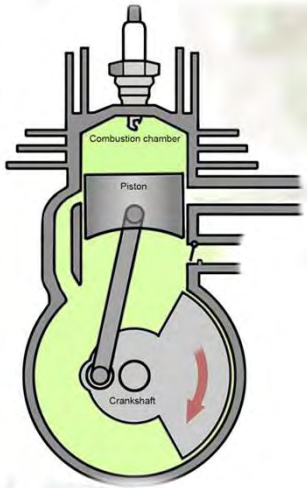
The 2S engine

- Advantages
  - Simplicity
  - Reliability
  - High power density
  - Lightweight / Compactness
  - Low mechanical friction



- Drawbacks
  - High fuel consumption
  - Oil consumption
  - High raw emissions

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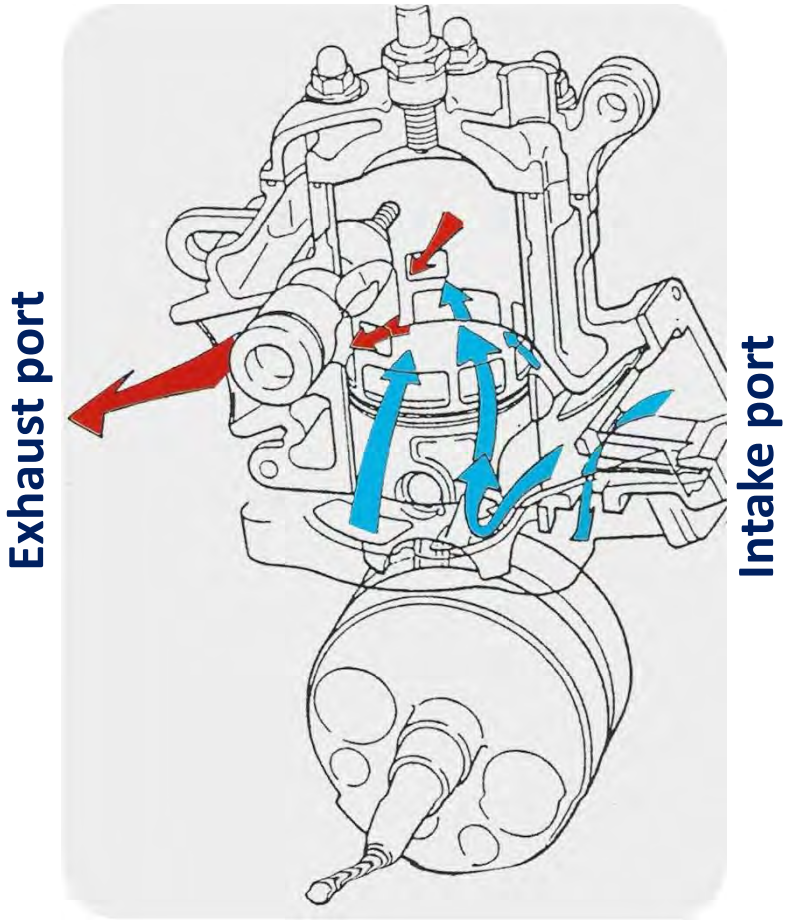
How to face the problem …

- Short circuit issues
  - Premixed air and fuel
  - Intake and exhaust ports contemporary opened
  - Unburned fuel at exhaust port
  - High fuel consumption
  - High raw HC emission
- … the solution
  - High Pressure Direct Injection (HPDI)
  - Low Pressure Direct Injection (LPDI)



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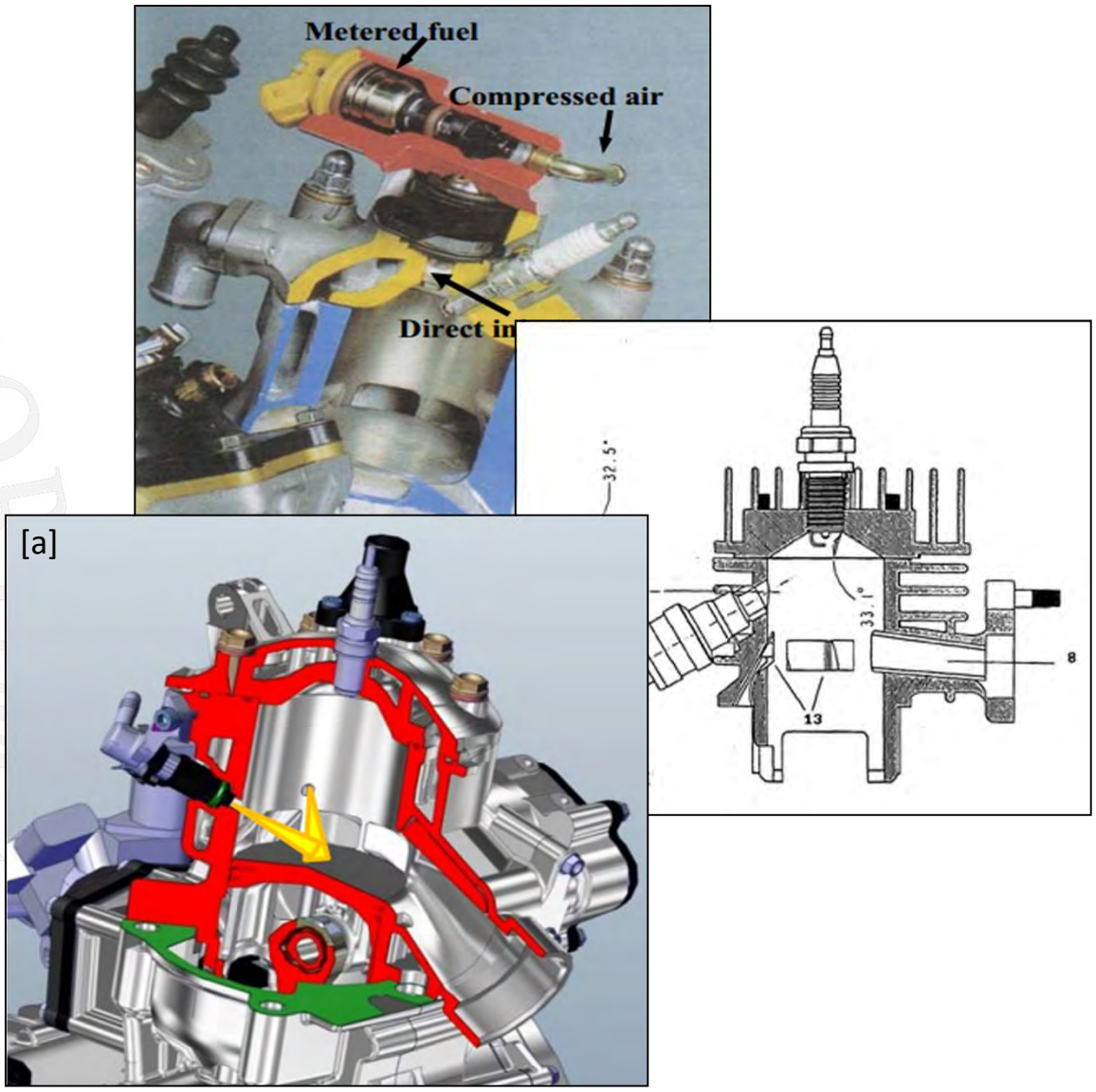
On the market …

- In the past
  - Systems by Orbital, Athena, Graz University …



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On the market …

- In the future
  - Strong interest is back not only for 2-wheeler application …
  - Excellent candidate as a range extender for EV
- But it has to be compliant with the emission regulations!

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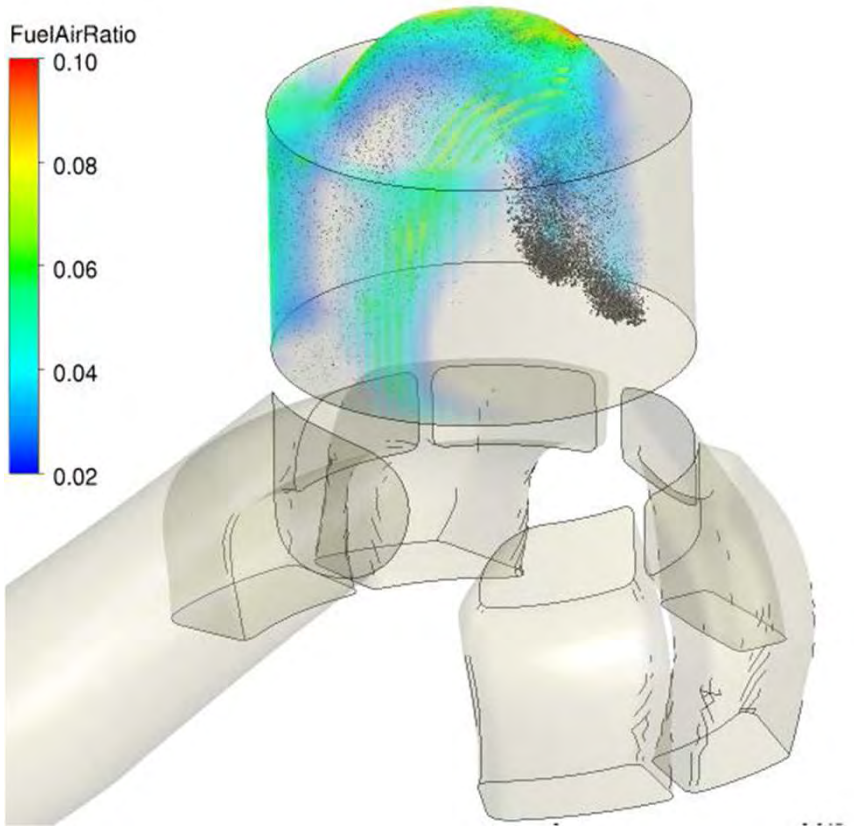
LPDI 2S engine

Low Pressure Direct Injection

- Strong **reduction of fuel short-circuit**
  - Interaction between injected fuel and scavenged air
- **Same costs** of PFI or carbureted engine
  - Low pressure fuel pump
  - Low pressure injectors
- **No increase in mass** or layout issues even for small 2 stroke engine
  - Lightweight

Fuel Short circuit reduction

- Fuel consumption reduction
- HC emission reduction



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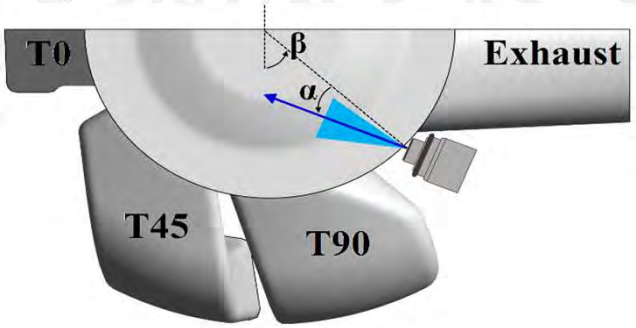
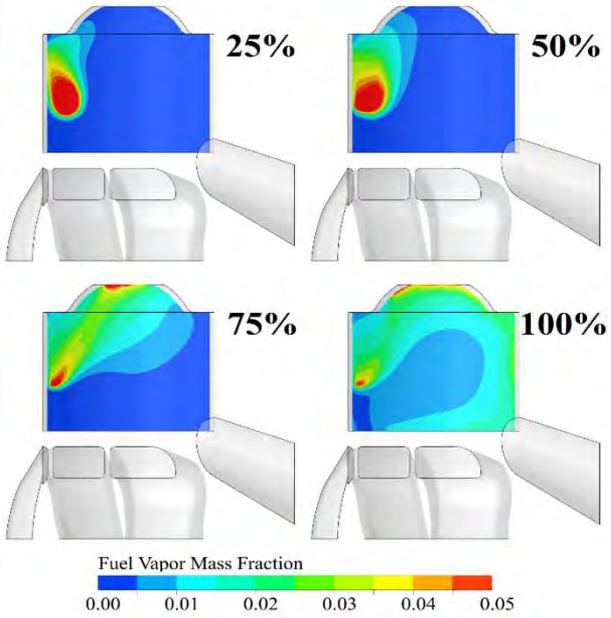
CFD Analysis

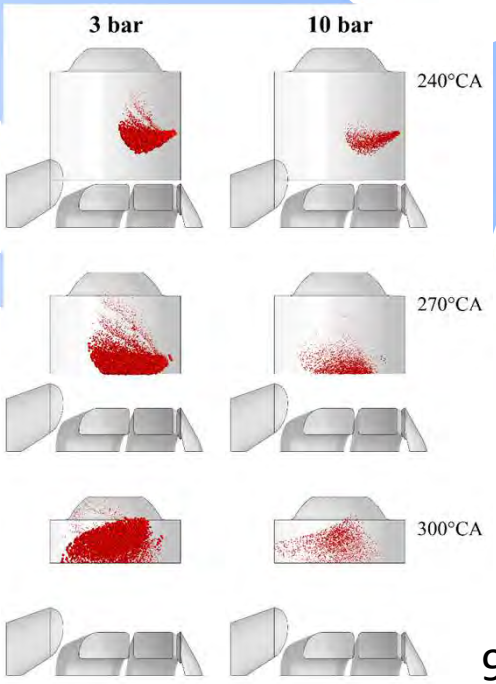
Injector location and orientation angle



Performance verification for the whole operating range



Injection Pressure analysis



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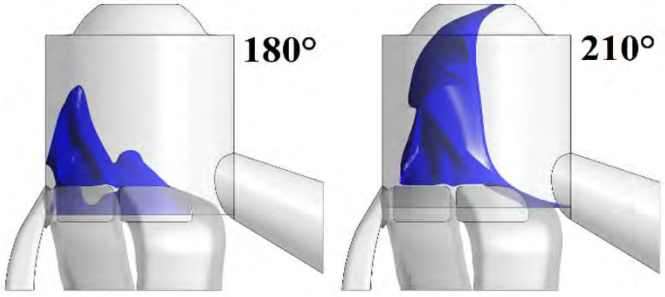
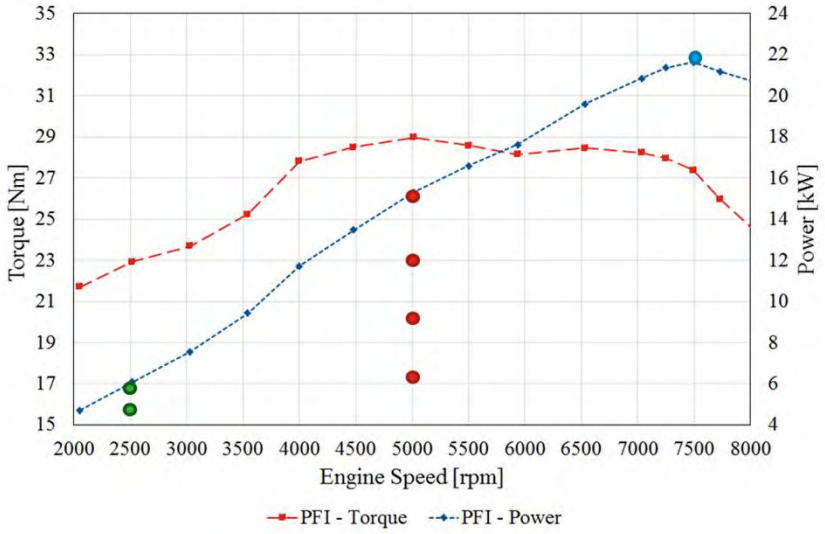
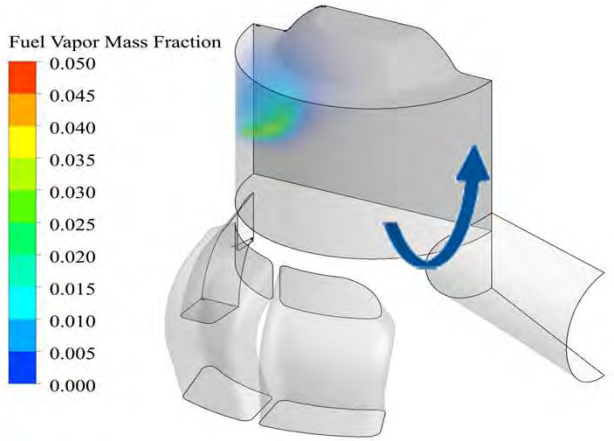
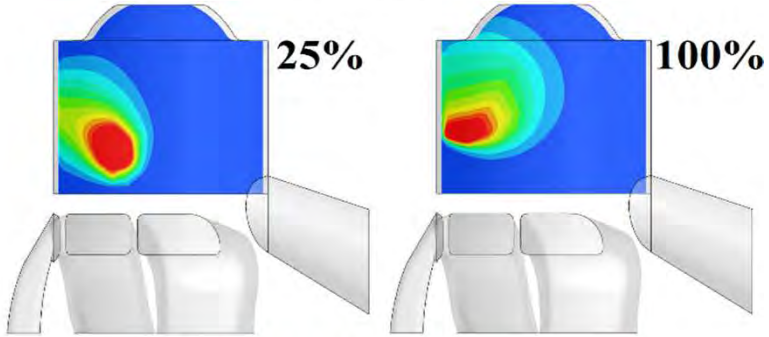
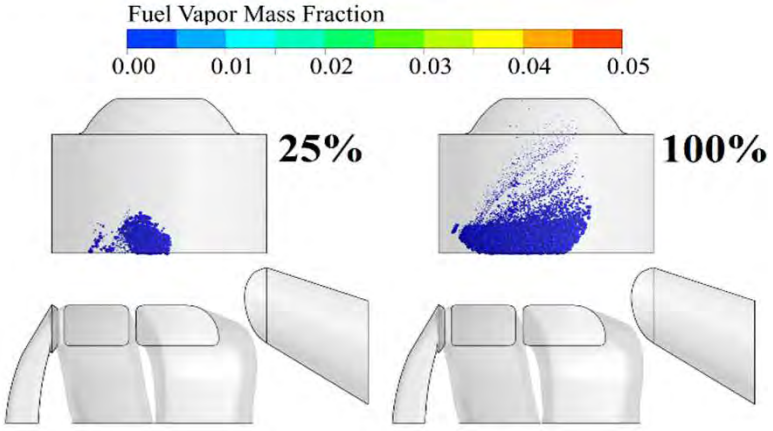
CFD Analysis











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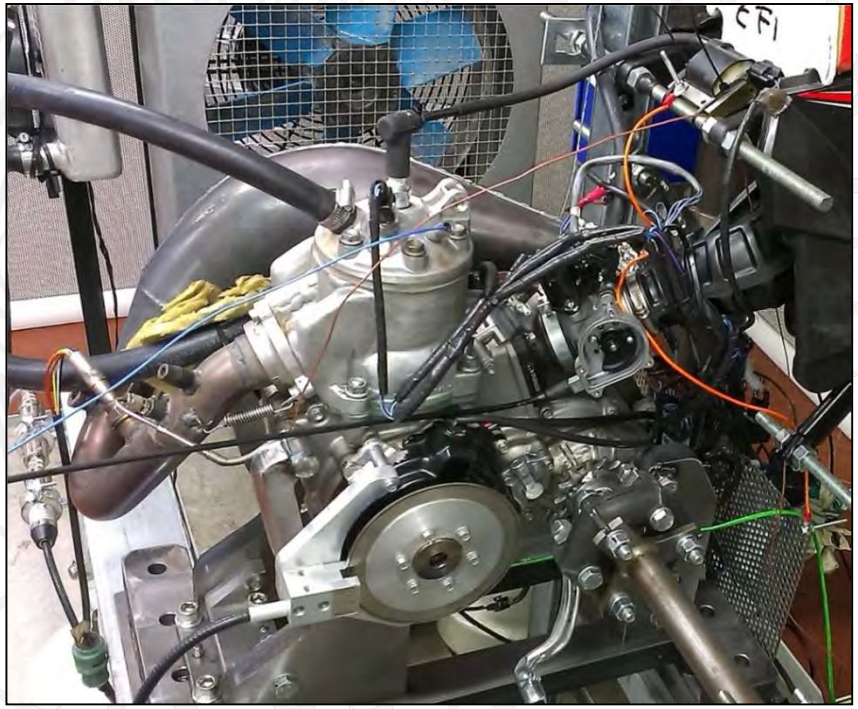
PFI engine

New electronic hardware for injection management

- Open ECU

New Throttle body + injector

- Pre mixed Fuel - Oil injected
- Throttle position sensor



Type	Single Cylinder, 2-Stroke, Spark-Ignition, Liquid Cooled
Displaced volume	293.1 cc
Stroke	72 mm
Bore	72 mm
Connecting Rod	125 mm
Geometric Compression Ratio	12:1
Trapped compression Ratio	8.2:1
Exhaust Valve	No
Engine Oil	SAE 10W/40
Starter	Electric Starter
Spark Plug	NGK BR7ES
Induction System	Induction Reed
Original Fuel System	Carburetor (Keihin PXK 36)
PFI Fuel system	Sinerject throttle body 42mm

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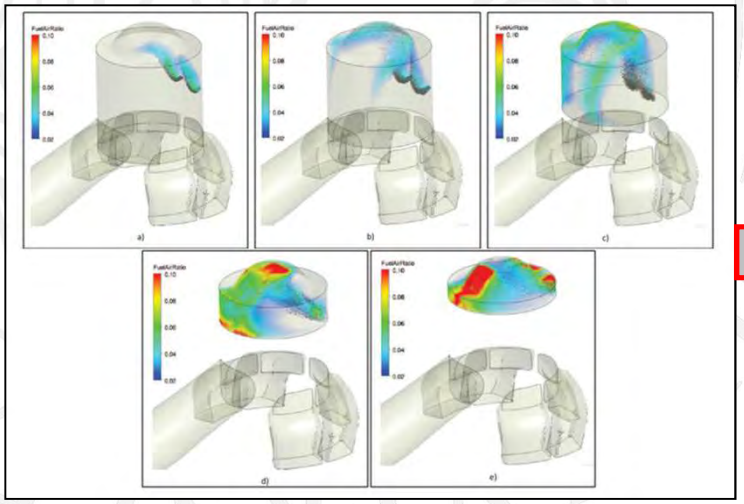
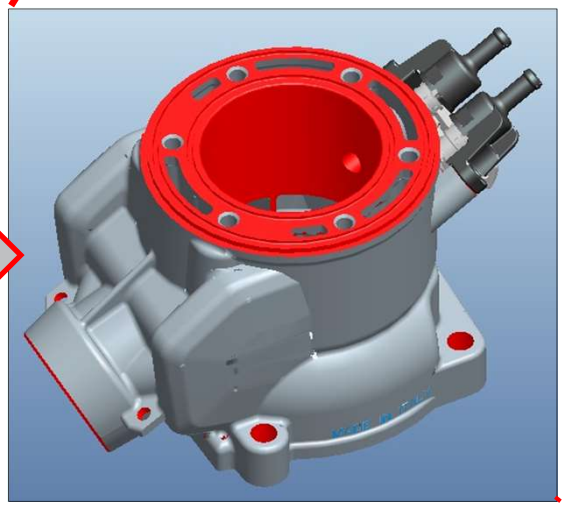
LPDI engine

- CFD Analysis
- CAD Modelling
- New cylinder
  - 2 Parallel injectors on the cylinder liner
    - Low pressure gasoline injectors (5 bar)
  - Injection direction toward discharge port
- New **lubricant system**
  - Miniaturized **reciprocating oil pump**
  - Oil injected into the intake manifold





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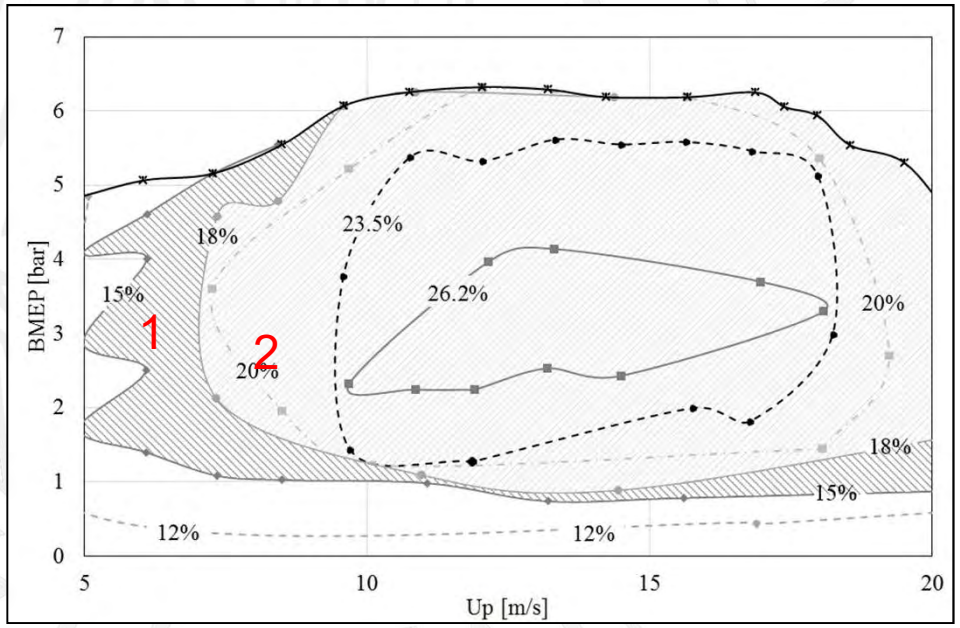
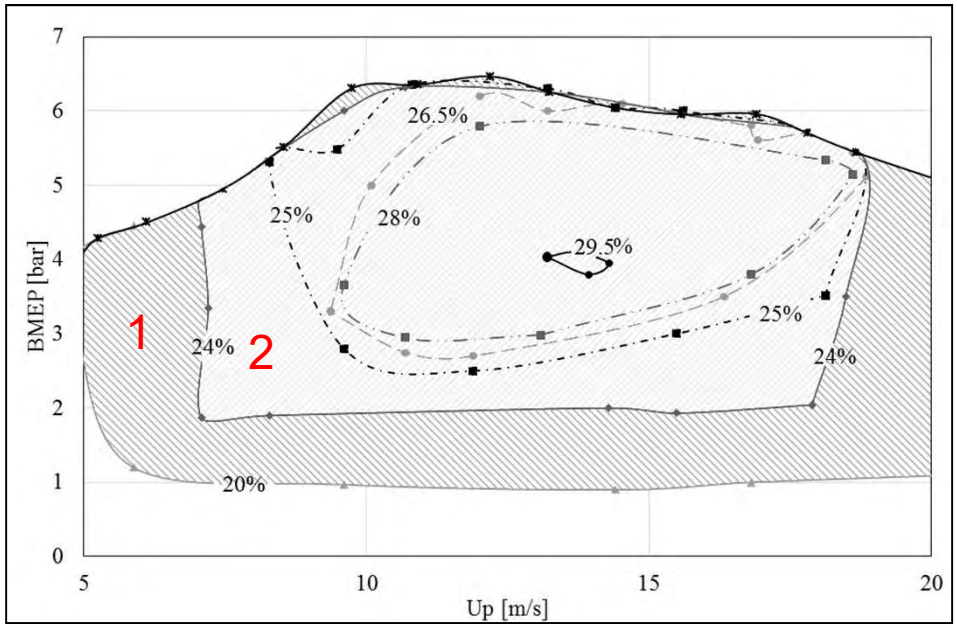
Engine efficiency Comparison - PFI vs LPDI

- Max efficiency: PFI 26.2%; LPDI 29.5%
- Area (1) efficiency: PFI 15-18%; LPDI 20-23.5%
- Area (2) efficiency: PFI 18-23%; LPDI 24-25%

PFI



LPDI



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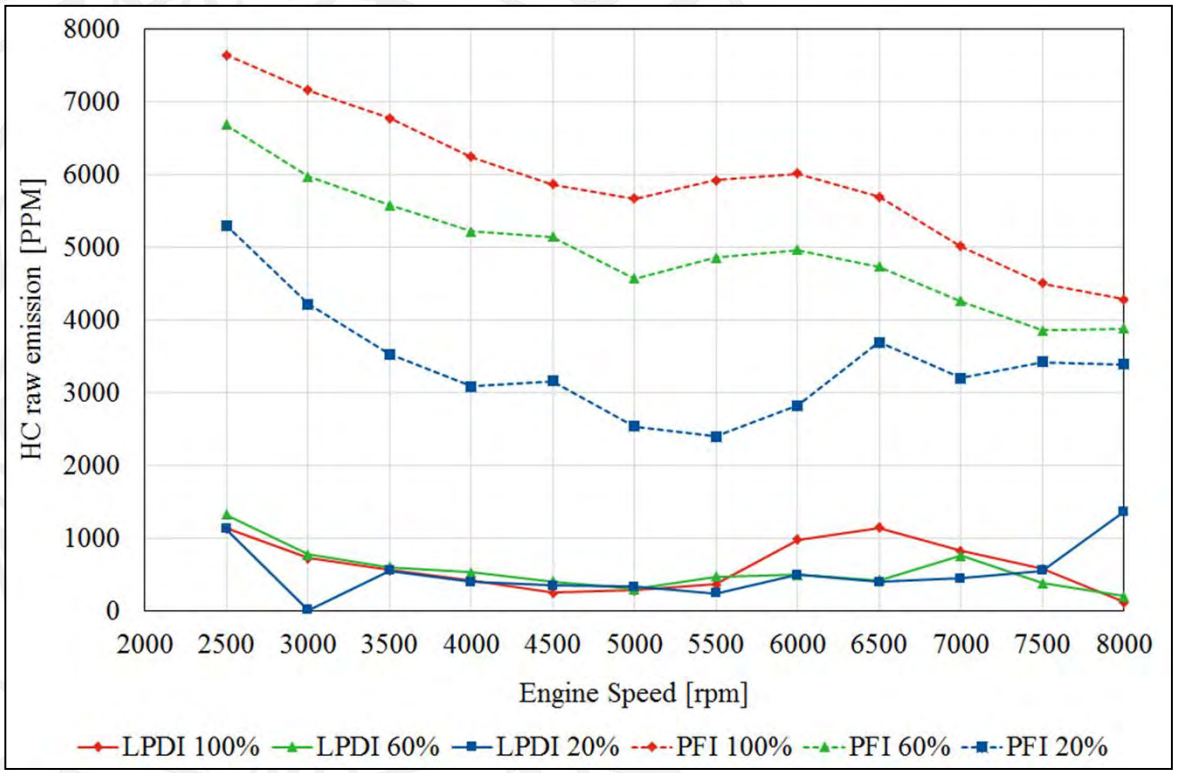
Exhaust gas emission

PFI vs LPDI

- HC raw emission



- LPDI HC raw emission considerably **reduced** respect to PFI
- PFI HC raw emission proportional to load
  - Fuel short circuit grows with load
- LPDI HC emission under 1000 PPM
  - Comparable to 4S SI engine
- LPDI HC emission are almost flat from 3000 to 7500 rpm

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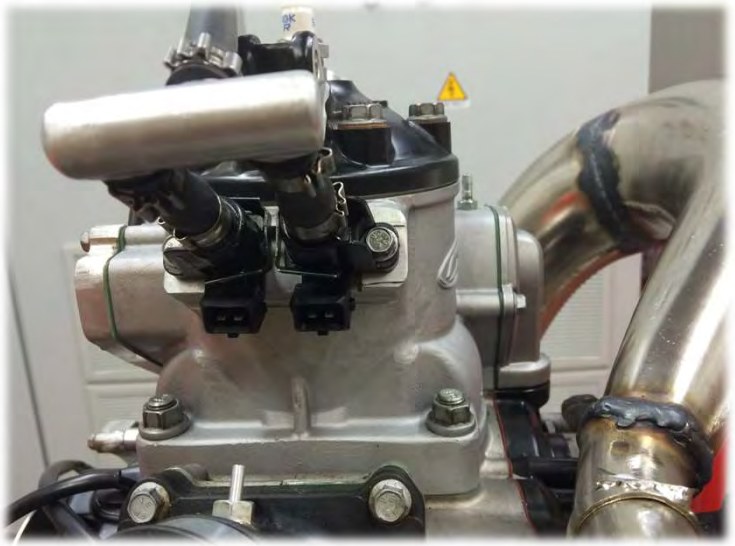
Next steps

Test and tuning on the full power engine in LPDI configuration

- Port dimension and Timing
- Exhaust System
- Flap valve on the exhaust

Test and tuning on the full power engine in HPDI configuration



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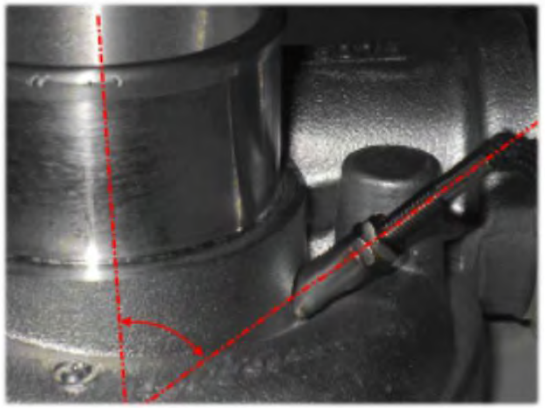
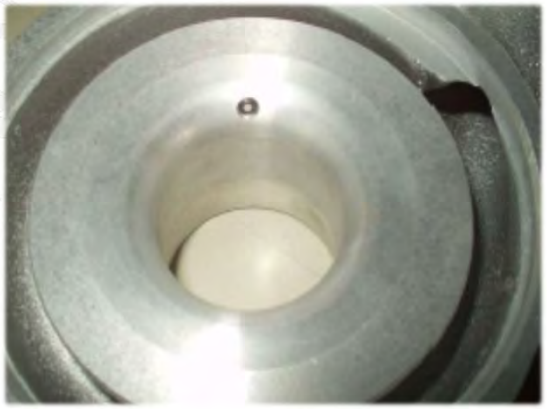
Turbo Speed Sensor for engine diagnostic





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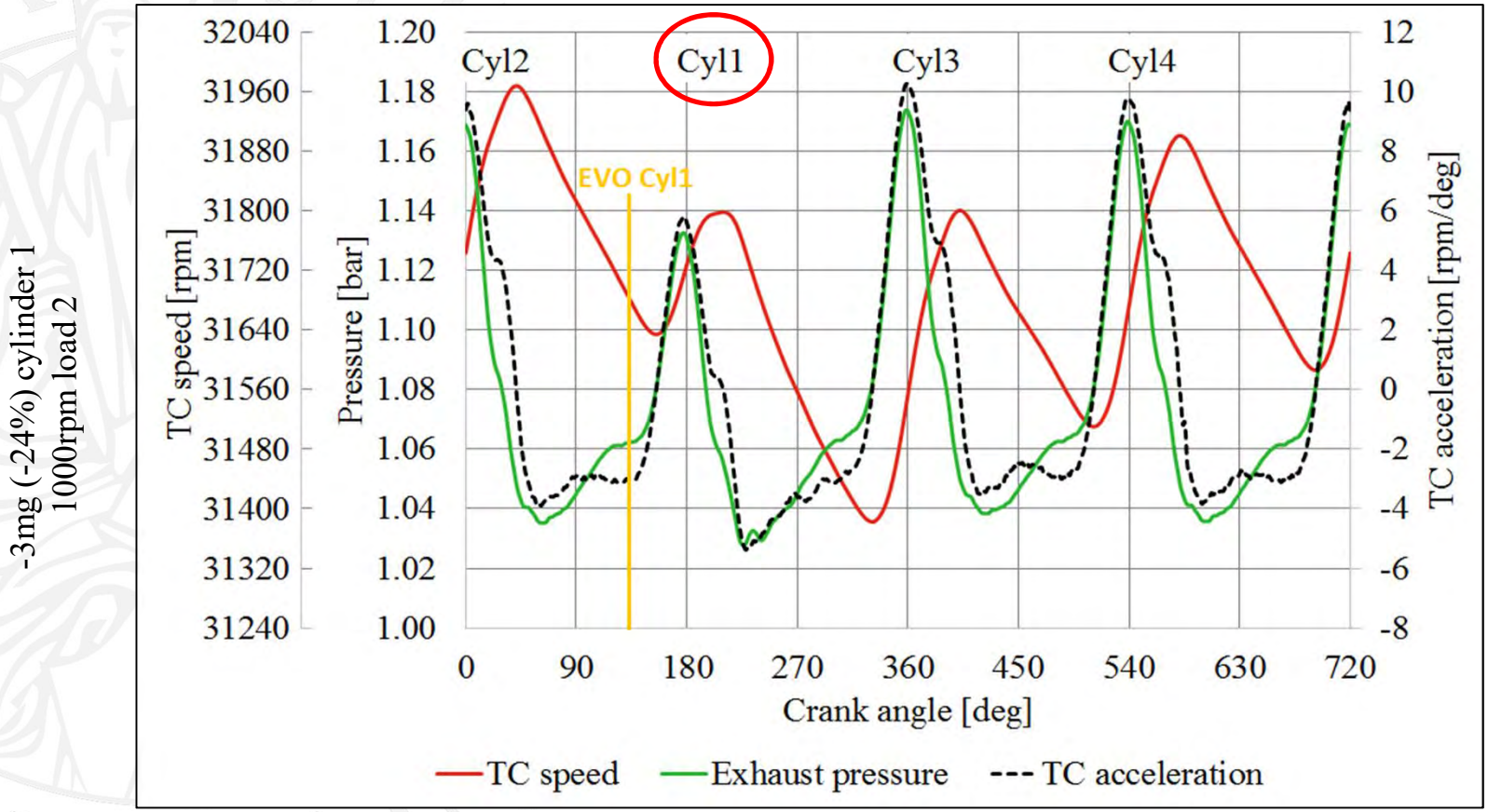
Physical concept



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"History" of the approach

Experimental campaign on the real engine @ Yanmar/Bosch facilities in Japan

1D Numerical Model and its calibration

Sensitivity analysis of TC speed for several engine parameters variation

Deep analysis on Cyl-to-Cyl injection variation

Next step
Experimental validation @ Unifi

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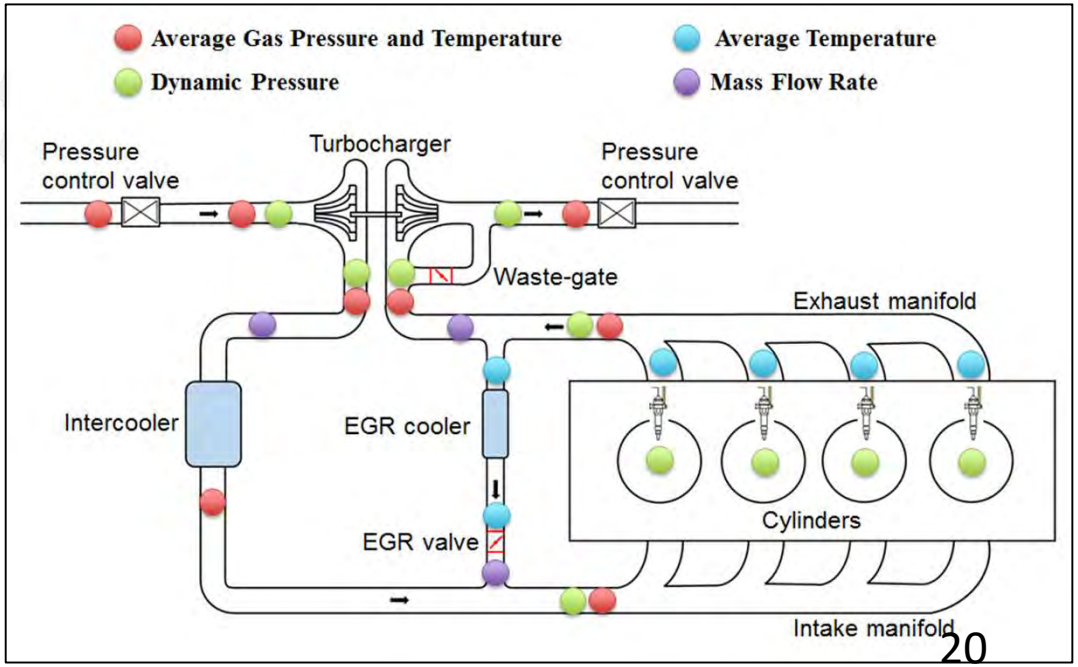
Experimental setup

- Acquired parameters
  - Torque / Power and FMEP
  - Average TC speed
    - » Hall-effect commercial sensor
  - Air mass flow
  - Injection timing and Injected fuel quantity
  - EGR rate
  - In-cylinder pressure (in all the cyls)
  - Intake and exhaust dynamic pressure
  - Air and exhaust gas temperature
  - Intake and exhaust wall temperature
  - ECU data

N° cylinders	4
Strokes per cycle	4
Engine type	Turbocharged CI
Bore [mm]	86
Stroke [mm]	90
Displacement [l]	2.1
Compression ratio	19.2



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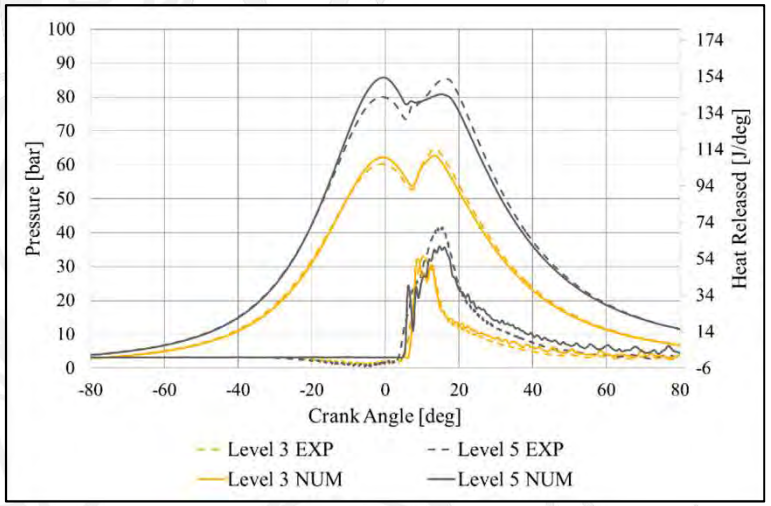
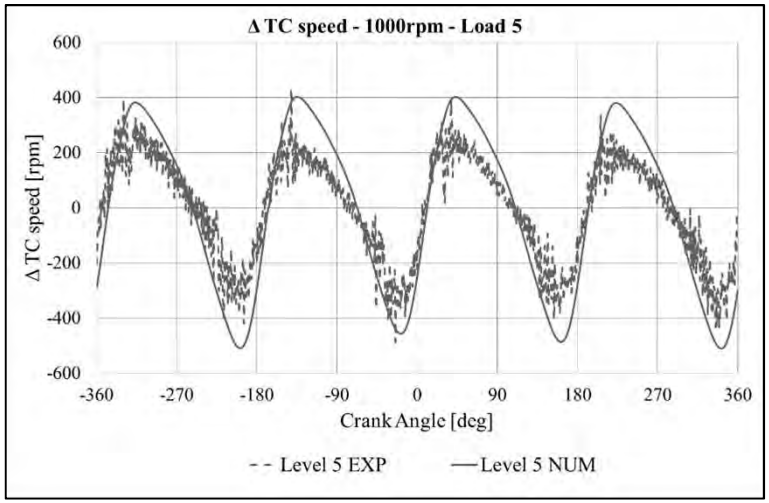
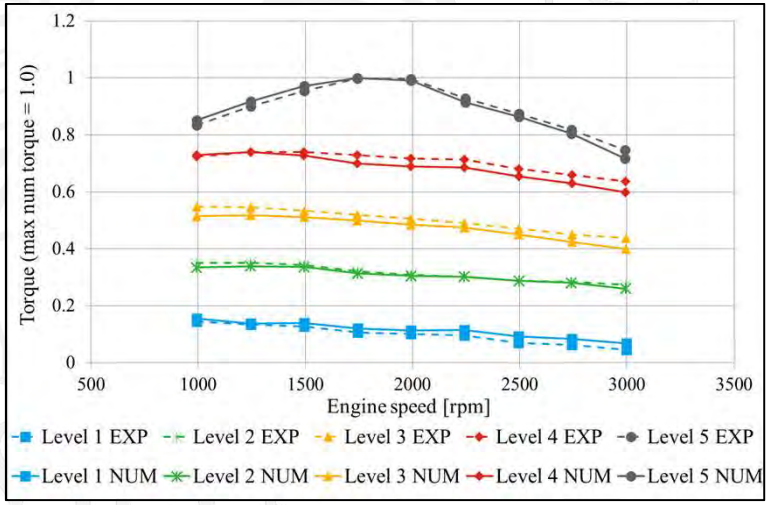
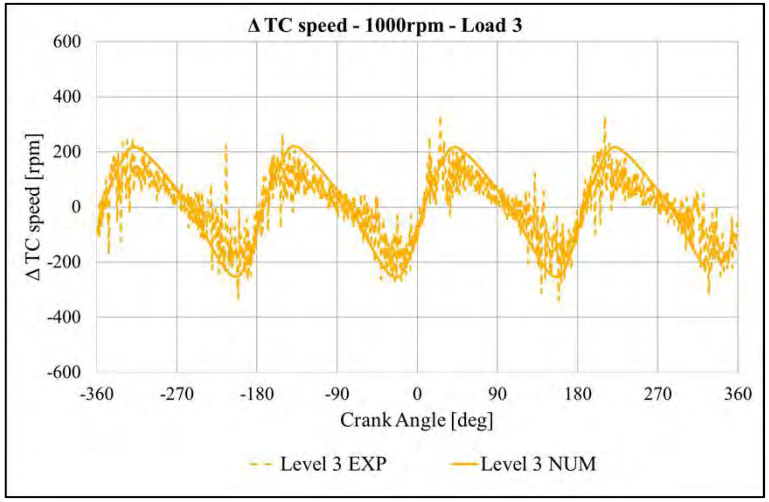
Numerical model calibration









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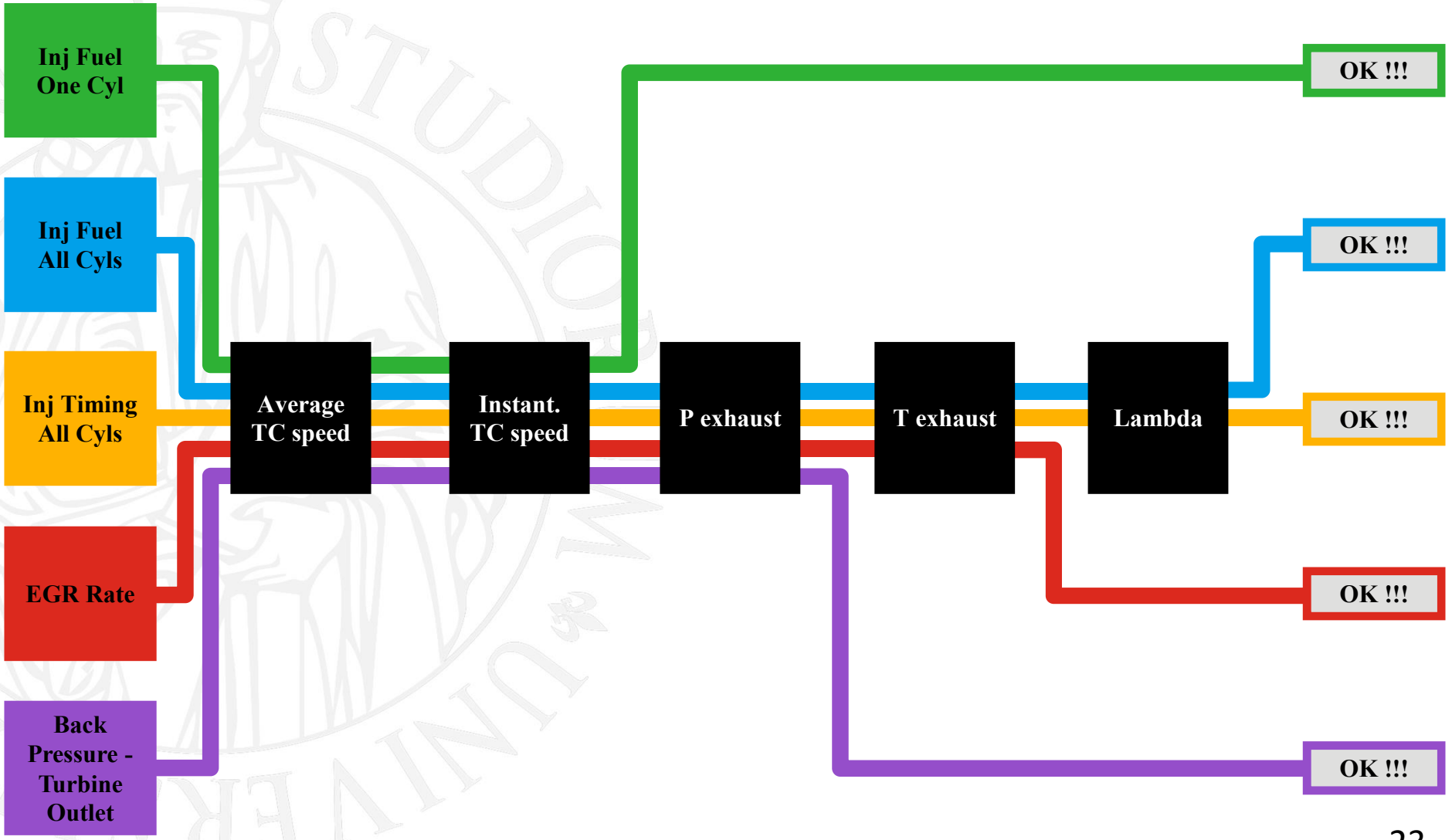
Parameter correlation



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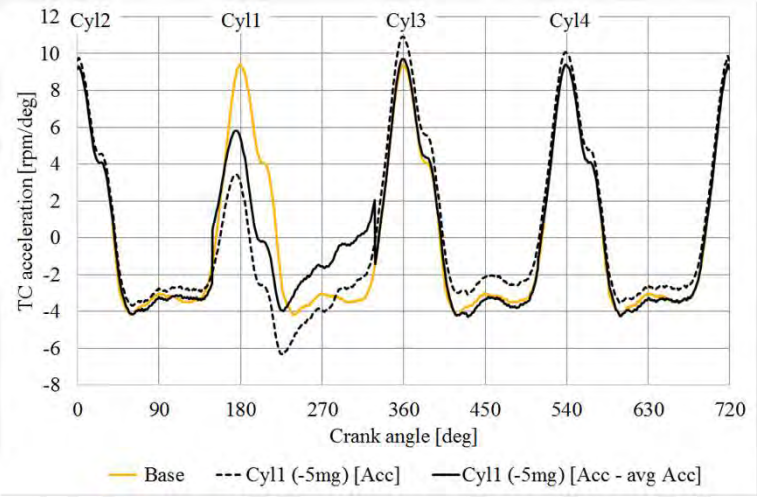
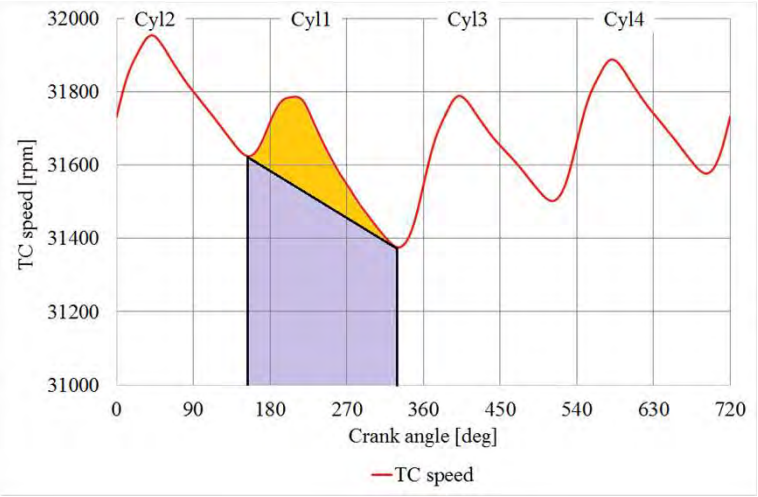
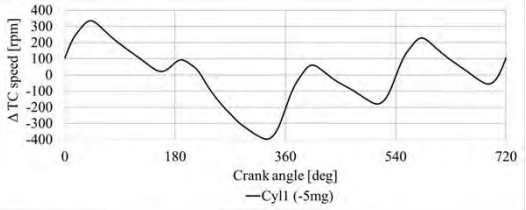
Analysed approaches

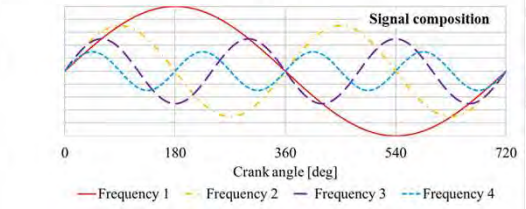
Derivative of the TC speed



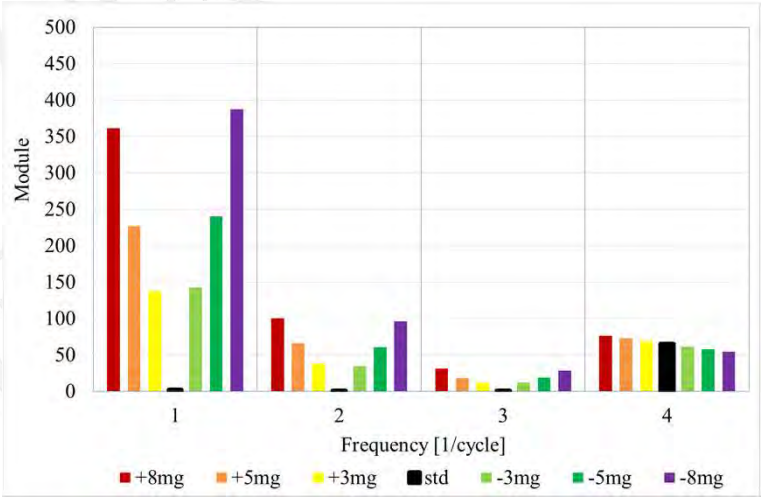
Integration of the TC speed







FFT of the TC speed



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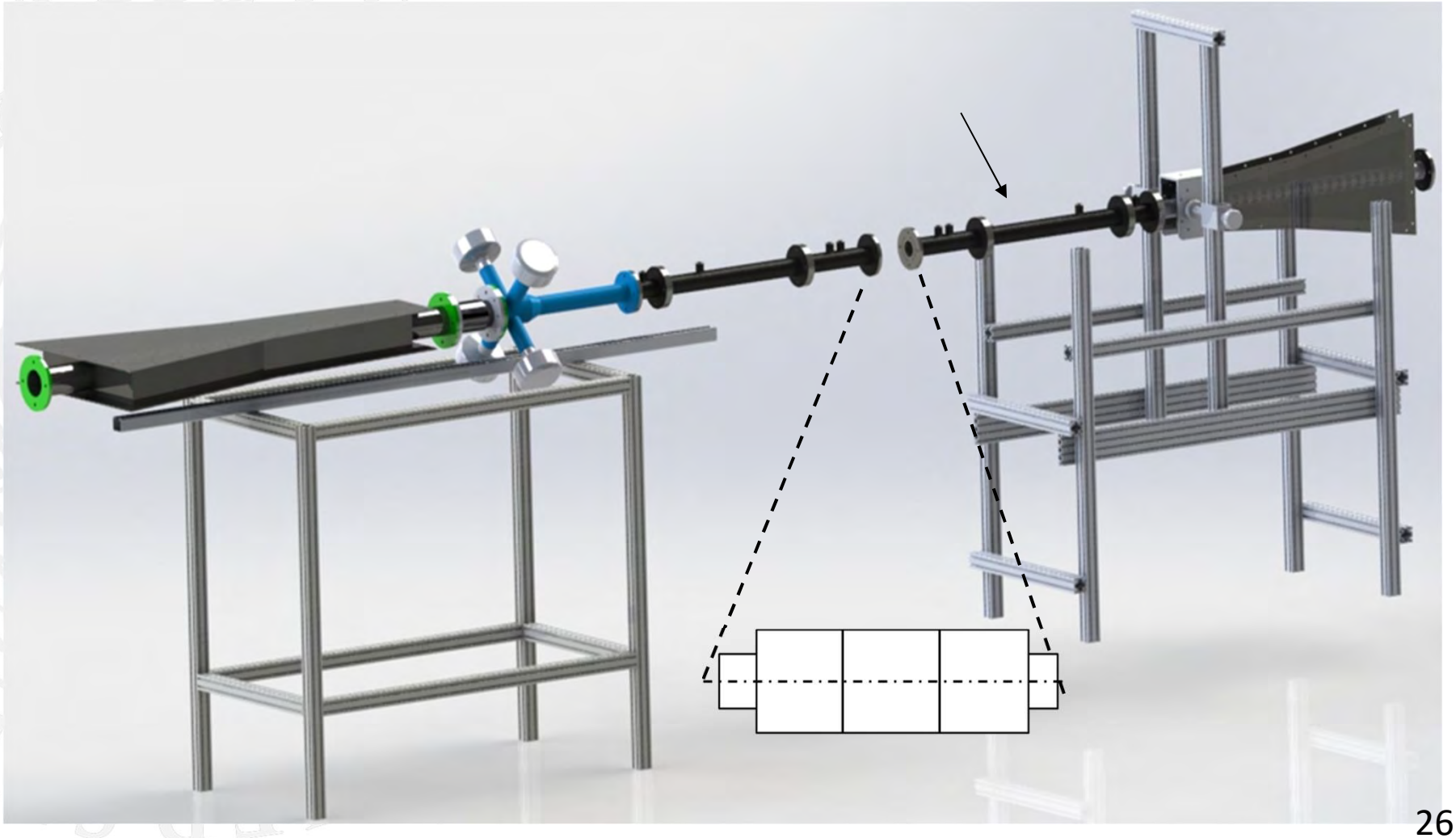
Acoustic analysis of Inlet & Exhaust Systems



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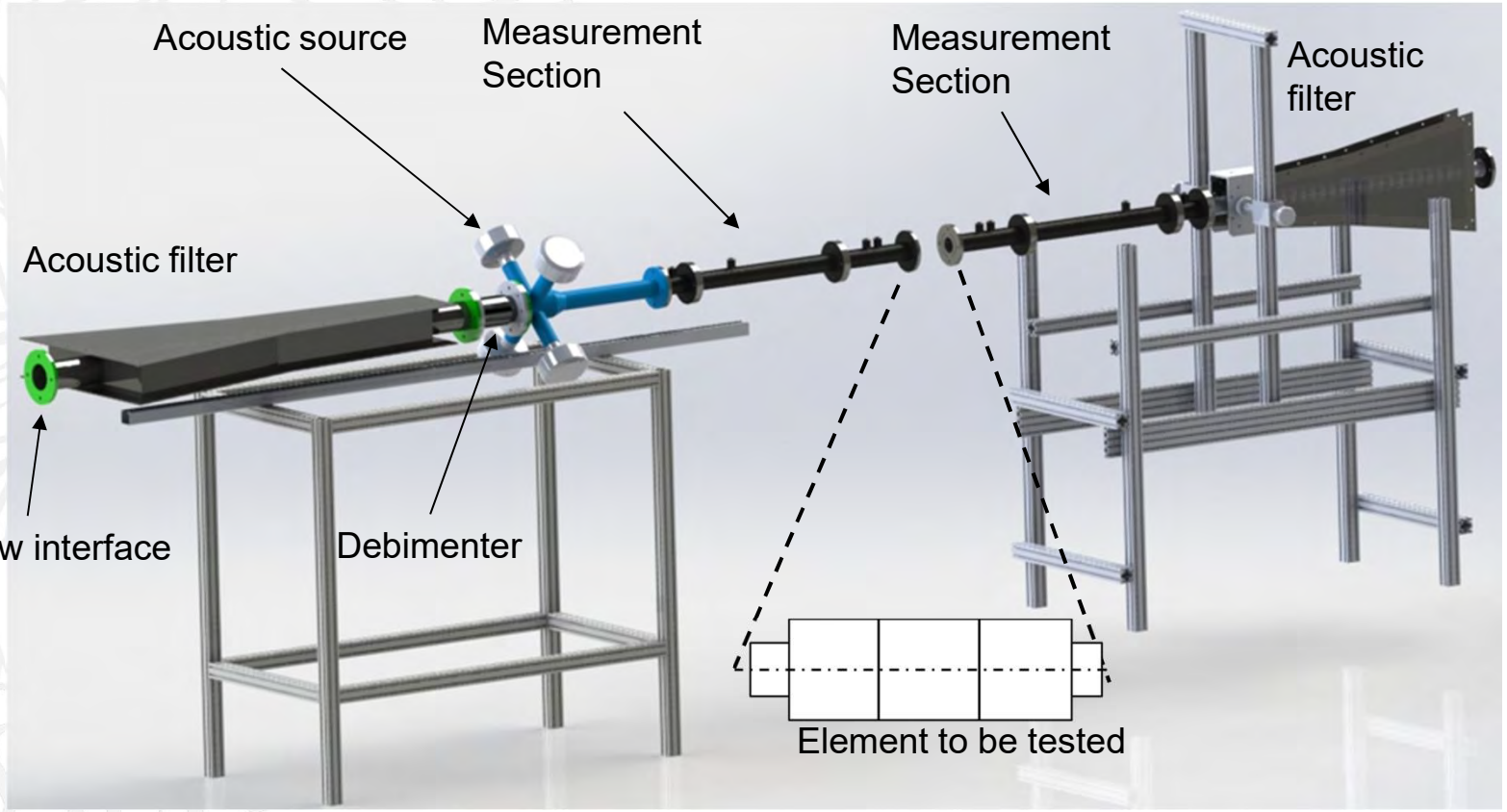
Acoustic analysis of Inlet & Exhaust Systems

Main technical specifications

- Acoustic source: 120 dB
- multi-microphone technique implemented
- Frequency range 40 – 4500 Hz



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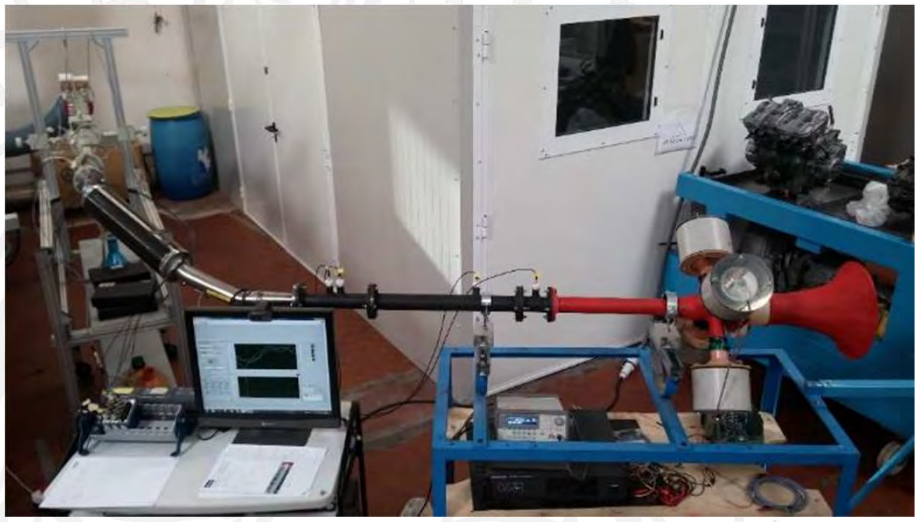
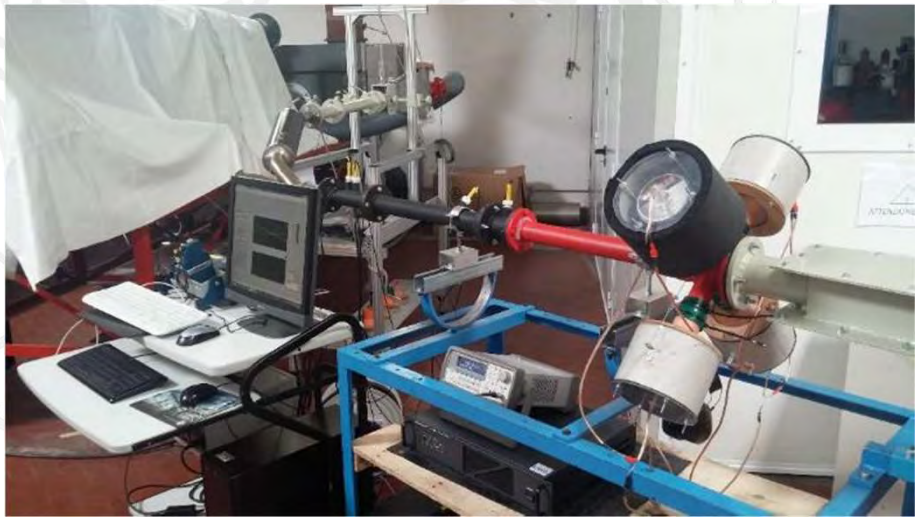
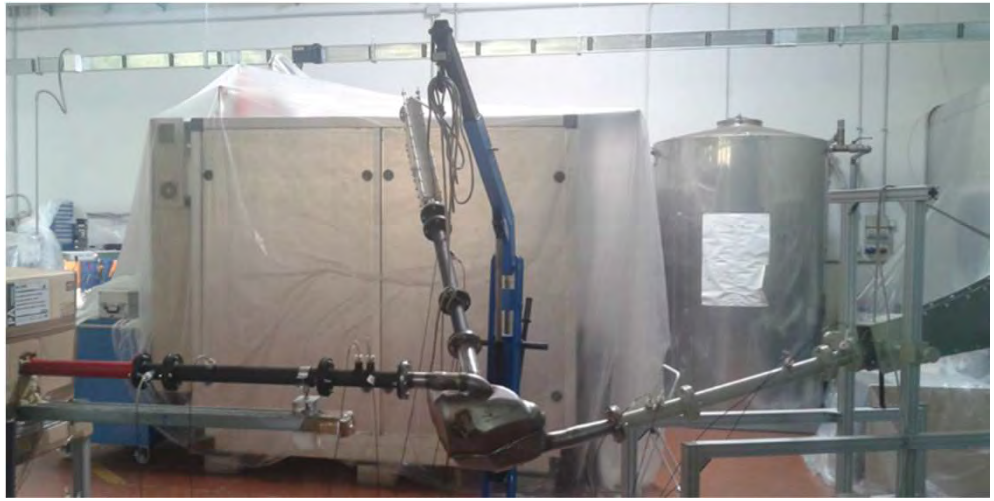
Possible configurations

2 station rig configuration





3 station rig configuration



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Setup

- 12 capacitive microphones TEDS ¼”, GRAS ®
  - High sensitivity 1.6mV/Pa
  - Diameter 7mm
  - Range 44 – 170dB
- J Termocouples
- SETRA ® differential pressure transducers (for P loss evaluation)
- AERZEN ® roots mass flow meter
  - 10m3/h – 5000m3/h
- National Instruments ® acquisition system
  - NI9215 100 kSamples/channel
- LABVIEW ® based, own acquisition software

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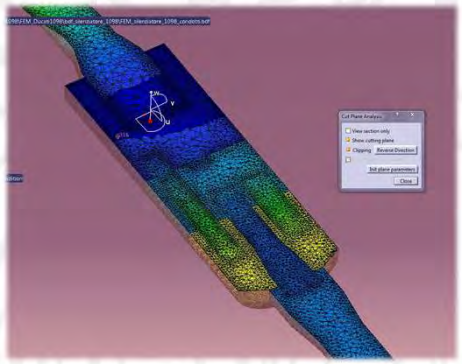
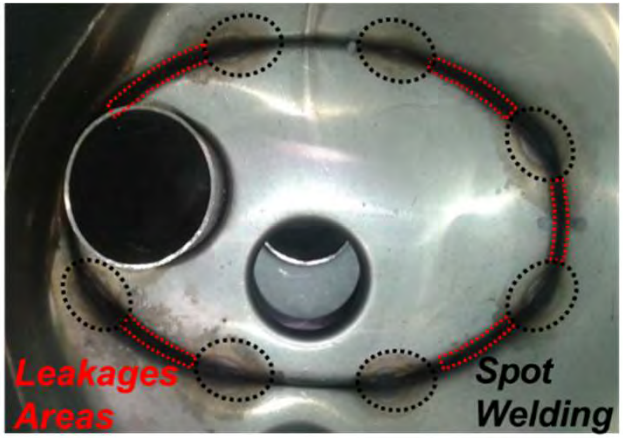
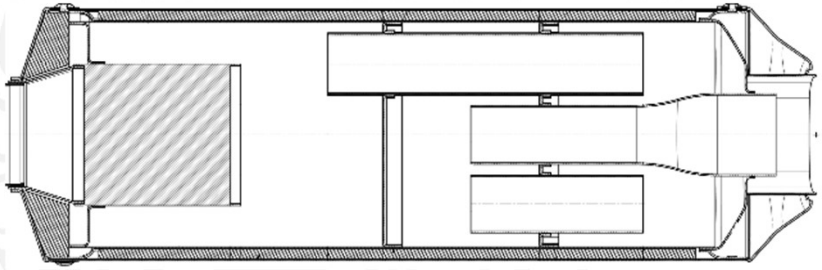
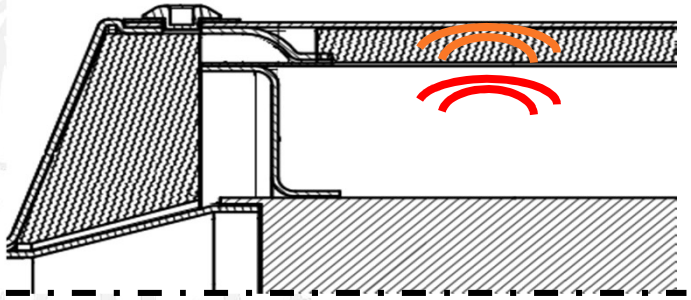
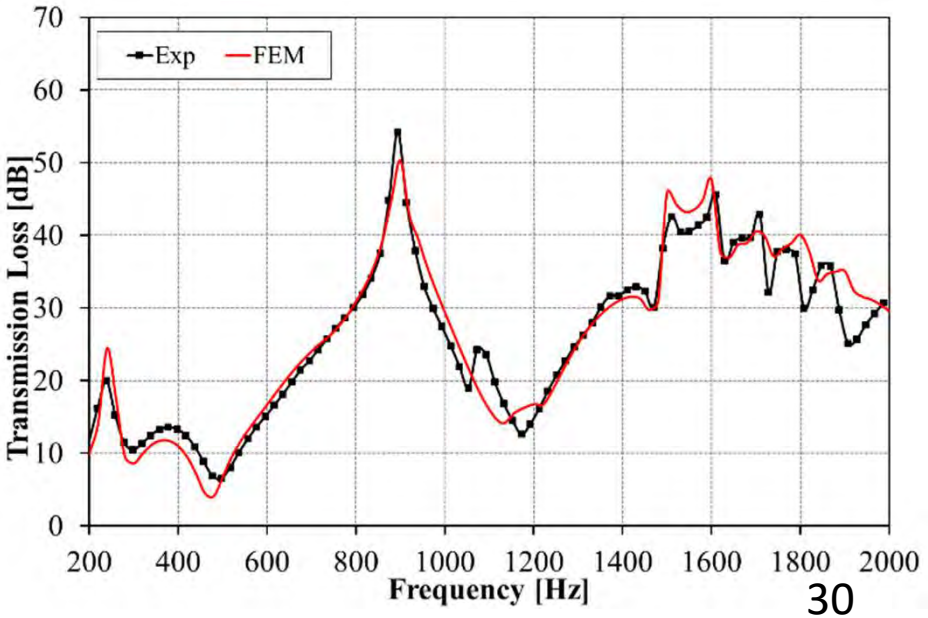
Experimental and numerical investigations (FEM 3D)











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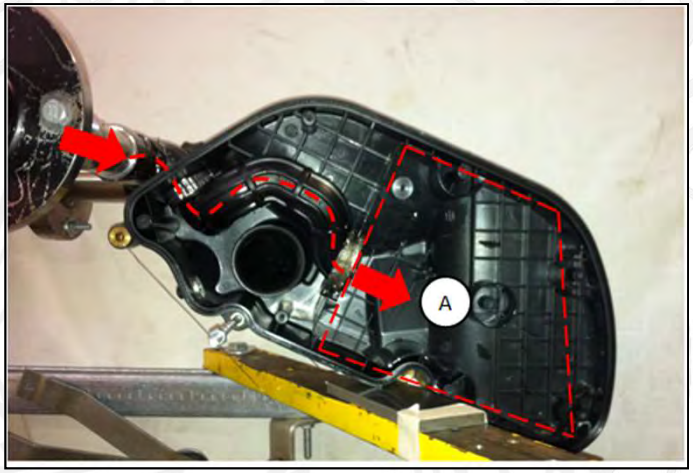
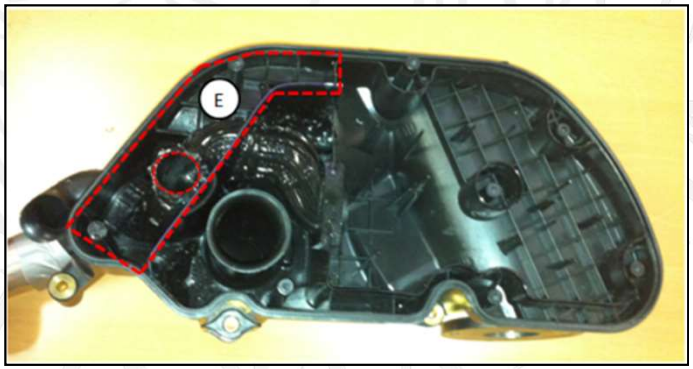
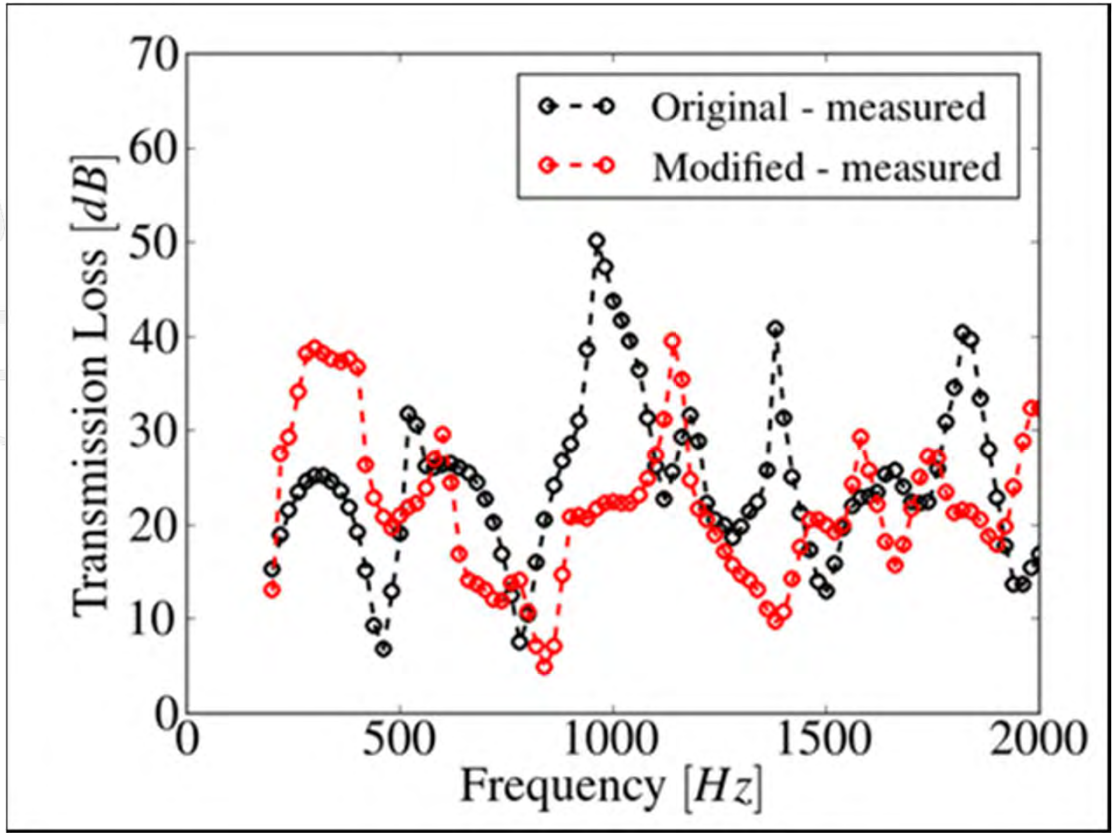
Some examples

Piaggio PoliMI-Unifi collaboration for noise reduction of an intake system







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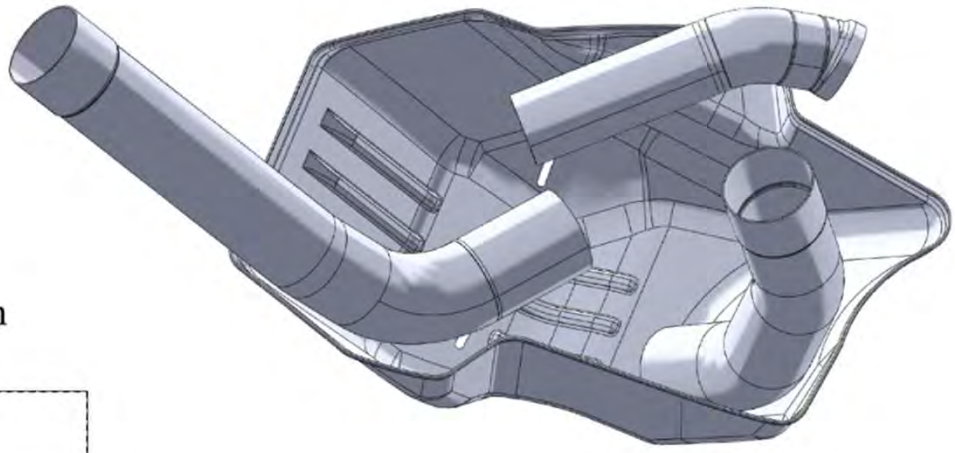
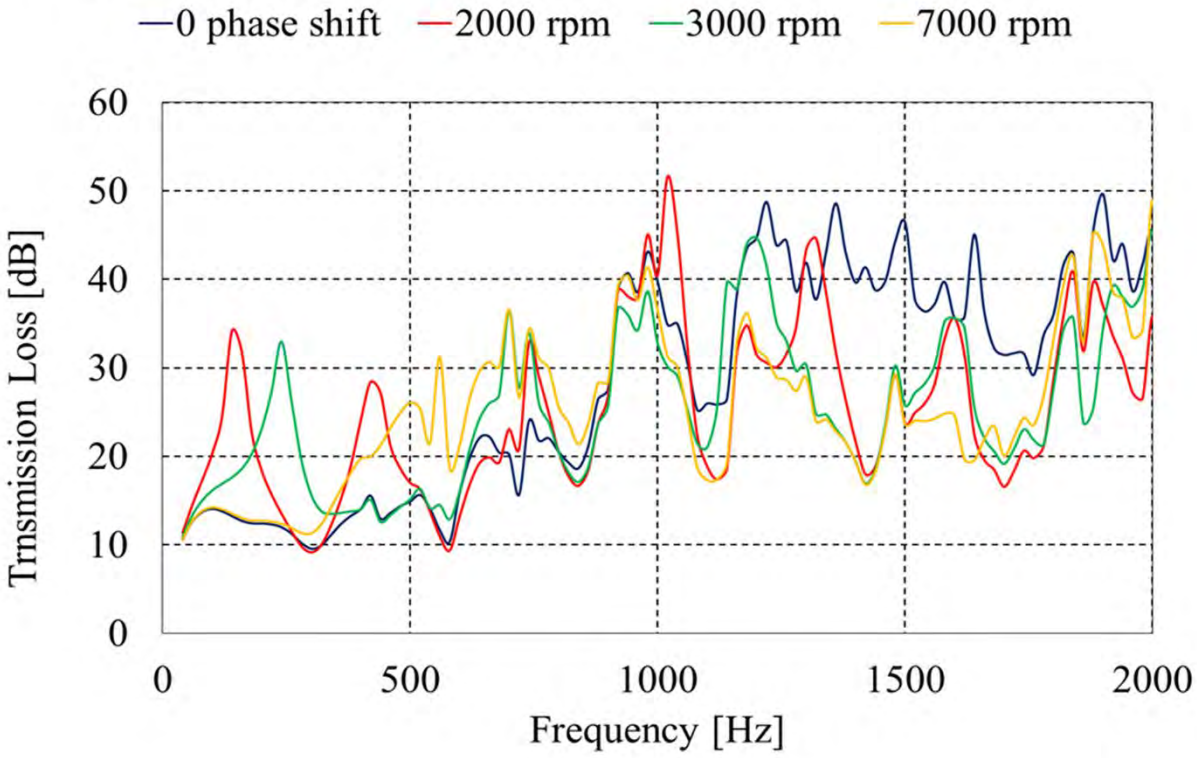
Some examples

Experimental evaluation of TL (2 in, 1 out) for a Ducati muffler

- TL analysis as a function of source fase
- Fase value related to RPM and timing of the cylinders





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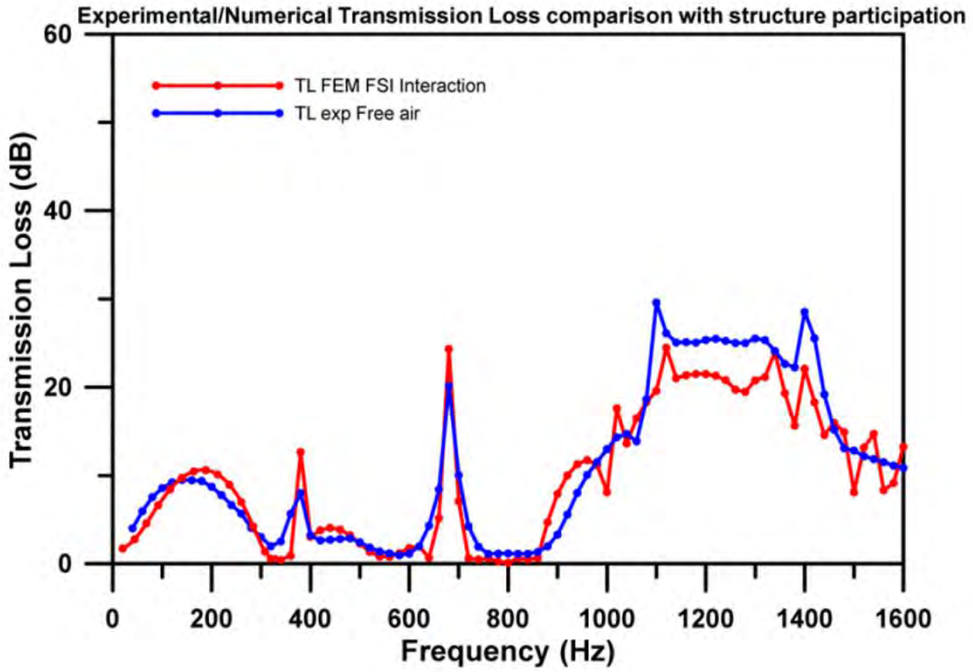
Some examples

CNR Istituto Motori – UniFI investigation on the fluid-structure interaction for a TWIN AIR intake system



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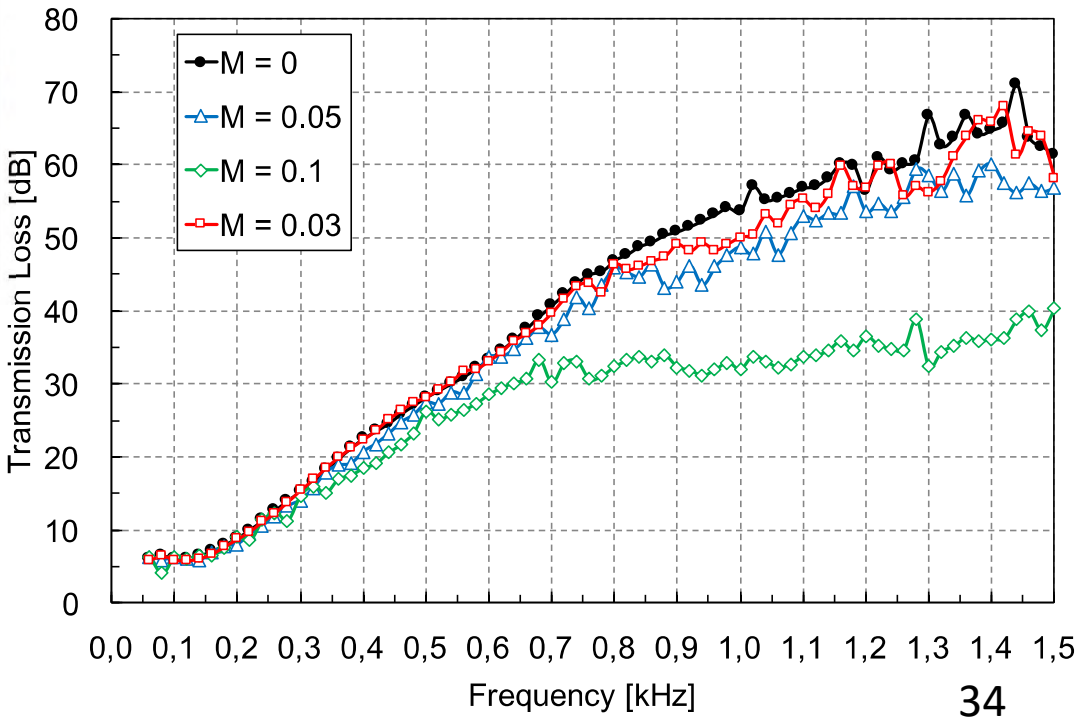
Some examples

Flow influence in a dissipative muffler



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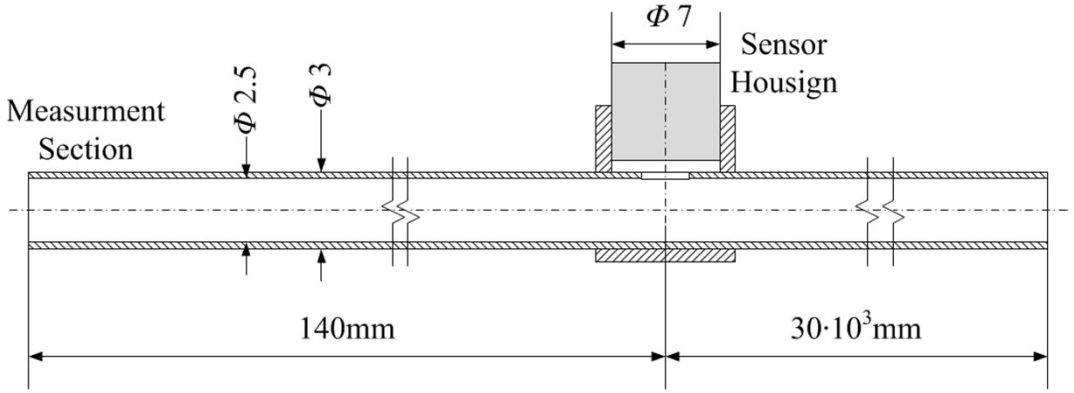
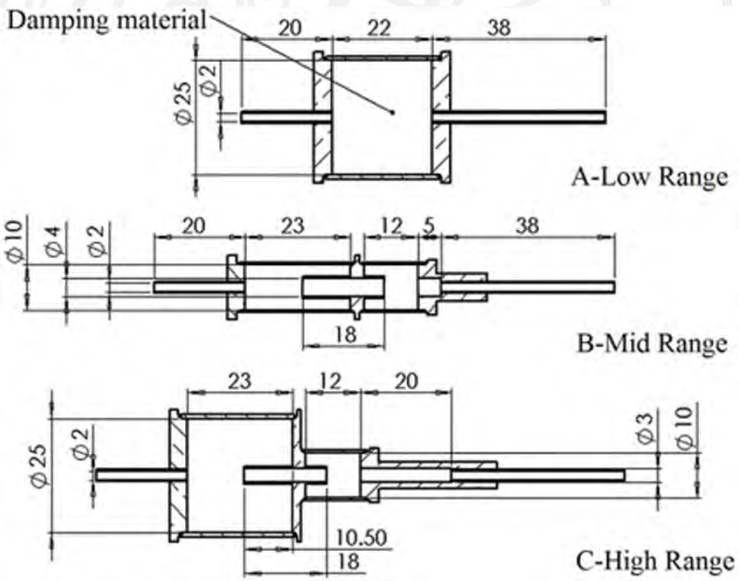
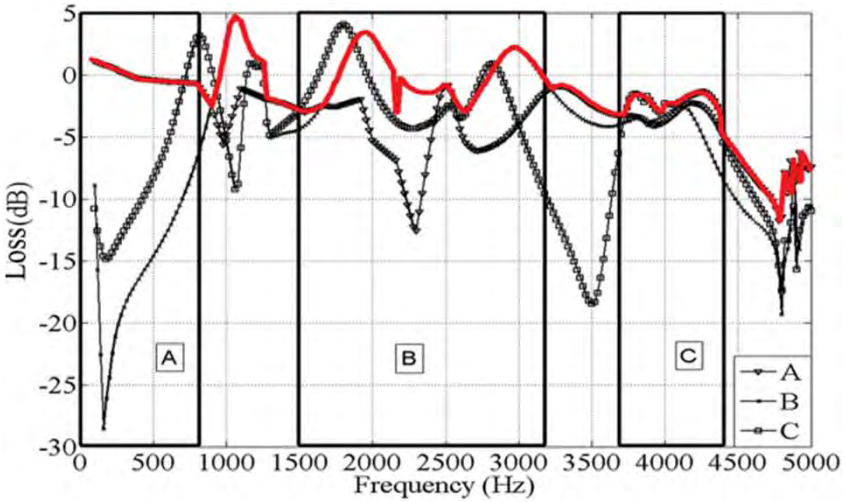
Test rig future development

Test with hot (warm!) gas

- Mics placed by means of wave guide







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Modena, 25 maggio 2016 – Giornata Studio sui MCI