Giornata di Studio "Giorgio Minelli"

Le prospettive future dei Motori a Combustione Interna

Bologna, 20 Aprile 2018

Attività di ricerca su componenti, motori e veicoli sviluppate dall'ICEG

ICEG research activities on components, engines and vehicles

Giorgio Zamboni, Silvia Marelli, Massimo Capobianco

Internal Combustion Engines Group (ICEG)

Dipartimento di Ingegneria Meccanica, Energetica, Gestionale e dei Trasporti (DIME)

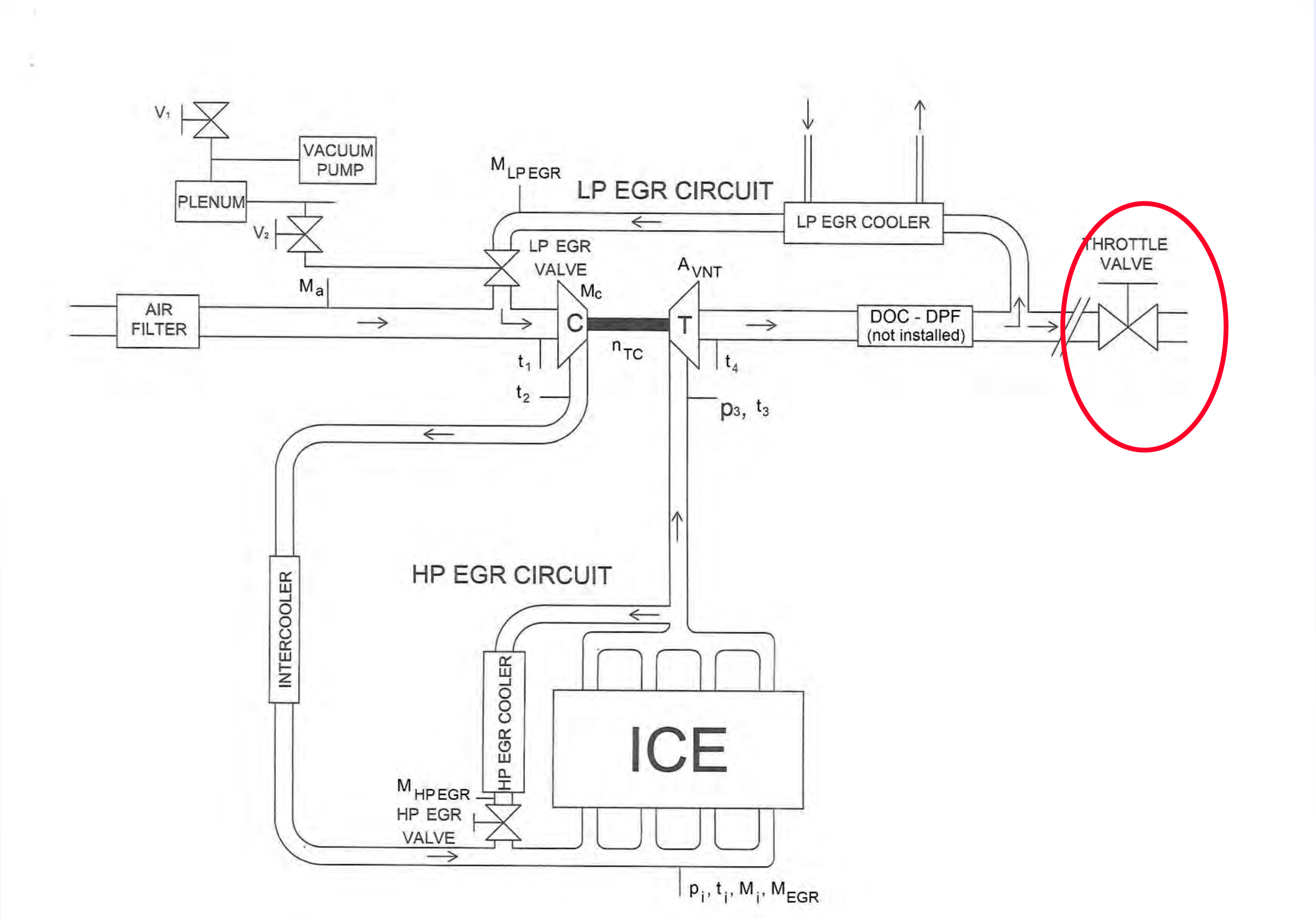
Università di Genova

Engine Control

Engine characteristics

Engine	Diesel, Direct Injection 4 stroke Euro 5
Number of cylinders	4, in-line
Displacement	1247,9 cm^3
Bore	69,9 mm
Stroke	82 mm
Compression ratio	16,8:1
ECU	Magneti Marelli 8F2, open
HP EGR system	**Electronically controlled valve, cooler**
LP EGR system	**Manually controlled valve, cooler**
Turbocharging system	**Borg Warner turbocharger with variable nozzle turbine, intercooler**
Fuel injection system	**Multijet II common rail**

Engine layout



Zamboni G., Moggia S., Capobianco M., Effects of a Dual-Loop Exhaust Gas Recirculation System and Variable Nozzle Turbine Control on the Operating Parameters of an Automotive Diesel Engine. Energies 2017, 10(1), 47

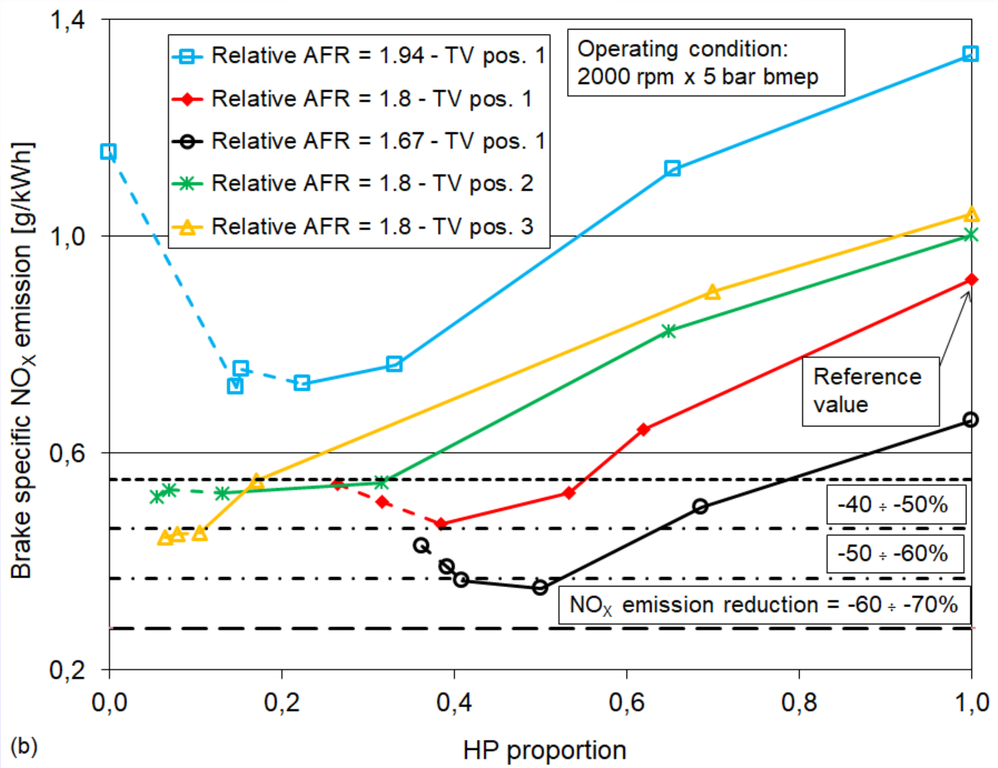
Operating conditions and experimental programme (first stage)

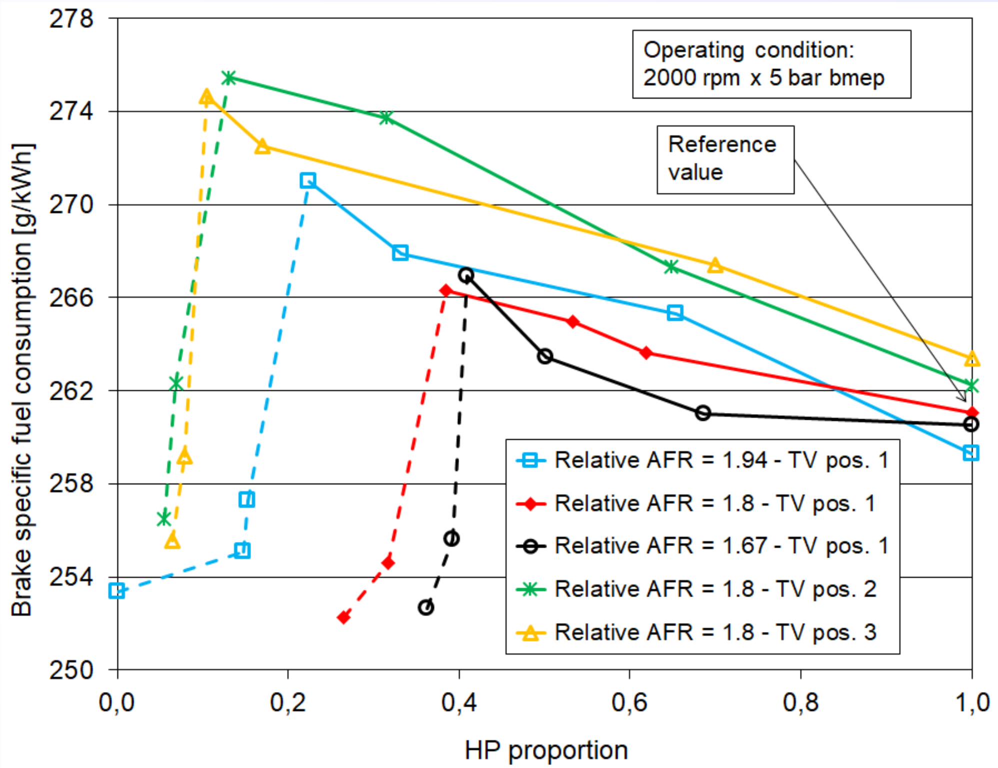
Operating condition ID = n x bmep [rpm x bar]	Control variables (fixed in each test set)	Control variables (LP EGR and VNT control)	Test sets
No.1 = 1500x2	Relative air-fuel ratio Exhaust throttle valve position	LP EGR valve opening VNT opening degree	Rel.AFR = 3.01 - TV pos. 1 Rel.AFR = **2.90** - TV pos. **1**/2/3 Rel.AFR = 2.77 - TV pos. 1/2 Rel.AFR = 2.62 - TV pos. 1/2
No.2 = 2000x5			Rel.AFR = 1.94 - TV pos. 1 Rel.AFR = **1.80** - TV pos. **1**/2/3 Rel.AFR = 1.67 - TV pos. 1/2
No.3 = 2500x8	Relative air-fuel ratio Exhaust throttle valve position Intake pressure	LP EGR valve opening	Rel.AFR = 1.60 – Intake pressure = 1.48 bar – TV pos. 1 Rel.AFR = **1.60** – Intake pressure = **1.52**/1.57 bar – TV pos. 0/**1** Rel.AFR = 1.47 – Intake pressure = 1.52 bar – TV pos. 1

Standard calibration values in bold

Zamboni G., Moggia S., Capobianco M., Effects of a Dual-Loop Exhaust Gas Recirculation System and Variable Nozzle Turbine Control on the Operating Parameters of an Automotive Diesel Engine. Energies 2017, 10(1), 47

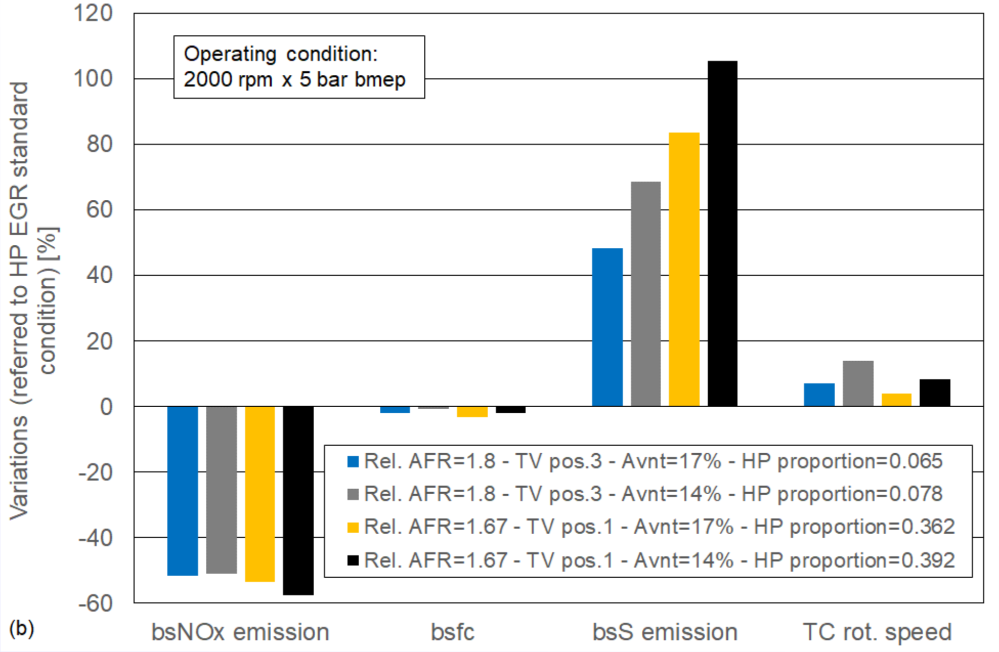
Results (first stage 1/2)

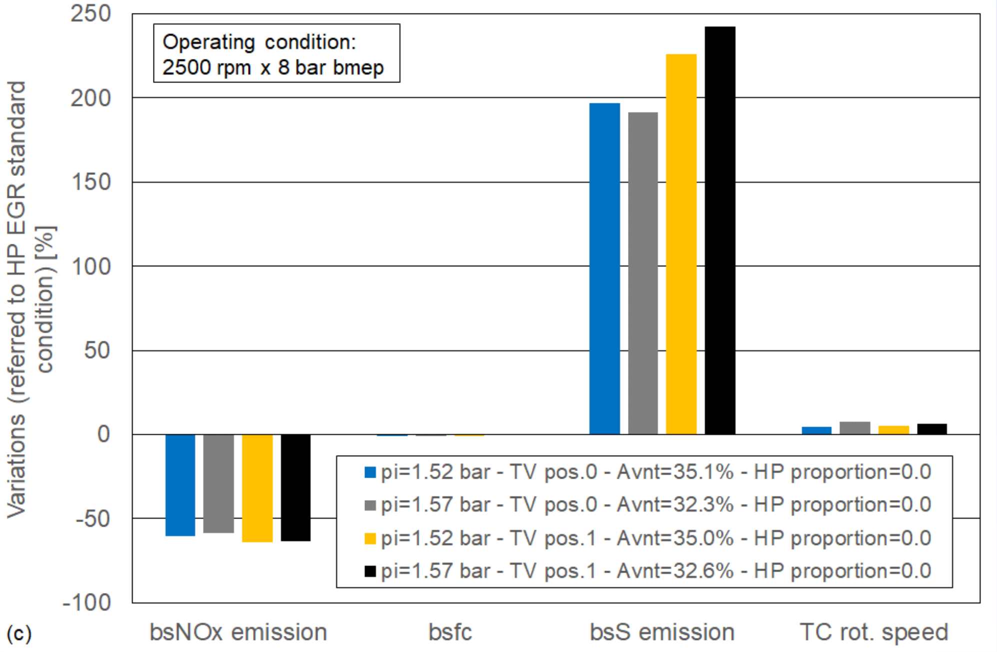




Zamboni G., Moggia S., Capobianco M., Hybrid EGR and turbocharging systems control for low NOX and fuel consumption in an automotive diesel engine. Applied Energy, 2016, vol.165, pp.839-848.

Results (first stage 2/2)



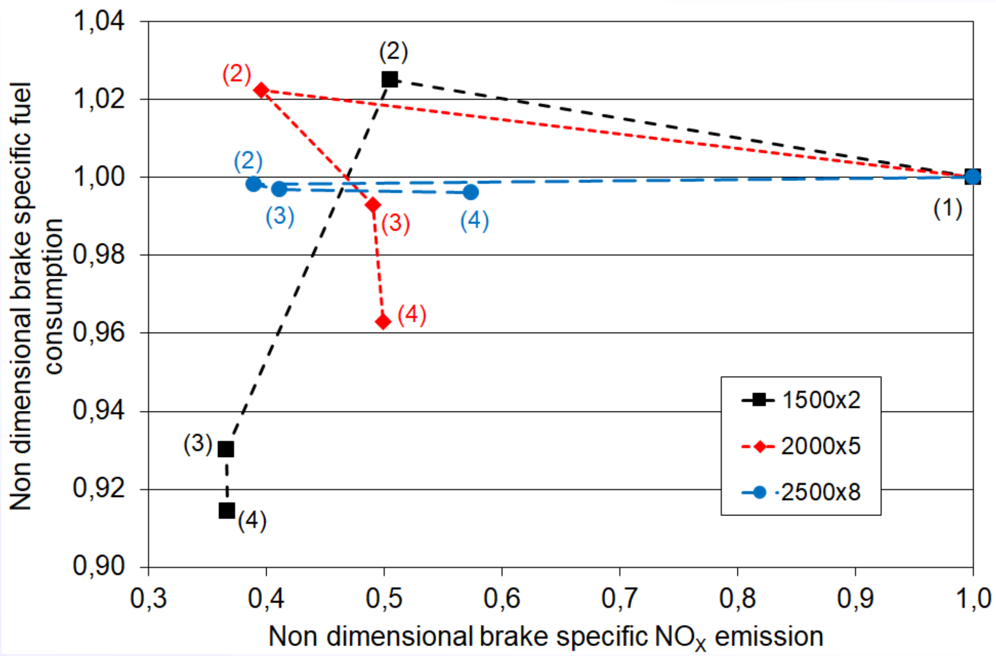


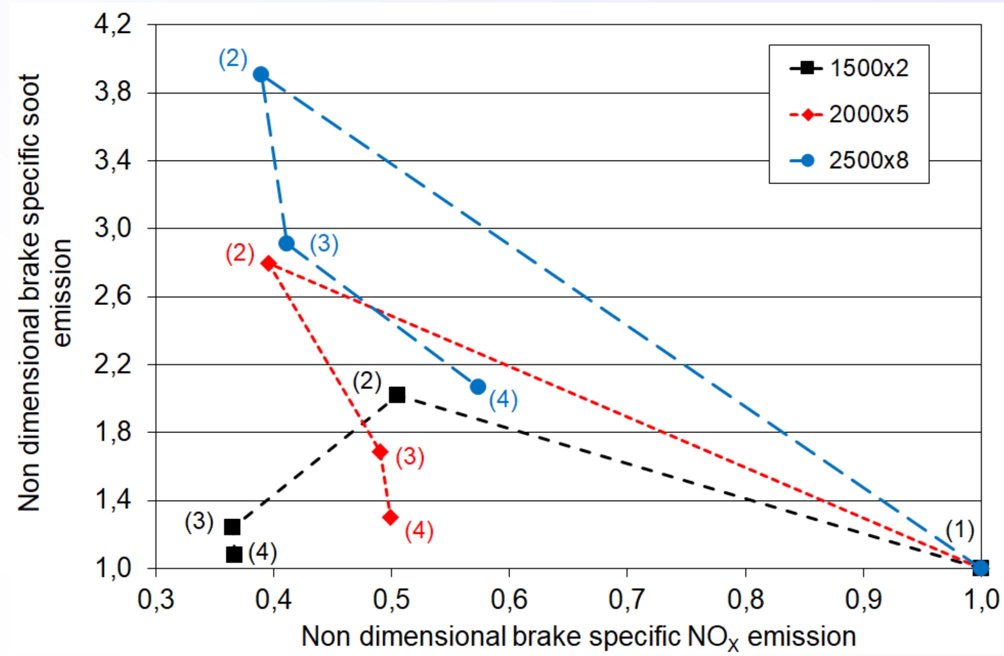
Zamboni G., Moggia S., Capobianco M., Hybrid EGR and turbocharging systems control for low NOX and fuel consumption in an automotive diesel engine. Applied Energy, 2016, vol.165, pp.839-848.

Experimental programme (second stage)

Operating condition ID = n x bmep [rpm x bar]	Fixed variables	Control variables	Rail pressure [bar]
No.1 = 1500x2	Rel. AFR = 2.62 TV position = 2	DC_{VNT} = 80 and 86% (A_{VNT} = 16.5 and 9.5%)	345 (-6.75%) 370 (standard level) 395 (+6.75%) 420 +13.5%
No.2 = 2000x5	Rel. AFR = 1.80 DC_{VNT} = 82% (A_{VNT} = 17%)	Exhaust throttle valve position = 1 and 3	544 (-7.5%) 588 (standard level) 632 (+7.5%) 676 (+15.0%)
No.3 = 2500x8	Rel. AFR = 1.60 TV position = 0	Intake pressure = 1.520 and 1.570 bar	747 (-8.0%) 812 (standard level) 877 (+8.0%)

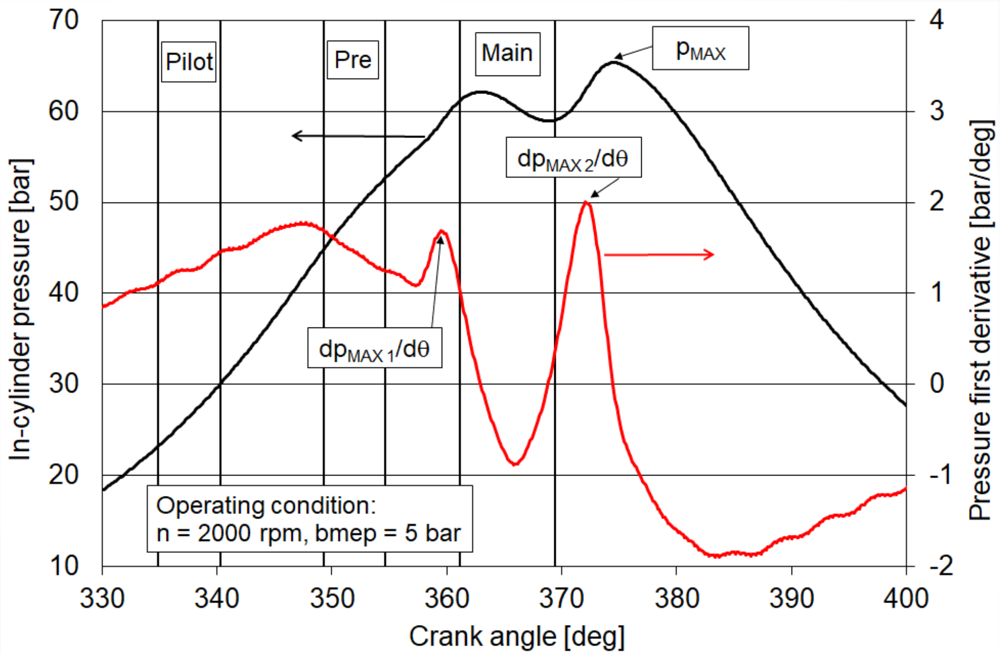
Results (second stage)

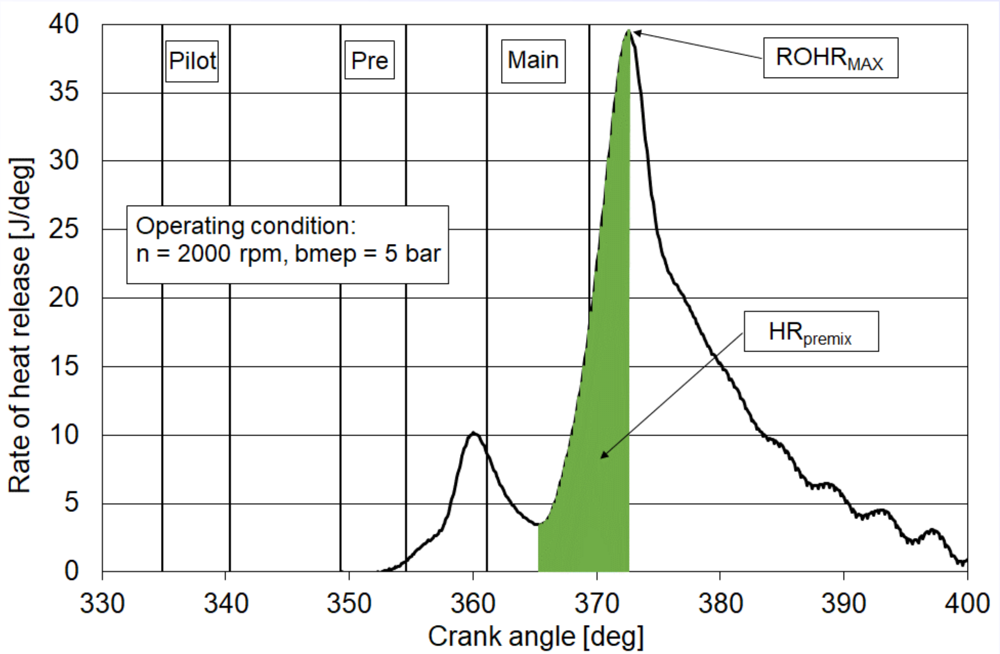




(1) Reference condition (HP EGR)
(2) + LP EGR
(3) + VNT control
(4) + p_{rail} control

Combustion parameters





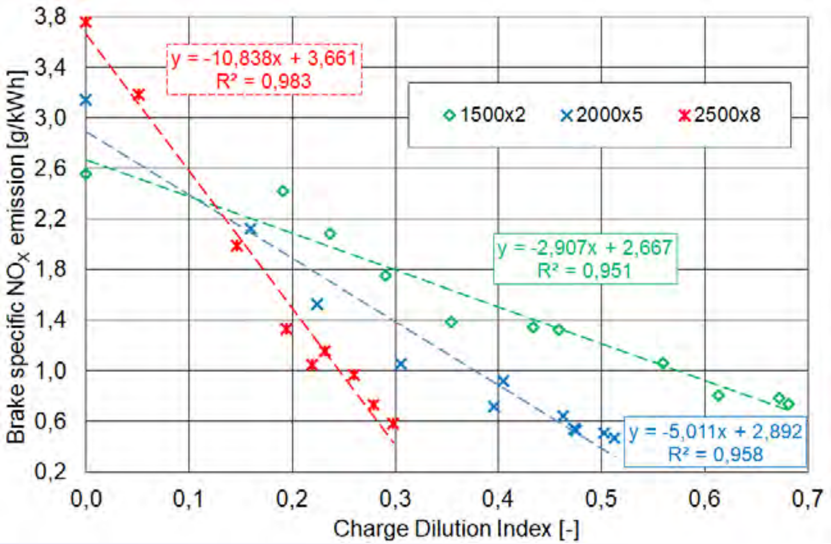
Combustion centre θ_{50}

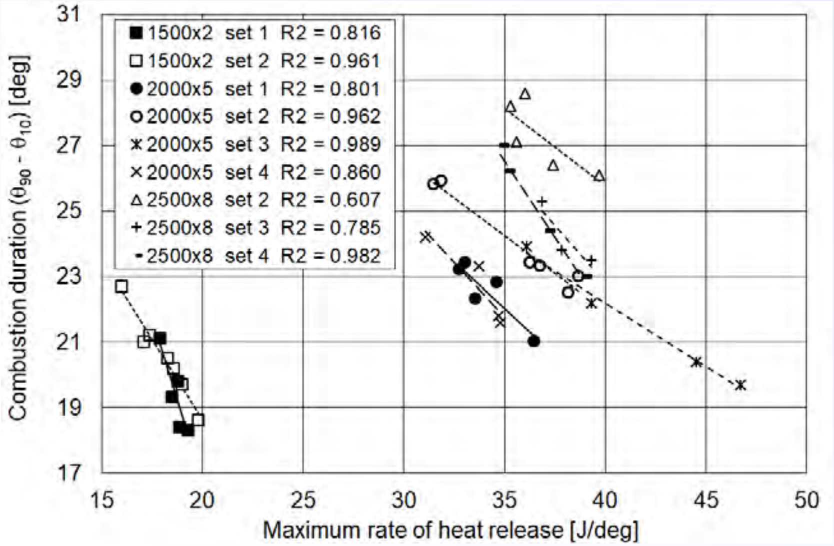
Combustion duration θ_{90} - θ_{10}

Noise combustion index $I_n = n / n_{idle} \times [(dp_{MAX\ 1}/d\theta + dp_{MAX\ 2}/d\theta) / dp_{MAX}/d\theta]$

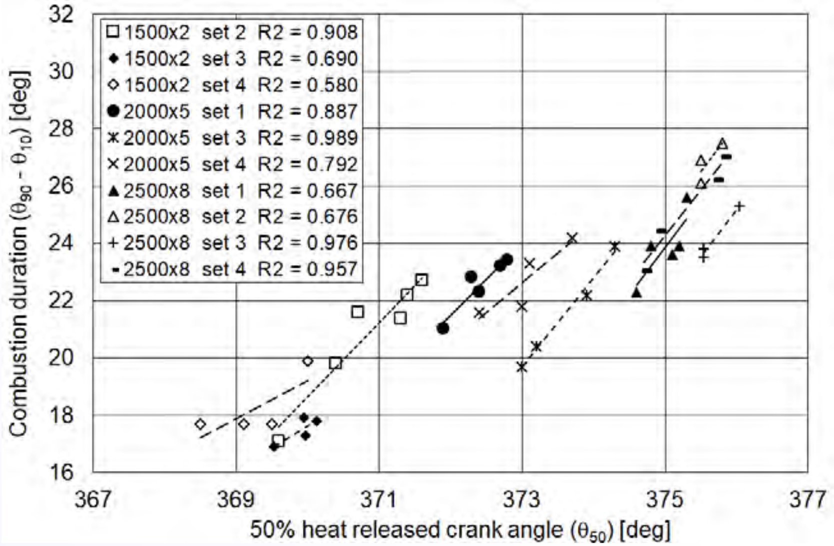
Charge Dilution Index CDI = EGR rate / engine load = $[(X_{O2\ a} - X_{O2\ i}) / (X_{O2\ i} - X_{O2\ e})]$

Relationship between engine quantities, CDI and combustion parameters





Data from two test sets: HP EGR control and HP EGR + LP EGR + VNT control



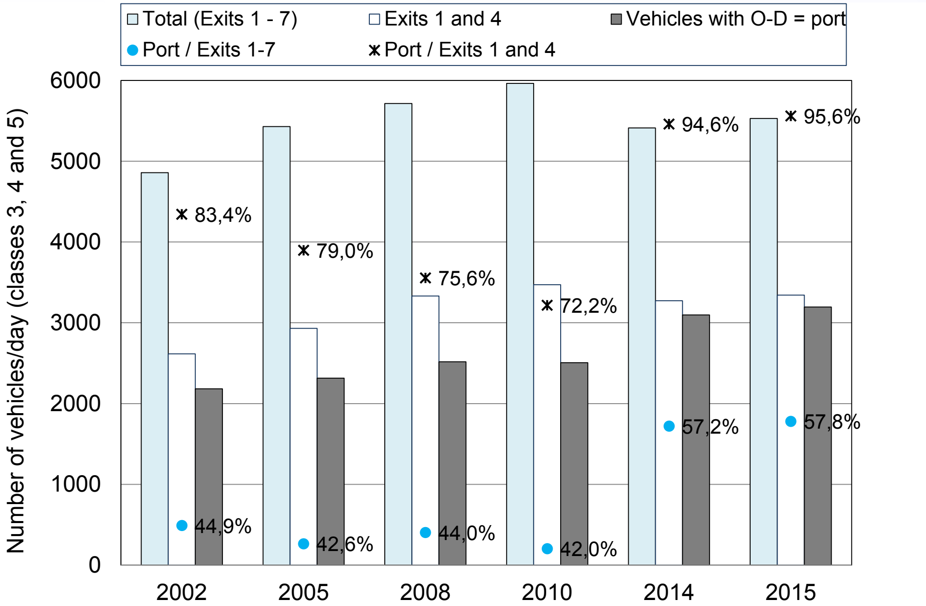
Set 1: HP EGR control
Set 2: HP EGR + LP EGR + VNT control
Set 3: HP EGR + LP EGR + VNT and p_{rail} control
Set 4: p_{rail} control with standard HP EGR

Assessment of road vehicles environmental impact in real-world conditions

Upgrade of PROGRESS model

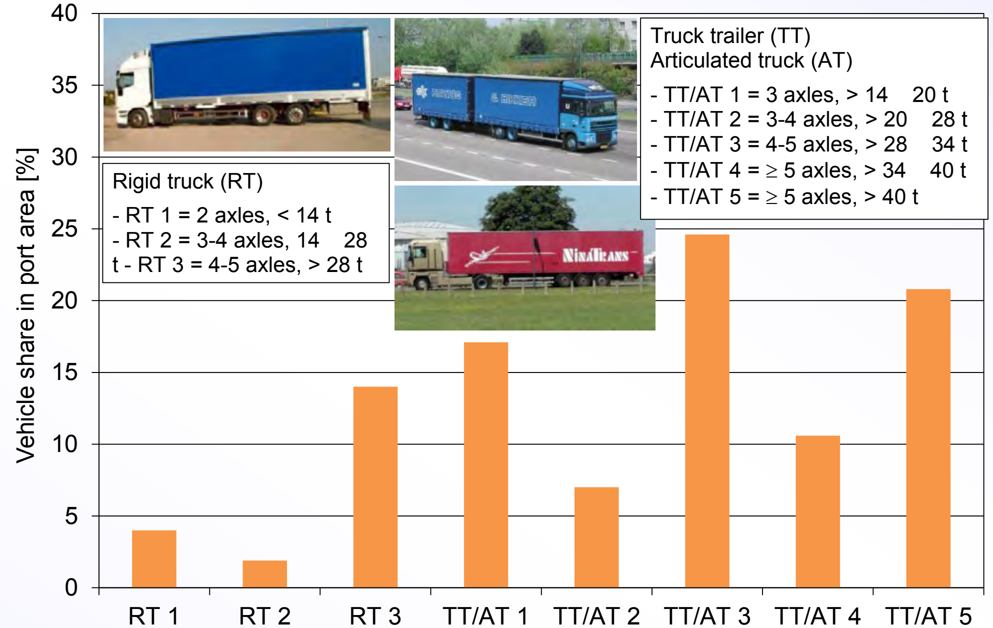
- Calculation of total emissions (cold and hot contributions) of pollutants (CO, HC, NO_X, NO_2, PM), CO_2 and fuel consumption for eight vehicle categories (SI and diesel cars and light duty vehicles, heavy-duty vehicles, buses, motorcycles and mopeds), further divided in classes (with a total number of 60) taking into account exhaust emissions legislation and engine type (2 or 4 stroke)
- Cold and hot emissions factor are obtained from Artemis project and HBEFA model databases, considered vehicle mass (HDV and buses) or engine displacement (motorcycles)
- Vehicle fleet composition and driving mileage are derived through processing of ACI, ANCMA and ISPRA data
- Recent enhancements are also related to the integration of results obtained in two studies, with reference to:
  - Definition of cold start behaviour of powered two wheelers (in co-operation with IM-CNR)
  - Assessment of HDV activities in Genoa Port Area (in co-operation with IFSTTAR)
- Calculation procedure is typically applied to an urban area on a yearly time base

HDV activities in Genoa Port Area



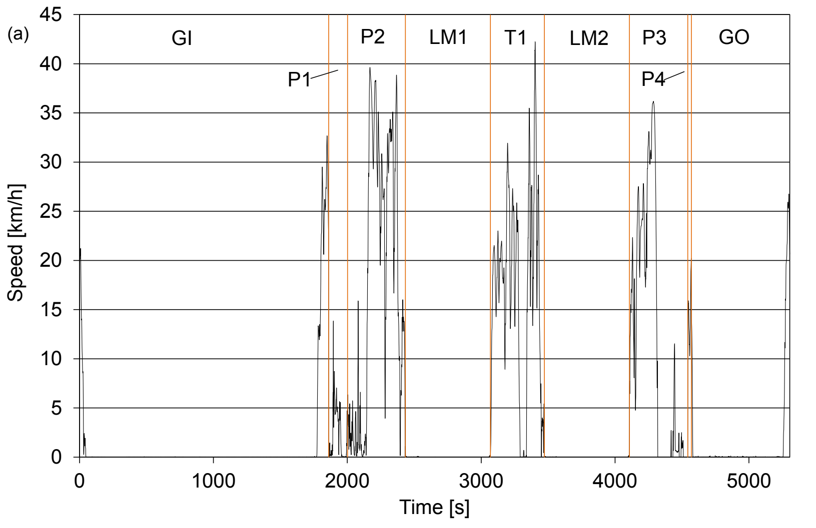
Definition of HDV daily flows through highway exits and share of vehicles entering port terminals

Classification of vehicles involved in port activities referring to type, mass range and number of axles



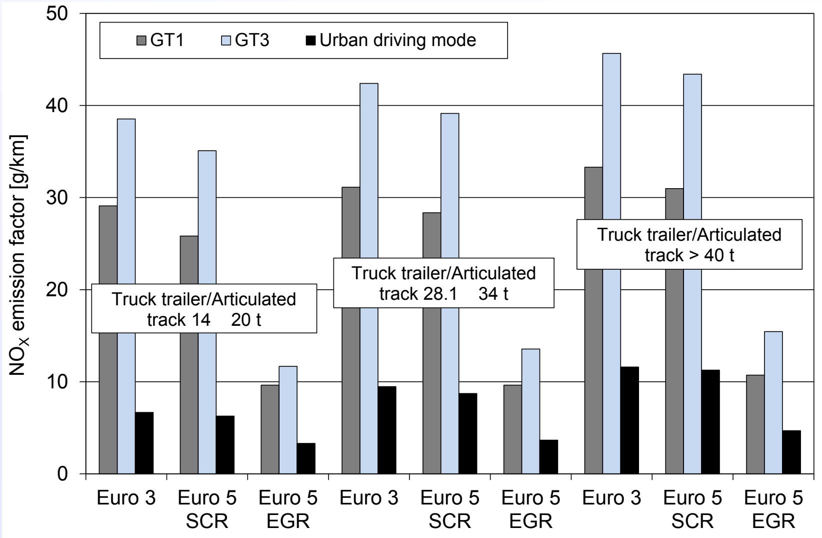
Zamboni G., Malfettani S., André M., Carraro C., Marelli S., Capobianco M., Assessment of heavy-duty vehicle activities, fuel consumption and exhaust emissions in port areas. Applied Energy, 2013, vol. 111, pp. 921-929

HDV activities in Genoa Port Area



Acquisition and processing of instantaneous speed related to the typical trips in urban zones (highway exit – port gates) and within the port area

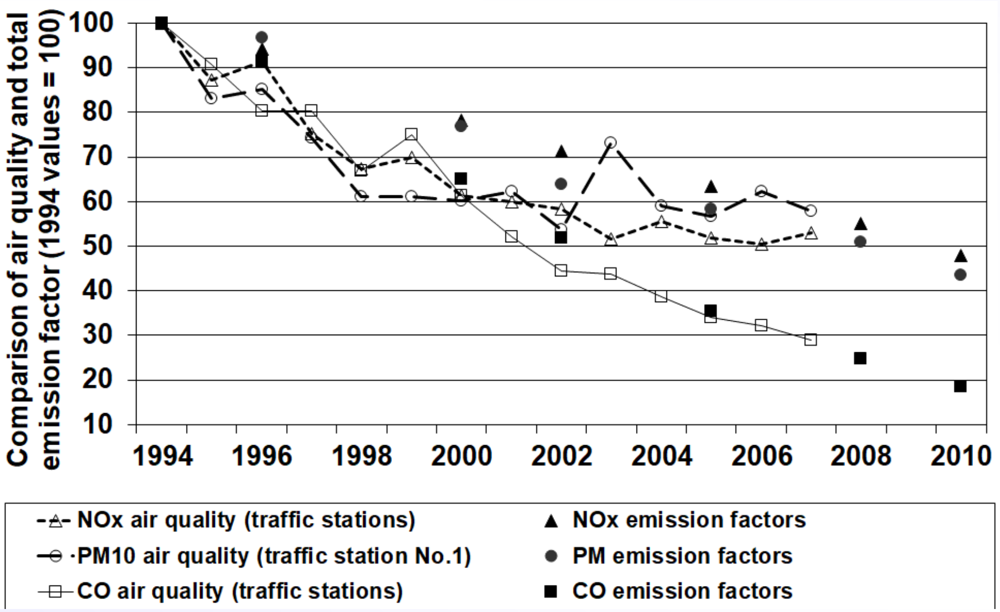
Average speed in port area = 4.4 km/h, idling time = 74%, travelled distance = 6.6 km



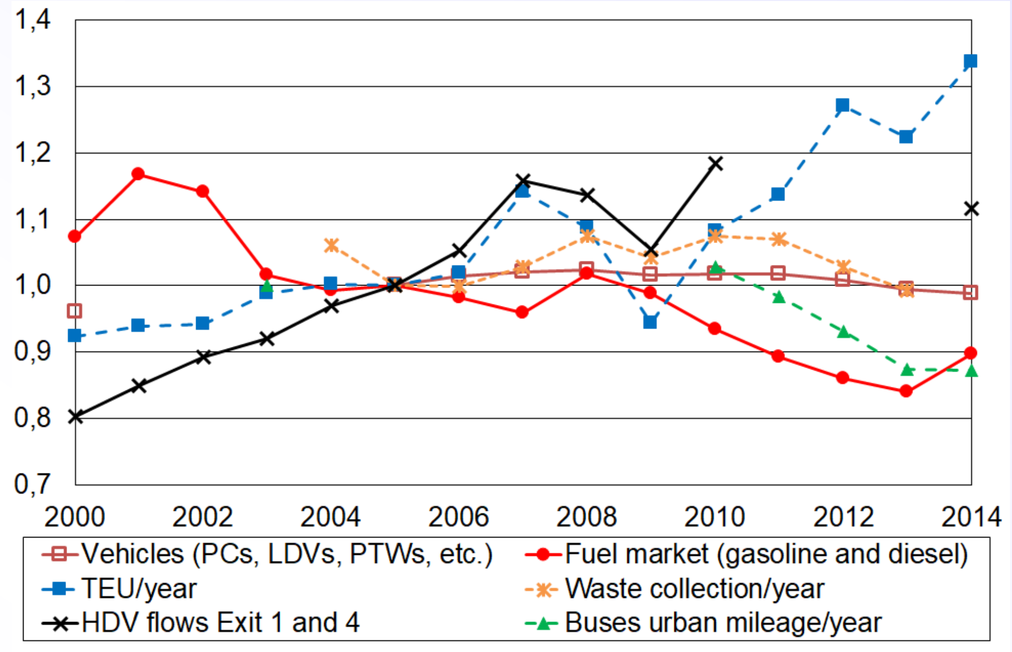
Application of PHEM to the experimental speed profiles to estimate fuel consumption and emission factors for selected HDV classes

Zamboni G., André M., Roveda A., Capobianco M., Experimental evaluation of Heavy Duty Vehicle speed patterns in urban and port areas and estimation of their fuel consumption and exhaust emissions. Transportation Research Part D: Transport and Environment, 2015, vol.35, pp.1-10

Examples of PROGRESS application



Comparison of average emission factors – air quality (situation in Genoa)



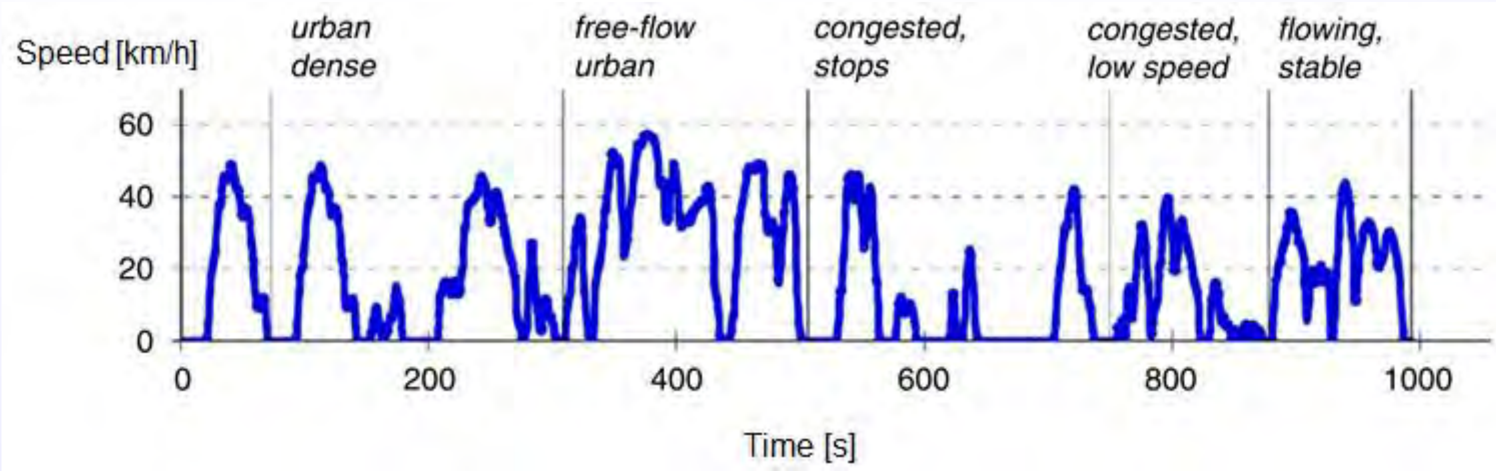
Definition of the most polluting vehicle categories, taking into account activities indexes

Zamboni G., Capobianco M., Daminelli E., Estimation of road vehicle exhaust emissions from 1992 to 2010 and comparison with air quality measurements in Genoa, Italy. Atmospheric Environment 43, pp. 1086 - 1092

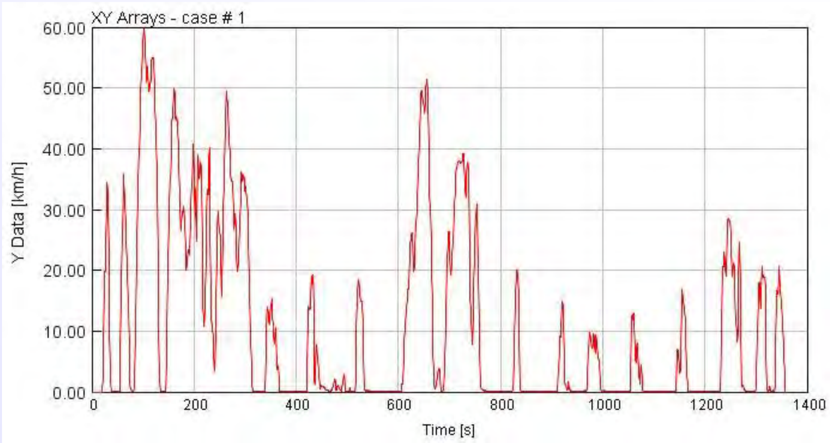
Evaluation of emissions and fuel consumption of Heavy-Duty Vehicles in urban areas. 21st International Conference "Transport and Air Pollution", Lyon, May 24 – 26, 2016.

Vehicles modelling

- Models of conventional, electric and hybrid vehicles in GT-Suite to compare emissions and fuel consumption on different driving cycles, aiming at the development of WTW analysis (in co-operation with Université Savoie Mont Blanc)



Artemis Urban
Average speed = 17,7 km/h
RPA = 0,272 m/s^2
Stop/km = 1,8



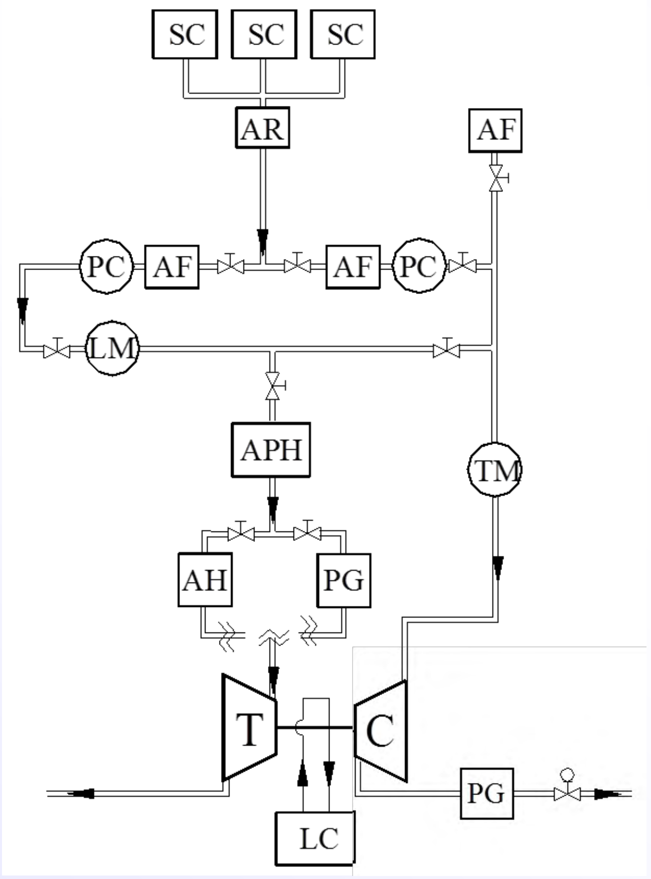
Speed profile on a typical trip in Genoa city centre
Average speed = 10,7 km/h
RPA = 0,310 m/s^2
Stop/km = 4,4

Intake and Exhaust Components Research Activity

Intake and Exhaust Components Research Activity

- The test facility allows to study the behaviour of different automotive I/E components and subsystems both under steady and unsteady flow operation, with special reference to exhaust turbochargers
- Experimental tests can be addressed to:
  - define the steady flow characteristics of I/E components in a wide operating range through suitable investigation techniques
  - investigate the behaviour of I/E components under pulsating flow conditions, highlighting the influence of the main flow parameters on components performance
  - study the transient response of I/E components and subsystems in order to optimize the relevant control strategies
- Information provided by experimental research activity are used to define empirical correlations and to improve theoretical models within engine simulation codes (GT Power environment, …)

I/E Components Test Facility



AF	Air Filter	LM	Laminar Flow Meter
AH	Air Heater	PC	Pressure Control
AR	Air Reservoir	PG	Pulse Generator System
APH	Air Pre-Heater	SC	Screw Compressor
C	Compressor	T	Turbine
LC	Lubricating Circuit	TM	Thermal Mass Flow Meter

- "Cold" (about 400 K) and "hot" (max 1000 K) air tests on I/E components and subassemblies
- Maximum available air flow rate 0.65 kg/s at 8 bar
- Particularly suitable to test automotive turbochargers: two independent feeding lines available for the TC turbine and compressor
- Electrical air heating modular system (max power 320 kW)
- In the case of turbine investigations the turbocharger compressor acts as a dynamometer and proper experimental techniques are used to extend the definition of turbine characteristics
- Turbine and compressor performance can also be investigated under unsteady flow by using two different pulse generator systems:
  - Rotating valves pulse generator
  - Cylinder head pulse generator

Investigation topics for efficient engine turbocharging

- Correlation between hot and cold turbine maps
- Direct measurement of turbine isentropic efficiency
- Heat transfer phenomena within the turbocharger (air-oil-water-exhaust gases)
- Evaluation of turbocharger mechanical losses
- Optimization of TC regulating device control (waste-gate, VGT) under unsteady flow conditions
- Effect of unsteady flow and transient operation on compressor and turbine performance
- Definition of twin entry turbine maps in full, partial and unequal admission under steady and unsteady flow conditions
- Compressor surge detection and active control
- Interactions between EGR and turbocharging circuits
- Effect of aftertreatement device position on turbocharger performance
- E-boosting and waste heat recovery systems
- Subassembly characterization (TC + engine I/E circuit)
- …..

Improvement of turbocharger simulation models within commercial codes (GT Power, etc)

Contacts

Thank you for your attention!

- **Prof. Massimo Capobianco** (ICEG Coordinator)
  phone +39.010.353.2446 mobile +39.328.1004793
  e-mail massimo.capobianco@unige.it
- **Dr. Silvia Marelli** (Assistant Professor)
  phone +39.010.353.2443 mobile +39.335.8726110
  e-mail silvia.marelli@unige.it
- **Dr. Giorgio Zamboni** (Researcher)
  phone +39.010.353.2457 mobile +39.320.4320003
  e-mail giorgio.zamboni@unige.it

Università di Genova – DIME
Via Montallegro 1 - 16145 Genova – Italy
www.iceg.unige.it