Coordinamento Nazionale dei Professori

di Macchine a Fluido e Sistemi per l'Energia e l'Ambiente

Giornata di Studio sui Motori a Combustione Interna

Modena, 25 Maggio 2016

Attività di ricerca dell'Università di Genova sulle prestazioni dei componenti di aspirazione e scarico di MCI automotive e sulle emissioni dei veicoli stradali in condizione di reale utilizzazione

Massimo Capobianco, Silvia Marelli, Giorgio Zamboni

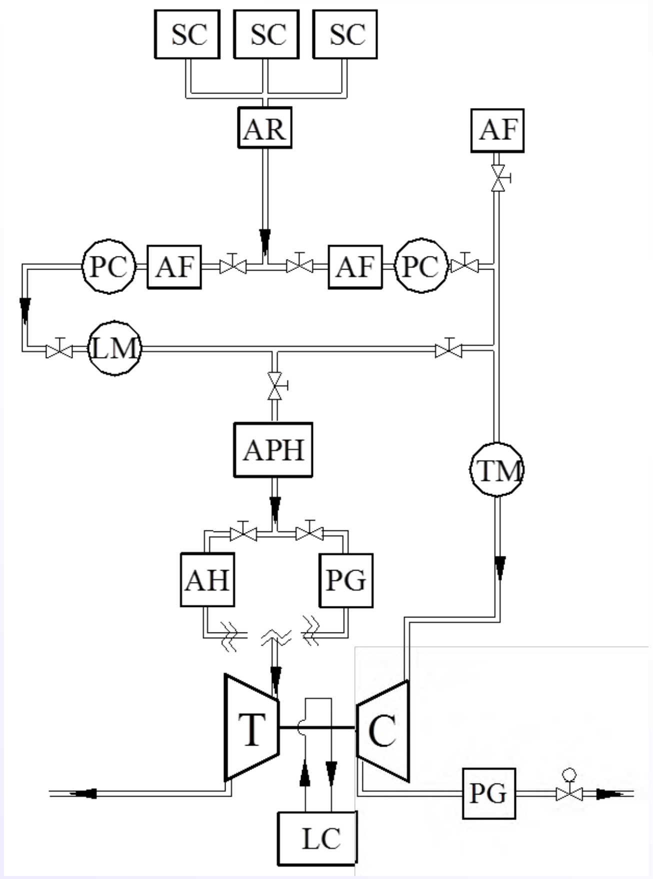
Internal Combustion Engines Group (ICEG)
Dipartimento di Ingegneria Meccanica, Energetica, Gestionale e dei Trasporti (DIME)
Università di Genova

Intake and Exhaust Components Research Activity

Intake and Exhaust Components Research Activity

- A dedicated 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, …)

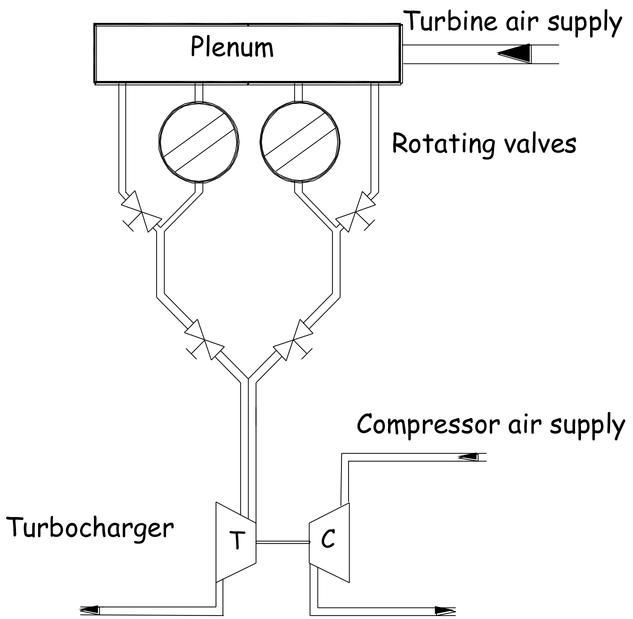
I/E Components Test Facility



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

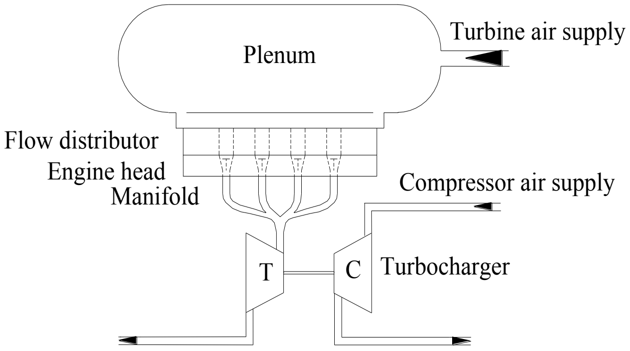
Rotating Valves Pulse Generator System



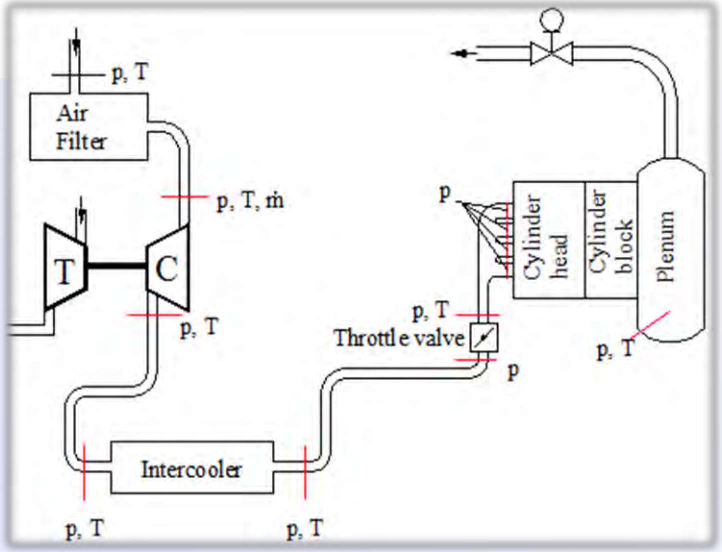
- Designed to perform parametric studies (effect of unsteady flow parameters on component performance)
- Tests on single and two-entry devices allowed
- Pulsating flow generated by diametral slot rotating valves
- Easy control of pressure pulse parameters (amplitude, mean value) at each device entry by controlling the upstream plenum pressure and by properly mixing a steady and a pulsating flow component
- Pulse frequency can be adjusted in the typical range of automotive I/E circuits (10-200 Hz)
- Unequal admission and not-phased pulsating flow conditions can be reproduced when testing two-entry devices

Cylinder Head Pulse Generator System

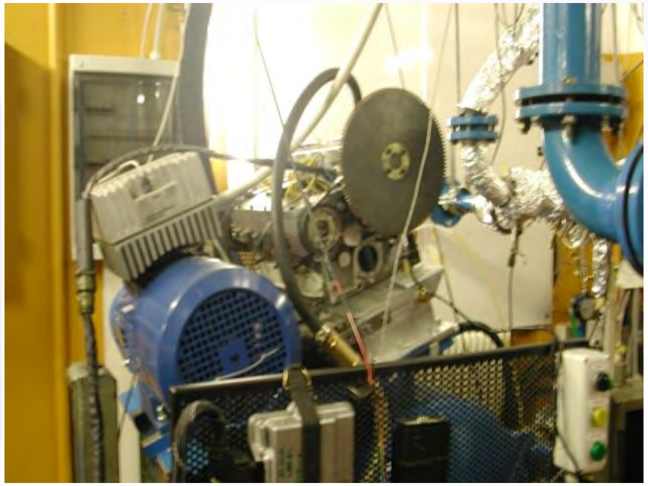
Application to the turbine circuit



Application to the compressor circuit

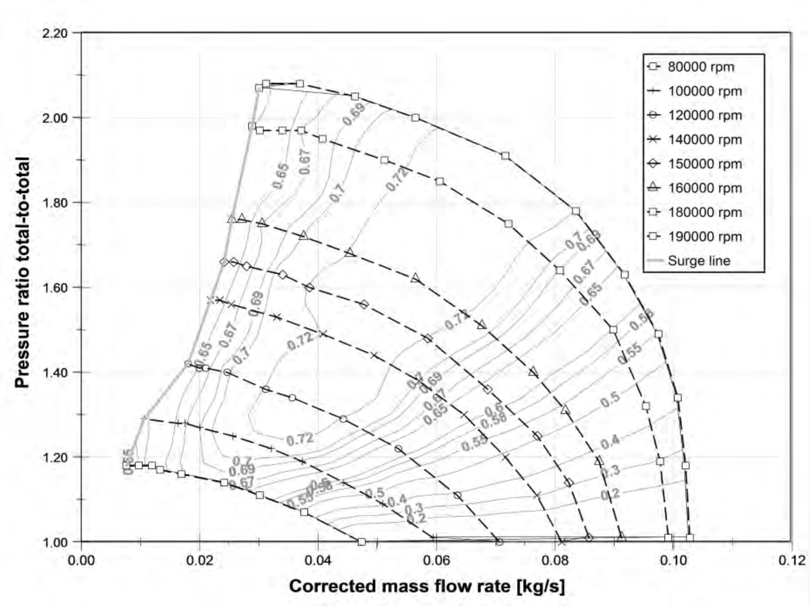


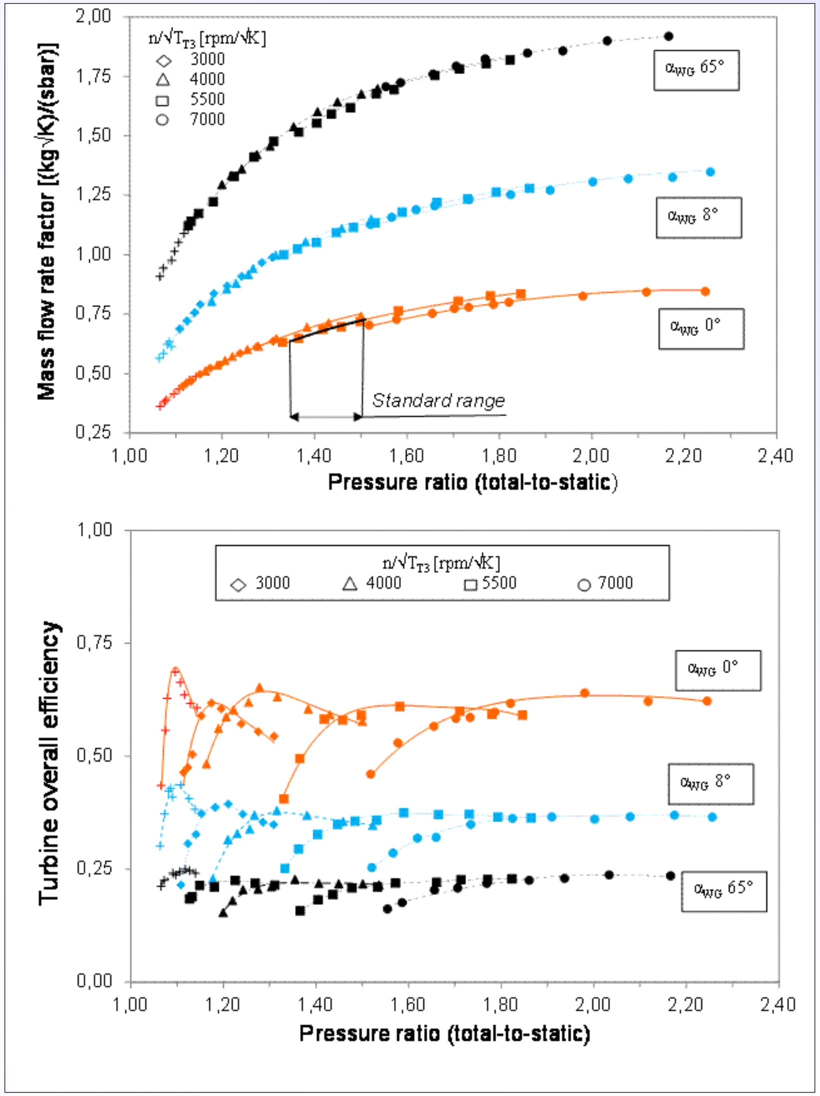
- Designed to investigate engine intake and exhaust subsystem behaviour under unsteady flow conditions, including the effect of:
  - circuit geometry
  - valve actuation strategies
- The system is based on a motor-driven cylinder head connected to a device designed to reproduce the engine cylinder block
- The cylinder head can be fitted with a fully flexible VVA system



Experimental definition of TC maps

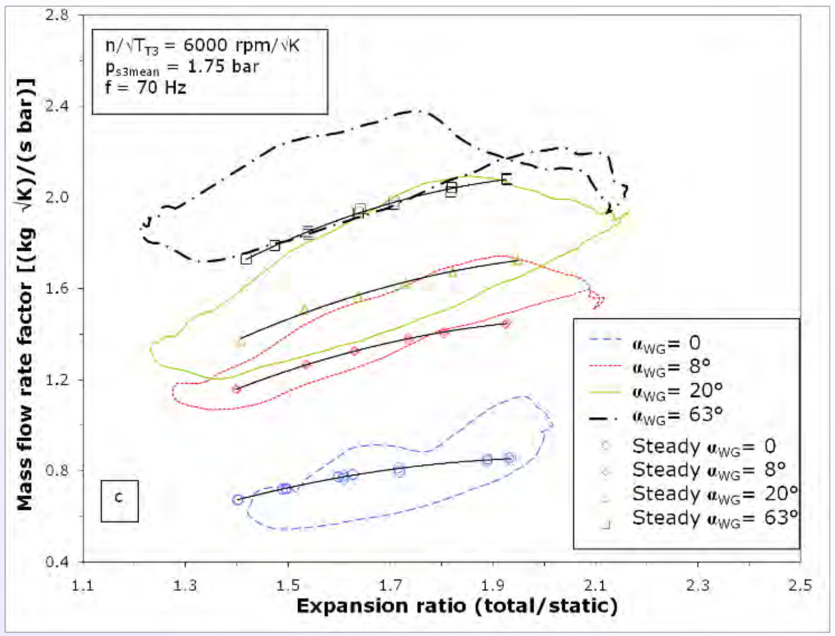
- Measurement of turbocharger steady flow maps over an extended range to improve simulation models results
- Experimental techniques to extend turbocharger steady flow curves
- Turbine performance defined considering the effect of waste-gate valve or VGT
- Turbine efficiency decreases when the waste-gate valve is open (if isentropic power is referred to the total mass flowing through the system)

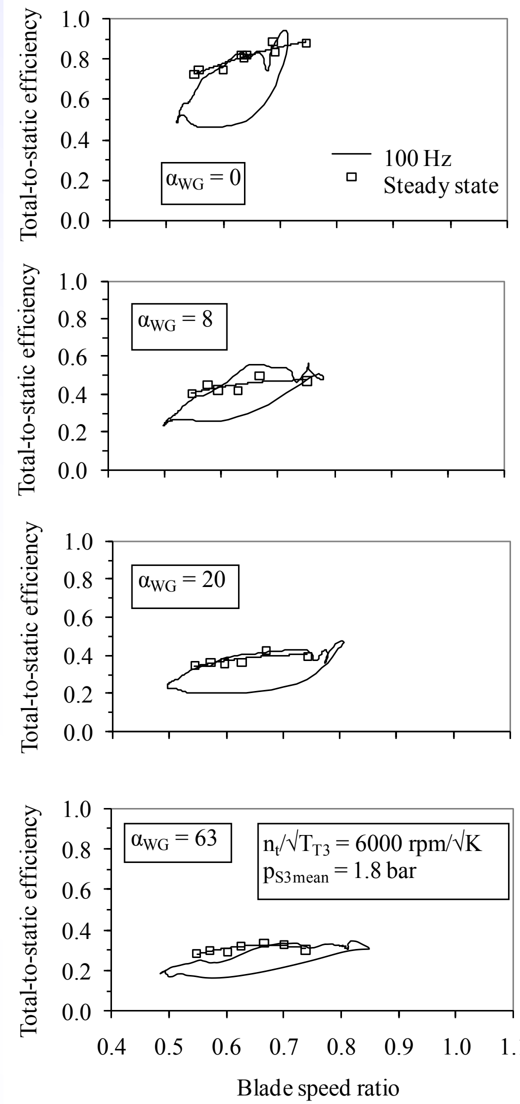




Turbine unsteady performance

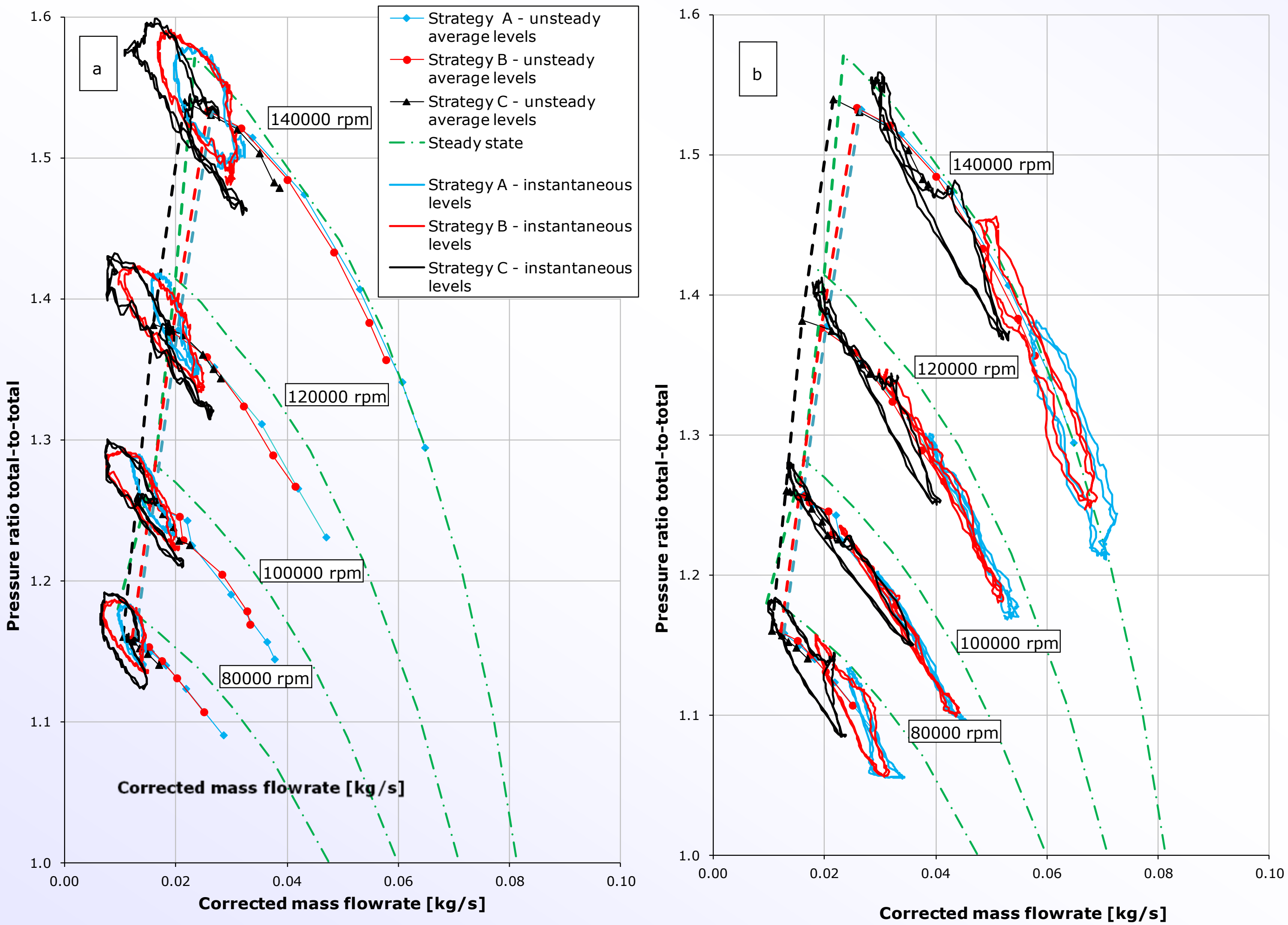
- At typical pulsating flow frequencies occurring in the exhaust system of automotive engines the pulse is so rapid that mass flow does not have enough time to incrementally fill the volute volume with pressure → hysteresis loop
- Deviation of unsteady efficiency from the steady state values
- Loop area variation by changing pulse frequency and waste-gate valve opening





Compressor unsteady performance

2-cylinder configuration



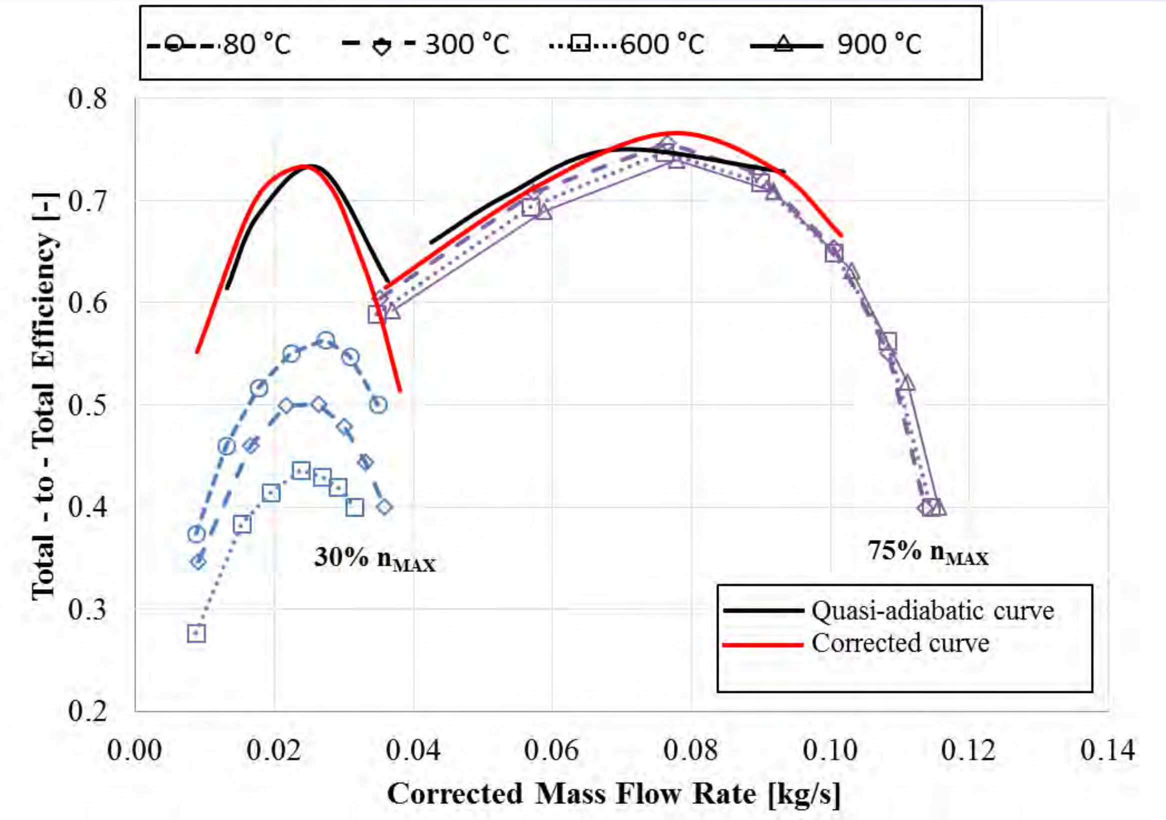
- Significant deviation from steady state resulting in a hysteresis loop surrounding the steady state
- Surge line shifting towards lower mass flow rate levels
- Compressor stable zone enlarged under heavier unsteady flow conditions

Heat transfer effects

- At low n_{TC}, compressor is strongly affected by heat transfer from turbine and oil casing → compressor outlet temperature (T_{T2}) results overestimated
- Significant impact of heat transfer on both compressor and turbine (termo-mechanical) efficiency

$$\eta_c = \frac{T_{T2s} - T_{T1}}{T_{T2} - T_{T1}}$$

$$\eta'_t = \eta_{tTS} \cdot \eta_{mTC} = \frac{P_t}{M_{tot} \cdot \Delta h_{st}} \cdot \eta_{mTC} = \frac{P_c}{M_{tot} \cdot \Delta h_{st}}$$

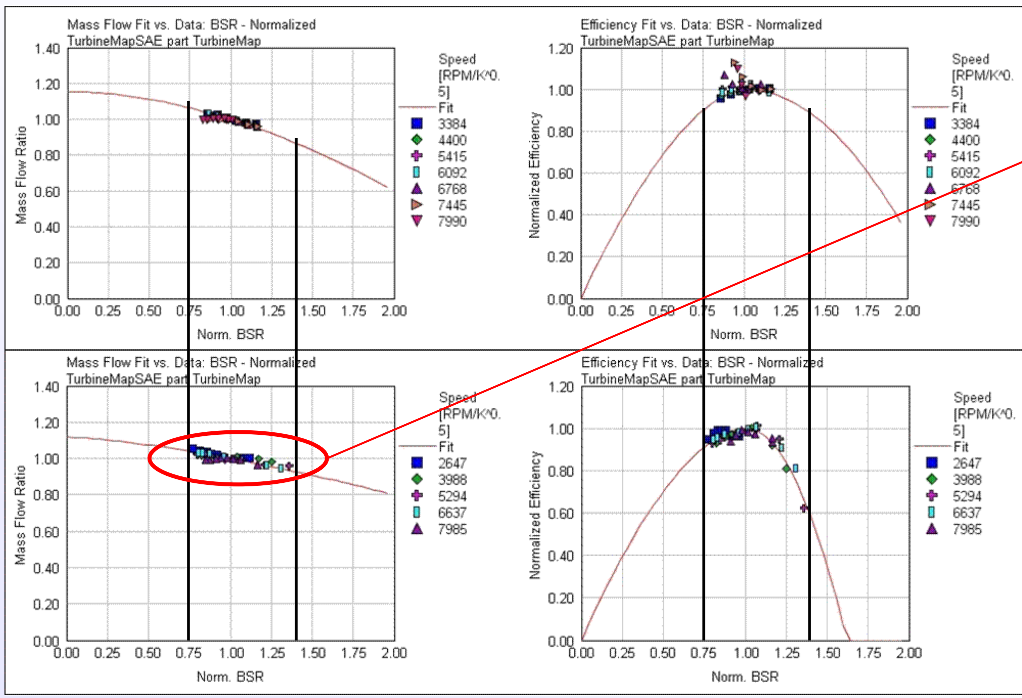


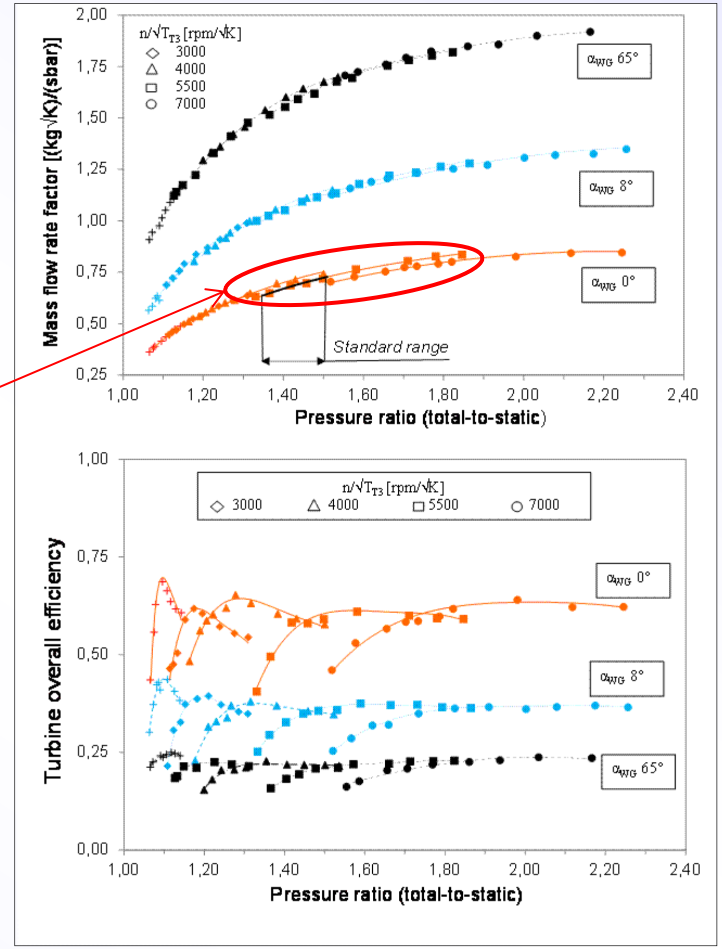
- Development of a specific model to correct TC maps for heat transfer

Modelling activities in GT-Power

Specific studies on turbocharging systems aimed at deepening and improving GT-Power interpolation and extrapolation procedure of turbocharger performance maps and engine-turbocharger matching

- Characteristic curves extension
- Improvement of variable geometry and waste-gate turbine modelling
- Extrapolation of compressor curves on the left side of the surge line

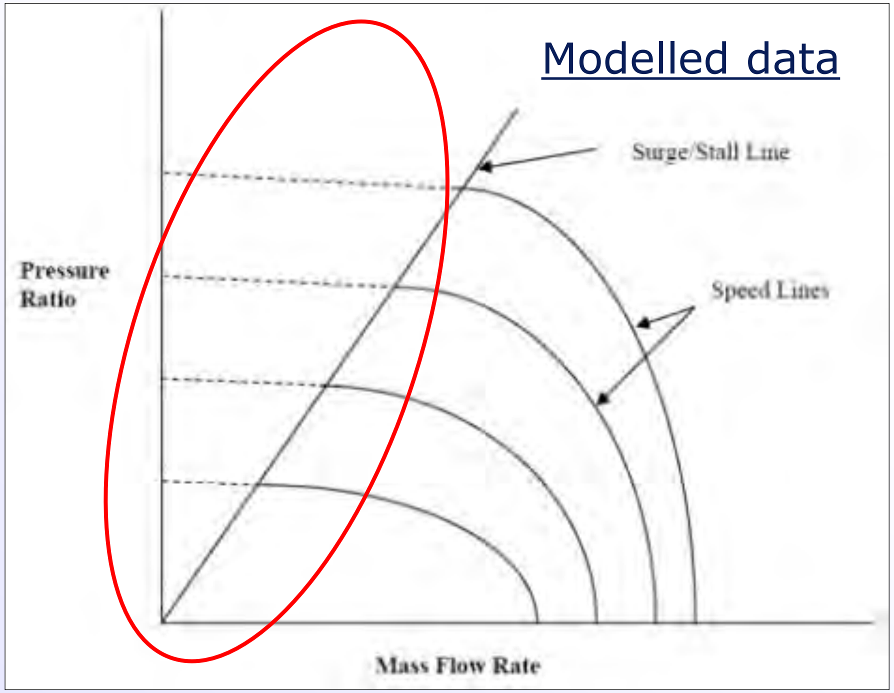


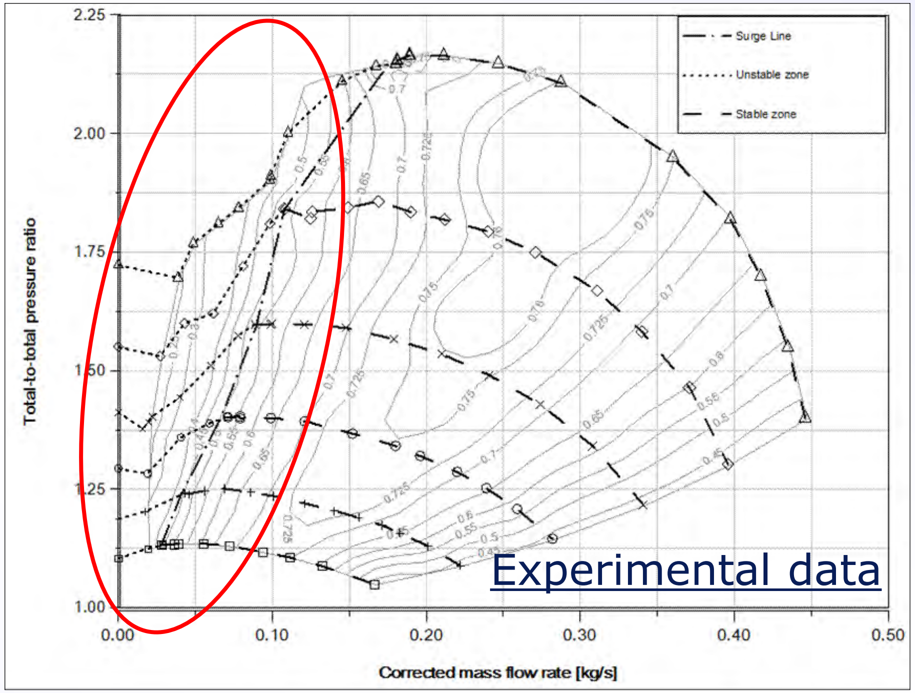


Modelling activities in GT-Power

Specific studies on turbocharging systems aimed at deepening and improving GT-Power interpolation and extrapolation procedure of turbocharger performance maps and engine-turbocharger matching

- Characteristic curves extension
- Improvement of variable geometry and waste-gate turbine modelling
- Extrapolation of compressor curves on the left side of the surge line





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
- Compressor surge detection and active control
- Interactions between EGR and turbocharging circuits
- Effect of aftertreatement device position on turbocharger performance
- E-boosting systems
- Subassembly characterization (TC + engine I/E circuit)
- …..

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

Some ICEG References on I/E Components

- M. Capobianco, A. Gambarotta, "Unsteady flow performance of turbocharger radial turbine", 4th International Conference on Turbocharging and Turbochargers, 1990.
- M. Capobianco, A. Gambarotta, "Variable geometry and waste-gated automotive turbochargers: measurements and comparison of turbine performance", ASME Transactions, Journal of Engineering for Gas Turbine and Power, 1992.
- M. Capobianco, A. Gambarotta, "Performance of a twin-entry automotive turbocharger turbine", ASME Energy-Sources Technology Conference and Exhibition, 1993.
- M. Capobianco, S. Marelli, "Turbocharger turbine performance under steady and unsteady flow: test bed analysis and correlation criteria", 8th International Conference on Turbochargers and Turbocharging, 2006.
- M. Capobianco, S. Marelli, "Waste-gate turbocharging control in automotive SI engines: effect on steady and unsteady turbine performance", SAE paper 2007-01-3543, 2007.
- F. Piscaglia, A. Onorati, S. Marelli, M. Capobianco "Unsteady Behavior In Turbocharger Turbines: Experimental Analysis And Numerical Simulation", SAE Paper 2007-24-0081, 2007.
- S. Marelli, M. Capobianco, "Steady and pulsating flow efficiency of a waste-gated turbocharger radial flow turbine for automotive application", Energy 36, pages 459-465, doi: 10.1016/j.energy.2010.10.019, 2011.
- F. Bozza, V. De Bellis, S. Marelli, M. Capobianco, "1D Simulation and Experimental Analysis of a Turbocharger Compressor for Automotive Engines under Unsteady Flow Conditions", SAE Paper 2011-01-1147, 2014.
- S. Marelli, M. Capobianco, G. Zamboni, "Pulsating Flow Performance of a Turbocharger Compressor for Automotive Application", Int. J. of Heat and Fluid Flow 45, pages 158-165, doi: 10.1016/j.ijheatfluidflow.2013.11.001, 2014.
- S. Marelli, C. Carraro, G. Marmorato, G. Zamboni, M. Capobianco , "Experimental Analysis on Steady Flow Performance under Unstable Operating Conditions and on Surge Limit of a Turbocharger Compressor", Experimental Thermal and Fluid Science 53, pages 154-160, doi: 10.1016/j.expthermflusci.2013.11.025, 2014.
- S. Marelli, G.Marmorato, M. Capobianco, A. Rinaldi, Heat transfer effects on performance map of a turbocharger compressor for automotive application, SAE Technical paper no. 2015-01-1287, 2015.
- S. Marelli, S. Gandolfi, M. Capobianco, Experimental and Numerical Analysis of Mechanical Friction Losses in Automotive Turbochargers, SAE Technical paper no. 2016-01-1026, 2016.

Assessment of road vehicles environmental impact in real-world conditions

Road vehicles emissions in real-world conditions

The main investigations developed in this field are focused on:

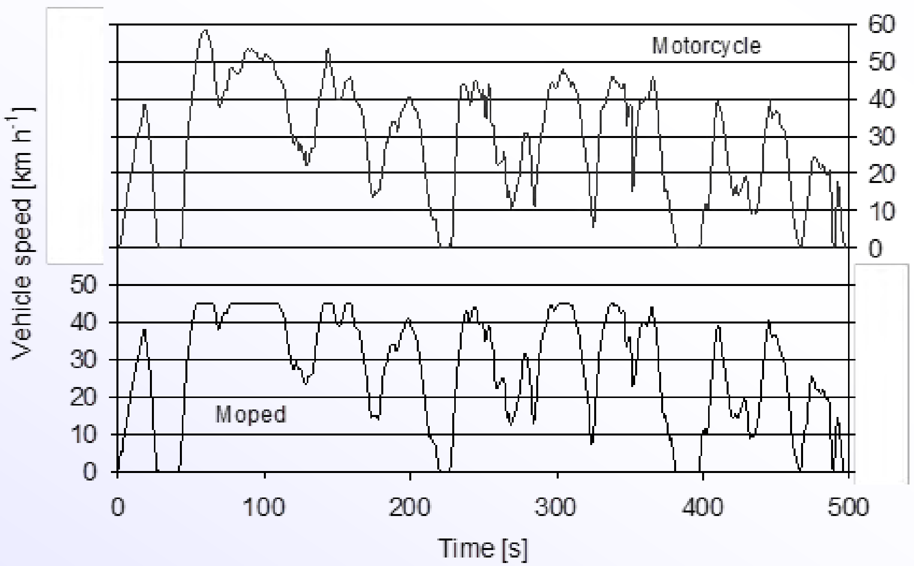
- Definition of hot and cold exhaust emission factors for pollutants (CO, HC, NO_X, NO_2, CO_2 and PM) referred to different vehicle categories (passenger cars, light and heavy duty vehicles, buses, motorcycles, mopeds, waste collection vehicles)
- Development of experimental and/or statistical methodologies for the assessment of the real circulating fleet and mileage and the definition of typical trips with the relevant driving characteristics
- Development and application of a dedicated theoretical model (PROGRESS code) to predict the environmental impact of road vehicles in urban areas

Next step:

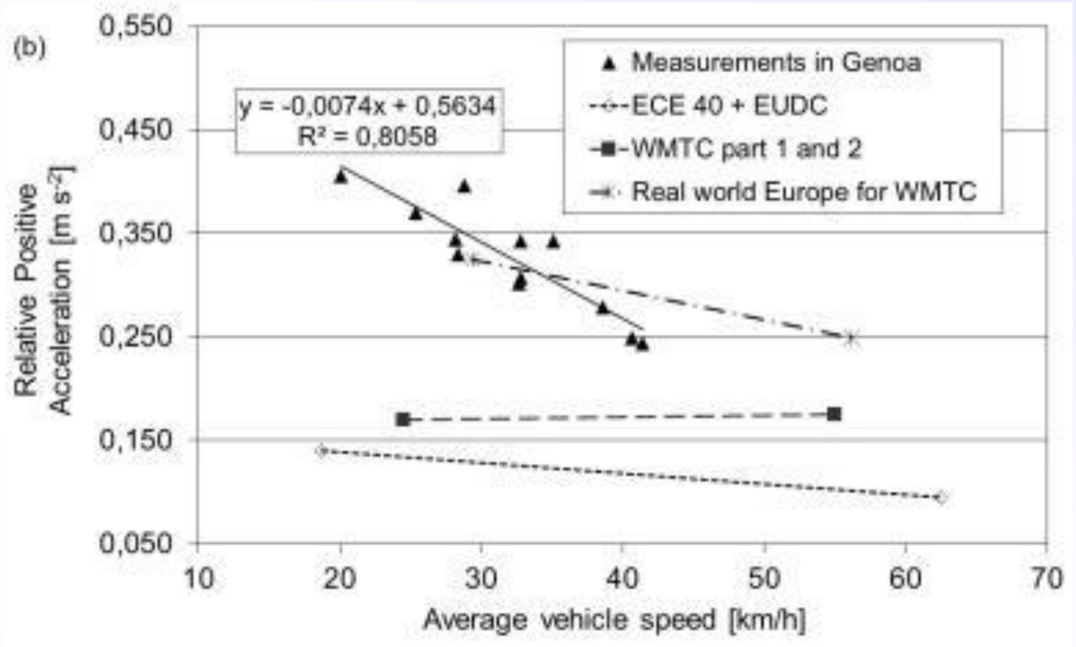
- Vehicles modeling in GT-Suite environment to compare emissive and energy behavior on different driving cycles

Motorcycles and mopeds behavior in cold start and hot conditions (in co-operation with Istituto Motori-CNR)

- Analysis of the influence of driving cycles and real world speed patterns on hot and cold emission factors
- Effects of engine and catalyst operation on exhaust emissions in the cold transient phase



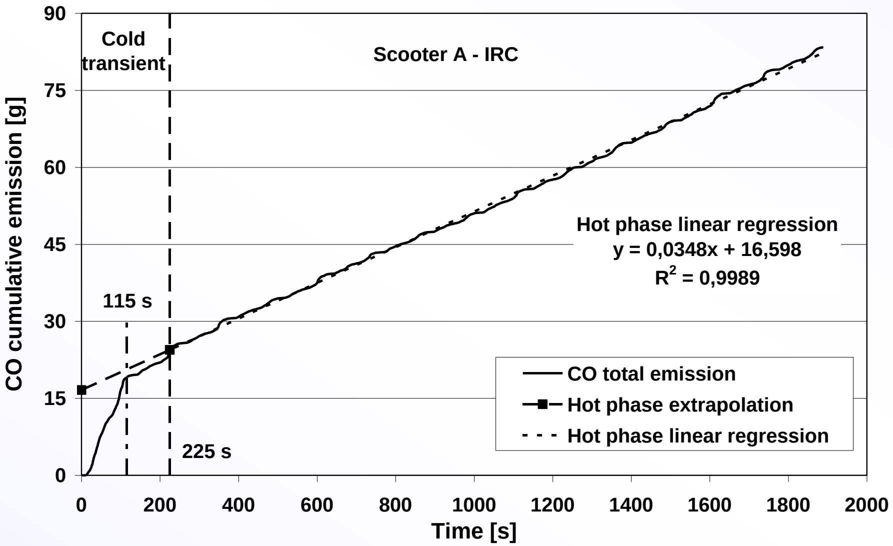
Genoa experimental speed patterns

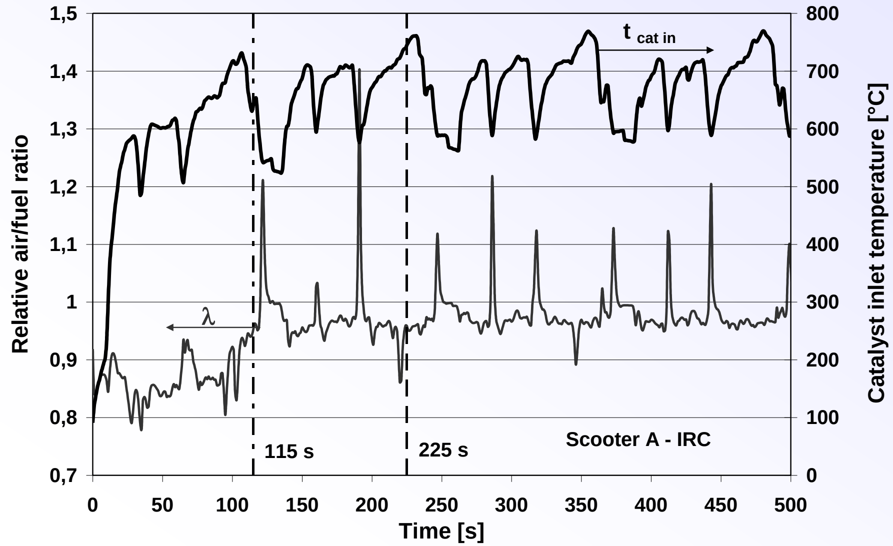


Measured levels of speed above UDC and comparable to WMTC

RPA levels (that is, cycle dynamics) significantly higher in real conditions

Motorcycles and mopeds behavior in cold start and hot conditions (in co-operation with Istituto Motori-CNR)



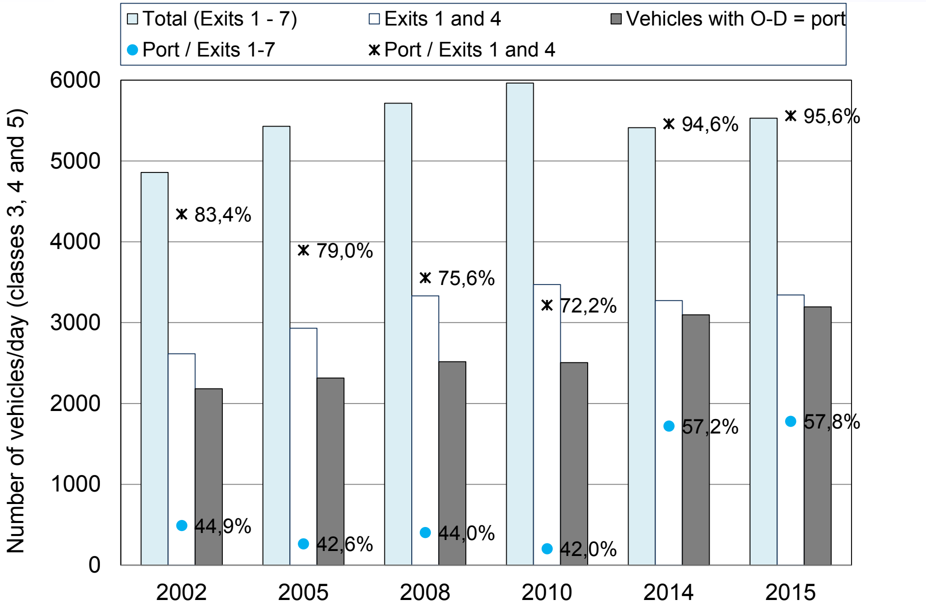


CO cumulative emissions, relative air/fuel ratio and catalyst temperature during a real world driving cycle

Driving cycle/speed pattern	CO	HC	NO_x	Fuel consumption
ECE 47	68.8	72.9	-	6.5
IUFC (real world)	32.3	53.5	27.8	6.9
24-slow (Genoa speed pattern)	39.5	52.3	26.2	9.3
3-slow (Genoa speed pattern)	35.6	48.4	6.9	7.6

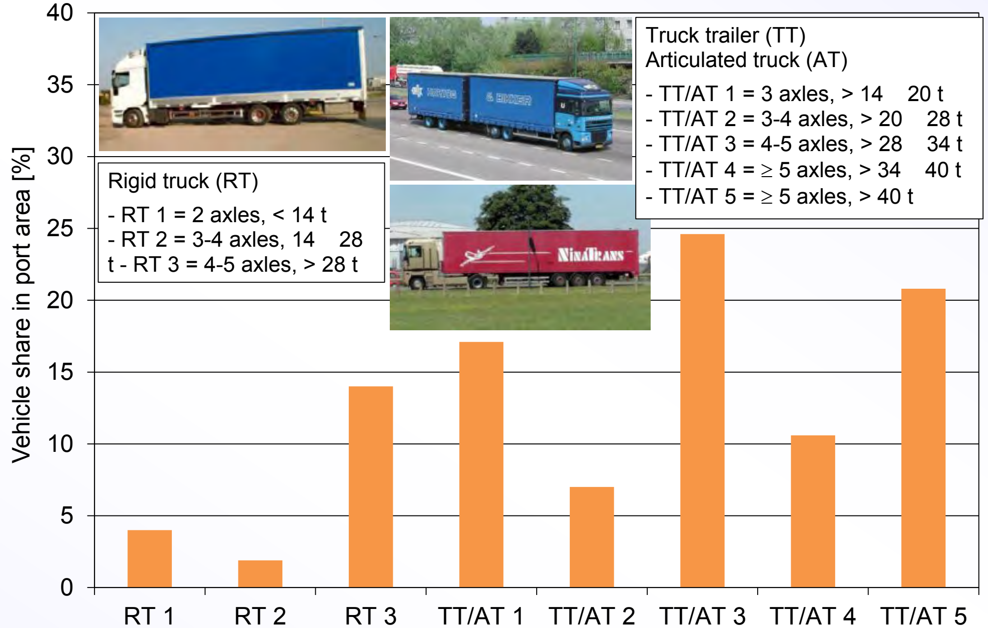
Cold contribution as percentage of the total emission and fuel consumption on different driving cycles – Euro 2 moped

HDV Activities in Genoa Port Area
(in co-operation with Lab. Transports et Environnement – IFSTTAR)

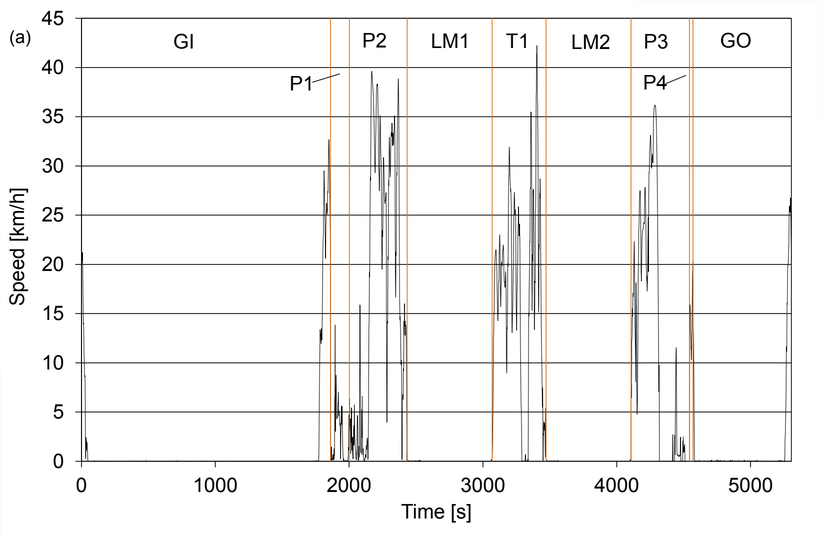


Definition of HDV daily flows through highway exits and share of vehicles entering port terminals

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

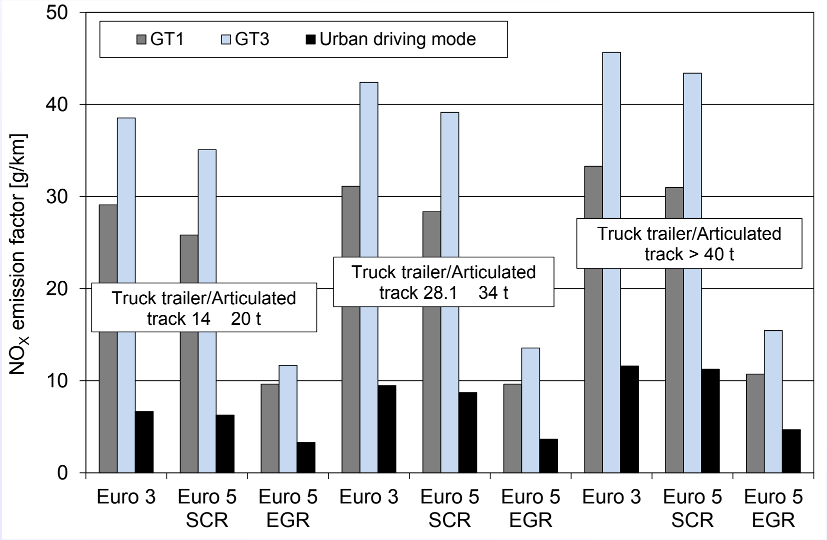


HDV Activities in Genoa Port Area
(in co-operation with Lab. Transports et Environnement – IFSTTAR)



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

Recent papers from ICEG on road vehicle emissions

- G. Zamboni, M. Capobianco, E. Daminelli, Estimation of road vehicle exhaust emissions from 1992 to 2010 and comparison with air quality measurements in Genoa, Italy. Atmospheric Environment 43, pages 1086-1092, 2009, doi:10.1016/j.atmosenv.2008.11.014.
- G. Zamboni, C. Carraro, M. Capobianco, On-road instantaneous speed measurements on powered two-wheelers for exhaust emissions and fuel consumption evaluation. Energy 36, pages 1039-1047, 2011, doi: 10.1016/j.energy.2010.12.004.
- M.V. Prati, G. Zamboni, M.A. Costagliola, G. Meccariello, C. Carraro, M. Capobianco, Influence of driving cycles on Euro 3 scooter emissions and fuel consumption. Energy Conversion and Management, 52, pages 3327-3336, 2011, doi: 10.1016/j.enconman.2011.06.004.
- G. Zamboni, M.V. Prati, C. Carraro, S. Malfettani, M.A. Costagliola, G. Meccariello, S. Marelli, M. Capobianco, Influence of Driving Cycles on Powered Two-Wheelers Emissions, Fuel Consumption and Cold Start Behavior. SAE Technical Paper 2013-01-1048, doi:10.4271/2013-01-1048.
- G. Zamboni, S. Malfettani, M. André, C. Carraro, S. Marelli, M. Capobianco, Assessment of heavy-duty vehicle activities, fuel consumption and exhaust emissions in port areas. Applied Energy, vol. 111, pp. 921-929, 2013, doi: 10.1016/j.apenergy.2013.06.037.
- G. Zamboni, M. André, A. Roveda, M. Capobianco, 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, vol.35, pp.1-10, 2015, doi: 10.1016/j.trd.2014.11.024.
- G. Zamboni, M. André, Evaluation of emissions and fuel consumption of Heavy-Duty Vehicles in urban areas, 21st Transport and Air Pollution Conference, Lyon, 24-26 May 2016.

Thank you for the attention!

Contacts

- **Massimo Capobianco**
  phone +39.010.353.2446 mobile +39.328.1004793
  e-mail massimo.capobianco@unige.it
- **Silvia Marelli**
  phone +39.010.353.2443 mobile +39.335.8726110
  e-mail silvia.marelli@unige.it
- **Giorgio Zamboni**
  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