Università di Genova
DIME DIPARTIMENTO
DI INGEGNERIA MECCANICA, ENERGETICA,
GESTIONALE E DEI TRASPORTI

Giornata di Studio

«Idrogeno e tecnologie per la generazione energetica e la propulsione nei trasporti green»

The Role of Boosting Technologies in Hydrogen Propulsion Systems

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H2: a new chapter for ICEs?

170 years

Property	Unit	Gasoline	Hydrogen
Stochiometric Ratio (α_s)	-	14,7	34,3
Flammability limits (Φ)	-	0,7-4	0,1-7,1
Density @15,6°C,@1 bar	$[kg/dm^3]$	0,75	0,07
Octane number	-	~95	~120
Minimum ignition energy	$[mJ]$	0,24	0,02

Ultra-Lean

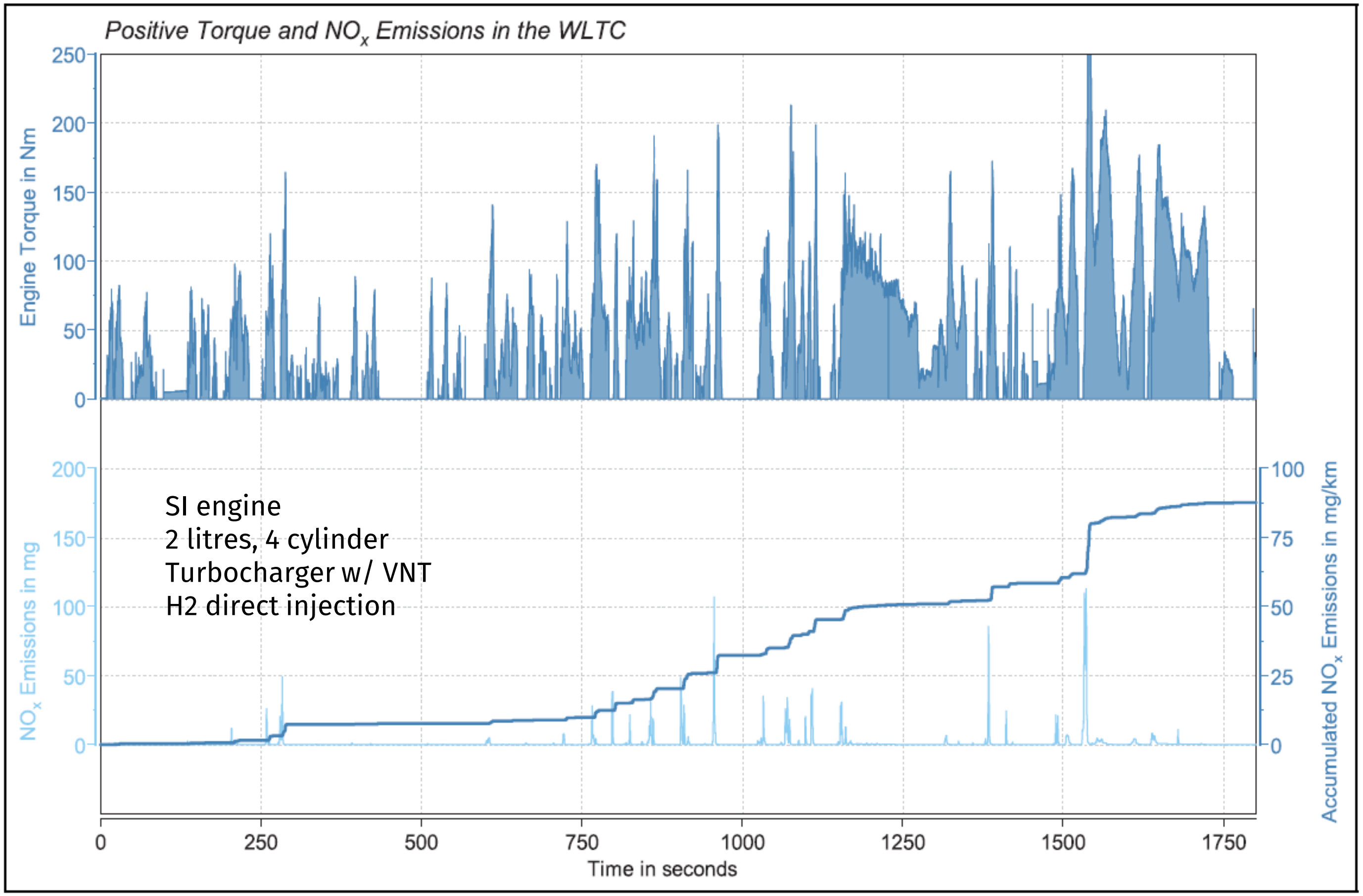
Storage

Knock

Pre-ignition

NOx formation in H2 ICEs

NOx emissions are predominantly formed in **ultra-lean H2 ICEs** when load changes occur or the engine is operated at high loads, where the **boost pressure** or the **time-to-boost** is insufficient.

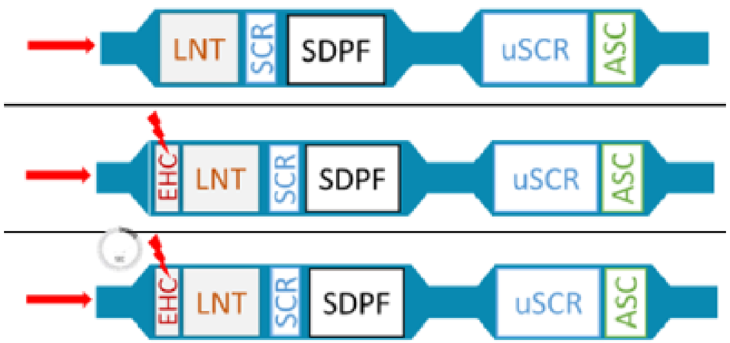


Roiser, S., Christoforetti, P., Schutting, E., Eichlseder, H. "Emission behaviour and aftertreatment of stationary and transient operated hydrogen engines“ International Journal of Engine Research, 2023

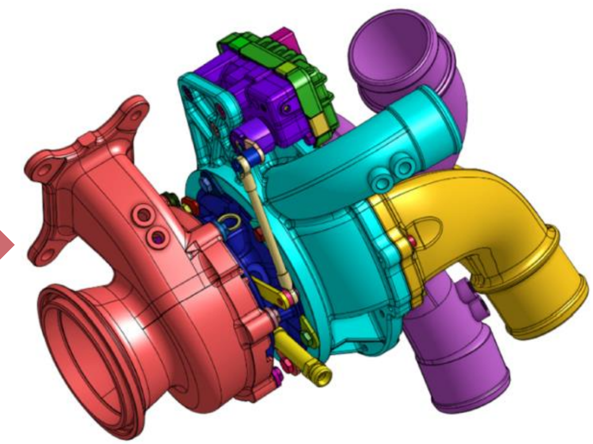
Why boost an H2 ICE?

Avoid complex aftertreatment systems

Boosting system with high boost pressure and fast transient response



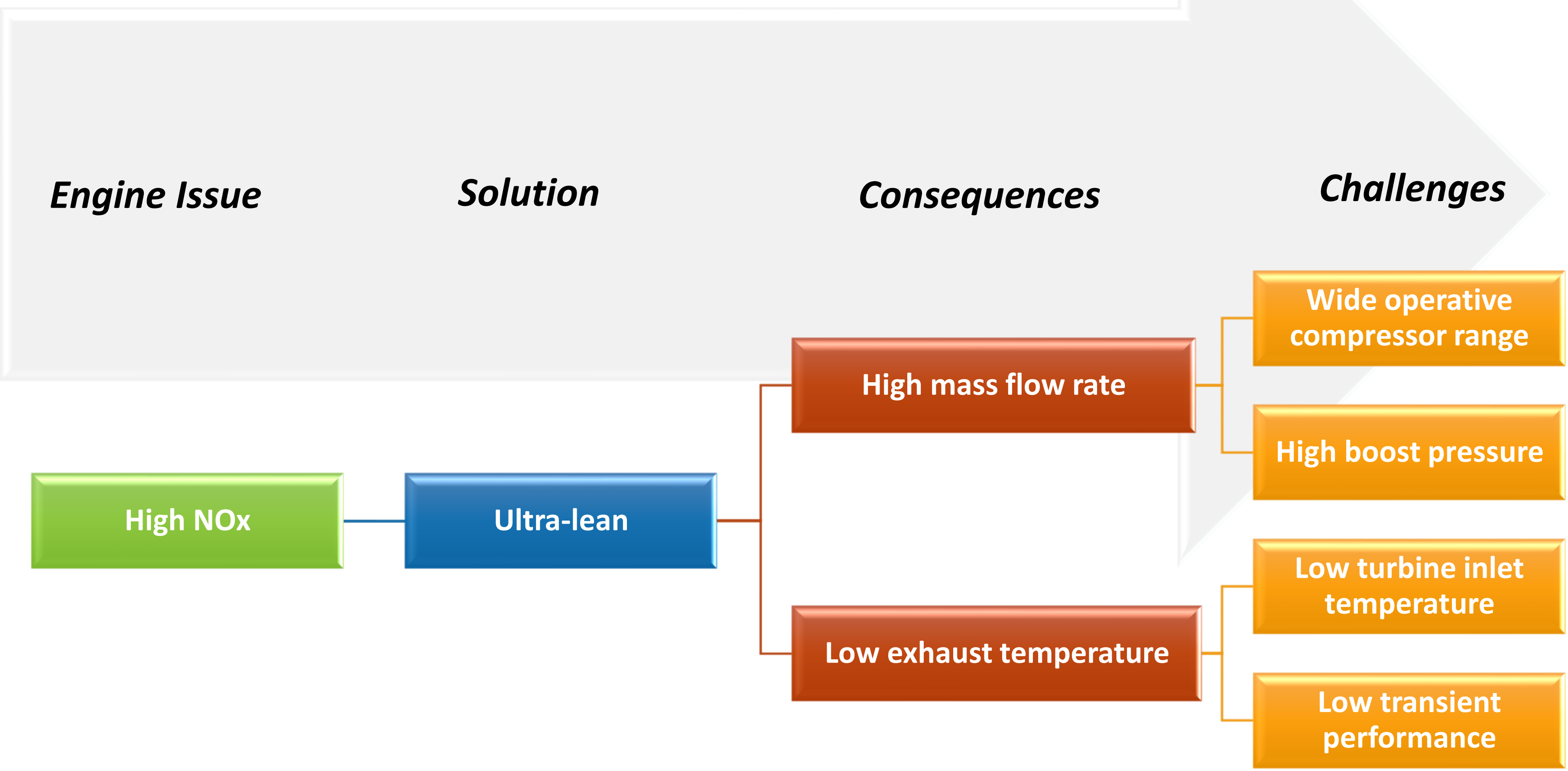
Solution



Samaras, Z.C., et al, "A European Regulatory Perspective towards a Euro 7 Proposal" SAE Technical Papers, 2022.

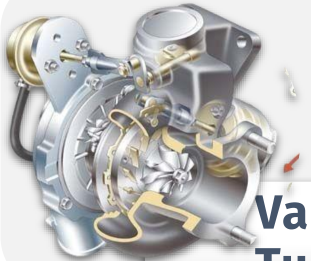
Bontemps, N., et al, "SC-VNT™ a route toward high efficiency for Gasoline Engines " Proceedings of 14th International Conference on Turbochargers and Turbocharging, 2021.

Challenges of boosting an H2 ICE



Akar, F., Jaeger, L., Pribyl, P., Davies, P., "Novel Boosting Solution for the Challenges of H2-ICE," Proceedings of 19th Symposium Sustainable Mobility, Transport and Power Generation, 2023.

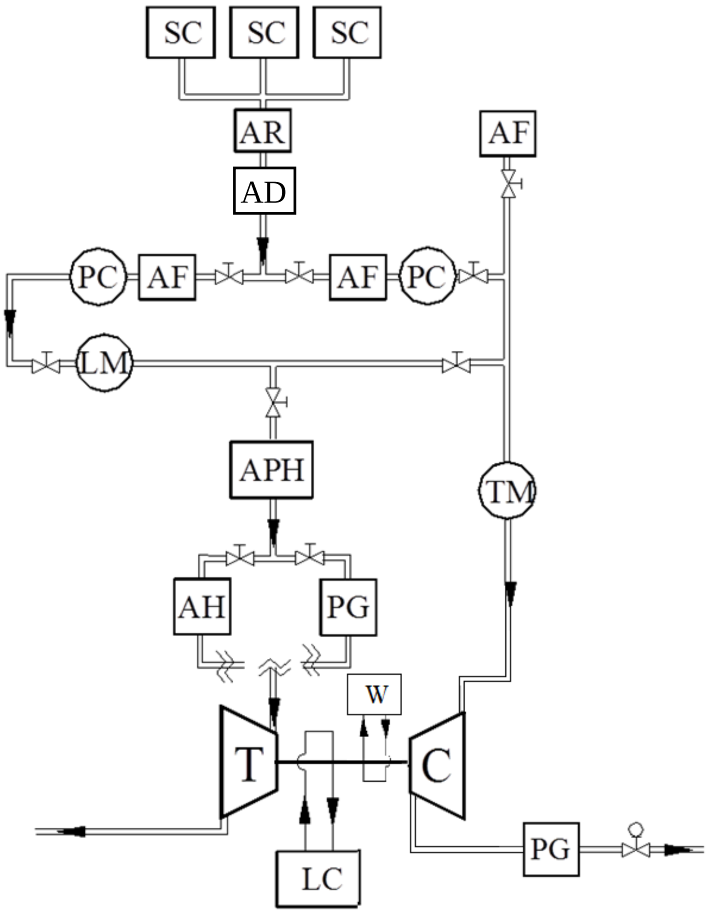
Boosting architecture for H2 ICE
Traditional solution



- VNT
- Multi-entry turbine
- 2stage

- 2stage w/ e-booster
- E-turbo

Test bench for components of propulsion system

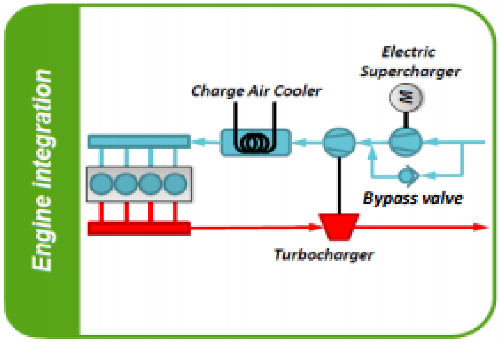


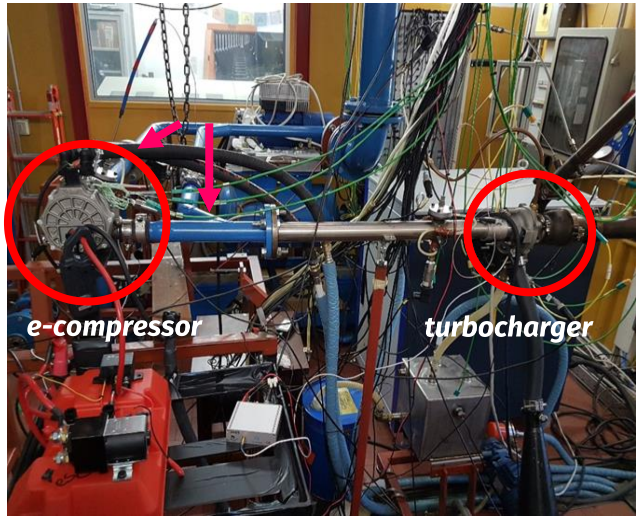
AD	Air Dryer	LM	Laminar Flow Meter
AF	Air Filter	PC	Pressure Control
AH	Air Heater	PG	Pulse Generator
APH	Air Pre-Heater	SC	Screw Compressor
AR	Air Reservoir	T	Turbine
C	Compressor	TM	Thermal Mass Flow Meter
LC	Lubricating Circuit	W	Water Cooling Circuit

- “Cold” (about 400 K) and “hot” (max 1000 K) air tests on components and subassemblies
- Maximum available air flow rate 0.8 kg/s at 8 bar
- Particularly suitable to test turbochargers: two independent feeding lines available for the TC turbine and compressor
- Electrical air heating modular system (max power 320 kW, maximum turbine inlet temp. 600 °C)
- Availability of water cooling and lubricating oil circuits characterized by controlled working temperatures, mass flow and pressures
- For automotive application, turbine and compressor performance can be investigated under unsteady flow by using two different pulse generator systems:
  - Rotating valves pulse generator
  - Cylinder head pulse generator

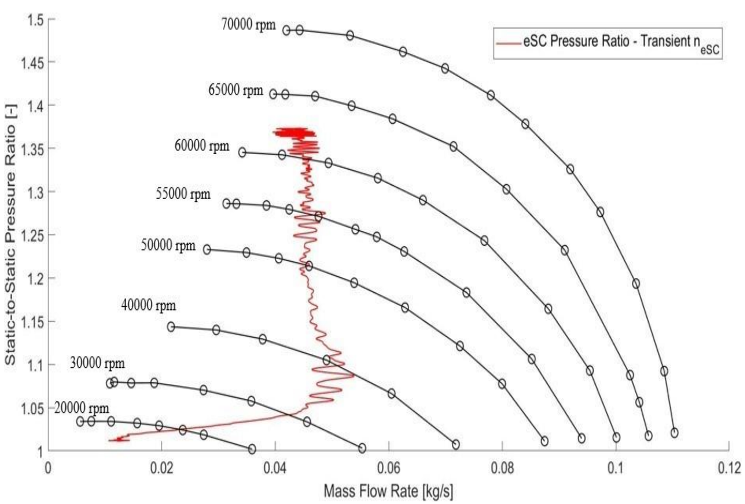
Results - Time-to-boost

Integration of a low voltage battery emulator by AVL to supply the e-compressor.

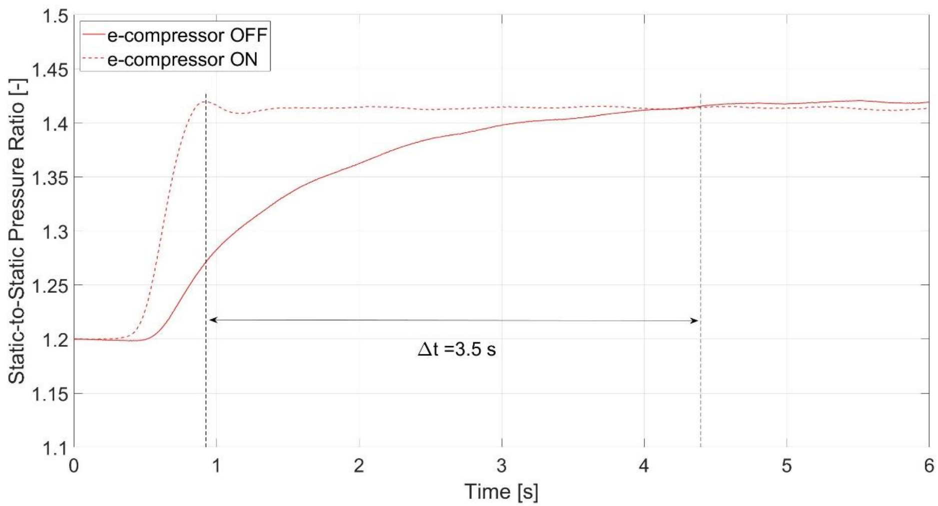




Fast and **stable transient operation** achieved without the need for scavenging strategies



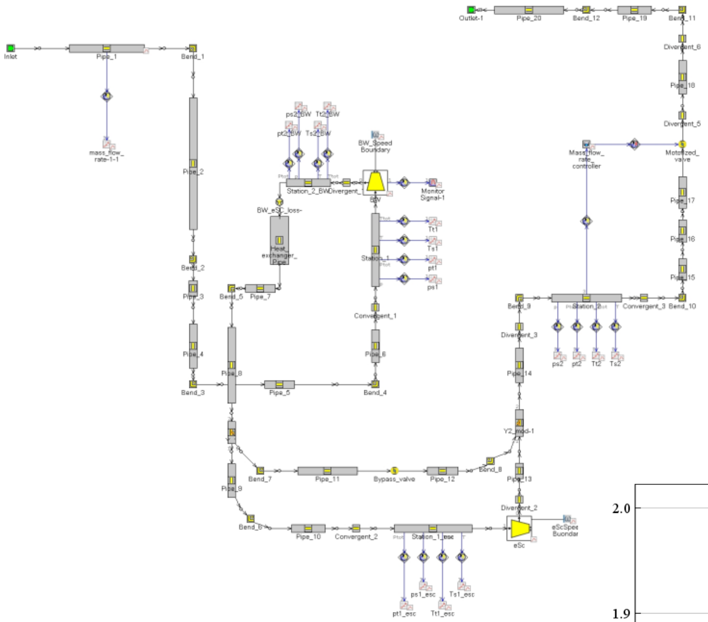
Significant **reduction of the time-to-boost** when the e-compressor is activated.



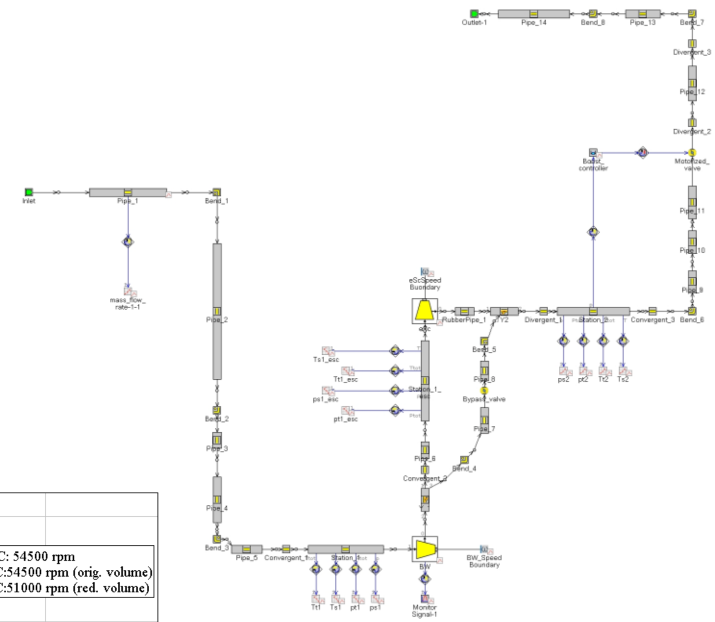
Marelli, S., Usai, V., "Experimental analysis and 1D simulation of an advanced hybrid boosting system for automotive applications in transient operation," International Journal of Engine Research, 2023.

Results - Time-to-boost

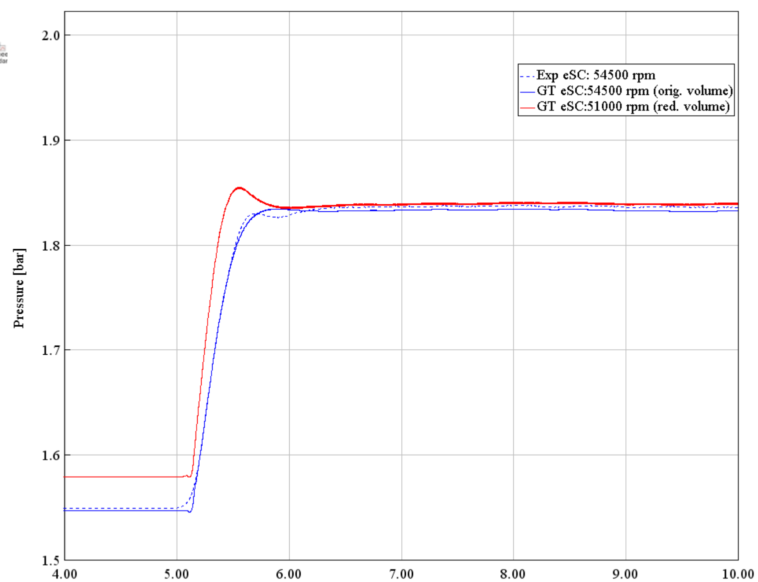
Experimental layout



Reduced volume layout



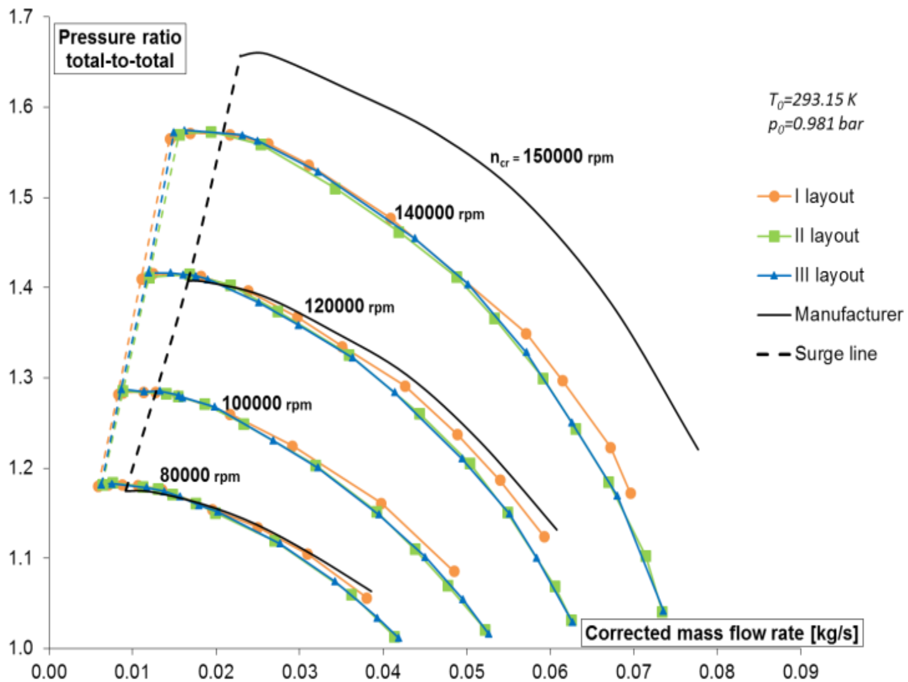
Validation of the model over steady and transient experimental data

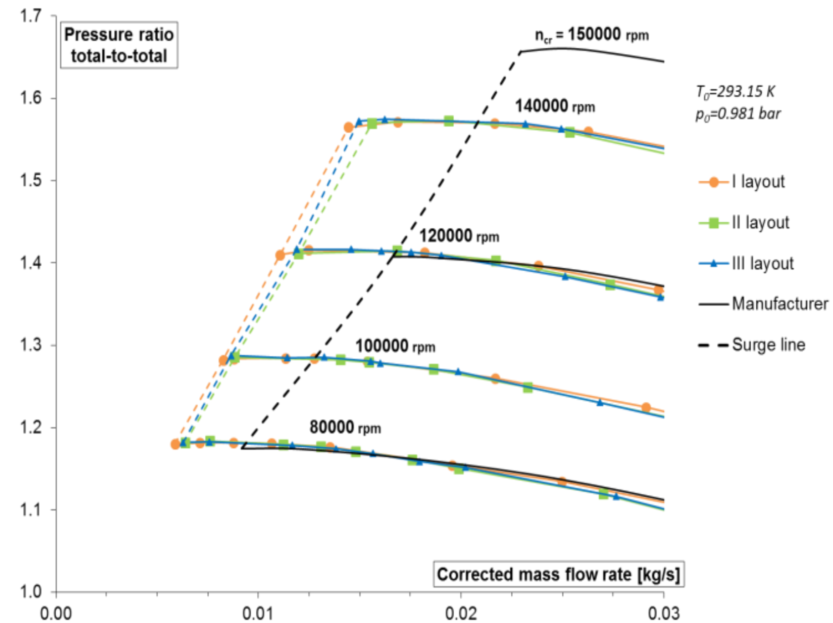


Evaluate different layouts with different volume and length

Results – Compressor surge line definition

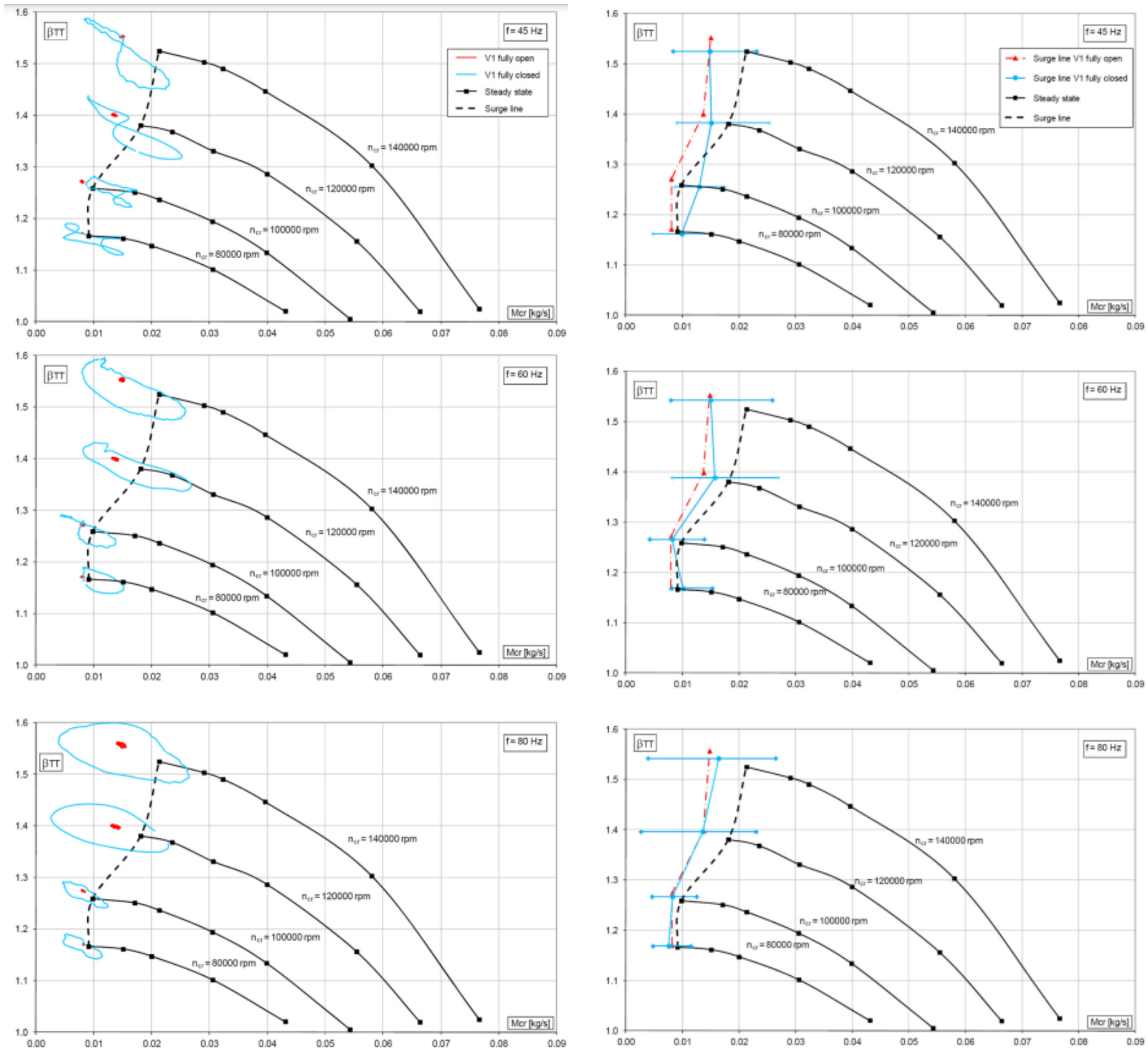
Need to measure compressor steady flow map considering the **intake circuit geometry**
(with special reference to surge line position and maximum mass flow rate)

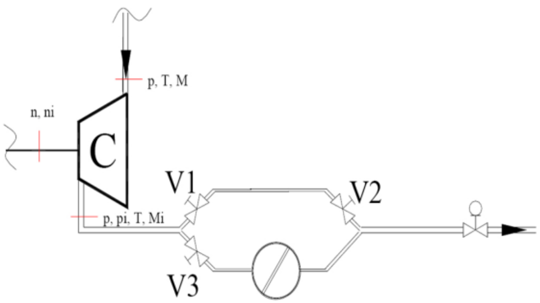




Marelli, S., Carraro, C., Moggia, S., Capobianco, M., ” Effect of Circuit Geometry on Steady Flow Performance of an Automotive Turbocharger Compressor,” Energy Procedia, 2016

Results – Compressor unsteady flow



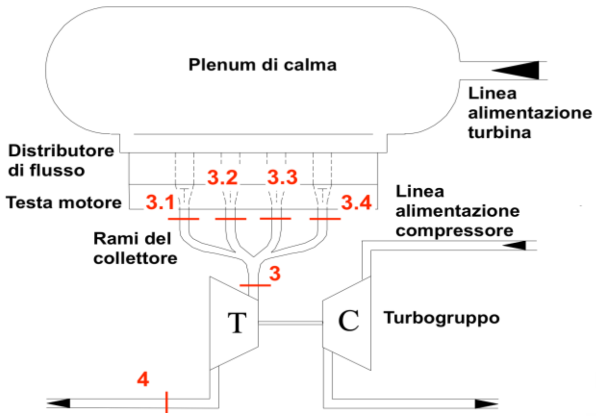


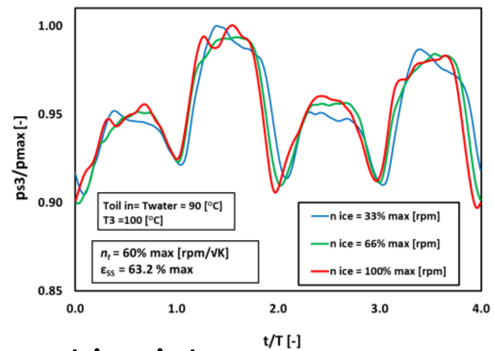
When flow unsteadiness becomes prominent, the pulse frequency has the effect of deviating the surge line position towards a **lower mass flow** rate level.

It's highlighted that under pulsating flow conditions, the compressor **stable zone is enlarged**.

Marelli, S., Carraro, C., Capobianco, M., "Effect of Pulsating Flow Characteristics on Performance and Surge Limit of Automotive Turbocharger Compressors," SAE International Journal of Engines, 2012

Results – Turbine unsteady flow



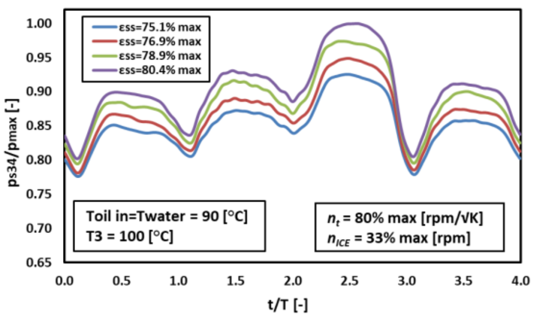


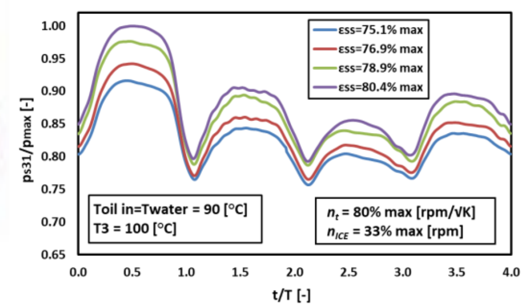
Pressure diagrams are measured in various sections of the exhaust circuit to highlight **wave propagation and reflection** phenomena.

Turbine inlet

Branch 4

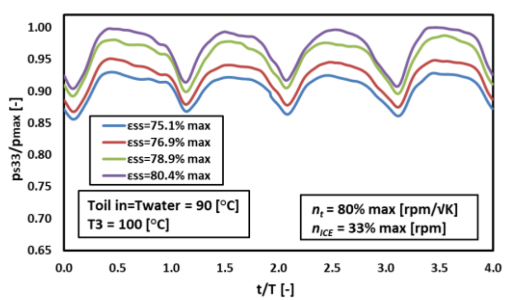
Branch 1

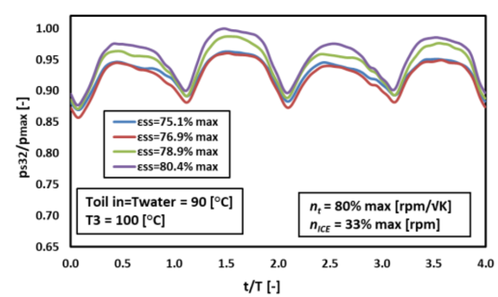




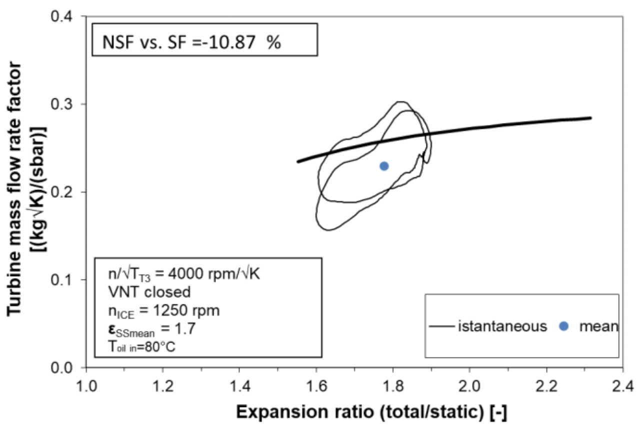
Branch 3

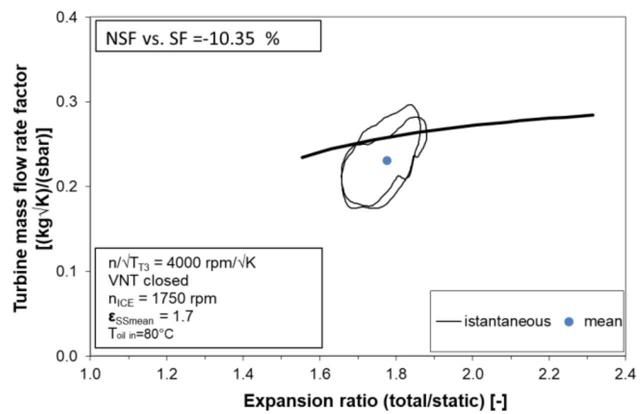
Branch 2

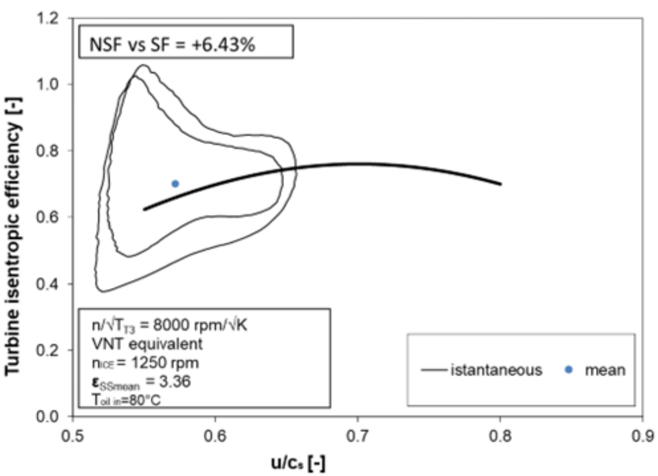


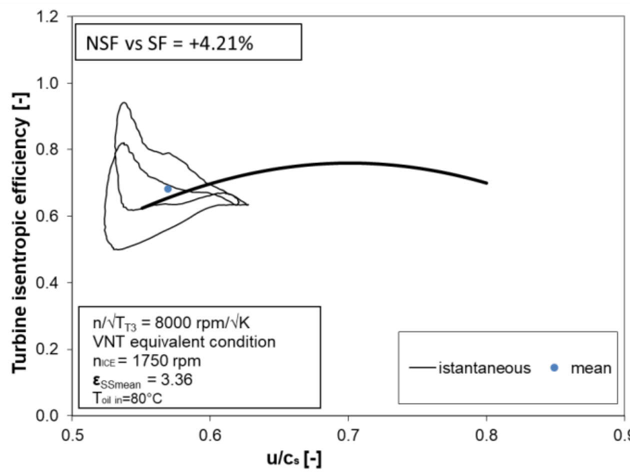


Results – Turbine unsteady flow







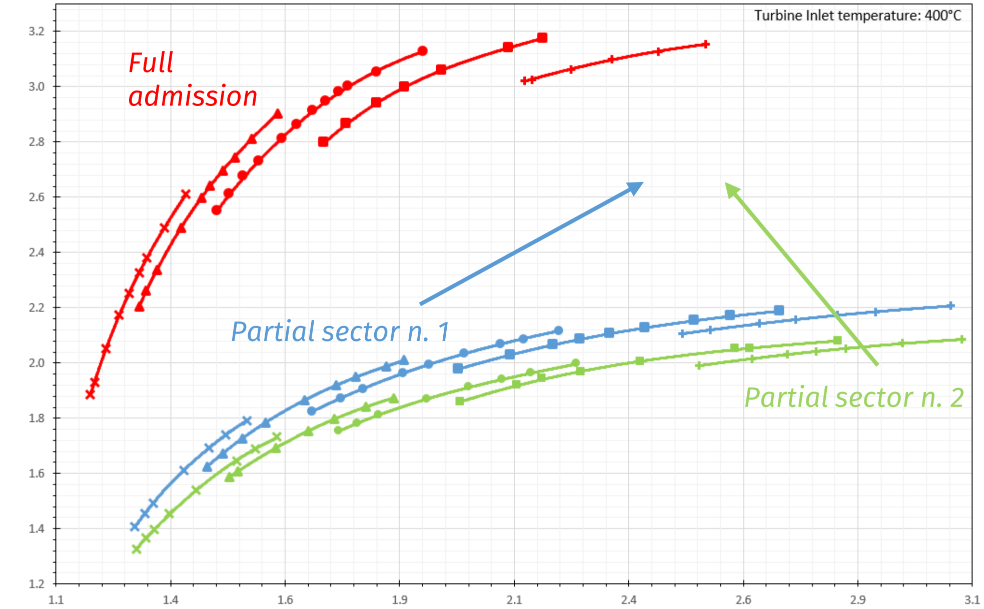


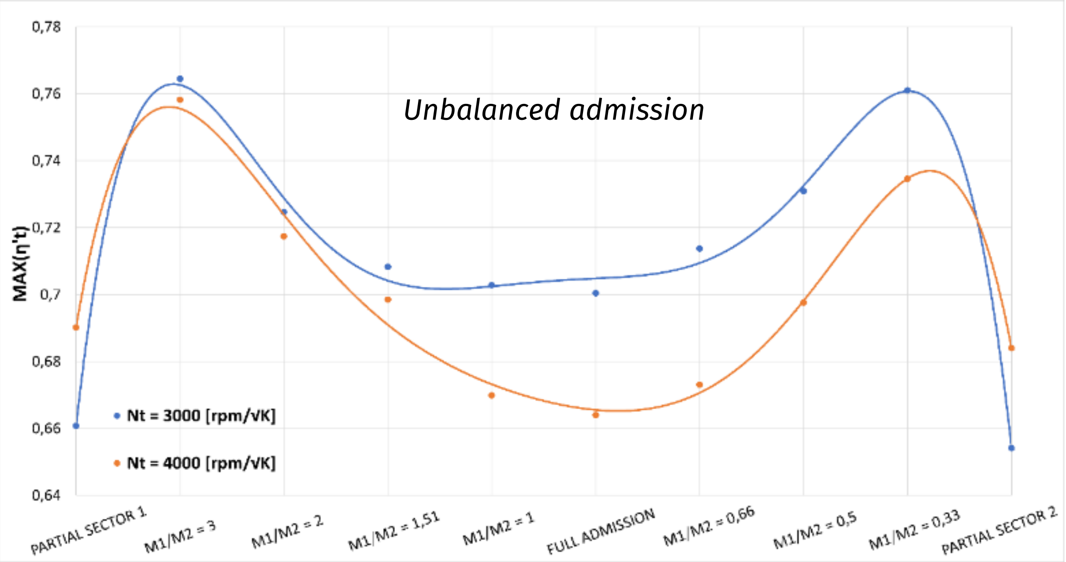
The **filling** and **emptying** of the volute are highlighted by the hysteresis loop surrounding the steady-state curve.

At typical automotive engine pulsating flow frequencies, the pulse is so rapid that the volute volume does not incrementally fill with pressure, resulting in the observed **hysteresis loop** between the measured mass flow rate and pressure.

Marelli, S., Capobianco, M., " Measurement of Instantaneous Fluid Dynamic Parameters in Automotive Turbocharging Circuit," SAE Technical Paper, 2009.

Results – Twin entry turbine





Specific layout to perform parametric studies on twin entry turbine in full, partial and unequal admission

Usai, V., Marelli, S. "Steady state experimental characterization of a twin entry turbine under different admission conditions," Energies, 2021

Contacts

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