Experimental analysis and one-dimensional modeling of heat transfer phenomena in turbochargers for internal combustion engines

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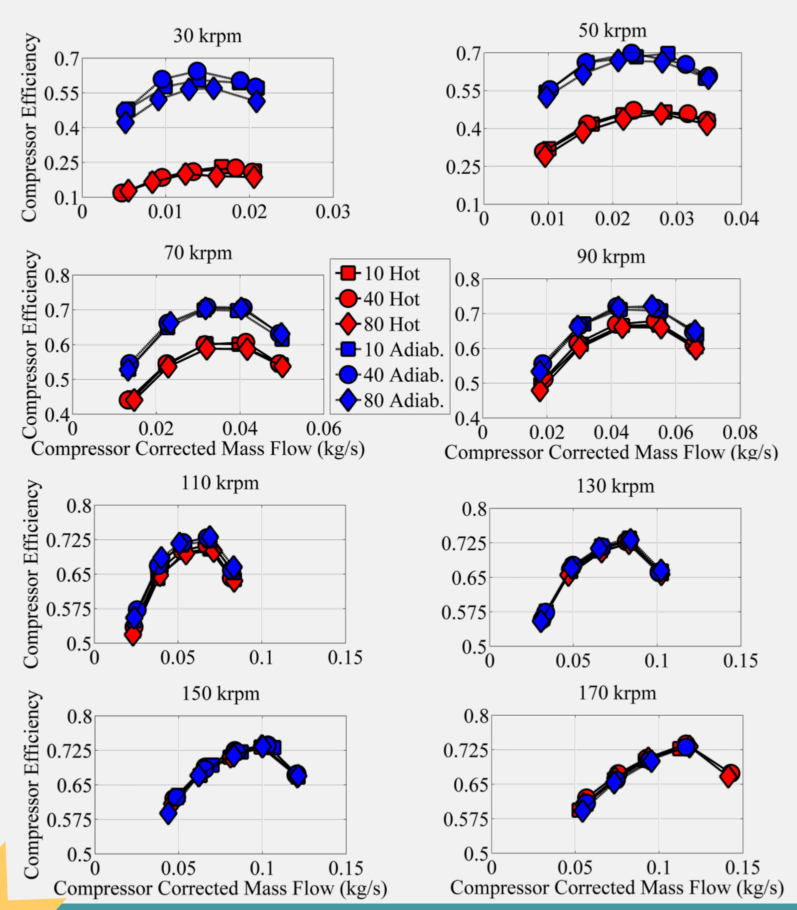
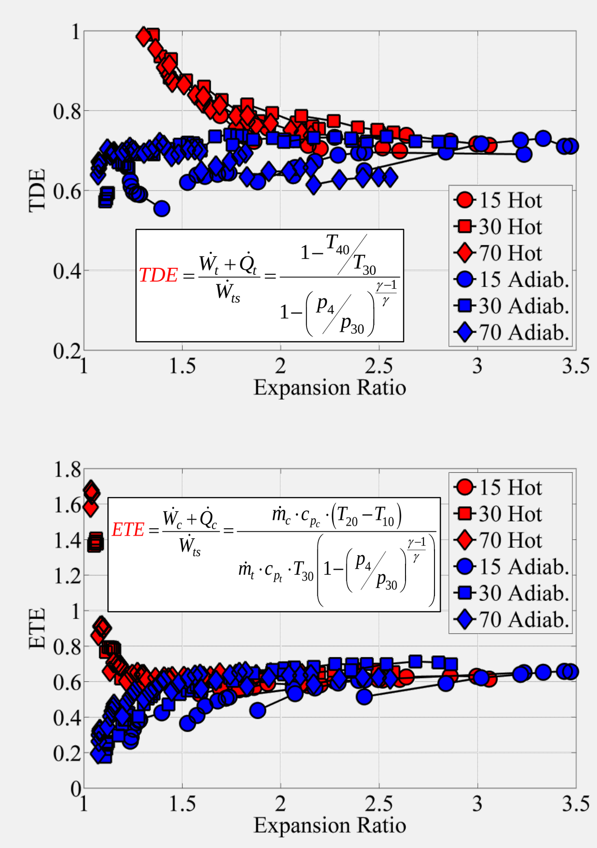
Introduction and Objectives

Experimental and 1D-modelling effort to:

- ❑ Study and analyze experimentally the effect of heat transfer.
- ❑ Identify variables that are strongly affected by heat transfer.
- ❑ Quantify the effect of these phenomena on engine operation.
- ❑ Develop a methodology to take into account all these effects.
- ❑ Validate the developed model against experimental data.
- ❑ Propose a general methodology to obtain heat transfer properties

Gas stand hot and adiabatic steady tests

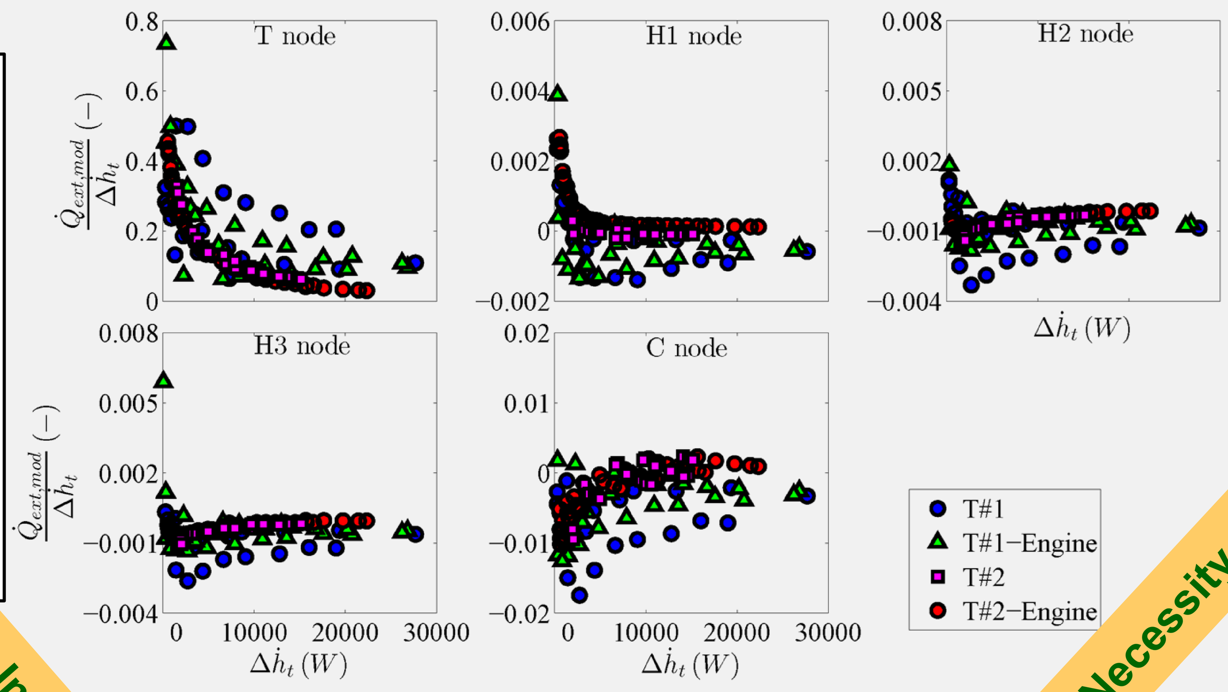




External convection and radiation modeling

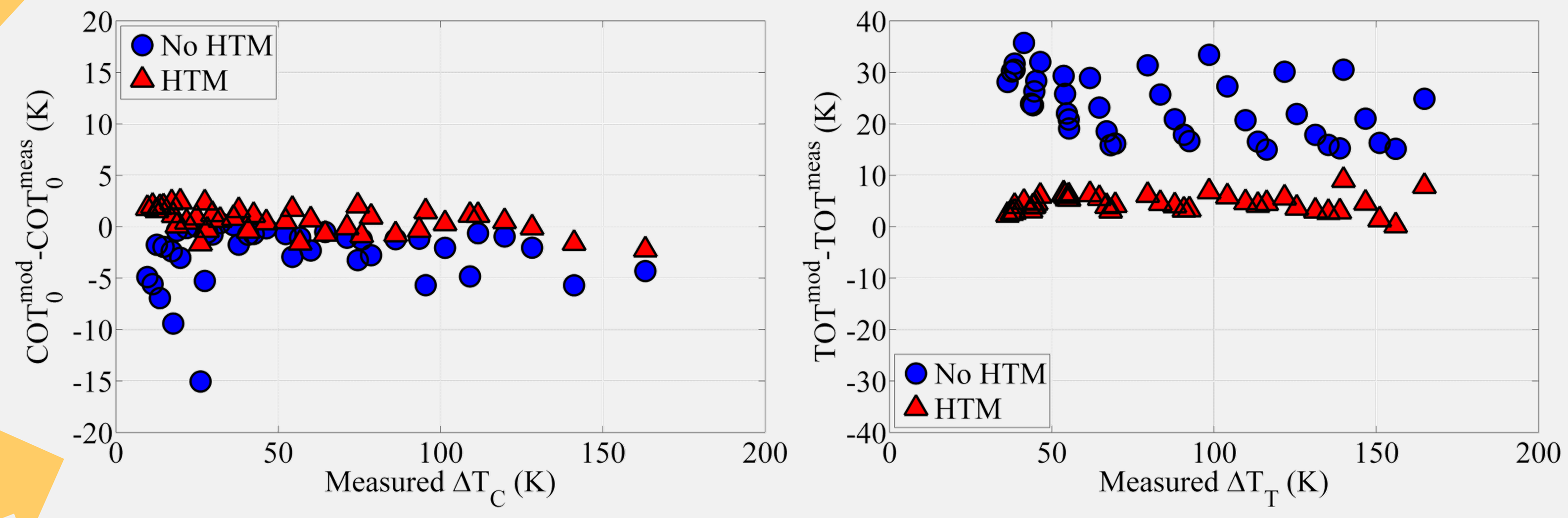
Simplified model

- ❑ Fitted using test data from gas stand and engine
- ❑ Geometrical simplification
- ❑ Grey surfaces
- ❑ Analytical expressions of view factors
- ❑ Correlations for external convection



Improvement of

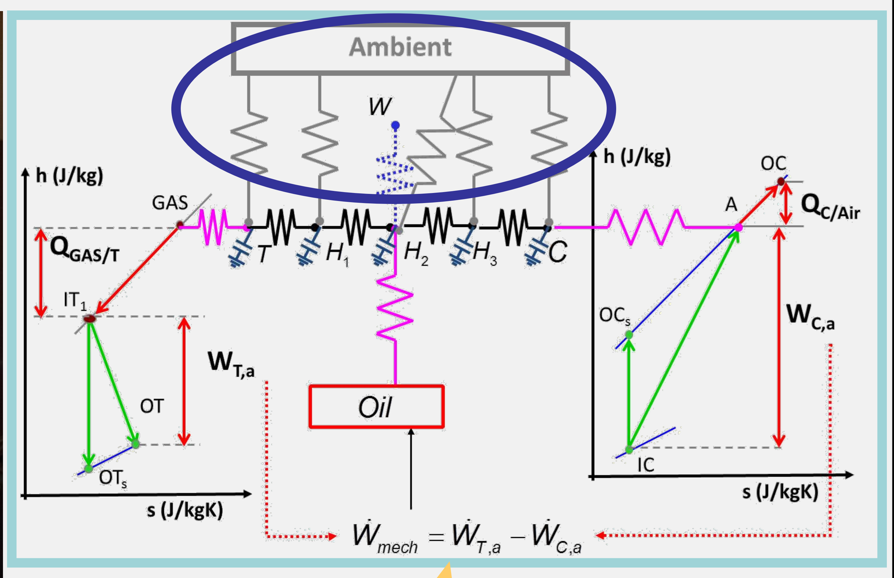
Necessity of



1D Simulation

Heat Transfer Model (HTM)

Turbocharger divided in 5 discrete nodes



Experimental data needed:

- ❑ Thermohydraulic test bench for conductive conductances and capacitances
- ❑ Gas stand adiabatic tests for mechanical losses
- ❑ Gas stand hot insulated tests for internal convection
- ❑ Gas stand hot exposed tests for external heat transfer

Save Costs

General procedure to calculate heat transfer properties

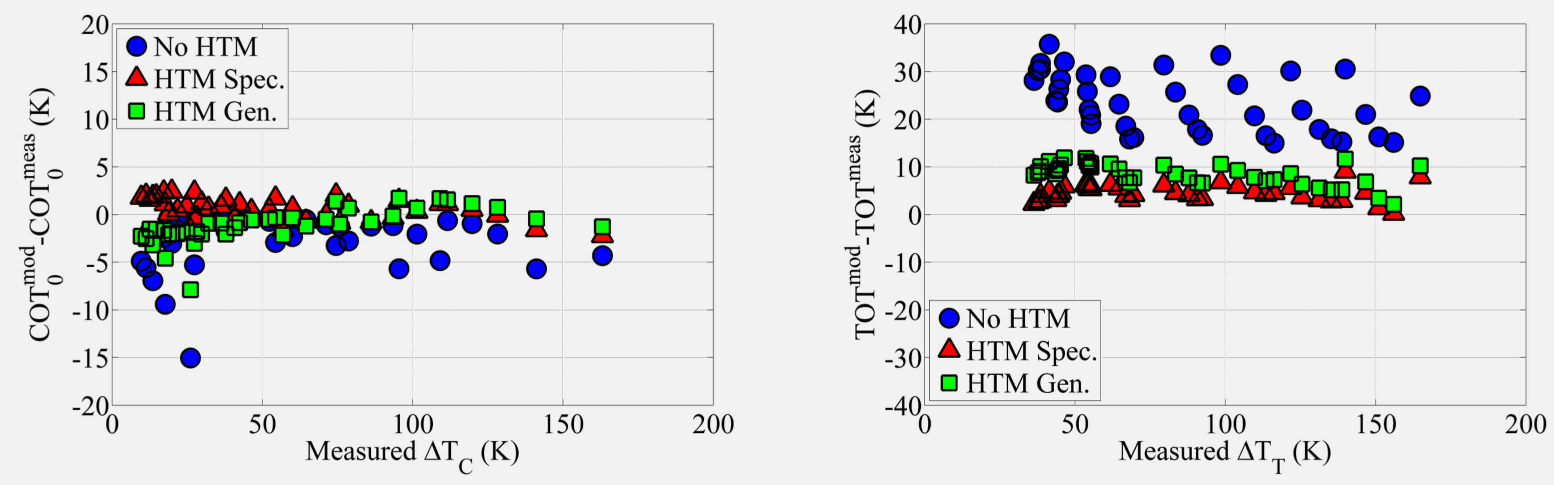
Capacitances

$$C_T = \alpha \cdot m_T \cdot c_T$$
$$C_{H1} = (1-\alpha) \cdot m_T \cdot c_T + \beta \cdot m_H \cdot c_H$$
$$C_{H2} = (1-\beta-\gamma) \cdot m_H \cdot c_H$$
$$C_{H3} = (1-\varepsilon) \cdot m_C \cdot c_C + \gamma \cdot m_H \cdot c_H$$
$$C_C = \varepsilon \cdot m_C \cdot c_C$$

Conductances

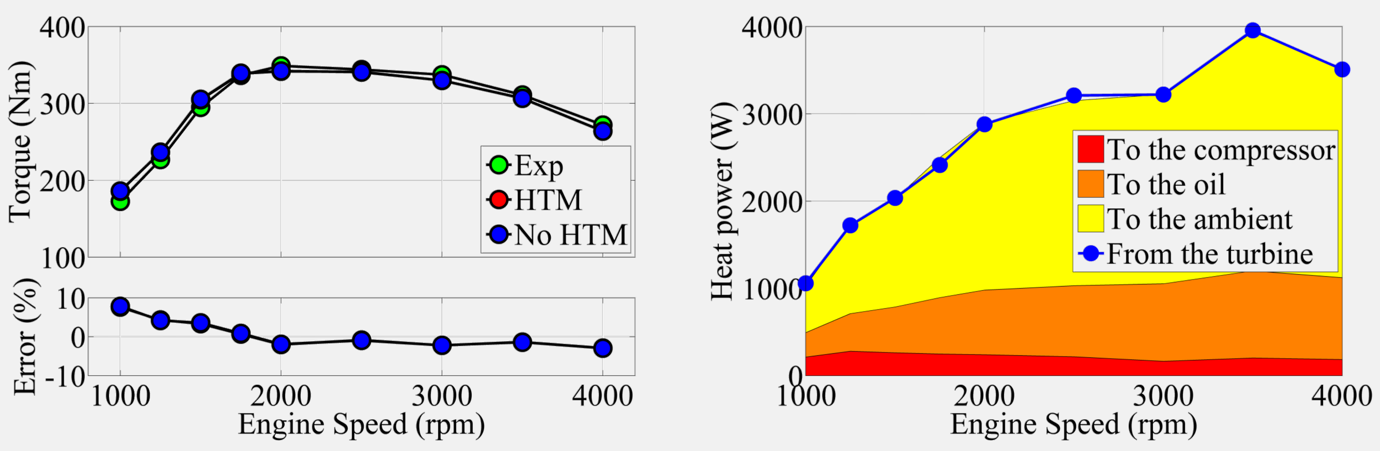
$$K_{ij} = \frac{k_i \cdot k_j}{e_i \cdot k_j + e_j \cdot k_i} \cdot \pi/4 \cdot (\delta_i \cdot D_i + \xi_j \cdot D_j)^2$$

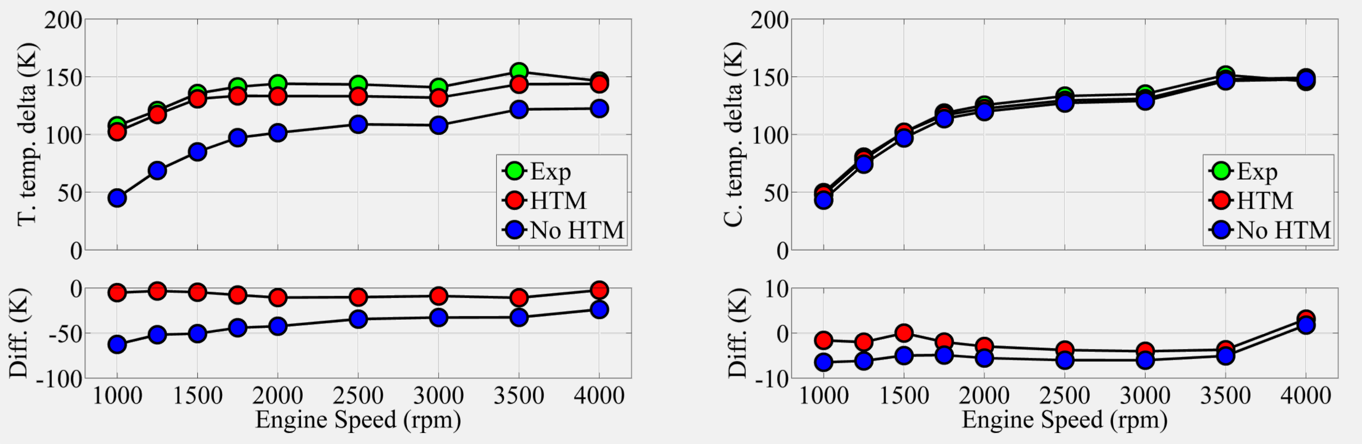
Comparison between general and specific correlations



1D Simulation

Whole-engine 1D model results





Conclusions

- ❑ Compressor and turbine efficiencies are affected by heat transfer.
- ❑ The relative importance of this effect depends on turbocharger speed.
- ❑ Heat transfer model is mandatory if TOT has to be predicted accurately.
- ❑ External heat transfer in turbine side can reach half of the total enthalpy drop.
- ❑ Turbocharger bearing housing external heat transfer is negligible.
- ❑ The sign of external heat transfer in compressor depends on operative conditions.
- ❑ Engine full load conditions are affected by turbocharger heat transfer phenomena.
- ❑ At full load engine operation up to 70% of turbine heat power goes to the ambient.
- ❑ Engine torque prediction is not affected by the usage of heat transfer model.
- ❑ A general procedure to obtain all the heat transfer properties can be used.

[1] Payri, F., Olmeda, P., Arnau, F.J., Dombrovsky, A., and Smith, L., 2014, "External heat losses in small turbochargers: Model and experiments", Energy, 71, pp. 534-546, doi:10.1016/j.energy.2014.04.096.

[2] Serrano J. R., Olmeda P., Arnau F. J., Dombrovsky, A., and Smith, L., "Analysis and Methodology to Characterize Heat Transfer Phenomena in Automotive Turbochargers", J. Eng. Gas Turbines Power 137, 021901 (2014) (11 pages); Paper No: GTP-14-1352; doi:10.1115/1.4028261

[3] Serrano, J., Olmeda, P., Arnau, F., and Dombrovsky, A., "General Procedure for the Determination of Heat Transfer Properties in Small Automotive Turbochargers", SAE Int. J. Engines 8(1):2015, doi:10.4271/2014-01-2857.

[4] Serrano, J. R., Olmeda, P., Arnau, F. J., Dombrovsky, A. and Smith, L., "Turbocharger heat transfer and mechanical losses influence in predicting engines performance by using 1D simulation codes", under review for Applied Energy Special Issue on Clean Transport.

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