Modeling and Control of Advanced Turbocharged Engines

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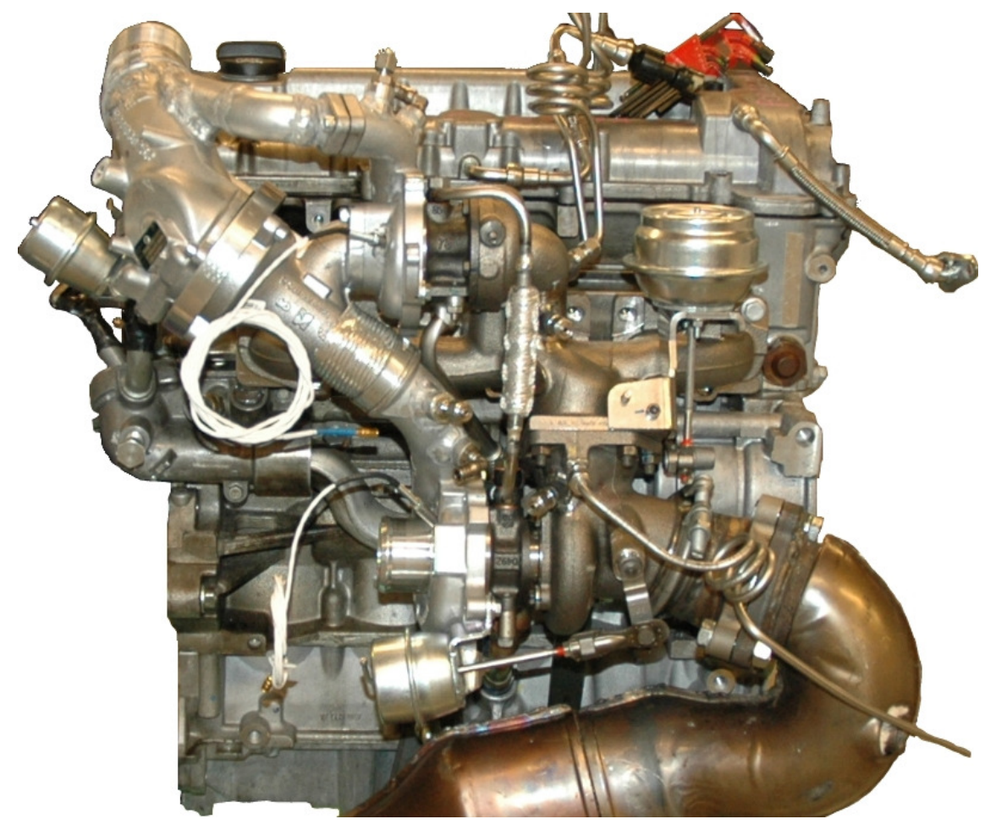
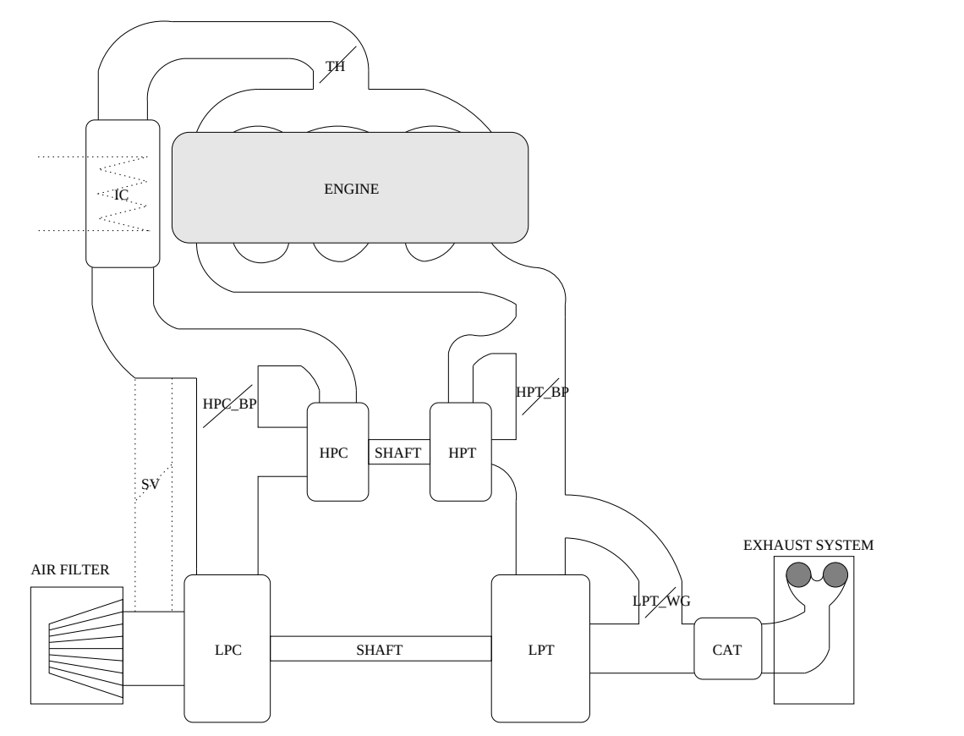
Project Background and Status

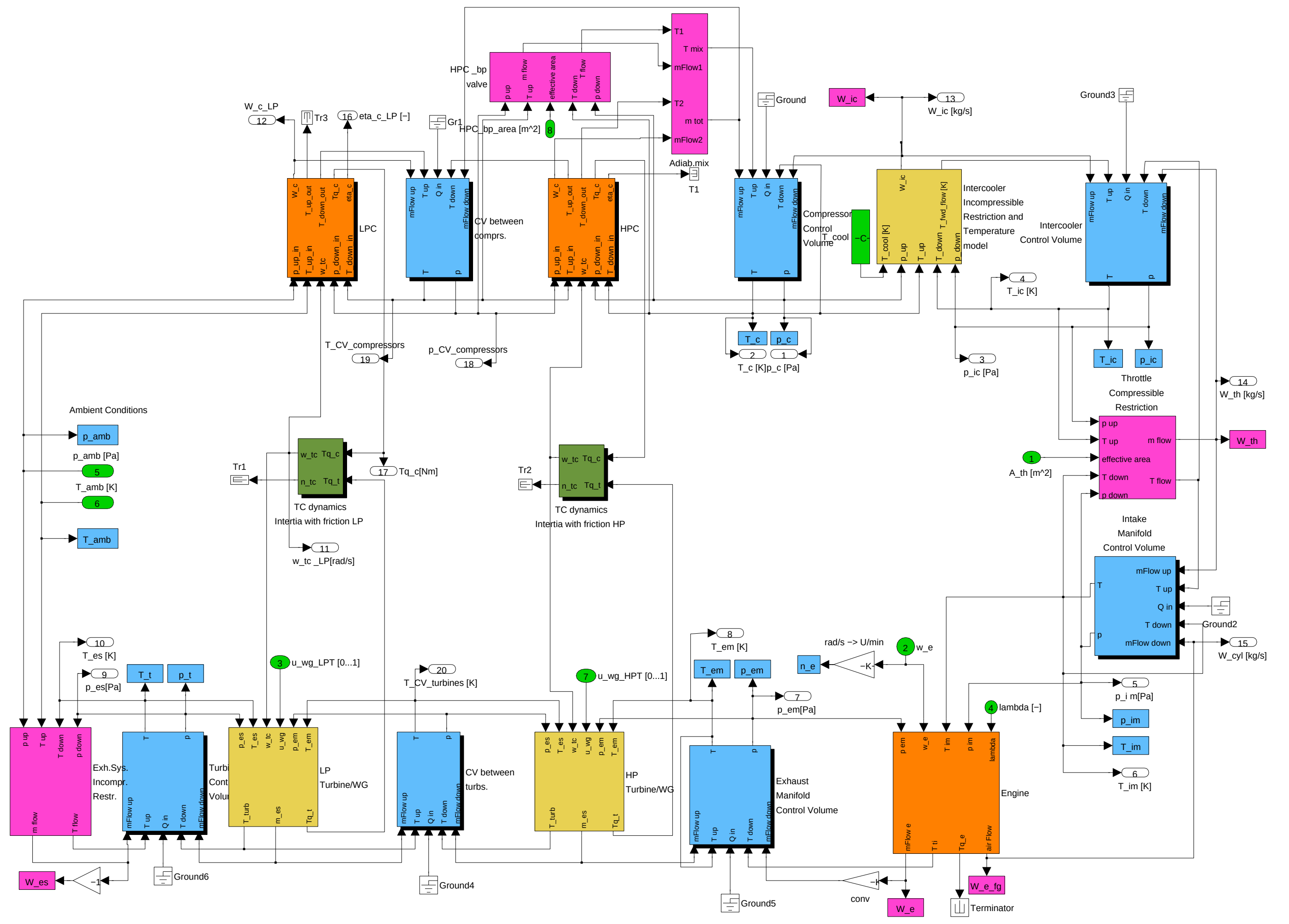


The ever increasing focus on fuel efficient vehicles forces the automotive industry towards more advanced engine concepts. Downsizing and turbocharging has been one possible solution. To still be able to provide the desired vehicle and engine behavior a single turbo is more often insufficient. This project focuses on modeling and control of turbo systems with more than one turbo.

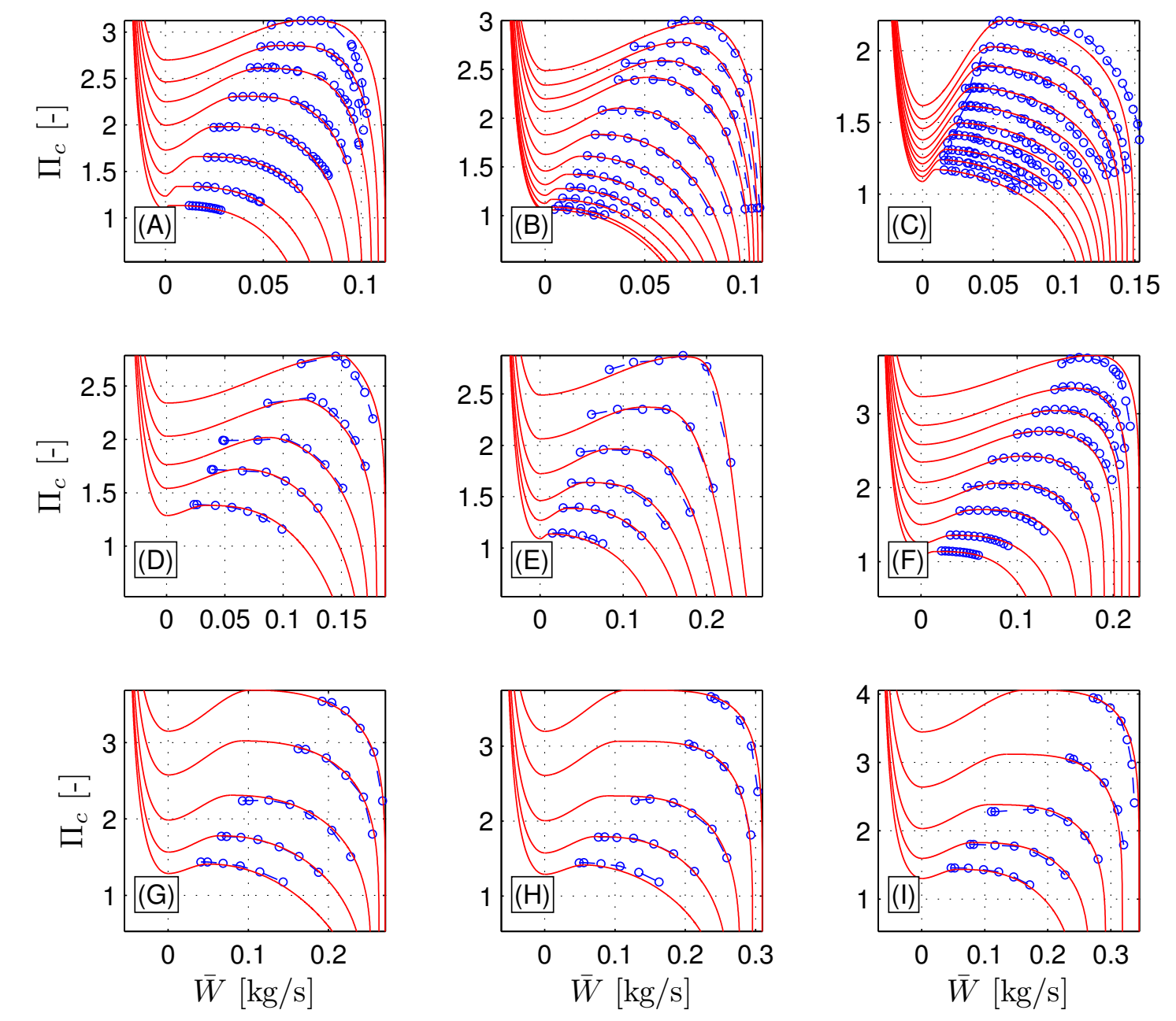
The fourth stage of the project has been devoted to further component model development and measurements of a two stage turbo system on the common engine platform. The modeling efforts include surge, co-surge and choke. Choke modeling is especially motivated by two stage system, and co-surge is a phenomenon, where a parallel twin turbo compressor system surges.



The work, therefore, evolves around development of component models capable of reproducing these phenomenons, and extension of the available Mean Value Engine Model framework. The extended MVEM is suitable for investigation of both instability issues and control principles, for advanced turbocharged engines. The availability of experimental facilities within LINK-SIC is greatly appreciated, and used during the model development.



Compressor Performance Modeling



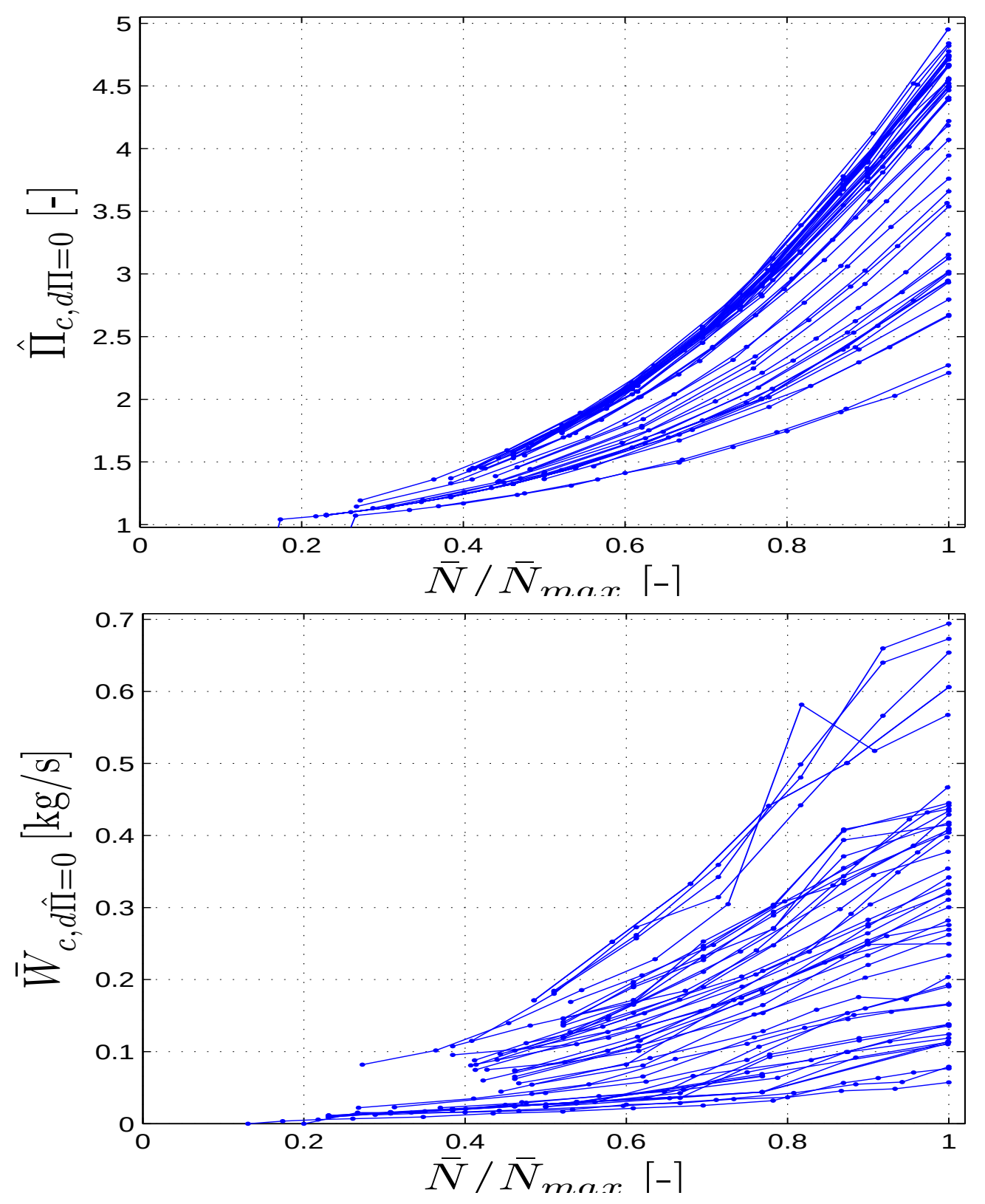
A compressor model has been developed[1], and the implemented model is parametrized and validated using experimental data.

The experimental data is collected from three different platforms: a compressor driven by a separate electric motor in a surge test stand, a compressor as part of a single stage turbocharger installed in a test stand, and a two stage turbocharged engine mounted in an engine test stand. A data base of turbo maps is further used in the development process.

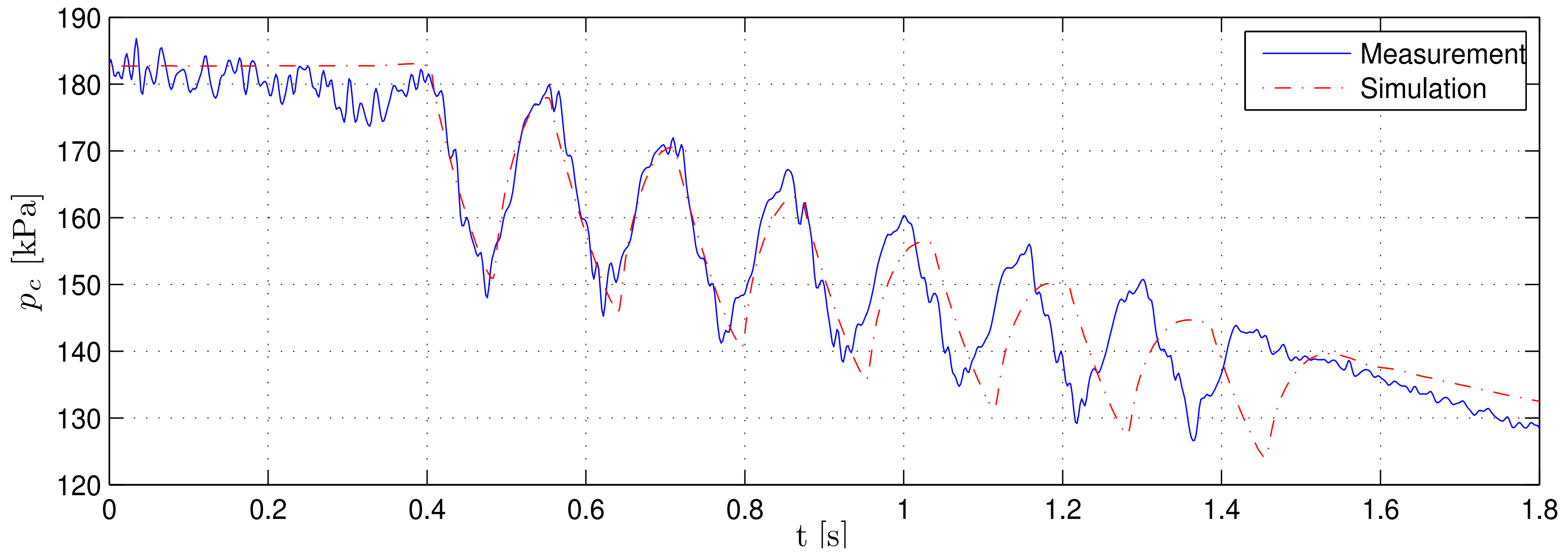
$$\bar{W} > \bar{W}_{\mathrm{SuL}} \begin{cases} \hat{\Pi} &= \left(1 - \left(\frac{\bar{W}-\bar{W}_{\mathrm{SuL}}}{\bar{W}_{max}-\bar{W}_{\mathrm{SuL}}}\right)^{c_1}\right)^{1/c_2} \hat{\Pi}_{\mathrm{SuL}} \\ \hat{\Pi}_{\mathrm{SuL}} &= 1 + c_{5,1}\bar{N}^{c_{5,2}} \\ \bar{W}_{\mathrm{SuL}} &= 0 + c_{4,1}\bar{N}^{c_{4,2}} \\ \bar{W}_{max} &= c_{3,0} + c_{3,1}\bar{N} \\ c_j &= f_{c_j}(\bar{N}),\ j = 1,2 \end{cases}$$

$$0 < \bar{W} < \bar{W}_{\mathrm{SuL}} \begin{cases} \hat{\Pi} &= \hat{\Pi}_{c0} + b_2\bar{W}^2 + b_3\bar{W}^3 \\ \hat{\Pi}_{c0} &= \hat{\Pi}_{\mathrm{SuL}} - f_{\Gamma_{\Pi_{cs}}}(\bar{N})(\hat{\Pi}_{\mathrm{SuL}} - 1) \\ b_2 &= 3(\hat{\Pi}_{\mathrm{SuL}} - \hat{\Pi}_{\mathrm{c0}})/\bar{\mathrm{W}}^2_{\mathrm{SuL}} \\ b_3 &= -2(\hat{\Pi}_{\mathrm{SuL}} - \hat{\Pi}_{\mathrm{c0}})/\bar{\mathrm{W}}^3_{\mathrm{SuL}} \end{cases}$$

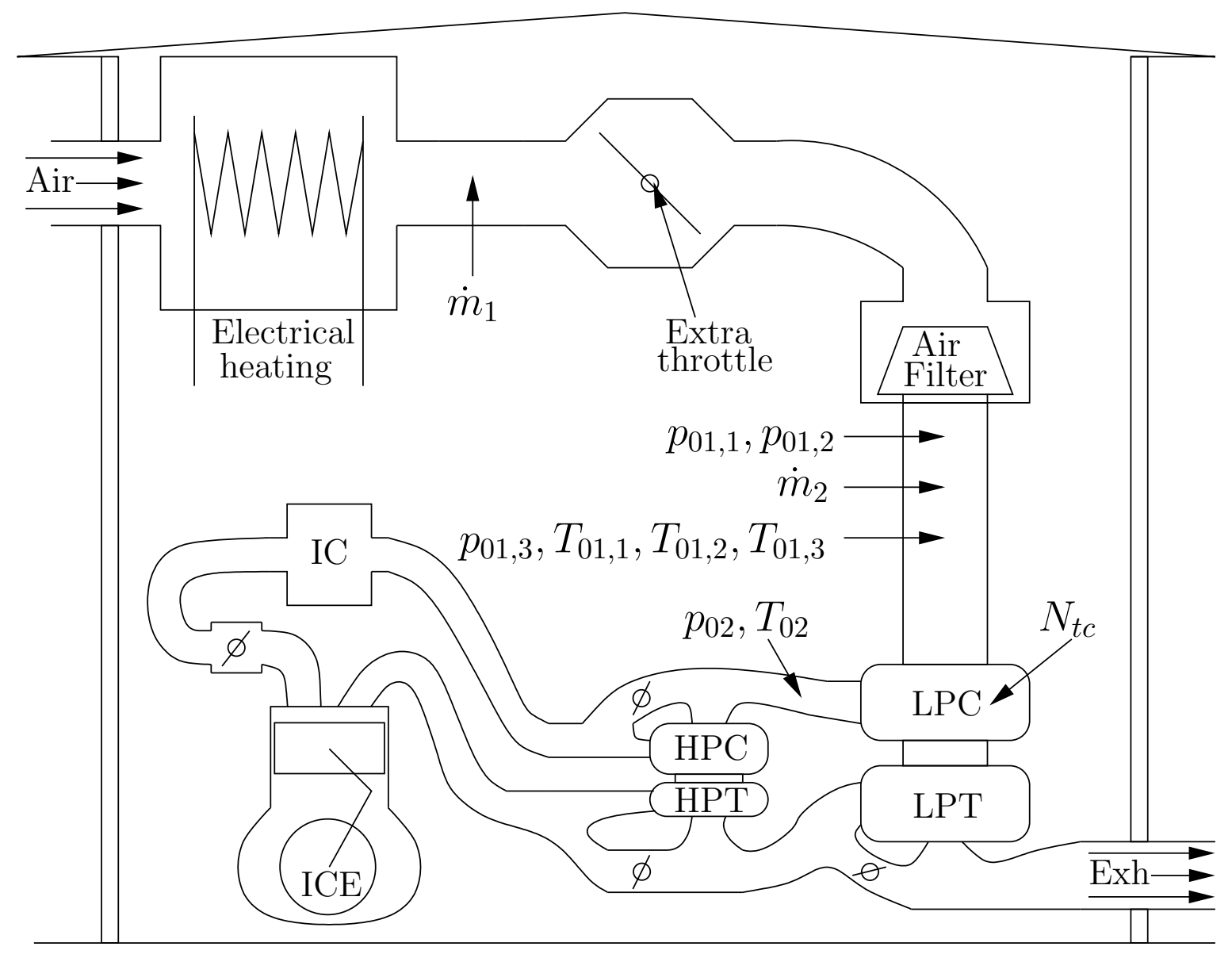
$$\bar{W} < 0 \begin{cases} \hat{\Pi} &= \hat{\Pi}_{c0} + \left(1 - (\bar{\mathrm{W}}/\mathrm{k}_1)^2\right)^{-1/\mathrm{k}_2} - 1 \\ k_1 &= \frac{\bar{W}_t}{\sqrt{1-\left(\hat{\Pi}_{ct} - \hat{\Pi}_{c0} + 1\right)^{-k_2}}} \end{cases}$$



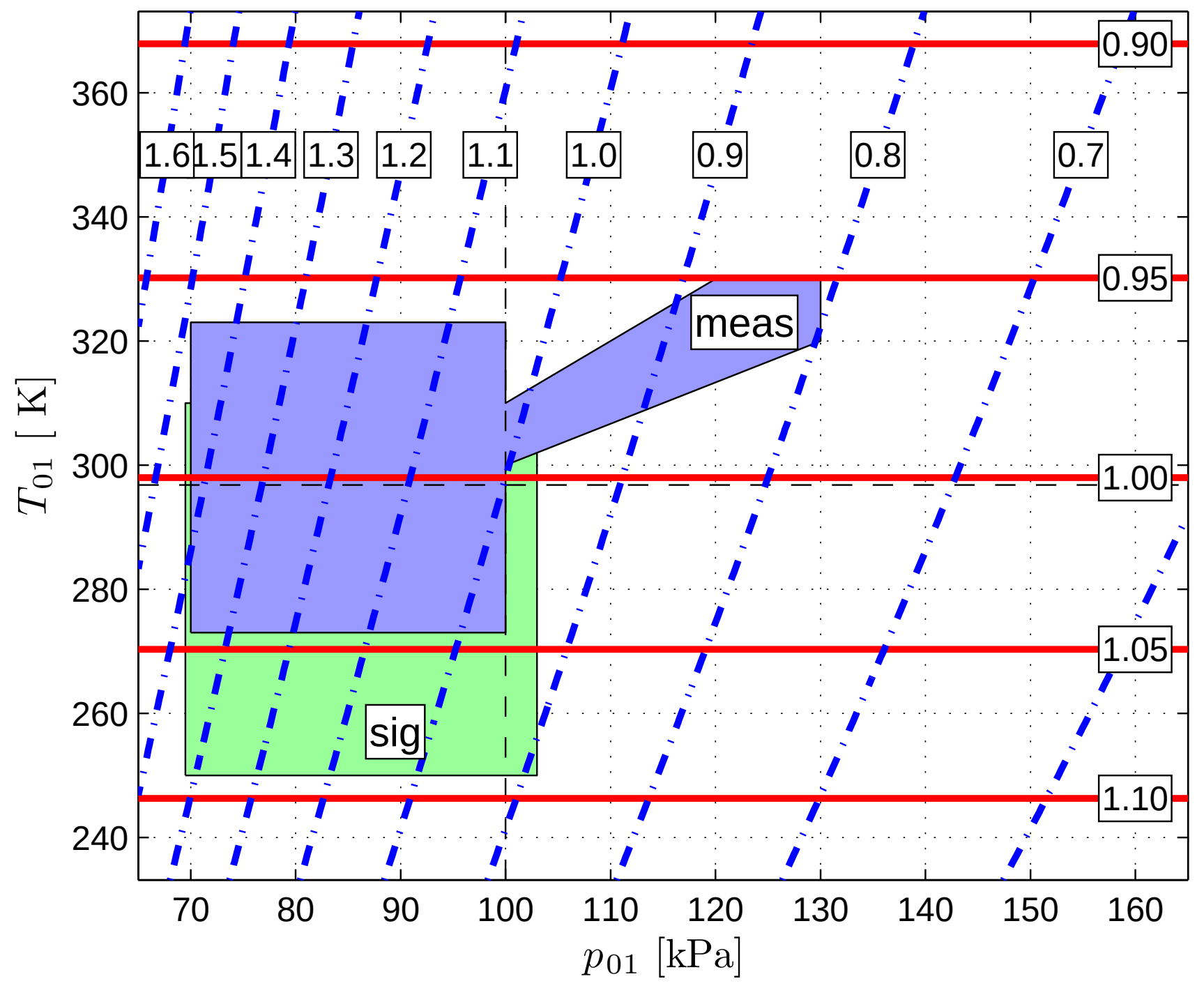
The model is capable of representing mass flow and pressure characteristic for three different regions: surge, normal operation as well as for when the compressor acts as a restriction. A compressor model capable of handling all operating modes is beneficial when investigating control strategies and controller design for turbocharged (TC) engines. Different submodels were investigated and methods to automatically parametrize the proposed model structure were developed.



Turbo characterization and correction equations

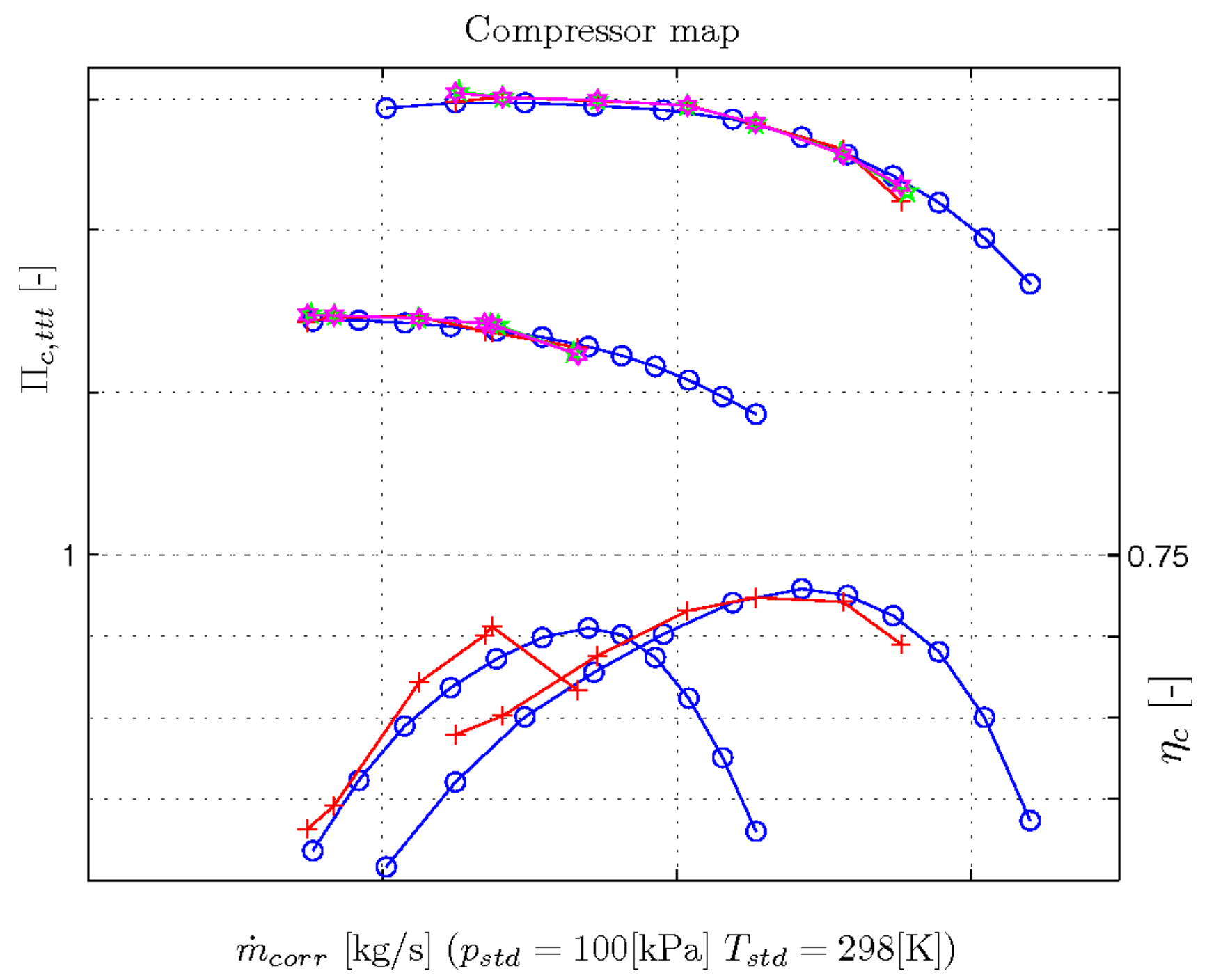


Turbo performance is usually characterized by a map, measured in a gas stand with continuous flows and well defined in- and outlets. The goal with a map is to determine turbocharger performance so that it covers its full operating region. However, when turbocharger performance is measured, the characteristics obtained are valid for the inlet conditions under which the measurements were conducted. To overcome this deficiency, different correction factors are applied to scale the performance variables to cover other inlet conditions.



The applicability of the commonly used correction equations for the compressor side have been investigated[2]. The importance of the corrections are motivated and their validity are investigated experimentally. It is shown that the turbo speed correction equation can be enhanced with a inlet pressure ratio variable.

Further, methodology to measure and characterize a turbo system installed in an engine test stand has been developed [3]. It was shown that extending the engine test stand with an extra throttle upstream of the compressor inlet extends the potentially measured compressor map.



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[1] Surge and Choke Capable Compressor Model, Oskar Leufven and Lars Eriksson, IFAC WC2011

[2] Investigation of compressor correction quantities for automotive applications, Oskar Leufvén and Lars Eriksson, Submitted to Int. J. of Engine Research

[3] Engine Test Bench Turbo Mapping, Oskar Leufvén and Lars Eriksson, SAE World Congress 2010