3-WP06 High Efficiency Turbochargers for Large-Bore ICEs

Coordinator of the WP:

Brno University of Brno (BUT), prof. Ing. Pavel Novotný, Ph.D.

Participants of the WP:

Czech Technical University (CTU), doc. Ing. Oldřich Vítek, Ph.D.
PBS Turbo (PBST), Ing. Jiří Klíma

Main Goal of the WP

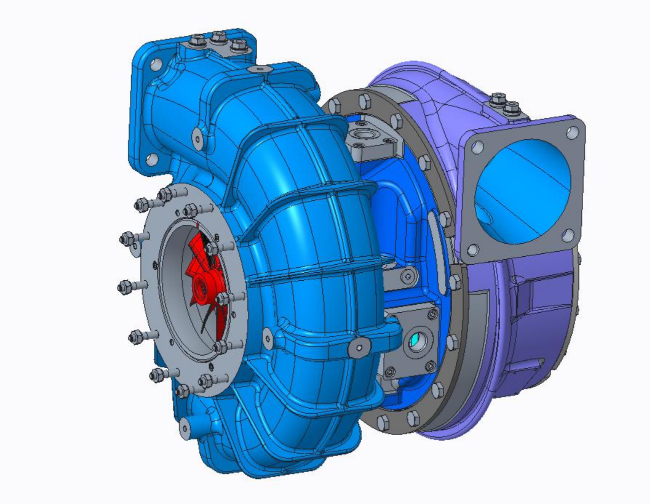
Research on new ways to improve the overall efficiency of turbochargers with application in large-bore internal combustion engines.

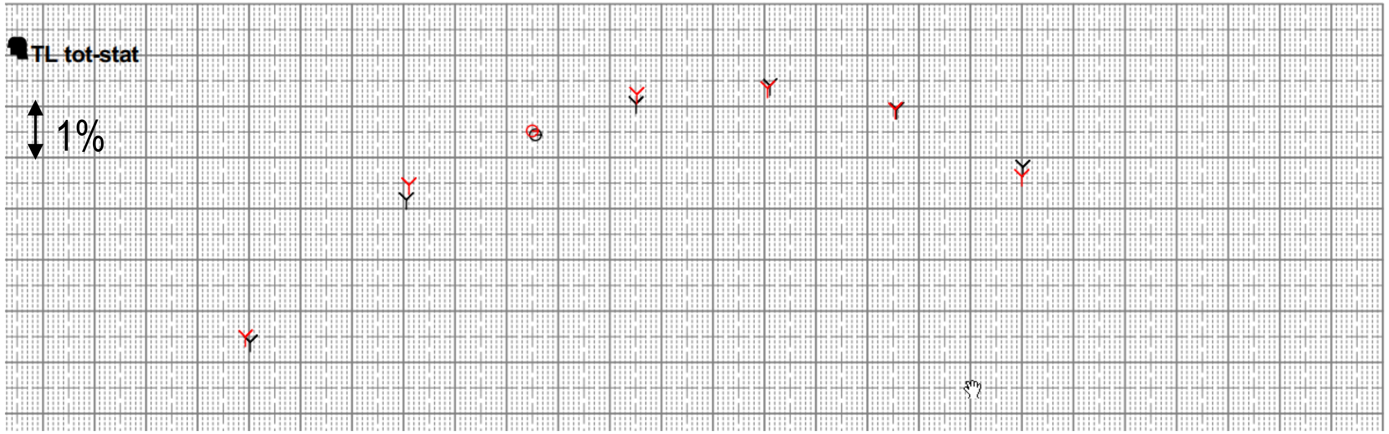
Partial Goals for the Current Period

3-WP06-001 (G-funk): Turbocharger with implemented measures to increase the mechanical efficiency
3-WP06-002 (R-SW): Software for heat transfer estimation in turbocharger rotor system
3-WP06-003 (O): Report on Milestones – Large turbochargers

Activities in 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

- 3-WP06-001: Turbocharger with implemented measures to increase the mechanical efficiency is under development, initial analyses were realized.
  - → PBST provided the data for the simulations of compressor and turbine fluid flows and verified the results of CFD simulation on initial turbocharger geometry.

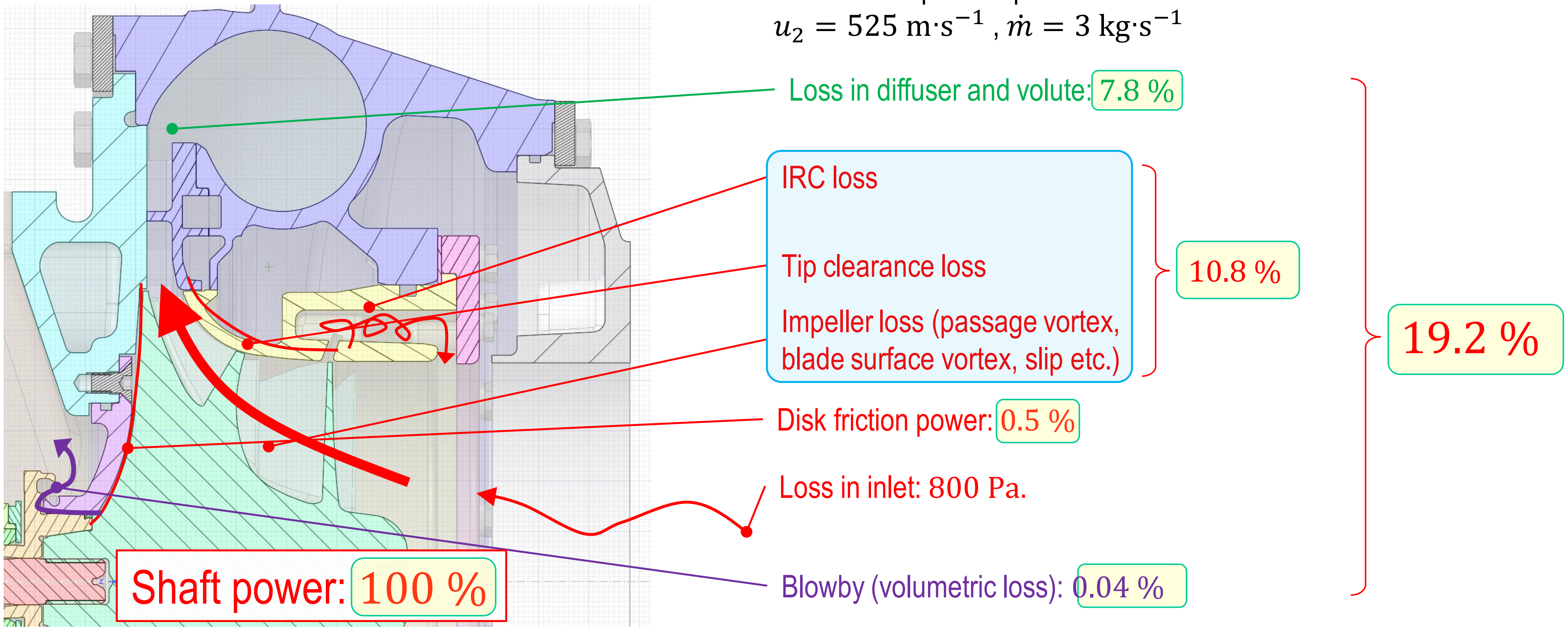




Activities in 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

- 3-WP06-001: Turbocharger with implemented measures to increase the mechanical efficiency.
  → Compressor loss sources were analyzed in detail (BUT).

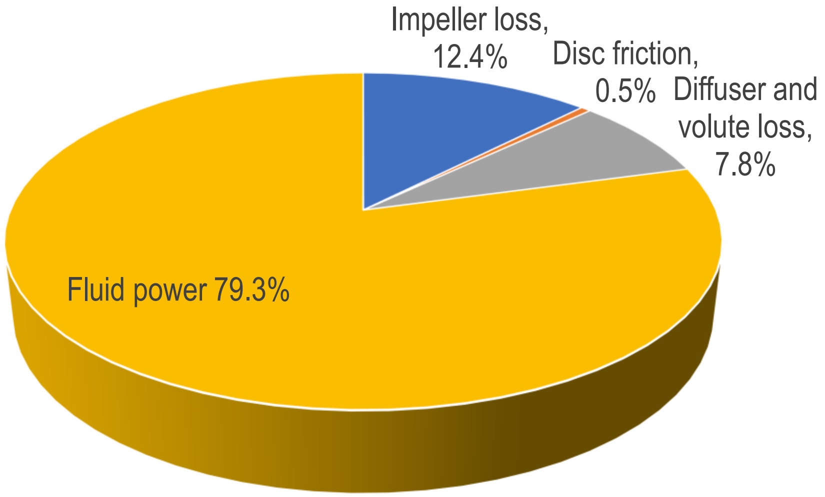
Relative compressor power losses under $u_2 = 525\ \mathrm{m{\cdot}s^{-1}}$, $\dot{m} = 3\ \mathrm{kg{\cdot}s^{-1}}$



Activities in 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

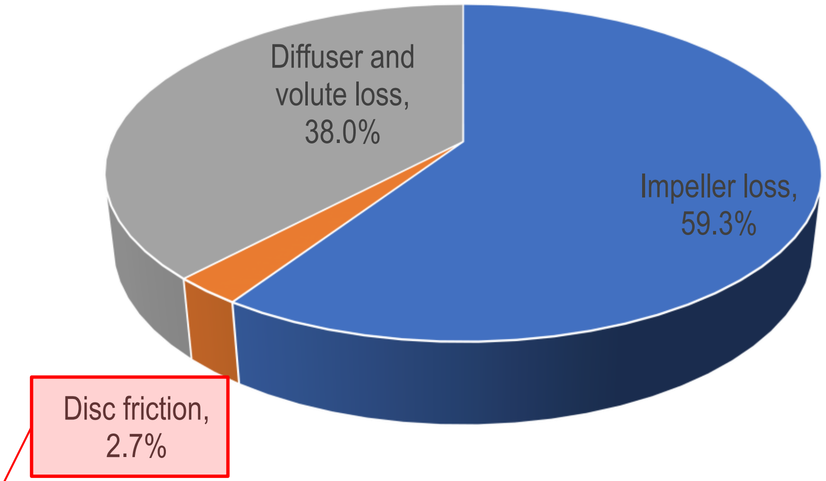
- 3-WP06-001: Turbocharger with implemented measures to increase the mechanical efficiency.
  - → A significant part of the research activities focused on the analysis of the interaction between the compressor backwheel and the stator, the so-called disc friction.

Average power share on the compressor



Shaft power is represented as 100%.

Average proportion of power losses



All losses are represented as 100%.

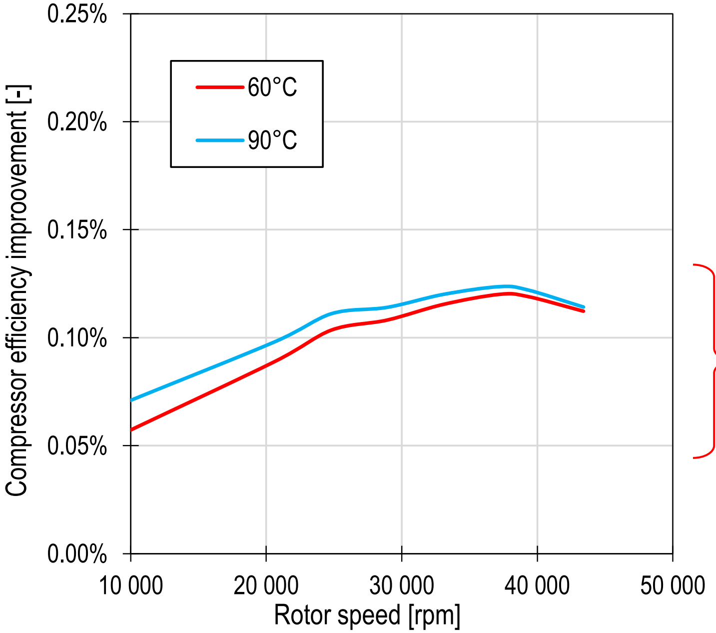
The compressor disc friction share only small portion of losses and the reduction is ineffective.

Activities in 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

- 3-WP06-001: Turbocharger with implemented measures to increase the mechanical efficiency.
  - → Theoretical compressor efficiency improvements by reducing compressor disc friction under steady state operating conditions for oil temperature at inlet $T_{\mathrm{in}} = 60$ and $90°\mathrm{C}$.

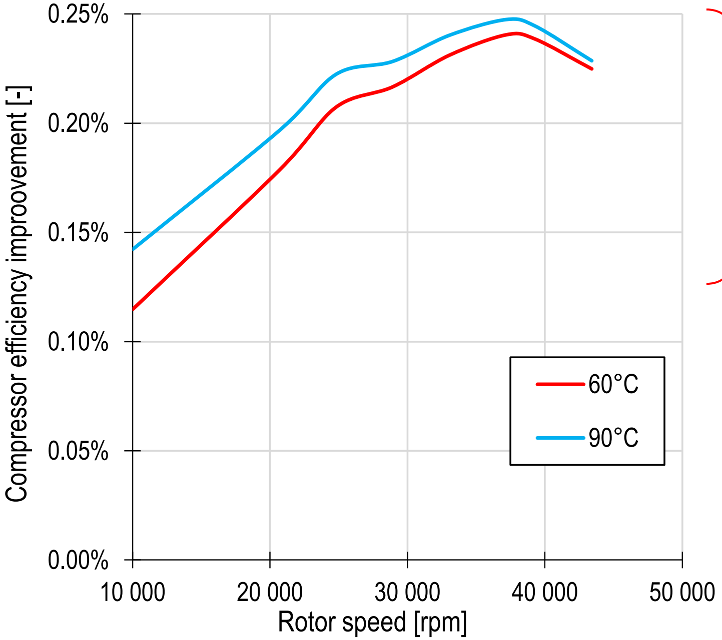
$$\mu_{\mathrm{tc}} = \mu_{\mathrm{c}} \mu_{\mathrm{m}} \mu_{\mathrm{t}}$$

Reduced compressor disc friction by **20%**



$0.06 \div 0.12\ \%$

Reduced compressor disc friction by **40%**



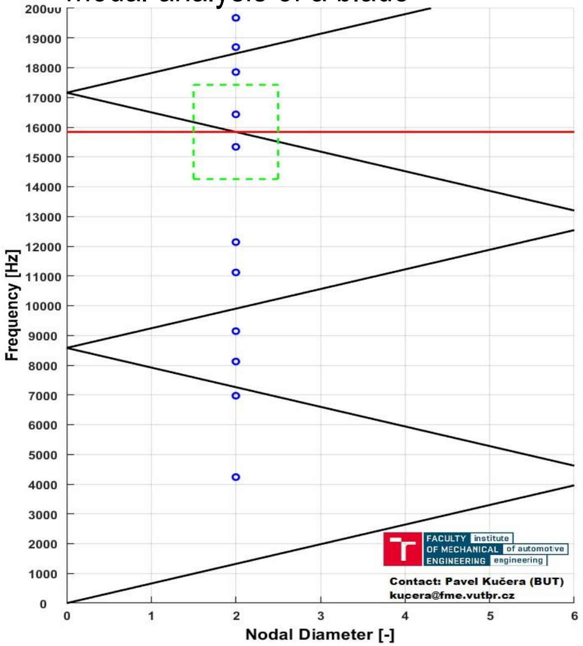
$0.12 \div 0.25\ \%$

Decreasing the disc friction on the compressor wheel has only **small effects** on efficiency under **high-speed** conditions. The effects under low speeds are mostly insignificant.

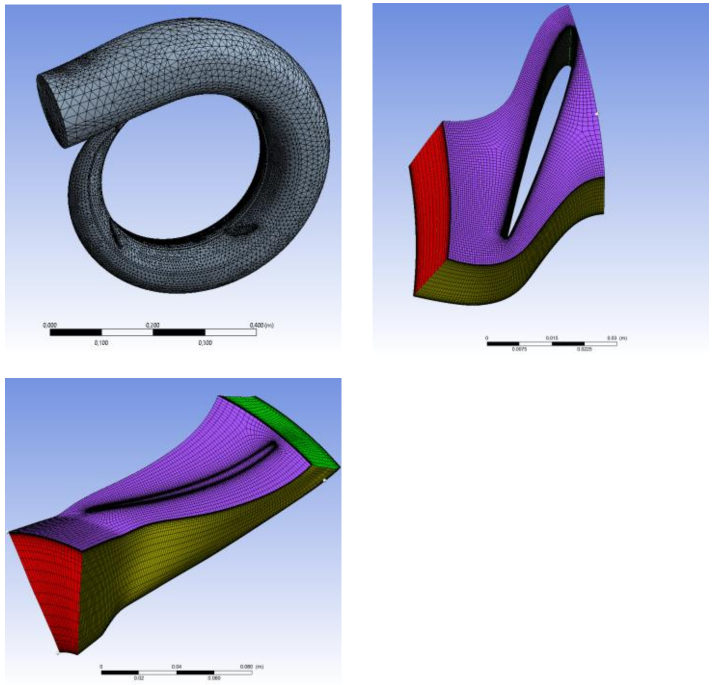
Activities in 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

- 3-WP06-001: Turbocharger with implemented measures to increase the mechanical efficiency.
  - → Stress reduction due to vibrations of the blades caused by interactions of the gas flow and turbine structure.
  - → PBST provided the turbine geometry and thermodynamics data of pulsating flow for the fluid–structure simulation methodology.
  - → Analysis of original and modified blades under vibration including modal analyses, excitation frequency estimations, fluid flow analyses and strength analyses.

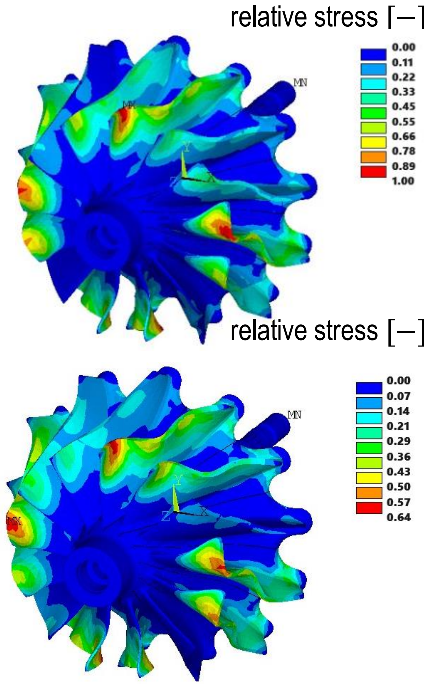
Blade interference diagram based on modal analysis of a blade



CFX model of turbine fluid flow



Stress levels for original and modified blades

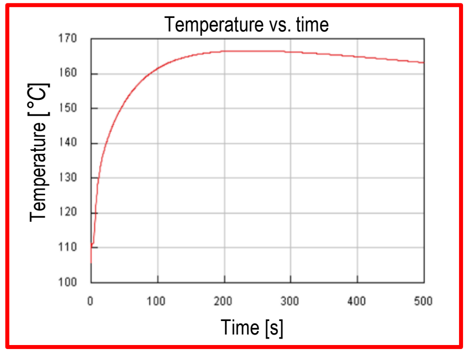


The vane modification produced a reduction of blade max. stresses by 36 %.

Activities in 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

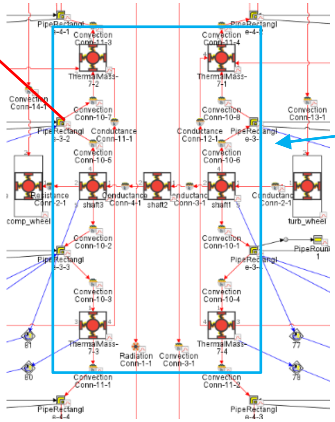
- 3-WP06-002: Software for heat transfer estimation in turbocharger rotor system is under development. The analysis of the heat flows to the turbochargers was realised using the 1D models. The SW capabilities will cover:
  - → Input values will be experimentally determined quantities.
  - → The model will include TC rotor – bearing system.
  - → The results will provide information for turbocharger design improvement.

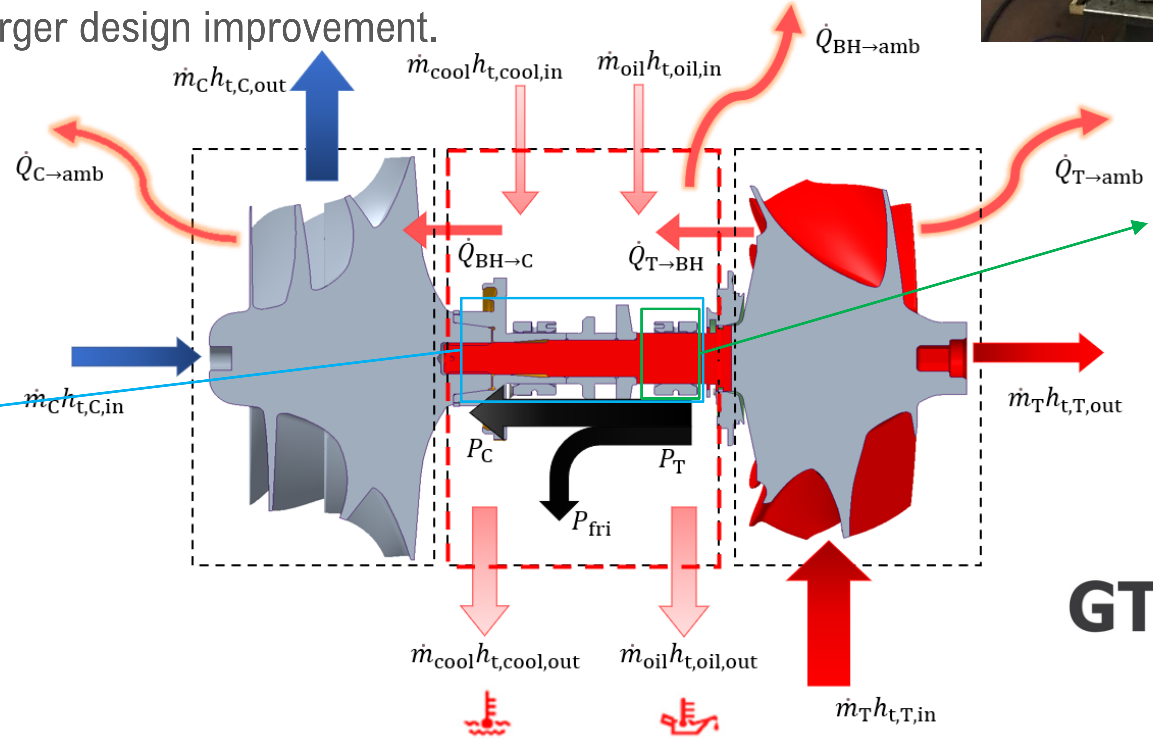
Experimental data as input



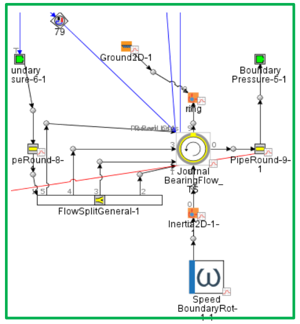
New bearing concept

Model of rotor system





Model of radial bearing



GT Gamma Technologies

Activities in 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

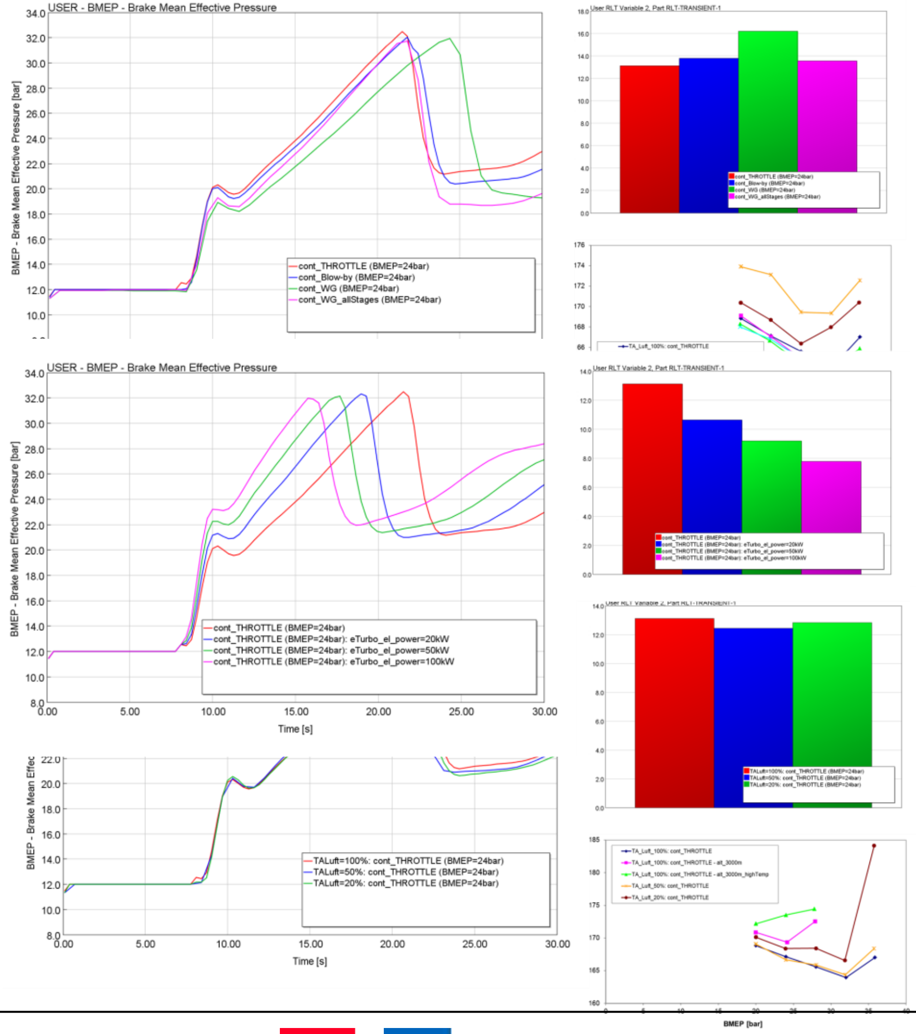
3-WP06-003: Report on Milestones – Large turbochargers

→ Transient performance of turbocharger was analyzed in detail.

→ Transient performance is always verified, however it may not be that important/critical for typical applications of such gas SI ICE.

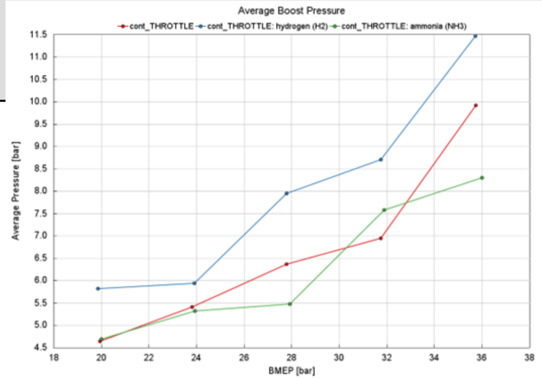
→ The following was analyzed:

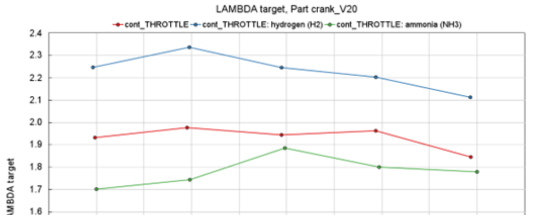
- influence of BMEP control means,
- influence of NOx level,
- influence of optimization target for BMEP,
- influence of applied turbocharger bearing(s) – sliding bearings (default) and ball bearings,
- influence of ambient conditions – standard (default), high altitude (3000 m) and high altitude combined with increased temperature (40 C),
- effect of applied fuel – methane (default) and hydrogen,
- influence of minimum air excess during fuel enrichment phase,
- influence of blow-by level and combustion phasing/delay during transient
- influence of turbocharger efficiency, effect of electrical assistance for HP turbocharger.

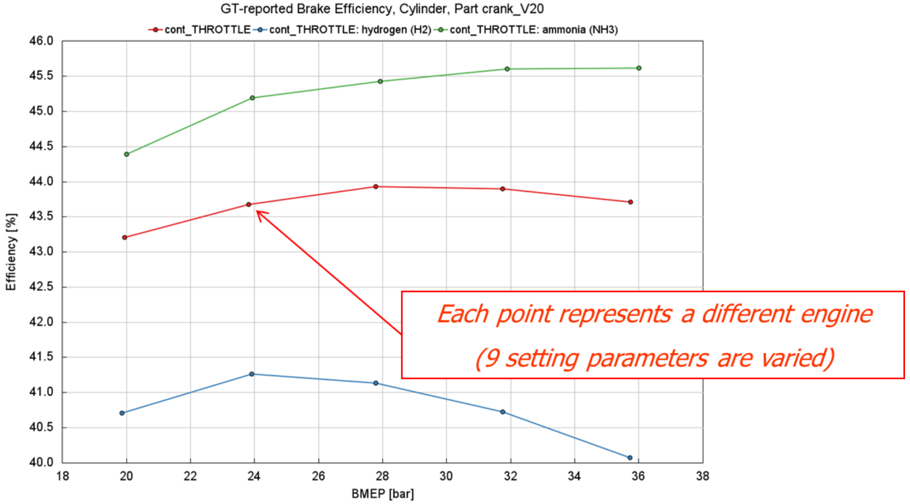


Activities in 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

- 3-WP06-003: Report on Milestones – Large turbochargers. The effect of applied fuel was investigated:
  - → Fully optimized data for 3 fuel types: methane (def.), hydrogen and ammonia under constant NOx level + constant engine speed.
  - → Due its very low density, the application of hydrogen (H2) requires higher boost pressure, higher air excess ⇔ weaker Millerization effect can be applied and combustion is shifted more in expansion stroke to help boost group performance => decrease of efficiency.
  - → On the other hand, the application of ammonia (NH3) is more effective ⇔ higher energy content per unit volume + higher mass/density leads to even better performance than the default case (methane: CH4)

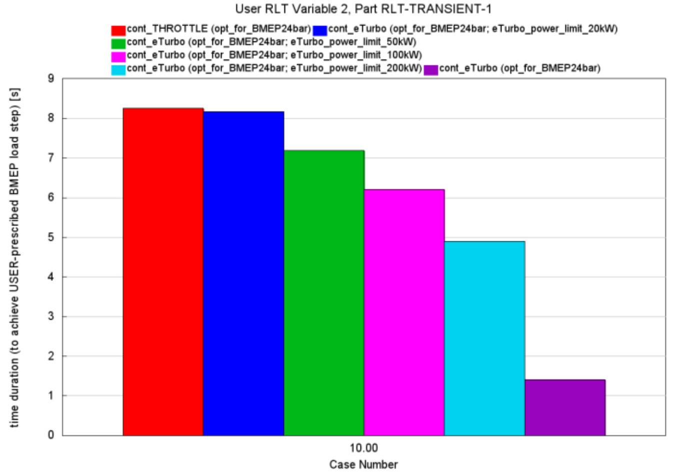


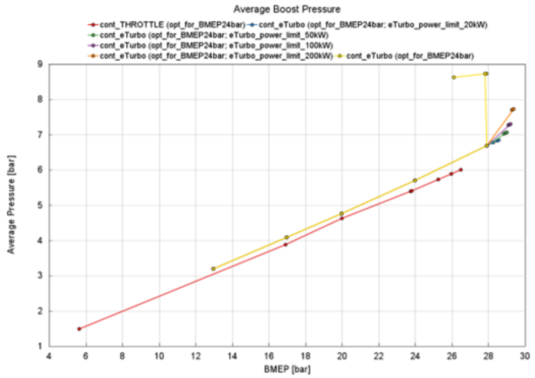


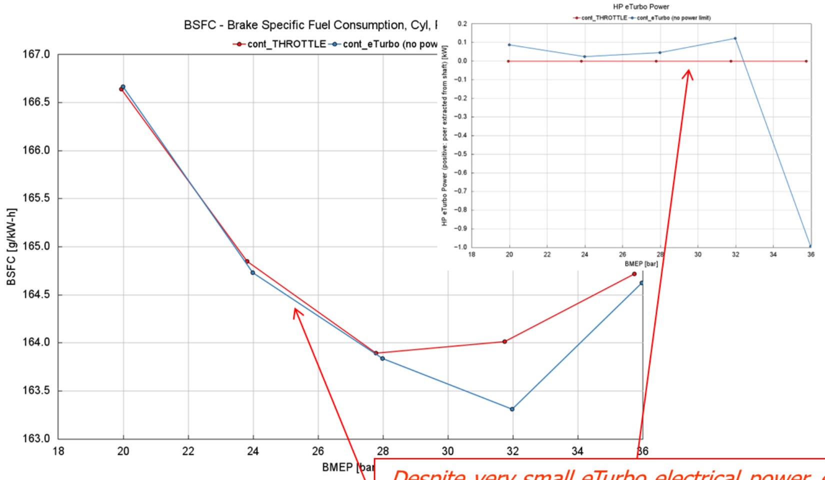


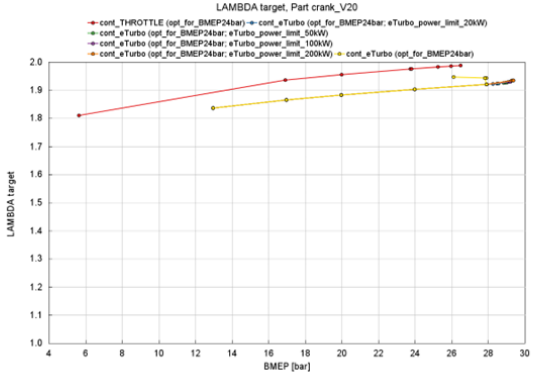
Activities in 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

- 3-WP06-003: Report on Milestones – Large turbochargers. The electrically assisted turbocharging was investigated:
  - → Fully optimized data to compare standard case with electrically assisted one (no limitation of eTurbo power).
  - → Under optimal setting, eTurbo power is zero ⇔ this was to be expected due to limited efficiencies of energy transformation (internal => mechanical => electrical => mechanical) => no efficiency benefit when eTurbo is applied.
  - → However, eTurbo has potential:
    - to improve BSFC when ICE operates under lower load/BMEP (when compared with the optimal/reference one) ⇔ more effective BMEP control than standard ones (e.g., throttle, waste-gate, blow-by);
    - to increase achievable maximum of BMEP;
    - to speed up significantly a transient response;









Despite very small eTurbo electrical power, engine setting is different => eTurbo allows to reach 'different' turbocharger operating conditions

Fulfillment of goals and deliverables of 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

- 3-WP06-001: Turbocharger with implemented measures to increase the mechanical efficiency, Gfunk - funkční vzorek, VI/2026, PBST 0.8; BUT 0.1; CTU 0.1 – in progress & no major delays:
  → Research work in evaluations of overall efficiency under steady state or transient operating conditions will serve to significantly improve the existing design of the turbocharger and develop the functional sample.

- 3-WP06-002: Software for heat transfer estimation in turbocharger rotor system, R-software, VI/2026, BUT 0.9; PBST 0.1 – in progress & no major delays:
  → The SW is under development. Research activities will be used for the development of a software solution. An open question is a software graphical user interface (GUI) that is sufficiently flexible for use in industrial practice and prepared for defined industrial standards.

- 3-WP06-003 | Report on Milestones - Large turbochargers, O-ostatní, VI./2026, PBST 0.1; CTU 0.9 – in progress & no major delays:
  → Turbochargers maps were transferred (from PBST) and important topics were agreed.
  → The model was updated – mainly with focused to HP electrically assisted turbine including its control.
  → Large-scale optimization have been performed with focus to different topics.
  → Transient performance is always verified for each selected/optimized variant.

Fulfillment of goals and deliverables of 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

Assessment of the Contribution of Deliverables

- → Thermodynamics of very high boosted ICEs with low NOx level – (3-WP05), (3-WP07), (4-WP08), (4-WP06).
- → Transient response and low mechanical losses – (3-WP05), (4-WP08), (4-WP06).
- → Fuel Cells super-/turbocharging – 4-WP06

Result dissemination:

- → Vitek, O., Macek, M., Mares, B., Klima, J. and Vacek, M. Two-Stage Turbocharged Large-Bore SI ICE - Transient Operation Under Different Conditions. 54th international scientific conference of Czech and Slovak universities and institutions focused on research and teaching methods related to ICEs, alternative powertrains and transport. Hustopeče, VUT v Brně, 2023. ISBN 978-80-214-6164-2.
- → Novotný, P., Kudláček, P., Vacula, J., Kocman, F. Innovative approach to reduce friction losses in turbocharger journal bearings. 54th international scientific conference of Czech and Slovak universities and institutions focused on research and teaching methods related to ICEs, alternative powertrains and transport. Hustopeče, VUT v Brně, 2023. ISBN 978-80-214-6164-2.

Current contribution of 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

- Assessment of the formal/administrative goals of the work package

	PBST	BUT	CTU
Finances (reporting/spending)	OK	OK	OK
Commercialization (the whole organization)	OK	OK	OK
Deliverables	OK	OK	OK

3-WP06: High Efficiency Turbochargers for Large-Bore ICEs

Thank you for your attention

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Acknowledgment

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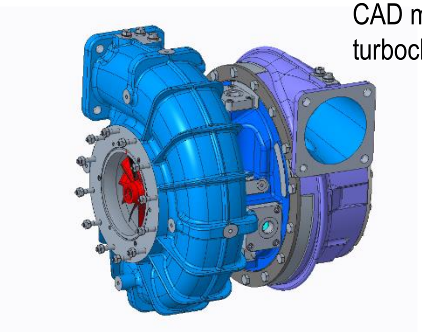
Výtah z prací 2023 za 3-WP06: Vysoce účinná turbodmychadla pro velké spalovací motory

PBST: návrh turbodmychadla a experimentální ověření

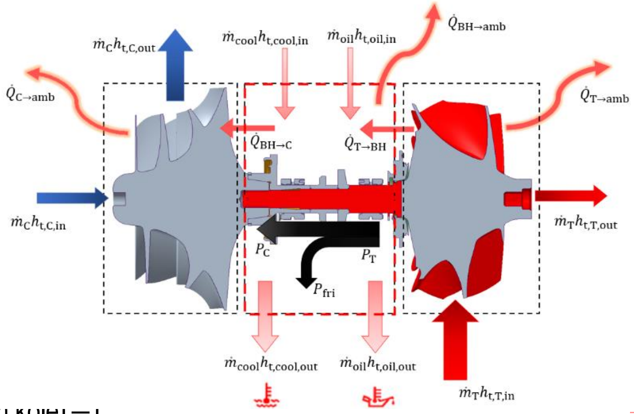
CAD model of turbocharger



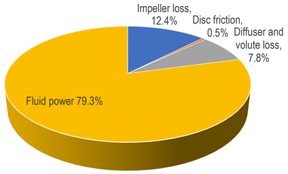
rozváděcí turbínové lopatky pro experimentální ověření výsledků CFD

BUT: účinnost kompresoru, mechanická účinnost, vibrace

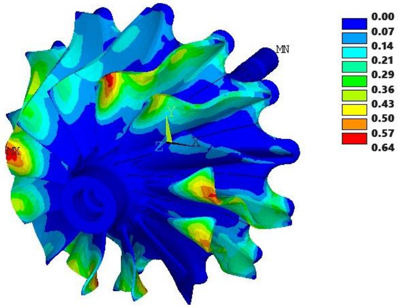
schéma přenosu tepla



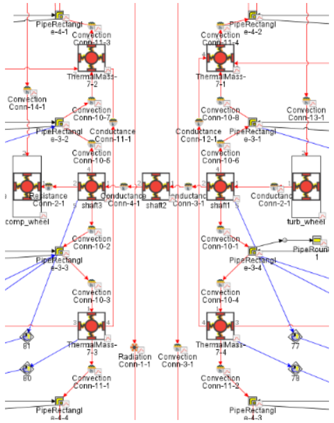
průměrný výkonový podíl na kompresoru



relativní n
turbínovém kole [−]

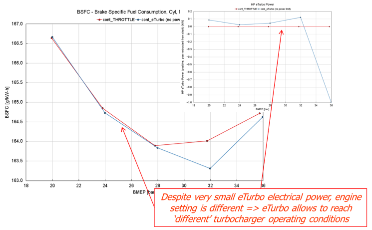


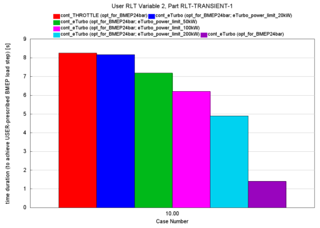
1D výpočtový model systému rotor- ložiska turbodmychadla pro odhad přestupu tepla



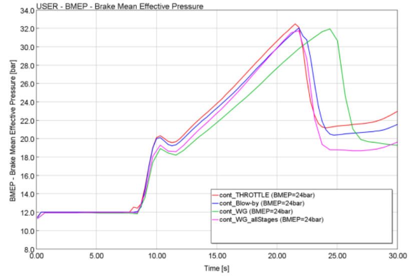
CTU: termodynamika, paliva, přechodové chování turbodmychadla

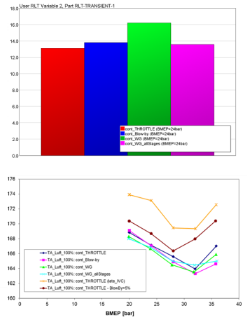
výsledky analýzy e-turbo





výsledky analýzy přechodových jevů turbodmychadla

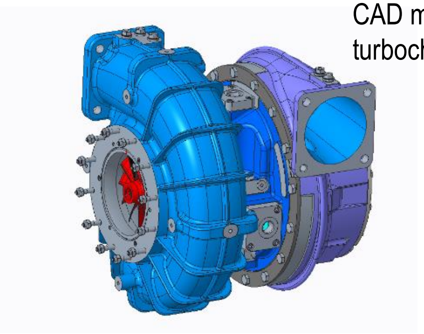




Results of 3-WP06: High Efficiency Turbochargers for Large-Bore ICEs Achieved in 2023

PBST: turbocharger design and experimental validation

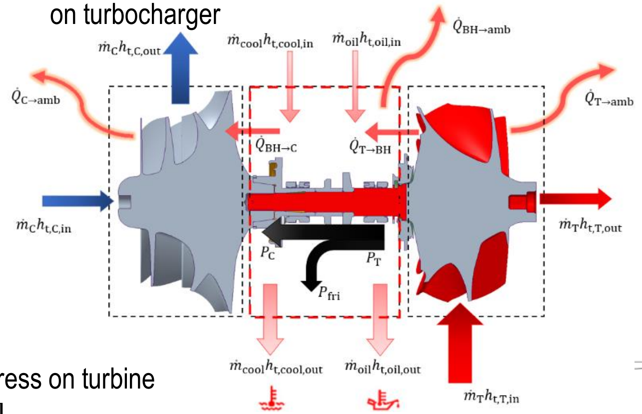
CAD model of turbocharger



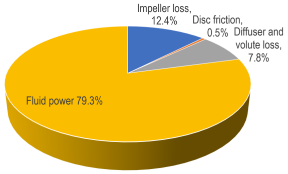
turbine nozzle ring used for experimental verification of CFD results

BUT: compressor efficiency, mechanical efficiency, vibrations

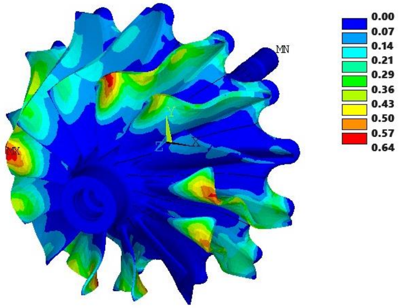
scheme of heat transfer on turbocharger



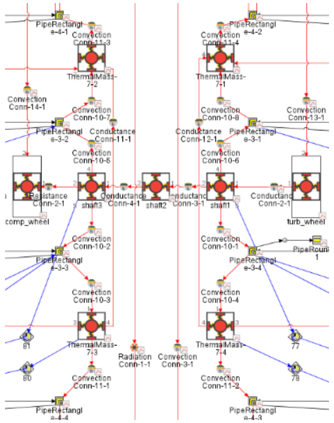
average power share on the compressor



relative stress on turbine wheel [–]

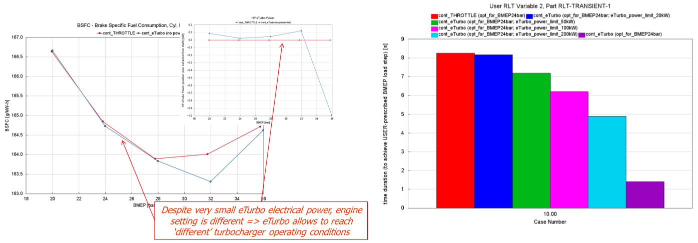


1D computational model of turbocharger rotor-bearing system for heat transfer estimation



CTU: thermodynamics, fuels, turbocharger transient behavior

comp. analysis results of e-turbo



comp. analysis results of transient performance of turbocharger(s)