Contents of Work Package 3-WP05: Future Automotive Boosting Solutions

3-WP05: Future Automotive Boosting Solutions

Coordinator of the WP

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Participants of the WP

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Main Goal of the WP

The WP is focused on future solutions in automotive turbocharger/boosting sector. This concerns efficient utilization of highly-pulsating exhaust gases, optimal design towards high-flow low-temperature solutions (due to LTC), detection and reduction of noise inside the turbomachinery devices and future trends in turbocharging of automotive ICEs.

Partial Goals for the Current Period

BUT + Garrett: Perform dedicated experiments focused on noise, analyze the data and propose algorithm to identify/estimate noise sources => build SW tool(s) based on that.

CTU + Garrett: Update the existing SW tools, perform selected sensitivity studies, analyze exiting data, propose new stator geometries, perform initial steps towards automation (of the whole process).

CTU + Garrett: Create a fully-calibrated baseline SI ICE model, calibrate predictive hydrogen combustion model (including lean operation), derive FRM and transient model versions.

Contents of Work Package 3-WP05: Future Automotive Boosting Solutions

Official 3-WP05 Deliverables:

- 3-WP05-001 | **Unconventional turbocharger optimized for highly pulsating operation and decreased noise**, G-funk, VI./2026, Garrett 0.8; CTU 0.1; BUT 0.1
- 3-WP05-002 | **Noise Emission Finder for Centrifugal Compressor**, R-SW, VI./2026, Garrett 0.1; BUT 0.9
- 3-WP05-003 | **Software tools to design, optimize and evaluate unconventional turbine design(s) under highly pulsating operation**, R-SW, VI./2026, Garrett 0.1; CTU 0.9
- 3-WP05-004 | **Report on Milestones - Unconventional turbine and Future boosting technologies**, O-ostatní, VI./2026, Garrett 0.2; CTU 0.8

Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-001: Unconventional turbocharger optimized for highly pulsating operation and decreased noise

- Objective is to develop advanced turbine stage for pulse turbocharging of large ICE engines (diesel or hydrogen) for commercial on-road and non-road vehicles and applications with up-to-date valve train helping to meet future Euro VII and Stage VI emission standards. The related issues of noise will be considered. This will be achieved by combination of advanced simulation techniques and dedicated experiments and the main focus will be highly unsteady operation conditions. A functional sample will be manufactured and tested.

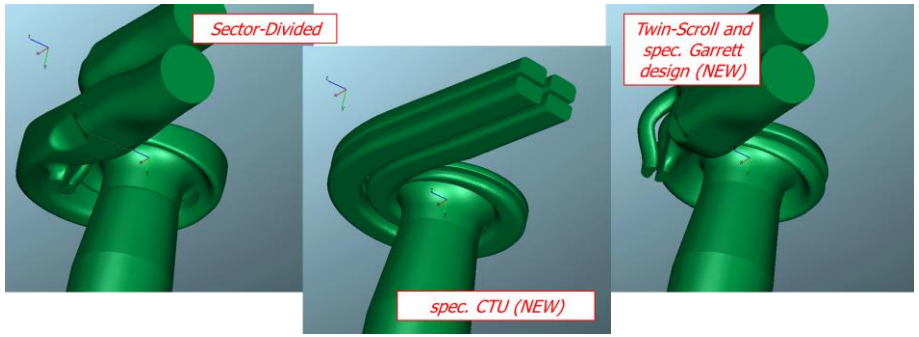
- Main topics (for the current time period):
  - Necessary data transfer to ROs (CTU, BUT).
  - To provide samples for experiments (e.g., noise testing at BUT).
  - Perform experiments on selected turbocharged SI ICE => data & geometry transfer to CTU.
  - To provide needed CAD/CAE data to ROs and support their R&D activities.
  - **Unconventional turbine design** => **3-WP05-003** + **3-WP05-004** are focused on that.
  - Topic of (compressor) **noise** => **3-WP-002** delas with that.

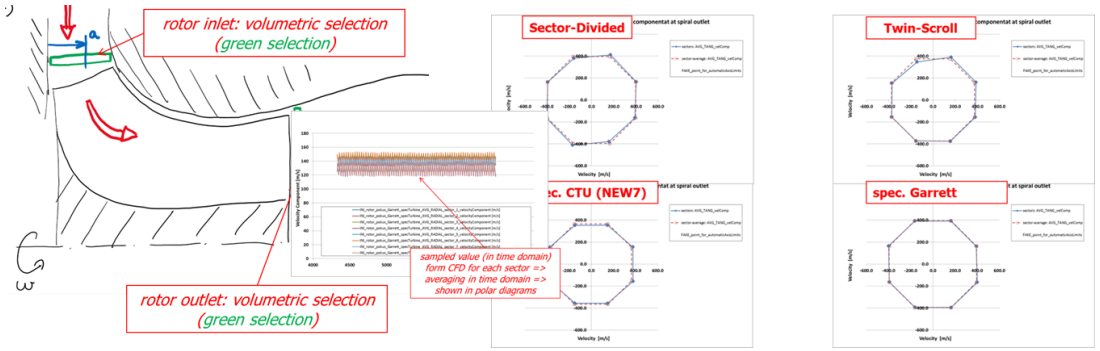
Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-001: Unconventional turbocharger optimized for highly pulsating operation and decreased noise

- Unconventional turbine design:

– Standard multi-entry solutions (twin-scroll, sector-divided), special CTU design(s) and special Garrett design.
– Optimization procedure is focused on highly-pulsating operation (i.e., very unsteady process).
– It cannot be tested/verified under steady-state operation => interaction between ICE and turbine has to be considered => co-simulation between 0-D/1-D CFD (ICE model) and 3-D CFD (turbine) is necessary.
– Future requirements will be considered => highly diluted exhaust gases (due to LTC) => both stator and rotor are to be optimized.





Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-001: Unconventional turbocharger optimized for highly pulsating operation and decreased noise

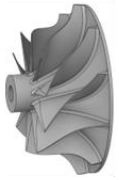
- Reduction of compressor aerodynamic noise:

– Compressor casing surface treatment was converted to larger size turbos and parametric (the number of grooves and groove radiuses) were realized.

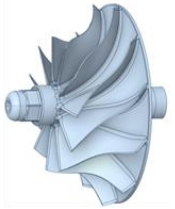
– Both simulations (3-D CFD) and experiments were performed.

GT12	
Number of grooves [–]	Groove radius [mm]
18	0.15
18	0.3
28	0.15
9	0.15
9	0.3
18	0.1
9	0.1
28	0.1
18	0.4

GT15	
Number of grooves [–]	Groove radius [mm]
16	0.3
16	0.4
6+10	0.3+0.4
13	0.3
16	0.2
30	0.1
6+6+4	0.4+0.3+0.2
20	0.3
5	0.4
6+10	0.5+0.3
14	0.3

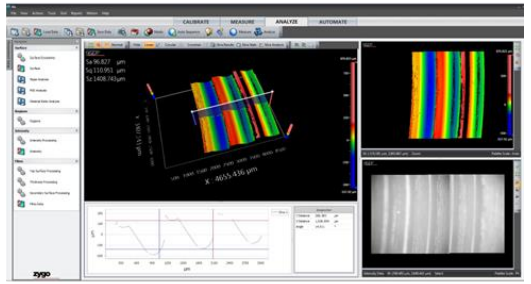


GTD2056	
Number of grooves [–]	Groove radius [mm]
1	1
10	0.4



GT40	
Number of grooves [–]	Groove radius [mm]
3	0.3
6	0.5

This variant was experimentally measured on test bench. Manufacturing process quality turned out to be crucial. Numerical prediction was not confirmed.

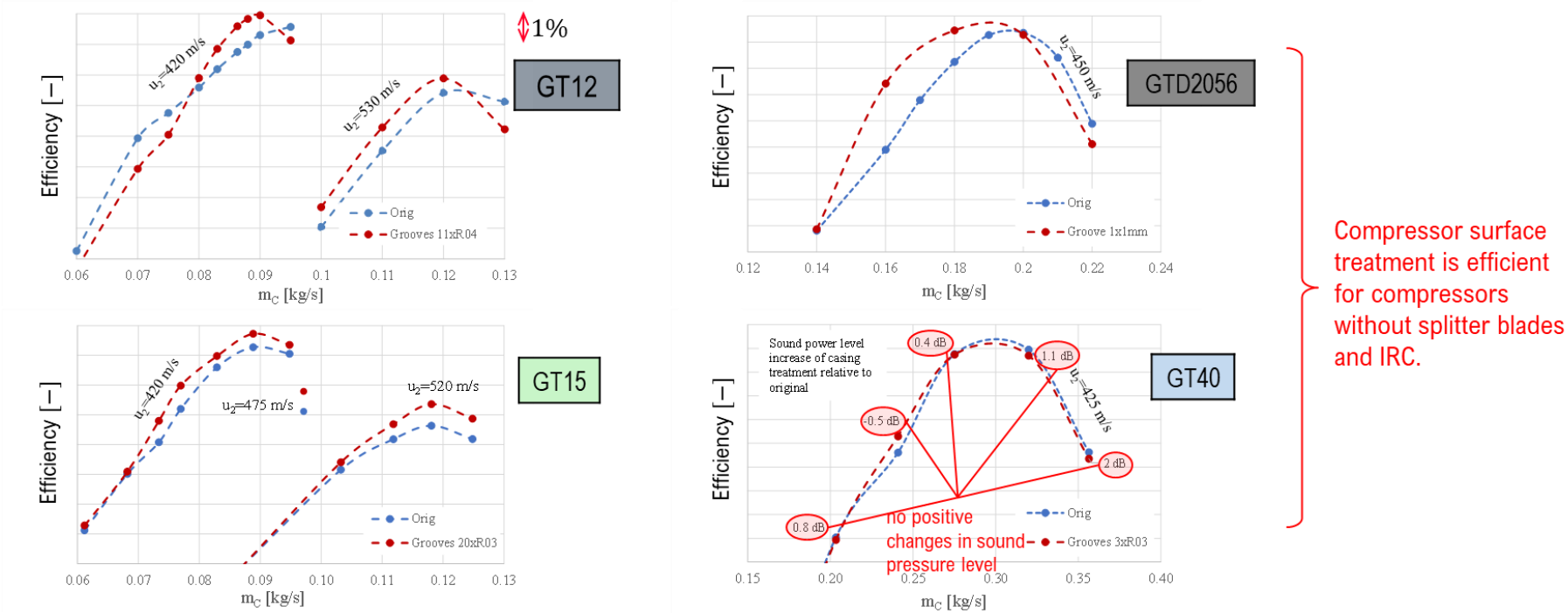


Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-001: Unconventional turbocharger optimized for highly pulsating operation and decreased noise

- Reduction of compressor aerodynamic noise:

– Based on the numerical results (3-D CFD), the surface treatment has a positive effect on the radial compressors without splitter blades and without IRC and under operating conditions to the left of the speed line optimum.



Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-002: Noise Emission Finder for Centrifugal Compressor

- The software automatically analyses input data such as sound pressure, vibration and identifies typical sources of aerodynamic noise under different operating conditions. The software's functions are to evaluate the probability of occurrence of each source and to find problematic components or interactions.
- Closely related to 3-WP05-001.

- Main topics (for the current time period):
  - Perform dedicated experiments.
  - Analyze exp. data and propose an algorithm to identify possible noise sources.
  - Create a SW tool based on the above-mentioned algorithm.

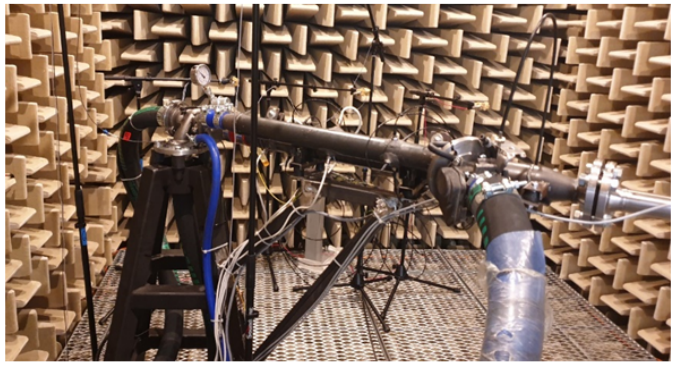
Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-002: Noise Emission Finder for Centrifugal Compressor

- Dedicated experiments:

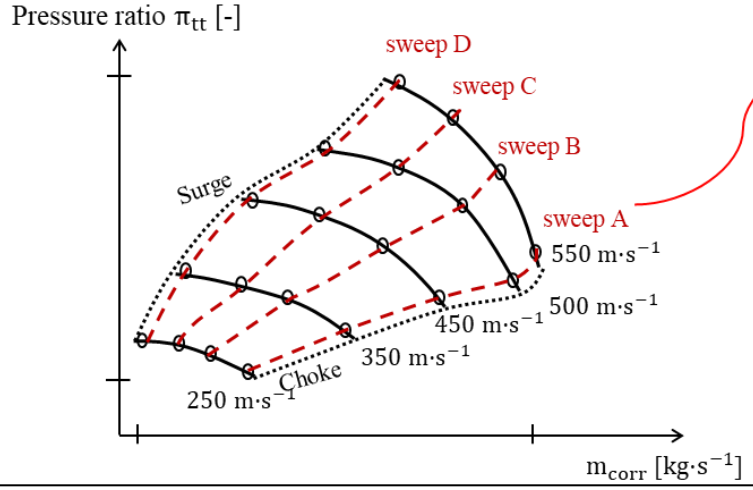
  - Identification of compressor noise sources were investigated by numerical and experimental methods.
  - Provided NVH data of the target turbocharger are used for NVH algorithm development and to develop a software solution.

turbocharger NVH measurement in full anechoic room at BUT

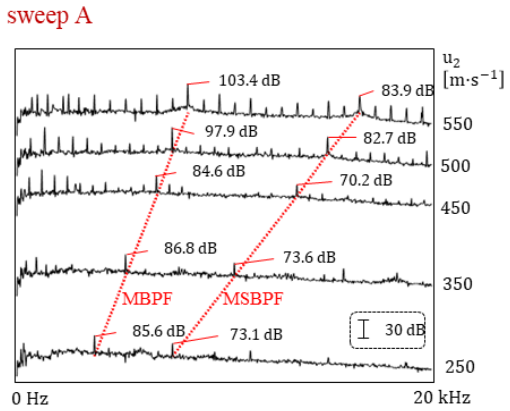


Representative image not necessarily corresponding to the measured size of the turbocharger.

turbocharger compressor map defining operating conditions



frequency analysis of compressor noise



Activities in 3-WP05: Future Automotive Boosting Solutions

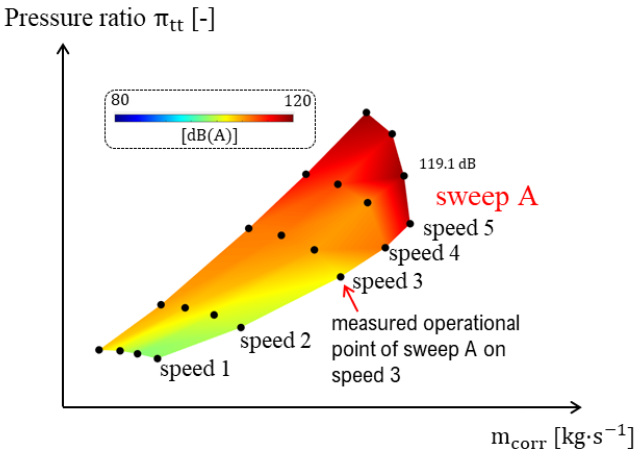
3-WP05-002: Noise Emission Finder for Centrifugal Compressor

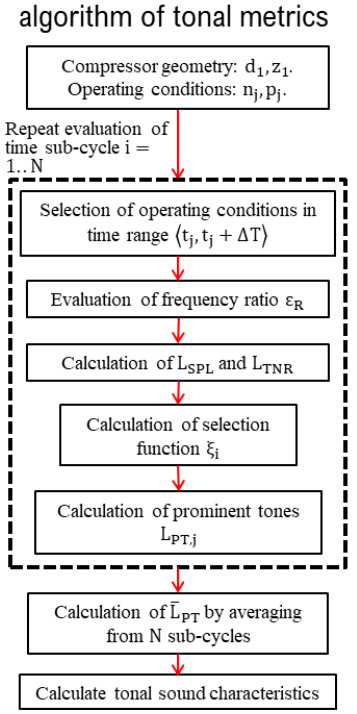
- SW tool to analyze experimental data/pattern:

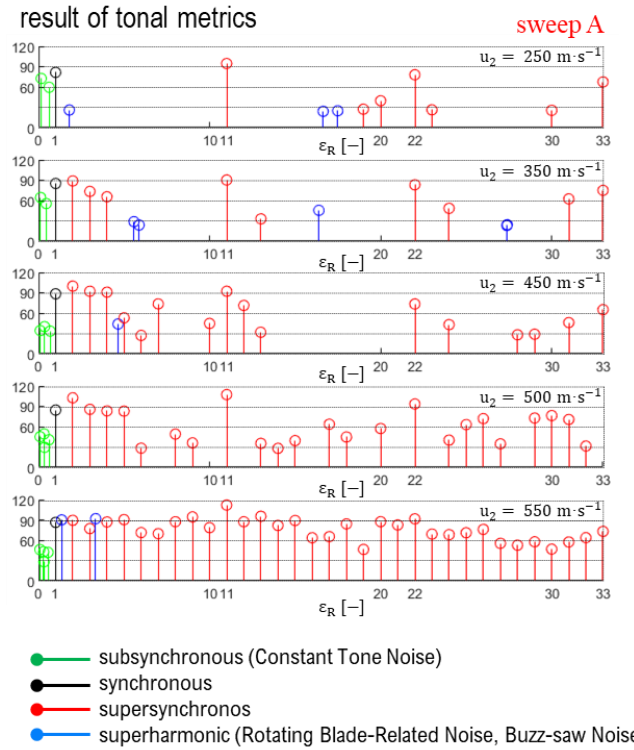
– Research work focused on the description and recognition of the tonal components of the compressor noise.

– A tonal metrics was developed for the identification of tonal noise components (Rotating Blade-Related Noise, Buzz-saw Noise).

– Possibly a dedicated phone app. will be developed to perform initial fast analysis 'on-site' using a cell phone.







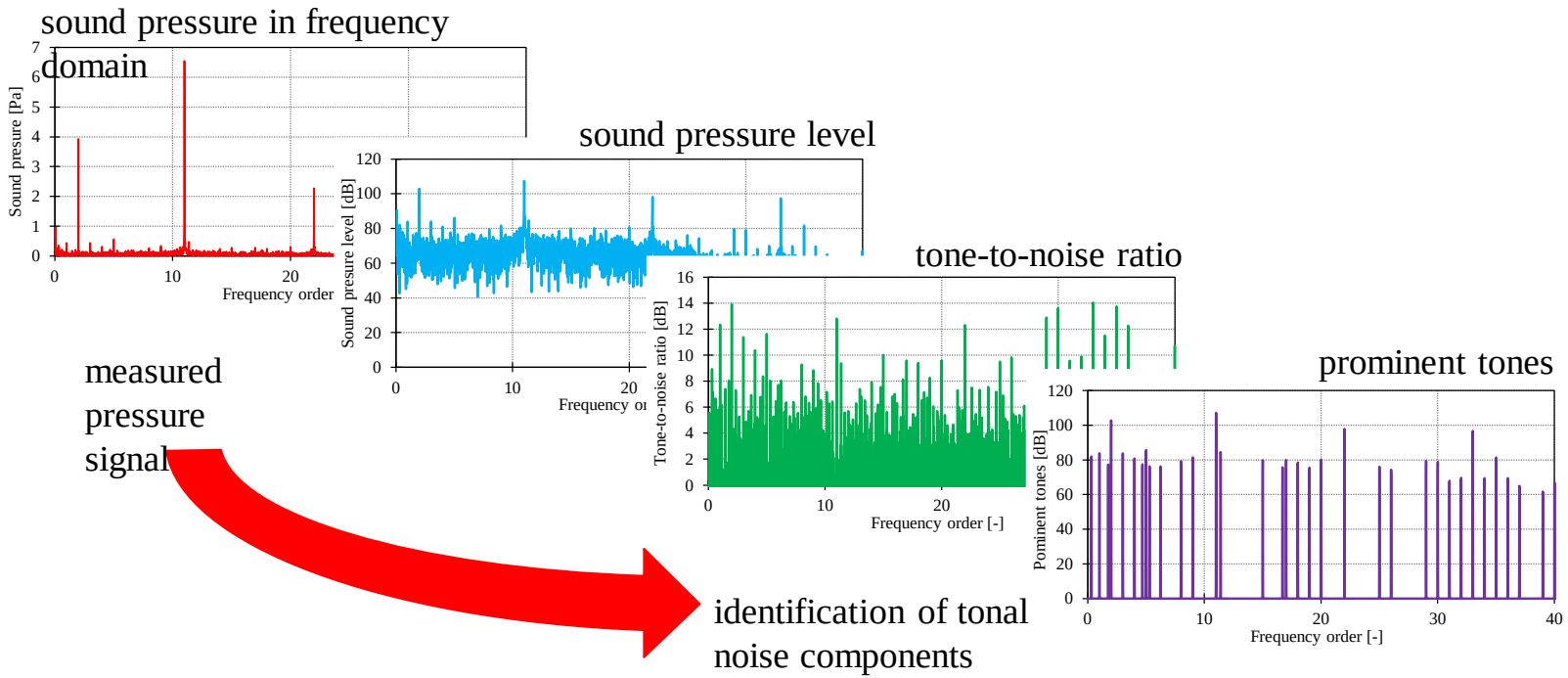
Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-002: Noise Emission Finder for Centrifugal Compressor

- SW tool to analyze experimental data/pattern:

– A tonal metrics was – data processing to identify important/prominent tone(s) from experimentally obtained signal(s).

– Then, based on literature knowledge and experience, the tone(s) are identified with expected noise sources.

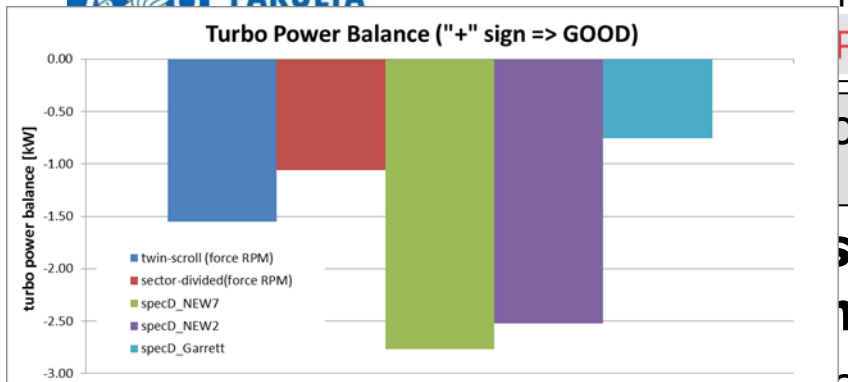


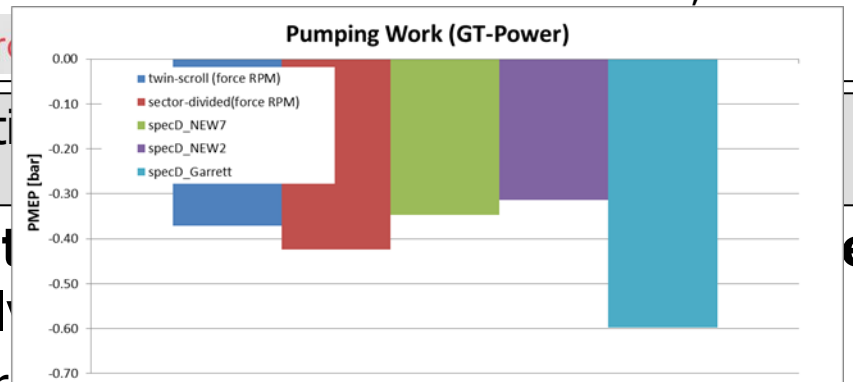
Activities in 3-WP05: Future Automotive Boosting Solutions

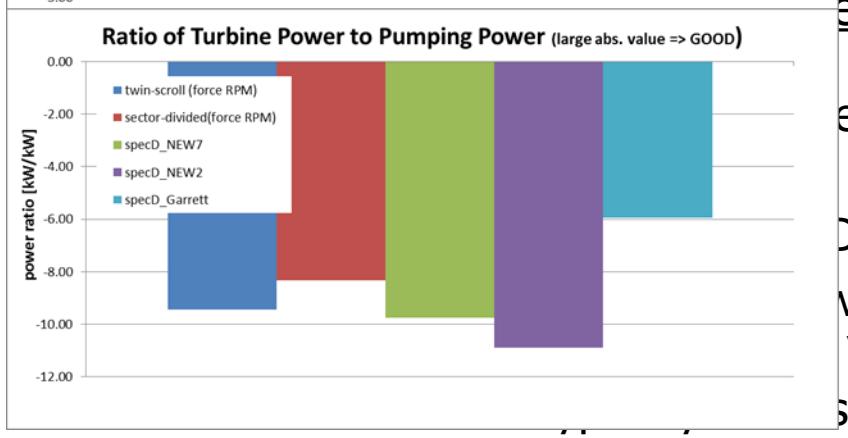
3-WP05-003: Software tools to design, optimize and evaluate unconventional turbine design(s) under highly pulsating operation

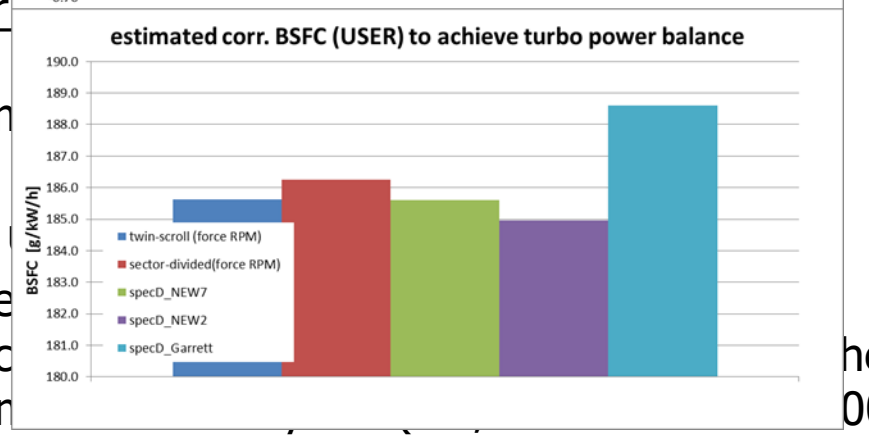
- The software enables fast initial design of important turbine parts to speed up the design, calculation and optimization process of different unconventional turbine variants. This includes complex 3-D CFD and 1-D CFD co-simulations and data analysis. The SW tool also enables fast preliminarily optimization of certain turbine parts before more complex simulation tools are applied.
- Closely related to 3-WP05-001.

- Main topics (for the current time period; all is based on simulations):
  - New unconventional turbine versions (both CTU variants and Garrett ones);
  - Updated versions of in-house SW tool(s);
  - Sensitivity studies (e.g., meshing, time steps, local BC);
  - Automation of the whole process (form basic geometry via mesh generation to 3-D CFD calculation & evaluation);
  - Optimization of turbine rotor (focused on LTC applications);

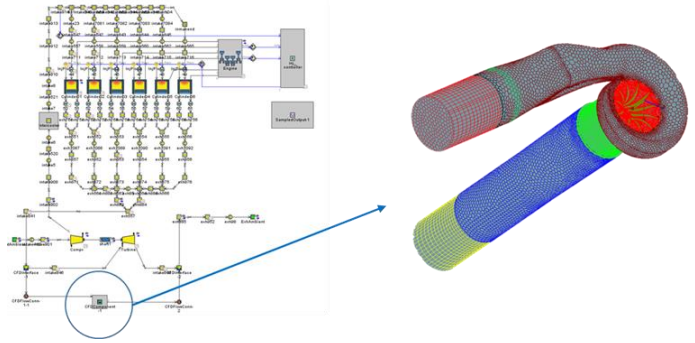


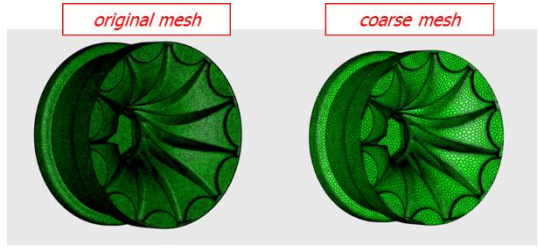






e unconventional





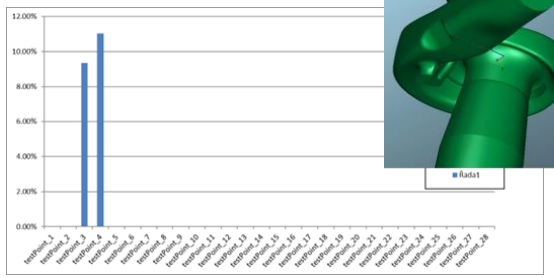
turbine revolutions) need to be calculated to reach 'converged status'.

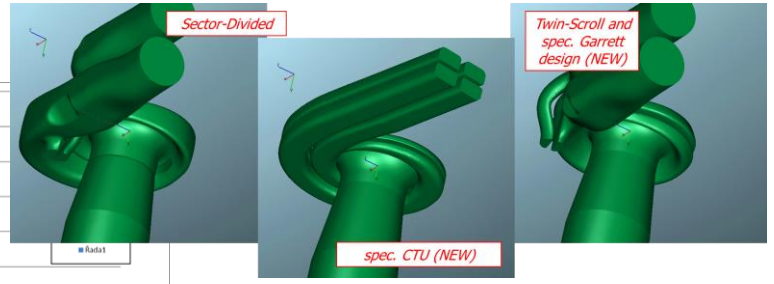
- Very time consuming: after a lot of testing, reasonable compromise seems to be 4 full ICE cycles (approx. 600 revolutions of turbine shaft) => 2.5 cycles with 'time' step of 10.0deg, 0.5 cycle with 2.0deg and 1 cycle (final cycle => data are used for evaluation) with 1.0deg.
- Application of 'optimal' coarse mesh is needed to minimize calculation time.

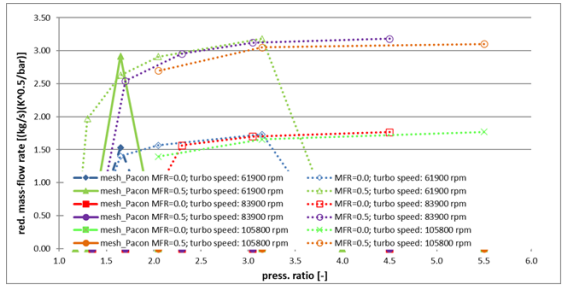
Activities in 3-WP05: Future Automotive Boosting Solutions

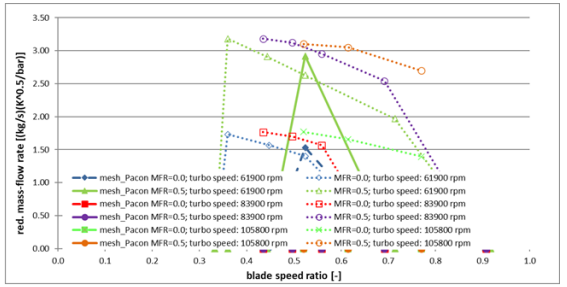
3-WP05-003: Software tools to design, optimize and evaluate unconventional turbine design(s) under highly pulsating operation:

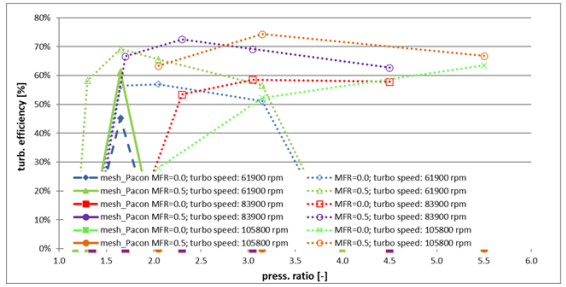
- <u>New turbine versions:</u>
  - Special Garrett design: goal was to increase swallowing capacity of the turbine and preserve (at least) turbine efficiency.
  - Trial & error method => more than 10 designs were proposed and tested (at reduced set of operating points) => none provided the desired results.
  - More comprehensive/systematic approach is needed to achieve that => **automated optimization** approach.

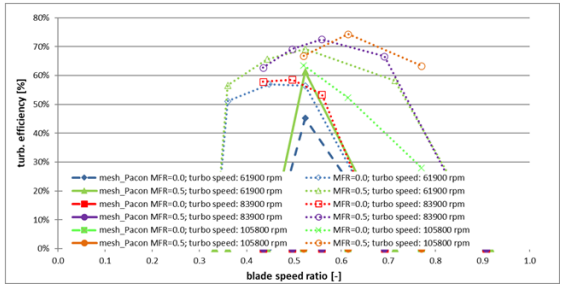








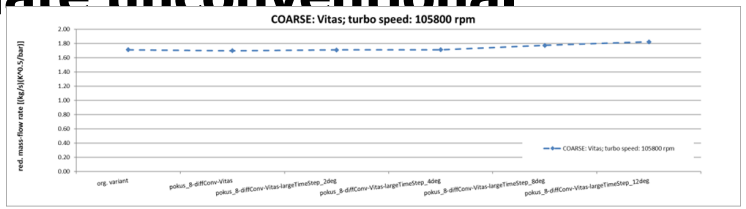


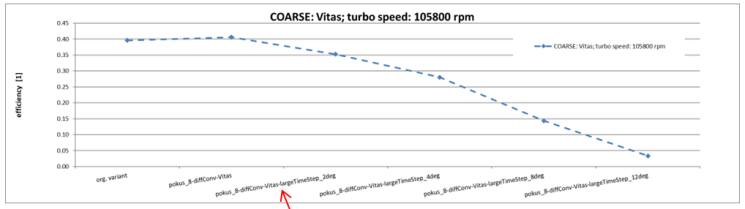


Activities in 3-WP05: Future Automotive Boosting Solutions

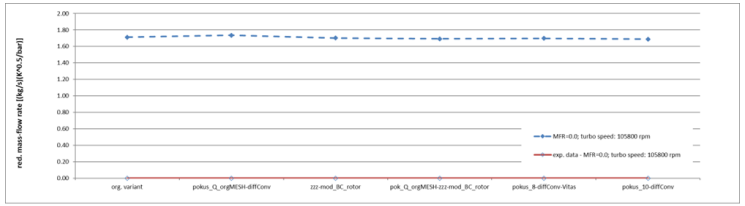
3-WP05-003: Software tools to design, optimize and evaluate unconventional turbine design(s) under highly pulsating operation:

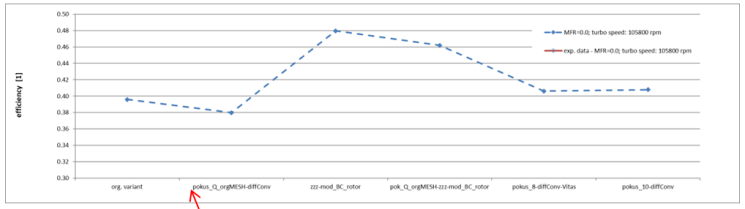
- Sensitivity studies:
  - Influence of mesh, time step, local BC => at certain operating points (close to of maximum thermodynamic efficiency), there is 'almost no' effect/influence of time step and local BC, however under different operating conditions (far from optimal BSR), these effects are very strong => no calculation speed-up is possible.
  - Mesh coarsening was already studied in NCK1 JOBNAC => rotor cell amount was reduced from 1.3M to 0.3M => further increase of cell size leads to significant change of results.
  - Applied time step strategy (for coupled 0-D/1-D + 3-D CFD calculation): running 4 full ICE cycles (approx. 600 revolutions of turbine shaft) => 2.5 cycles with 'time' step of 10.0deg (to stabilize mass-flow), 0.5 cycle with 2.0deg and 1 cycle (final cycle => data are used for evaluation) with 1.0deg.





Effect of time step (+ possibly mesh)



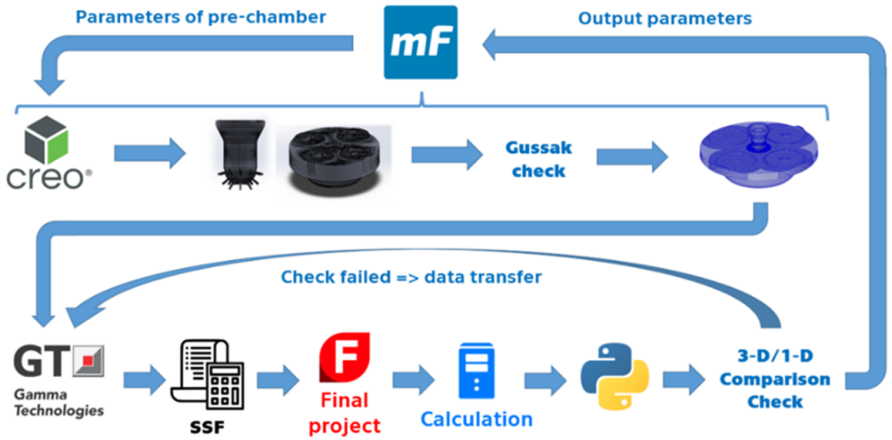


Effect of local BC (+ possibly other effects)

Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-003: Software tools to design, optimize and evaluate unconventional turbine design(s) under highly pulsating operation:

- Automation & updated SW version:
  - At the moment there are some technical difficulties when changing CAD/CAE tool (from CREO to CATIA), however these are expected to be solved before the end off 2023.
  - Once the different CAD/CAE tool (including the streamlined procedure to transfer the simplified geometry from in-house SW tool into complete 3-D geometry) is verified, the next steps of automation process will be started.



  - In-house SW tool was amended/updated during 2023.
  - Additional turbine version were proposed (based on special CTU design) => they will be tested (both steady state and transient operation) after technical problems are resolved.

Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-004: Report on Milestones - Unconventional turbine and Future boosting technologies:

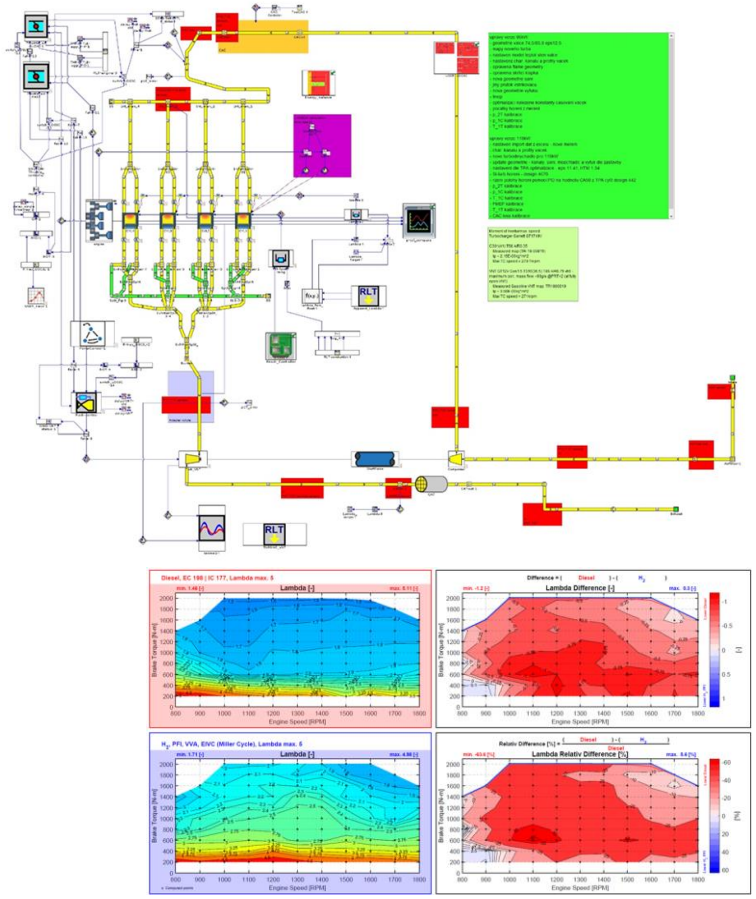
- Virtual Engine and Vehicle test rig complying with Green deal targets as well as EU7, CHN7 & SULEV 20 legislations. Gasoline engine with Predictive simulation model in GT-SUITE with cold start and driving cycle simulation capabilities. Virtual value assessment of various boosting architectures (Waste Gate Mono Scroll, Twin Scroll and Variable Turbine Geometry, non-electrified & electrified, etc.) in hybridized powertrains and with down selected catalyst light off technologies and strategies. Detailed target setting for boosting technology, turbine stage and compressor stage, leveraging simulation model developed and for gasoline engine thermal efficiency >45%.

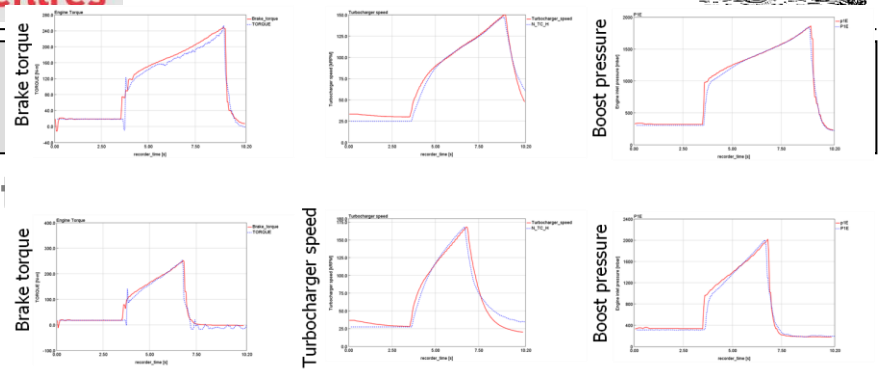
- Main topics (for the current time period; all is based on simulations):
  - Detailed calibration of baseline gasoline model (full engine map).
  - Calibration of predictive hydrogen combustion model (data from SCRE) to cover wide range of operating conditions (engine speed, load, air excess).
  - Turbocharger matching for (very) lean operation.
  - Transient model + fast-running model.

Activities in 3-WP05: Future Automotive Boosting Solutions

3-WP05-004: Report on Milestones - Unconventional turbine and Future boosting technologies:

- Baseline & Hydrogen ICE model calibration:
  - Baseline ICE calibration (1.5TSI):
    - Standard calibration process based on detailed experimental campaign (engine layout & geometry, valvetrain properties, intake/exhaust channels flow data, mechanical losses, combustion analysis – TPA, etc.);
  - Hydrogen ICE version:
    - fuel injection system and fuel amount control model modifications to use/apply a hydrogen (gas);
    - physical combustion model calibration – SI-turb combustion model calibration with help of measured data from single cylinder research engine (burn profiles) including wide range of operating conditions ⇔ CTU exp. Data (from SCRE);
    - new turbocharger matching with respect to different exhaust stream conditions to reach demanded engine output parameters;
    - transformation to high speed Fast Running Model (factor of RT around 3);



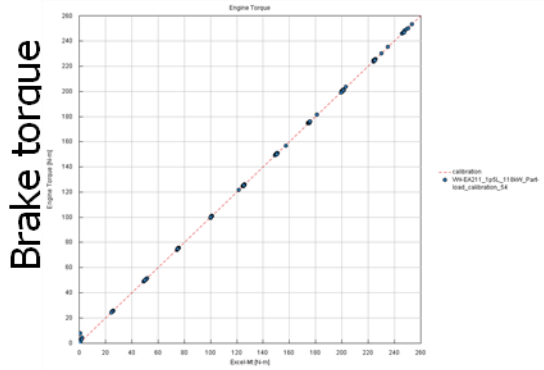


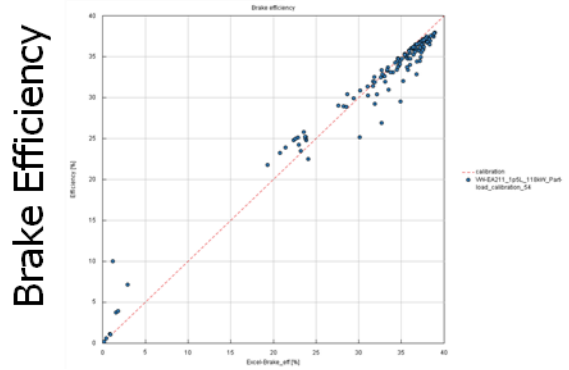
Activities in 3-WP05: Future Automotive Boosting Solutions

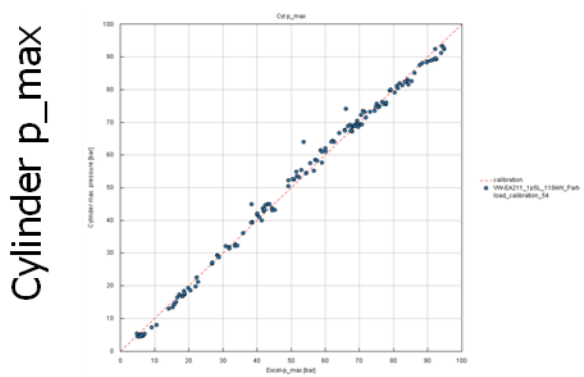
3-WP05-004: Report on Milestones - Unconventional technologies:

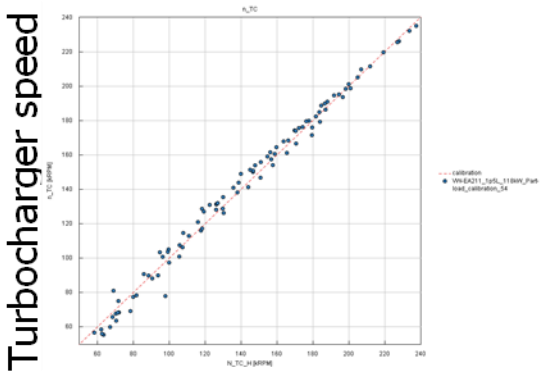
- Baseline model calibration:

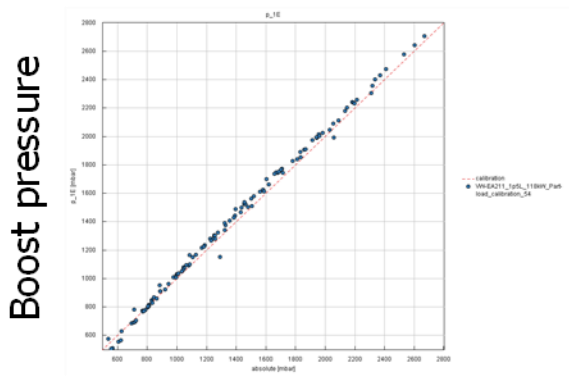
– Engine full map calibration was performed using predictive sub-models for important objects.
– Few more steps are still to be performed.
– Robust model control was developed (to achieve all necessary control targets).
– Transient model and FRM are being prepared.

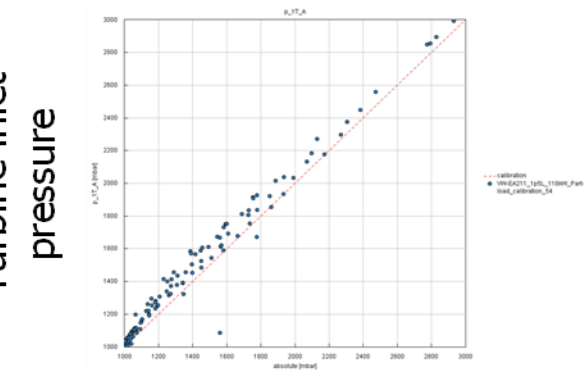












Fulfillment of goals and deliverables of 3-WP05: Future Automotive Boosting Solutions

Current State of Deliverables and Fulfillment of Goals

- 3-WP05-001 | **Unconventional turbocharger optimized for highly pulsating operation and decreased noise**, G-funk, VI./2026, Garrett 0.8; CTU 0.1; BUT 0.1 – **in progress & no major delays:**
  - This is the main results of the 3-WP05 and it is based on 3-WP05-002 and 3-WP05-003.
  - Garrett is supporting ROs (CTU, BUT) in their R&D activities in the early phase of the project.
  - Unconventional turbine design (3-WP05-003): new design variants were proposed and tested.
  - Noise (3-WP05-002): both 3-D CFD simulations and experiments were performed.

- 3-WP05-002 | **Noise Emission Finder for Centrifugal Compressor**, R-SW, VI./2026, Garrett 0.1; BUT 0.9 – **in progress & no major delays:**
  - Dedicated experiments were performed and the data were analyzed.
  - An algorithm (to process the data) was proposed and SW tool (based on that) was created.
  - Possibility to develop an app. (to run on a cell phone) is considered.

Fulfillment of goals and deliverables of 3-WP05: Future Automotive Boosting Solutions

Current State of Deliverables and Fulfillment of Goals

- 3-WP05-003 | **Software tools to design, optimize and evaluate unconventional turbine design(s) under highly pulsating operation**, R-SW, VI./2026, Garrett 0.1; CTU 0.9 – **in progress & no major delays:**
  - Updated SW version was created.
  - New turbine versions created/proposed – due to technical problems, they are yet to be tested under ICE-like operating conditions.
  - Selected sensitivity studies were performed (e.g., meshing, time step, local BC).
  - Technical problems/issues with new 'workflow' => expected to be solved before the end of 2023.
  - Initial steps towards automation were performed.

- 3-WP05-004 | **Report on Milestones - Unconventional turbine and Future boosting technologies**, O-ostatní, VI./2026, Garrett 0.2; CTU 0.8 – **in progress & no major delays:**
  - Baseline gasoline ICE model (1.5TSI) is ready <= calibration is (almost) finished.
  - Hydrogen combustion model is being prepared for calibration to match experimental data (from CTU SCRE).
  - Transient model and fast-running model (FRM) will be prepared soon.

Fulfillment of goals and deliverables of 3-WP05: Future Automotive Boosting Solutions

List of Due Deliverables and Their Added Value

- **3-WP05-001** – increase the level of knowledge and competitiveness in the field of highly-pulsating turbocharger operation (aerodynamics/thermodynamics, noise, design).
- **3-WP05-002** – deeper know-how in the field of turbocharger noise and its sources, close cooperation with industrial partner (Garrett) .
- **3-WP05-003 + 3-WP05-004** – deeper inside into turbine internal aerodynamics of automotive turbochargers (including highly-pulsating operation) and boosting system(s) of future automotive applications, close cooperation with industrial partner (Garrett) – both funded R&D projects and commercial ones.

Assessment of the Contribution of Deliverables

- Thermodynamics of boosted ICEs – (3-WP06), (3-WP07), (4-WP08), (4-WP06).
- Transient response of ICE – (3-WP06), (4-WP08), (4-WP06).
- Automated design & optimization – 3-WP07, 4-WP02.
- Unconventional combustion modes (e.g., LTC) – 3-WP07.

Current contribution of 3-WP05: Future Automotive Boosting Solutions

Assessment of the Formal/Administrative Goals of the Work Package

All formal and administrative requirements are expected to be fulfilled.

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

Current contribution of 3-WP05: Future Automotive Boosting Solutions

Acknowledgment

This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Centres II, project # TN02000054 Božek Vehicle Engineering National Center of Competence (BOVENAC).

Výtah z prací 2023-2025 za 3-WP05: Budoucí systémy přeplňování

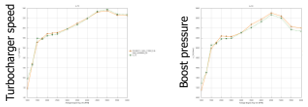
Garrett: konstrukce turba

Měření na vybraných přeplňovaných motorech

Výroba & návrh/konstrukce (např. 3-D tisk nekonvenční turbiny)

Povrchově upravené díly kompresoru + vzorky protestování

Podpora: data + konstrukce



CTU: termodynamika

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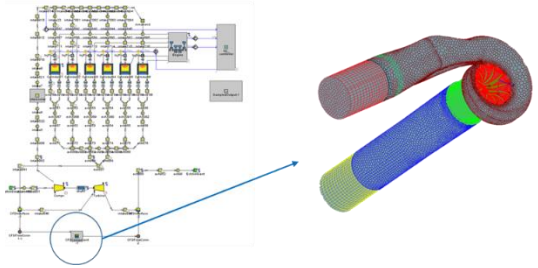
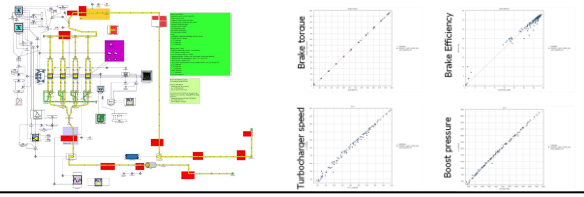
Propojená paralelní simulace mezi 1-D a 3-D CFD pro simulaci skutečných podmínek práce turbiny



Prediktivní 1-D CFD model pro analýzu budoucích konceptů v oblasti přeplňování



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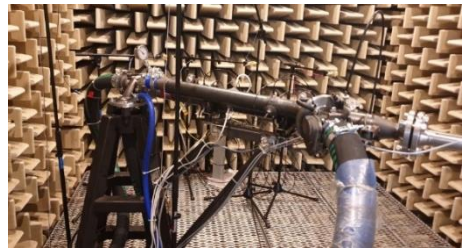
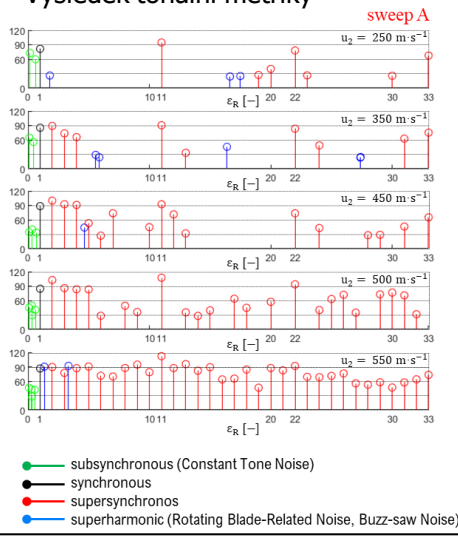


Výsledek tonální metriky



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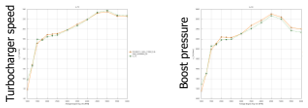

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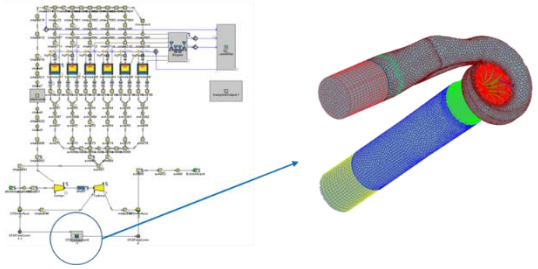

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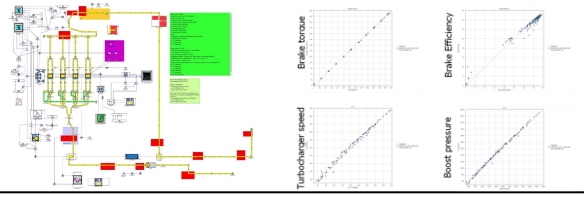

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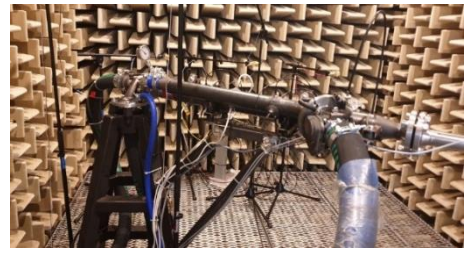
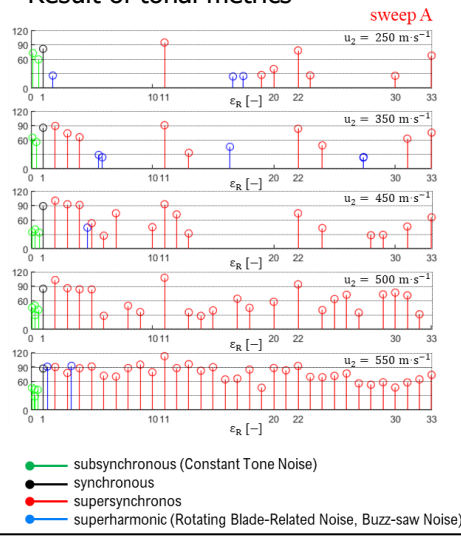


Result of tonal metrics



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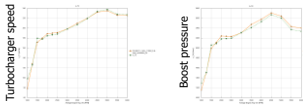

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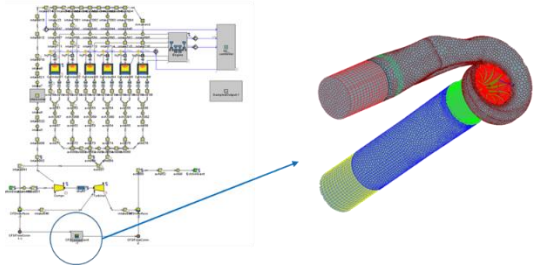

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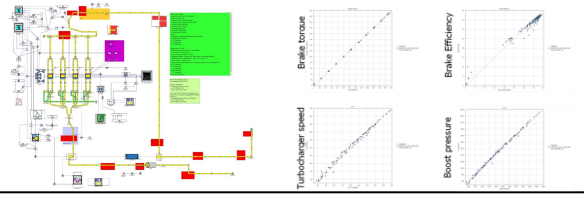

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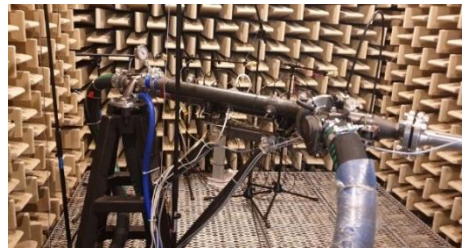

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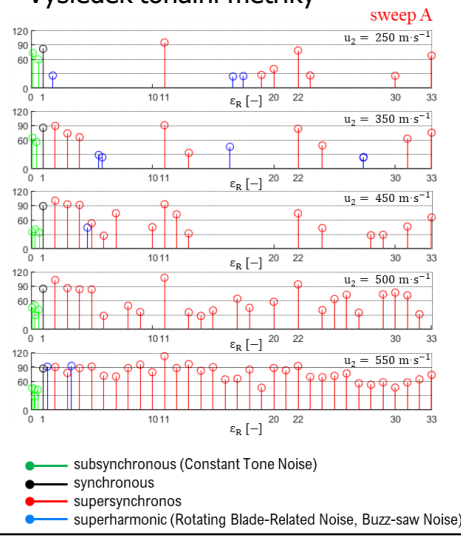

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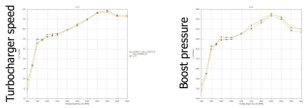

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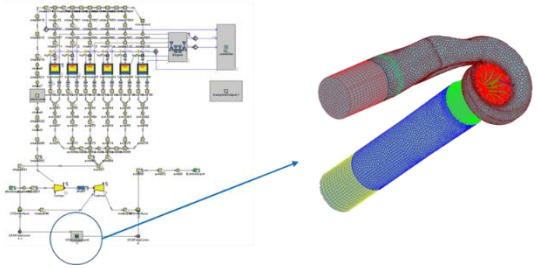

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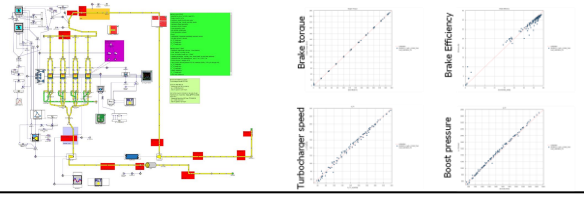

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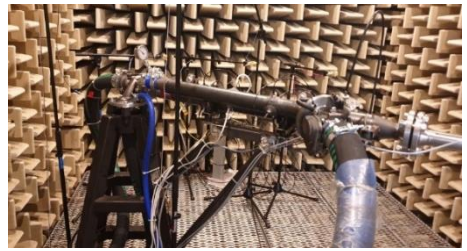

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