KTH ROYAL INSTITUTE
OF TECHNOLOGY

CCGEx, Status New Projects 2018-2021

Mihai Mihaescu, Anders C. Erlandsson

11-12 October 2018, CCGEx Research Days, Stockholm

CCGEx Research Areas
2018-2021

- i-COLD: Integrated COLD-side
- i-HOT: Integrated HOT-side
- i-SYS: Integrated System Studies

Time-table: Research Projects

Research Area	2017				2018				2019				2020				2021				2022	
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
i-COLD: Mihai Mihaescu																						
Bertrand Kerres, PhD student, ICE, EXP/1D		PhD																				
Elias Sundström, PhD student, Mek, CFD				PhD																		
Raimo Kabral, PhD student, MWL, EXP		PhD																				
Asuka Pietroniro, **Ind. PhD stud Volvo Cars**, MWL/Mek, CFD/CAA									Lic										PhD			
Valeriu Dragan, **Post-doc BW**, Mek, CFD on non-axisymmetric diffusers																						
Emelie Trigell, PhD student, Mek, CFD. Compressor Response to upstream/downstream ins							**NEW**															PhD
Aerodynamically generated noise of Centrifugal Compressors-Experiments, Post-doc, MWL, EXP									**NEW**				+ 1 year SCANIA/VCC'									
Niloofar Sayyad Khodashenas, Marie Curie **Assoc. PhD Project**, MWL., Exp/model/Non-linear system ID for TC																						
i-HOT: Mihai Mihaescu																						
Ted Holmberg, PhD student, ICE, 1D/EXP		Lic							PhD													
Marcus Winroth, PhD student, Mek-CICERO, EXP		Lic								PhD												
Shyang Maw Lim, PhD student, Mek, CFD	Lic							PhD														
Nicholas Anton, **Ind. PhD stud SCANIA**, ICE, 2D AeroDesign					Lic						PhD											
Roberto Mosca, PhD student, Mek, CFD/optimization. Turbine performance optimization w							**NEW**															PhD
Yushi Murai, PhD student, Mek, EXP. Turbocharger turbine efficiency in steady and pulsatir							**NEW**															PhD
i-SYS: Anders Christiansen Erlandsson																						
Ghulam Majal, PhD student, MWL/Mek, Numerics				Lic							PhD											
Arun Prasath, PhD student, ICE, EXP						Lic							PhD									
Zhe Zhang, **Assoc. CSC PhD Project**, MWL, "Slow Sound"												PhD										
Senthil Mahendar, PhD student (Volvo GTT), ICE, 1D Intr Turbo							Lic							PhD								
Sandhya Thantla, **Assoc. PhD Project**, ICE							Lic							PhD								
Engine, charging and EAT interaction during transients PhD student, ICE, EXP/1D							**NEW**															PhD
Exergy losses in high efficiency chargin systems, PhD student, ICE, EXP/1D							**NEW**															PhD
Jianhua Zhou, Post-doc, MWL. Waste Heat Recovering in pulsating flows-Thermoacoustics,							**NEW**	Continuation from 2018 CSC														

i-COLD: Integrated Cold-side

Research Questions - iCOLD

- Which are the mechanisms & key factors leading to stall onset in centrifugal compressors?
  - Impact of upstream / downstream perturbations and installation effects on compressor stability and performance
  - Assess & mitigate flow phenomena leading to stall/surge

R1

- Understand compressor system's components, their interactions, for an optimal, variable boosting system
  - Impact of hybridization; El-booster/power-boost system integration; Two stage/sequential system integration
  - Optimised component interaction/connections

R2

- Which are the mechanisms for the aerodynamically generated noise in compressor systems?
  - Assess & mitigate the dominant acoustic sources

R3

Research Projects: i-COLD

Research Area	2017				2018				2019				2020				2021				2022		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q
i-COLD: Mihai Mihaescu																							
Bertrand Kerres, PhD student, ICE, EXP/1D		PhD																					
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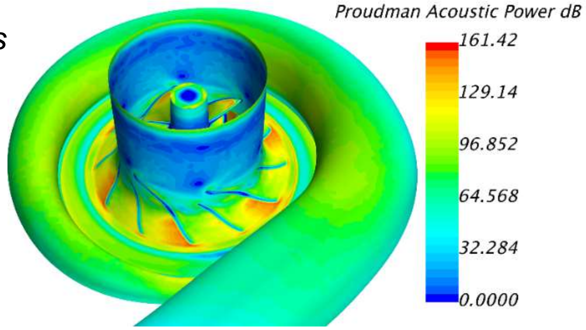
Aerodynamically generated noise of Centrifugal Compressors-Experiments, Post-doc, MWL, EXP									**NEW**				+ 1 year SCANIA/VCC'										
Niloofar Sayyad Khodashenas, Marie Curie **Assoc. PhD Project**, MWL., Exp/model/Non-linear system ID for TC																							

i-COLD: PhD Individual projects

On the aerodynamically generated sound of centrifugal compressors

Ind. Doctoral student (Volvo Cars); started 05/12/2016:
Asuka Gabriele Pietroniro (CFD/CAA)

Supervisors:
Mihai Mihaescu, Mats Åbom, Magnus Knutsson (VCC)



Compressor response to upstream/downstream installation effects and perturbations

Proposed PhD student (HT2018):
Emelie Trigell (CFD), Mek

Supervisors:
Mihai Mihaescu, Mats Åbom, Lisa Prahl-Wittberg

Compressor response to upstream/downstream installation effects and perturbations

R1, R2

Project advisors: Mihai Mihaescu, Mats Åbom, Lisa Prahl-Wittberg
PhD student: Emelie Trigell (HT2018)

- Understand the mechanisms responsible for the onset of flow instabilities in centrifugal compressors and noise generation with upstream and downstream installation effects by means of high-fidelity simulations and mode decomposition techniques (for the selected operating conditions).
- Asses sensitivity to temperature conditions, to upstream / downstream perturbations (e.g. pressure pulses caused by engine breathing), to surface roughness (impeller/diffuser); analyse the impact on the onset of compressor instabilities and compressor noise
- Assess EGR-compressor interaction and impact on instabilities at off-design conditions; Investigate the limits for formation of condensation upstream of compressor inlet (possible with low pressure EGR injection), depending on coolant and intake air temperatures.
- Develop an efficient and accurate method for modelling compressor stability and performance

Compressor response to upstream/downstream installation effects and perturbations

R1, R2

Project advisors: Mihai Mihaescu, Mats Åbom, Lisa Prahl-Wittberg
PhD student: Emelie Trigell (HT2018)

Activity / Time (Q)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
Review of the existing technology and state of the art for turbomachinery CFD modeling and data analysis	■															
High-fidelity transient simulations without installation effects	■	■	■													
Stability analysis; theoretical approach; Development of a stability model of the flow in a vaneless diffuser			■	■	■											
Impact of installation effects and geometry particularities on flow instabilities and noise					■	■	■	■								
Impact of surface roughness on compressor stability and noise							■	■	■	■						
Impact of the operating conditions (e.g. temperature, mass flow rate, pressure fluctuations) on flow and acoustics									■	■	■	■	■	■		
Stability model; Analysis of the impact of realistic boundary conditions													■	■	■	
Reports/Manuscripts/Thesis				■				■		■			■		■	■
Deliverables / Milestones																
Complete literature review		D1														
High-fidelity flow and pressure data base: compressor without installation effects				D2												
Precursor to surge instabilities & Surge criterion definition / no-installation effects				M1												
Stability analysis & stability model						M2										
Evaluated Impact of installation effects and pressure perturbations on on-set of instabilities									D3							
Evaluated Impact of roughness (surface - diffuser) on the on-set of instabilities											D4					
Evaluated Impact of operating conditions & temperature on compressor stability and noise														D5		
Extended stability model to acount for upstream/downstream installation effects and perturbations																D6
Publications /Conferences				P1				P2		P3			P4	P5	P6	
Theses									Lic							PhD

Compressor response to upstream/downstream installation effects and perturbations

R1, R2

Interaction with other projects:

- Geometries, initial data, mass flow rates and pressure ratio data from industry; Boundary conditions provided by 1D models & experiments (parallel projects CICERO Lab/ Industry)
- Developed accurate 1D stability model of the compressor (output to i-SYS stud.) to be used towards deriving an optimized integration: bended pipes & compressor & EGR
- Use the topology optimization method developed as part of i-HOT (parallel project) for geometry optimization purposes to minimize the pressure losses and maximize the flow uniformity at the entrance of the compressor.
- Provide data for performing calibrated 1D engine process simulation and/or experiments as part of the i-SYS research area.
- Interaction with the experimental and computational projects dealing with compressor noise (data & knowledge transfer)

Emelie Trigell, PhD Student

- M.Sc in Engineering Physics at KTH started 2013
- Bachelor Thesis in Analytical Mechanics
- Master in Fluid Mechanics
  - Turbulence, CFD, Compressible flow, aerodynamics, etc
  - Signal analysis, Experimental Structure Dynamics, FEM
- Internship at Scania
- Master thesis at Scania working on after-treatment simulations
  - *CFD-simulations of urea-water spray in an after-treatment system using Star-CCM+*
  - Multi-phase flows, spray, wall film formation, solid deposits, LPT, URANS

Activities

- iTrue *Energy efficiency potential for autonomous driving*
  - ECO_2 Vehicle Design
- Algoryx *Verification of 1D lumped element beam simulation model*
  - Visual and interactive physics based simulations
- Mentorship program *Pepp*
- Outdoor activities

Aerodynamically generated noise of centrifugal compressors- Experiments

R3, R2

Project advisors: Mats Åbom, Jens Fransson, Mikael Karlsson
1 Post-doc (VT2019)

- To apply multi-port methods for acoustic characterization of turbo compressors. In particular to develop procedures to **measure the reflection free sound power per mode at the inlet/outlet**.
- To develop methods for **correlation of acoustic** multi-port **data (or sound power per mode) with flow field data** inside the compressor.
- The project is related to VCC industrial PhD Asuka Pietroniro plus the interest from several partners to develop their turbo-testrigs.

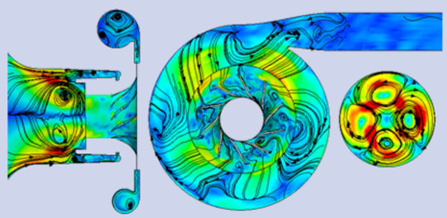
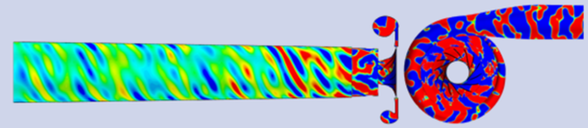
Nonlinear system identification techniques for acoustic characterization of turbochargers under high level pulsating flow excitation

Project advisors: Hans Bóden, Mats Åbom, Jens Fransson R3, R2

*1 year finance for one Marie Curie student (*Niloofar Sayyad Khodashenas, *4:th year) – Associated project*

- To develop **nonlinear acoustic system identification techniques** for analysis of numerical simulation and experimental data for turbocharger turbines and compressors
- To determine **nonlinear turbocharger characteristics** at different operating conditions. This will make it possible to assess the importance of nonlinear acoustic characteristics and give input to improved 1-D models.

i-COLD activities

	Enhance understanding of Flow instabilities at low mass flow rate	Understand and mitigate the aerodynamically generated noise
Problem statement	• Triggering factors for instabilities at Off-design operating conditions are unknown. • Impact of upstream/downstream installation effects and perturbations on the on-set of instabilities is unknown. • Gas-stand experiments limited to stable operating conditions; standard CFD approach: RANS based modeling • High fidelity, efficient CFD & advanced post-processing techniques (e.g. DMD/POD, Fourier surface spectra) are used.	• Standard techniques relay on RANS modeling not suitable for aeroacoustic calculations. • Quantification of the dominant acoustic sources in the centrifugal compressor for operating conditions of interest. • Determine the role of flow-acoustics coupling and its effects on the compressor stability and performance. • Establish a correlation between the acoustic sources and the propagating noise in the far-field.
Goal statement	• Enhance understanding of the mechanisms and key factors leading to stall on-set in centrifugal compressors. • Asses system sensitivity to temperature conditions, to upstream / downstream perturbations (e.g. pressure pulses caused by engine breathing), to surface roughness. • Provide guidelines for advanced flow control technologies.	• A physics-based understanding of the aerodynamically generated noise in centrifugal compressors. • Characterization of acoustic appearance: monopole, dipole and or quadrupole sources. • Provide guidelines for developing noise suppression technologies at the source.
Envisioned outcomes	• A physics based knowledge of flow instabilities emerging at low mass flow rate in compressor systems. • Concepts for flow control technologies to improve compressor's operating range at low mass flow rates. • An efficient and accurate method for modelling charging system's stability and performance. 	• High fidelity sound mapping using computational efficient CFD technique with FW-H far-field propagation. • Concepts for noise supression technologies at the source. 
Impact on Industry	• Improved product performance at low mass flow rates (5 % surge margin extension for high-speed lines). • Provide an efficient and accurate tool for modelling charging system's stability and performance.	• Computationally efficient CFD/optimization methodology for developing noise suppression technologies. • Viable strategies for reducing the aerodynamically generated noise.

i-HOT: Integrated HOT-side

Research Questions: i-HOT

- Understand the impact of pulsating hot flows on component & connections (interaction between components) R1
  - Identify and mitigate aero- and thermal losses
  - Identify the available enthalpy (exergy)
- How to take advantage of the pulsating conditions to maximize the average turbine power output? R2
- Understand the heat-harvesting mechanisms from pulsating hot gas
  - Pressure drop penalties vs. heat transferred
  - Fluctuations impact on performance R3

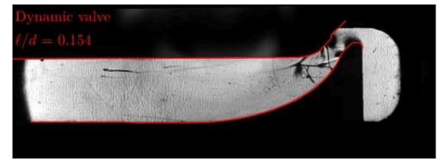
Research Projects: i-HOT

Research Area	2017				2018				2019				2020				2021				2022		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q
i-HOT: Mihai Mihaescu																							
Ted Holmberg, PhD student, ICE, 1D/EXP		Lic							PhD														
Marcus Winroth, PhD student, Mek-CICERO, EXP		Lic								PhD													
Shyang Maw Lim, PhD student, Mek, CFD	Lic							PhD															
Nicholas Anton, **Ind. PhD stud SCANIA**, ICE, 2D AeroDesign					Lic						PhD												
Roberto Mosca, PhD student, Mek, CFD/optimization. Turbine performance optimization w							**NEW**															PhD	
Yushi Murai, PhD student, Mek, EXP. Turbocharger turbine efficiency in steady and pulsatir							**NEW**															PhD	

HOTSIDE: Individual projects

Gas Dynamics at the Exhaust Valves and Ports
Doctoral student:
Marcus Winroth (Exp), Mek-CICERO

Supervisors:
Henrik Alfredsson, Ramis Örlü

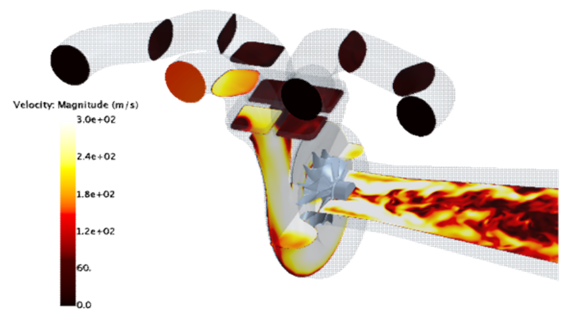


Valve Strategies and Exhaust Pulse Utilization
Doctoral student:
Ted Holmberg (1D modeling, Exp), ICE

Supervisors:
Andreas Cronhjort, Ola Stenlåås (KTH/Scania)

Flow and Heat-transfer in a Turbocharger Radial Turbine
Doctoral student:
Shyang Maw Lim (CFD), Mek

Supervisors:
Mihai Mihaescu, Anders Dahlkild, Christophe Duwig



Engine Optimized Turbine Design
Ind. Doctoral student:
Nicholas Anton (Aero-design, Exp), SCANIA

Supervisors:
Anders Christiansen Erlandsson, Magnus Genrup, Per-Inge Larsson

HOTSIDE: Individual projects

Turbocharger turbine efficiency in steady and pulsating inlet flow

Proposed PhD student (HT2018):
Yushi Murai (Experiments CICERO Lab), Mek
Supervisors:
Jens Fransson, Mihai Mihaescu, Anders C. Erlandsson

Turbine performance optimization with focus on maximising exergy transfer from hot-side to cold-side

Proposed PhD student (HT2018):
Roberto Mosca (CFD & reduced order modelling), Mek
Supervisors:
Mihai Mihaescu, Anders C. Erlandsson, Anders Dahlkild

Turbocharger turbine efficiency in steady and pulsating inlet flow - experiments

R1-R3

Project advisors: Jens Fransson, Anders C. Erlandsson, Mihai Mihaescu
PhD student: Yushi Murai (HT2018)

- To define a suitable measure of turbine efficiency under pulsating flow conditions.
- To determine turbine characteristics at steady and pulsating flow conditions for various inlet flows; this includes geometry (straight pipe inlet versus bend inlets), pulse amplitude and shapes, as well as pulse frequencies.

Turbocharger turbine efficiency in steady and pulsating inlet flow - experiments

R1-R3

Project advisors: Jens Fransson, Anders C. Erlandsson, Mihai Mihaescu
PhD student: Yushi Murai (HT2018)

Activity / Time (Q)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
Background review on turbocharger efficiency and of pulse generation																
Getting acquainted with different velocity and temperature measurement techniques																
CFD simulations to gain experience on the velocity pulse dependency on the open area-phase relation																
Experiments to determine the velocity pulse dependency on the open area-phase relation																
Assess impact of steady flow conditions on the flow field upstream and downstream of the turbine																
Assess impact of different pulse shapes on the flow field upstream and downstream of the turbine																
Perform simultaneous velocity and temperature measurements upstream and downstream of the turbine																
Data postprocessing including statiscal, spectral and modal analyses																

Deliverables/Milestones	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
Complete background literature review			D1													
Brief report on different velocity and temperature measurement techniques					D2											
Brief report on velocity pulse dependency on the open area-phase relation							D3									
Experimental data on steady flow conditions										M1						
Experimental data on pulsating flow conditions with various pulse shapes													M2			
Theses										Lic					PhD	

Turbocharger turbine efficiency in steady and pulsating inlet flow - experiments

R1-R3

Interaction with other projects:

- This experimental project in the CICERO lab will have a numerical counterpart (CFD at KTH Mechanics within CCGEx). The experimental results will partly be used for validating the CFD simulations in steady as well as unsteady flow conditions.
- Inflow conditions in terms of real pulse shapes will be provided by the industry for repeatable replication in the controlled CICERO environment.
- Input and guidance from the numerical project running in parallel in i-HOT to perform CFD simulations. Results that will guide the experimental investigation to understand the influence of the *open area*-phase relation of the valve on the velocity pulse shape.
- The industry will provide input on the choice of turbocharger.
- Develop using high-fidelity data an efficient and accurate performance model, able to predict turbine power output data as a function of incoming engine pulses (output to i-SYS stud.).

Turbine performance optimization with focus on maximising exergy transfer

R1-R3

Project advisors: Mihai Mihaescu, Anders C. Erlandsson
PhD student: Roberto Mosca (HT2018)

- Consider the heat-transfer problem in engine exhaust manifold under realistic flow and temperature conditions; use the built knowledge towards minimizing aerothermodynamic losses.
- Methodology development to be able to perform topology optimization of the hot-side to improve pressure drop, uniformity index and velocity profile distribution.
- Improve understanding of the character of the pulsating exhaust gas flow and its effect on the turbine power output; understand to which extend engine exhaust port control is a measure for turbine optimization.
- Assess the sensitivity of system performance when modifying certain geometrical features of the turbine volute and in particular of the manifold; assess turbine aero-design impact on energy transfer to the shaft.
- Develop a simplified model approach for predicting turbine power output as a function of engine pulses, manifold pipes volume, length and shape in combination with performance-relevant turbine & turbine volute design parameters.

Turbine performance optimization with focus on maximising exergy transfer

R1-R3

Project advisors: Mihai Mihaescu, Anders C. Erlandsson
PhD student: Roberto Mosca (HT2018)

Activity / Time (Q)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
Review of the existing technology and state of the art for turbine modeling	■															
Transient simulations of pulsating exhaust flow interacting with turbine at Baseline	■	■	■													
Develop topology adjoint optimization method for time-dependent and compressible flows		■	■	■	■											
Implementaion of exergy based model for assessing aerothermodynamic losses				■	■	■										
Assess the sensitivity of turbine performance when modifying geometrical features of volute & manifold						■	■	■	■	■						
Assess turbine aero-design impact on energy transfer to the shaft									■	■	■	■	■			
Develop a model to predict turbine performance under realistic operating conditions												■	■	■	■	
Reports/Manuscripts/Thesis			■			■				■			■	■	■	■
Deliverables / Milestones																
Complete literature review		D1														
High-fidelity data-base associated with realistic pulsating flow and temperature conditions at Baseline				D2												
Evaluated impact of exhaust valve strategies on turbine performance and losses in the system						D3										
Topology adjoint optimization method							M1									
Identified exhaust pulse - manifold and volute characteristics for maximum performance and minimal loses										D4						
Identified optimized turbine design for maximum energy transfer to the shaft													D5			
Model for predicting turbine power output as a function of incoming engine pulses and manifold parameters															M2	
Papers/Conferences			P1			P2				P3			P4	P5	P6	
Theses									Lic							PhD

Turbine performance optimization with focus on maximising exergy transfer

R1-R3

Interaction with other projects:

- Geometries, initial and boundary conditions to be provided by industrial partners. The project benefits from the knowledge already built with respect to the pulsating flow characteristics and impact on turbine performance.
- The project will have an experimental counterpart (experiments in CICERO Lab); Turbine performance, temperature and heat transfer data obtained in CICERO Lab will be used for validation purposes. Benefit from on-engine data measurements provided by a parallel project (Machine Design) or from our industrial partners.
- Knowledge on impact of pulse characteristics on aerothermodynamic heat-losses and turbine performance from high-fidelity CFD data to be used to develop / calibrate the exergy based model developed at KTH-Mechanics.
- The developed models and the topology optimization method will be used by parallel projects within CCGEx (including i-COLD and i-SYS)
- High-fidelity CFD data base (under pulsating flow conditions) to be used for calibration and verification and for complementing the 1D and experimental data (from parallel project).

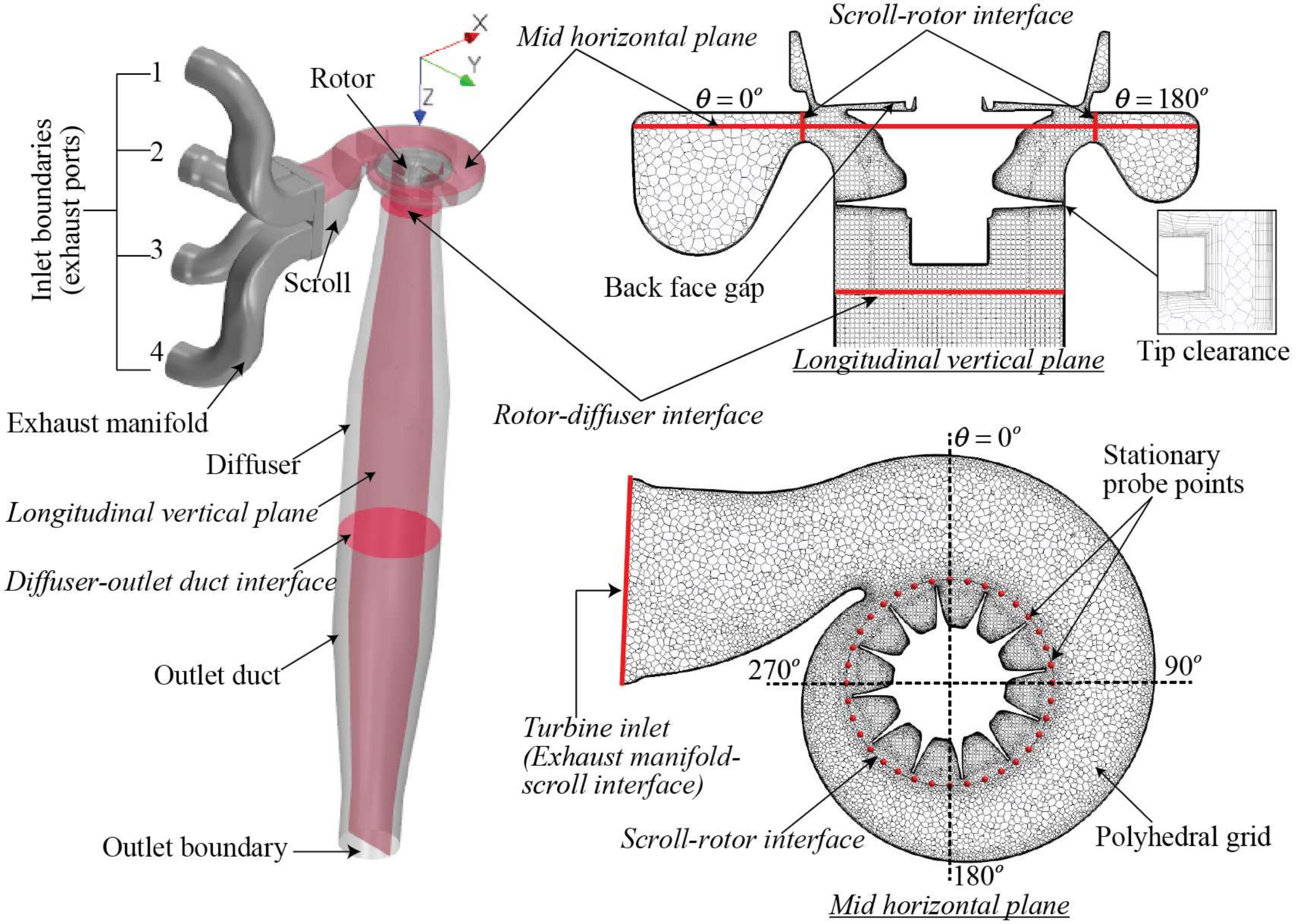
Roberto Mosca, PhD Student

Education Background

- **B.Sc., Mechanical Engineering**
  - *Università degli studi di Bergamo, Italy*

- **M.Sc., Aeronautical Engineering (Aerodynamics)**
  - *Politecnico di Milano, Italy*
  - **Thesis**: *Adjoint-Based Shape Optimization of a Micro T-mixer*

Subject

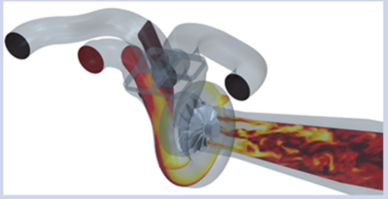
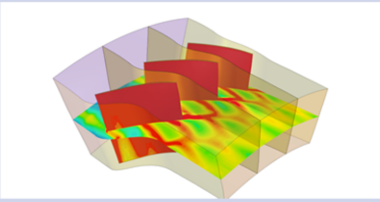

Inlet boundaries (exhaust ports)
1
2
3
4
Rotor
Scroll
Exhaust manifold
Diffuser
Longitudinal vertical plane
Diffuser-outlet duct interface
Outlet duct
Outlet boundary
X
Y
Z
Mid horizontal plane
Scroll-rotor interface
$\theta = 0^o$
$\theta = 180^o$
Back face gap
Tip clearance
Longitudinal vertical plane
Rotor-diffuser interface
$\theta = 0^o$
Stationary probe points
270°
90°
Turbine inlet (Exhaust manifold-scroll interface)
Scroll-rotor interface
Polyhedral grid
180°
Mid horizontal plane

Short-term Strategy

- **Geometry Optimization in order to reduce aerothermodynamics losses**
  - *Adjoint Topology and Shape Optimization: both methods rely on the calculation of the gradient of a specified cost function.*

- **Fast Analysis Tool**
  - *Development of a 1D model tool where the system is schematized by a sequence of fixed (inlet, scroll, wheel gap, and outlet) and rotating (turbine) pipes.*

i-HOT activities

	Gas dynamics of exhaust valves	Turbine pulsating flow	Reduced order model
Problem statement	• Steady vs. unsteady conditions for exhaust valve flows. • Standard approach: Exhaust valve design and performance controlled based on steady measurements. • Risk: Flawed design and inaccurate engine simulations. • To provide knowledge on how unsteady conditions affect valve efficiency and gas dynamics during the blowdown-phase.	• Gas-stand (steady, continuous flow) vs. On-engine (pulsatile flow, complex geometry). • Standard approach: turbine development based on steady flow assumption. • Risk: deliver non-optimized turbine for on-engine operation. • To provide knowledge for developing high performance on-engine turbine, by understanding the aerothermodynamics of pulsatile hot flow and heat transfer.	• Time scale: automotive engine cycle vs. turbine blade passing event. • Standard approach: conventional time-domain CFD; turbine optimization based on several steady-state operating points. • Risk: Infeasible for industrial optimization process; long turbine development period. • To improve development lead time, computational efficient CFD/optimization methodology is necessary.
Goal statement	• To illustrate the influence of dynamic conditions on exhaust valve efficiency. • To explore the differences, in terms of gas dynamics, between steady and dynamic processes.	• To provide turbine design guidelines in general and for specified (by industrial partener) engine exhaust valve strategy .	• To explore the potential of reduced order modeling for pulsatile turbine conditions; Retain key phenomena for reduce modeling of turbine performance. • To identify (a) representative steady-state operating points for pulsatile flow turbine optimization.
Envisioned outcomes	• Firm confirmation or discard of the quasi-steady assumption of exhaust valve flows. • Visually display the difference in shock patterns and locations for steady and dynamic operation of the exhaust valve. 	• Knowledge on impact of pulse characteristics on aerothermodynamic heat-losses and turbine performance; high-fidelity CFD data complemented by experiments. • Assessment of the interaction among manifold volume-pulse shape-turbine characteristics. 	• Computational efficient frequency-domain CFD technique with harmonic balance. • Efficient optimization process by using a single most representative steady-state operating point as metric. 
Impact on Industry	• More accurate engine simulations and increased knowledge on how system dynamics affects valve flows.	• Broaden turbine performance maps for improved on-engine application.	• Reduce the overall turbine development process by an order of magnitude.

i-HOT activities

<table>
<tr><th></th><th>Turbine heat transfer</th><th>Engine Optimized Turbine Design</th></tr>
<tr><td>Problem statement</td><td>

- Unknown: influence of heat loss for on-engine turbine performance.
- Standard approach: turbine assessment under adiabatic assumption.
- Risk: underestimate aerothermodynamics losses associated with heat transfer.
- To provide knowledge for maximizing on-engine turbine output, by understanding heat transfer related losses.

</td><td>

- Unknown: Influence of turbine design and turbine types with regards to engine system performance for pulse-turbocharged concepts.
- Challenges: To attain as high utilization of exhaust energy as possible in order to improve system performance
- Solution: A system-based approach integrating engine, turbine and exhaust system design.

</td></tr>
<tr><td>Goal statement</td><td>

- To provide guidelines for maximizing the available energy extraction by turbine.

</td><td>

- To assess influence of turbine design parameters with respect to system performance.
- To show possibilities and limitations of different turbine types.

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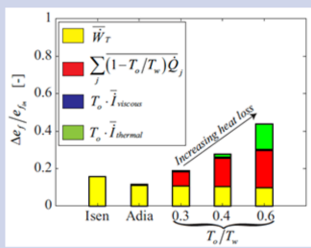
<tr><td>Envisioned outcomes</td><td>

- Exergy based models for analysis of aerothermodynamic heat losses and associated mechanisms.
- Quick assessment of available energy utilization.



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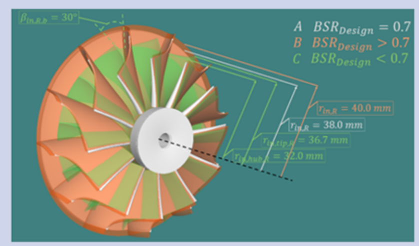
- Turbine designs for a pulse-turbocharged engine with focus on energy utilization
- Assessment of turbine design parameters and exhaust manifold design with regards to "on-engine" turbine performance



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<tr><td>Impact on Industry</td><td>

- Effective tools to quantitatively assess the performance and associated losses of two or more turbines on the same engine.

</td><td>

- Turbine concepts for energy utilization of pulse-turbocharged engines

</td></tr>
</table>

i-SYS: Integrated System Studies

Research Questions: i-SYS

- Understand the characteristics of gas exchange systems for effective, highly boosted, diluted (EGR) cold combustion with renewable fuels & near zero emissions. R1
- How to leverage the potential of hybridization to increase efficiency, transient response, and integrate WHR. R2
- How to simulate real drive emissions (RDE) in laboratory and virtual real time environments to achieve near zero emissions. R3
- Understand particle characterization and treatment. R4
- Urea SCR revisited – from fundamental understanding to system view. R5

Research Projects: i-SYS

Research Area	2017				2018				2019				2020				2021				2022		
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
i-SYS: Anders Christiansen Erlandsson																							
Ghulam Majal, PhD student, MWL/Mek, Numerics				Lic							PhD												
Arun Prasath, PhD student, ICE, EXP						Lic							PhD										
Zhe Zhang, **Assoc. CSC PhD Project**, MWL, "Slow Sound"												PhD											
Senthil Mahendar, PhD student (Volvo GTT), ICE, 1D Intr Turbo							Lic							PhD									
Sandhya Thantla, **Assoc. PhD Project**, ICE							Lic							PhD									
Engine, charging and EAT interaction during transients PhD student, ICE, EXP/1D							**NEW**															PhD	
Exergy losses in high efficiency chargin systems, PhD student, ICE, EXP/1D							**NEW**															PhD	
Jianhua Zhou, Post-doc, MWL. Waste Heat Recovering in pulsating flows-Thermoacoustics,							**NEW**	Continuation from 2018 CSC															

Research Projects: i-SYS

Engine, charging & EAT interaction in transients

Project advisors: Anders C. Erlandsson, Mikael Karlsson
1 PhD student

R2, R3

- Establish fundamental understanding of the transient interaction process between engine, charging system and the emission after treatment system.
- Are there typical lab transients that in reality can serve to characterize transient engine operation?
- Is the main real drive emission, RDE, coming from transient conditions where load and speed or pressure, temperature and mass flow is changing?
- How can new electrification technologies like e-boost, air-injection in the inlet manifold /exhaust receivers or directly into the engine help emissions and transient performance control?
- Can a method for developing a robust thermal management strategy be found to keep EAT system conditioned thus limiting the RDE emissions?

Engine, charging & EAT interaction in transients

Activity / Time (Q)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
Review of the state-of-art of modeling and experiments for transient engine operation																
Define engine experiments for characterization of transient engine operation - based on real driving																
Acquire baseline data from transient experiments on engines																
Initial transient 1-D simulation model development using known methods																
Identify weakness areas of modeling and propose new model methods for realistic transient prediction																
Simulate and evaluate experimentally e-boost and air injection for transient performance and emissions																
Method for: Robust thermal management strategy development for great performance and emissions																
Reports/Manuscripts/Thesis																
Deliverables																
Literature review		L1														
Set of typical elementary cases for transients in test bed operation			E1													
Data from transient testing at test bed			D1													
Basic ENCHEAT model for transients				M1												
SWOT of basic ENCHEAT model					S1											
Refined ENCHEAT model						M2										
Evaluation of improvementmethods for transient performance								E1								
Development of concept for improved transeints									E2							
Method for developing a robust thermal management strategy and transient performance												R1		R2		
Paper 1-6				P1		P2		P3		P4			P5		P6	
Thesis									L							D

KTH ROYAL INSTITUTE OF TECHNOLOGY

Project Introduction:

Engine, Charging and EAT interaction during transients

Varun Venkataraman

varunve@kth.se | 08 790 83 34

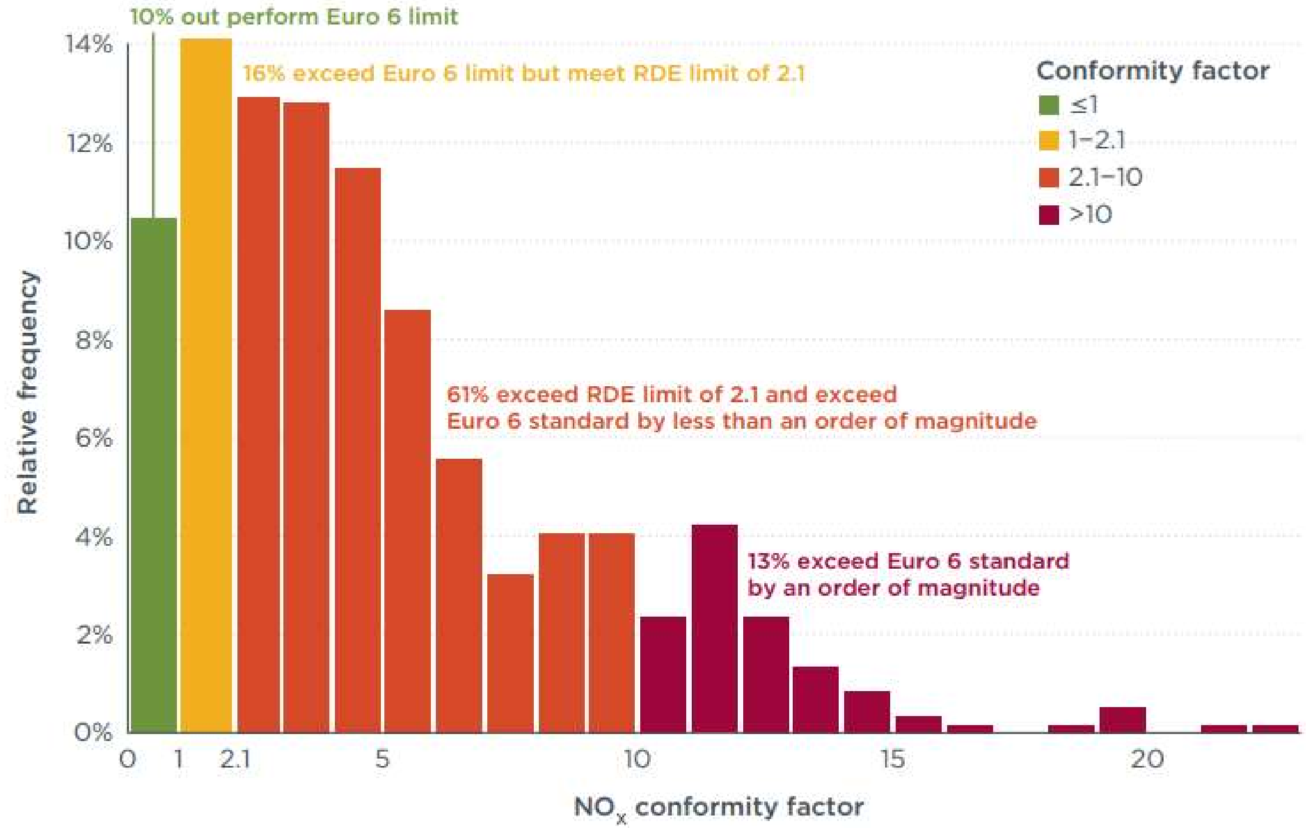
Supervisor: Prof. Anders Christiansen Erlandsson

12.10.2018, CCGEx – Research Day

Introduction: Varun

- Bachelor in Mechanical Engineering, Amrita University, India (2008-2012)
- LD compact diesel engine development, Hindujatech, India (2012-2015)
- Master in Engineering Design, track ICE, KTH (2015-2017)
- Master thesis: “The Miller Cycle on Single-Cylinder and Serial Configurations of a Heavy-Duty Engine”
- Research Engineer, SUNFUELS, KTH-KAUST (2017-2018)
  - HD DISI methanol combustion system
  - Fuel injector geometry and injection strategy

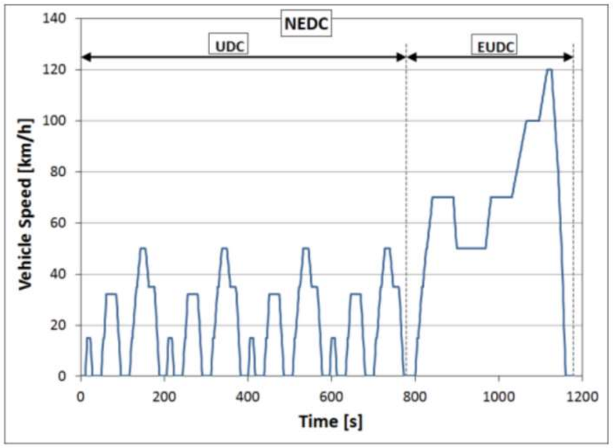
Background

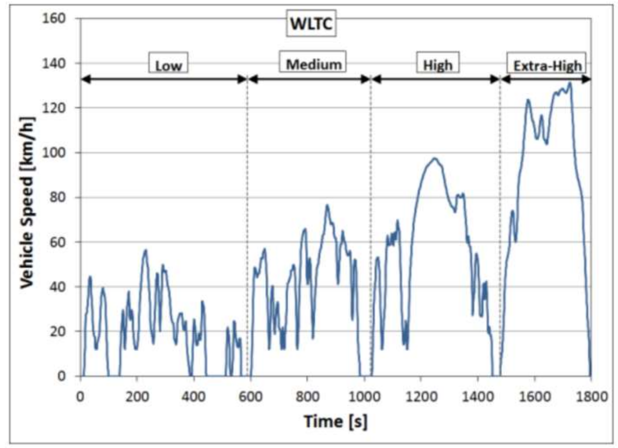


[1]

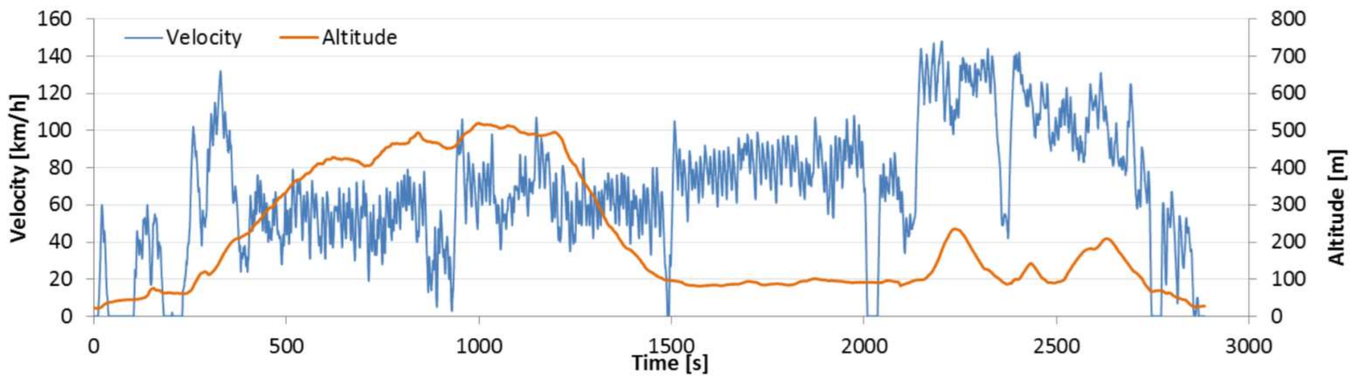
- Dieselgate exposed discrepancy between lab tested emissions and real drive emissions

Motivation





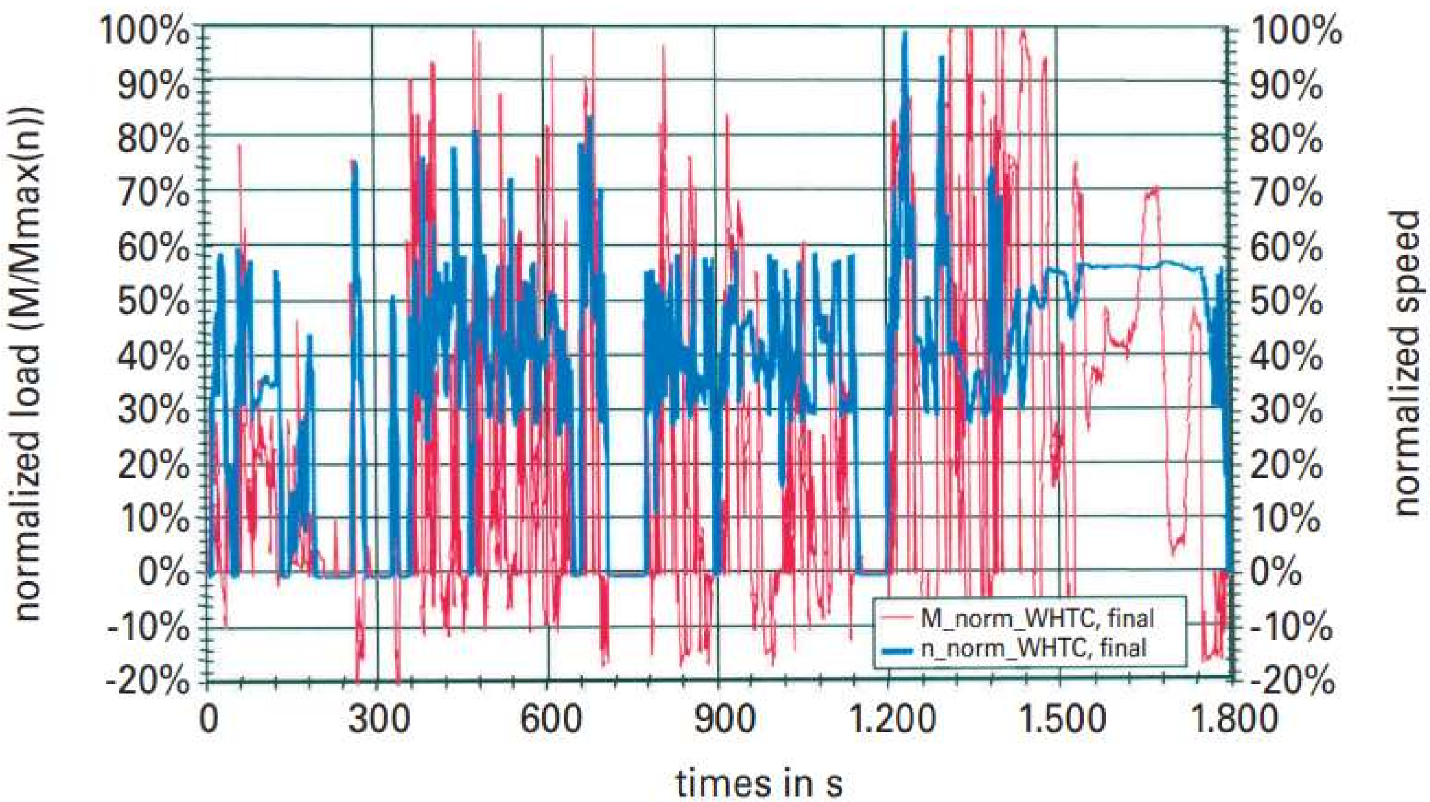
[2]



[2]

- Transient nature of real drive cycle not represented under test conditions including WLTC

Motivation

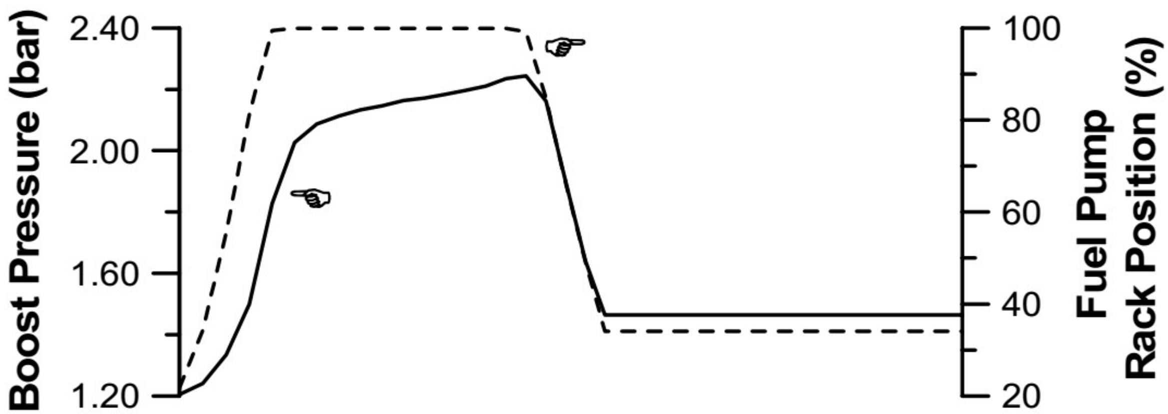


[3]

- Heavy-duty has in-service conformance with PEMS and Off-cycle emission (HD RDE) limits in addition to WHTC

Motivation

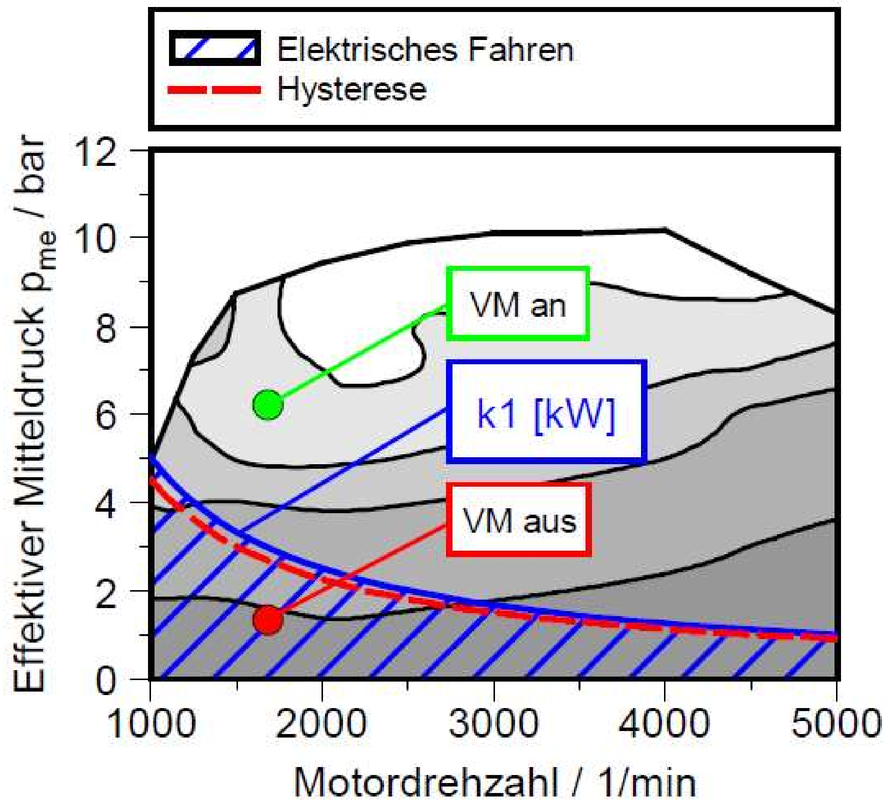
- Transient challenge **engine level**
  - Electrified fuel system (instantaneous response)
  - Largely mechanical air system (fluid/mechanical/thermal inertia)
  - Lambda mismatch makes RDE relevant for SI engines as well (TWC catalyst limit)



[4]

Motivation

- Transient challenge **drivetrain level**
  - operational modes
  - Low engine/EAT temperature upon restart from El.mode
  - Engine operating point in cycle (enriched zone/low efficiency zone)



[5]

Research Questions

- What is/are significant transients on the engine from a real drive cycle and what are the parameters used to characterise them?

  (example: engine acceleration/jerk and 1^{st} /2^{nd} derivative of BMEP)

- How do the “significant transients” vary across:
  - Vehicle class and fuel (LD vs HD/ SI vs CI)?
  - Drivetrain architecture (conventional vs hybrid)?
  - Transmission logic (manual vs automatic)?

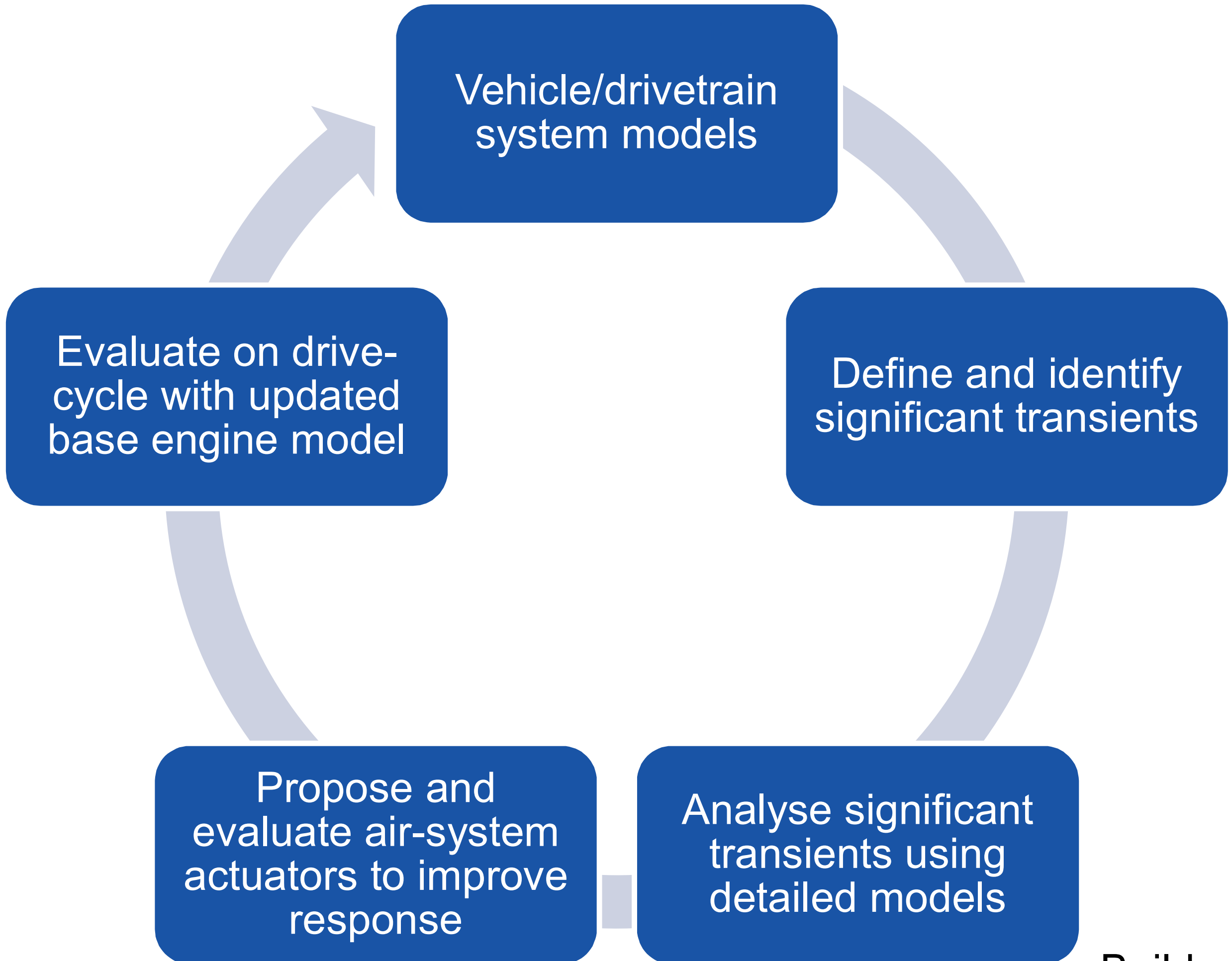
Research Questions

- What is the contribution of the engine, charging system and EAT to detrimental efficiency and emissions over "significant transients"?

- What is the impact of turbo/air-path actuator dynamics on emissions and performance and over the "significant transients"?

  (example: electric compressor)

Approach



Builds on approach in [6]

References

[1] Baldino C., Tiegte U., Muncrief R., Bernard Y. and Mock P., “Road Tested: Comparative Overview of Real-world Versus Type-Approval NO_x and CO_2 Emissions from Diesel Cars in Europe”, White Paper-ICCT, September 2017

[2] Dimaratos A., Triantafyllopoulos G., Ntziachristos L. and Samaras Z., “Real-world emissions testing on four vehicles” EMISA SA Report for ICCT, August 2017

[3] Delphi Worldwide Emissions Standards Heavy Duty and Off-Highway Vehicles

[4] Rakopoulos C. and Giakoumis E., “Diesel Engine Transient Operation”, Springer-Verlag London, DOI 10.1007/978-1-84882-375-4, 2009

[5] Balazs A., “Optimierte Auslegung von ottomotorischen Hybridantriebssträngen unter realen Fahrbedingungen”, Doctor Thesis, RWTH Aachen, July 2015

[6] Böhmer M., “Simulation der Abgasemissionen von Hybridfahrzeugen für reale Fahrbedingungen”, Doctor Thesis, RWTH Aachen, October 2017

Research Projects: i-SYS

Exergy Losses in high efficiency charging systems

R1, R2

Project advisors: Anders C. Erlandsson, Mikael Karlsson, Mihai Mihaescu
1 PhD student

- Establish fundamental understanding of the high pressure charging processes, combining radial/axial turbines, high compression ratio, EGR and miller valve timing.
- Analyze the system with respect to energy flow by making use of Exergy analysis – energy availability to do work.
- Develop modelling tools for x-D exergy flow analysis over components.
- Identify potential improvement areas on all parts of the gas exchange system for higher efficiency. Where do the major losses occur and why? How large are the respective losses?

Exergy Losses in high efficiency charging systems

Activity / Time (Q)	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
Review of Exergy modeling and experiments for engine application	■															
Initial 1-D simulation model development using known methods		■	■													
Identification of weaknesses of 1-D model and propose remidy		■	■													
Define engine experiments for generation of validation data			■	■												
Acquire baseline pulsting flow data from experiments on engines and turbo machinery in rig				■	■											
Identify weakness areas of modeling and propose new model methods for exergy prediction x-D					■	■										
Simulate and evaluate exergy flow in DEP, 2stage, E-boosting/E-compounding for high efficiency							■	■	■	■						
Validate method for Exergy flow analysis in engines by experiments										■	■	■	■	■		
Reports/Manuscripts/Thesis				■		■		■		■			■		■	■
Deliverables																
Literature review	L1															
Basic model 1-D			M1													
Data set on on transient exergy loss in advanced charging systems					D0											
Exergy prediction model using x-D						M2										
Evaluation of high efficyncy cocepts by means of exergy modeling							C1		C2							
Validatioon data										D1		D2		D3		
Papers 1-6				P1		P2		P3		P4			P5		P6	
Thesis									L							D

Exergy Losses in high efficiency charging systems

Beichuan Hong

I completed my master majoring in ICE at China, 2014. After one-year working at Cummins, I came to Stockholm as a scholarship student at KTH, and was involved in projects concerned with the optimization and controlling for autonomous construction vehicles. In 2018 November or later, I will join in the CCGEx as a doctoral student.

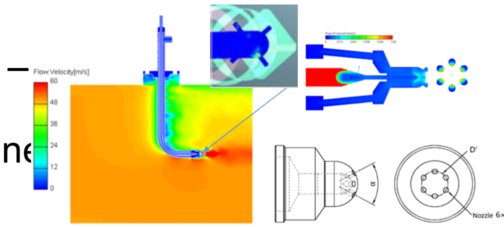
My research experience:

- CFD & 1D simulation for ICE performance
- ICE experimental techniques
- Modelling and controlling theory with its applications to thermal and especially automotive systems

Wuhan University of Technology, China
2012 –

Master majoring in Diesel Engine and Emission Control

- Multi-fluid urea injector design of SCR system for a marine engine
- Emission upgrade for an 8.9L diesel engine

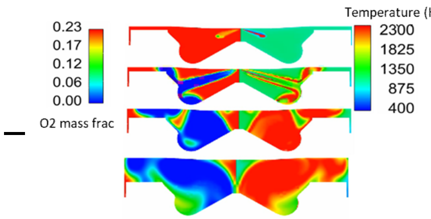


Multi-fluid urea injector of SCR system for marine engine

Cummins East Asian Research & Development Center
2014 - 2015

Advanced Engine & Technology Department

- Pneumatic boost system (PBS) for reducing turbocharger lag
- Adaptive algorithm for designing engine virtual sensors

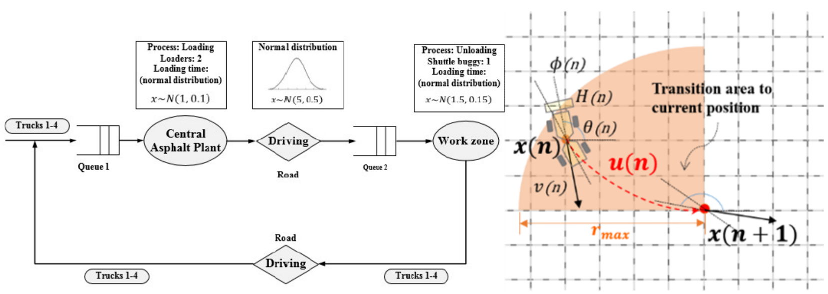


Optimization of combustion chamber & Fuel injection for emission upgrade

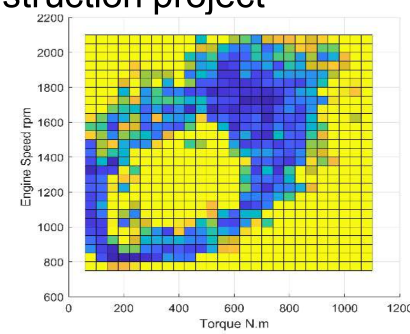
KTH Royal Institute of Technology
2016 – 2018

Sustainable Construction Operations for Reduced Emissions

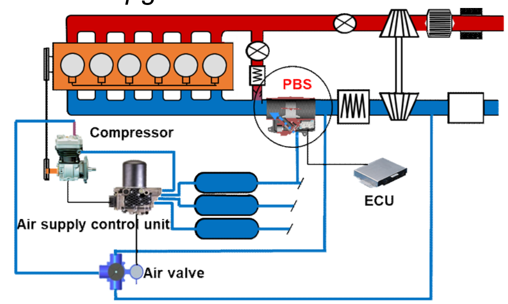
- Optimal control of autonomous construction vehicles
- Simulation platform for optimizing a construction project



Simulation platform for optimizing construction operation



Covariance matrix of map-based virtual sensors



Pneumatic boost system

Research Projects - iSYS

WHR in pulsating flows – new techniques

R2, R3

Project advisors: Mikael Karlsson, Mats Åbom
1 Post-doc

- Exploring **THERMOACOUSTICS**, a little investigated WHR technology, where waste heat is used to create high intensity acoustic waves that can be harvested effectively e.g. to electricity.
- **The work is based on 1 year FFI-prestudy + 1 year work by a Chinese CSC Post-doc (Jianhua Zhou**).
- Improved models for heat transfer and loss mechanisms in a thermoacoustic system.
- **Development of 1D network models including non-linear elements, useful for a number of acoustic problems and related to other MWL projects**.
- Experiments planned in co-operation with other universities

KTH VETENSKAP OCH KONST

GEx

Competence Center for Gas Exchange

CCGEx

KTH VETENSKAP OCH KONST

”Charging for the future”

Energimyndigheten

SCANIA

VOLVO

VOLVO

BorgWarner