CENTRE OF VEHICLES FOR SUSTAINABLE MOBILITY

CENTRUM VOZIDEL UDRŽITELNÉ MOBILITY

CZECH TECHNICAL UNIVERSITY, FACULTY OF MECHANICAL ENGINEERING
Science and Technology Park Roztoky

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI

2007-13
OP Výzkum a vývoj pro inovace

VTP ROZTOKY A.S.

trigema

2010 - 2017

The Czech Technical University in Prague (established 1707) and the Mechanical Engineering Faculty of the CTU

8 faculties - Civil Eng, MechEng, ElEng, Informatics, NucEng, TranspEng, BioMedEng and Architecture/Styling

21 000 students (mostly MS level, partially BS and PhD)
1 550 academic staff

Faculty of MechEng: 2 500 students (6-8 semesters Bc, 5 semesters MS studies, 4 years PhD studies)

300 academic staff

Automotive Eng. (incl. ICE, electric powertrains - 50 MS (Dipl.-Ing.) graduates/year, currently 20 active PhD. students. 50 academic-research staff

www.cvum.eu http://bozek.cvut.cz www.vtp-roztoky.cz

Josef Božek - the Head of Mechanical Engineering Labs 1806 - 1825,

the designer of a steam car 1815 and a steam boat 1817

Objectives and strategies

- Enhancing of applied research level for the automotive industry
- Building on a successful project VCJB I. and II. (team of experts from different branches)

Creating a high level research institute

  - Training new experts from among students
  - Enhancing collaboration and existing strong link to partners from application sphere
  - Increase cooperation in international R&D projects

- Partner TÜV-SÜD Czech

SYNERGY OF TWO PROJECTS

VEHICLE CENTRE FOR SUSTAINABLE MOBILITY (CVUM)

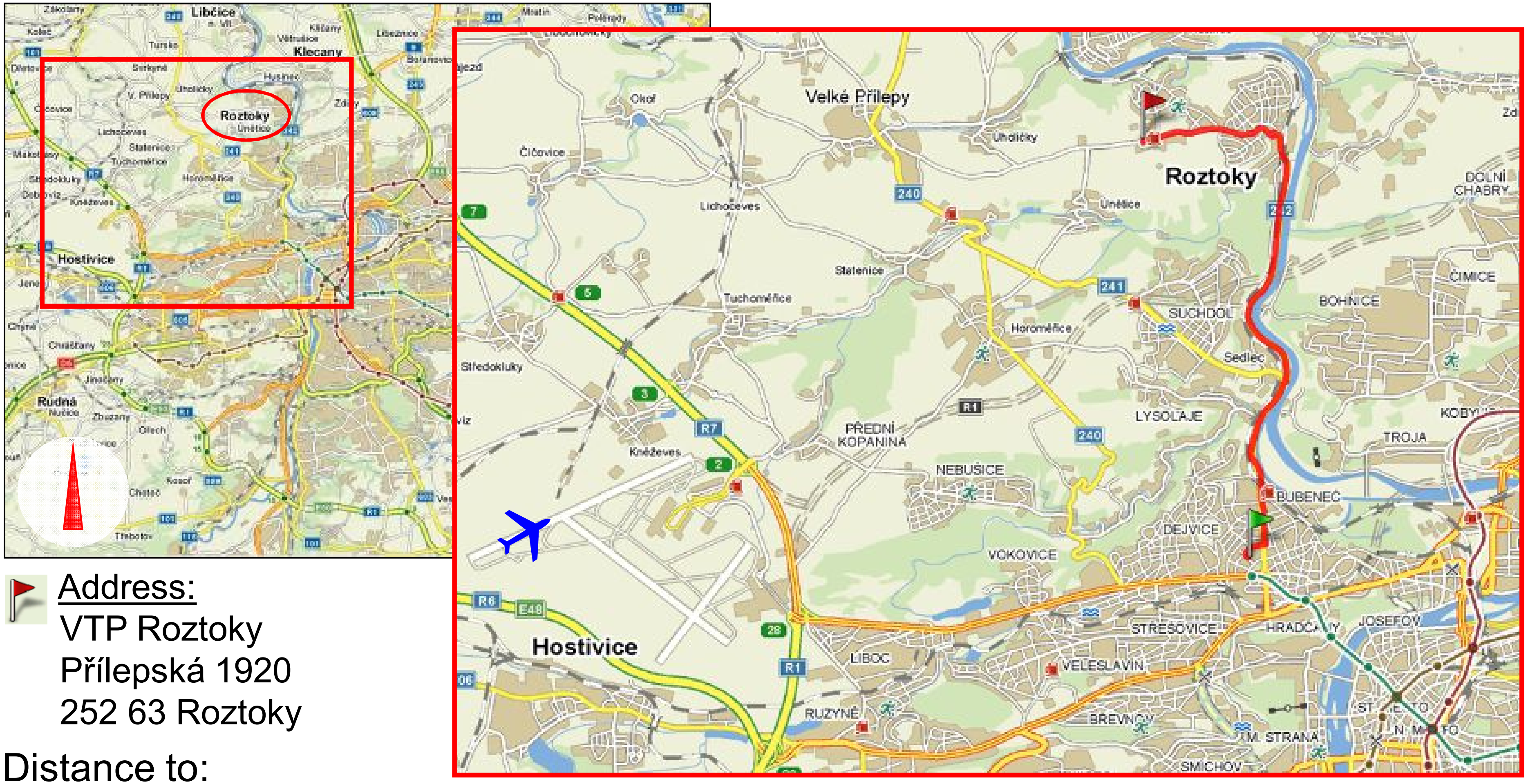
Time Schedule

08/2011 Closing of tenders for heavy technology investment
03/2012 Delivery of capital equipment with a direct link to infrastructure building
04/2012 Initiation of trial operation
08/2012 Closing of tenders for other investments
12/2012 Installation and commissioning of equipment for simulation center
01/2013 Starting research activities, including required staff & startup of all laboratories in routine operation

SCIENCE AND TECHNOLOGY PARK with business incubator and center for technology transfer

Floor area 4200 m^2
04.08.2010 Foundation Stone Laying Ceremony
22.08.2011 Final building approval
10.11.2011 Official opening

LOCATION OF VTP ROZTOKY



Address:
VTP Roztoky
Přílepská 1920
252 63 Roztoky

Distance to:

9 km Czech Technical University in Prague, subway station Dejvická

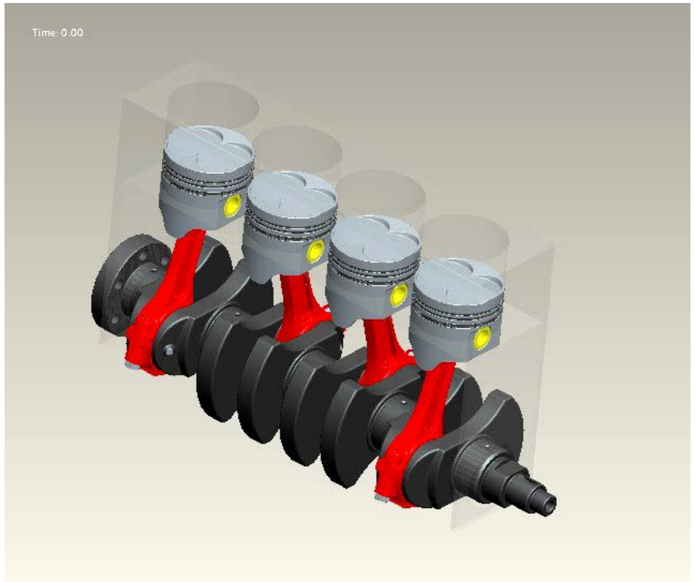
10 km Airport Praha-Ruzyně

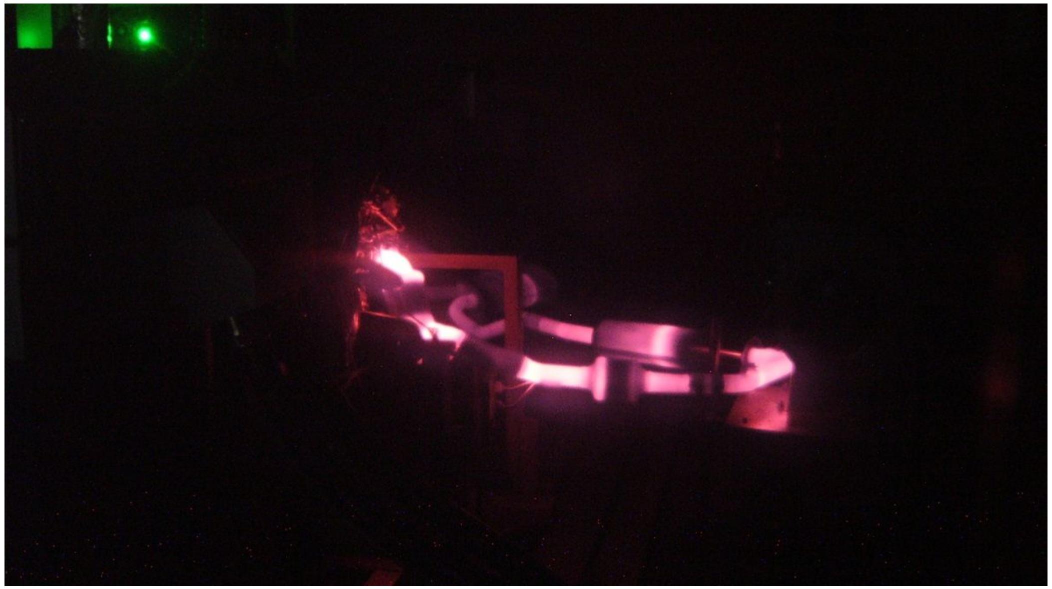
CVUM ACTIVITIES

- **Research and development of spark ignition engines (gasoline, gas, alternative fuels) and diesel engines for cars and heavy-duty vehicles**

Engine research focused on

- Thermodynamics
- Internal flow aerodynamics
- Turbocharging and supercharging of engines using conventional and emerging technologies
- Emission reduction and aftertreatment
- Engine management by intelligent controllers
- Engine dynamics and structural strength of components applied to the design optimisation



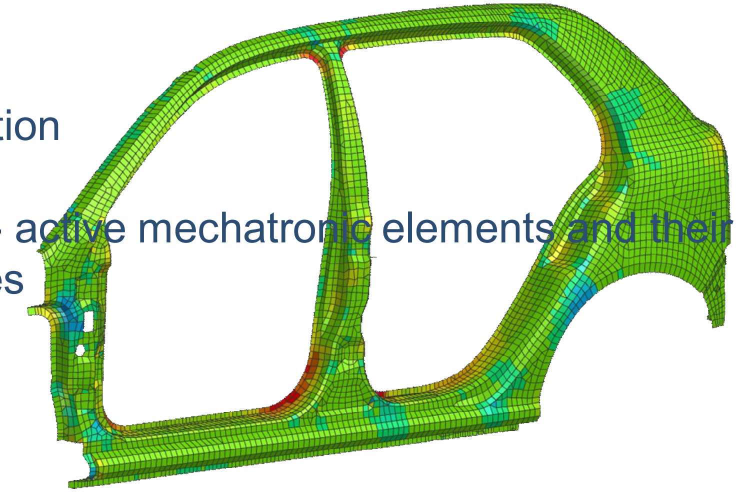


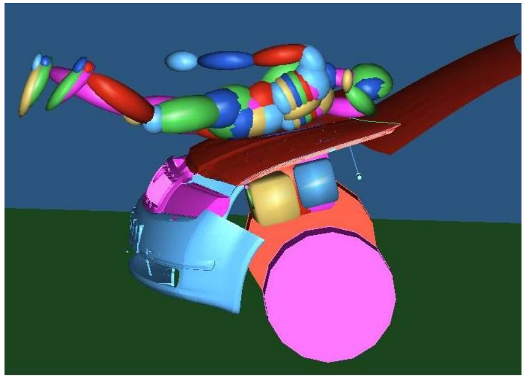
CVUM ACTIVITIES

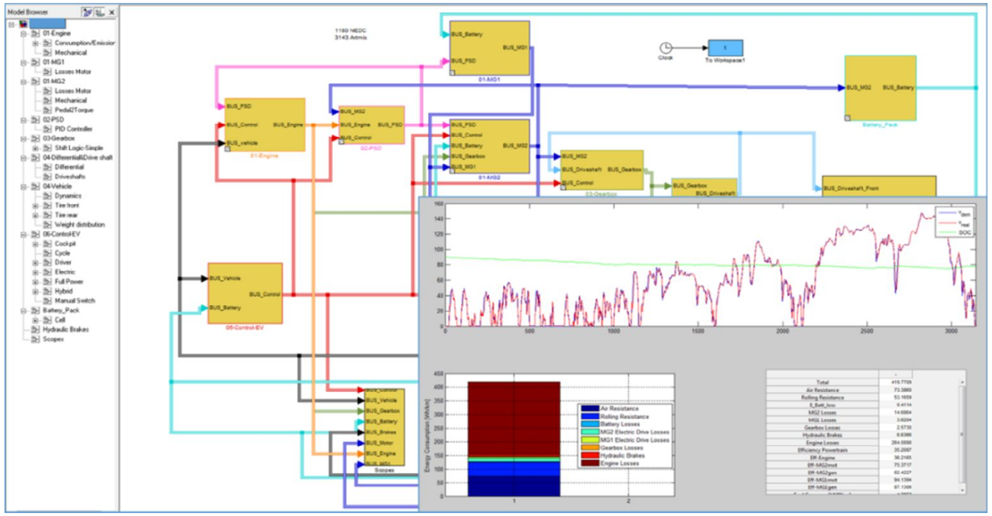
- **Research and development results for whole vehicle**

Research focused on

- Powertrain design
- Powertrain optimization
- Powertrain testing
- Suspension design - active mechatronic elements and their control
- Passive safety issues
- Brakes tests
- NVH
- Body aerodynamics



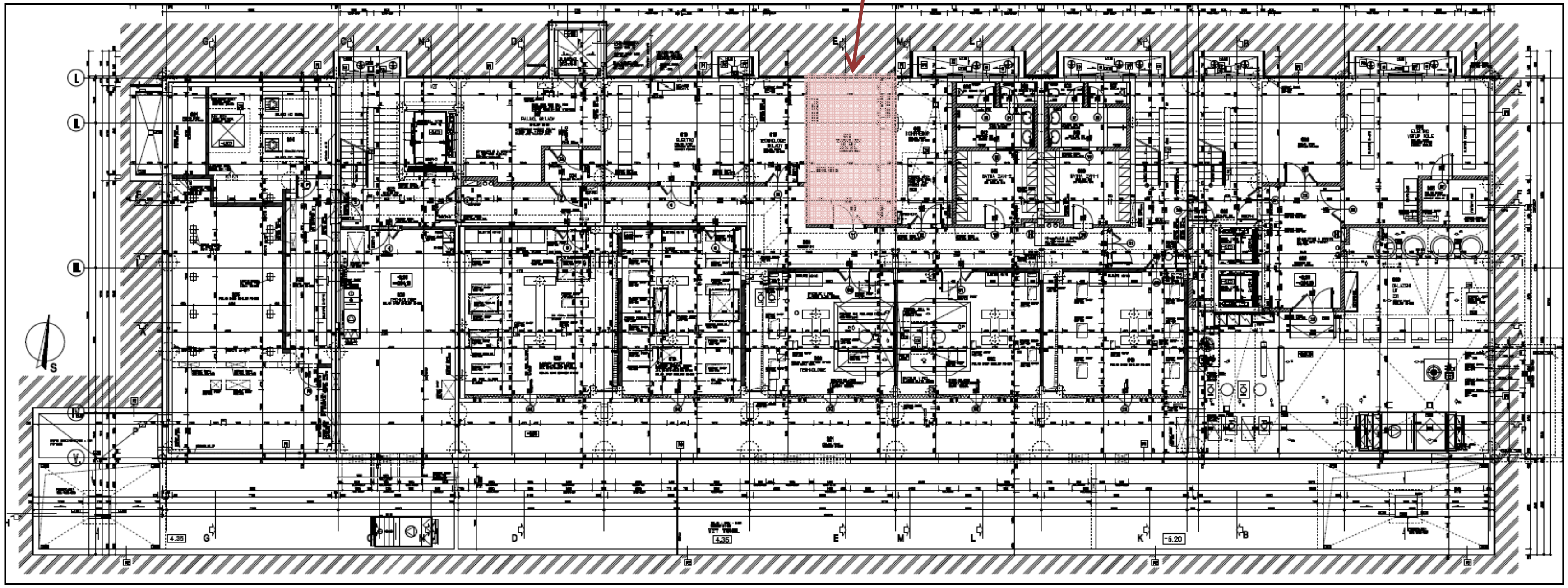




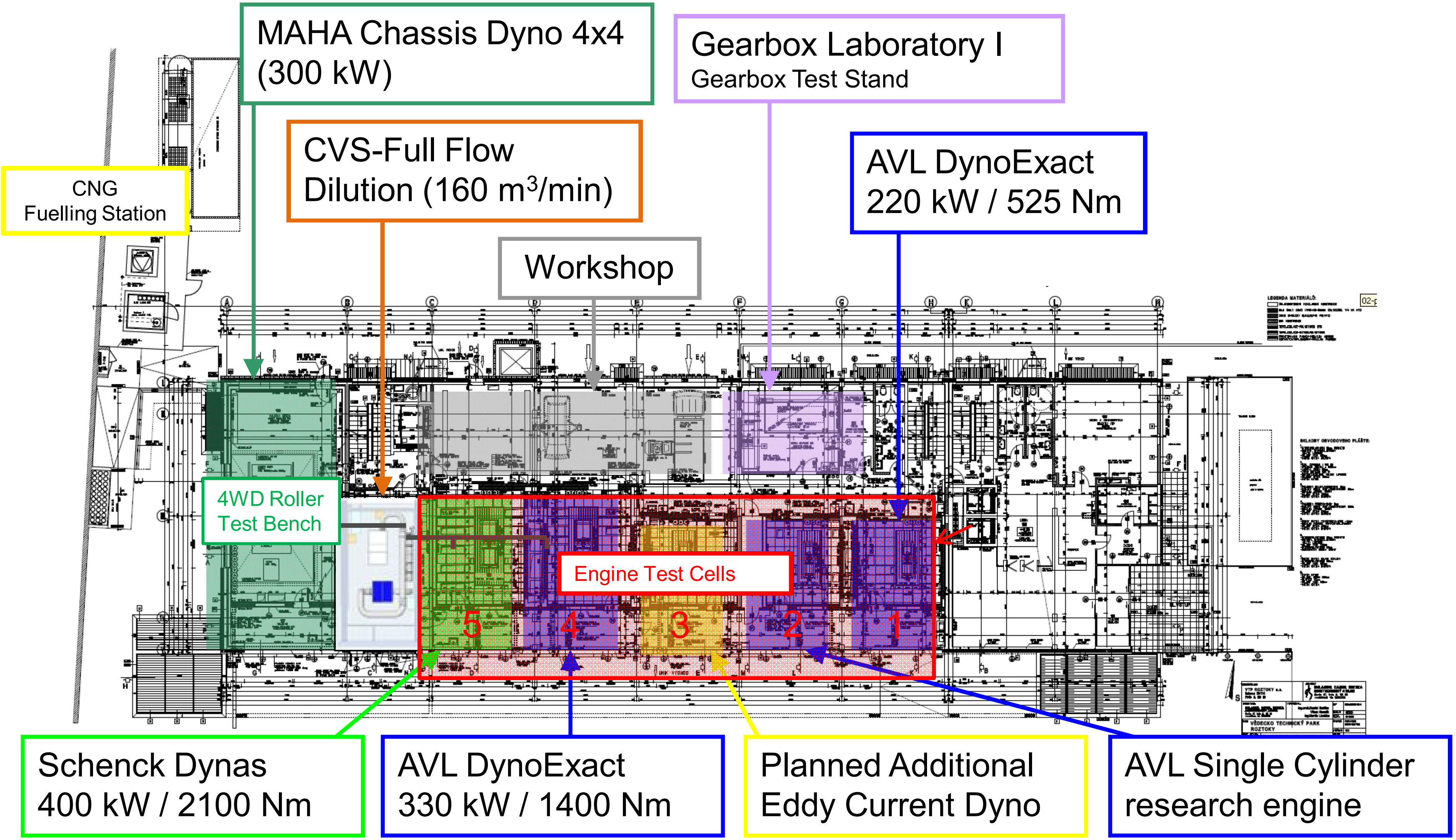
LABORATORY OVERVIEW – basement

FIE LABORATORY

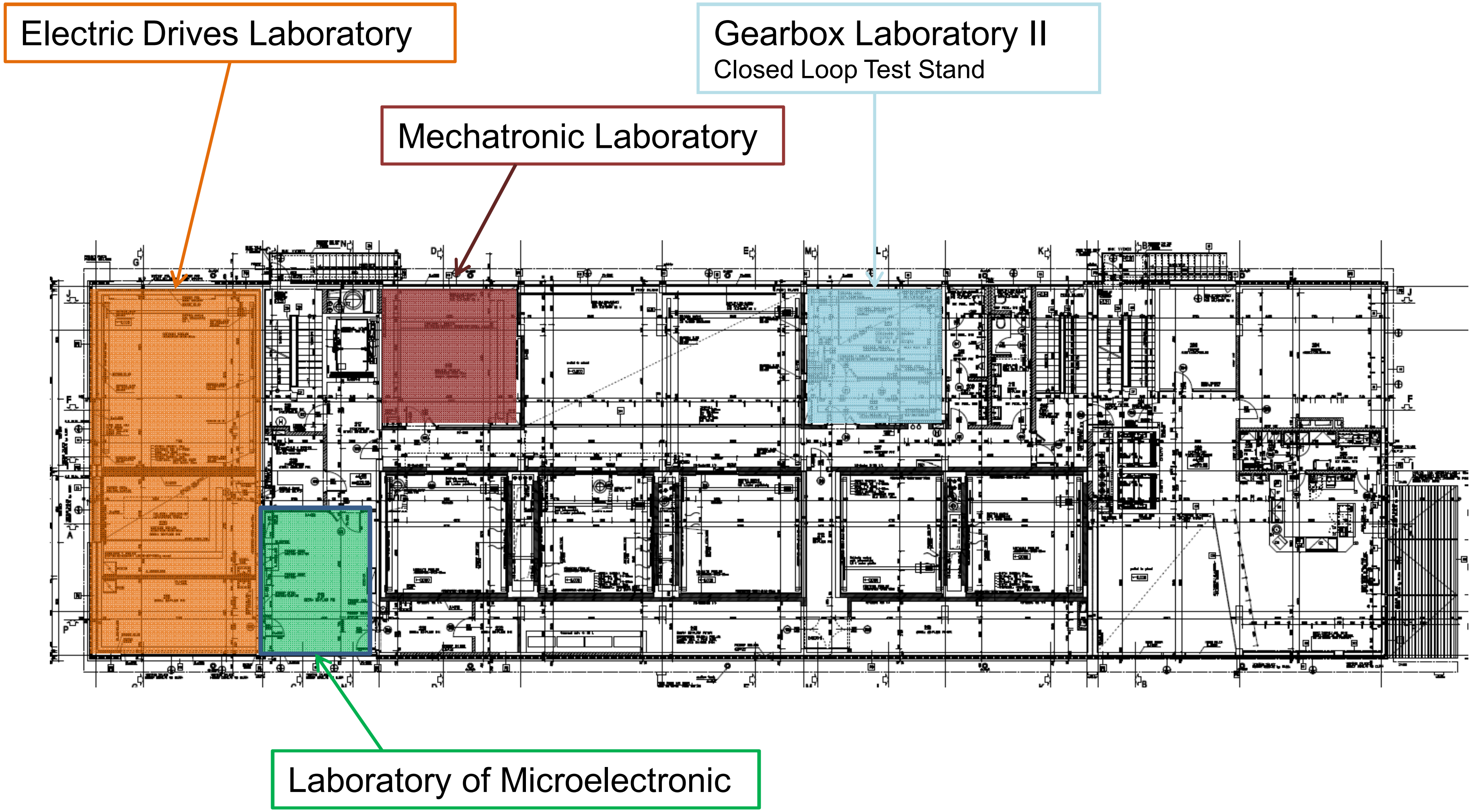
EFS TEST BENCH FOR INJECTION COMMON RAIL SYSTEMS



LABORATORY OVERVIEW – ground floor



LABORATORY OVERVIEW – 1st floor



FIE LABORATORY

ITB 240 RC–V injection system test bench for common rail systems

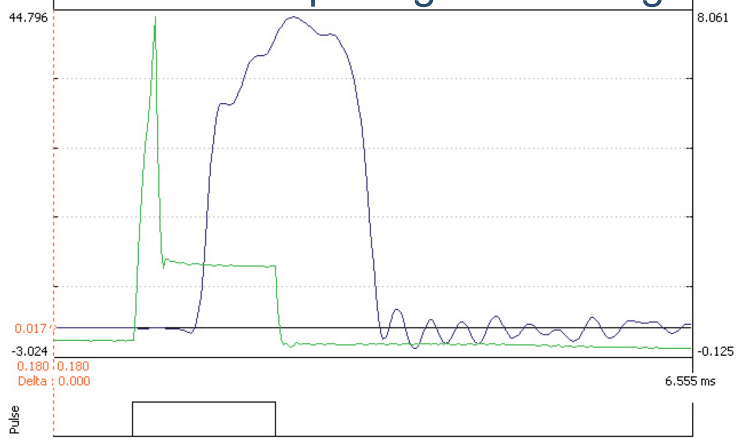
unit pumps, inline pumps, distribution pumps, injectors, injector-pumps

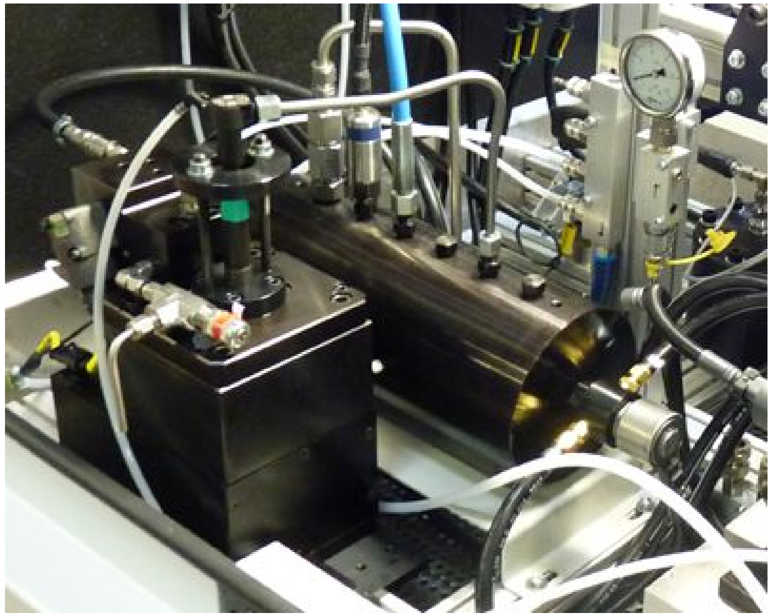
- **Specification**
  - HP Pump speed 0-6000 RPM
  - HP Pump feed 0,8 – 6 bar
  - Big rail 250 cm^3
  - Measurement of:
    - HP pump shaft torque
    - HP pump flow rate
    - Injection quantity and flow rate
    - Injector back leak flow
    - InjetVision system

FIE LABORATORY

ITB 240 RC–V injection system test bench - IFR

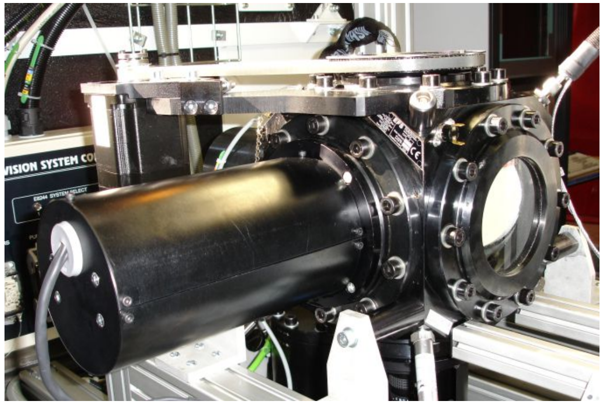
- **Injection Quantity and Flow Rate measurements**
  - up to 10 injection per revolution
  - Injection frequency 0,5 Hz – 50 Hz
  - Back pressure 5 – 100 bar
  - Bench synchronization
  - Quantity up to 150 mm^3 (accuracy 0,1 mg/inj.)
  - Detection of opening and closing time



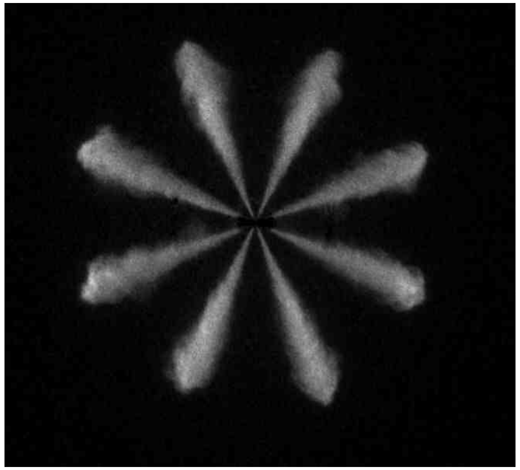


FIE LABORATORY

EFS ITB 240 RC–V injection system test bench - INJETVISION

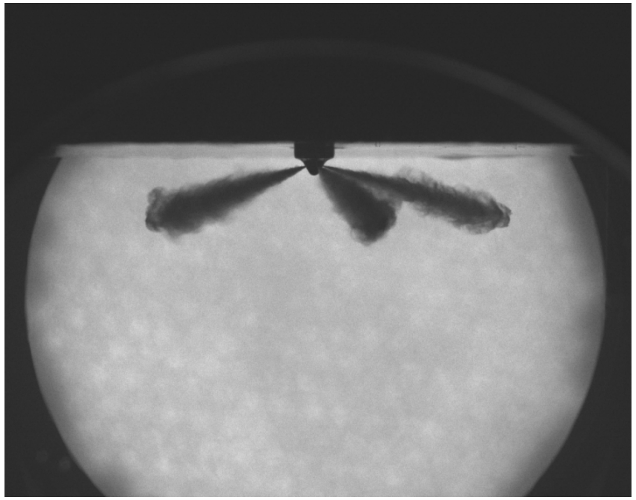


- **InjetVision System**
  - possibility to observe and study jets from high pressure diesel injectors
  - alfa and lambda view
  - inert atmosphere (N_2 or CO_2) up to 50 bars
  - fog extraction



Example results

- Jet penetration percentage
- Jet opening angle
- Jet surface
- Jet volume
- Symmetry
- Spray cone angle in lambda view
- Angle λ of a jet in lambda view
- Statistical analysis

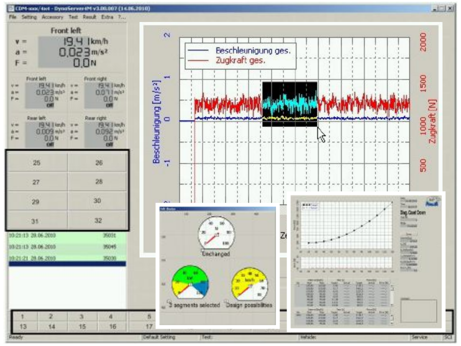


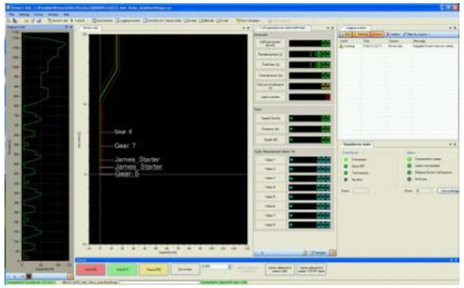
CHASSIS DYNO 4WD

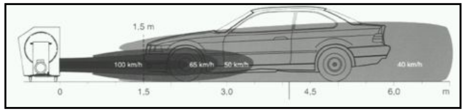
Producer: MAHA-AIP GmbH & Co. KG
Model: AIP-ECDM 48L-4mot

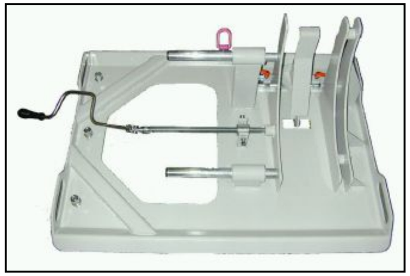
CHASSIS DYNO 4WD – TECHNICAL DESCRIPTION

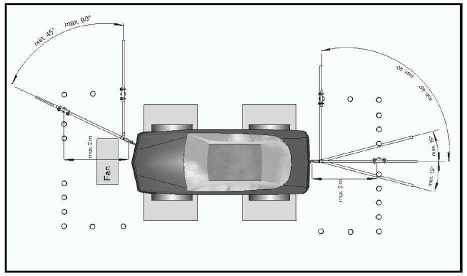
- maximum speed 240 km/h
- total power 300 kW (4x4 or 4x2), overload to 400 kW / 60 s
- maximum traction force 8200N (0-120 km/h), overload 12000N / 60s
- independent drive of each roller (diameter 48“)
- adjustable wheelbase 1800 ÷ 3600 mm, centering and fixing devices
- maximum axle load 2000 kg
- adapter for motorbike testing
- Drivers AID (including database of driving cycles base on the latest legislation in EU, Japan, USA)
- Data Acquisition System (16x AI, 2x AO, 8x Pt100, 8x TC, 2x counter, 16x DIO)











ENGINE TEST CELL NO.1 and NO.4 – TECHNICAL DESCRIPTION

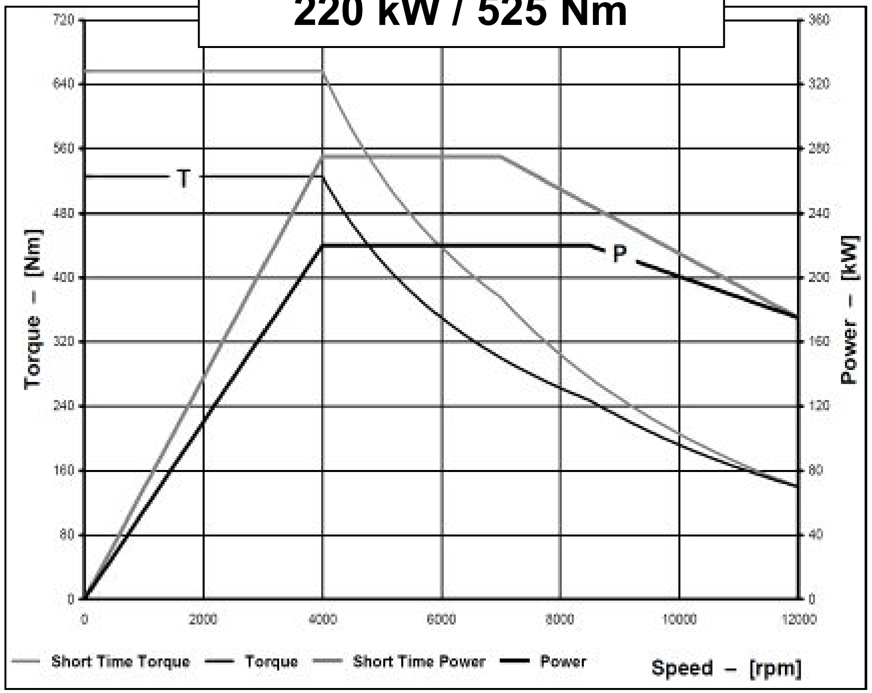
AVL List GmbH. has supplied two engine test cells equipped with:

- **The DynoExact** - robust high accuracy cradled-mounted AC Dynamometers with squirrel cage rotor especially designed for engine testing under harsh conditions equipped with hydrostatic bearings. High accuracy torque measurement (**<±0,1% F.S.**)
- **Automation System PUMA Open Software & Hardware**
  - Drive-by-Wire 400 / E-Gas Potentiometer Simulation
  - Vehicle, Driver and Road Simulation including Manual Transmission Simulation
  - Engine and Dynamometer Controller EMCON
  - Safety Module compliant to safety standards ISO 13849-1 and IEC 62061
- **Testbench is ready to operate in transient mode based on UN ECE 49 and UN ECE 85**
  - Testcell no.4 (330 kW) is connected to CVS (full flow dilution)

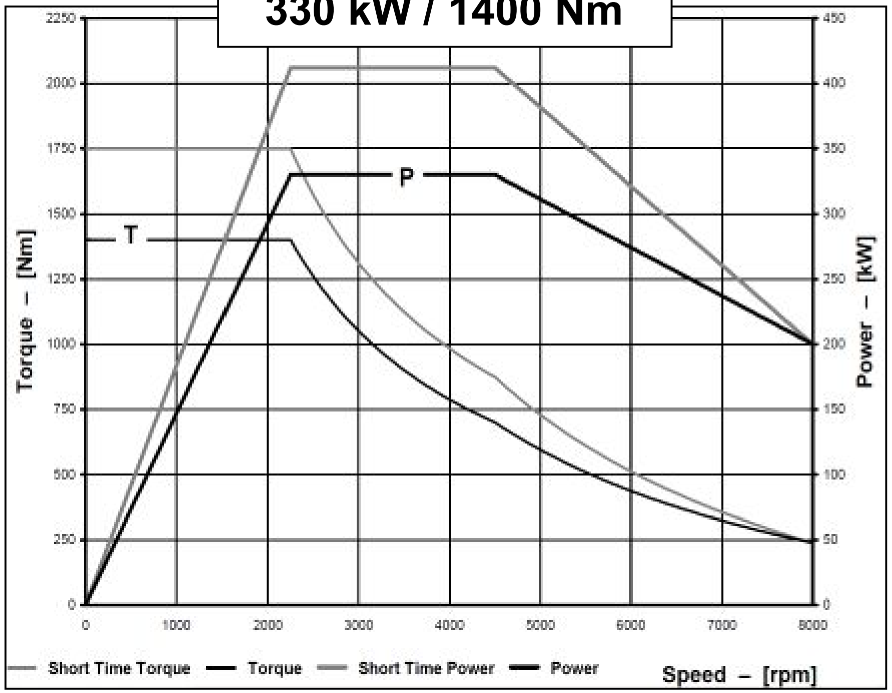
ENGINE TEST CELL NO.1 and NO.4 – TECHNICAL DESCRIPTION

Load diagrams:

Test cell no.1
DynoExact 202/12
220 kW / 525 Nm



Test cell no.4
DynoExact 304/8
330 kW / 1400 Nm



ENGINE TEST CELL NO.1 and NO.4

Each test cell has its own accessories:

- **Fuel Consumption meter with temperature control** (AVL 735S+753C)
  - Flexfuel – Gasoline, Diesel, Biodiesel, Ethanol (E100), Methanol (M100)
  - Max. fuel consumption 125 kg/h
  - Fuel Feed Pressure 1…6 bar
  - Based on Coriolis force measurement - suitable for fast response in transients (t_{10}-t_{90}=125 ms)
  - Temperature control in range 10...80°C with a stability of ±0,02°C in steady state operation
- **Engine Coolant conditioning Unit** (ConsysCool)
  - Coolant temperature control with accuracy ±1°C in steady state operation
- **Raw Emission System** (AMA i60 R1)
  - Analysers: CO, CO_2, CO_2 for EGR estimation, NOx, O_2, THC, CH_4
- **Blow-by measuring system** (Blow by meter 442)
  - Accuracy better than ±1,5% F.S.

ENGINE TEST CELL NO.1 and NO.4

AVL

Shared equipement:

- **Equipment for indicating is placed in moveable trolley**
  - 8 channel universal analog inputs - 1,2 MS/channel (IndiModul 622)
  - 4 channel piezoelectric amplifier and 4 multi purpose channels (Combi-microIFEM 4C3G)
- Incremental Sensor (365C)
- Crank Angle Calculator (4CA1)
- Indicating and evaluating software IndiCom and Concerto
- Set of Piezoresistive and Piezoelectric Pressure transducers



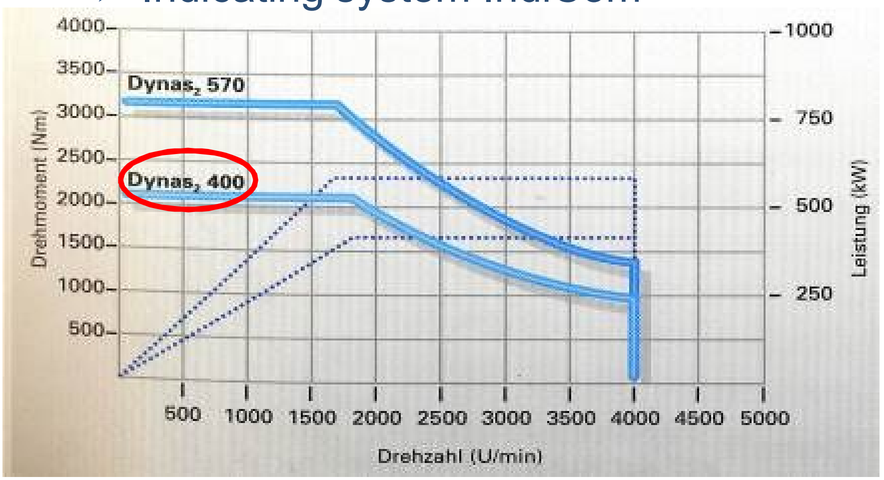
- **Etas Inca 7.0**
- **AVL Opacimeter 439**
- **AVL Smoke Meter 415 SE**
- **AVL Smart Sampler**
- **TSI Scanning mobility particle sizer** (TSI SMPS 3936L10)



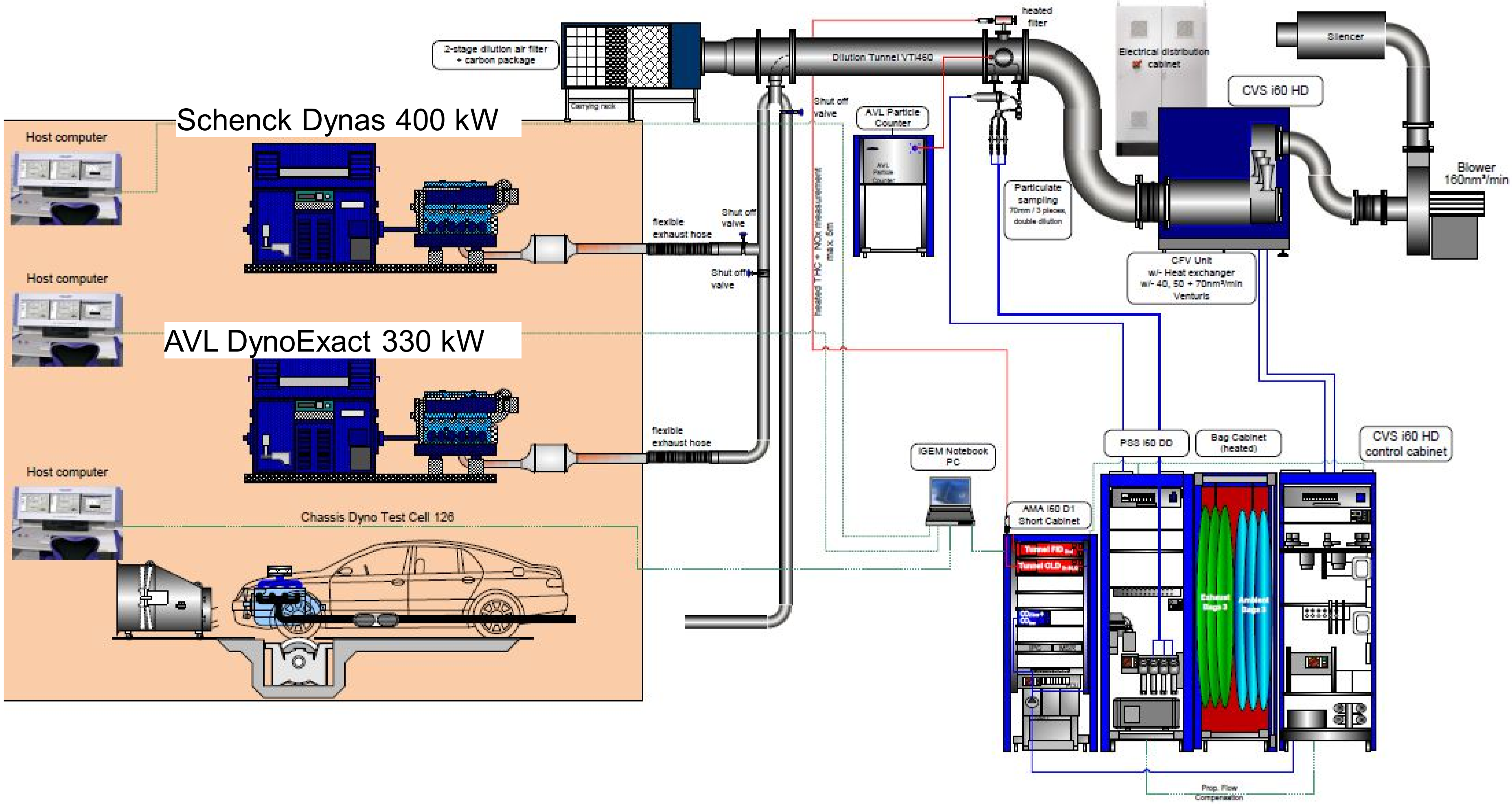

ENGINE TESTING ROOM NO.5

<u>Schenck Pegasus Dynas$_2$400 (400 kW / 2100 Nm) – existing equipment</u>

- **Testbench is ready to operate in transient mode base on EHK 49 and EHK 85**
  - Predefined cycles: ETC, ESC, NRTC, NRSC, WHTC, WHSC, ELR
- **Testbench is connected to new CVS (full flow dilution)**
  - authorized testing laboratory, homologation according to EHK 49 including Euro VI. **(Particulate Counter AVL 489 APC ADVANCED)**
- Test cell is equiped with
  - Blow-by meter
  - Coriolis fuel consumption meter (Pierburg)
  - Raw Gas Analyzer Mexa 7100D
  - Indicating system IndiCom

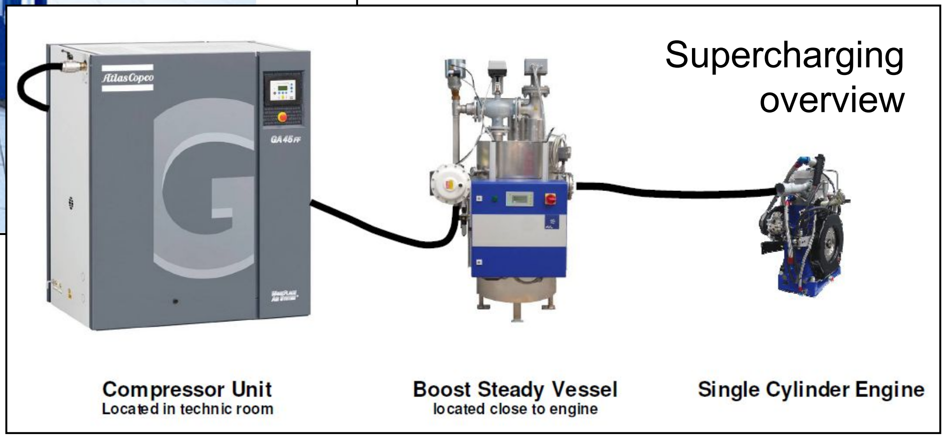


CVS OVERVIEW



ENGINE TEST LABORATORY – SINGLE CYLINDER RESEARCH ENGINE

Compact Single Cylinder Engine Test Bed, system supplied by: AVL List GmbH.



ENGINE TEST LABORATORY – SINGLE CYLINDER RESEARCH ENGINE

APPLICATION FOR ENGINE R&D TASKS

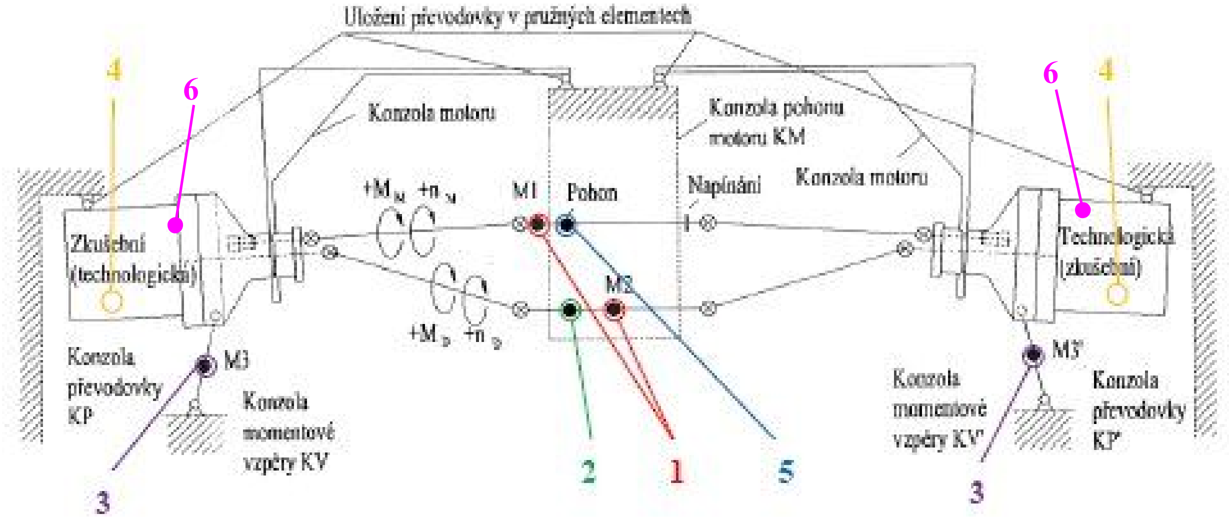
- Combustion Research
  - oil and coolant temperature effect
  - exhaust gas recirculation
  - combustion chamber shape & compression ratio
  - advanced fuels research
  - exhaust emissions and thermal efficiency
  - effect of boosting and air temperature
- Research in mechanical losses
  - oil and coolant temperature effect
  - engine load effect
  - structure and surface effect
  - lubricants
- Advanced combustion methods
- Optical combustion diagnostics

Modular and robust diesel engine externally supercharged (up to 5 bar absolute) , variable DOHC valve train, two counterbalance shafts, exhaust throttle for a back pressure adjustment.	
Bore x stroke, compression ratio	85 x 90 mm, 17:1 (maximum cylinder pressure 150 bar)
Maximum dyno / crankshaft speed	8000 min^{-1} / 4200 min^{-1}
Injection type	BOSCH CommonRail (maximum injection pressure 1800 bar)
Engine control unit	Open control unit BOSCH + SW/HW ETAS INCA
Cylinder pressure measurement	Cylinder pressure transducer AVL GU22C
Nominal dyno torque/power	180 Nm (0-3000 min^{-1}) / 58 kW (3000-8000 min^{-1})
Cooling/heating power – coolant – oil	40 / 3,5 kW (within temperature range of 35-120°C with accuracy of ±1°C) 6 / 4 kW (within temperature range of 35-110 °C with accuracy of ±1°C)

GEARBOX LABORATORY – CLOSED LOOP TEST STAND

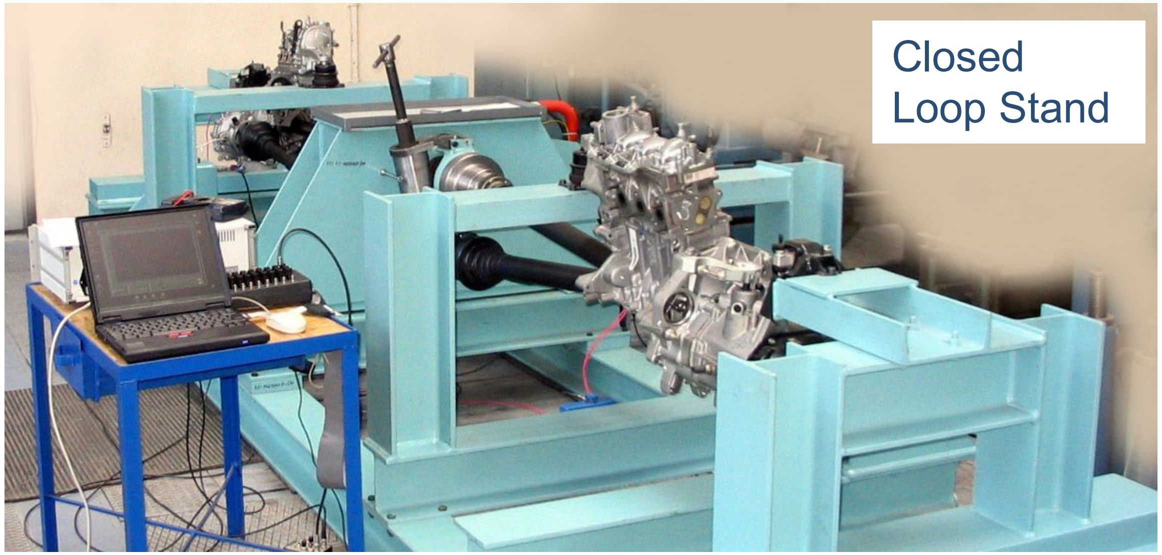
- Lifecycle test of automotive gearboxes for transversal disposition of drivetrain
- Gearbox vibration measurements
- Measuruments of gearbox case and shaft deformation
- Gearboxes mounted in the same manner as in the vehicles with help of silenblocks and torque rod

Maximal power of electromotor	22 kW
Maximal electromotor rpm	3000 1/min
Maximal rpm on the gearbox input shaft	4100 1/min
Maximal nominal torque of the electromotor	275 N.m
Maximal torque on the input shaft of the gearbox	200 N.m
Maximal circulating power inside the closed loop	80 kW
Maximal torque on input shaft for I speed	100 N.m



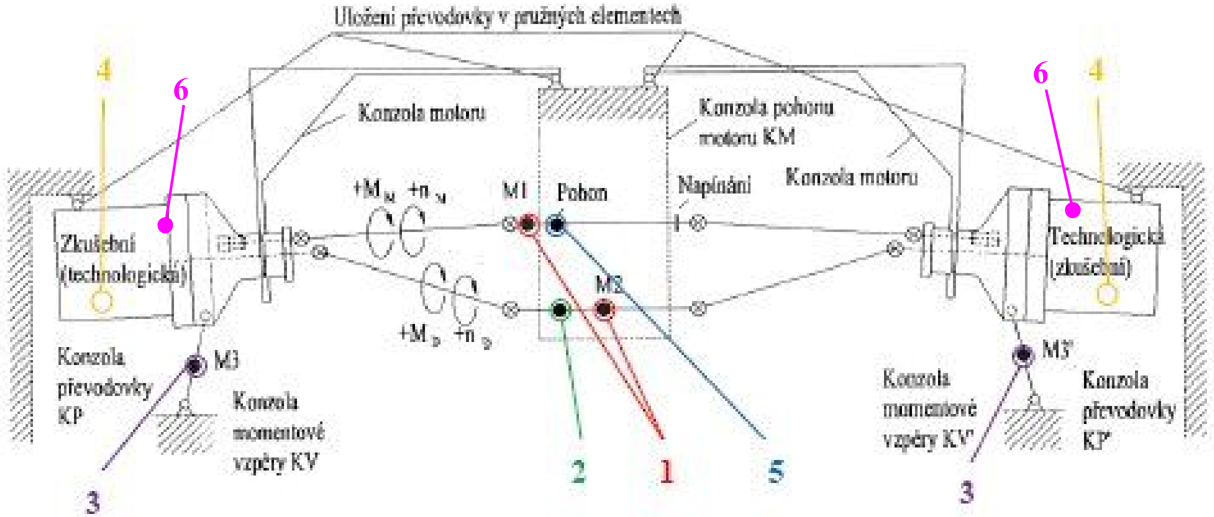
1 – Torque strain gauge measurement
2 – RPM capture
3 – Strain gauge measurement of reactive force
4 – Temperature measurement
5 – Electromotor date
6 – Vibration monitoring with help of Brüel&Kjaer equipment

GEARBOX LABORATORY – CLOSED LOOP TEST STAND



Closed Loop Stand

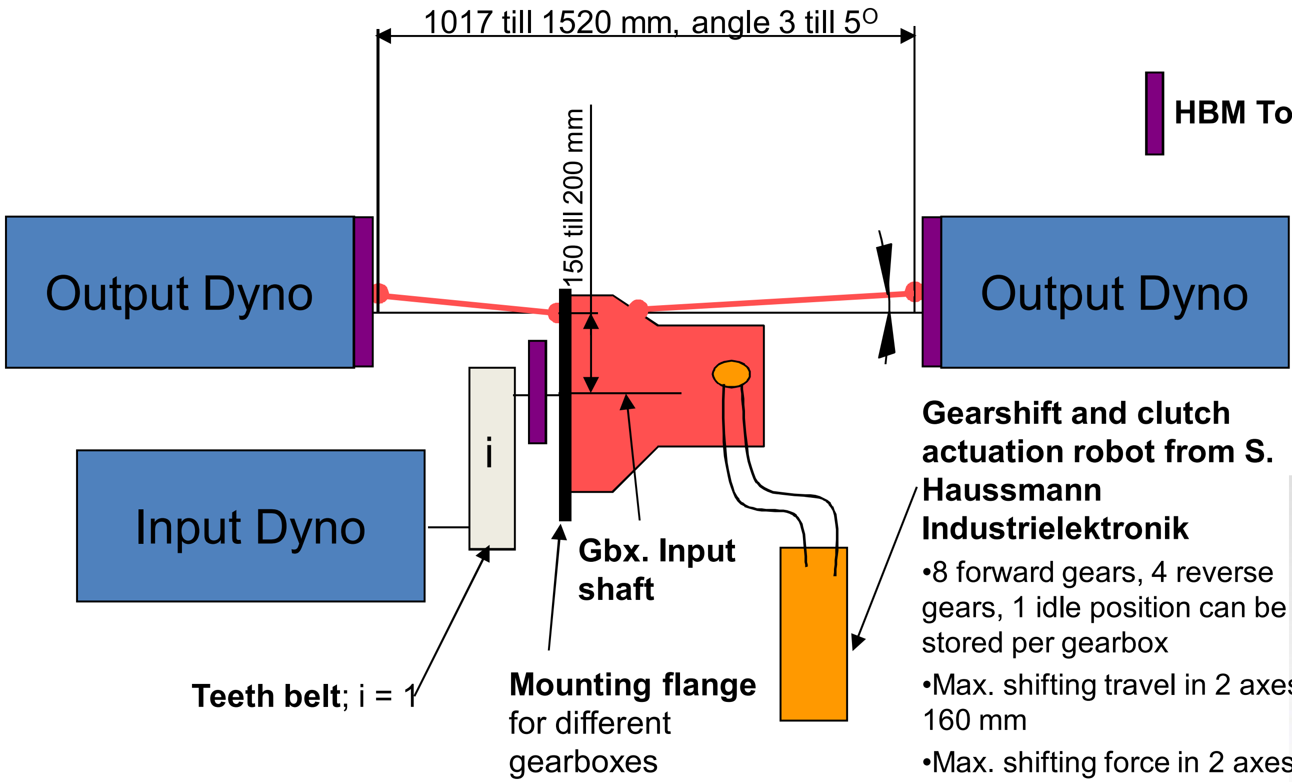
Brancing flange for constant torque measurements



1 – Torque strain gauge measurement
2 – RPM capture
3 – Strain gauge measurement of reactive force
4 – Temperature measurement
5 – Electromotor
6 – Vibration monitoring with help of Brüel&Kjaer equipment

GEARBOX TEST STAND

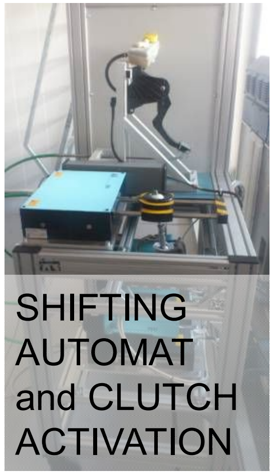
- Gearbox and differential (incl. shafts) test bed
- Automated test of gearbox fatigue life incl. automatic shifting and clutch actuation
- Input and output torque measurement using torque flanges

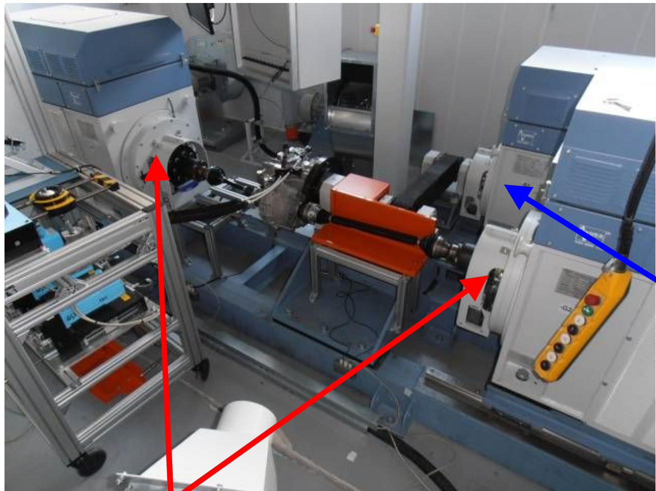


Gearshift and clutch actuation robot from S. Haussmann Industrielektronik

- 8 forward gears, 4 reverse gears, 1 idle position can be stored per gearbox
- Max. shifting travel in 2 axes: 160 mm
- Max. shifting force in 2 axes: 450 N / 2000 N (dyn.)
- Max. shifting speed: 1.66 m/s

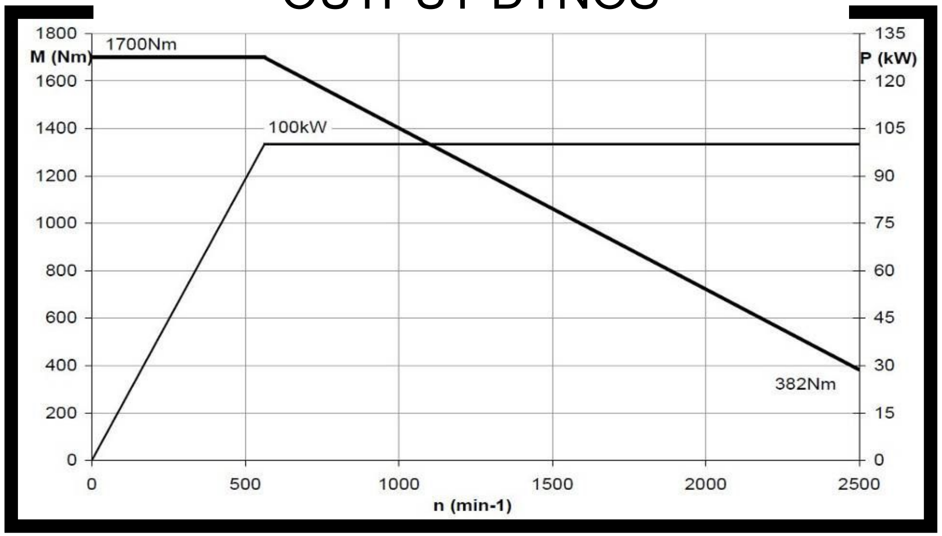
GEARBOX TEST STAND

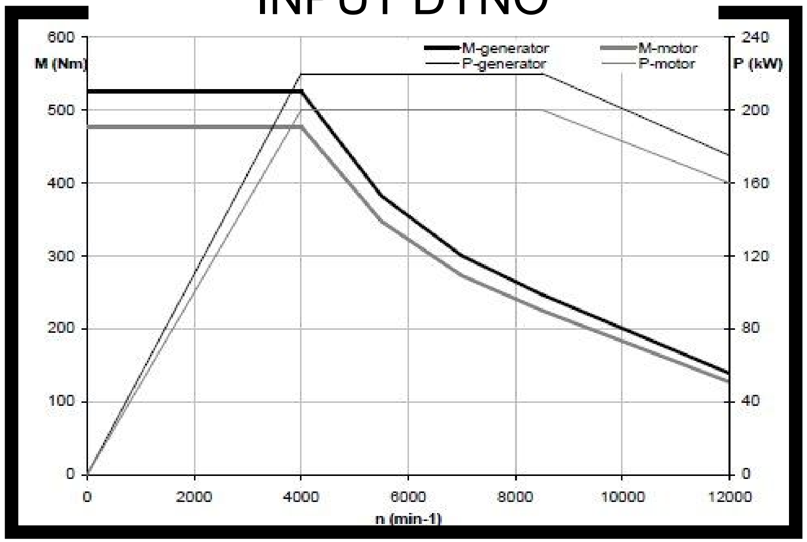




OUTPUT DYNOS

INPUT DYNO

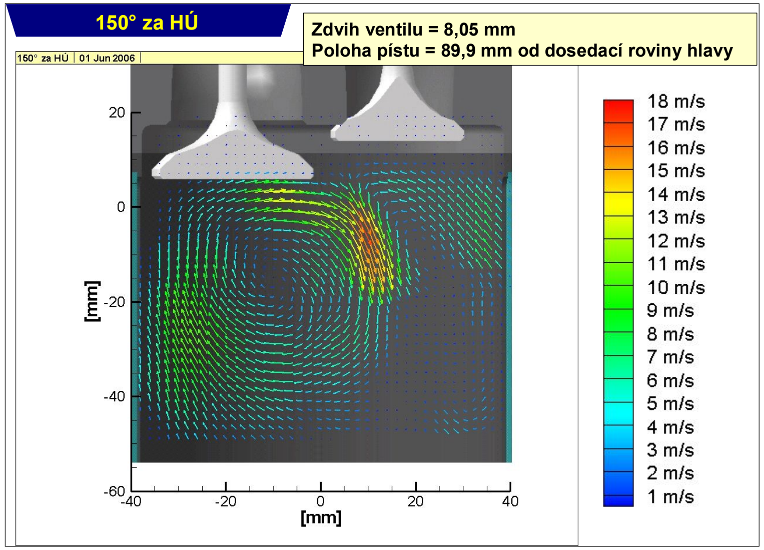




LABORATORY OF OPTICAL FLOW MEASUREMENT TECHNIQUES

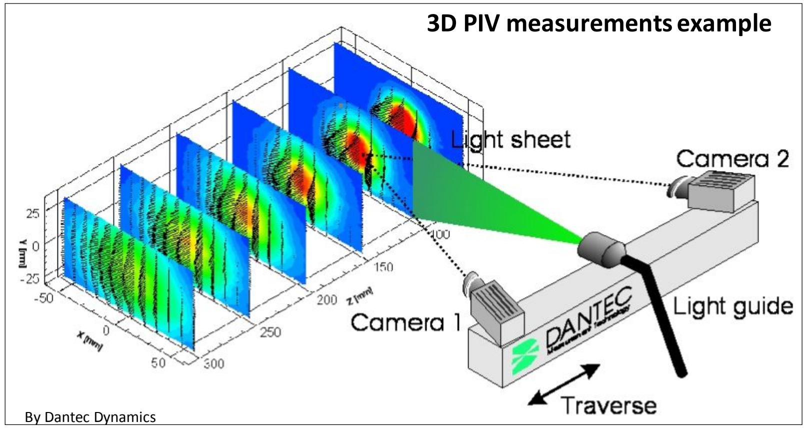
Equipment for velocity measurement by Particle Image Velocimetry PIV) technique

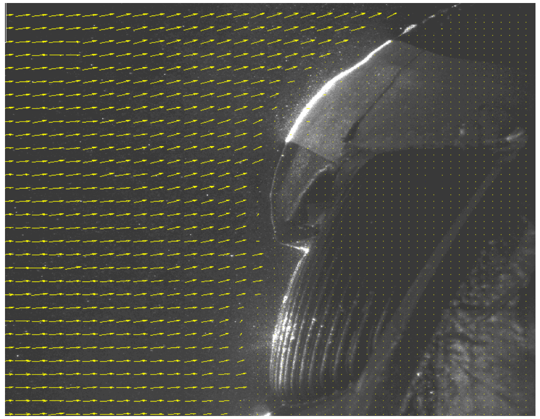
- optical non-intrusive technique for particle-seeding flow fields measurements
- measurement area from approx. 10 mm to 1m
- measurement frequency from 7 Hz
- applicable for various types of measurements in internal and external aerodynamics
- endoscopic optics = possibility to measure in some problematic places (housing, pipes etc.)
- image intensifier unit extends PIV applicability for difficult internal aerodynamics measurements



Assembly:

- dual pulsed Nd-YAG laser 200mJ, laser head sealing IP67, standard and endoscopic light sheet optics
- complete 3D PIV system (2 cameras 4Mpx, standard lenses, timer box, imaging software, PC, tripods etc.)



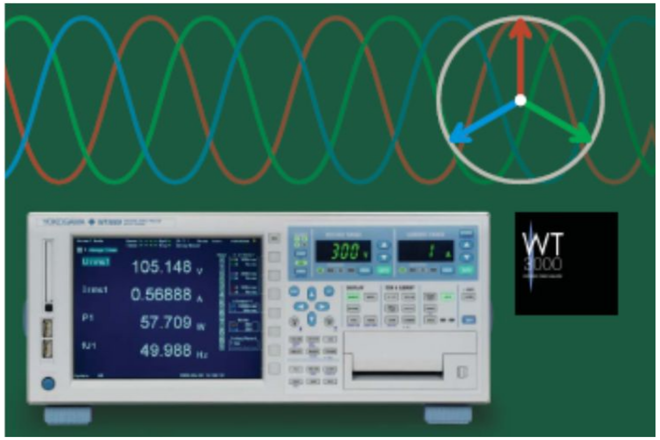


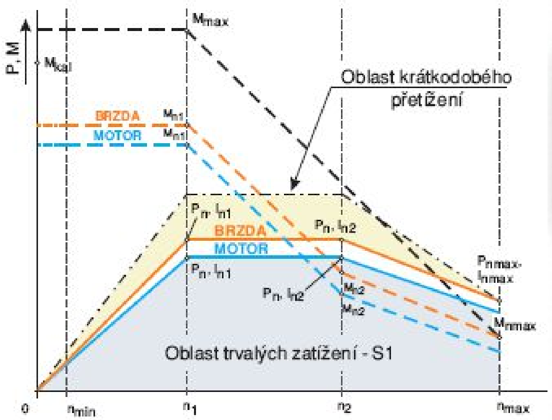
- image intensifier unit (for low-light-level or/and high-speed measurements)

ELECTRIC DRIVES LABORATORY

Testing bench for electric cars powertrains characteristics measurement

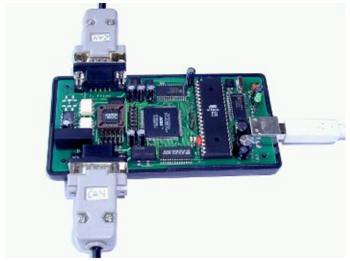
- automated dynamometric testing bench for torque characteristics of electric machines measurement. Maximal revolutions 6000 rev./min
- automated data logging and plotting
- Testing of advanced electric energy storages for EV applications (chemical accumulator, super-capacitor, fuel cell)
- possibility of electric energy recuperation to the network
- working bench for high-revolutions electric machines (up to 80000 rev./min)

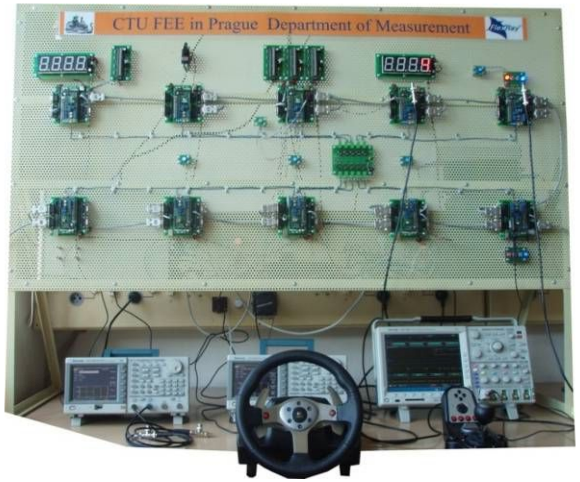


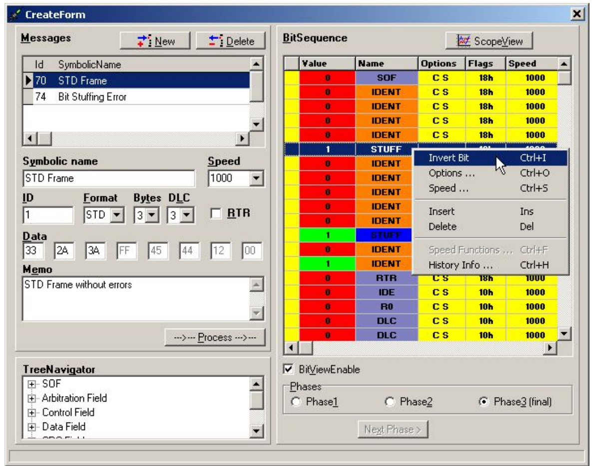


LABORATORY OF MICROELECTRONICS

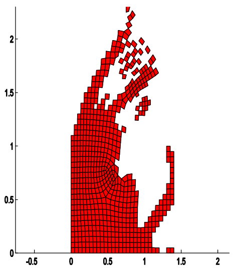
- R&D of test methods for vehicle distributed systems (CAN, LIN FlexRay based).
- EMC of distributed systems, fault-tolerant systems.
- X-by-Wire systems.
- Research and development of robust test methods, that:
  - are performed on precisely defined conditions,
  - provide repeatable results with known uncertainty,
  - minimally affect the test objects.

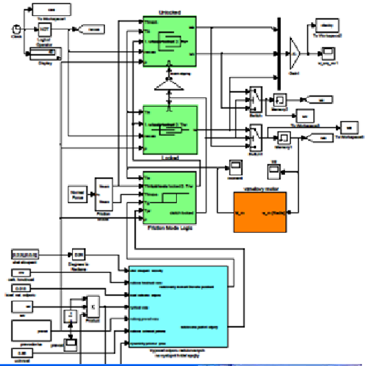




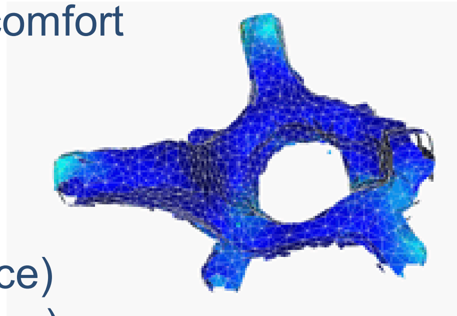


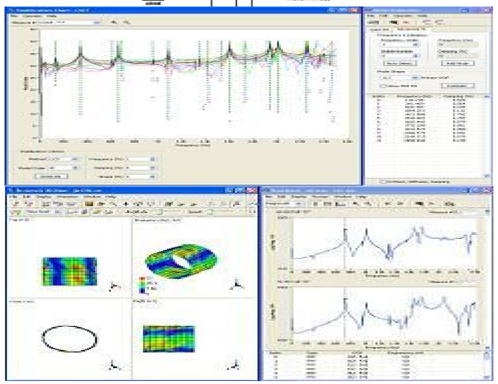
MECHATRONIC LABORATORY - OVERVIEW





- Vehicle Integrated Control Development (Controlled Suspension, ABS, ESP, synergy of all the systems)
- Combustion Engine Predictive Control
- Noise and vibration (NVH) problem solution based on
    - Solid powerful experimental equipment (EMA, ODS, OMA)
    - Theoretical experience and tools (FEM modelling, analyses, optimization (PENOPT), experiment-model correlation)
- Objective evaluation of the vehicle vibration comfort
- HIL and SIL experiments



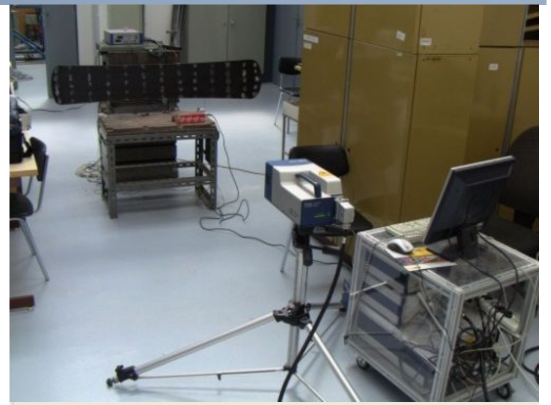


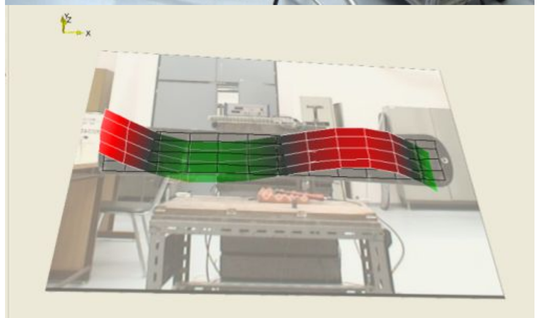
<u>Equipment</u>

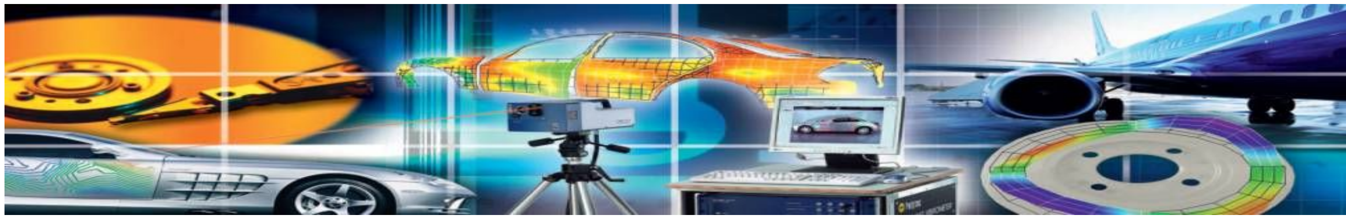
- RapidPrototyping platform:
    - General purpose (CompactRIO, PXI, dSpace)
    - Combustion engine (ETAS ECU and software)
- Software: LabView, ModalView, Matlab, Simulink, Ansys, PENOPT, …
- Electromechanic, hydraulic excitation, strain gauge technology, accelerometers, eddy currents sensors
- MIMO multichannel vibration analyzer
- Laser scanning vibrometer
- Acoustic camera – spatial acoustic field measurement

MECHATRONIC LABORATORY – Laser Scanning Vibrometer POLYTEC PSV-400

- Non-contact velocity measurement realized by laser beam (based on doppler effect)
- Ideal for vibration measurement of flexible structures (both for low and high frequencies)
- Automatic scanning of large grids (up to 512x512], both small (mm^2) and big structures (many m^2)
- Swift visualization
- Moving - rotating parts measurement possible
- Fastscan option for periodic transient events
- Operating deflection shapes measurement
  - Used for brake squealing problem solution in the lab
- Automatic operational modal analyses for many points
- Direct data export into Matlab, ModalView or other EMA software
- Direct structural modification (e.g. item scanned, treated with damping material and quickly re-measured)
- FEM models validation







MECHATRONIC LABORATORY – Vibration Measurement

Equipment

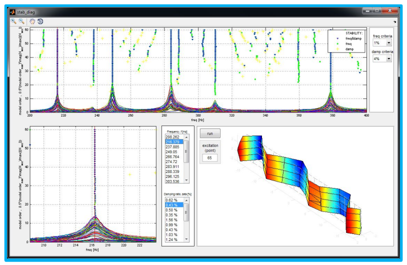
- NI based DAQ hardware
  - 48 synchronized input channels up to simultaneously sampled analog channels at up to 204.8 kS/s, 24 bit resolution
  - High dynamic range - voltages from 10 V to 2.2 µV (2 amplifier gains for measurement flexibility), low noise
  - Automatic antialiasing filters, IEPE, TEDS
- Actuation: Modal hammer or two-channel 400N elektro-mechanical shaker
- 1ax and 3ax accelerometers B&K and Endevco and force sensors Endevco
- Integration with laser doppler vibrometer for very accurate measurement

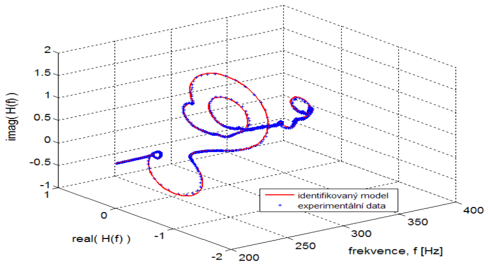
Software

- ModalView (DAQ, EMA, OMA, ODS)
- In-house software with improved regression algorithms and data export

Application

- Modal properties measurement - Experimental modal analyses
- Operational vibrations – Operational deflection shapes
- Modal properties identification under operation – Operational modal analyses



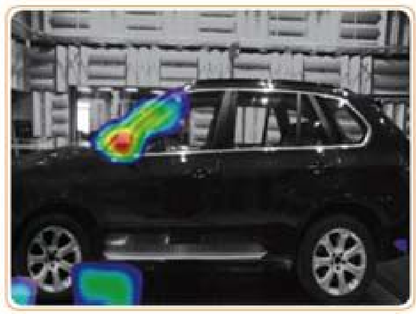


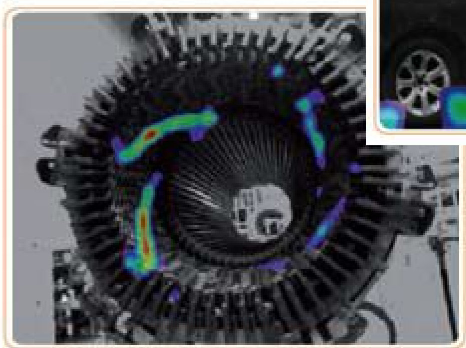
MECHATRONIC LABORATORY – Acoustic Camera - Noise field real-time measurement

Methods
- Beamforming, DAMAS, MUSIC-Algorithm
- CAPON-Algorithm, CleanSC, Acoustic Holography
- Rotating Beamforming (RB)
- „user interface“ for special data processing and algorithms

Properties
- Near field and far field
- Free microphone configuration, synchronous data acquisition
- Standard arrays like 2Dlinear, spirale, cross, ring, 3D, spherical, box…
- Real time operation
- Integrated USB Camera to “blend” acoustic field visualization with camera image
- Frequency, Time-Frequency (Sonogram) operation
- Selection of Time-Frequency windows for accurate analyses
- Standard A, B, C weighting or linear
- Video function – save as avi

Application
- Localization of noise sources
- Accurate and swift detection of vibrating machine parts





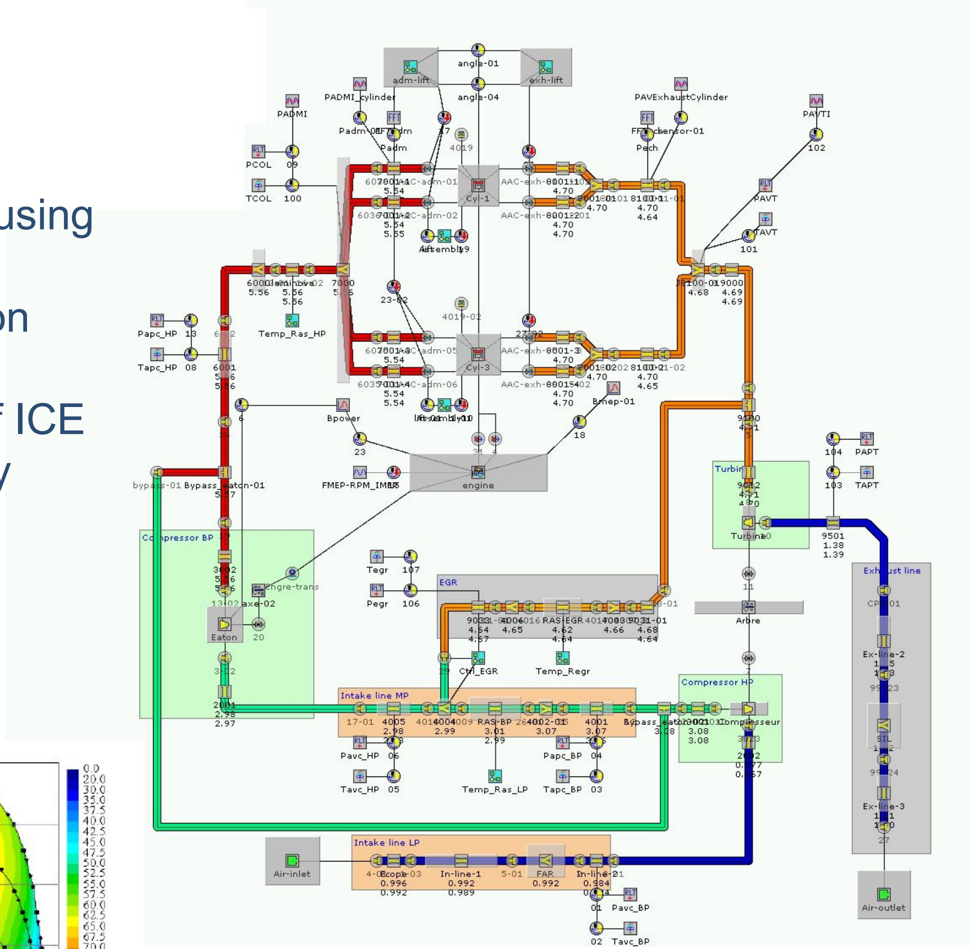
SIMULATION CENTRE

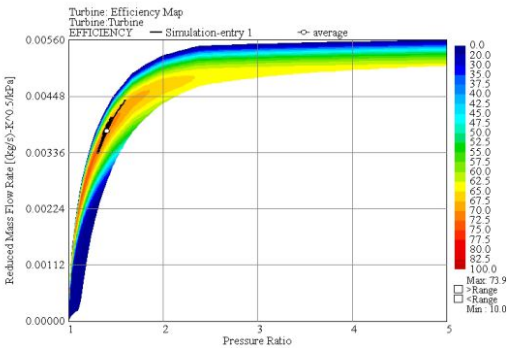
<u>HW Equipment:</u>

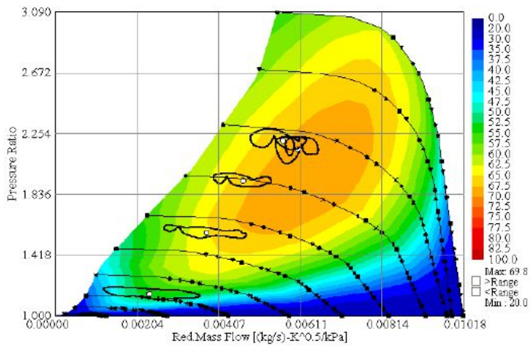
- powerful server for computations

<u>Application:</u>

- optimization of internal combustion engines using combined experimental/simulation approach
- multi-zone models (e.g. SI engine combustion including detailed chemistry)
- 0-D/1-D (GT-Power) – complex simulation of ICE cycle including accessories ⇨ multi-disciplinary approach:
    - super/turbo-charging
    - detailed modeling of radial turbine
    - combination of 1-D with 3-D
    - unconventional thermal machines

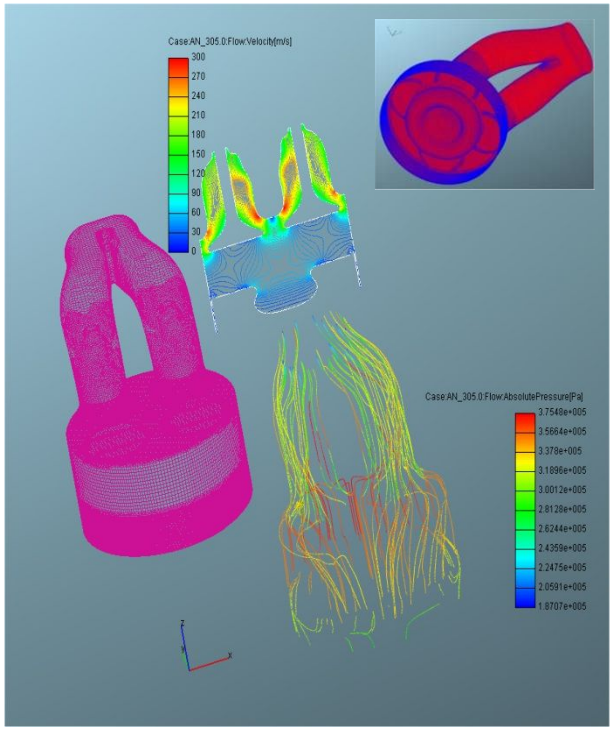


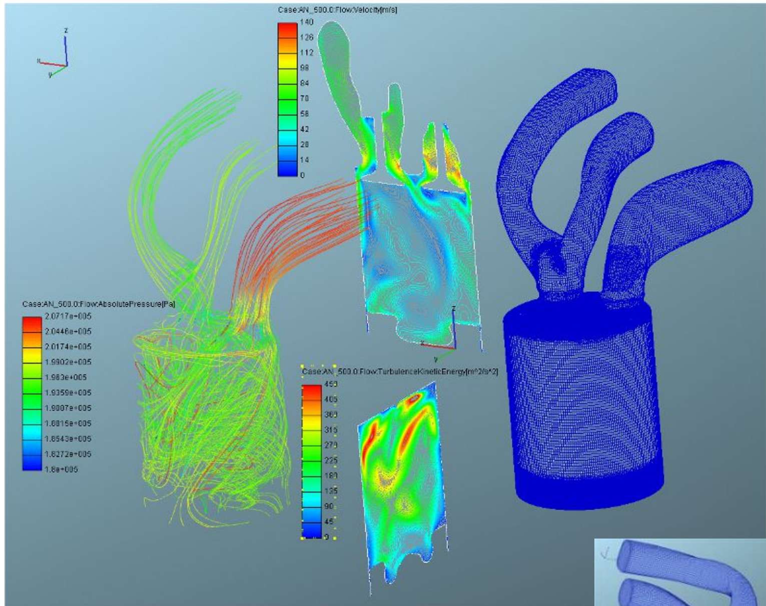


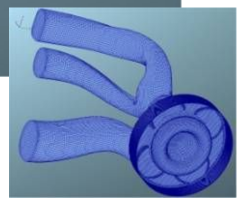


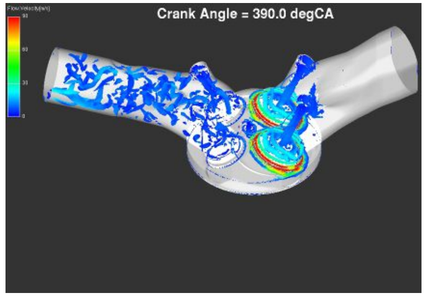
SIMULATION CENTRE

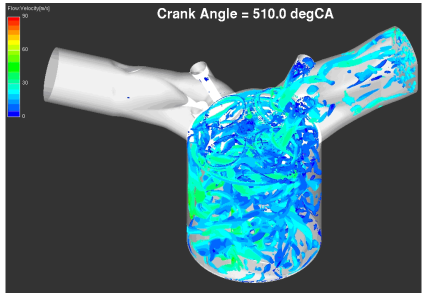
- 3-D CFD (AVL FIRE) – detailed modeling of in-cylinder thermodynamics including combustion and pollutant production
- 3-D FEM (ABAQUS) – detailed modeling of stresses caused by mechanical/thermal load

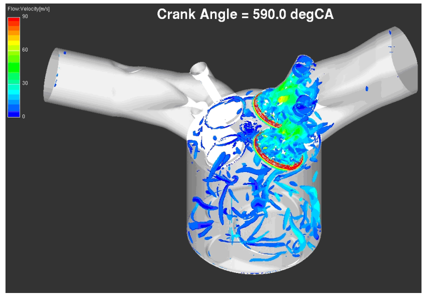










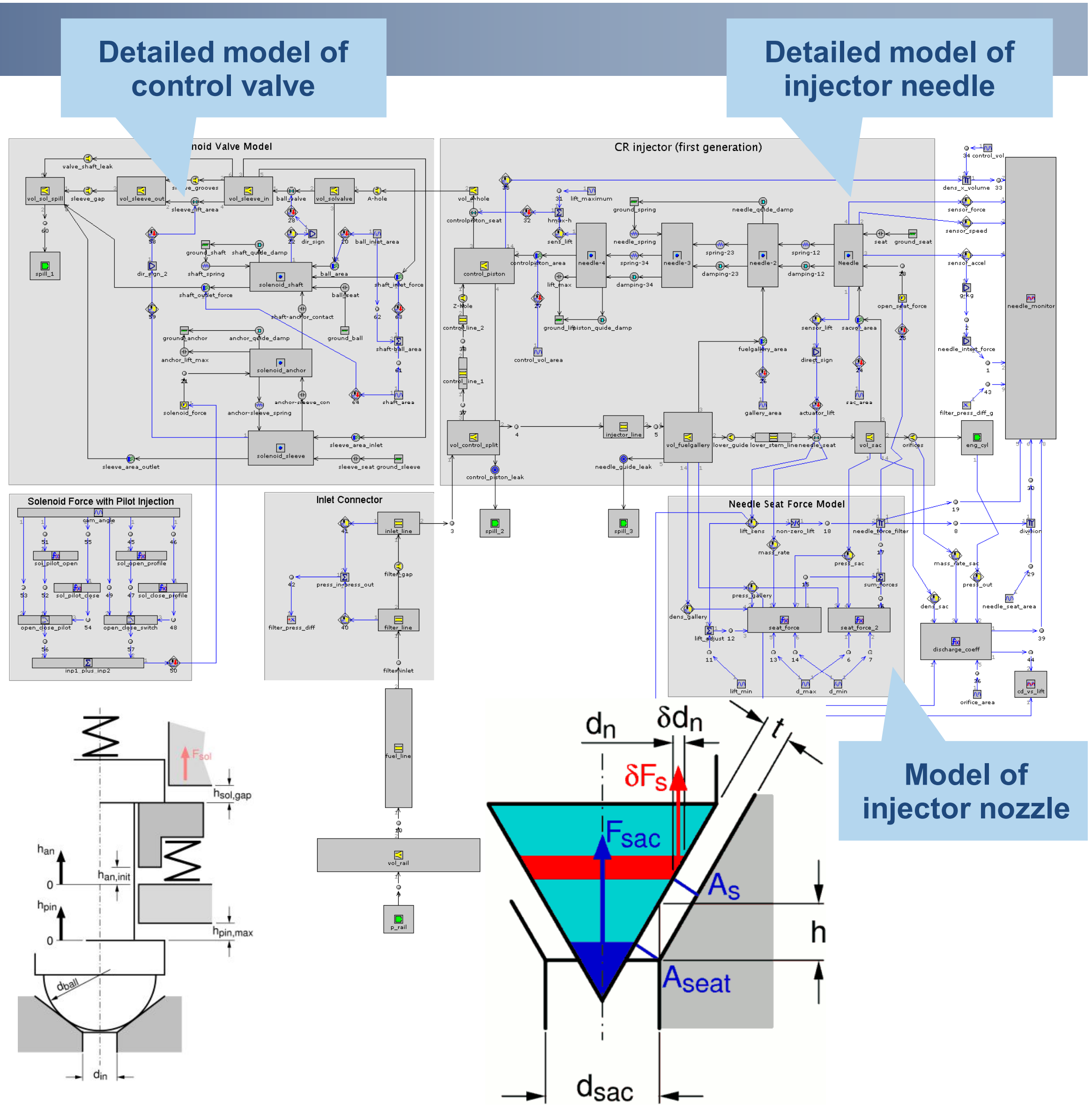


SIMULATION CENTRE

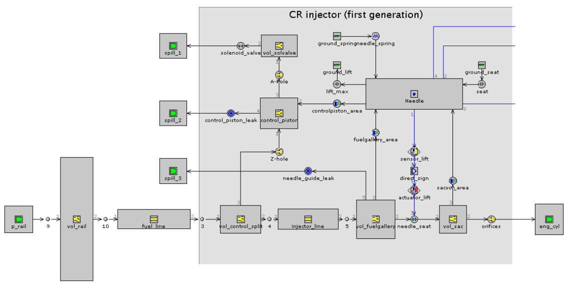
1D Hydrodynamic Simulations of Fuel Injection Systems

Applications:

- ➢ detailed hydrodynamic models of CR injectors and HP pumps
- ➢ optimization of FIE components using combined experimental-simulation approach:
  - ➢ verification of overall performance
  - ➢sensitivity studies
  - ➢use of alternative fuels



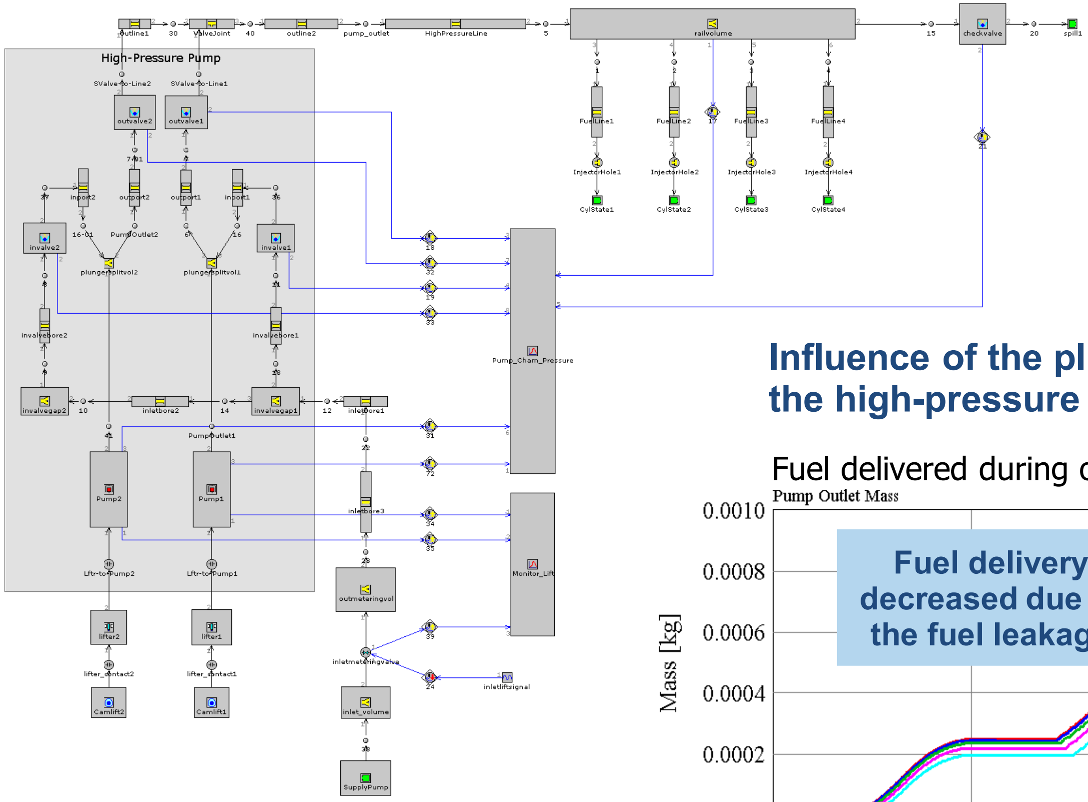
Basic CR injector model



SIMULATION CENTRE

Optimization of Fuel Injection Systems for Diesel Engines

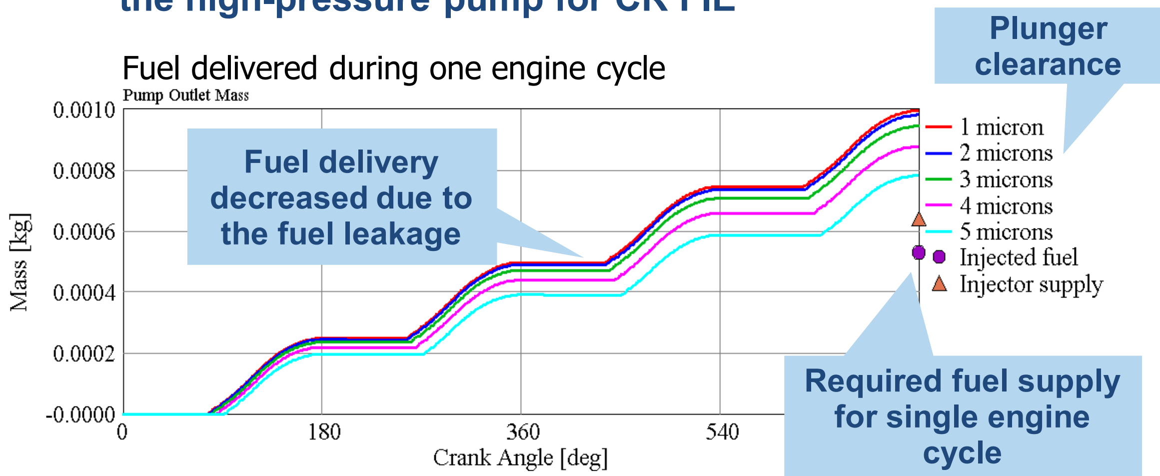
Layout of a hydraulic model of high-pressure system of Common Rail FIE for a four-cylinder engine



Development of hydraulic models of Common Rail fuel injection system components

The models are employed to verify overall functionality and to further optimize various components of Common Rail FIE in cooperation with industry

Influence of the plunger clearance on fuel delivery of the high-pressure pump for CR FIE

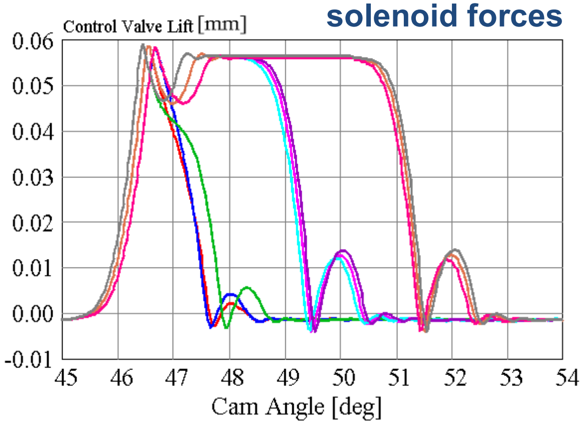


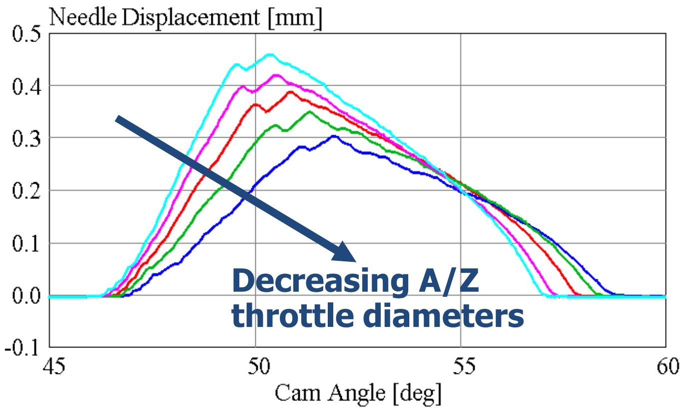
SIMULATION CENTRE

Optimization of Fuel Injection Systems for Diesel Engines

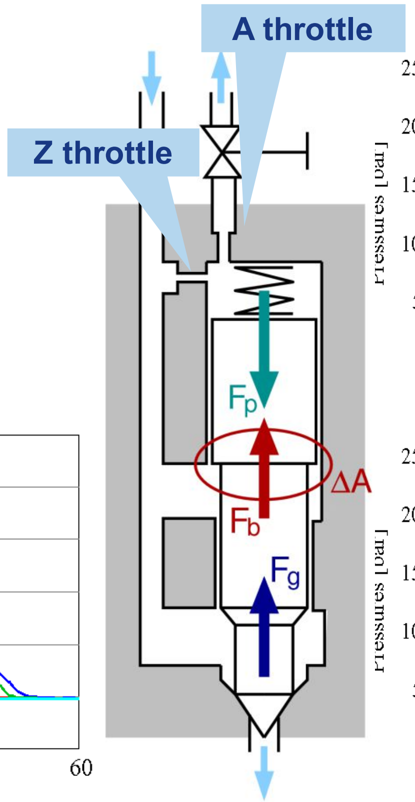
Optimization of the Common Rail injector performance for given application

Control valve lifts for various solenoid forces

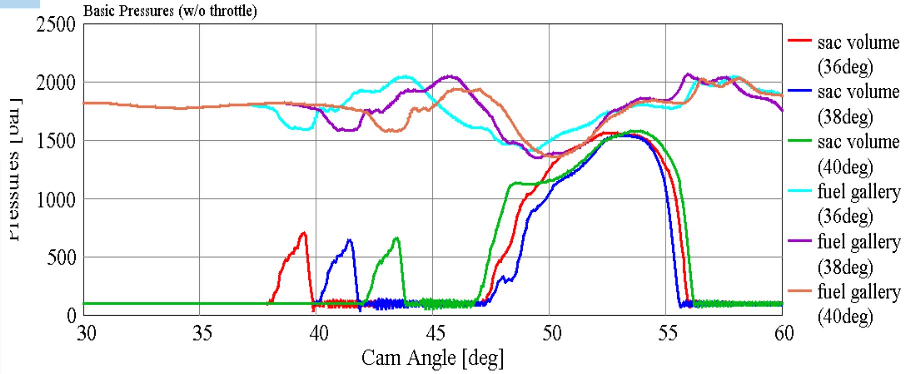


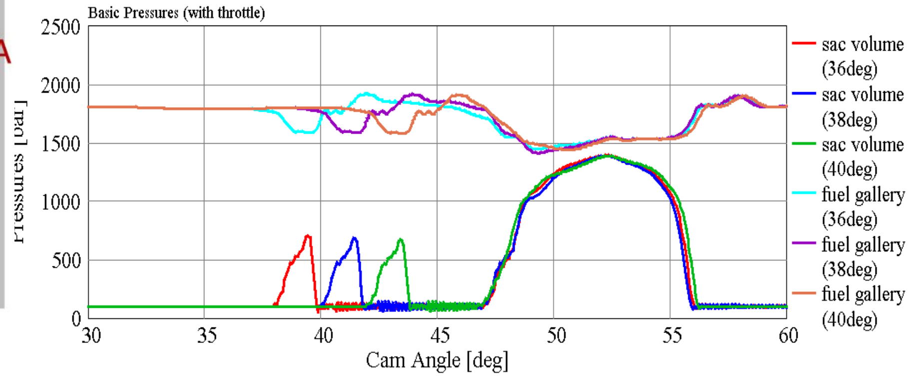


Common Rail injector scheme



Optimization of fuel injector behaviour for split-injection strategy (pilot and main injection)

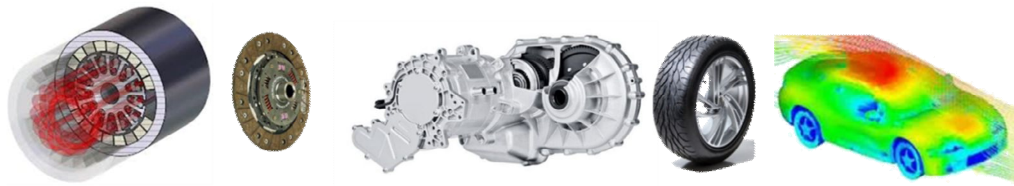




SIMULATION CENTRE

Vehicle Performance Evaluation Tool for a Transient Driving Cycle

Models of investigated powertrain topologies can be build from the library of custom blocks designed in Matlab/ Simulink environment.

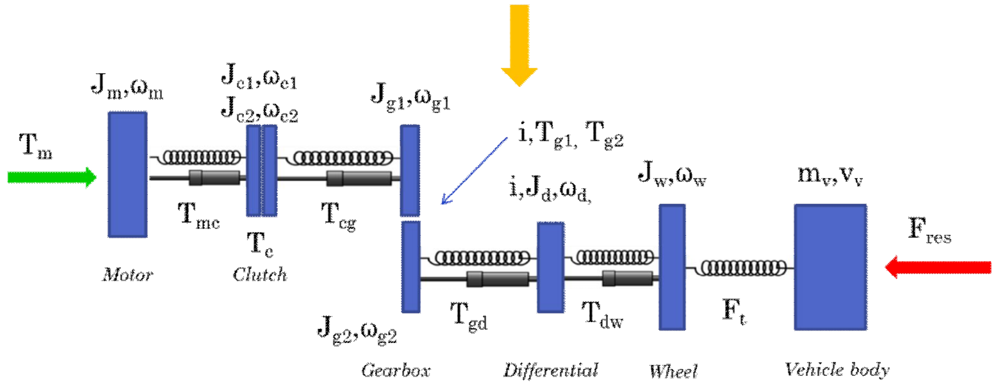


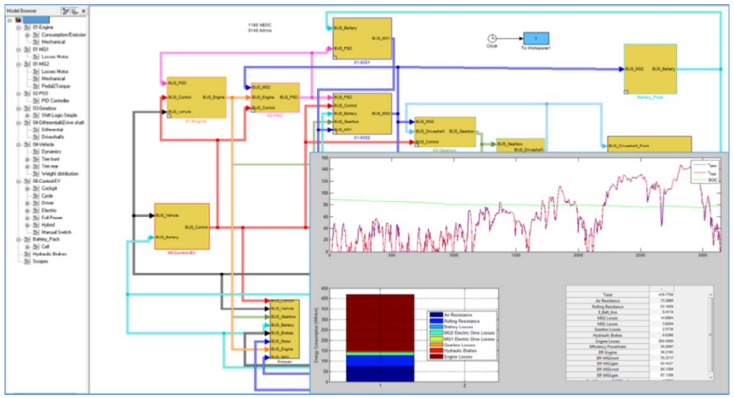
Longitudinal vehicle dynamics
Driving resistances
- Rolling res., Air res., Road incline res., Inertia forces

Powertrain losses
- Gearbox, Differential, Brakes, Tires

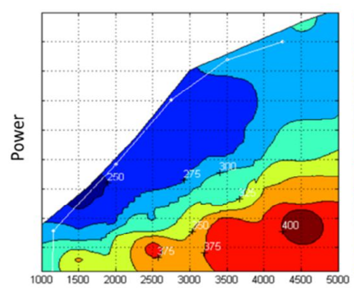
Combustion engine efficiency
- Quasi-static map based engine model

Electric drive efficiency
- Inverter and traction motor losses
  - Quasistatic map based models
- Battery charging/ discharging efficiency
  - Modified Thevenin model

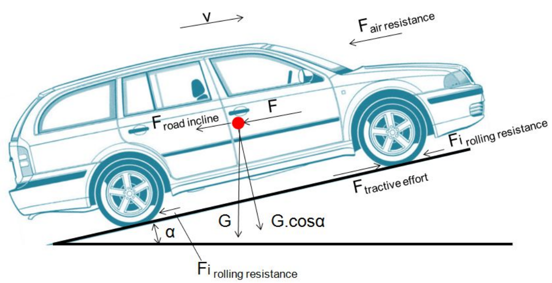




RideSim- Simulation model and post-processing tool



Engine bsfc map



Driving resistances

Thank you for your interest

…we are looking forward to our future cooperation

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