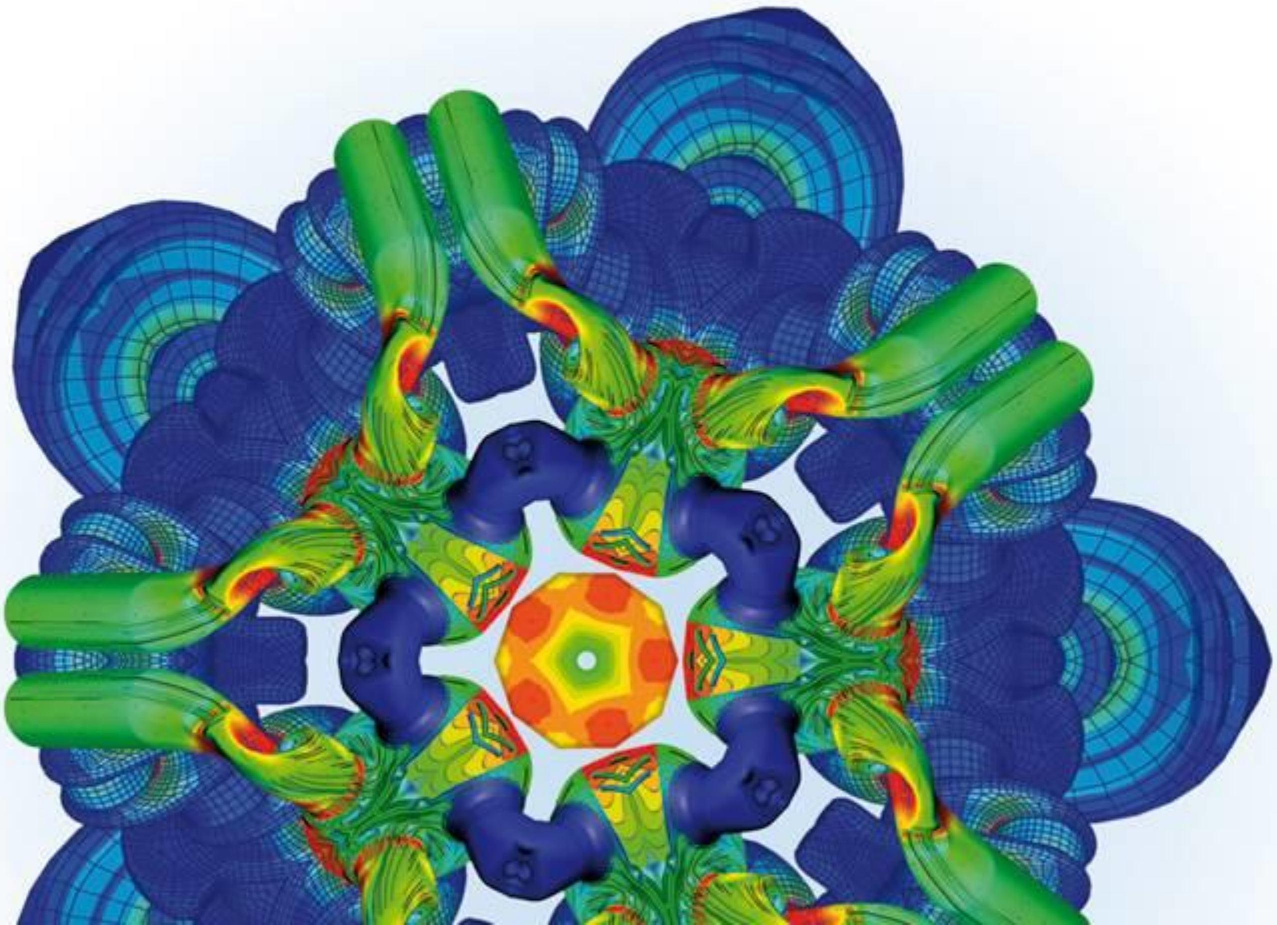
AVL BUSINESS UNIT AST
Advanced Simulation Technologies

SOFTWARE SOLUTIONS
AND
METHOD DEVELOPMENT



Content

- Overview on AST and AST Tools & Services
- CRUISE→ From concept to testing
- EXCITE→ Durability and NVH of Power Unit and Drivelines
- 1D CFD
  - BOOST→ 1D Thermodynamic Simulation
  - HYDSIM→Injector Simulation
- FIRE→ 3D CFD Thermodynamic Simulation

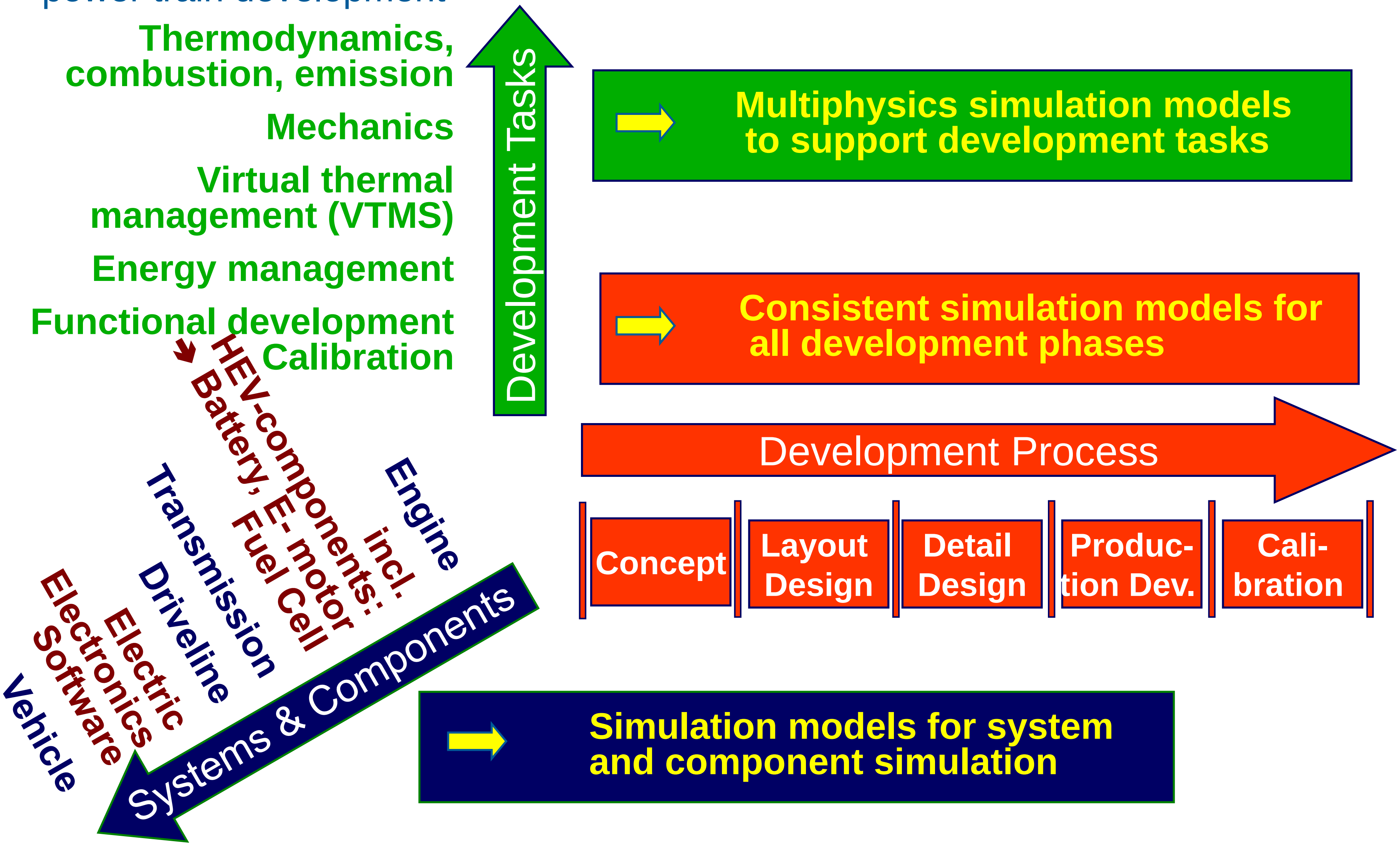
AST INTRODUCTION

Basics

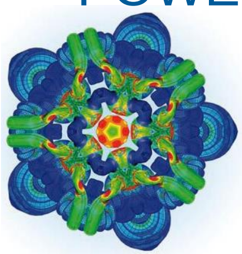
- AST is separate business unit within AVL and works close together with the other business units ITS and PTE (even shares simulation teams)
- AST actually as about 140 employees worldwide
- AST has local support and development teams
- AST tasks:
  - Software development
  - Simulation services (technical and customer oriented support, method development (R&D, J&R) and problem solving projects)
  - → AST support engineers have a lot of engineering and project experience

THE POWERTRAIN DEVELOPMENT PROCESS

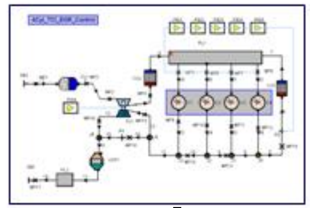
The Challenge: Cover all simulation requirements for power train development

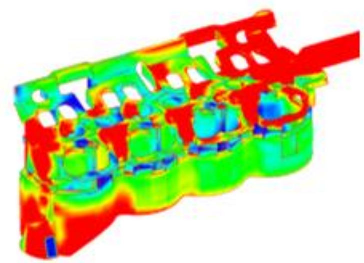


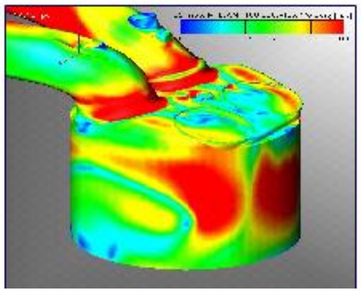
THE SOFTWARE SOLUTIONS TO SUPPORT THE POWERTRAIN DEVELOPMENT PROCESS



Advanced Simulation Technologies-
Simulation models for system and component simulation





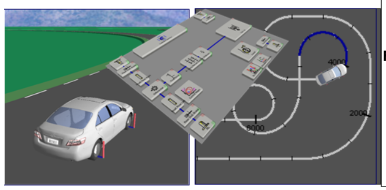


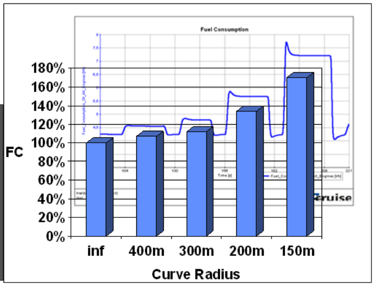
BOOST
FIRE®
HYDSIM

Complete IC-engine simulation platform

CRUISE

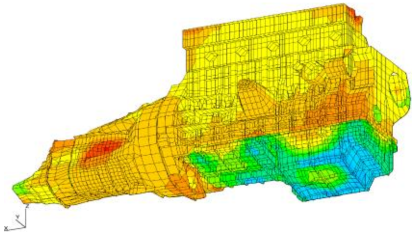
Driving performance & emission analysis

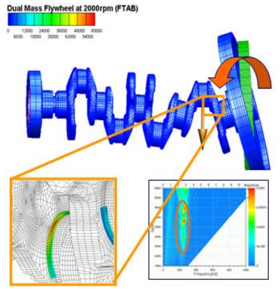




EXCITE

Powertrain & drive line durability and NVH analysis



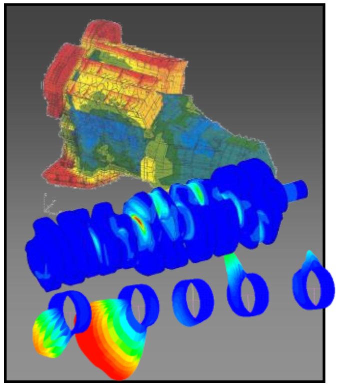


….. interfacing and integrating other AVL software and 3rd party software

AST – The Products

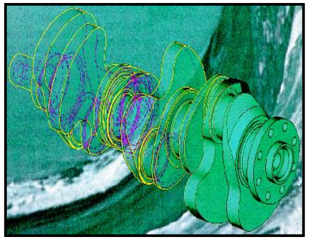
Structure Dynamics

EXCITE POWER UNIT



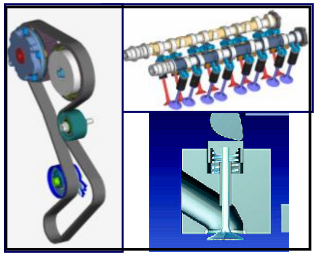
NVH of Power Units and Drive Lines, Durability of Engine Components, Advanced Bearing Design

EXCITE DESIGNER



Crank Train Design Analysis

EXCITE TIMING DRIVE



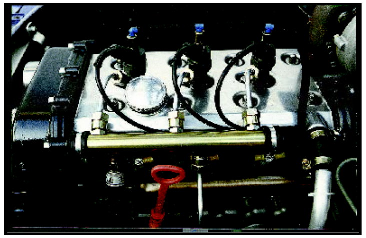
Valve Train Analysis, Timing Drive Dynamics

EXCITE PISTON&RINGS

Piston Dynamics Oil Consumption

Hydraulics

HYDSIM



Injection System Simulation

EXCITE is the Central Tool for NVH and Durability Analysis

EXCITE Timing Drive, EXCITE Piston & Rings and HYDSIM are Used for Pre-Calculation of Necessary Additional Excitations

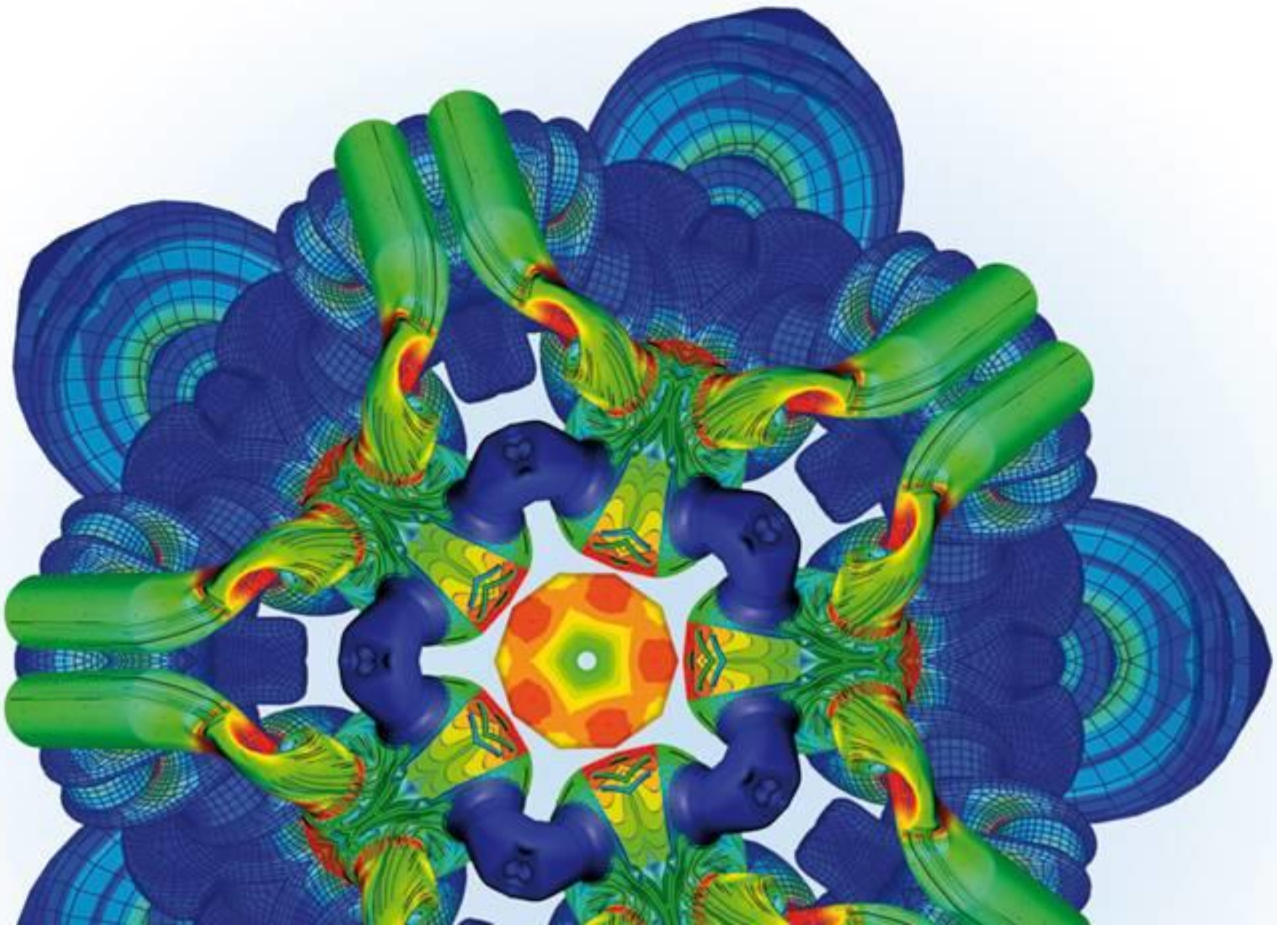
Drive Cycle Simulation

CRUISE

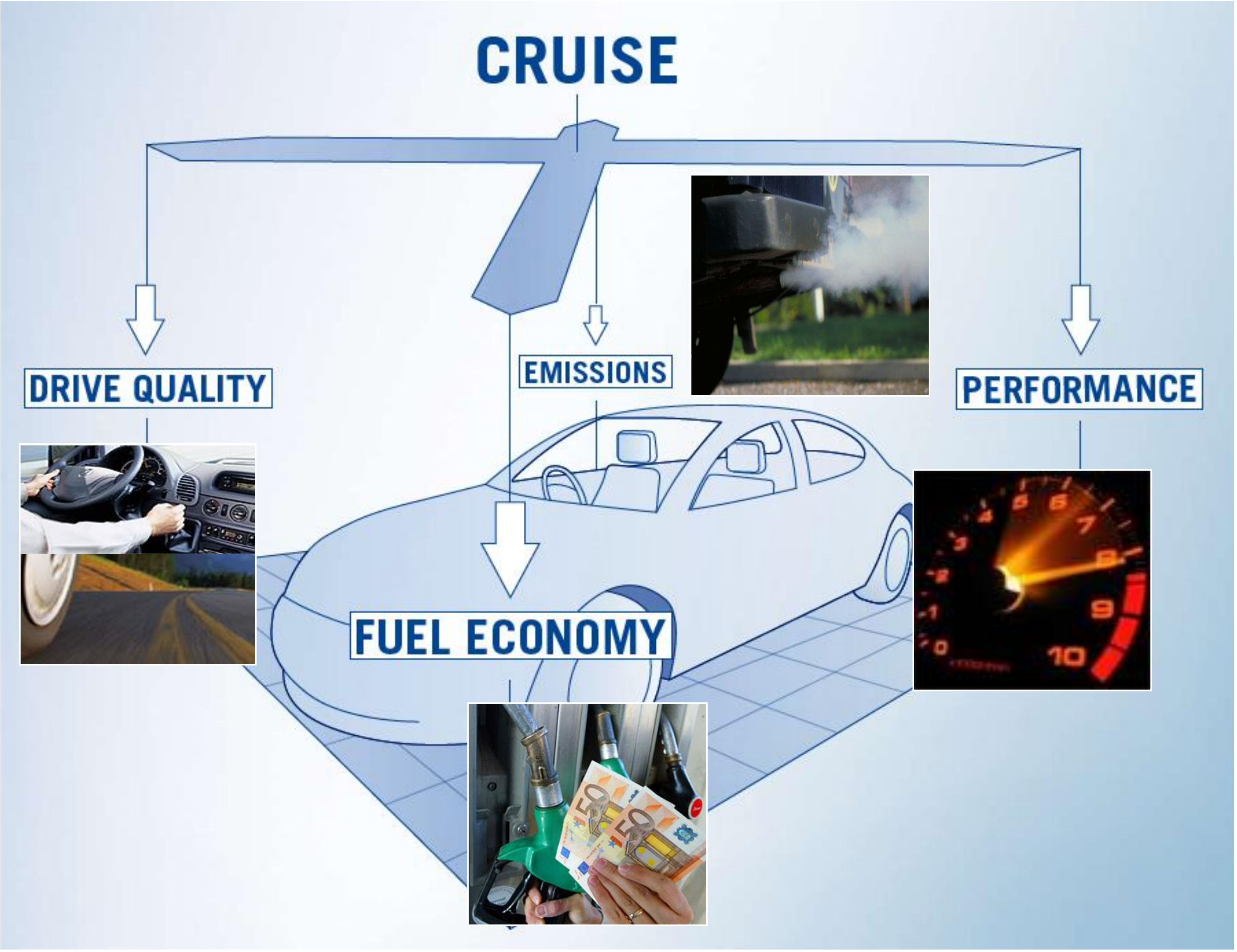
Vehicle Simulation: Driving Performance, Fuel Consumption, Emissions

CRUISE – VEHICLE SYSTEM AND DRIVELINE ANALYSIS

FROM CONCEPT TO TESTING



CRUISE VEHICLE SYSTEM SIMULATION – FINDING THE BEST COMPROMISE FOR YOUR TARGETS

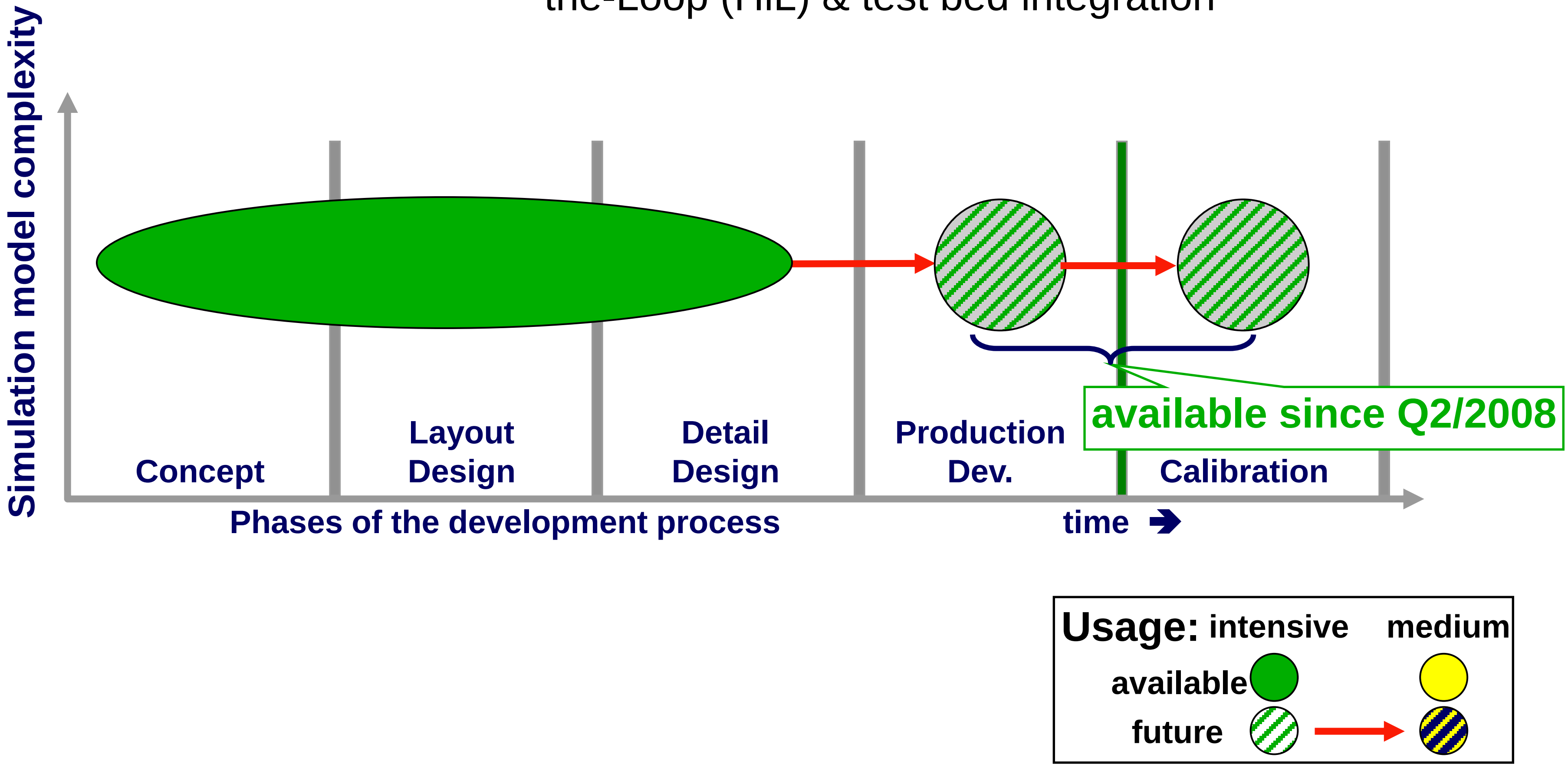


CRUISE SYSTEM SIMULATION – AN INTEGRATED PART OF THE DEVELOPMENT PROCESS

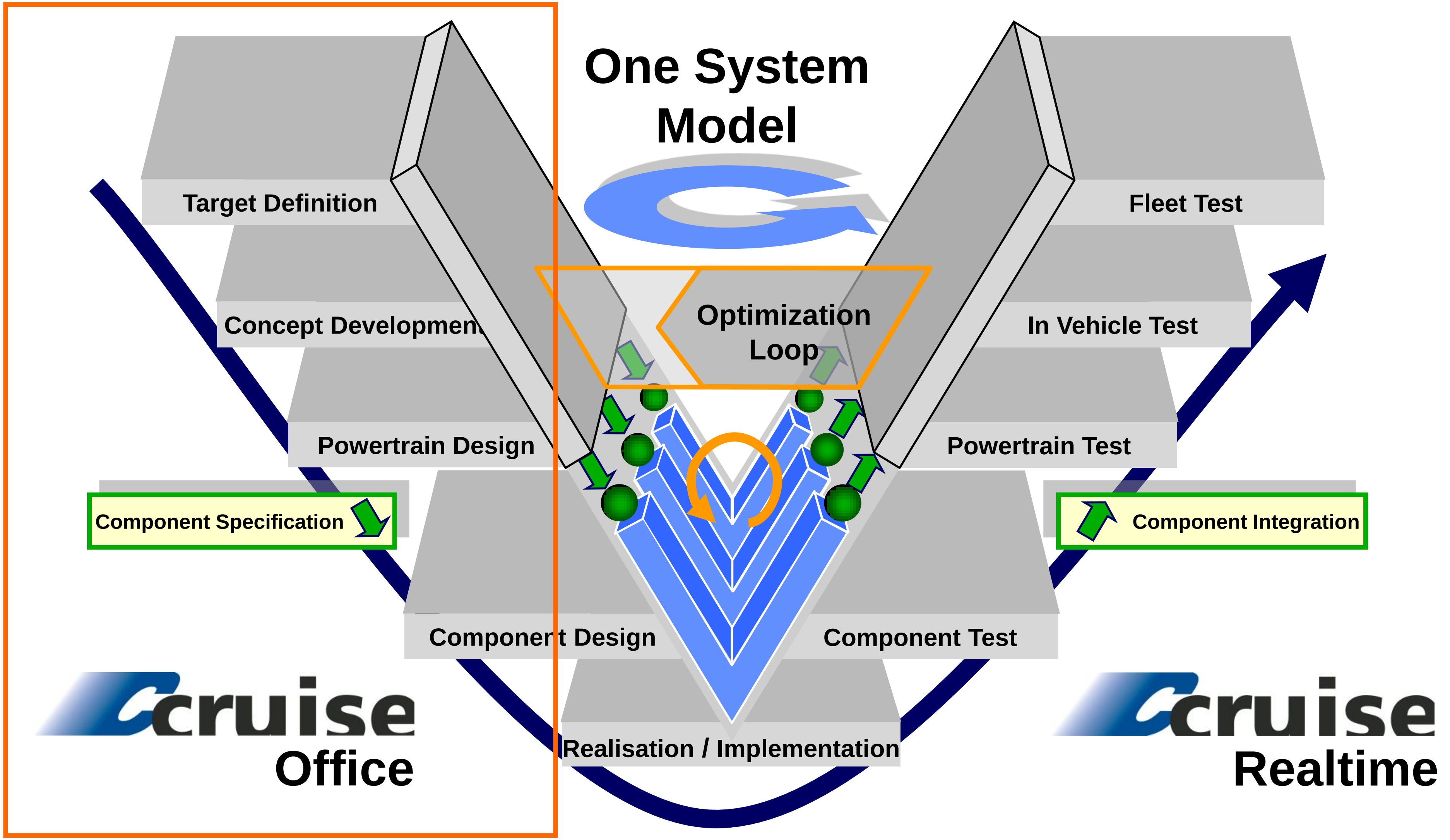
Consistent simulation models for all development phases

The Benefit:

➔Component and subsystem testing by Hardware-in-the-Loop (HiL) & test bed integration

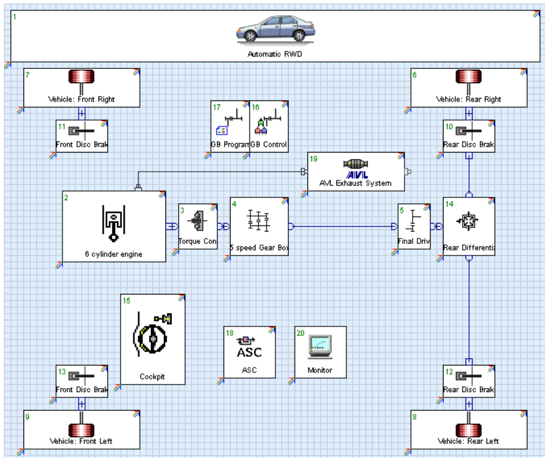


CRUISE SYSTEM SIMULATION – AN INTEGRATED PART OF THE DEVELOPMENT PROCESS

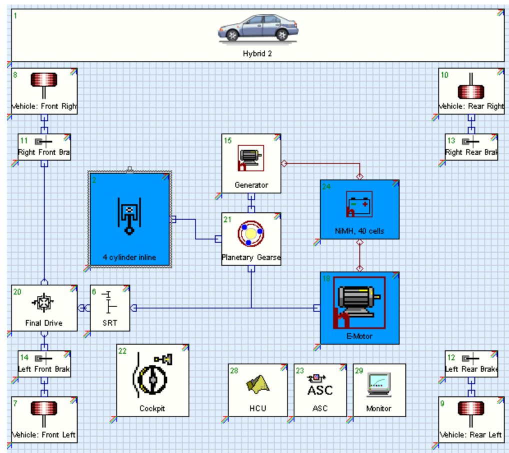


SOME EXAMPLES OF VEHICLE SYSTEM MODELS

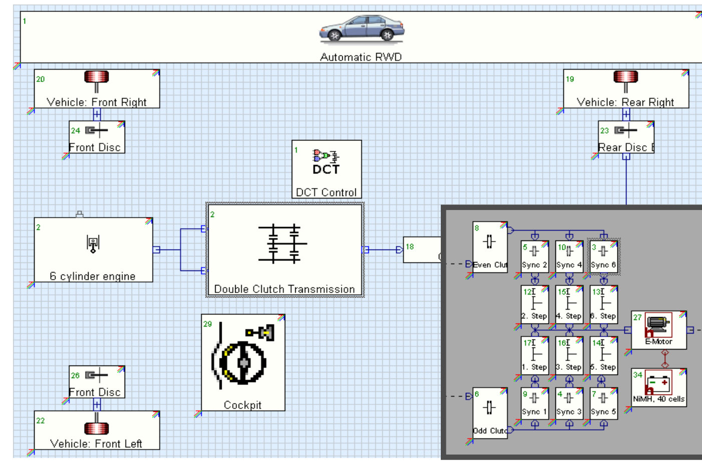
Conventional Passenger Cars

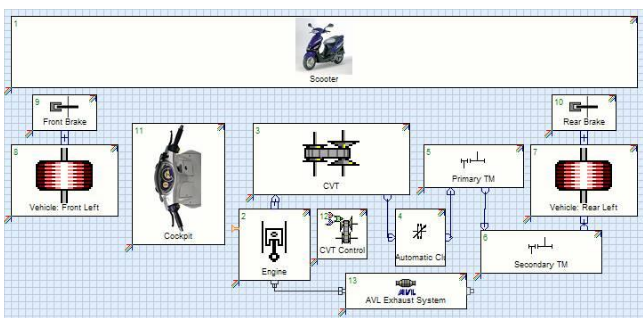


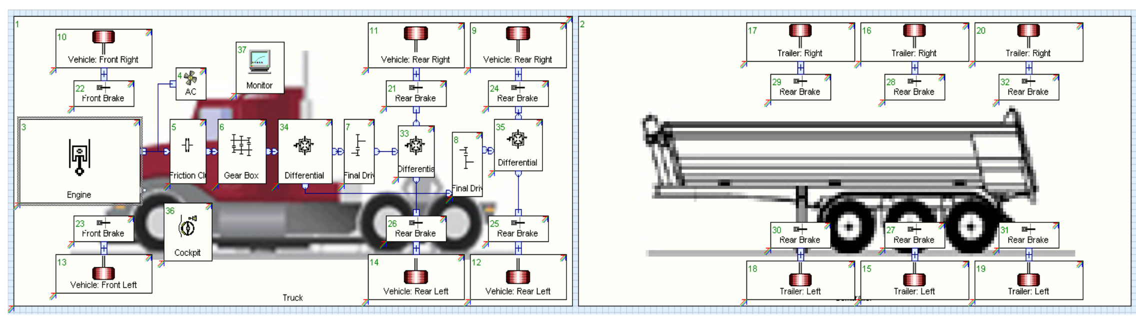
Hybrid Vehicles



Advanced Transmission Concepts

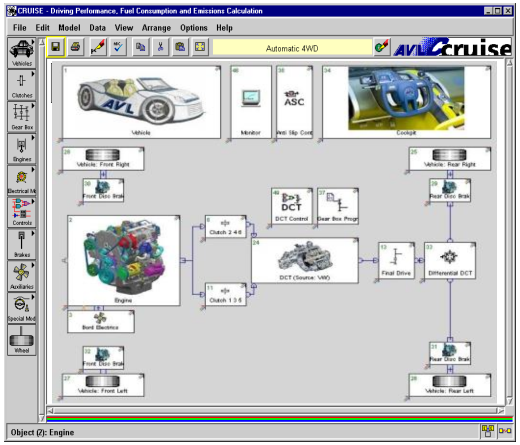




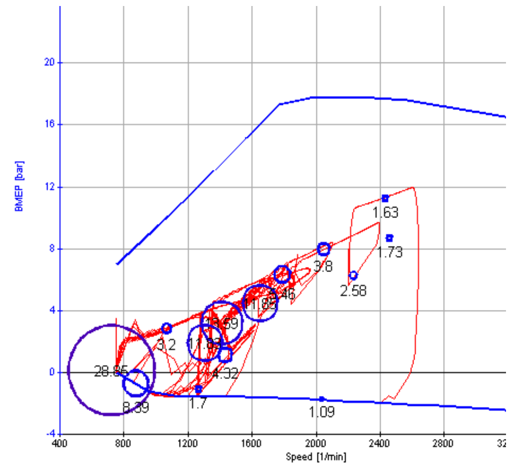


Motorbikes CVT-Scooters Trucks Busses Special Purpose Vehicles Trailers

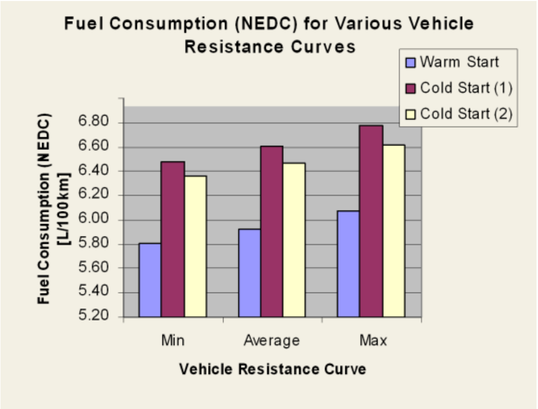
FUEL CONSUMPTION CYCLE CALCULATION



Input / Model



Analysis



Results

Task description / Input, Output

Prediction of drive cycle fuel consumption and raw emissions of passenger cars, commercial vehicles and other engine applications, based on measured or predicted steady state FC and emission maps within legal or custom defined driving or operation cycles;

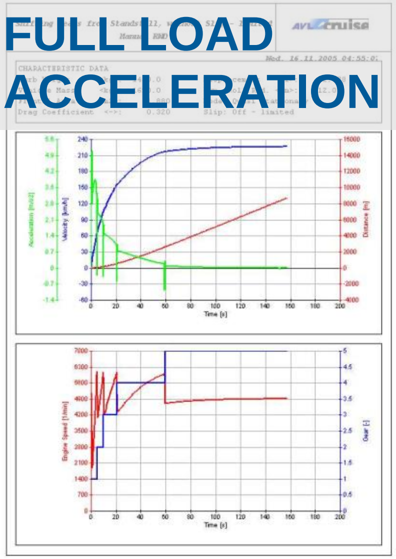
Results are limited by the steady-state maps of the engine;

Development value / insight

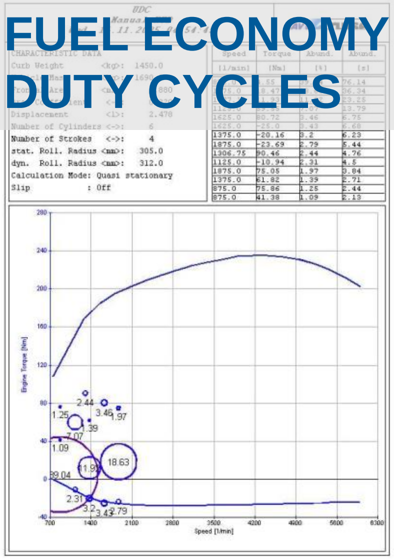
- Influence of vehicle parameters (vehicle weight, wheels, final drive, etc.) on expected FC and emissions
- Influence of powertrain (topology -manual vs. automated transmission, auxiliaries, hybrids, etc.)
- Optimization of powertrain & auxiliary operation strategy (gear shifting program, ..)
- Definition of steady state test-bed load points (prediction of cycle results)

ALL STANDARD VEHICLE ANALYSIS METHODS INCLUDES

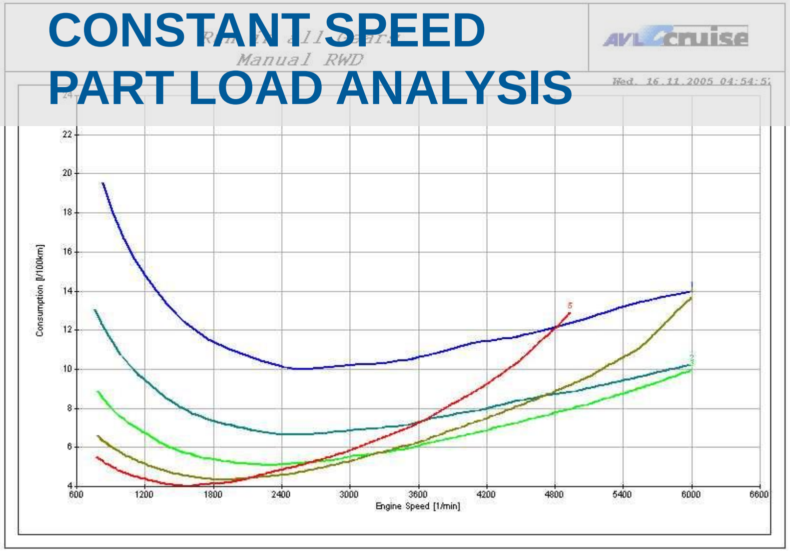
FULL LOAD ACCELERATION



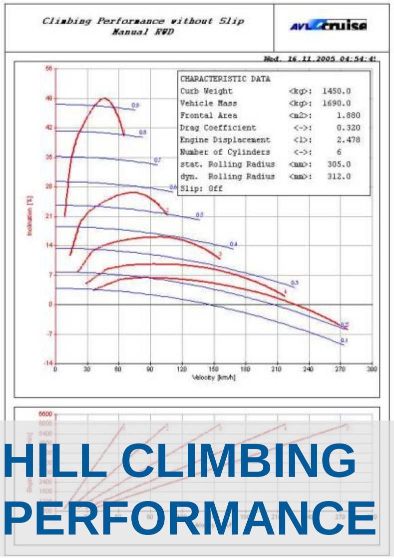
FUEL ECONOMY DUTY CYCLES



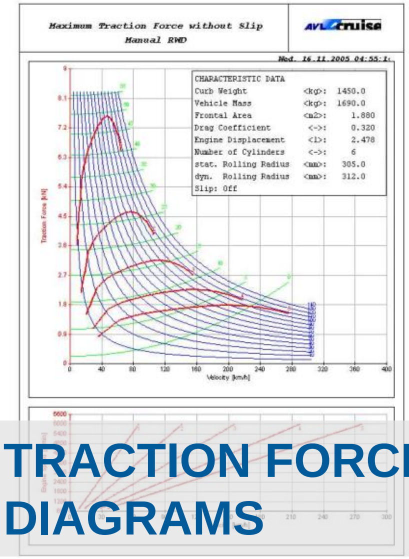
CONSTANT SPEED PART LOAD ANALYSIS



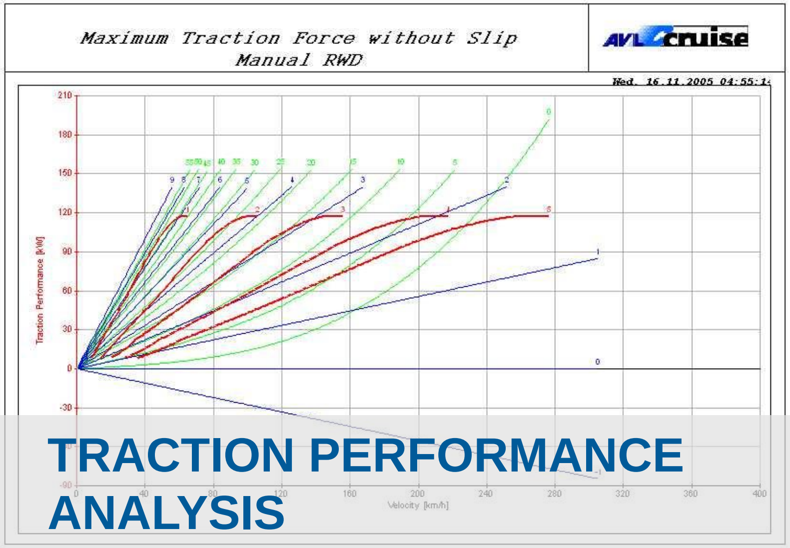
HILL CLIMBING PERFORMANCE



TRACTION FORCE DIAGRAMS

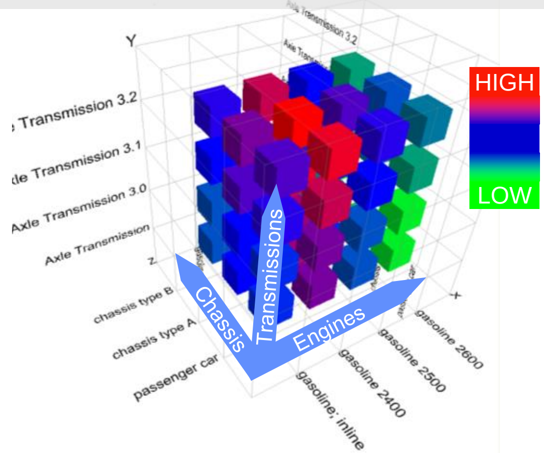


TRACTION PERFORMANCE ANALYSIS

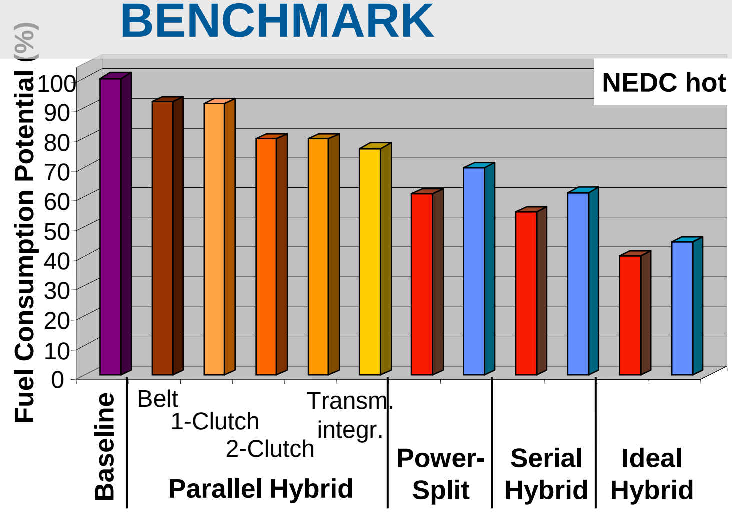


APPLICATION EXAMPLES

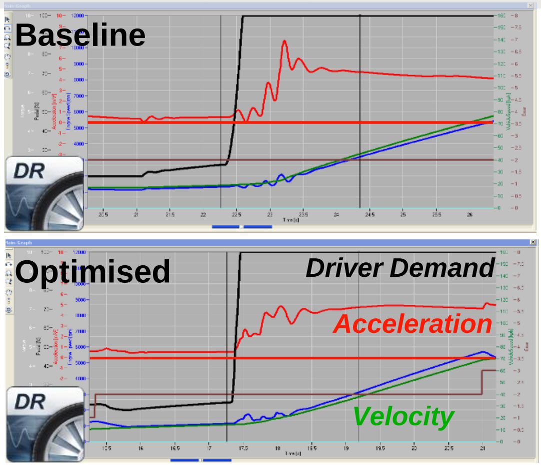
FUEL ECONOMY PERFORMANCE

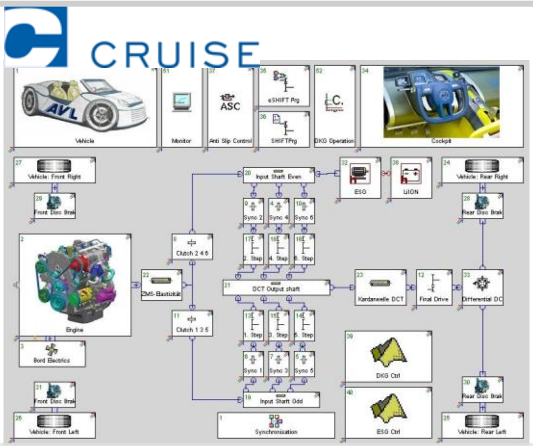


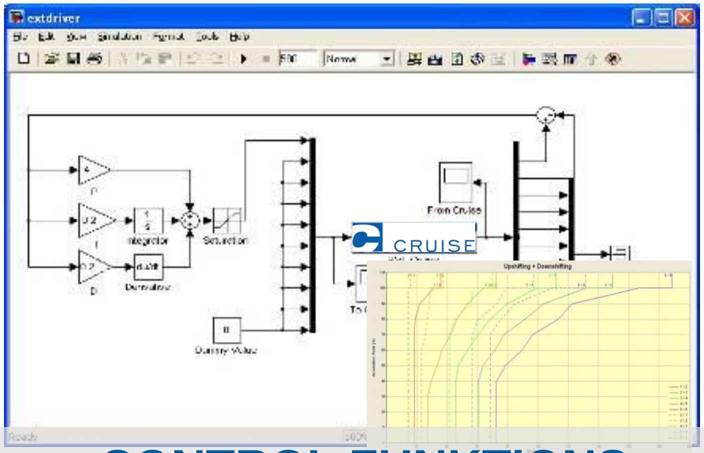
CONCEPT POTENTIAL BENCHMARK

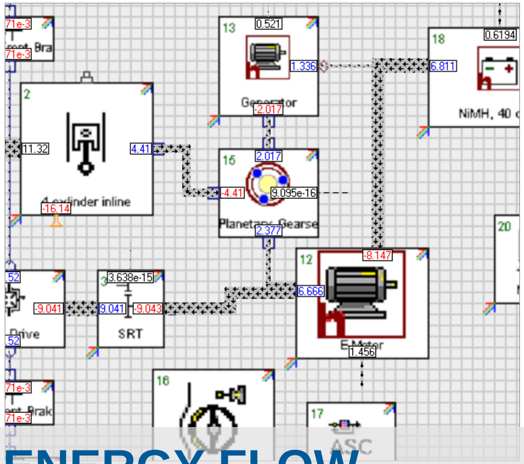


DRIVEABILITY SHIFTING QUALITY







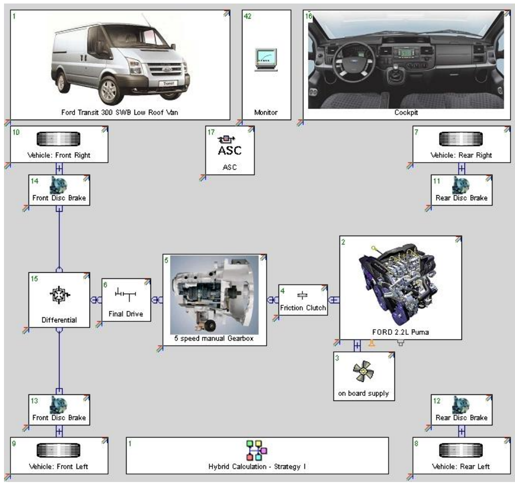


TRANSMISSIONS HYBRID SYSTEMS

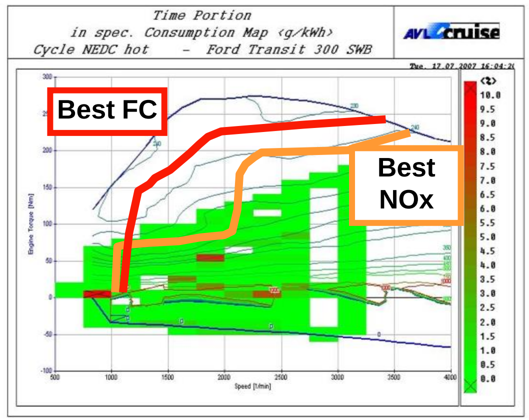
CONTROL FUNKTIONS CALIBRATION

ENERGY FLOW LOSS POWER

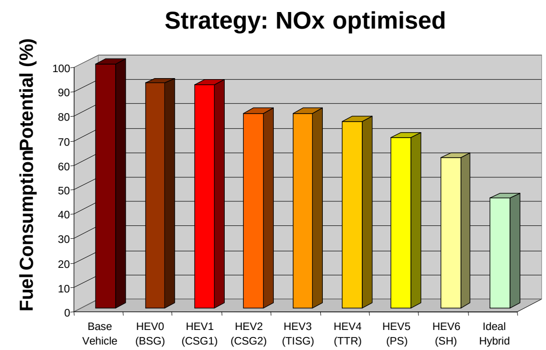
HYBRID POTENTIAL ESTIMATOR



Input / Model



Analysis



Results

Task description / Input, Output

Estimation of the fuel consumption and emissions potential of different hybrid topologies based on a CRUISE simulation of a conventional, baseline vehicle

Input: conventional vehicle model, driving and duty cycles

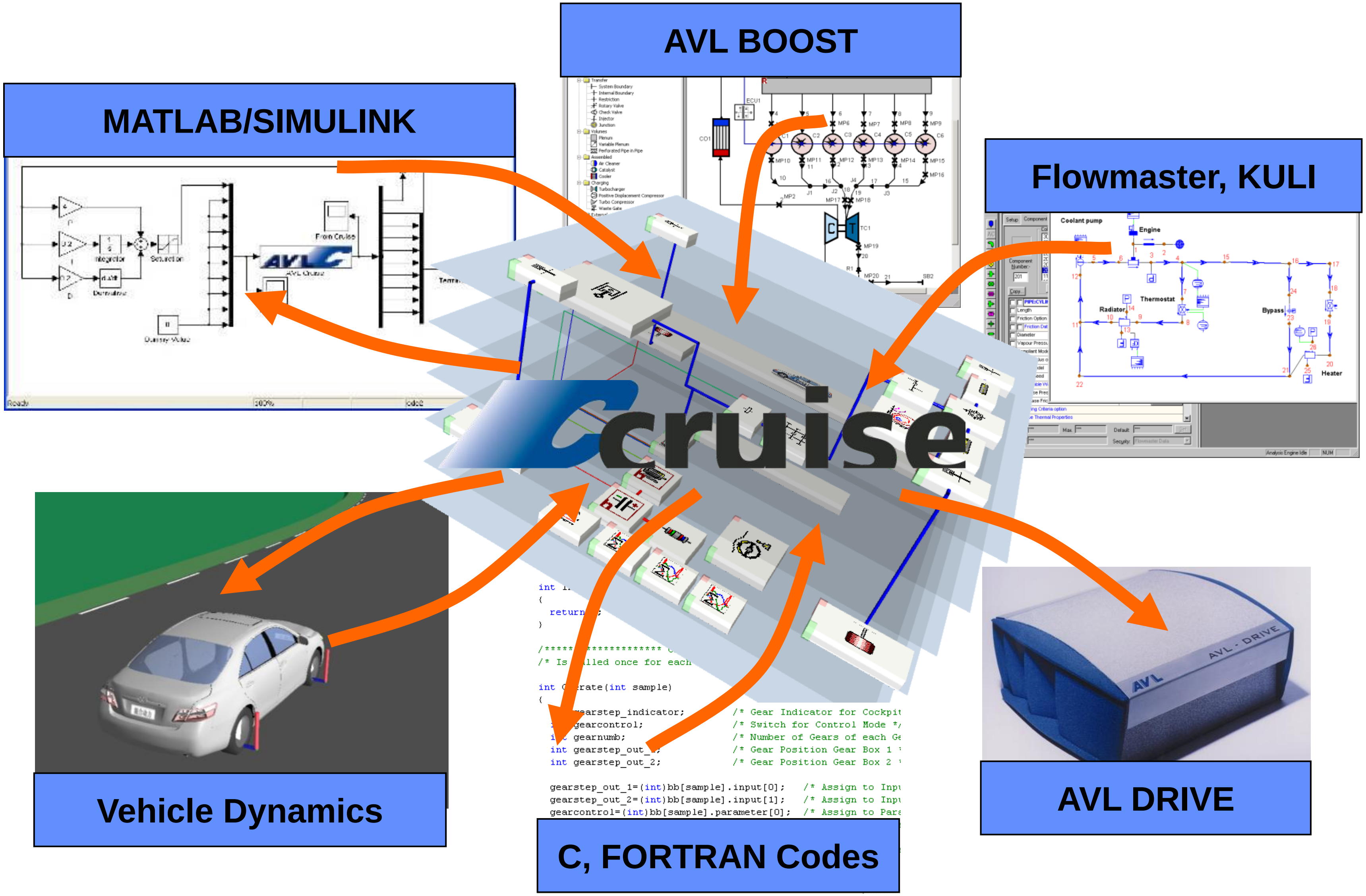
Output: prediction of fuel consumption and emissions

Development value / insight

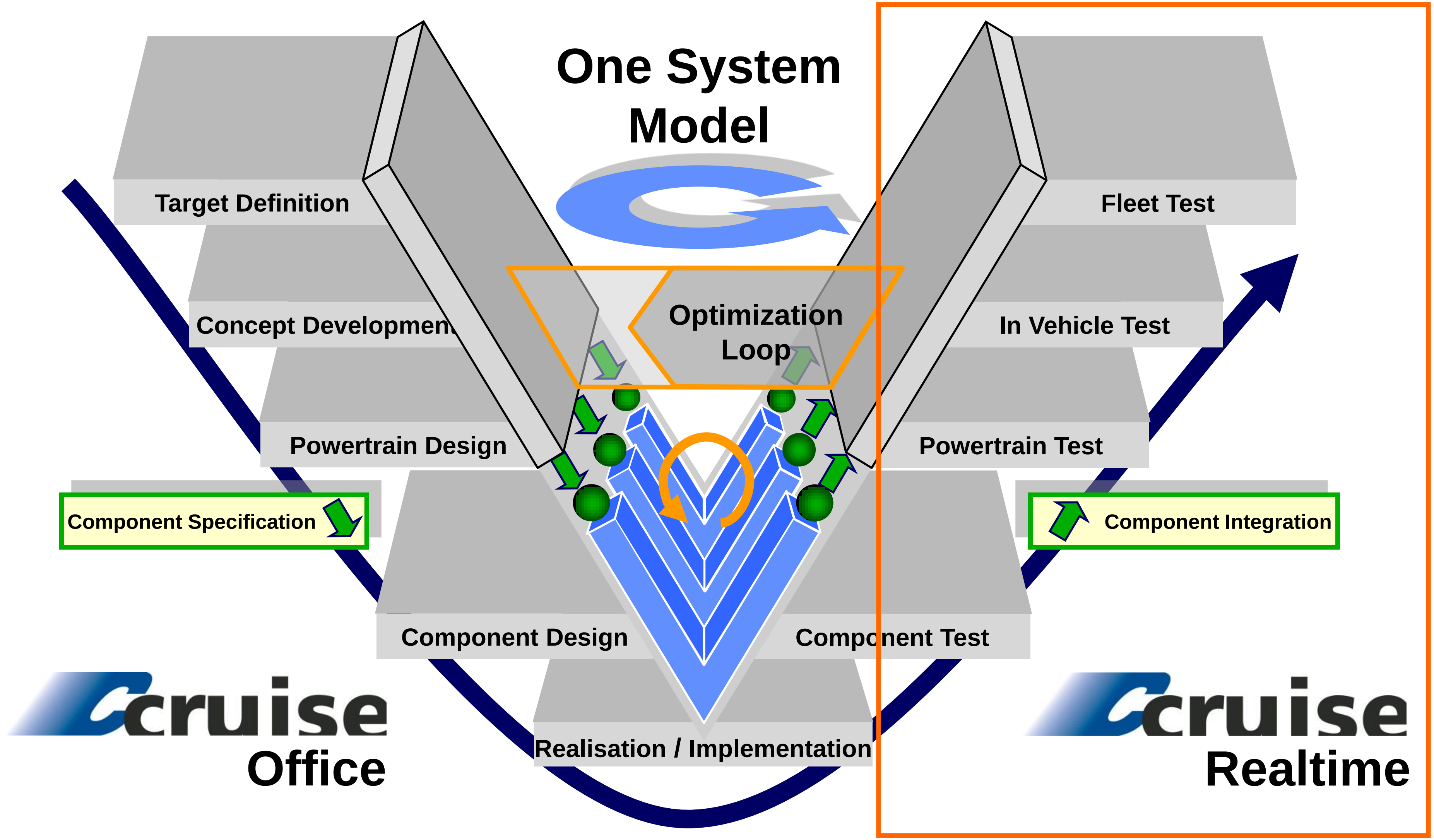
- Influence of
  - topology
  - component performance
  - basic control functions and strategy

  on fuel consumption and emission

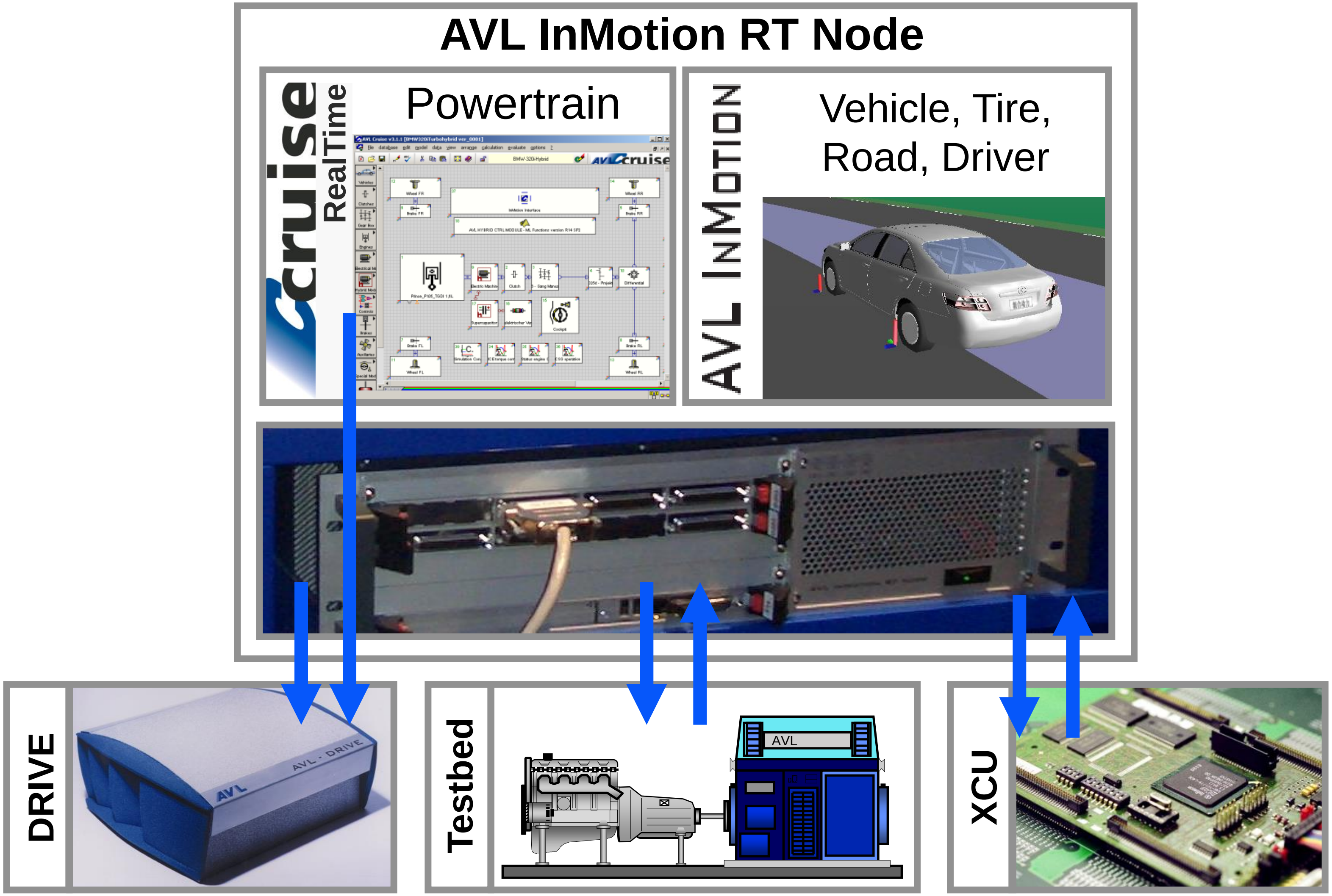
CRUISE
THE SUB-SYSTEM INTEGRATION CONCEPT



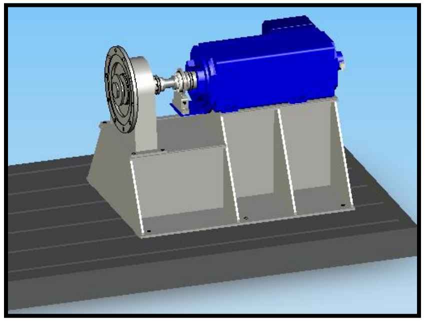
CRUISE SYSTEM SIMULATION
AN INTEGRATED PART OF THE DEVELOPMENT PROCESS

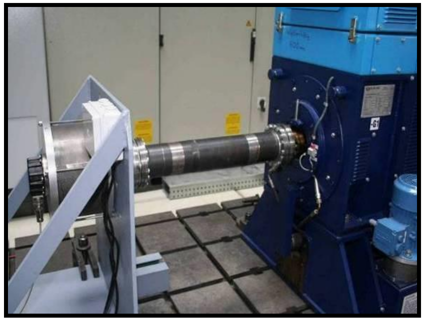


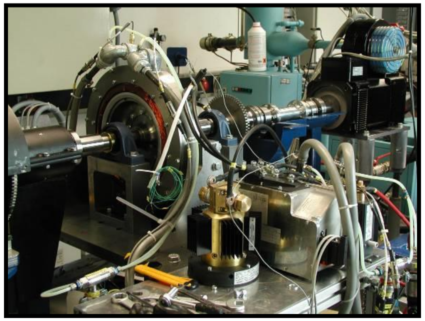
INMOTION-CRUISE
THE VEHICLE TESTING SYSTEM

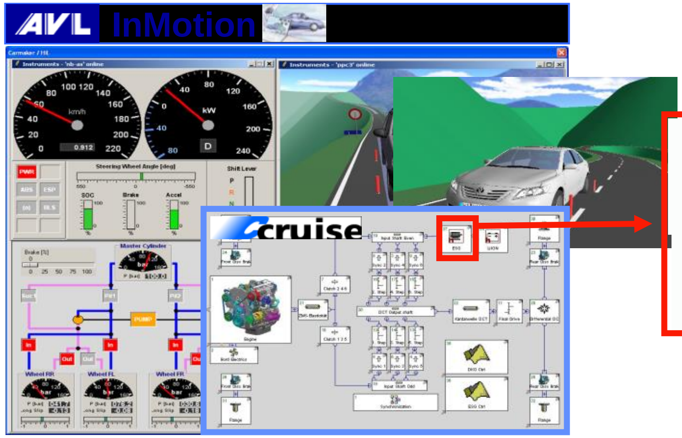


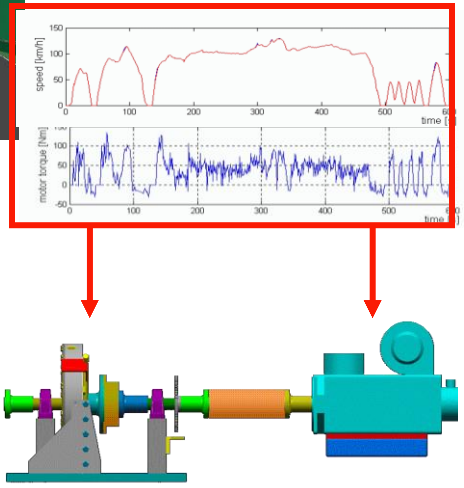
COMPONENT TEST
ELECTRIC MOTOR TESTING

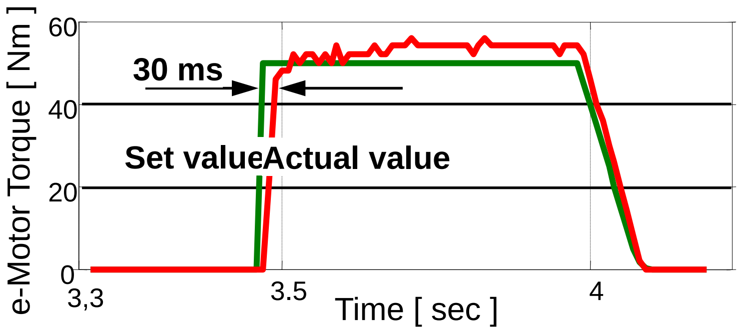




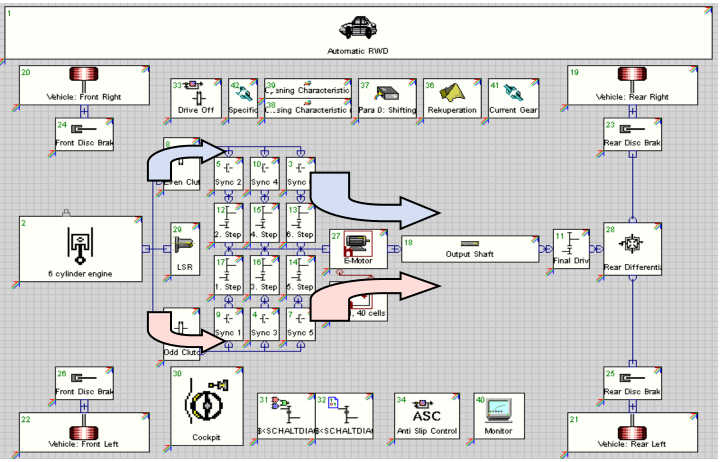


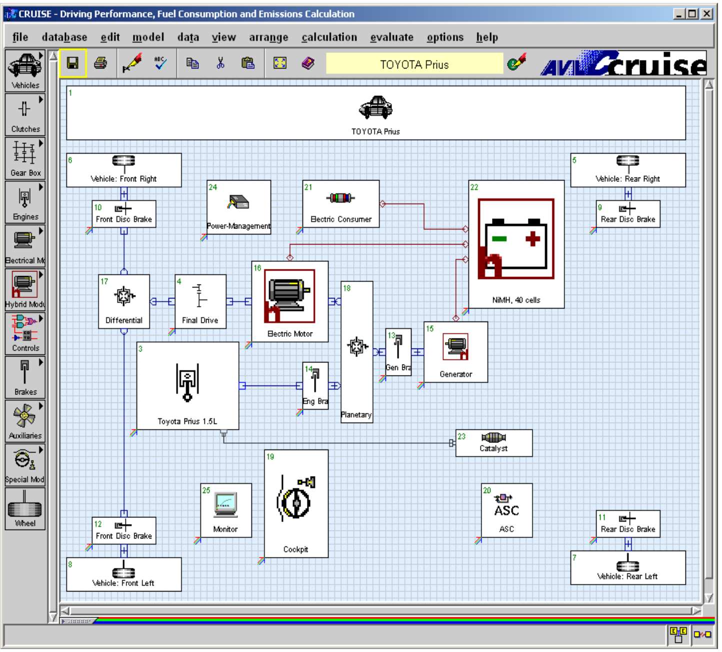






AVL CRUISE
THE VEHICLE SYSTEM ANALYSIS ENVIRONMENT

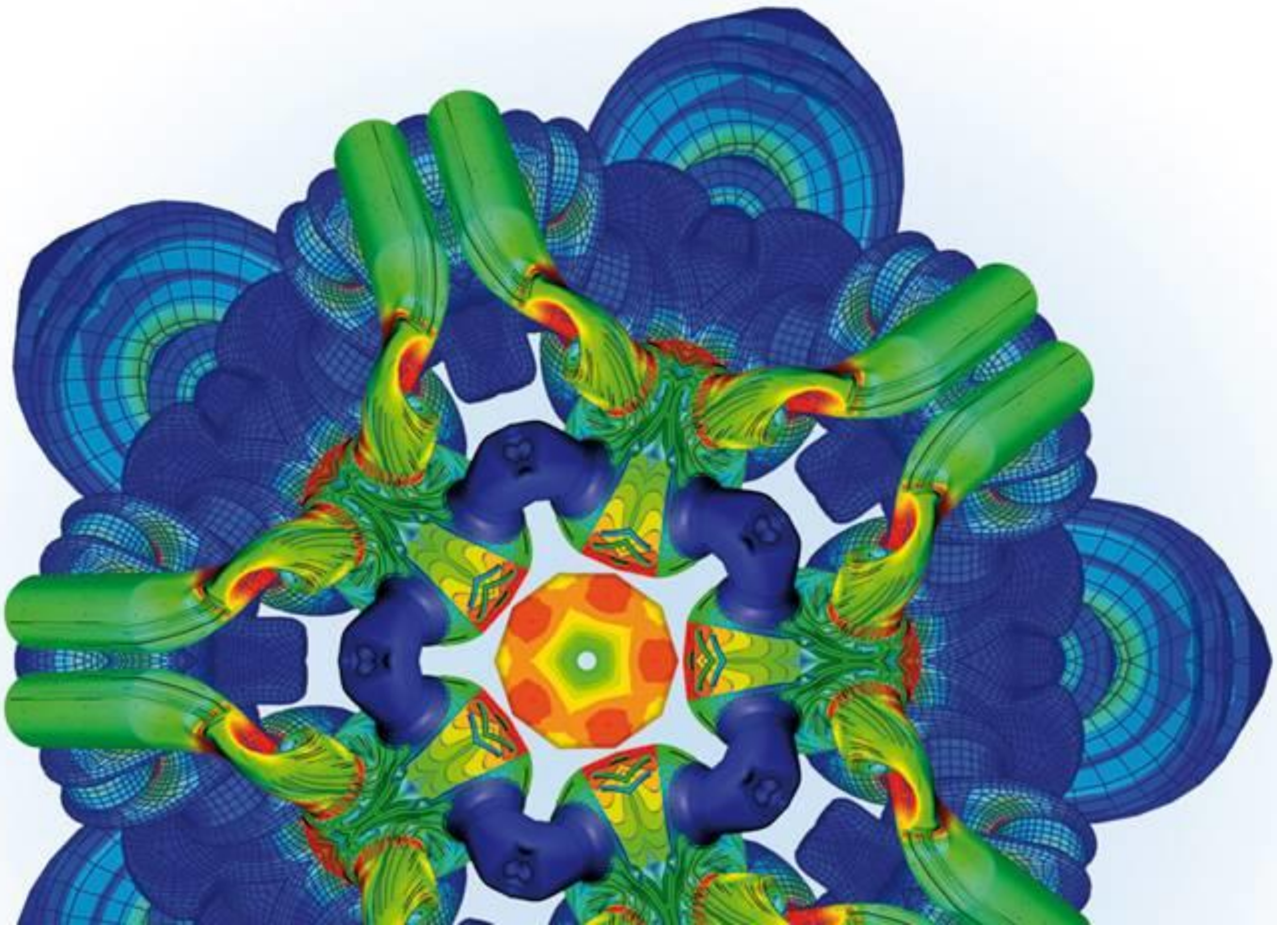




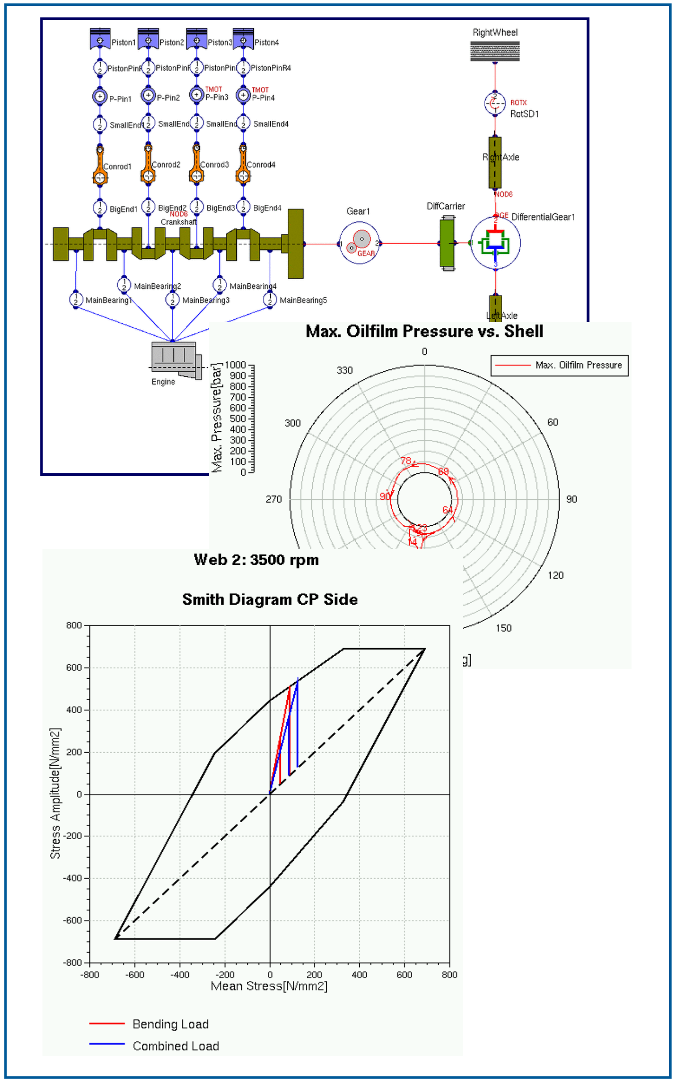
- Flexibility to change driveline configurations within minutes
  - Hybridization of a conventional vehicle with a few mouse clicks
  - Advanced transmission concepts (AMT, DCT, …)
  - Electrical components esp. designed for HEVs
  - More time to focus on HEV engineering tasks
- System model fidelity can easily be adjusted
  - Starting with only a few input parameters in the early phases
  - Model maturity is growing during the development process
- Database functionality for an efficient exchange of data between teams
- All application tasks are fully implemented
- Streamlined workflows included
  - Parameter optimization
  - Component matching
  - Sub-system integration

AVL EXCITE

DURABILITY AND NVH OF POWER UNITS AND DRIVELINES



EXCITE DESIGNER
POWER TRAIN DESIGN ANALYSIS



Calculation model and main capabilities

- Torsional mass – spring system
- Linear calculation model – solution in frequency domain
- Hydrodynamic radial slider bearing

Area of application

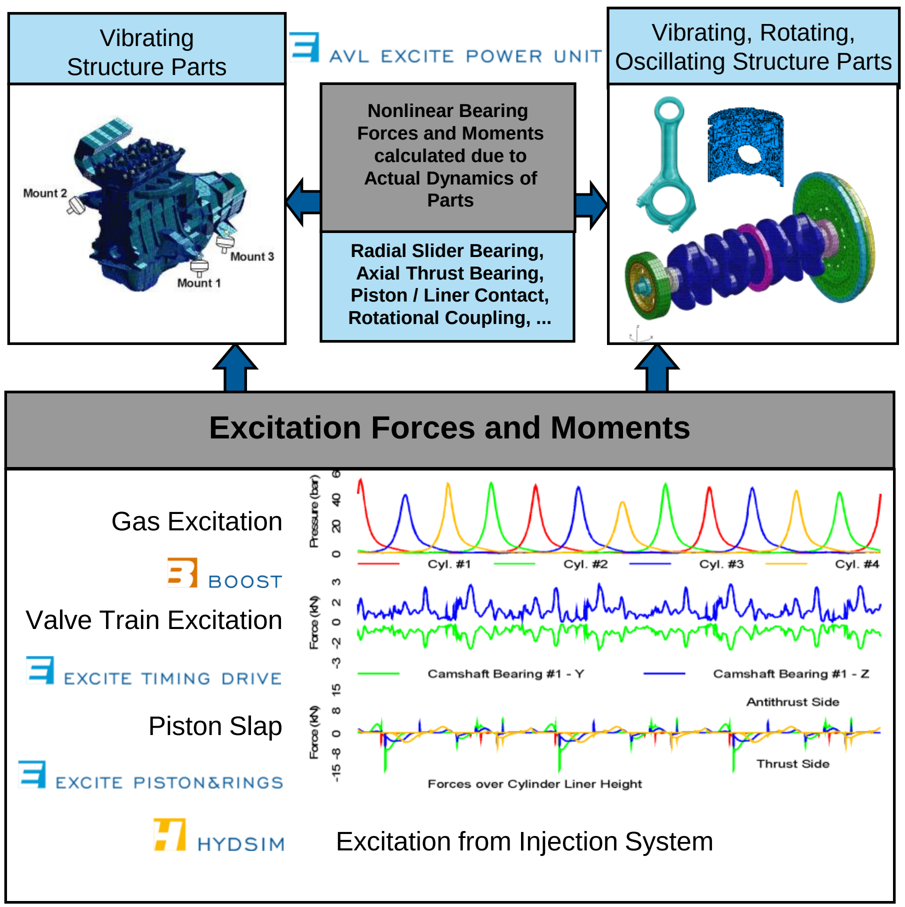
Layout and design of crank train

- Torsional crankshaft vibrations
- Hydrodynamic bearing analysis
- Crankshaft fatigue strength
- Ignition timing, cylinder deactivation, misfiring

Vehicle drive line & test bed analysis

- Torsional vibrations of drive lines
- Torsional stresses in drive train shafts
- Optimization of test bed shaft couplings

EXCITE POWER UNIT
FLEXIBLE MULTI-BODY DYNAMIC ANALYSIS



Solution

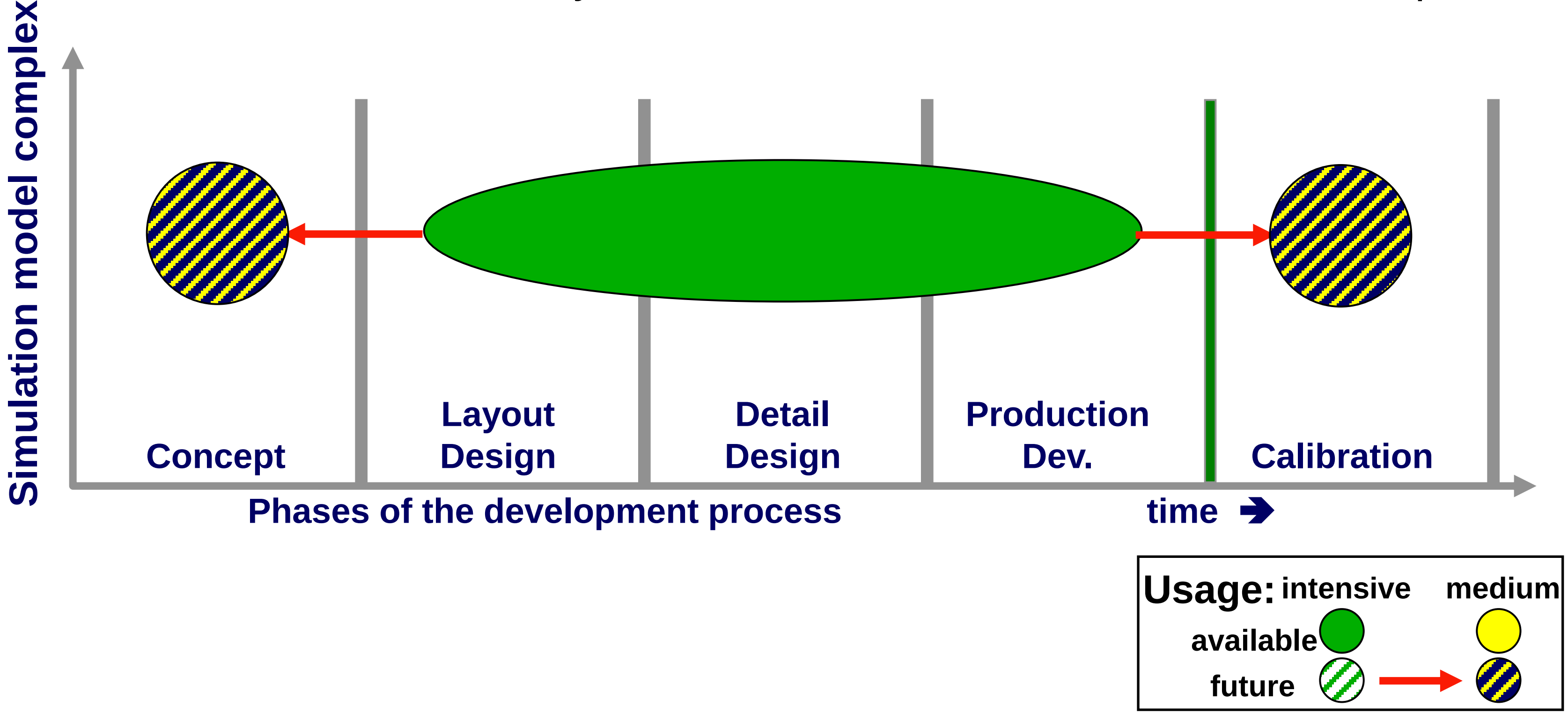
- Elastic/rigid bodies interacting via non-linear joints
- Vibrating, rotating and oscillating elastic structure parts represented by condensed FE models (CMS)
- Various contact models up to highly complex thermo elasto-hydrodynamic joints including mixed lubrication
- Non-linear transient forced vibration analysis in time domain
- Excited by external forces

Consistent simulation models for all development phases

<u>The Benefit:</u>

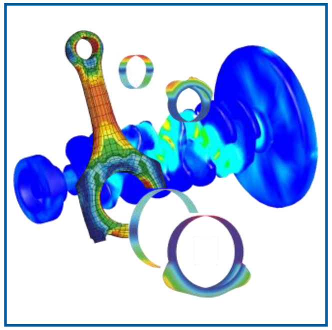
➔ Concept design is supported by fast models based on EXCITE

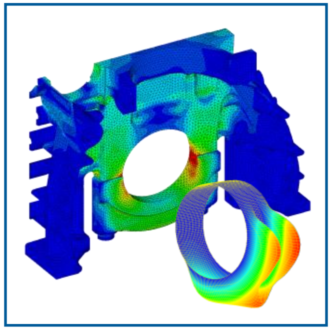
➔ System related simulations incl. vehicle are performed

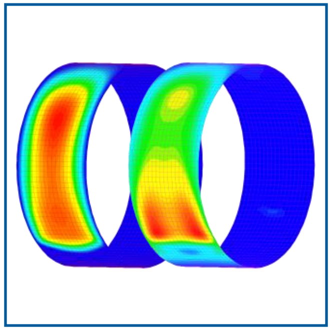


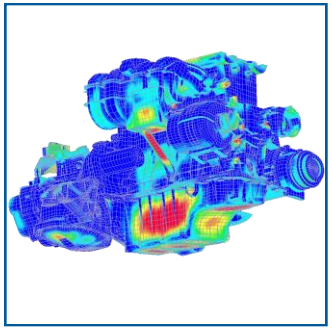
EXCITE POWER UNIT
APPLICATION OVERVIEW

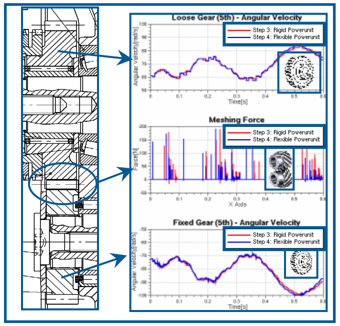
AVL





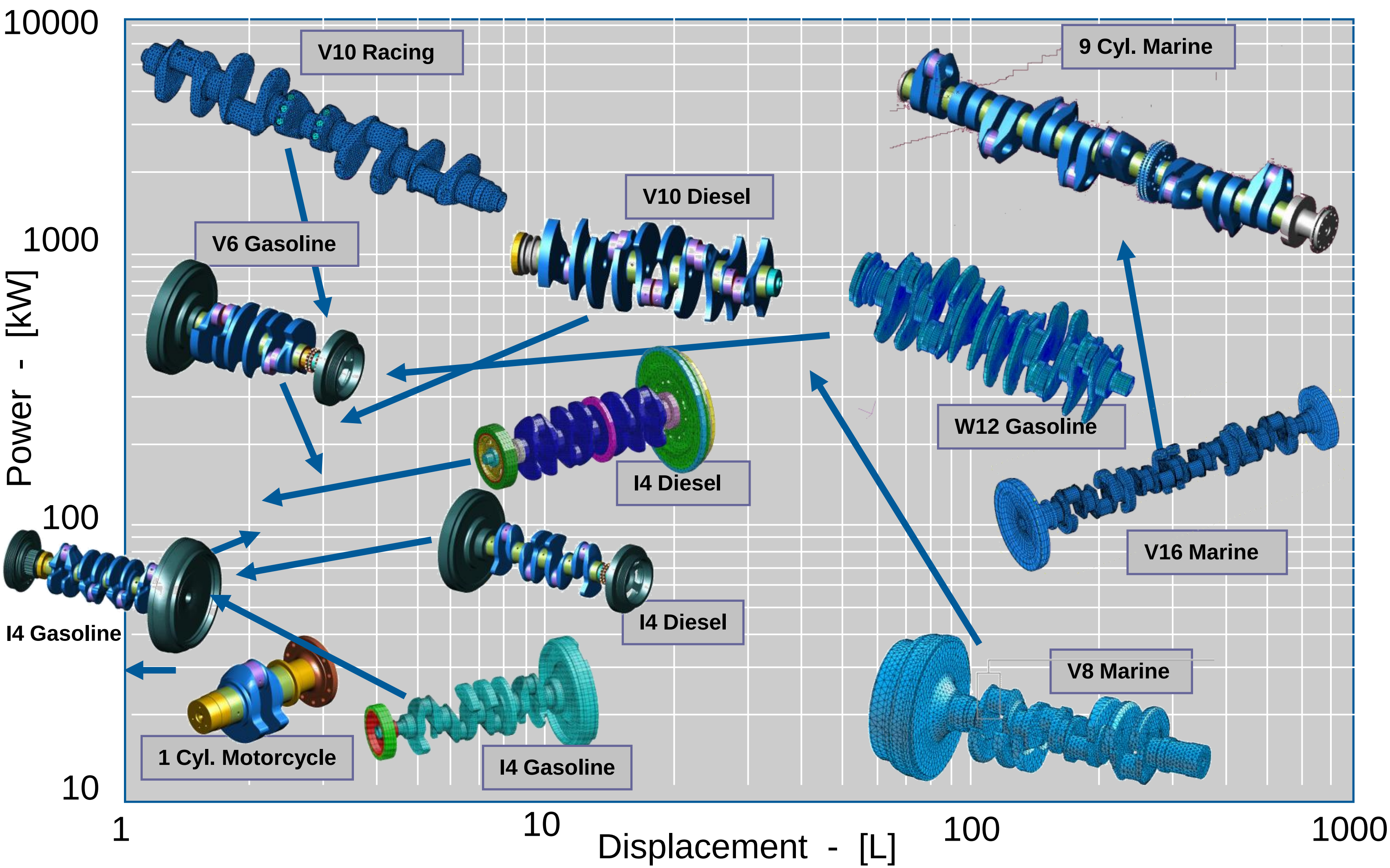




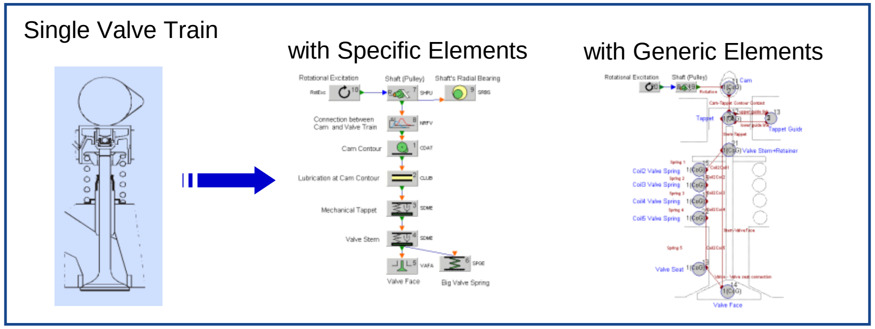


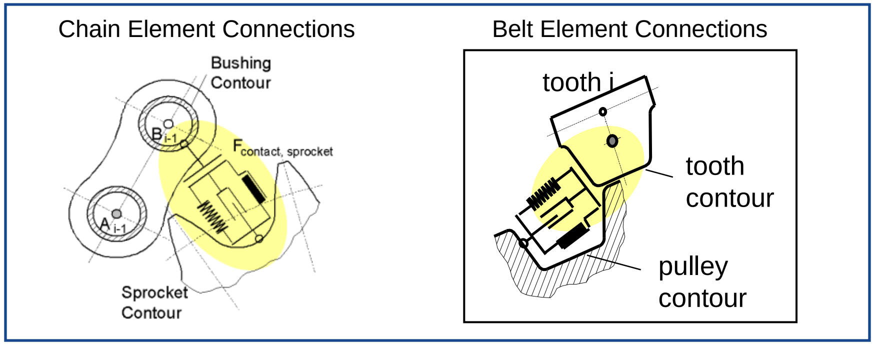
- Transient strength and durability analysis of engine components
  - Crankshaft, con-rod, main bearing wall, piston, engine brackets, …
- NVH of power units
  - Low frequency vibrations (engine mounts)
  - Structure borne noise (surface velocities)
- Dynamics and acoustics of transmissions, hybrid engines, drivelines
  - Analysis of in-stationary conditions
  - High frequency noise phenomena
- Advanced analysis of lubricated contacts (EHD)
  - Radial and axial slider bearing design
  - Bearing failure analysis
  - Piston-liner contact analysis
  - Detailed investigation in friction losses

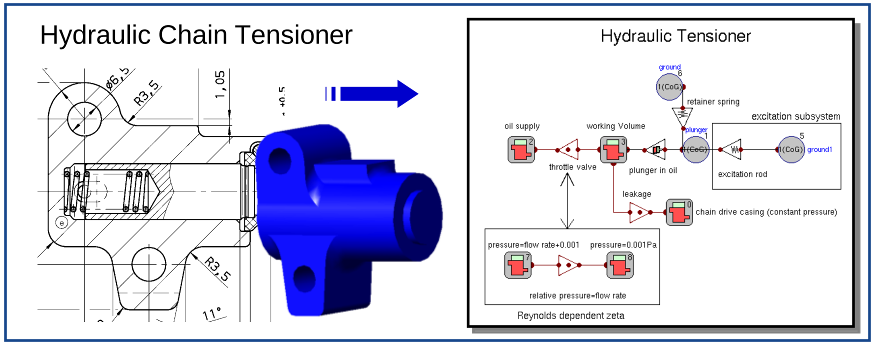
EXCITE CRANKSHAFT STRENGTH ANALYSIS PROVEN FOR ANY ENGINE SIZE



EXCITE TIMING DRIVE
VALVE TRAIN AND TIMING DRIVE ANALYSIS



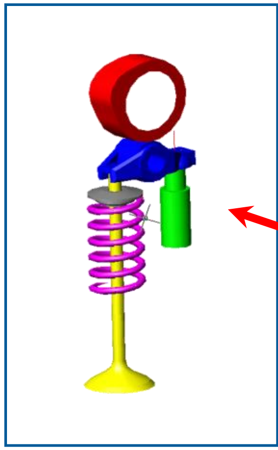




Calculation Model

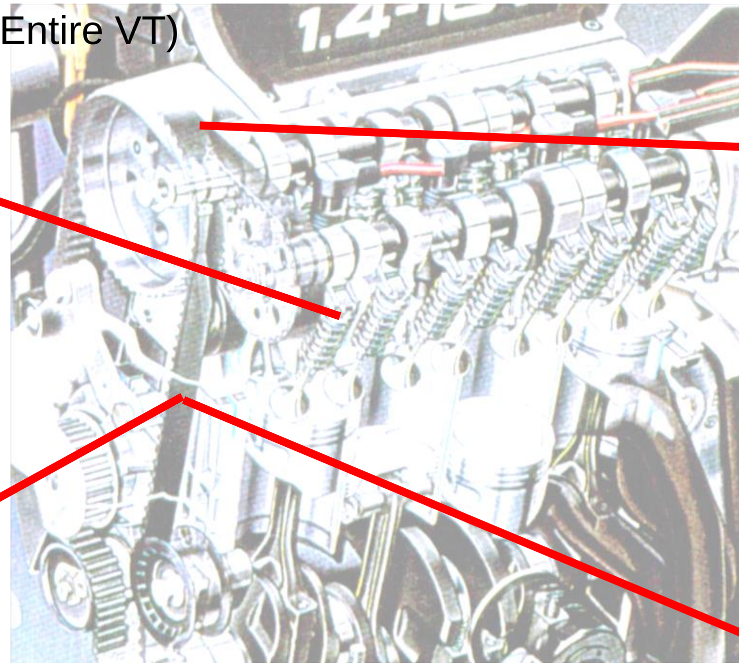
- Lumped mass model solved in time domain (rigid bodies connected by force elements)
- Non-linear behavior considered: contacts, clearance, non-linear properties
- Provides multiple sets of elements / components for different levels of modeling:
  - Specific elements for standard valve and timing drive systems
  - Generic mechanic and hydraulic element pool, arbitrary combinable with specific elements

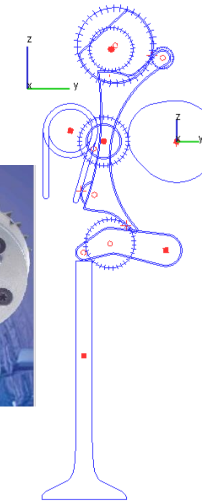
EXCITE TIMING DRIVE
AREA OF APPLICATION (1)

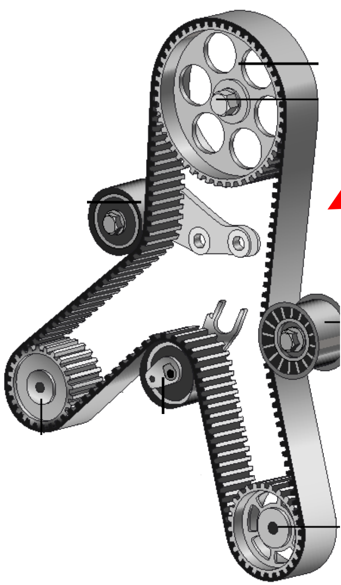


Valve Train Kinematic and Dynamic Analysis (Single and Entire VT)

Variable Valve Trains (VVT)



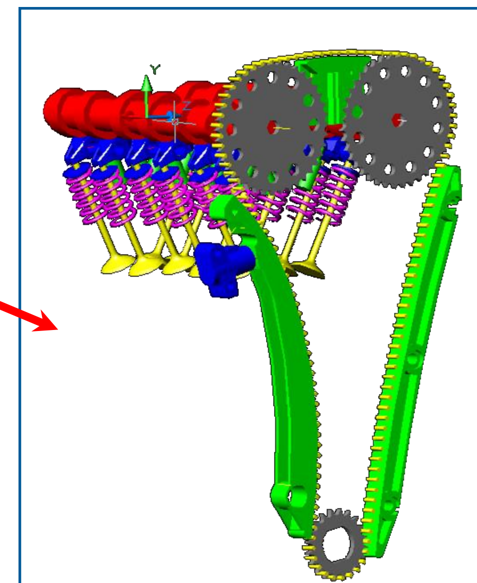




- Investigation of new mechanisms in VVT’s, mechanical tensioner systems, drive-line systems

Timing Belt & Chain Drives

Entire Timing Drives

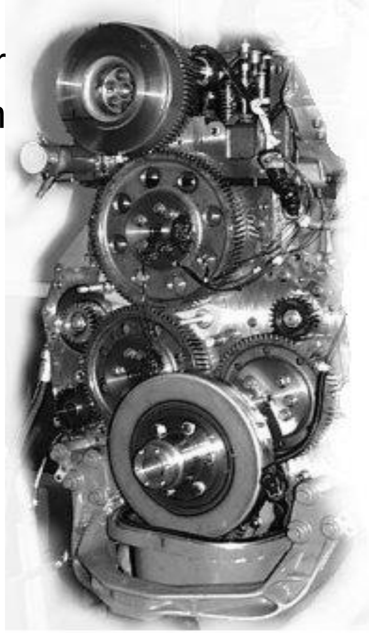


EXCITE TIMING DRIVE AREA OF APPLICATION (2)

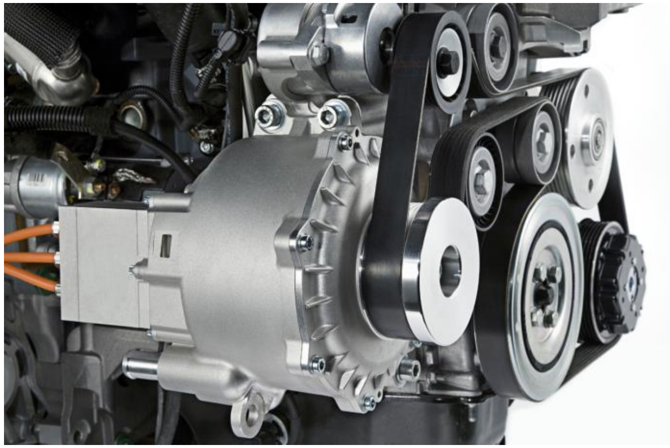
Accessory Belt Drives

- Accessory Drives
- Hybrid Engine Drive Systems
- Gear Drives
- Non-automotive Drives

Timing Gear Train

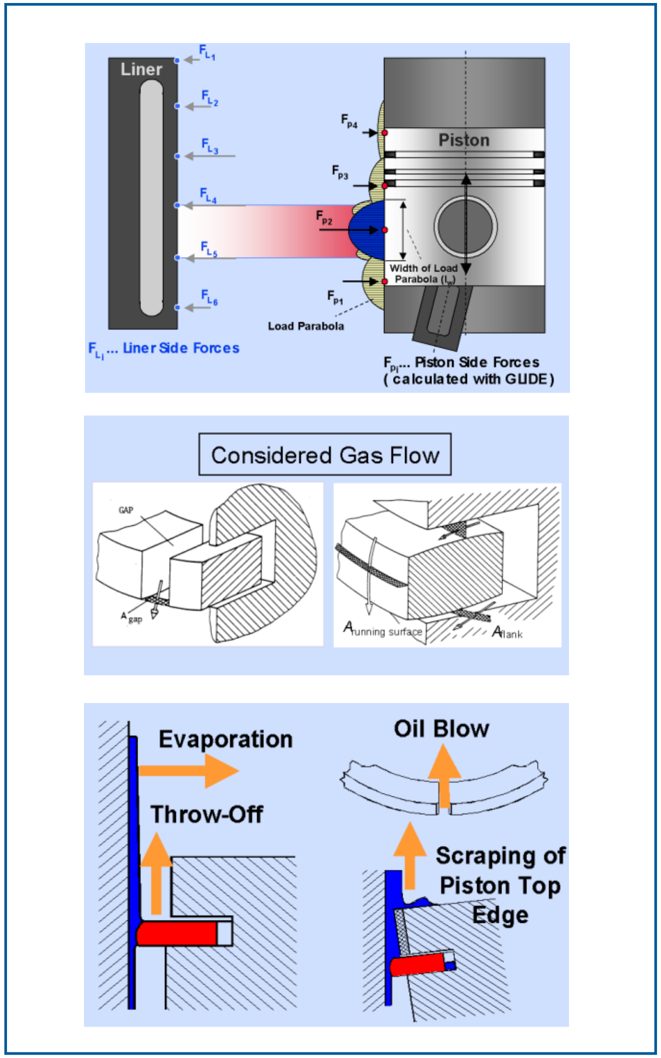


Hybrid Engine Drives



Non-automotive Chain Drives

EXCITE PISTON&RINGS SOLUTION APPROACH



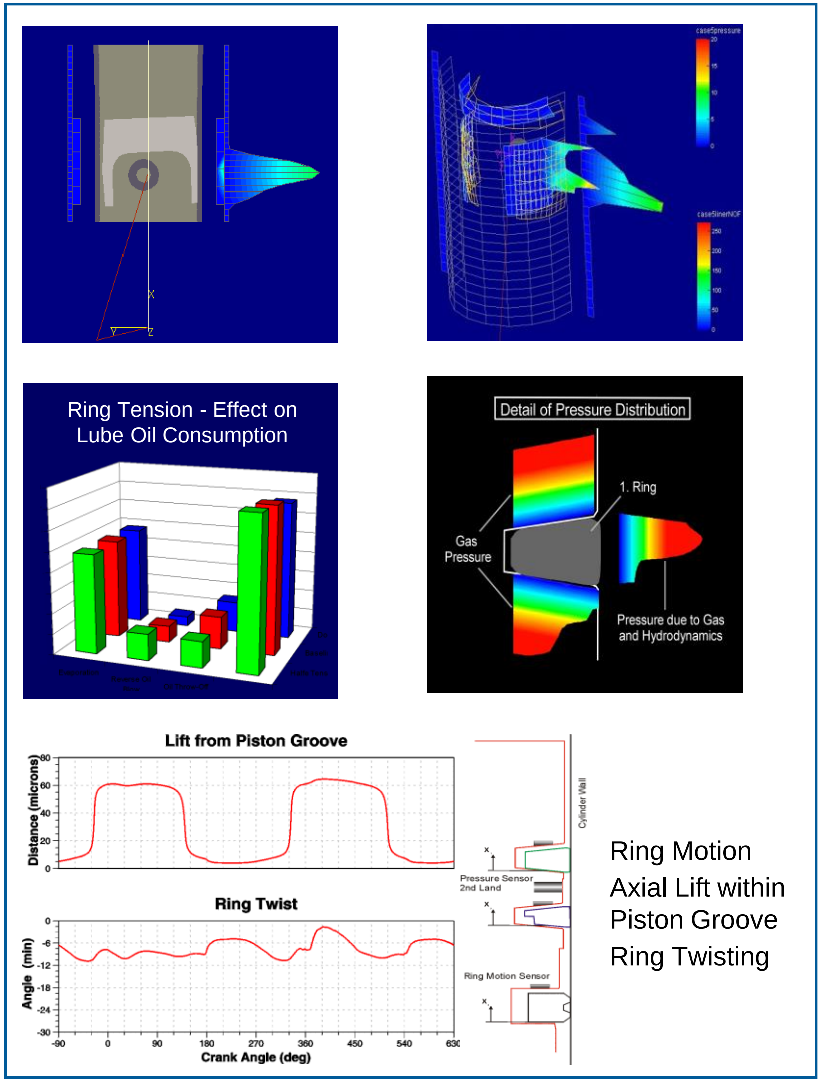
Piston Dynamics

- Multi-body-system (radial elastic piston) with dry piston - liner contact
- Piston and liner contour due to manufacturing, assembly and thermal load

Piston Ring Dynamics

- Single mass ring models including influence of twist angles (2.5D representation)
- 1D - hydrodynamics (Average Reynolds) with asperity model for ring-liner contact
- Influence of surface roughness included
- Mass balance of lubricating oil on liner within ring package
- Gas flow based on inter-ring volumes due to actual clearances and ring positions
- LOC determined by evaporation, throw-off, oil blow and oil scrapping of the piston top

EXCITE PISTON&RINGS
AREA OF APPLICATION

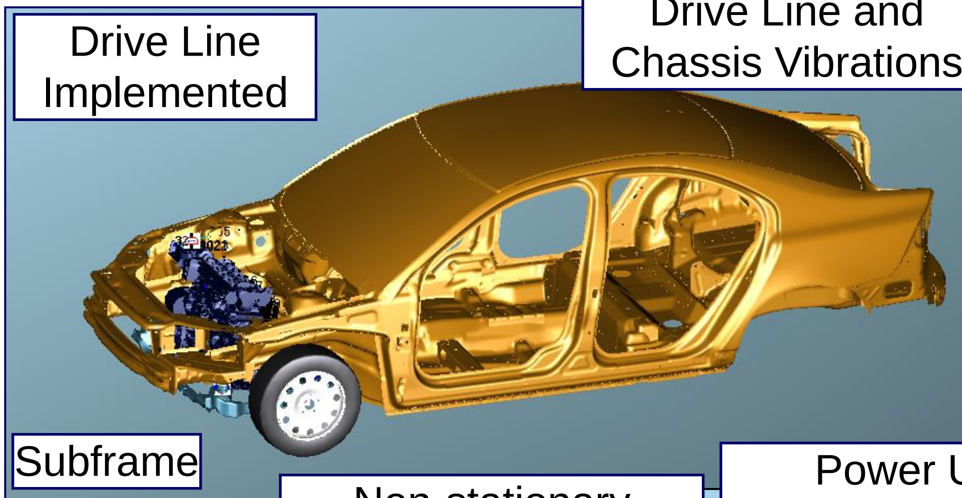


- Piston secondary motion, piston slap induced noise (impact forces for AVL EXCITE)
- Influence of piston design parameters (e.g. piston contour, piston pin offset)
- Evaluation of ring motion (fluttering, twisting), interring pressures and blow-by
- Assessment of ring running surface (e.g. hydrodynamic friction losses, liner and ring wear)
- Prediction of lube oil consumption

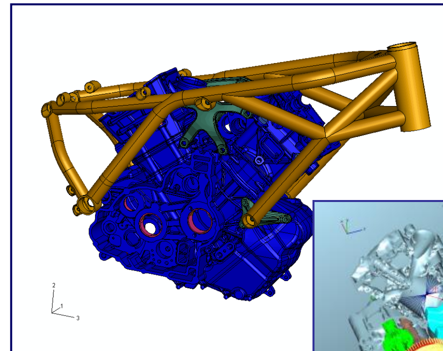
Application Examples

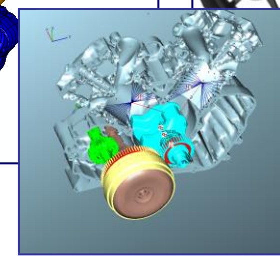
Drive Line Implemented

Drive Line and Chassis Vibrations



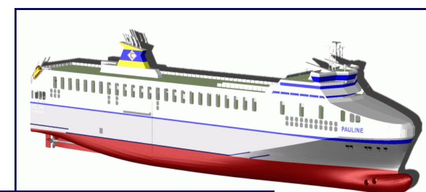
Subframe



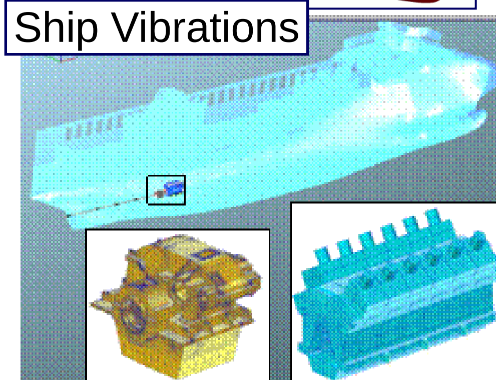


Non-stationary Operating Conditions

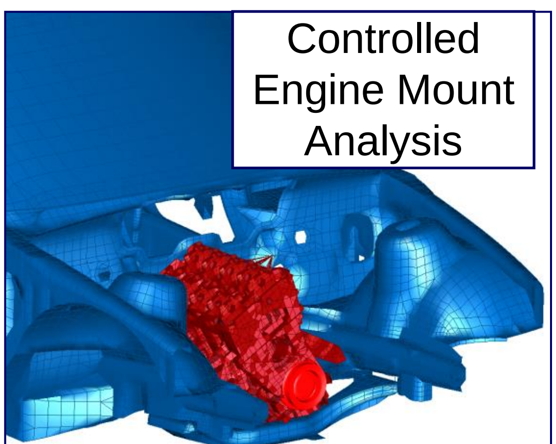
Power Unit Assembled within Chassis at Mounting Positions

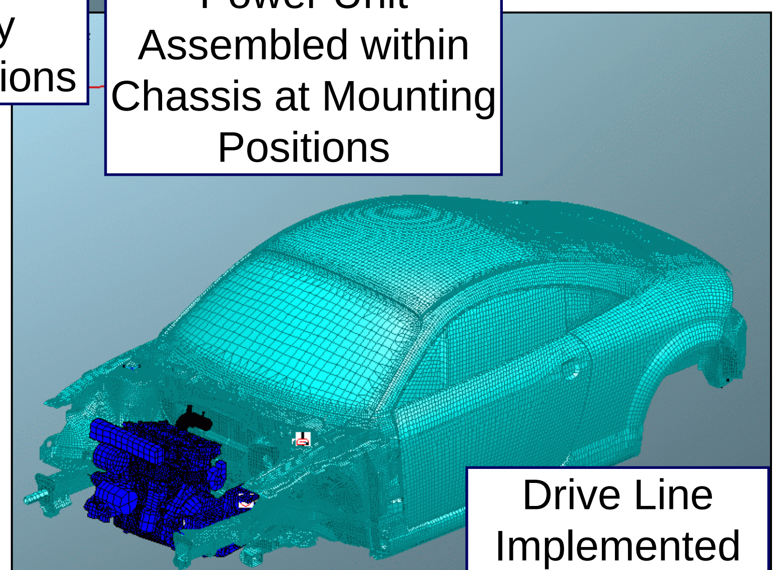


Ship Vibrations



Controlled Engine Mount Analysis

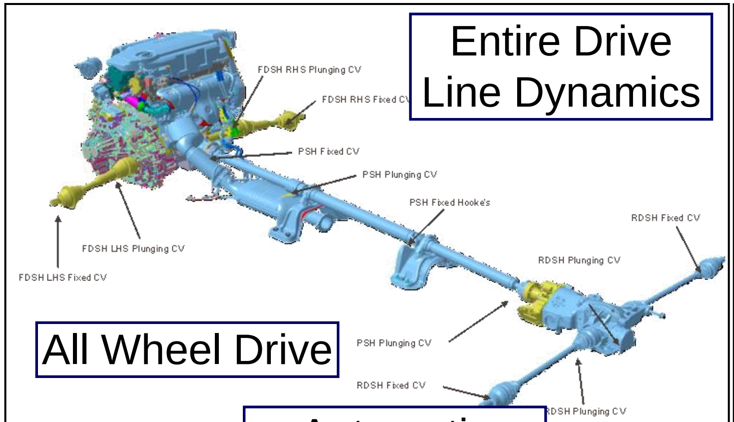




Drive Line Implemented

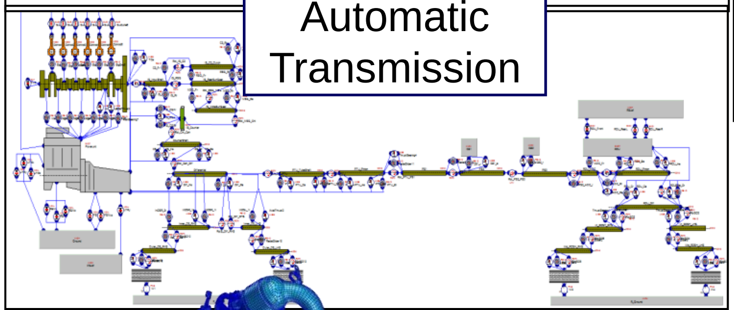
ENGINE, TRANSMISSION, DRIVE LINE, CHASSIS APPLICATION EXAMPLES

Application Examples

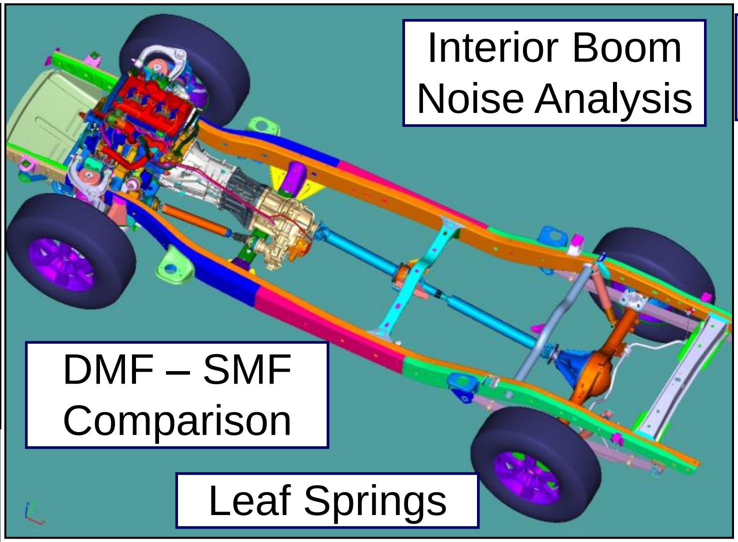


Entire Drive Line Dynamics

All Wheel Drive



Automatic Transmission



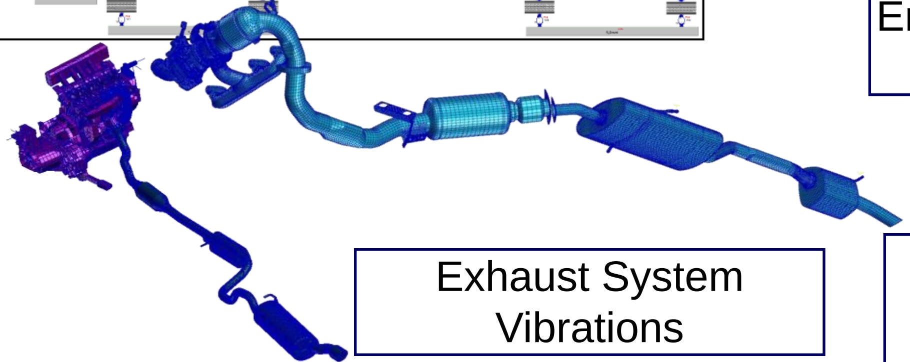
Interior Boom Noise Analysis

DMF – SMF Comparison

Leaf Springs

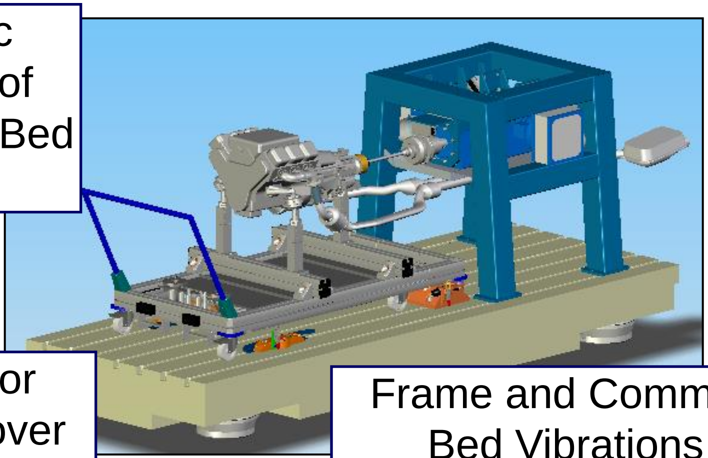
MBS Analysis of Wind Turbine

CFD Based Excitation



Exhaust System Vibrations

Dynamic Analysis of Entire Test Bed System

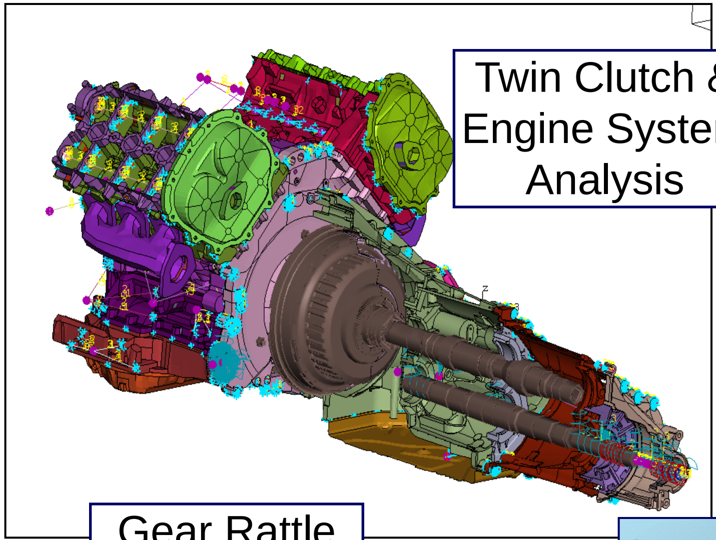


Engine or Prime Mover Excitation

Frame and Common Bed Vibrations

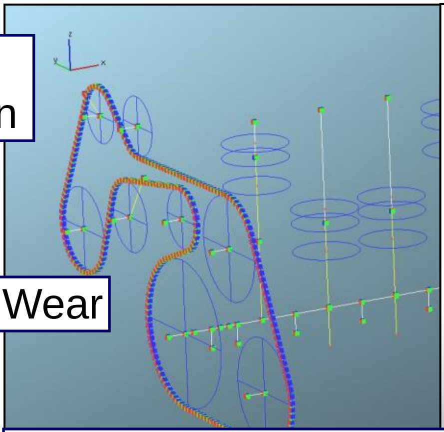
ENGINE, TRANSMISSION, DRIVE LINE, CHASSIS APPLICATION EXAMPLES

Application Examples



Twin Clutch & Engine System Analysis

Start-Stop Investigation

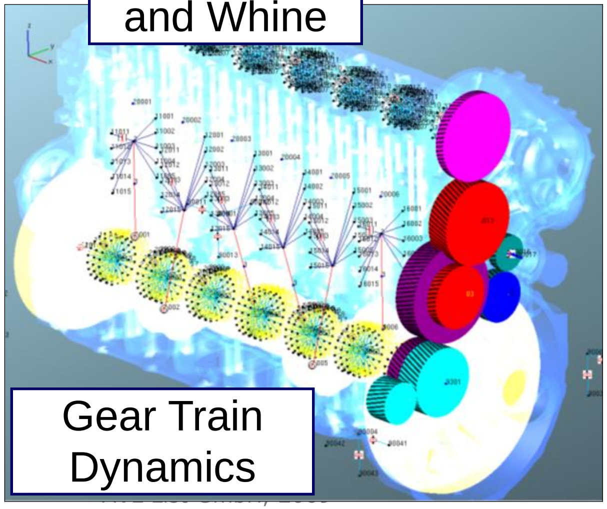


Bearing Wear

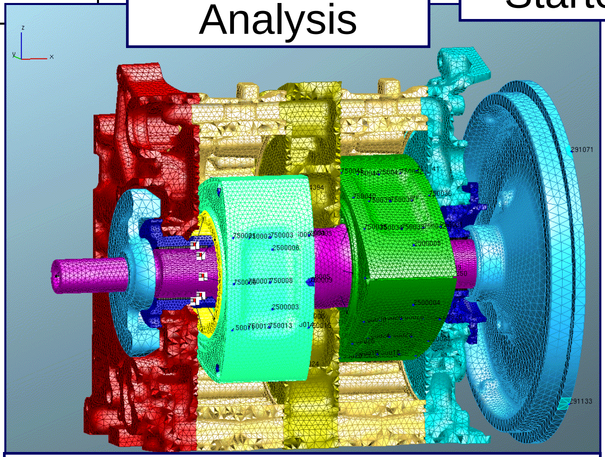
Non-Stationary Belt-Driven Starter Generator Analysis

Rotary Engine Dynamics and Bearing Analysis

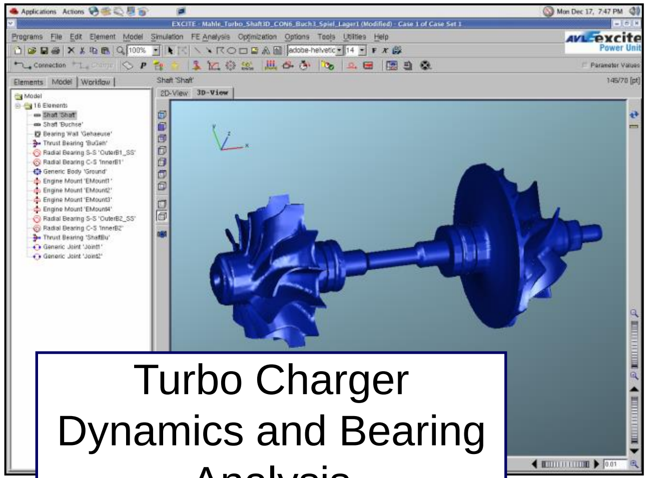
Gear Rattle and Whine



Gear Train Dynamics



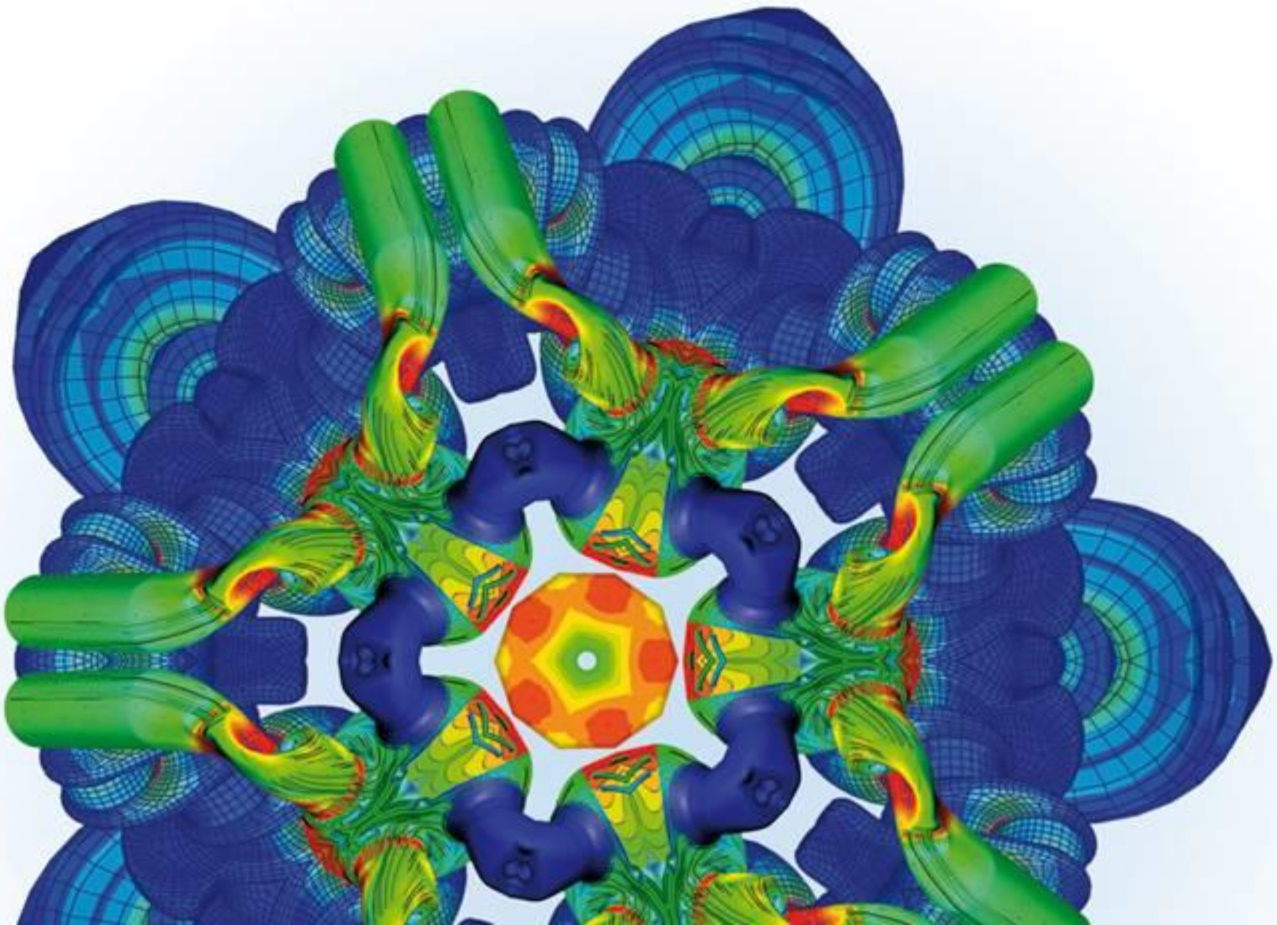
Rotor Tumbling and Axial Contact



Turbo Charger Dynamics and Bearing Analysis

AVL BOOST & HYDSIM

1D CFD Simulation



BOOST
OVERVIEW ON THE 3 MODULES

BOOST
Triple Solver Solution

1D Flow and Combustion Simulation	Acoustics Linear and Non-Linear	Exhaust Gas Aftertreatment

Defining Engine Layout, Concept and Control Management with respect to:

1D Flow and Combustion Simulation

- Intake and exhaust system layout
- Gasexchange optimisation
- Combustion simulation
- Emission simulation
- Turbo charger matching
- Transient cycle simulation
- High pressure analysis

Acoustics

- Transmission loss
- Insertion loss
- Noise reduction
- Sound pressure levels
- Free field and in-duct acoustics
- Octave Band analysis

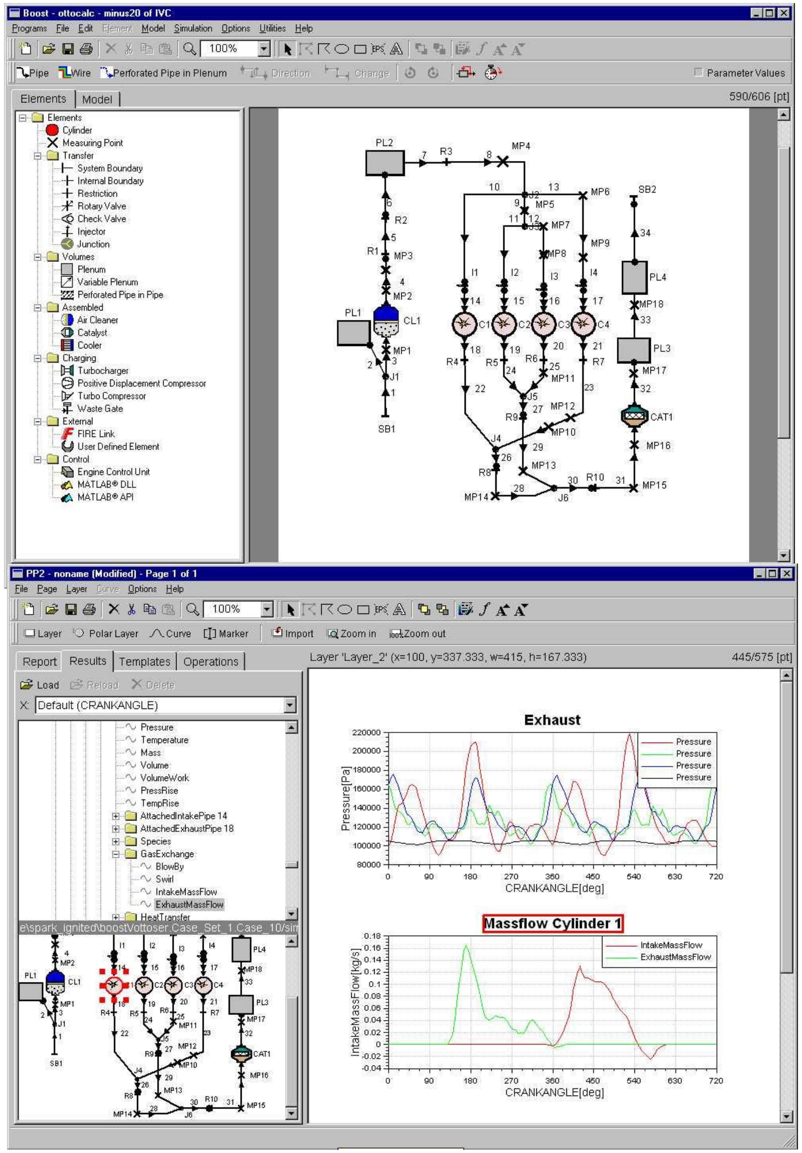
Catalytic Convertor

- Light Off
- Heat-Up during cold start
- NO <-> NO2 conversion
- Test cycle simulation

DPF:

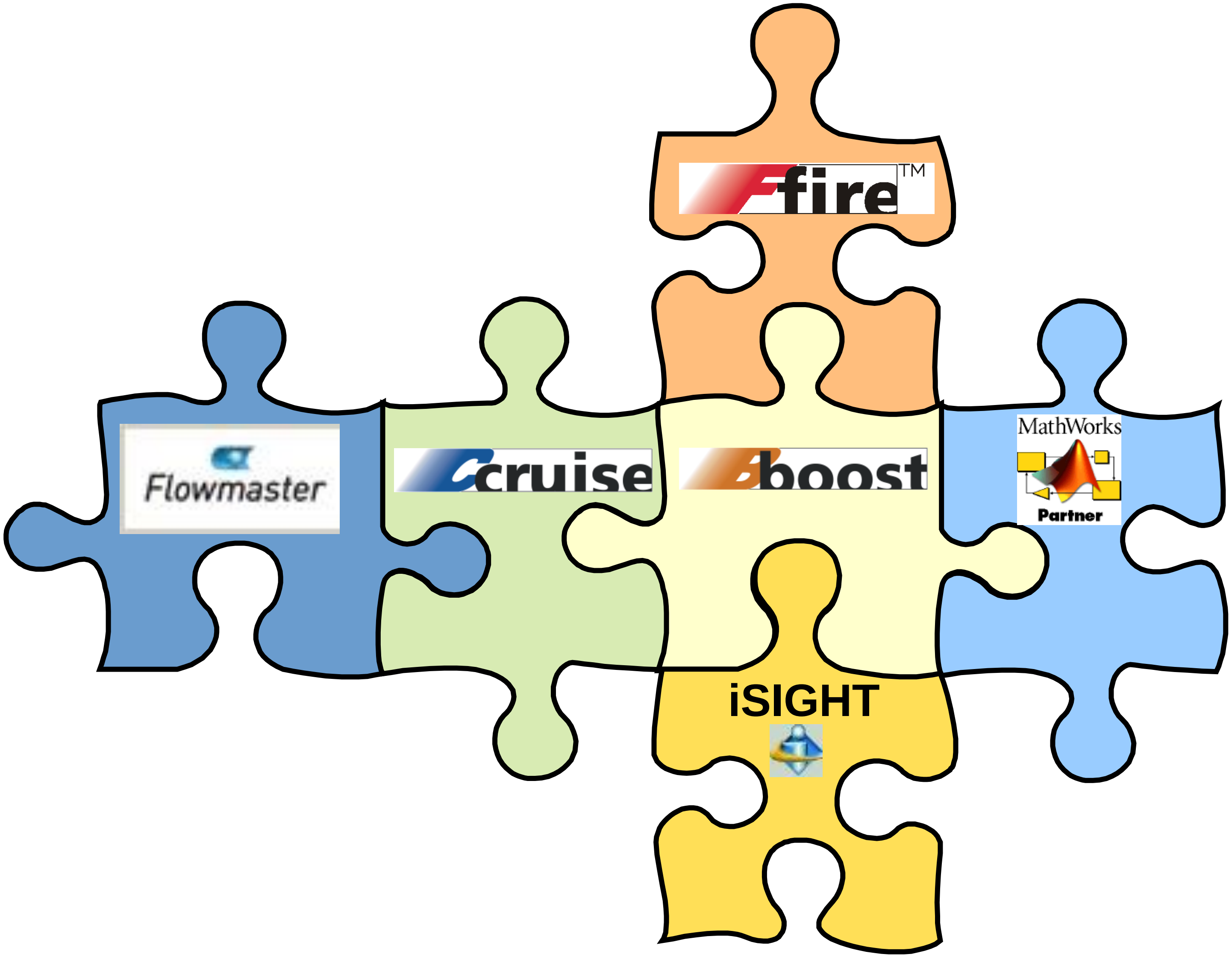
- Soot loading
- Regeneration

BOOST MODULS
1 / ENGINE PERFORMANCE ANALYSIS

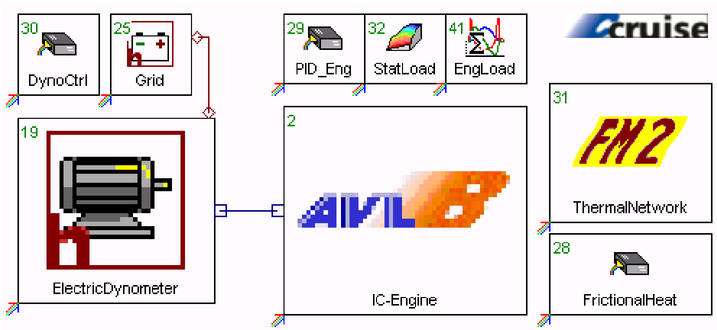


- Reliable Tool for Engine Cycle and Gas Exchange Simulation
- Considering 1D Gas Dynamics in Pipes
- Quasi-dimensional Combustion Simulation
- Steady State and Transient Calculations
- Ideal Concept for Engine Application
- Required Torque and Power
- Engine Control Management Design with BOOST ECU or MATLABTM
- For considering 3D Effects a Link to AVL FIRE is Provided
- Model Creation, Simulation and Post-Processing GUI Supported

BOOST LINKS TO OTHER AVL TOOLS AND 3rd PARTY SW



BOOST COUPLED ANALYSIS APPLICATION VTMS (VEHICLE THERMAL MANAGEMENT)



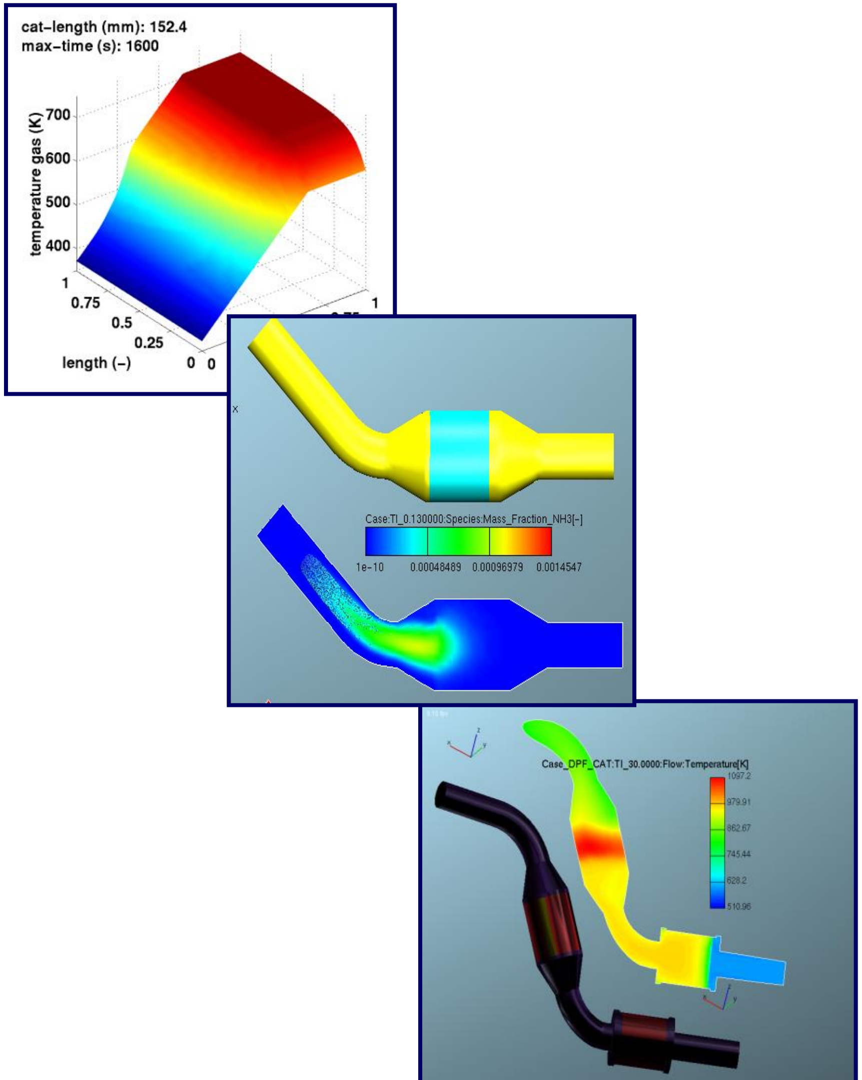
Thermal Management

BOOST-CRUISE-FLOWMASTER

Co-Simulation

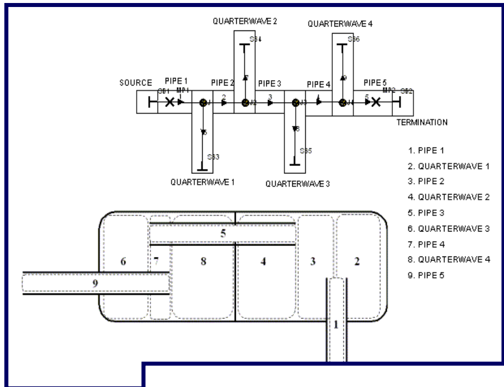
- Optimize standard and conceptual vehicles and vehicle components
- 1D gas dynamics simulation of internal combustion engine cycles
- 1D internal fluid flow simulation

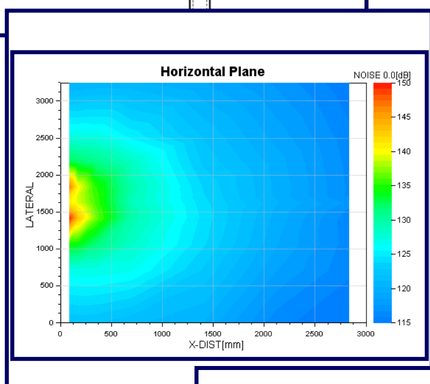
BOOST MODULS
2 / AFTERTREATMENT

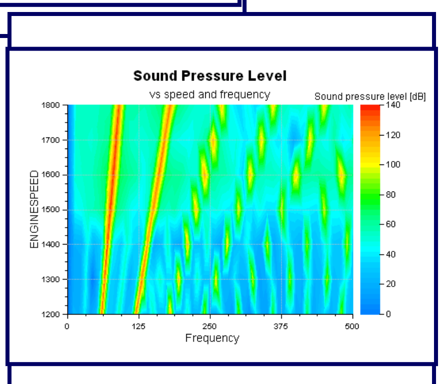


- Light-Off-Simulations
- Cycle Emission Simulation (NEDC, FTP,...)
- DPF Loading and Regeneration
- User-Kinetic Model for 1D
- BOOST - FIRE Workflow
- Catalytic Converter
  - Diesel Oxidation Catalyst (DOC)
  - Three-Way-Catalyst (TWC)
  - Selective Catalytic Reduction (SCR)
  - Lean NOx Trap (LNT), simplified BaCO3-Storage Model
- Diesel Particulate Filter
  - Bar-Traps, Fuel-Additive DPFs, CRTs

BOOST MODULS
3 / ACOUSTICS



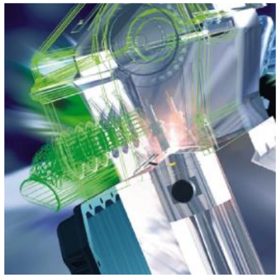


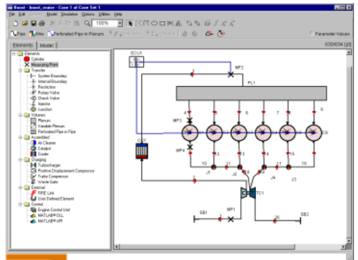


- Generating the Typical „Brand Sound“
- Orifice Noise Reduction
- Exhaust Manifold Optimization by Means of:
  - BOOST Non-Linear Acoustics
    - Calculating Entire Engine
    - No Additional Calculation
  - BOOST-SID : Linear Acoustics
    - Extremely fast
    - No Engine Input Data Required

ENGINE DEVELOPMENT PROCESS : GCA METHODOLOGY

- BOOST integrated in Test Bed Software as Gas Exchange and Combustion Analysis Module (GCA)
- Direct Access to Key Values of Combustion and Gas-Exchange During Measurement Process

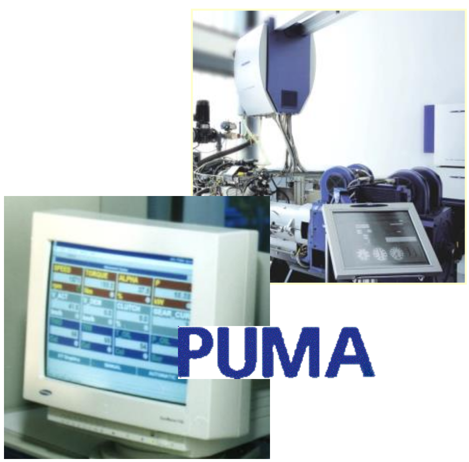




AVL BOOST

Simulation

Measurement



GCA

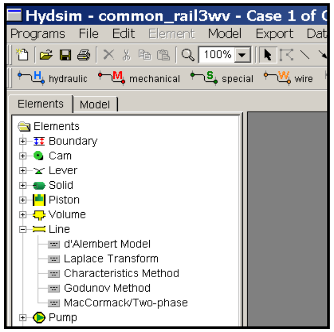
Gas Exchange
and Combustion
Analysis

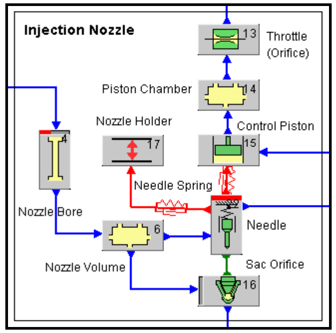
Application

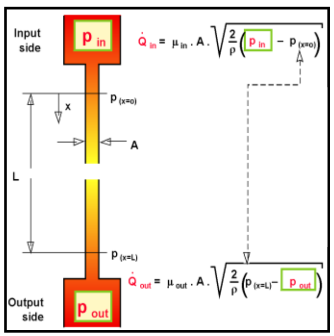
Combustion Data
Residual Gas Content
Heat Fluxes
Scavenging Data
Mass Fluxes

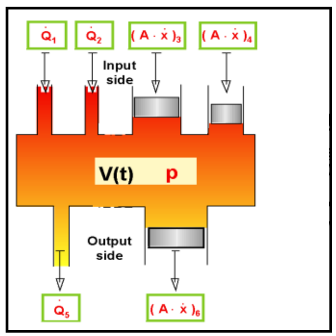
AVL HYDSIM

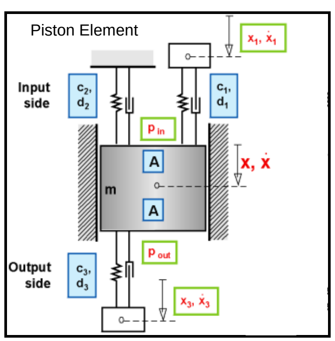
Dynamic analysis of hydraulic systems

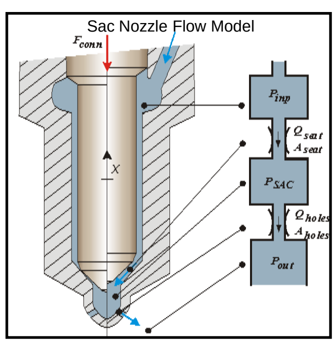










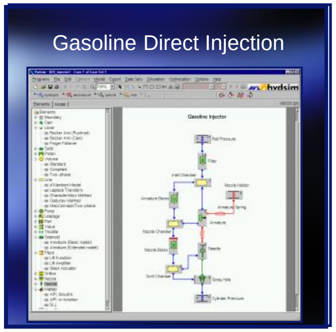


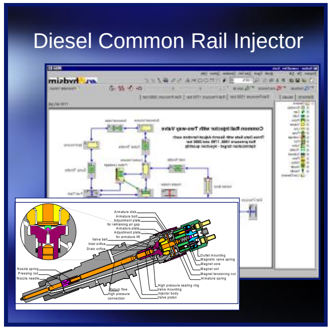
Main Features

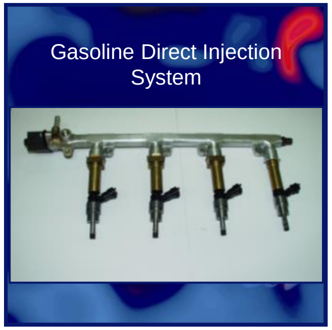
- flexible modeling technique of hydraulic and mechanical elements
- specifically designed for fuel injection systems
  - pressure waves
  - hydraulic SOI / EOI
  - needle lift
  - injection rate diagrams
- applicable to analyze general hydraulic systems

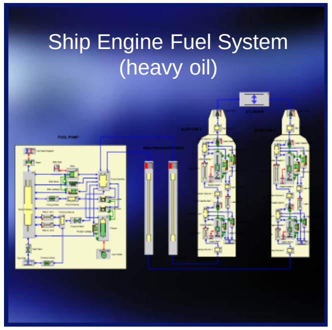
AVL HYDSIM

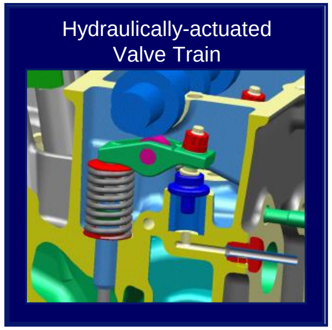
Dynamic analysis of hydraulic systems

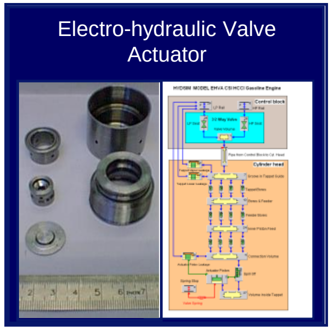






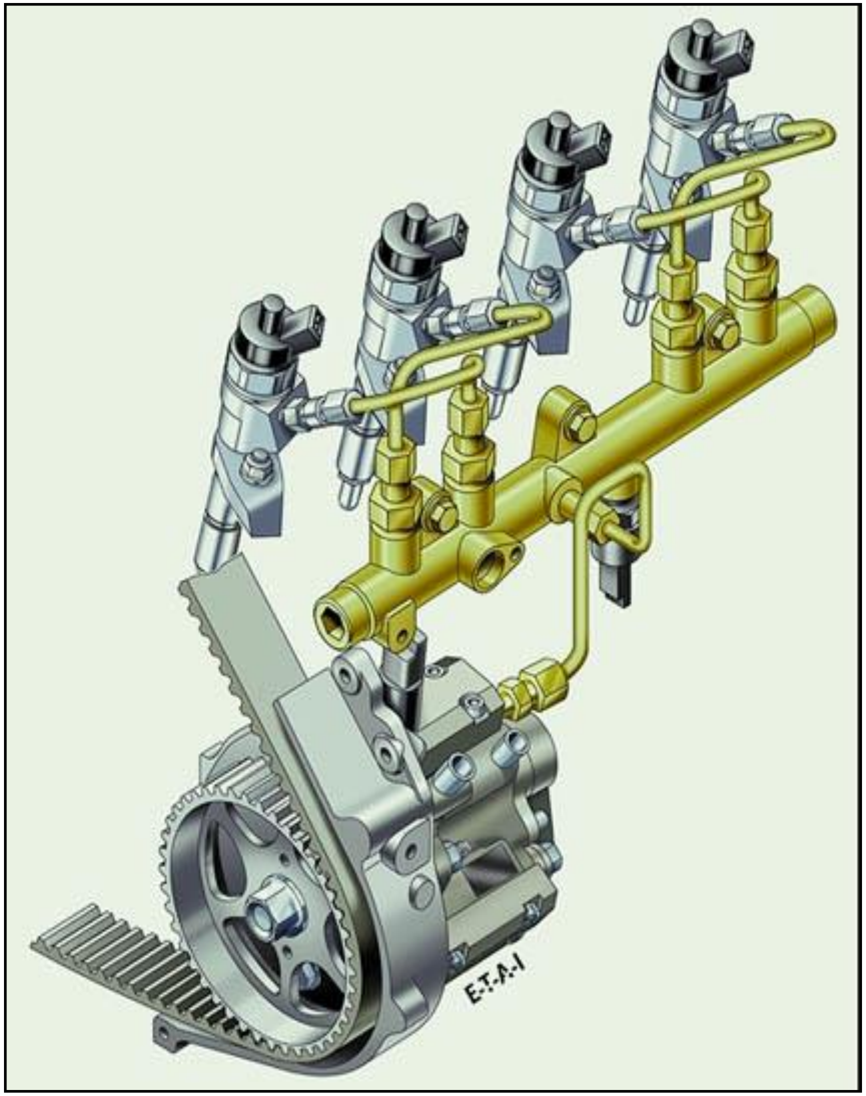






Areas of Application

- fuel injection systems for Diesel engines
- gasoline injection systems
- alternative fuel injection systems
- low pressure fuel injection systems
- electro-hydraulic valve trains
- hydraulic control units and networks



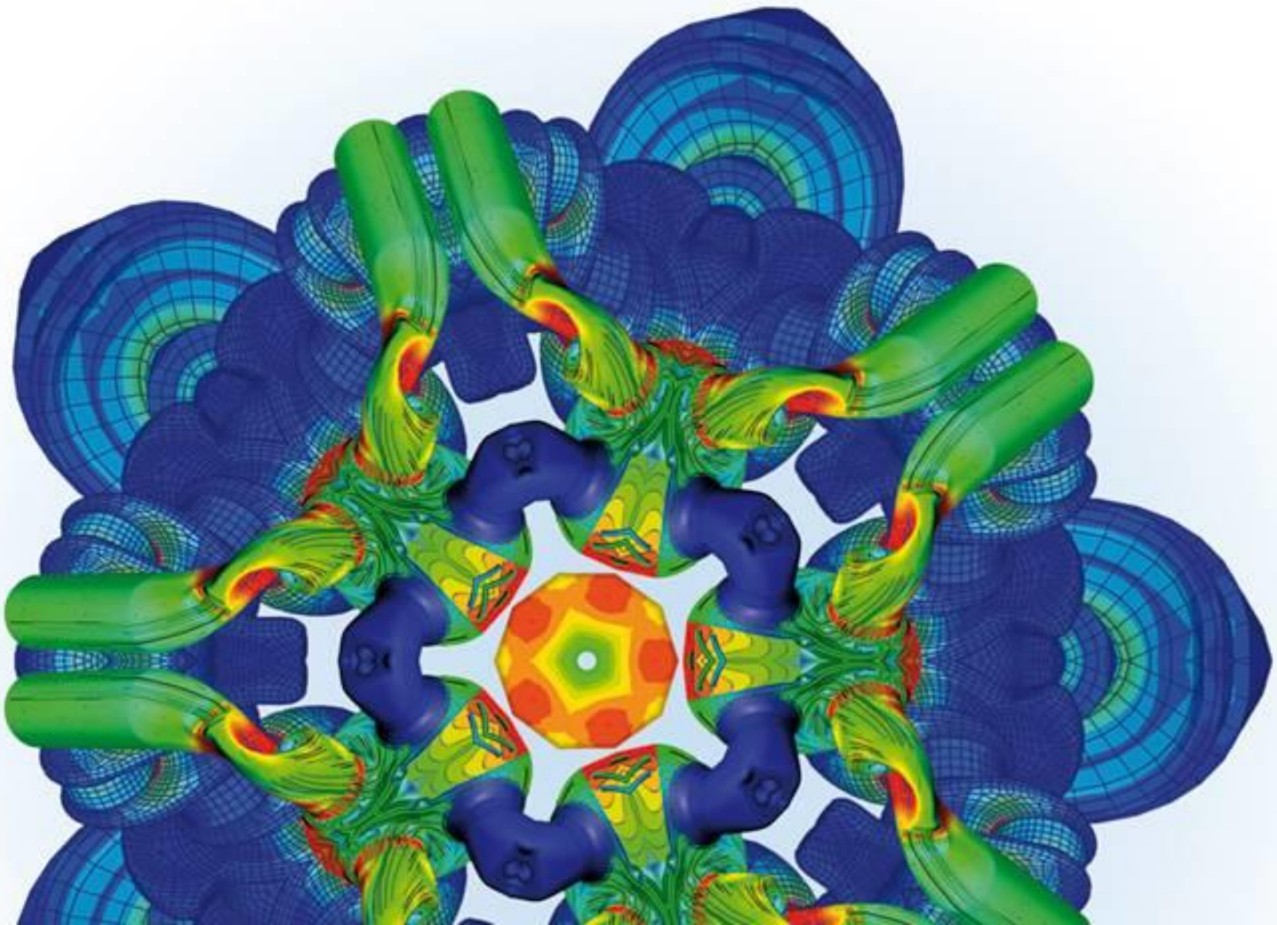
1D High Pressure Fluid Flow and 2D Dynamics of Mechanical Parts

Applications

- **Diesel Engines**
  - Common Rail Systems
  - Unit Injectors
  - Conventional Inline-pump & other Systems
- **Gasoline Engines**
  - Direct Injection Systems
  - Intake-Port Injection
- **Alternative Fuel Systems**

AVL FIRE

3D CFD Simulation



AVL SIMULATION SOFTWARE –STRATEGIC DEVELOPMENTS

Consistent simulation models for all development phases

BOOST

FIRE®

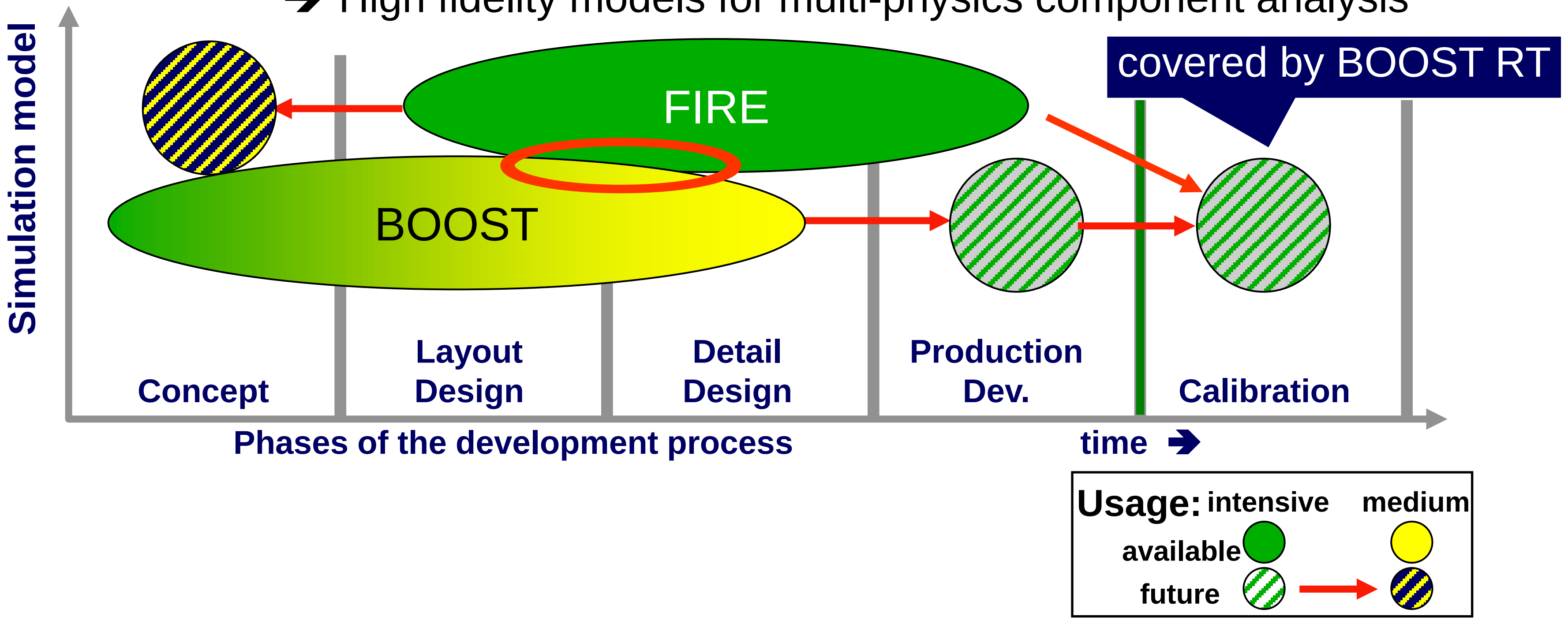
The benefit:

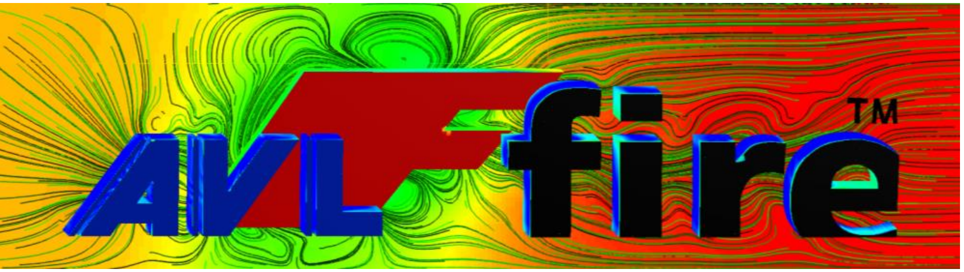
➔ Combustion simulation with common 1d/3d physical models (BOOST- FIRE coupling enables „Virtual engine“)

➔ Fast calibration with integrated engine & vehicle real time model (BOOST RT and CRUISE RT)

➔ Engine simulation on test bed (Simulation based testing) (BOOST- CAMEO, BOOST- GCA, CONCERTO)

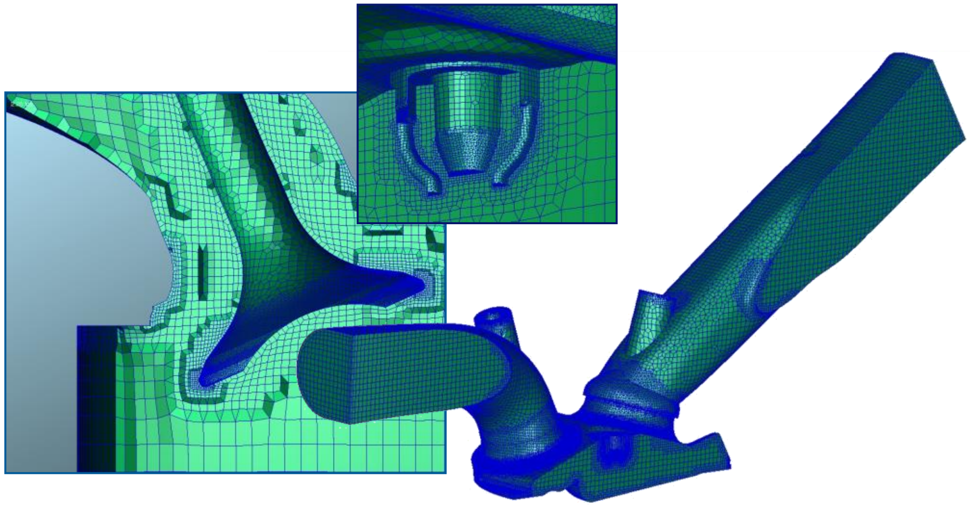
➔ High fidelity models for multi-physics component analysis

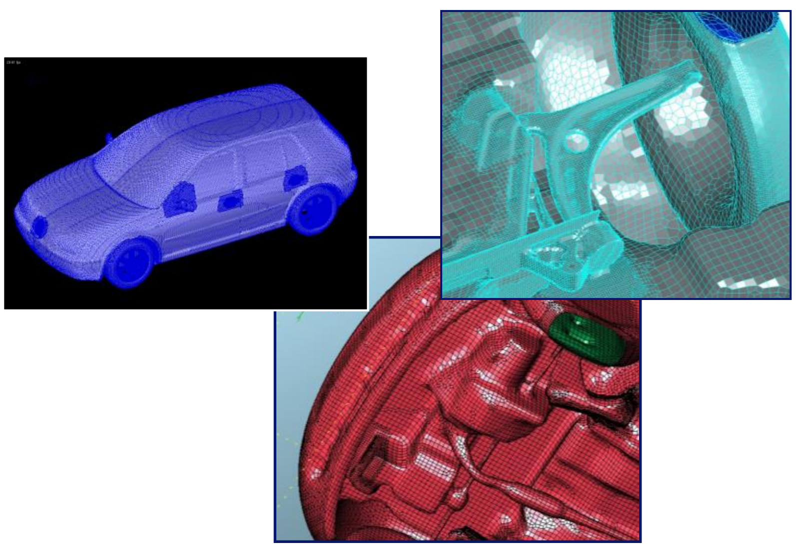




General tool description

- general fluid flow solver with full support of polyhedral cells
- modules tailored to applications in IC engine research and development
- features for specific vehicle related applications
- integrated pre-/post-processing, simulation setup and control





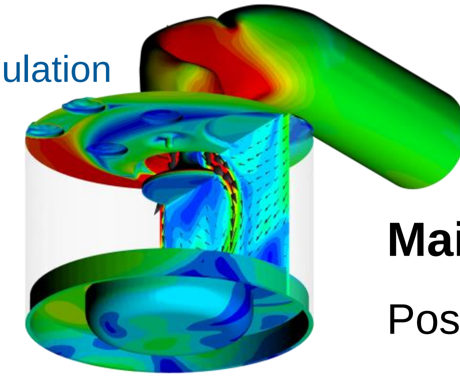
Main features

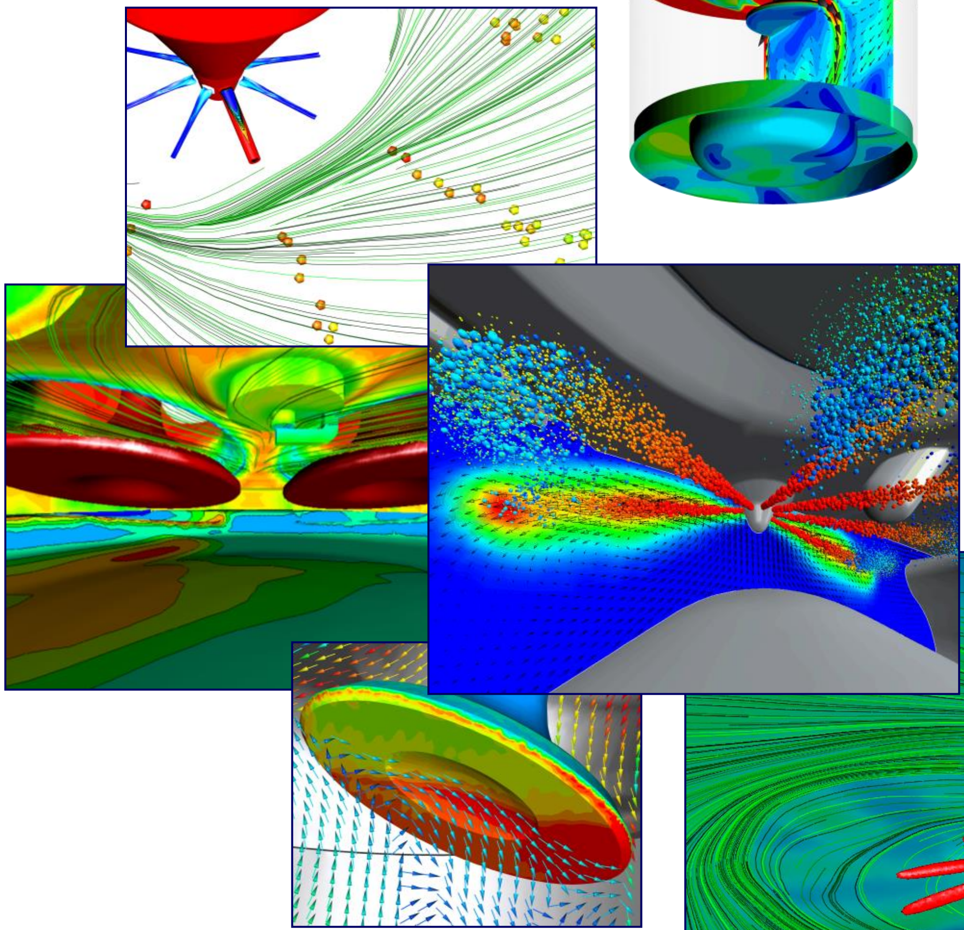
Pre-processing

- CAD data import and manipulation
- automated grid generation resulting in either
  - hexahedron-dominated (FAME Hexa) or
  - tetrahedron-dominated (FAME Tetra) grids
- setup and handling of models with (multiple) moving boundaries
- includes a series of tools for grid, surface and edge model manipulation

AVL FIRE

Computational fluid dynamics simulation

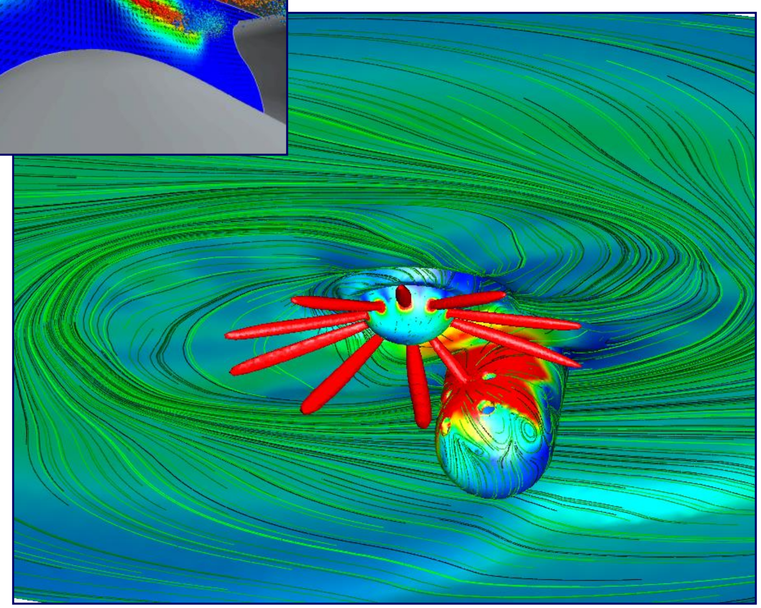


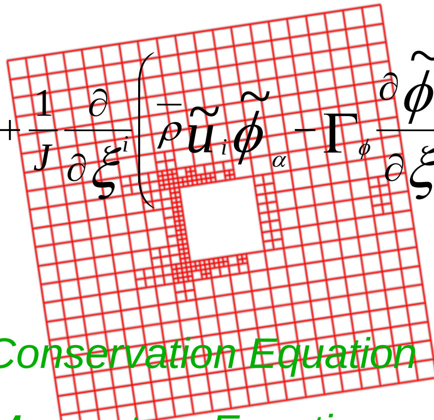


Main features

Post-processing

- simulation online monitoring
- 2D and 3D result visualization
- result analysis (formula, macro)
- plots and animations





$$\frac{\partial}{\partial t}\left(\bar{\rho}\tilde{\phi}_{\alpha}\right)+\frac{1}{J}\frac{\partial}{\partial\xi^{i}}\left(\bar{\rho}\tilde{u}_{i}\tilde{\phi}_{\alpha}-\Gamma_{\phi}\frac{\partial\tilde{\phi}_{\alpha}}{\partial\xi^{n}}\gamma_{i}^{n}\right)\gamma_{i}^{j}=S_{\phi_{\alpha}}$$

Conservation Equation

Momentum Equation

Enthalpy Equation

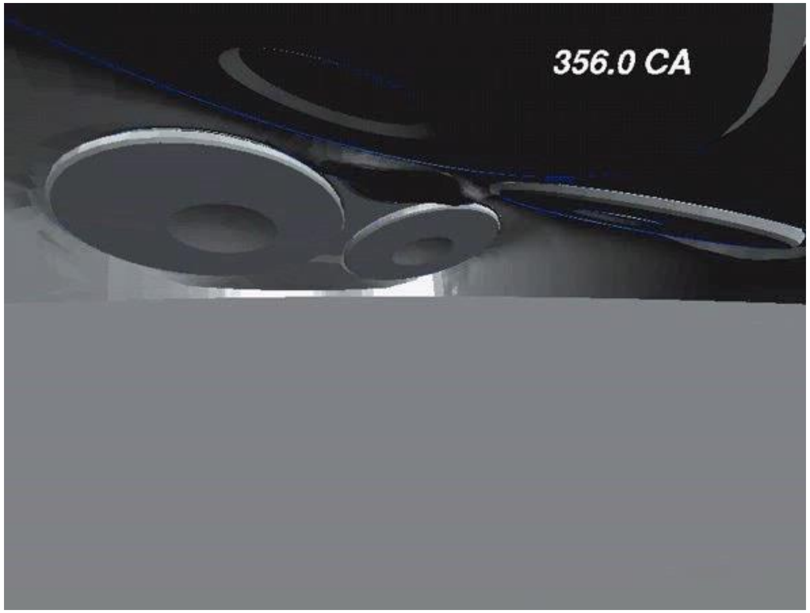
Species Transport Equation

…

Main features

Main program (1)

- Reynolds averaged Navier Stokes equation solver
- generalized body-fitted non-orthogonal coordinates
- full support of polyhedral elements
- arbitrary and sliding interfaces
- moving and non-moving boundaries
- rotating and multiple frame of reference
- incompressible / compressible flows
- laminar and turbulent flows
- conjugate heat transfer
- porosities
- user defined functions
- fully MPI parallelized



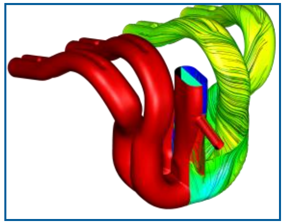
Main features

Main program (2)

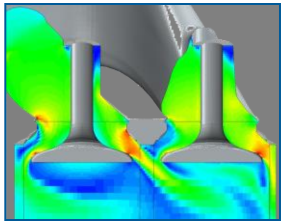
- species transport, chemistry interpreter, general gas phase reaction solver
- ignition, combustion, emission simulation
- Lagrangian multiphase capabilities including wall film modeling
- Eulerian multi-phase module
- exhaust gas aftertreatment simulation
- de-icing and de-fogging capabilities, rain drop separation in A/C usints
- polymer electrolyte membrane fuel cell simulation capabilities
- …

AVL FIRE

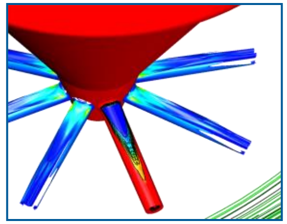
Computational fluid dynamics simulation



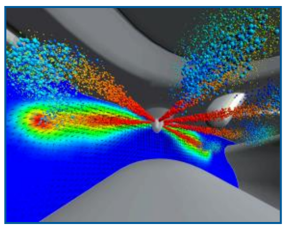
Intake system



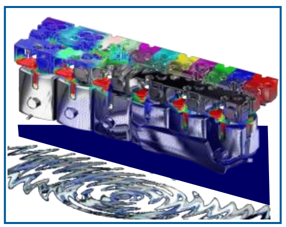
Intake / exhaust ports



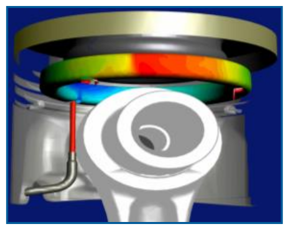
Injection nozzle



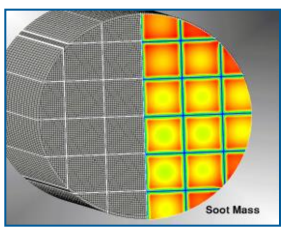
In-cylinder flow



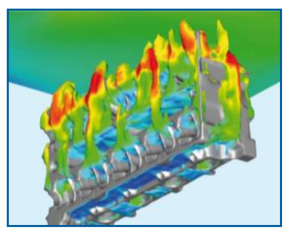
Coolant system



Crank case



Exhaust line and aftertreatment systems

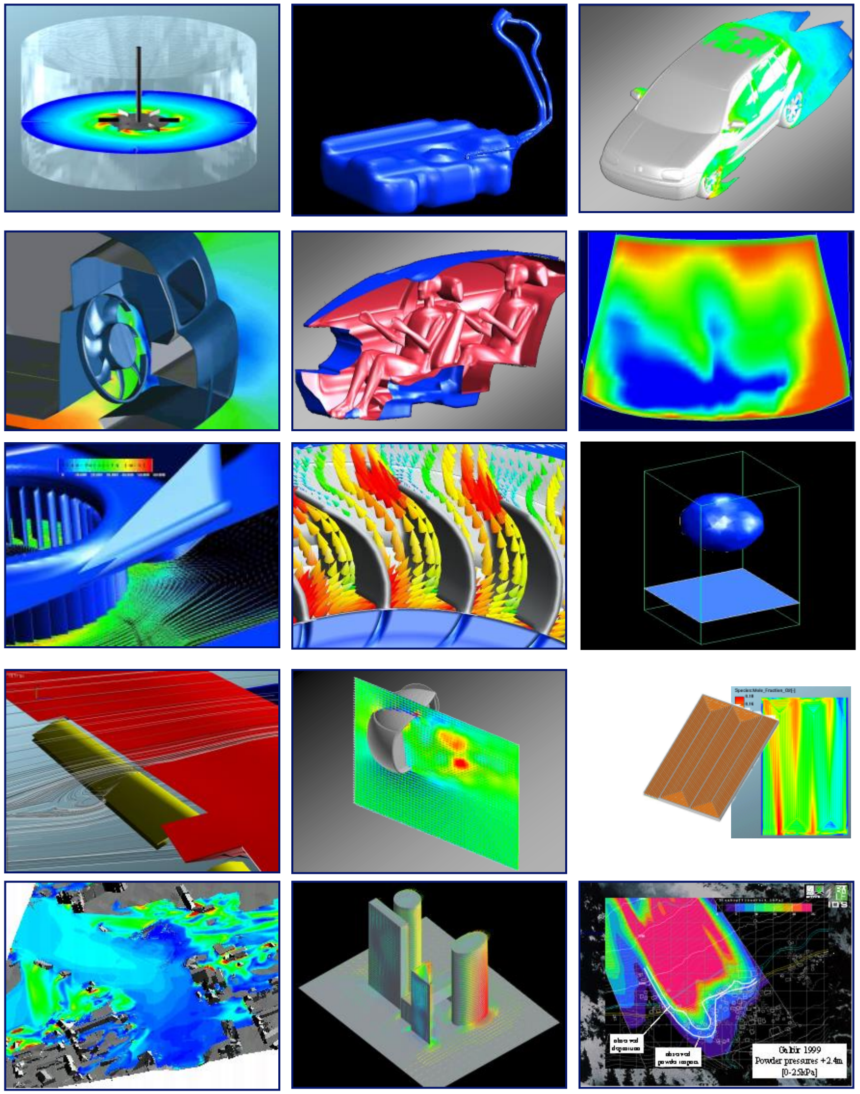


Fluid / solid interaction

Areas of application

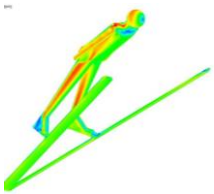
IC Engine

- intake and exhaust systems
- intake and exhaust ports
- liquid and gaseous fuel injection nozzles
- direct and indirect injection engines, carburetor engines
- 2 and 4 stroke engines, rotary engines
- air and liquid engine cooling systems, cooling system components
- exhaust gas lines and aftertreatment systems
- …



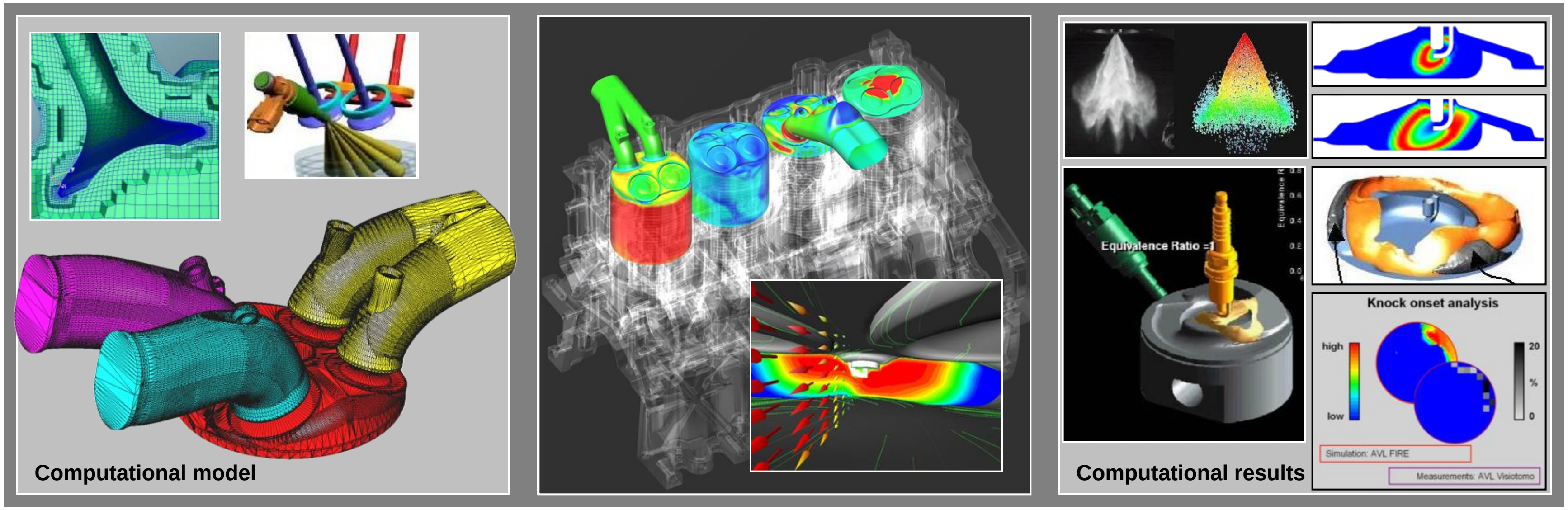
Areas of application

Non-engine



- mixing flows
- filling of tanks and vessels
- vehicle aerodynamics, engine and passenger compartment flows
- wind screen de-icing and defogging
- flows in pumps, compressors and turbines
- turbulence induced noise (wing, side view mirror, …)
- PEM fuel cells
- environmental flows, flooding, avalanches
- …

FIRE – AREA OF APPLICATION
GASOLINE ENGINE CYCLE SIMULATION (A)



Worksteps and targets

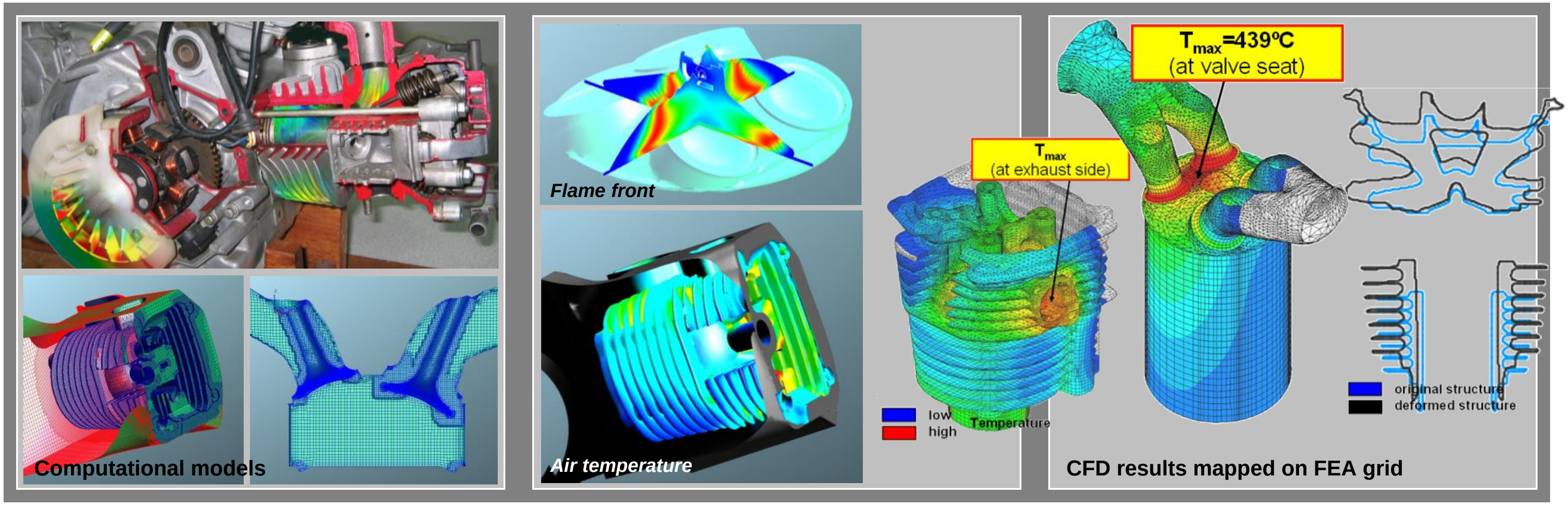
Engine cycle simulation

- *intake stroke:* scavenging during valve overlapping, cylinder charge and air motion, mixing between fresh air and EGR
- *compression stroke:* global air motion and local conditions (squish, injector, spark plug)
- *fuel injection, ignition and combustion:* fuel injection and vaporization, wall film, spark plug position, ignition, peak pressure, heat release, knock tendency, emission formation
- *exhaust stroke:* completeness of scavenging

Parameter to vary

- valve timing
- valve / valve seat geometry
- piston and head geometry, squish
- injector position and inclination
- injection timing and strategy
- spark plug position
- residual gas content
- thermal boundary conditions
- engine operating conditions

FIRE – AREA OF APPLICATION
GASOLINE ENGINE CYCLE SIMULATION (B)



Worksteps and targets

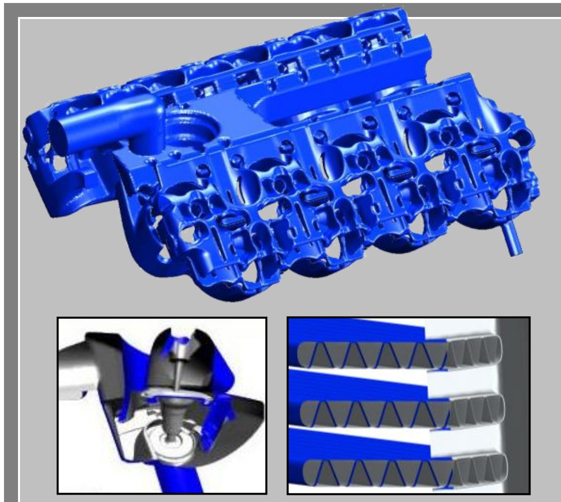
Engine thermal load

- deriving gas side thermal boundary conditions

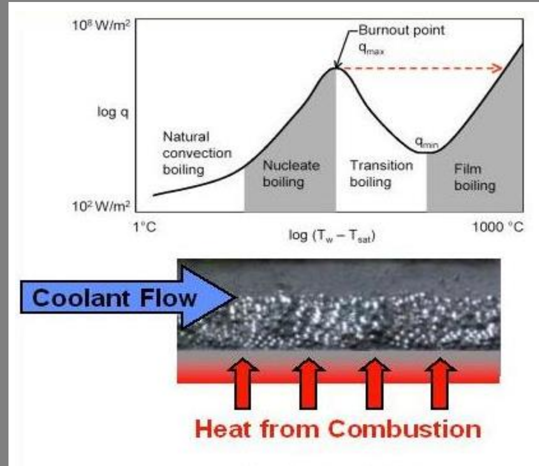
Parameter to vary

- engine operating conditions

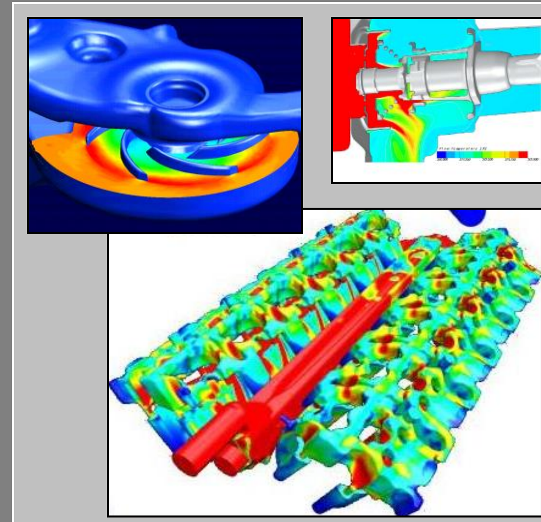
FIRE – AREA OF APPLICATION
COOLING JACKET



Computational models



Nucleate boiling model



Worksteps and targets

Coolant jacket flow analysis

- flow split between head and block, left and right bank (V-engines)
- uniform cooling conditions for all cylinders
- precision cooling for thermally highly loaded parts
- removal of stagnation zones
- evaluation of heat transfer between liquid and structural parts
- determination of thermal boundary conditions for HBC analysis

Parameter to vary

- gallery design
- coolant inlet / outlet
- fire deck geometry and coolant jacket design
- cylinder head gasket design (size, shape, location, number of holes)
- drillings between cylinders
- coolant mass flow

DOE AND OPTIMISATION
USING AWS DESIGN EXPLORER

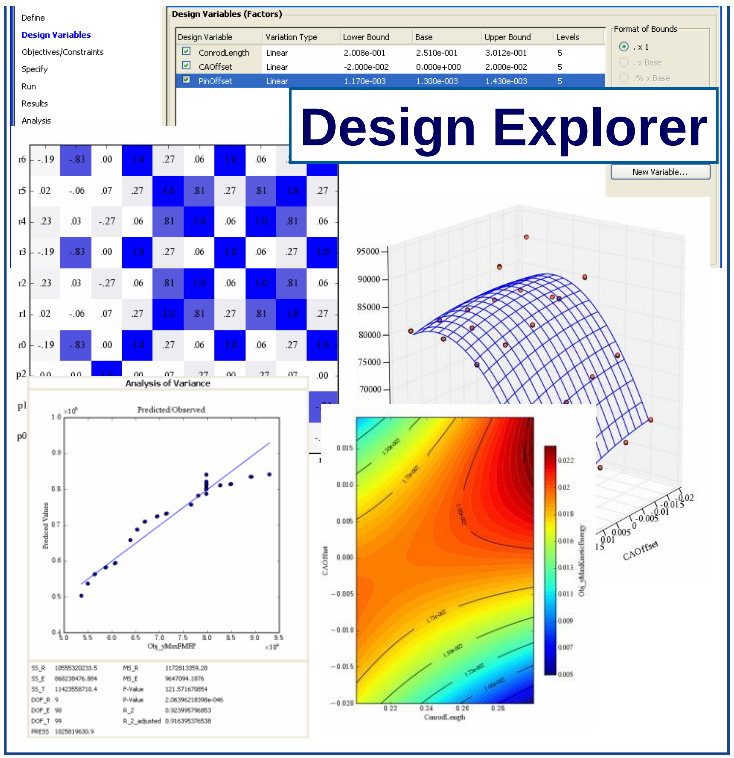
<u>Benefit:</u>

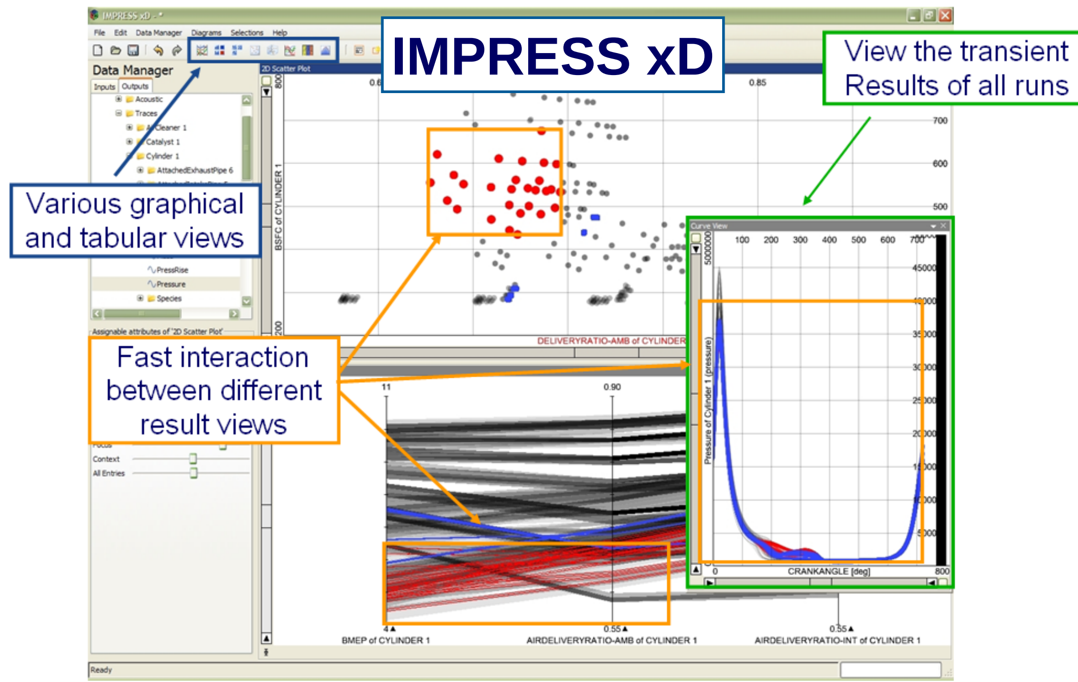
Integrated environment for basic application task of AVL´s simulation products for

- Design Optimization
- Sensitivity Analysis
- Parameter Identification

<u>Benefit:</u>

- Interactive analysis of all DoE simulation results
- Fast interpretation of sensitivities





LIST OF CUSTOMERS (INCOMPLETE)

AVL's mathematical simulation software

AUDI AISIN VW BMW TOYOTA TCRDL Bocar GM KTM DAIHATSU DC VOLVO HONDA FIAT TICO MAN PSA MAZDA RENAULT Ferrari VM Motori PORSCHE Siemens FORD Otosan BOSCH Federal Mogul GOETZE Duap ISEKI Ducati Indian Oil Perodua Tecumseh Mahindra&Mahindra Navistar RICARDO AE&E DENSO FAURECIA ARAI YANMAR TOKYO GAS OSAKA GAS ORDC OMG Krupp Metalurgica HMC / KIA Pankl Dr. Schrick Woodward Governor FINNVEDEN MANB&W IHI DOOSAN Infracore KHI DOOSAN Engine Futaba Industrial Lycee Claveille GMDAT RSMC HHI HEC IAE Scania Eagle Pilcher Cummins Wärtsilä TATA Motor KOEL HINO CRF Visteon NISSAN NTSEL NISSAN Diesel MMC Suncall ZeunaStaerker John Deere MHI Mercedes HPE Nippon Piston Ring Diesel United NIIGATA DAEDONG SYMC STX DongYang Piston SK DAEKI FAURECIA SERA Cars Fairbanks Morse L´Orange Int. Truck & Engine Corp. AshokLeyland DAIDO Metal Aichi Kikai Teikoku Piston Ring MITSUI ZOSEN OTICS ISUZU FUSO KOMATSU AISAN NICO Precision Kubota TVS HUT AvtoVAZ SanYang FAW Chery JAC KIER SAIC SAW Dalian DEW Binzhou Bohai Machinery Shindaiwa Kogyo Wuxi DEW Wuxi FIE Weifang DEW Shaan´xi DEW Jinan DEW ShanXi 70 Inst. Shan Dong Piston Qianjiang Motor Zongshen Motor Jianshe Motor Yuling DEW RIKEN Wuxi Weifu Ajou Univ. Seoul National Univ. Kookmin Univ. Hanyang Univ. Sungkyunkwan Univ. CHANGWON Univ.