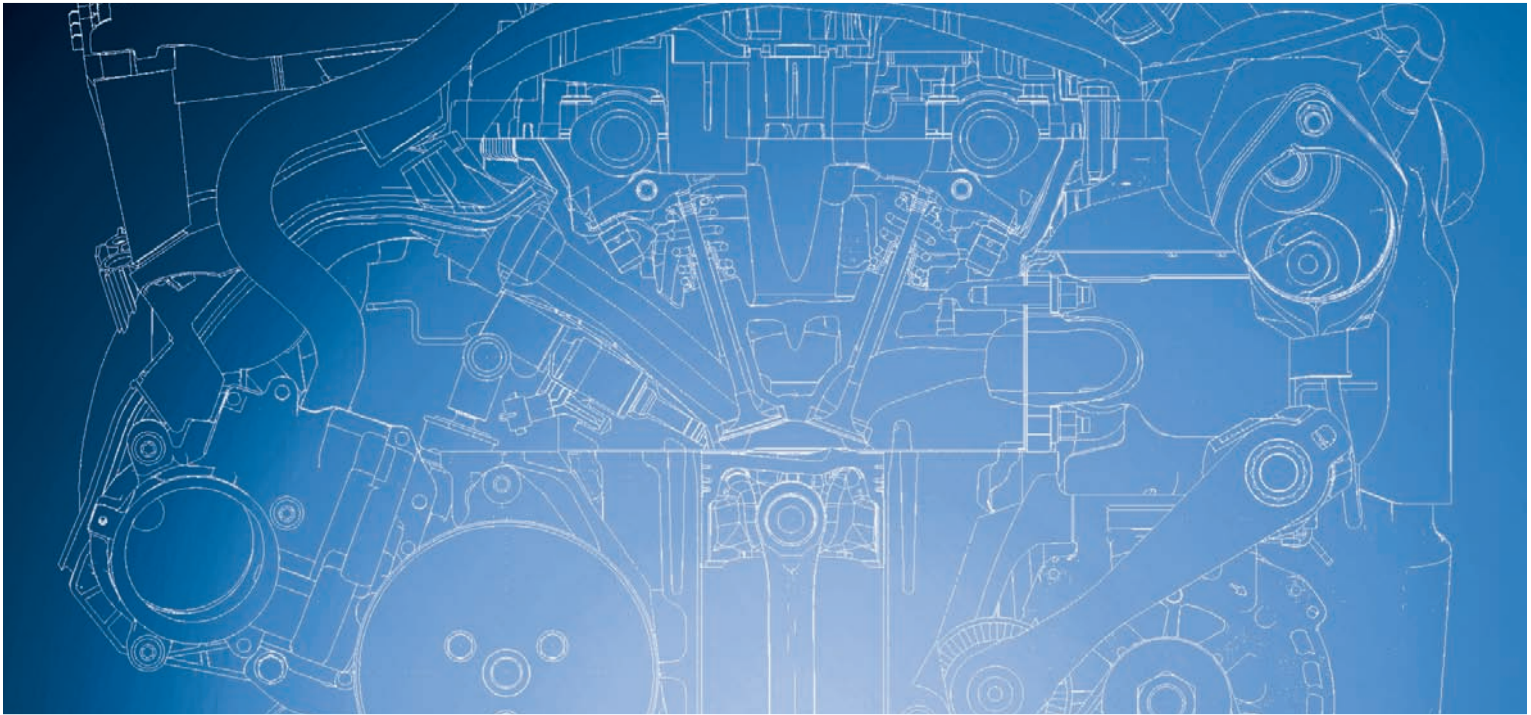


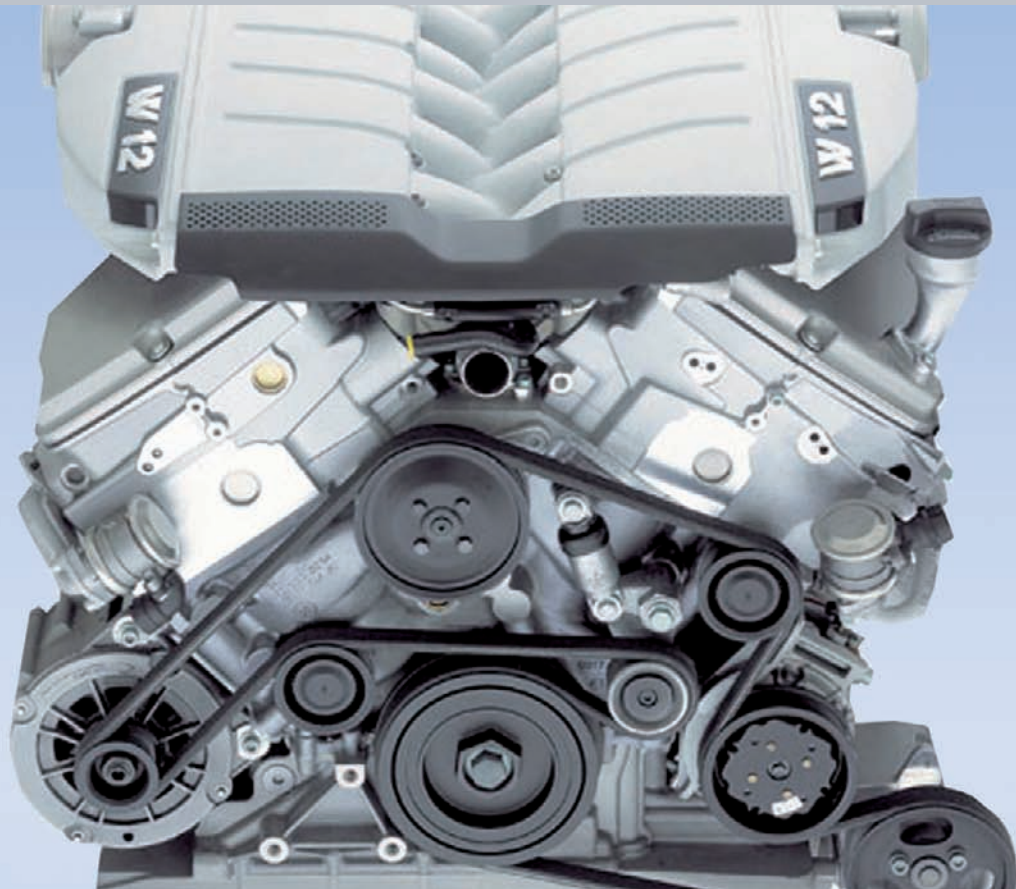
Base Engine Design

for Diesel & Spark-Ignited Engines



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IAV develops engines to meet the increasingly challenging demands of performance, economy and emissions

Designing the World's Future Engines

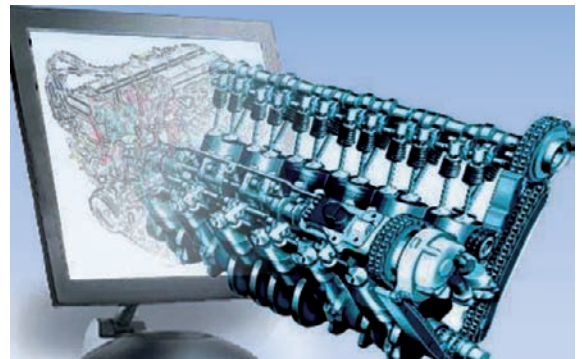
Although IAV was founded in 1983, its engine development center was founded nearly 80 years ago as the German Auto Union in Chemnitz. Following the 1932 merger of Horch, Audi, Wanderer and DKW, the German Auto Union became a primary German base for engine engineering and technical innovation. After the reunification in 1990, IAV took over key elements of the Chemnitz facility and established its center of competence for powertrain engineering and development.

Since then, IAV has been at the forefront of the design and development of advanced gasoline and diesel engines from single cylinder, up to W12 layouts and larger engines. IAV has delivered many innovative engine concepts through to production, meeting the ever increasing demands for excellent fuel economy and low emissions. In-house expertise is driven by high fuel prices and tough emissions legislation in Europe and the US, especially concerning CO₂ and other tailpipe emissions.

IAV is rapidly growing its base engine development capability in the US, and draws directly from its skills and experience in Europe. Meeting US customer demand in

areas such as downsizing and boosting, direct injection technologies, combustion control, friction reduction and hybridization. Alternative fuels are also a primary focus at IAV.

IAV has commissioned an initial phase of four state-of-the-art engine dynamometers with capacities between 450hp/700 Nm to 875hp/3500 Nm. From here, IAV can develop and prepare the certification of the performance and emissions of US engines and powertrains, including hybrid electric systems.



Rapid development of engine technologies across the globe



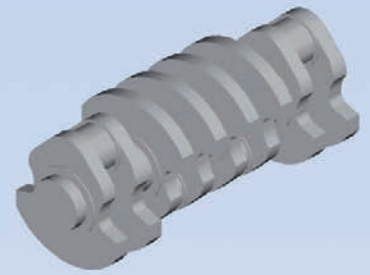
Ventil

- ▶ Valve-train concepts
- ▶ Kinestatic dimensioning and optimization



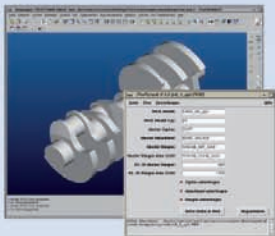
V-Engine

- ▶ Engine concepts
- ▶ Free mass forces
- ▶ NVH



P-Crank

- ▶ Crankshaft concept
- ▶ Optimum mass balance



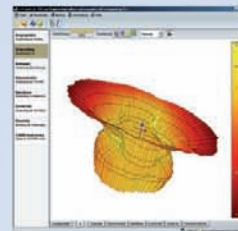
CAD-Tools

- ▶ Tools to support CAD packaging



V-CD

- ▶ Generation of control-drive layouts
- ▶ Kinestatics of control drives
- ▶ Preprocessor for dynamic simulations



V-Site

- ▶ Cylinder deformation
- ▶ Bearing deformation
- ▶ Analysis of cylinder head sealing
- ▶ Analysis of cam wear
- ▶ Database connection



Knowledge Database

- ▶ Administration and processing of technical characteristics
- ▶ Engine, vehicle and other knowledge data

IAV engineers and maintains its own comprehensive suite of engine simulation, design and virtual validation toolsets

Processes & Toolsets

To create rapid and advanced engine solutions for customers, IAV has developed its own suite of simulation, design and virtual validation toolsets. IAV engineers utilize specific tools to undertake component level, sub-system and system level analysis, calculation and simulation tasks. Toolsets are constantly upgraded to meet the growing technical demands in engine development, and to meet the tightening constraints of reduced program time and budget.

IAV templates the processes required to develop the logistics, timing and cadence for an engine program. Such templates can be adapted to serve a simple component project or a full turnkey engine program including production launch. With highly disciplined data management, design and release processes, IAV can adopt the customer's own design release and control systems. The best elements of two systems may be brought together to optimize the timing, control and execution of a program.

IAV Virtual Powertrain

- ▶ Methodology development and digital mock-up
- ▶ Data strategy management
- ▶ Data integration into customer processes
- ▶ Process support and strategic consulting

IAV Virtual Powertrain Tools

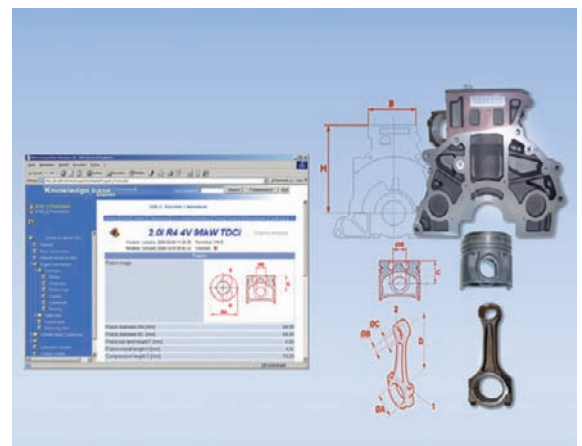
- ▶ Virtual engine V-Tool chain
- ▶ Engine mechanics (V-ENGINE, V-Site)
- ▶ Cranktrain mechanics (P-CRANK)
- ▶ Valvetrain mechanics (V-CD, VENTIL)
- ▶ Optimization

IAV Knowledge Database

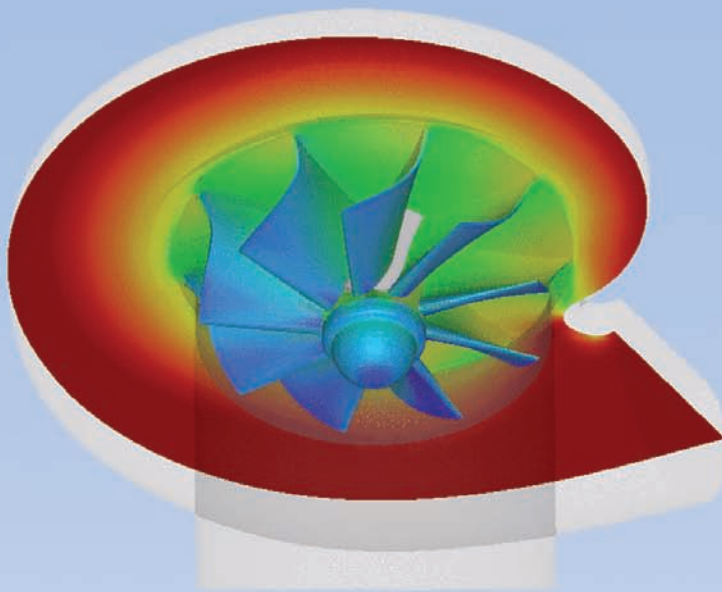
- ▶ Knowledge network (vehicle, engine, gears, etc.)
- ▶ Knowledge-based engineering for design, computation and testing
- ▶ Benchmarking of engine parameters
- ▶ Benchmarking of competitor engines
- ▶ Approximately 3,000 engines, 600 transmissions

Frontloading Methods

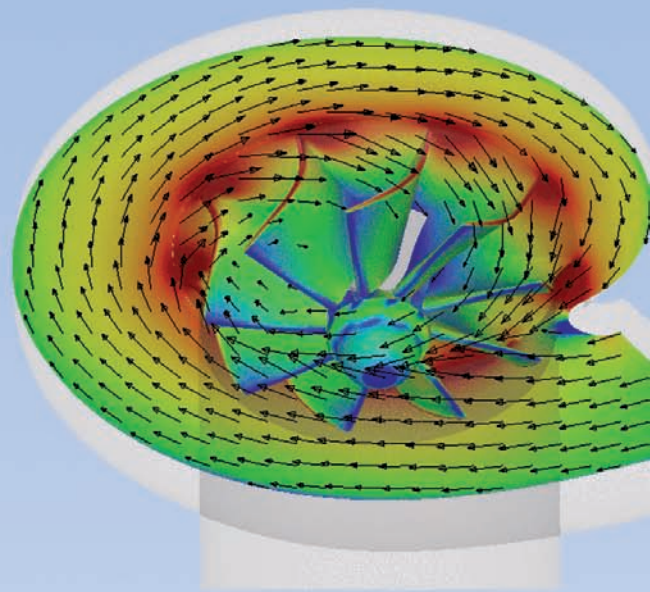
- ▶ Development of schematics
- ▶ 3D tolerance simulation and costs
- ▶ Casting simulation – pouring and grainflow
- ▶ Fitting simulation and assembly simulation



IAV maintains a global database of engines



Pressure Distribution



Flow Field

Such images are generated using CFD for flow optimization and thermo-mechanical development of a turbocharger

Concept Design & Simulation

IAV uses a range of advanced analytical tools to perform 1D and 3D simulation, structural mechanics and NVH engineering.

One-dimensional fluid mechanics analysis addresses charge-cycle flow simulation, thermodynamic and thermo-mechanical simulation, and boosting system design, such as turbocharging and supercharging.

Three-dimensional fluid mechanics analysis includes intake and exhaust system gas flow analysis, cooling system flow analysis, combustion process flow and thermodynamics.

Meshing

- ▶ ICEM Hexa/Tetra
- ▶ IC3M
- ▶ Pro-star/pro-am
- ▶ Hypermesh
- ▶ Paramesh
- ▶ Sculptor
- ▶ Interfaces to all CAD packages

CFD

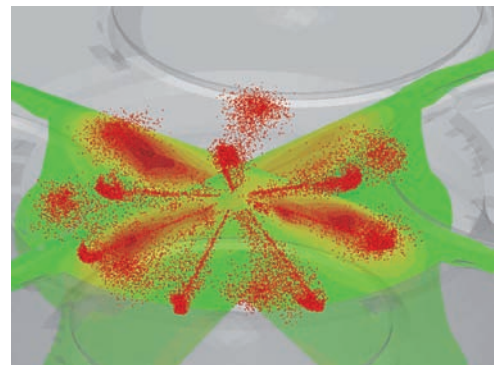
- ▶ STAR CD
- ▶ VECTIS
- ▶ CCM+
- ▶ Open FOAM

1D-Simulation

- ▶ AMESim
- ▶ GT-POWER®/GT-SUITE
- ▶ PROMO
- ▶ Flowmaster
- ▶ ITI Sim
- ▶ IAV Thermodynamics Simulation®
- ▶ MATLAB®/Simulink®

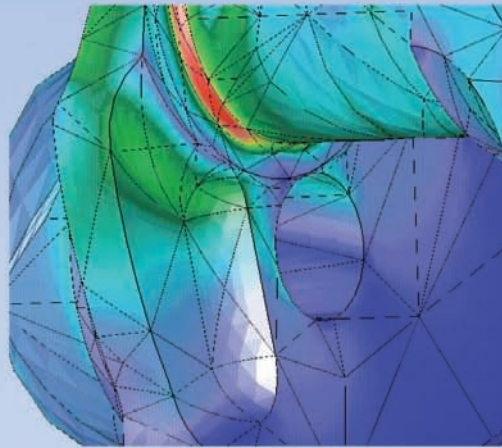
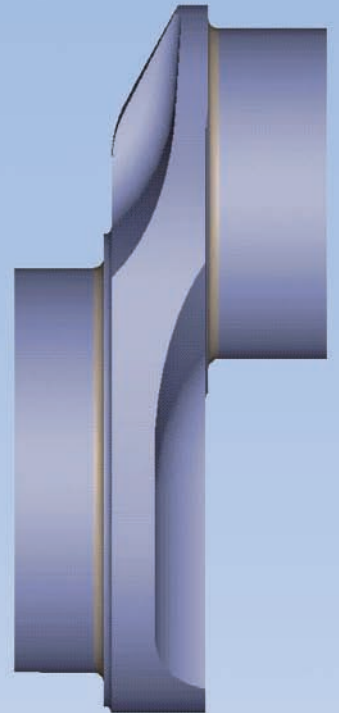
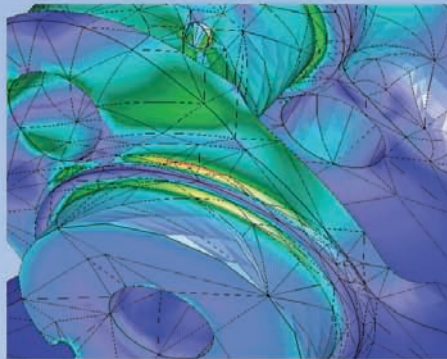
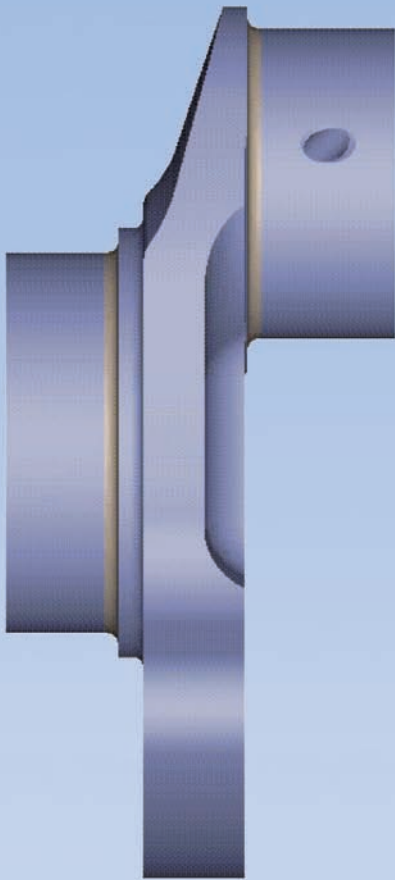
Optimizer

- ▶ ModeFRONTIER
- ▶ IAV Engineering Toolbox®
- ▶ Hyperstudy
- ▶ NOA (University of Magdeburg)



Design of injector spray pattern

Stress peak at stop collar of main bearing pin



Stress peak in clearance (non-machined area)

During base engine design, IAV deploys experts in mechanical engineering and analysis

Mechanical Design

To create rapid and advanced engine solutions for customers, IAV deploys its world class expertise in the mechanical design of engine components, sub-assemblies, assemblies and systems.

This includes the calculation of forces and accelerations through all modes of engine operation within the total operating environment. It allows the IAV engineer to accurately realize effects such as bending, torsion, shear, compression and tension. Furthermore, IAV's expertise is in the analysis and understanding of the thermo-mechanical stresses within the engine system, caused by repeated heating and cooling cycles throughout engine operation.

IAV has special expertise in engineering for noise, vibration and harshness (NVH). This includes the requirements to analyze and smooth out damaging or disruptive forces through precise balancing and mass adjustment. NVH engineering also affects all aspects of structural design, including the major castings, bearings, load points and materials throughout the entire engine.

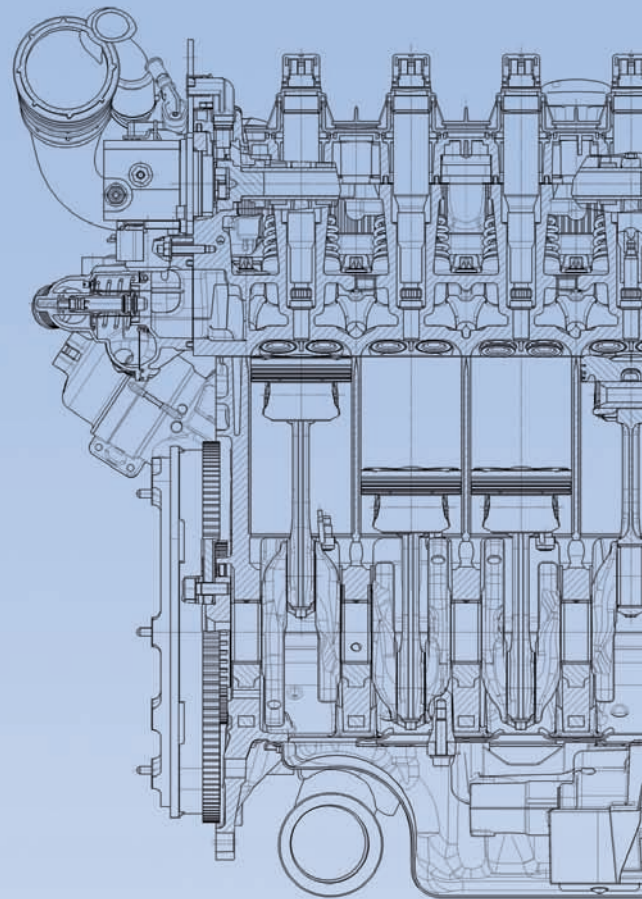
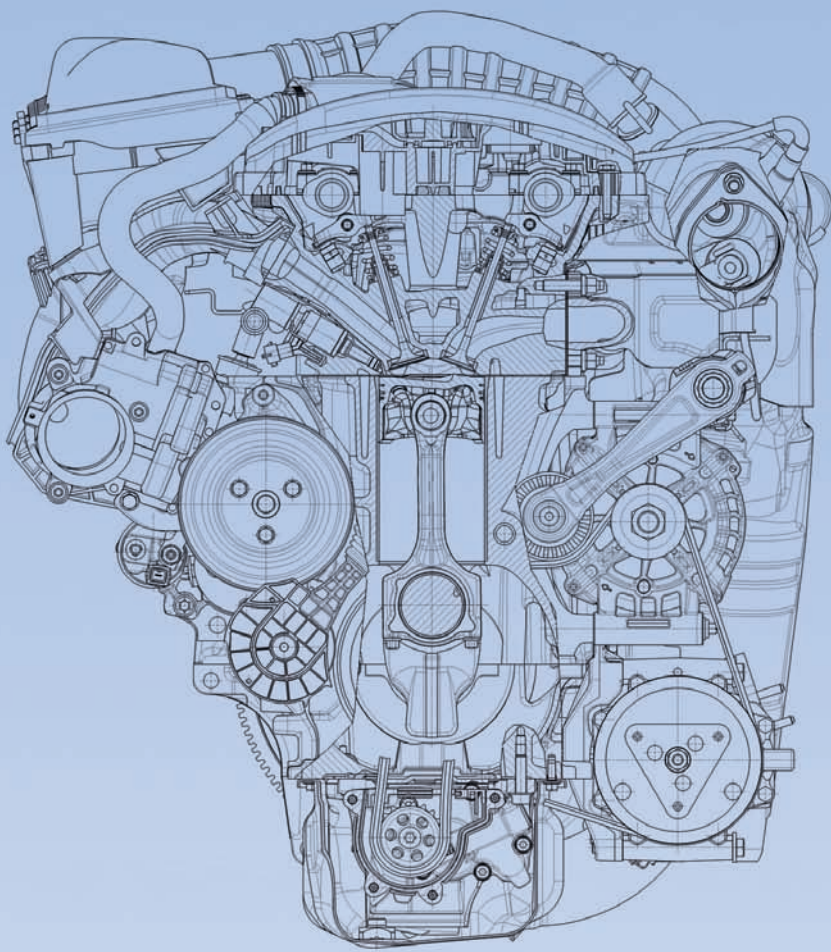
Not only does IAV apply its expertise in mechanical design to an engine's internal components, but also to the external components, such as the crankshaft damper, harmonic balancer shafts, the flywheel system and the front end accessory drive system (FEAD).

Structural Mechanics

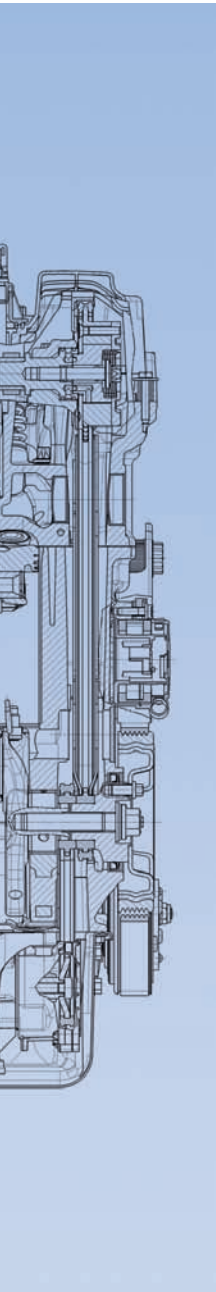
- ▶ ADAMS engine/multi-body simulation
- ▶ Xketsim - multi-body simulation (chain drives)
- ▶ SimPac - multi-body simulation
- ▶ ITISim - multi-body simulation
- ▶ ABAQUS - strength-stiffness-thermo mechanics
- ▶ NASTRAN - strength-stiffness-dynamics
- ▶ FEMFAT - fatigue strength and durability
- ▶ Optistruct - topology optimization
- ▶ IAV-SB Noise - dynamics and acoustics
- ▶ ExCite - ElastoHydroDynamics
- ▶ IAV toolbox - optimization



A typical valve analysis model



IAV's base engine design capability includes gasoline, diesel and alternative fuel engine design, package and construction



Packaging & Construction

IAV hires and trains the very best engine system design engineers. Concentrating on efficiency and technical capability, IAV's degree qualified engineers take full design and release responsibility for their components and assemblies. By carrying out the required specification, design calculations, digital modeling, design packaging, construction and design release with subsequent supplier management, IAV's engineers make sure that all system requirements are considered and met. In effect, IAV engineers become their own total component project leaders.

IAV utilizes its in-house suite of engine sub-system and component virtual design tools, plus industry standard packages for computer aided design. Interfacing to IAV's customers' product data management systems ensures strict revision level control for data transfer and release. Throughout the development of the design, IAV deploys rigorous quality processes including DFMEA, GD&T, DFM/DFA, value analysis and cost management.

Crankcase, Cylinder Head & Sump System

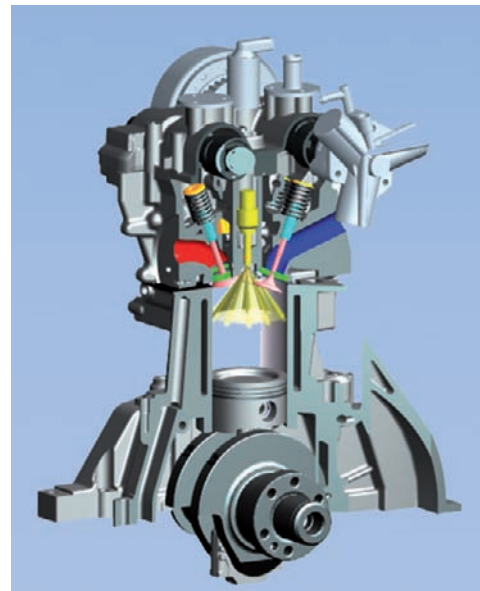
- ▶ Structures and layout
- ▶ Casting design and optimization
- ▶ Cylinder liner design and integration
- ▶ Front cover design
- ▶ Design and optimization of cooling
- ▶ Combustion chamber design
- ▶ Runner - port design and layout
- ▶ Injector unit integration (DI)
- ▶ Valvetrain system integration
- ▶ Chain and belt drive system integration
- ▶ Lubrication engineering
- ▶ Oil pickup and delivery
- ▶ Oil pump design and integration
- ▶ Ventilation and oil aeration
- ▶ Baffles and windage plates
- ▶ Sump pan and sealing

Engine Mechanical Design

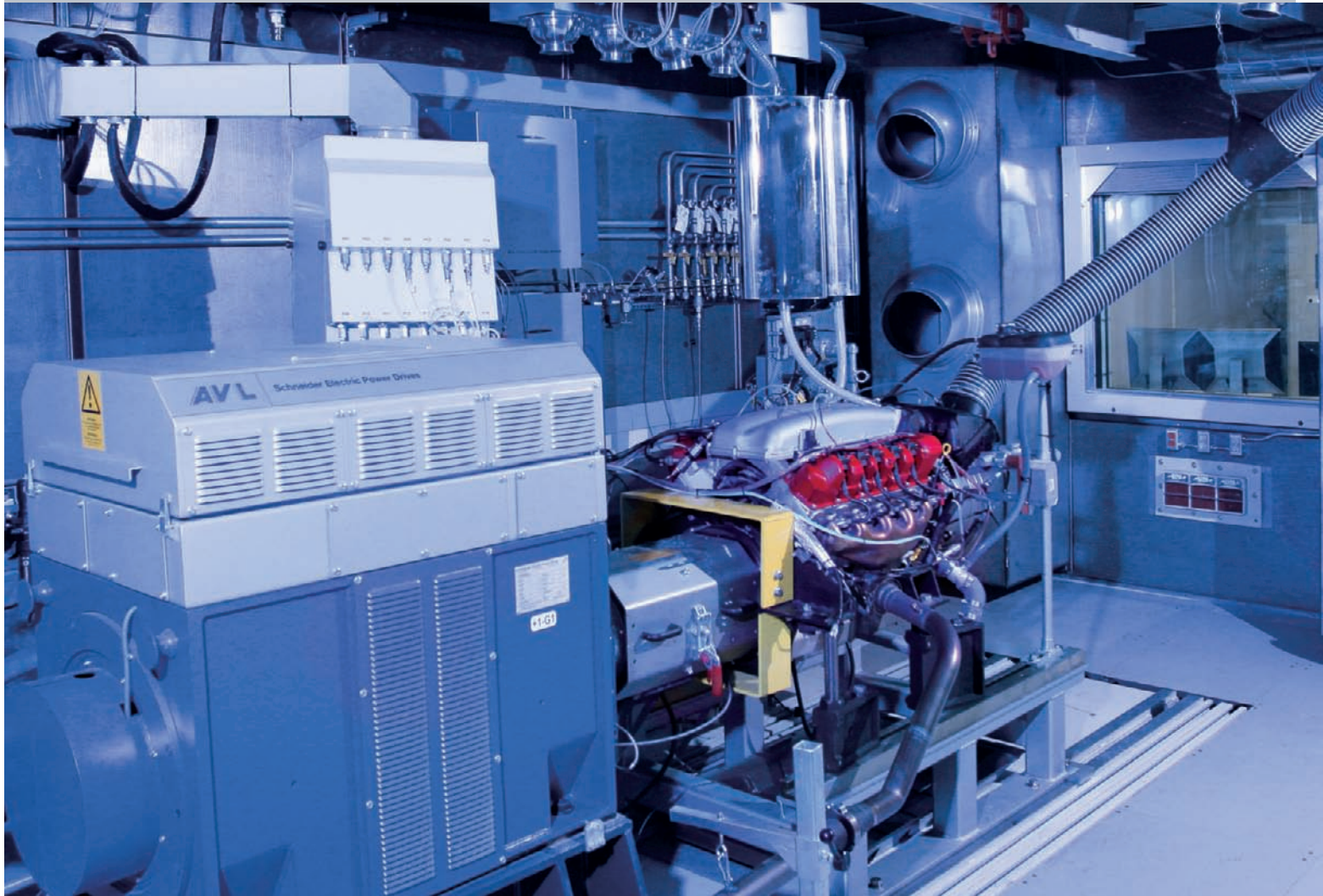
- ▶ Crankshaft, pistons, conrods, bearings
- ▶ Valvetrain - VVT design
- ▶ Balancer shaft design and integration
- ▶ Dampers and isolators
- ▶ FEAD design and machine integration
- ▶ Forces, accelerations and mass-motions
- ▶ NVH engineering

Charge Exchange Process Design

- ▶ Intake and exhaust system
- ▶ Integrated air fuel manifolds
- ▶ Integrated exhaust manifolds
- ▶ Turbocharger system application-integration
- ▶ Supercharger system application-integration



A typical DI system layout



IAV operates high-end dynamometers, test measurement equipment and laboratories to support engine testing and development



Verification Testing

The focus on advanced powertrain engineering has earned IAV a reputation as a reliable and flexible development partner. IAV understands the challenges customers face when developing and refining powertrains to meet strict industry and regulatory requirements.

The new state-of-the-art IAV Technical Center in Northville, MI houses test and measurement equipment to fulfill the demands of today's increasingly complex gasoline, diesel and hybrid powertrain systems. The facility is equipped with four engine dynamometers with full transient emissions capability. Two units are used for light-duty engines, a third is designated for heavy-duty diesels, and the fourth is specified to evaluate and develop hybrid drivetrain applications.

IAV's engineers are dedicated to the development of gasoline, diesel and alternative fuel engines, including direct-injection and turbocharging technology. Sophisticated automation software and diverse measurement devices allow the test cells to operate unmanned around the clock to meet current and future emissions standards while maximizing fuel economy.

Performance & Emissions

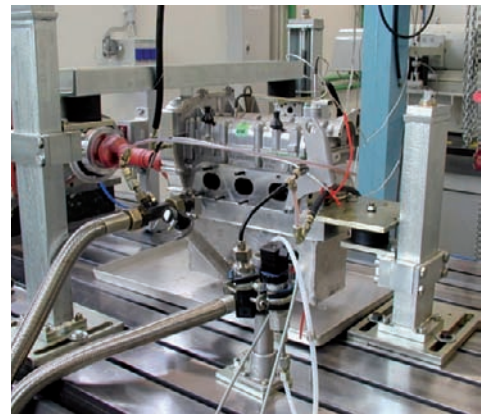
- ▶ Emission concept definition
- ▶ Base engine calibration
- ▶ Exhaust aftertreatment development
- ▶ Advanced process simulation and control function development
- ▶ OBD development and validation

Engine Mechanical Testing

- ▶ Power loss and efficiency
- ▶ Engine system and component durability
- ▶ Key life and DVP&R testing

Lubrication & Cooling

- ▶ Powertrain cooling system
- ▶ Oil circuit and aeration test and development
- ▶ Lubricant analysis and tribology



Component test bench



IAV's new Technical Center - North America



About IAV

IAV Group is a leading global automotive engineering service provider, employing more than 3,000 personnel throughout Europe, Asia and the Americas. Founded in 1998 as the North American subsidiary of IAV GmbH, IAV Automotive Engineering Inc. develops breakthrough concepts and technologies – from powertrain design and development to controls and electronics – for future vehicle generations. Clients include leading automotive manufacturers and component suppliers, all of whom rely on the knowledge of IAV's engineers to help them design and develop some of the industry's most advanced engines and powertrains. The IAV Technical Center North America is now open in Northville, MI. The technical center includes four state-of-the-art development/test cells. With this exciting new facility, IAV's engineering capabilities have expanded to include full service projects, further cultivating the inventive spirit, enthusiasm and commitment to success for which the IAV Group is known.

Development Trends Drive IAV's Capabilities

- ▶ Downsizing and boosting
- ▶ High specific power
- ▶ High specific torque
- ▶ Friction reduction
- ▶ NVH improvement - mechanical
- ▶ NVH improvement - combustion
- ▶ Cost reduction
- ▶ Weight reduction

- ▶ Fully variable valvetrain
- ▶ Hybridization
- ▶ Stricter combustion control
- ▶ Source emissions reduction
- ▶ Low temperature combustion
- ▶ Waste heat recovery
- ▶ Gaseous fuels - CNG/LNG/LPG
- ▶ Alternative and bio fuels



Excellence in automotive research and development – a concept IAV applies across the globe

