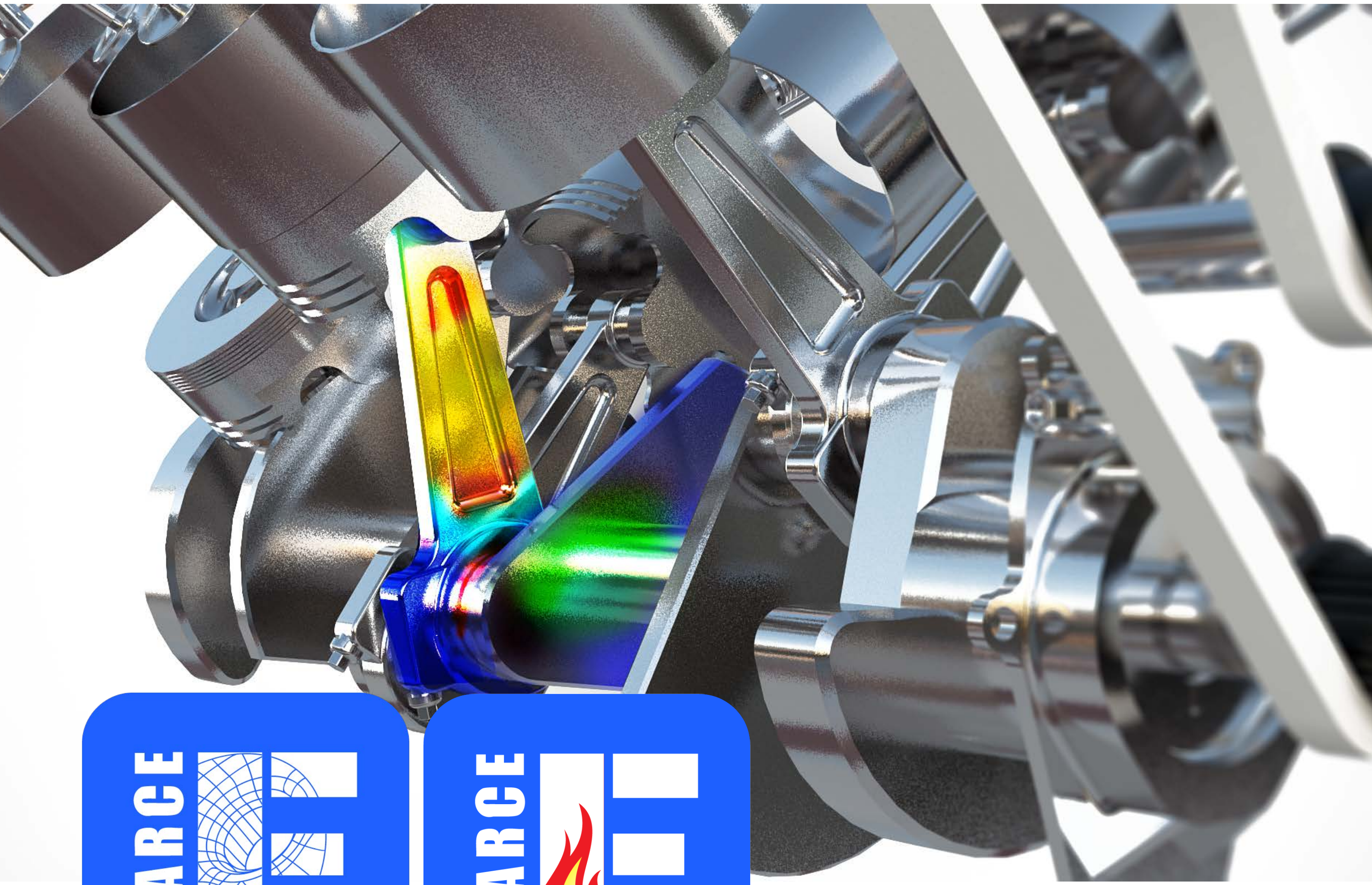

FEARCE / FEARCE-Vulcan

THERMAL AND STRUCTURAL FE ANALYSIS OF POWERTRAIN SYSTEMS

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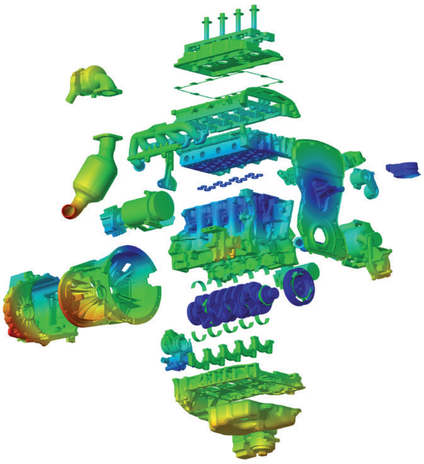
What is FEARCE ?

FEARCE is a finite element (FE) pre- and post-processing environment written specifically to support engine and vehicle analysis. FEARCE acts as an interface to integrate each stage of an FE analysis, from assembling of component models into larger systems, through the application of loads and boundary conditions, to the solution and post-processing of results. FEARCE adds automation to these key tasks so that complex analyses can be performed quickly and accurately whilst ensuring common processes are identical between iterations.

Key features

- Integrated graphical user interface providing a single environment for each stage
- Unique network approach allows user to construct complex FE assemblies from component models
- Automated joining of interfaces between components
- All types of connectivity can be applied, including advanced non-linear interfaces such as contact joins and structural or thermal gaps
- Dissimilar meshes can be joined using multi-point constraints
- All connectivity is automatically checked, with conflicts, fixes and warnings flagged and documented
- Easy application of force, pressure or displacement loads to the system
- Automatic mapping of boundary conditions from external sources
- Internal linear solver and translators to automatically set up solution decks for all major third party FE packages
    - Full suite of post-processing tools, including
    - Plots and animations
    - Loadcase combination and factoring
    - Bore, bearing and valve distortion studies
    - Durability analyses
    - NVH studies



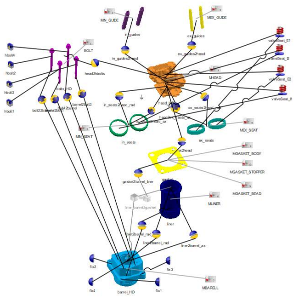
Model assembly

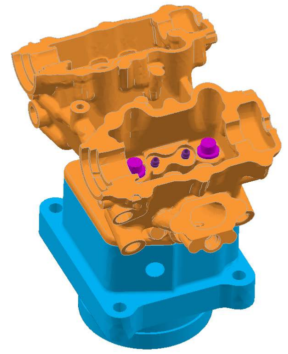
FEARCE provides powerful tools that automate the creation of systems built from one or more individual model components. The pre-processing GUI allows a user to build-up a 2D network of models and connection, whilst at the same time displaying the fully 3D view of the resulting assembly.

Connectivity between contact surfaces is defined identifying surface geometry rather than relying on the individual node IDs of the models. This allows components to be easily replaced within assemblies whilst retaining the same physical joins. Mating surfaces can be defined using the FEARCE GUI – or with third-party modelling packages, if preferred.

FEARCE provides tools for the automatic generation of bolts. This can be done using a simplified beam model, where the user defines the head and thread contact regions along with the bolt shaft diameter and material.

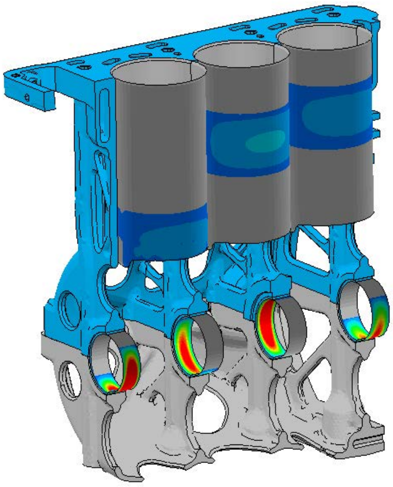
- Importing component models from different sources
- Scaling, translation and transformation of models for assembly
- Enabled copying of repeated components (e.g. valve seats) to reduce modelling overhead
- Joins are based on mating surfaces rather than node numbers–allowing for changes to be made easily
- Various types of connections (e.g. slide, contact, weld, thermal and structural gaps) can be generated automatically
- Automatic joining of dissimilar meshes using multi-point constraints
- Automatic checking of assemblies, with conflicts, fixes and warnings flagged





Application of loads

FEARCE incorporates a range of features to aid the engineer in applying loads to FE structures and assemblies. A user only has to select a named area, choose what type of load is required and FEARCE will automatically distribute pressure across a surface, ensuring that individual nodes are supplied with the correct force components.



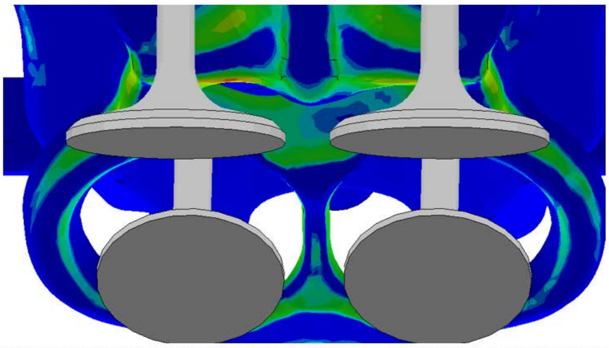
- Pre-processing time reduced through automation of load application
- Increased accuracy as loads are defined explicitly and any conversions (for example pressure into force) are carried out by FEARCE
- Load regions are defined as named areas rather than relying on individual node IDs – allowing component models to be easily replaced
- Bearing models allow accurate profiles to be added automatically regardless of mesh distribution
- Mapping of loads between models

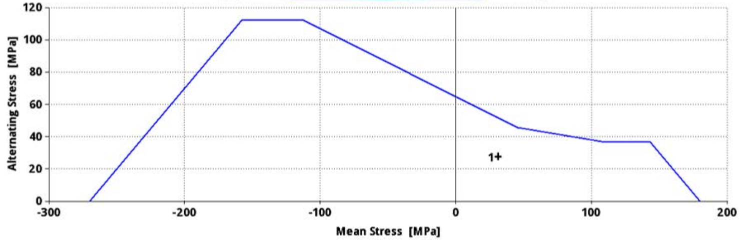
Durability analysis

FEARCE incorporates a fatigue module that includes a large array of linear and non-linear durability algorithms. Linear algorithms include the Goodman and Gerber methods. Multiaxial algorithms include Dang Van, McDiarmid and Multi-axial Goodman methods. For non-linear analyses the SWT, Brown-Miller and Fatemi-Socie methods can be employed. The toolset also provides alternative approaches to calculating a stress tensor from the principal stresses; these include the Von Mises (signed and unsigned), the maximum principal stress approach, the P1 principal stress approach and the ASME approach.

Another fatigue algorithm included in FEARCE is the FKM method where stress gradient and material notch sensitivity effects are considered. FEARCE will calculate fatigue safety factors for defined regions based upon either infinite or defined life. All results can be displayed on the actual FE model as numeric values or colour contours.

FEARCE can also perform reliability calculations by defining the standard deviation on all material properties and loads. This enables the calculation of the number of failures within a given life span.





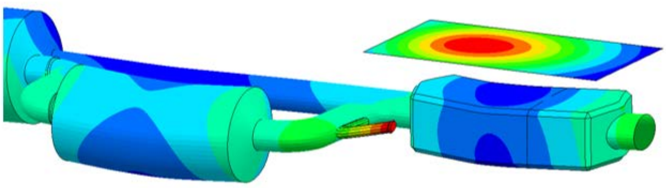
- Large array of linear and non-linear fatigue algorithms
- Flexibility in equivalent uniaxial stress calculation
- Automatic generation of Haigh diagrams
- Results displayed directly onto models
- Prediction of Number of Failures

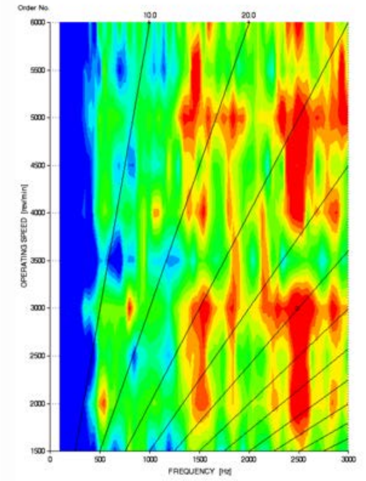
Noise, Vibration and Harshness (NVH)

FEARCE includes an advanced NVH module for vibration and sound prediction.

The FEARCE NVH module carries out vibration analyses on models by performing a forced response after a modal analysis has been run. A sinusoidal forcing function is applied to the mode shapes as a Fourier loading on individual nodes in the frequency domain. This loading is then solved to calculate the resulting contribution of each mode. Finally, the modal contributions are combined to give complex vibration levels for each forcing frequency. Output can be in either the time or frequency domain. Calculated values are nodal displacement, velocity and acceleration spectra.

- Direct and indirect vibration solutions
- Rayleigh and BEM solution methods
- Automatic creation of BEM meshes





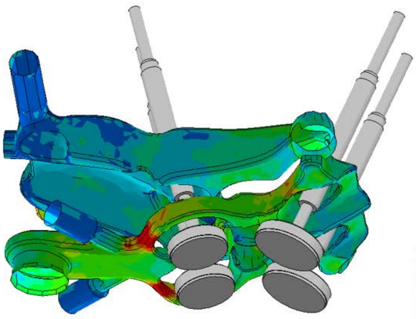
Thermal boundary conditions

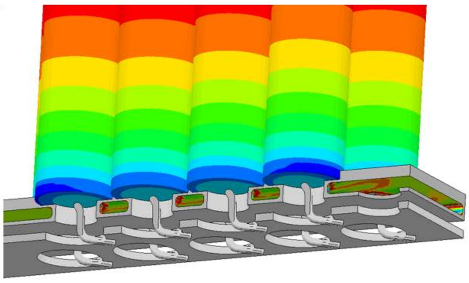
FEARCE has unique capabilities for the prediction of temperatures in combustion systems. In powertrain analysis, the accurate determination of the temperature distribution at key operating conditions is critical to component design. FEARCE has been developed specifically to address these needs and so provides a number of tools for the application of thermal boundary conditions to an FE analysis.

For coolant side boundary conditions, FEARCE can quickly and efficiently map fluid temperature and heat transfer coefficients (HTCs) from CFD analysis onto the appropriate coolant surfaces of the FE models. This can be done by either linking directly into Realis's VECTIS CFD code, or by mapping from ASCII tables of co-ordinate temperature and HTC values output from any major CFD solver.

In addition to linking directly to VECTIS to extract results, the FEARCE GUI can also display the VECTIS models, allowing an engineer to visualize the CFD results alongside the loaded FE models. The effect of nucleate boiling can be simulated as part of an iterative solution using a map of heat transfer coefficients dependent on the resultant wall temperature.

- Flux, temperature, HTC and pressure interpolated CFD results
- Links directly with VECTIS for results extraction and visualization
- Time averaging of transient results for steady state analyses
- ICE thermal boundary conditions module





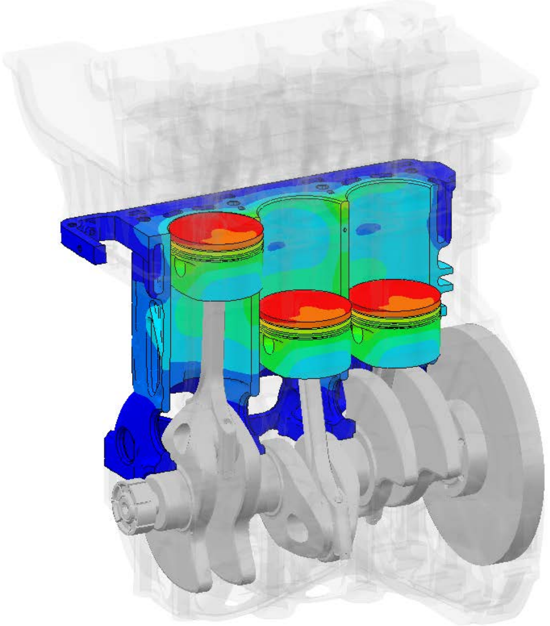
In cylinder thermal boundary conditions

For in-cylinder thermal boundary conditions a dedicated FEARCE-Vulcan module is available.

This tool considers all the heat paths of the power cylinder using physical models and semi-empirical correlations, without necessarily the need for CFD analysis.

Alternatively, results from VECTIS or other CFD solvers can be imported to predict gas-side HTCs resulting from combustion.

FEARCE then calculates cycle averaged loads from the imported full-cycle values to calculate steady-state temperatures.



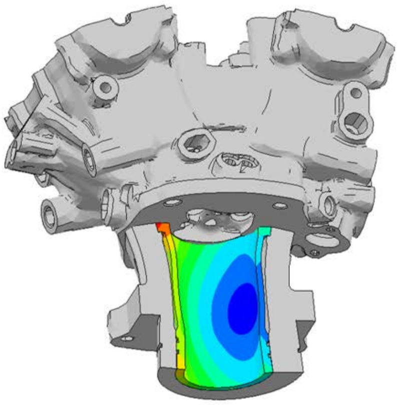
Solution and post processing

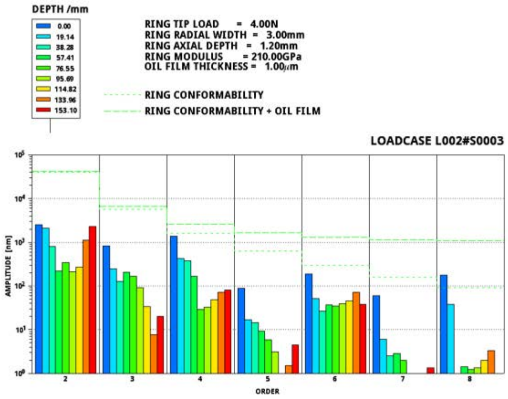
FEARCE contains it’s own linear solver. Ideal for thermal analysis – the solver has been benchmarked and proven to be as accurate and faster than the major 3rd party alternatives – it can be used for a range of solutions, including; displacement prediction, stress prediction, modal contribution, forced response analysis, eigenvalue calculation and model reduction.

Beyond the initial solution, FEARCE includes a large number of post-processing tools, many of which have been developed for the specific needs of powertrain and vehicle analysis. For linear analyses, results loadcases can be combined and factored to create more complex conditions. This includes calculations to account for the amelioration of bolt loads in an assembly. In non-linear solutions, nodal stress and strain histories can be identified and plotted.

For powertrain analysis, FEARCE can perform bore, bearing and valve distortion calculations and produce suitable plots of deformations, harmonics, alignment and ring conformability.

For vehicle analysis FEARCE can carry out design sensitivity analyses, perform quick checks for modal assurance, and provide transient difference plots between models undergoing crash analyses.





- Built-in linear solver
- Solution set-up for any major 3rd party FE package
- Range of post-processing tools
- Loadcase combination and factoring
- Stress and strain history plotting
- Thermocouple and strain gauge predictions
- Bore, bearing and valve distortion plots
- Design sensitivity analysis
- Durability calculations

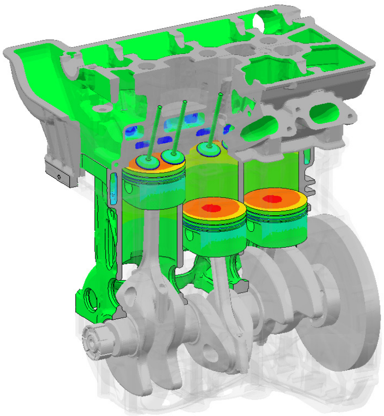
What is FEARCE-Vulcan ?

FEARCE-Vulcan uses a unique iterative Finite Element (FE) solution that considers all the heat paths in detail to calculate the thermal boundary conditions of the power cylinder components using physical models and semi-empirical correlations, without the need for CFD analysis. This overcomes the limitation of database methods which are not predictive and delivers a reliable and accurate predictive tool for conclusive structural investigations.

The iterative solution runs quickly enough to allow different design variants to be assessed for multiple operating conditions. The calculated temperatures and the corresponding deformations can then be used to predict piston secondary motion and ring dynamics and to better predict friction, wear and oil consumption of the power cylinder and the structural durability of the components.

Key features

- All heat paths of the power cylinder are considered
- Dedicated graphical user interface
- Supports diesel, gasoline, natural gas, hydrogen, ammonia and ethanol combustion
- Optional CFD combustion boundary conditions can be included
- Automatic generation of piston and piston rings' dynamic models
- Support of sodium cooled valves
- Considers Piston cooling jets (PCJ) and pistons with a gallery
- Includes nucleate boiling effects on coolant side of cylinder bore
- Run Distribution Manager (RDM) allows cases to be run in parallel
- Deivers thermally efficient IC engines in ever-shorter timescales

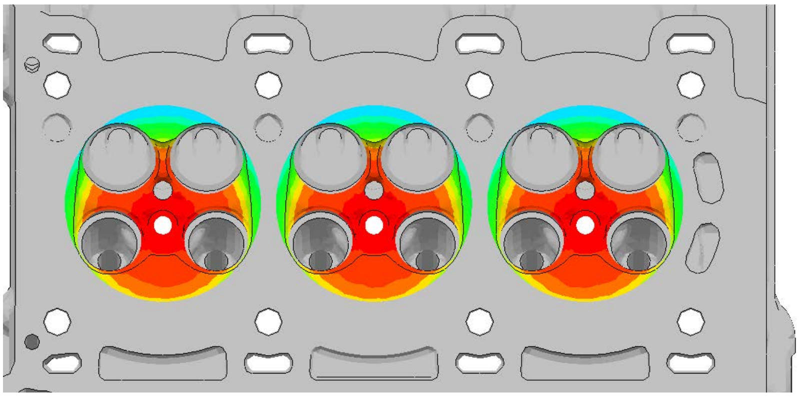


Thermally modelling smaller, more efficient and lower emission IC engines

As IC engines become smaller, often in a hybrid system, this requires higher peak cylinder pressures to improve fuel economy, which drives higher in-cylinder temperatures. Analytical tools are required to optimize the design to deliver more durable components, whilst minimising extensive testing to reduce product development costs.

Thermal survey measurements are an important part of engine development and are used together with CFD to predict component temperatures. However, these measurements and analytical methods can be costly, time and labour intensive, and in the case of the measurements require a physical engine.

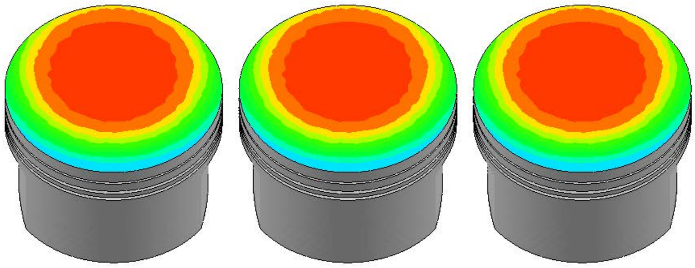
FEARCE-Vulcan can be used early in product development before hardware exists reducing CFD and thermal survey costs making the engine development cycle more efficient. This new tool also meets the future challenges of ICE design and development, by accurately predicting the thermal loading and temperatures of an ICE quickly under multiple full-load and part-load conditions.



In-cylinder thermal modelling

The in-cylinder model generates thermal boundary conditions considering the heat transfer between the cylinder gas and surrounding components exposed to the cylinder gas - namely the piston crown, cylinder wall, cylinder head flame face and the flame faces of each valve.

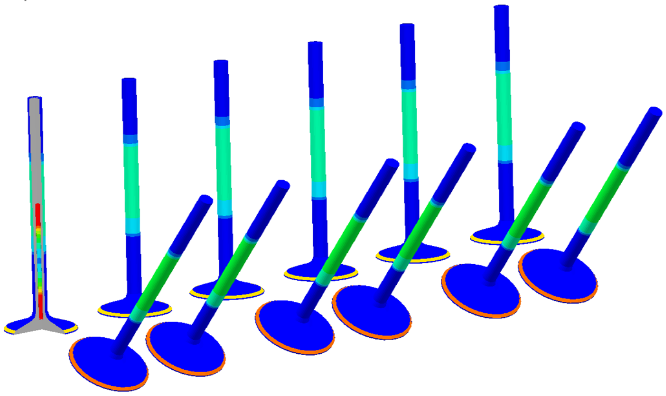
Piston crown and flame face boundary conditions are based on the propagation of burned gas during combustion. Spatial variation of gas temperature is determined using a two-zone combustion model by splitting the average temperature into temperatures of burnt and unburnt zones, to calculate for each point on the surface its exposure to each zone.



Valve modelling

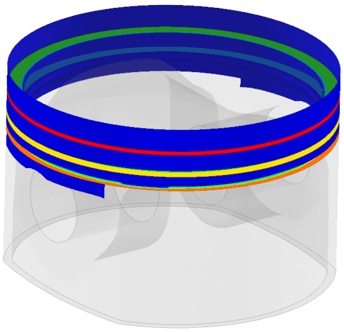
The valve model generates thermal boundary conditions from the convective heat transfer between the valve, cylinder and port gases, together with the heat transfer between contact interfaces, namely the seats and guides. For those surfaces of the valve exposed to the gas in the cylinder, the in-cylinder model calculates the thermal loads and projects them onto the exposed valve surfaces. For sodium cooled valves the sodium temperature is simulated as part of the iterative solution

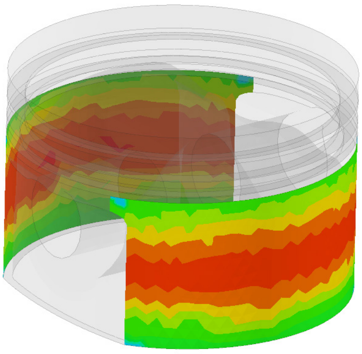
- Gas load on the valve head
- Gas flow over the back face
- Gas flow around the stem
- Oil film conduction to the guide
- Seat contact when the valve is closed
- Gas flow over the seat when valve is open



Piston to liner interface modelling

The piston to liner model considers ring dynamics and piston secondary motion to generate thermal boundary conditions, considering heat transfer between the piston rings and liner, as well as the piston skirt and liner.





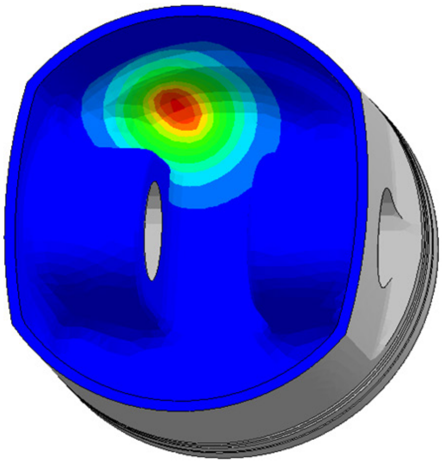
Piston secondary dynamics and piston rings' dynamic models are automatically generated from the supplied geometric and FE data to calculate clearances and heat transfer between the skirt, rings, piston grooves and liner. The heat transfer data are mapped and cycle-averaged onto the FE models of the piston and cylinder bore.

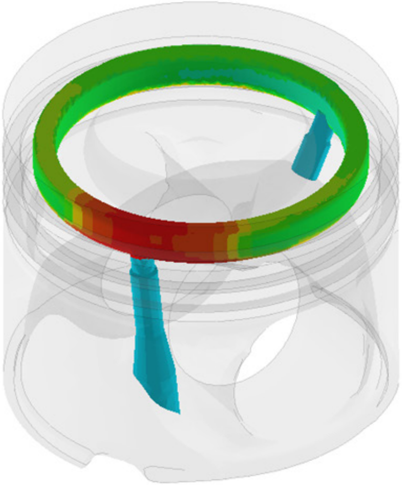
Piston cooling

The piston cooling model considers cooling mechanisms due to piston cooling jets, gallery cooling and crankcase oil.

The piston cooling jet model requires as input the position, angle of each jet and oil supply boundary conditions. The model considers the following features to derive the thermal boundary conditions:

- Impingement durations
- Spatial variation due to the jet spreading
- Varying impingement location
- Asymmetric flow due to compound impingement angle



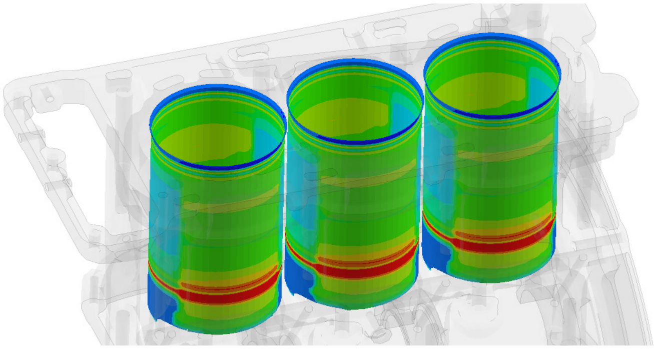


Cylinder bore

Cycle-averaged boundary conditions are applied to the cylinder bore due to in-cylinder combustion and piston thermal loading via the ring pack and skirt, together with cooling due to the oil.

Boundary conditions due to flow of the coolant are either applied as constant HTC and fluid temperature values to the surfaces defining the water jacket, or mapped from an isothermal CFD analysis of the coolant circuit.

The effect of nucleate boiling is simulated as part of the iterative solution using a map of heat transfer coefficients dependent on the resultant wall temperature. In the locations where the resultant wall temperature is predicted above the boiling point, the heat transfer coefficient is adjusted (increased) and used for the next iteration.



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