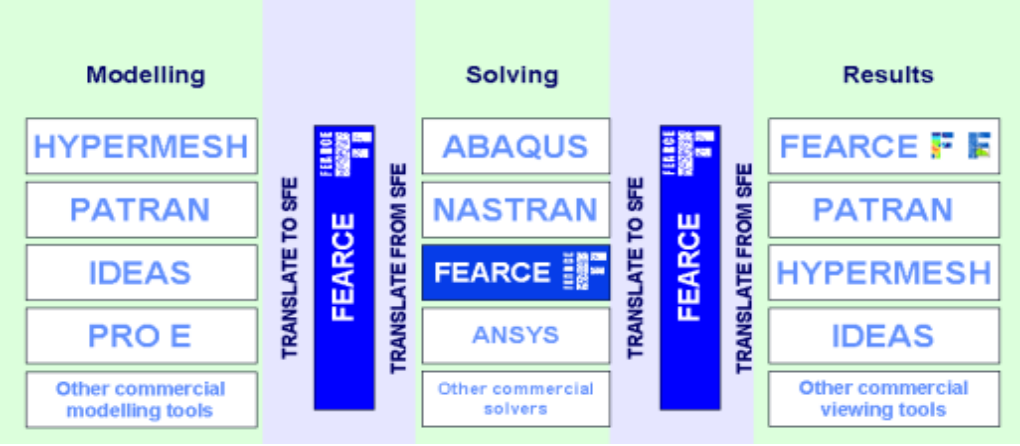
FEARCE Overview

Ricardo Software

Contents

What is FEARCE?

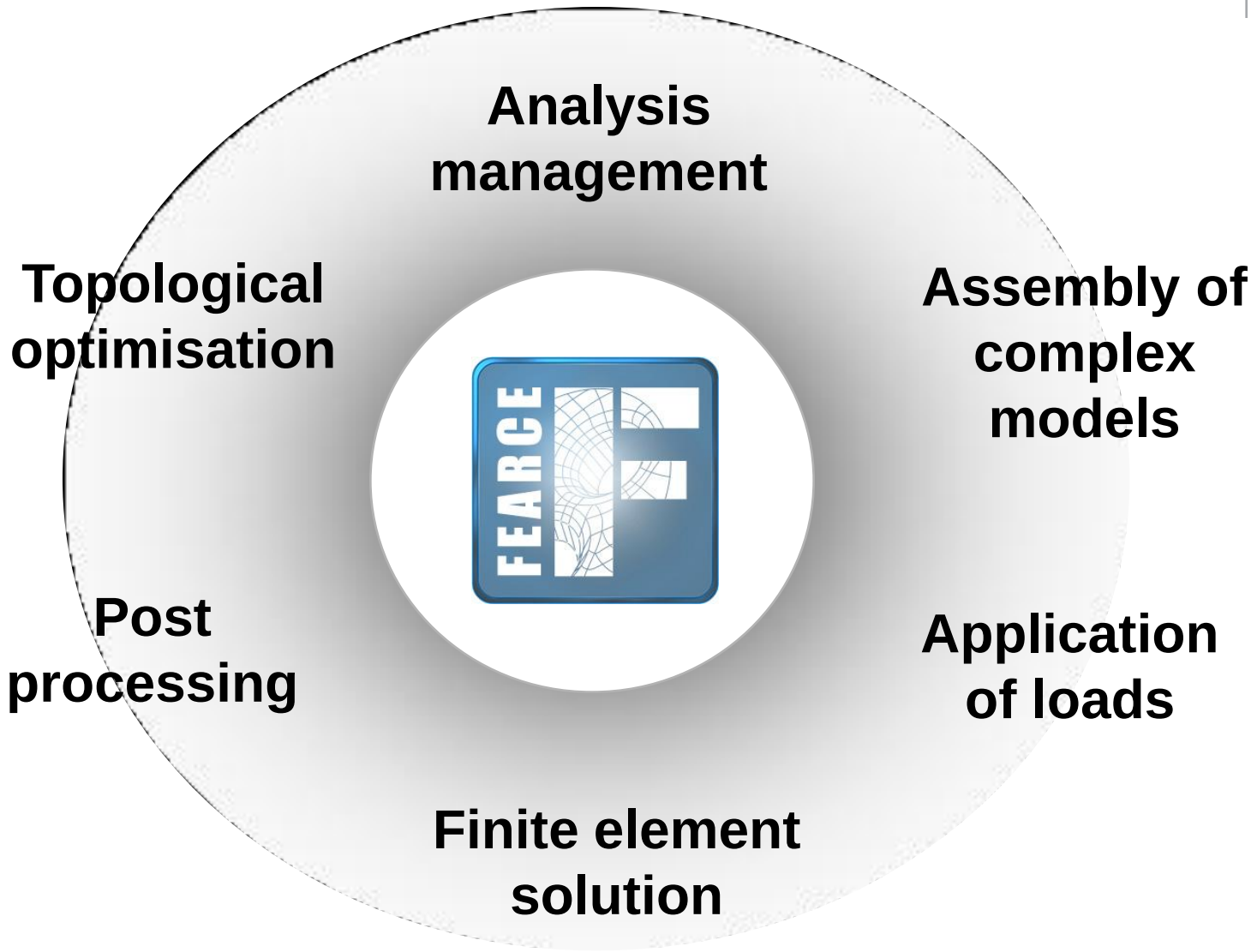
- FEARCE is a finite element pre and post processing package written specifically to support engine and vehicle analysis which has been used at Ricardo for over 20 years
- FEARCE acts as an interface to integrate each stage of a finite element analysis (FEA)
  - From the assembly of component models into larger systems
    - Through the application of loads and boundary conditions from a variety of sources
      - 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
- With its ability to manage the data flow from multiple sources, coupled with an extensive set of pre and post processing tools, FEARCE is a natural hub for powertrain FEA



Contents

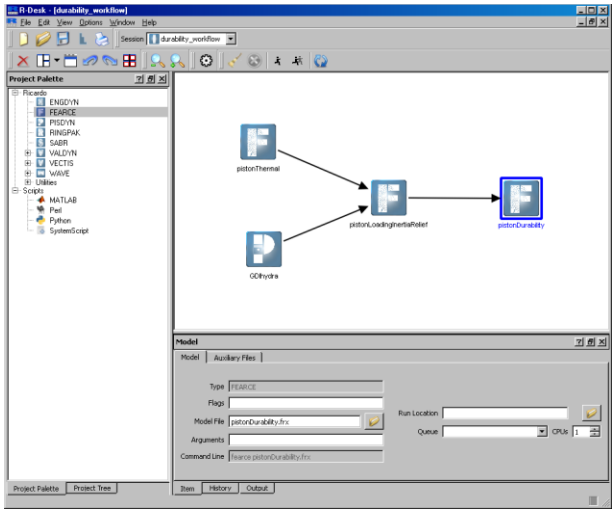
- What is FEARCE?
- **What does FEARCE do?**

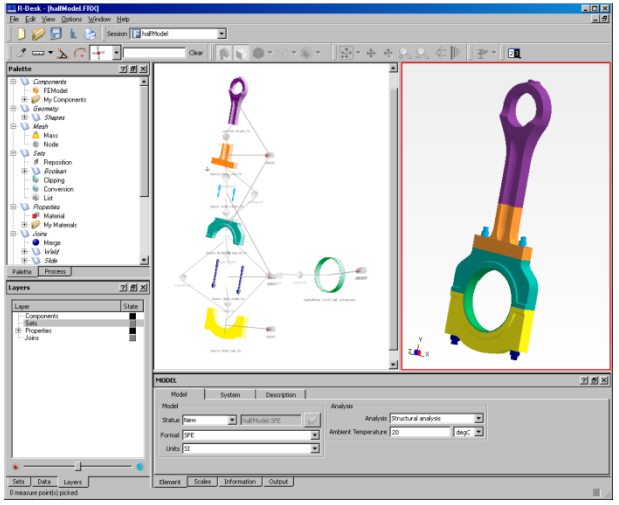
What does FEARCE do?



What does FEARCE do?
Analysis management

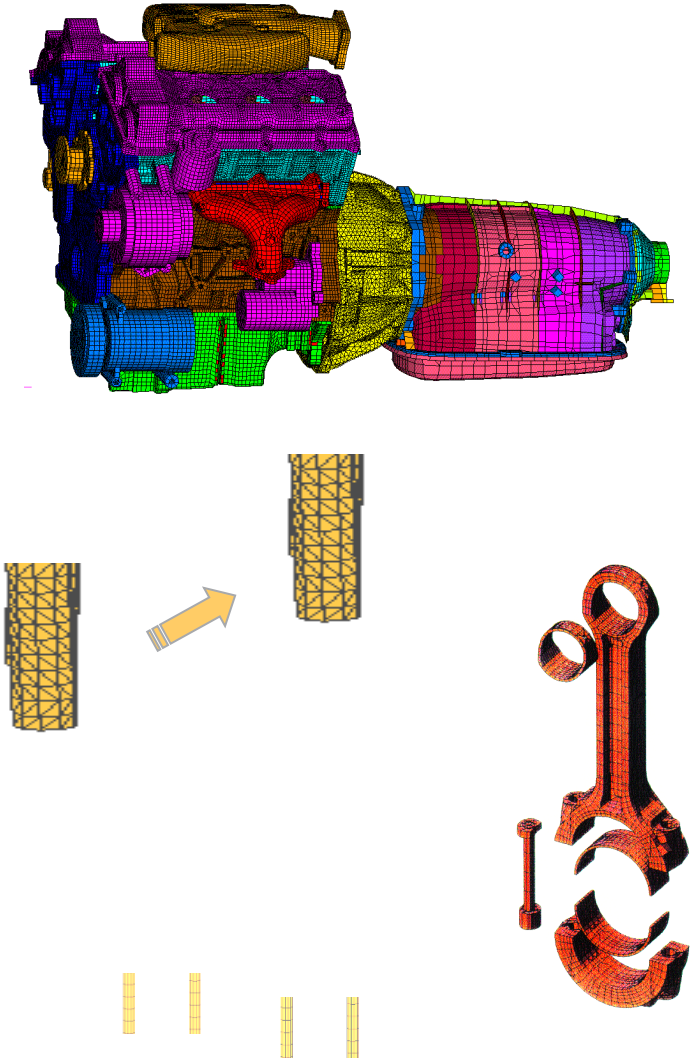
- Common applications:
  - Setting up and running whole analysis workflows using the top level Project tool
    - Several analyses using various tools can be linked together into a continuous workflow
    - Dependencies are handled through the Project
    - All Ricardo products fully linked
      - Third party software can be linked through run scripts
  - Setting up and managing complex finite element assemblies
    - Component parts selected through a parts store
      - Each part easily replaced for iterations
    - Joins and loads defined within the process and easily modified without changing mesh





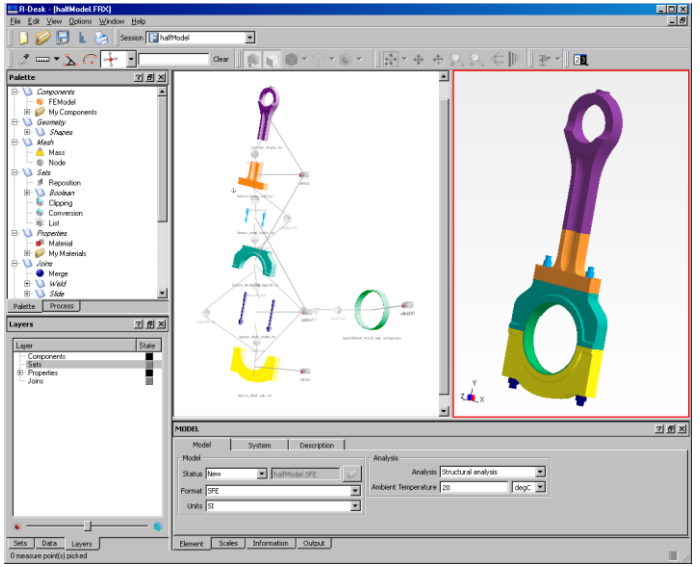
What does FEARCE do?
Assembly of complex models

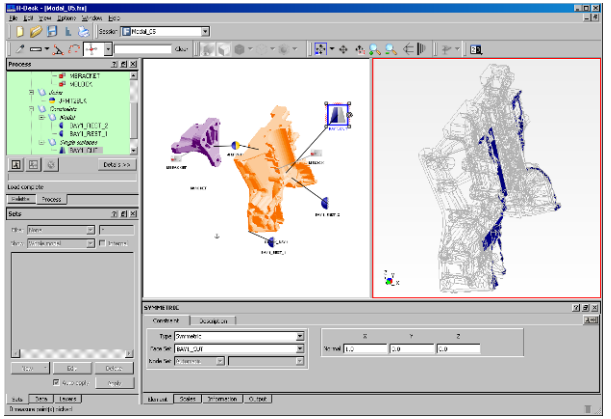
- Common applications:
  - Importing component models from different sources
  - Scaling, translation and transformation of models for assembly
  - Copying of repeated components (e.g. valve seats) to reduce modelling overhead
  - Automatic joining of dissimilar meshes
  - Defining and editing the material and physical properties of model components
  - Addition of mass and spring elements to a system
  - Automatic generation of bolts and other simple FE components
  - Automated application of constraints and restraints to the assembly



What does FEARCE do?
Assembly of complex models

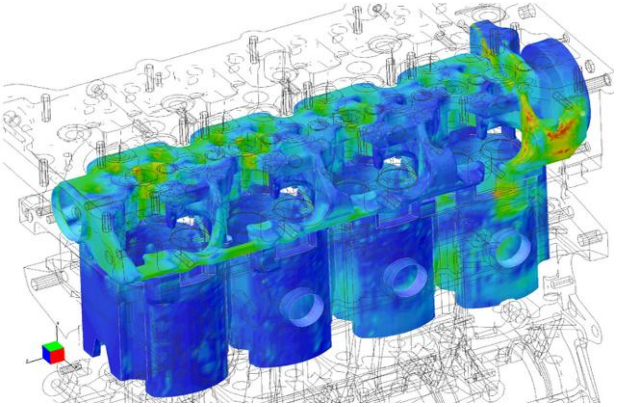
- Technical features:
  - Automated tools for the joining of non matching meshes between component models
    - No reliance on matching nodes or pre defined node numbers
      - User simply specifies the surfaces to be joined
    - Numerous types of joins can be generated including
      - Weld, slide, contact, thermal and structural gaps
    - All standard mesh types supported
    - Automatic checking of joins with conflicts, fixes and warnings flagged
  - Single and multi surface constraints easily applied by simply specifying the surfaces and type of constraint required
    - Often used to define physics on cut planes for models representing sections of an assembly
  - Simple FE models automatically generated from geometric definition
    - E.g. bolts, bearing shells, primitive shapes

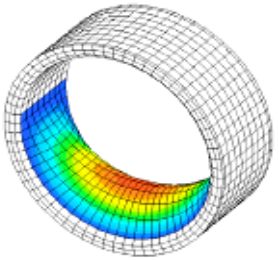


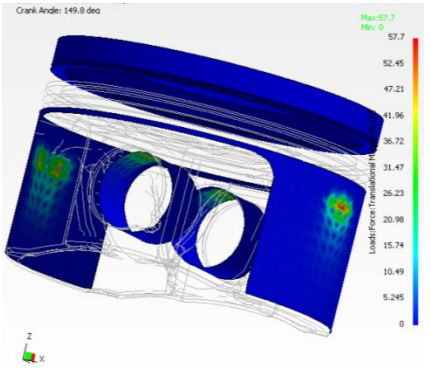


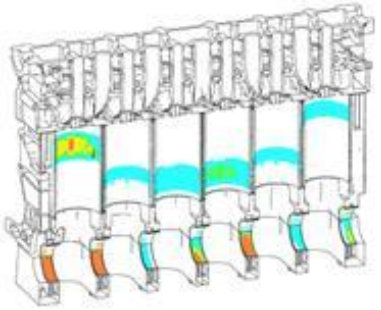
What does FEARCE do?
Application of loads

- Common applications:
  - Linking data from various sources to manage complex FE projects
    - Interpolation of CFD results onto FE models
      - Direct links to VECTIS binary file
      - Ability to visualise data from ASCII files
    - Mapping of complex mechanical loads onto FE assemblies directly from dynamic solvers
      - VALDYN, PISDYN and ENGDYN
  - Applying correctly distributed bearing loads across loaded surfaces
    - Bearing model just requires maximum load bearing type and reference to the loaded surface
  - Automatic generation and loading of bolts in FE assemblies



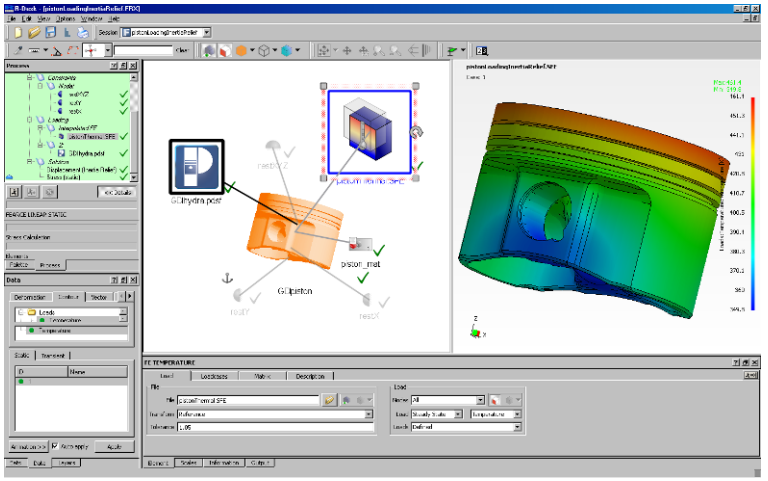


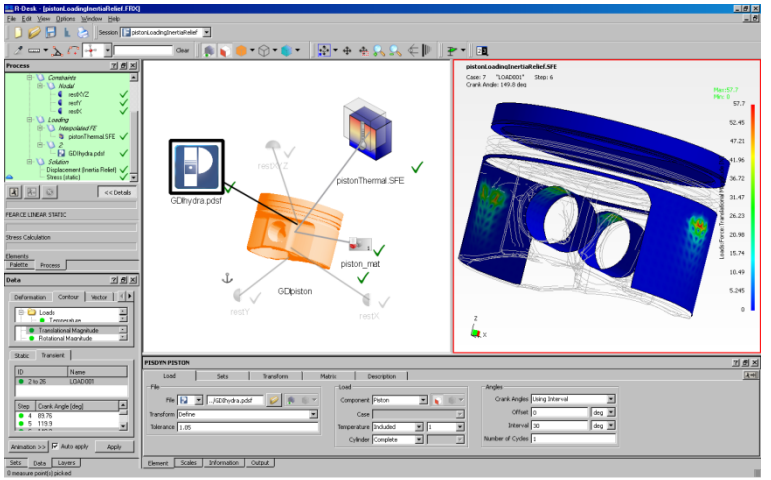




What does FEARCE do?
Application of loads

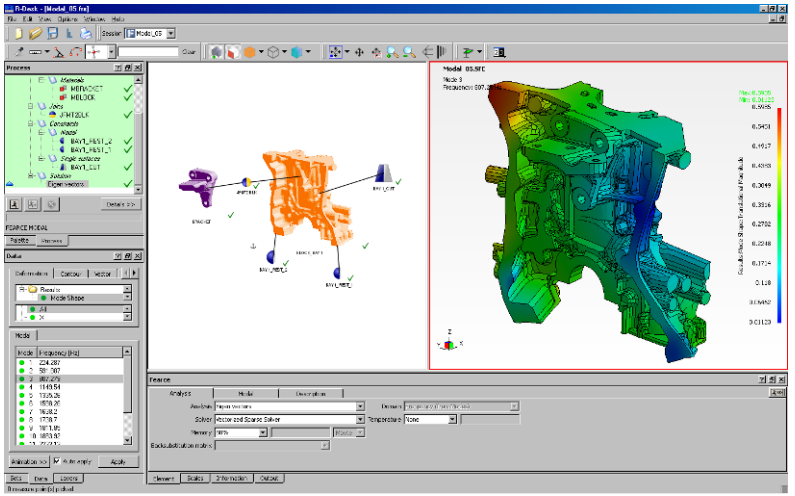
- Technical features:
  - FEARCE contains numerous tools for the management and application of data to the nodes of the FE assembly
  - Data can be interpolated from external FE or CFD models with different meshes with FEARCE ensuring that the distribution of the nodal data is accurately applied
  - In a similar way data can be extracted and applied from ASCII files containing no more than nodal co-ordinate and associated data
    - Again this co-ordinate space does not need to match the current FE assembly
  - Direct links to other Ricardo solvers provides simple, fast and accurate mapping of loads from other analyses

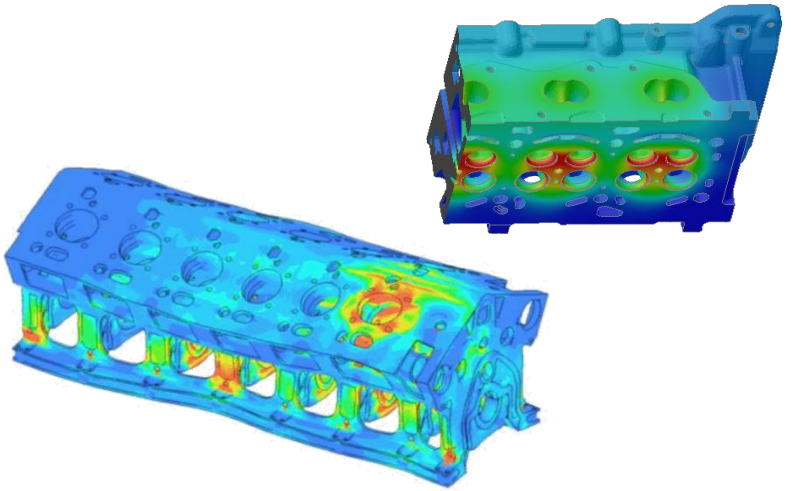




What does FEARCE do?
Finite element solution

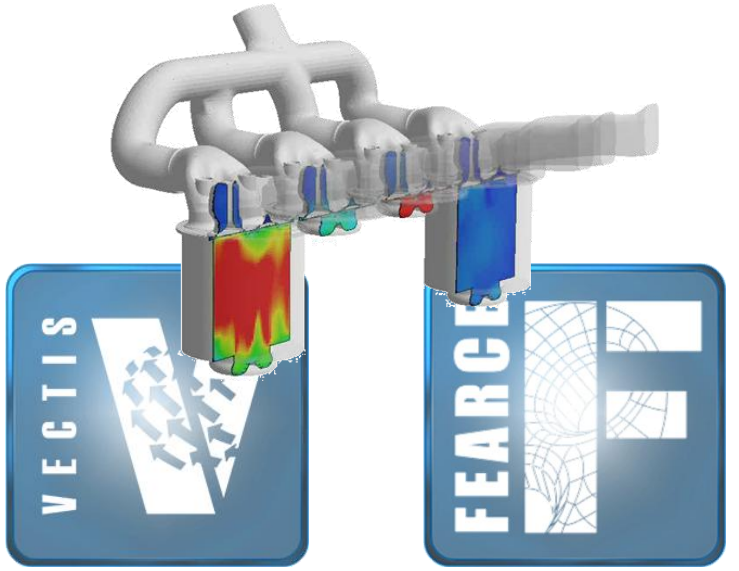
- Common applications:
  - All common solutions supported
    - Either directly through FEARCE linear solver
    - Or linking to major third party solvers for non linear and advanced solutions
  - Typical linear solutions handled directly include
    - Thermal analysis
    - Linear displacement and stress
    - Strain energy analysis
    - Modal frequency analysis
    - FE model reduction
      - Static and dynamic
  - Typical links to third party solvers include
    - Non-linear join or material property analysis
      - ABAQUS and ANSYS supported

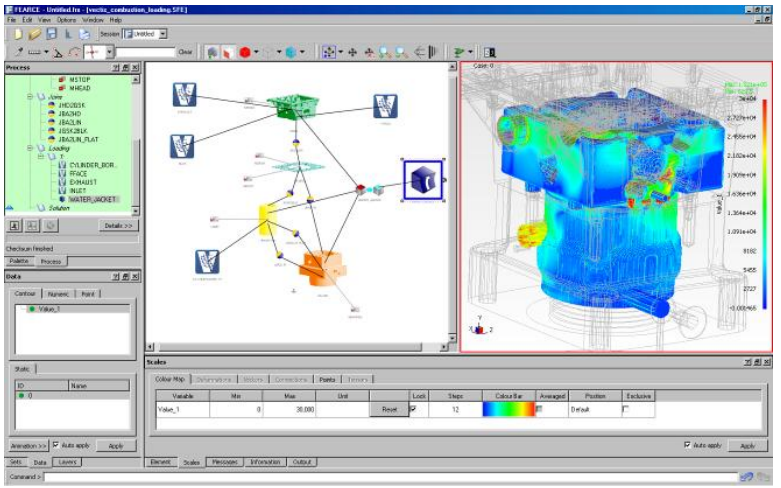




What does FEARCE do?
Finite element solution: Thermal analysis

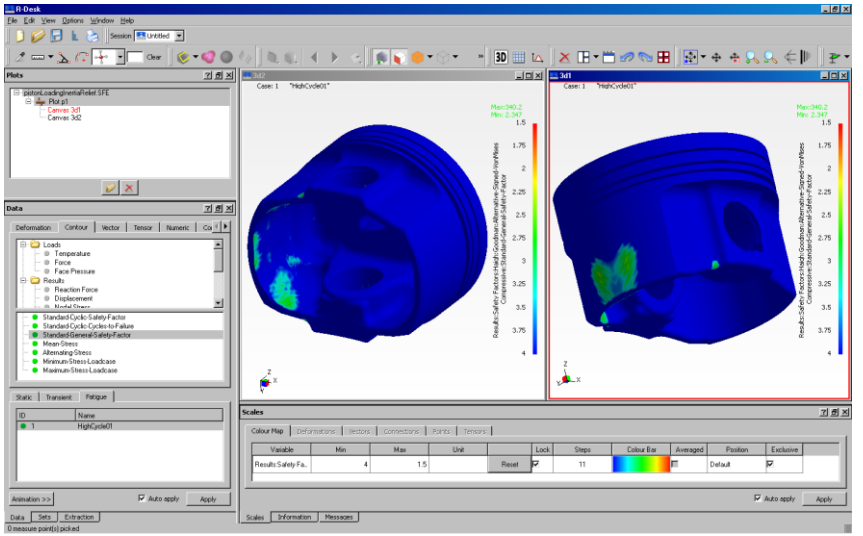
- The FEARCE thermal solver is benchmarked to be one of the fastest and most efficient available
- Combining this solver with FEARCE's vast array of tools for acquiring and defining thermal boundary conditions provides a unique system delivering real work flow advantage
- Further, by linking directly with the VECTIS a fully integrated CFD/FE thermal system tool is available
- Key features
  - Fully integrated CFD/FEA toolset
    - More flexible than just CHT or FE alone
  - Industry leading speed and performance
  - Solution can be performed on local machines
    - Frees up non-linear licenses and clusters

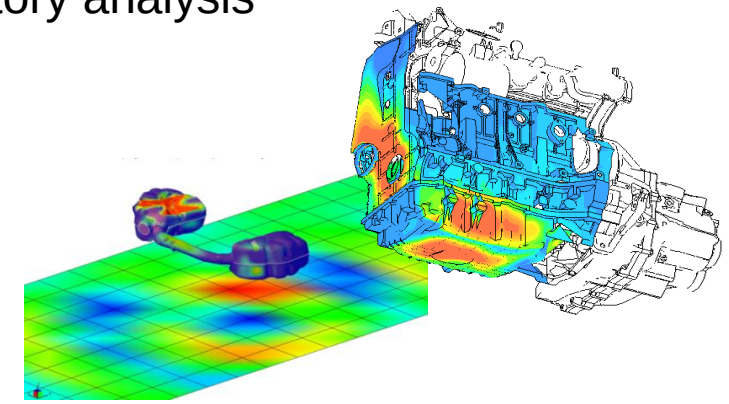


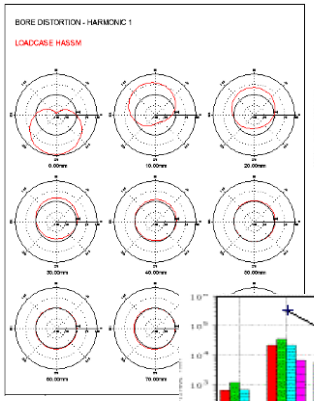


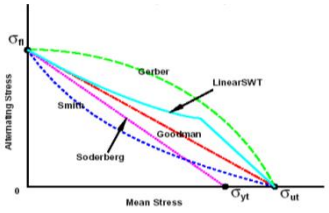
What does FEARCE do?
Post processing

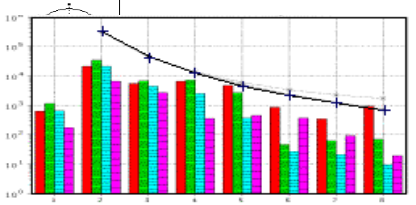
- Common applications:
  - Visualisation of results
    - 3D plotting and animation
    - Extraction of data
    - 2D plots
  - Bore, bearing and valve distortion analysis
    - Distorted shape, harmonics and alignment
  - Results combination and factoring
  - Thermocouple and strain gauge plots
  - Stress and strain history analysis
  - Durability analysis
  - NVH analysis





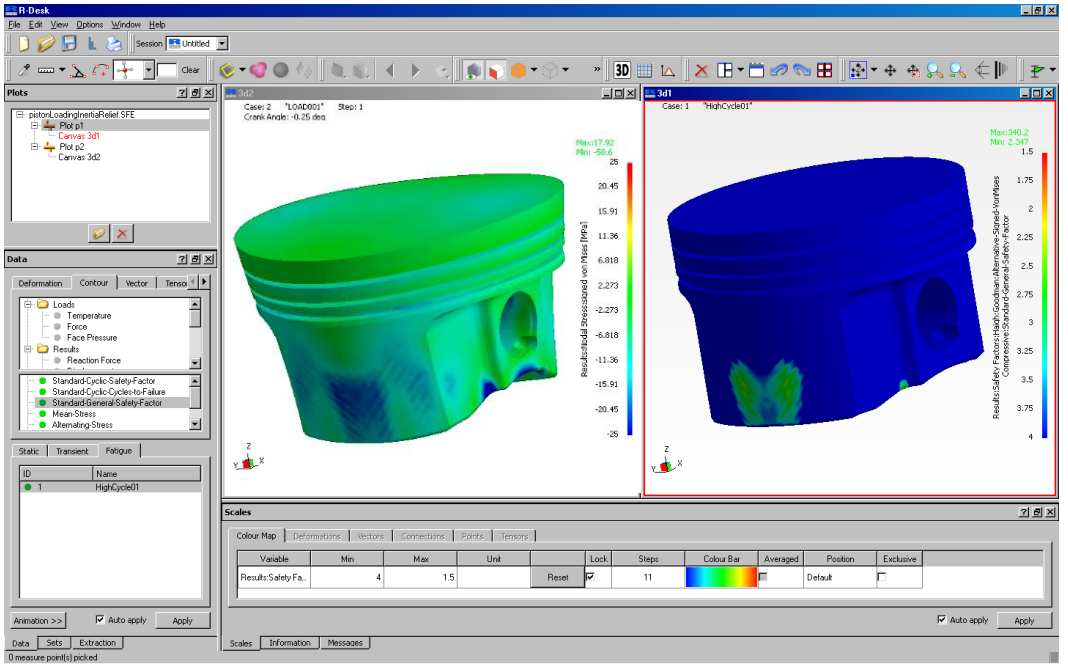






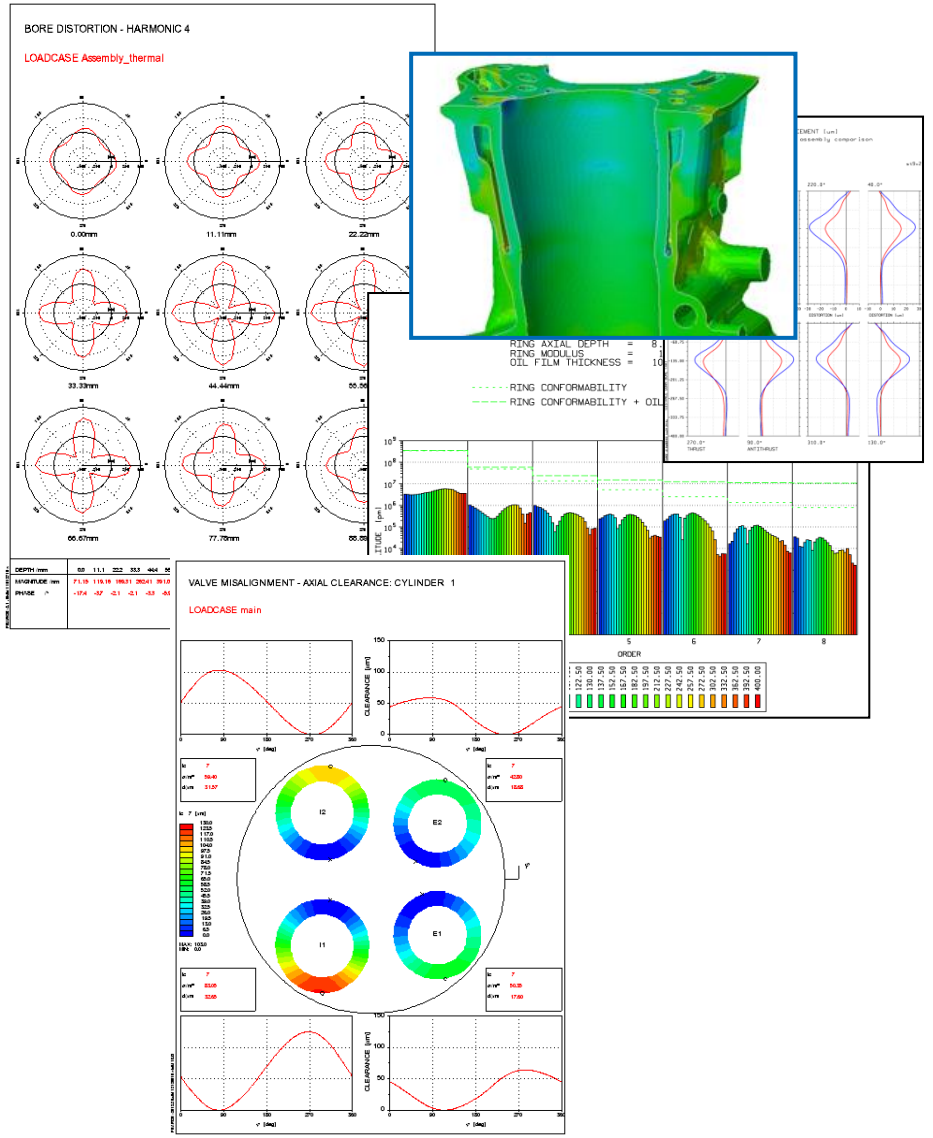
What does FEARCE do?
Post processing: Visualisation

- Technical features:
  - The FEARCE GUI contains advanced 3D viewing tools allowing results to be displayed in a number of ways, including
    - Displaced shapes
    - Contour plots
    - Vector, tensor and numeric plots
  - Results can be animated through sub-steps of the results or separate cases can be combined to create animations



What does FEARCE do?
Post processing: Distortion analysis

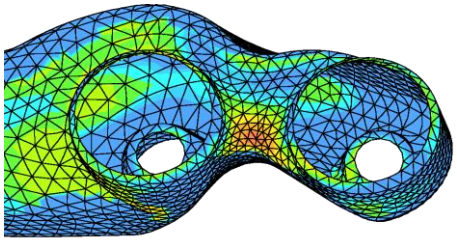
- FEARCE contains a number of tools for the detailed analysis of distortions specific to the powertrain system
  - Bore distortion provides absolute and harmonic analyses of the deformation of the cylinder liner under any load condition
    - Advanced options allow thermal dilation to be removed and conformability of the piston top ring to be estimated
  - Bearing distortion provides detailed analysis around the bearing as well as providing alignment analyses for multiple bearings on a shaft
  - Valve distortion calculates alignment between the valve guide and seat providing contact and sealing prediction at the seat to valve surface

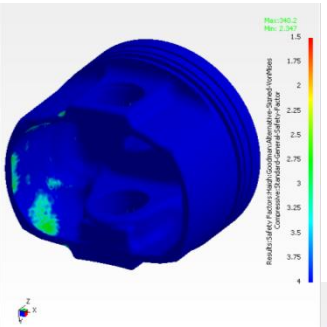


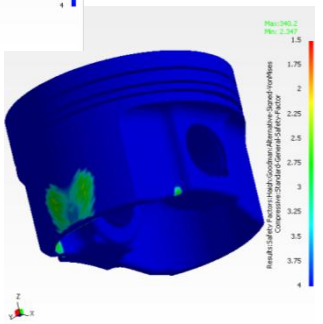
What does FEARCE do?
Post processing: Durability

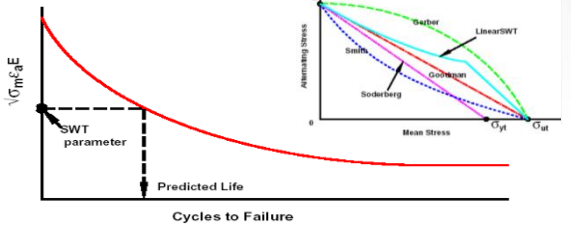
Details

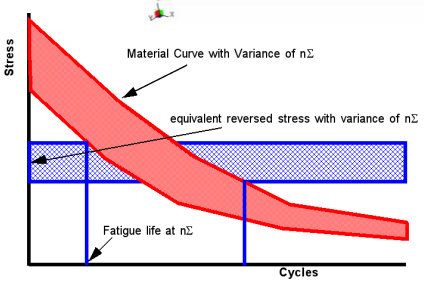
- Technical features:
  - FEARCE has its own durability solver that has been used extensively by Ricardo for over 20 years
  - The solver contains numerous linear and non-linear algorithms including;
    - Haigh (Goodman, Gerber, Smith and Soderberg curves)
    - Brown-Miller
    - Crossland
    - Dang Van
    - SWT
  - The solver also provides a number of alternate equivalent stress options as well as stress correction methods to account for such phenomena as high ductility
  - With 8.0 the solver was updated to include reliability analysis
    - With which a user can provide material data with statistical variation to obtain a confidence level of the final result







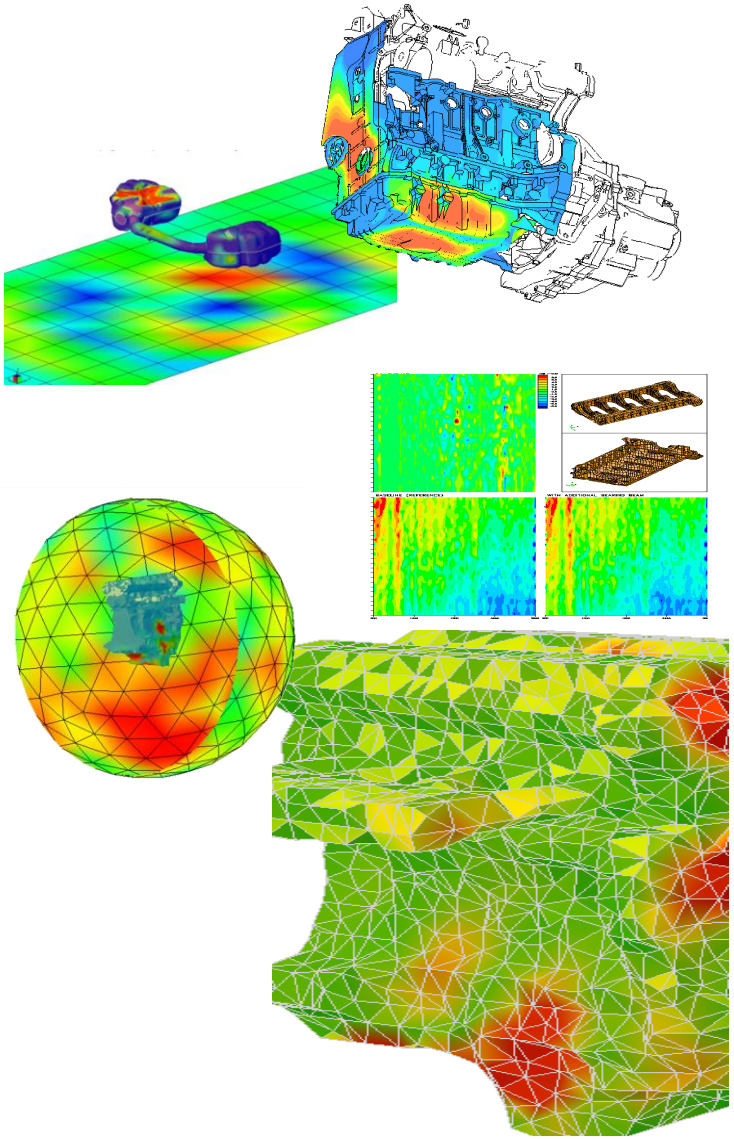




What does FEARCE do?
Post processing: NVH

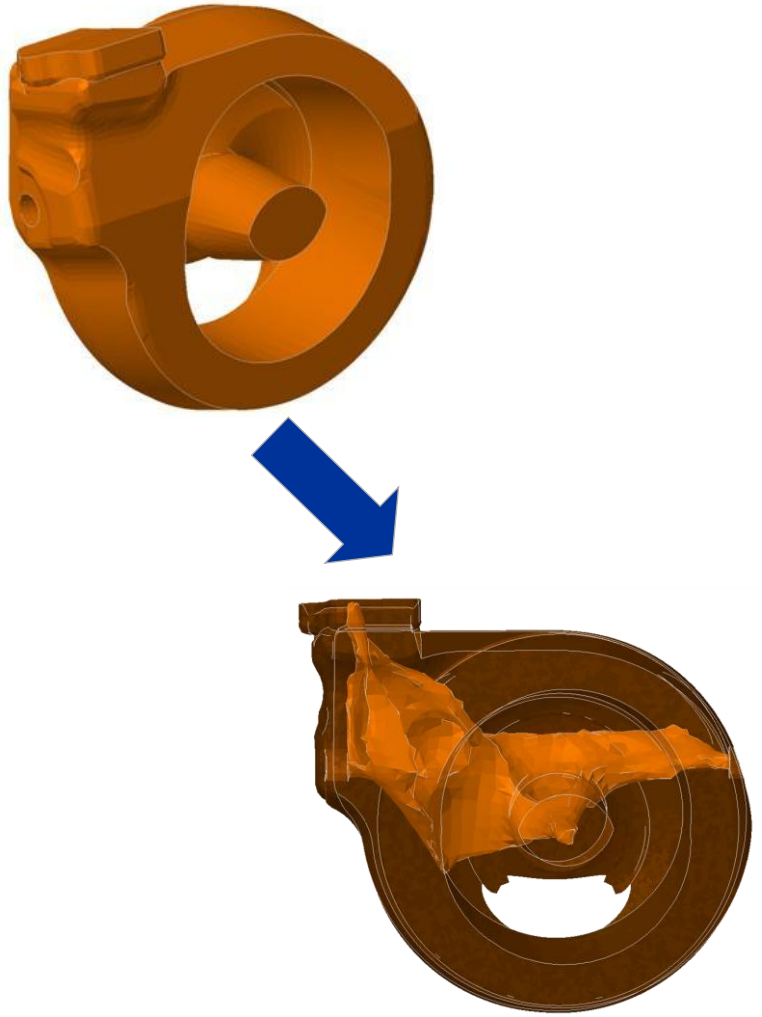
Details

- Technical features:
  - FEARCE carries out vibration analyses on models by performing a forced response after a modal analysis has been run
  - FEARCE closely couples with ENGDYN to generate the vibratory loads for a powertrain structure
    - FEARCE is used to apply the ENGDYN solution directly to the powertrain structure for further FE analysis
  - As a part of the vibration tools, FEARCE can carry out radiated noise analyses
    - Either the Rayleigh (or Helmholtz) method
    - Or the more rigorous Boundary Element Method
      - For this latter analysis FEARCE can also create the boundary mesh directly from the FE powertrain assembly



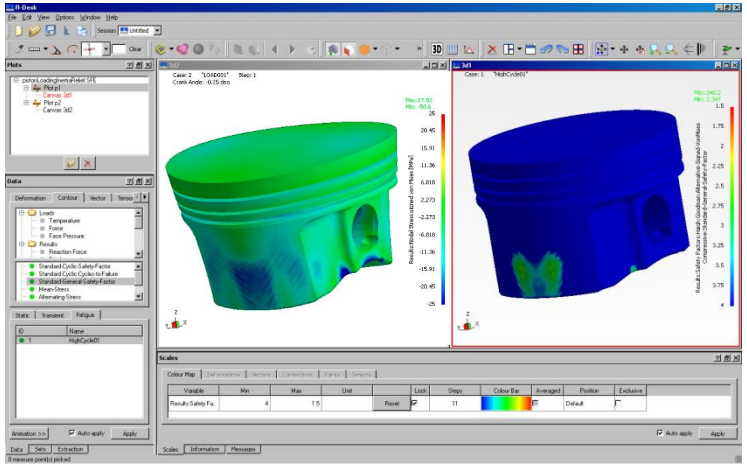
What does FEARCE do?
Topological optimisation

- Common applications:
  - The FEARCE Structural Exploration solver is used to ascertain paths of least work from a general design volume
    - This allows component shapes to be defined from basic packaging constraints and so uses FEA early in a design analysis
  - Current implementation allows optimisation based upon either displacement or frequency targets
    - Future plans include the inclusion of stress and durability as design targets



FEARCE Durability Overview

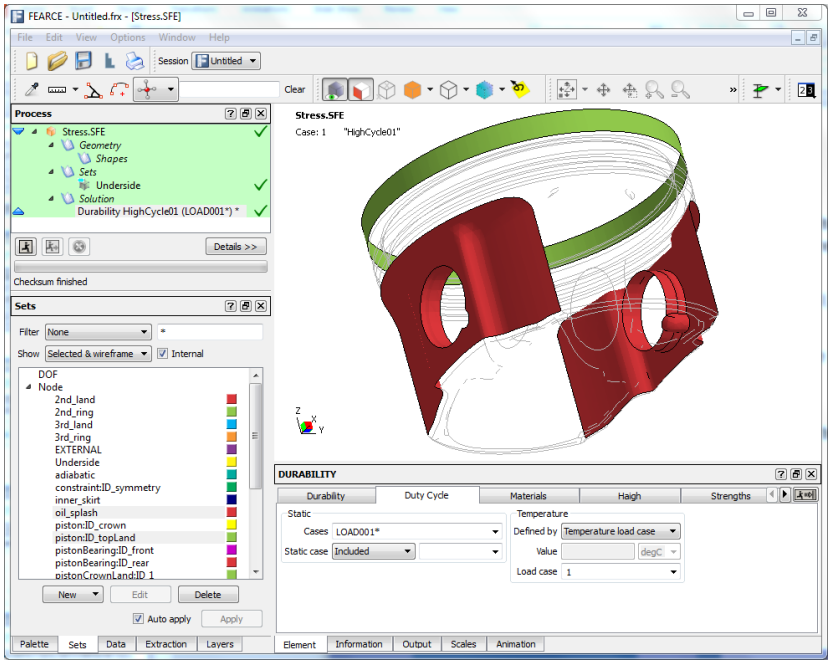
- Ricardo have used their own durability solver in all engineering projects since CAE began a core part of the engine design process
- The durability solver has been designed to meet the following criteria to ensure that it is the option of choice for every project
  - Easy to use
  - Fast and reliable
  - Able to work with results from any analysis
  - Provide a broad range of algorithms
  - Include advanced options
  - ...and most importantly to be accurate



- With durability at the heart of most powertrain design and development activities, the FEARCE solver has been a well proven tool used on hundreds of successful projects for nearly three decades

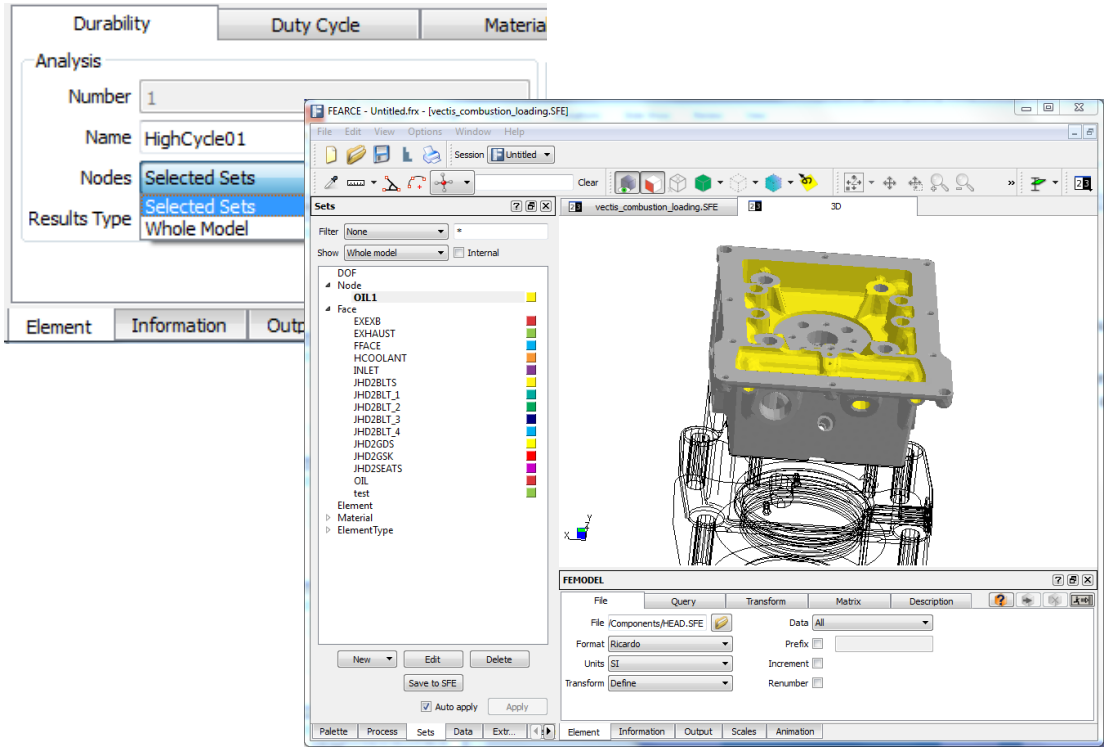
FEARCE Durability
Easy to use

- The FEARCE durability solver uses the same principals and techniques used in the FEARCE pre-processor to provide a tool that is extremely easy to use even for non FE specialists
- The solver can be used directly from the FEARCE GUI, or via simple batch files giving flexibility to how the system is used
- The system gives the user full control over the how the component is solved, providing simple options for;
  - Solving all or part of a system
  - Applying or changing the material data on the selected region of the component
  - Selecting the required load cycles
  - Choosing which equivalent stress criteria to use
  - Choosing which durability algorithm to use



FEARCE Durability
Easy to use: Defining the extent of the model

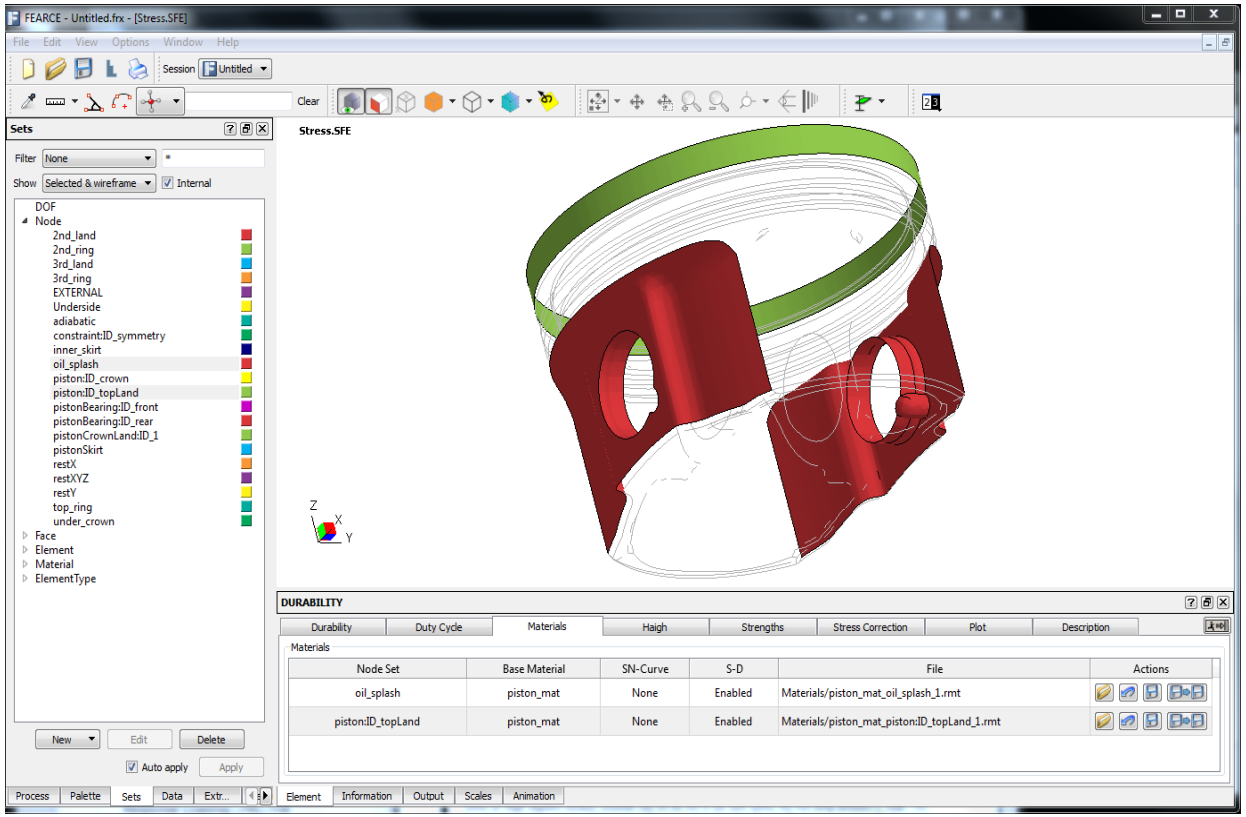
- Large assemblies, single components or selected sub regions of a component can all be analysed within the solver
- All the user needs to do is make a selection between whether to submit the whole system to the solver, or to only calculate results for a defined sub set of the model



- Sub sets of the model can be created very easily in the FEARCE GUI
- SETs can be created by painting surfaces or capturing large sections of the model using mouse selection tools
- SETs can also be imported from models created in other systems

FEARCE Durability
Easy to use: Defining extent of the model

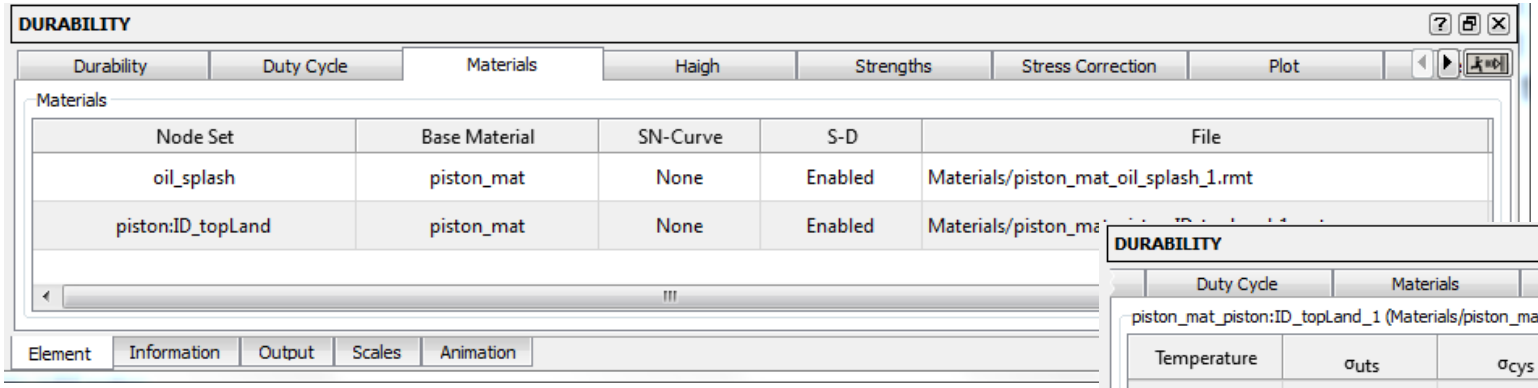
- Once the subsets have been defined the user just selects one or more for analysis
  - With FEARCE allowing the user to apply different material properties to each selected sub set

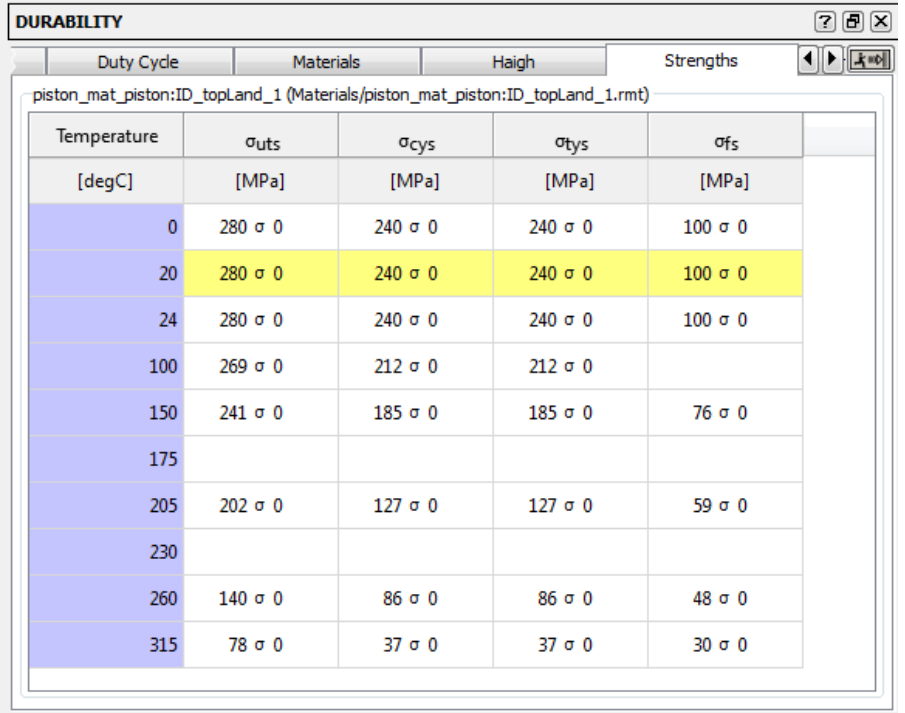


- The same region of the model can be included in multiple sub sets
- Therefore the sub set method can be used to perform material comparison analyses on the same region
  - With different properties being applied to each set representing the region

FEARCE Durability
Easy to use: Applying material data

- Material properties can be applied to the model or subsets either directly from a database material file or by applying or editing the material data directly through the GUI

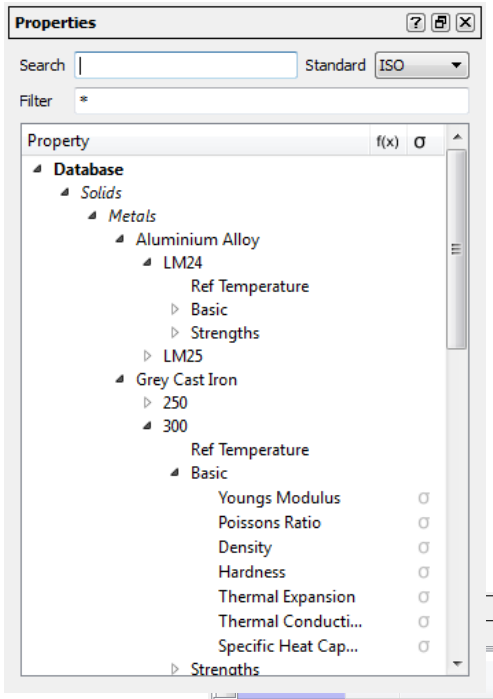




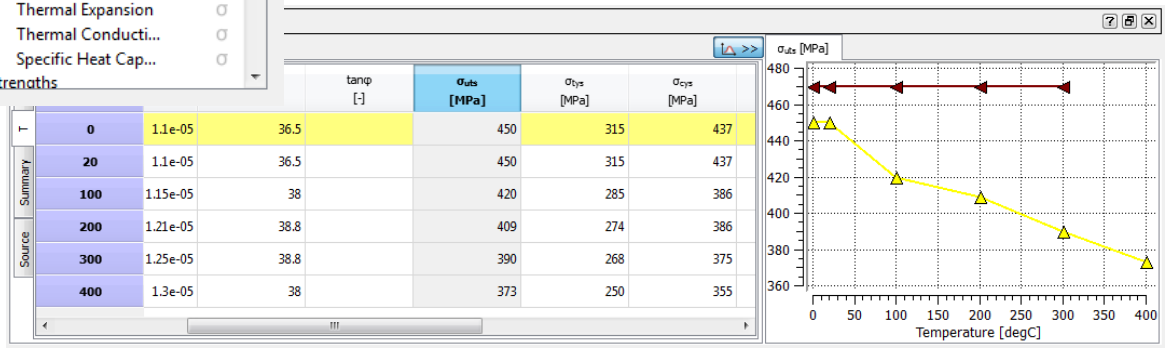
- FEARCE 2013 will contain a property database of common materials
  - Which can be easily extended by users to include their own data and so providing an easy to use and very visible system for applying the strengths to the analysis

FEARCE Durability
Easy to use: Applying material data

- FEARCE 2013 will contain a property database of common materials
  - Which can be easily extended by users to include their own data and so providing an easy to use and very visible system for applying the strengths to the analysis



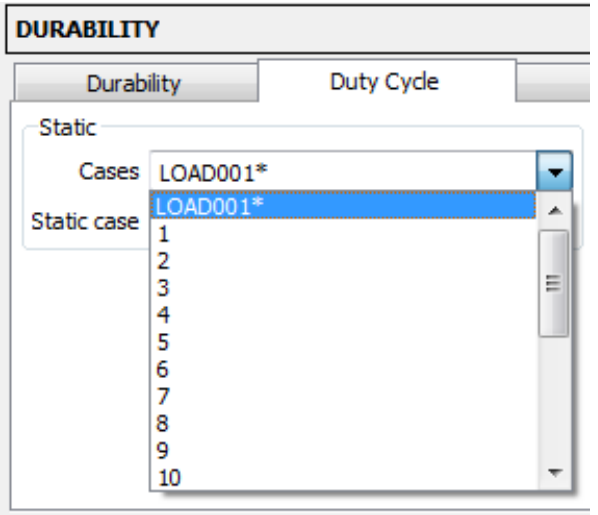
- Features of the property library will include
  - Support of different specifications for a given material
    - For example different heat treatments of a given base material
  - Derived material data
  - Lubrication data
    - Derivation of asperity data from Abbot curve
  - Support of metadata (e.g. notes, chemical composition)
  - Support of different standards (ISO, ASTM etc)
  - Supply of data store as part of installation

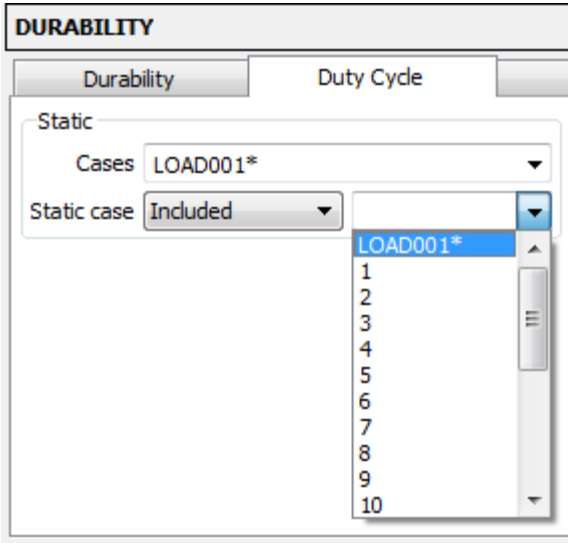


FEARCE Durability
Easy to use: Selecting the duty cycle

- All results cases are stored on the model with unique number ID's
  - …and results from FEARCE's own stress analyses are given a group ID to represent the complete duty cycle in a full quasi-static solution

- Choosing the load history to apply to the solver is as easy as selecting the cases from a list

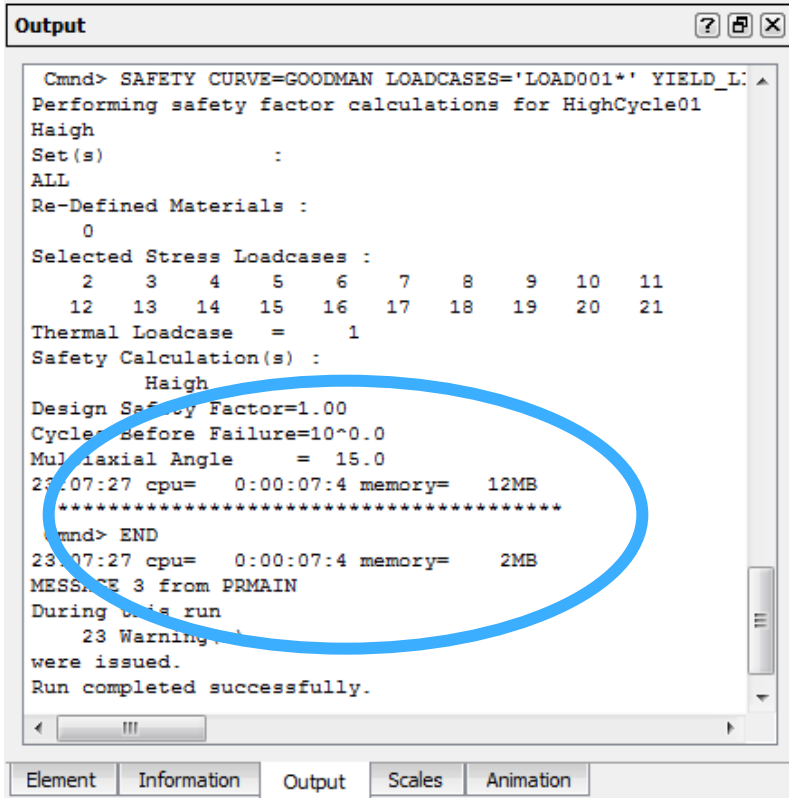




- FEARCE also provides the option of adding extra data via an additional case to every load in the duty cycle
- This can be used to represent such phenomena as surface tensions induced by operations such as casting or rolling

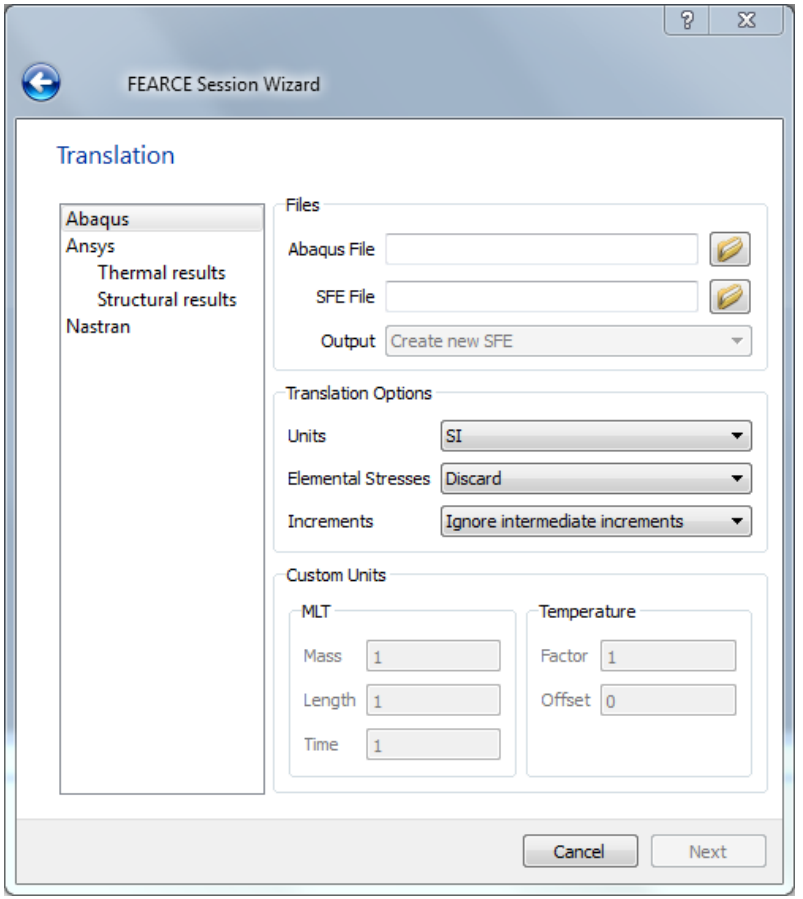
FEARCE Durability
Fast and reliable

- The FEARCE durability solver has been benchmarked as one of the fastest systems currently available
- Run times are measured in seconds or minutes and so even the largest models can be used for multiple calculations and provide results instantly so that the engineer can compare and investigate
- The FEARCE system does not incur any memory overheads and so very large models can be solved on desktop or laptop computers and without the need of specialist hardware
- The solver is stable and reliable, ensuring results are repeatable and providing confidence in both delivery and solution



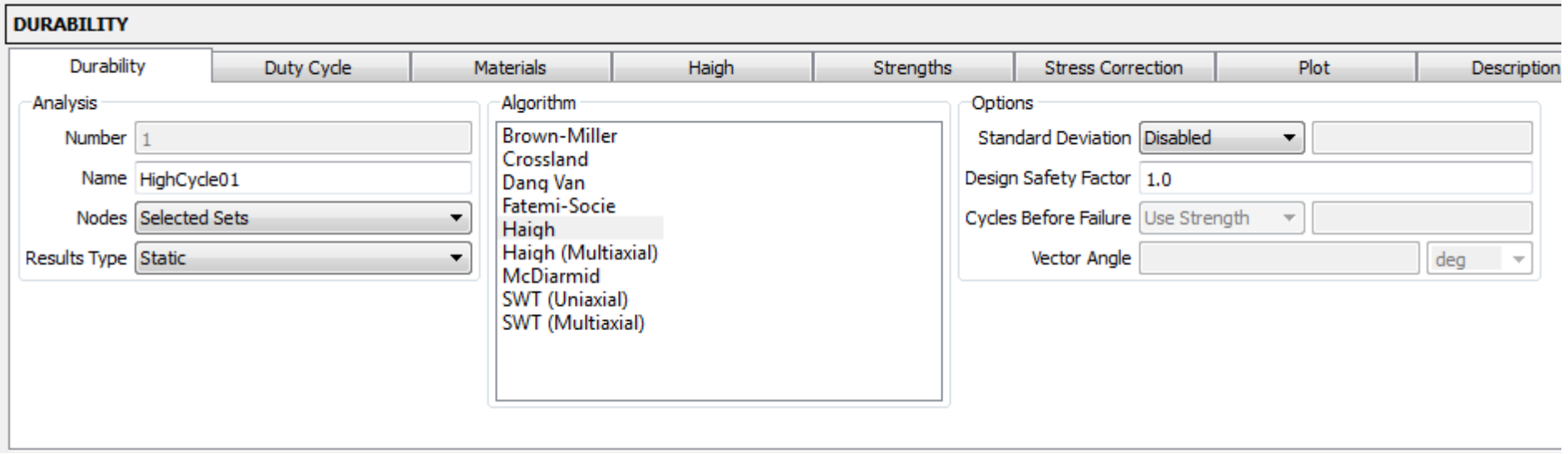
FEARCE Durability
Able to work with any system

- The FEARCE durability solver has been developed for Ricardo's consulting activities and so like the rest of the FEARCE system is designed to work with all of the major FE solvers and packages
- The FEARCE GUI provides direct translators from ABAQUS, ANSYS and NASTRAN
  - …and translators for other major systems can be supplied for use
- In addition to direct translation, FEARCE can also interpolate data from one FE mesh to another even across different mesh types and structures
  - Hence results from different solvers or solutions can be applied to a single model to build up multiple load histories for comparison



FEARCE Durability
Providing a broad range of algorithms

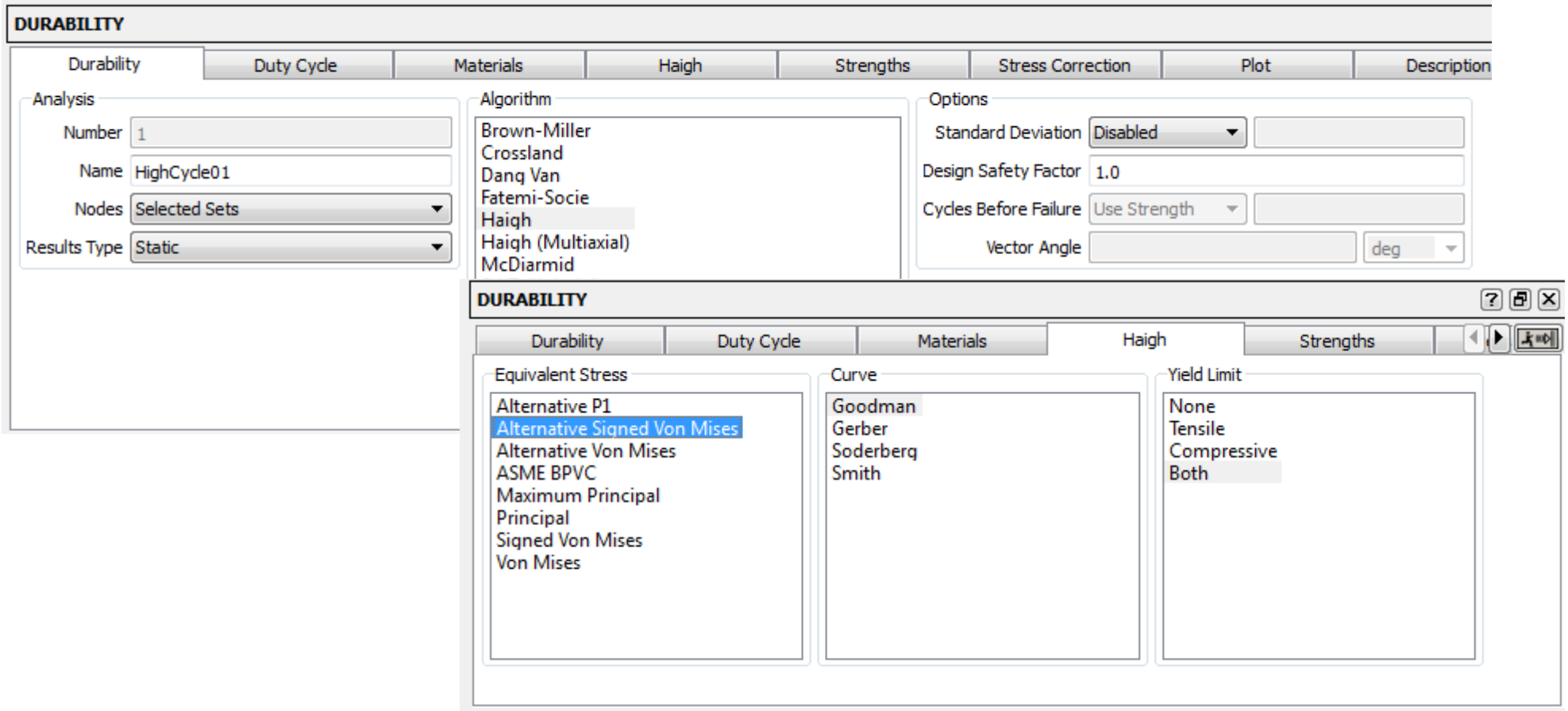
- The FEARCE durability solver provides a wide variety of algorithms for linear and non-linear durability analysis



- The FEARCE solver is also written in a very flexible way so that it is very easy to add new equations to the system
  - A number of client requests for algorithms they prefer are currently being added to the system and some will be released in version 2013

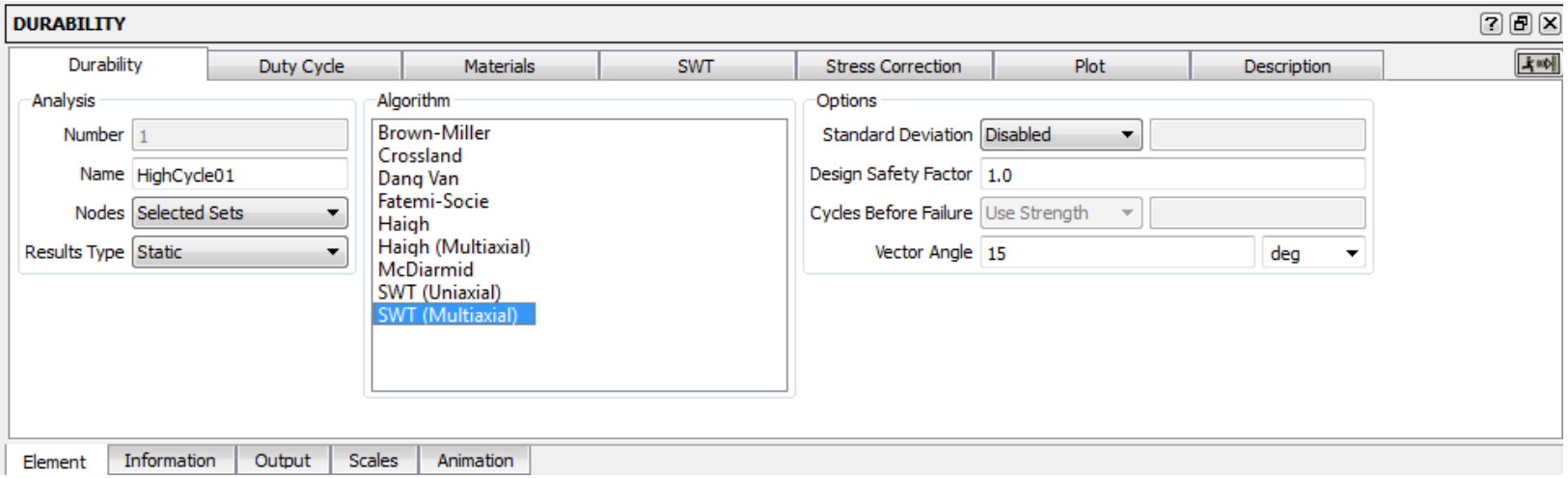
FEARCE Durability
Providing a broad range of algorithms

- FEARCE provides a full range of curves and equivalent stress options for the Haigh family of durability algorithms
  - Additionally FEARCE provides a multi-axial version of the Haigh methods



FEARCE Durability
Providing a broad range of algorithms

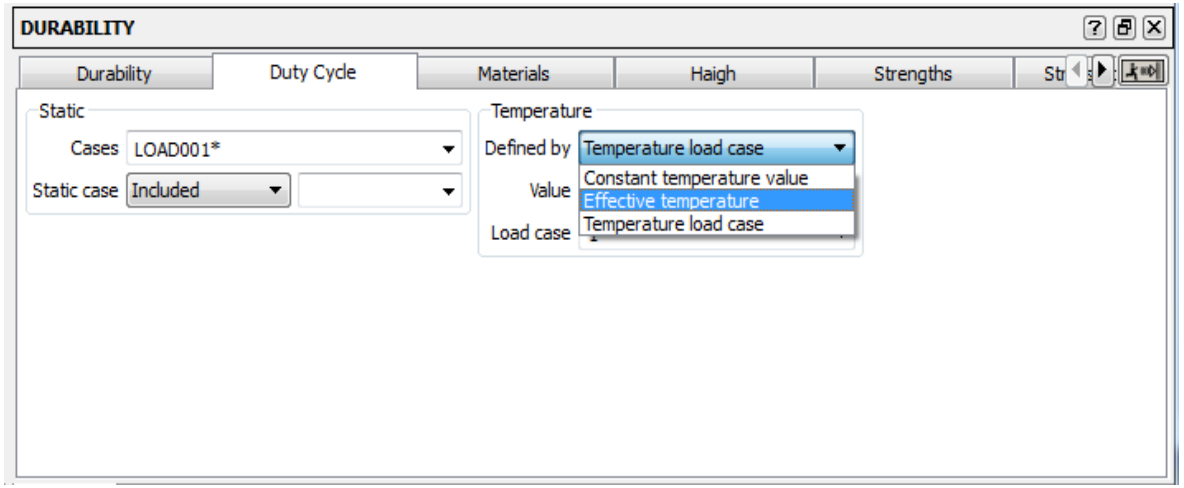
- FEARCE provides a number of critical plane and multi-axial based algorithms
  - For the critical plane systems such as McDiarmid the plane of maximum shear stress range is calculated by FEARCE at each node
  - For Brown-Miller and Fatemi-Socie, the plane of maximum strain range is used



- Multi-axial methods provide a much better control over calculating the direction of most influential stress
  - With these methods FEARCE gives the ability to explicitly choose the angle between vectors used to identify the required stress direction

FEARCE Durability
Giving advanced options: Effective temperature calculation

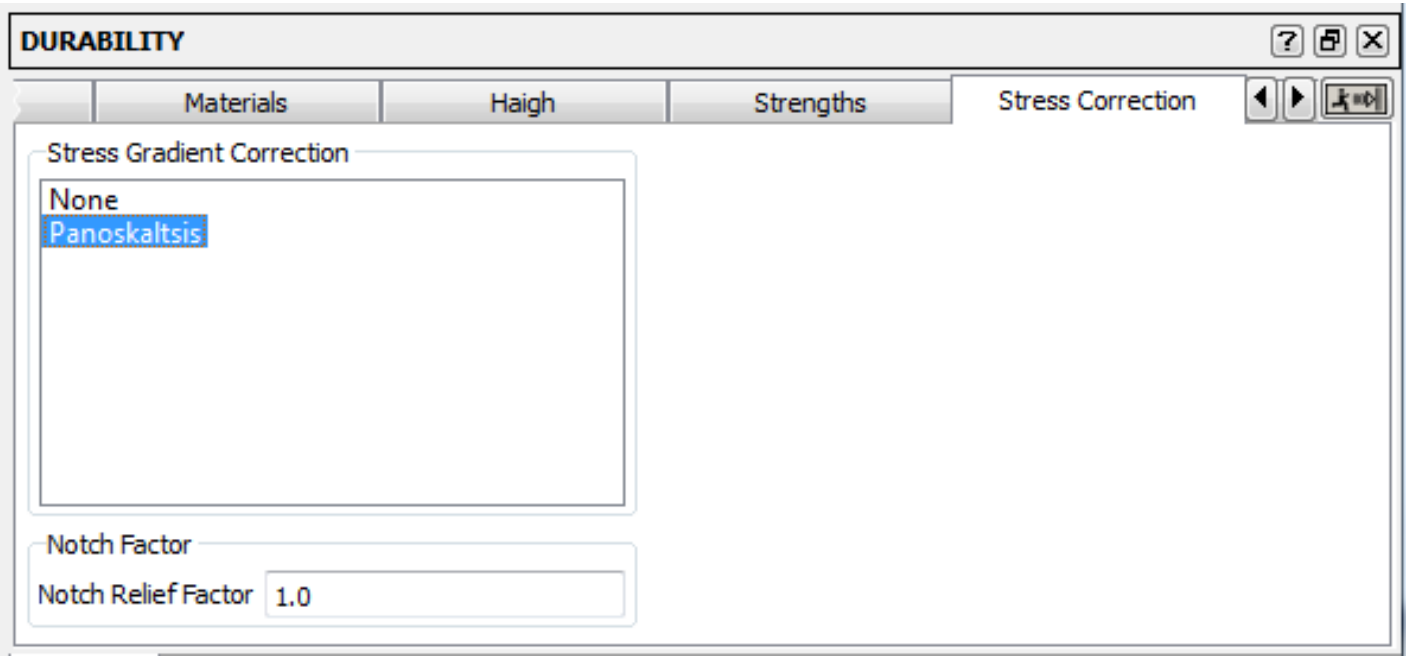
- The FEARCE durability solver provides a number of advanced options to ensure that results provide the best data for investigation
- For low cycle analysis where systems experience high temperature variation across the load cycle, FEARCE provides algorithms to calculate an effective nodal equivalent temperature, based upon damage, that can then be submitted to the solver
  - This removes the need to adjust material properties, or provide a false estimate of temperature to try and achieve sensible results



- The algorithm considers how both the stress at each node and the strength at each node varies with temperature across the duty cycle
  - Both are then used to assess which temperature in the range provides the most representative of the damage caused in the system

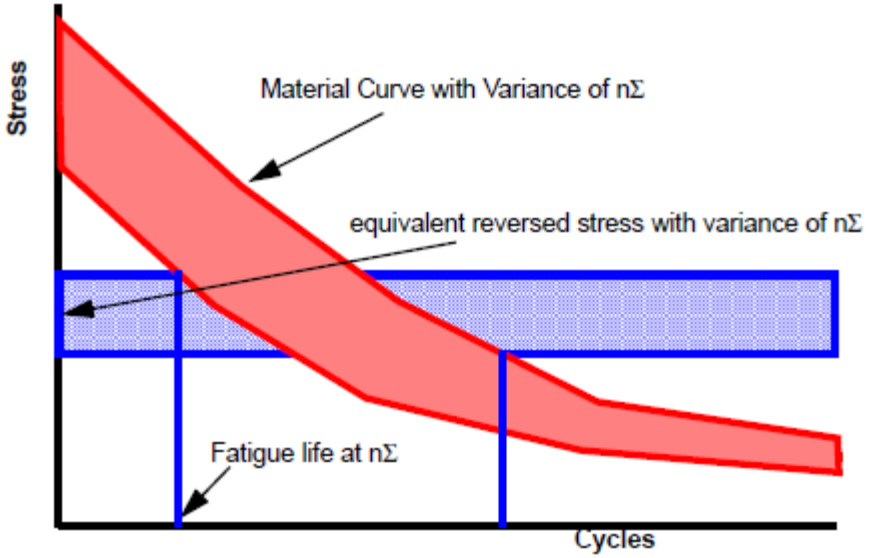
FEARCE Durability
Giving advanced options: Stress correction

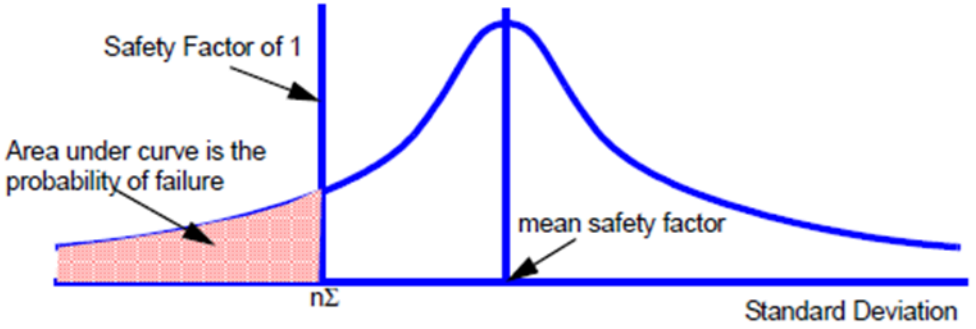
- For systems which experience large changes between tensile, torsion and bending stress in their load cycle, FEARCE provides stress correction algorithms to apply the most appropriate data in the correct regime
- FEARCE can also apply notch correction factors to account for localised yielding experienced where stress is concentrated due to the geometry of the system



FEARCE Durability
Giving advanced options: Statistical variance

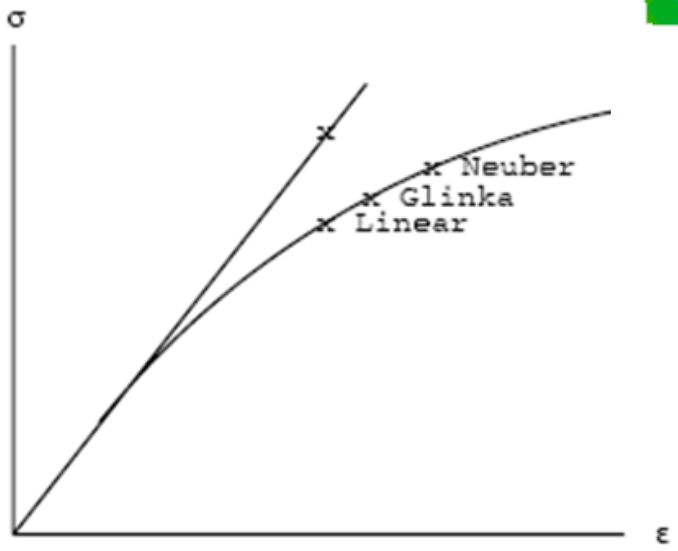
- FEARCE allows the user to consider statistical variance within the applied material properties
  - This variance is carried through all of the calculations, so providing a margin of error in the final derived safety factor
  - This bandwidth gives a reliability factor to the result with narrow bandwidths indicating greater confidence

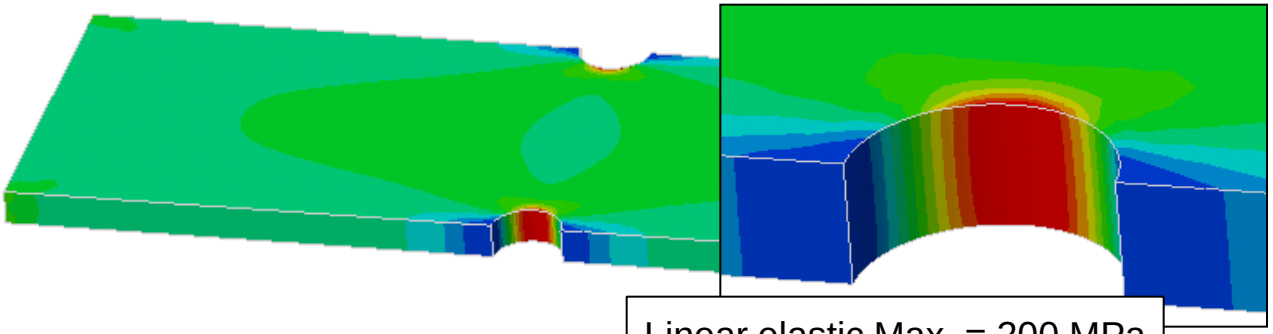




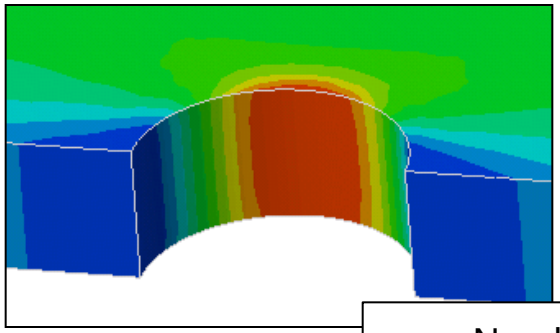
FEARCE Durability
Giving advanced options

- FEARCE provides a number of elastic to plastic correction algorithms allowing the user to see the effects of material deformation even in a linear analysis
  - This gives the opportunity to derive results with simpler systems and so begin investigations earlier in the design process





Linear elastic Max. = 200 MPa



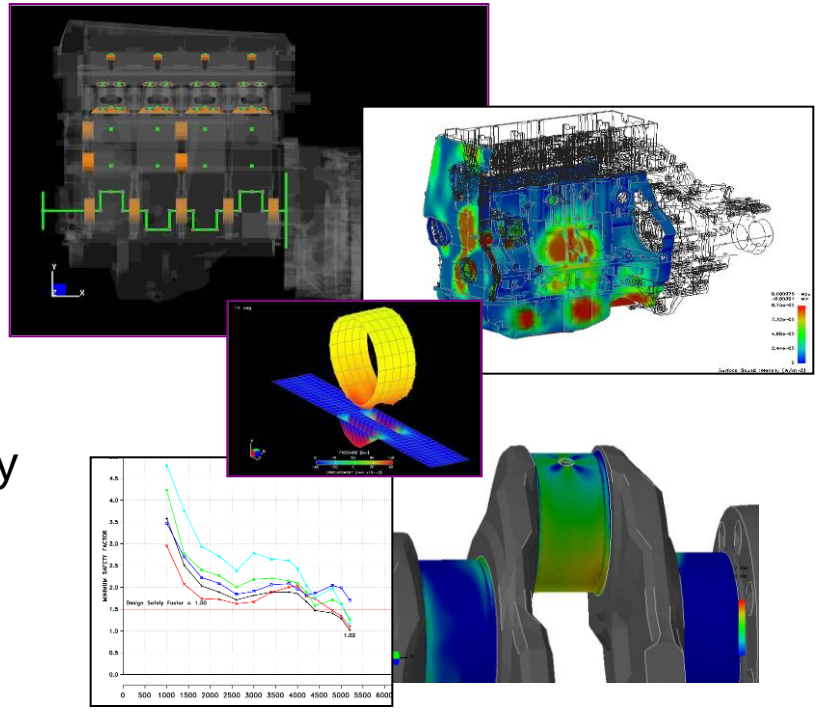
Non-linear plastic Max. = 168 MPa
Linear with Glinka correction Max. = 166 MPa

FEARCE NVH
Overview

- Ricardo has developed a package of tools that work together to provide the entire solution of loads, vibration prediction and post processing required for powertrain NVH analysis
  - These tools make up the Ricardo software mechanical dynamics and finite element analysis suite, namely;
  - ENGDYN
    - For solving the equations of motion of the couple powertrain-crankshaft structure
  - PISDYN
    - For solving the coupled piston-liner dynamics
  - VALDYN
    - A multi-body dynamics simulation tool for the solution of systems that can be reduced to 1D/2D problems
  - FEARCE
    - Ricardo Software's own finite element environment which performs the NVH calculations based upon the loads generated through the mechanical dynamics packages

FEARCE NVH
What is ENGDYN?

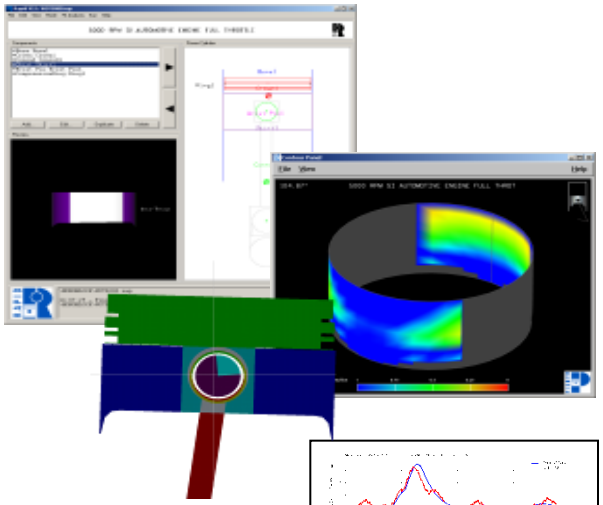
- ENGDYN is a dedicated 3D engine analysis tool essential to the design and analysis of the crank-train, engine structure and associated components
- Analysis applications include:
  - Engine mechanical load prediction
  - Bearing analysis
  - Crankshaft torsion and bending vibration
  - Crankshaft durability
  - Connecting rod dynamics and durability analysis
  - Crankcase and engine block stress and durability
  - Powertrain NVH

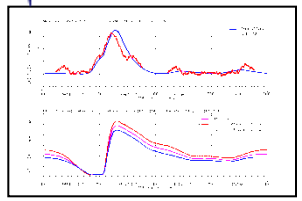


- Key technical features include:
  - Full hierarchy of modelling tools from concept level to fully 3D and non linear
  - Extensive tools to interface with finite element models, solvers and post-processing
  - Direct coupling with VALDYN to extend analyses

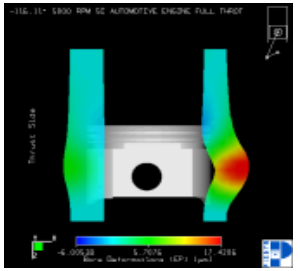
FEARCE NVH
What is PISDYN?

- PISDYN is an advanced 3D simulation package designed to predict the full dynamics of the piston and connecting rod assembly in reciprocating engines and compressors
- Analysis applications include:
  - Prediction of secondary dynamics
  - Hydrodynamic and boundary lubrication oil film analysis
  - Friction and wear analysis
  - Piston slap analysis and cavitation analysis
  - Generation of loads for stress and durability analysis



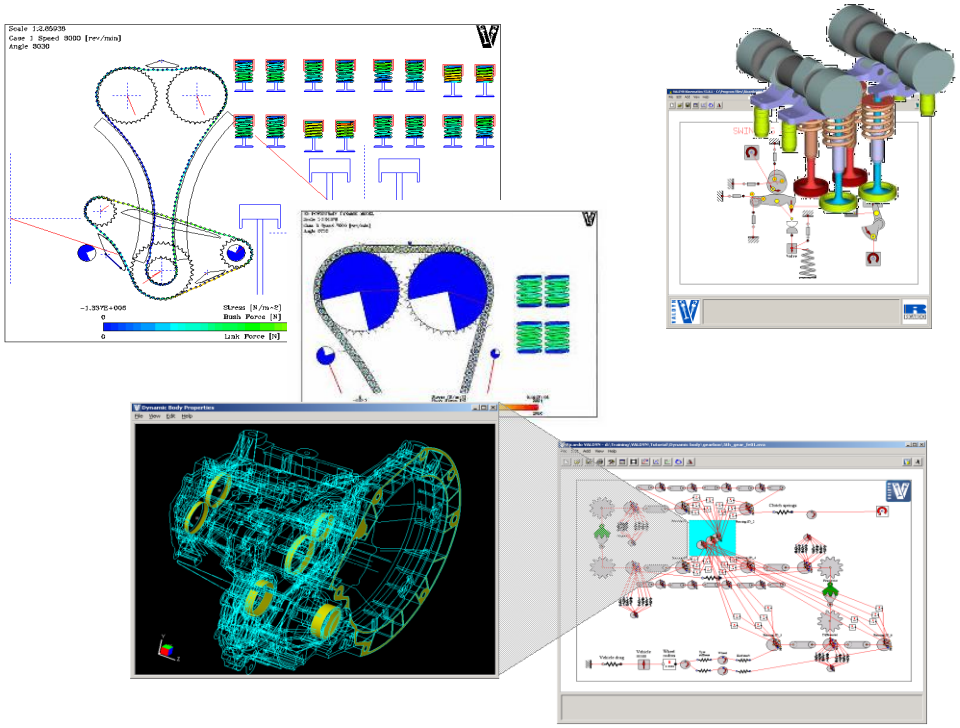


- Key technical features include:
  - Advanced EHL oil film models for studying the piston to liner interface
  - Integrated tools for the inclusion of finite element models in the system
    - Compliant and dynamic analyses
  - Comprehensive 2D and 3D post processing suite
  - Seamless links to FEARCE for further processing of the system
    - Piston stress and durability analysis

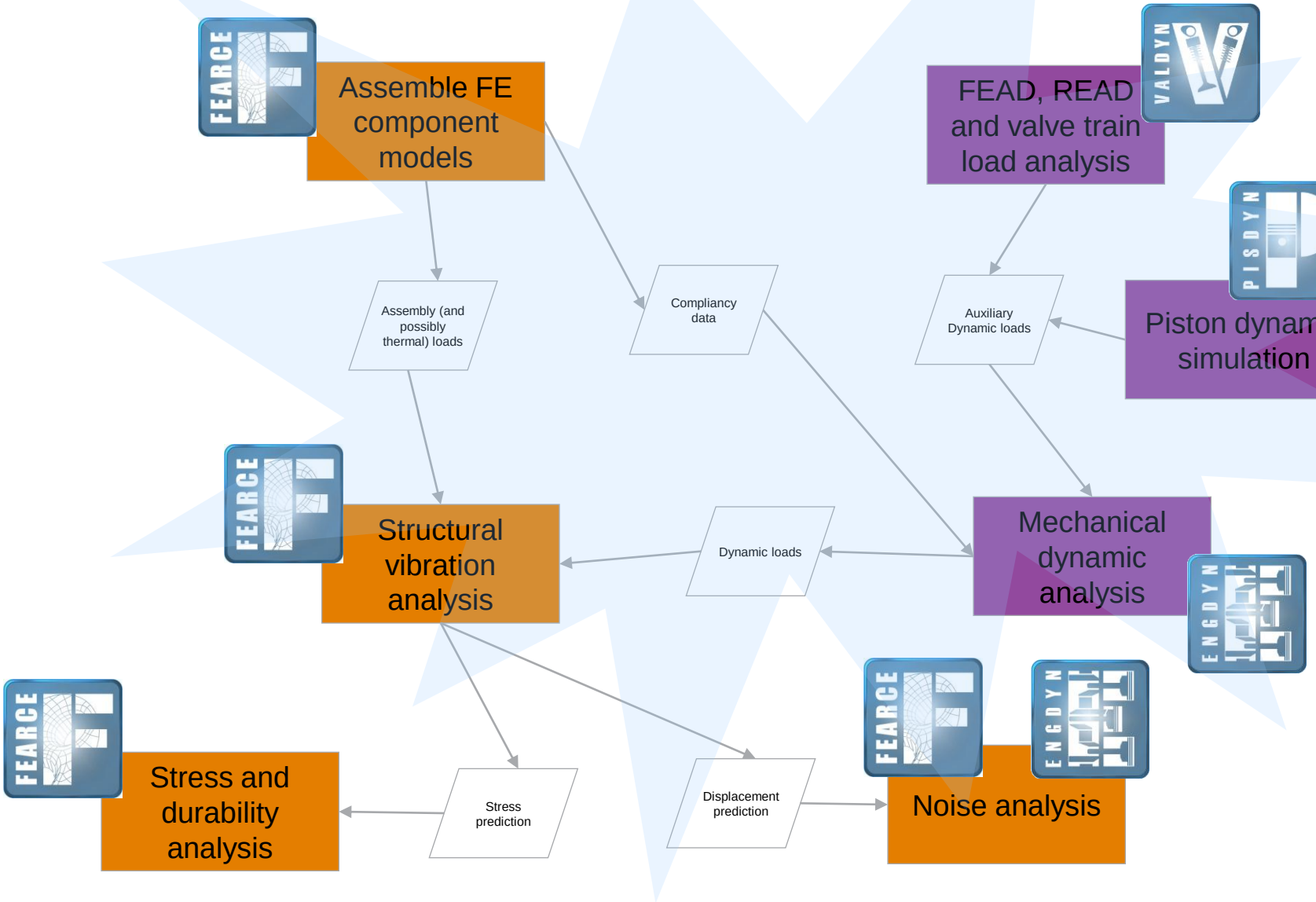


FEARCE NVH
What is VALDYN?

- VALDYN is a multi-body dynamic and kinematic simulation package that has been specifically developed for valve train and drive system analysis as well as cam and spring pack design
- Analysis applications include:
  - Valve train design
  - Shaft and gear analysis
  - Chain and belt dynamics
  - Transmission dynamics
  - Complex system modelling
  - Coupled simulations with external solvers
- Key technical features include:
  - Class leading build and solution times
  - Fully parametric solver
  - Integrated tools for the inclusion of finite element models into the system
  - Seamless links to ENGDYN and FEARCE for engine structural analysis



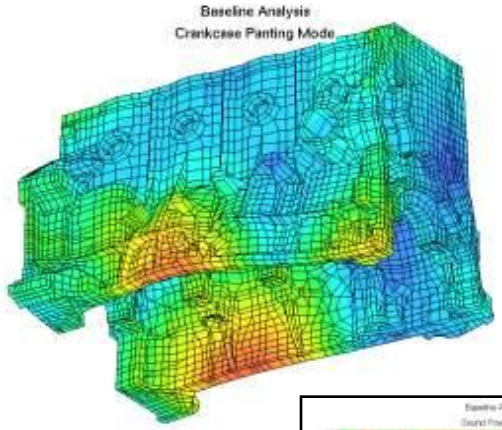
FEARCE NVH
A typical analysis map for powertrain NVH



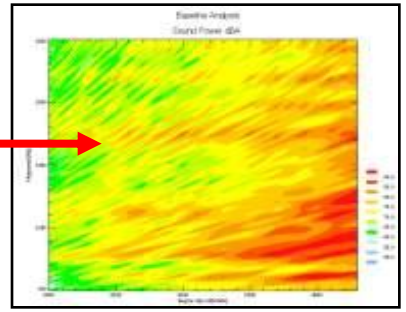
FEARCE NVH
Overview of noise prediction

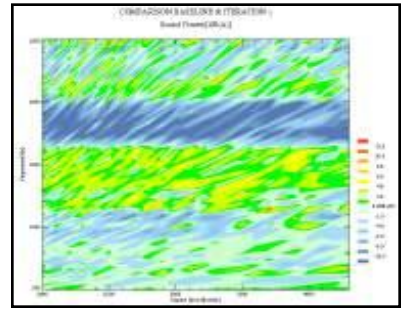
- Vibratory response is predicted and visualised over operating speed range of engine
- For acoustic analysis two methods are possible
  - Rayleigh Method
    - Approximation to wave equation
    - Idealises external wall surfaces of powertrain to be planar
    - Yields good results very rapidly
  - Boundary Element Method
    - Computationally intensive
    - Useful for detailed investigation
- Radiated noise predicted over speed range and we predict
  - Sound power
  - Acoustic intensity
  - Acoustic attenuation
  - Modal contribution
  - Design Sensitivity Analysis

Mode shape

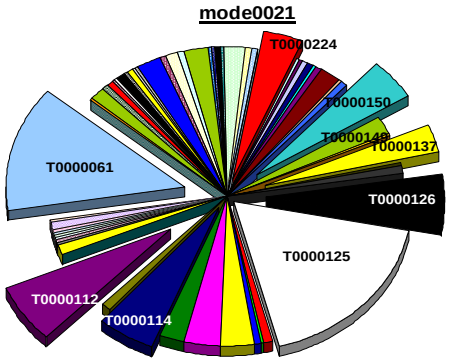


Radiated noise





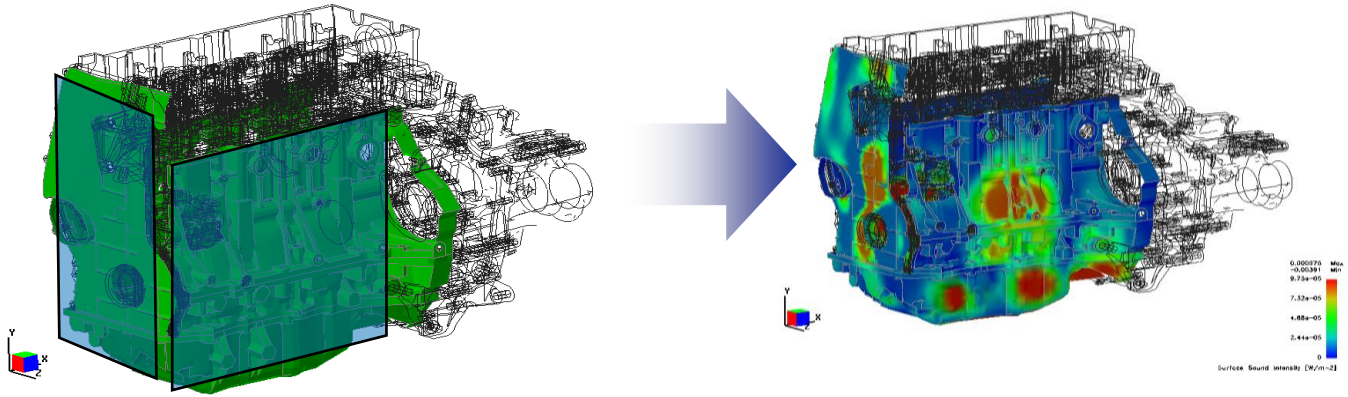
Sensitivity of modal frequency to material properties

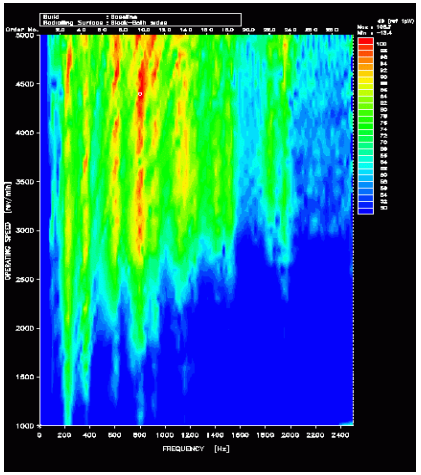


FEARCE NVH
Noise calculations: Rayleigh method

- The basic noise calculation uses either the Rayleigh or Helmholtz methods
  - Each node is ‘projected’ onto best-fit plane
  - Idealised external wall surfaces of powertrain to be planar

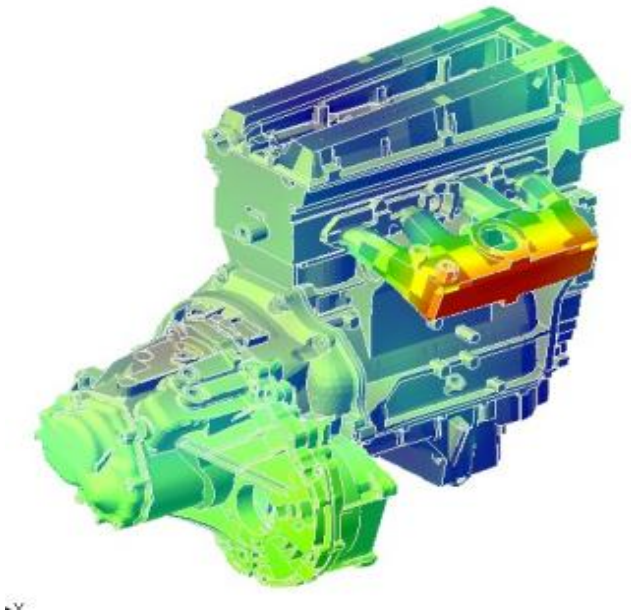
- Calculation is an approximation of the wave equation
  - Yields good results very rapidly – solution time ~ N^2 (N=number of surface elements)

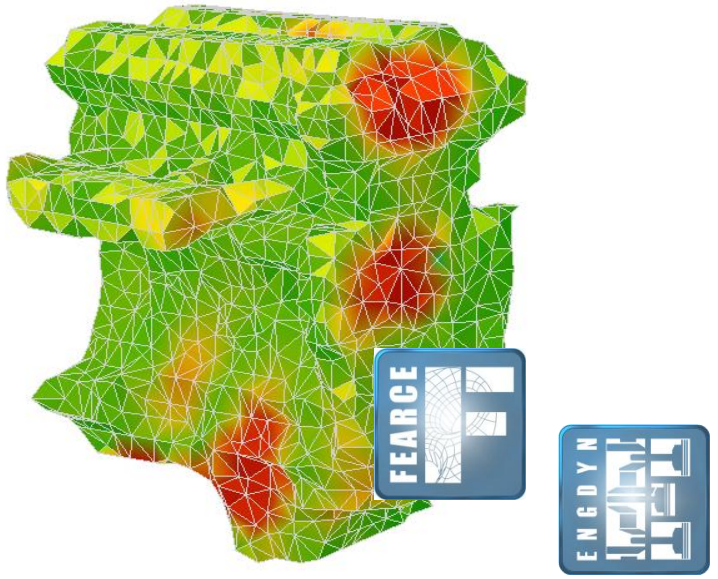




FEARCE NVH
Noise calculations: BEM method

- In the more advanced approach ENGDYN/FEARCE employs Boundary element method
  - More rigorous than Rayleigh method
  - Requires vibration predictions on surface of enclosed volume
  - Solved by simultaneous equation
  - Computationally intensive – solution time ~ N3 (N=number of boundary elements)
  - Useful for detailed investigation

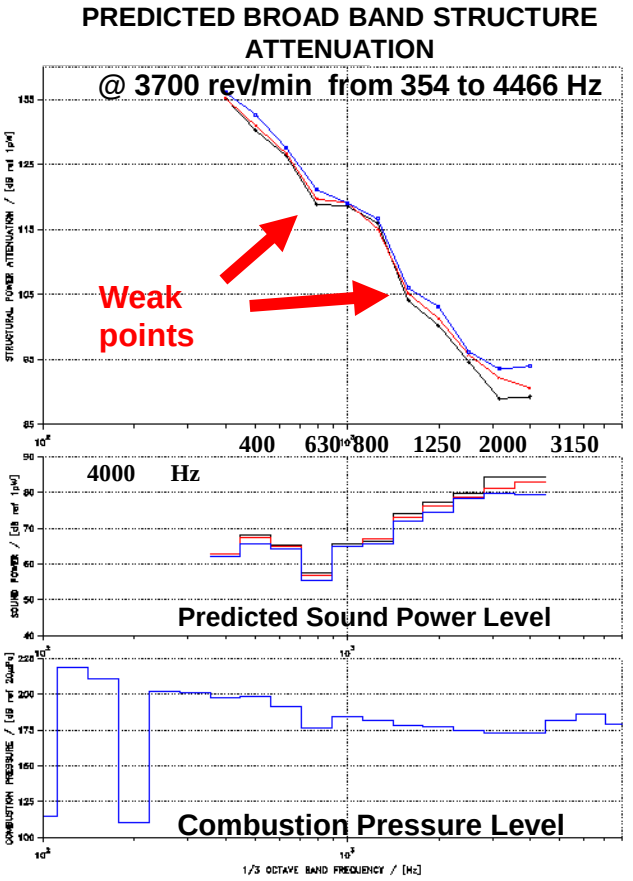




Closed volume mesh

FEARCE NVH
Noise calculations: Structural attenuation

- FEARCE and ENGDYN can also perform structural attenuation calculations (SPA)
- Sound Power Attenuation (SPA) is defined as the difference between the in-cylinder combustion excitation level (PWL dB re: 20µPa) and the predicted sound power level (CPL dB re: 1pW)
  - PWL(dB) - CPL(dB)
- Predicted in 1/3 octave bands
  - assessment and comparison with measured data
  - Allows identification of week points for improvement
- Sound power levels generated from in-cylinder combustion excitation are predicted
  - Quasi-static statically in-determinate solution of coupled cranktrain and powertrain allow transmission of combustion excitation noise through the crank train to the cylinder block
  - Dynamic vibration of the crank train is excluded from the calculation



FEARCE NVH
Noise calculations: Structural attenuation

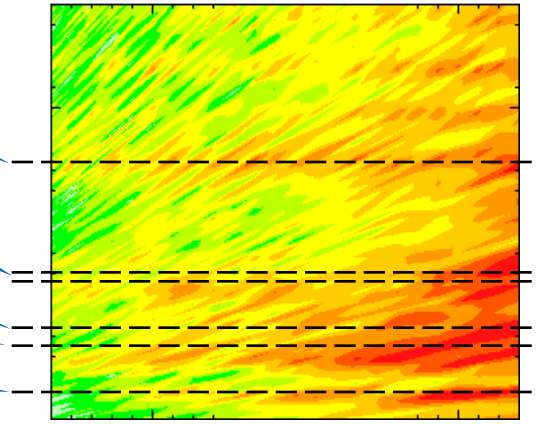
Mode 63 - 1740 Hz
Crankcase panting

Mode 34 - 1145 Hz
Mode 38 - 1206 Hz
Bearing cap flapping modes

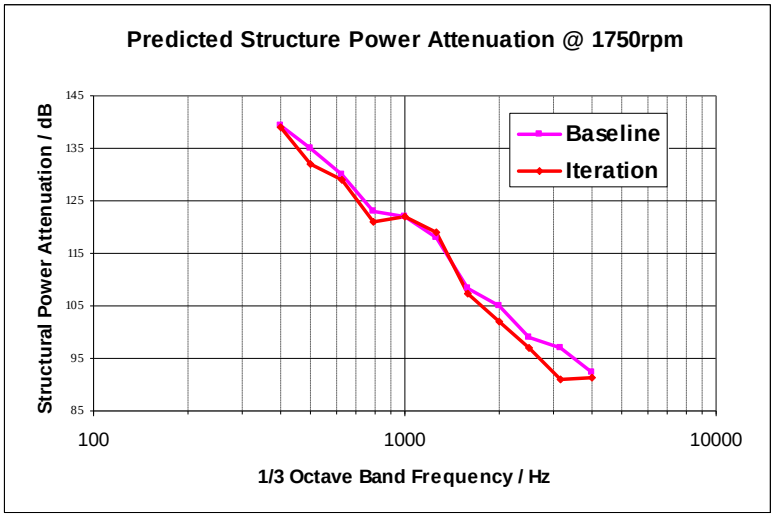
Mode 23 - 928 Hz
Block twisting

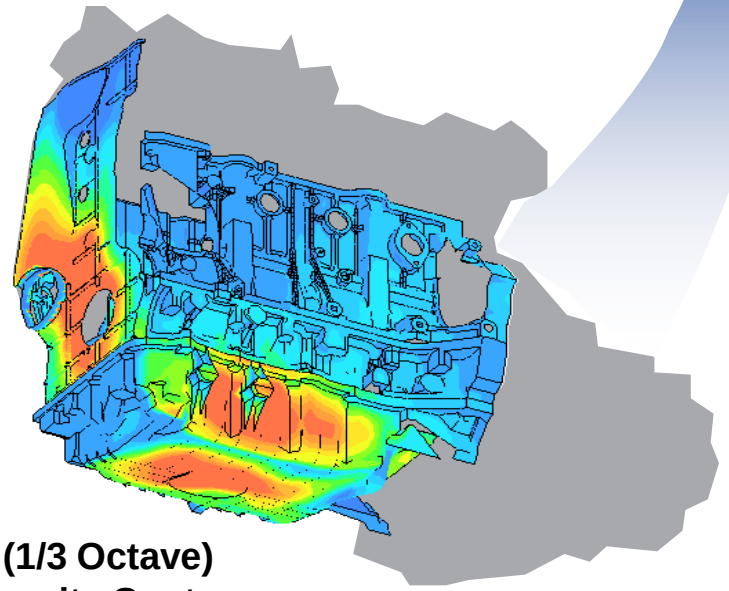
Mode 20 - 822 Hz
Crankcase skirt panting, oil pan rail deforming

Mode 15 - 655 Hz
Front of crankcase skirt panting



Derivation of Acoustic Attenuation





Broad Band (1/3 Octave)
Acoustic Intensity Contours