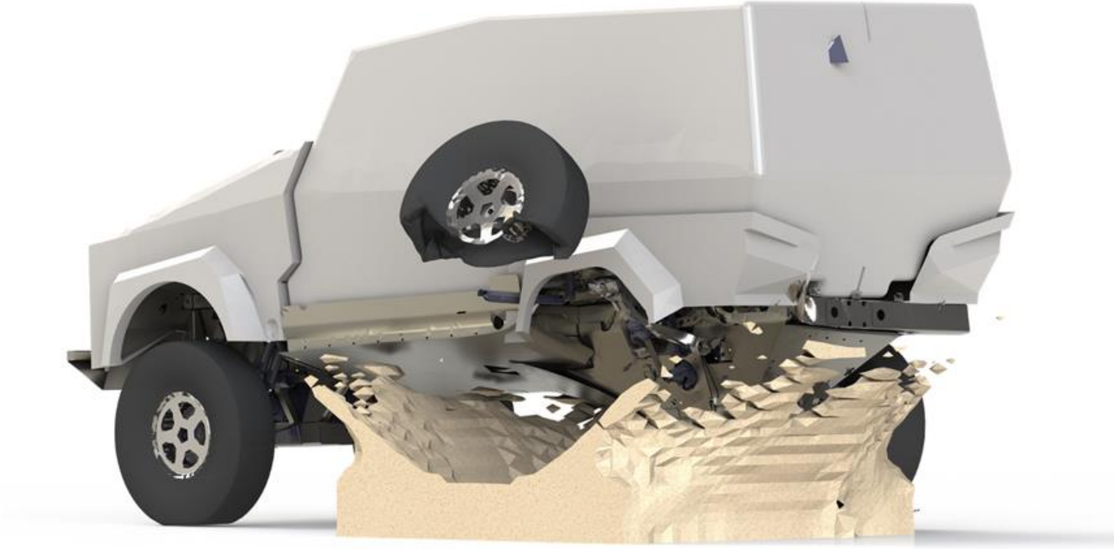
An Investigation Into Optimisation Methods In A Multiphysics Domain.

Lawrence Holness, GRM Consulting
Lawrence.holness@grm-consulting.co.uk

NAFEMS

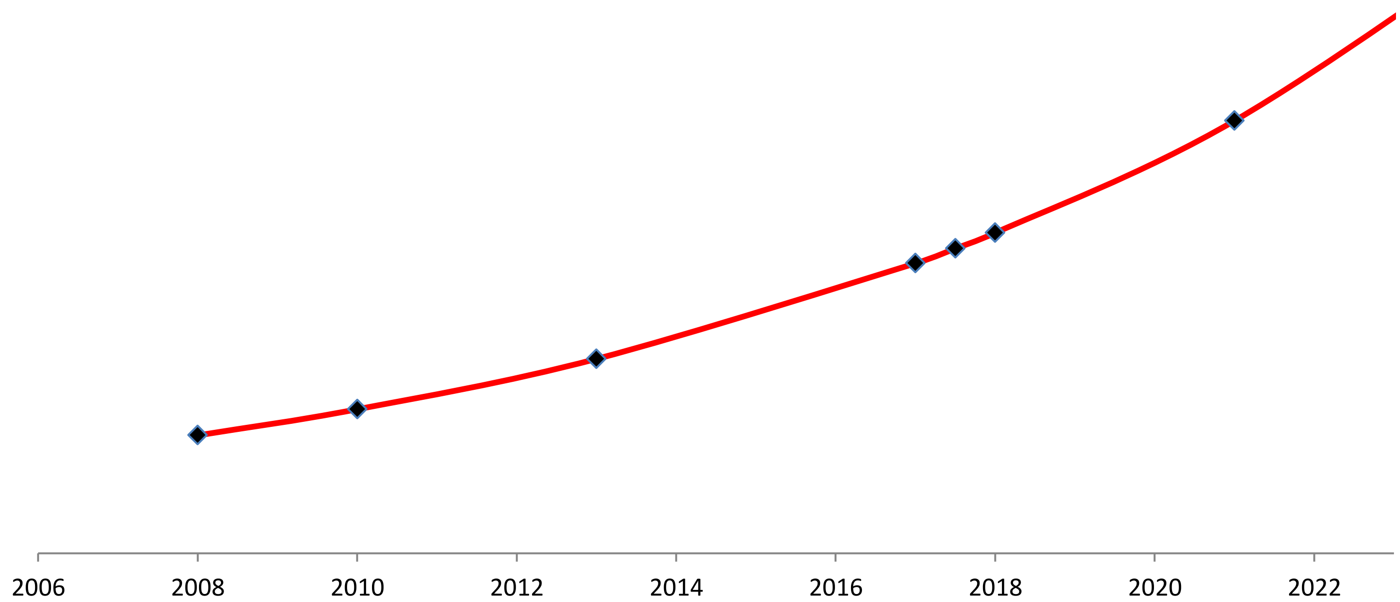
Introduction

- How can complex Multiphysics based analyses be used efficiently to drive optimisation?



Content

- Equivalent Static Load (ESL) based methods
- Response based methods (library and MDO based)
- Direct gradient level interaction



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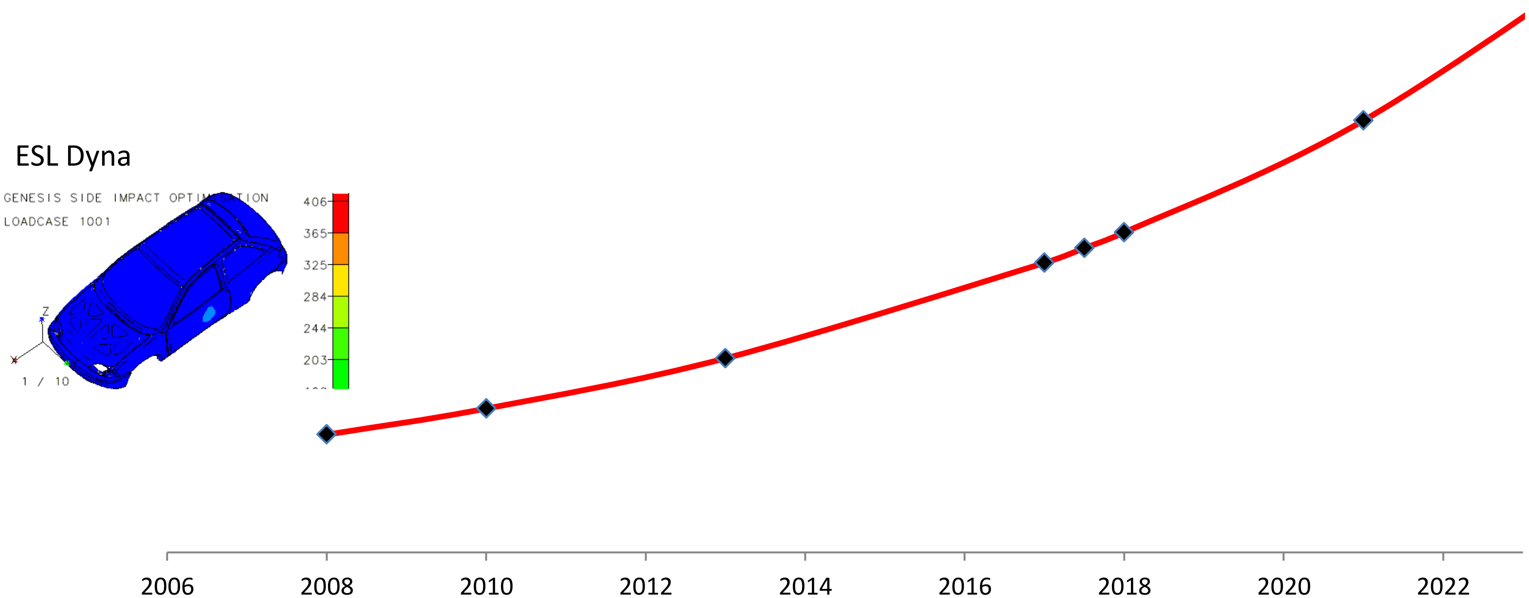

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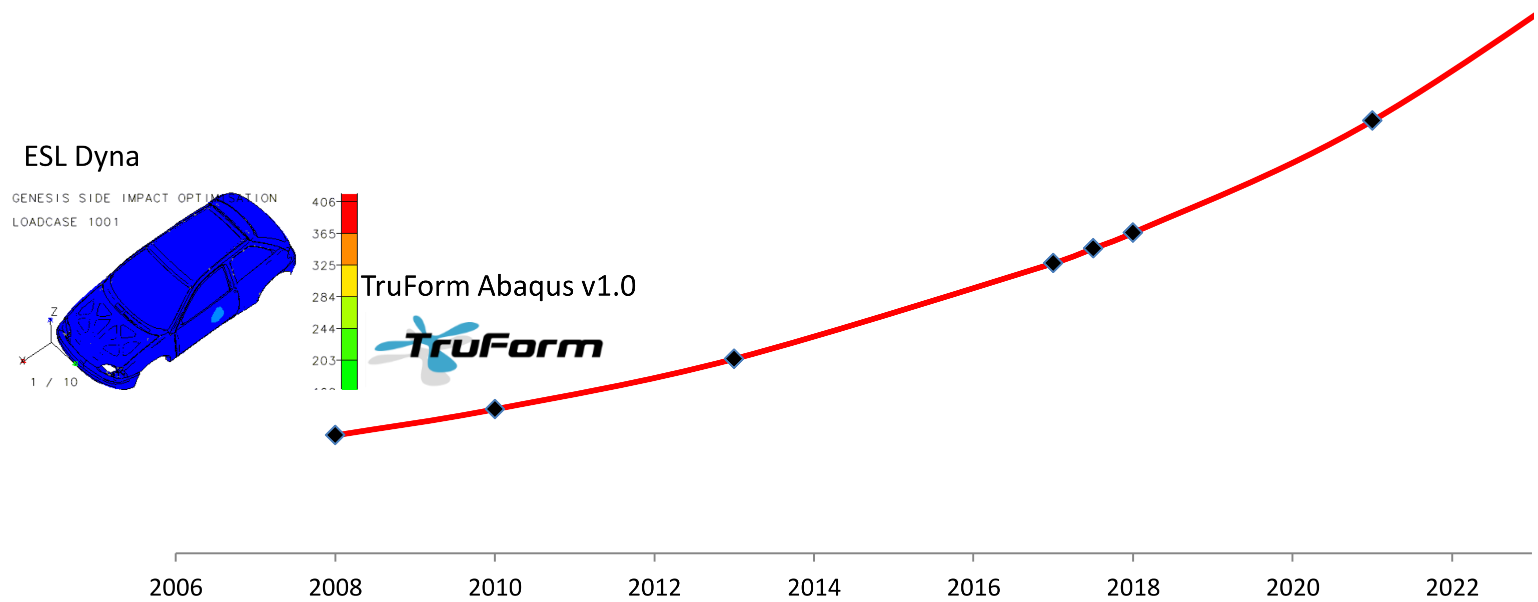

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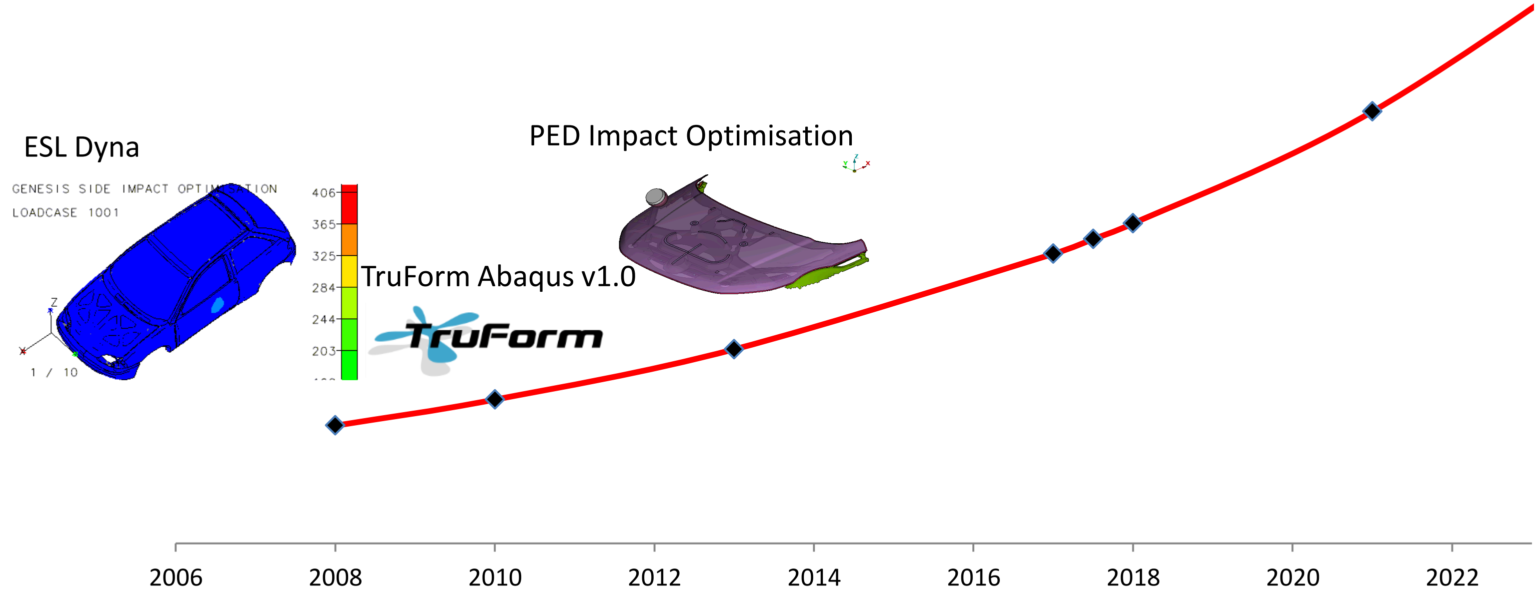

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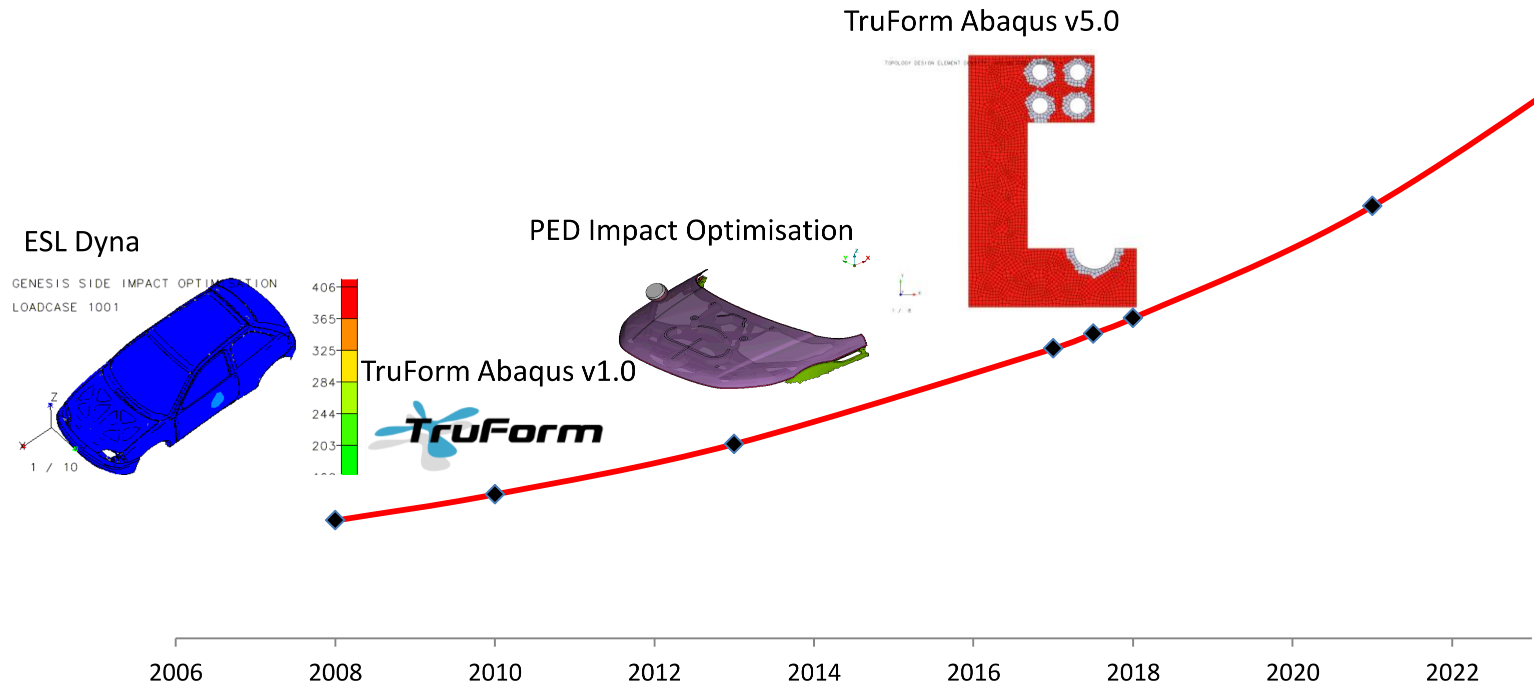

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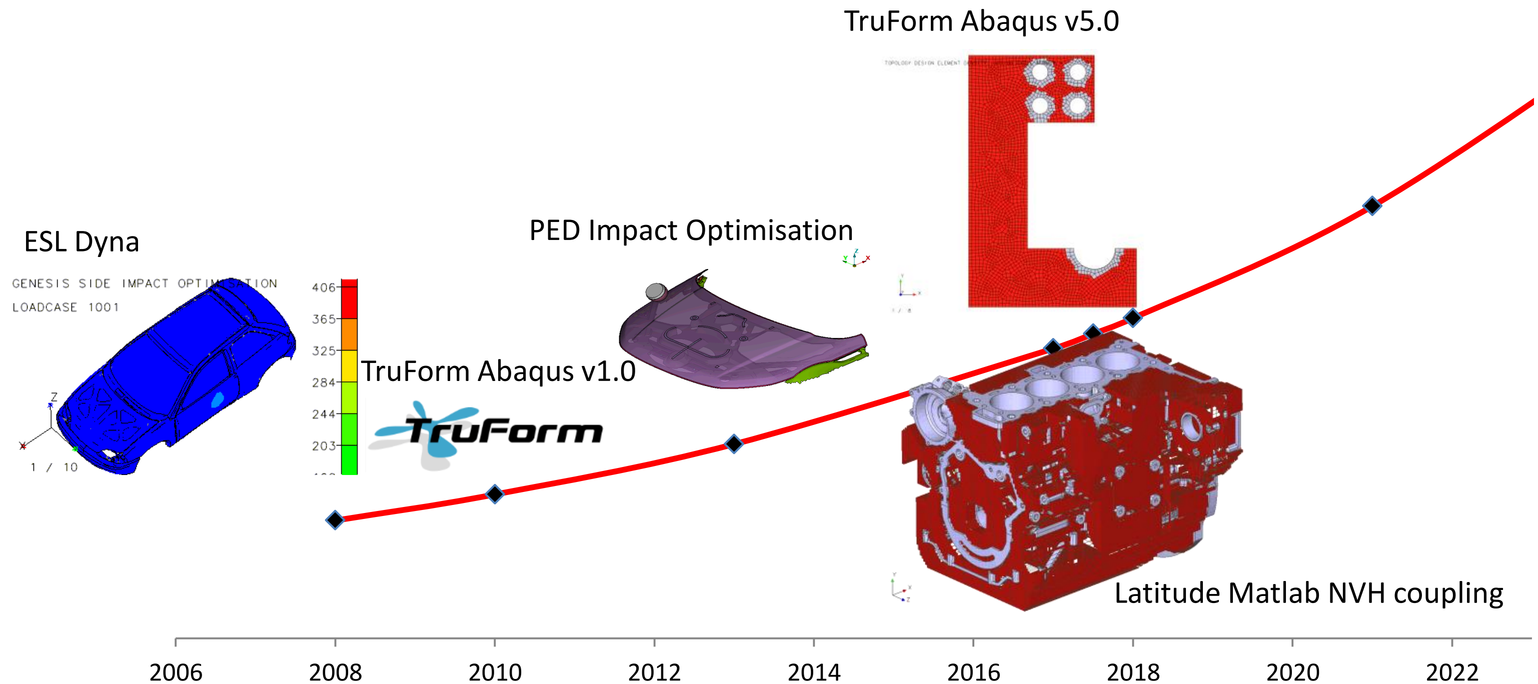

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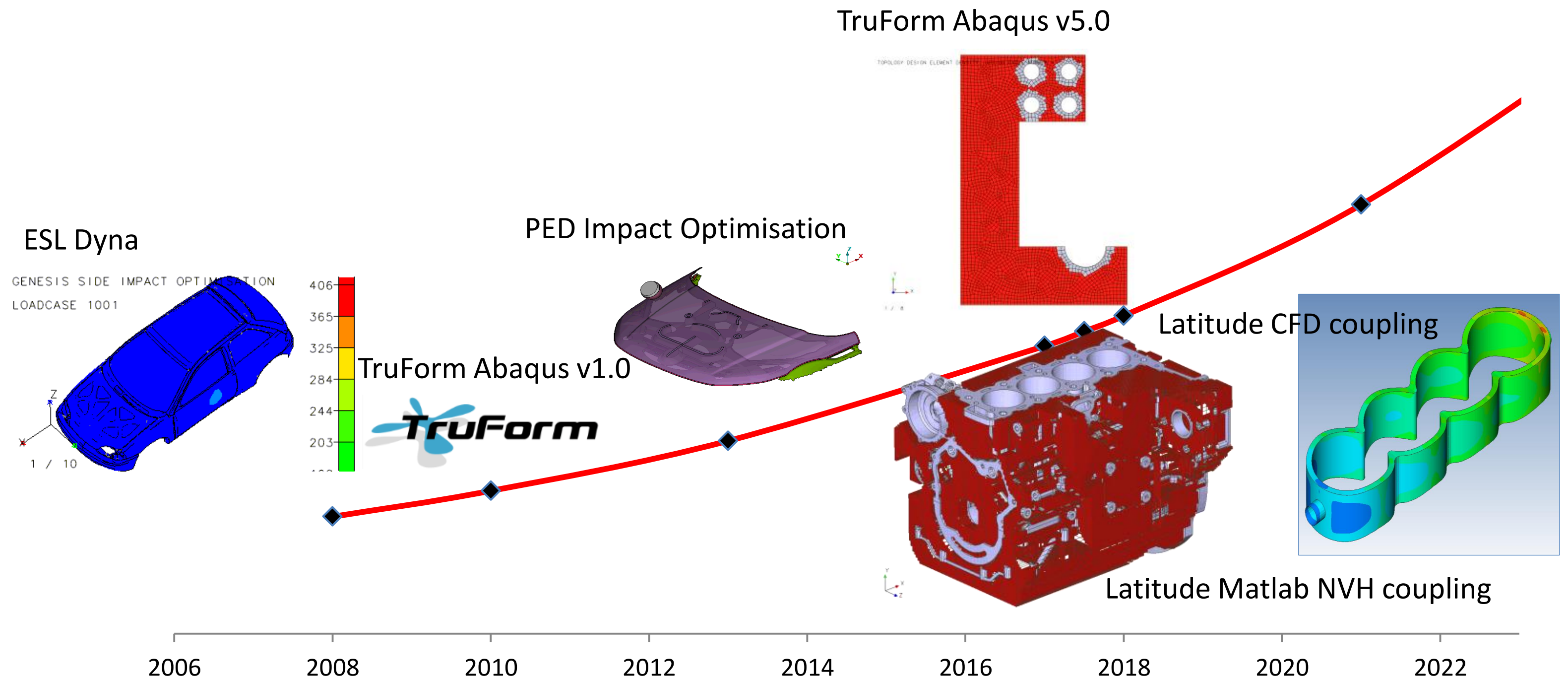

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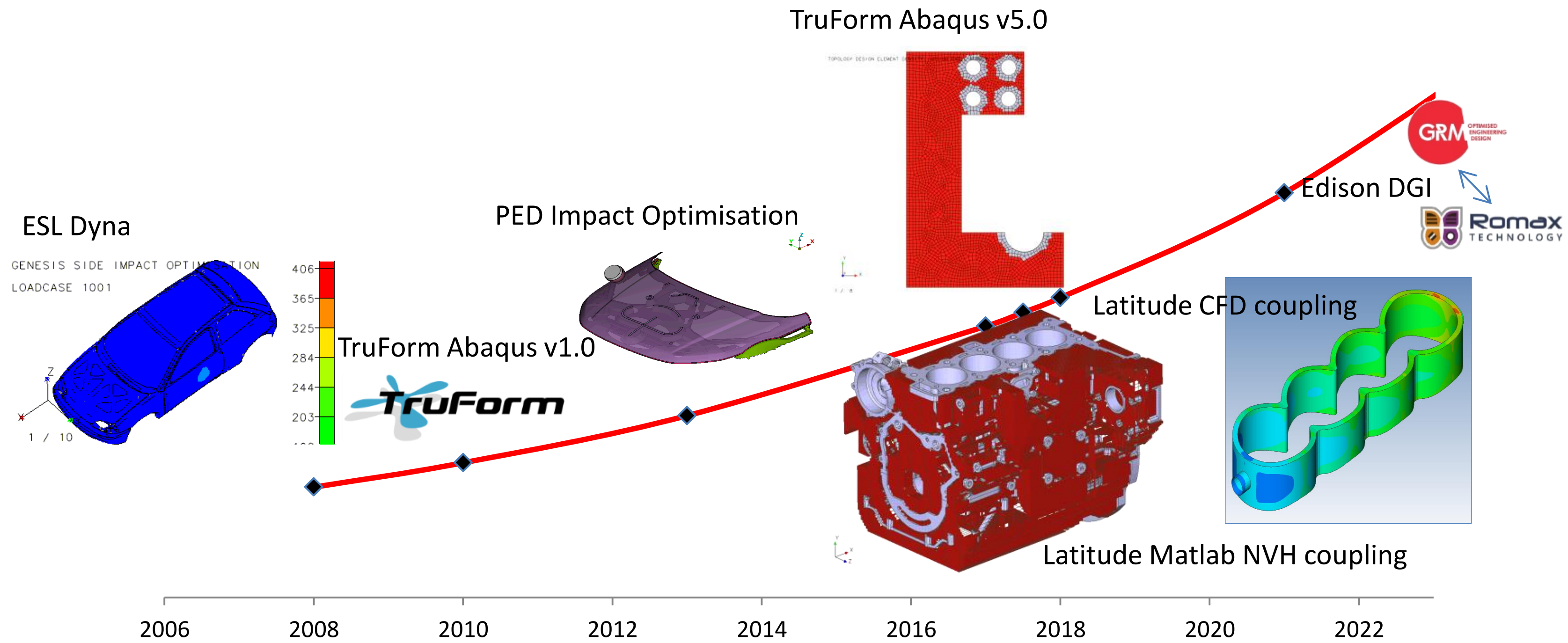


ESL Methods

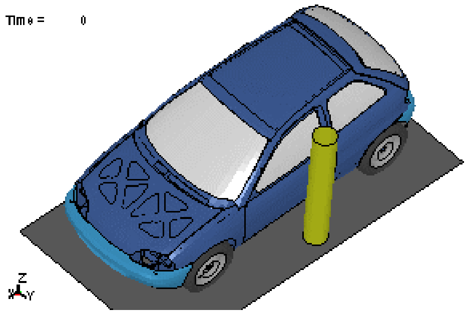
- Global Multiphysics model
- Local Optimisation model

- Displacements from Global Model drive loading of the local model

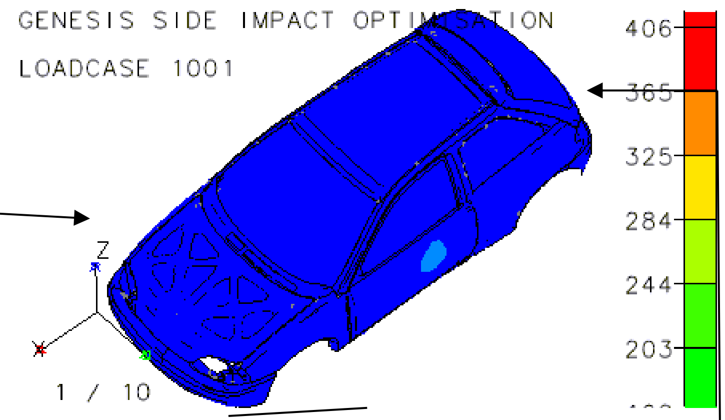
- No requirement for expensive Global model analysis to determine design sensitivities or DOE's to define gradients.

ESL DYNA – Nonlinear Side Impact

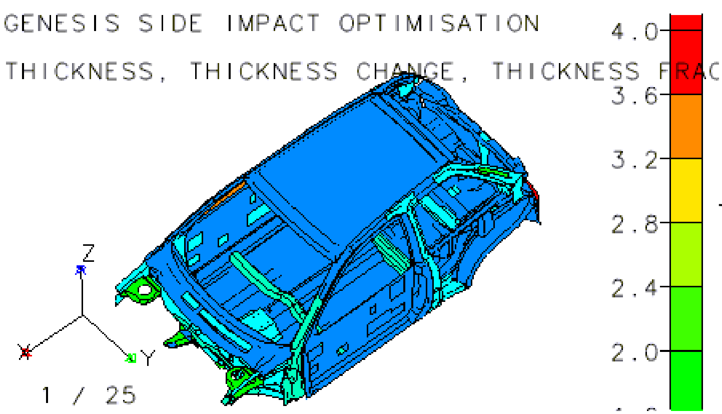
Baseline Non-Linear Model(s)



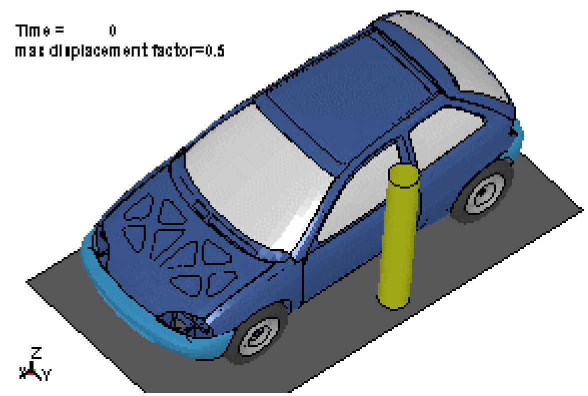
GENESIS Interpretation of Non-Linear Model



GENESIS Optimisation



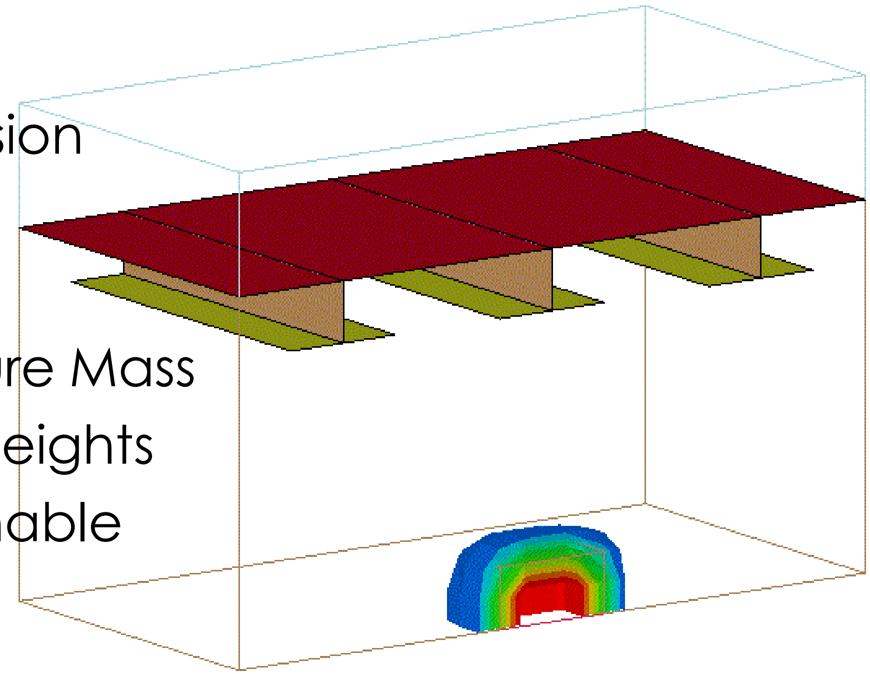
Updated Non-Linear Solution



ESL Dyna – ALE Blast Coupling

Loading

- One loading condition
- LS-DYNA Underwater explosion



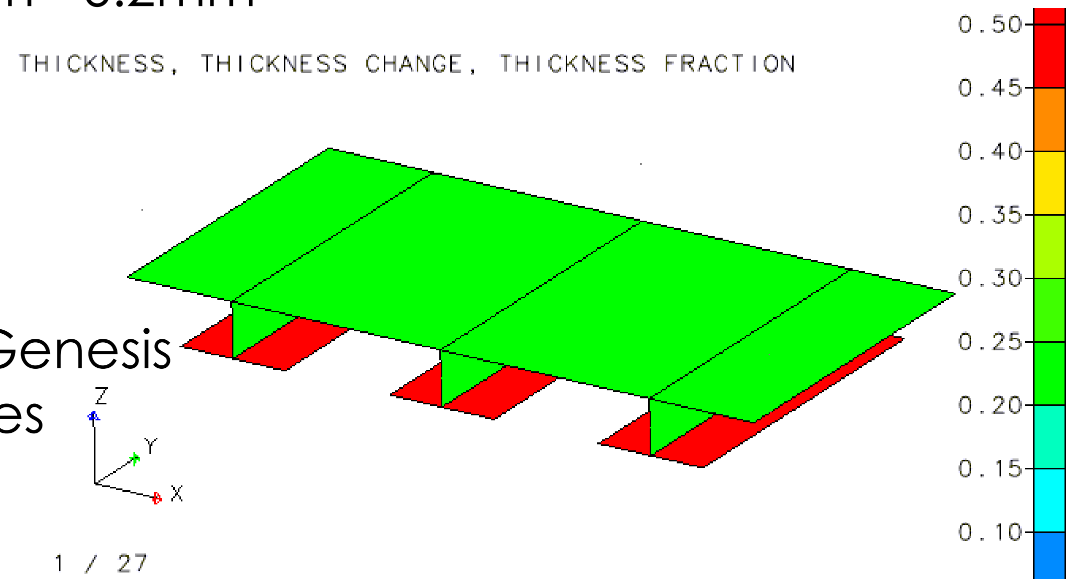
Design Problem

- Objective = Minimise Structure Mass
- Constraint = Relative deck heights
- Variables = 290 Sizing designable elements

ESL Dyna – ALE Blast Coupling

Result

- Relative deck optimised from ~6.2mm to <5mm



Final Optimised Solution

- Mass Increase of 15.5%
- Solution achieved after 26 Genesis cycles and 20 LS Dyna Cycles

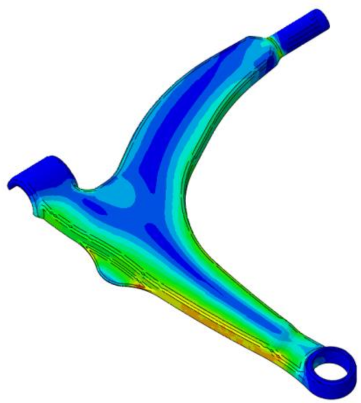
TruForm Abaqus

- Bi-product of 2-3 years of ESL R&D led to the creation of commercial optimisation tools
  - ESL DYNA
  - TruForm

- Demonstrates the speed and versatility of ESL approach when compared to Abaqus native optimisation.

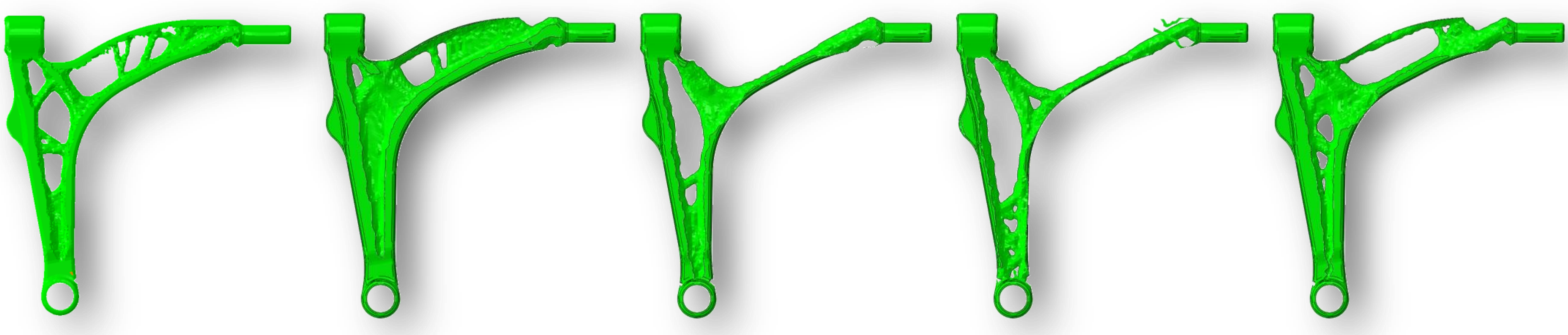
- Full Optimisation usually takes ~8 Abaqus solves

TruForm Abaqus



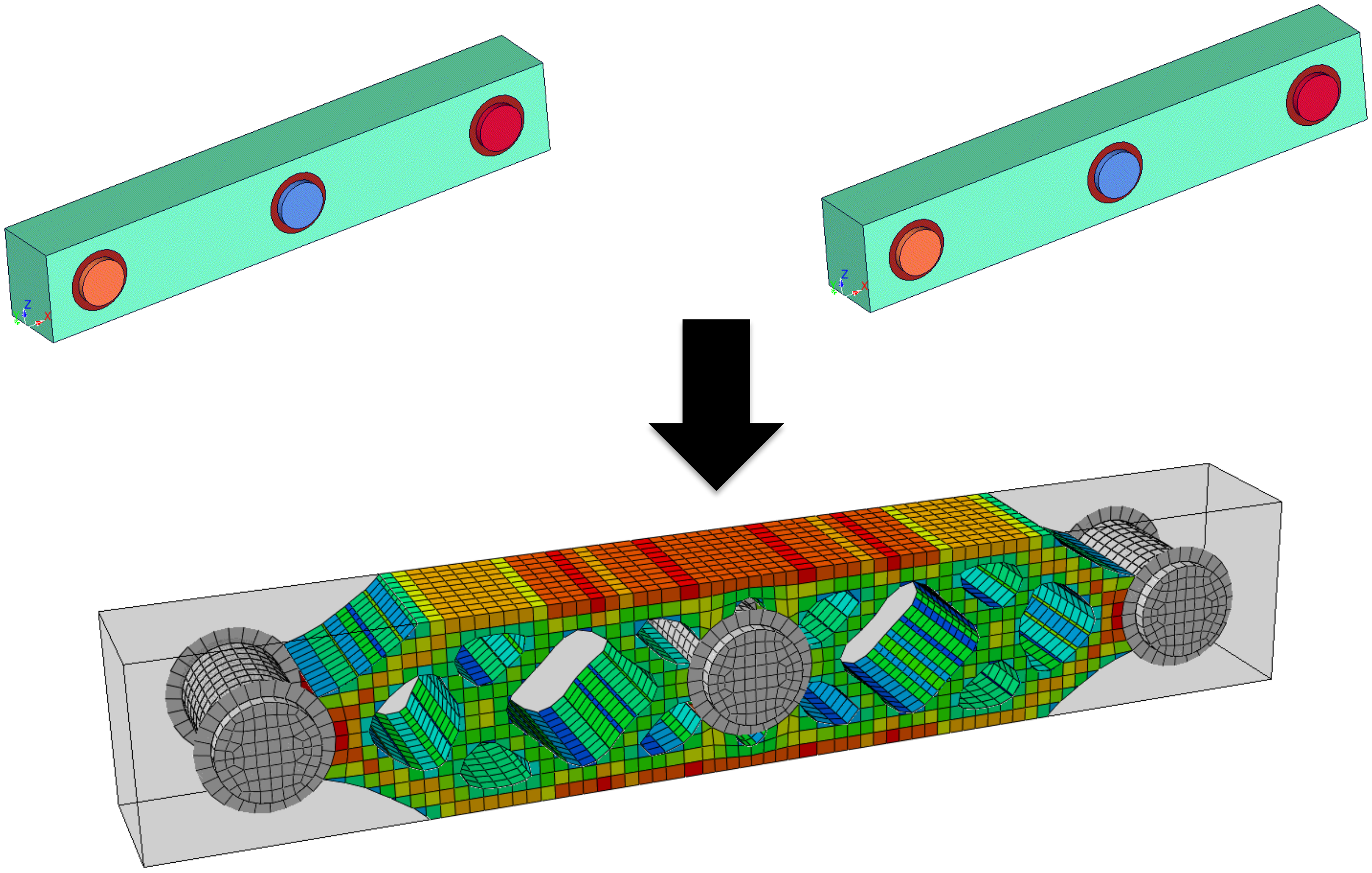
Control Arm Benchmark

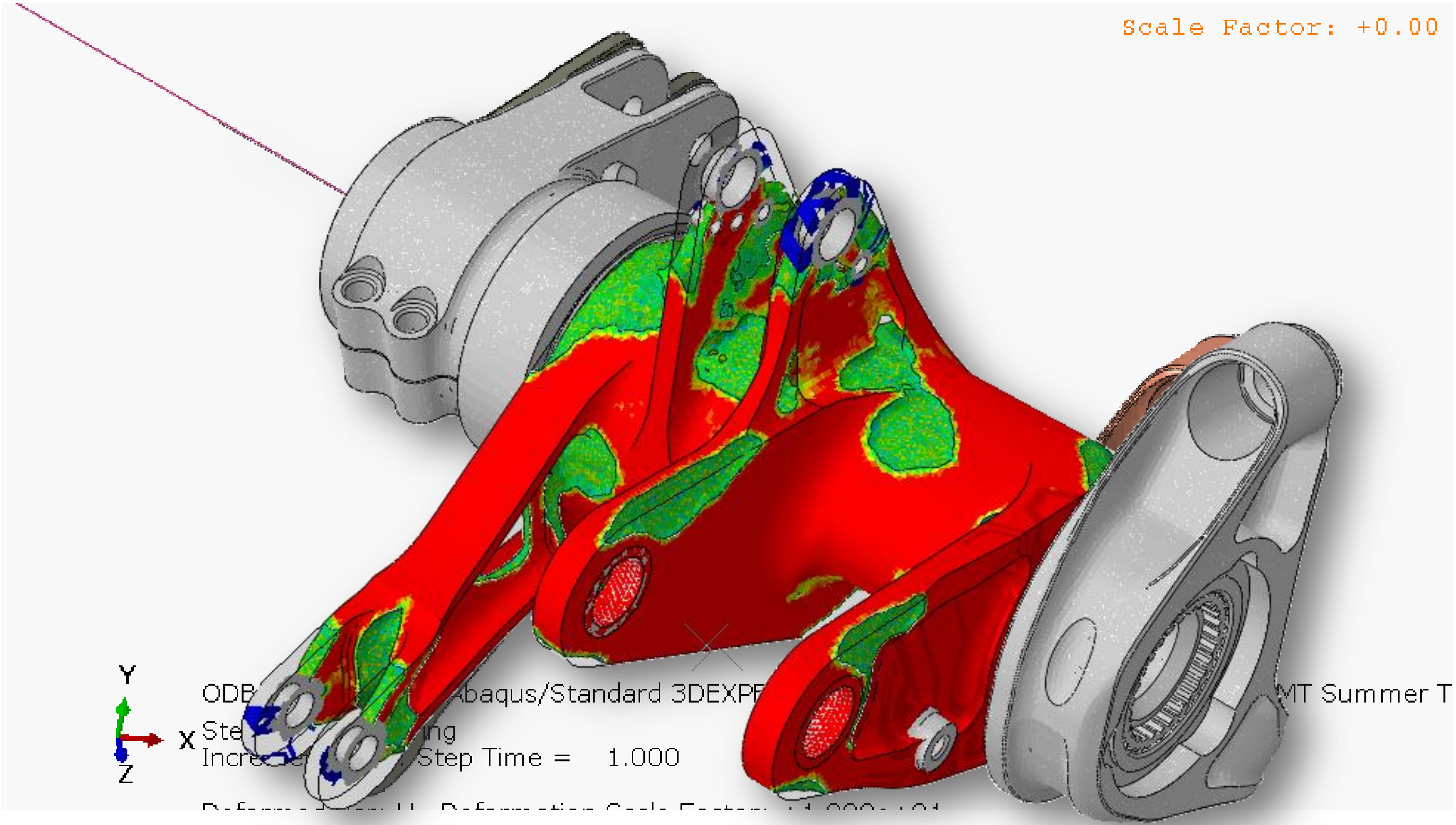
TruForm converged in 5 Abaqus solves



Maximise Stiffness Mass Fraction = 0.57	Constrained Linear Stress Mass Fraction = 0.64	Constrained Non-Linear Stress Mass Fraction = 0.45	Constrained Plastic Strain (355 Yield) Mass Fraction = 0.34	Constrained Plastic Strain (180 Yield) Mass Fraction = 0.54

TruForm Abaqus



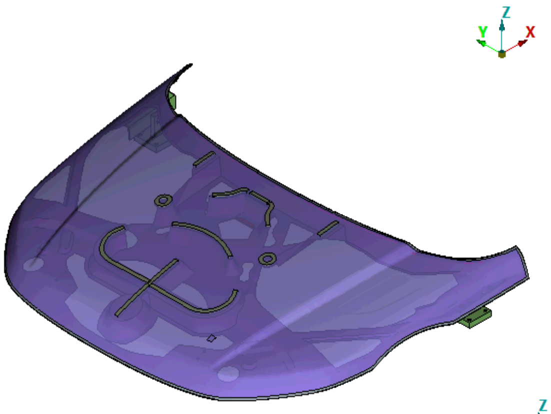

Scale Factor: +0.00
Y
X
Z
Step Time = 1.000

Gradient Based Optimisation with External Solver Evaluations

- Coupling Optimisation models to external libraries to calculate desired metrics and gradients based on current performance.
- Gradients calculated externally are fed back into the optimiser and drive the next iteration.

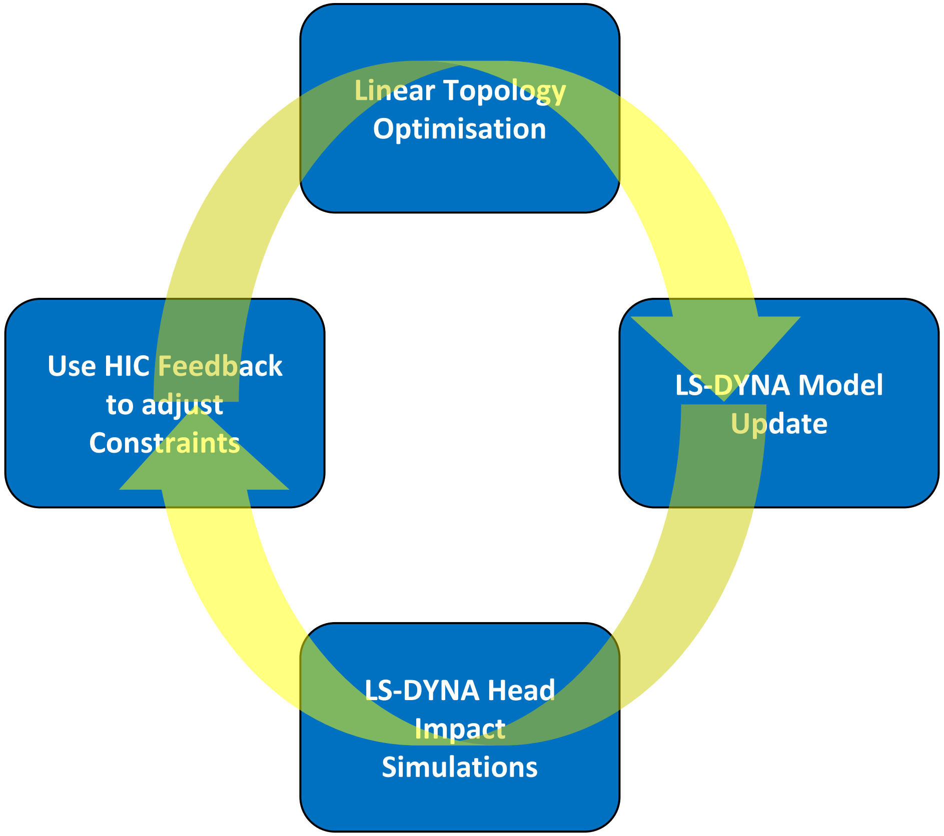
GRM COUPLING – HEAD IMPACT OPT PROCESS

- NVH Requirements
  > Torsion
  > Bending
  > Rear Beam Stiffness
  > Corner Stiffness
  > Centre of Pressure Load



- Safety – Head Impact Requirements
  > Adult and Child Head Impacts

GRM COUPLING – HEAD IMPACT OPT PROCESS

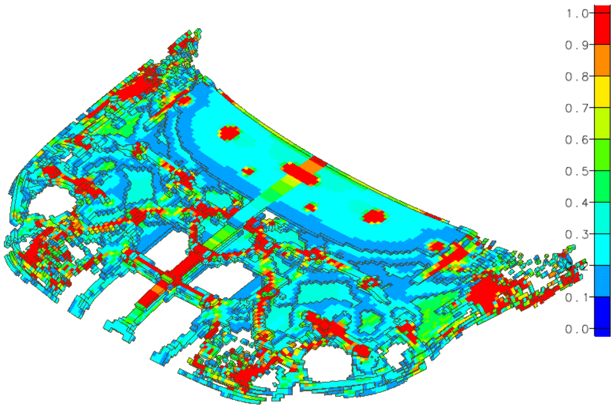


Automated Management Process

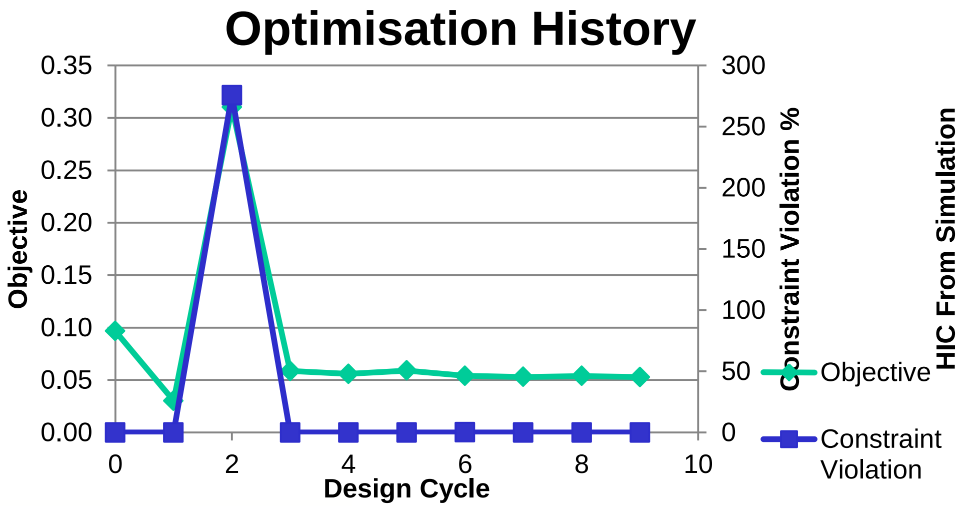
GRM COUPLING – HEAD IMPACT OPT PROCESS

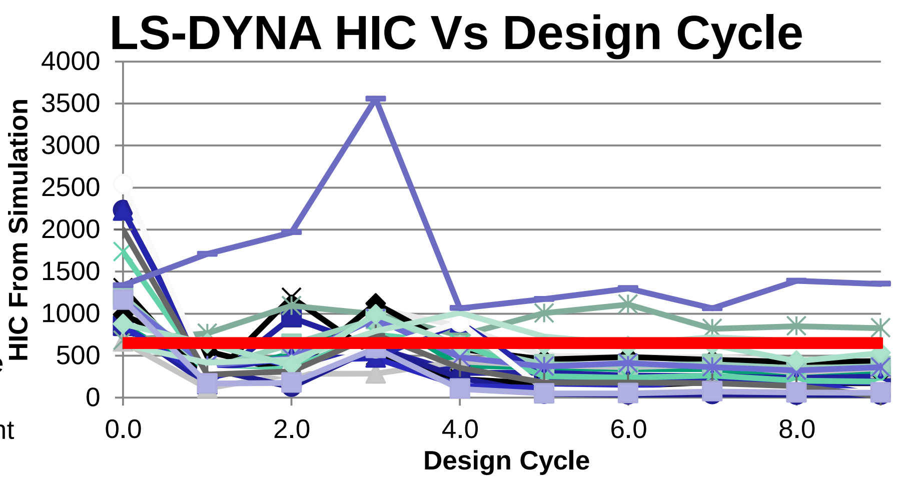
Topology Results Considering:

- Torsion
- Bending
- Rear Beam Stiffness
- Head Impacts

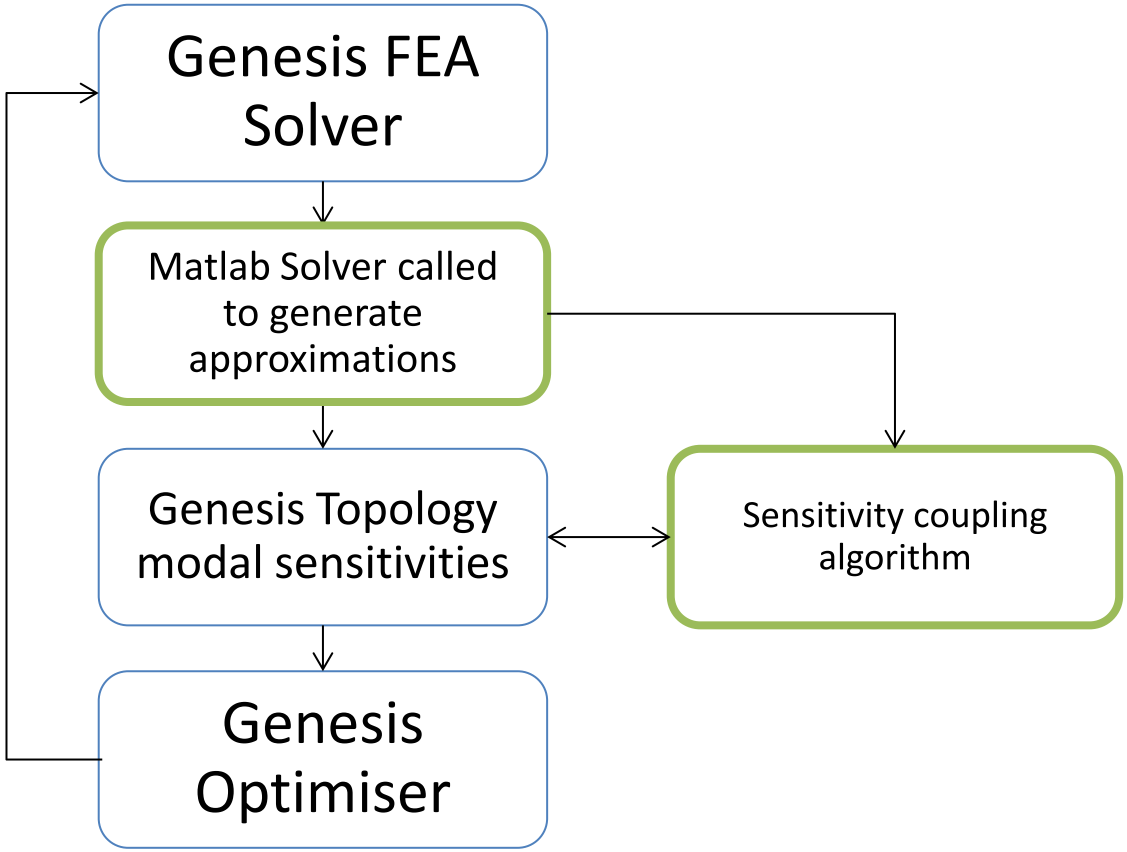


Topology Result for Each Design Cycle





Coupling to Matlab for NVH



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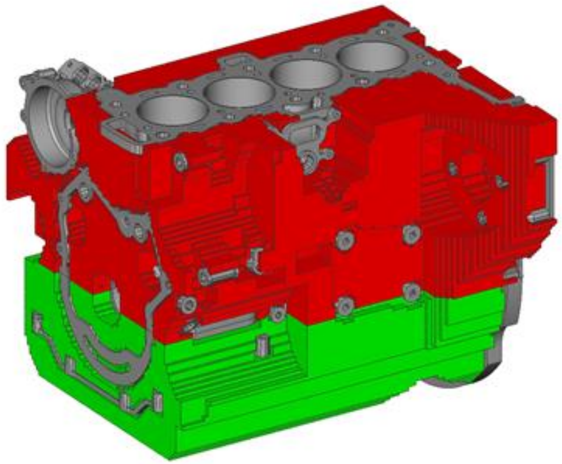
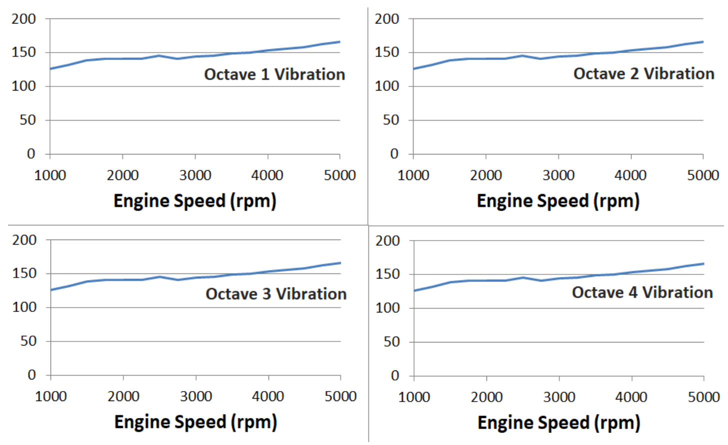


MATLAB



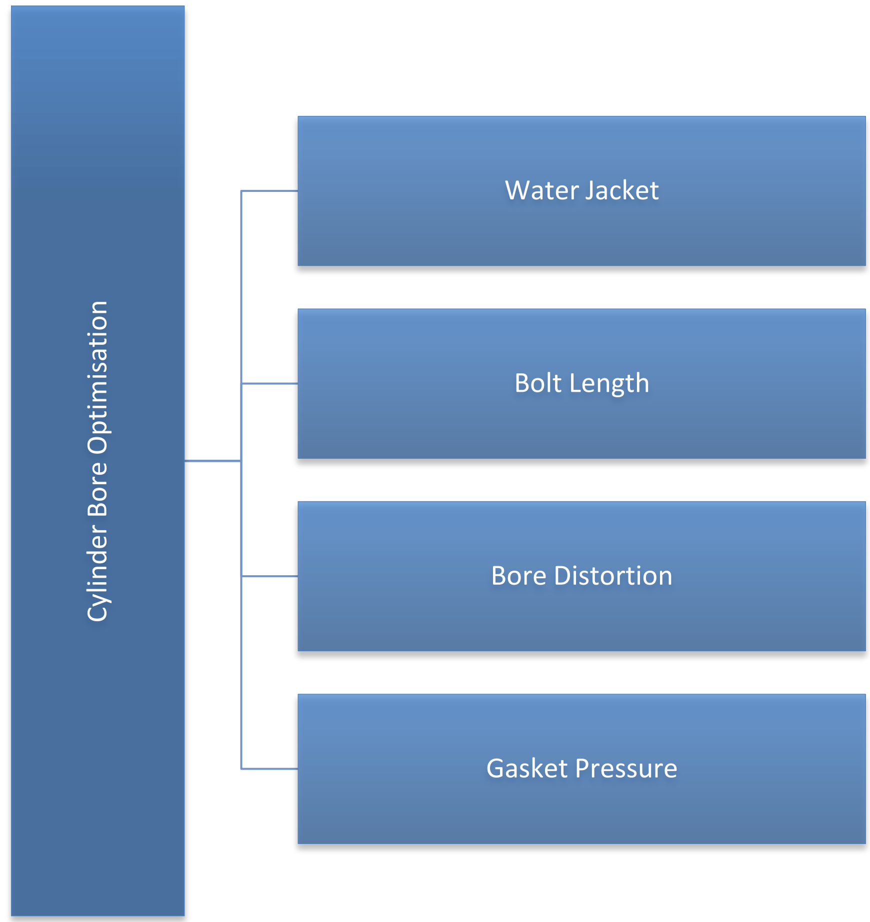
Content taken from:

Lightweight Cylinder Block and Lubrication Circuit Thermal Management Solutions for Low CO2 Emissions
SIA Conference Rouen 2018

Multiphysics Optimisation of an Engine Cylinder Bore

Cylinder Bore Optimisation

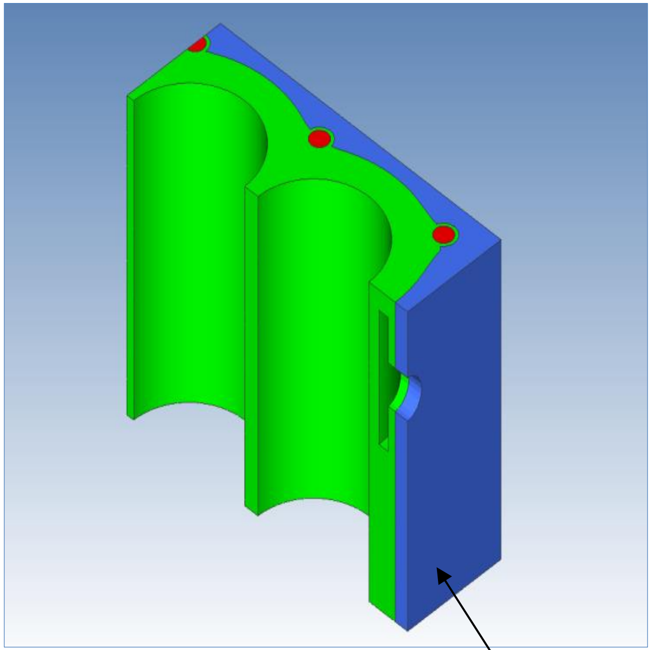
- Water jacket shape and cooling variability during optimisation
- Cylinder head bolt length as a design variable
- Cylinder bore distortion as a response
- Gasket sealing pressure as a response



Design Variables & Constraints

Optimisation will include a combination of shape and topology optimisation:

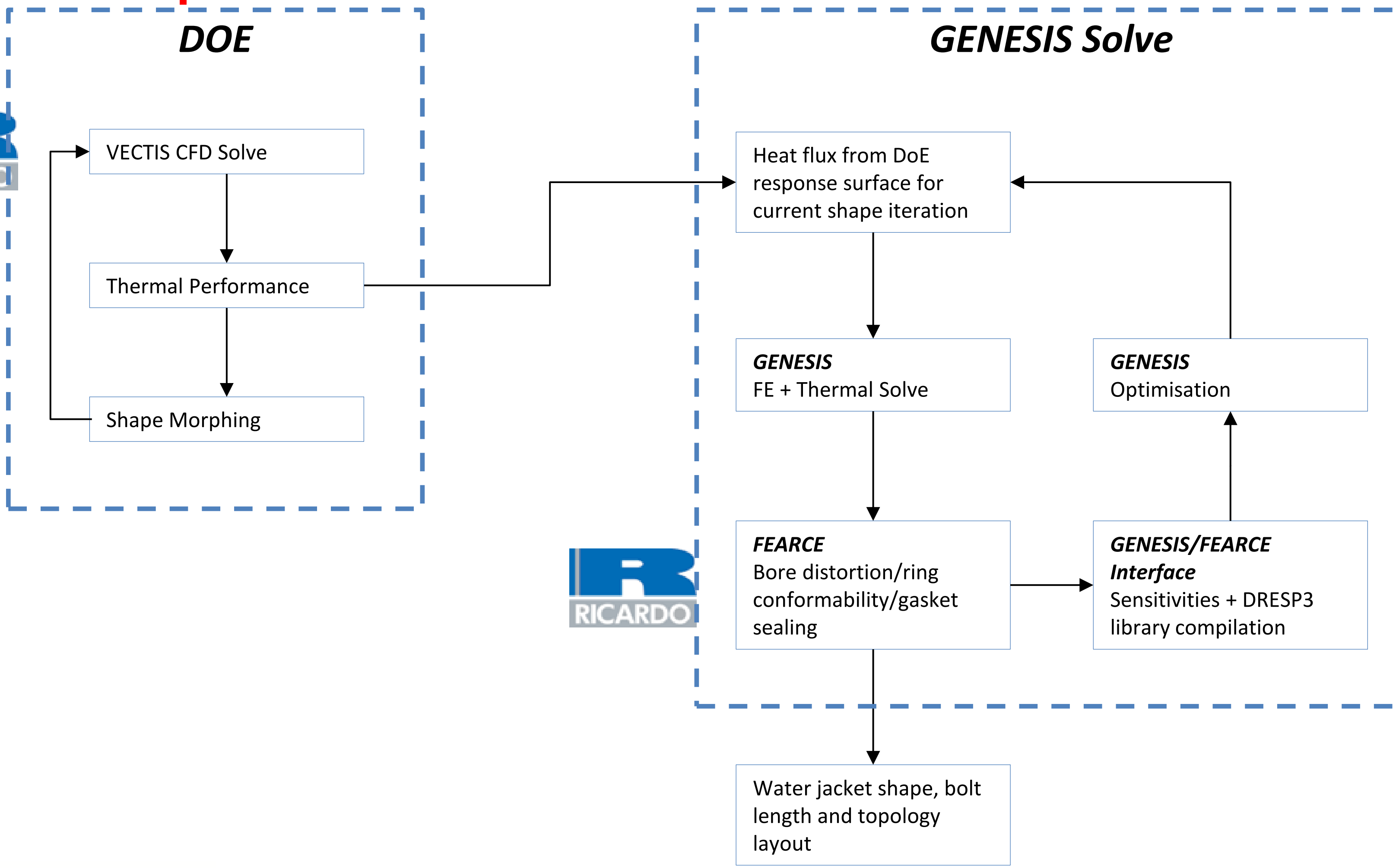
- Water jacket defined by shape optimisation.
- Outer block material layout defined by topology.



Topology region shown in blue

Shape Optimisation Design Variables	Other Design Variables	Responses
Water jacket depth	Cylinder head bolt length	Bore distortion
Water jacket thickness	Outer block material	Peak bore temperature
Water jacket profile at top and bottom		Gasket sealing pressure
Distance between water jacket and bore		
Inter-bore region		

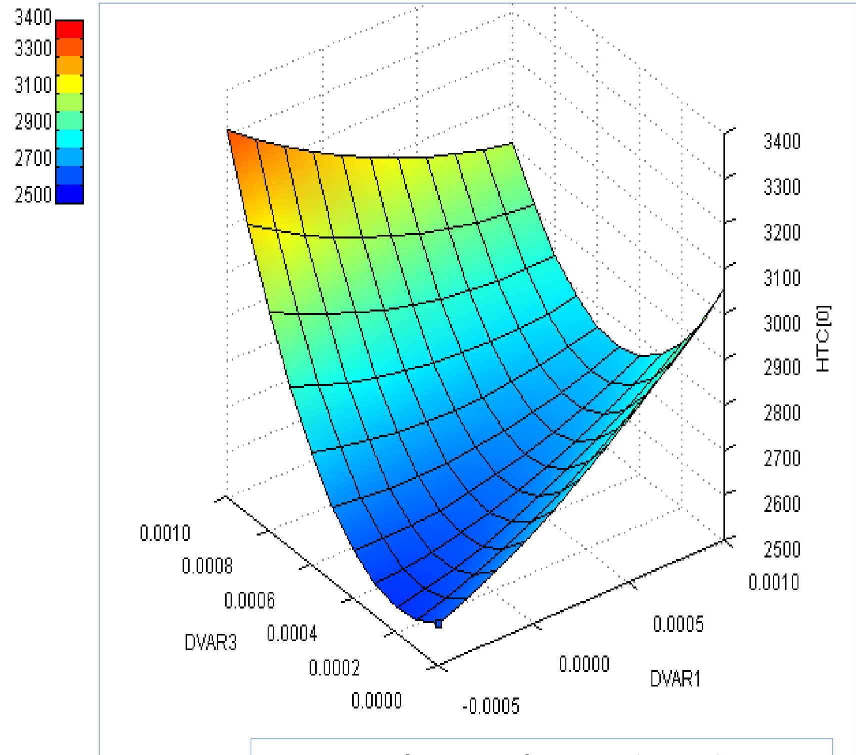
Thermal/Structural Optimisation



Development of Response Surfaces

Each element at the water jacket surface has a Heat Transfer Coefficient (HTC) and temperature defined.

- The DoE provides a relationship between the HTCs/temperatures and shape design variables.
- A quadratic response surface is fitted to a number of design variable points for each element HTC and temperature.
- Response surfaces are produced via python script or custom plugin to VisualDOC.
- Number of response surface equations is currently in the order of 50k.



Response surface output from DoE, showing how HTC at a single element face varies depending on the value of two design variables, DVAR3 and DVAR1.

Design of Experiments
HTC and temp at a number of values for each design variable.

→

Quadratic Equation
HTC = F(DV1, DV2, …DVn)
Temp = G(DV1, DV2, …DVn)

→

Update Area of Beam Element
Via design property in GENESIS

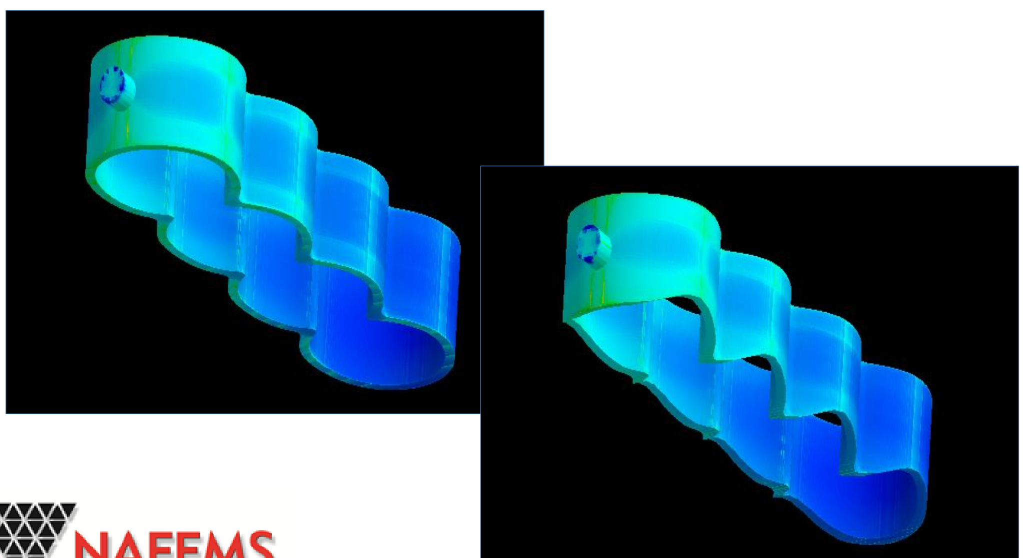
→

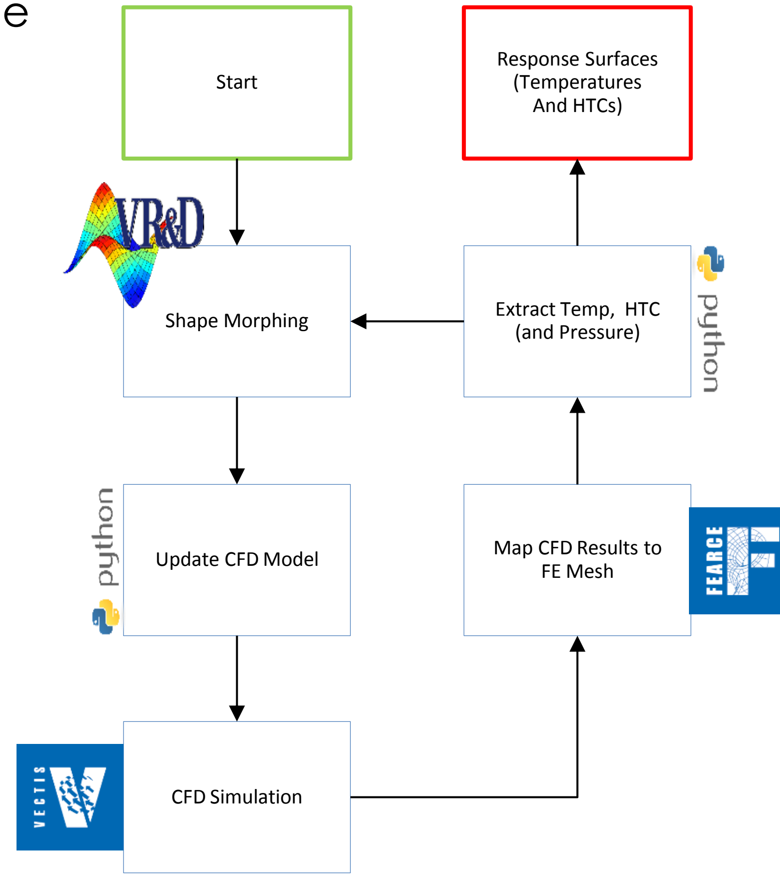
Applied Temperature and HTC at water jacket surface

Morphing of CFD (VECTIS) Model

Method developed to automatically update the shape and mesh of the CFD model, based on shape morphing in GENESIS model.

- Shape design variables in test model include:
  - Height of water jacket
  - "Sine wave" at bottom and top of water jacket
  - ***More shape variables are to be considered/agreed when the method is applied to detailed engine block structure.***



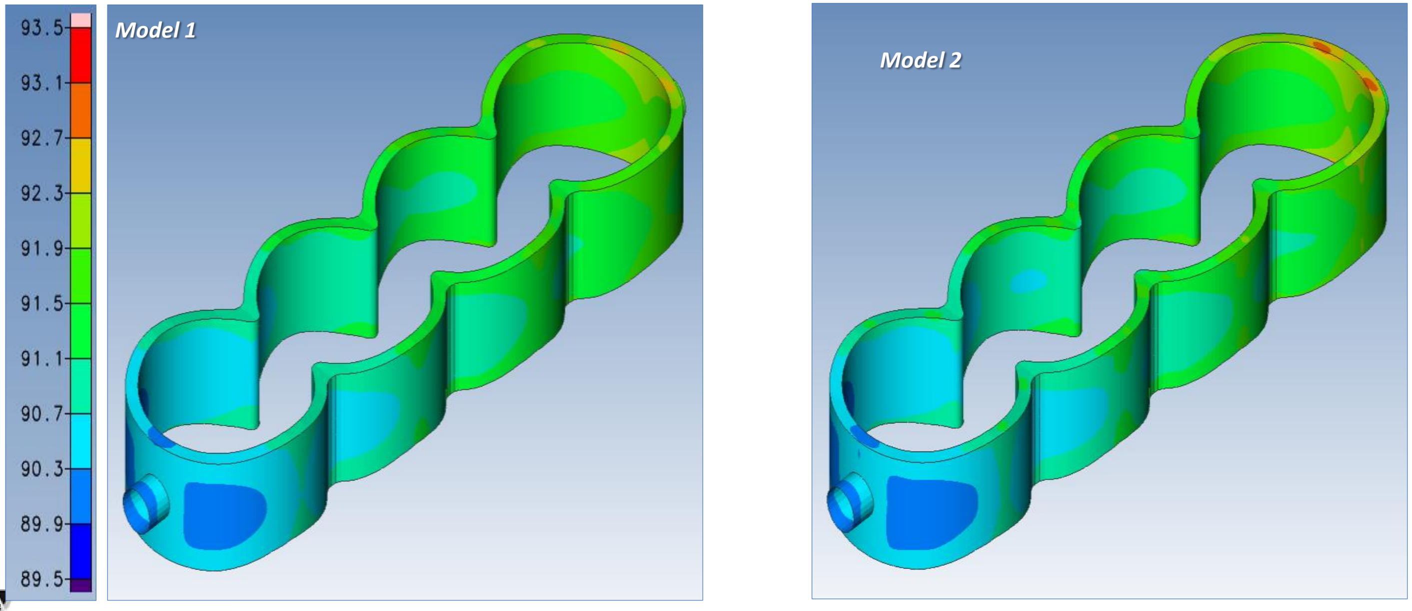


Validation of Response Surfaces

In order to validate the thermal modelling techniques and response surfaces generated from the DoE, three models have been compared:

1. Temperatures and HTCs explicitly defined and mapped directly using traditional methods.
2. Temperatures and HTCs linked to design variables and applied using geometric bar element method.

Models show excellent correlation, with a maximum nodal temperature difference of 0.63%.



LATITUDE

- Both The CFD –thermal/structural coupling case study and the Matlab Coupling optimisation process have been developed with Riccardo as part of the LATITUDE project.

- The Latitude Project is funded through the Advanced Propulsion Centre. Its partners include Jaguar Land Rover, Ricardo, Borg Warner, Bosch and GRM.

Ongoing Research : Direct Gradient Integration

- Unifying chain rule approach Working with 3rd party solutions to directly access the jacobians of the solution sequences

- No in loop calculations required, direct knowledge of the third party solutions will be available to the optimiser

- Being actively developed to optimise gearbox housings with respect to internal gear metrics.

Any Questions?

- Email me: Lawrence.holness@grm-consulting.co.uk