Open source software tools for powertrain optimisation

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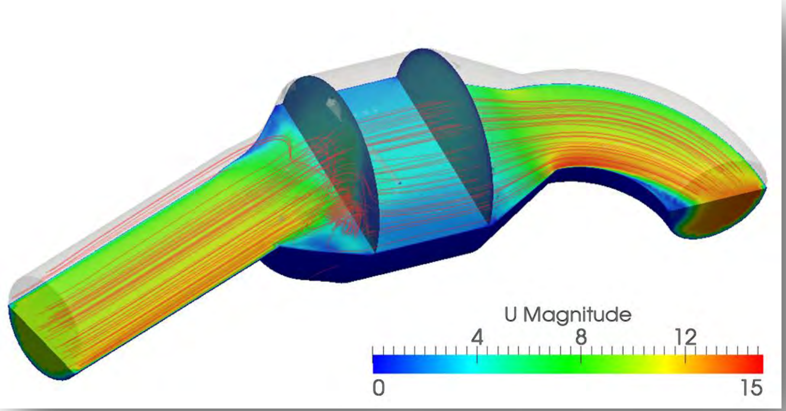
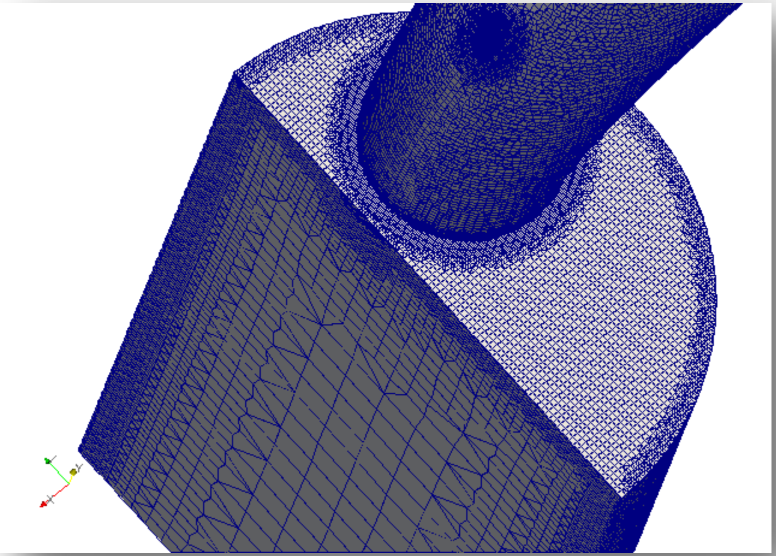
TWO-DAY MEETING ON INTERNAL COMBUSTION ENGINE SIMULATIONS USING OPENFOAM® TECHNOLOGY

11-12 July, 2011





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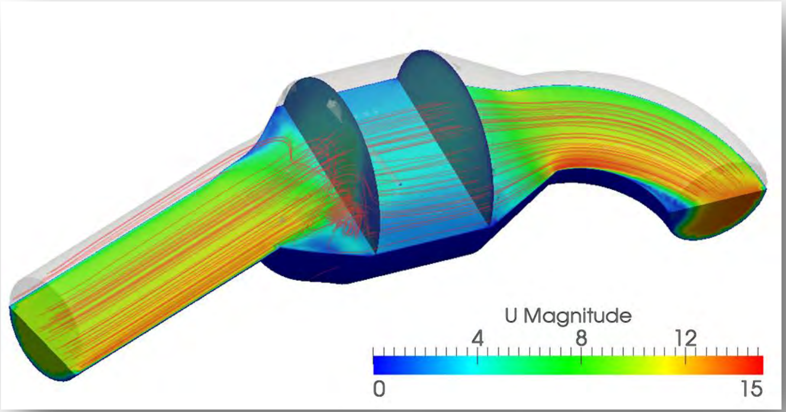
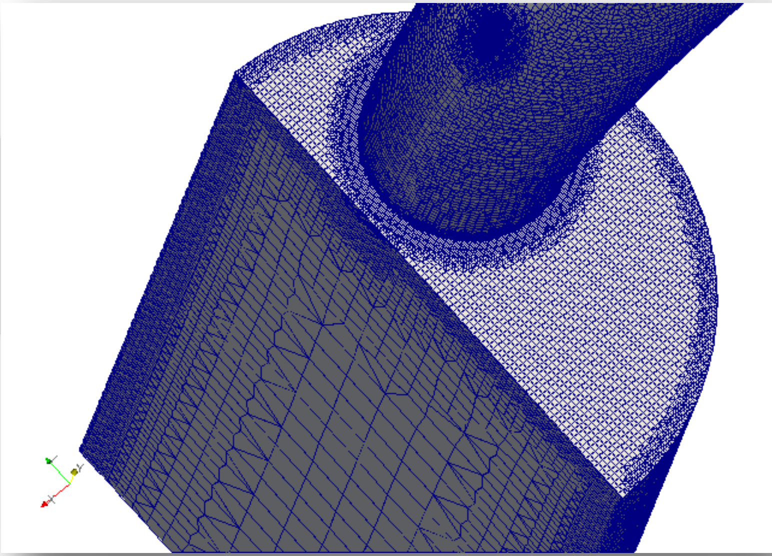
Contents

- Background
- Example 1: Catalytic Converter Optimisation
- Example 2: Intake Port Optimisation
- Conclusions



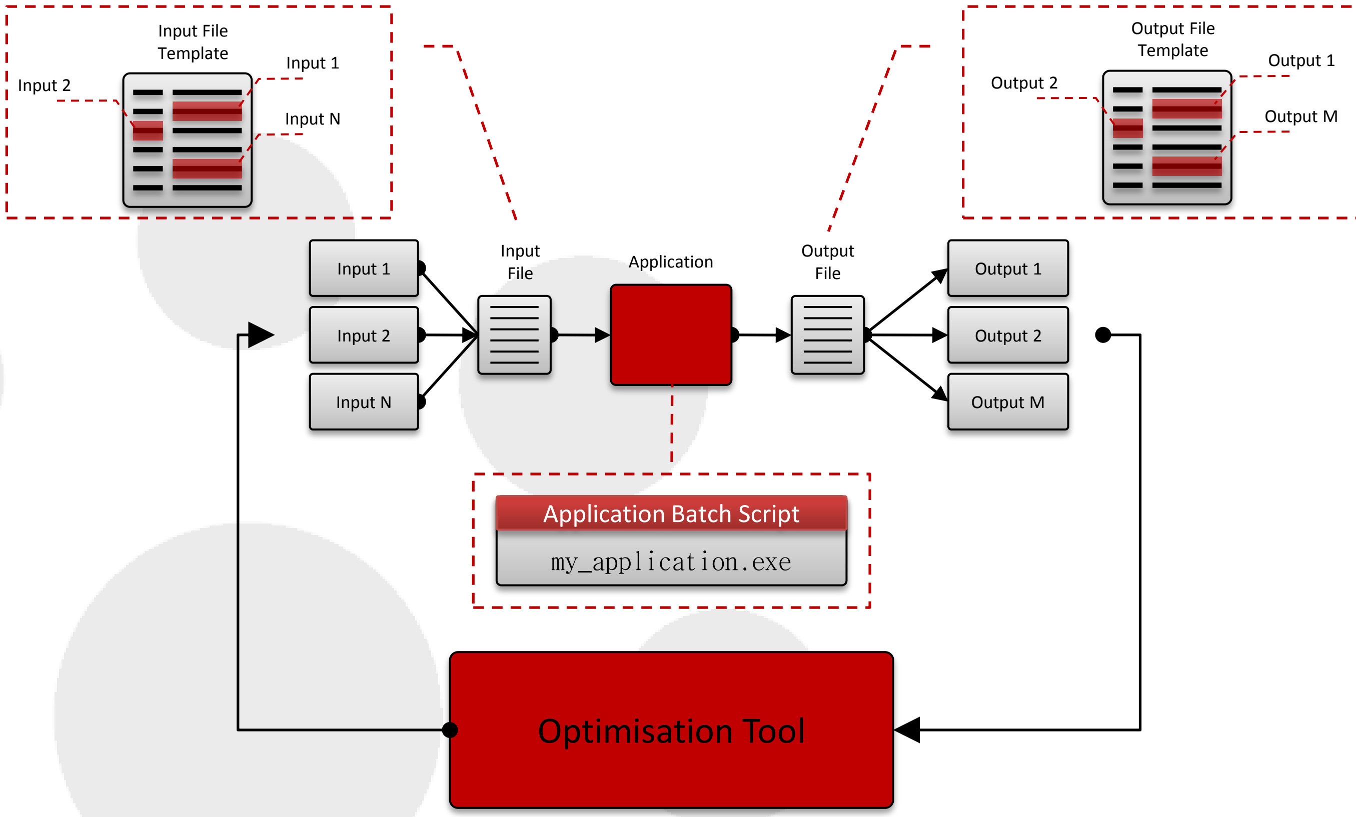


Why Optimisation?

- Multi-objective design optimisation techniques are ideal for:
  - Finding the optimal layout of the design solution
  - Automating the design process instead of trial-and-error approach
  - Multi-disciplinary process integration (e.g. CAD+Mesh+FEM+CFD)
  - Finding the most relevant design parameters affecting the solution
  - Evaluating the robustness and stability of a solution for a given range of parameters
  - Better understanding of design space response

→ Better design with reduction of costs and speed-up of time-to-market

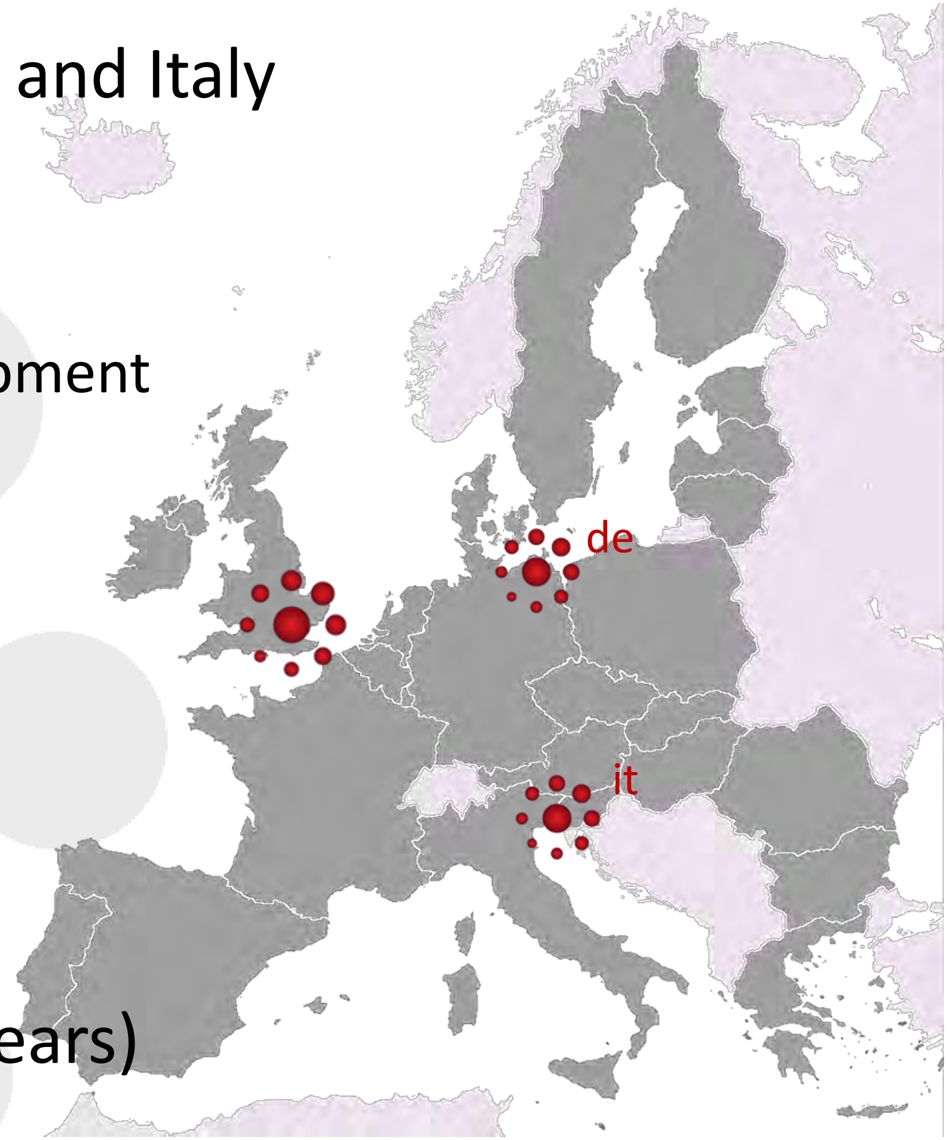
How Traditional Optimisation Works



- Optimisation tools work like software "robot"
- For each design evaluation, the optimiser automates the following steps:
  - Input file(s) creation with updated values of design parameters
  - Batch run of application(s)
  - Reading of results from the output file(s)

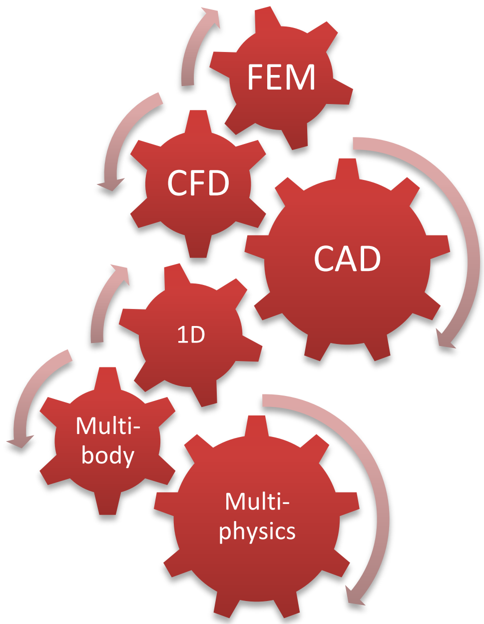
Company Details

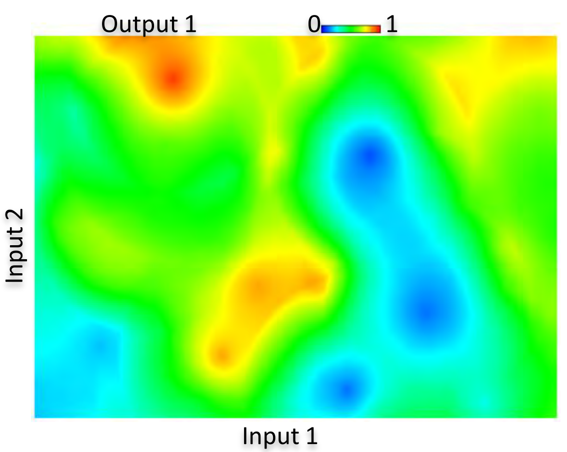
- Registered in UK, Germany and Italy
- CAE services company:
  - Consultancy
  - Software & Methods Development
  - User support & Training
- Open Source engineering software for industry:
  - CFD → OPENFOAM®
  - Optimisation → DAKOTA
  - FEM → Code_Aster
- Extensive expertise (> 10 years)



Optimisation Services

- DAKOTA user support & training
- Coupling with most CAE tools
  - OSS, commercial and in-house tools
  - CFD, FEM, 1D, Multiphysics, Multibody, Manufacturing process simulation, etc
- Design Of Experiments (DOE)
- Multi-objective constrained optimisation
- Model calibration
- Sensitivity analysis
- Tolerance/Robust design
- Model creation for data analysis, prediction, regression and correlation





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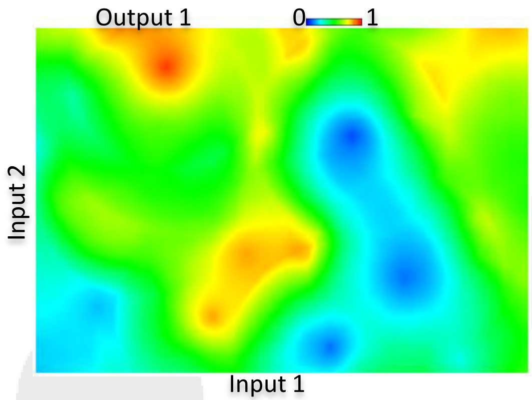
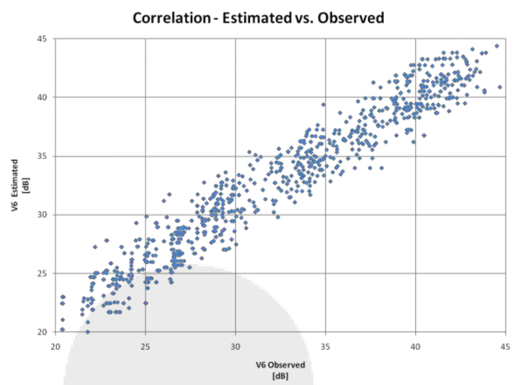
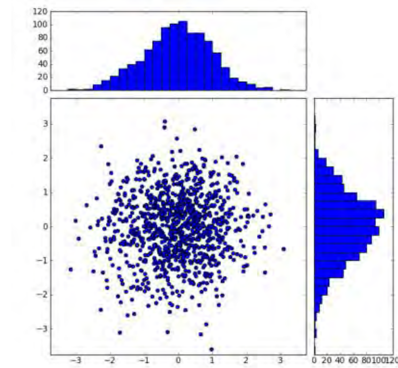
Optimisation Services

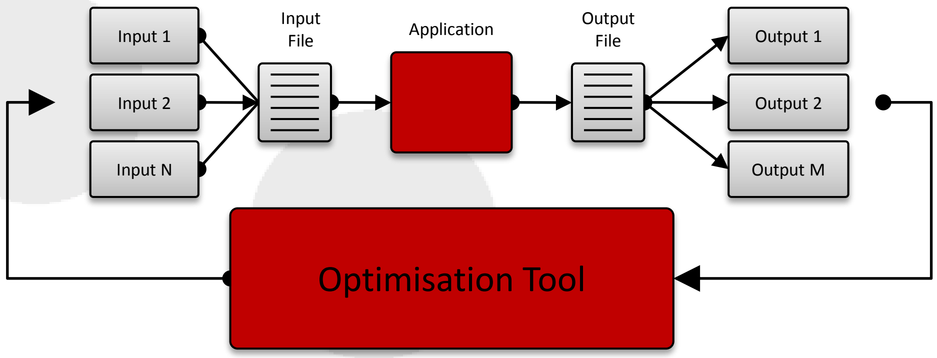






- **Optimisation**: What is the best performing model?
- **Calibration**: What parameter values or models best match a specific dataset?
- **Regression / Classification**: Which is the value predicted of the model in different conditions based on an existing dataset?
- **Sensitivity Analysis**: What are the crucial parameters?
- **Uncertainty Quantification**: How safe, reliable, robust, variable is my system?
- **Clustering**: Are there any similarities among existing samples? Can the model complexity be reduced?

Expertise | Partial List of Coupled Software



CAD
- CATIA V5
- ProENGINEER
- Unigraphics NX
- SolidWorks
- SolidEdge

CFD
- OPENFOAM
- ANSYS CFX
- ANSYS Fluent
- STAR-CCM+
- STAR-CD

FEM
- ABAQUS
- ANSYS
- LS-Dyna
- Madymo
- Marc
- Nastran

1D
- Adams
- AVL
- Flowmaster
- GT-SUITE
- MATLAB
- Simulink
- Wave

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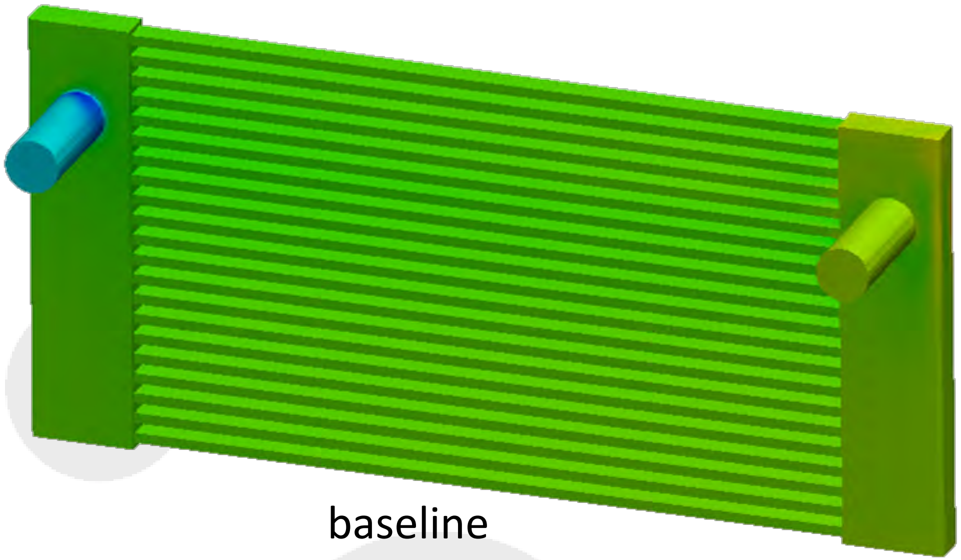
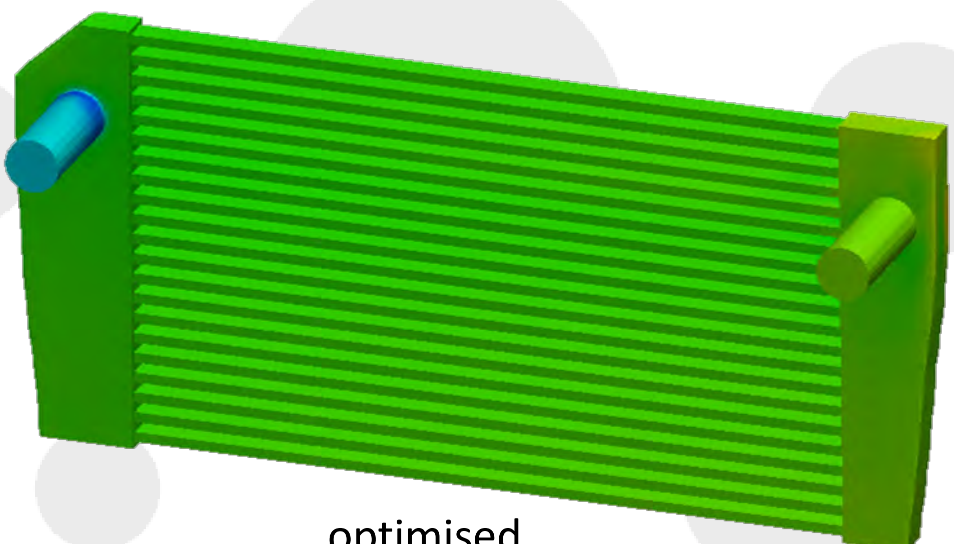
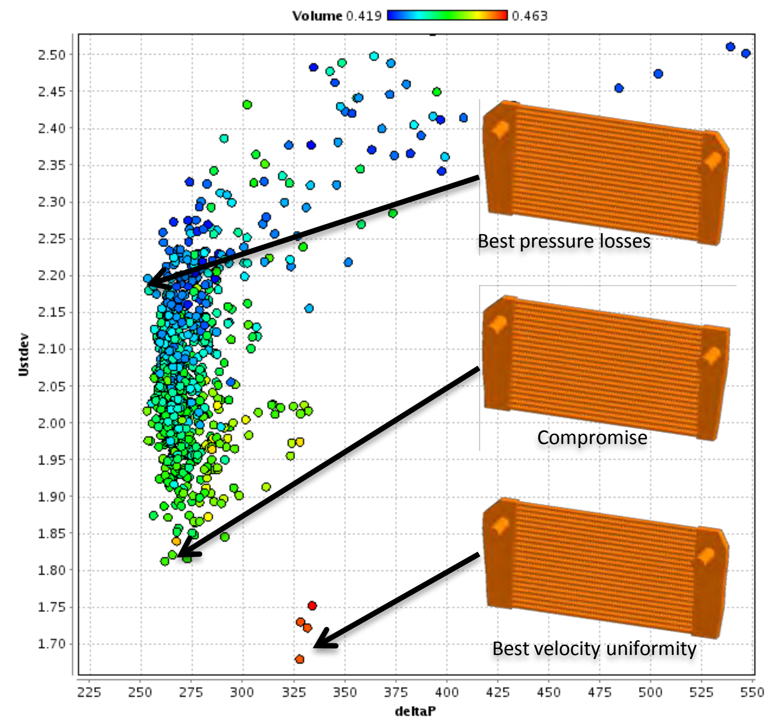
Expertise | Optimisation



baseline



optimised



Engine charge air cooler tanks optimisation

Input Variables

14 tank cross-section height

Design Objectives

MIN pressure losses

MAX flow uniformity

MIN volume of tanks

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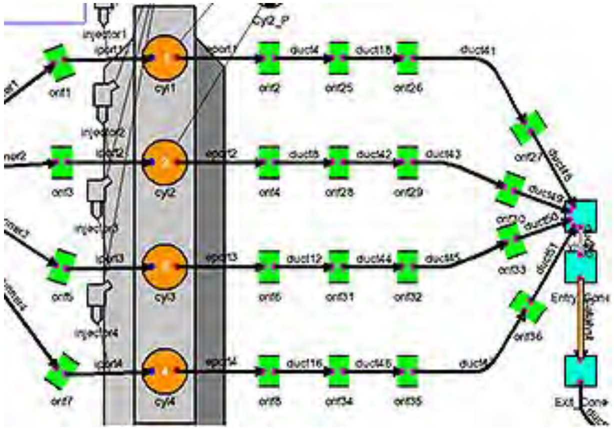
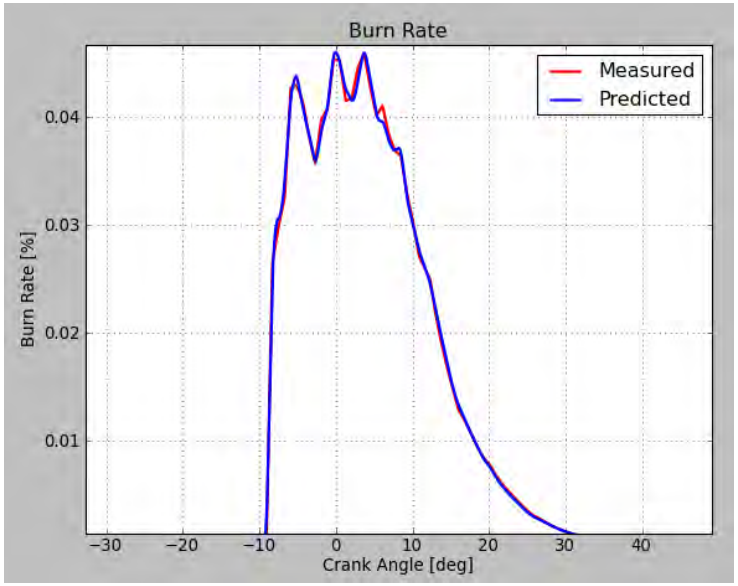
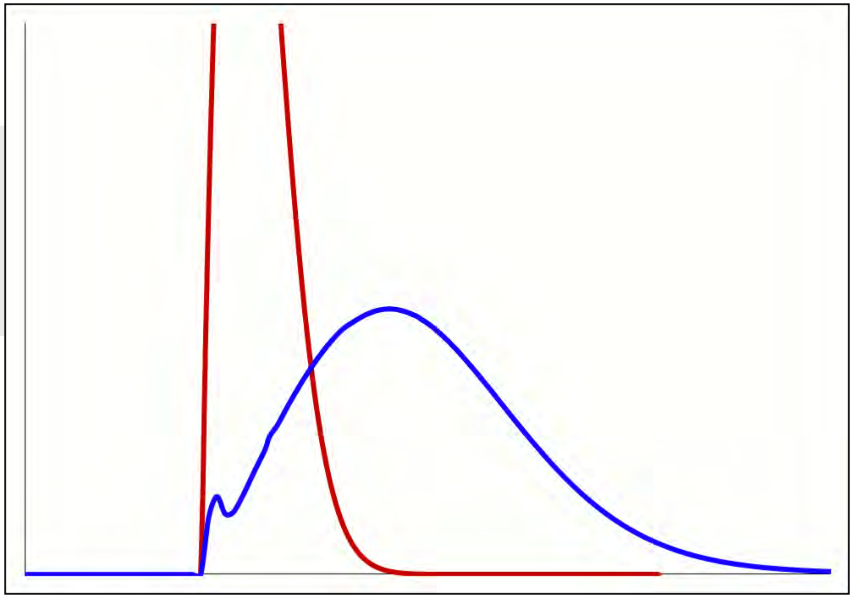
Expertise | Model Calibration

- Parameters estimation
- Non linear least-squares methods
- Calibration under uncertainty

→ Ideal for 1D/3D engine models.







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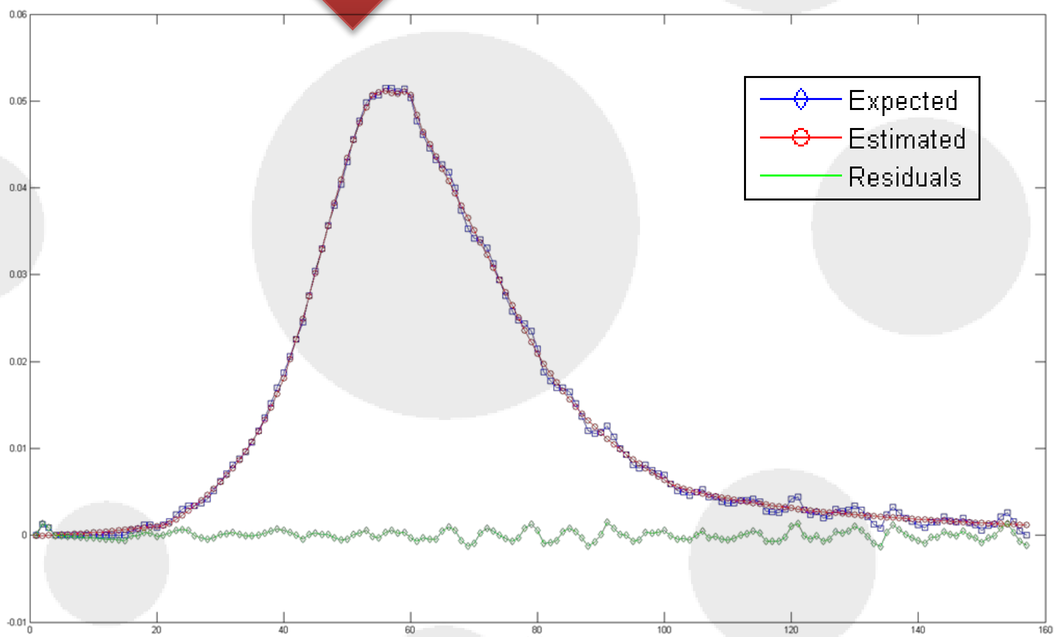
Expertise | Regression Analysis

- Input: four-stroke SI Engine measured burn rate curve
- Goal: find the mathematical expression of burn rate vs. rev angle



$f(\theta)$

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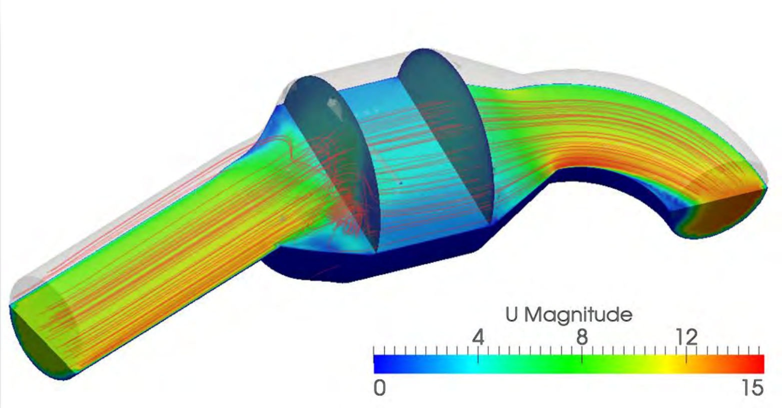
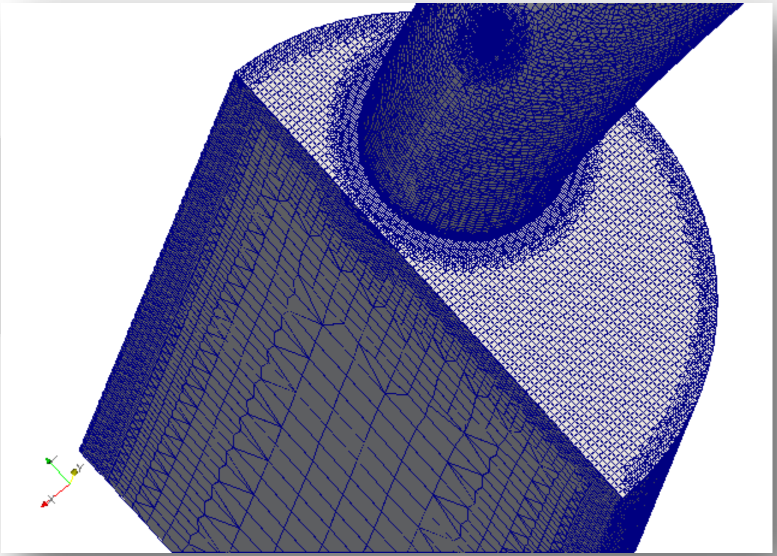
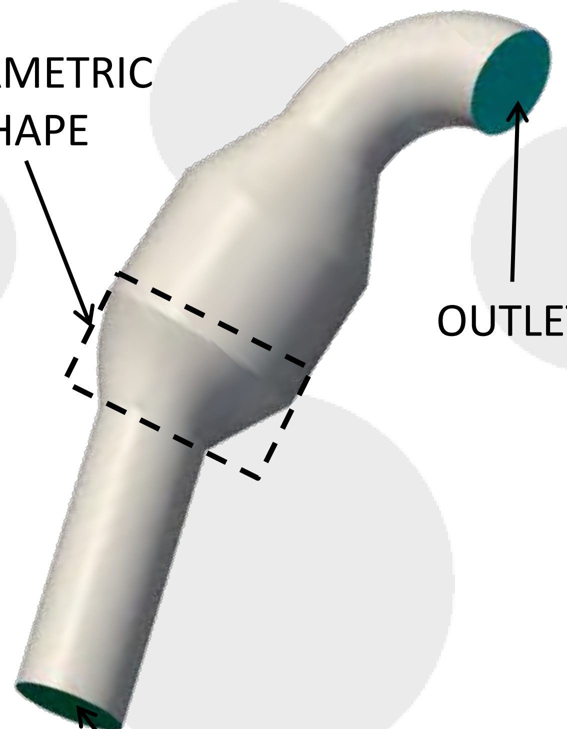




Problem Description



- The optimisation problem can be stated as follows:
- Minimise

$$\Delta p = p_{in} - p_{out}$$

and

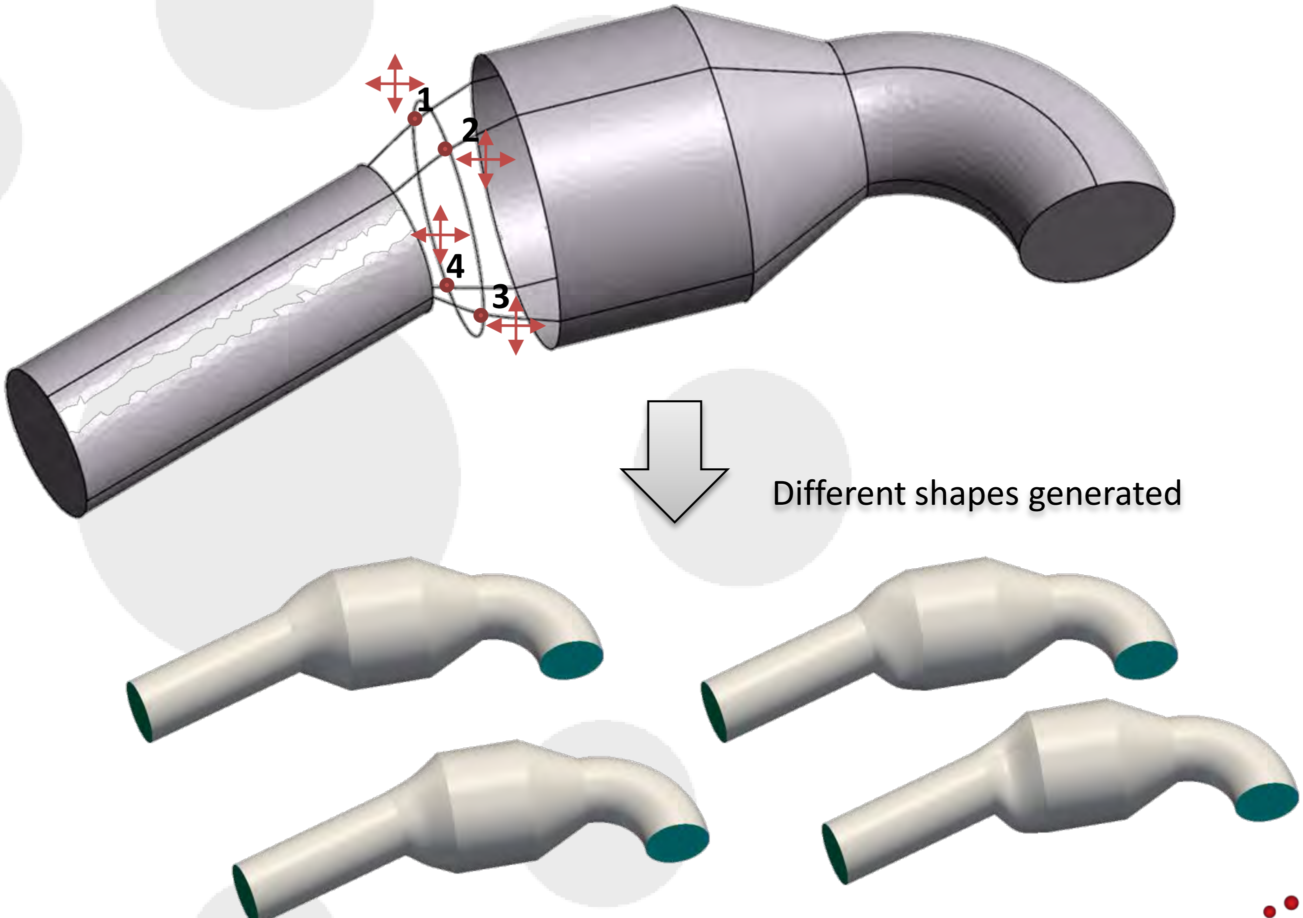
$$U_{stdev} = \sqrt{\sum_i \frac{(U-\bar{U})^2}{N}}$$

where:

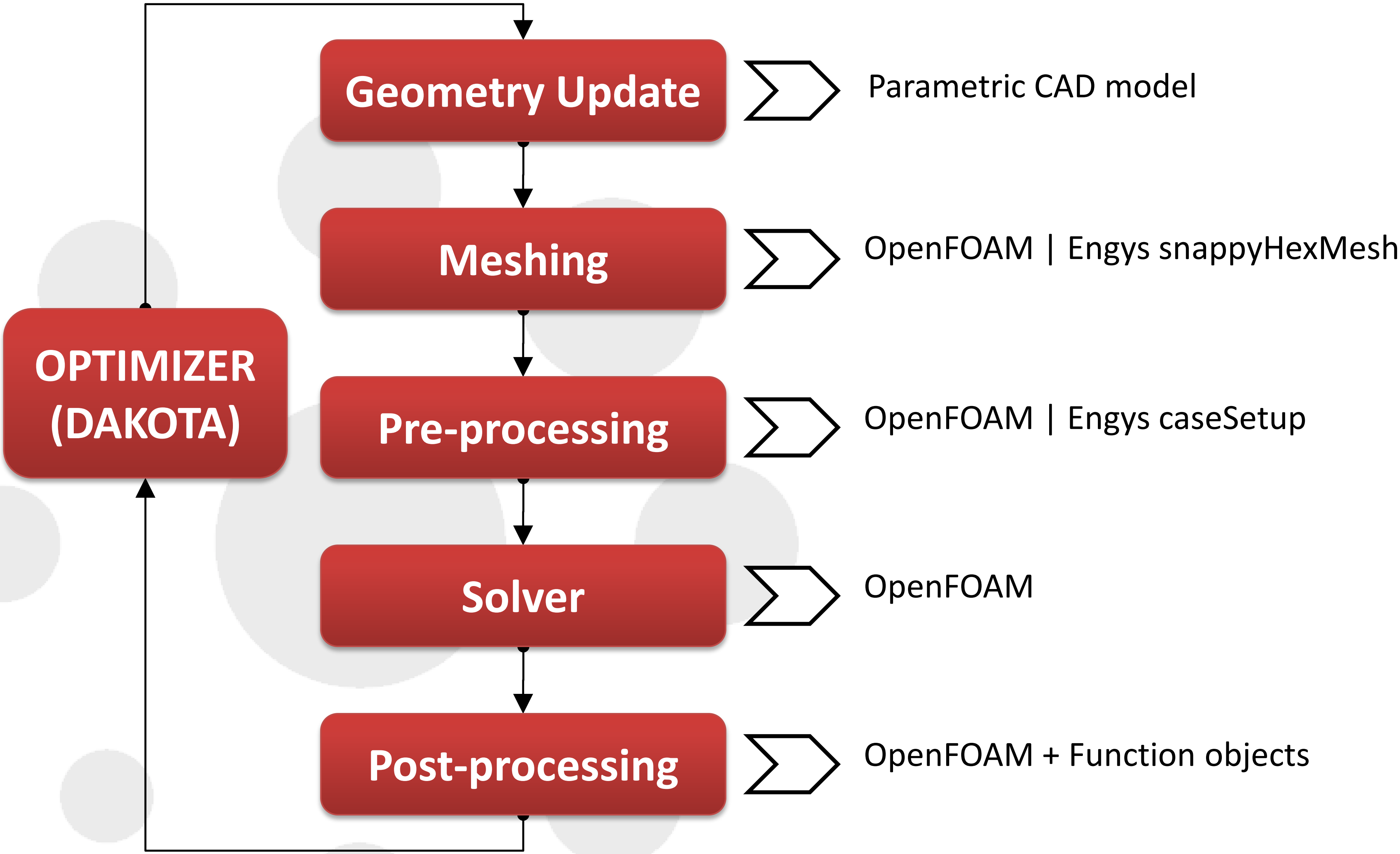
- Δp is pressures losses between inlet and outlet sections
- U_{stdev} is a measure of the velocity uniformity at the outlet section

Geometrical Parameterisation

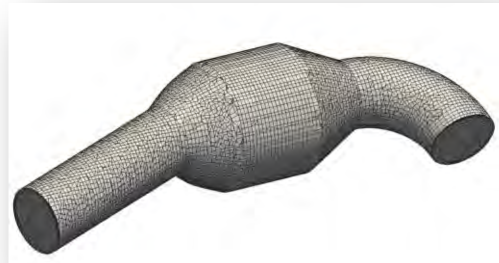
- CAD geometrical shape parameterisation
- X,Y position of 4 cross-section points

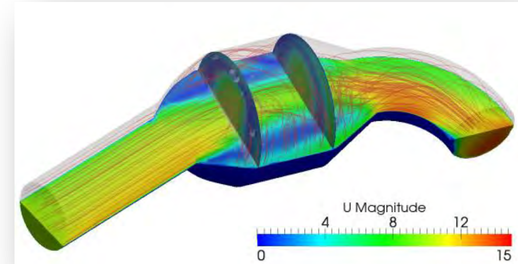


CAD Shape Optimisation Approach



The Optimisation Workflow





CAD → SnappyHexMesh → OpenFOAM → DAKOTA → CAD

Design Parameters

Input Variables

X and Y coordinates of 4 cross-section points

Output Variables

Flow uniformity

Pressure drop

Design Objectives

Maximise flow uniformity

Minimise pressure drop

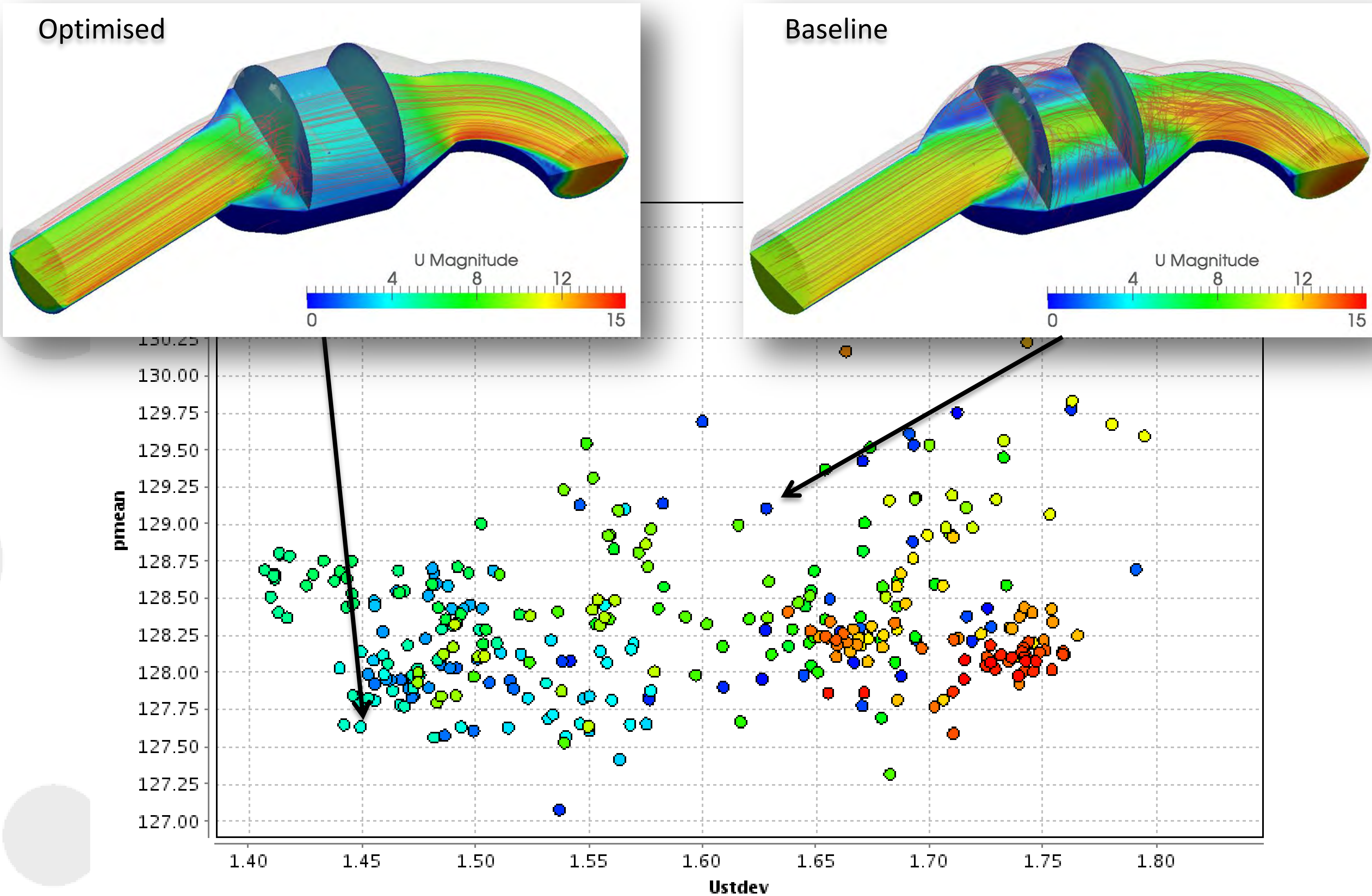
Optimization Setup

Exploration Phase:

Surrogate-based global MOGA algorithm – max no. of iterations: 10

Generation size: 32

Optimisation Results



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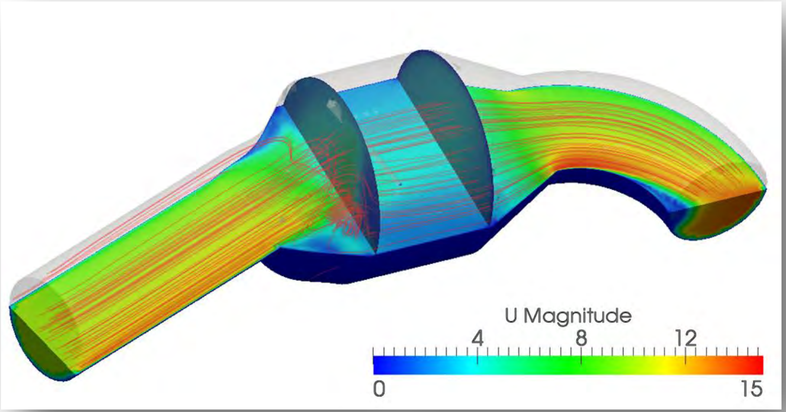

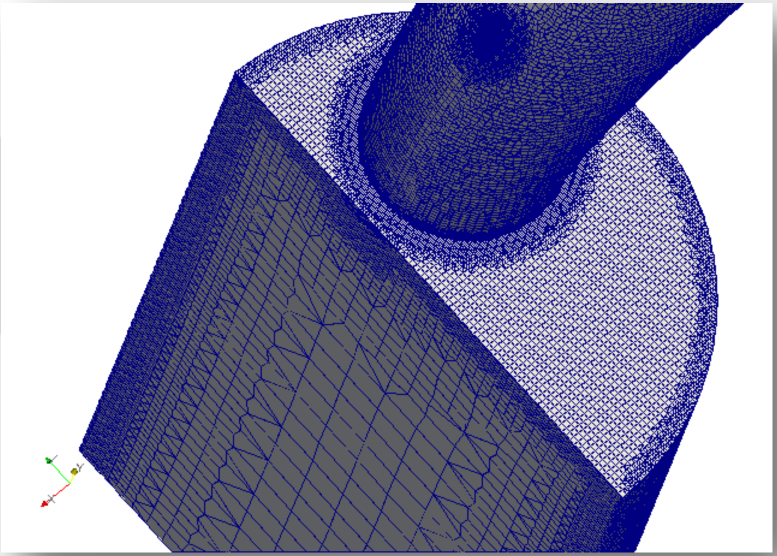

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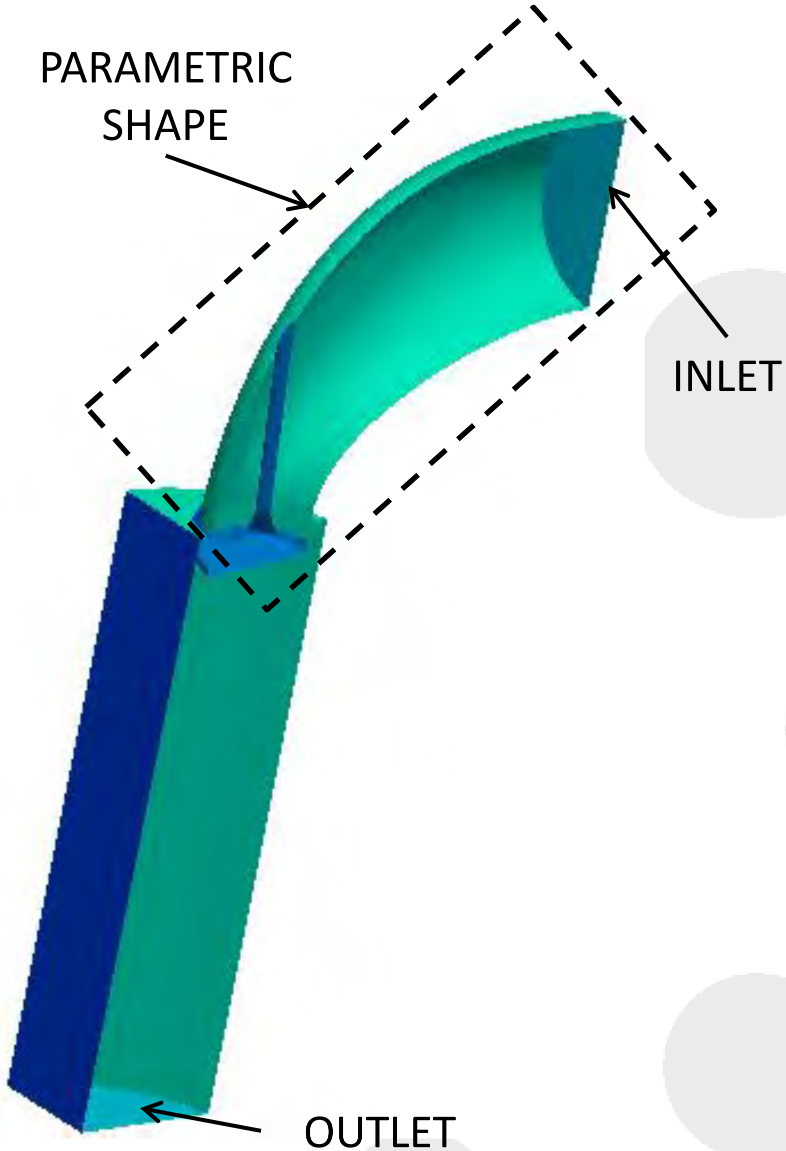

- The optimisation problem can be stated as follows:
  - Maximise discharge coefficient, defined as:

$$C_d = \frac{\dot{m}}{\dot{m}_{IS}}$$

  - Maximise total angular momentum flux (i.e. swirling, tumbling and cross tumbling), whose components are computed as follows:

$$Swirl_Y = \int_A \rho U_Y (zU_X - xU_Z)$$

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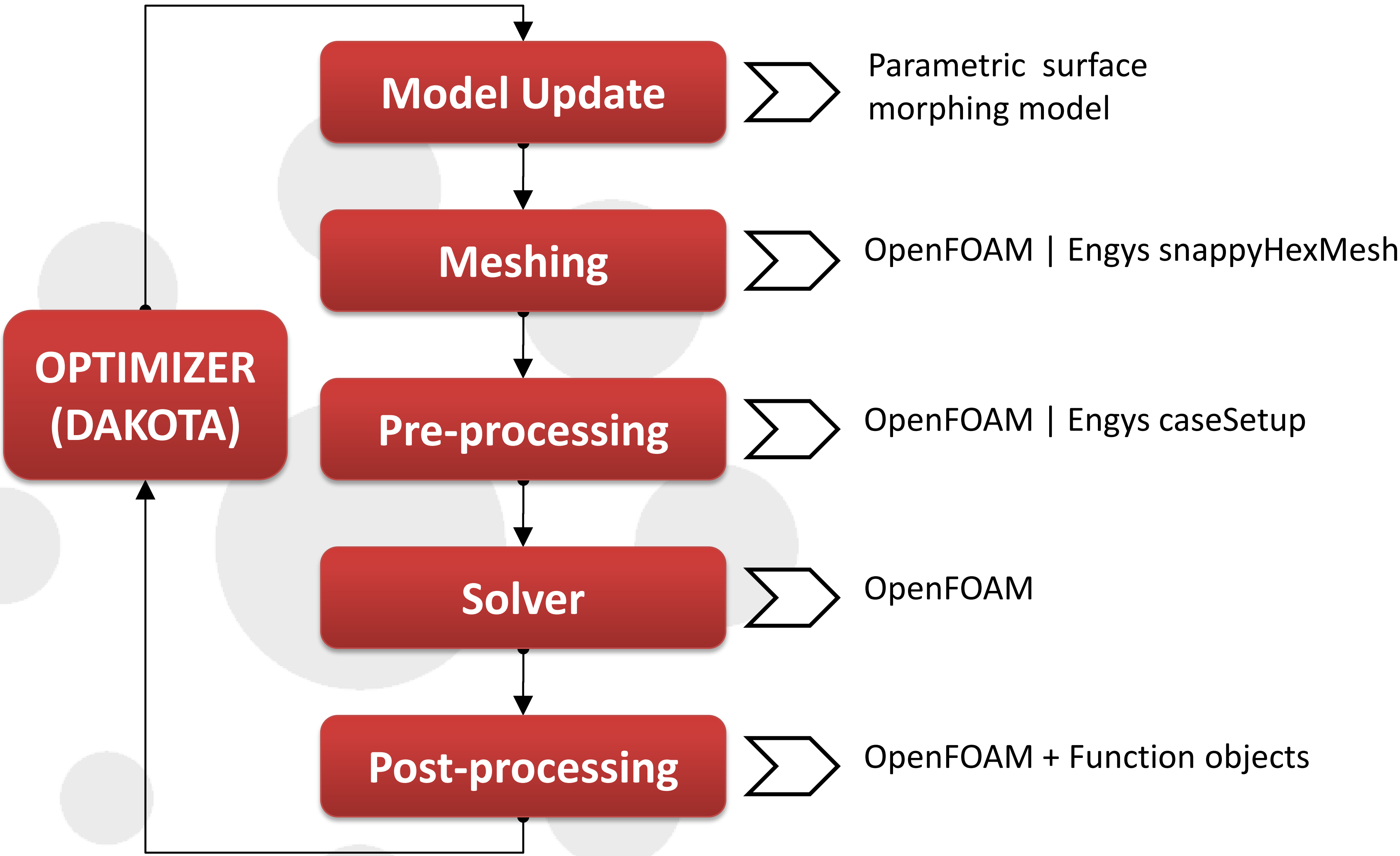
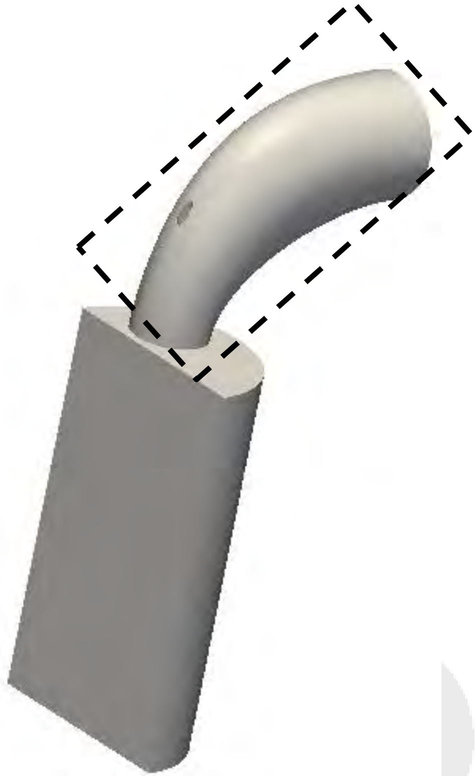
Surface Morphing Optimisation Approach

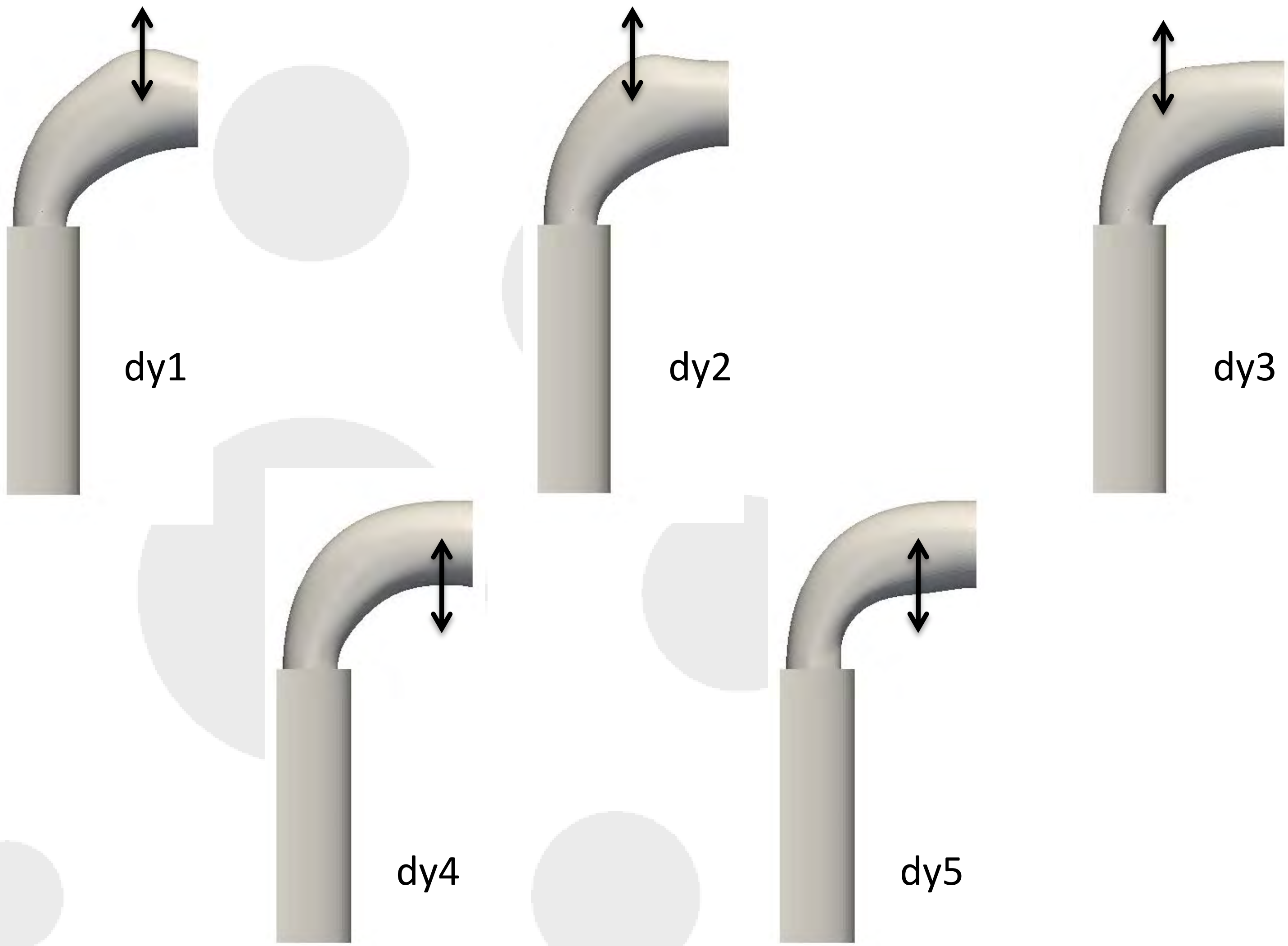


Geometrical Parameterisation



- Morphing boxes were defined in Blender to perform STL surface morphing of the intake port duct
- 8 degrees of freedom:
  - Y translation of five control points
  - Z translation of three symmetrical control points

Geometrical Parameterisation | Y Translation



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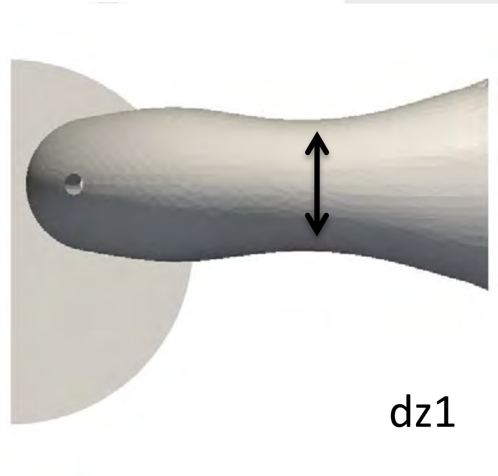
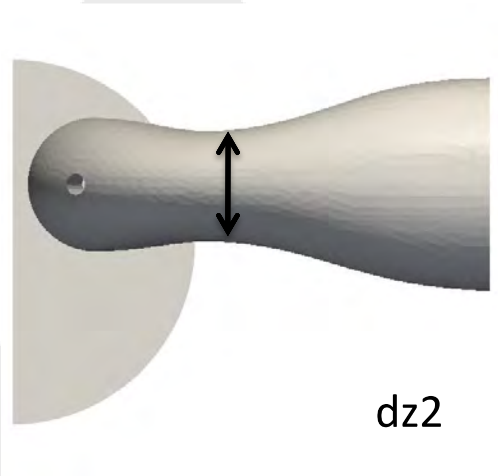
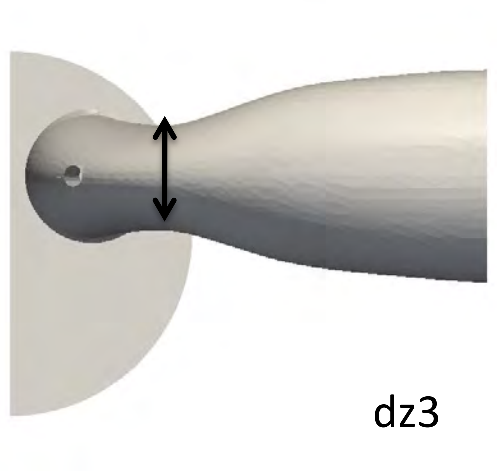
Geometrical Parameterisation | Z Translation

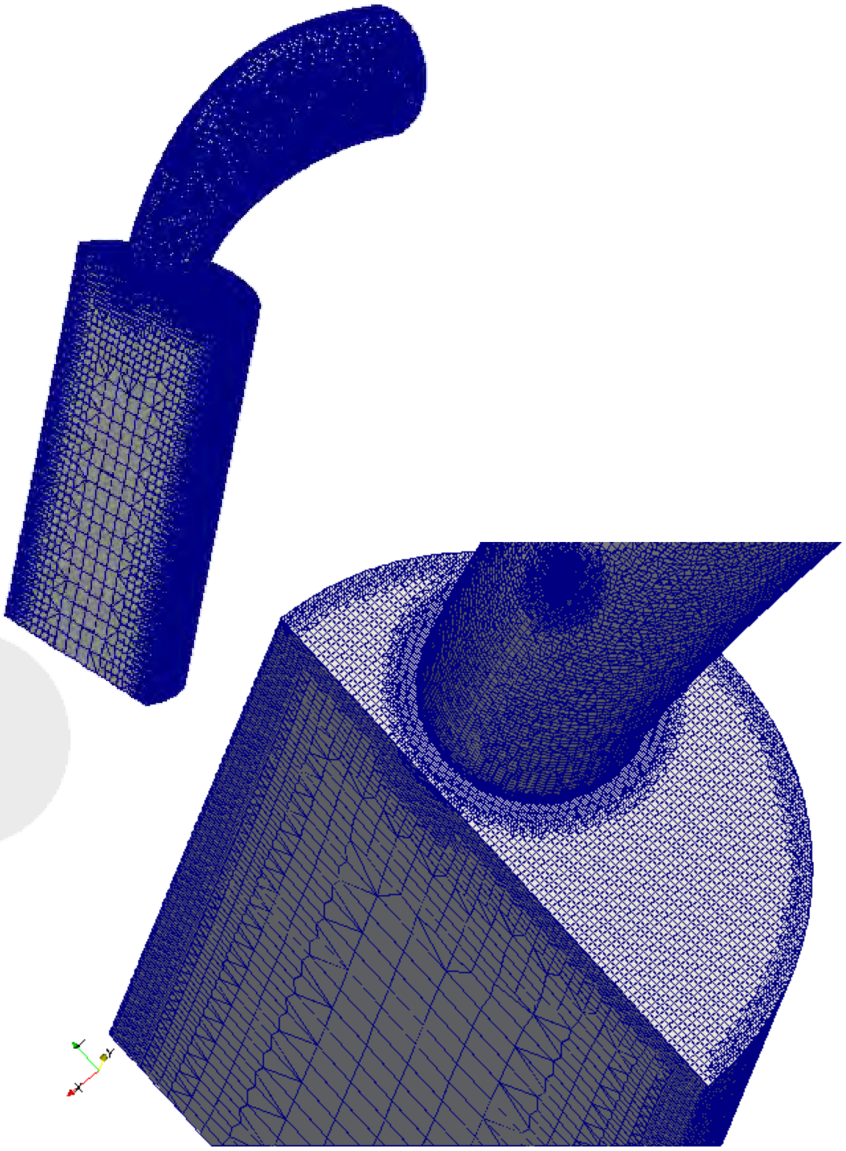






Model Setup | Meshing

- All meshes created with enhanced snappyHexMesh
- Mesh statistics:
  - Cells: 1,250 K
  - Wall layers: 5
  - Max cells size: 19.2 mm
  - Surface cell size: 0.6-1.2 mm
  - Min cell size: 0.3 mm (port arm and valve features)



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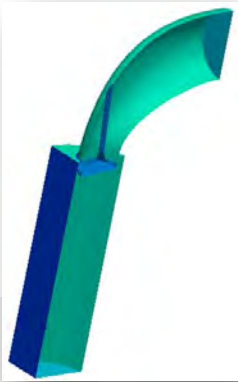
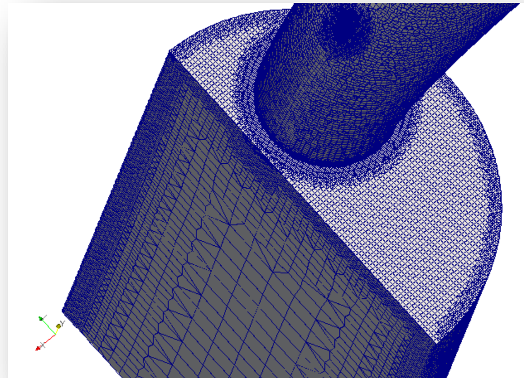
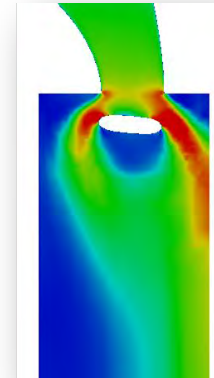
The Optimisation Workflow







Blender → snappyHexMesh → OPENFOAM → DAKOTA → Blender

Design Parameters

Input Variables

Morphing boxes Y, Z translation of 8 control points

Output Variables

Discharge coefficient

Swirl

Tumbling

Cross tumbling

Design Objectives

Maximise discharge coefficient

Maximise angular momentum

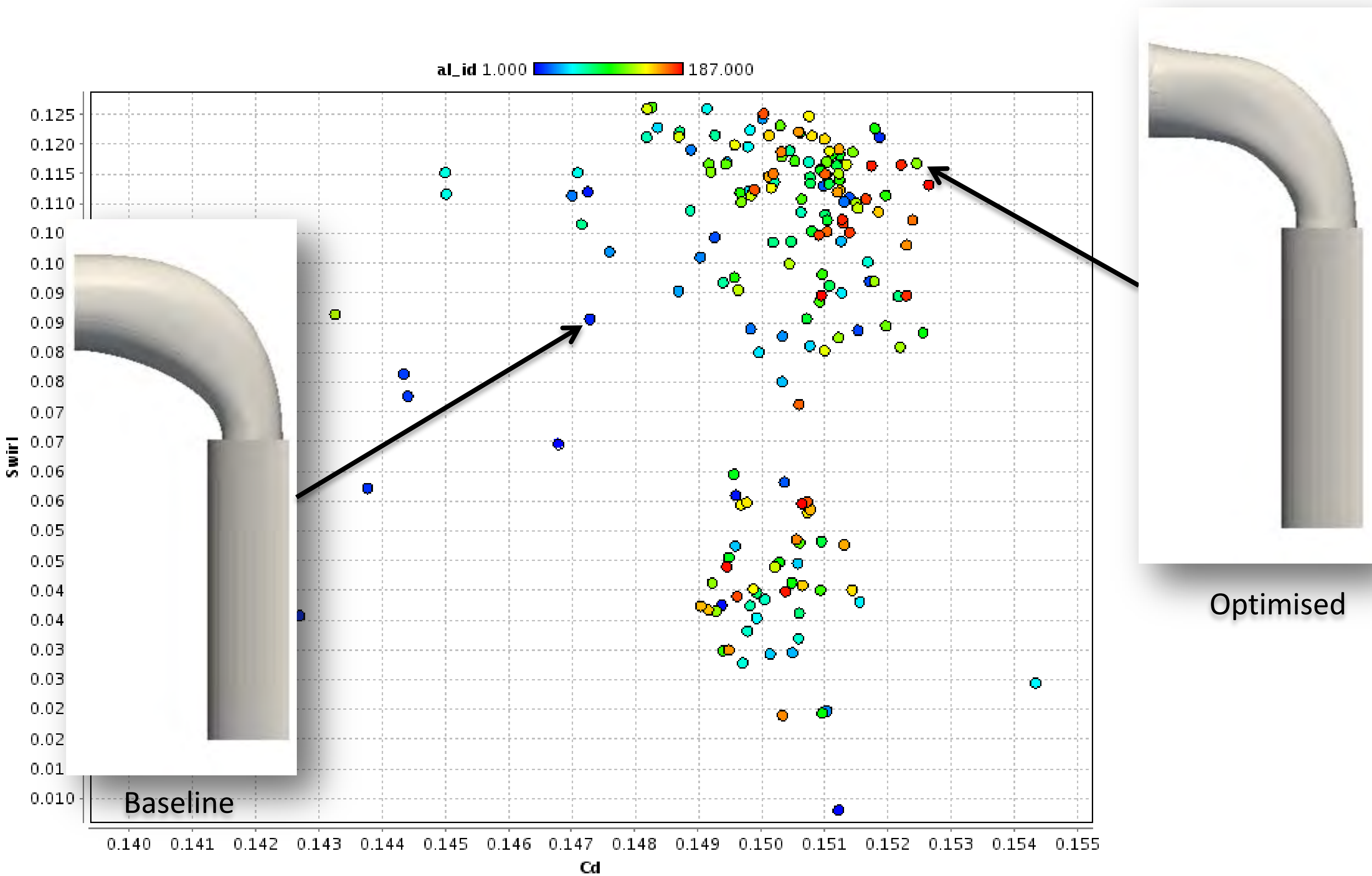
Optimization Setup

Exploration Phase:

MOGA algorithm- max no. of iterations: 250

Generation size: 40

Optimisation Results | Objectives



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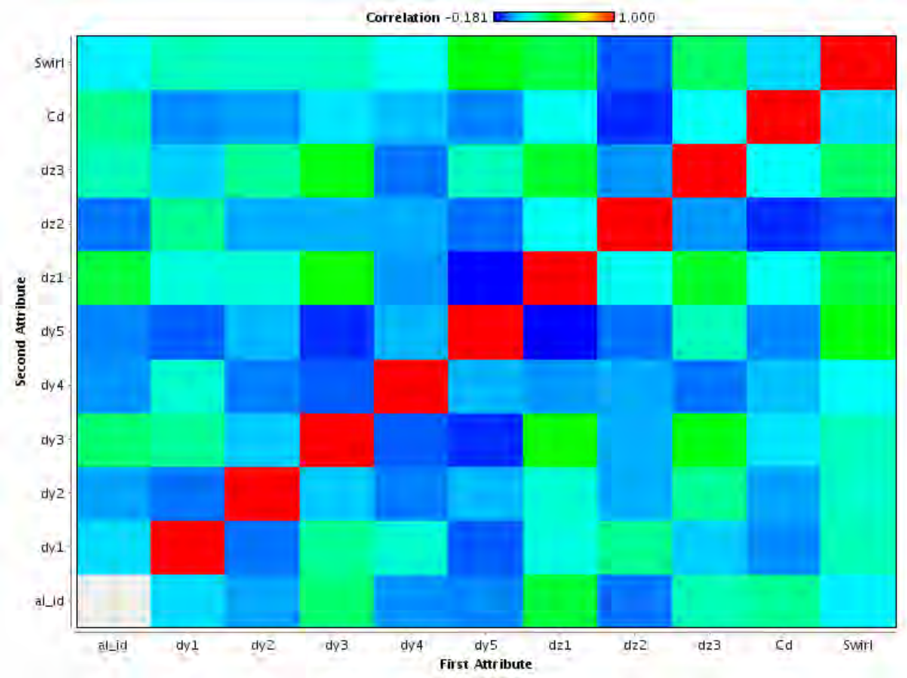
Optimisation Results | Correlation



- Simple Correlation Coefficient is a measure of linear relationship between two variables:
  - +1 indicates two variables positively linearly correlated
  - 0 indicates two variables not correlated
  - -1 indicates two variables negatively linearly correlated

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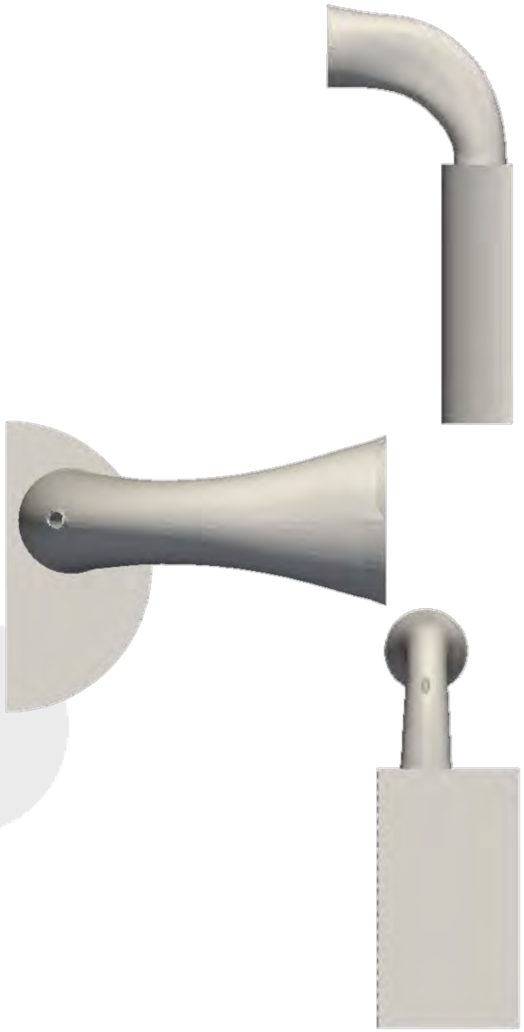
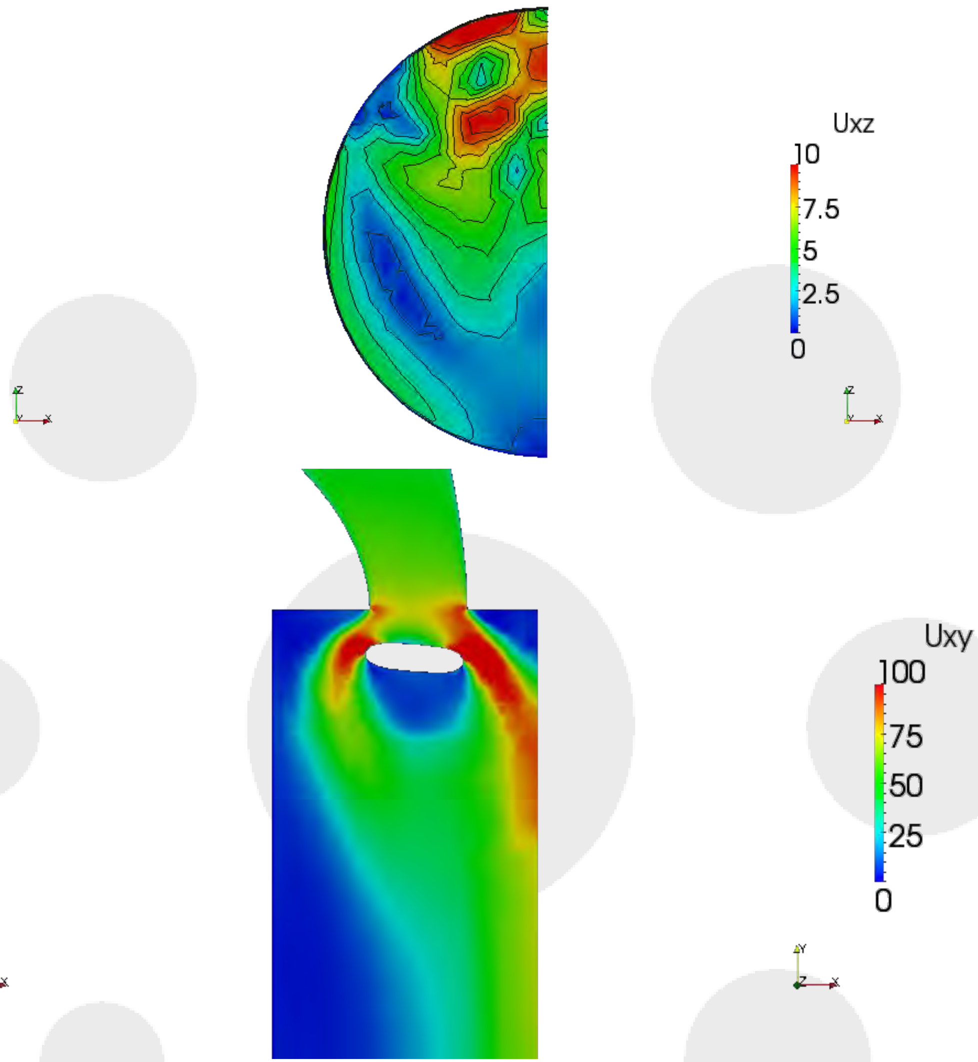
Optimisation Results | Geometry

Baseline

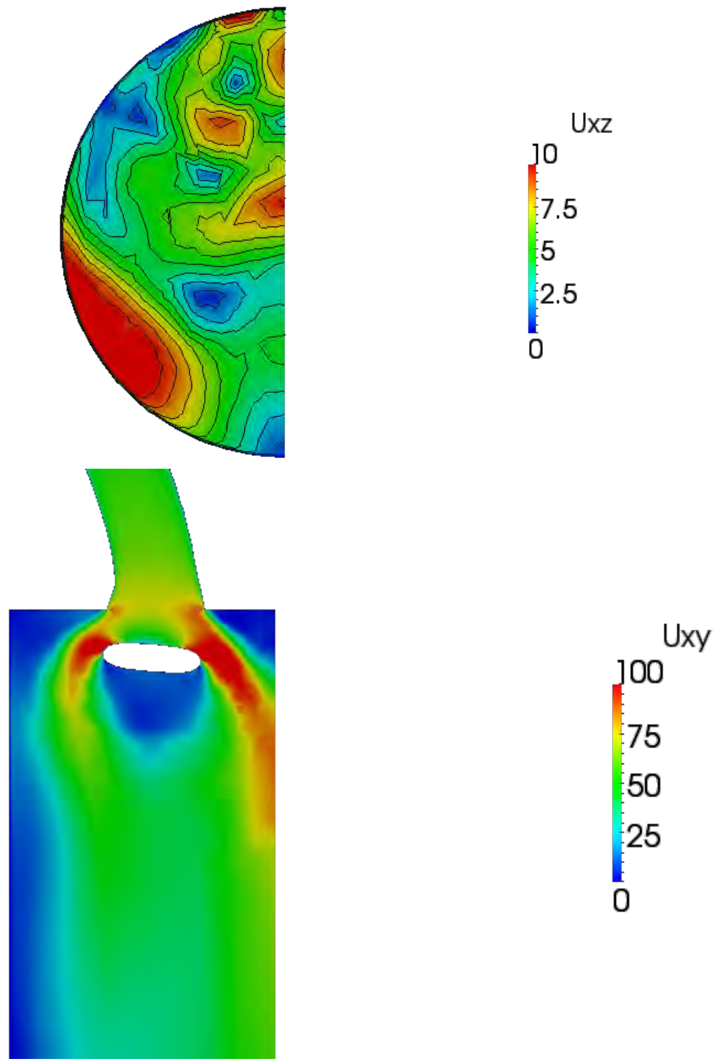


Optimised

Optimisation Results | Swirl

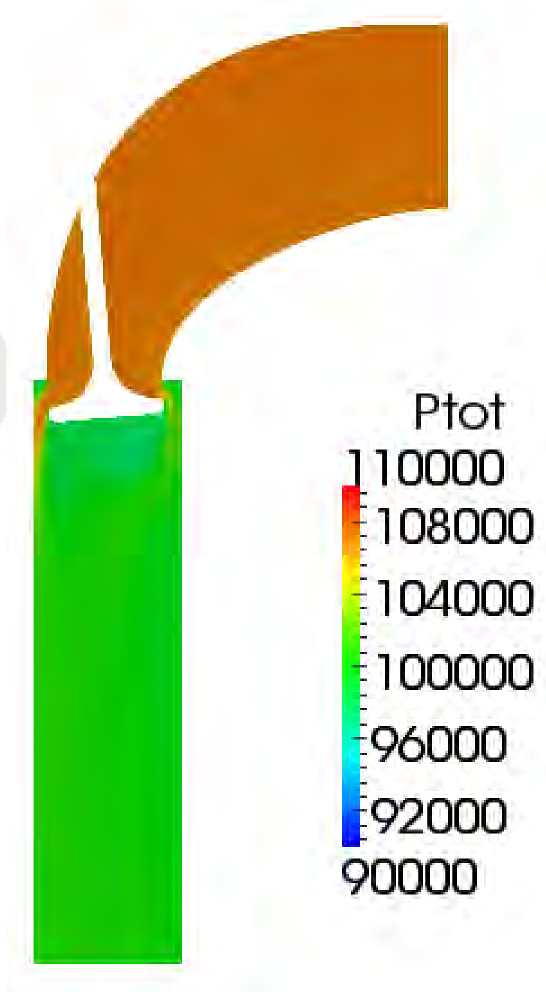


Baseline

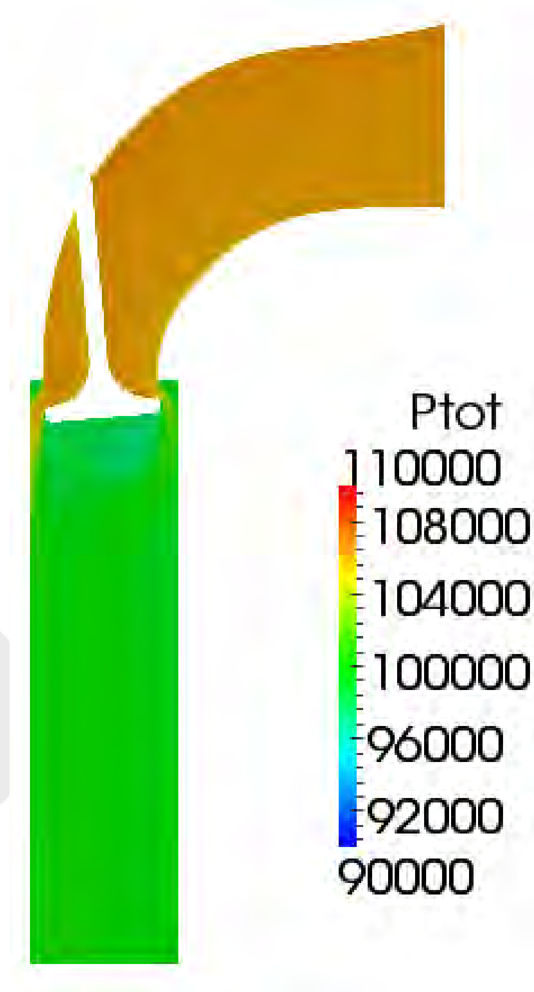


Optimised

Optimisation Results | Discharge Coefficient



Baseline



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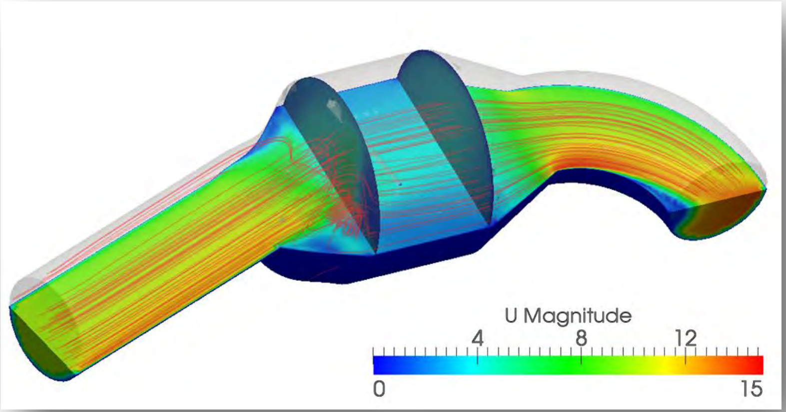
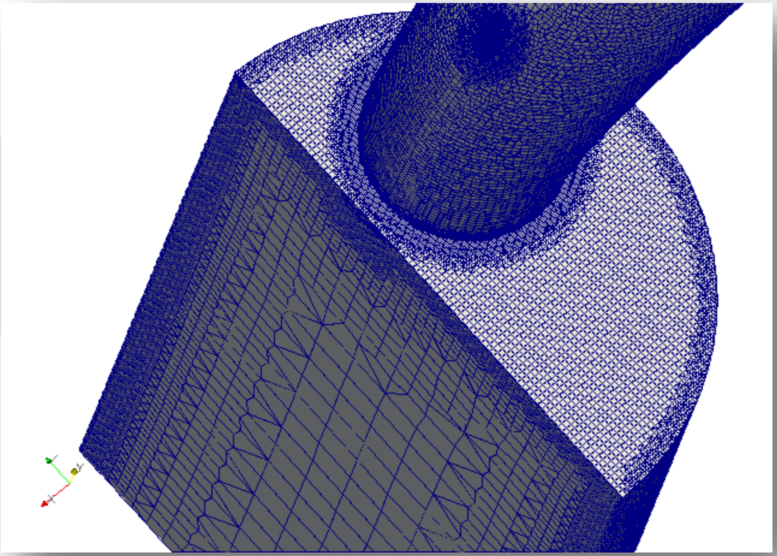
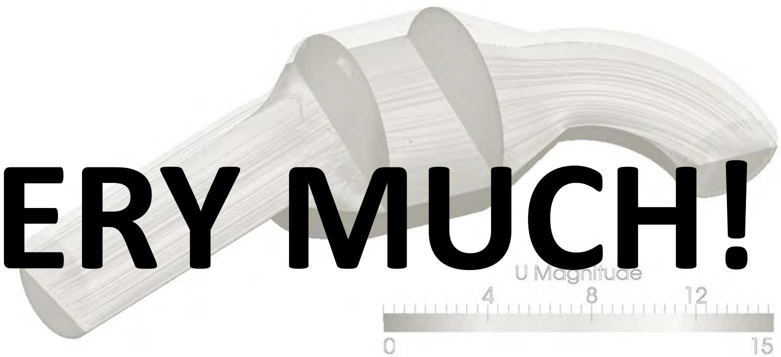




Conclusions

- The coupling between OSS DAKOTA and OPENFOAM was done successfully.
- Different shape parameterisation techniques were evaluated.
- DAKOTA capabilities were efficiently exploited for different engineering applications.
- Benefits of DAKOTA and OPENFOAM scalability are huge for product development speed-up and reduction in costs.

THANK YOU VERY MUCH!



QUESTIONS?