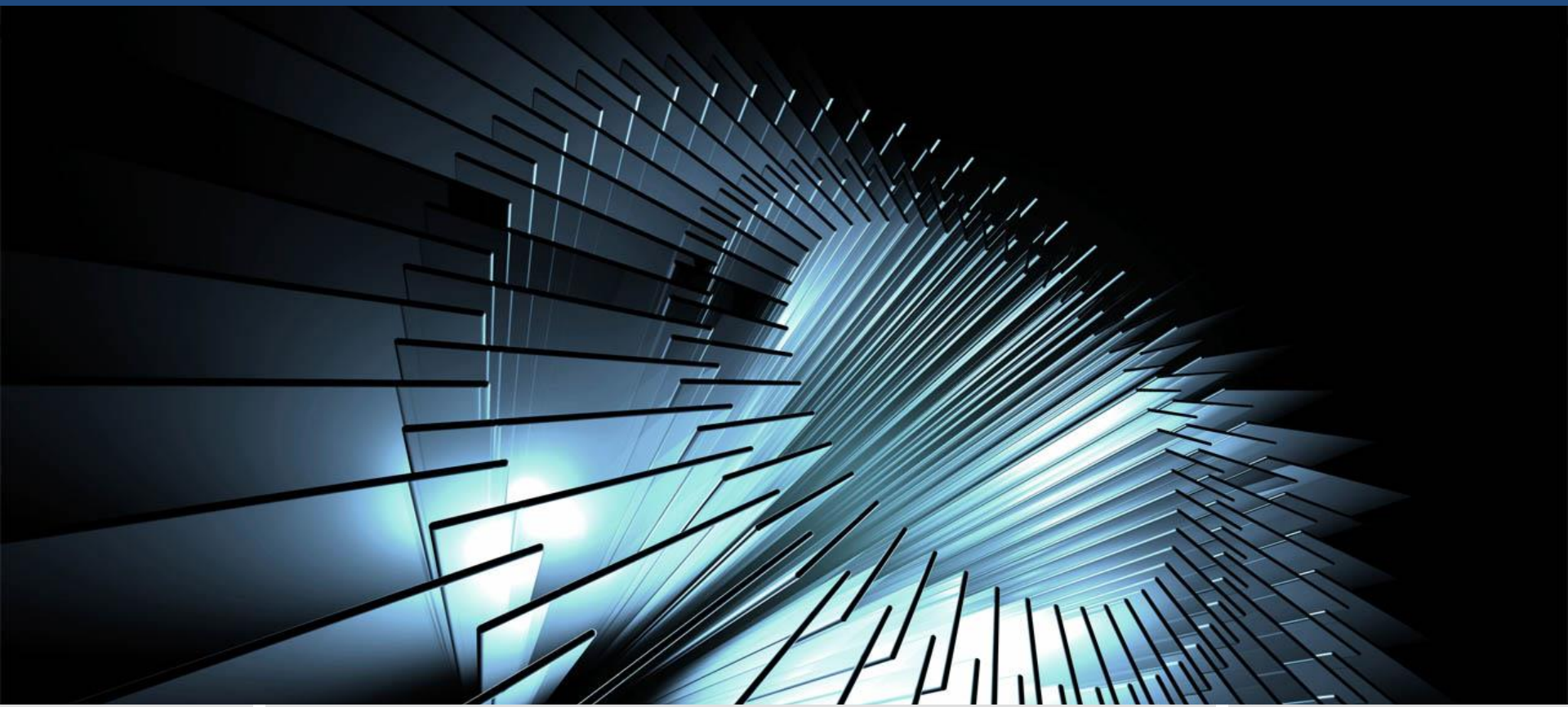

2014

Optimisation of a LP steam turbine stage & diffuser in FINE™/Design3D

Dr. Thomas Hildebrandt, Jana Vachova, Sven Albert

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Overview

1	FINE™/Design3D: Neural Network & Genetic Algorithm
2	Case: LP Steam Turbine & Exhaust Casing
3	Results: Database
4	Results: Optimisation

1

FINE™/Design3D:
Neural Network & Genetic Algorithm

Challenges in Turbomachinery Optimisation:

- Multiple & contradictory targets, e.g. increased efficiency, pressure ratio, surge margin…
- Secondary targets & constraints, e.g. blade thickness & strength, fabrication
- Complex geometries, hence large number of free parameters

→ N-dimensional objective function
& lots of local extrema

FINE™/Design3D:
Package Overview

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FINE™/Design 3D

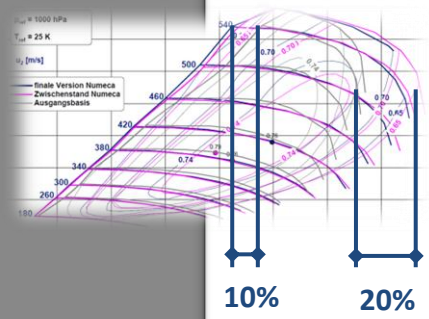
AutoBlade™
Para. modeling

FINE™/
Design 3D
Meshing, Solving &
Post-Processing

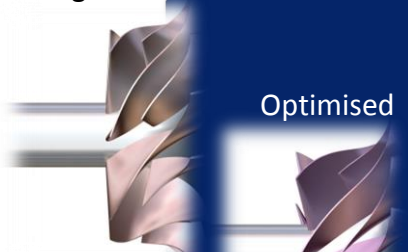
Screening
Manual design

Database
DOE

Optimisation
automatically



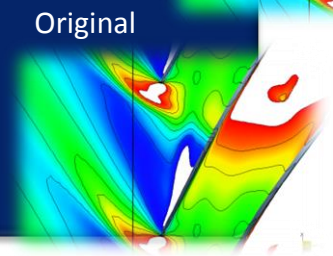
Original

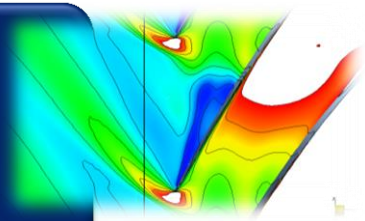


Optimised

Applications:
- Aeronautics & Space
- Turbomachinery
- Hydro
- Energy
- …

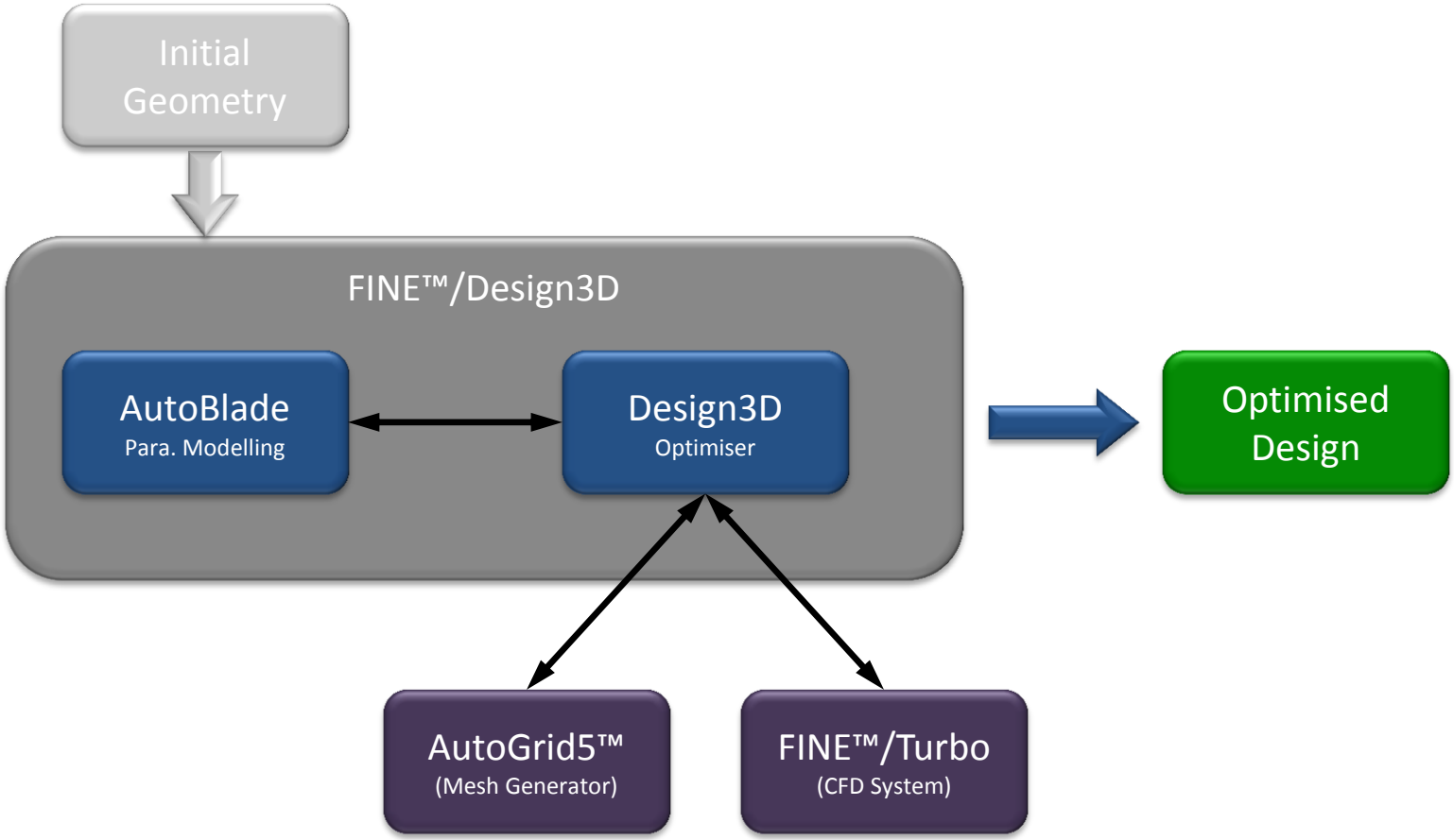
Original





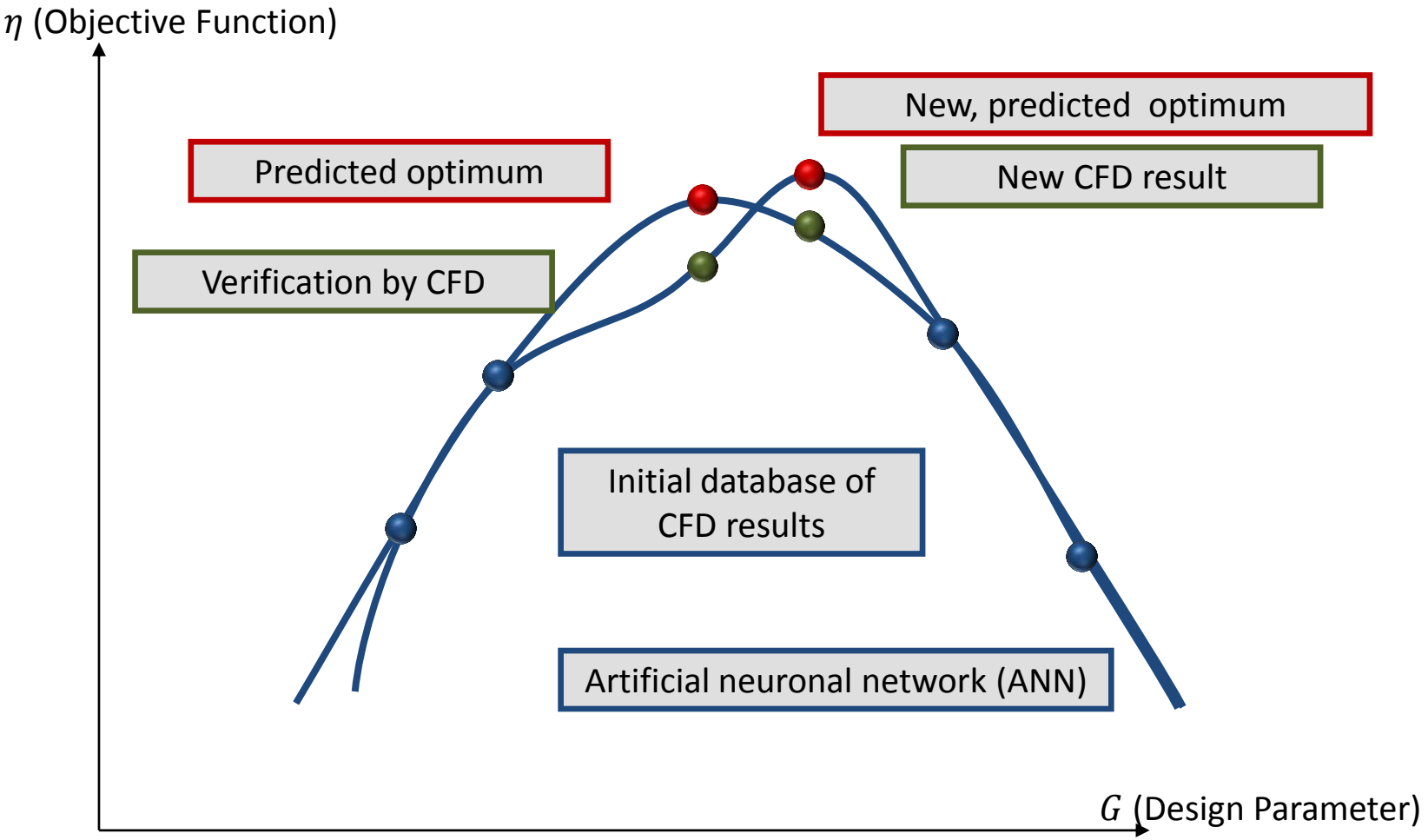
Optimised

FINE™/Design3D:
Optimisation Cycle



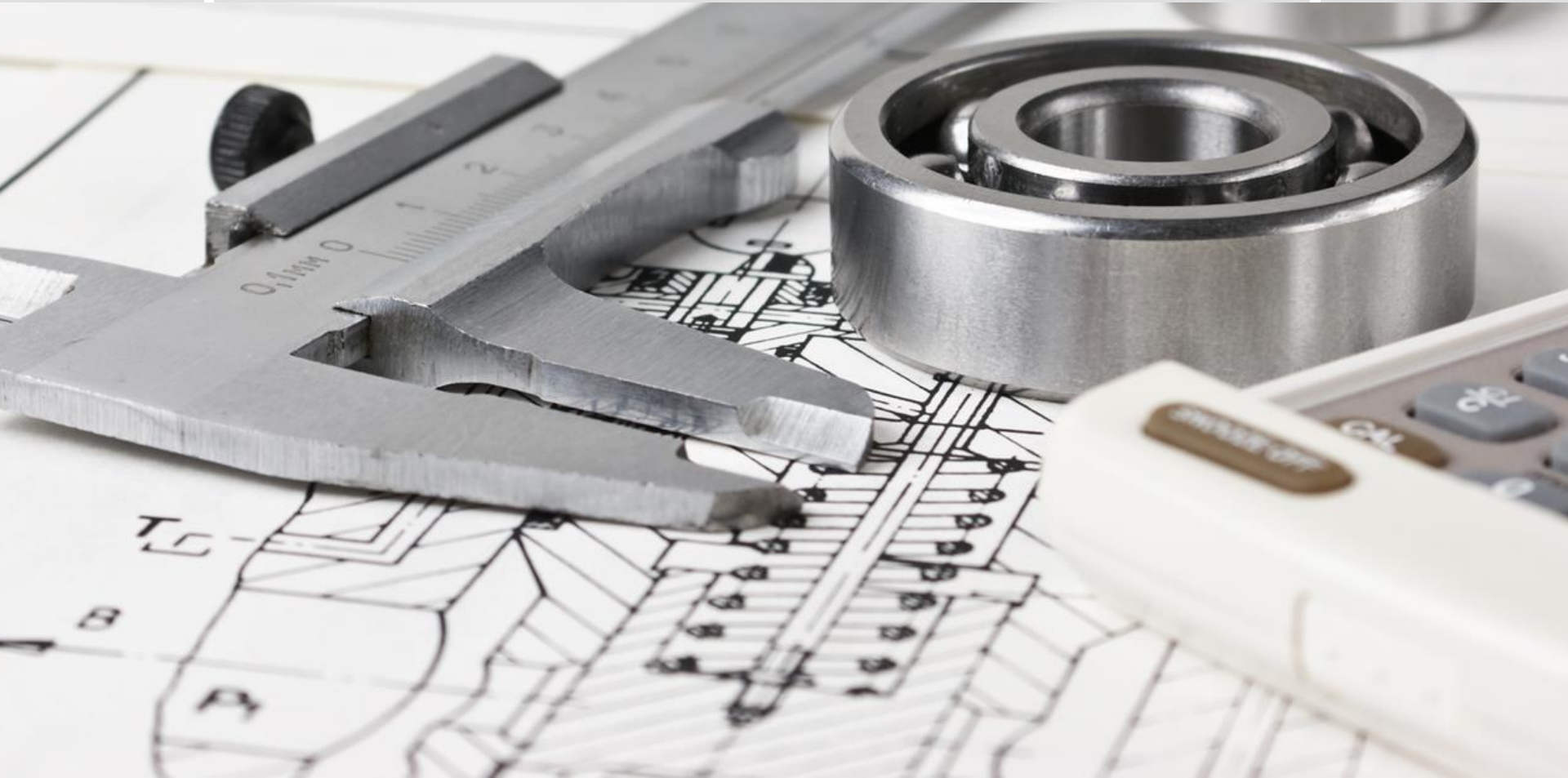
FINE™/Design3D:
Working Principle for 1D Case

Step 7: CFD Verification of Improved Parameter Combination



2

Case: LP Steam Turbine & Exhaust Casing



Case: LP Steam Turbine & Exhaust Casing

Overall Turbine Sketch

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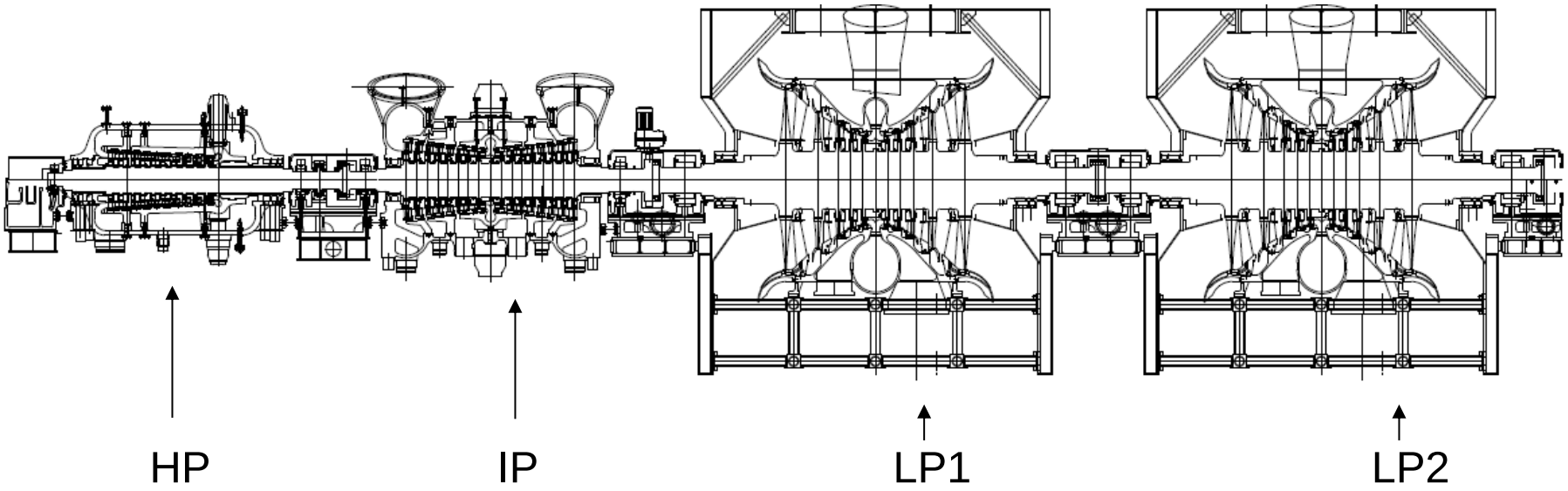
USC 660 MW Turbine



Total turbine length to LP 2 flange > 30000 mm
Overall weigth ~1100 t

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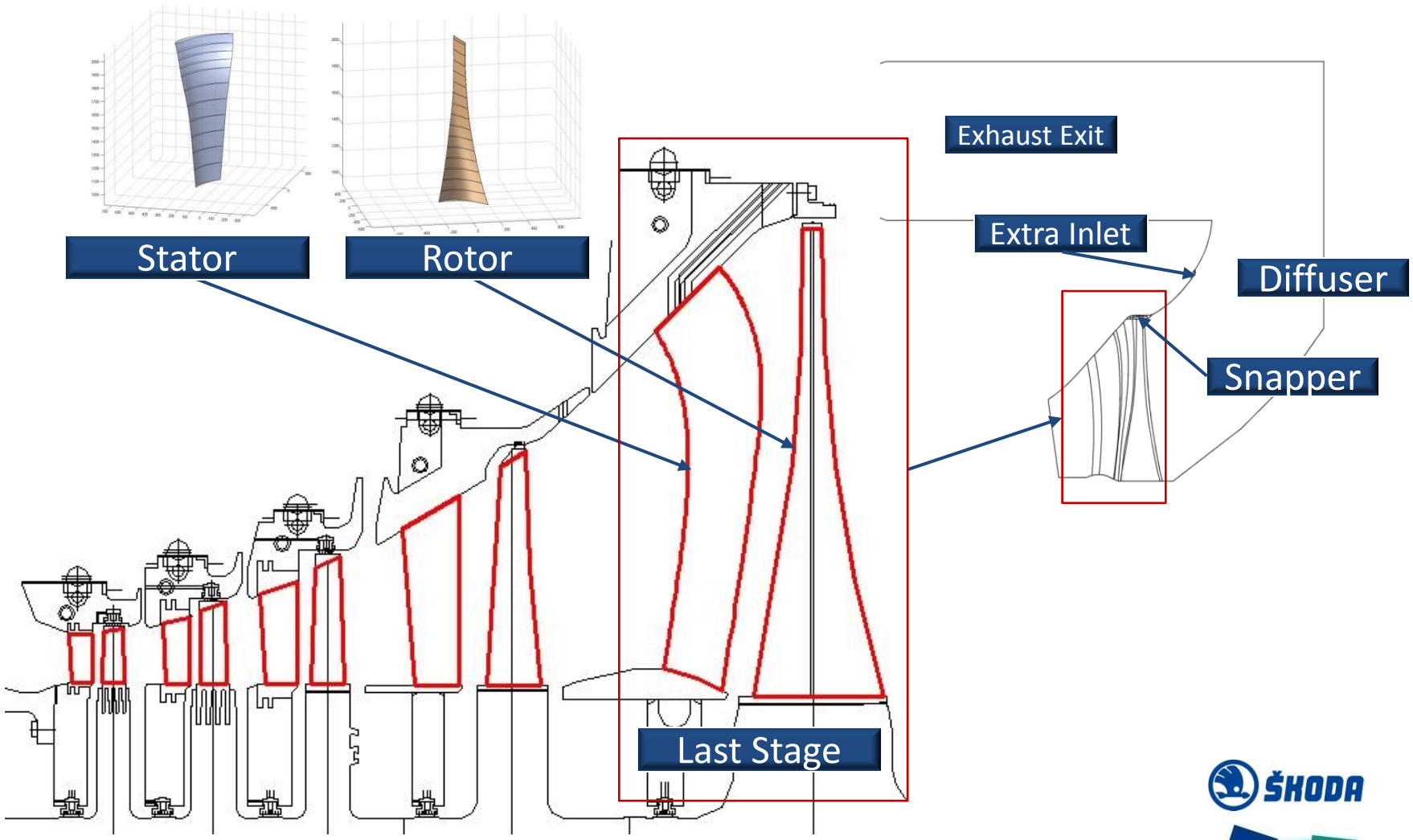
Case: LP Steam Turbine & Exhaust Casing

Low Pressure Stage, Diffuser & Exhaust Exit

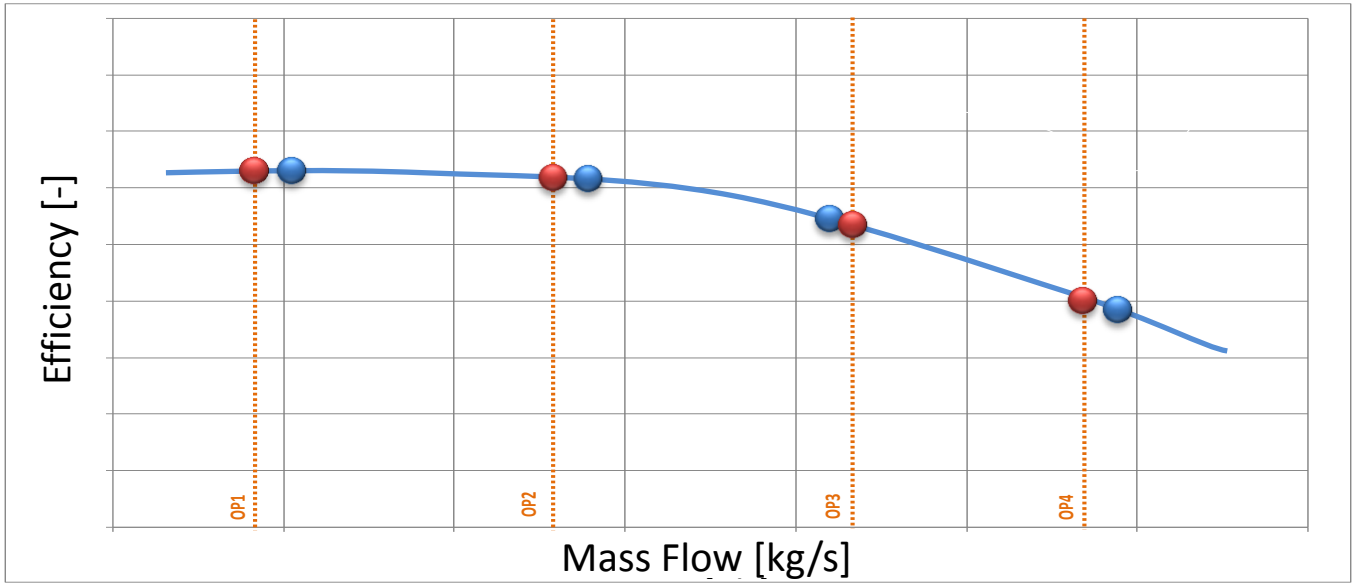


USC 660MW – Low Pressure Turbine Part

Case: LP Steam Turbine & Exhaust Casing

Optimisation Targets

- **Main goal: increase global efficiency & maintain mass flow**
- Four operating points per design



Operating point by Polynom

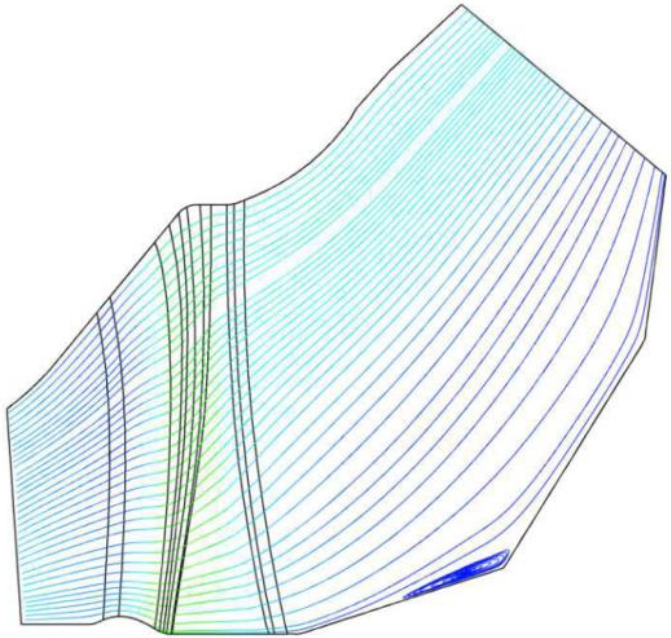
Operating point by FINE/Design 3D

$\eta_{TS_{MK},opt}$ for the sample by weighting function

Case: LP Steam Turbine & Exhaust Casing

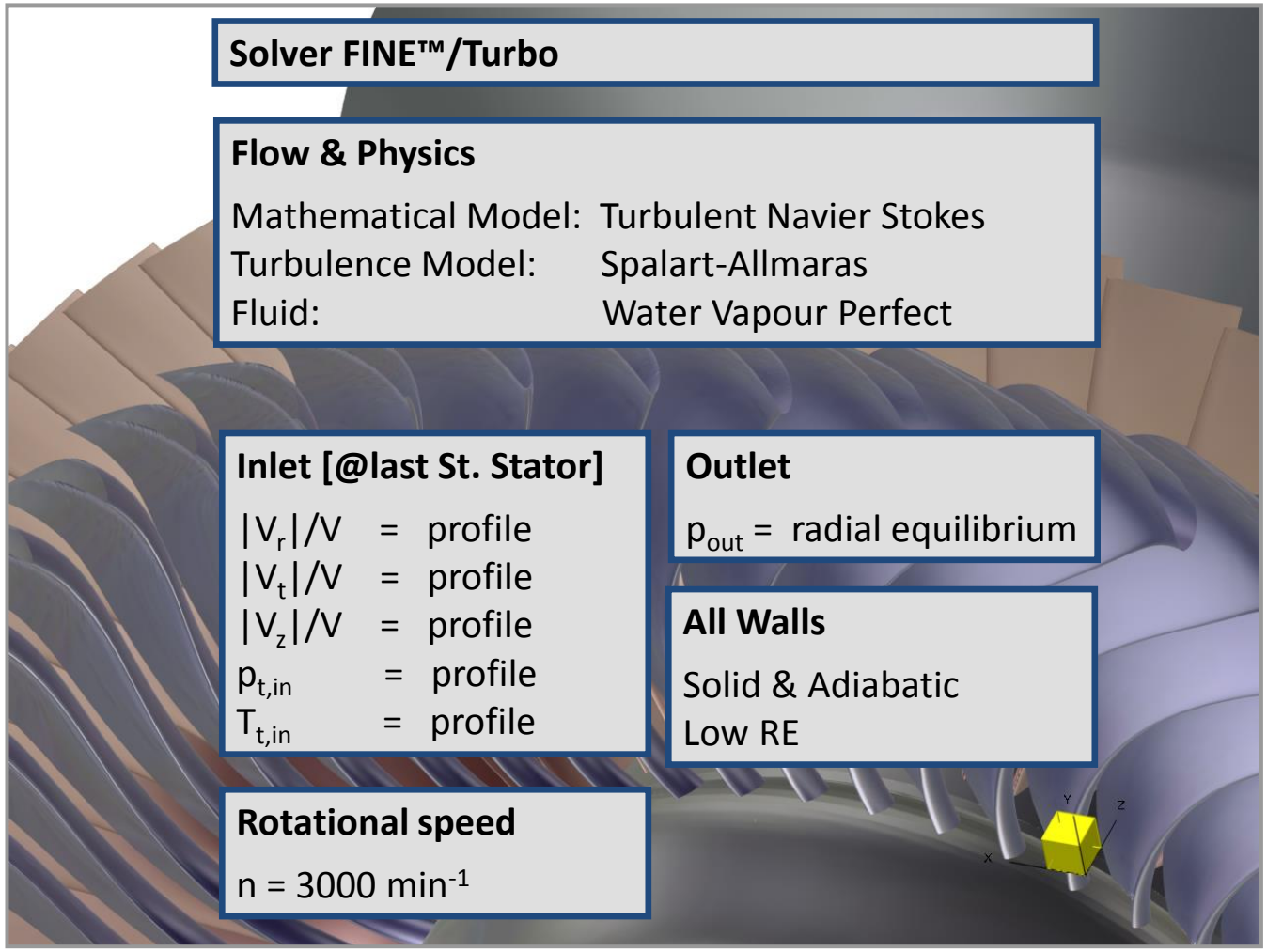
Parameters & Constraints

- Main parameters:
  - 7 parameters sweep
  - 7 parameters lean — **Blade Shaper**
  - 7 parameters hub
  - 10 parameters for shape of the diffuser — **AutoBlade™**
- Constraints:
  - Polylines at the diffuser hub (welded construction)



Case: LP Steam Turbine & Exhaust Casing

CFD Setup



Solver FINE™/Turbo

Flow & Physics

Mathematical Model: Turbulent Navier Stokes
Turbulence Model: Spalart-Allmaras
Fluid: Water Vapour Perfect

Inlet [@last St. Stator]

$|V_r|/V$ = profile
$|V_t|/V$ = profile
$|V_z|/V$ = profile
$p_{t,in}$ = profile
$T_{t,in}$ = profile

Outlet

p_{out} = radial equilibrium

All Walls

Solid & Adiabatic
Low RE

Rotational speed

$n = 3000\ min^{-1}$

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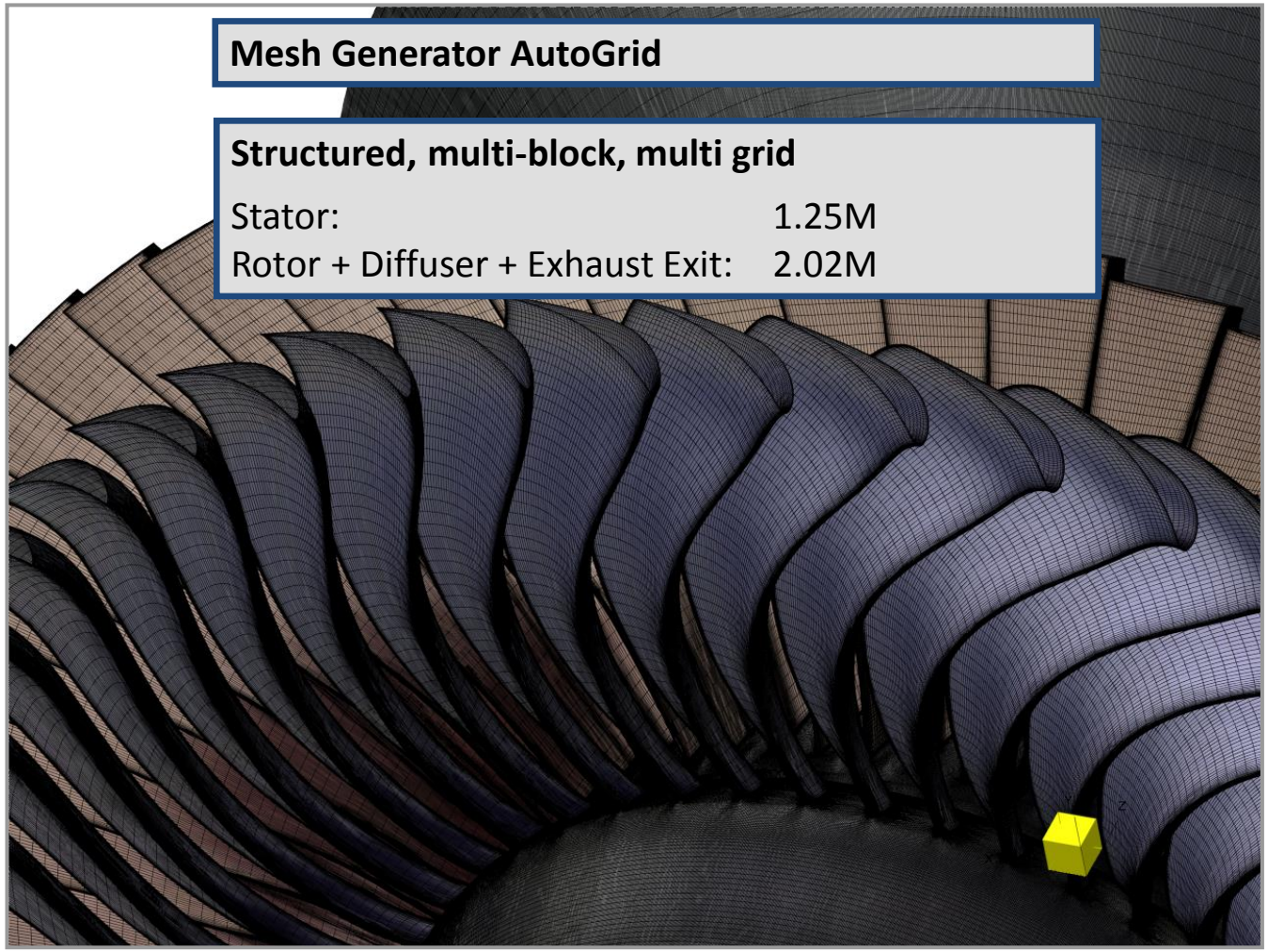
Case: LP Steam Turbine & Exhaust Casing

CFD Setup



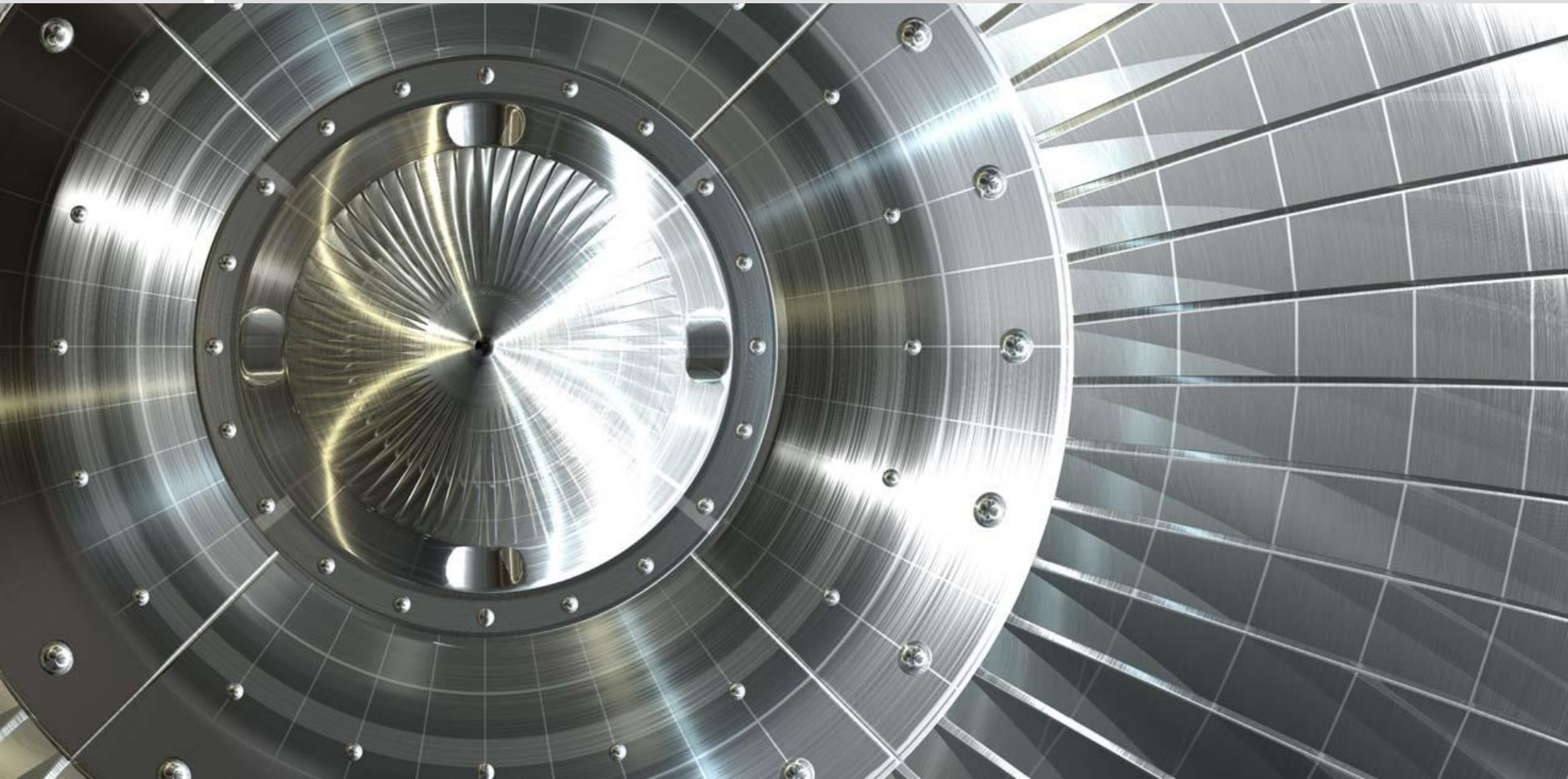
Mesh Generator AutoGrid

Structured, multi-block, multi grid

Stator:	1.25M
Rotor + Diffuser + Exhaust Exit:	2.02M

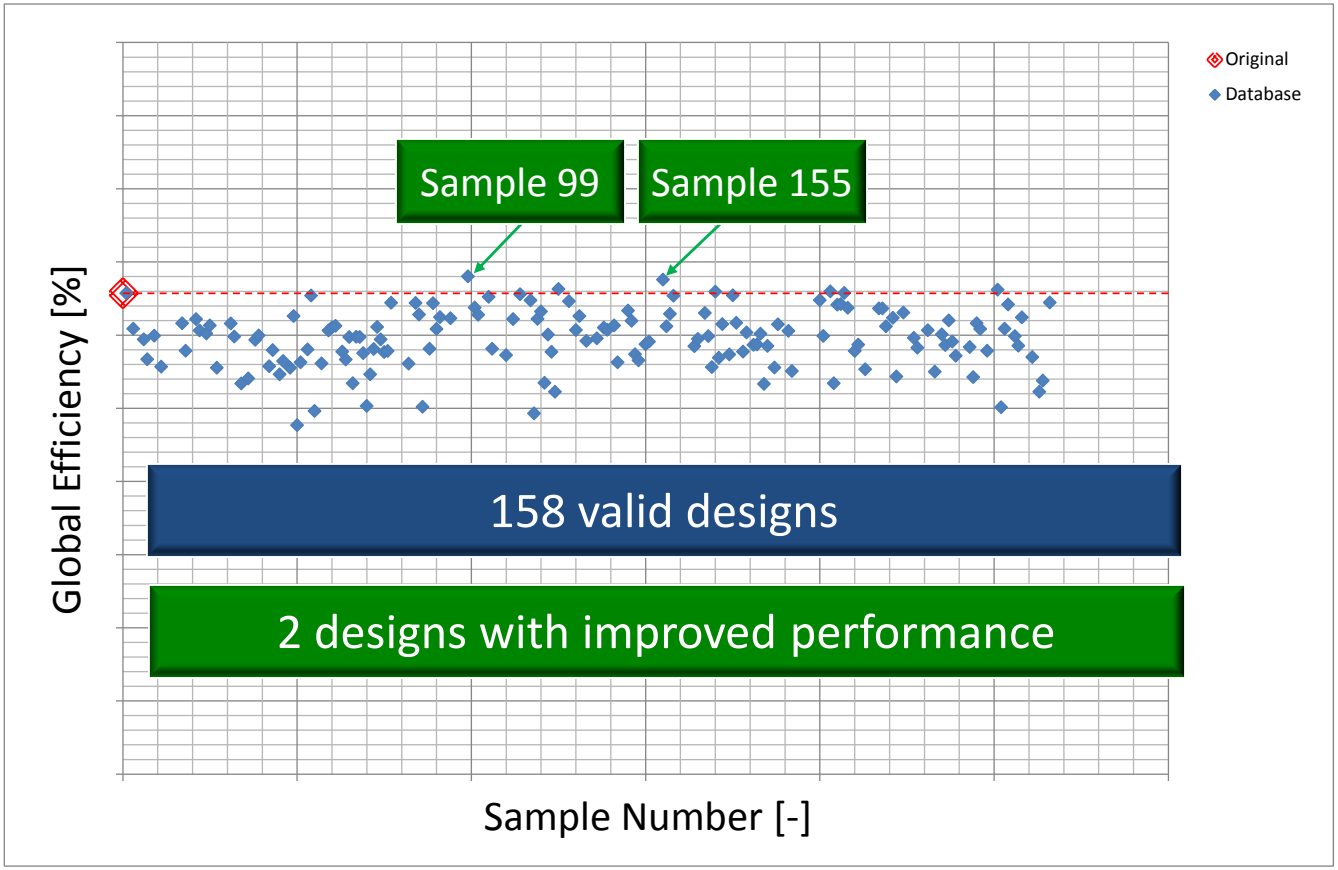
3

Results: Database



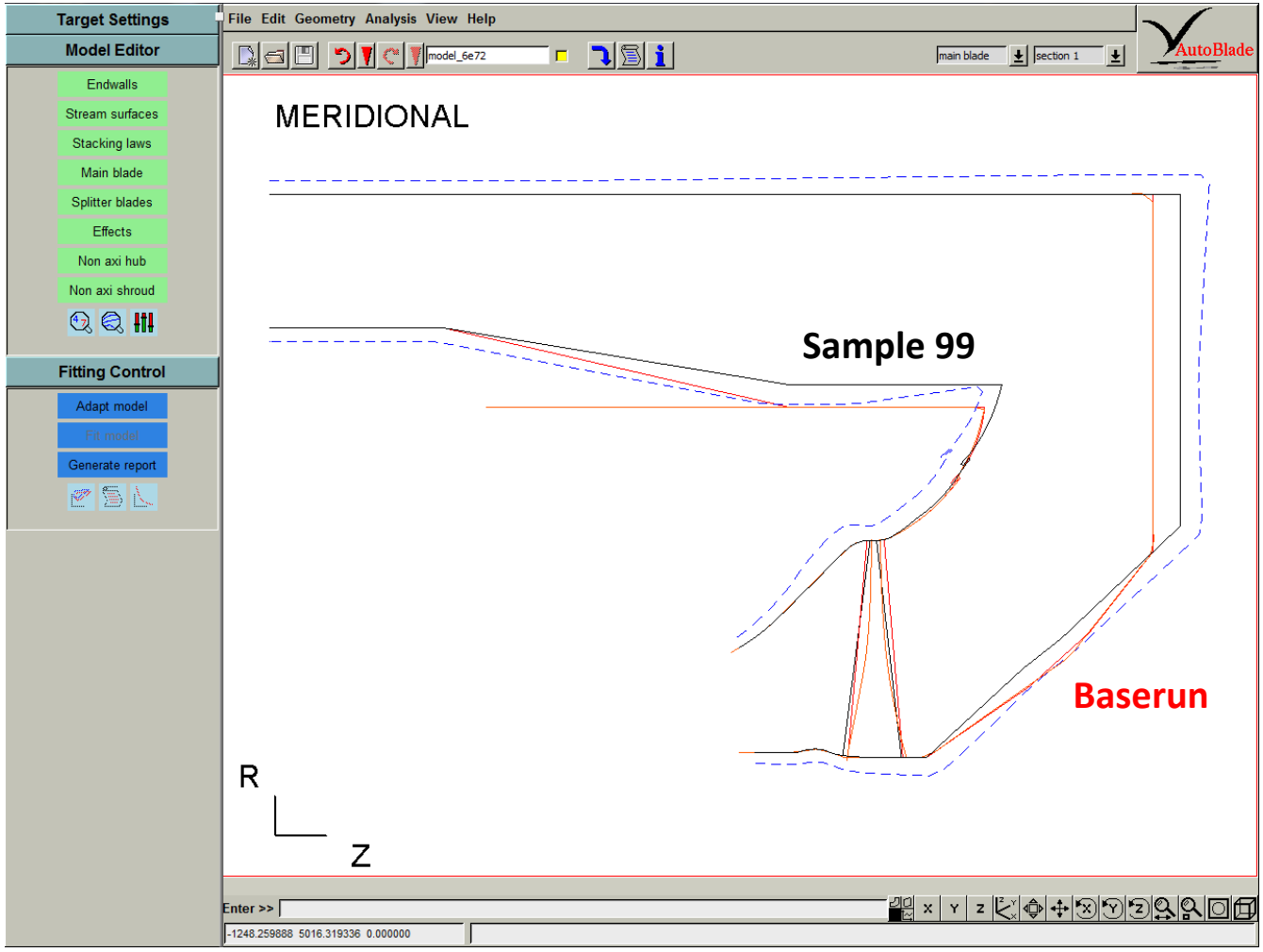
Results: Database

Global Efficiency vs. Sample Number



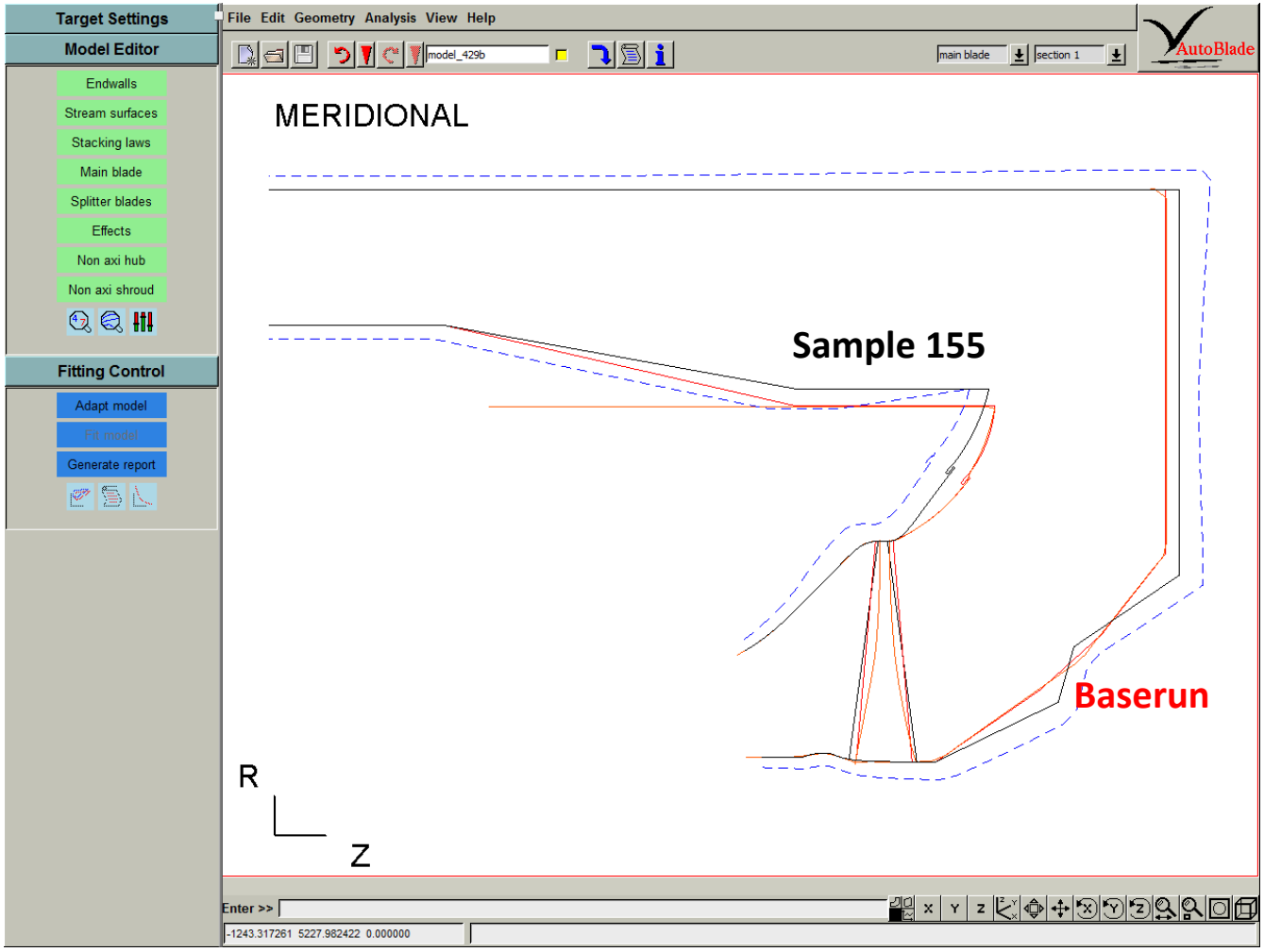
Global Efficiency

Results: Database
Sample 99



Meridional geometry Sample 99

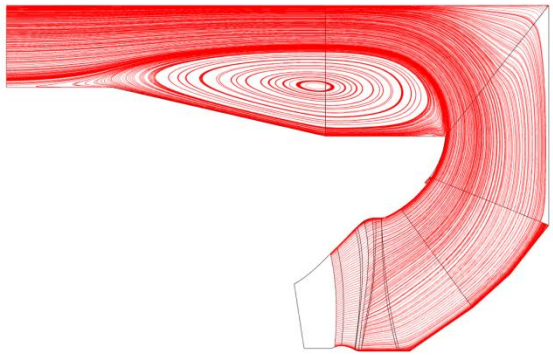
Results: Database
Sample 155



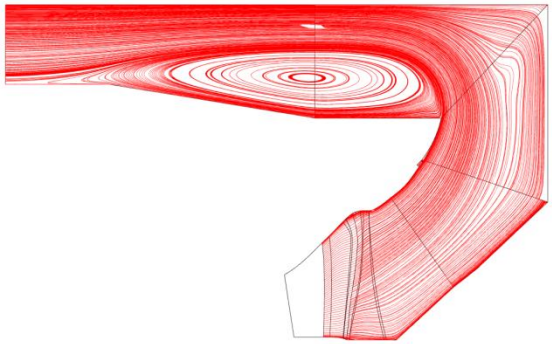
Meridional geometry Sample 155

Results: Database

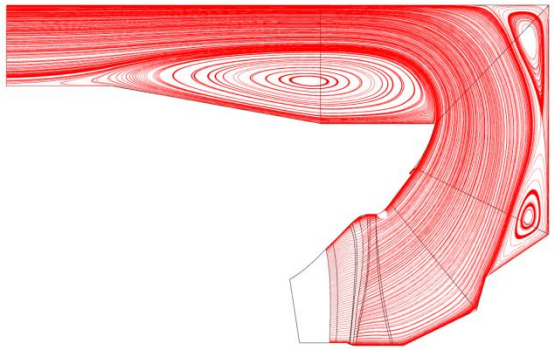
Meridional Averaged Results for OP1



Original



Sample 99

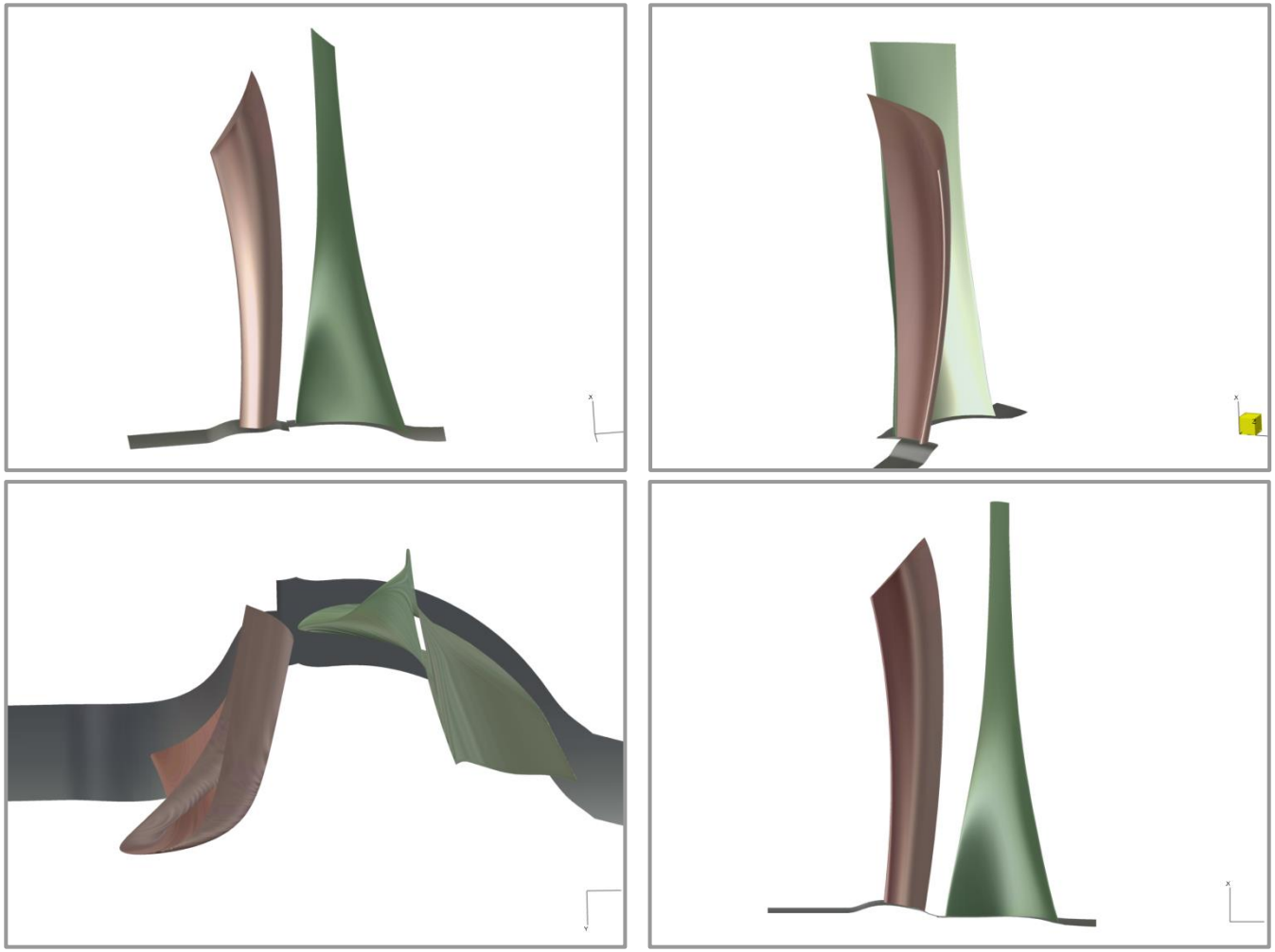


Sample 155

Streamlines: Original & best designs in Database

Results: Database

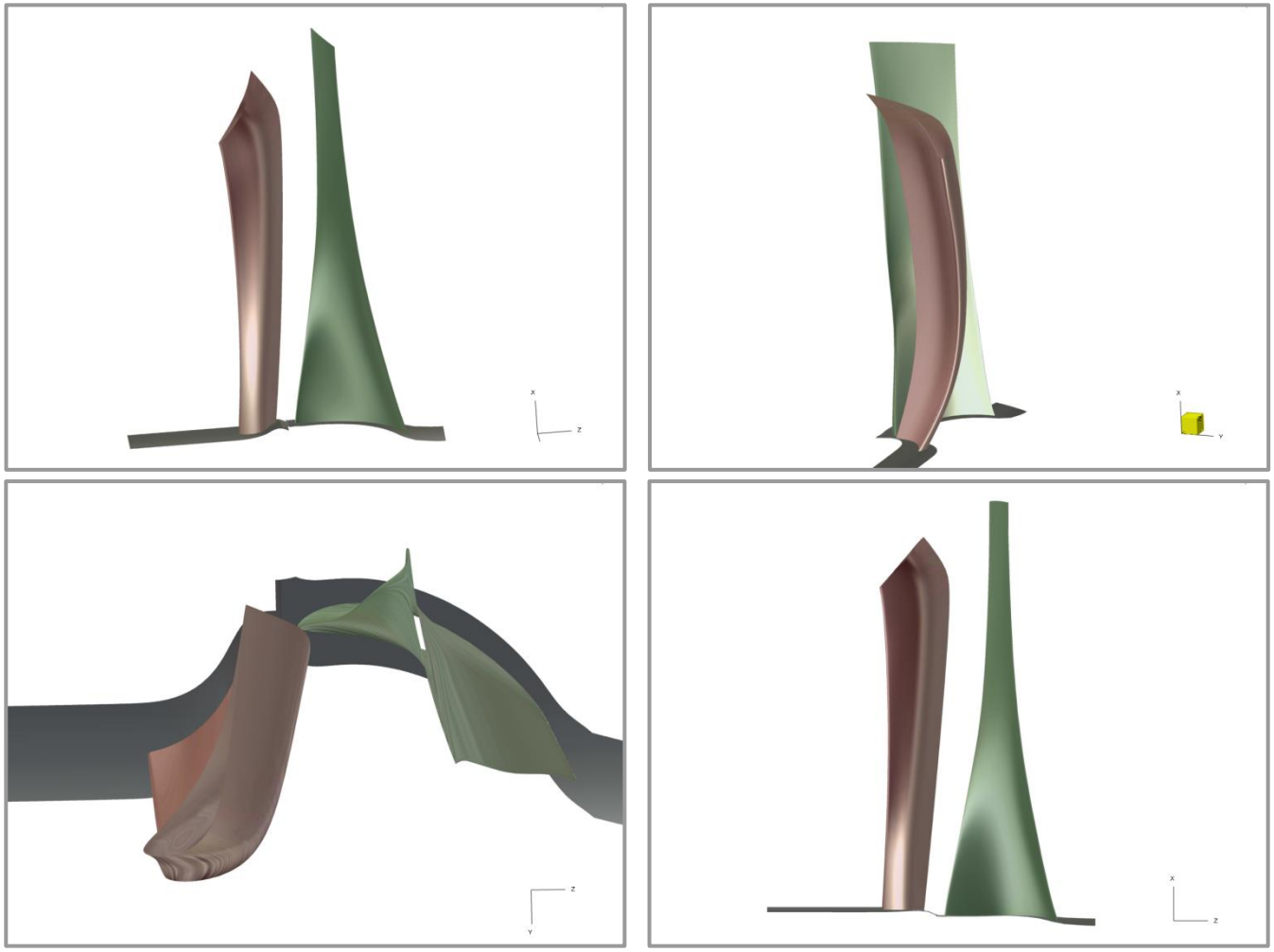
Blade Geometry: Original



Original

Results: Database

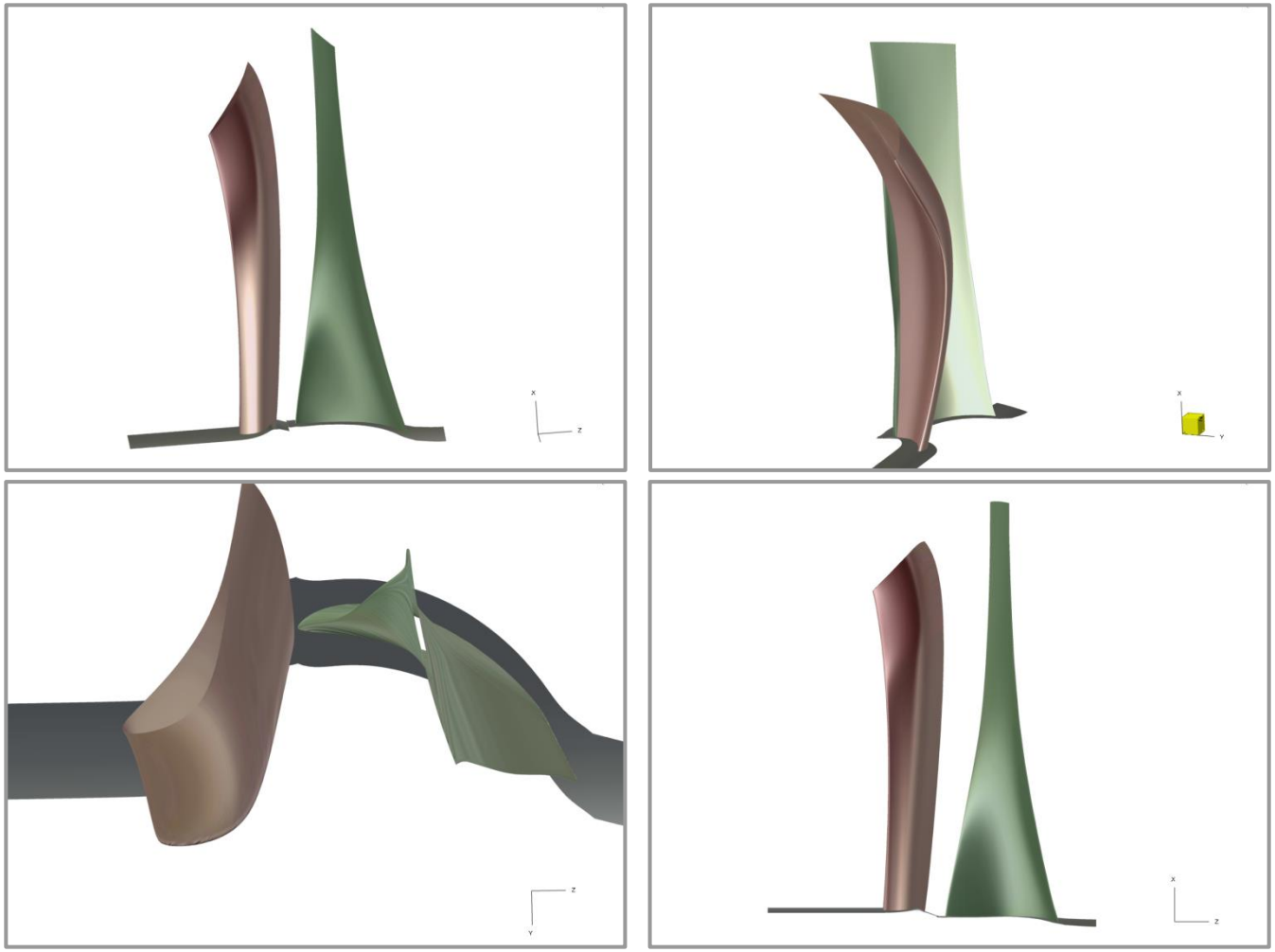
Blade Geometry: Sample 99



Sample 99

Results: Database

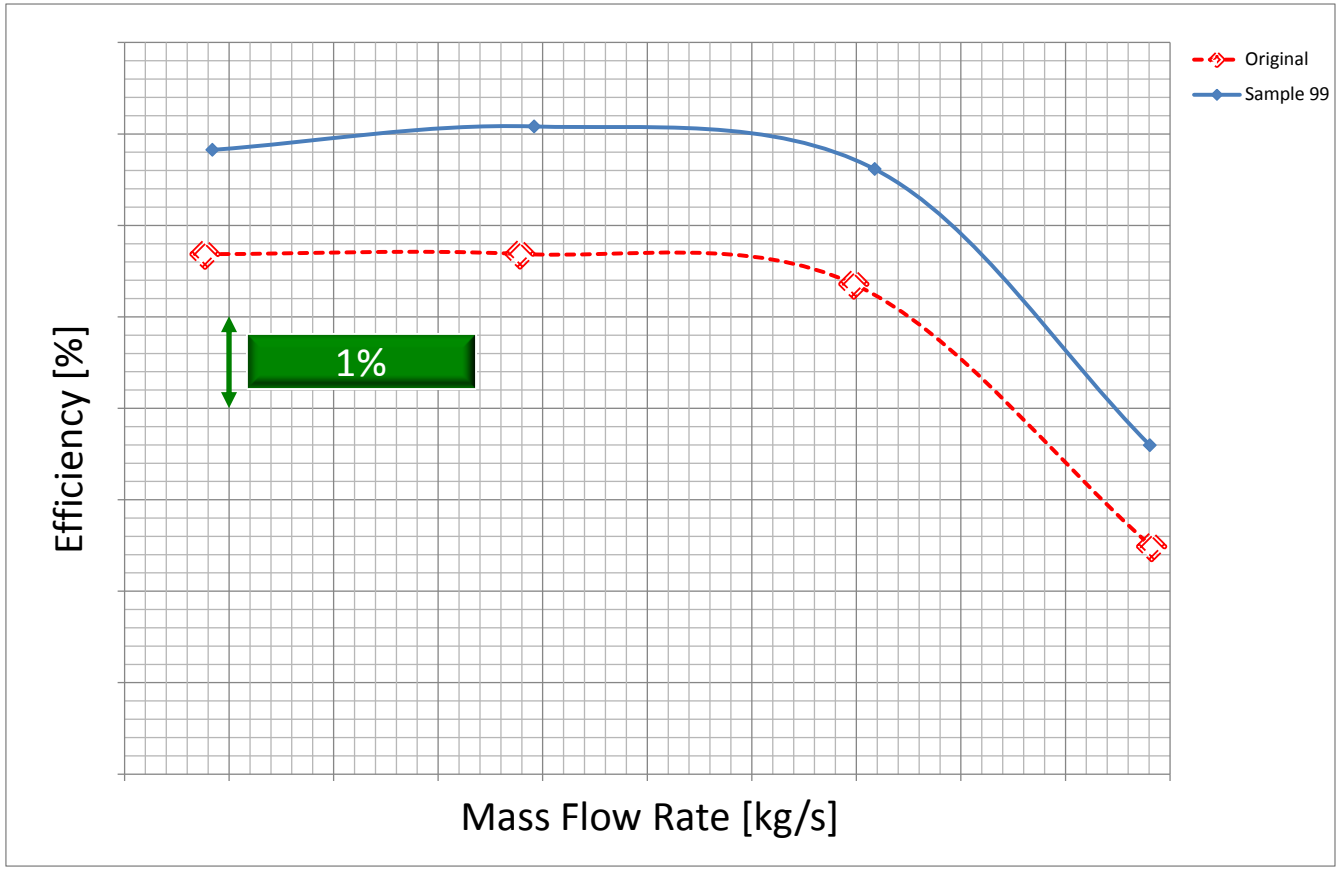
Blade Geometry: Sample 155



Sample 155

Results: Database

Characteristic for Sample 99



Original Design vs. Sample 99

4

Results: Optimisation

Results: Optimisation

Overview: Objective Function Definition

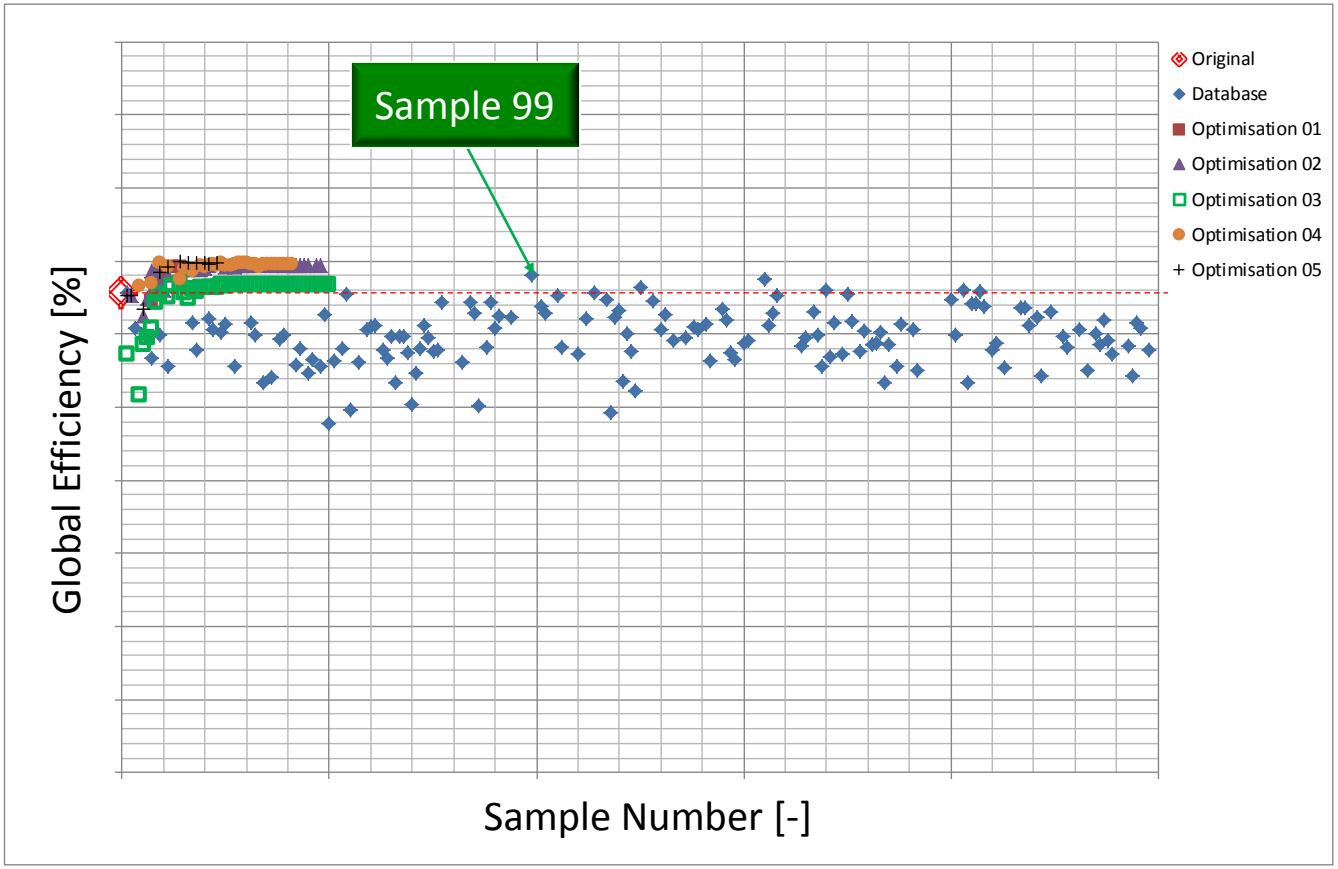
Database complete: Start Optimisation

OPT1: no mass flow restrictions

OP3 & OP4 critical: large increases in mass flow led to lots of failed designs

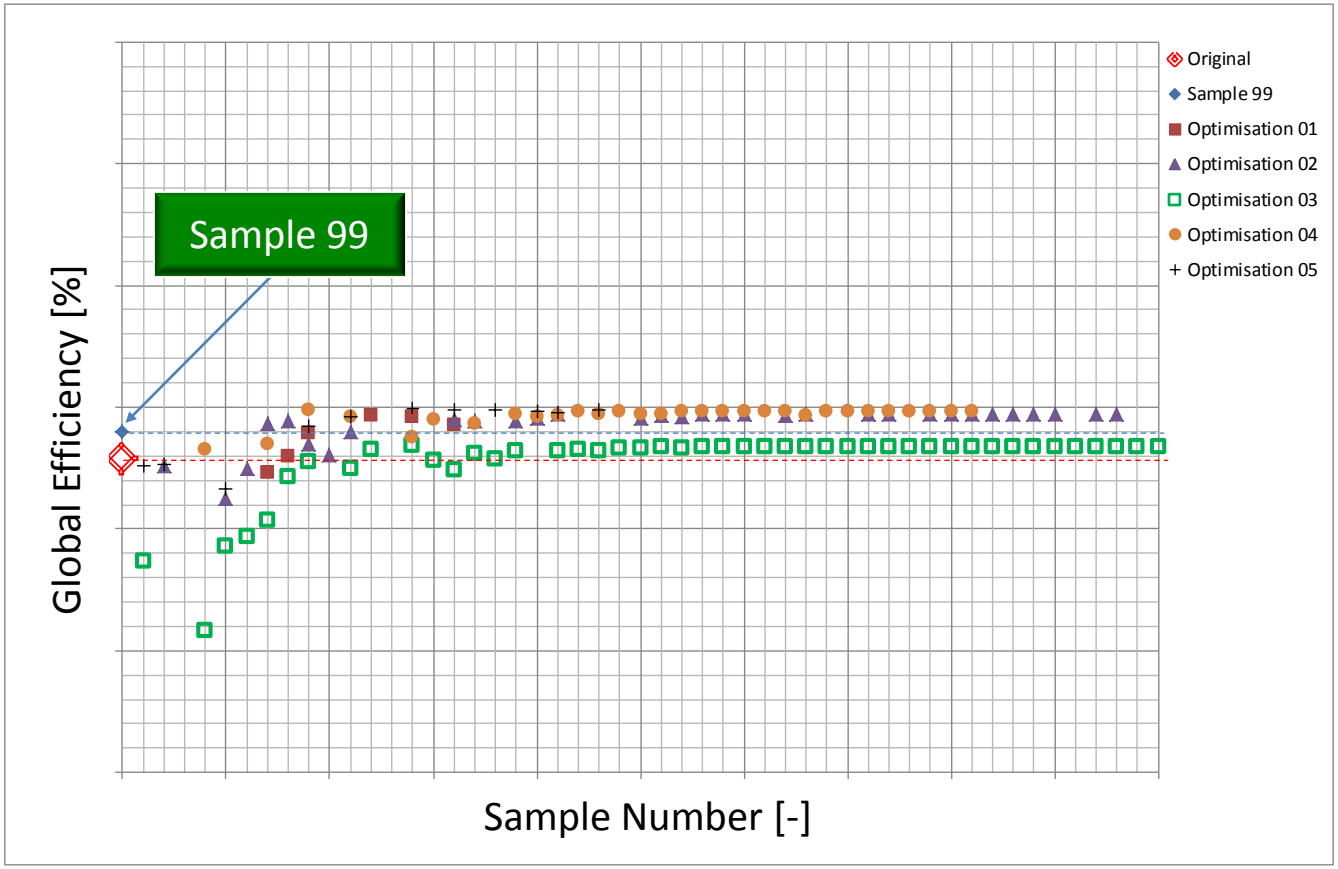
OPT2 – OPT5: diverse constraints on mass flow for different OPs

Results: Optimisation



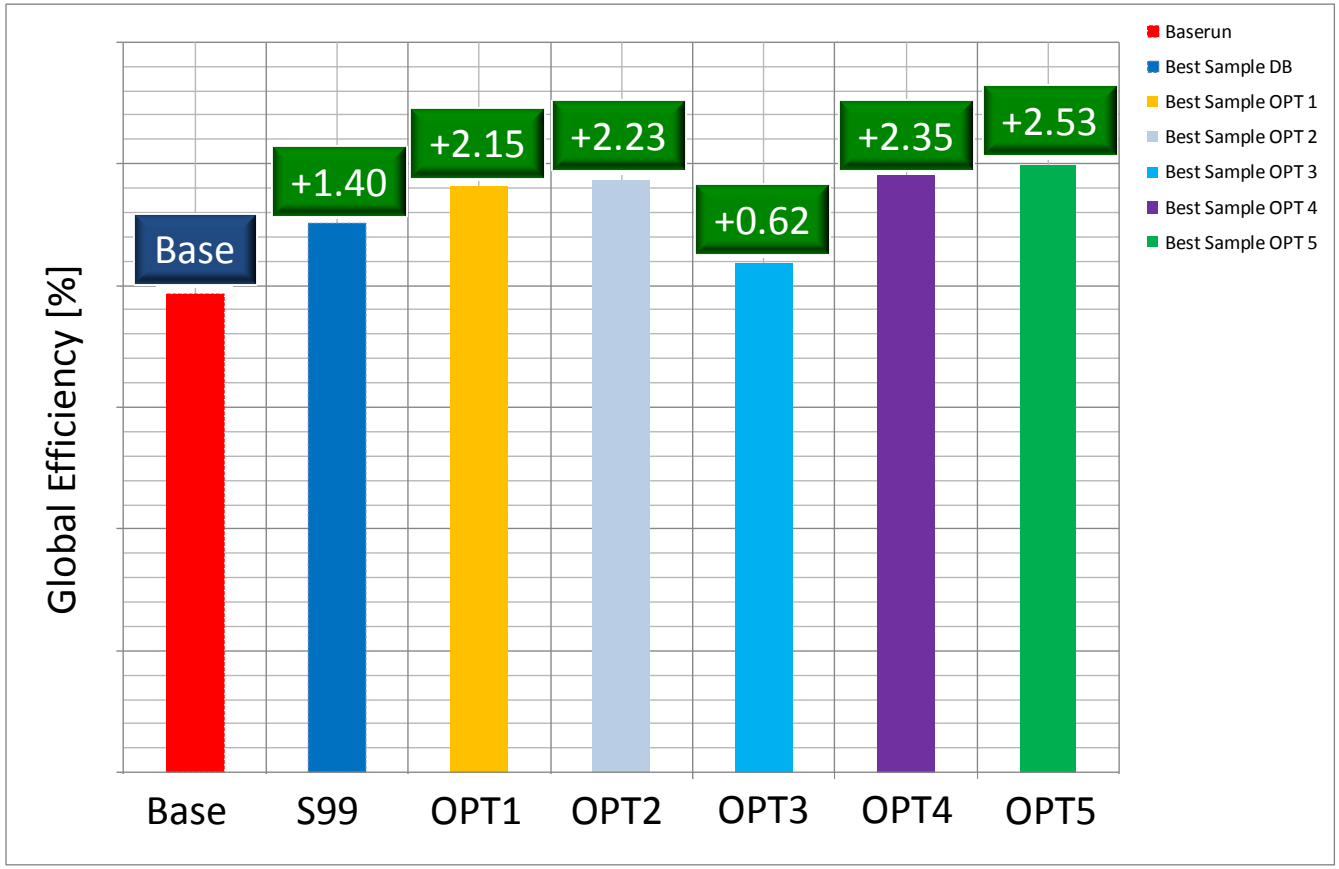
Global Efficiency Distribution in OPTs

Results: Optimisation



Global Efficiency Distribution in OPTs

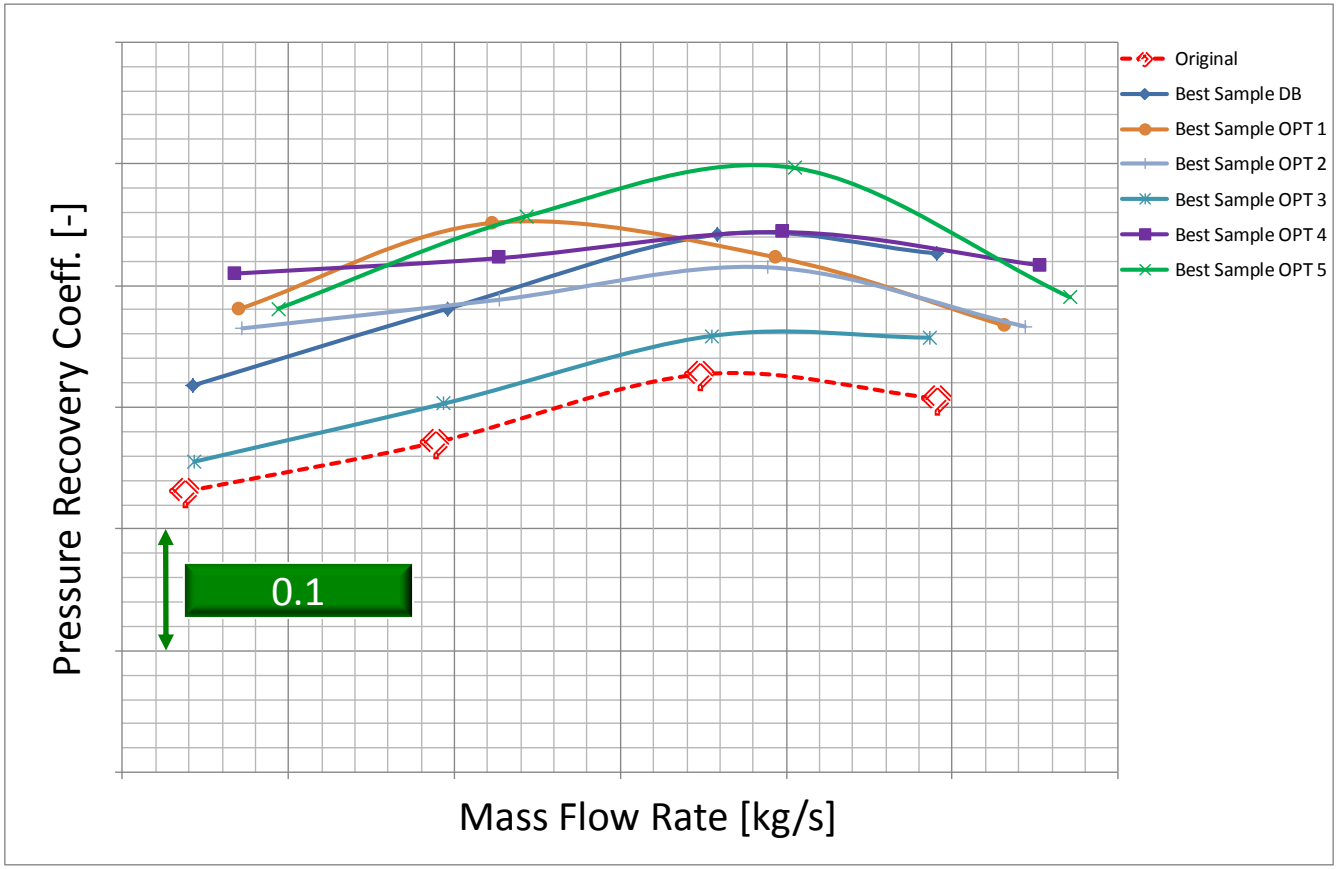
Results: Optimisation
Global Efficiency Gain



Global Efficiency: Original vs. Sample99 vs. best OPTs

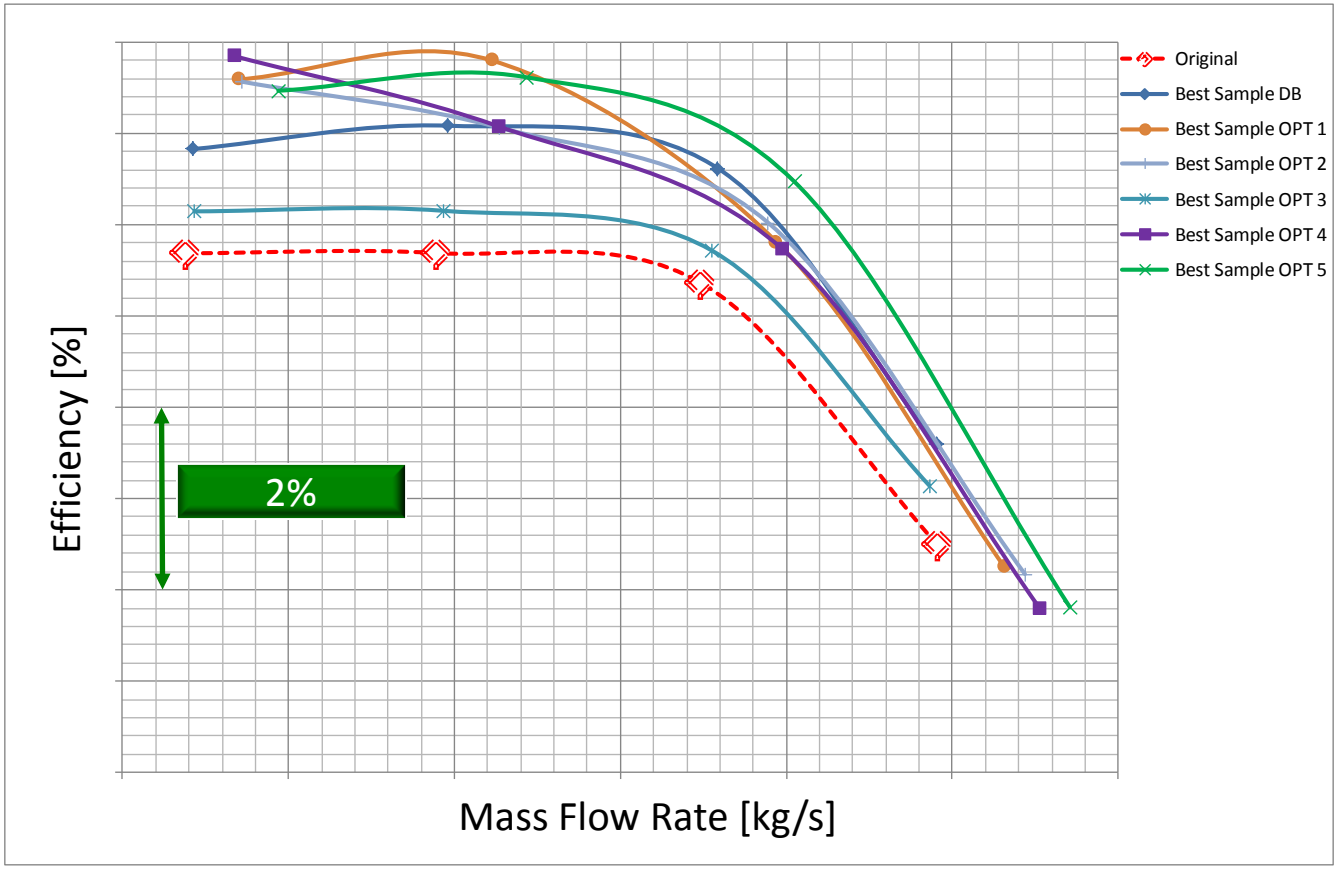
Results: Optimisation

Pressure Recovery Gain



Pressure Recovery Coefficient

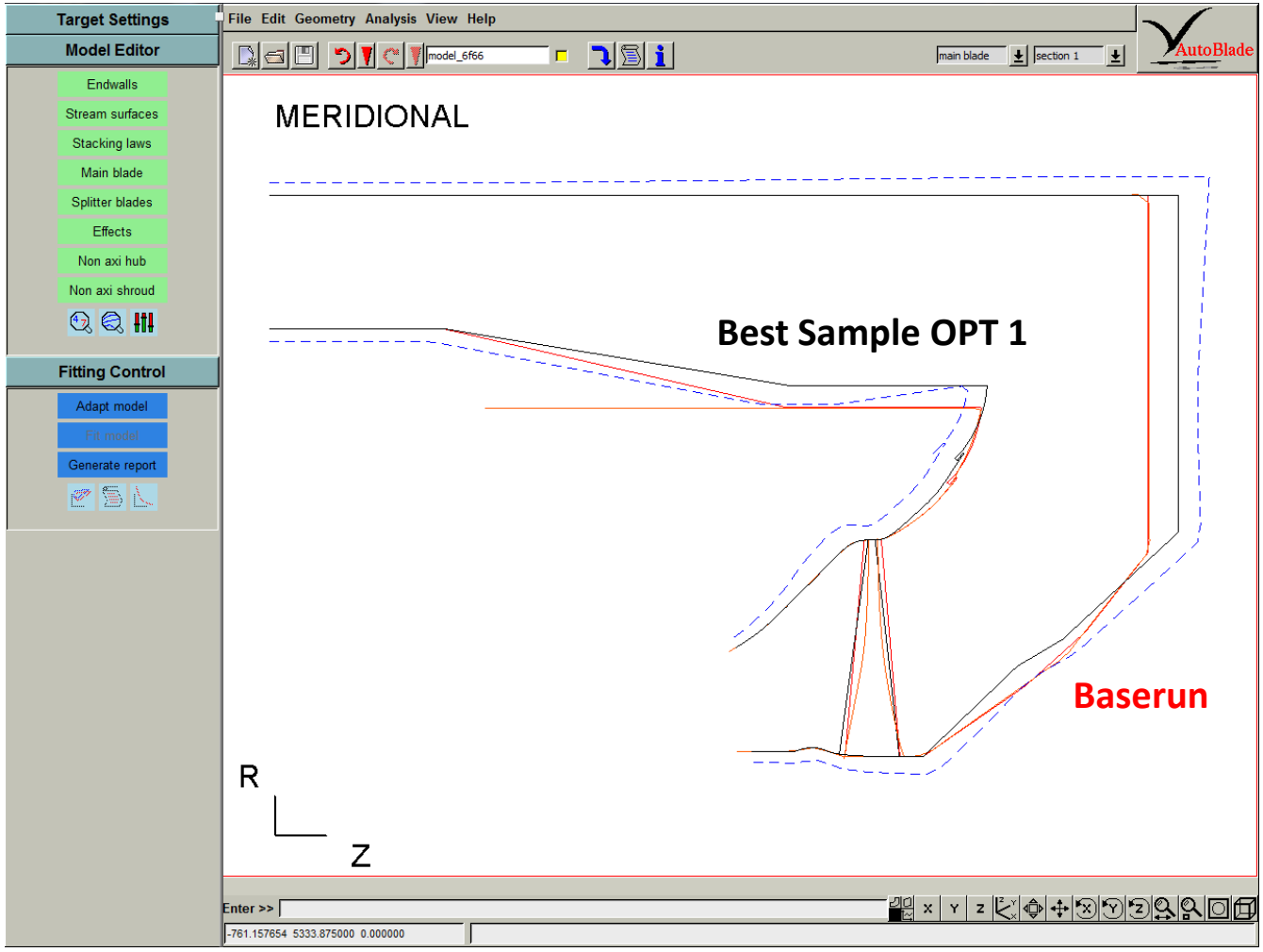
Results: Optimisation
Characteristics



Efficiency of last Stage & Diffuser

Results: Optimisation

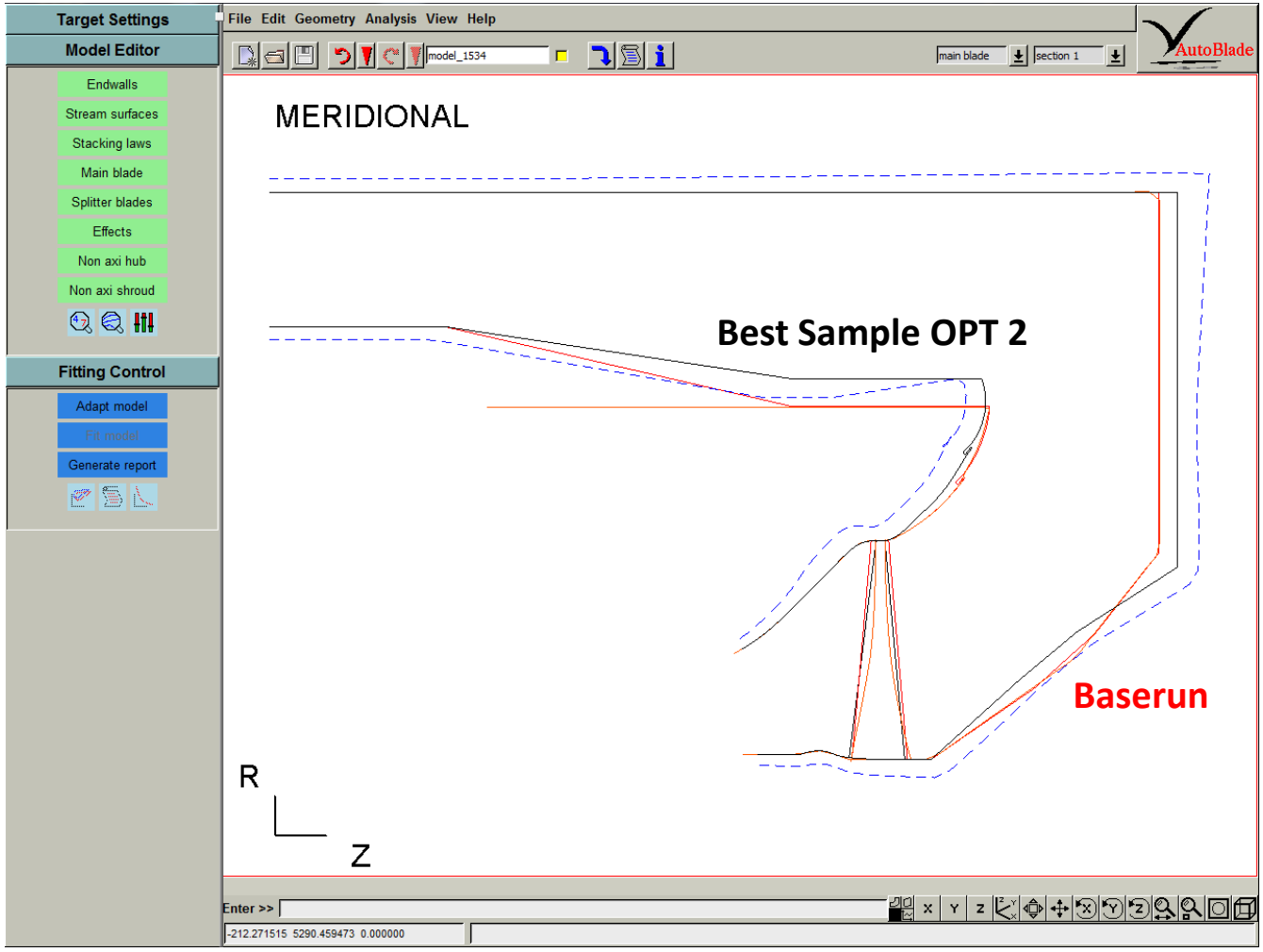
Diffuser & Exhaust Channel Geometry



Meridional geometry

Results: Optimisation

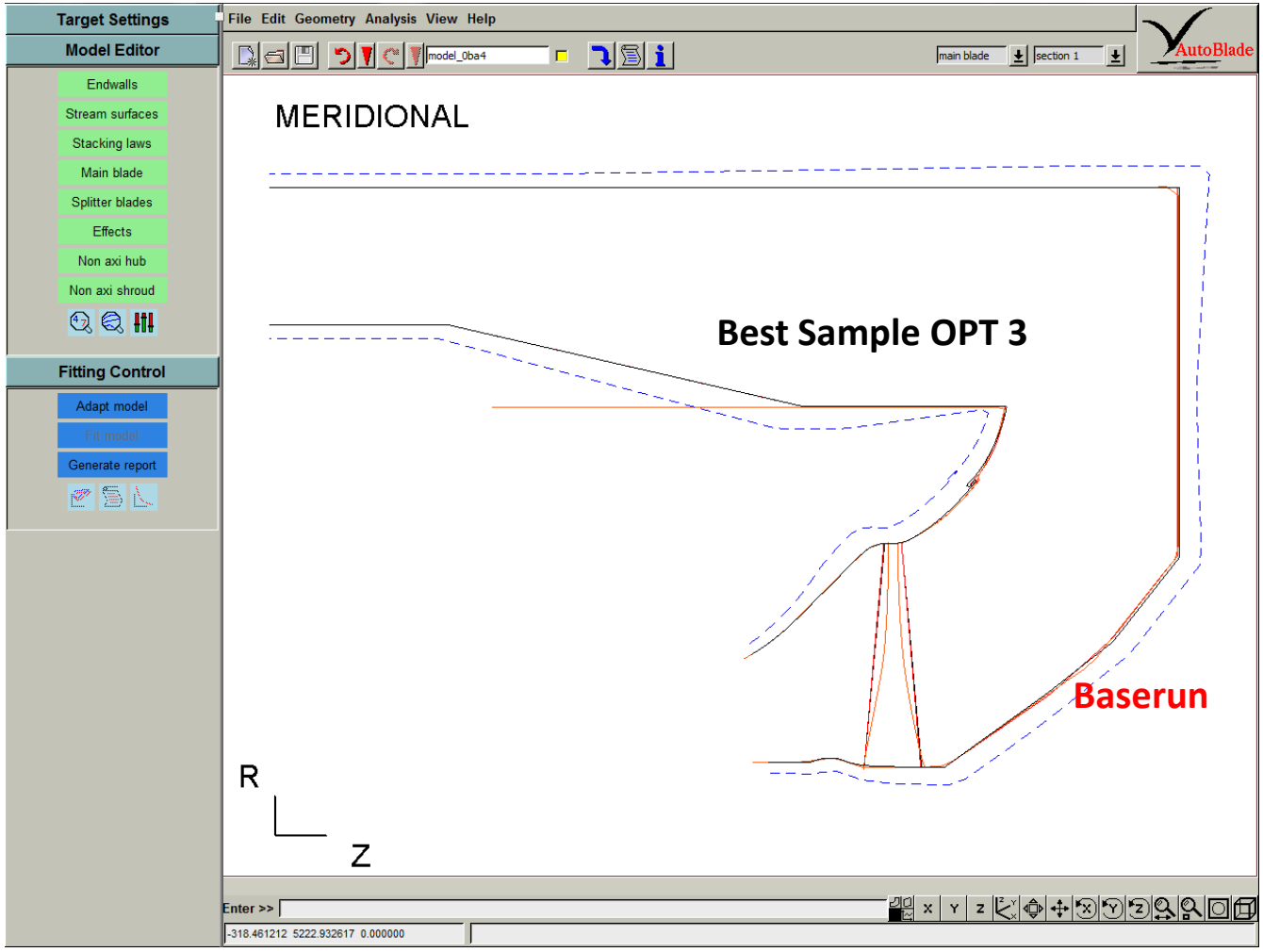
Diffuser & Exhaust Channel Geometry



Meridional geometry

Results: Optimisation

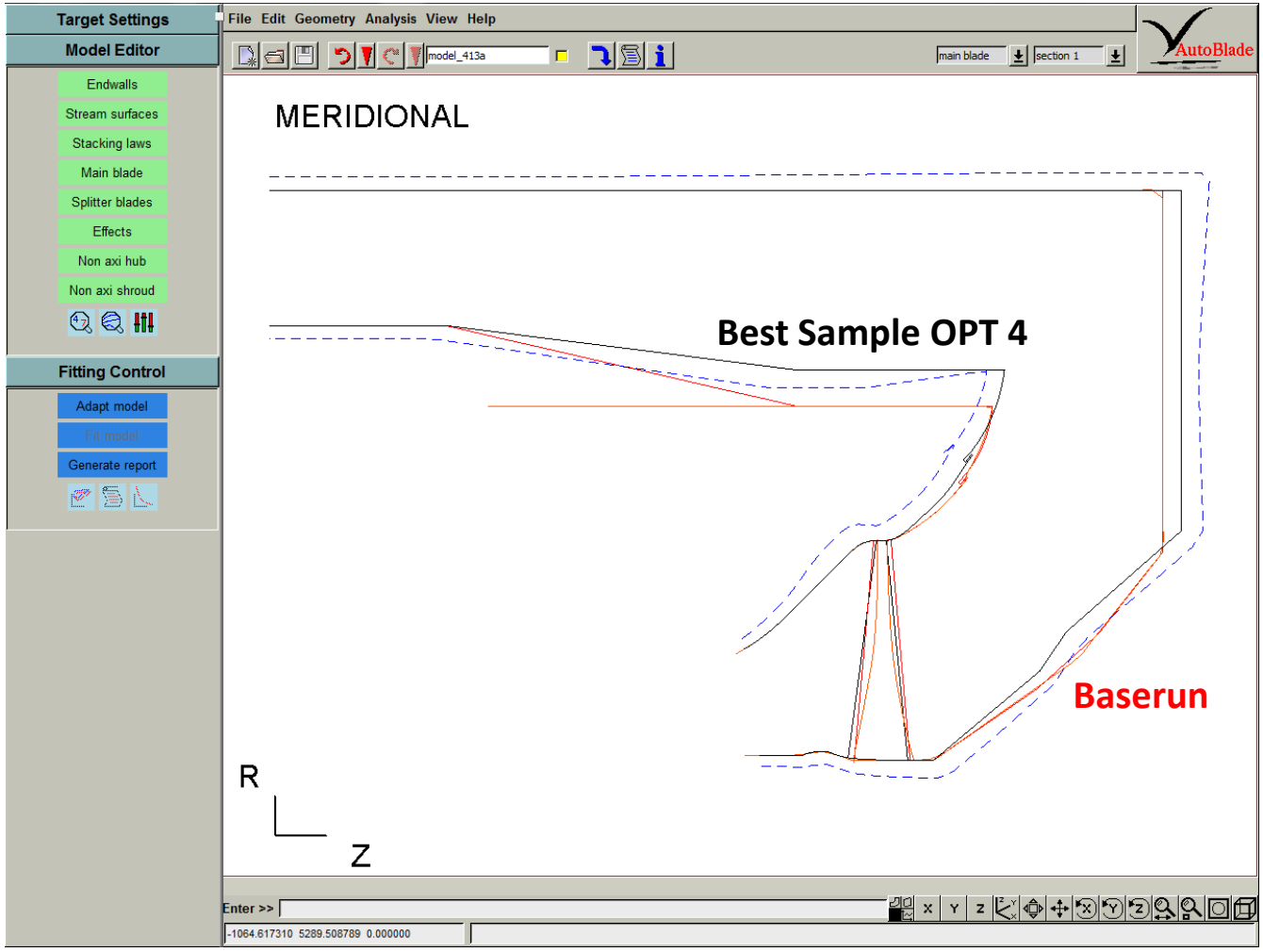
Diffuser & Exhaust Channel Geometry



Meridional geometry

Results: Optimisation

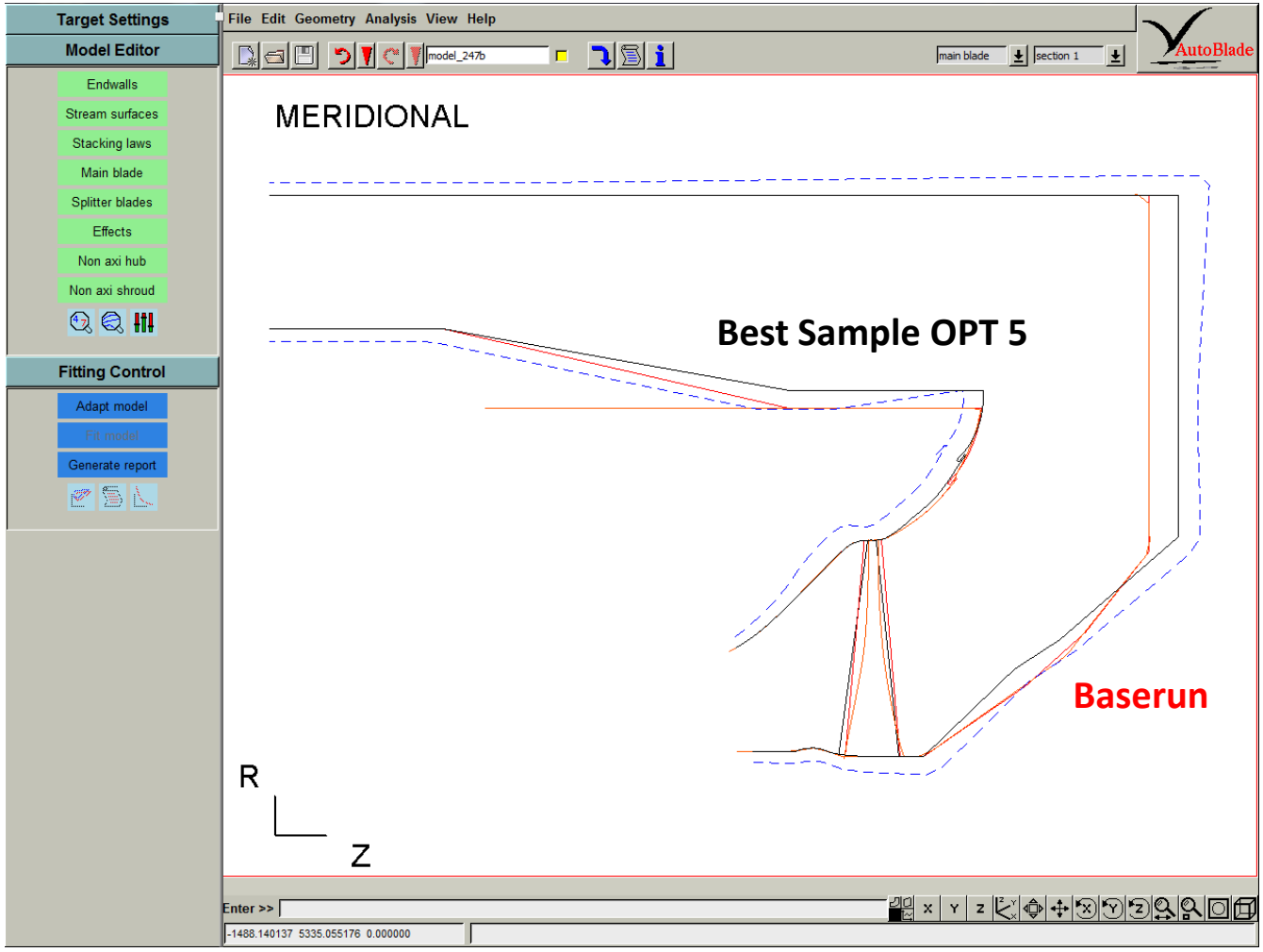
Diffuser & Exhaust Channel Geometry



Meridional geometry

Results: Optimisation

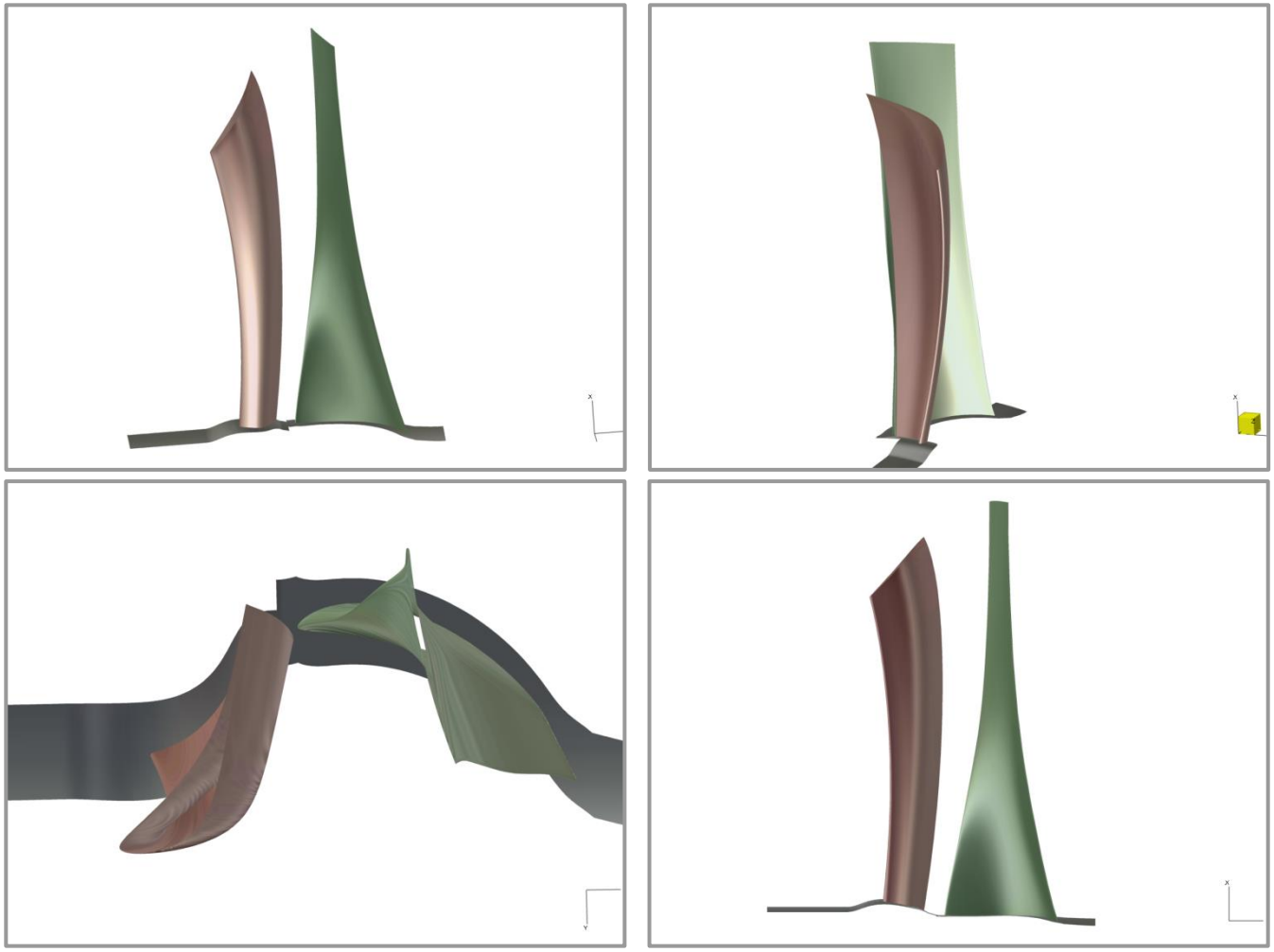
Diffuser & Exhaust Channel Geometry



Meridional geometry

Results: Optimisation

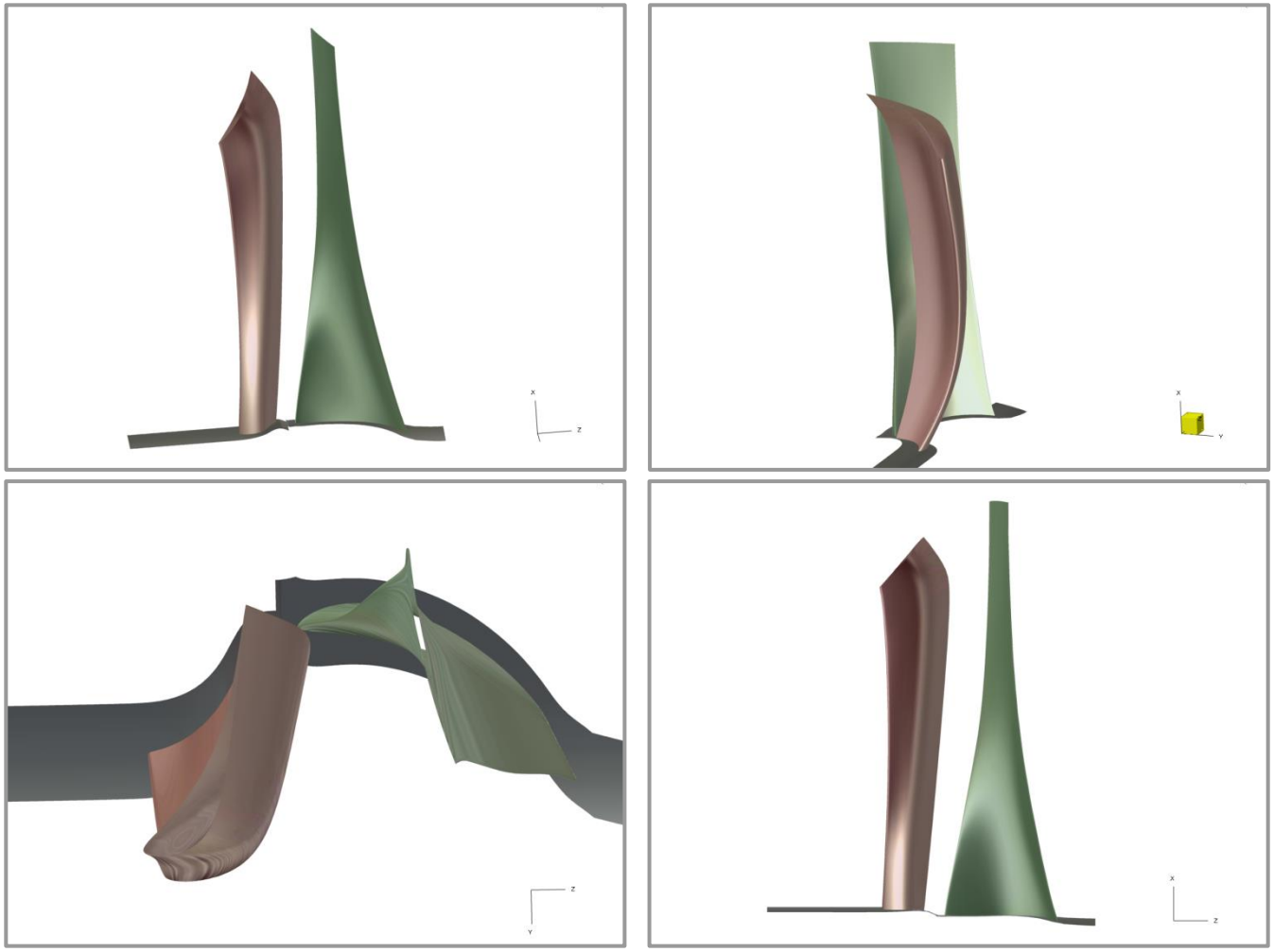
Blade Geometry



Original

Results: Optimisation

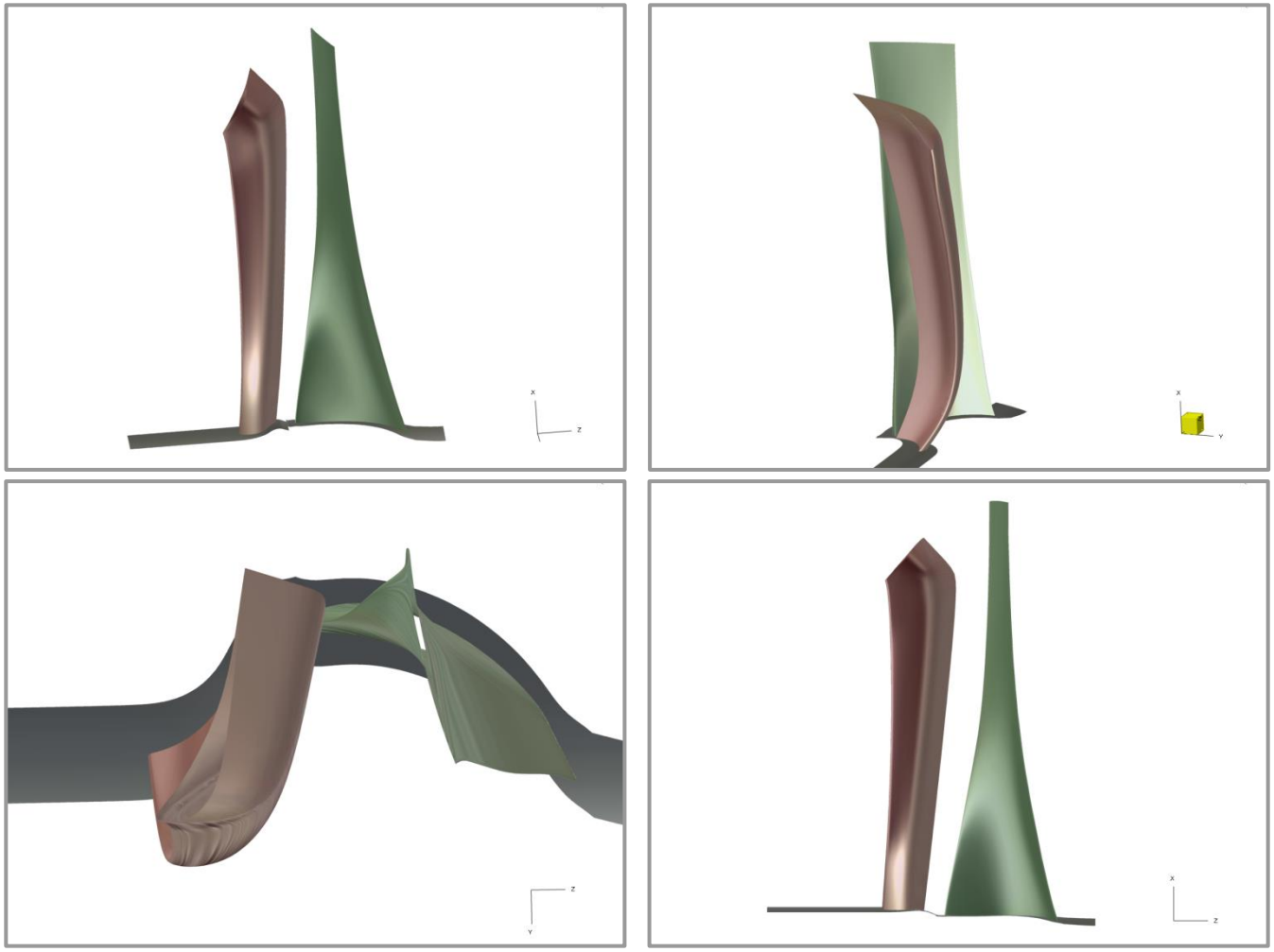
Blade Geometry



Best sample DB

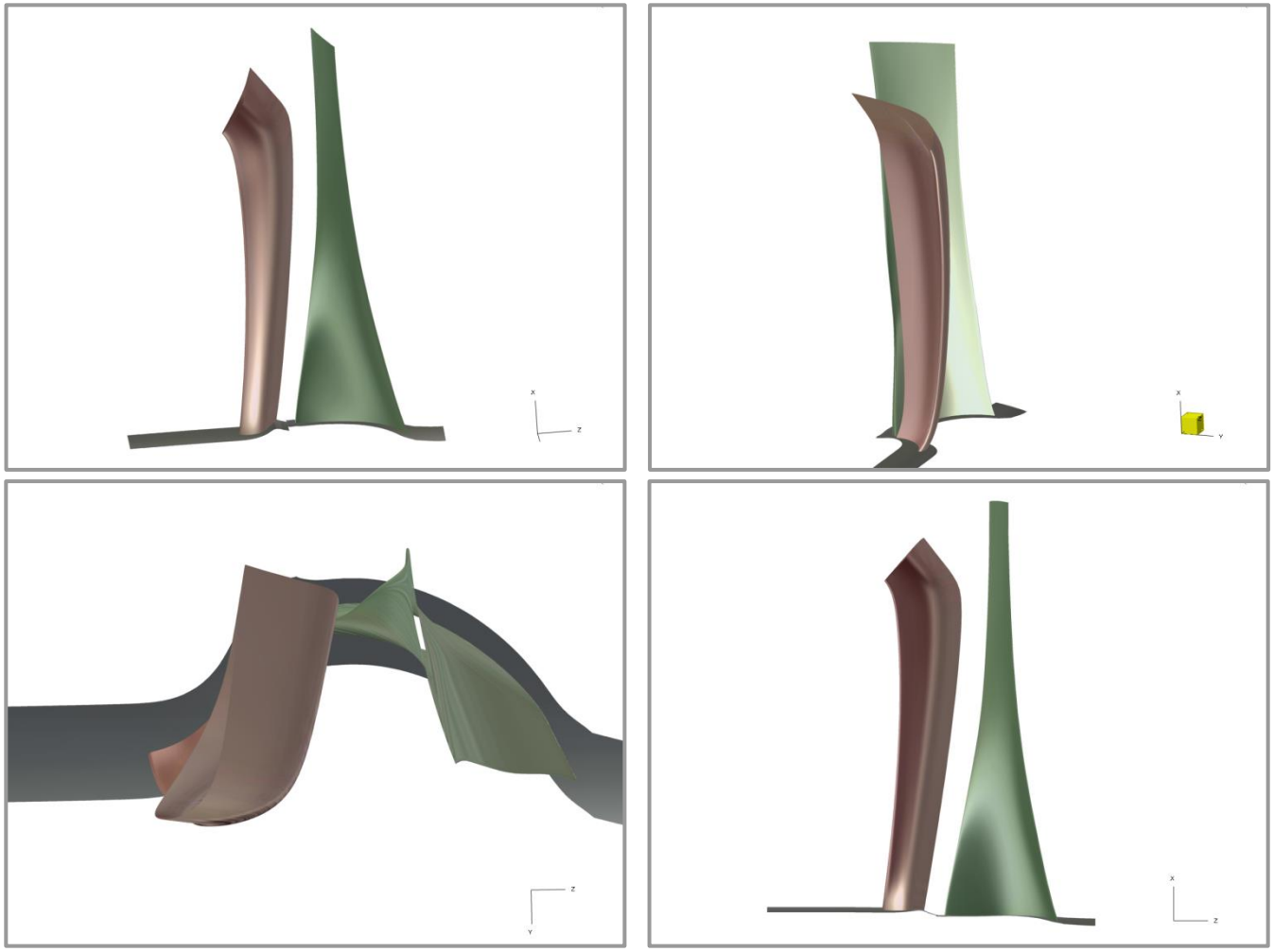
Results: Optimisation

Blade Geometry



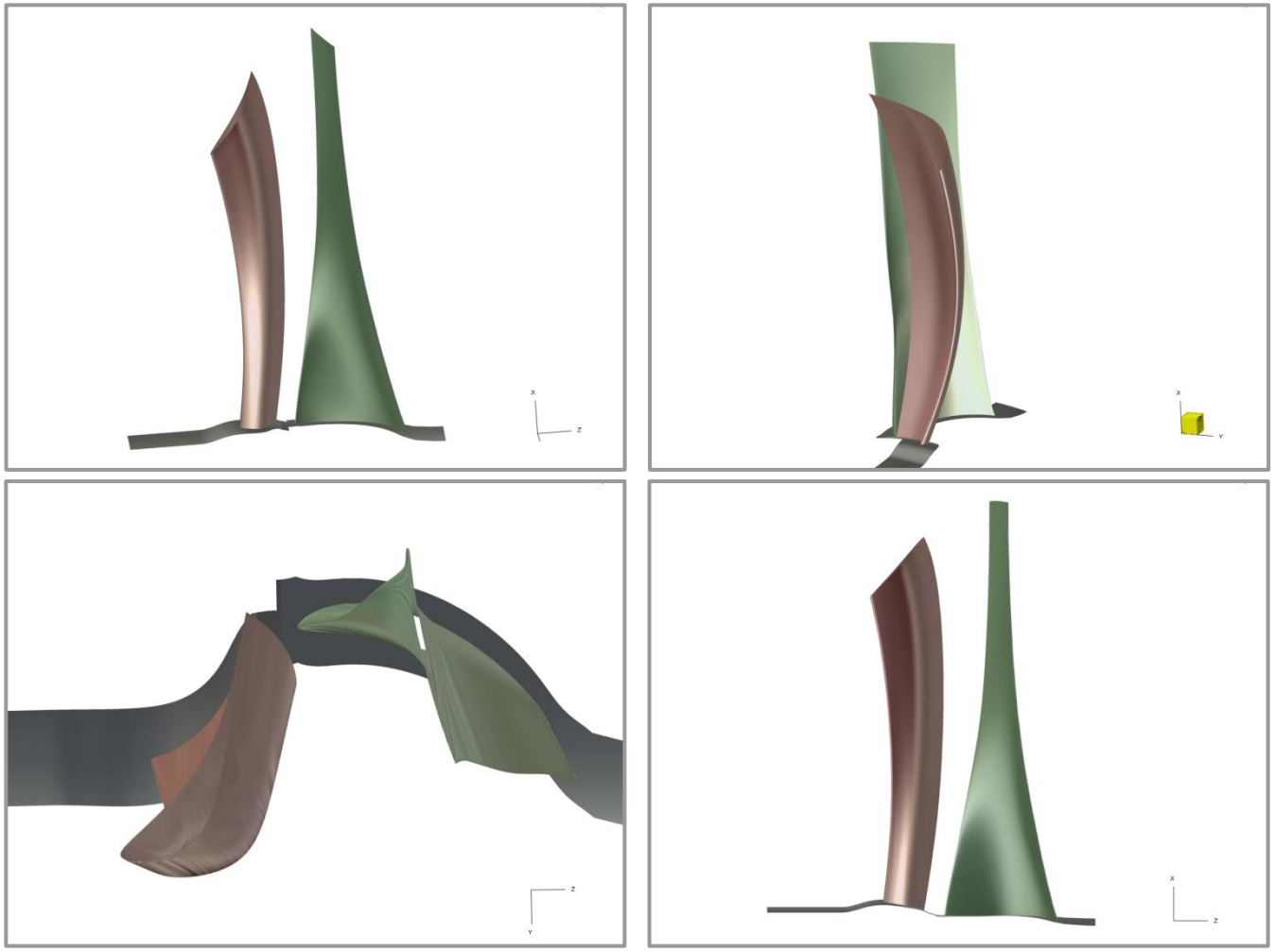
Best sample OPT 1

Results: Optimisation
Blade Geometry



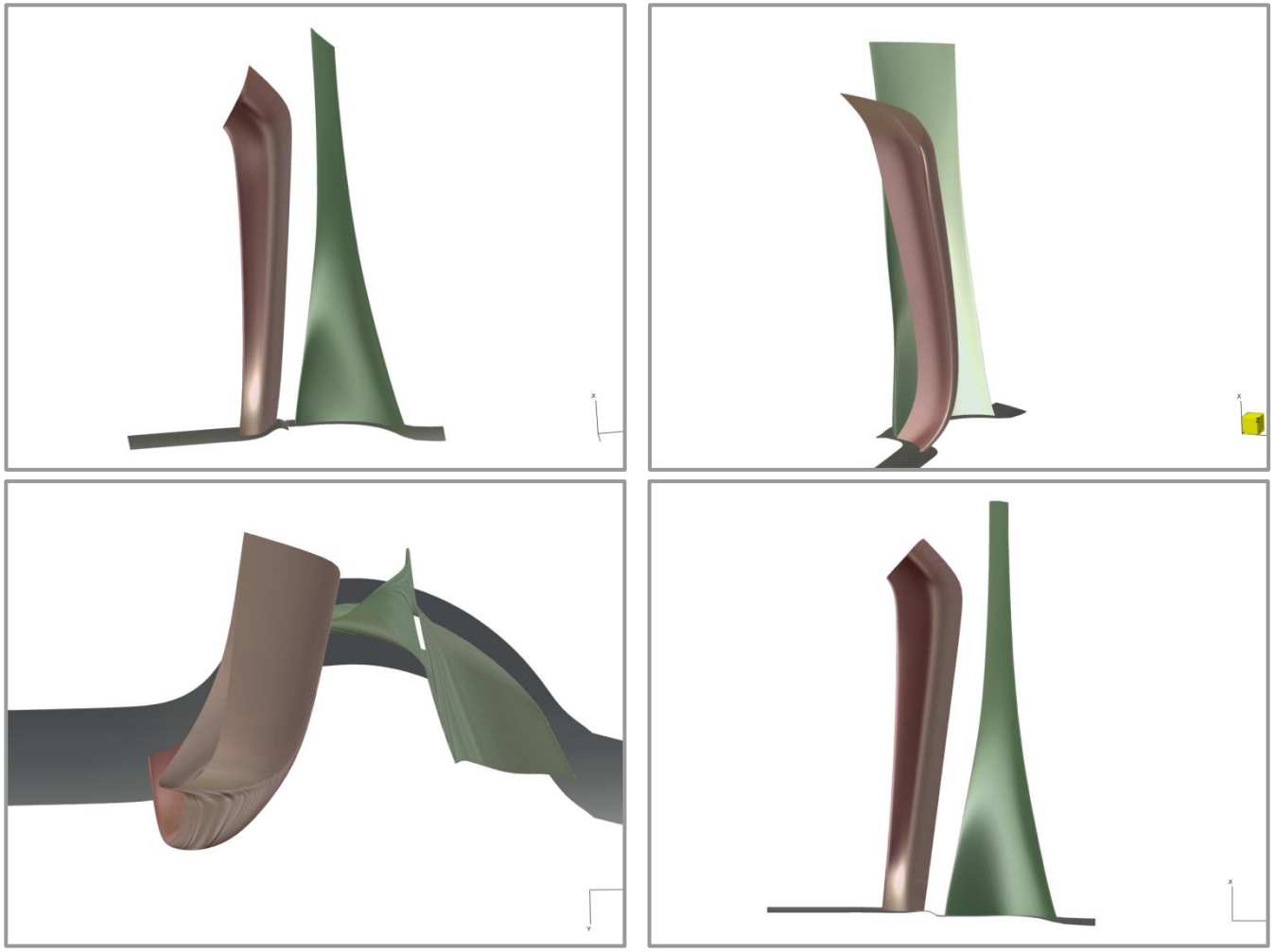
Best sample OPT 2

Results: Optimisation
Blade Geometry



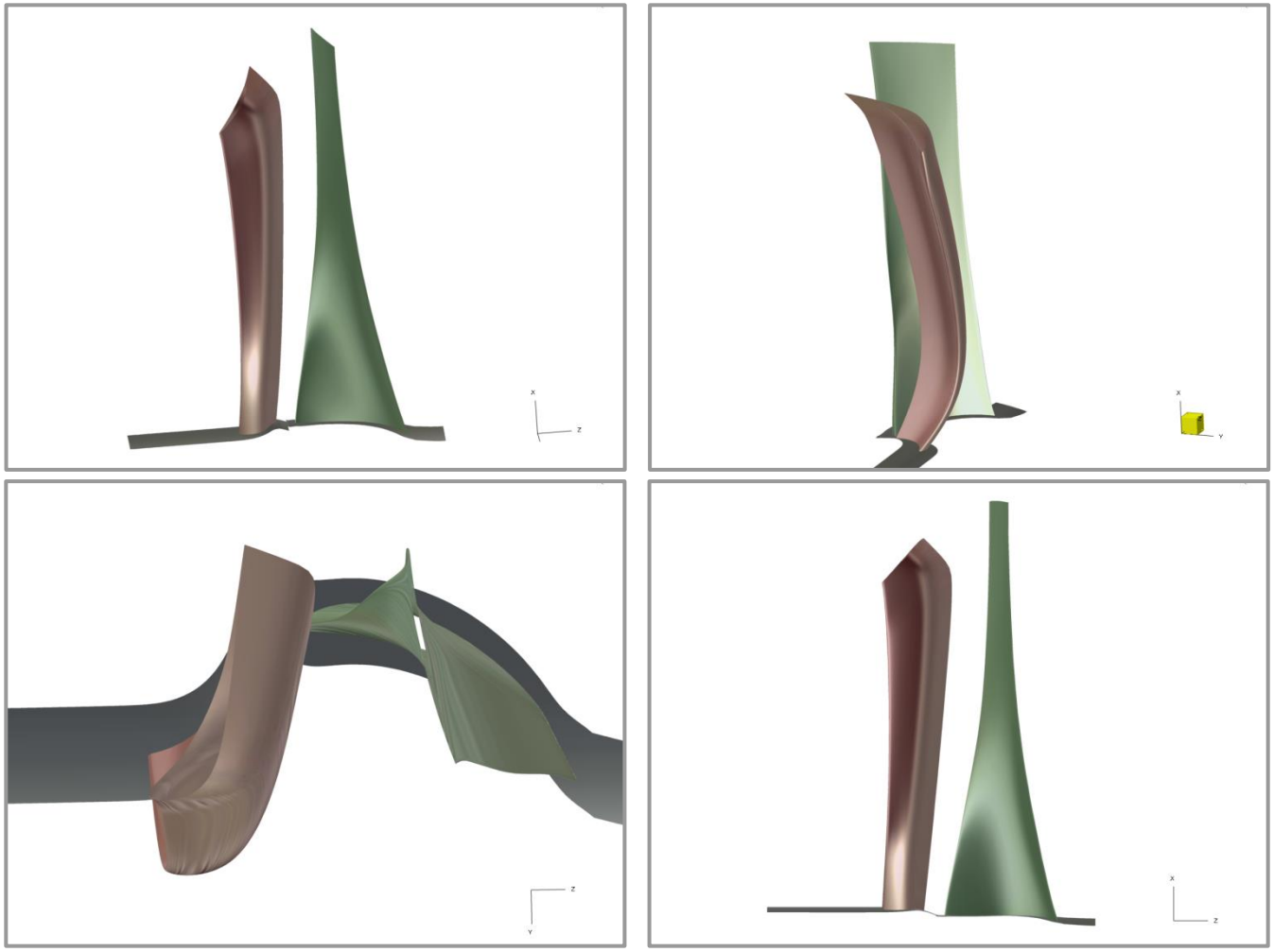
Best sample OPT 3

Results: Optimisation
Blade Geometry



Best sample OPT 4

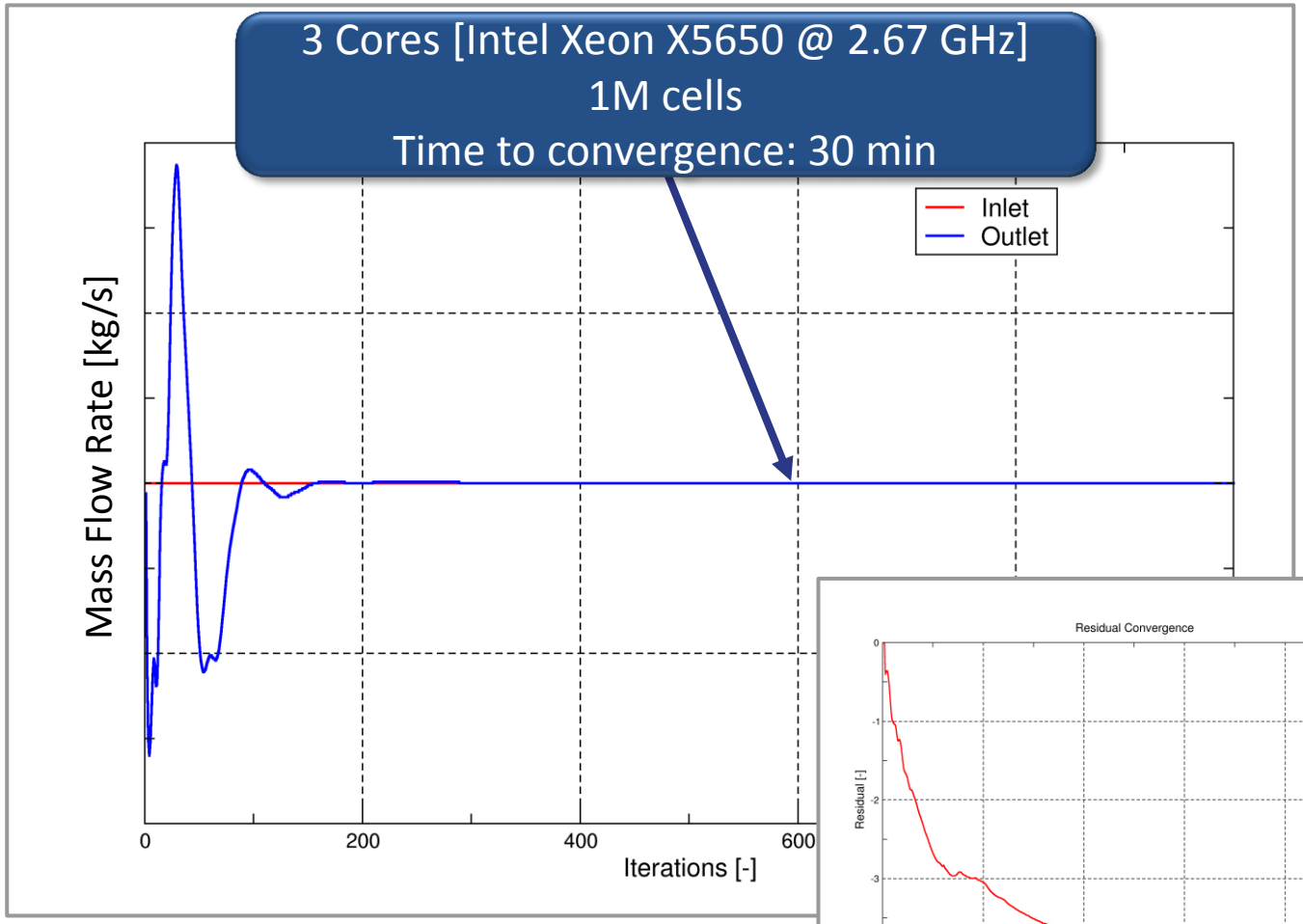
Results: Optimisation
Blade Geometry



Best sample OPT 5

Results: Optimisation

Typical Convergence & CPU Time



Results: Optimisation
Conclusion

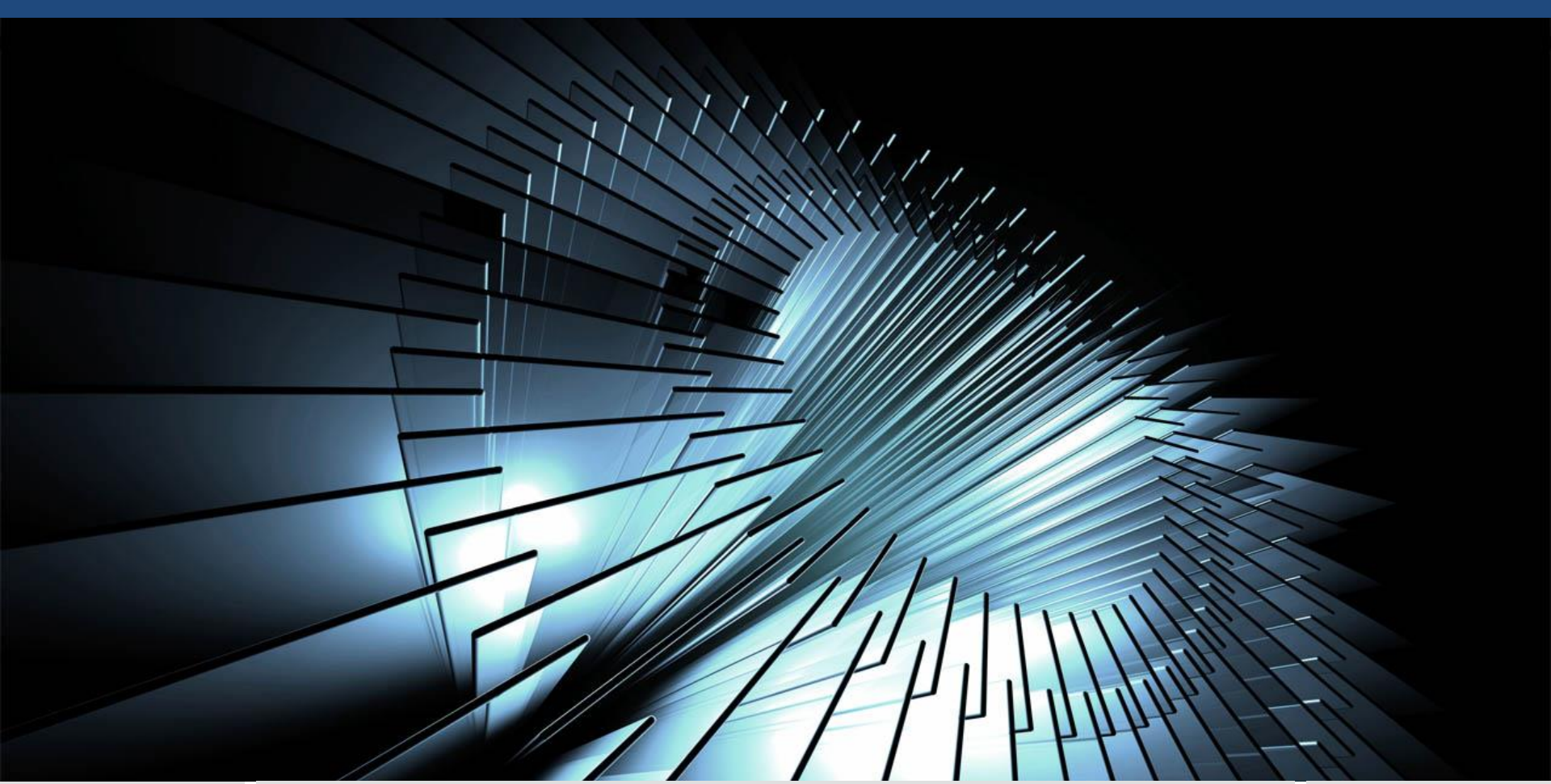
Total : ~ 700 designs [700 meshes, 2800 CFD runs, 700 post-processing runs]

Database already contained more efficient designs

Up to 2.5% increase in global efficiency is observed during optimisation

Whole characteristic shifted towards higher efficiency

Objective function definition very important



2014

End of Presentation

Thank you for your attention!

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