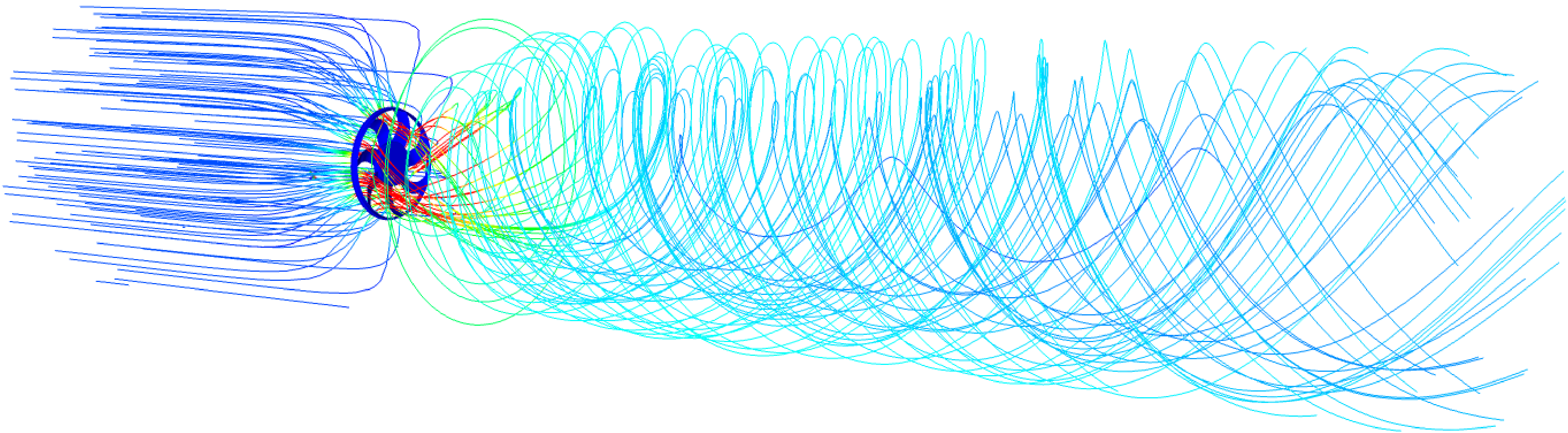

Aerodynamic optimization of low pressure axial fans with OpenFOAM

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Optimization of low pressure axial fans

Outline

1 Introduction

Objective and Motivation

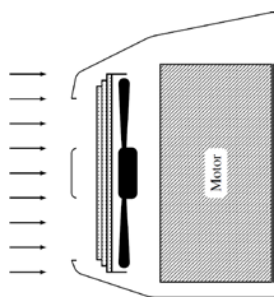
- Axial fans are typically used to pump air through the car underhood
- Cooling fans belong to the highest electrical consumers in conventional cars (up to ~1200 W)
- While the needed vol. flowrate is quite high (> 2500 m^3/h), the needed pressure rise is rather low (< 300 Pa)

Aim

- ➢ Lower max. power consumption or
- ➢ Increase vol. flowrates at specific operating points

1 Introduction
Design Principle of Axial Fans

Development of a MATLAB™-program for axial fan design



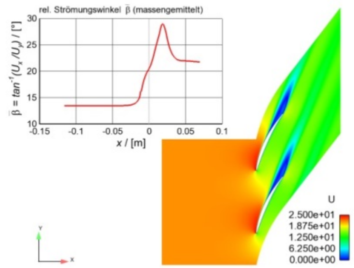
$$\frac{\partial c_x^2}{\partial r} + \frac{1}{r^2}\frac{\partial}{\partial r}(rc_u)^2 + 2T\frac{\partial S}{\partial r} = \frac{2}{\rho}\frac{\partial p_0}{\partial r}$$

Mathematical description of the airflow

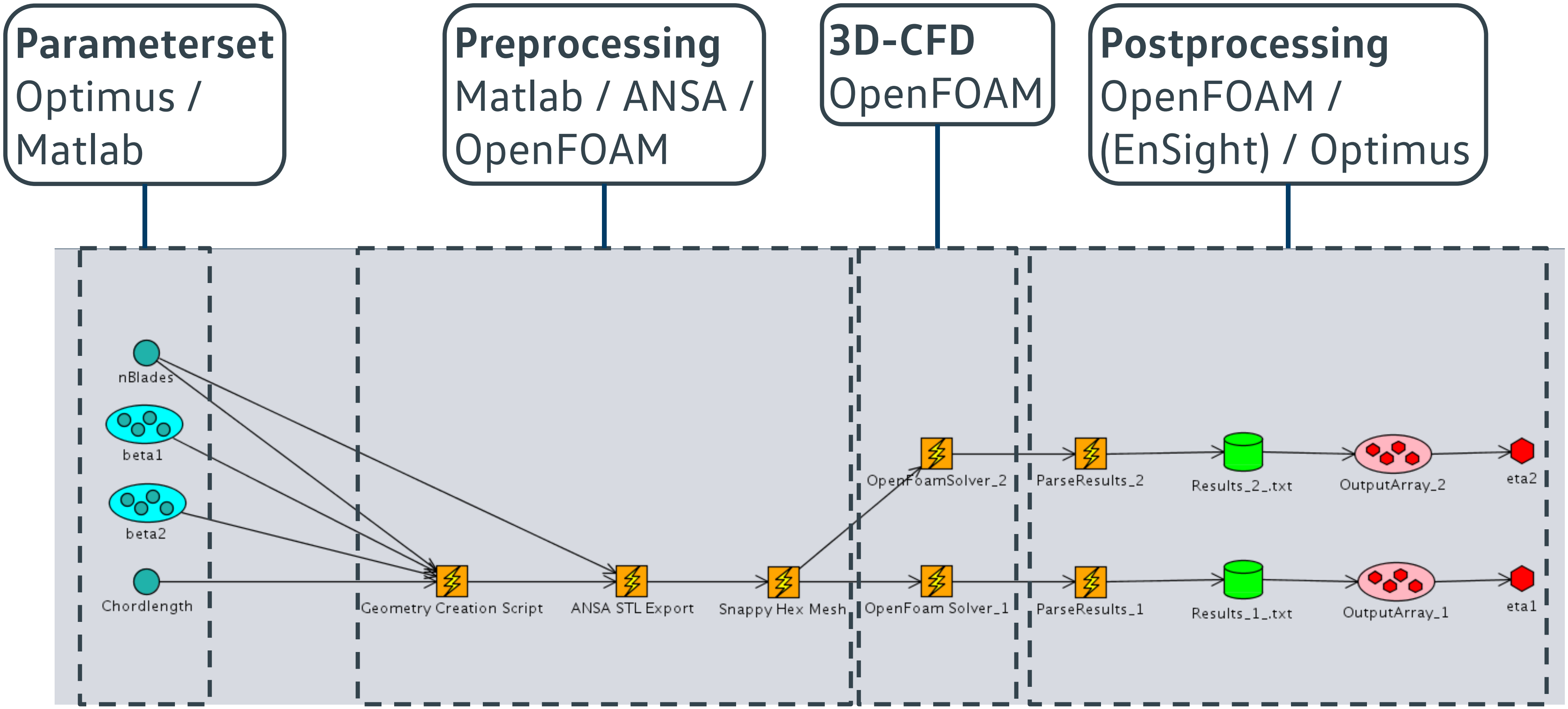
Boundary conditions / operating point

Empirical models and cascade correlations

Fan Designer

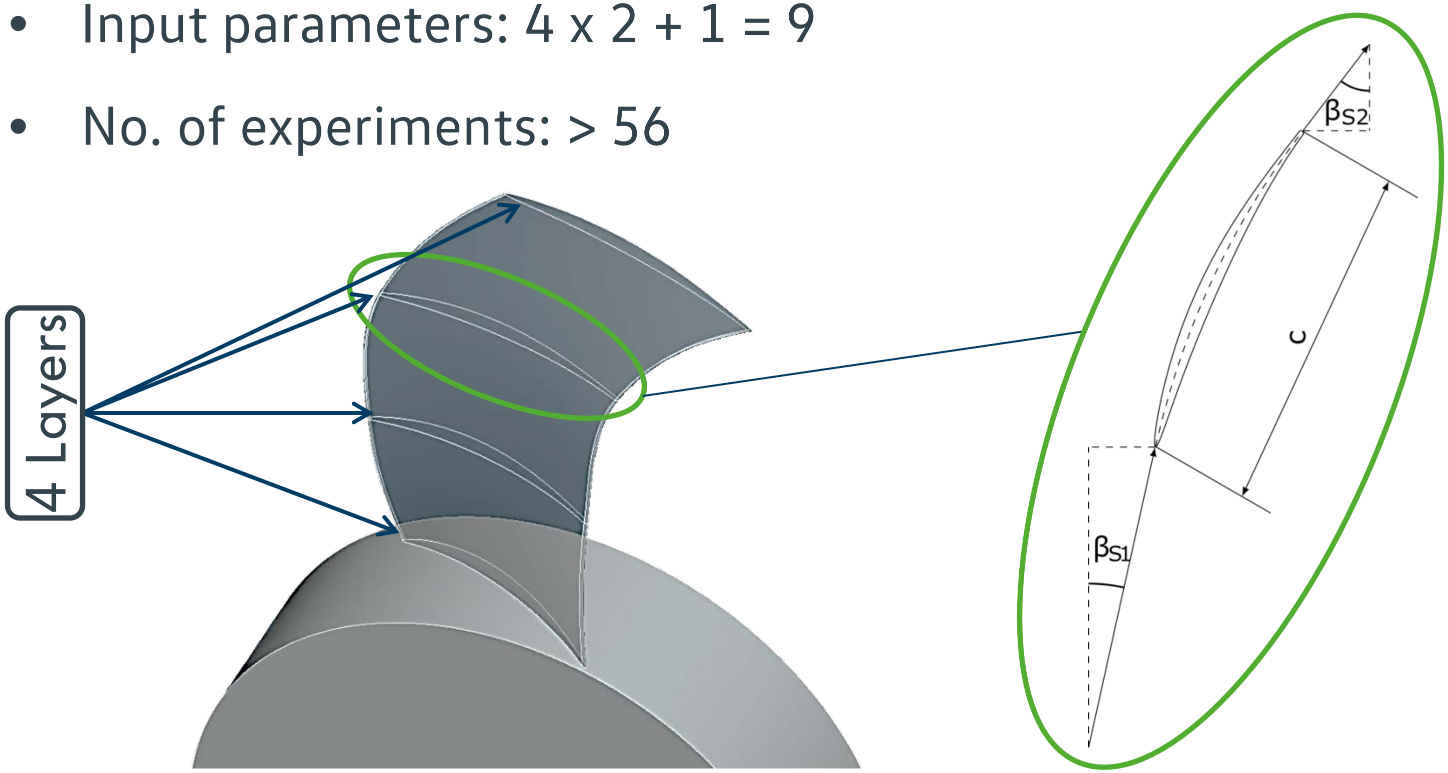


2 Optimization
Overview



2 Optimization
Design of Experiments

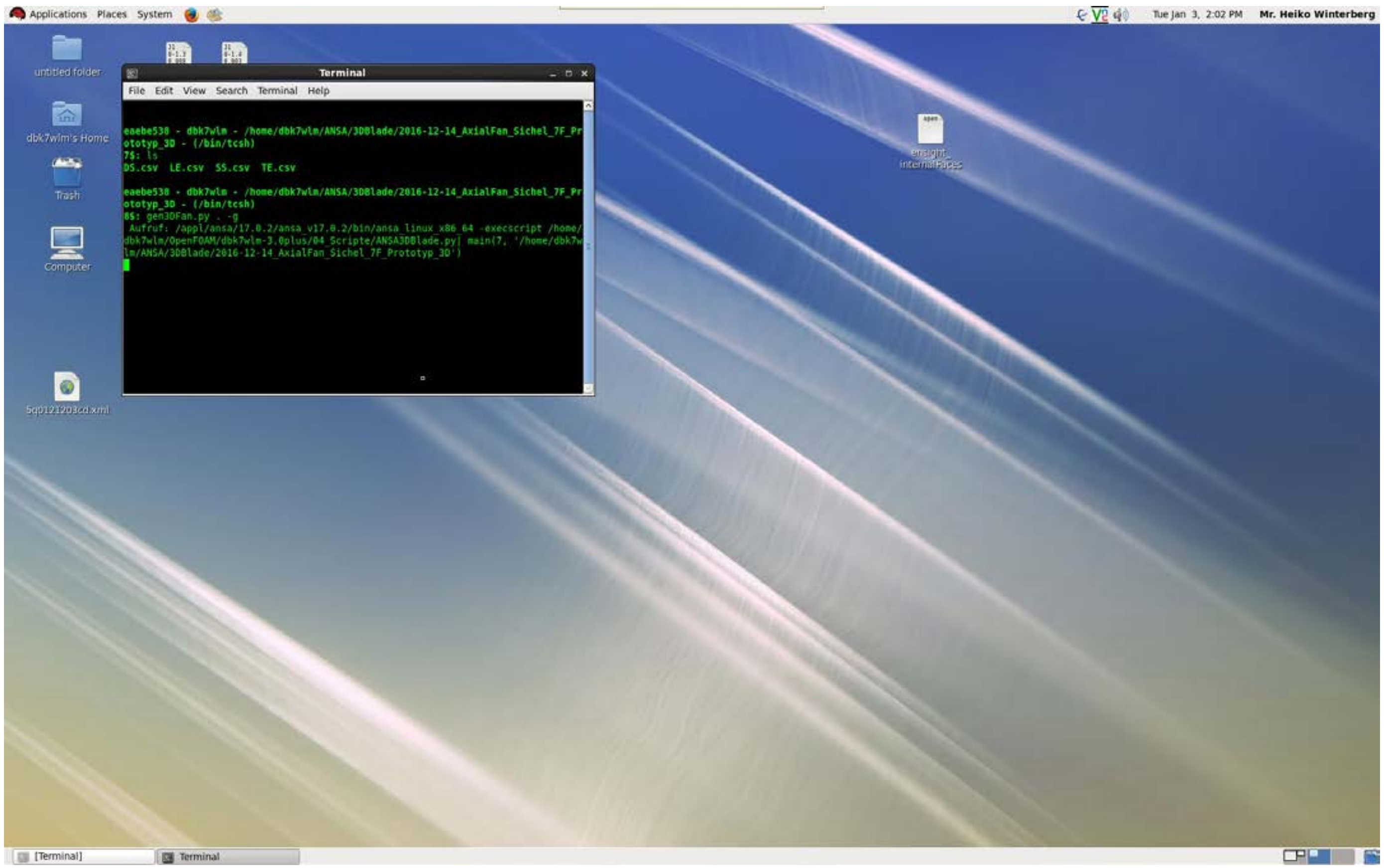
- Optimus® used to generate the DoE (Latin Hypercube)
- Input parameters: 4 x 2 + 1 = 9
- No. of experiments: > 56



2 Optimization

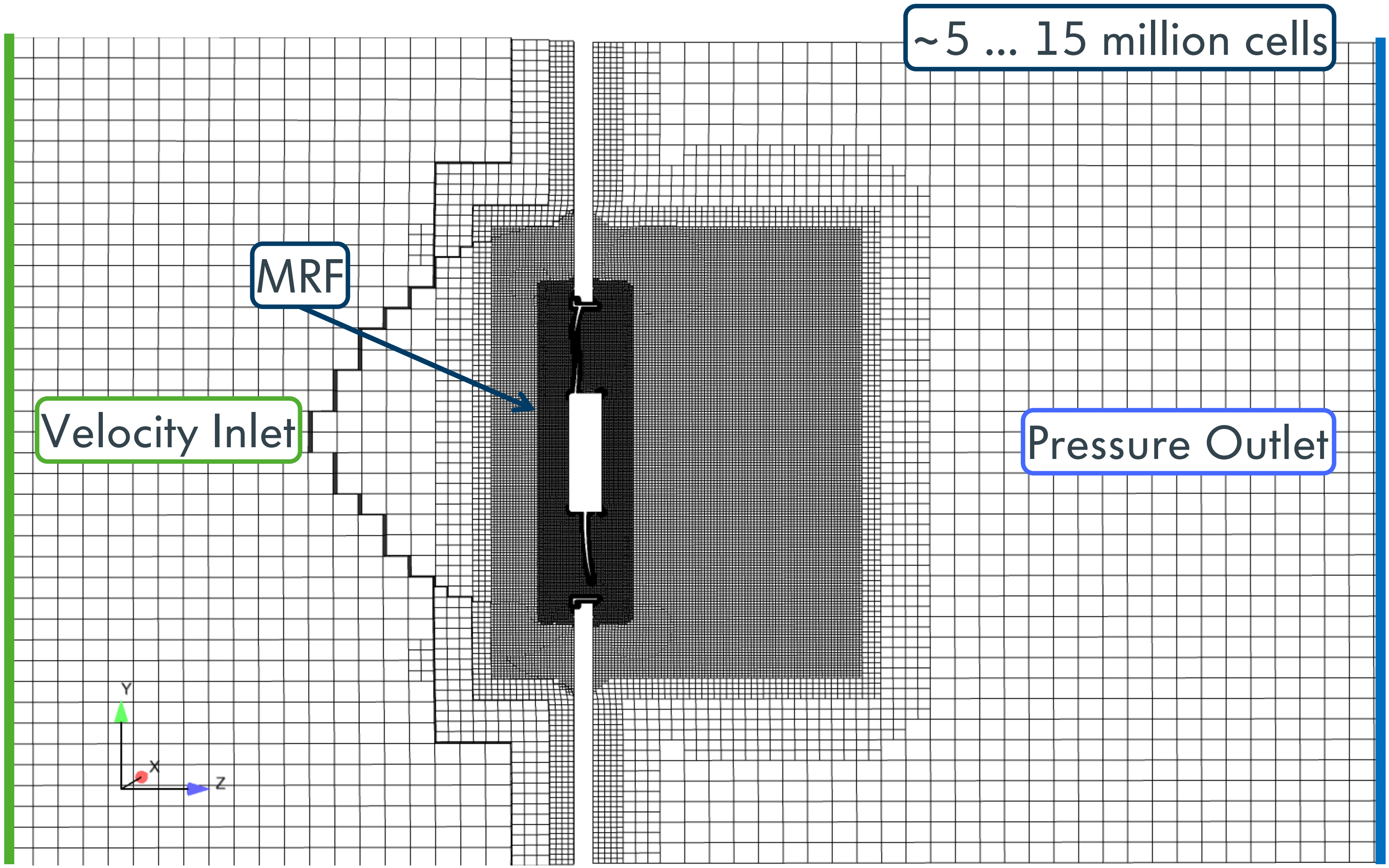
Preprocessing (3D-CAD generation)

Development of an interface between Fan Designer and ANSA™ using the Python API



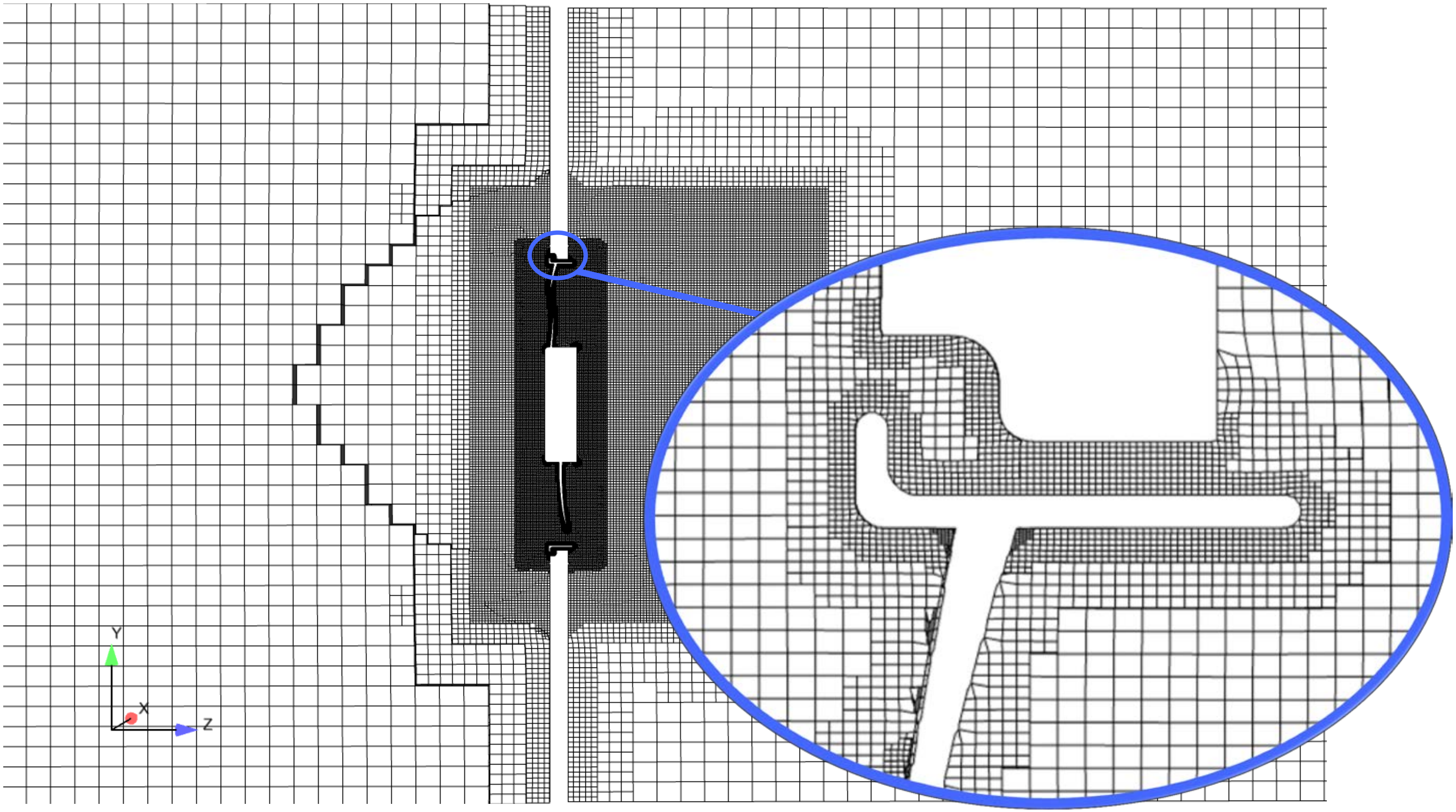
2 Optimization

Preprocessing (Meshing with shm)



2 Optimization

Preprocessing (Meshing with shm)



2 Optimization
3D-CFD

- Solver: simpleFoam
  - steady state
  - frozen rotor (MRF) approach
  - kOmegaSST (optional: kklOmega) turbulence model
  - Running parallel on 64 cores
- Automatic case setup using a python-script
- Runtime max. 10 h

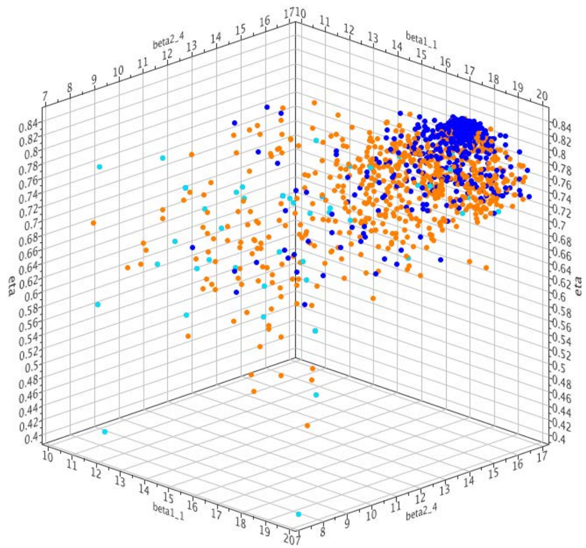
2 Optimization

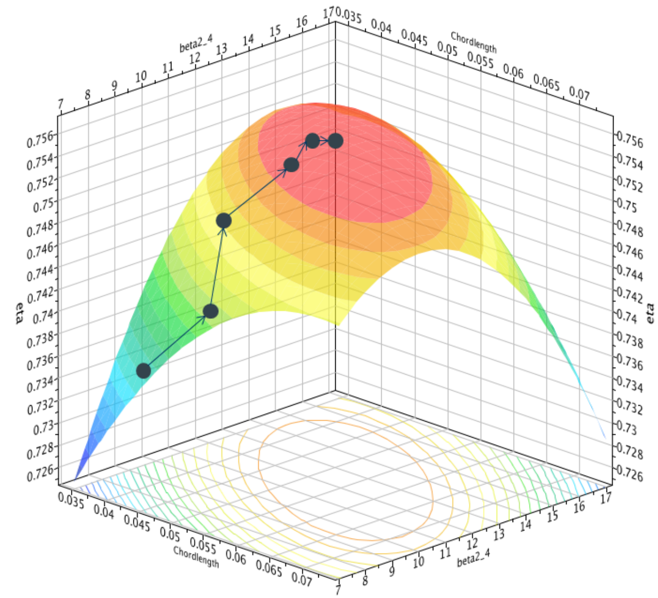
Postprocessing

- Fully automatic postprocessing using the OpenFOAM toolbox coupled with a python script
- Export of the integral results ($\dot{V}, \Delta p, \eta, \ldots$) into *.txt, *.PPTX and *.XLSX
- Import and storage of the results in Optimus®

2 Optimization

Strategy





1. Parameter variation based on DoE (Latin Hypercube)
2. Response Surface Model (RSM) using the DoE-data
3. Find the global optimum of the RSM
4. Validation of the best fan-setup (3D-CFD)

2 Optimization
Response Surface Model

RSM using a Second Order Taylor Polynomial:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum \sum_{i<j=2}^{k} \beta_{ij} x_i x_j + \epsilon$$
$$= \beta_0 + \boldsymbol{x}'\boldsymbol{\beta} + \boldsymbol{x}'\boldsymbol{B}\boldsymbol{x} + \epsilon$$

Where:

$$\boldsymbol{x} = \begin{pmatrix} x_1 \\ \vdots \\ x_k \end{pmatrix}, \quad \boldsymbol{\beta} = \begin{pmatrix} \beta_1 \\ \vdots \\ \beta_k \end{pmatrix}, \quad \boldsymbol{B} = \begin{bmatrix} \beta_{11} & \beta_{12}/2 & \cdots & \beta_{1k}/2 \\ & \beta_{22} & \cdots & \beta_{2k}/2 \\ & & \ddots & \vdots \\ \text{sym.} & & & \beta_{kk} \end{bmatrix}$$

$\boldsymbol{\beta}$ is obtained by the method of least-squares.

2 Optimization

Optimization-Algorithm

Objective function:

$$\min_{\boldsymbol{x}\in\Omega} F(\boldsymbol{x}) = 1 - (\eta_1(\boldsymbol{x}), \dots, \eta_m(\boldsymbol{x}))'$$

Where Ω is the chosen parameter space, $\boldsymbol{x} = (x_1, \dots, x_k)'$ and η_m represents the efficiency for m different OPs

Constraints:

- Operating Point ($\dot{V}_{\mathrm{op}}, \Delta p_{\mathrm{op}} \pm \varepsilon$), **or**
- Power consumption ($\dot{V} \cdot \Delta p/\eta = c \pm \varepsilon$)

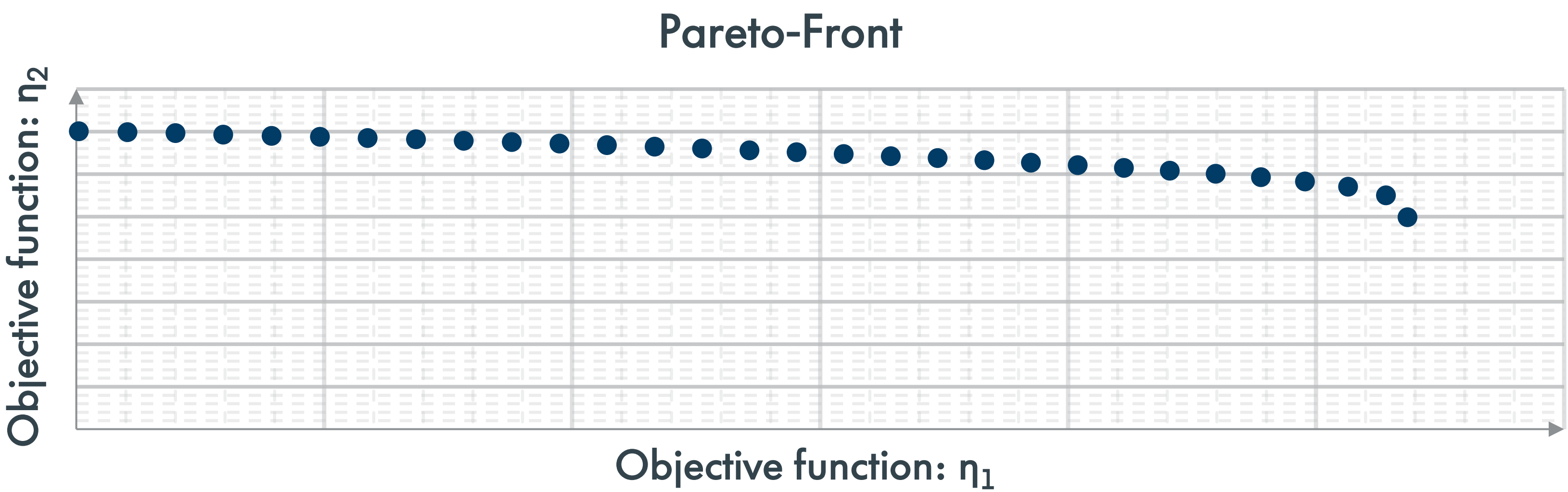
Optimization algorithm:

- Normal boundary intersection method

3 Some results

Pareto-Front

- The optimization returns the Pareto-Optimal geometries
  - ➢ Every point represents a fan-geometry, where objective function (OF) 1 can't be increased without lowering OF 2

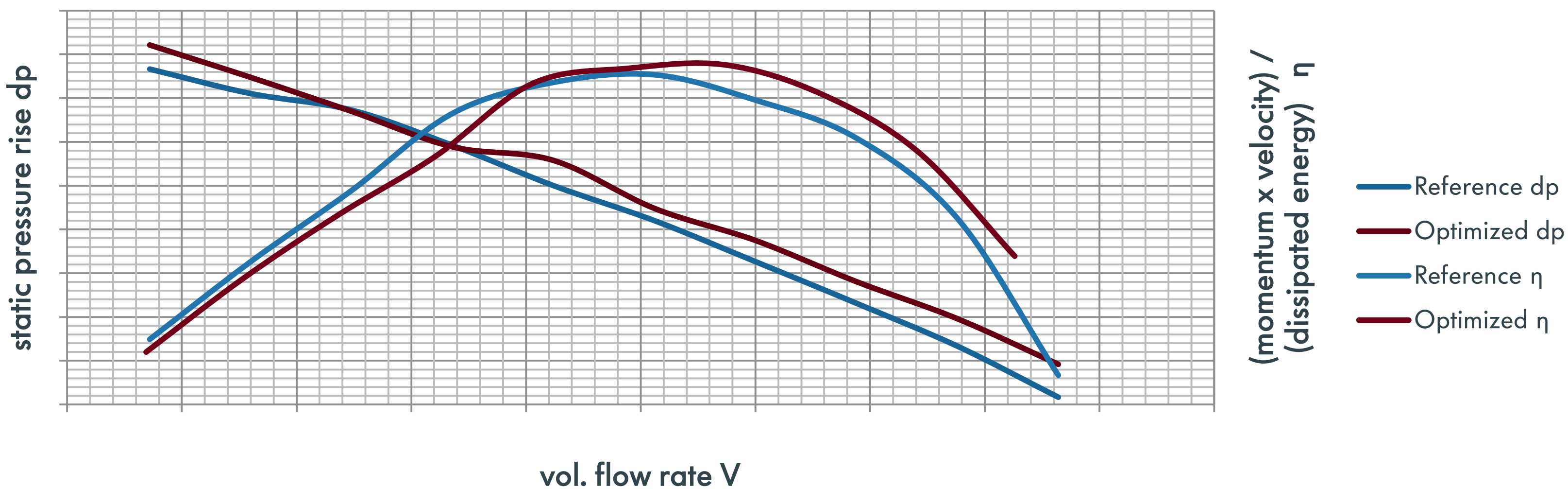


3 Some results

Fan curve

Qualitative comparison to a chosen reference fan

- Fan curve in terms of OPs optimized
- Maximum efficiency increased
- Partial load region with decreased efficiency



4 Summary and outlook

- Development of a tool for the purpose of accurate fan design
- Setup of a DoE-process using Optimus® coupled with Fan Designer, ANSA and OpenFOAM
- Response Surface Model of the DoE-Data using a 2nd order Taylor Polynomial
- RSM-Model based optimization to find the best design

4 Summary and outlook

Next Steps:

- Further Robust Design Analysis (fan curve optimization)
- Influence no. of experiments on RSM
- Benchmarking of different optimization algorithms
- Further validation of the process

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Backup