A Simple Pump Impeller Performance Surrogate Model

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Introduction

- Daily radial impeller design at KSB is performed by CFD calculations of a simplified rotational symmetric part of a blade passage
- Approved and reliable procedure

- Nowadays more flexible and fast impeller designs tools are necessary especially regarding energy consumption regulations (e. g. circulator pumps)
- First application of such a tool - based on surrogate modelling - presented at last User Conference - "High-Efficiency Circulator Pump Design"
- At the end method was not general enough

KSB Calio Circulators

ErP 2015+

KSB

Task/Boundary Conditions

➔ Develop a more general pump impeller performance surrogate model

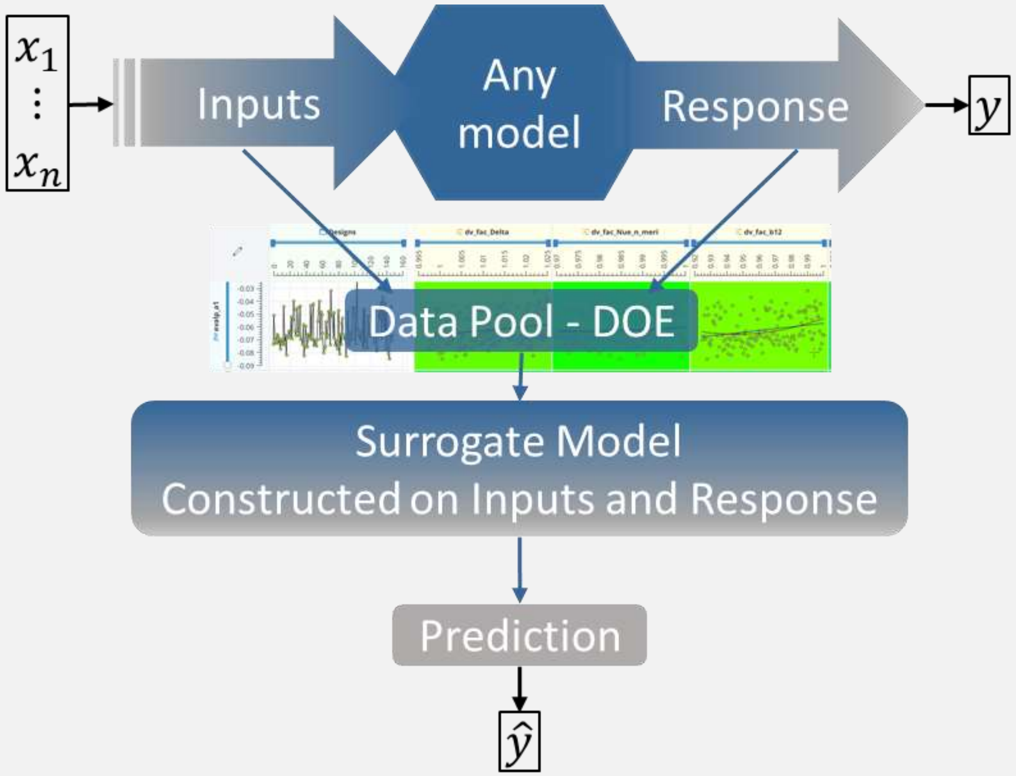
$$n_q = n(1/min) \cdot \frac{\sqrt{Q}}{H^{3/4}}$$

- Geometry range
  - Specific speed between $30 \leq n_q \leq 40$
  - Fixed speed and design flow rate (definition of base size)
  - Origin existing type series
  - Fixed blade profile
  - Number of blades 5 - 7
- Numerical model
  - Pump performance is generated by steady-*state* impeller blade passage CFD simulations
- Definition of geometry and surrogate model
  - CAESES

Surrogate Model

- Simplified approximation of more complex relationships (any model) between a certain combination of inputs → x_i and a response variable → y on basis of a data pool (DOE)
- Predicting response data → $\hat{y}$

- Any model → Numerical model of the impeller
- Input data → Design variables of the geometry
- Responses → Impeller performance data



Problem description

How to transfer the calculated theoretical curves into surrogate models in an efficient way?

Typically 3 fixed flow rates are chosen for curve approximation

- Adv.: Small amount of CFD calculations required
- Disadv.: If curve characteristic is changed not always best fit for power approximation

Theoretical background (incompressible, no friction losses, vortex free inflow, $\beta_2 < 90°$):

$$H_{th} = \frac{u_2^2}{g} - \frac{u_2 ctg\beta_2}{g} c_{2m}$$

$\Downarrow$

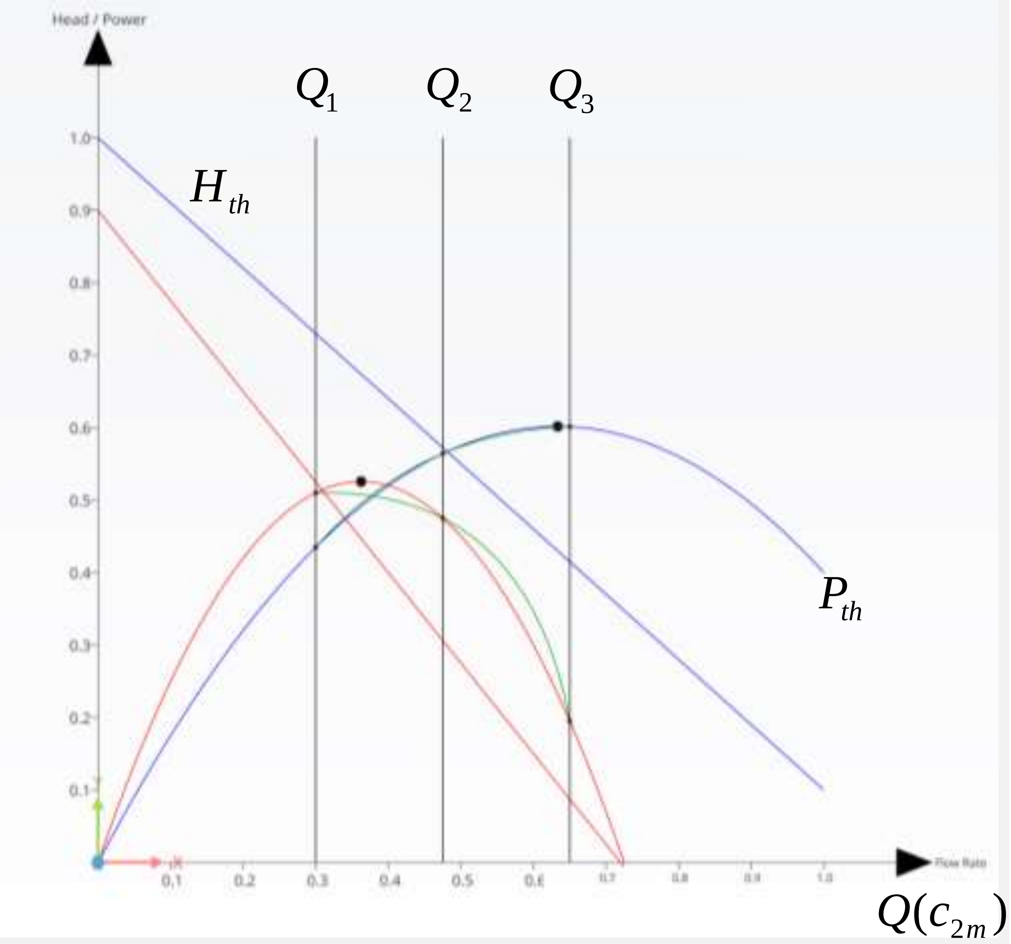
Linear curve for head

$$P_{th} = g\rho Q H_{th}$$

$$P_{th} = \rho Q (u_2^2 - u_2 \frac{Q}{A_2} ctg\beta_2)$$

$\Downarrow$

Polynomial curve of 2nd order for power

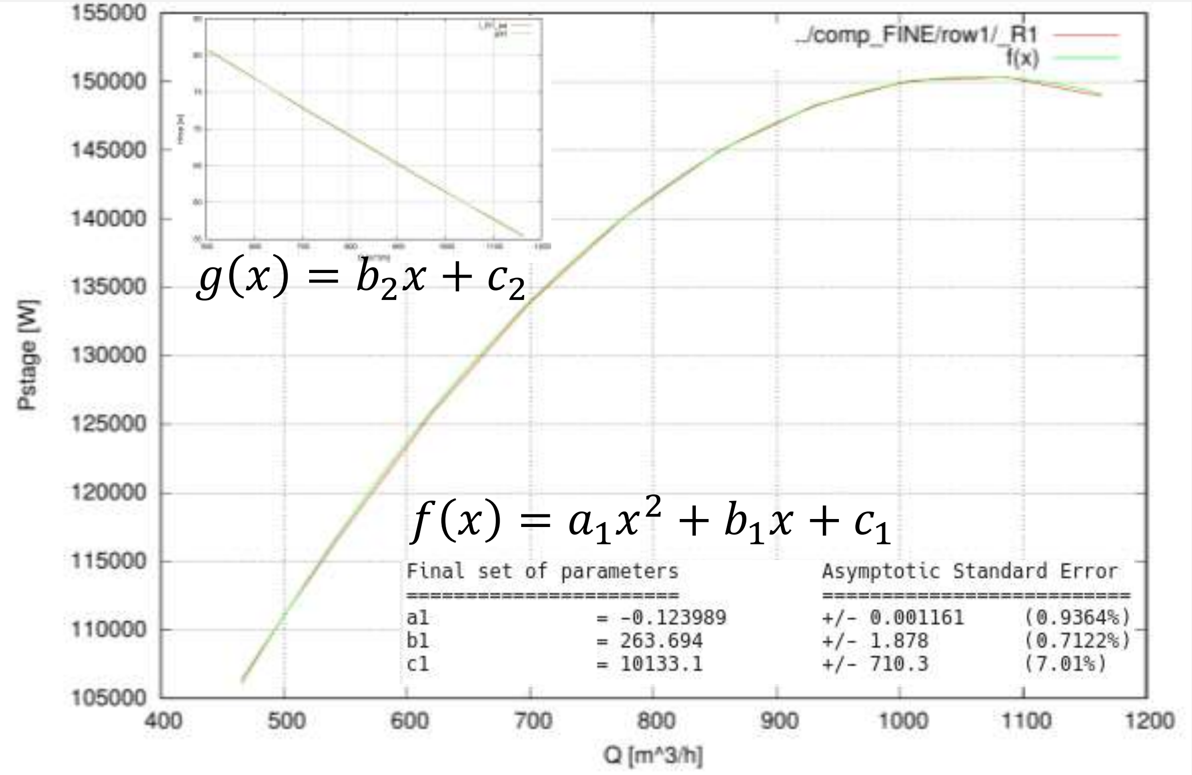


Take Advantage of theoretical curve characteristics

- Fit the performance curves and use the coefficients and constants as response variables
- 5 surrogate models required (linear approach head curve, 2nd order approach power curve)

Adv.: Correct prediction of power curve and minimum number of surrogate models

Disadv.: Increased amount of CFD calculated flow rates (10) for a correct approximation of the curves



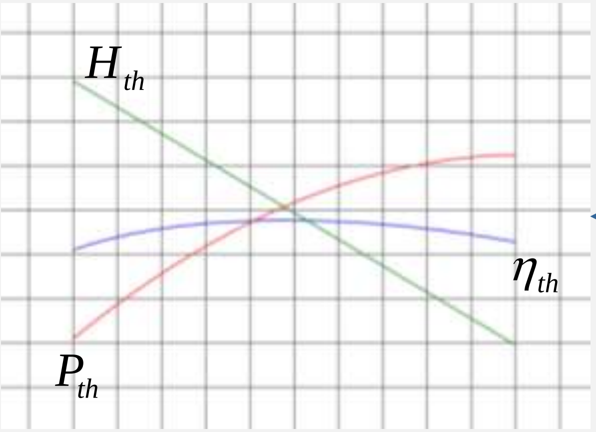
Workflow

Divided into 2 loops

- Outer loop tool chain to provide data pool
- Inner loop to use predicted performance data directly from surrogate model

CAESES:
- Geometrical Model

Cadence FINE Turbo:
- CFD simulation of different flow rates
- Get theoretical performance data



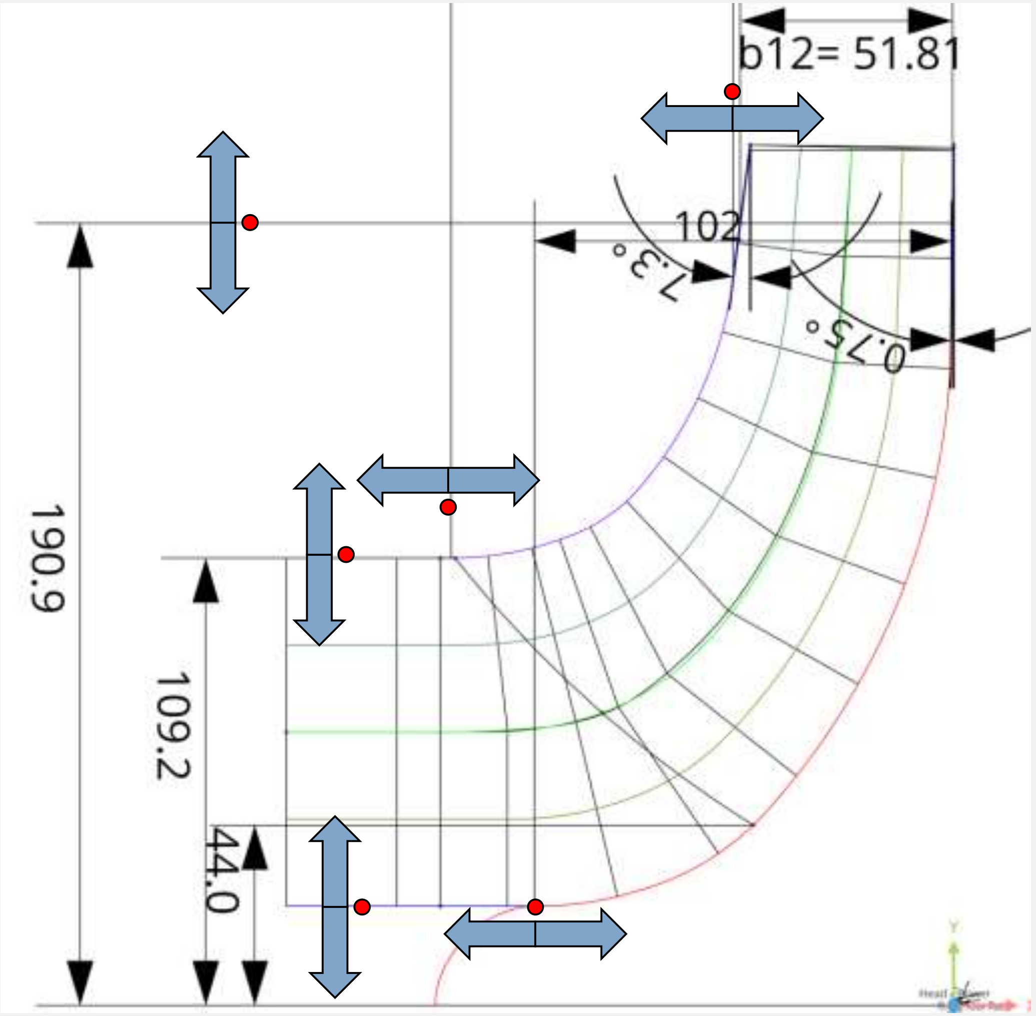
Plot performance curves based on responses directly in CAESES

Gnuplot:
- Fitting of the theoretical performance curves
- Provide fit parameters as evaluation parameters

CAESES:
- Surrogate Models (RSMtools)

Meridional Contour

- Minimizing number of input variables
- Hub and shroud contours are generated by circles and lines
- Geometry is varied by design variables relatively to an existing type series
- To avoid unshaped contours all other geometrical changes are dependent from physical and geometrical conditions



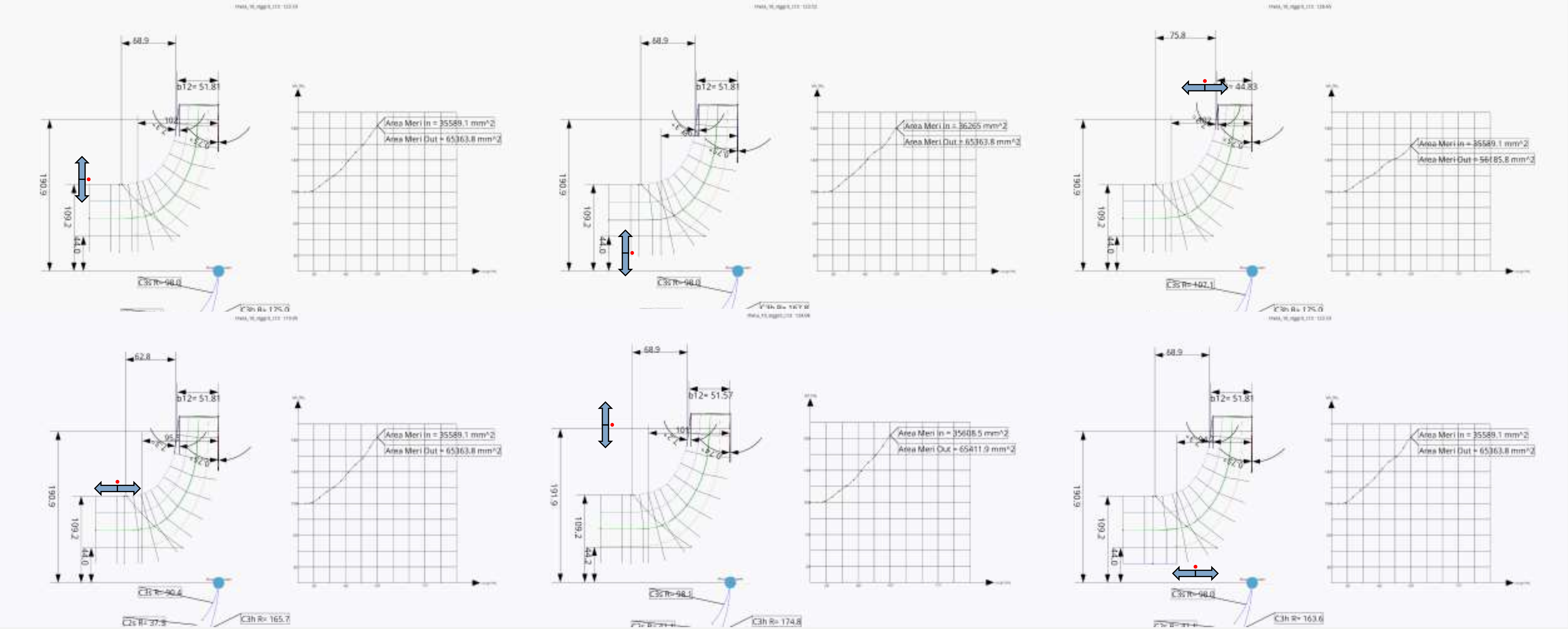
6 design variables remain:

dv_fac_Nue_n_meri	0.75	1.1	1.25
dv_fac_L_hyd	0.9	1	1.1
hub_ax_pos_start	0.5	0.5	1.25
dv_fac_Delta	0.95	1	1.15
dv_fac_b12	0.9	1.0978516	1.1
Hopt	55	60.444336	80

Variation Examples

Meridional Contour

Effect of each design variable on the meridional contour

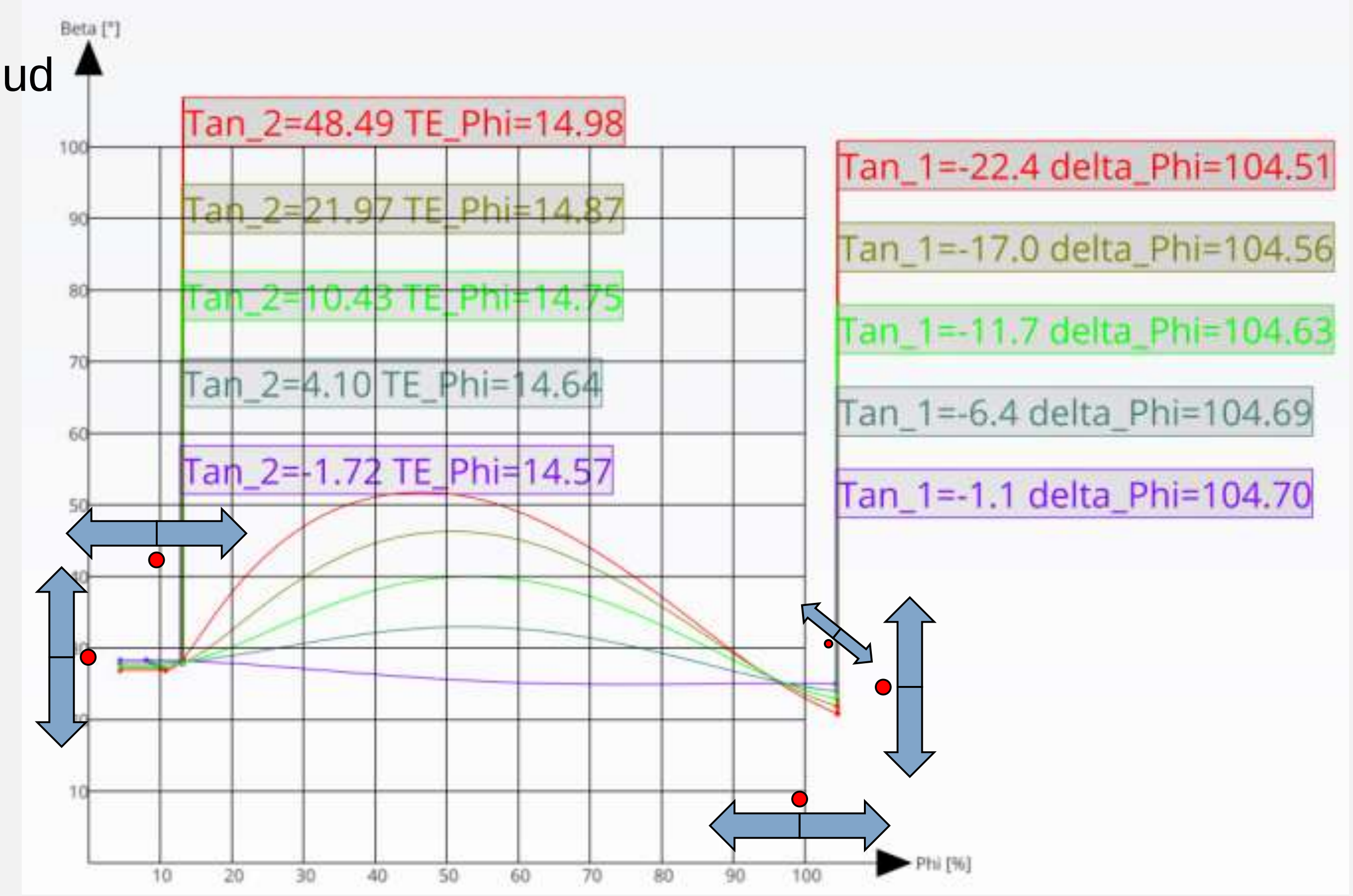


Camber Surface

- Camber line angle distribution with Fspline and Line
- Set variables at hub and shroud
- Linear interpolation between hub and shroud

10 design variables:

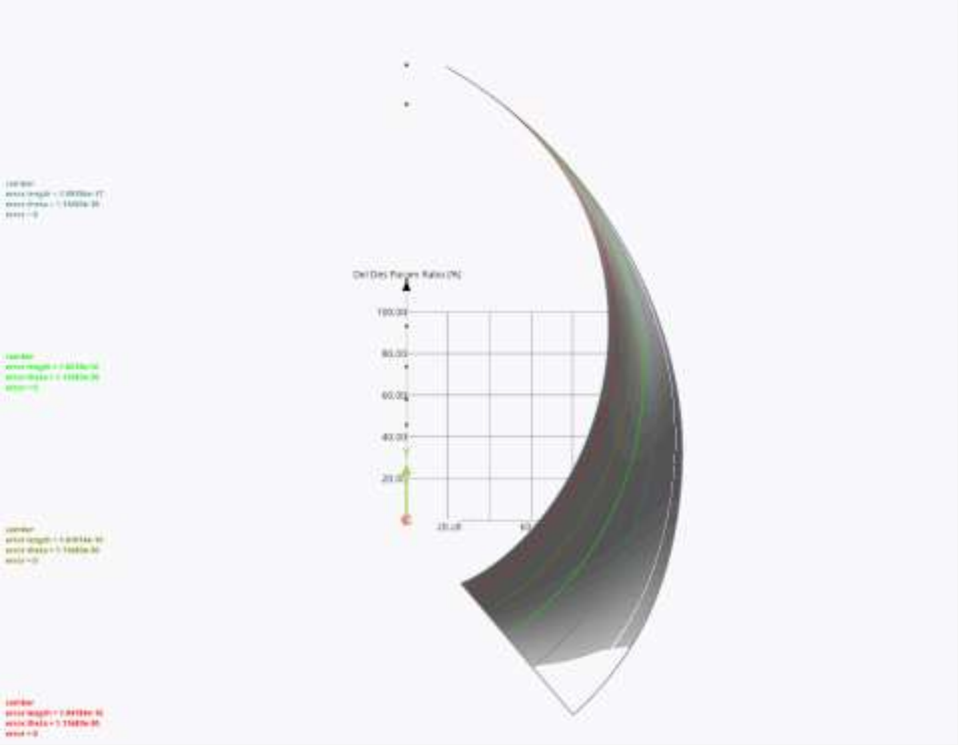
	Design Variable	Lower	Value	Upper
1	beta11_10	15	25	30
2	beta12_10	20	28.291016	30
3	dv_pm_sweep_10	0.6	0.60981445	0.75
4	dv_del_Sweep_Phi_00	-10	0.21484375	10
5	Beta11_00_Tangent	-30	-22.353516	0
6	Beta11_10_Tangent	-5	-1.0839844	5
7	beta11_00	15	20.844727	30
8	beta12_00	20	26.907297	30
9	dv_00_Const_Phi_12	0	7.2558594	10
10	dv_10_Const_Phi_12	0	4.2382812	20

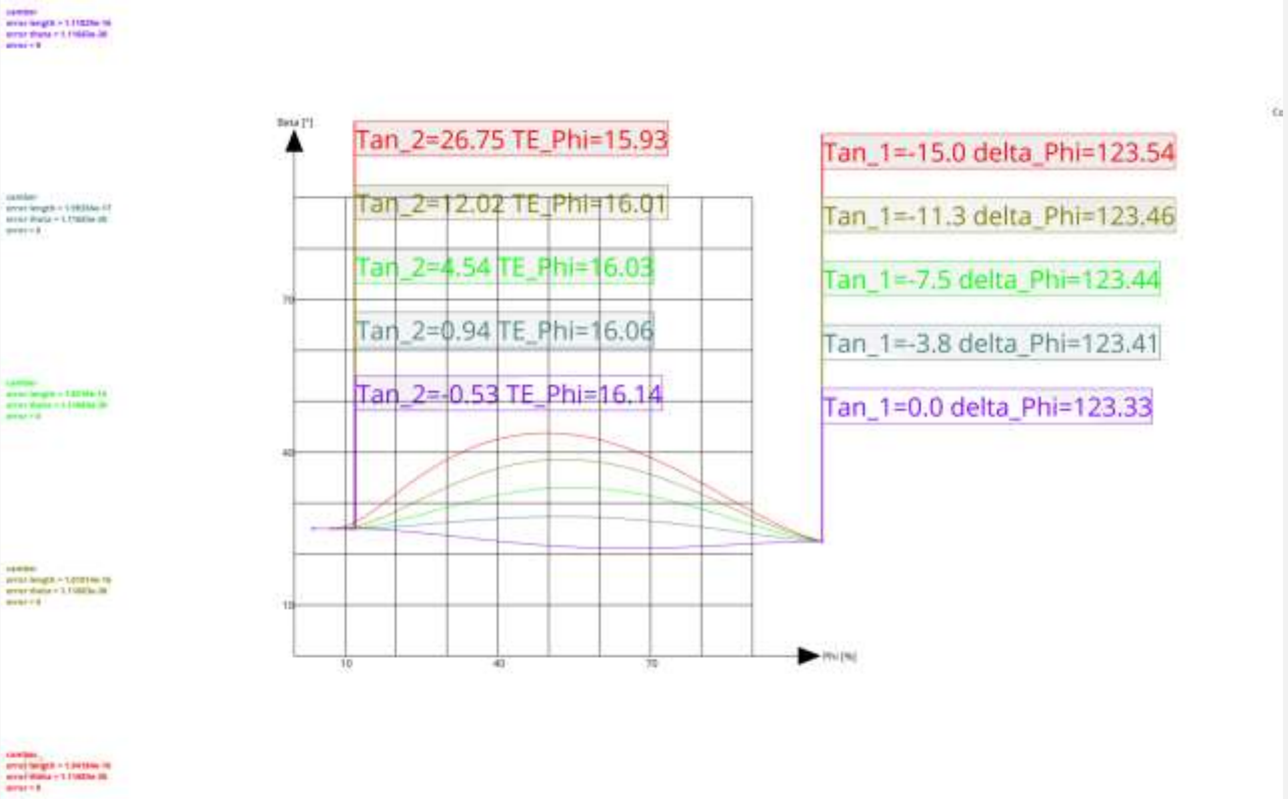


Variation Examples

Camber Surface

Overall changes of the camber surface in the defined design space

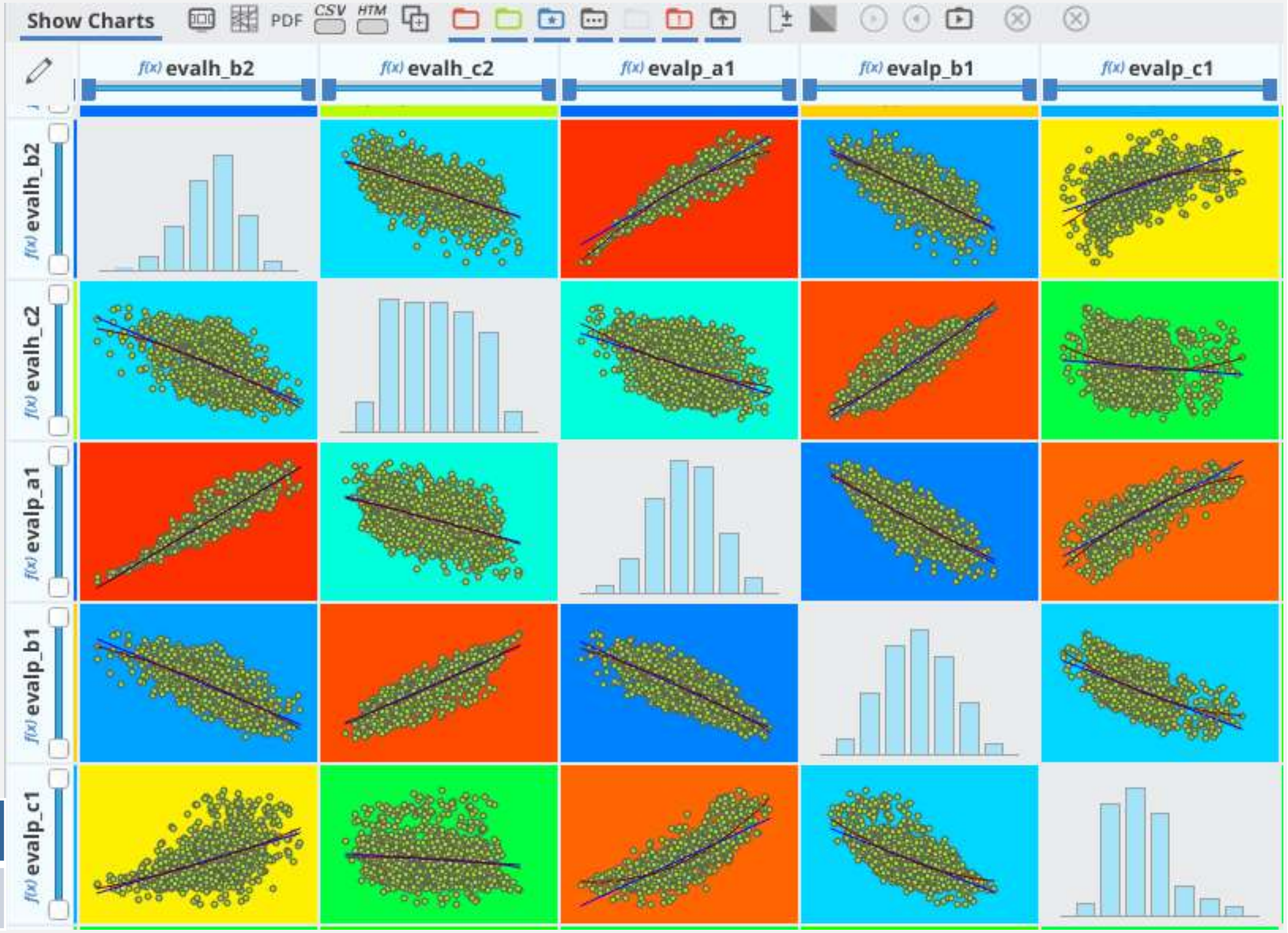




Data Pool/Evaluation

Surrogate Model

- Data pool with 17 inputs (nob) and 5 responses
- 2225 sets of inputs (DOE)
- Cleaning data for surrogate model
  - Remove geometrical failures (~7%)
  - Remove unconverged simulations (show charts functionality)
- Ideal homogeneous response value distribution but P_c1 shows some clustering so still more data is needed
- 1150 input designs



Resp	H_b2	H_c2	P_a1	P_b1	P_c1
CoP	0.98	0.99	0.92	0.91	0.75

Evaluation

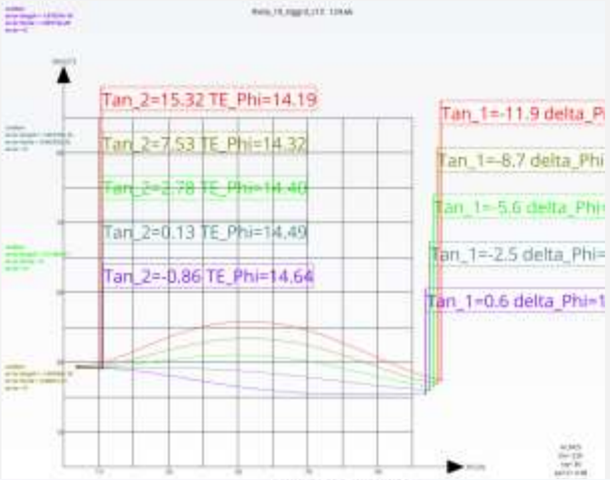
Accuracy of Pump Performance Curves?

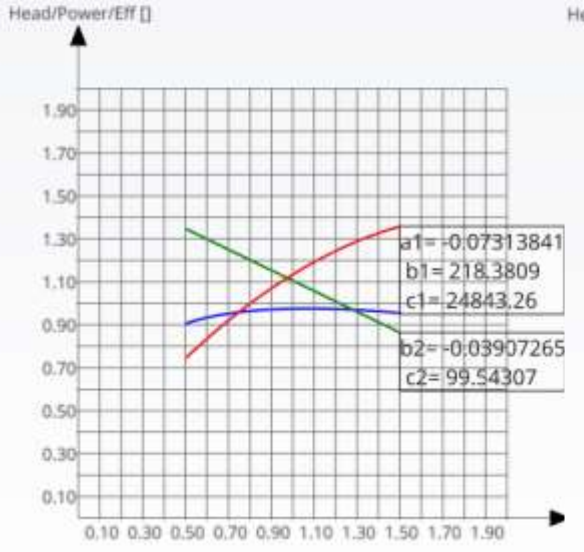
Stepwise procedure:

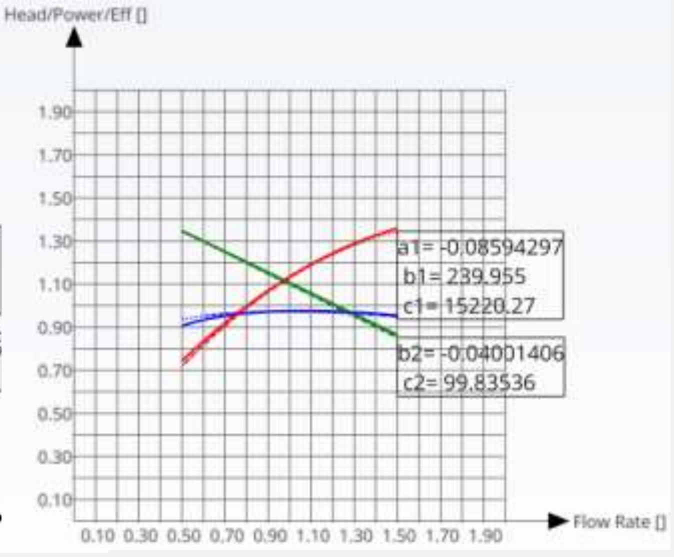
1. Choosing randomly a meaningful design configuration which is included in the data pool
2. Compare predicted with calculated response values – 99.5% matching
3. Generate identical surrogate model except for one difference - the previous chosen design is now unseen
4. Compare unseen predicted with calculated response values

- Acceptable differences between both models

- Another indicator for accuracy: calculated efficiency



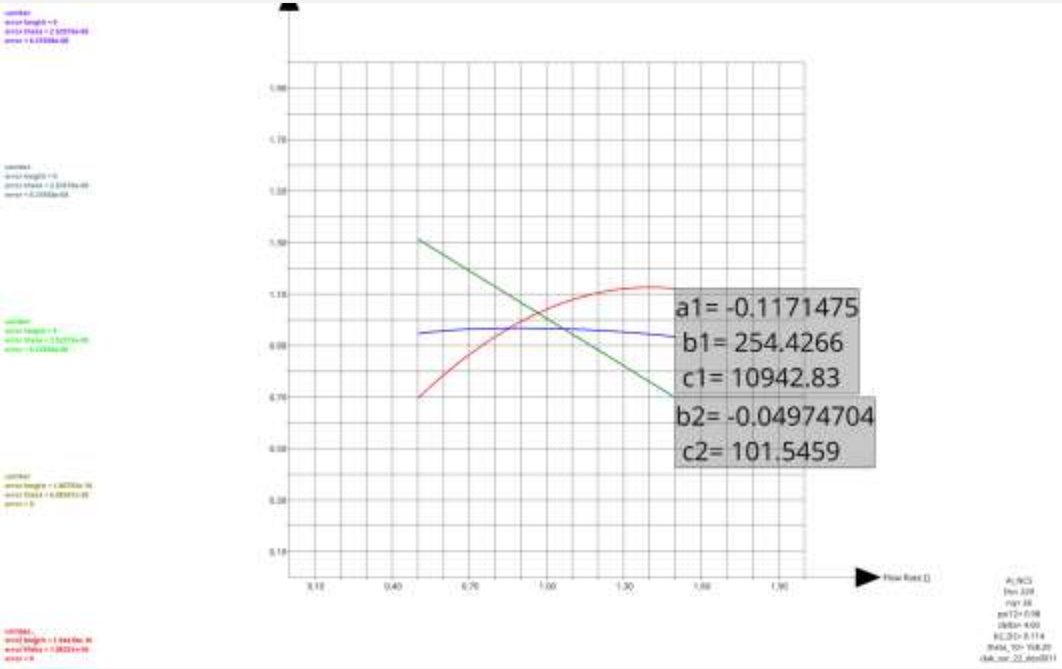


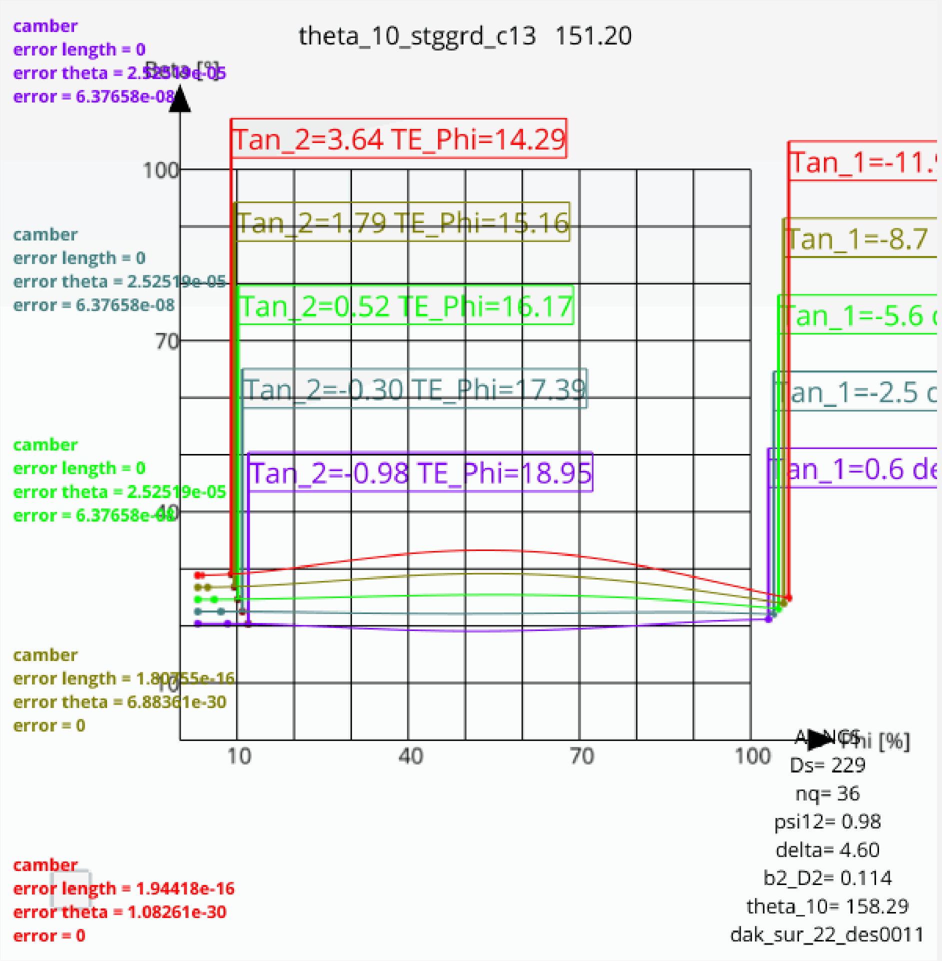


Usage example

Predicted Impeller Pump Performance Curves

- Outlet angle at shroud is varied between 20° and 30°
- Slopes of power and head curves are changing, specific speed is changing
- Efficiency remains below 1





Summary

Demand on more flexible and fast pump design tools

- Can be based on the use of surrogate models
- Simple parametric geometry modelling is suitable

Task: Prediction of theoretical pump impeller performance curves

→ *Realization within CAESES as main application*

1. Geometry simplification to minimize number of input variables of the surrogate model
2. Generation of a data pool by steady-*state* impeller CFD calculations
3. Creation of 5 valid surrogate models to predict performance curves fitting parameter

↓

Method can be used for fundamental investigations of the influence of input parameters and as well as for daily impeller design