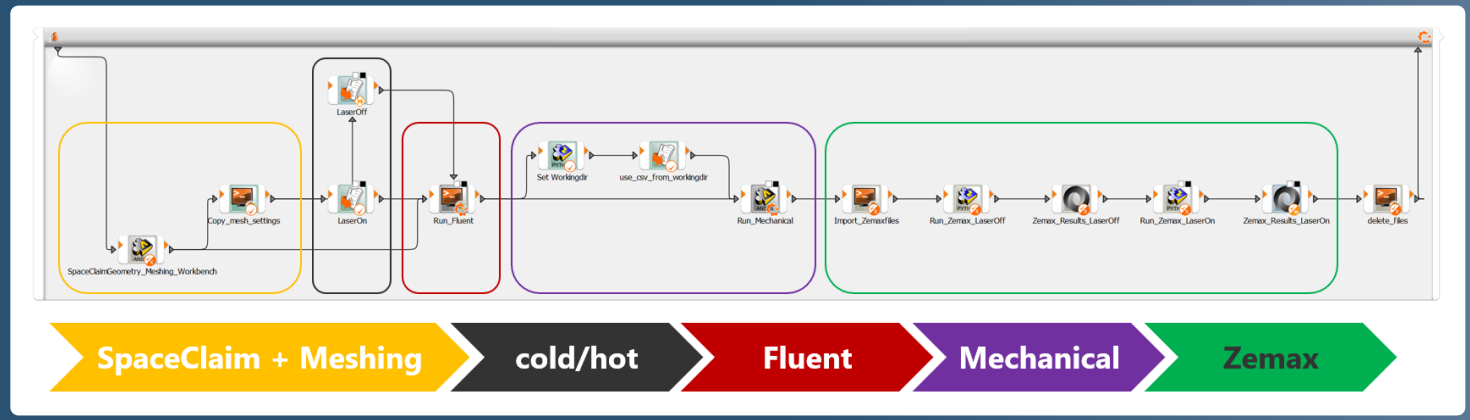

Multiphysical optimization of a high-performance optics using optiSLang

Hilgermann | TLSM541 / Dev. BTS

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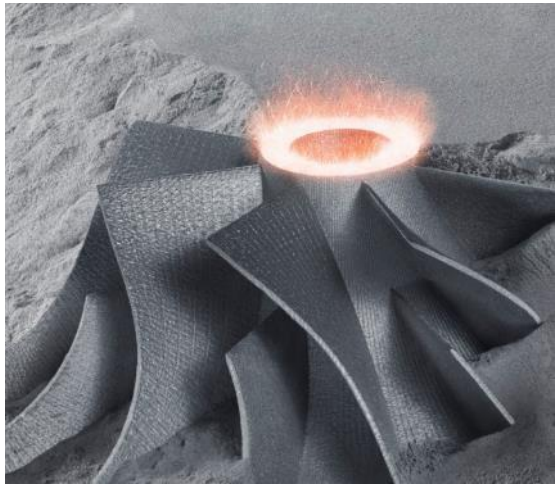
TRUMPF is…

Family business

Technology leader

Close to the customer



Innovation guarantor

TRUMPF

Our business divisions

Machine tools for flexible sheet metal processing

Laser technology

Extreme ultraviolet light

Additive Manufacturing

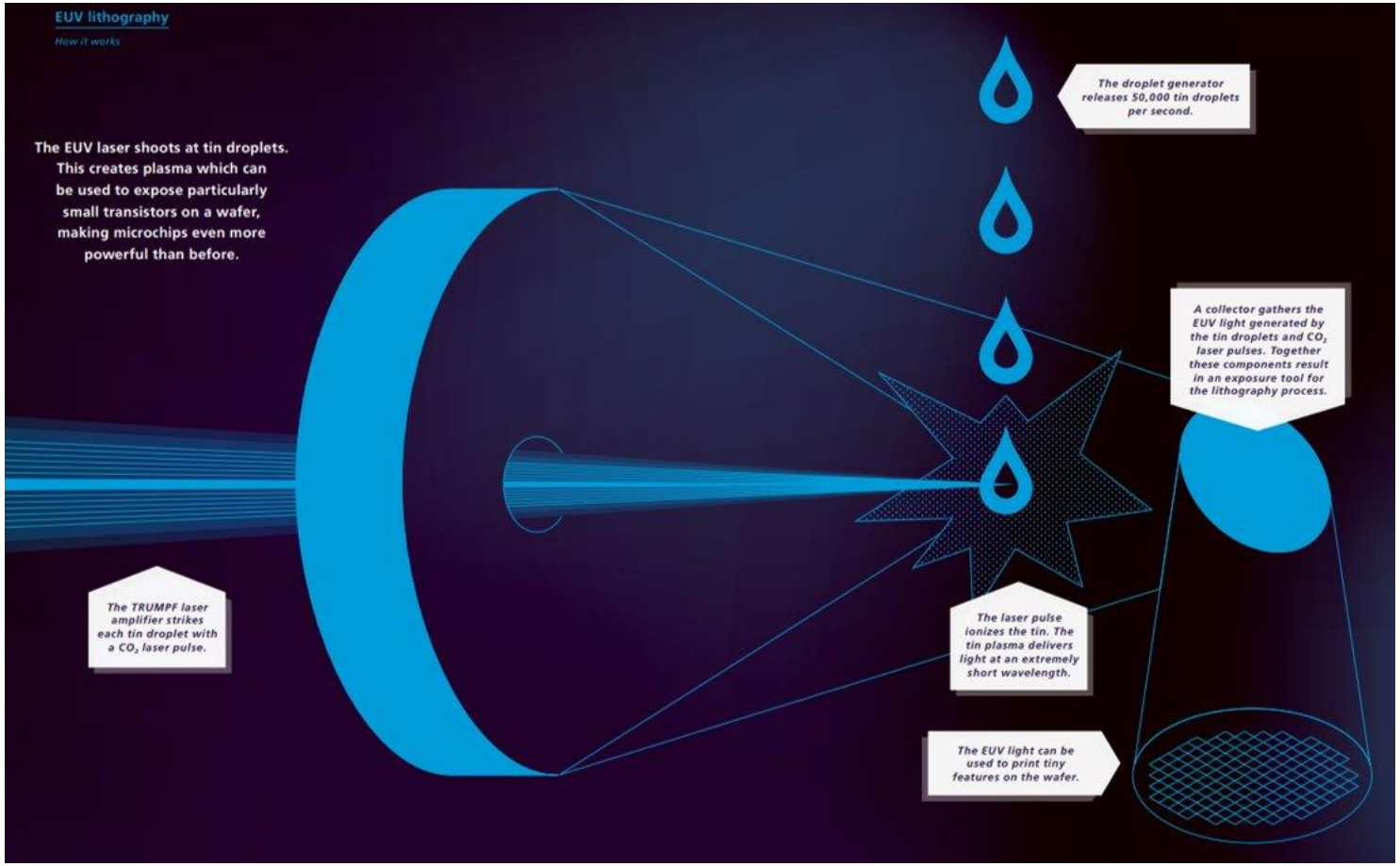
Photonic Components

Financial Services

TRUMPF

EUV lithography
how it works

- **EUV laser shots at tin droplets which are release by a droplet generator 50.000 times per second**
- **This creates plasma delivers light at an extremely short wavelength which can be used to expose particularly small transistors on a wafer making microchips even more powerful than before**
- **The EUV laser light is focused by mirrors to the droplet.**
  Extreme high precision is needed to hit the droplet and to enable high efficiency of the process.



What is the optimal design of a high-performance optics?

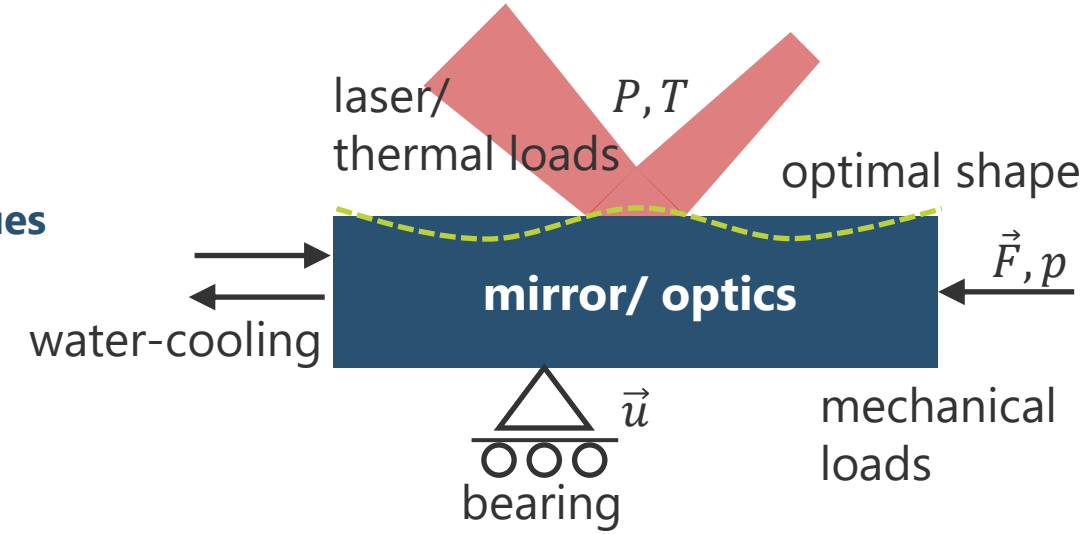
Input parameter:

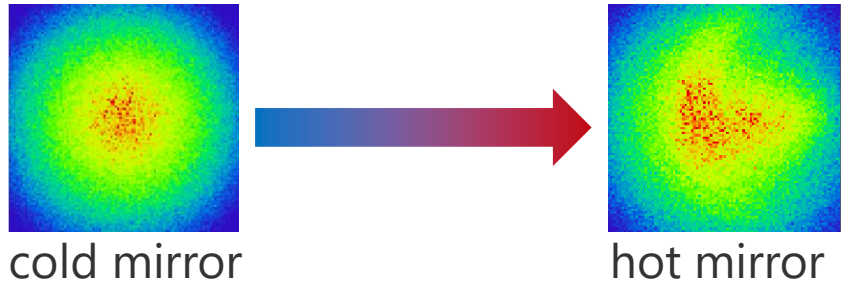
- design/ shape of optics → parameterize the geometry
- thermal load (beam-size and -shape, power)
- mechanical load (force, pressure)
- bearing, mounting

} given values

Previous approach to find optical design

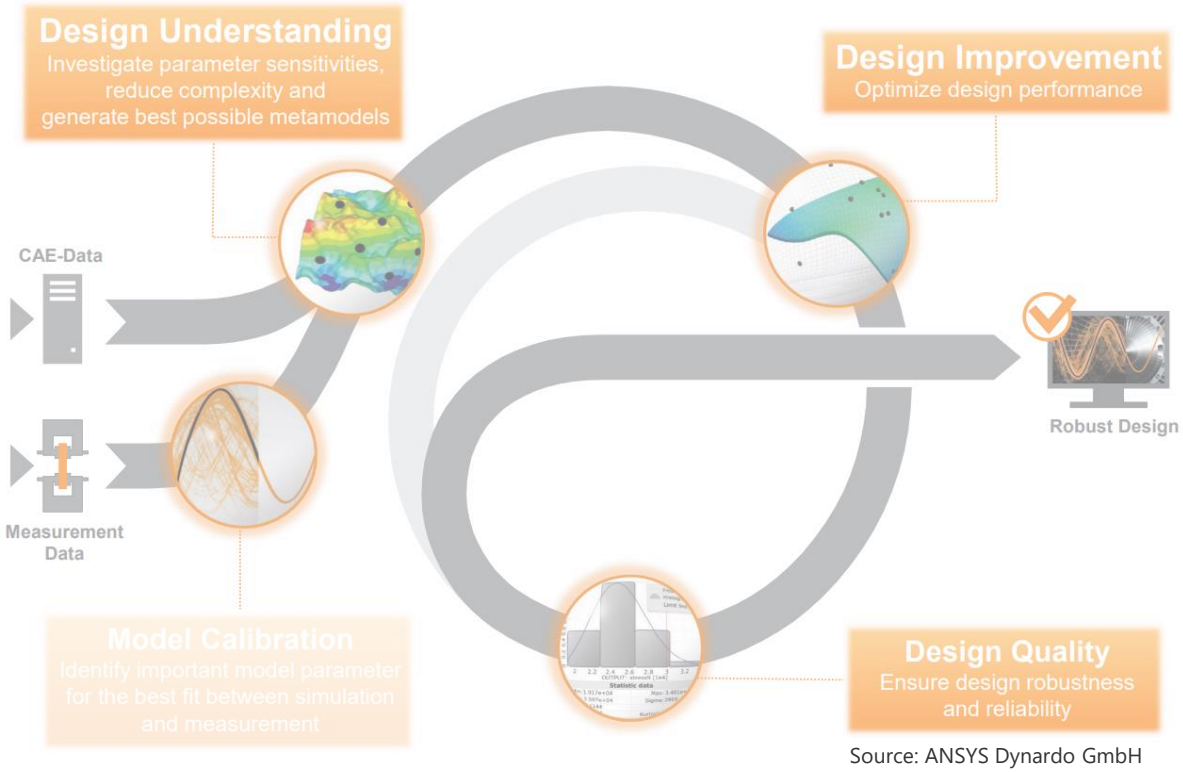
- experience of the designers
- theoretical approaches
  → optimal design ≈ f(P, T, F, p, u, w, r, …)
  → considering ideal constraints
- trial and error/ manual optimization





Goals to achieve

1. **Creating automated workflow**
   handling different models and solvers, automating the workflow
2. **Design Improvement:**
   Finding the best design
3. **Design Understanding:**
   find the relevant parameters
4. **Design Quality:**
   Ensure robustness

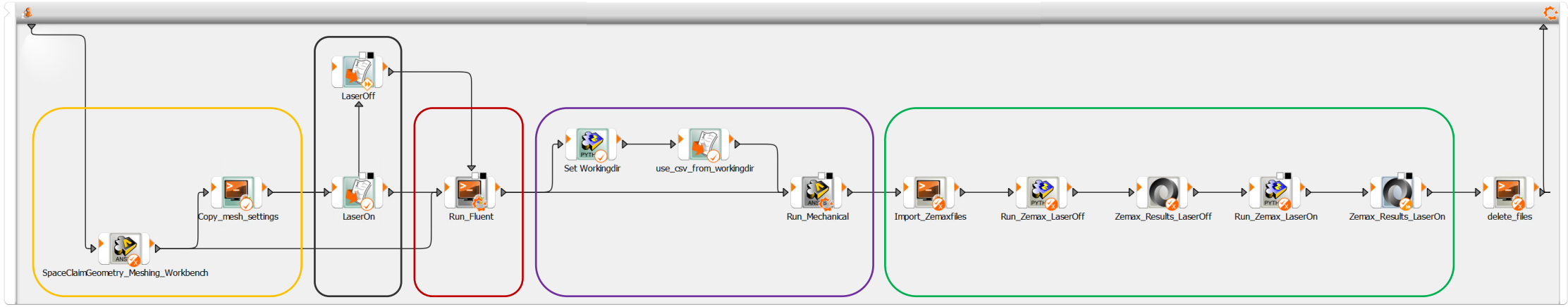


Source: ANSYS Dynardo GmbH

TRUMPF

Workflow overview

- **Integrated workflow to optimize the mirror design**
- **Definition of separate subsystems; each node for one task, enabling testing of one subsystem**
- **Goal: find the best design and gain insight on the optical performance**



Workflow overview

SpaceClaim + Meshing

- Parameter based geometry creation
- Data send nodes for later use of the mesh file

Fluent

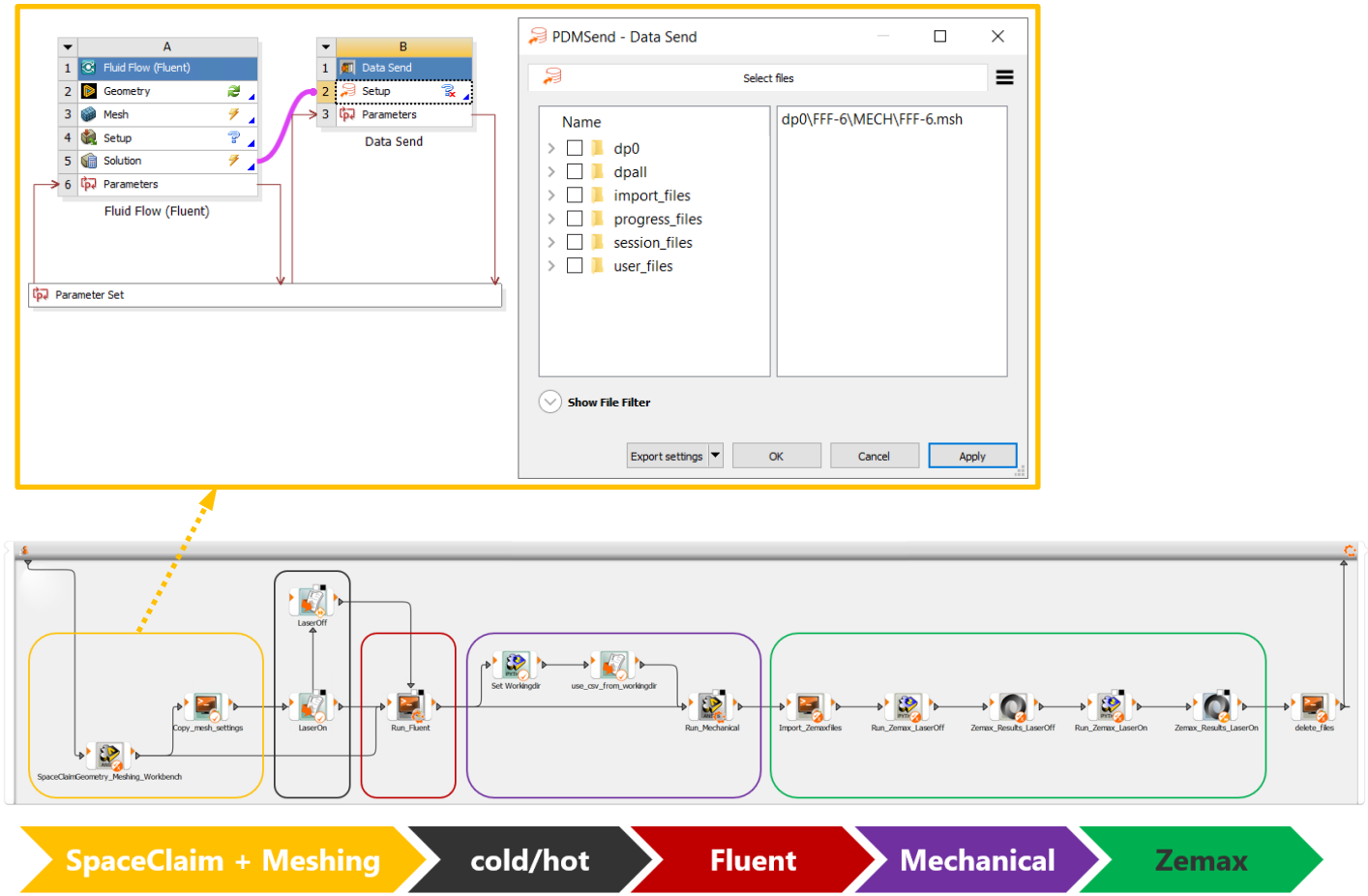
- Using journal-file to define model settings
- Substitute current mesh-file
- Exporting temperature.csv and pressure.csv

Mechanical

- Importing temperature.csv and pressure.csv
- Exporting deformation.txt of mirror

Zemax

- Importing mirror deformation.txt
- Calculating focal-length and Zernike-terms



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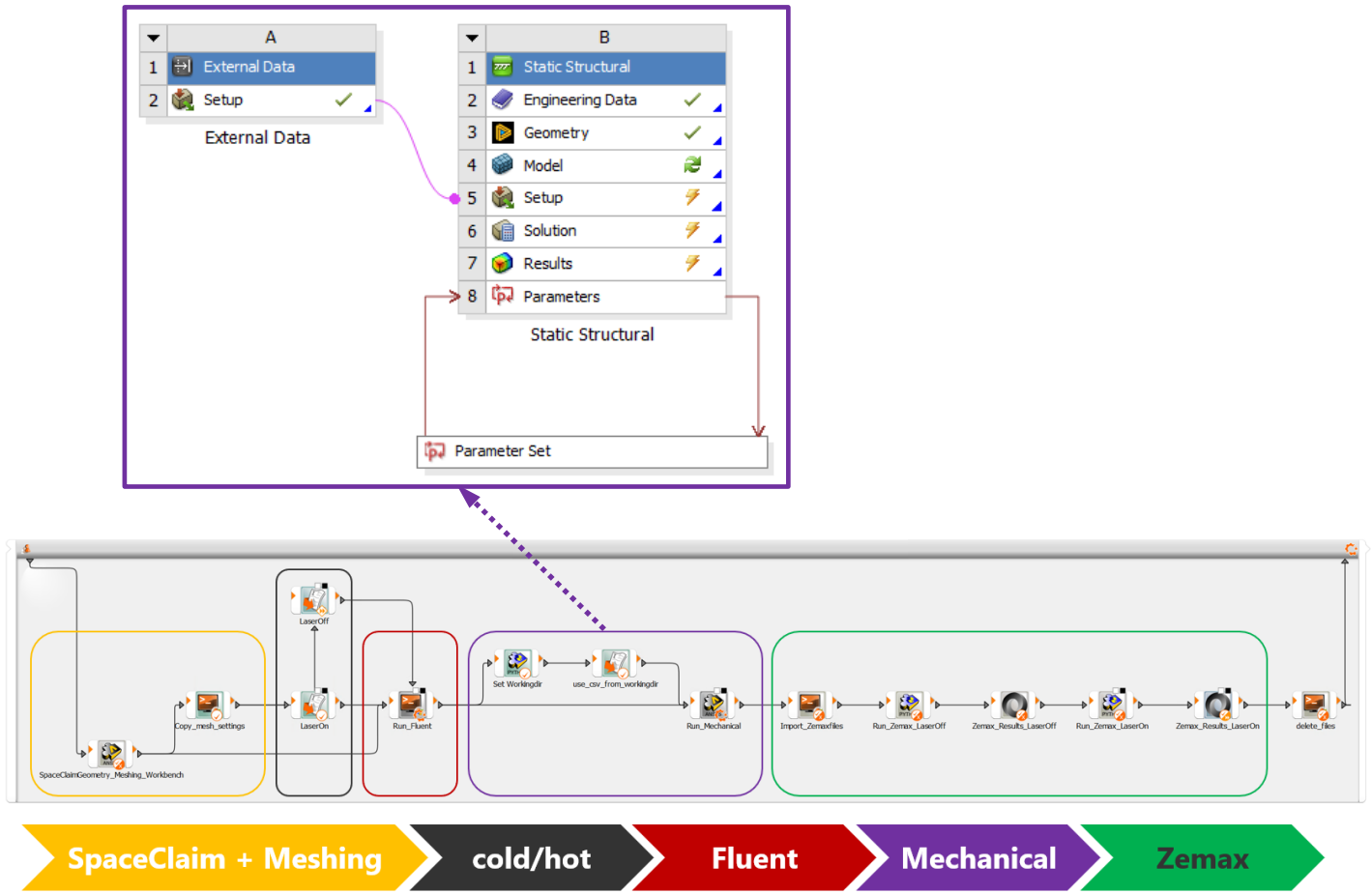


TRUMPF

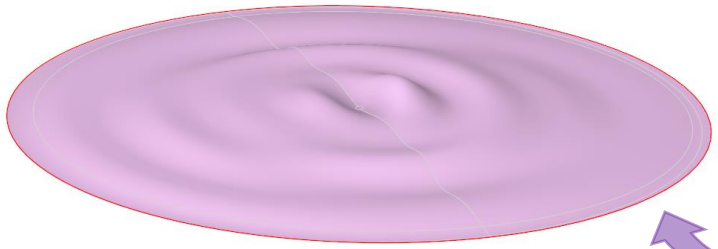
SpaceClaim
creating a complex geometry based on parameters

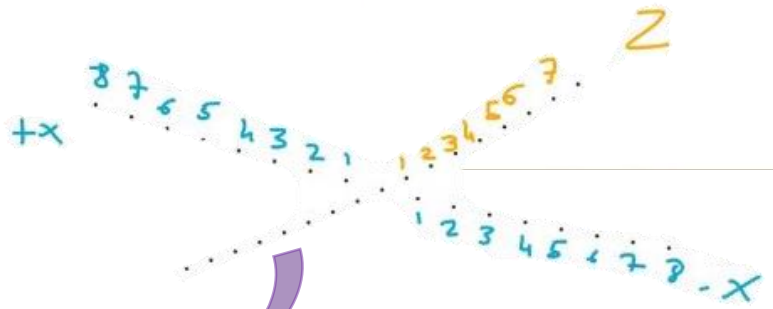
Parameter-based geometry structure of the mirror surface

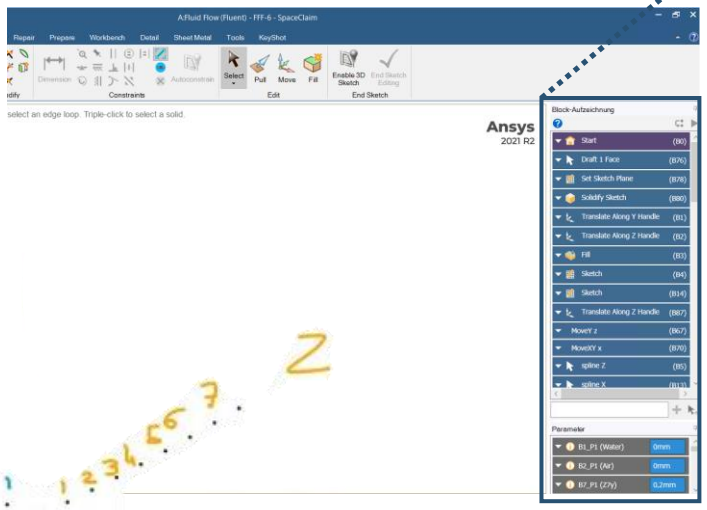
- Definition of points along the coordinate axes and their connection by splines
- Extruding the splines to surfaces
- Generation of solids based on the spline surface

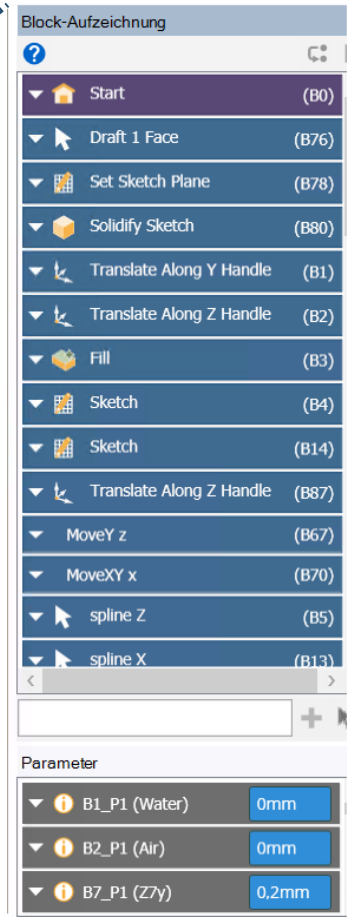
Definition of the valid parameter space (trial-and-error)

- Preventing body-intersections
- Avoiding invalid geometries





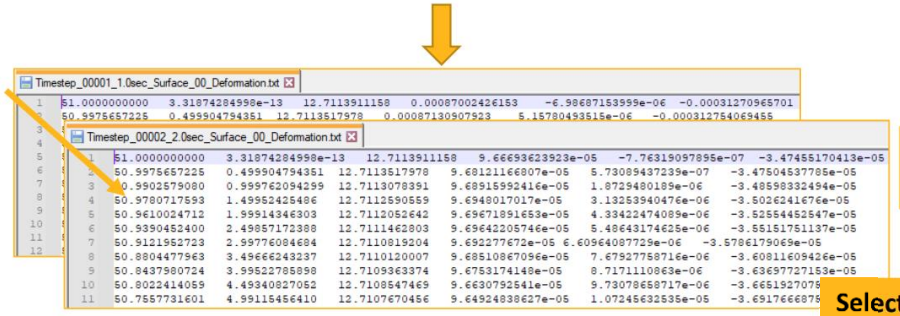




Date transfer from Mechanical to Zemax

- **ACT-Extension – "ExportAnsysToZemax" used in Mechanical to export the data to Zemax**
- **One file exported for each load step**

  → exported data is a text file containing the x, y, z coordinates and x, y, and z displacements for each load-step in mechanical



Scope Mirror Front & Back surfaces

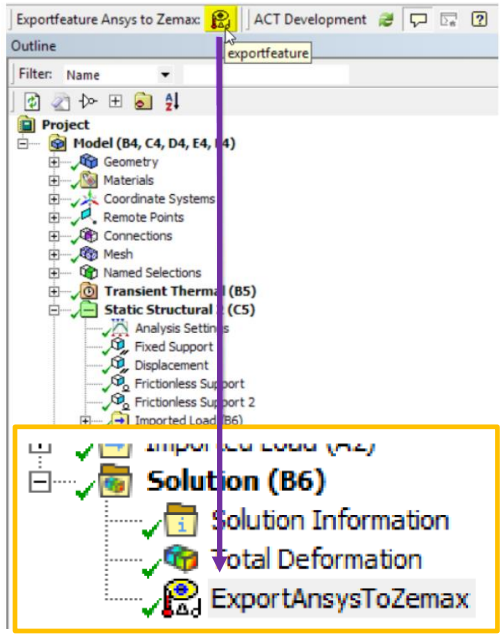
Select Coordinate System

Select time points for which data needs to be exported

Select surface for which data needs to be exported

Details of "ExportAnsysToZemax"

Volume	
Scoping Method	Named Selection
Named Selection	AllBodies
Front-Surface	
Scoping Method	Named Selection
Named Selection	Mirror_Deformations_Export
Back-Surface	
Scoping Method	Named Selection
Named Selection	Mirror_Deformations_Export
Definition	
Front Surface Zemax ID	0
Front Coordinate System	local_FCA
Back Surface Zemax ID	1
Back Coordinate System	local_FCA
Exported Timesteps	All Timesteps
Data to be exported	deformation of frontsurface
By	Time
Display Time	Last
Results	
Minimum	0, mm
Maximum	0, mm
Minimum Occurs On	
Maximum Occurs On	

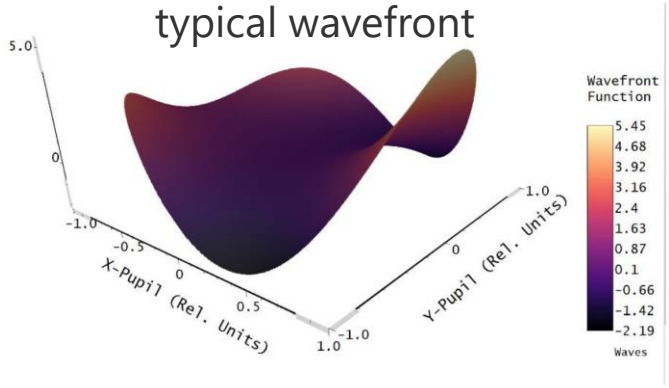


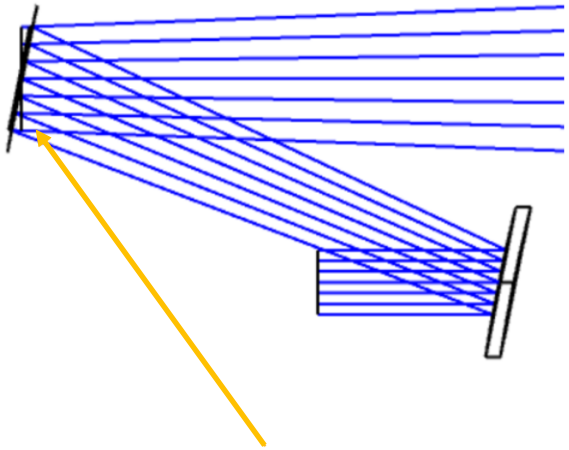
Zemax OpticStudio – optical Simulation

Objective

- flatten the wavefront after reflection with the mirror
- Wavefront should be as flat as possible and can be represented by Zernike polynomial

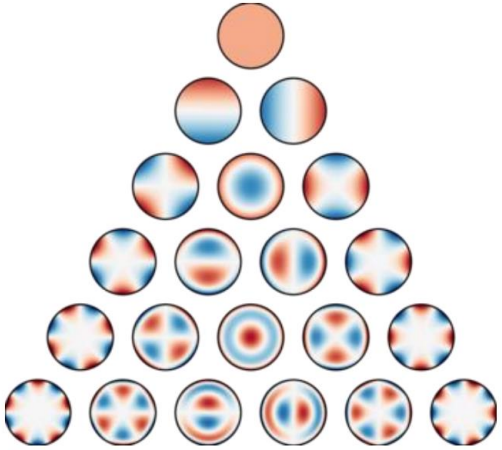
typical wavefront





Mirror to be optimized represented in Zemax

Z	1	0.69787942	:	1
Z	2	0.08166784	:	(p) * COS (A)
Z	3	0.08627344	:	(p) * SIN (A)
Z	4	0.68848275	:	(2p^2 - 1)
Z	5	1.92202764	:	(p^2) * COS (2A)
Z	6	0.37718034	:	(p^2) * SIN (2A)
Z	7	0.03767268	:	(3p^2 - 2) p * COS (A)
Z	8	0.04179261	:	(3p^2 - 2) p * SIN (A)
Z	9	-0.00060731	:	(6p^4 - 6p^2 + 1)
Z	10	2.10109044	:	(p^3) * COS (3A)
Z	11	0.00258931	:	(p^3) * SIN (3A)

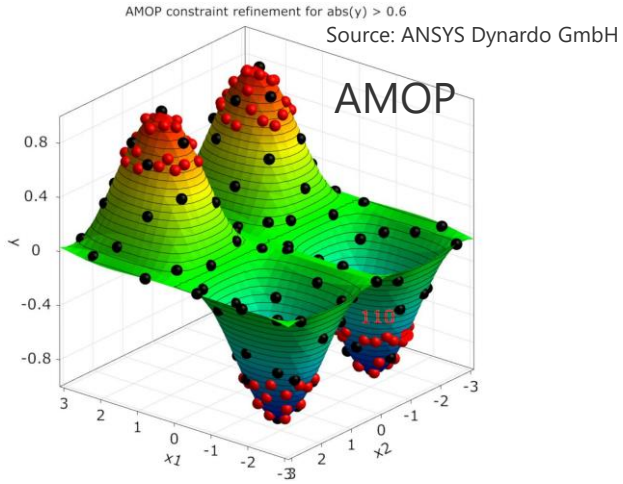


Methods
Adaptive Algorithms

Used adaptive systems:

- **AMOP: Adaptive Metamodel of Optimal Prognosis → for Sensitivity Analysis**
  - Automatic adaption of an initial sampling set
  - Global refinement with advanced and space-filling Latin Hypercube Sampling
  - Local refinement considering sample density, local approximation errors and optimization criteria
- **ARSM: Adaptive Response Surface Method → for Optimization**
  - Approximation of responses by linear or quadratic polynomial
  - Optimization is performed on response surface
  - Local DoE scheme is moved and shrinked iteratively

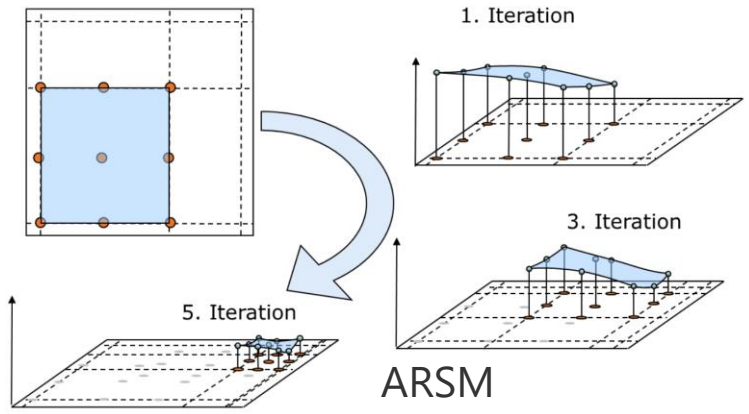
no correlation between input and Zernike polynomial



Source: ANSYS Dynardo GmbH

Limitations:

- Low metamodel quality
- New samples are added based on the gradient approximation from previous iteration designs; need of a number of successful simulations for gradient approximation



Source: ANSYS Dynardo GmbH

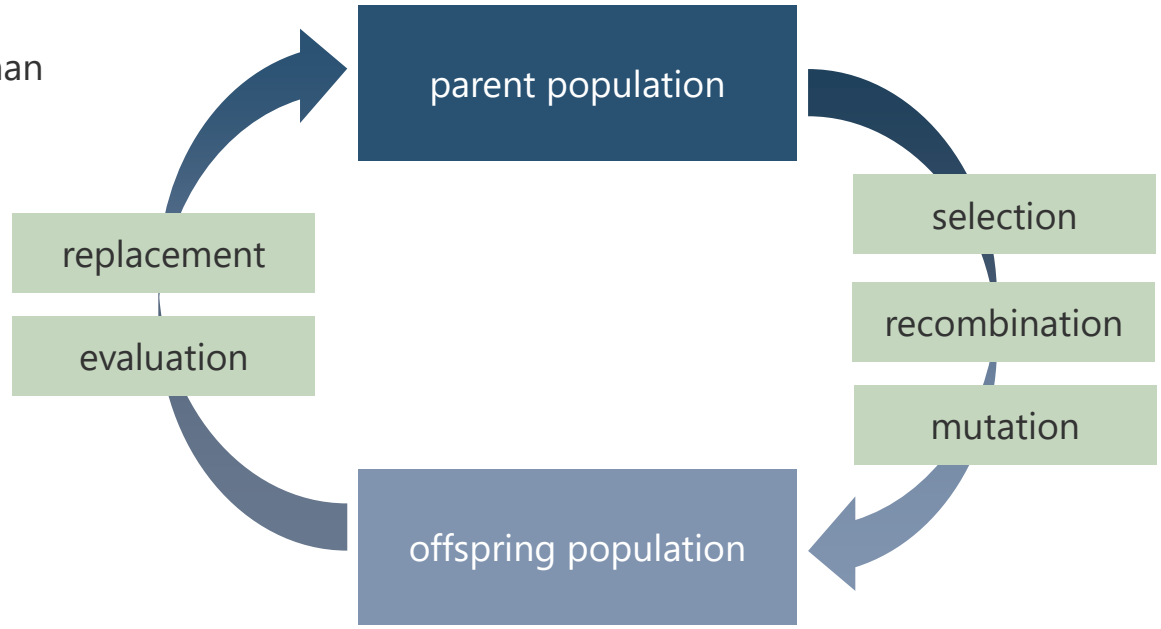
Methods
Evolutionary Algorithm (EA)

Properties

- Picks best of imported start designs for the start population
- Stochastic generation of new designs → robust search approach
- No gradient information or regression is necessary (More efficient than NLPQL or ARSM for large number of variables)
- Failed designs are considered in selection procedure
- Ordinal and nominal discrete carriable types can be considered
- Global search can treat multiple local optima

Recommended area of application

- Optimization tasks with multiple local minima
- Discovering of new design variants
- For (nominal) discrete and binary design variables
- Many constraint conditions
- Elevated ratio of failed designs
- Strong solver noise



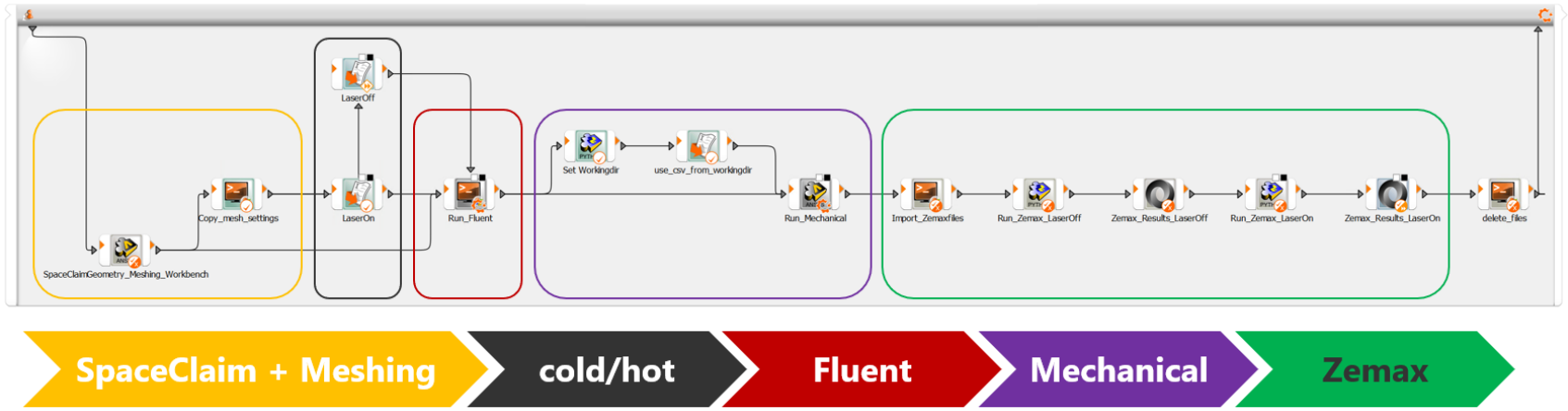
Source: ANSYS Dynardo GmbH

Goals that has been achieved

Source: dpa/Uncredited/rp-online.de/ Rheinische Post
SpaceX-Rakete explodiert nach Testflug bei Landung, 10.Dec. 2020, 12:41 o'clock

Goals that has been achieved

1. **Creating an automated workflow** ✓
2. **Design Improvement:** ✓
   A design that fulfills all constraints and objectives has been found. Because of the parameterization without manufacturi
   producible.
3. **Design Und**
   Because of t
   too large nu
   parameter r
   input and ou
   parameters
4. **Design Qua**
   An evaluation of design quality and robustness was no longer pursued due to lack of parameter identification and time.



Goals that has been achieved

1. **Creating a workflow manager** ✓
2. **Design Improvement:** ✓
   A design that fulfills all constraints and objectives has been found. Because of the parameterization without manufacturing restrictions, the found design was not producible.
3. **Design Understa**
   Because of
   too larg
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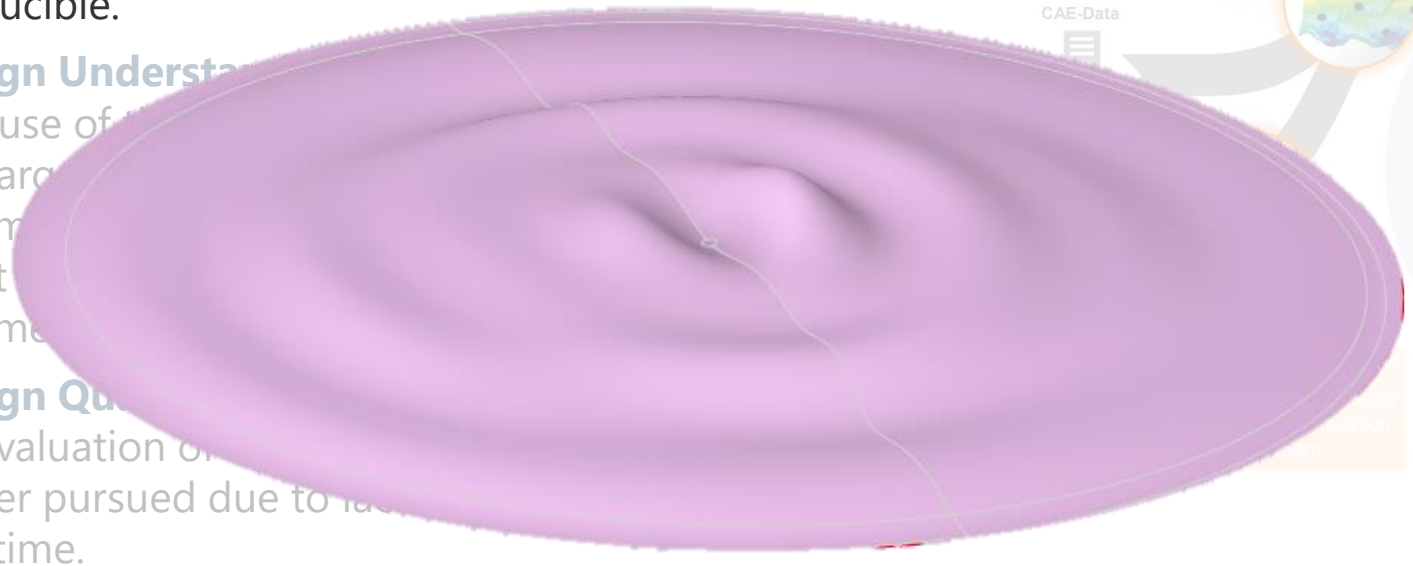
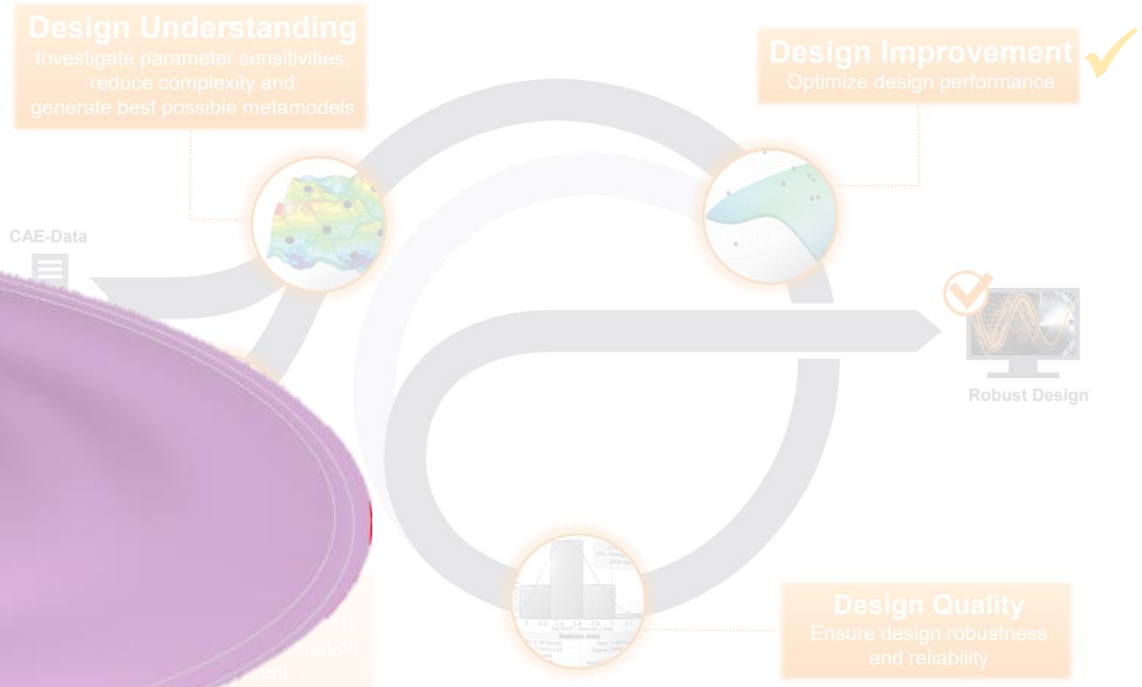
4. **Design Qu**
   An evaluation o
   longer pursued due to la
   and time.





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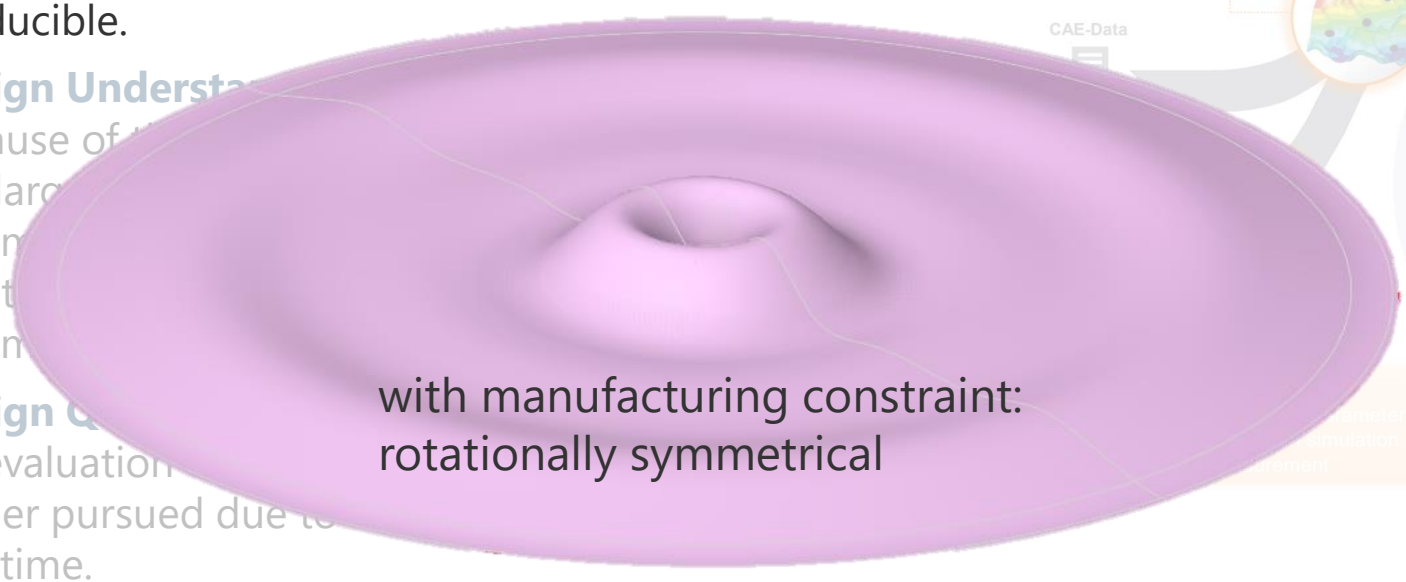
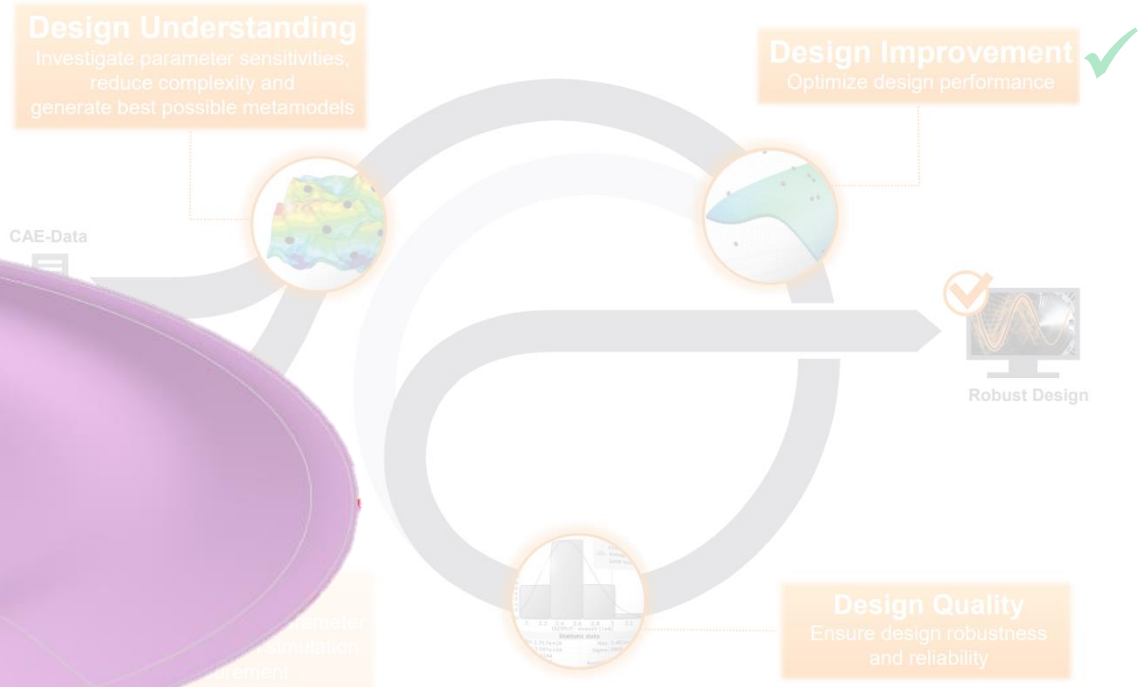
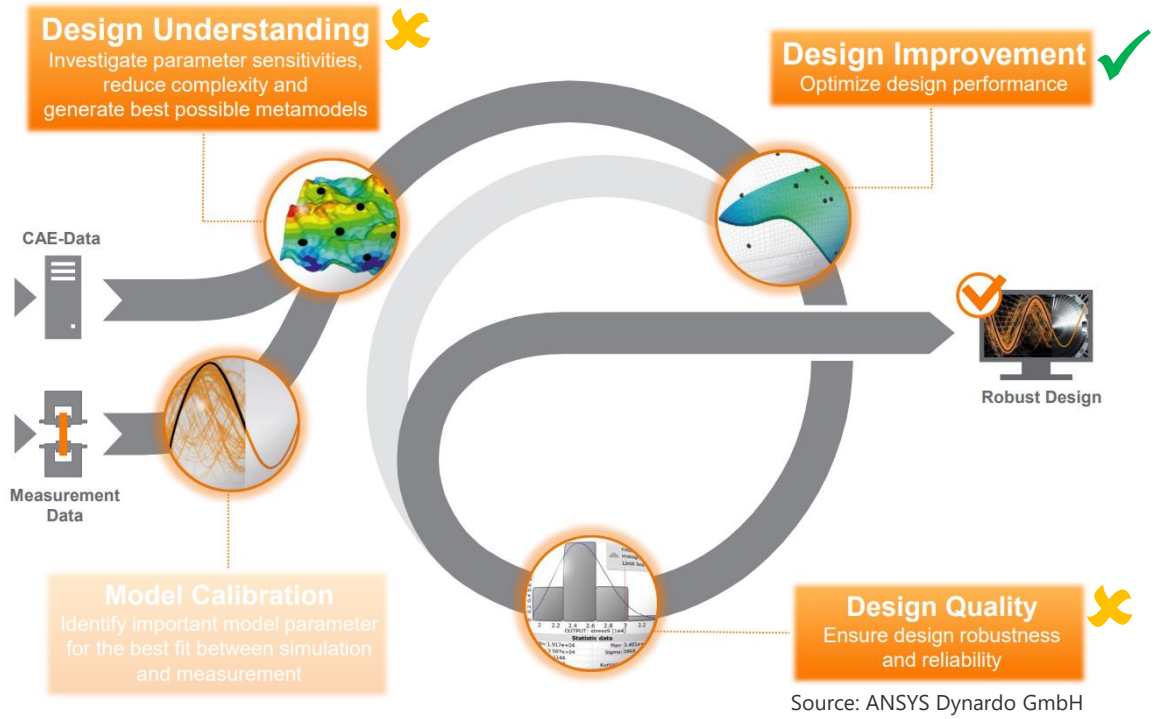


with manufacturing constraint:
rotationally symmetrical



Goals that has been achieved

1. **Creating a workflow manager** ✓
2. **Design Improvement:** ✓
   A design that fulfills all constraints and objectives has been found. Because of the parameterization without manufacturing restrictions, the found design was not producible.
3. **Design Understanding:** ✗
   Because of the too general parameterization and the too large number of parameters, as well as a too large parameter range, no sufficient correlation between input and output parameters could be found. Relevant parameters were therefore not identified.
4. **Design Quality:** ✗
   An evaluation of design quality and robustness was no longer pursued due to lack of parameter identification and time.



Source: ANSYS Dynardo GmbH

Lessons learned

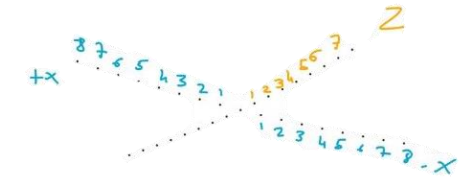
- **Clearly define expectations and goals first**

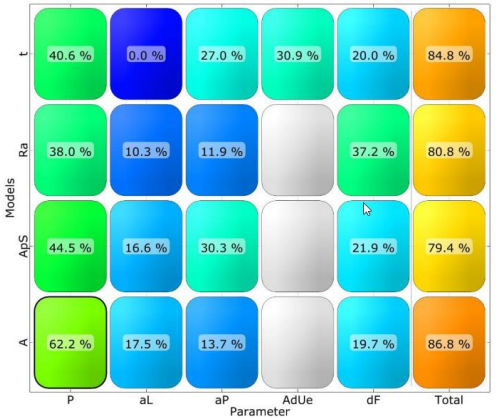
- **Parameters:**
  The parameters should be defined in such a way that an implementation of the found geometry is possible. Also, the **number of parameters** should be as small as possible to minimize the computation time of the model.

- **Correlation/ MOP:**
  For the example of high-performance optics presented here, a correlation between the geometry and the optical performance is only given for small geometry changes. No correlation was found for a general search for the optimal geometry. As a result, the optimization took an enormous amount of time.

  For this example, it is recommended: Starting from a **good initial design**, the optimal geometry is searched for by **small geometry variations.**

better correlation





Source: ANSYS Dynardo GmbH

Thank you!

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Special thanks go to:

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- **Rohith Patchigolla**
- **Michael Schimmelpfennig**

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