EVOLUTIONARY ENGINEERING

Design Optimization of Hull Structures for the America's Cup

Weimarer Optimierungs- und Stochastiktage 2.0

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Contents

- EVEN – Evolutionary Engineering AG
- Intro: The design process as a series of decisions
- Example I: Evaluate two versions of a keel support
- Example II: Amount and distribution of UD-carbon

EVEN – Evolutionary Engineering AG

- Spin-off company of the Swiss Federal Institute of Technology Zurich

- Proprietors:

O. König	Dr. sc. techn.	ETH Zurich 2004
M. Wintermantel	Dr. sc. nat.	ETH Zurich 2004
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- Foundation: January 28 2004

- Location: Zurich, Switzerland

Core competencies

- Optimization of mechanical structures
- Structural analysis of mechanical structures using FEM
- Structural design of mechanical structures
- CAD technology
- Engineering software development

PARTNERS:

dynardo

TRANSCAT
A Dassault Systemes Company

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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The design process as a series of decisions

- In the design process of a complex structure (an America's Cupper) a series of decisions regarding the design concept have to be taken far ahead of any detailed construction.
- Classically this decision making is guided by guts feeling and rough calculations.
- Nowadays the decision making process is often supported by simulation tools (FEM, etc.)
- The coupling of these simulations with an optimization tool helps to reveal the potential of a distinct design concept quickly.

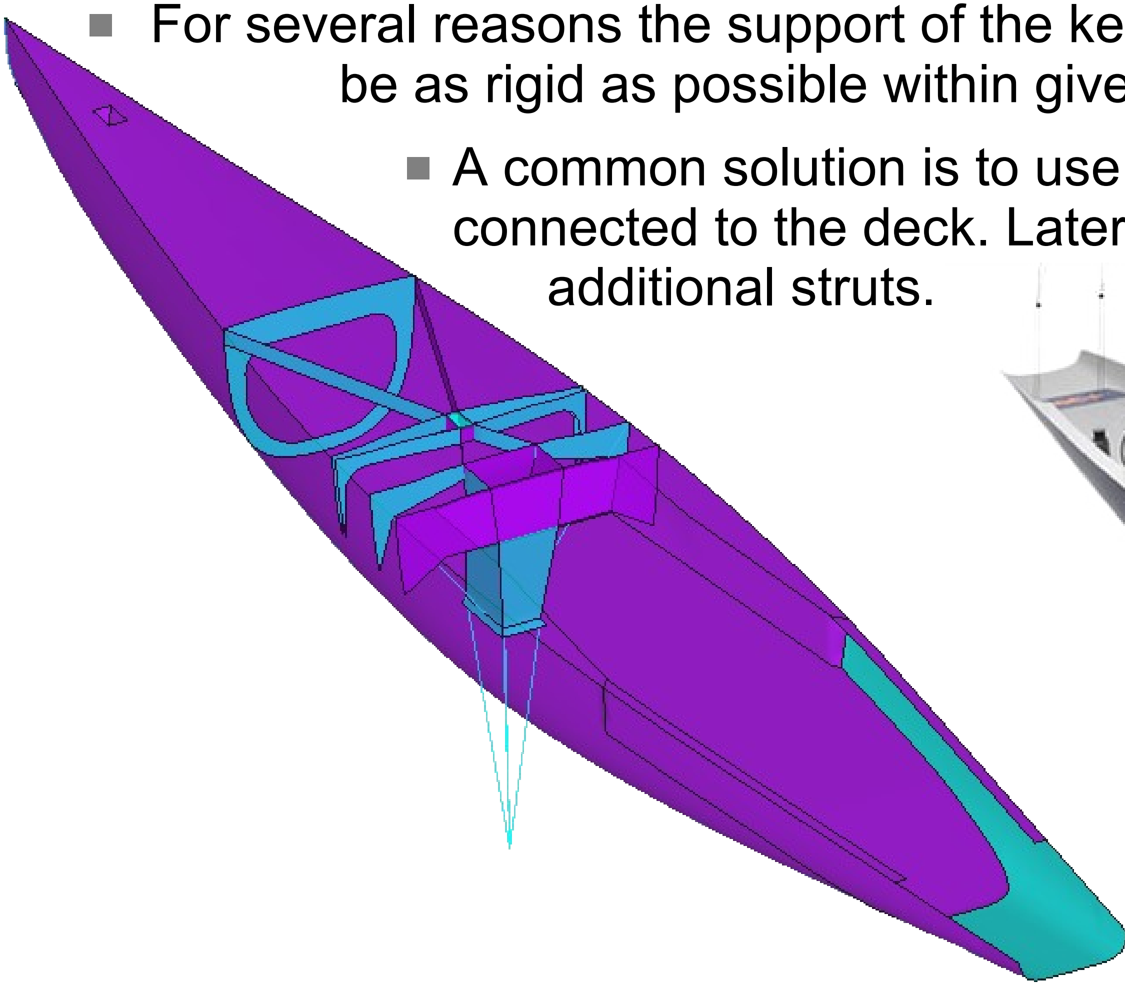
  ➔ Following two examples of numerical optimization in an early stage of an America's Cupper design process

Contents

Evaluate two versions of a keel support

Problem description

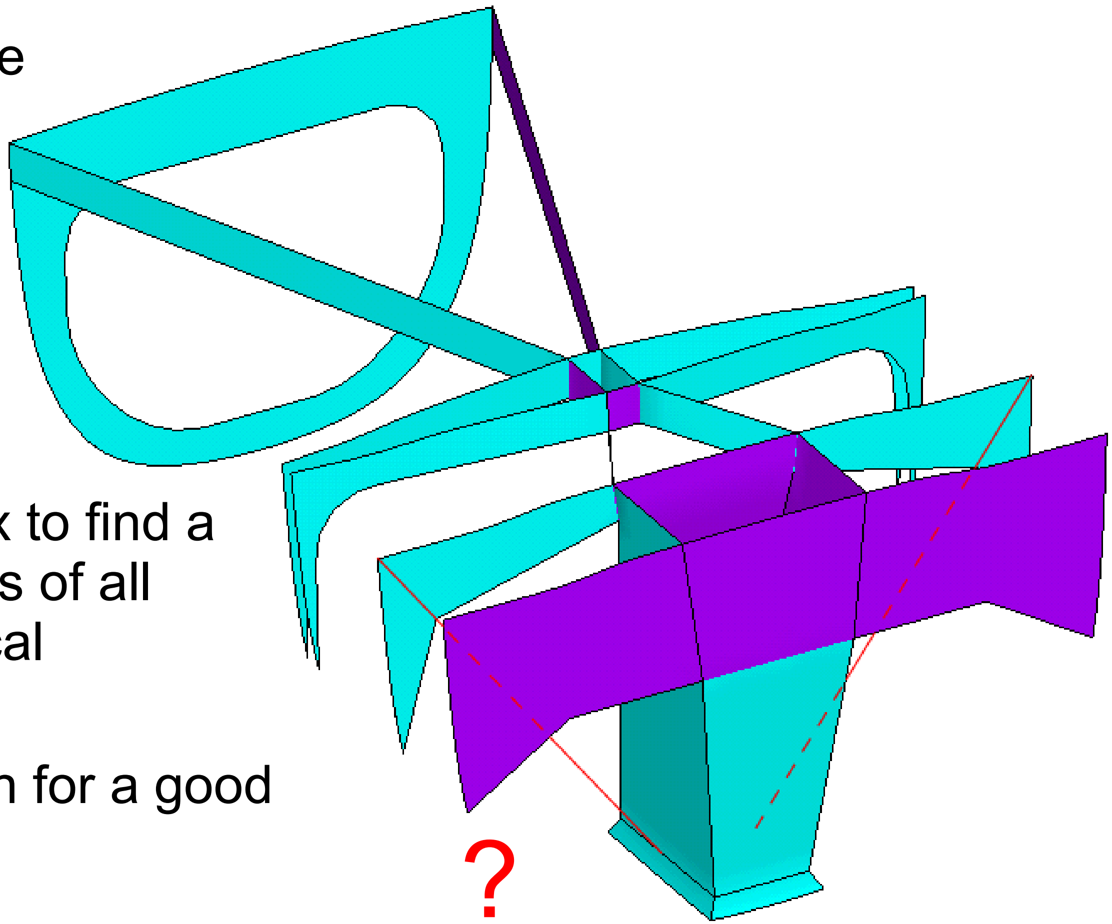
- The keel fin supports the entire weight (20 to) of the keel bulb.
- For several reasons the support of the keel fin of an America's Cupper must be as rigid as possible within given weight limits.
  - A common solution is to use a so called keel tower which is connected to the deck. Lateral forces are supported with additional struts.



Evaluate two versions of a keel support

Engineering questions

- Is it advantageous to use the struts under tension only or is it preferable that they carry compression loads too?
- How does it affect the weight of the keel tower and the overall construction?
- For the two versions, the laminate plans of the structures adjacent to the struts must be adjusted for every version respectively.
- The problem is already to complex to find a good solution under considerations of all aspects without the aid of numerical simulation.
- Optimization speeds up the search for a good solution.



Evaluate two versions of a keel support

Optimization task

- Objective:
  - ➔ Minimal deformation of the keel support
- Constraints:
  - ➔ Mass of the structure must remain constant
  - ➔ The strains in the entire structure must be smaller than a given threshold
- Parameters:
  - ➔ Eight different laminate thicknesses of the adjacent structures
  - ➔ The sectional area of the struts

Evaluate two versions of a keel support

Implementation

- Simulation
  - ➔ The relevant parameters in this case are the laminate thickness of the internal structures including the keel tower and the sectional area of the struts in question.
  - ➔ The finite element model is very coarse and shows little detailed structural information, which mirrors the early project phase. The struts for example are modeled as single finite elements, the laminates as “black sheet metal”.
  - ➔ The two versions are distinct by one or two struts.
- Optimization
  - ➔ The optimization engine is an Evolutionary Algorithm which is capable to address parameter sets with mixed types of parameters (bool, real, integer, etc.)
  - ➔ The population size is 20
  - ➔ ~200 generations are computed, resulting in ~4000 evaluations
  - ➔ Performed on 5 dual-processor computers in parallel
  - ➔ Optimization time: 5 hours

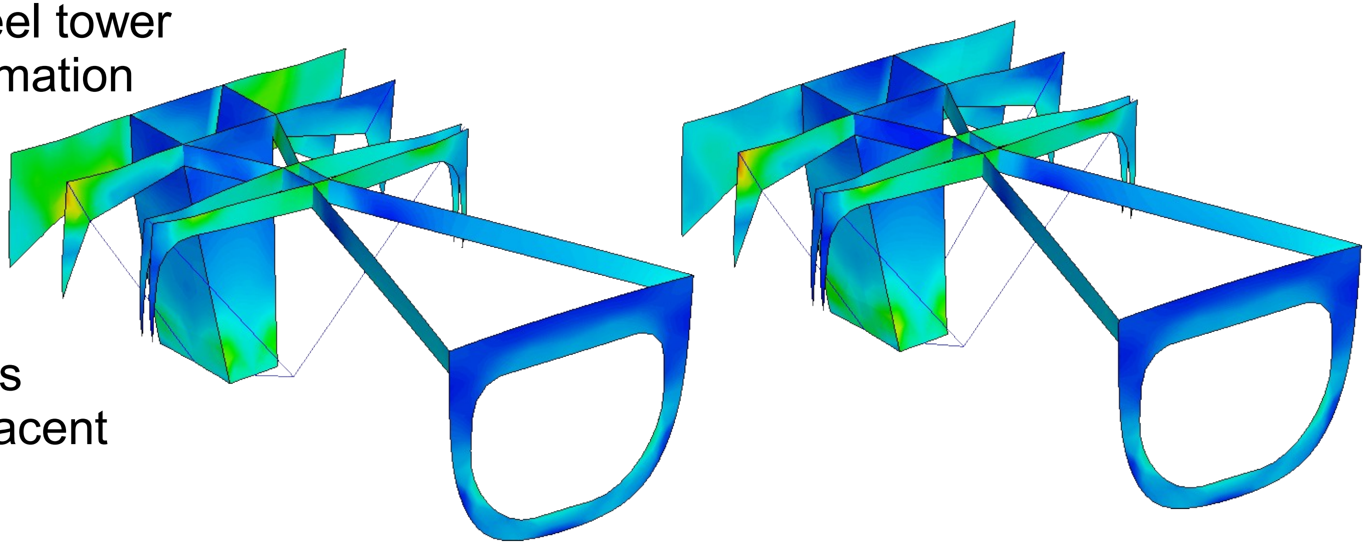
Evaluate two versions of a keel support

Results

- The results show:
  - ➔ Significant reduction of the deformation value
  - ➔ The design, with one strut performs better

	Deformation [%]	Mass [%]
First try	100	100
Two struts	67	100
One strut	58	99.36

- The results build a basis for the designer to chose the better design version
  - ➔ In this example the solution which performs better is also the easier one to build
  - ➔ With one strut, the keel tower transmits more deformation to other structures
  - ➔ With two struts the tension strut takes the major forces, the pressure strut delivers little forces to the adjacent structures.

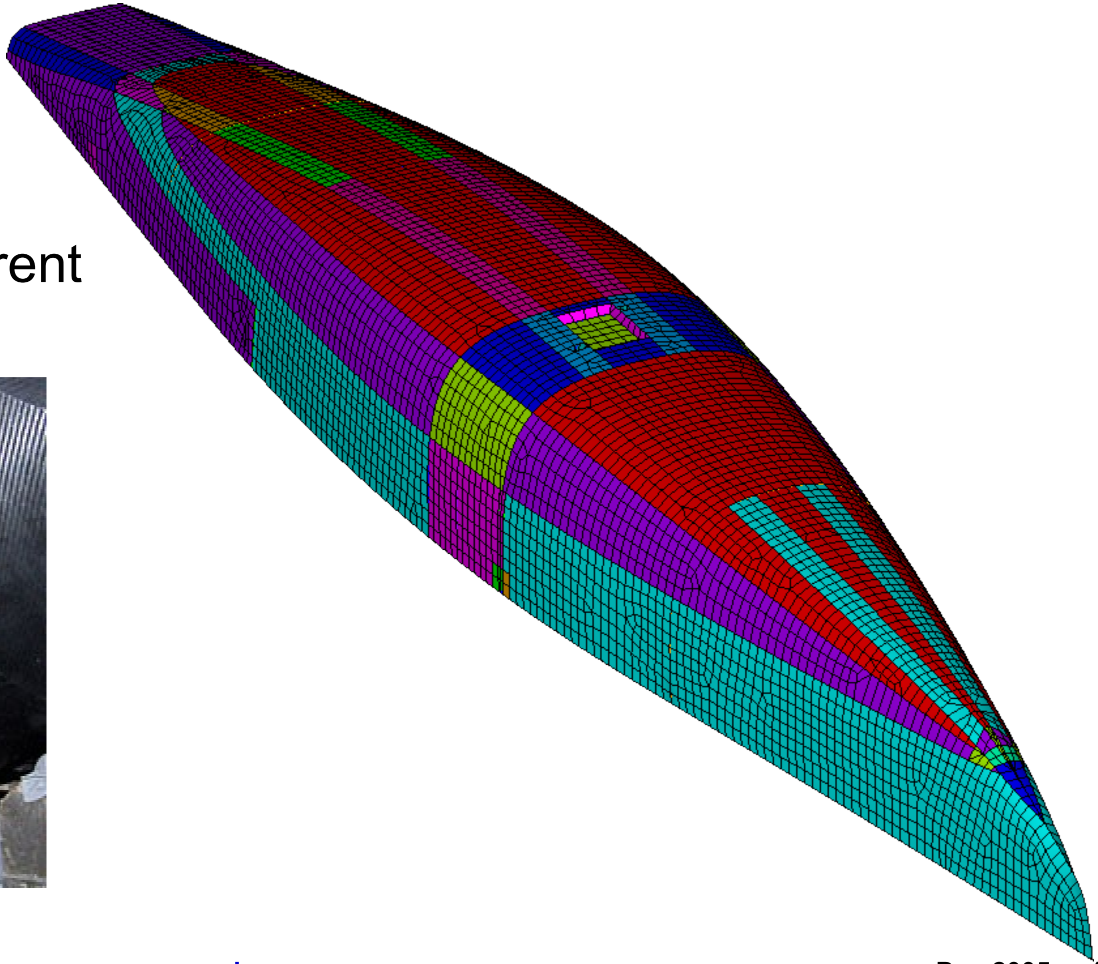


Contents

Amount and distribution of UD-carbon

Problem description

- The stiffness of the entire hull is adjusted with unidirectional carbon reinforcements in the deck and the hull.
- The thickness of the reinforcements changes over the length of the boat
- The colored areas denote different laminate regions



Amount and distribution of UD-carbon

Engineering questions

- How much additional unidirectional carbon is needed to reach the desired deformation?
- What is the best distribution of unidirectional carbon reinforcements in the hull, the deck, and over the length of the boat?
- What is the effect on the deformation if more/less carbon reinforcement is added?

➔ In terms of optimization:

The Pareto front of the two objectives weight and deformation is searched for.

Amount and distribution of UD-carbon

Optimization task

- Since the optimization engine in use does not support Pareto-Optimization, a series of individual optimizations have been performed with changing constraint values.

- Objective:
  - ➔ Minimal mass of the entire boat
- Constraints:
  - ➔ Deformation of the entire boat is preset
  - ➔ The strains in the entire structure must be below a chosen threshold
- Parameters:
  - ➔ Eight different laminate thicknesses in predefined regions in the deck
  - ➔ Eight different laminate thicknesses in predefined regions in the hull

Amount and distribution of UD-carbon

Implementation

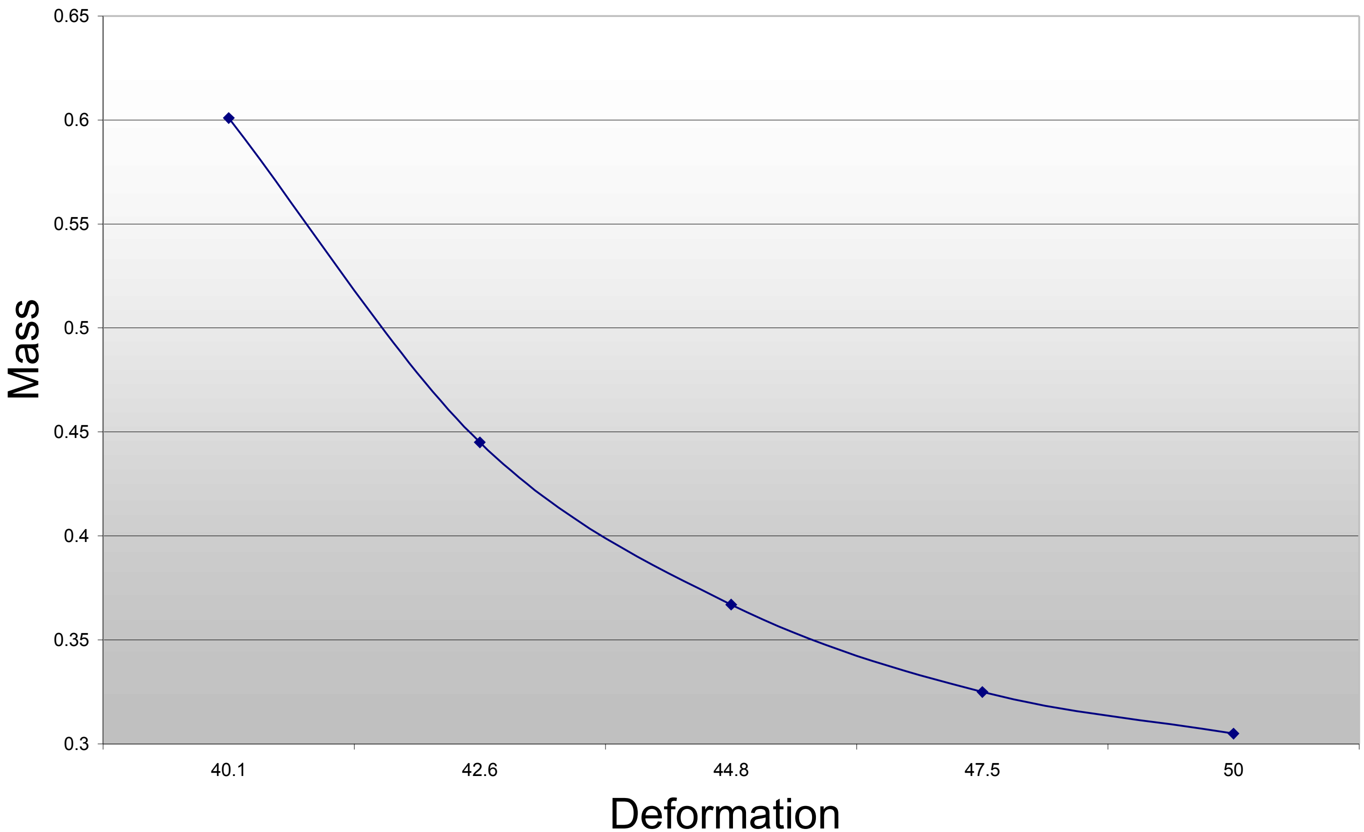
- Simulation
  - ➔ The finite element model is coarse and shows little detail

- Optimization
  - ➔ Five different optimizations are performed
  - ➔ The population size is 30
  - ➔ Per optimization ~200 generations are computed, resulting in ~6000 evaluations
  - ➔ Performed on 5 dual-processor computers in parallel
  - ➔ Optimization time: 8 hours

Amount and distribution of UD-carbon

Results I: Amount

- The following Pareto front is used as a source of information for the amount of carbon fiber reinforcements to be placed in the boat
- It is based on five different optimizations



	Mass [%]	Deformation [%]
Version 1	100	80
Version 2	74	85
Version 3	61	90
Version 4	54	95
Version 5	51	100

Amount and distribution of UD-carbon

Results II: Distribution

- For the five optimized Versions, the detailed data for the optimized laminate thicknesses is available.
- For low weights all reinforcements are placed in the deck. Only the minimum specified is placed in the hull.
- With larger amounts of reinforcements additional layers are placed in the hull as well.

```
BUD_1=15.31          ! Range 1-200  [REAL]
BUD_2=1.14           ! Range 1-200  [REAL]
BUD_3=1.00           ! Range 1-200  [REAL]
BUD_4=1.00           ! Range 1-200  [REAL]
BUD_5=1.00           ! Range 1-200  [REAL]
BUD_6=1.00           ! Range 1-200  [REAL]
BUD_7=1.00           ! Range 1-200  [REAL]
BUD_8=1.00           ! Range 1-200  [REAL]
dckud_ar_1=1.88      ! Range 1-2000 [REAL]
dckud_ar_2=289.25    ! Range 1-2000 [REAL]
dckud_ar_3=711.07    ! Range 1-2000 [REAL]
dckud_ar_4=1460.57   ! Range 1-2000 [REAL]
dckud_ar_5=1669.62   ! Range 1-2000 [REAL]
dckud_ar_6=994.45    ! Range 1-2000 [REAL]
dckud_ar_7=823.73    ! Range 1-2000 [REAL]
dckud_ar_8=632.48    ! Range 1-2000 [REAL]
```

```
BUD_1=56.94          ! Range 1-200  [REAL]
BUD_2=34.71          ! Range 1-200  [REAL]
BUD_3=65.44          ! Range 1-200  [REAL]
BUD_4=75.37          ! Range 1-200  [REAL]
BUD_5=45.93          ! Range 1-200  [REAL]
BUD_6=8.87           ! Range 1-200  [REAL]
BUD_7=6.90           ! Range 1-200  [REAL]
BUD_8=1.04           ! Range 1-200  [REAL]
dckud_ar_1=19.19     ! Range 1-2000 [REAL]
dckud_ar_2=1140.37   ! Range 1-2000 [REAL]
dckud_ar_3=1874.01   ! Range 1-2000 [REAL]
dckud_ar_4=1996.59   ! Range 1-2000 [REAL]
dckud_ar_5=2000.00   ! Range 1-2000 [REAL]
dckud_ar_6=1999.36   ! Range 1-2000 [REAL]
dckud_ar_7=1865.14   ! Range 1-2000 [REAL]
dckud_ar_8=1986.73   ! Range 1-2000 [REAL]
```

Closure

- Summary
  - ➔ A 'good' optimization tool can help to improve the design process significantly
  - ➔ The potential of a specific version can be shown in an early design phase in short time
- The optimization tool
  - ➔ Flexible regarding simulation tools
  - ➔ Flexible regarding design objectives and constraints
  - ➔ Must allow mixed sets of parameter types
  - ➔ The optimization tool must find good solutions in possibly rough design spaces