Shape Optimisation for Crashworthiness

F. Duddeck[1], S. Hunkeler[1,2], H. Zimmer[3],
L. Rota[4], M. Zarroug[4]

[1] Queen Mary University of London, [2] Ecole des Ponts ParisTech, [3] SFE GmbH, [4] PSA Peugeot-Citroen

Shape Optimisation for Crashworthiness
Content

- Motivation
- SFE CONCEPT for geometrical variations
- Test examples for validation (front rail)
- Industrial examples (front rail)
- Optimisation results and recommendations
- Conclusions and outlook

Motivation
State-of-the-Art in Shape Optimisation

Example:

7th Europ. LS-DYNA Conf. 2009

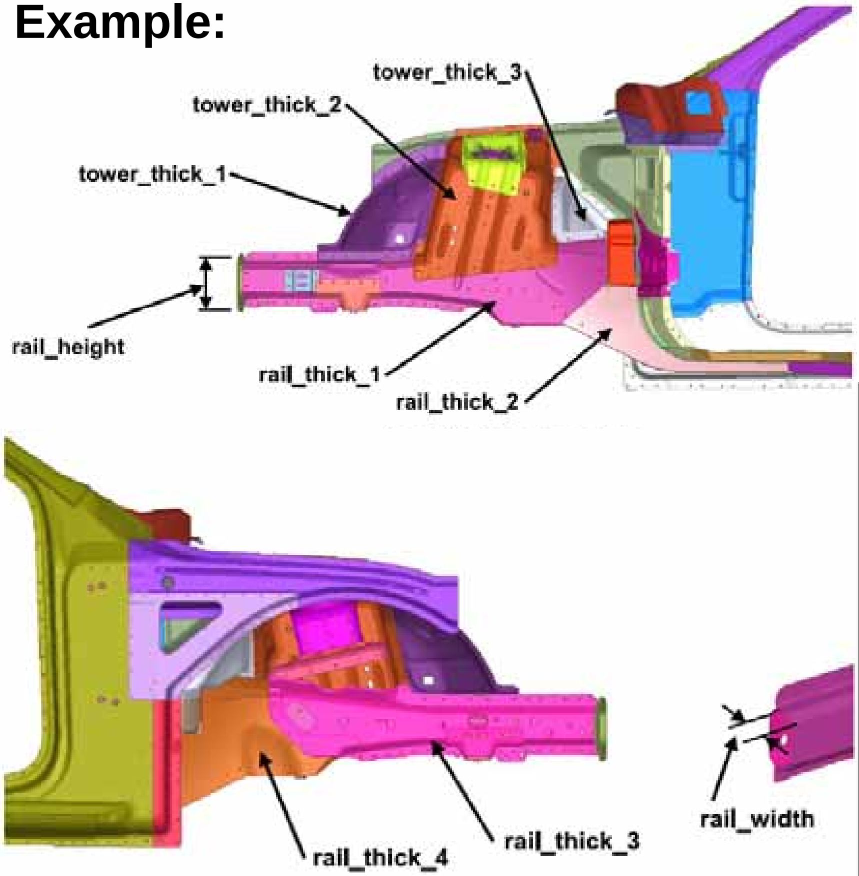


Figure 3: Design variables

Multi-Disciplinary Design Optimization exploiting the efficiency of ANSA-LSOPT-META coupling

Korbetis Georgios, Siskos Dimitrios,

BETA CAE Systems S.A,

Design Variable	Type	Initial Value [mm]	Lower Bound [mm]	Upper Bound [mm]
Rail_thick_1	Discrete	1.6	1.2	2
Rail_thick_2	Discrete	1.8	1.4	2.6
Rail_thick_3	Discrete	1.6	1.2	2
Rail_thick_4	Discrete	2.0	1.6	2.8
Tower_thick_1	Discrete	1.4	1	2
Tower_thick_2	Discrete	2.	1.6	3
Tower_thick_3	Discrete	0.8	0.6	1
Rail_height	Continuous	160	140	180
Rail_width	Continuous	64	60	68
Bead_depth	Continuous	0	0	6

Motivation

State-of-the-Art in Shape Optimisation

Figure 6: Rail initial shape

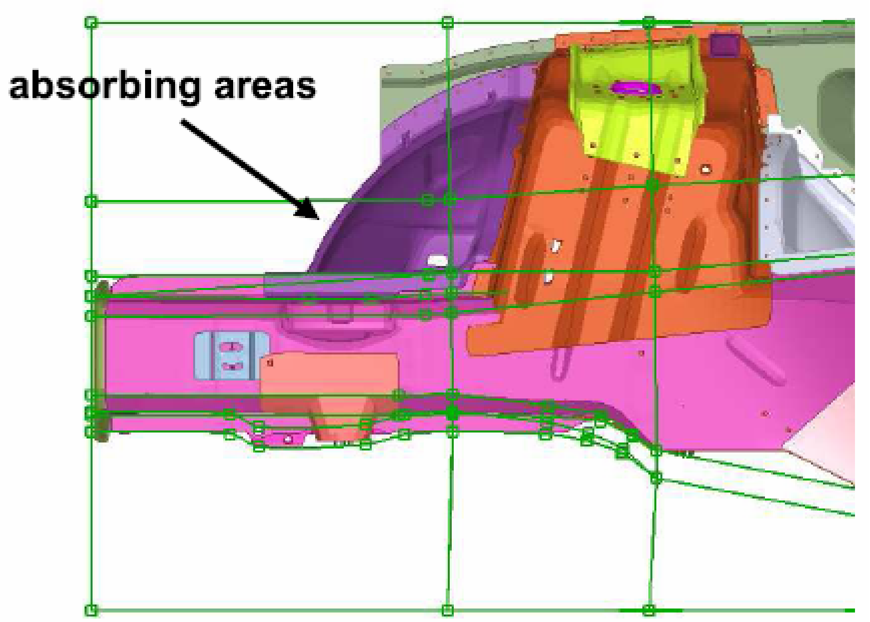


Figure 7: Rail modified shape

Morphing can only realise small geometrical modifications
⇨ Truly shape optimisation methods required

SFE CONCEPT – Parametric Design for Simulation
Simulation & Optimisation – CAD Integration

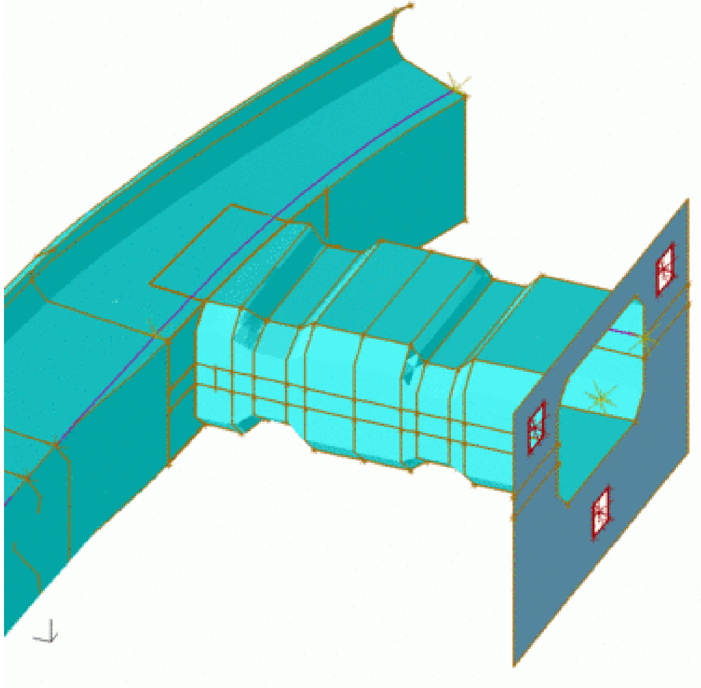
Automated Variation of Geometries for Shape Optimisation

October 2009

Hans Zimmer
President & CEO
h.zimmer@sfe-berlin.de
SFE GmbH, Berlin
http://www.sfe-berlin.de

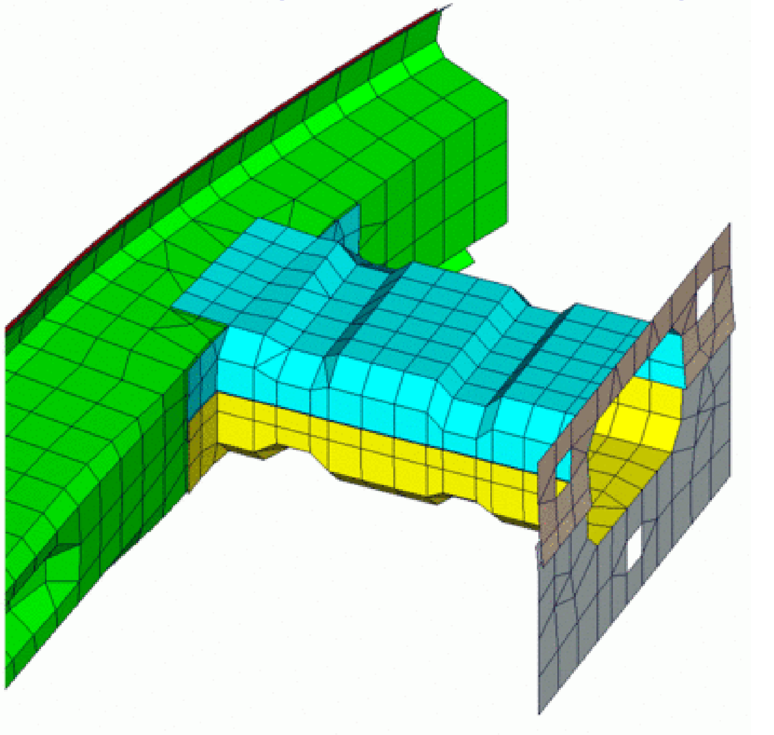
SFE CONCEPT Model

Fully parametric model for shape optimisation



SFE CONCEPT FE Mesh

Parametric geometry change
Automatic mesh adaptation
includes the capability of morphing and goes far beyond morphing

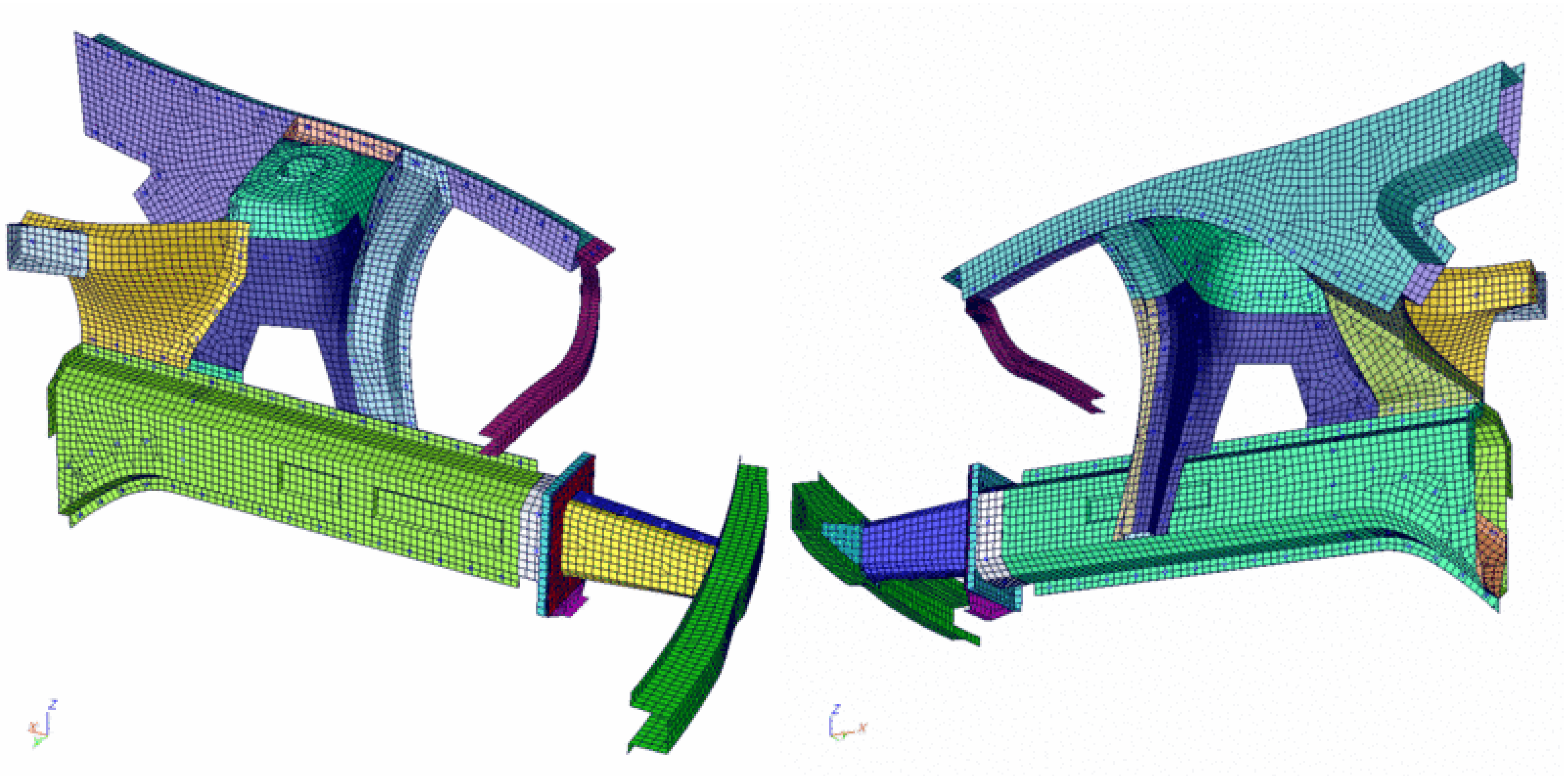


Automated Variation of Geometries for Shape Optimisation

October 2009

Hans Zimmer
President & CEO
h.zimmer@sfe-berlin.de
SFE GmbH, Berlin
http://www.sfe-berlin.de

Complex geometries in complex environments

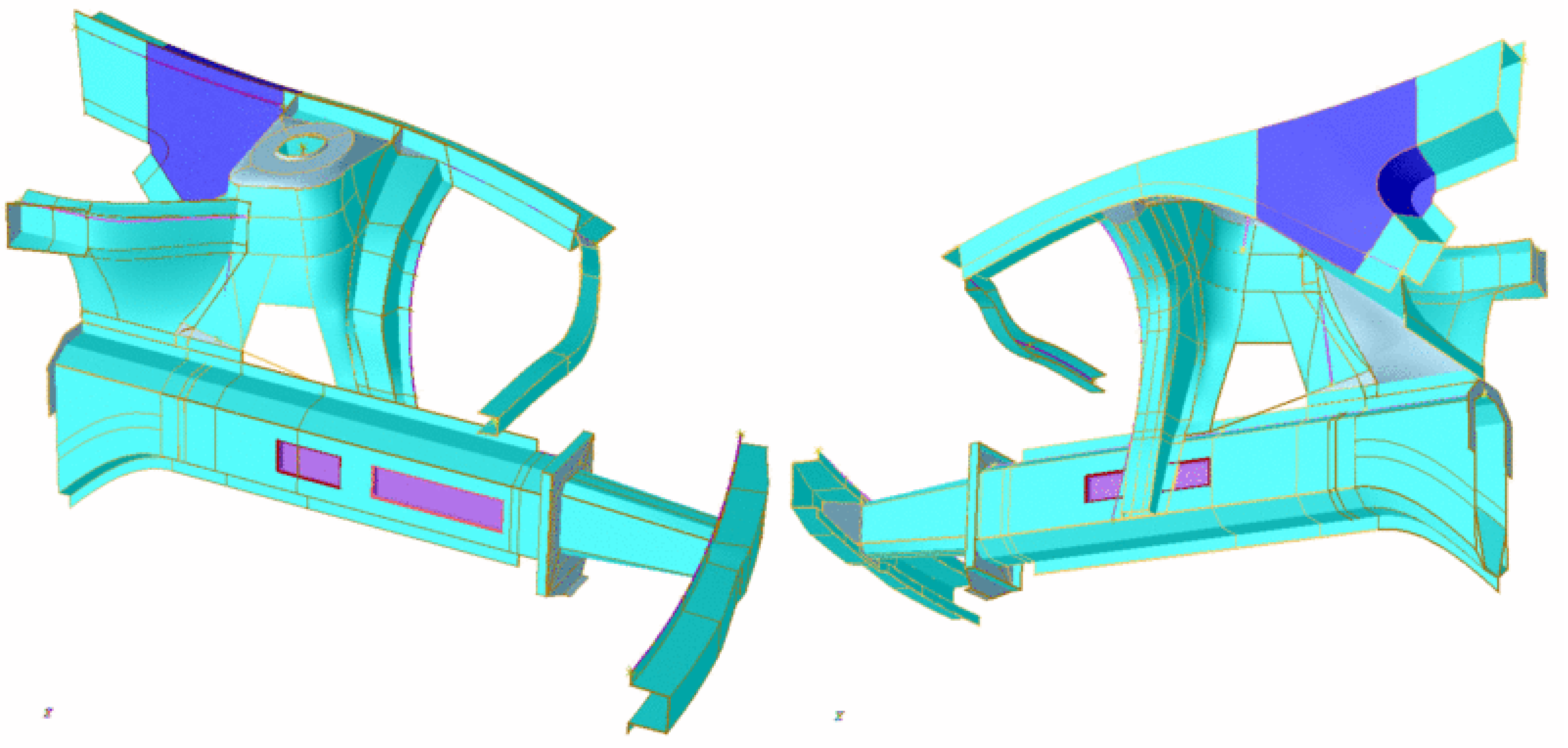


Automated Variation of Geometries for Shape Optimisation

October 2009

Hans Zimmer
President & CEO
h.zimmer@sfe-berlin.de
SFE GmbH, Berlin
http://www.sfe-berlin.de

Complex geometries in complex environments

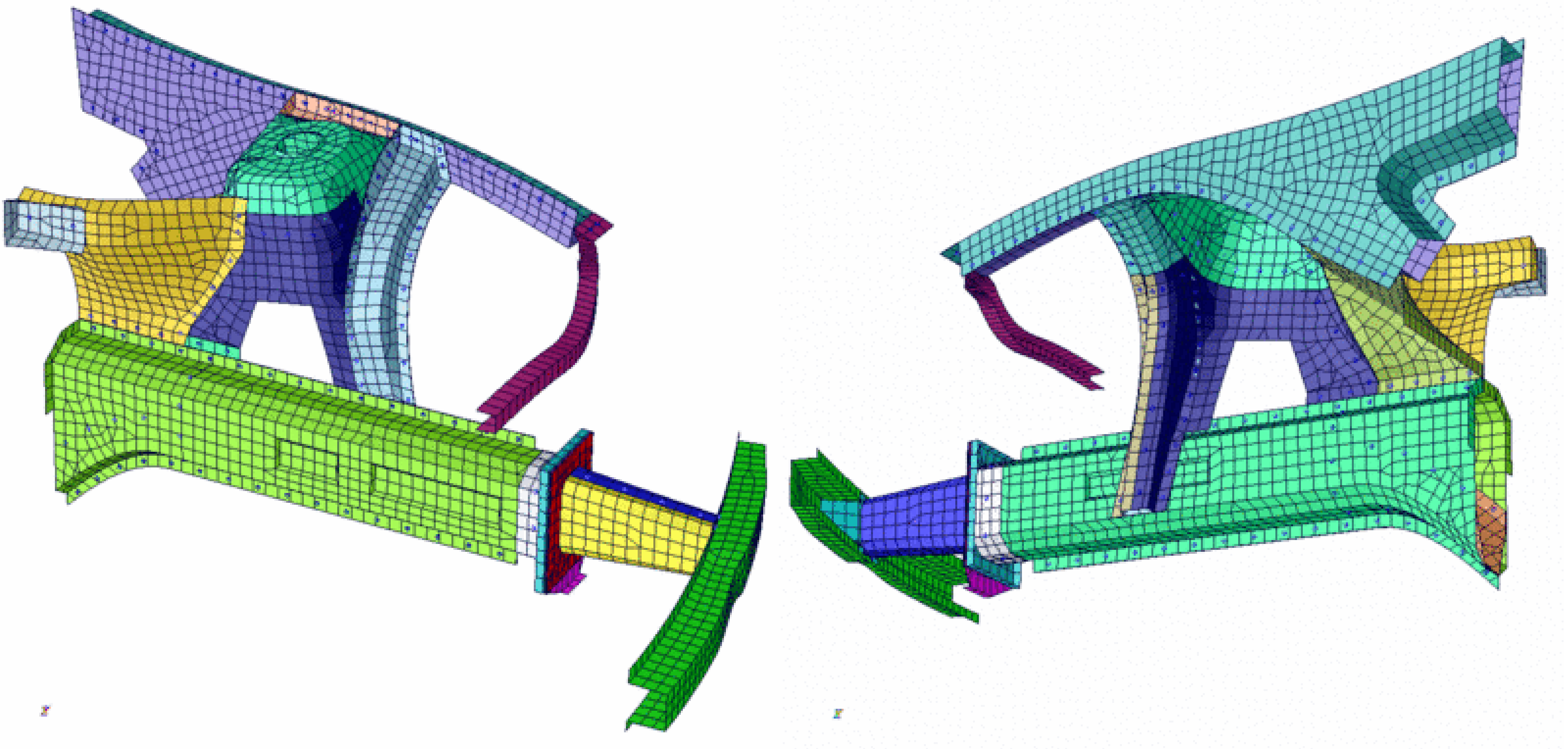


Automated Variation of Geometries for Shape Optimisation

October 2009

Hans Zimmer
President & CEO
h.zimmer@sfe-berlin.de
SFE GmbH, Berlin
http://www.sfe-berlin.de

Complex geometries in complex environments

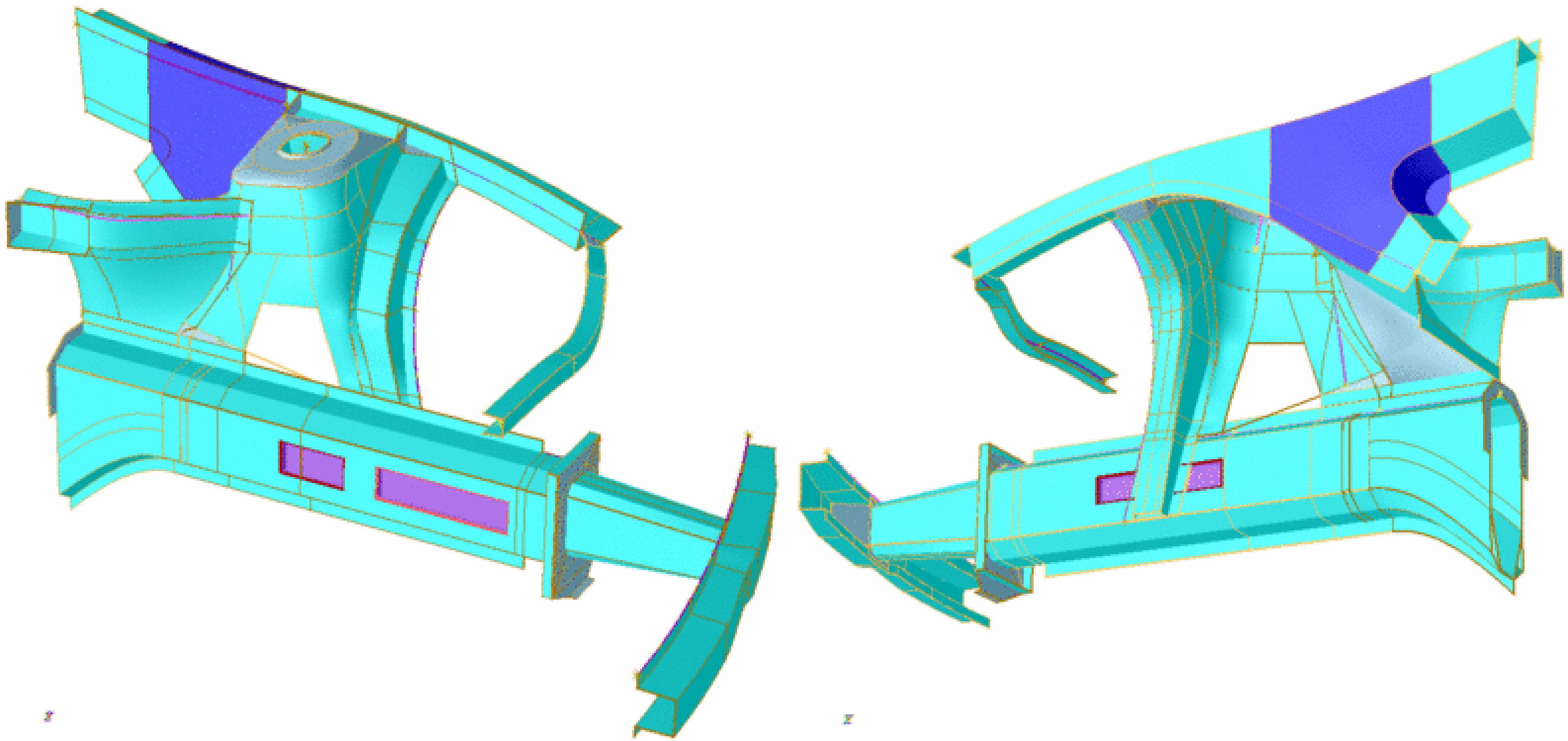


Automated Variation of Geometries for Shape Optimisation

October 2009

Hans Zimmer
President & CEO
h.zimmer@sfe-berlin.de
SFE GmbH, Berlin
http://www.sfe-berlin.de

Complex geometries in complex environments

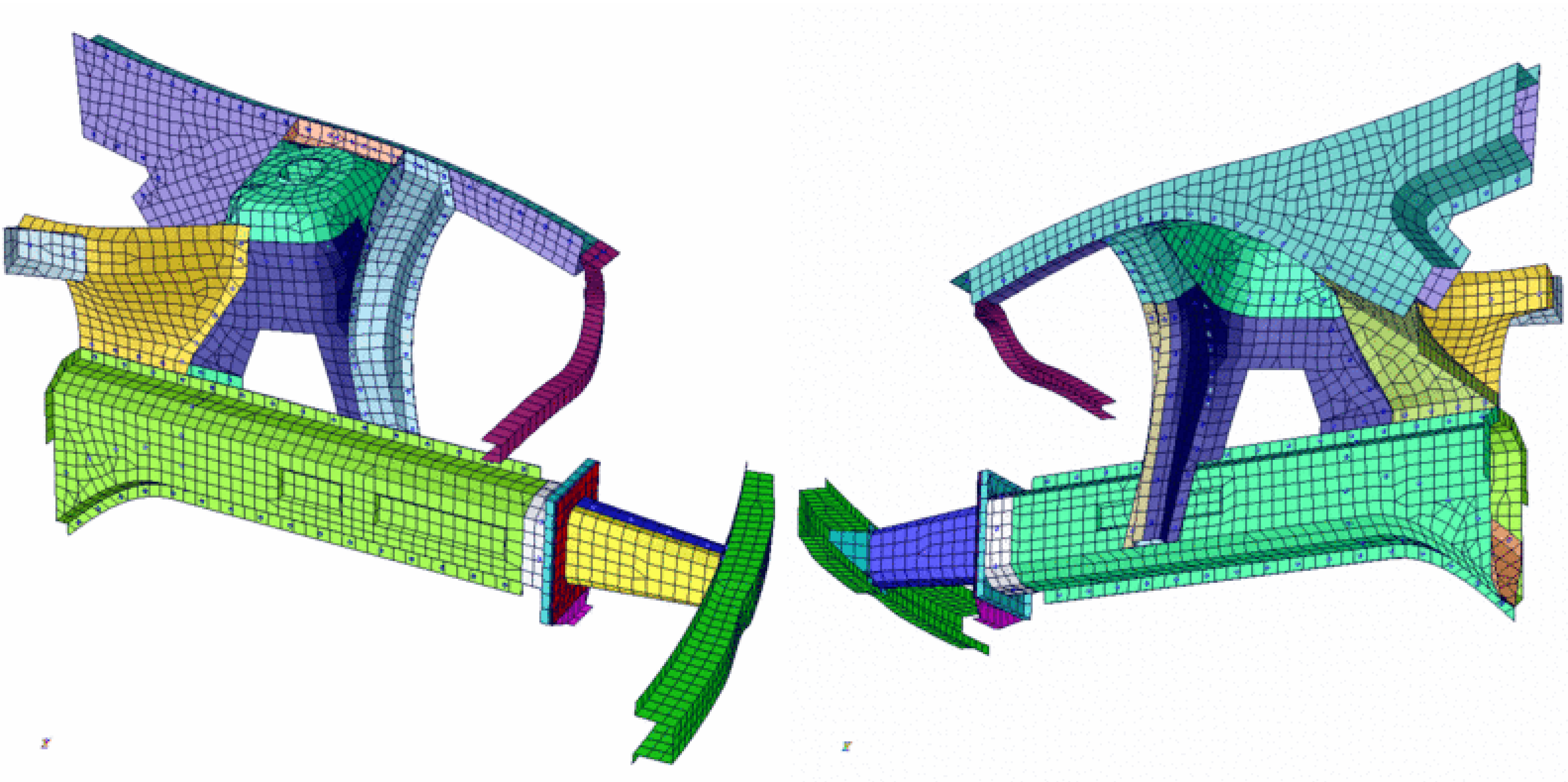


Automated Variation of Geometries for Shape Optimisation

October 2009

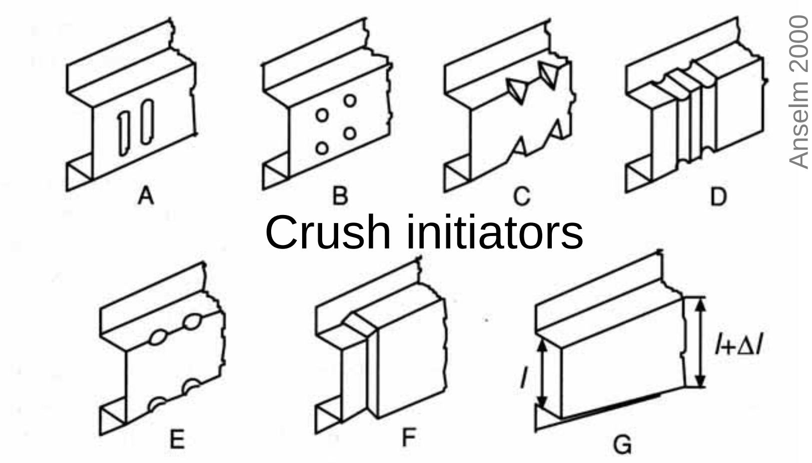
Hans Zimmer
President & CEO
h.zimmer@sfe-berlin.de
SFE GmbH, Berlin
http://www.sfe-berlin.de

Complex geometries in complex environments



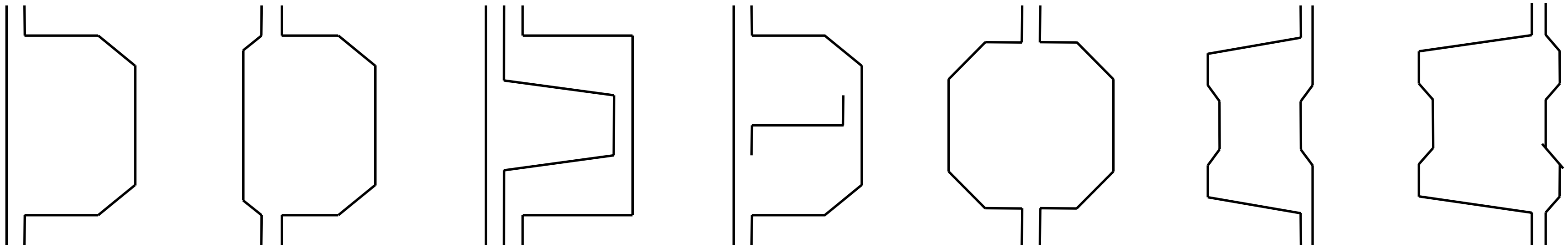
Example: Crash Boxes

- Simplest example
- But already a high number of design variables;
- High sensitivity to fluctuations in load configurations & other factors;
- Non-repetitive FEM computations if computed in parallel;



Example: Frontal Rail

- Very high number of design variables
- Complex geometrical situation
- High importance for crash

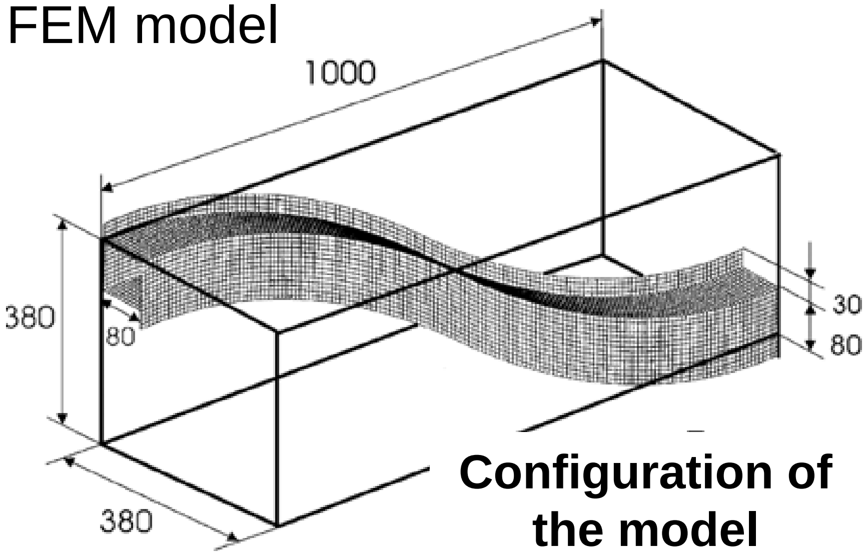


Industrial examples (cross-sections)

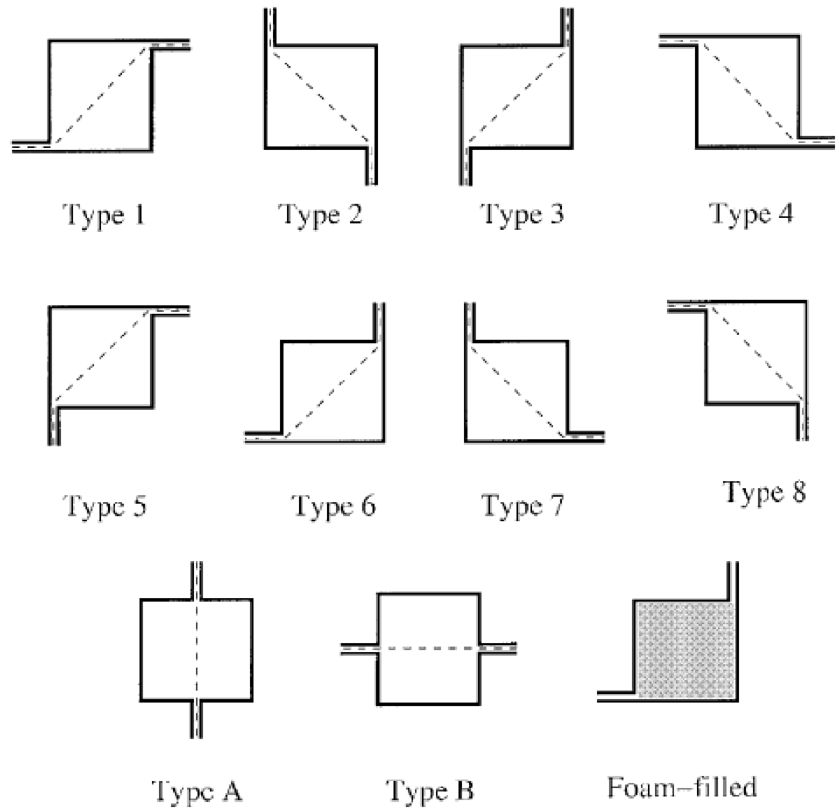
Example: Frontal Rail

Study by Wierzbicki et al. (MIT 2001)

FEM model



Configuration of the model



Various cross-sectional shapes considered

Kim & Wierzbicki (2001)

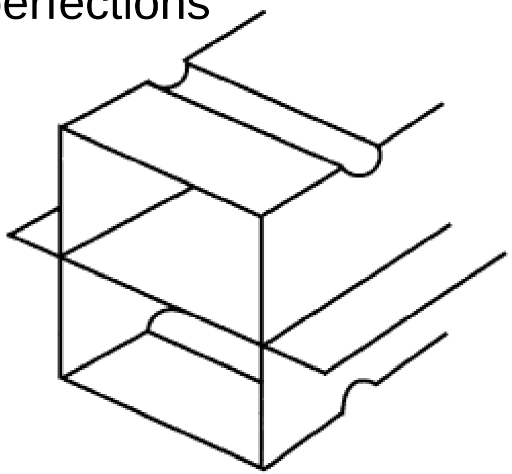
Not considered:

- Failure, strain rate dependency
- Real geometry variation
- Changes in longitudinal direction
- Other modes (global buckling)

Example: Frontal Rail
Geometrical Imperfections

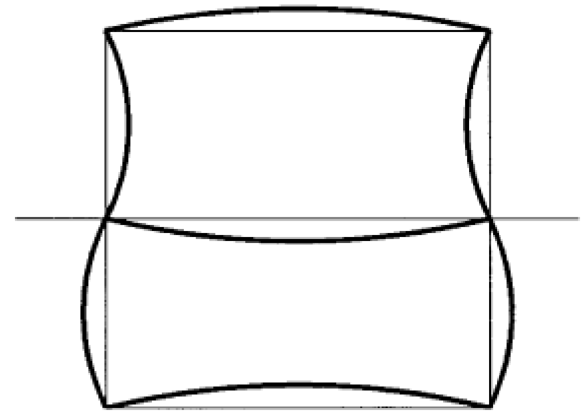
Kim & Wierzbicki (2001)

Local imperfections



Geometrical imperfection (type 1)

Global imperfections



Geometrical imperfection (type 2)

For real robustness analysis:

- Small local geometrical variations at arbitrary locations
- More general approach covering local and global imperfections
- Thickness fluctuations should be taken into account
- Global parameters (angle, position, location of other adjacent objects)

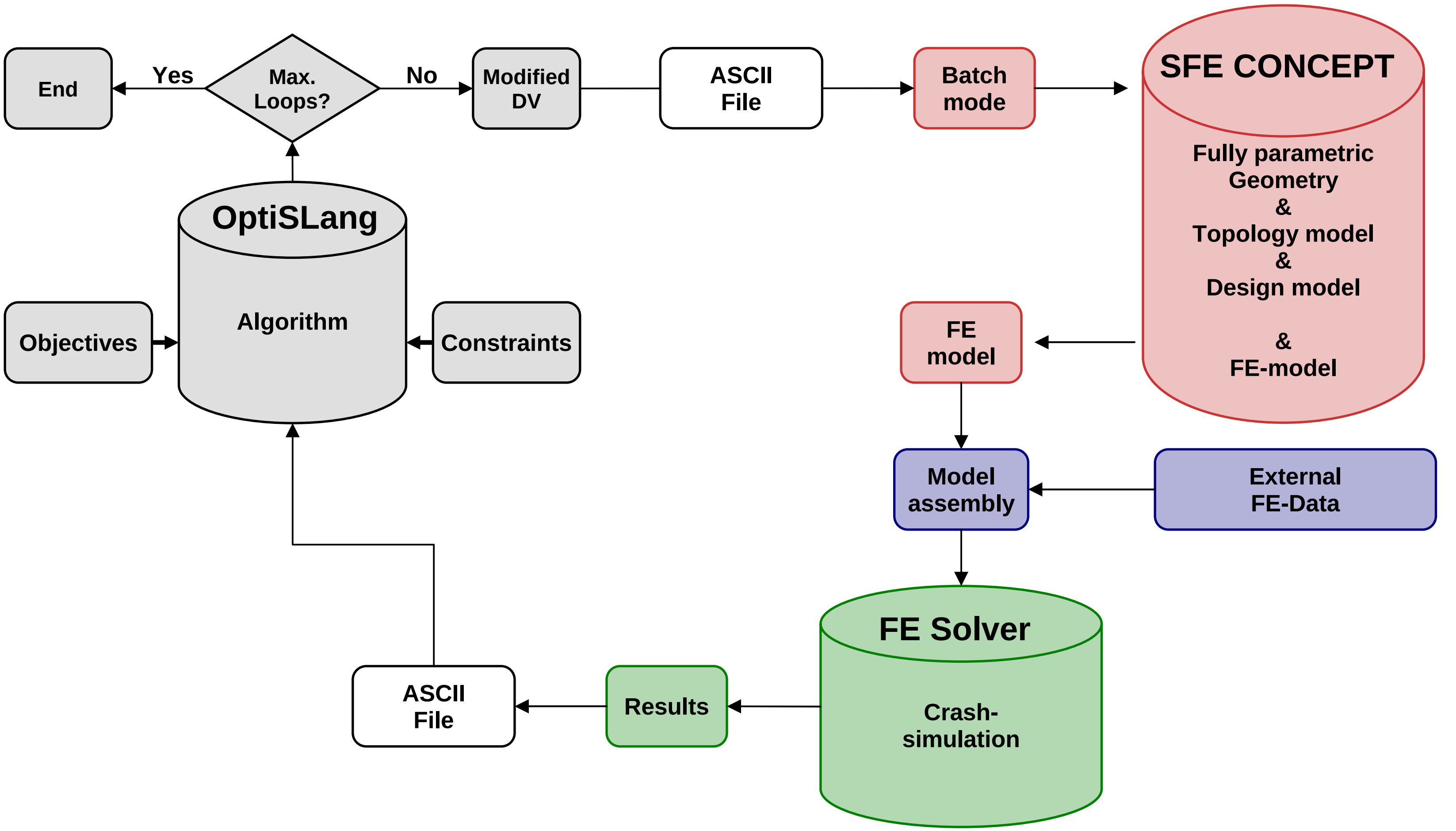
Example: Frontal Rail
Changes in Longitudinal Direction

For real shape optimisation:

- Different zones: folding at the beginning, buckling in the engine area;
- No constant cross-sectional area in longitudinal direction
- Thickness variations in axial direction
- Reinforcements and crush initiators, connection points etc.

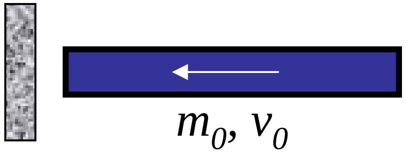
[redacted]

Optimisation Loop



Simplified Test Problem

- **First study to evaluate optimisation methods and investigate practical parameterisations**

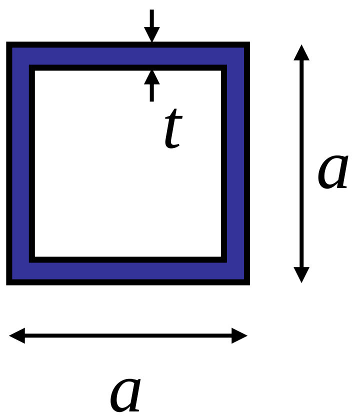


- Transverse crash on a beam encastred at one extremity (m_0 = 500 kg , v_0 = 10 m/s);
- **Objective:** maximise SEA (= specific energy absorption, i.e. internal energy / mass) during the first 20 ms;
- **Constraint:** maximal transverse force should remain lower than 70 kN;

Simplified Test Problem

Four Test Cases

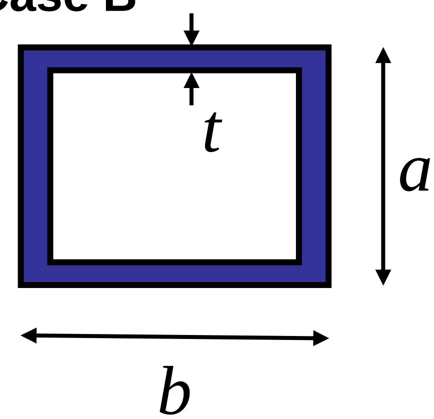
Case A



2 parameters

$$60 \le a < 100$$
$$1.4 \le t < 3.0$$

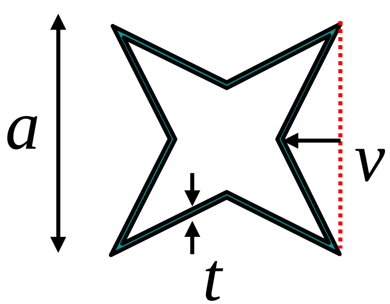
Case B



3 parameters

$$60 \le a < 100$$
$$60 \le b < 100$$
$$1.4 \le t < 3.0$$

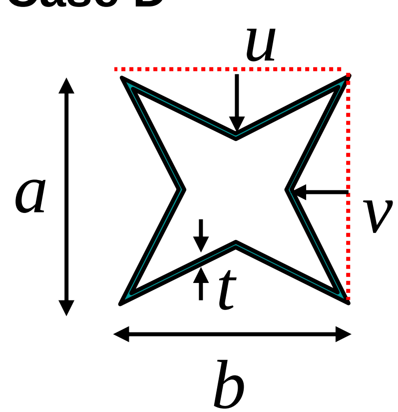
Case C



3 parameters

$$60 \le a < 100$$
$$-20 \le v < 20$$
$$1.4 \le t < 3.0$$

Case D

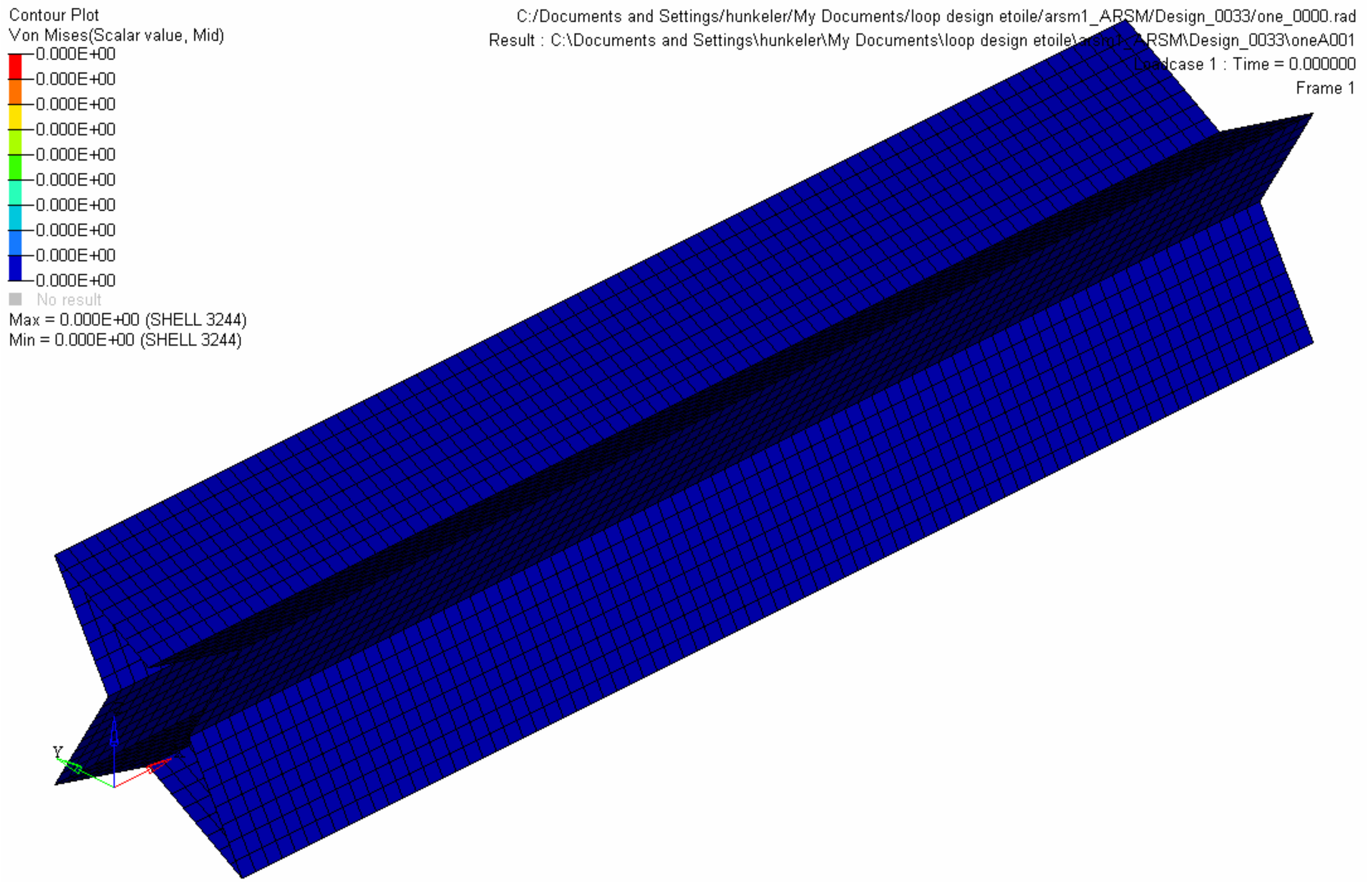


5 parameters

$$60 \le a < 100$$
$$60 \le b < 100$$
$$-20 \le v < 20$$
$$-20 \le u < 20$$
$$1.4 \le t < 3.0$$

All dimensions in mm

Simplified Test Problem
Initial Model



Initial model

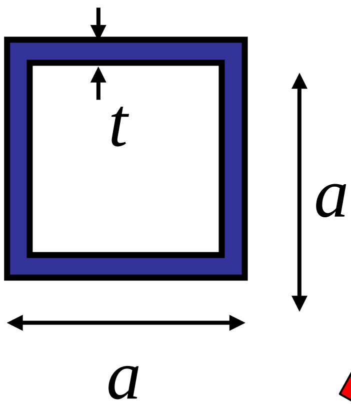
Simplified Test Problem
Optimisation methods

- Optimisation with adaptive response surface methods (ARSM) or evolutionary/genetic algorithms (optiSLang)
- There is no unique algorithm for all cases, hence an automated decision should be implemented and a hybrid approach realised;
- For ARSM, linear approximation and D-optimal sampling are acceptable to avoid high numerical effort
- RSM should be adaptive or successive;
- Evolutionary algorithms (EA) are in most cases better than genetic algorithms (GA).

Simplified Test Problem
Results (1)

Case A

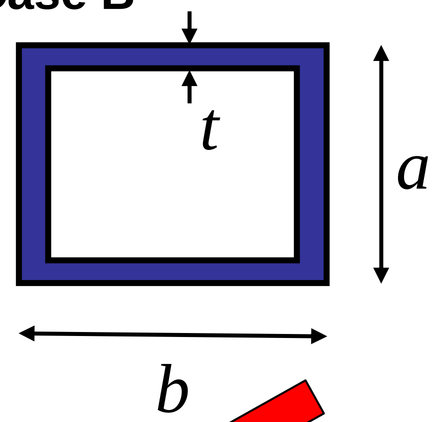
2 parameters



$$60 \le a < 100$$
$$1.4 \le t < 3.0$$

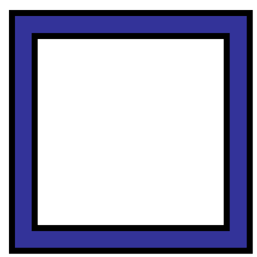
Case B

3 parameters



$$60 \le a < 100$$
$$60 \le b < 100$$
$$1.4 \le t < 3.0$$

ARSM
(39 shapes computed):
Opt energy absorption
SEA: 10.24 kJ/kg



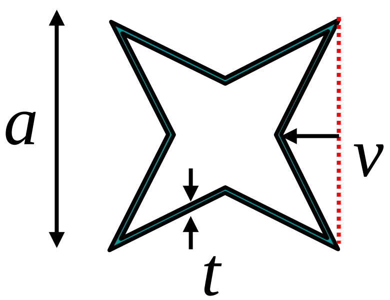
ARSM (111 shapes):
Opt SEA: 10.18 kJ/kg

EA (368 shapes):
Opt SEA: 9.39 kJ/kg

Square is the ideal rectangular shape

Simplified Test Problem
Results (2)

Case C

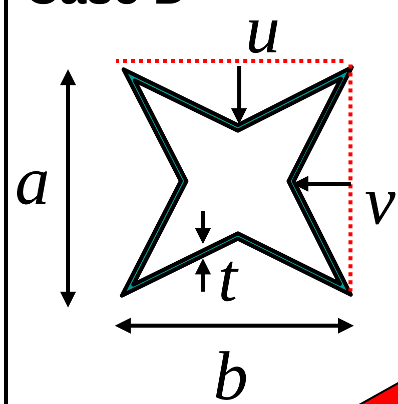


$60 \le a < 100$

$-20 \le v < 20$

$1.4 \le t < 3.0$

Case D



$60 \le a < 100$

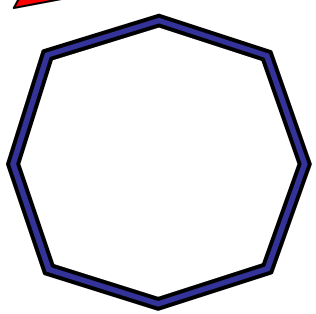
$60 \le b < 100$

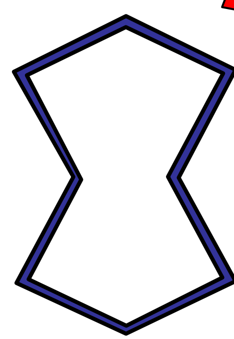
$-20 \le v < 20$

$-20 \le u < 20$

$1.4 \le t < 3.0$

ARSM (80 shapes)
Opt. SEA:
10.31 kJ/kg





ARSM (139 shapes)
Opt SEA: 11.36 kJ/kg

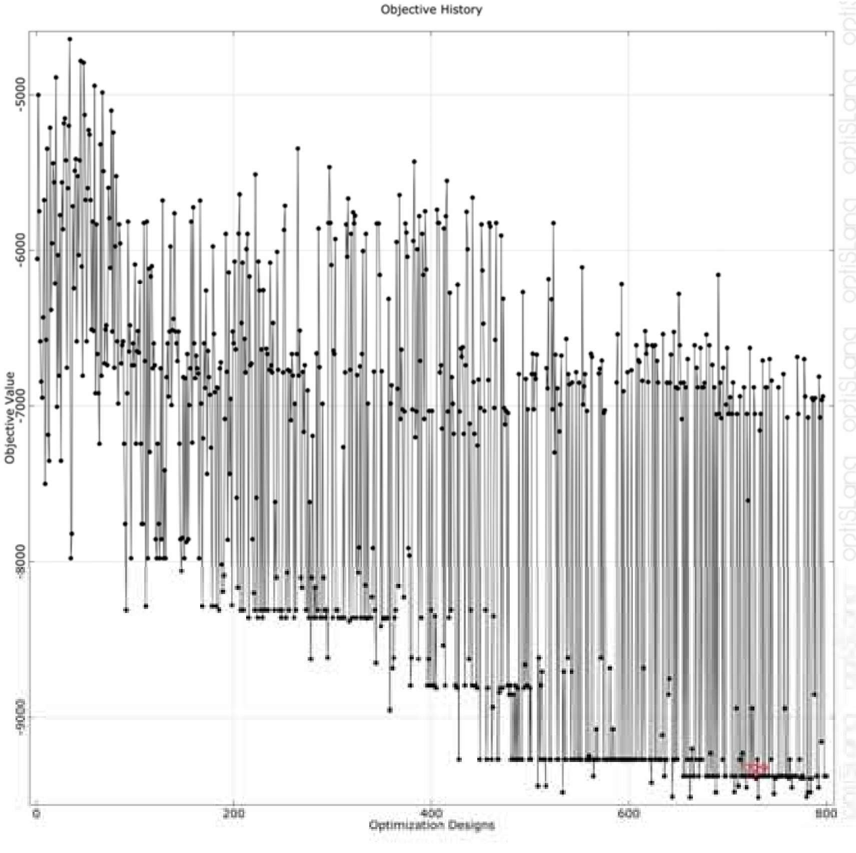
EA (292 shapes)
Opt SEA: 11.35 kJ/kg

Octagon as ideal symmetric shape

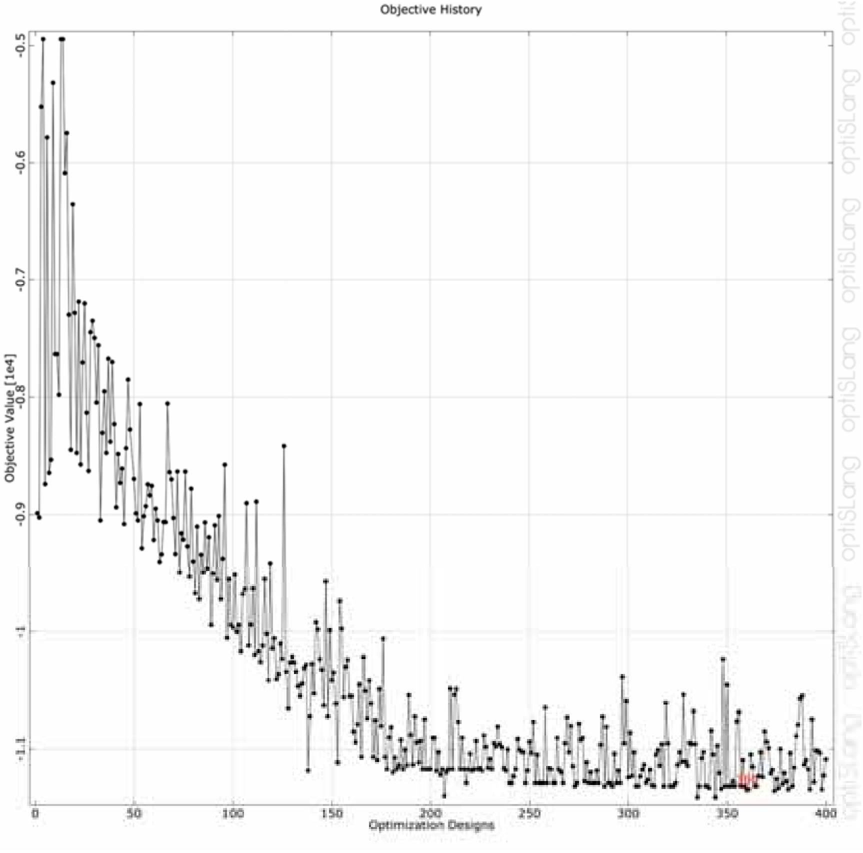
Non-symmetric octagon is better

Simplified Test Problem
Results (3)

Convergence EA



Convergence ARSM



Simplified Test Problem
Summary of Results

- Parameterisations 1 and 2 present almost identical optima
- Slight improvement on parameterisation 3
- Significant improvement on parameterisation 4
- ARSM faster and reaching better results than EA
- Still true with more parameters ?

Real Evaluation Problem (inspired from industry)

- Crash case slightly different (m_0 = 460 kg, v_0 = 12 m/s, duration 50 ms)
- Objective: minimise the mass of the front rail
- Constraints:
  - Final internal energy higher than 30 kJ
  - Highest axial displacement lower than 300 mm
  - Fit into the allocated space
  - Highest transverse displacement lower than 15 mm (no buckling mode)

Real Evaluation Problem
Natural Parameterisation

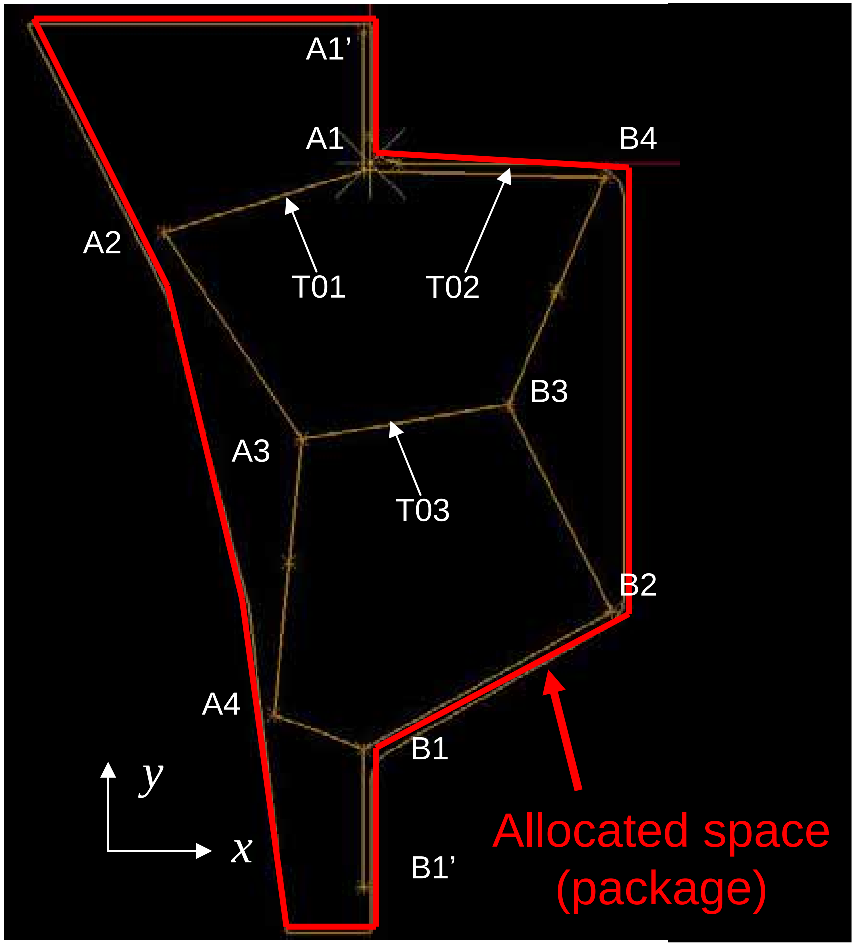
- 3 thickness parameters

Left: T01	Middle: T03	Right: T02

- 14 geometrical parameters

XA1	
XA2	YA2
XA3	YA3
XA4	YA4
XB1	
XB2	YB2
XB3	YB3
XB4	YB4

-



Advanced Parameterisation
Offset Mapping (SFE)

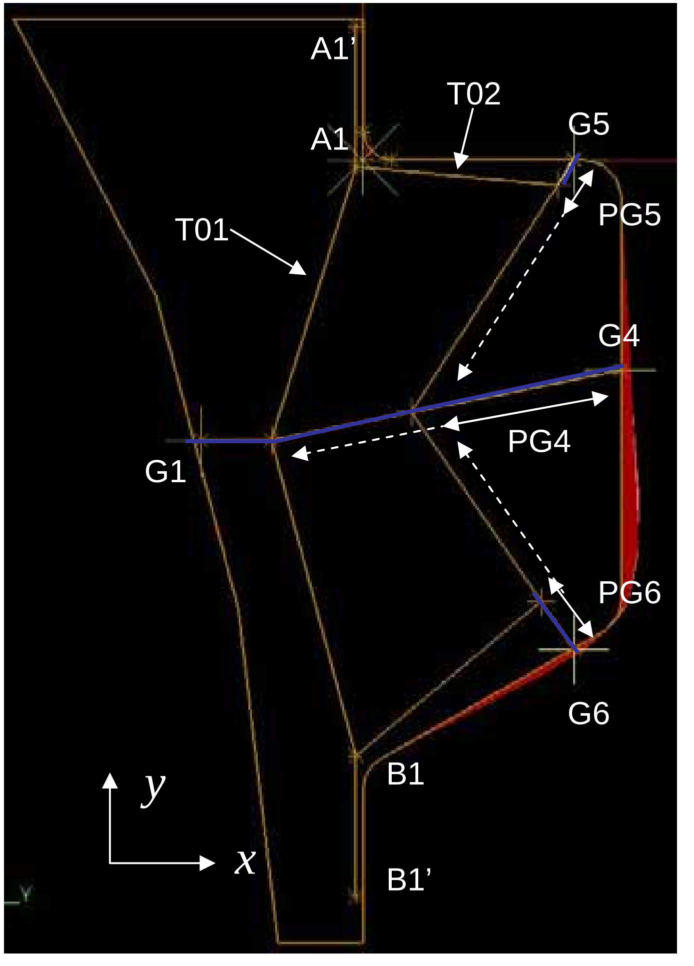
- 2 thickness parameters

Left: T01	Right: T02

- 10 geometrical parameters

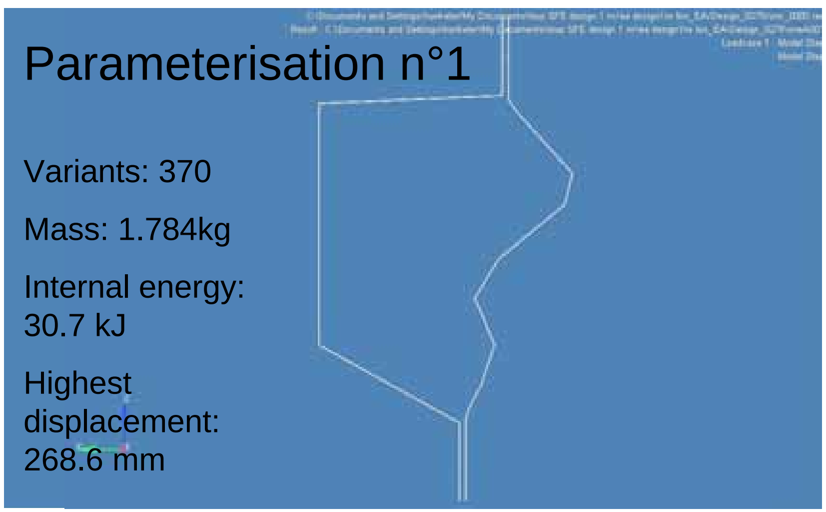
XA1	
LG1	YG1
XB1	
PG4	YG4
PG5	XG5
PG6	XG6

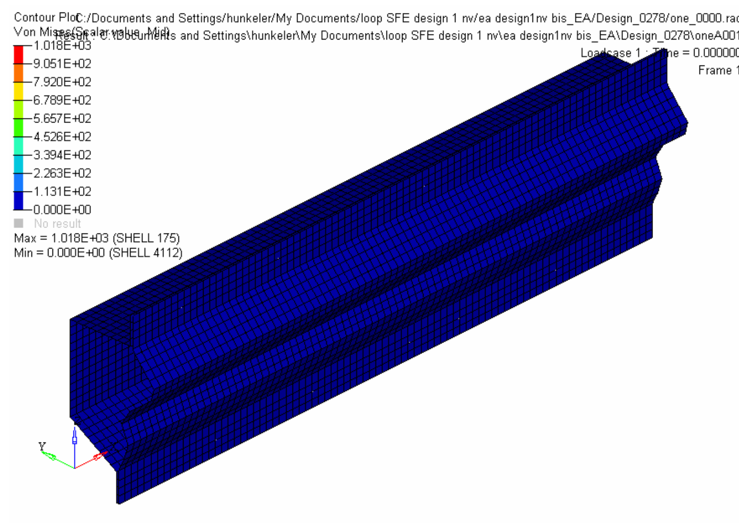
-



Real Evaluation Problem
Optimisation

- Ran exclusively with Evolutionary Algorithms
- Stochastically generated starting population (but inside the constrained design space)
- Several parameterisations tested





Real Evaluation Problem
Optimisation Results

- Results and number of designs computed are highly dependant on starting population;
- Difficulties to ponder between improving the objective function and reaching the output constraints;
- Though, good results for a few parameterisations (work in progress);

Further Developments

- Combination of ARSM on coarse parameterisation and EA on a complex parameterisation based on previous optimum
- Better way of dealing with the allocated space using « offset mapping »
- Combination with simplified crash models (VCS or similar)

Functions we could have used

- For response surface generation, an option to prioritise sample points
- For EA, population generation taking into account the input constraints (and correctly distributed in the design space)
- Post-treatment, check the accuracy of consecutive hyper-surfaces in ARSM methods

Conclusions

- Morphing approach should be complemented by true shape alterations via SFE CONCEPT
- High number of variables
- Good parameterisations required
- Good optimisation algorithms required (combination ARSM & EA)
- Further work necessary …

Acknowledgements

I would like to thank all people involved in the project

- Hans Zimmer and the collaborators of SFE GmbH
- Johannes Will and the team of Dynardo
- Laurent Rota / Malek Zarroug for industrial aspects
- Prof Ehrlacher and all people involved at the Ecole des Ponts ParisTech
- The friendly licensing by Altair/UK

- And especially: Stephan Hunkeler for his great work.

F. Duddeck, WOST 2009