Topology optimization for nonlinear applications using LS-TaSC

David Aspenberg, PhD
david.aspenberg@dynamore.se

Document information

Doc. no.:
Revision: 1
Prepared for: Webinar
Project no.:
Approved by:
Release date: 2021-03-11
Distribution: Approved for public release

DYNAmore Nordic AB
Brigadgatan 5
SE-587 58 LINKÖPING
Sweden

Org. no. 556819-8997
EC VAT: SE556819899701

Phone: +46 (0)13 236680
Fax: +46 (0)13 214104
E-mail: info@dynamore.se
Web: www.dynamore.se

Outline

- Introduction
  - General information
  - LS-TaSC or LS-OPT?
  - Topology Optimization
  - LS-TaSC 4.2 Features
- Working with LS-TaSC
  - Basic idea
  - LS-TaSC inputs
  - Optimization formulation
  - Local optimization formulation
  - Constrained optimization
- Examples
  - 2D bumper example
  - U-bend tool
  - 3D bumper example
    - From topology optimization to CAD
- Further reading

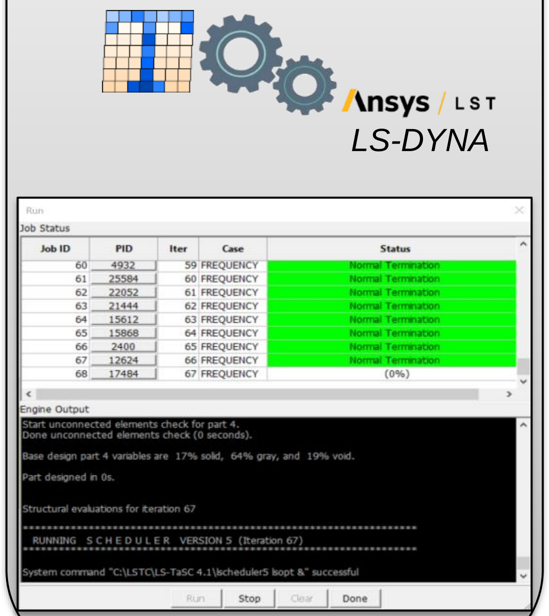
INTRODUCTION

Introduction – General Information

- Current production version is LS-TaSC 4.2 (November 2020)
  - Windows and Linux versions available
- LS-TaSC is closely integrated with
  - LS-DYNA
  - LS-PrePost
  - LS-OPT

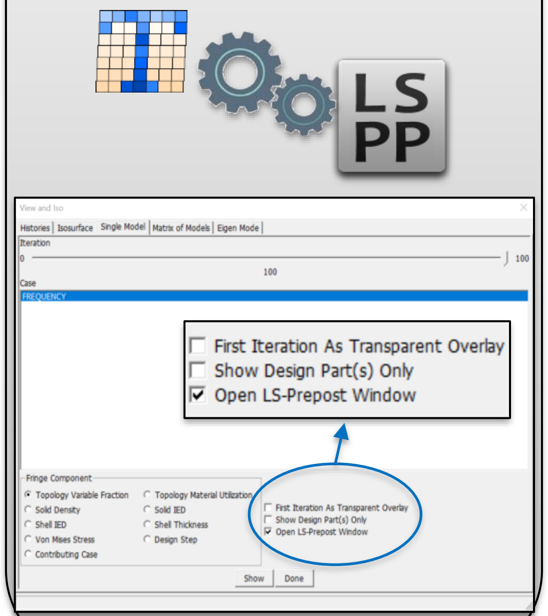
LS-TaSC with LS-DYNA

- no special treatment for non-linearities



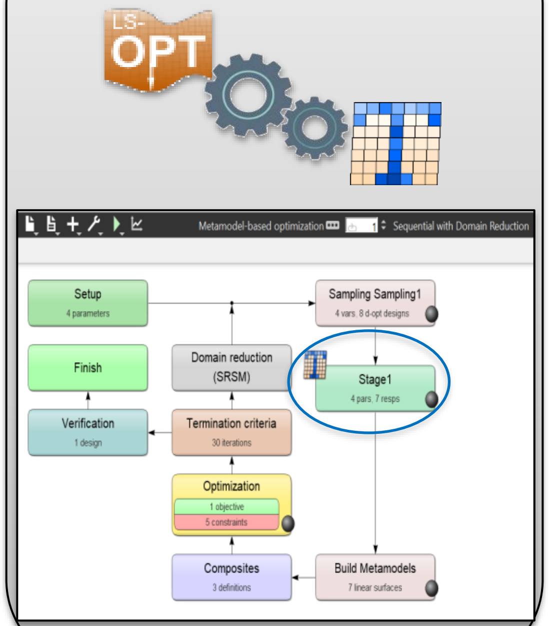
LS-TaSC with LS-PrePost

- results visualization
- model editing



LS-TaSC with LS-Opt

- multilevel and complex design schemes



Introduction – LS-TaSC or LS-OPT?

- Classification of Structural Optimization Techniques
  - Topology optimization
    - shape, size, and location of gaps in the defined domain is derived by the optimizer
  - Topometry optimization
    - shell thickness is designed per element basis
  - Shape optimization
    - a free shape of the outer surface contour is chosen

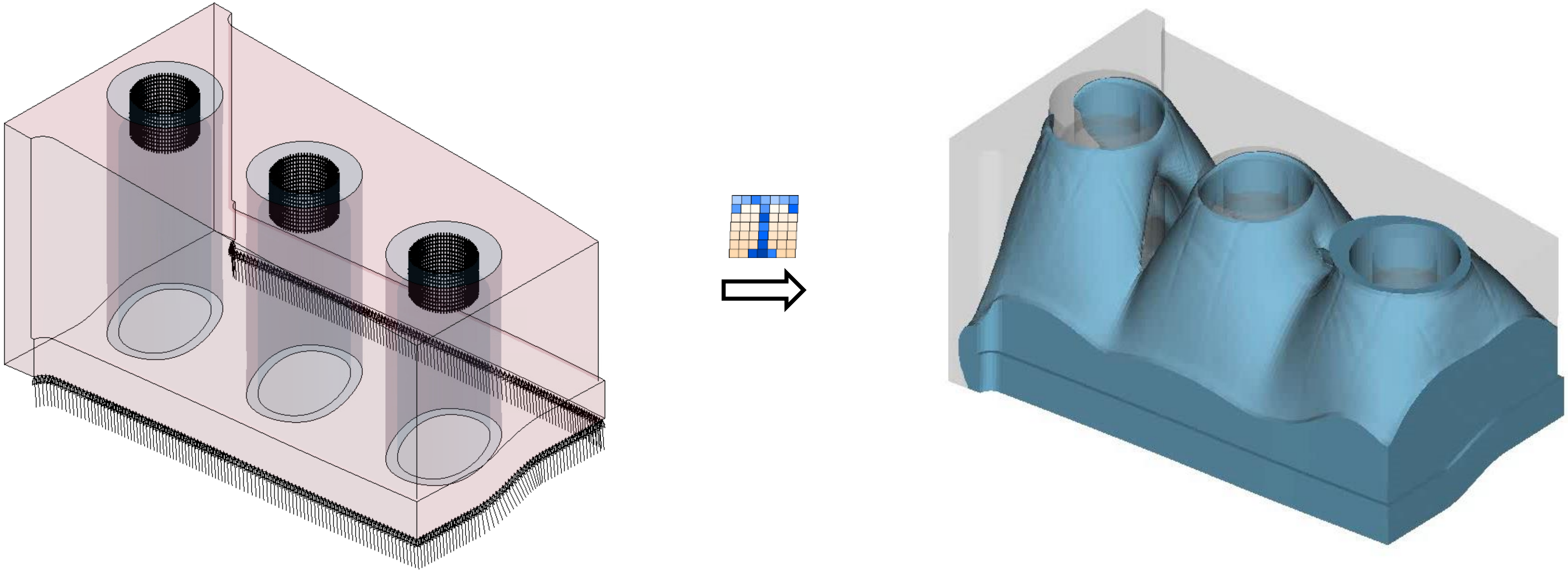
LS-TaSC

LS-OPT

  - Size optimization
    - shell thickness is designed per part basis
  - Shape optimization
    - parameterized geometry (e.g. a hole radius) is designed

Introduction – Topology Optimization

- *“**Topology optimization (TO)** is a mathematical method that optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints with the goal of maximizing the performance of the system.”* – Wikipedia



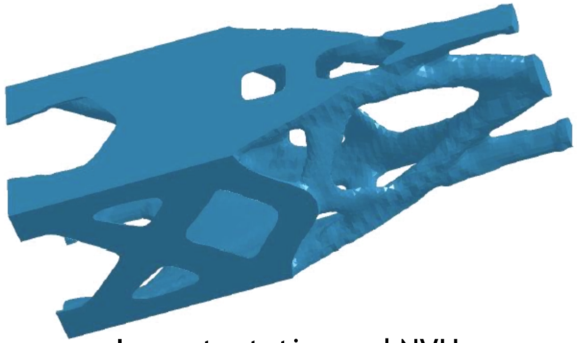
Asnafi N., Rajalampi J., Asoenberg D., Alveflo A., “Production Tools Made by Additive Manufacturing Through Laser-based Powder Bed Fusion”, Berg Huettenmaenn Monatsh 165, 125–136 (2020). https://link.springer.com/article/10.1007/s00501-020-00961-8

Introduction – LS-TaSC 4.2 Features

- Big development steps regarding features were taken to version 4.0. Versions 4.1 and 4.2 have continued to improve on the new features.
- LS-TaSC 4 focuses on the design of **huge models** for a combination of **statics**, **NVH** and **impact**, i.e. multidisciplinary topology optimization.
- Key features for LS-TaSC are:
  - **Non-linear problems** (material properties, contacts, deformations)
  - **Dynamic loads** (impacts, time-varying boundary conditions)
  - **Huge models** (examples of 10 million elements have been showed)
  - **Multiple load cases** (static, dynamic, NVH)
  - **Global constraint handling** using multipoint optimization and metamodeling techniques (energy absorption, maximum reaction force, maximum displacement)
- The projected subgradient method enabled the use of NVH in topology optimization, but it also enhanced the convergence of the optimizations.

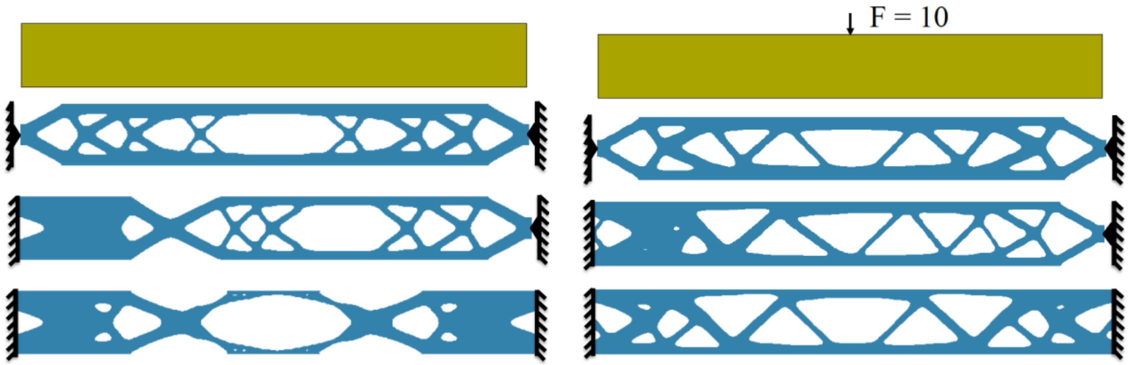
Introduction – LS-TaSC 4.2 Features

- For a full overview of the new features in LS-TaSC 4 and more examples, see: https://www.dynamore.de/de/download/presentation/2020/copy_of_dynamore-express-overview-on-ls-tasc-and-new-features-in-version-4.1

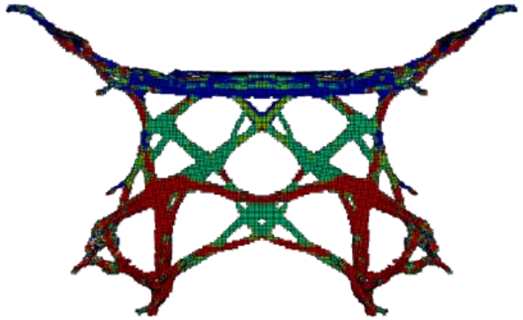


Impact, statics and NVH

Side impact



NVH and static loads

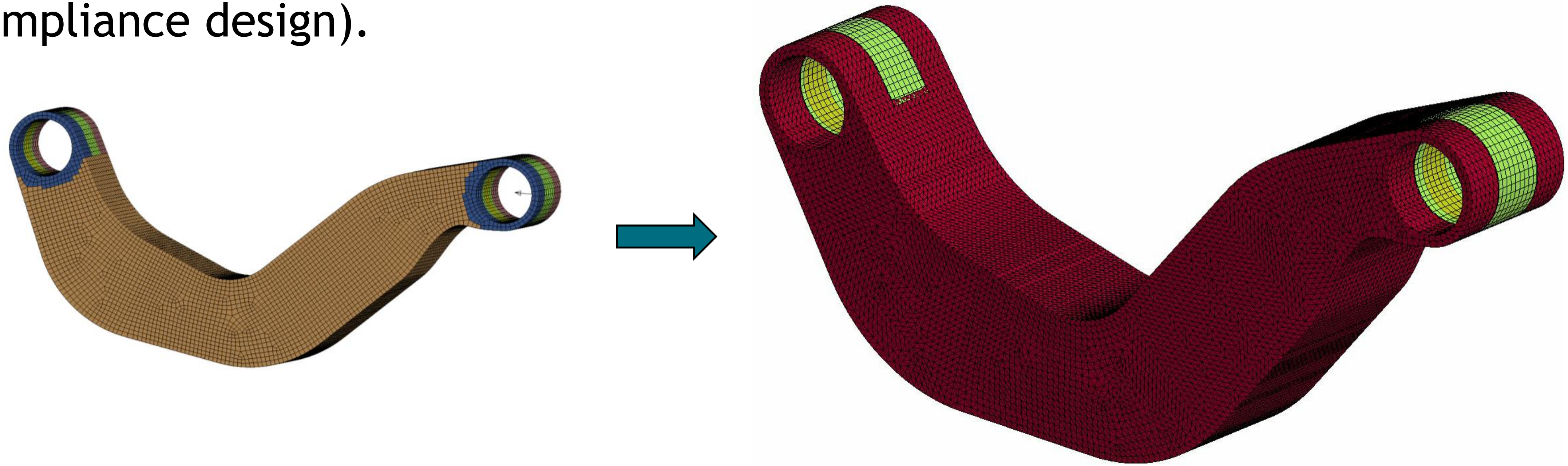


Hood design
Rear beam, bending and torsion

WORKING WITH LS-TASC

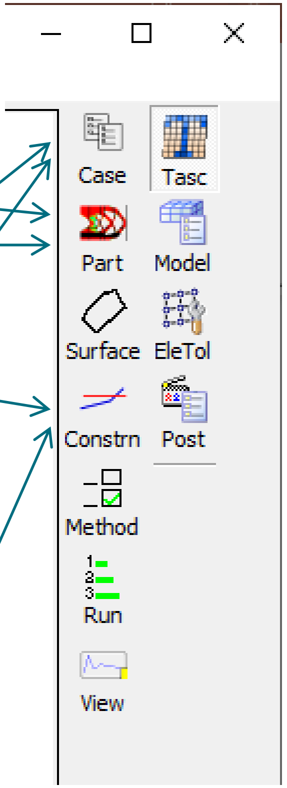
Working with LS-TaSC – Basic idea

- Through topology and shape optimization of very large non-linear problems, LS-TaSC is a tool for generating a concept design.
- This is achieved by redistributing material within a given domain to achieve a uniform strain energy density distribution.
- The outcome is typically the stiffest structure for the given weight (minimum compliance design).



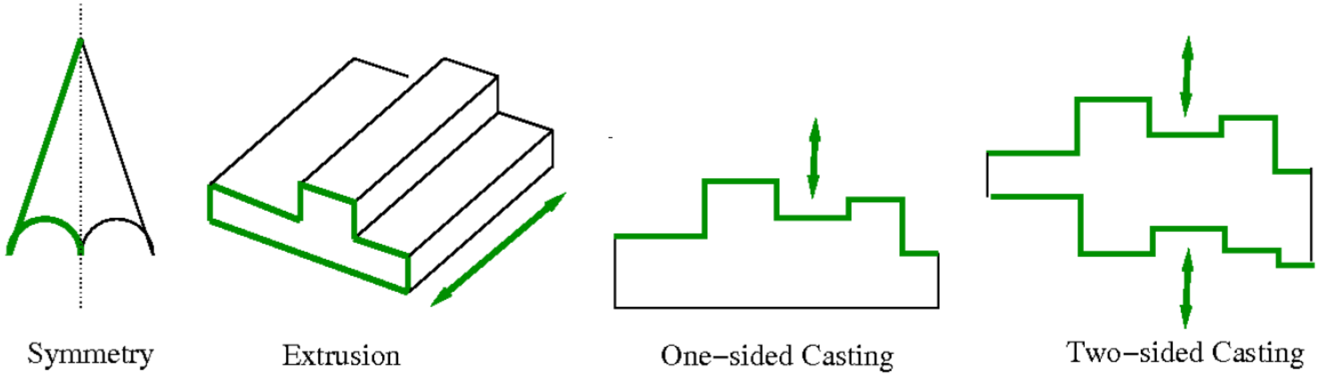
Working with LS-TaSC – LS-TaSC inputs

- What to optimize
  - Select parts to optimize, both shells and solids can be designed
  - Select mass fraction
  - Select global objective (only if multipoint method is set)
    - Minimum mass, target mass fraction, fundamental frequency, constraint
- Load cases
  - Specified through normal LS-DYNA input decks, linear or non-linear
  - Multiple load cases means that weighting can be used
- Define global constraints
  - Maximum displacement, energy absorption, maximum reaction forces, …



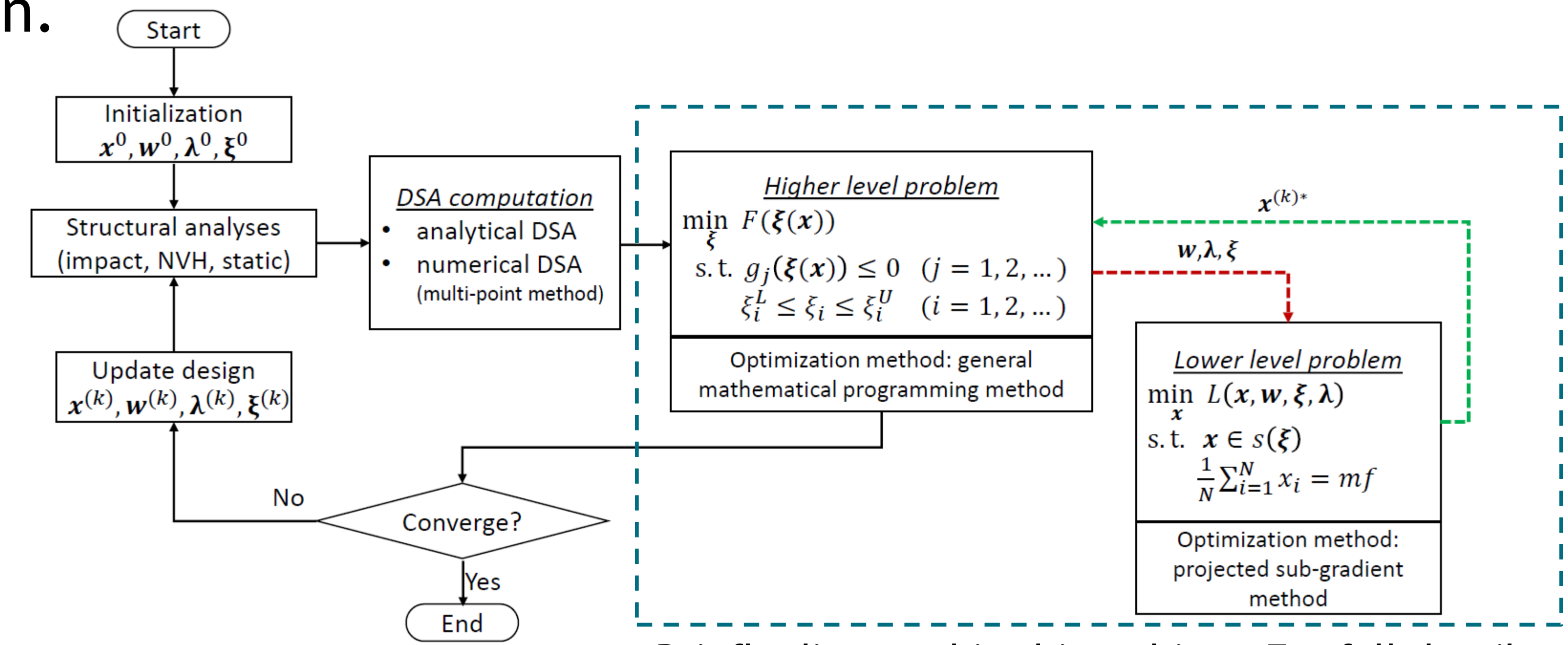
Working with LS-TaSC – LS-TaSC inputs

- Geometry definitions
  - Symmetry
  - Extrusion
  - Casting
    - One-sided
    - Two-sided
  - Forging
    - As two-sided casting but with minimal thickness preservation
  - No interior holes



Working with LS-TaSC – Optimization formulation

- The most general setup is the constrained multidisciplinary topology optimization.



Briefly discussed in this webinar. For full details, see e.g. paper below and its references or the Theory Manual.

Roux W., Gandikota I., Yi G., "Constrained Multidisciplinary Topology Optimization",16th International LS-DYNA® Users Conference, Virtual Event, 2020.
https://www.dynalook.com/conferences/16th-international-ls-dyna-conference/isogeometric-analysis-topology-and-shape-optimization-t10-1/t10-1-b-topology-and-shape-optimization-053.pdf/view

Working with LS-TaSC – Optimization formulation

- Topology design is formulated as a nested optimization including sequentially solved global and local problems.
  - Global variables:
    - Load case weighting factors
    - Mass fractions of the parts
  - Local variables:
    - Element volume fractions

Multi-point methods

Global problem

Global variables
- Mass fractions of design parts
- Load case weights
- Lagrange multipliers for eigenvalues analysis cases

Global constraints
- Maximum displacements
- Maximum reaction forces
- …

Design algorithm:
- Optimality criteria
- Projected subgradient method

Local problem

Local variables
- Element volume fractions

Local constraints
- Mass fractions of design parts

- LS-OPT can solve the global problem by setting LS-TaSC as a stage in LS-OPT. Again, this will not affect the solution of the local problem either, but help solving for the global constraints.

Working with LS-TaSC – Local optimization formulation

- For the original design algorithm "optimality criteria" (pre version 4), the local optimization aims at an equally stressed structure, achieved by adding mass where a lot of internal energy is seen and vice versa.

$$\min_{\boldsymbol{\rho}} \sum_{i=1}^{l}\sum_{j=1}^{n} w_i\left[U_{ij}(\rho)-\overline{U}_i\right]$$

create a design with uniform internal energy density

$$\text{s.t.:}\quad \chi(\boldsymbol{\rho})-1\leq 0$$

stay above current target mass

$$\boldsymbol{\rho}^L \leq \boldsymbol{\rho} \leq 1$$

where

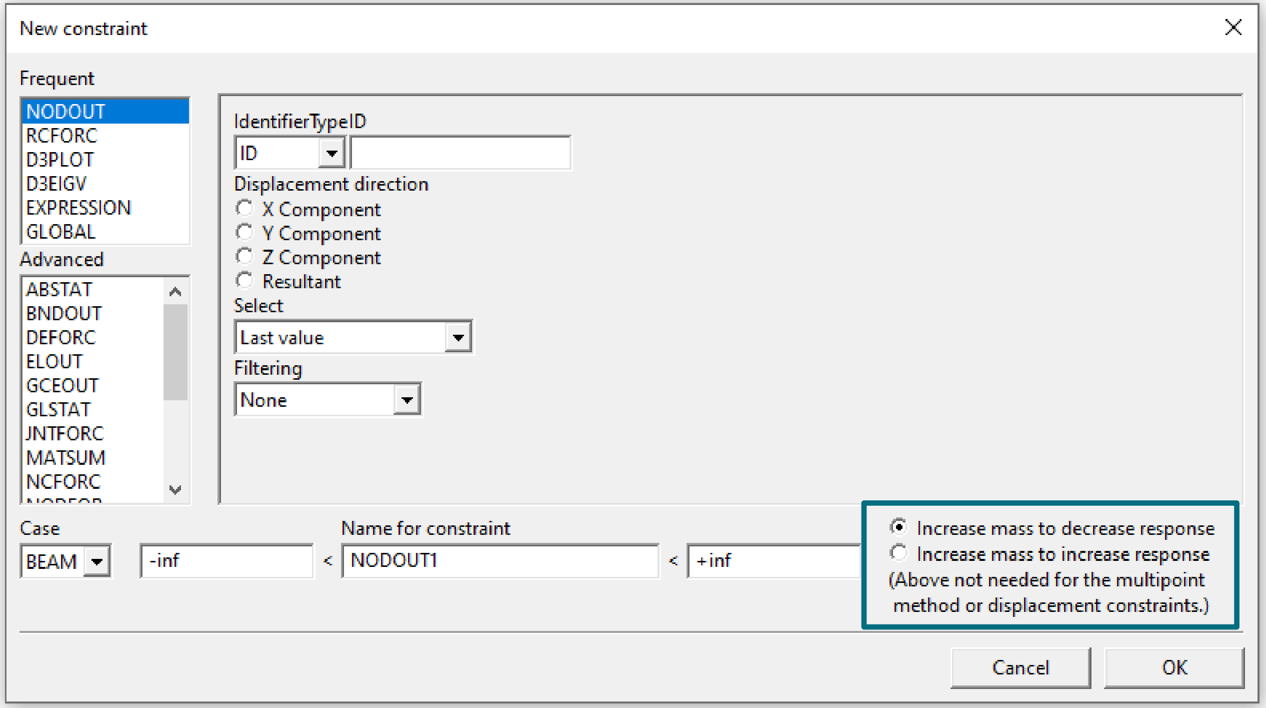
U_{ij} = internal energy density of the jth element in the ith load case

$\overline{U}_i$ = target internal energy density in the ith load case

- The new design algorithm "projected sub-gradient method" can also maximize the fundamental frequency, whilst maximizing the stiffness of the structure for the impact and linear statics load cases. It is also more efficient.

Working with LS-TaSC – Constrained optimization

- Constraint definition:



- The part mass fraction variables are used to fulfil the constraint.
- Similarly, changing the load case weights (manually or automatically) can help to fulfil a constraint.

Working with LS-TaSC – Constrained optimization

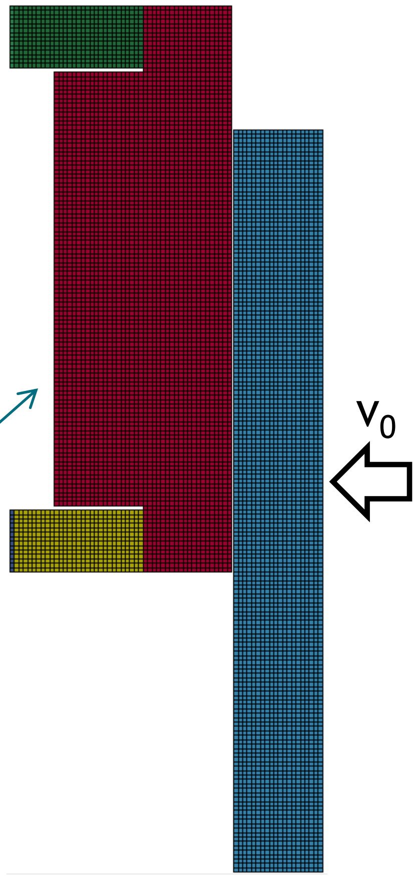
- *“It should be understood that the structure is always designed to be stiffest structure possible, but with the global variables selected such as to satisfy the constraints.”*
- Constrained optimization uses the part mass fractions, load case weights and Lagrange multipliers from eigenvalue analyses as global variables.
- To solve the global optimization problem, multipoint methods exist in LS-TaSC. Several simulations are performed in each iteration to set the global variables.
- Displacement constraints, being directly related to the stiffness of the structure, are good choices of constraints.
- The topology design process will not resolve issues such as stress concentrations.
- Also consult Section 2.8.6 in the User Manual – “*Best practices*”

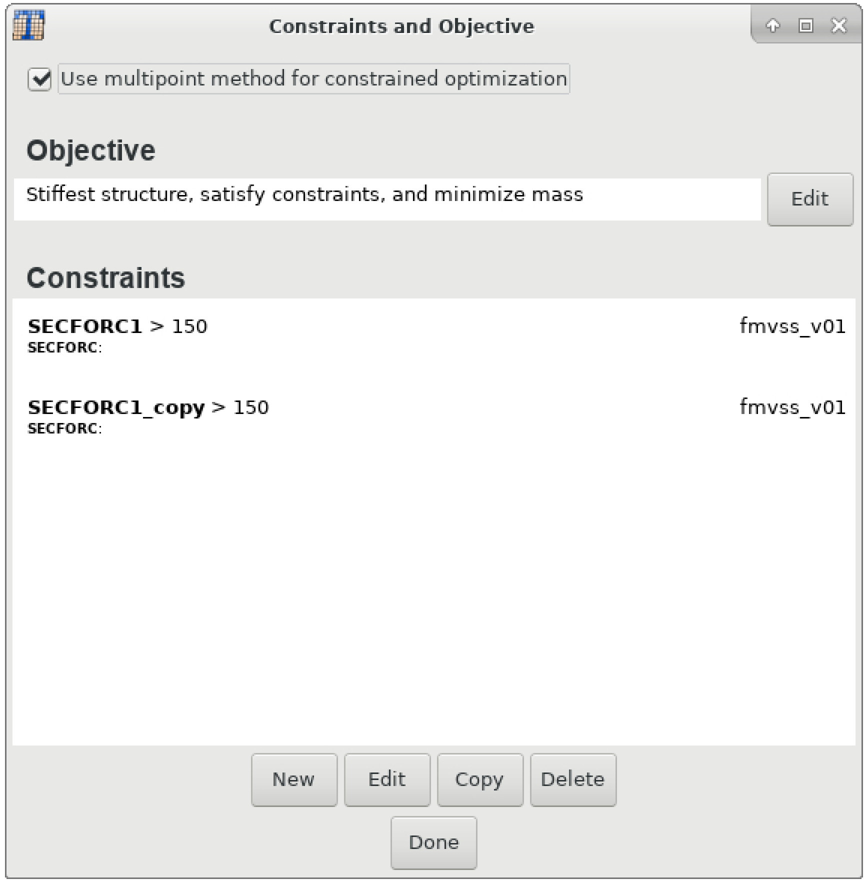
EXAMPLES

2D bumper example – original model

- It would be ideal to distribute the impact load on the two sides equally.
- A constraint is added to reach a certain force level on each side.

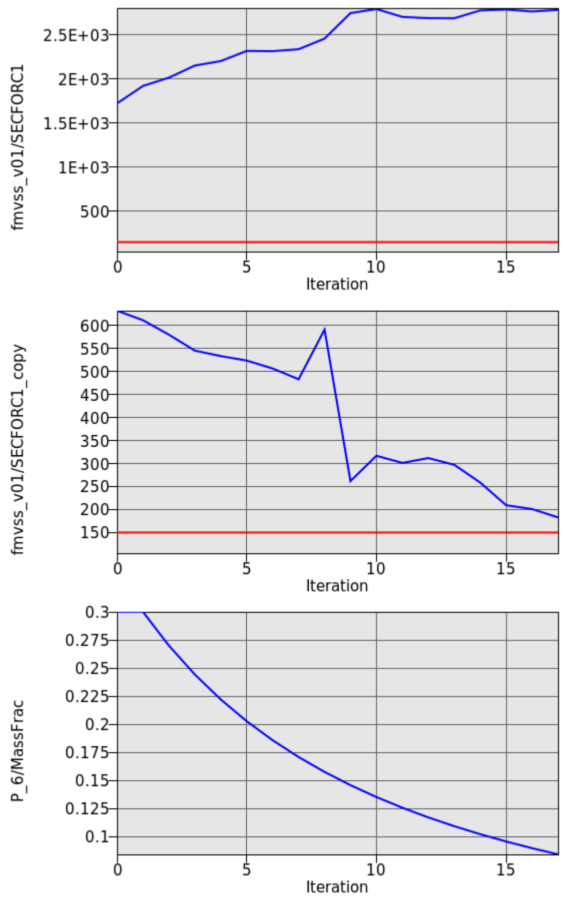
Design volume

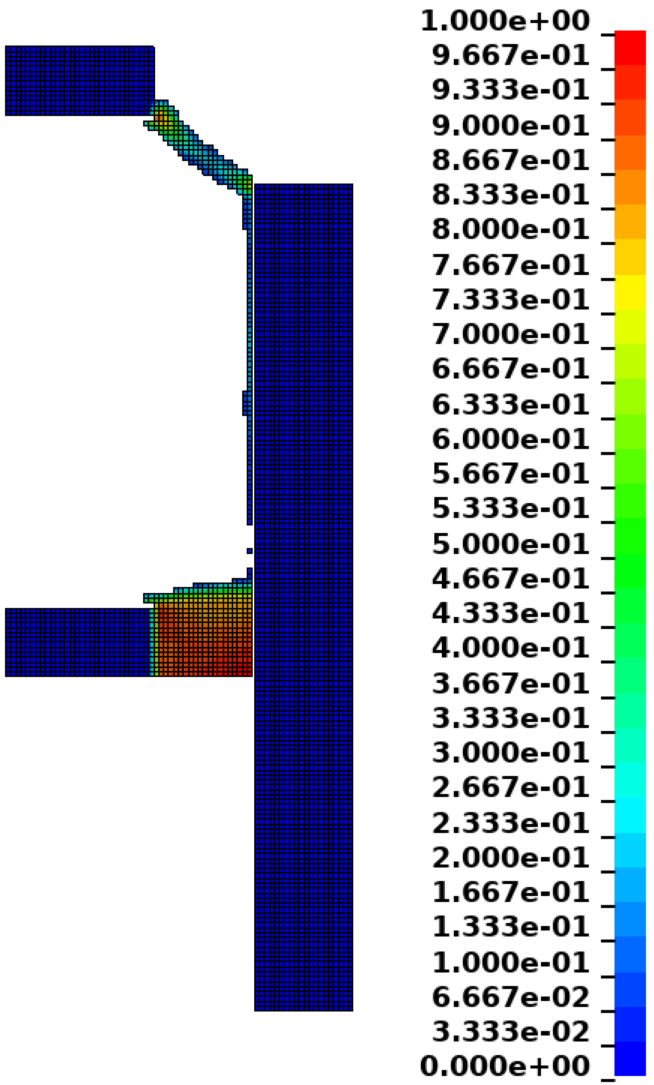




2D bumper example – original model results

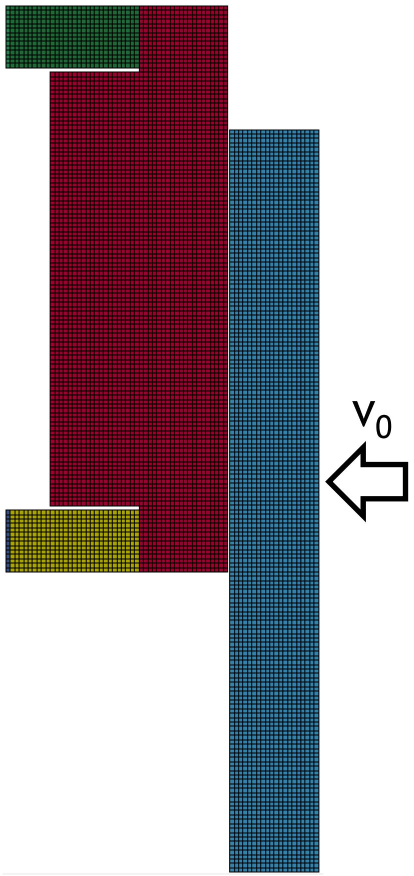
- Mass is removed from the model, but a high force level is achieved on one side
- The load will not be distributed equally to both sides.

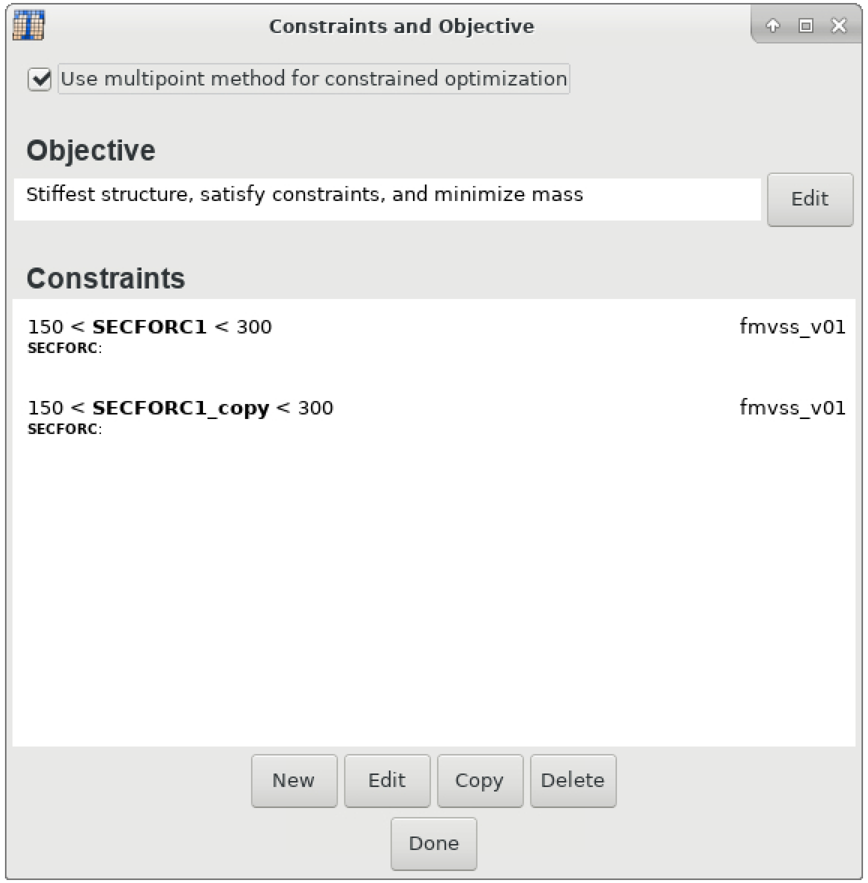




2D bumper example – upper force constraint added

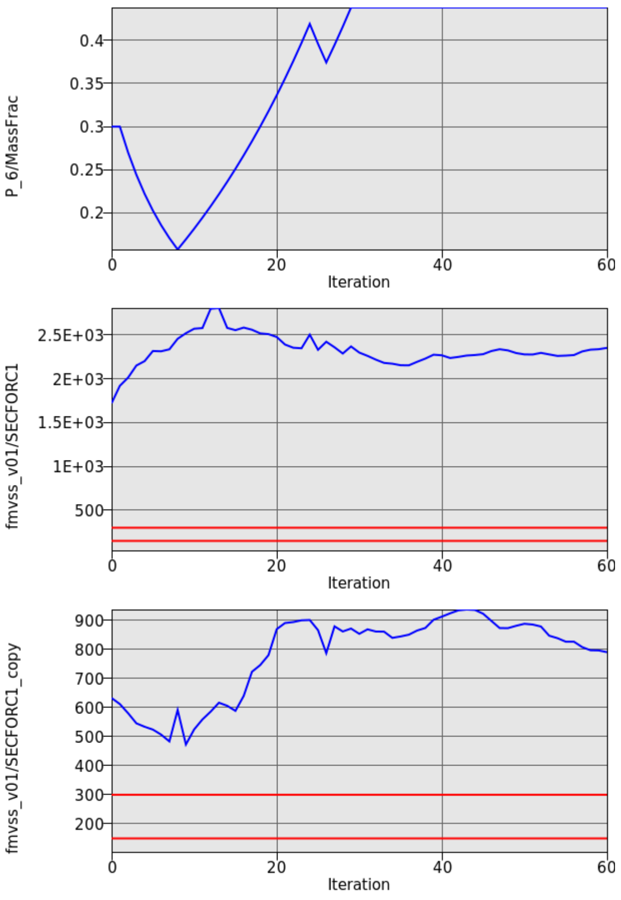
- Try to add a constraint for maximum force level.

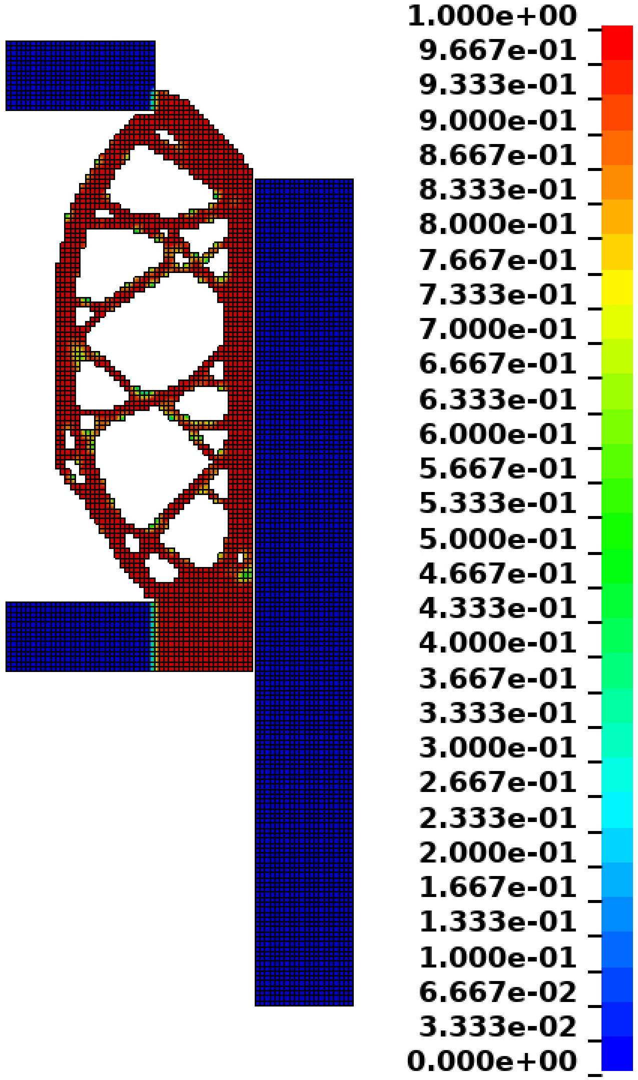




2D bumper example – upper force constraint added results

- Mass is initially removed from the model, but the force constraints cannot be fulfilled.
- Force distributions between sides more equal, a trade-off has been attempted.



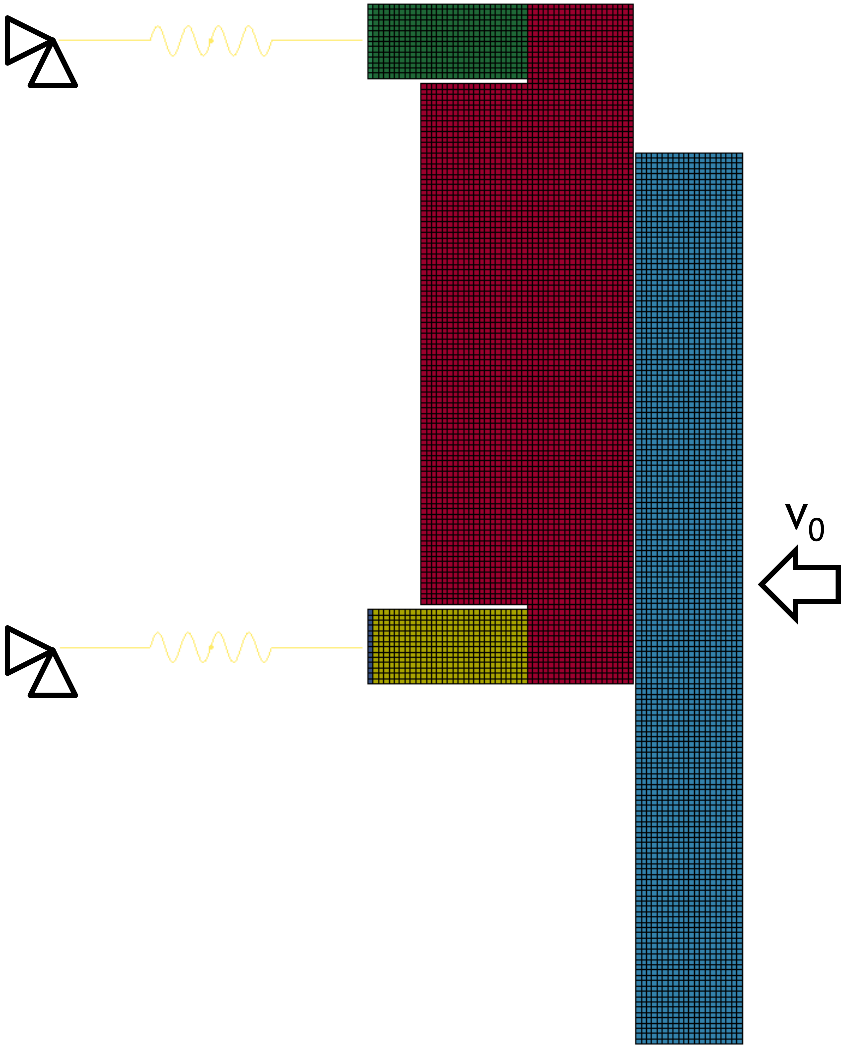


2D bumper example – Other possible modifications of set-up?

- There are some other modification of the set-up that can be made to get the results we want.
- General ideas:
  - Manipulate the boundary conditions in the model.
  - Add geometry definition, e.g. symmetry.
  - Add more load cases.
  - Split the design volume into several design volumes, thereby forcing mass to be put on many areas. (This is also a trick to increase the number of global variables if there are many constraints in the setup.)

2D bumper example – model with new boundary conditions

- Discrete elements behind rigid bodies.
- The discrete elements are set to carry a load of 150N.
- No constraints in the topology optimization set-up.

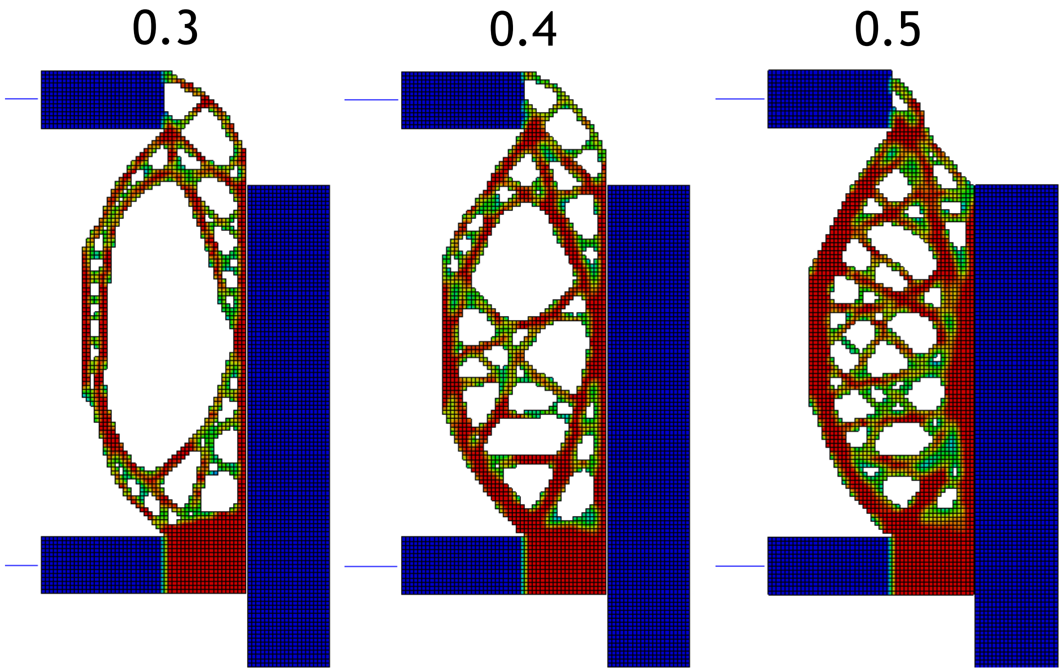



```
*PART
$#                                                                         title
discrete elements
$#     pid     secid       mid     eosid      hgid      grav    adpopt      tmid
         9         2         5         0         0         0         0         0
*SECTION_DISCRETE_TITLE
discrete section
$#   secid       dro        kd        v0        cl        fd
         2         0       0.0       0.0       0.0       0.0
$#     cdl       tdl
       0.0       0.0
*MAT_SPRING_INELASTIC_TITLE
nonlinear spring for discrete elements
$#     mid      lcfd        ku       ctf
         5         1       0.0       1.0
*DATABASE_DEFORC
$#      dt    binary      lcur     ioopt
*DEFINE_CURVE_TITLE
curve for nonlinear spring material
$#    lcid      sidr       sfa       sfo      offa      offo    dattyp     lcint
         1         0       1.0      0.15       0.0       0.0         0         0
$#                a1                  o1
                 0.0                 0.0
                 1.0                 1.0
               100.0                 1.1
```

2D bumper example – model with new boundary conditions results

- Similar optimal structure is retrieved.
- Bumper has maximized its bending stiffness, putting material on the inner and out edges.
- The new boundary condition triggers internal energy growth in elements towards the non-impact side.
- Both inner and outer sides are subjected to bend, thus there is a W-beam structure on both ends as well.
- For higher mass fractions, ribs are added in the model to handle the shearing of the bumper.

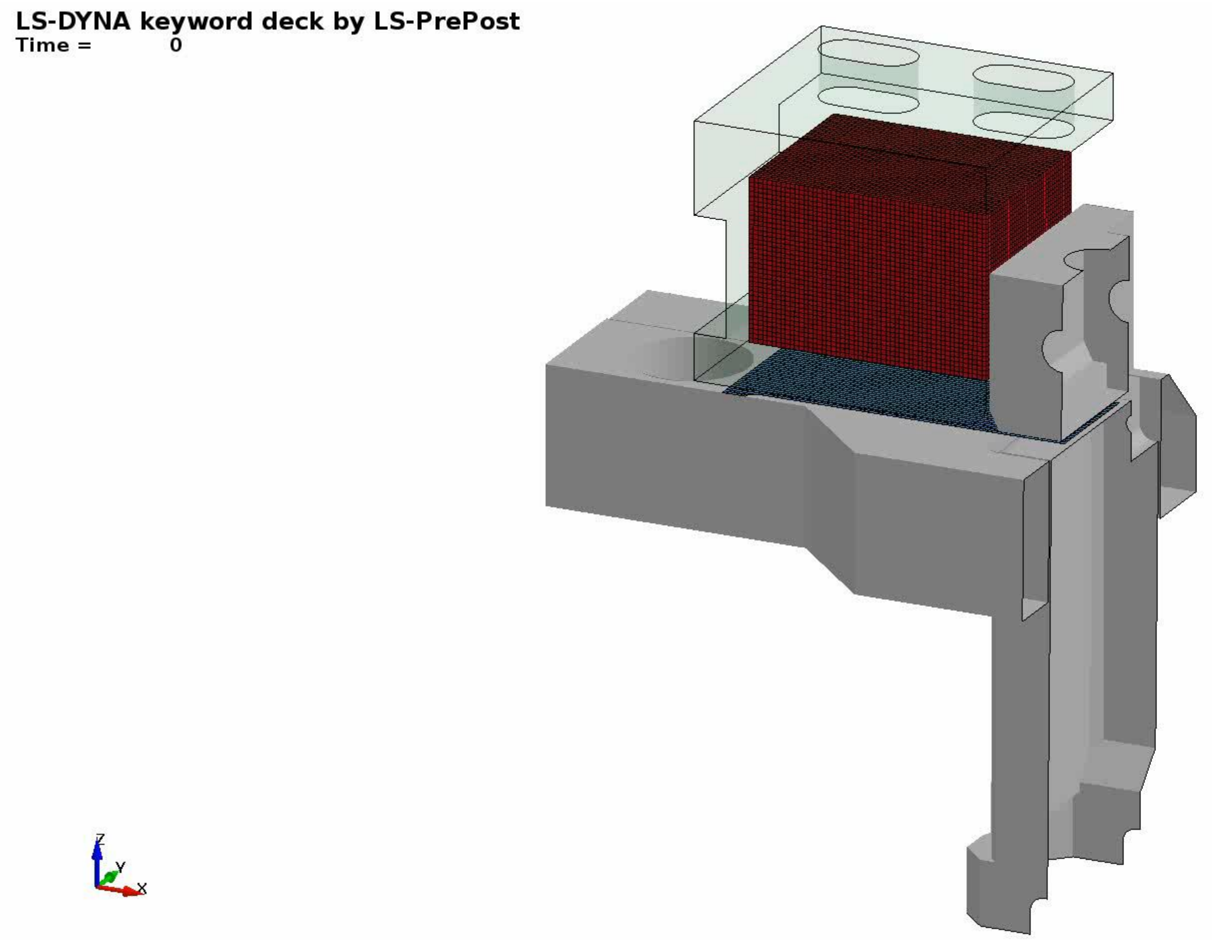
Different target mass fractions:



2D bumper example – knowledge gained

- If the goal is some kind of load distribution, an incentive for this to happen must be created.
- Global constraints are altered by changing the global variables. The local problem only knows about things like the internal energy in each element in the current load case, and does not know about the global constraints.
- Global constraint handling adds simulations to each iteration. In this bumper example, 3 simulations per iteration is performed for the case with constraints, compared to 1 simulation per iteration in the model where the boundary conditions have been changed.

U-bend tool example (symmetry model)



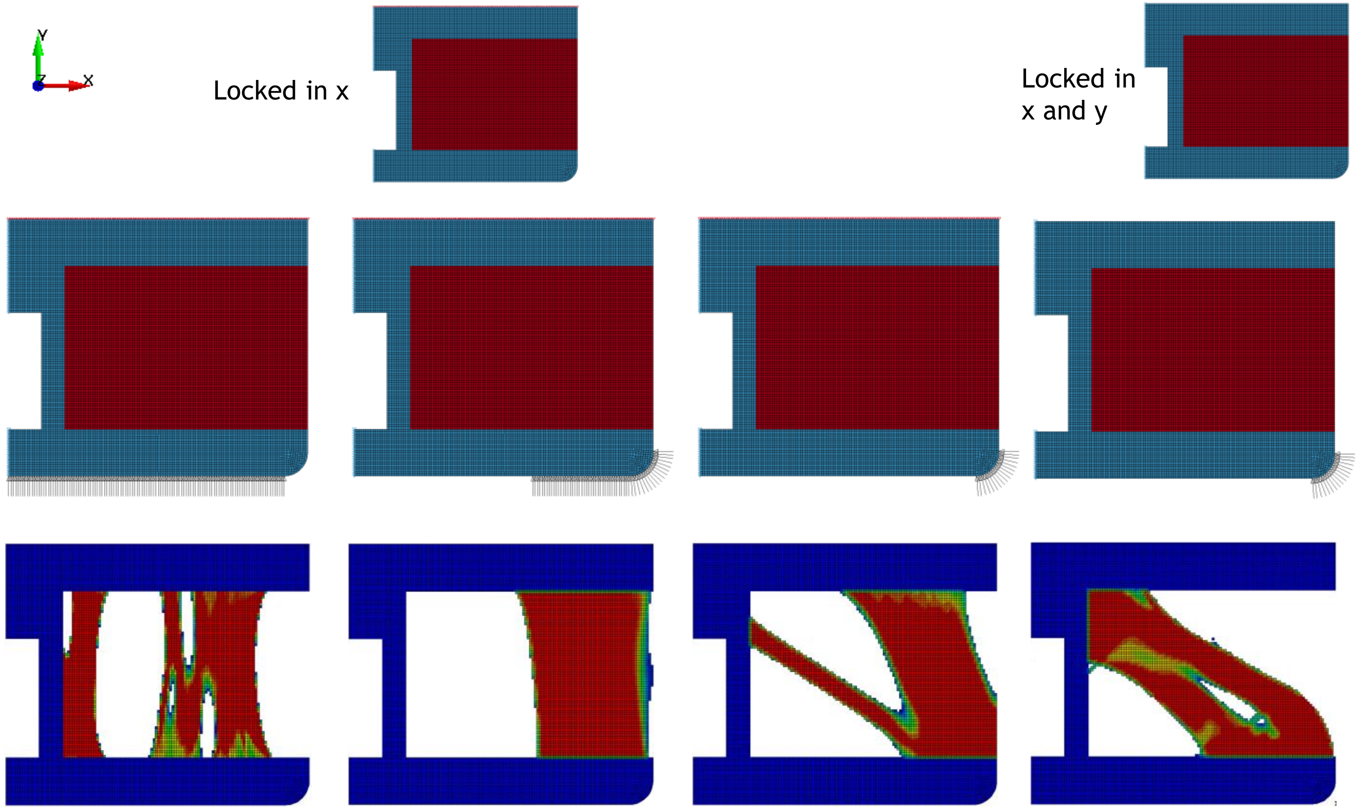
Example presented at the last European LS-DYNA conference, https://www.dynalook.com/conferences/12th-european-ls-dyna-conference-2019/optimization/aspenberg_dynamore_nordic.pdf/view

U-bend tool example – 2D model

- Test the influence of loads and boundary conditions.

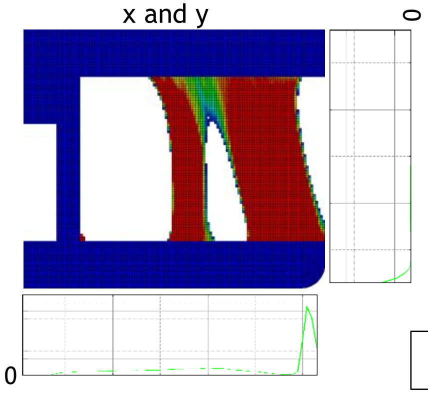
Volume fraction = 0.45

Locked in y



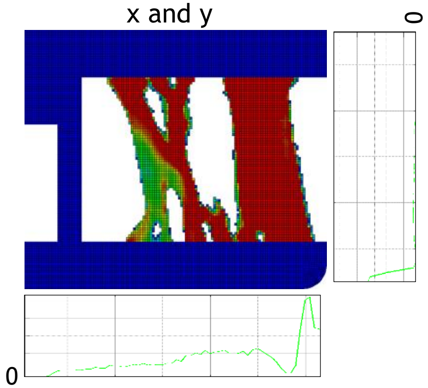
Integrated value

Locked in
x and y



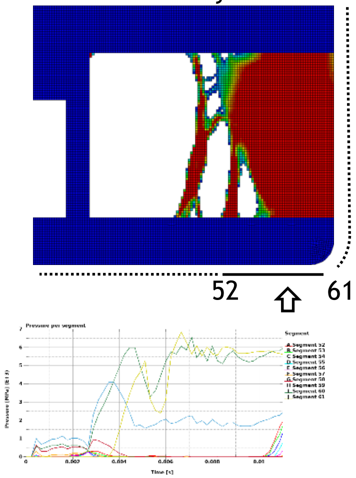
Max pressure

Locked in
x and y



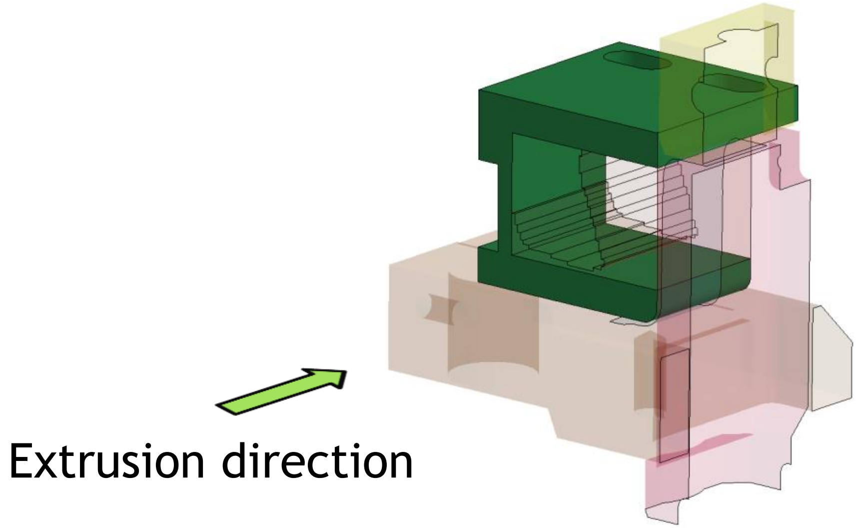
Time varying

Locked in
x and y



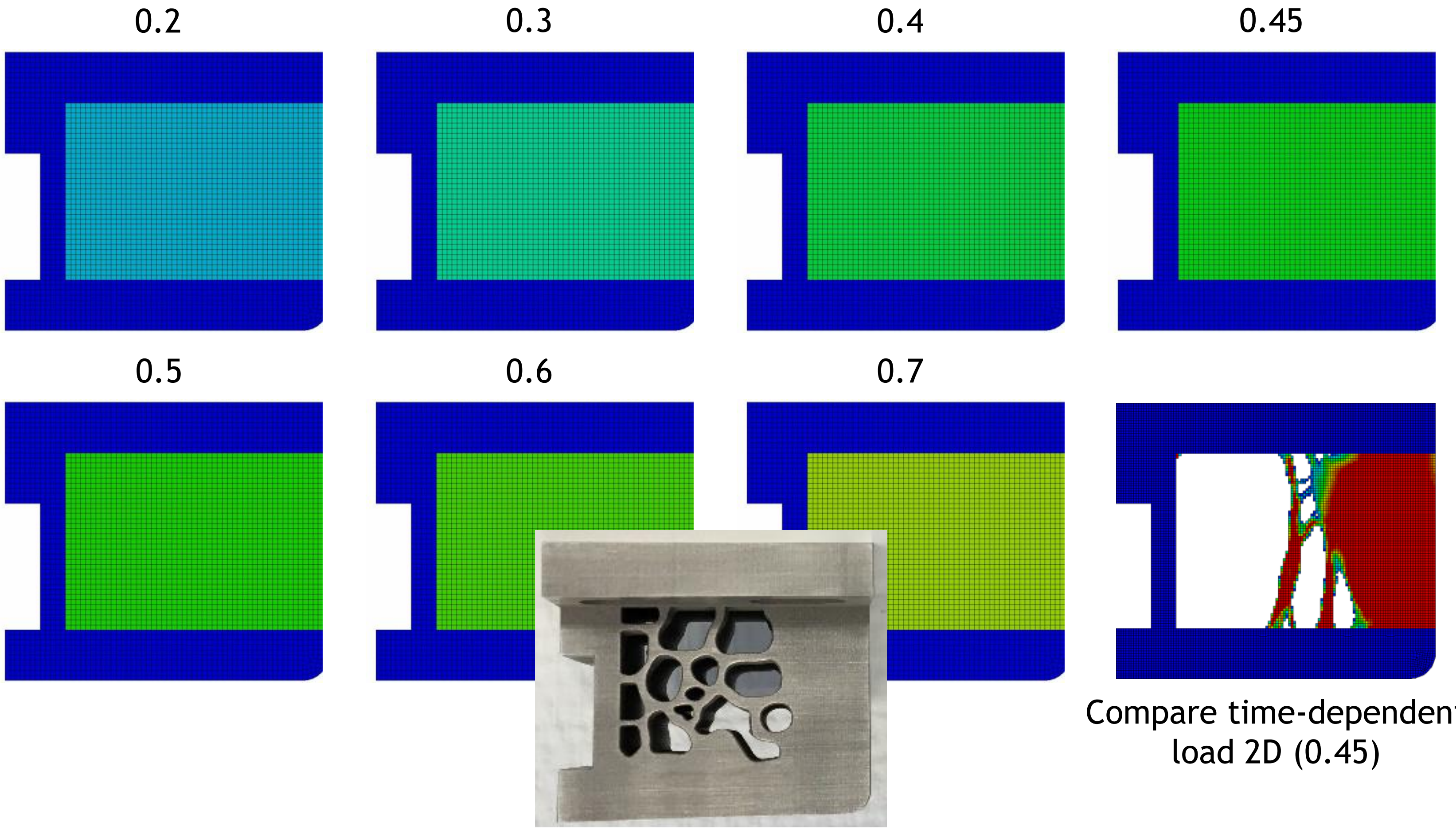
U-bend tool example – 3D model

- A 3D model with extrusion constraints was optimized in order to get results that are
  - easier to interpret
  - compare with previous results



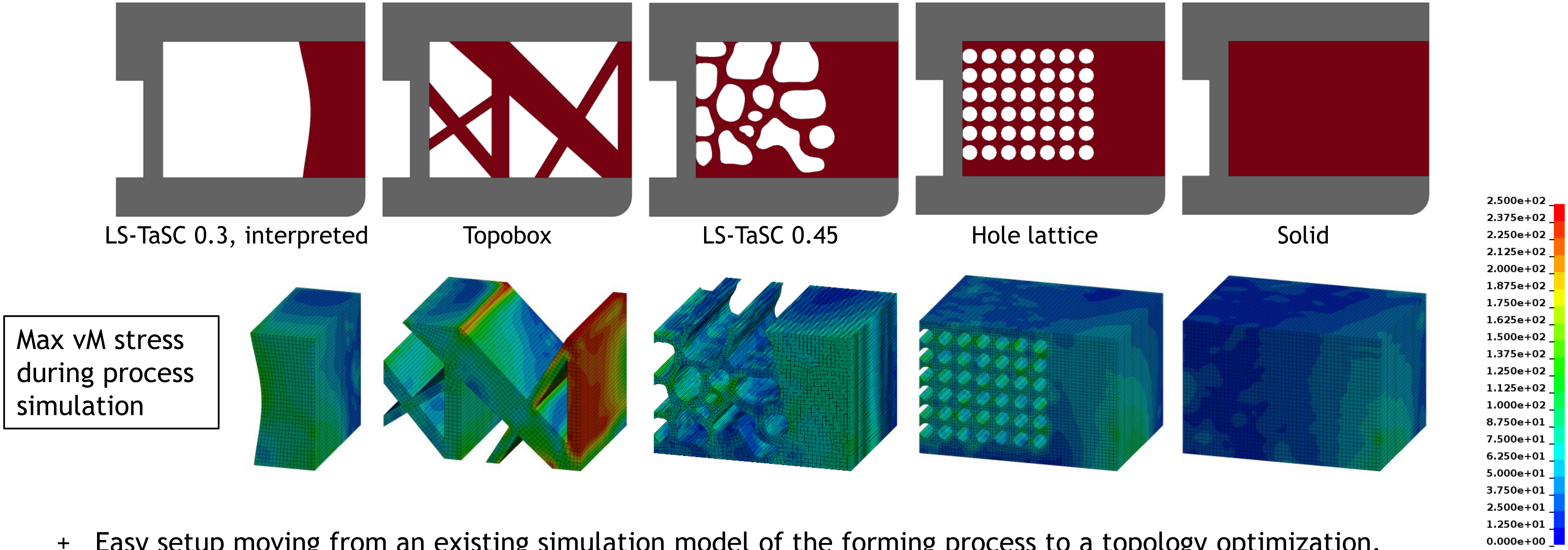
U-bend tool example – 3D model results for different mass fractions

Volume fractions:



Compare time-dependent load 2D (0.45)

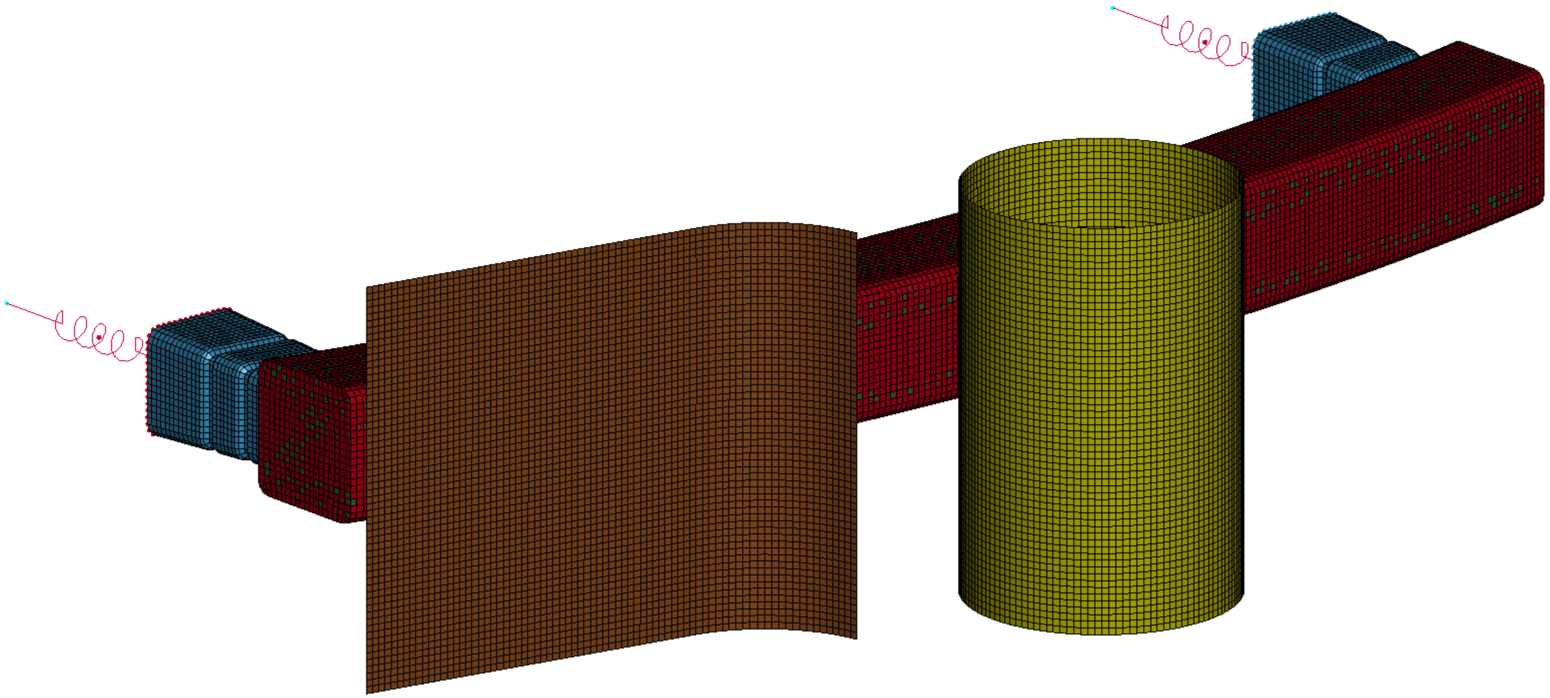
U-bend tool example – 3D model results for suggested solutions



- \+ Easy setup moving from an existing simulation model of the forming process to a topology optimization.
- \+ It seems relevant to use the actual process simulation without simplifications.
- \- Potential increase in computational cost if the process simulation is computationally expensive.
- \- Some engineering judgement of the suggested optimal topology is advised in order to make some possible simplifications to the final design.

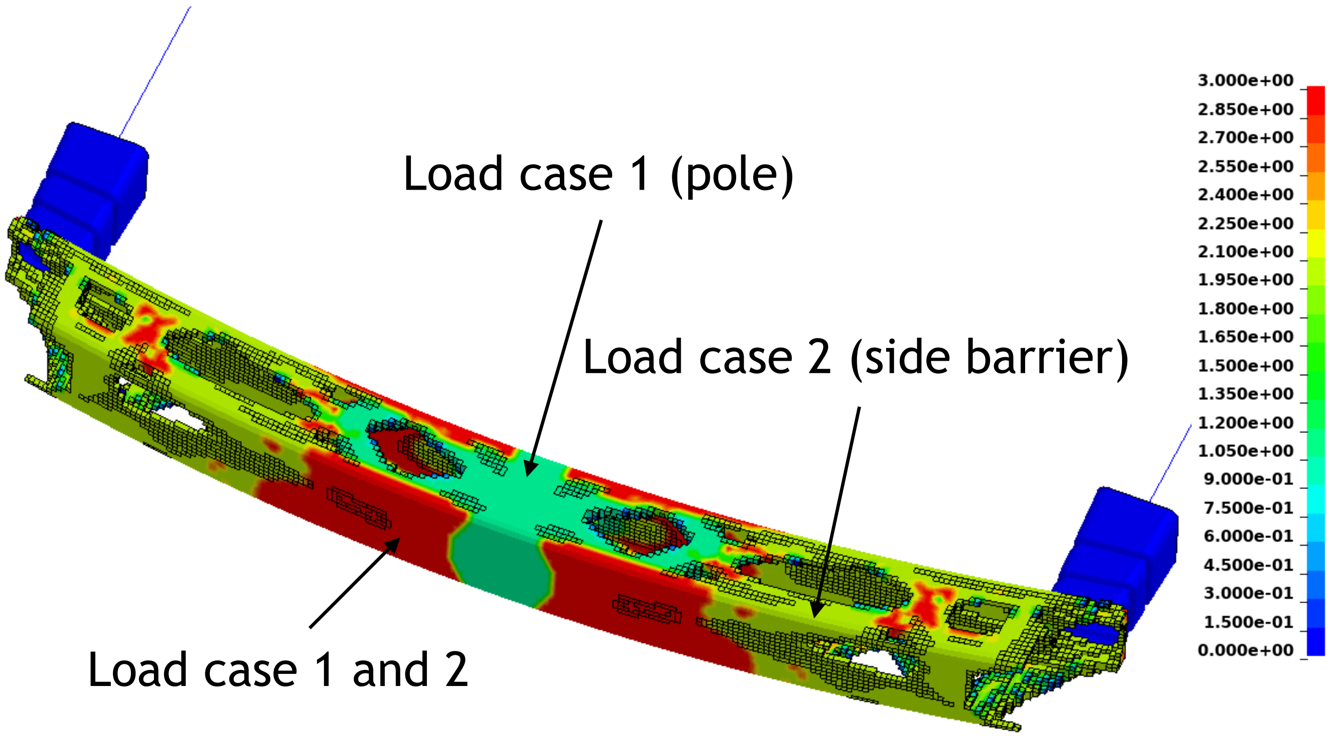
Bumper example

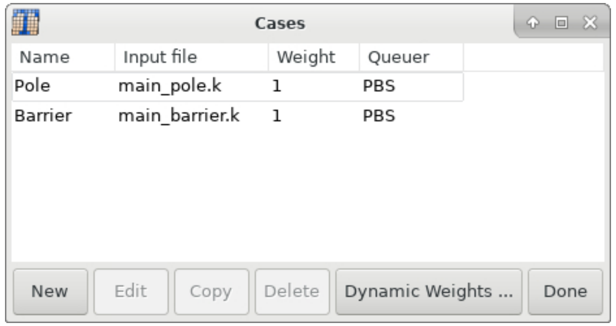
- Two impact loads are simulated on a bumper structure.
- The crossbeam is made of outer shells and filled with solid elements.
- The solid elements are to be filled with 30% material.



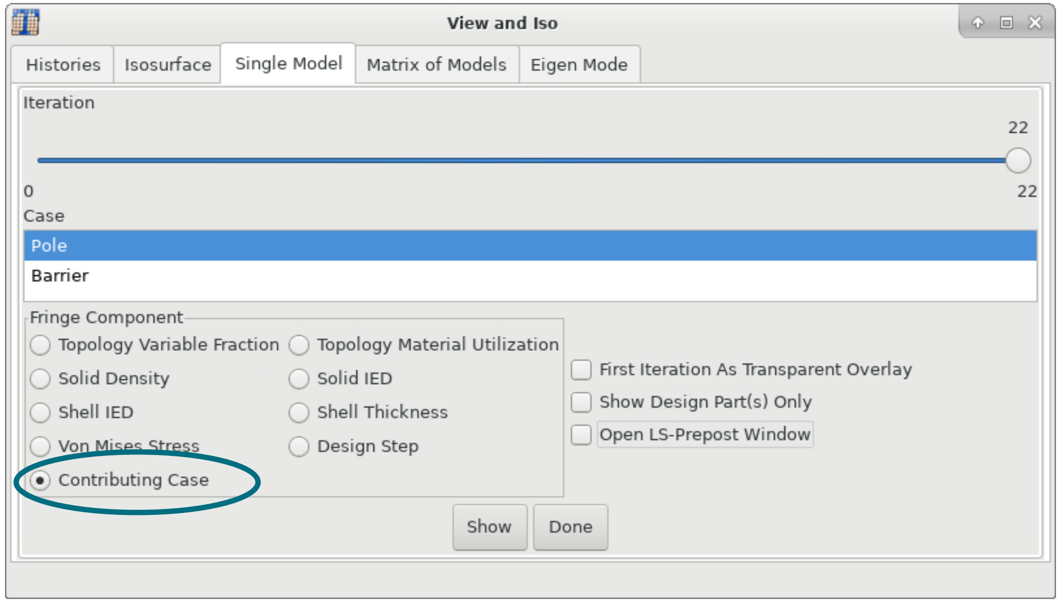
Bumper example – load case contribution

- Load case contribution can also be viewed.





MDO:
Contributing Case
0 = none
1 = LC 1
2 = LC 2
3 = LC 1+2
...

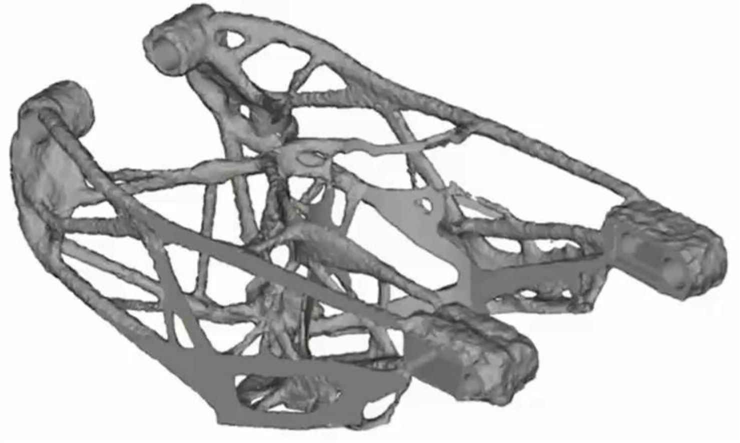


Bumper example – From topology optimization to CAD

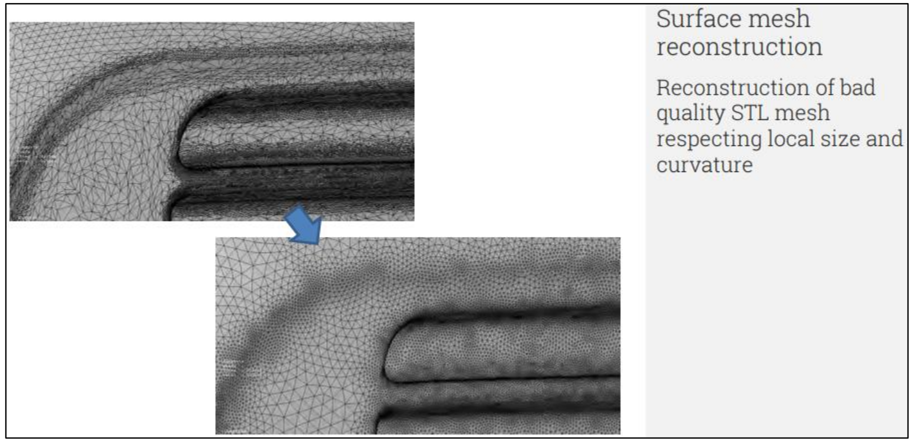
- Output from LS-TaSC has traditionally been on LS-DYNA keyword format.
- The output model can be read by LS-PrePost and in turn output to an STL model, which can be edited by most CAD software.
- In the next release, default output from LS-TaSC will be an STL model.

Bumper example – From topology optimization to CAD

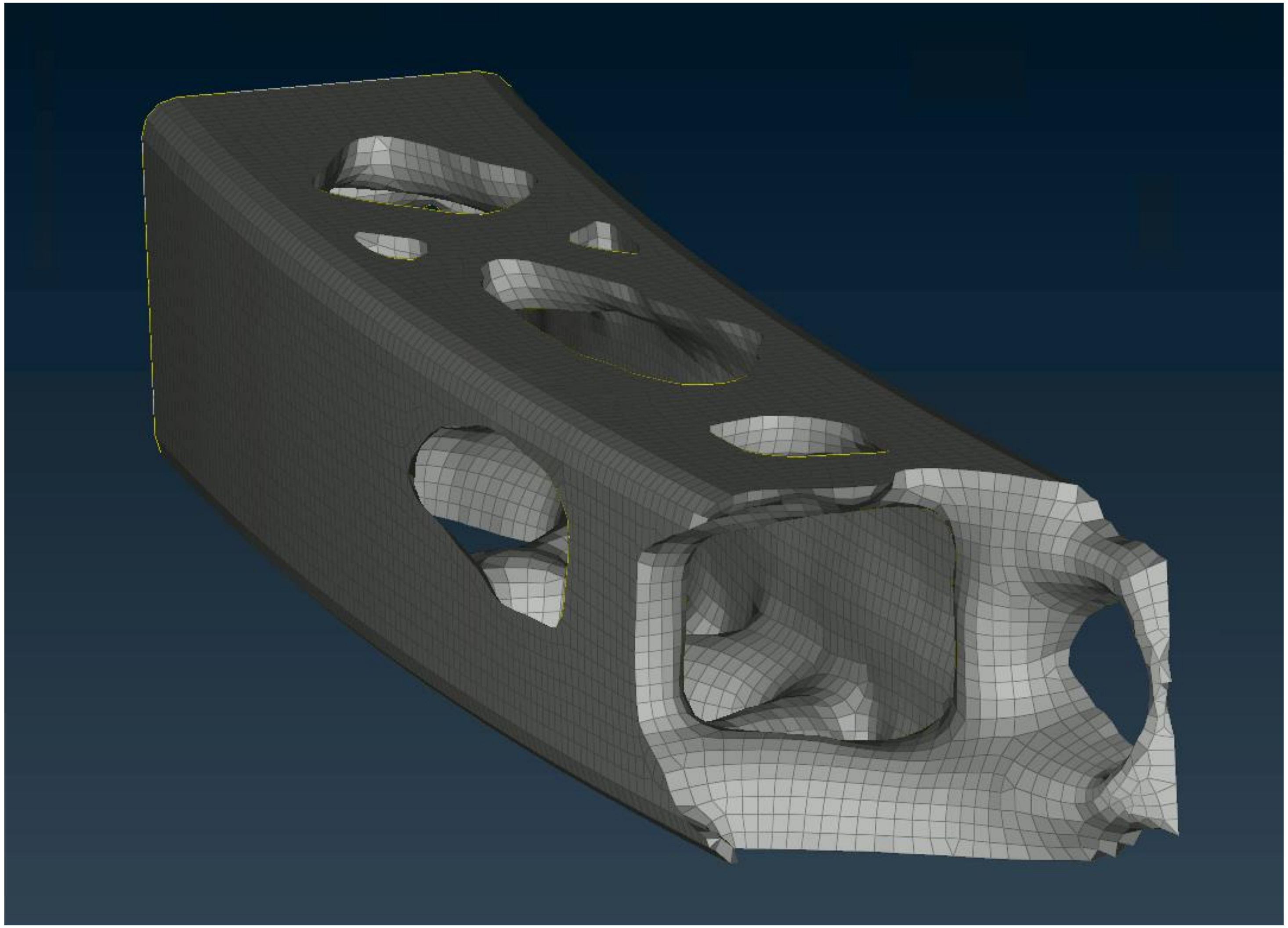
- Topology optimized structures need to be interpreted anyway?
- Sculpting, smoothing of topology optimized results, is available in Ansa for stl surfaces, see https://www.youtube.com/watch?v=us7cQExg9Z4



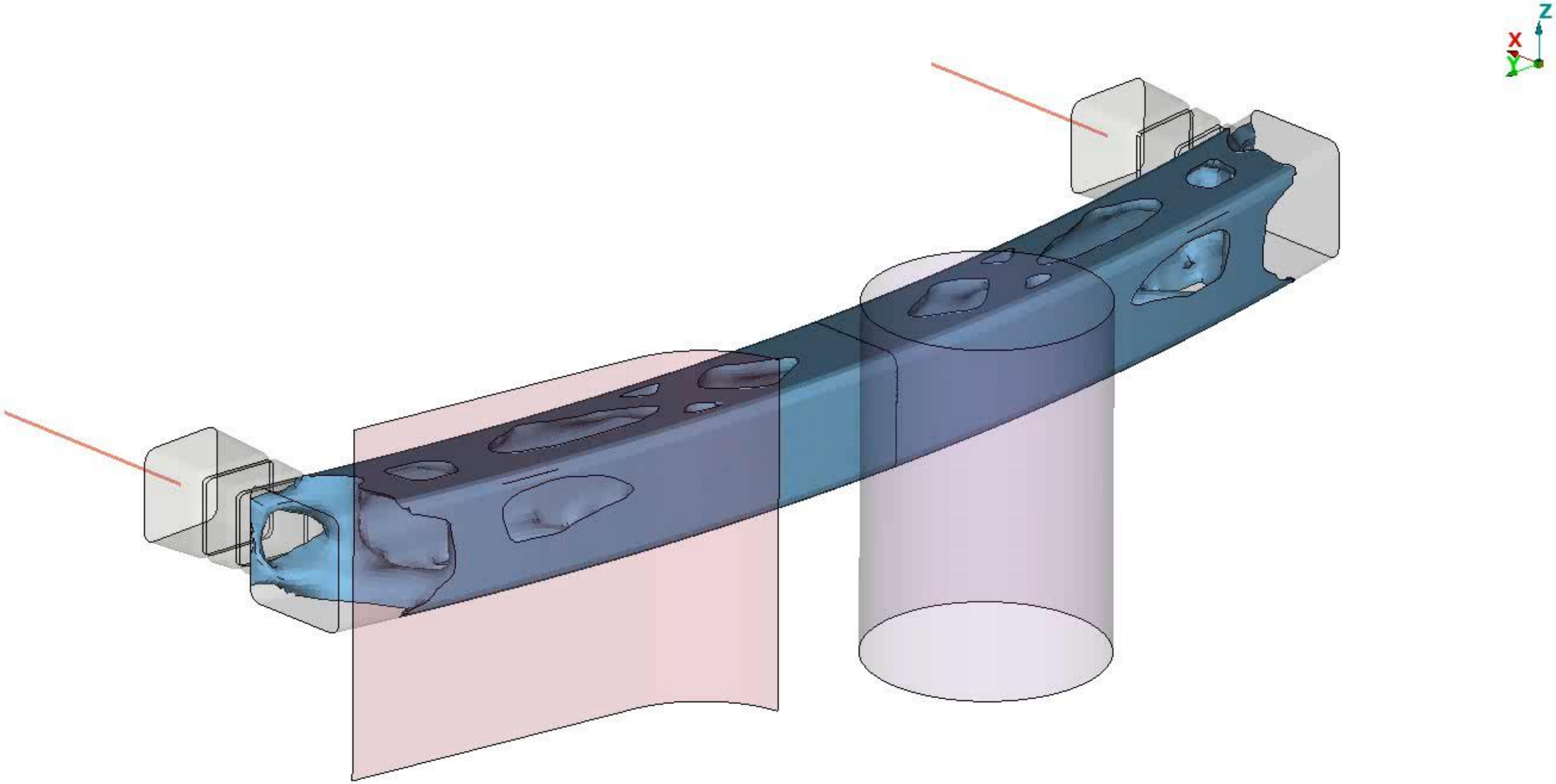
- Cleanup of stl in Ansa, https://www.beta-cae.com/pdf/ansa_meta_for_cfd_presentation.pdf.



Bumper example – From topology optimization to CAD

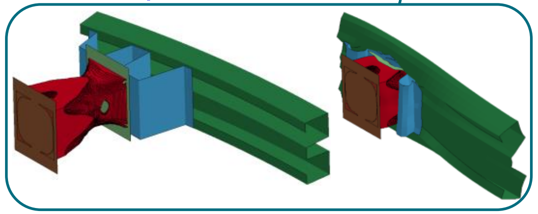


Bumper example – final suggested topology



Further reading

- Introduction to LS-TaSC https://www.youtube.com/watch?v=2RTrJwebmTo
- Overview on LS-TaSC™ and new Features in Version 4.1: https://www.dynamore.de/de/download/presentation/2020/copy_of_dynamore-express-overview-on-ls-tasc-and-new-features-in-version-4.1
- Conference papers:
  - "Topology Optimization of a U-Bend Tool using LS-TaSC", https://www.dynalook.com/conferences/12th-european-ls-dyna-conference-2019/optimization/aspenberg_dynamore_nordic.pdf/view
  - "Implementation of the Projected Subgradient Method in LS-TaSC™", https://www.dynalook.com/conferences/15th-international-ls-dyna-conference/topology-shape-optimization/implementation-of-the-projected-subgradient-method-in-ls-tasctm/view
  - "Constrained Multidisciplinary Topology Optimization", https://www.dynalook.com/conferences/16th-international-ls-dyna-conference/isogeometric-analysis-topology-and-shape-optimization-t10-1/t10-1-b-topology-and-shape-optimization-053.pdf/view



- LS-TaSC 4.2 release notes: https://www.lsoptsupport.com/news/ls-tasc-4-2-released
- LS-TaSC manuals:
  - User manual
  - Example problems manual ← 7 examples with input files is included in the installation
  - Theory manual
  - Scripting manual
  - Queuing system installation

Thank you!

Your LS-DYNA distributor and more