Ansys / LST

Topology optimization of an automotive hood for multiple load cases and disciplines

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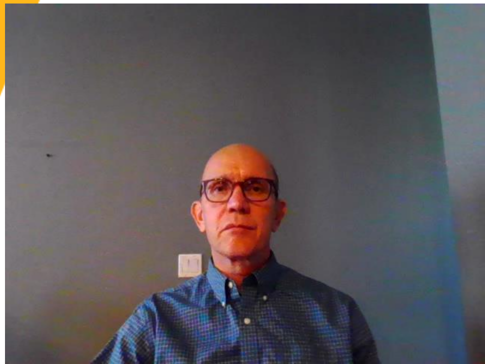
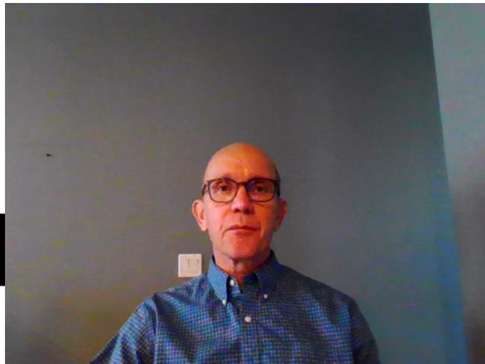


Overview

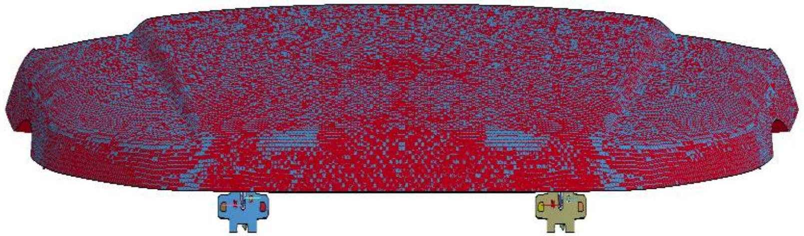
- Design Requirements
- Multidisciplinary Topology Optimization with Constraints
- Automotive Hood Topology Optimization – Design Studies
- Summary

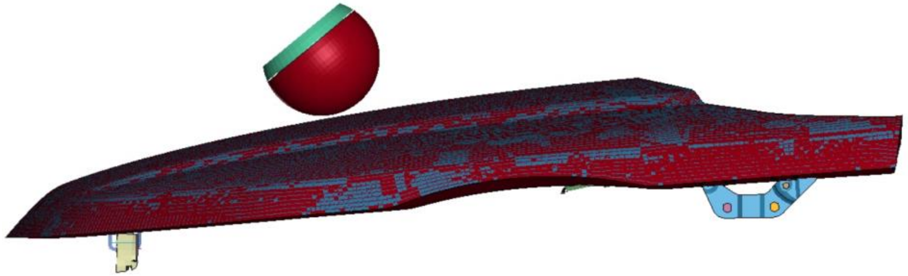


Design Requirements

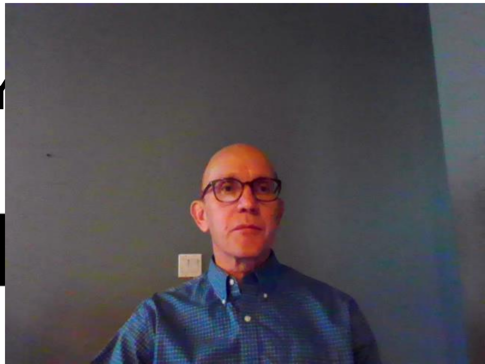
What do the customers want from the design?

- The important requirements are from the crash groups at various customers, e.g. Toyota, Mazda, Ford, GM, etc.
  - Topics such as ***Head Impact Criterion*** and ***maximization of energy absorption***
  - This is done as part of multi-disciplinary design optimization
  - The methodology is also used by clients outside the vehicle industry





- This resulted in insights, methodology, and success unique to ANSY



Multidisciplinary Topology Optimization with Constraints

Solving the saddle point problem

- Designing for impact is fundamentally different from designing for the other disciplines, in part because *the maximizing of the energy absorption requires special handling to have a stable structure*.
- Our implementation therefore solves for the saddle point problem instead of the normal energy minimization

$$\max_{\xi} \min_{x} E(\xi, x)$$

with ξ additional variables (typically global properties of the design) and x the standard topology design variables. The optimization scheme therefore solves a dual problem with the *higher level solving* for the properties of a feasible structure and the *lower level solving* for the topology of a stable

these properties.

Multidisciplinary Topology Optimization with Constraints

Design sensitivity analysis (DSA)

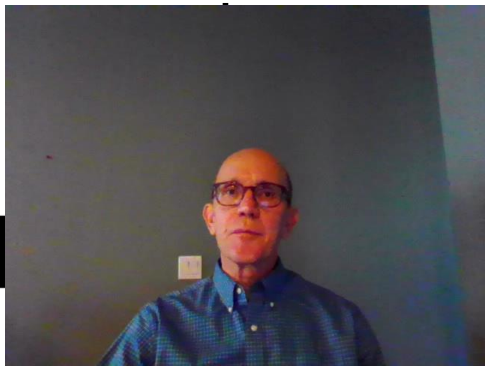
- Normally topology is based on using analytical DSA (gradients), but the implementation of analytical DSA is not feasible for the impact discipline.
- The constraints are therefore split into two sets: *analytical DSA* is used for the one set of constraints,

$$g_i^{\text{ana}}(\boldsymbol{x}) \leq 0 \text{ with } i = 1, \dots, n$$

while the other set uses a multi-point method to compute the DSA values *numerically*,

$$g_j^{\text{num}}(\boldsymbol{\xi}) \leq 0 \text{ with } j = 1, \dots, m$$

- This allows us to design for maximum energy absorption, maximu
forces, and bounds on eigenvalues simultaneously.



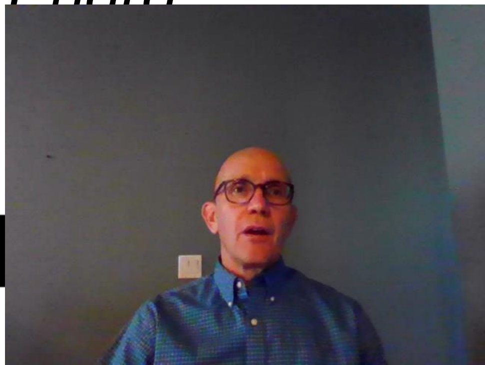
Multidisciplinary Topology Optimization with Constraints

Optimization Methodologies in LS-TaSC

- Minimax / saddle point problem (needed to maximize energy absorption).
  - One saddle direction uses shape/topology variables together with design sensitivity analysis. This is related to the schemes in the textbooks and others codes.
  - Other saddle direction uses parametric variables in a multi-point scheme. Related to the schemes in optiSlang™ and LS-OPT™.
  - And of course, a dual-optimization solver that can handle the above.

- The multipoint scheme is used by the crash discipline for constrained optimization – handling generic constraints is unique to ANSYS/LST.

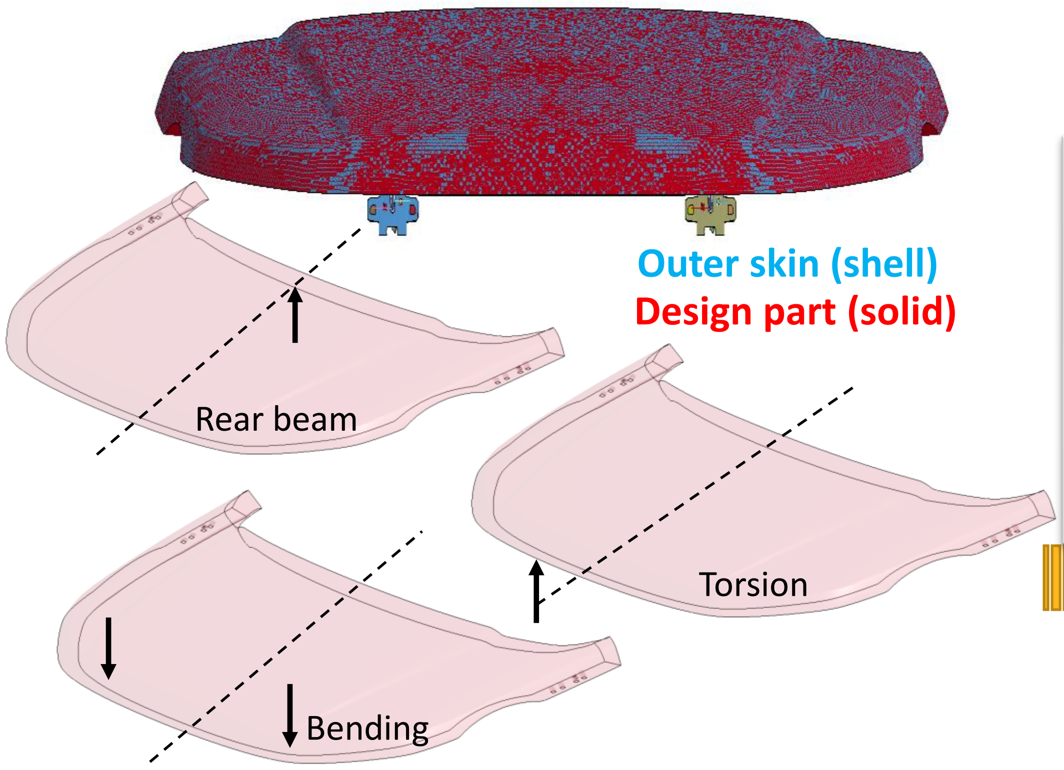
- Details of the theory: Willem Roux, Guilian Yi, Imtiaz Gandikota. A spatial kernel approach for topology optimization. *Comput. Methods Appl. Mech. Engrg* (2020)



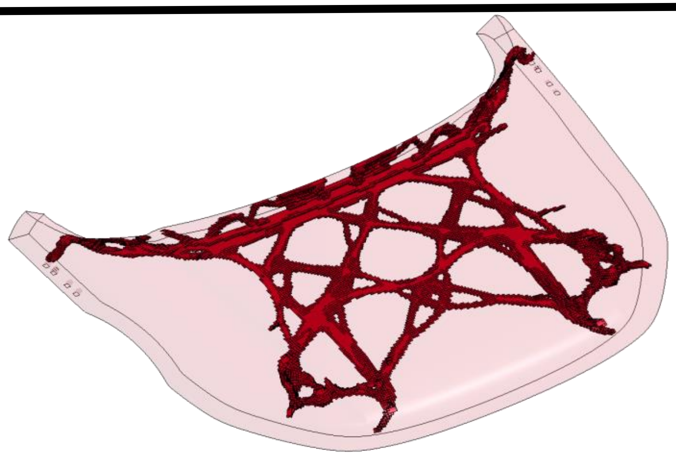
Automotive Hood Topology Optimization

Design study 1: design for three static load cases

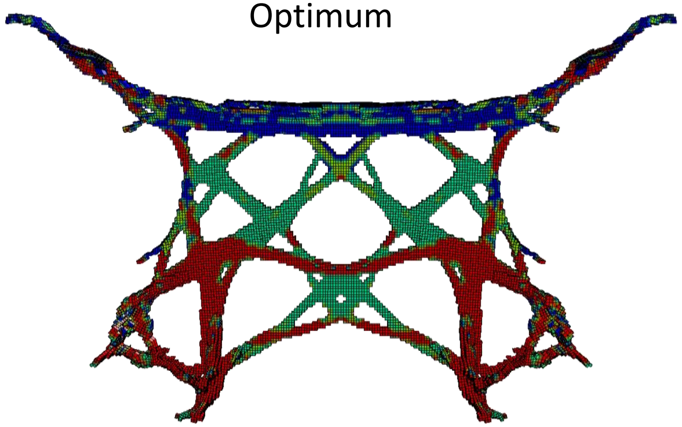
- Objective: Stiffest structure, satisfying constraints, and minimize mass
- Constraints: rear beam, bending, and torsion displacements



Initial Design has very low mass fraction of 0.01.



Optimum

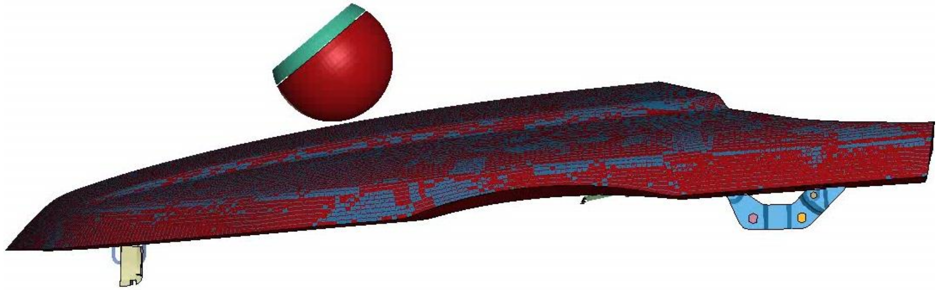


Design Contribution Plot
(Rear beam, torsion, bending)

Automotive Hood Topology Optimization

Design study 2: design for impact load case

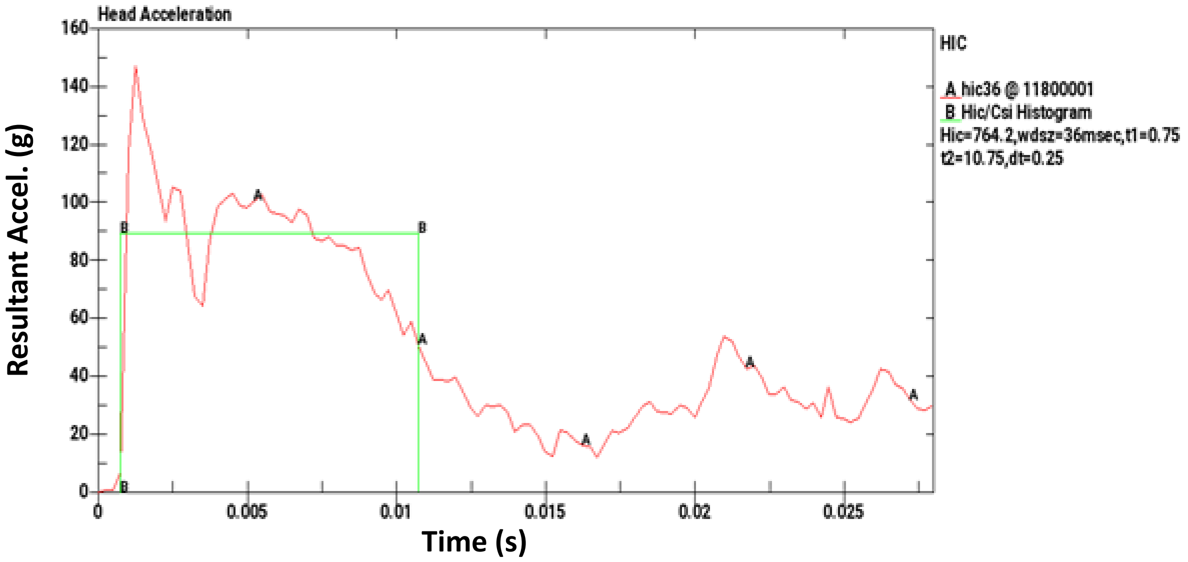
Model by courtesy of
Jaguar Land Rover

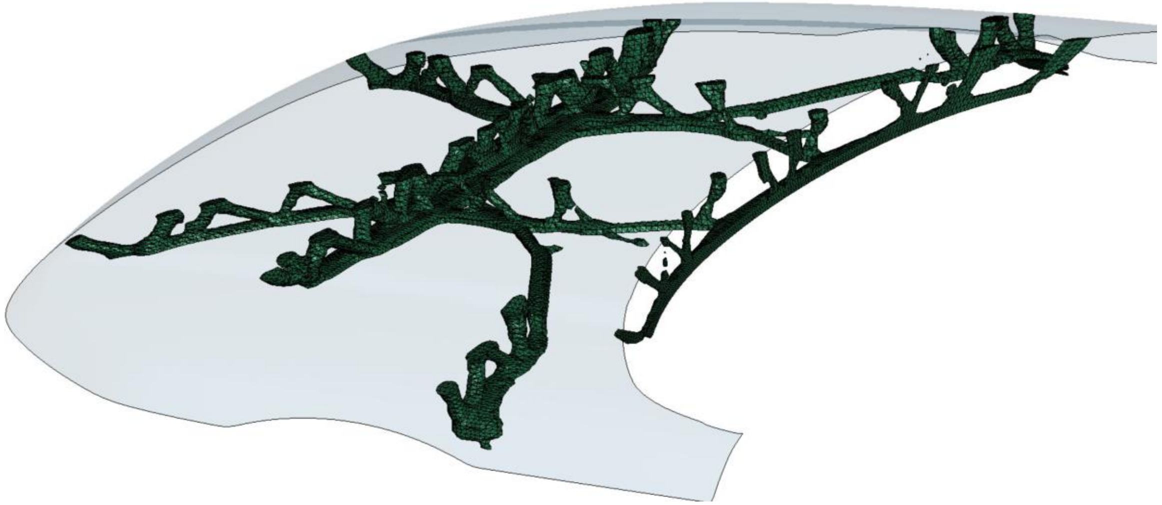


- Designing the solid inner/hidden part of hood with outer shell layer
- Optimization problem description:

  Min *mass (max. stiffness)*
  s.t. *HIC < 1000;*
  z-dir disp @ impact location ≤ 70 mm.

- Final mass = 0.74 kg (2.5% of original)





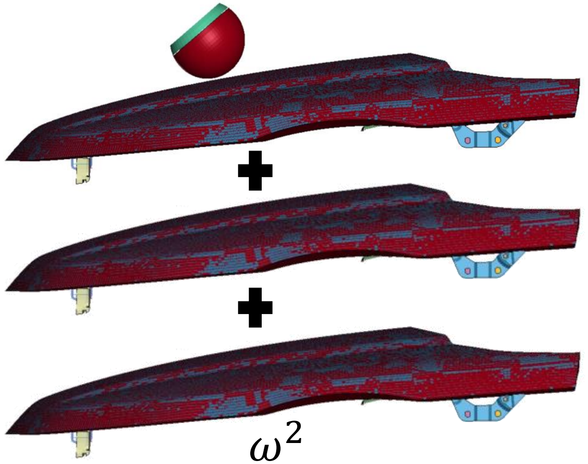
Automotive Hood Topology Optimization

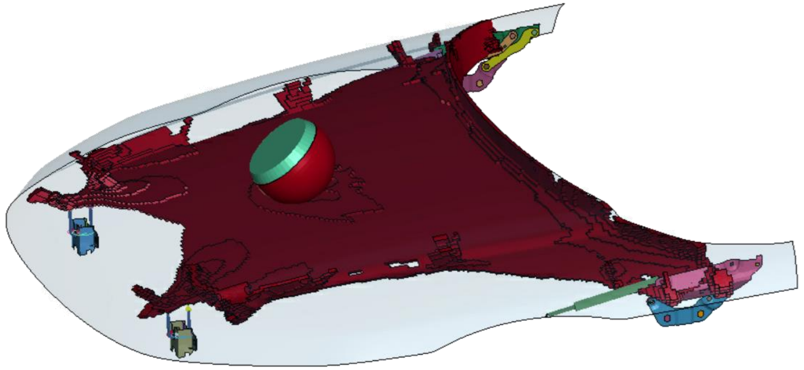
Design study 3: design for impact, NVH, and static load cases (1)

- Optimization problem description:

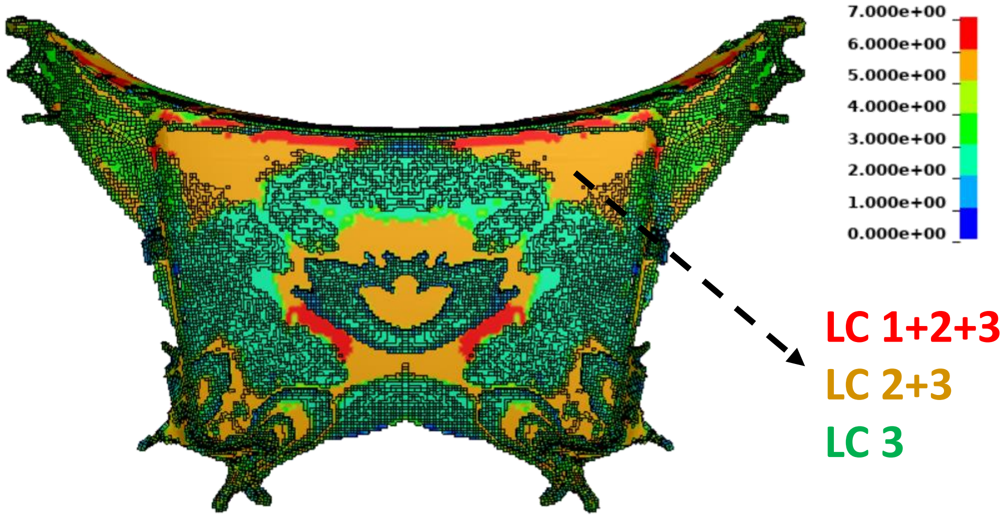
  Min. mass (max (stiffness, fundamental freq.))
  s.t. HIC ≤ 1000,
  Disp ≤ 70 mm (LC 1)
  torsion disp. ≤ 17.6 mm (LC 2)
  Bending freq. ≥ 45 Hz (LC 3)

- Final design mass = 3 kg (10% of original)





Iso-surface Plot



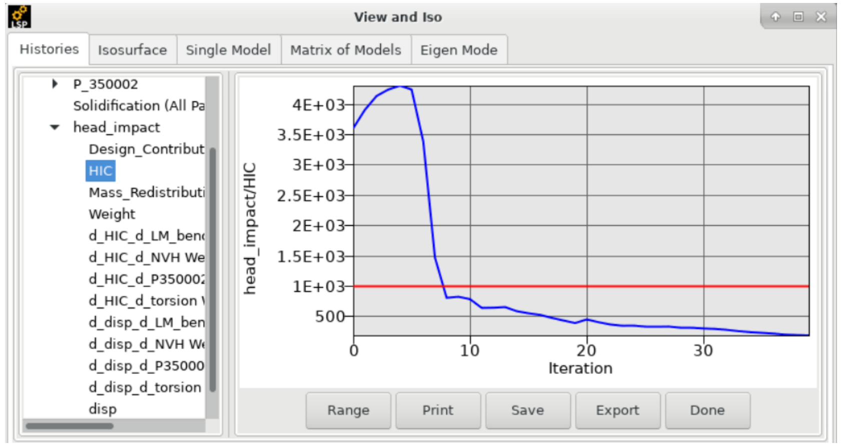
Design Contribution Plot

Automotive Hood Topology Optimization

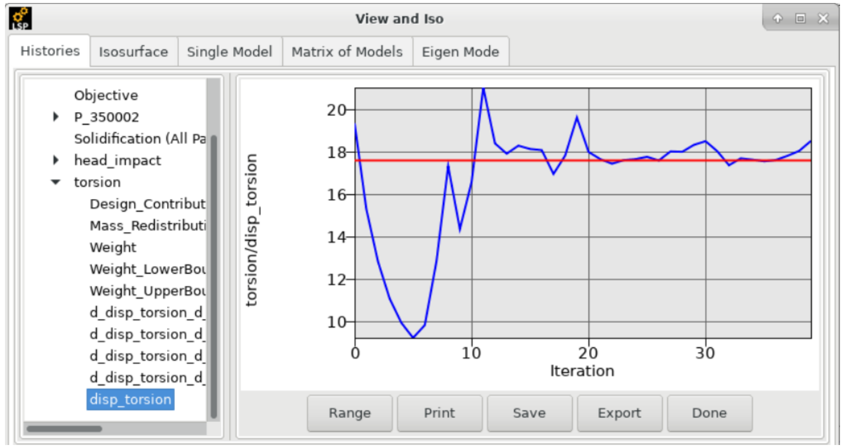
Design study 3: design for impact, NVH, and static load cases (2)

- Results

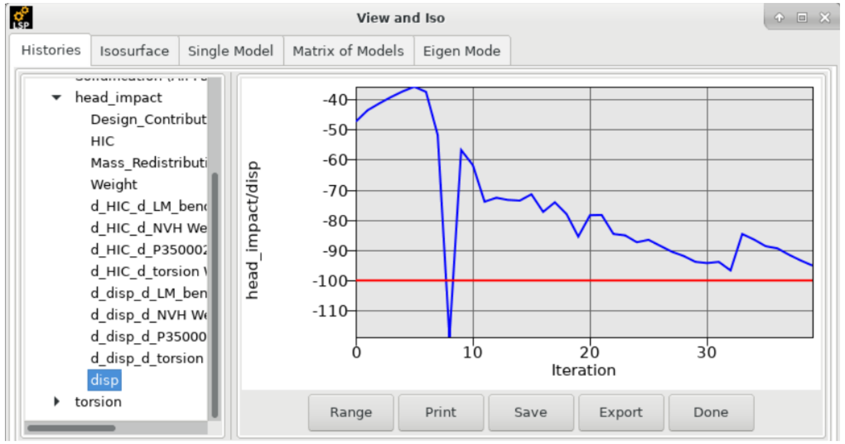
Iso-surface (movie)



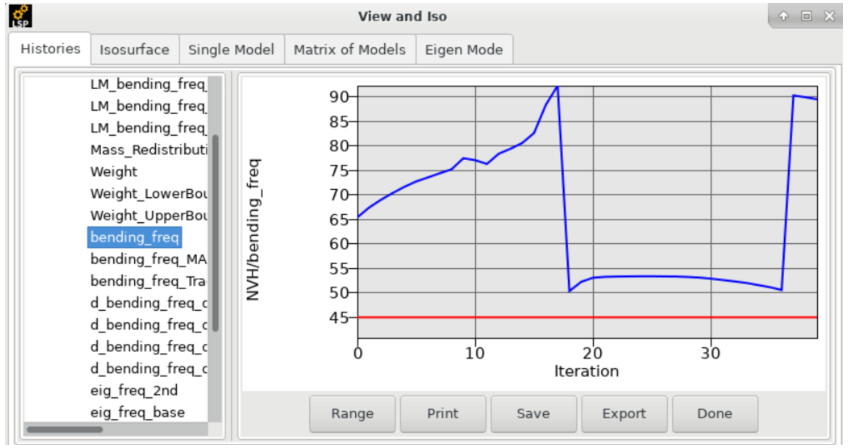
History plot of HIC



History plot of z-dir displacement



History plot of torsion displacement

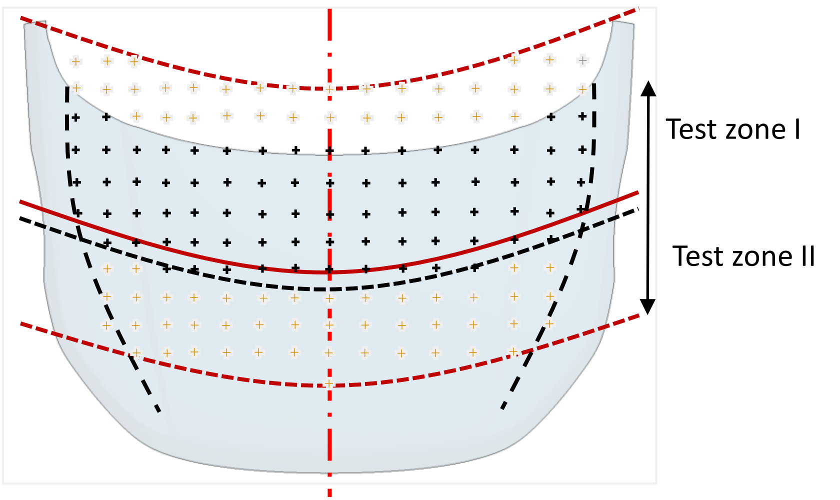


History plot of bending frequency

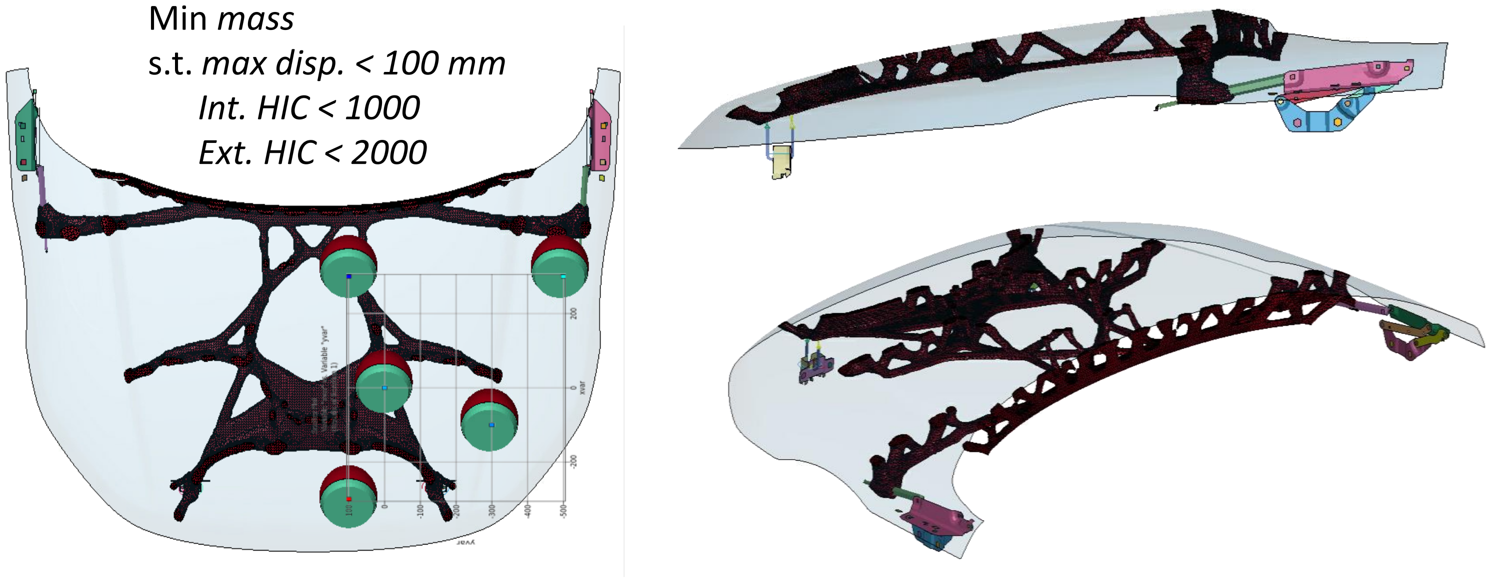
Automotive Hood Topology Optimization

Design study 4: design for multiple impacts (1)

- Hood must be evaluated at multiple impact locations according to *Euro NCAP Pedestrian testing protocol*.
- Ideally, all impact locations should be solved as a multi-load case optimization problem.
- Very expensive!



Area to meet low speed requirements by Euro NCAP protocol



Results of MLC optimization with five load cases (overall 540 LS-DYNA runs for 27 LS-TaSC iterations)

Automotive Hood Topology Optimization

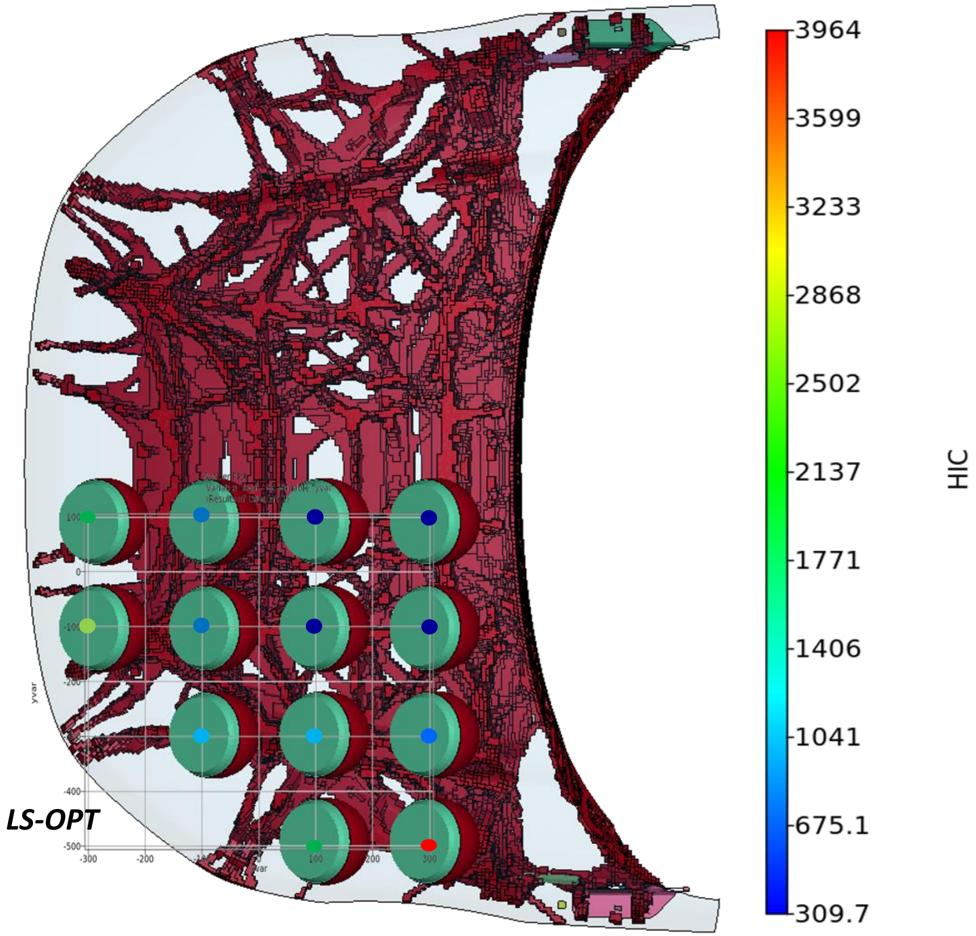
Design study 4: design for multiple impacts (2)

- Initial study to check potential load path from multiple impact locations.
- Single load case: one LS-Opt sampling point requires a full topology optimization design through LS-TaSC.

Optimization problem:

Min *mass*
s.t. *max disp. < 100 mm*

- The worst impact location is selected.

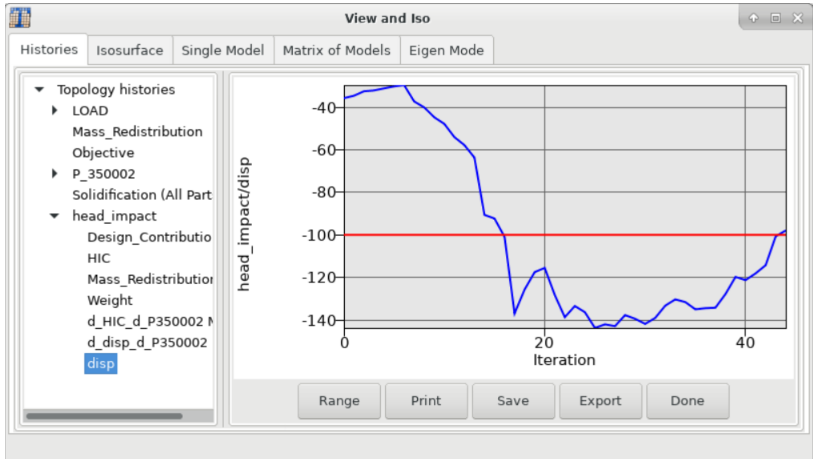


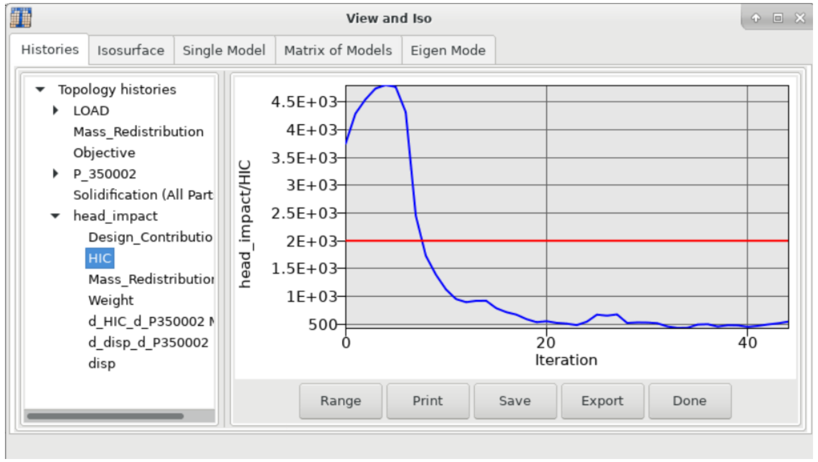
Overlay of topologies of single load case designs

Automotive Hood Topology Optimization

Design study 4: design for multiple impacts (3)

- For this we are doing a worst-case study using the LS-OPT / LS-TaSC link.
- Worst case impact load + distributed load (1:99 weighting)
  - Combination of one impact location and distributed loads
  - Constraint active only for impact load case
  - High load case weight for distributed load (99%) and small weight for impact (1%)
- Final mass = 1.7 kg (5.7% of original)



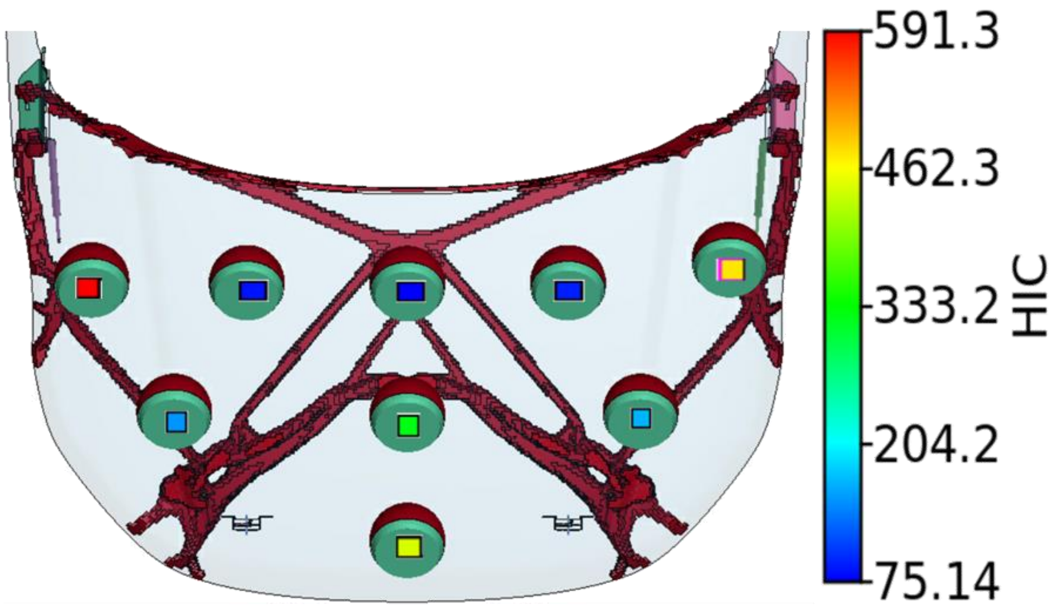


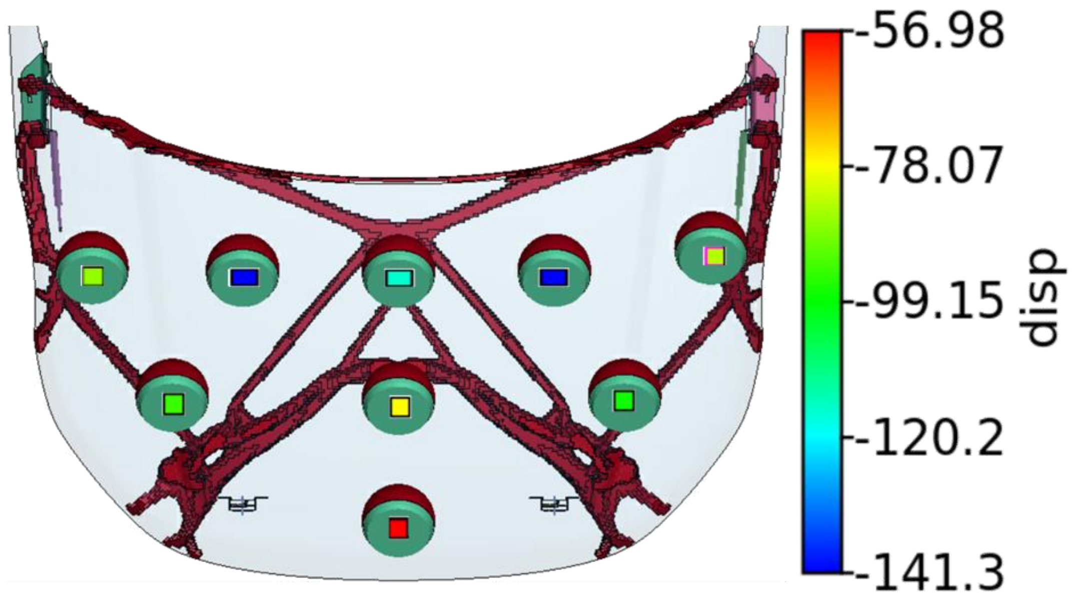
The investigation is being continued by both us and industry.

Automotive Hood Topology Optimization

Design study 4: design for multiple impacts (4)

- Verification of optimum design
  - Point loads replaced with head form model for impact analysis using optimum topology;
  - HIC requirement satisfied at all locations, and higher displacement at some locations;
  - Worst case design of highly nonlinear problems seems to require an iterative selection of the worst case(s).



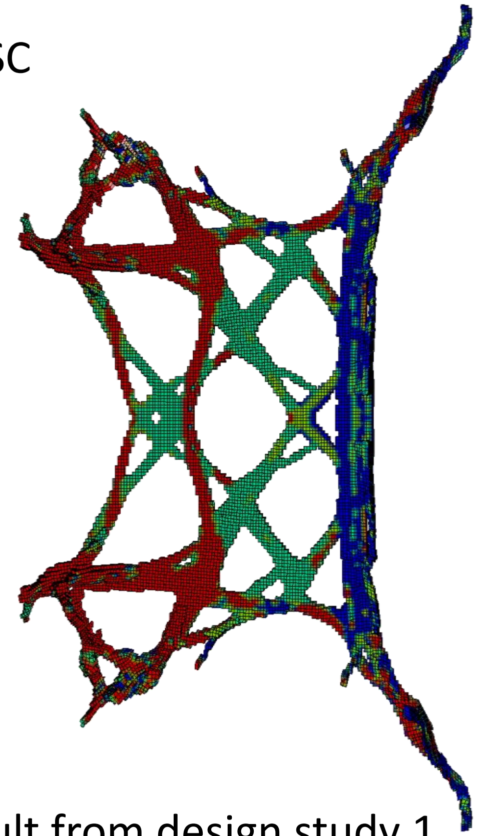


Automotive Hood Topology Optimization

Rendering topology geometry

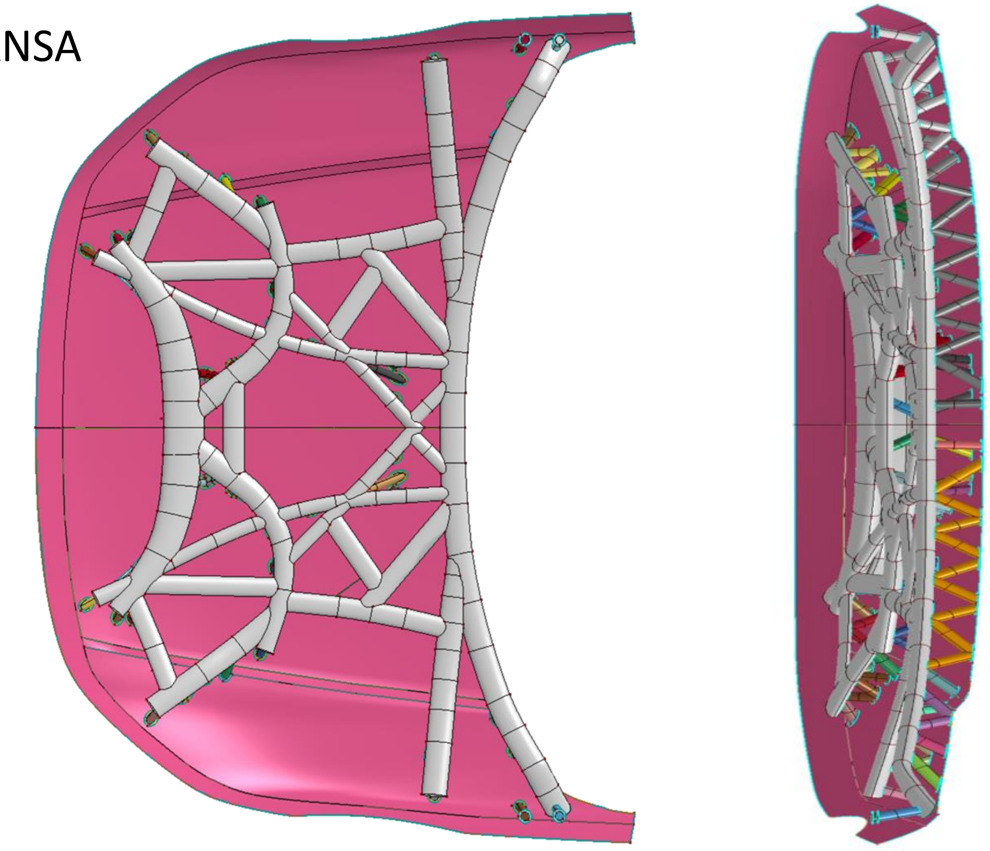
- STL to CAD using **SpaceClaim** or **ANSA**

LS-TaSC



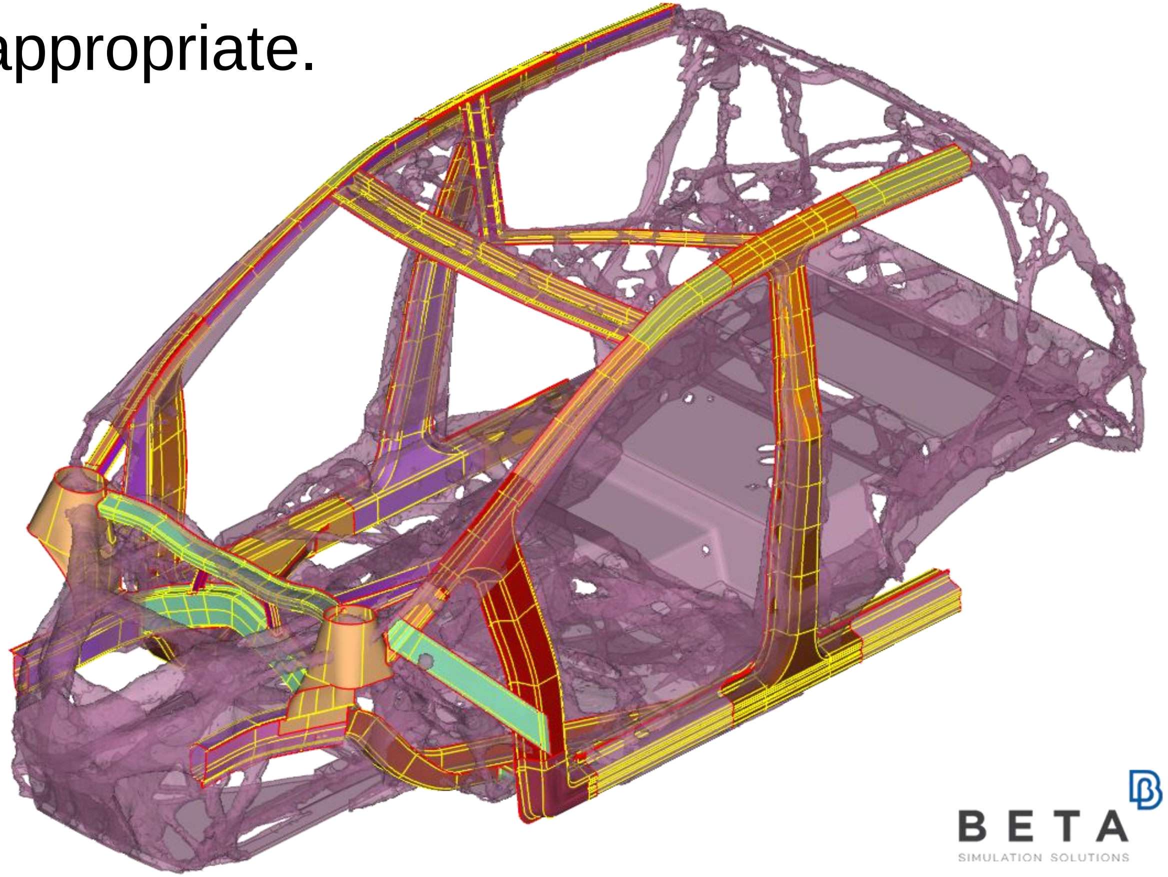
result from design study 1

ANSA



More CAD geometry

- A shell structure may be more appropriate.



Ansys

Summary

- Several innovative design studies on the topology optimization design of an automotive hood are discussed.
  - Bonnet pedestrian Head Impact Criterion, structural stiffness, and modal frequency are considered together to result in design compromises with the lightest structure.
  - A worst-case design scheme is proposed for the hood design with a number of impact locations.

- LS-TaSC has been expanded to handle constrained, multidisciplinary topology optimization problems.
  - Multiple cases and disciplines, e.g., a combination of impact, NVH, and statics load cases.
  - The method can use both *analytical DSA* and *numerical DSA*, e.g. designi energy absorption while placing bounds on the reaction forces and eigenv

Thanks!

Q&A