STRUCTURAL OPTIMIZATION OF MECHANICAL SYSTEMS

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PROJECT DESCRIPTION

Subject

- Topology Optimization with Parametrization of Hardpoint Positions (joint positions)

Tasks

- Develop a simplified FE-model of the wheel suspension system (Abaqus)
  - Validate with respect to force signals
- Propose concept load cases for optimization
- Optimize the system model w.r.t. stiffness and weight (Tosca)
- Prestudy for TO with parametrization of hardpoint positions
  - Simpler Two-link problem

WHEEL SUSPENSION SYSTEM - DEVELOPMENT

Two main loops

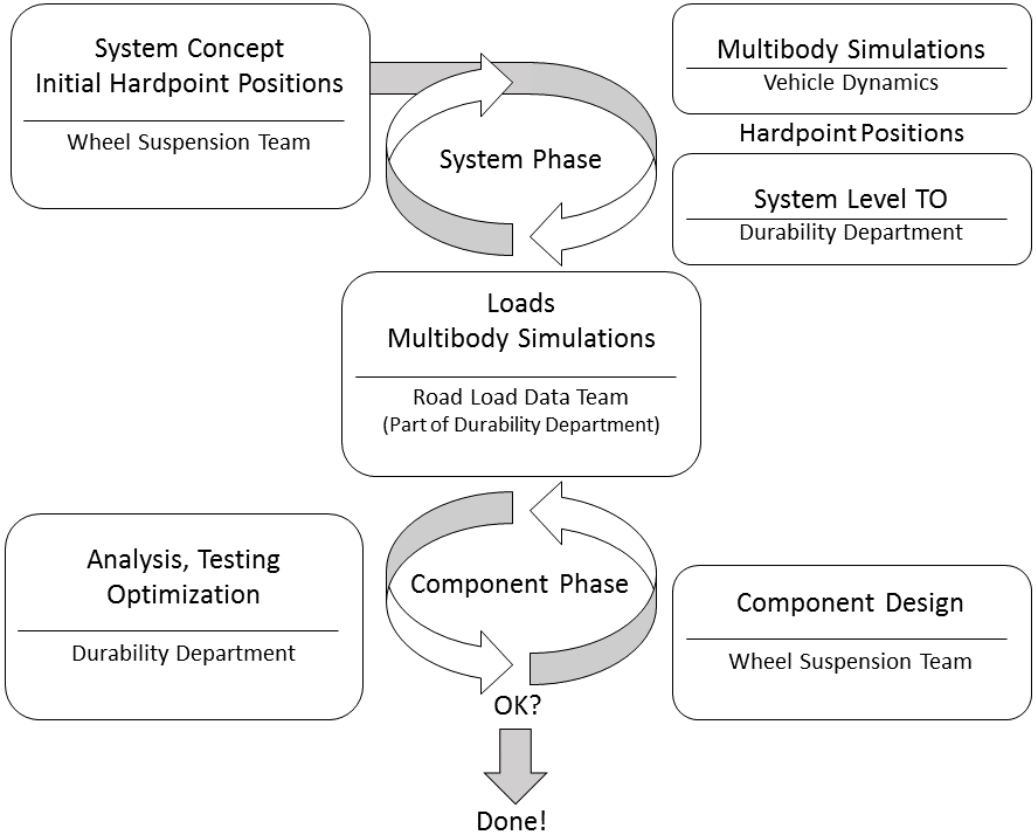
- System phase
  - Tuning of hardpoint positions (joint positions)
- Component phase
  - Analysis
  - Testing
  - Optimization (Topology, Shape, Size)

Optimizations today

- Component level
  - Predetermined Boundary Conditions
  - Narrow solution space

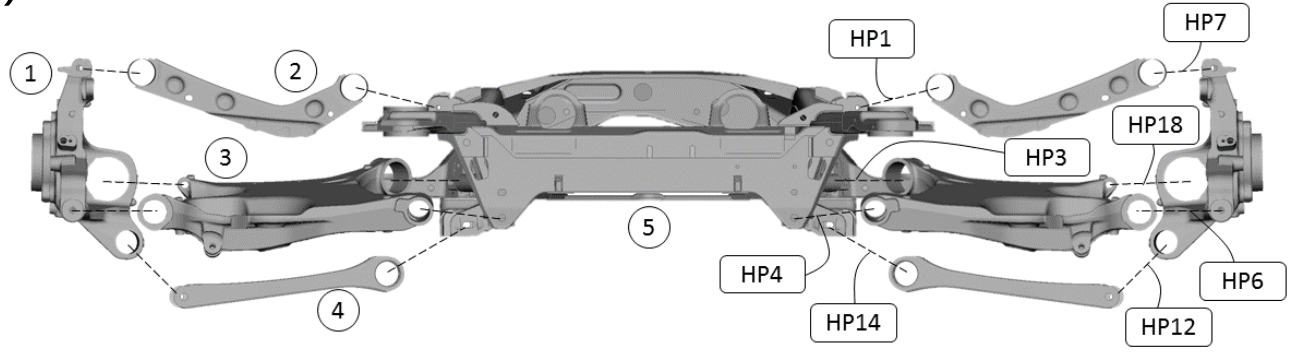
Optimizations in the future

- System phase
  - Broaden the solution space
  - Include hardpoint positions within the optimization



SYSTEM COMPONENTS AND HARDPOINT POSITIONS

1) Knuckle
2) Upper Control Arm (UCA)
3) Lower Control Arm (LCA)
4) Toelink
5) Subframe
6) Leaf spring

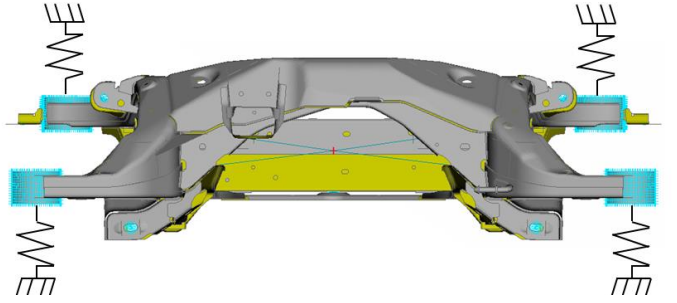


- Hardpoints for linkages

BOUNDARY CONDITIONS AND EXTERNAL LOADS

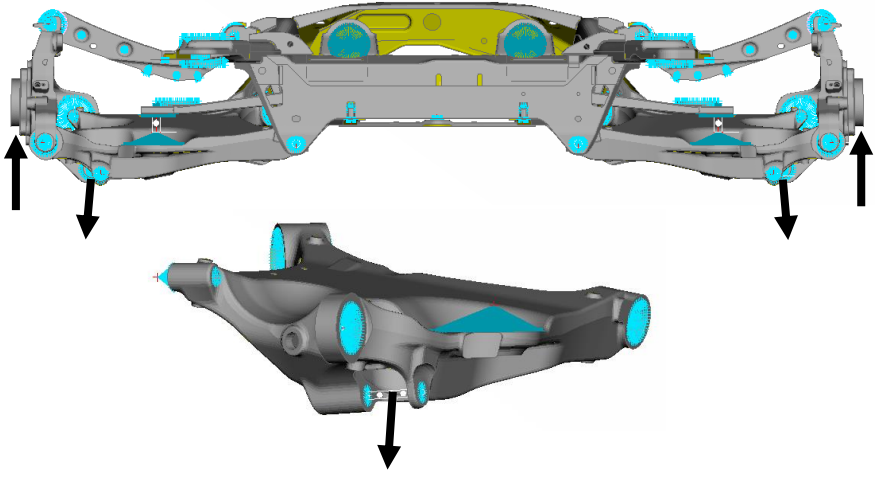
Boundary Conditions

- Similar to a chassis rig
  - Inner bodies of bushings are fixed
  - Elastic bushings enables relative movement

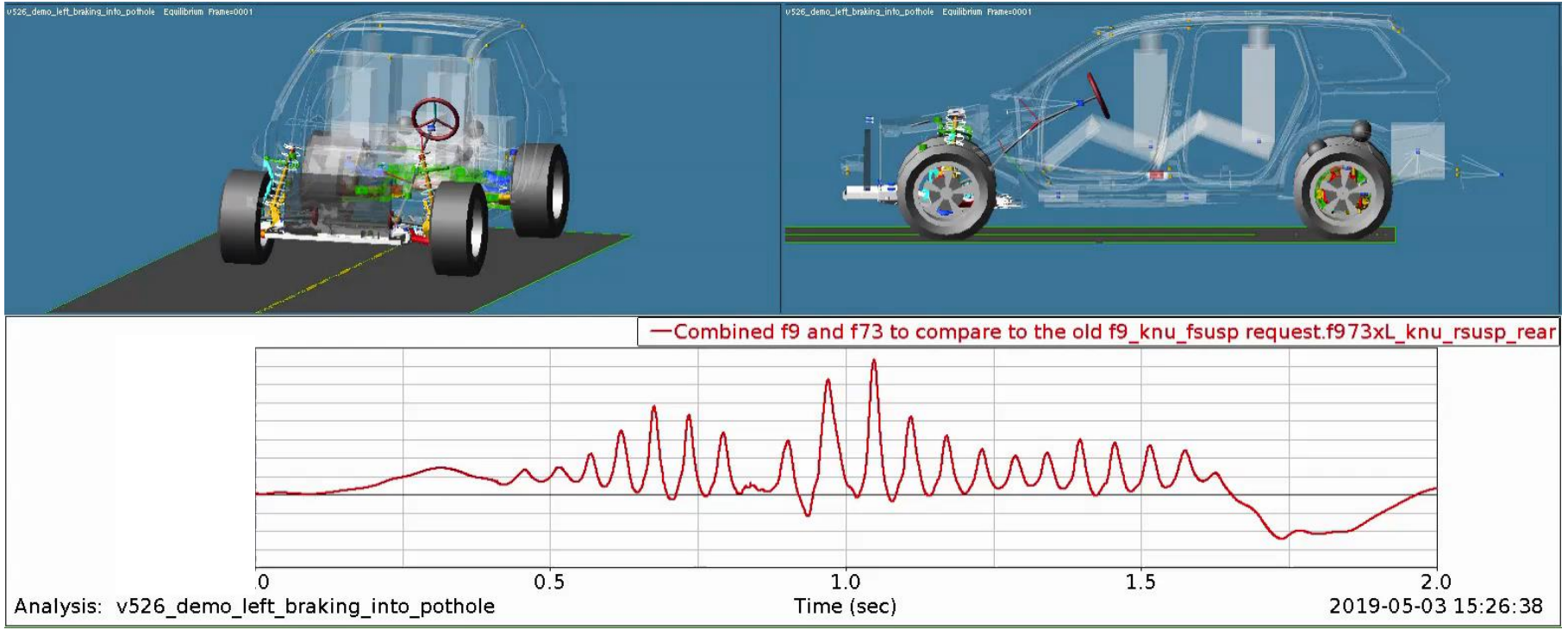


External Loads

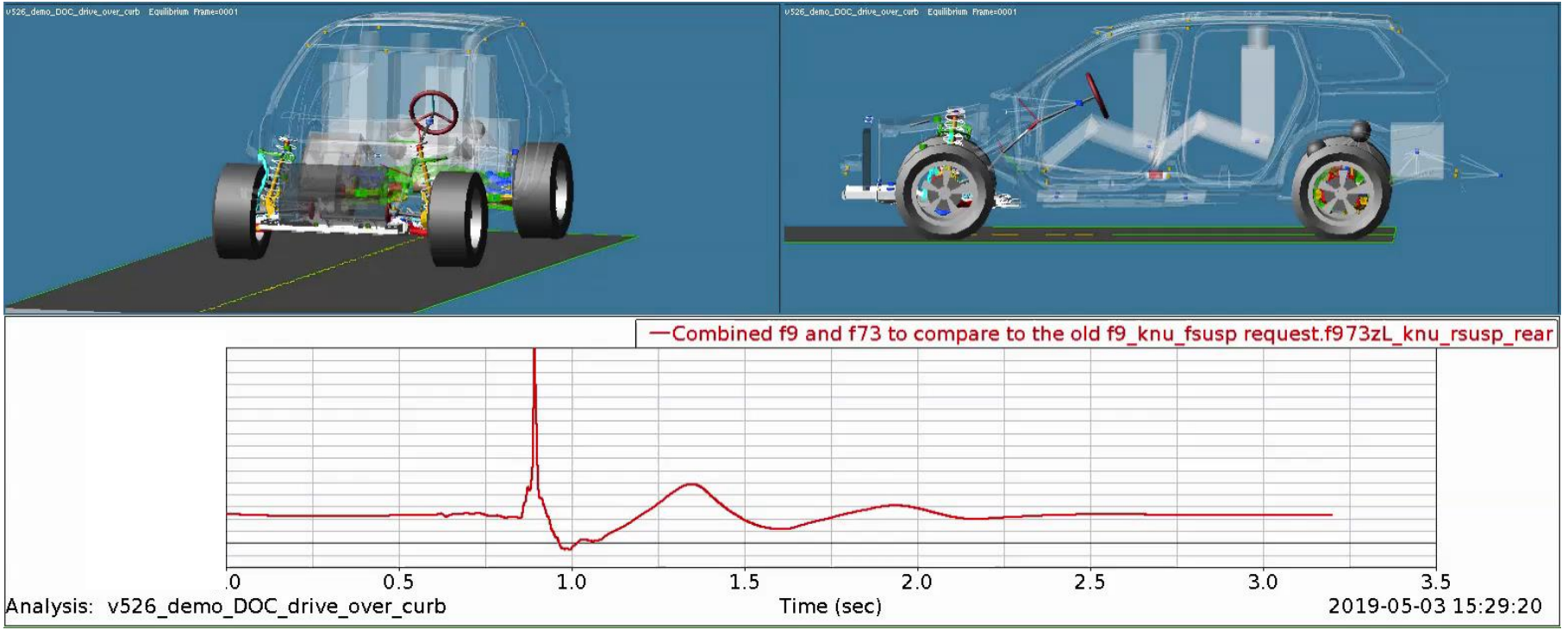
- Knuckles
- Dampers
  - Quasi-static analysis - No velocity
  - Damping characteristics has no effect



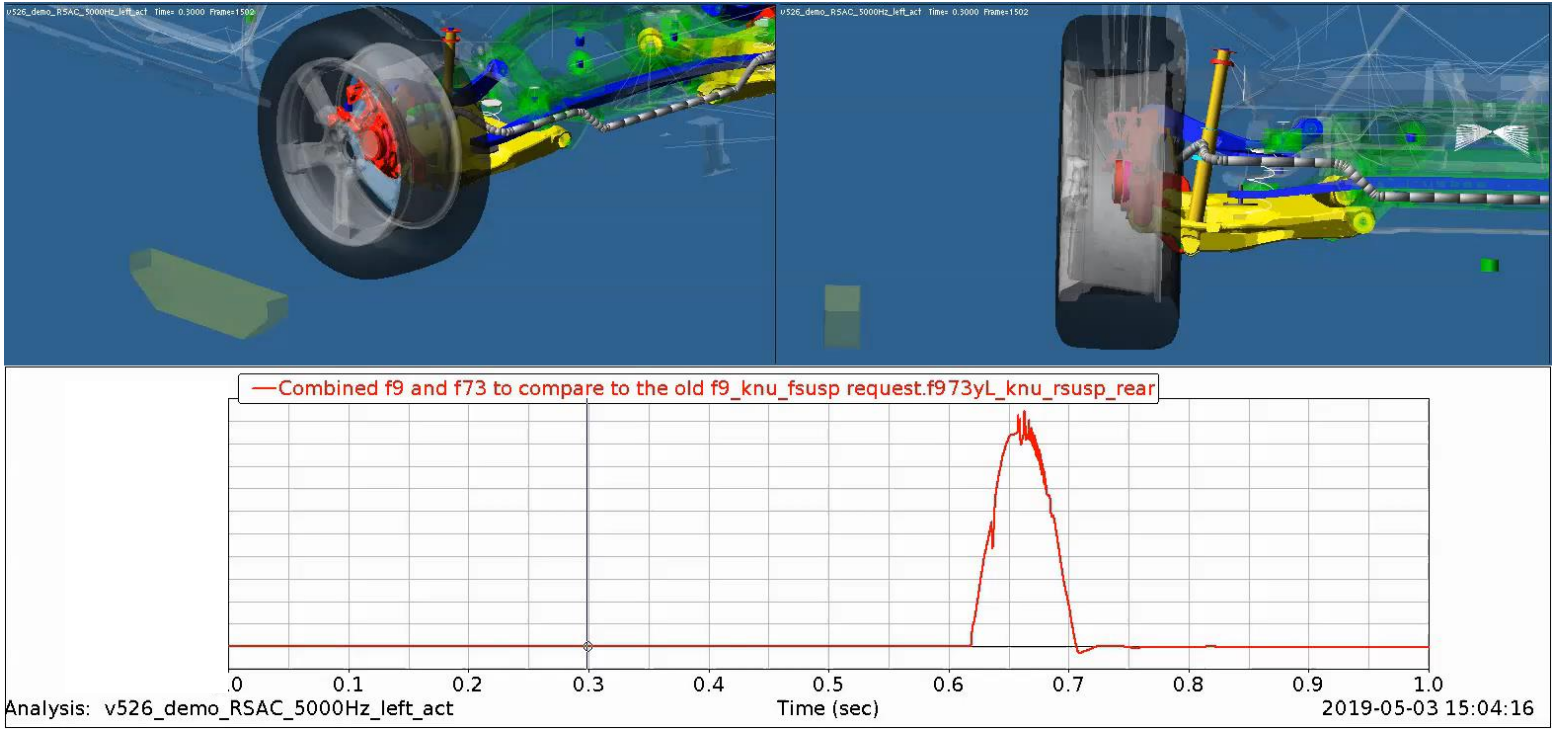
STRENGTH EVENTS – BIP (RLD)



STRENGTH EVENTS – DOC (RLD)

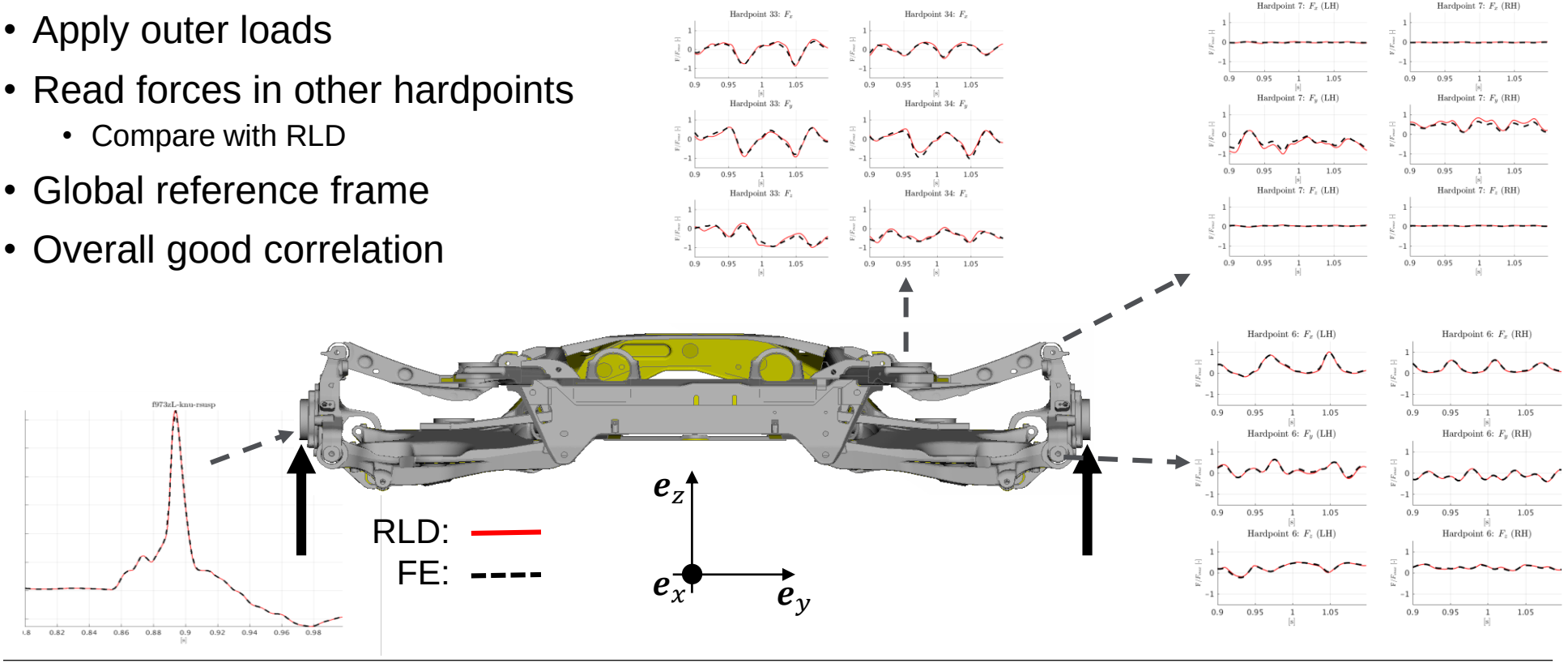


STRENGTH EVENTS – SAC (RLD)



STRENGTH EVENTS - VALIDATION

- Apply outer loads
- Read forces in other hardpoints
  - Compare with RLD
- Global reference frame
- Overall good correlation



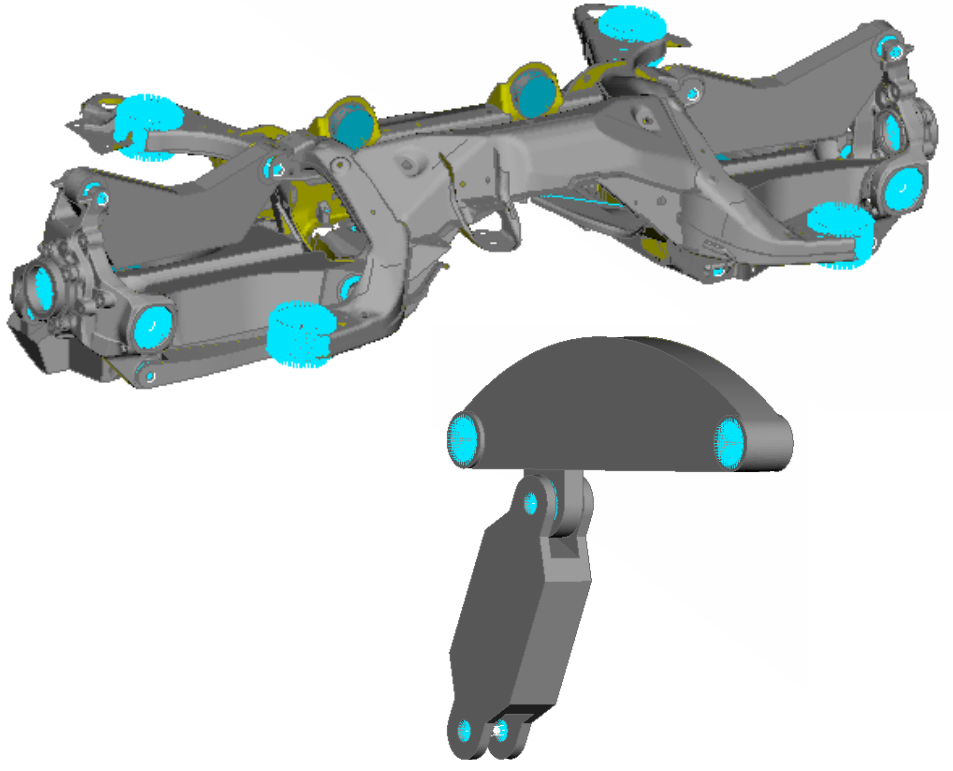
TOPOLOGY OPTIMIZATION

Wheel Suspension System

- Linkages as design volumes
- Given parameters on suspension system

Simple two-component model

- Try different optimization setups
- Parametrization of hardpoint



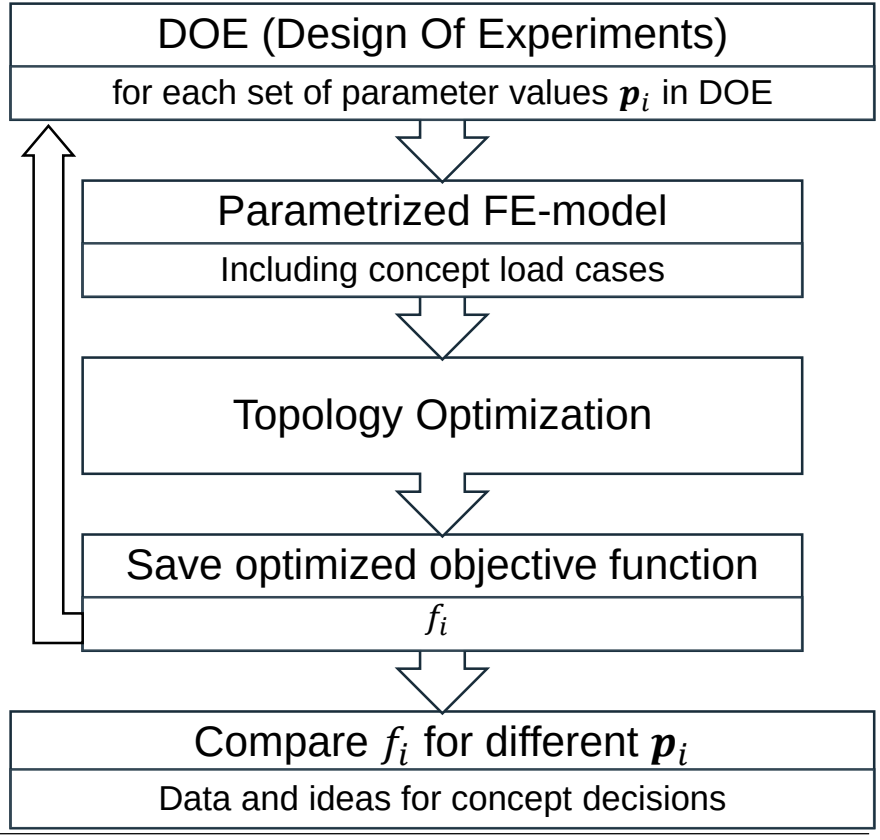
PARAMETRIZATION + NON-PARAMETRIC OPTIMIZATION

Introduce an outer parametric loop

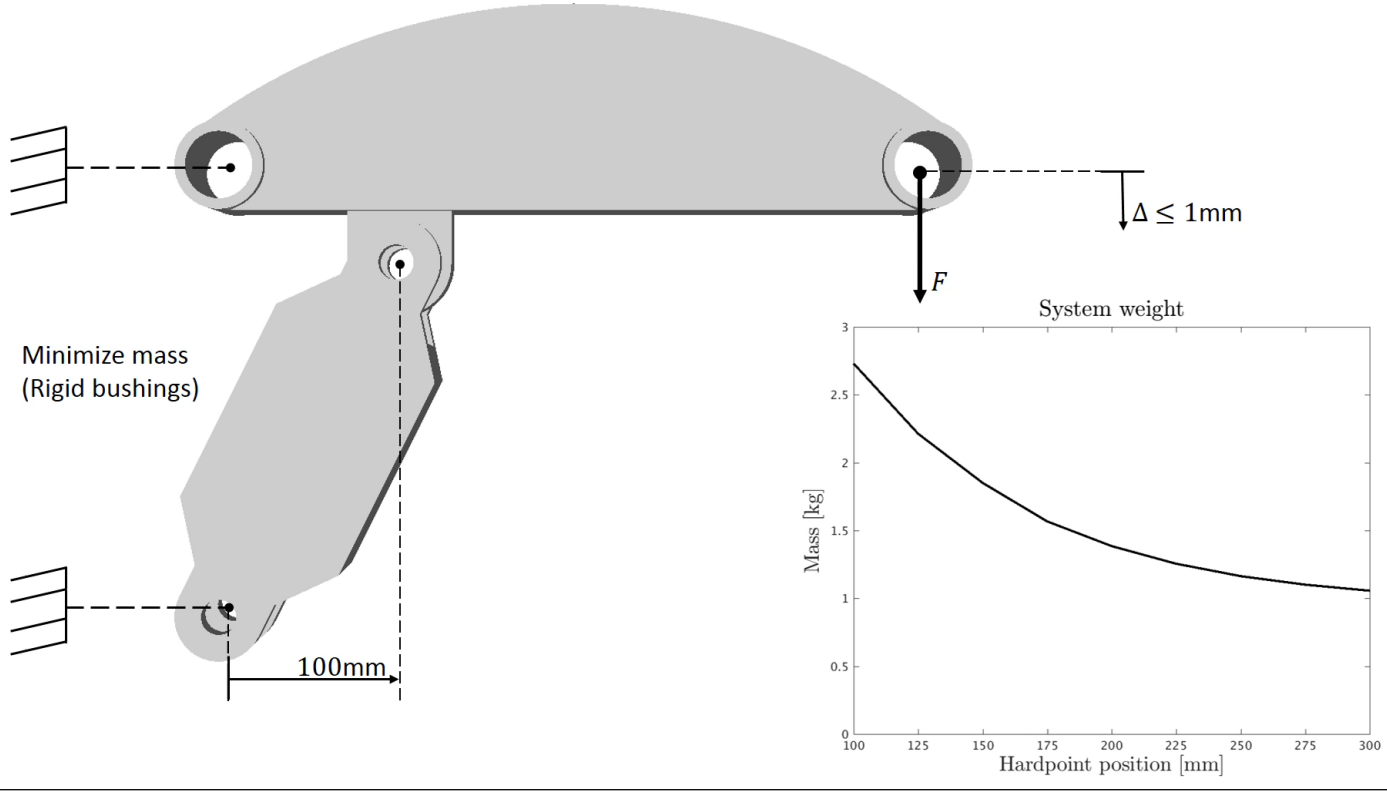
- Parameters (hardpoint positions)
  - Follows a DOE
- Save results for the current configuration
  - Optimized Geometry
  - Performance measurement (objective function)

What do we get?

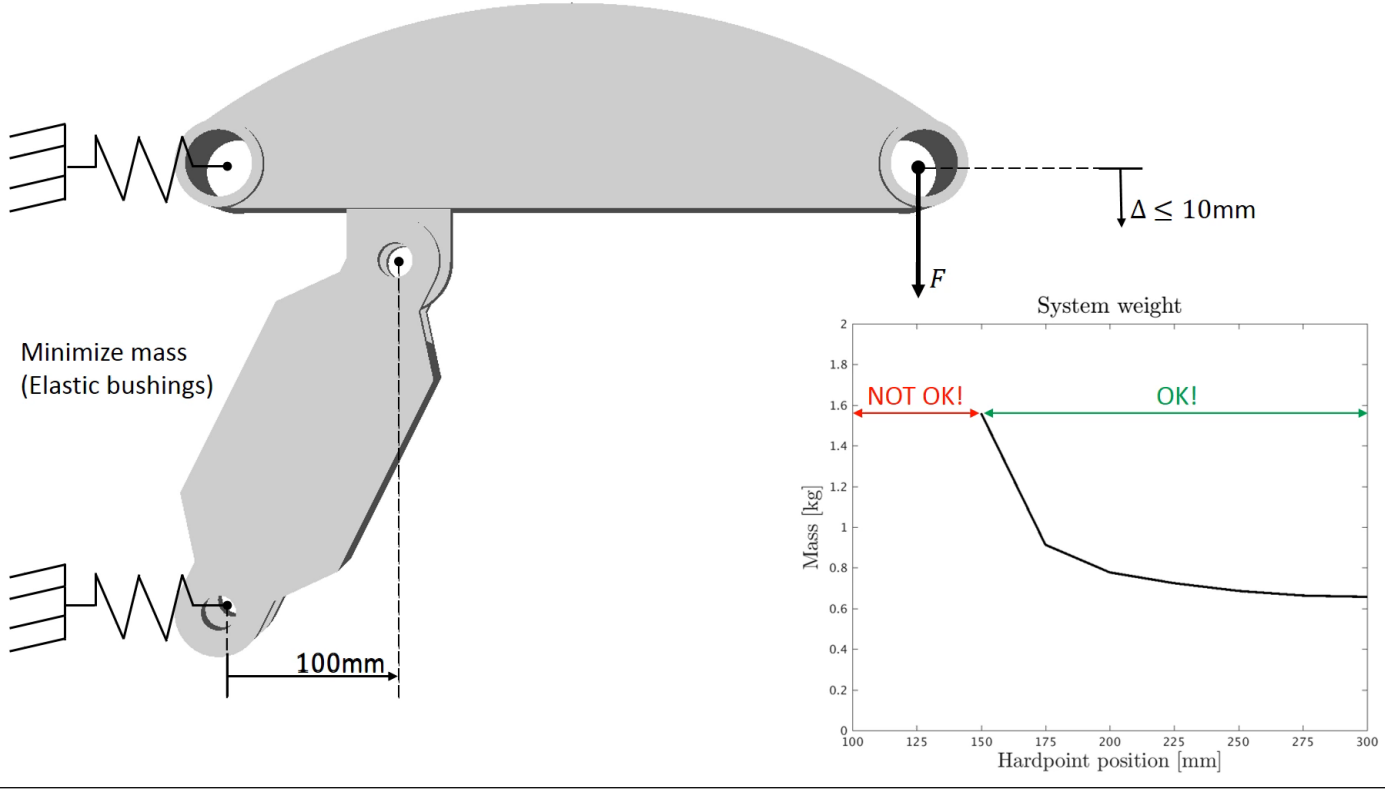
- A structural optimization process
  - Target system weight at an early stage



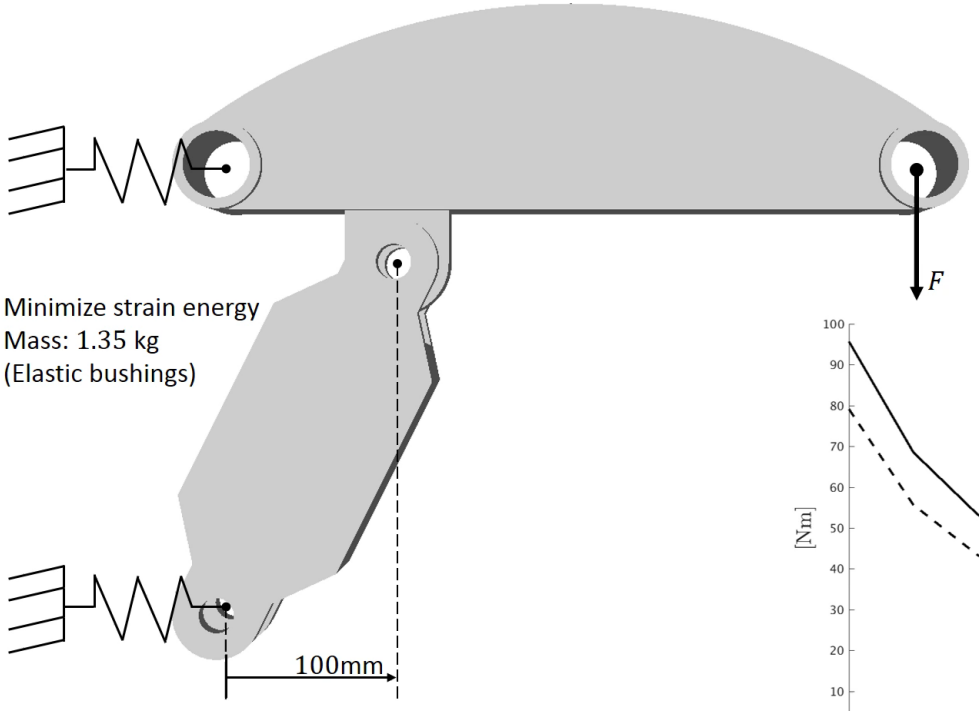
MINIMIZE SYSTEM MASS (RIGID BUSHINGS)

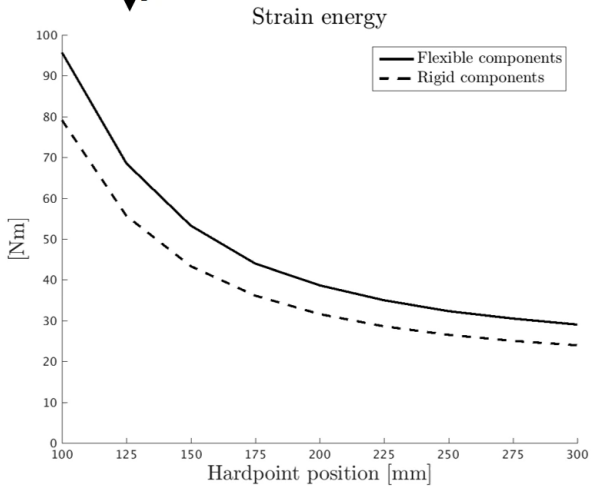


MINIMIZE SYSTEM MASS (ELASTIC BUSHINGS)



MINIMIZE STRAIN ENERGY (ELASTIC BUSHINGS)





OPTIMIZATION STRATEGIES – PROS AND CONS

Minimize Mass

+ Suitable for performance measurement
- Not as nice geometrical results
- Not as numerically stable

Minimize Strain Energy

+ Better geometrical results
+ Numerically stable
- Not very easy to understand and communicate

OPTIMIZATION STRATEGIES – WHAT TO USE

Parametrization of hardpoint position

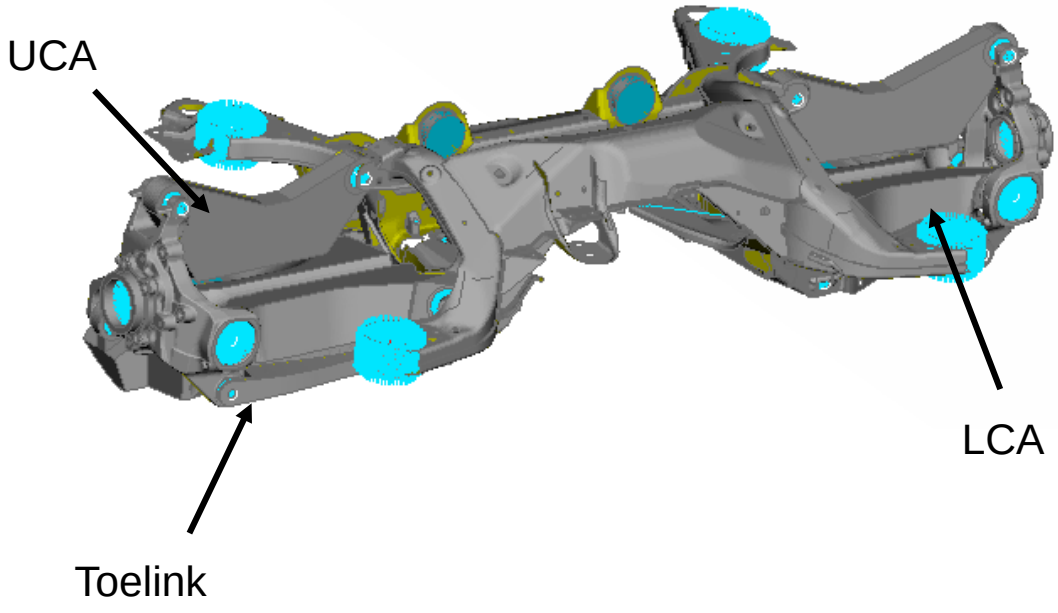
- Minimize Mass
  - The goal is to save weight and fulfill system requirements

For given hardpoint positions

- Minimize Strain Energy
  - If needed, to refine topology
  - Iterate with mass constraints

OPTIMIZATION WHEEL SUSPENSION SYSTEM

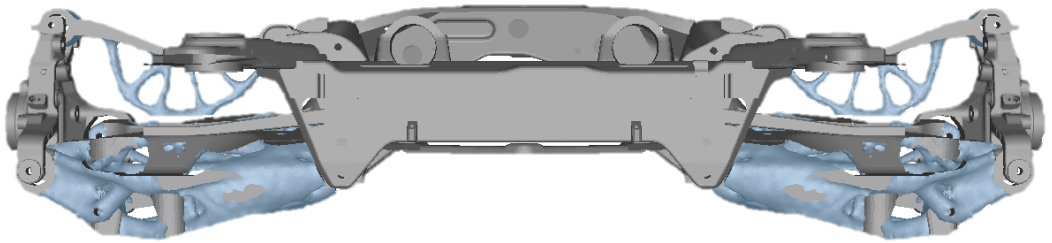
- Minimize Strain Energy
- Mass Constraint: $M^{OPT} \leq M^{REF}$
- Displacement Constraints
  - Knuckle (HP9)
- Load Cases – based on peak loads
  - BIP
  - DOC
  - SAC
- Symmetry Constraint



WHEEL SUSPENSION SYSTEM - MINIMIZE STRAIN ENERGY

- Result of Strain energy [Nm]

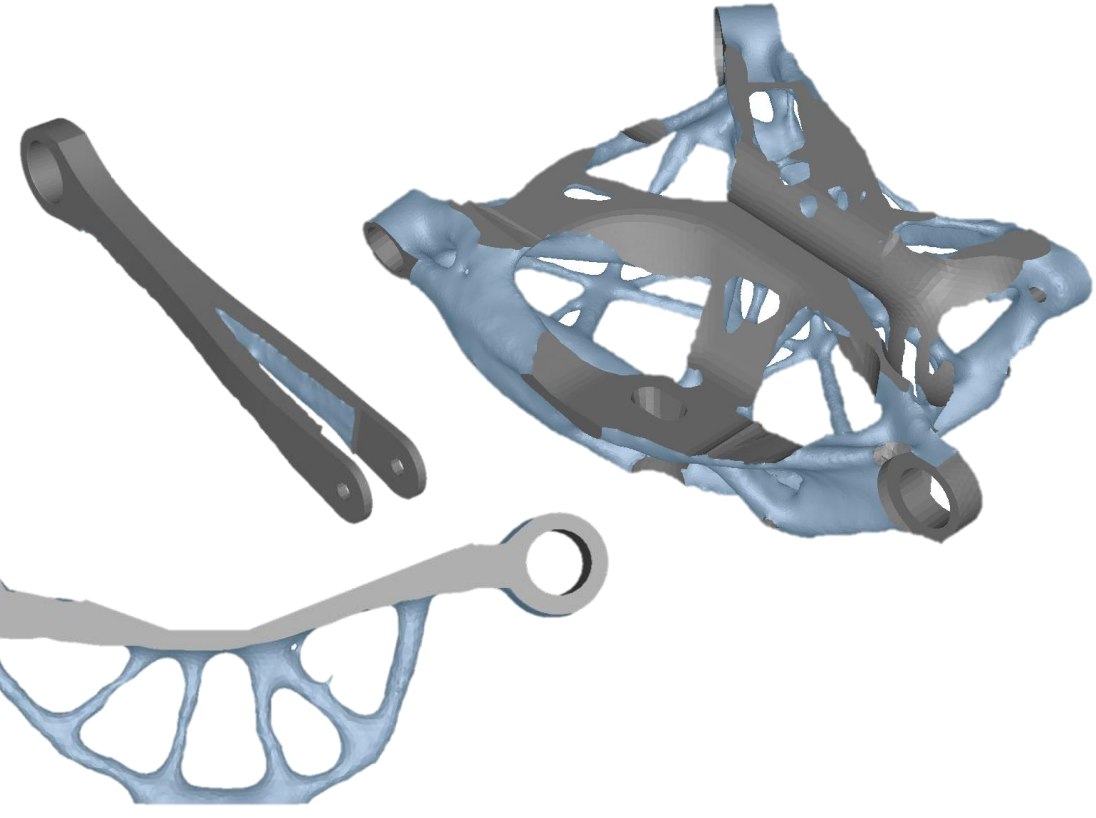
	Opt system	Ref model	Change
BIP	186	187	-0.4%
DOC	233	283	-17.5%
SAC	408	411	-0.7%
Sum	827	881	-6.0%



MASS DISTRIBUTION

- Mass [kg]

	Opt system	Ref model	Change
LCA	5.55	5.22	6.4%
UCA	0.73	1.19	-38.7%
Toelink	0.66	0.59	13.0%
Sum	6.95	7.00	-0.8%

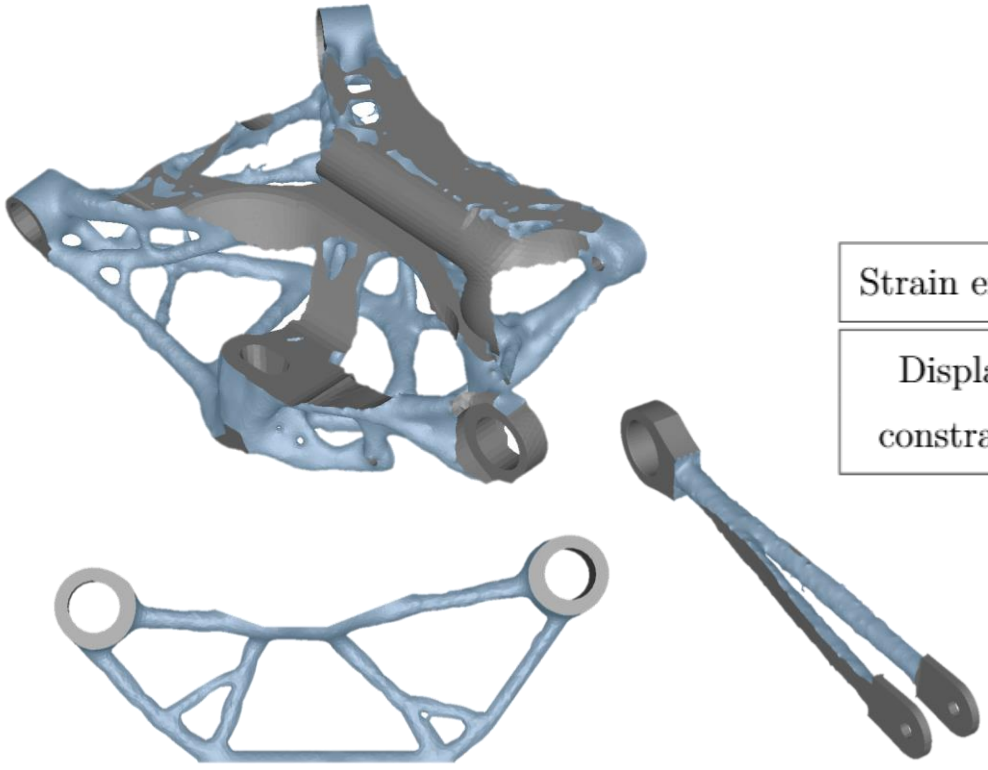


ITERATE MASS CONSTRAINT

- Iterate mass constraint until displacement constraints are no longer fulfilled
- Displacement Constraints
  - BIP – Longitudinal
  - DOC – Vertical
  - SAC – Lateral
- Only for illustrative purposes

	$0.9\bar{M}^{\text{Ref}}$	$0.8\bar{M}^{\text{Ref}}$	$0.7\bar{M}^{\text{Ref}}$	$0.6\bar{M}^{\text{Ref}}$	$0.5\bar{M}^{\text{Ref}}$
Strain energy [Nm]	-4.2%	1.9%	7.4%	25.2%	121.7%
Displacements constraints [mm]	Ok	Ok	Ok	Ok	Not Ok

ITERATE MASS CONSTRAINT



	$0.9\bar{M}^{\text{Ref}}$	$0.8\bar{M}^{\text{Ref}}$	$0.7\bar{M}^{\text{Ref}}$	$0.6\bar{M}^{\text{Ref}}$	$0.5\bar{M}^{\text{Ref}}$
Strain energy [Nm]	-4.2%	1.9%	7.4%	25.2%	121.7%
Displacements constraints [mm]	Ok	Ok	Ok	Ok	Not Ok

PROPOSED METHOD

Proposal

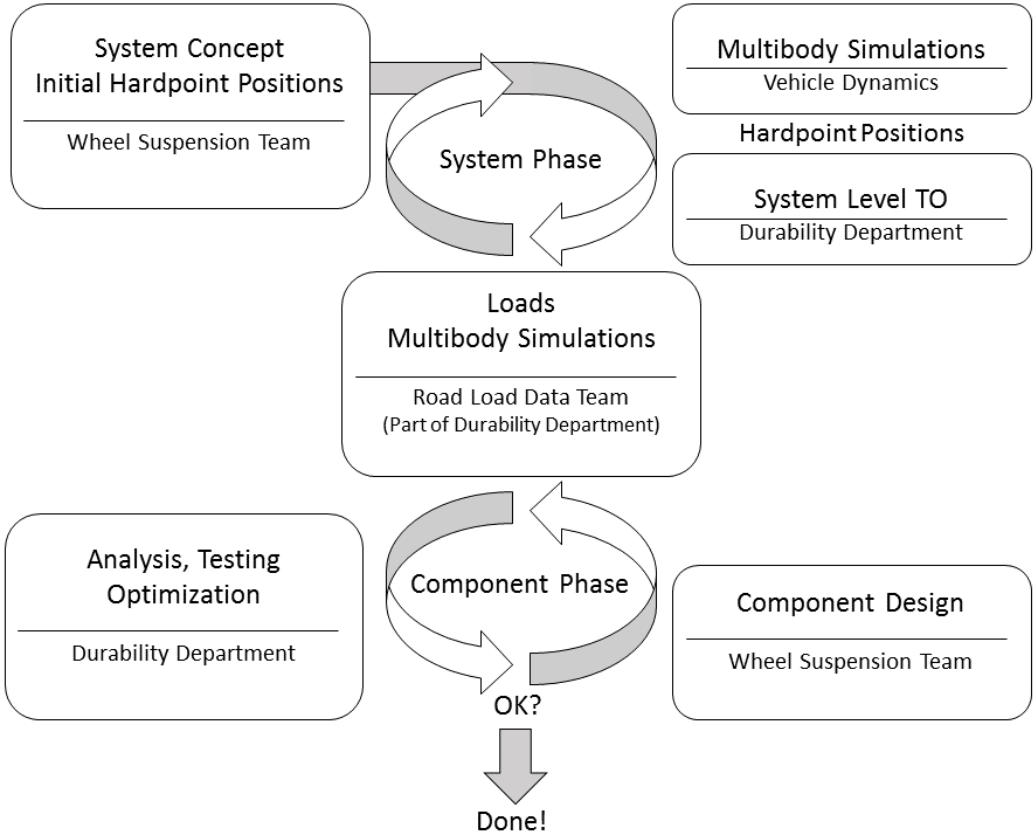
- System phase
- Topology Optimization with Parametrization of Hardpoint Positions
  - Broader solution space
  - Mass distribution between components

Further work

- Correlation with respect to displacements

Embrace the Future

- Efficient system level optimizations
  - Increased performance of products
  - Reduced costs of development



THANK YOU!