Non-Linear Optimization of Suspension Link for Optimal Performance using Altair's OptiStruct and HyperWorks

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Abstract

In recent times there is a high demand for lightweight automotive components which will reduce oil consumption and emissions. The components that are under non-linear load conditions would need optimization techniques that would yield a design which satisfies all performance targets and at the same time maintains the process efficiency with respect to time and cost. The use of CAE tools such as Altair's OptiStruct and HyperWorks allows engineers to explore various design solutions starting from concept level to matured design that meets multiple requirements simultaneously with due consideration of manufacturing methods that allows engineers to arrive at an optimal design and process.

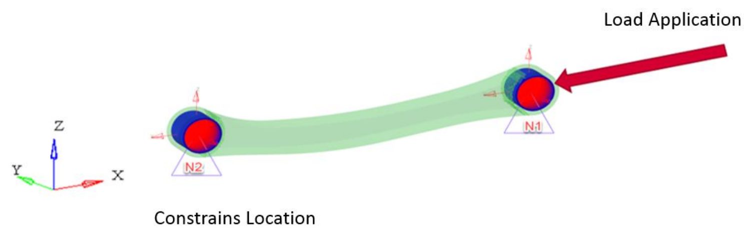
Introduction

Magna Cosma and Altair Engineering have collaborated on this design exploration study using Altair OptiStruct and HyperWorks in which a representative FEA model of the suspension link was subjected to various linear and non-linear load conditions, including bushings with nonlinear stiffness properties. Links of various sizes and shapes are used in a multi-link suspension that uses three or more lateral arms, and one or more longitudinal arms. Suspension links act as a rigid connection between wheel carrier to vehicle chassis which transmits forces and displacements without delay (stiffness), without geometrical instability (buckling, permanent set), without failure (strength) and most importantly with minimum inertia (mass). Performance metrics were used as targets in a topology optimization to estimate an optimal material layout/load path and cross sections which satisfy various design constraints and objectives. Multiple manufacturing options were considered in this study to explore the most efficient design. Further fine-tuning optimizations such as size and shape optimization were run to arrive at final size and form of the design which meets all design conditions.

This study also showcases the "single model work flow" using HyperWorks in which the user can perform baseline analysis, optimization, results interpretation and validation runs with minimum to zero CAD intervention from a single scalable environment.

Model setup and performance targets

Two-point suspension links are under various load conditions that involve material and geometric nonlinearities. Typically, each arm has a spherical joint or rubber bushing at each end. Consequently, they react to loads along their own length, in tension, compression, and twist due to the compliance of the bushings.



Material: HSLA Steel (Yield 370 MPa)

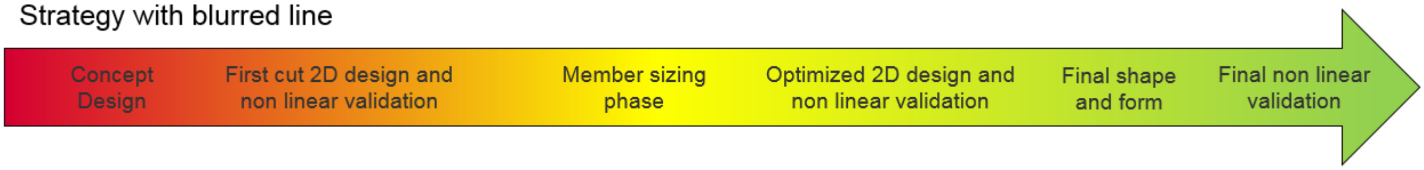
Loading	Magnitude	Target
Stiffness	1KN applied along N1-N2	>30KN/mm
Buckling (compressive/tensile)	Disp applied along N1-N2	>50KN
Permanent set (displacement)	40KN applied along N1-N2	<1mm
Durability (stress)	30KN applied along N1-N2	< 350MPa

Optimization strategy and single model workflow

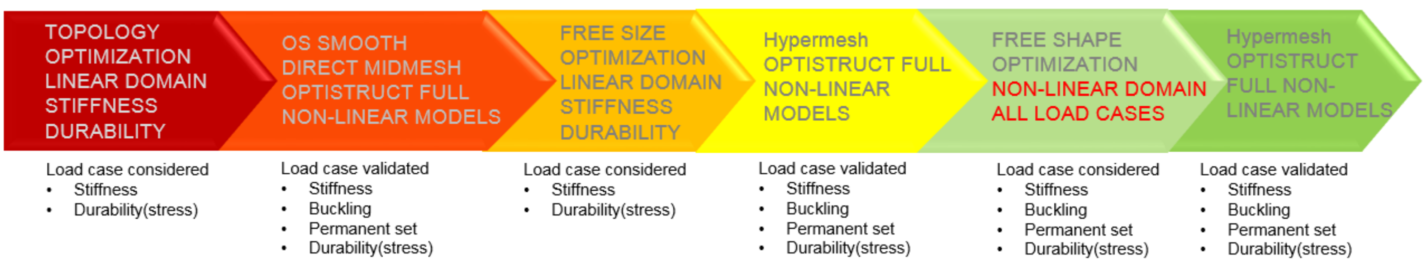
Initial planning and detailed work flow definitions with tool's capabilities and shortfalls in mind would increase the process efficiency and cost. In this study we limited the concept level topology and free size to linear domain with consideration of minimum and maximum members that satisfy the stress conditions. Fine tuning free shape optimization was run with all non-linear load cases as above.

Derived designs at various stages were validated with non-linear load cases to compared against the performance targets.

Strategy with blurred line



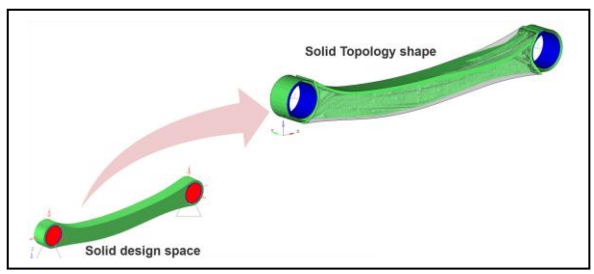
Workflow with clear tasks and tools



Topology Optimization setup

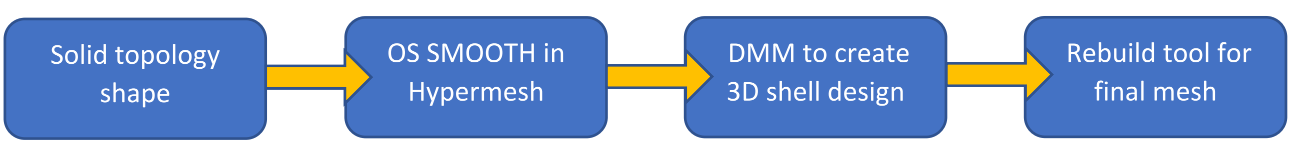
The objective of this stage was to derive an optimal load path and member size generation from a given design space, loads and boundary conditions, that can be interpreted into a 3D shell design which meets the performance targets.

- Loading considered- Stiffness and Durability
- Target Stiffness > 30KN/mm and Stress< 350MPa
- Linear optimization with 0.9mm average mesh
- Objective- Min mass
- Min and max member size control
- Draw constraints applied
- 43 design iterations to converge
- 2Hrs 10 Mins with 20 Cores DDM

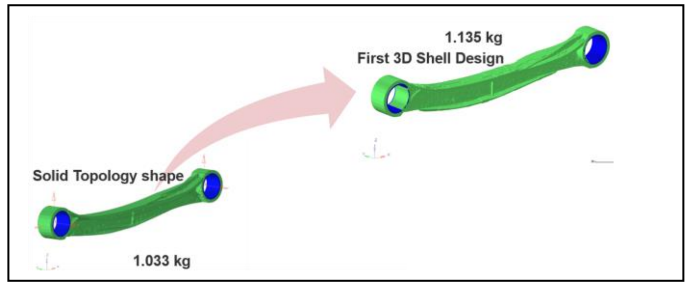


3D Shell design interpretation using HM 2017

Topology shape from optimization was used to run the OS SMOOTH utility in Hypermesh that created a smooth solid design. This solid design was submitted to Direct MidMesh (DMM) tool in Hypermesh that created a 3D shell interpretation. Also rebuild mesh utility was used to refine/improve resulting mesh from DMM.

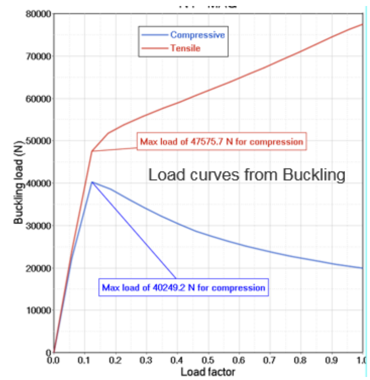


- Shape, form and variable thickness from solid model were mapped into 3D shell design.
- 30 mins including the DMM with manual correction
- 3D shell design was efficiently included into the NL analysis model to run all load cases.



The following table shows the design performance of all load cases after converting the topology geometry to shell mesh model without CAD intervention. Buckling and Durability (stress) being the driving load cases for optimization, the first shell design shows that it is marginally underperforming in Buckling and Durability.

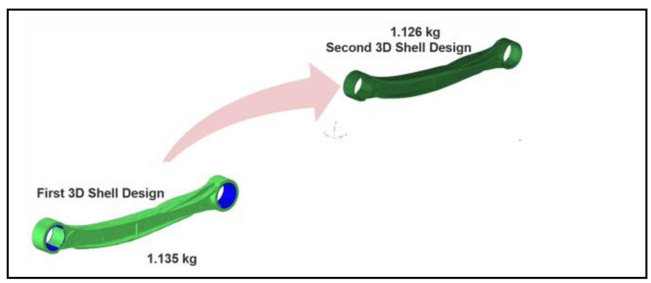
Loading	First Shell Design	Target
Mass	1.135 kg	
Stiffness	80KN/mm	>30KN/mm
Buckling (compressive/tensile)	40KN/48KN	>50KN
Permanent set (displacement)	3.4mm with 0.086mm set	<1mm
Durability (stress)	360 MPa	< 350MPa



Free size Optimization setup

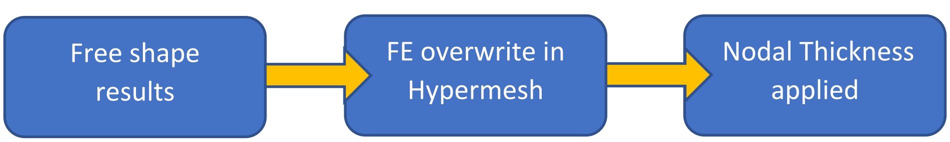
The objective of this stage was to derive a new design with an optimal cross section and material redistribution from an initial shell design, loads and boundary conditions, that can be manufactured, and which meets the performance targets.

- Loading considered- Stiffness and Durability
- Target Stiffness > 30KN/mm and Stress< 350MPa
- Linear optimization with 0.9mm average mesh
- Objective- Min mass
- min t=3mm and max t=8mm
- 26 design iterations to converge
- 10 Mins with 4 Cores Laptop

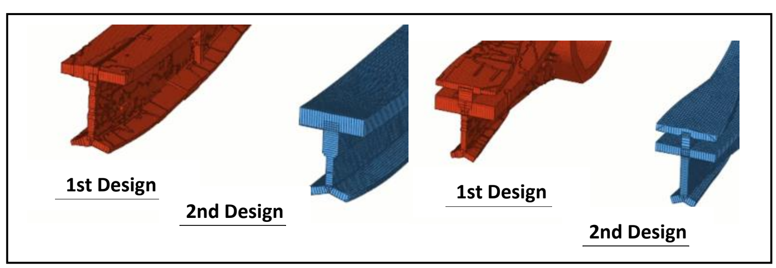


Free size design interpretation using HM 2017

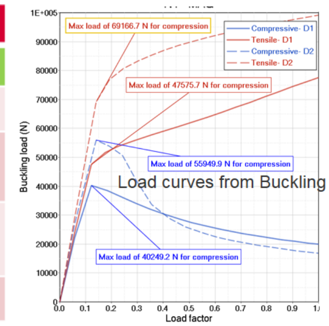
Free size thickness data from optimization was read through FE overwrite import in Hypermesh.



- 3D shell design was efficiently included into the NL analysis model to run all load cases.
- Section view shows the efficient redistribution of material to achieve superior performance with reduced mass.



Loading	First Shell Design	Second Shell Design	Target
Mass	1.135 kg	1.126 kg	
Stiffness	80KN/mm	98KN/mm	>30KN/mm
Buckling (compressive/tensile)	40KN/48KN	56KN/69KN	>50KN
Permanent set (displacement)	3.4mm with 0.086mm set	3.3mm with 0.079mm set	<1mm
Durability (stress)	360 MPa	359 MPa	< 350MPa

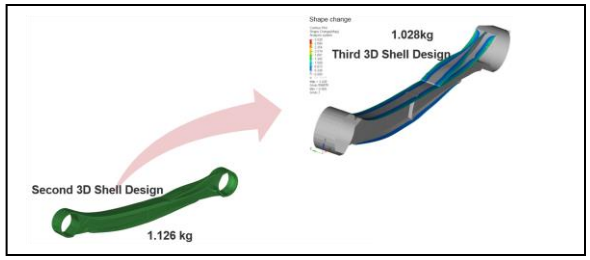


With 10 g reduction in mass, the second shell design exceeds the buckling loads. This shows the significance of running a free size that redistributes the material efficiently to meet the targets with reduced mass. Upon further investigation it is observed that the max stress occurs at a transition and can be addressed by smoothing the features.

Free shape Optimization setup

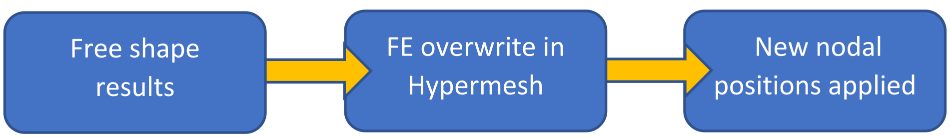
The objective of this stage was to derive an optimal section shape from a matured shell design, loads and boundary conditions, that can be manufactured, and which meets the performance targets.

- Loading considered- Buckling, Permanent set.
- Non-linear optimization with 0.9mm average mesh.
- Objective- Min mass
- Free shape defined along the flange edges
- 7 design iterations to converge
- 2Hrs 45 Mins with 48 Cores DDM

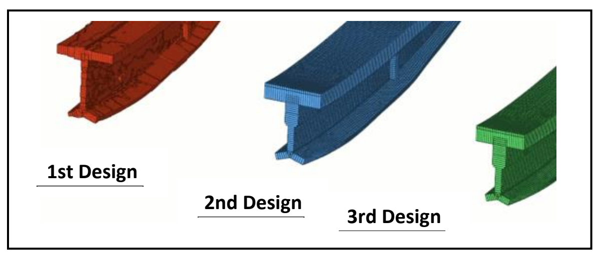


Free shape design interpretation using HM 2017

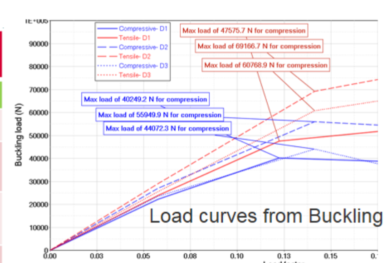
Free shape data from optimization was read through FE overwrite import in Hypermesh.



- 3D shell design was efficiently included into the NL analysis model to run all load cases.
- Section view shows the optimal section shape that resulted from optimization



Loading	First 2D Design	Second 2D Design	Third 2D Design	Target
Mass	1.135 kg	1.126 kg	1.028 kg**	
Stiffness	80KN/mm	98KN/mm	83KN/mm	>30KN/mm
Buckling (compressive/tensile)	40KN/48KN	56KN/69KN	44KN/61KN	>50KN
Permanent set (displacement)	3.4mm with 0.086mm set	3.3mm with 0.079mm set	3.3mm with 0.08mm set	<1mm
Durability (stress)	360 MPa	359 MPa	359 MPa***	< 350MPa



**Final design mass could be slightly different (+10%) when manufacturing and assembly considerations are met

*** Max stress occurs very locally at a transition and can be address with a fillet.

With 107 g reduction in mass, the third shell design marginally meets the buckling loads. Free shape optimization by its nature is very easy to setup and can yield very non-intuitive shape changes. In this case all flange edges were selected as the design space that was allowed to grow or shrink based on the constraints and objectives.

Conclusion

- This study focused on free shape optimization for nonlinear material and loading.
- Combining topology, size and shape along with the work flow that was used helped us reach optimal design much faster.
- This work flow yields minimum turnaround time with minimum to no CAD intervention in the design/development process.
- Non-linear bushing data can be used for analysis and optimization which improves the model fidelity in this case.
- Same optimization flow can be used with stampings, extrusion, forging etc.
- Having a single solver to optimization, linear and non-linear analysis (material and contact) simplifies the process which avoids the tedious process of converting the FE models to different solvers.