Structural Topology Optimization of Multilink Suspension System Using ATOM

by

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Agenda

- Challenges in Chassis Suspension Design
- Chassis Structural Design Process
- Multilink Suspension System Modeling, Correlation, and Simulation
- Design Synthesis Using ATOM (Abaqus Topology Optimization Module)
- Summary
Challenges in Chassis Suspension Design

Higher **Performance**, Lower **Mass & Cost** in vehicle design

- Nonlinear geometry & material in alternative light weight material design
- Hyperform and/or Hyperelastic (i.e. bushing, rubber like component, jounce bumper, lmsc, ... etc.) fatigue properties
- Welding fatigue analysis
- Nonlinear contact or self-contact design
- Explicit/Transient load cases
- Composite thermal plastic – Anisotropic material

**Compliant Suspension**

Geometrical & Material Nonlinearities may be significant

- **Bushing Push-In/Push-Out Effort**
- **Higher Performance, Lower Mass & Cost**
- **Compliant Suspension**

Strut Mount Analysis – Coning @ Strut Lower
Chassis Structural Design Process in The Past

CAE Structural Evaluation

Component Optimization

- Topology
- Sheet Metal Gage
- Shape Opt.
- General Opt.

Optimized Component Design

Vehicle system/subsystem model assessment; What-if Study & Trade-off analysis

CAE Establish Design Loads (Static or vRLDA)

Prototype Measured Loads

Validation & Durability Testing

FINAL DESIGN

Design Requirements
- Packaging
- Stiffness
- Fatigue
- Veh. Dynamic

N & V

Manufacturing
- Safety

Previous Model Design Data

Mule Vehicle Measured-Loads

Vehicle Content

Topology Optimization

LCA Gauge Optimization

UCA Shape Optimization

General Optimization

Multi-discipline Design Optimization (MDO)
- Design of Experiment (DOE)
- Response Surface Approach
- Stochastic Design Optimization
- Design For Six Sigma (DFSS)
Proposed Chassis Structural Design Process

CAE Structural Evaluation

Vehicle system/subsystem model assessment

System/Subsystem Optimization

What-if Study & Trade-off Analysis

Topology

Sheet Metal Gage Opt.

Shape Opt.

General Opt.

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Mule Vehicle Measured-Loads

Vehicle Content

Front Suspension System Model

Rear Suspension System Model

B bush

A bush

T Mnt

BJ

C bush

B bush

A bush

BJ

B bush

A bush

BJ

B bush

A bush
What’s Geometric & Material Nonlinearities

Geometric nonlinear

- Large deflections
- Deflection-dependent loads
- Deflection-dependent stiffness

Material nonlinear

- Material plasticity
- Material creep
**Nonlinear Structural Optimization in Literature**

**Slender Beam Example**


Fig. 1 Design domain for long slender beam.

Fig. 2. Optimal designs from (a) linear analysis; (b) materially nonlinear analysis; (c) geometrically nonlinear analysis; (d) materially and geometrically nonlinear analysis.

Fig. 3. Deformed shape of each design under combined nonlinear analysis of Fig. 2. (a) linear design (Mean compliance: 101,376 Nm); (b) materially nonlinear design (Mean compliance: 101,801 Nm); (c) geometrically nonlinear design (Mean compliance: 25,359 Nm); (d) materially and geometrically nonlinear design (Mean compliance: 12,924 Nm).
A Case Study in Nonlinear Topology Optimization

A case study for nonlinear geometric effects in topology optimization

Topology Design Task:
Maximize structural stiffness while using only 30% of the original mass.

What happened here?
- As material is removed from the design domain, the loading in the center region changes from shear dominated to bending dominated.
- The linear geometry model does not sense this change, causing it to evolve into a compression member.

Nonlinear geometric effect is a matter!
Front Suspension System Modeling

Suspension System Modeling Steps:

Step 1: Identify type of connection (Bushings, Ball Joint, Rev. Joint, Jounce Bumper, Shock, Spring, Top Mount, etc.) and connection points.
Step 2: Define Connector / Joint properties.
Step 3: Trim the vehicle – a. tune the spring preload; b. Jounce Bumper free height need to tune to match design position.
Step 4: Confirm the system model by checking interface joint force with ADAMS load prediction.
Step 5: Setup ATOM design problem for topology study; i.e. identify critical load cases, design space, manufacturing constraints, ... etc.
## Front Suspension Model & Correlation

![Diagram showing suspension components and forces](Image)

### Joint Force Comparison between ADAMS and ABAQUS System Model

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Handling Bushing</th>
<th>Top Mount</th>
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<tbody>
<tr>
<td></td>
<td>Fm</td>
<td>Fx</td>
</tr>
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<td></td>
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<td>1. Forward Braking - #3</td>
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<td>ADAM's Load</td>
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<td>ABAQUS System Model</td>
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<td>-586</td>
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<tr>
<td>%</td>
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<td>-22%</td>
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<td>2. Pothole (L Max vert)</td>
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<tr>
<td>ADAM's Load</td>
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<td>2000</td>
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<tr>
<td>ABAQUS System Model</td>
<td>15247</td>
<td>1545</td>
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<tr>
<td>%</td>
<td>-3%</td>
<td>-23%</td>
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Front Suspension Pothole Simulation
Rear Suspension System Modeling & Simulation

Rear 5 Links Suspension

Pothole Simulation

ABAQUS CAE Model
Rear Suspension Bushing Rate Sensitivity

Rear 5 Links Suspension

B Bushing Conical Rate Sensitivity @ Fore/Aft Braking Travel

B Bushing Rate Curve

Axial Rate (450 N/mm) vs. Displacement (mm)

Torsional Rate (0.7 N-m/deg) vs. Angle (deg)

Radial Rate (9 kN/mm) vs. Radial Displacement (mm)

Conical Rate (2.5 N-m/deg) vs. Angle (deg)
Handling Link Topology Study

Objective: Minimize link compliance
Subject to: 1. Volume fraction = 0.7 or 0.5
2. Manufacturing symmetry constraint on link neutral Plan

Load Case: Pothole
Link Material: AA6082M
Link Mass: 0.45 kg; Design Space: 0.31 kg

Component
Linear Geo & Mat

VF = 0.7

VF = 0.5

System Model
NonLinear Geo & Mat
VF = 0.7

Green – Design Space
Pink – Non Design Space

Component
NonLinear Geo & Mat

VF = 0.7

VF = 0.5
Summary

- Design synthesis capability of multi-link suspension system which includes structural components and connector elements representing linear and/or nonlinear interface joint is demonstrated.

- Design synthesis with system modeling techniques can better describe how components reacting to each other in a compliance mechanism. Hence, it can provide a more reasonable design suggestion than component level design study.

- Geometrical and material nonlinearities of multi-link suspension have a significant effect on both performance and design optimization.

- ATOM is a rational tool to exploit the critical load paths and suggests alternative component designs in structural system under a nonlinear behavior.

- GM Chassis CAE group is working to further expand this design capability to other chassis structural designs.