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A/SP Lightweight Suspension
Front Lower Control Arm Design Optimization

- Objective and Scope
- Design Targets
- Development Process
- Design Proposals
- Performance
- Mass
- Manufacturing
- Cost
- Summary & Conclusions
A/SP Lightweight Suspension
Front Lower Control Arm Design
Optimization

Hannes Fuchs, Ph.D.
Multimatic Engineering
Objective & Scope

• Develop lightweight steel suspension front lower control arm (FLCA) designs:
  – functionally equivalent, but at a reduced cost relative to the baseline FLCA assembly
• Forged aluminum production OEM baseline design
• Project timing: 20 weeks proof-of-concept design*

*Designs are subjected to “typical” OEM requirements
Design Targets

- **Structural Performance**: Equal to, or exceed the baseline and OEM requirements
- **Mass**: Less than, or equal to the baseline
- **Cost**: Reduced vs. the baseline (target 30%)
- **Corrosion**: Meet OEM corrosion requirements
- **Package**: Meet available packaging constraints
Structural Performance

Static Stiffness
\[ K_x \geq 2.9 \text{ kN/mm} \]
\[ K_y \geq 125 \text{ kN/mm} \]

Longitudinal Strength (Buckling)
\[ > 25 \text{ kN} \]

Extreme Loads
Set < 1.0 mm
Plastic Strain < 4%

Durability Life > 1.0
Mass

Handling bushing

Complete FLCA Assy
(3.07 kg)

Ball joint

Ride bushing
Package

Available package volume

- Stabilizer bar clearance zone
- Clevis clearance
- Knuckle clearance
- Rim clearance
- Tire clearance

Design environment

- Steering knuckle
- Wheel/tire envelope
- Subframe
- Subframe clevis
- FLCA
- Front of car

Design environment
Cost

• Target 30% cost reduction vs. baseline
• Estimate manufacturing costs relative to the aluminum baseline structure
• Assumptions
  – 30k, 100k, and 250k vehicles per year
  – 6 year program
Development Process

1. Concept Development - Size / Shape Optimization (stiffness)
   - Stiffness Optimization
   - Steel selection
     - Extreme Loads
     - Longitudinal Strength

2. Design Development
   - Forged
   - Sheet A
   - Sheet B

3. Manufacturing

4. Cost Assessment

Fine Tuning
- Durability
- Strength
Based on concept development size / shape optimization studies, three (3) candidate designs were selected for detailed development.
Design Proposal Comparison

Baseline
Forged AL

Machined T-pin
Machined bushing sleeve
Forged ball joint housing

Machined
Clamshell

Forged T-pin
Bushing sleeve
MIG weld
Upper & lower stampings
Forward Flange
Tube
Web
I-Beam

Forged Steel

Riveted forged ball joint housing

I-Beam
Finite element analysis (FEA) methods were used to predict the structural performance of each design.

Mass of each design was minimized while meeting the structural requirements.
Forged Designs – Materials

Baseline Design

Forged Design

6082-T6 forging

Steel washer

Steel bolt & washer

AISI 15V24 forged steel alloy

Min. 5.0 mm

Min. ~3 mm assumed

Note: Steel bolt & washer not required w/ press-on bushing

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Forged Steel Design

- Determined in the early design phase that an aggressive minimum gage target would be required (<4.5mm) to be mass competitive.

Thickness distribution for optimum stiffness:
Clamshell Design – Materials

Upper stamping**
(1.9 mm DP780)

Bushing sleeve*
(2.5 mm SAE1020 DOM)

Lower stamping**
(1.9 mm DP780)

T-pin*
(forging)

Rivets

Common ball joint*
housing
(forging)

Note: Steel bolt & washer not required w/ press-on bushing

*E-coat finish
**Hot dipped galvanized coating + E-coat
I-Beam Design - Materials

- Inboard flange - thick* (5.0 mm HSLA550)
- Inboard flange - thin* (2.2 mm DP980)
- Web* (2.3 mm DP980 web)
- Forward Flange* (2.7 mm DP780)
- Common ball joint housing* (forging)
- T-pin* (forging)
- Ball joint reinforcement** (1.5 mm HSLA550)
- Bushing sleeve* (2.5 mm SAE1020 DOM)
- Rivets
- Tube* (2.2 mm DP780)

Note: Steel bolt & washer not required w/ press-on bushing

* E-coat finish
** Hot dipped galvanized coating + E-coat
Durability Analysis Results

Results are presented for the (3) most severe load cases.

*Note: Highly localized issues not considered a design limitation.

Requirement > 1.0
Forging Comparison

Baseline design

Contoured to the target minimum of 1.0 life

Highly localized issues not considered a design limitation

Forged design

Worst Case Condition
Forward Braking Load Case

1.1 (minimum)

1.2 (minimum)
### Stamped Comparison

**Durability Analysis**

#### Worst Case Condition
- **Forward Braking Load Case**

**Clamshell design**
- Contoured to the target minimum of 1.0 life
- Results account for reduced fatigue properties in HAZ

**I-Beam design**
- 1.0 (minimum)
- 1.2
- 1.3
- 1.4

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Results are presented for the (3) most severe load cases:

- Static Pothole-LHS Max Vert
- Static Pothole-LHS Max Fore/Aft
- Forward Braking#3

Permanent Set / Target Set

Baseline AL Forging: 0.00, 0.03, 0.00
Stamped Clamshell: 0.12, 0.00, 0.01
I-Beam w/ tubular flange: 0.01, 0.02, 0.00
Forged Steel: 0.19, 0.01, 0.00

Requirement < 1.0
Forged Comparison

Extreme Load Cases

LHS Pothole
Fore/Aft

Plastic strain (<4%)
Plotted to a maximum of 1% to show areas undergoing deformation

Baseline design

Von Mises stress
Contoured as a percent of the material yield strength

Forged design

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Stamped Comparison

Extreme Load Cases

LHS Pothole Fore/Aft

Plastic strain (<4%)
Plotted to a maximum of 1% to show areas undergoing deformation

Von Mises stress
Contoured as a percent of the material yield strength

Von Mises stress
Contoured as a percent of the material yield strength

Clamshell design

I-beam design
Longitudinal Strength

**Longitudinal Load (25kN min.)**

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Buckling Load / Target Load</th>
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<tr>
<td>Baseline AL Forging</td>
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<tr>
<td>Stamped Clamshell</td>
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<tr>
<td>I-Beam w/ tubular flange</td>
<td>1.23</td>
</tr>
<tr>
<td>Forged Steel</td>
<td>1.08</td>
</tr>
</tbody>
</table>

Requirement: > 1.0

Buckling Load:
- Baseline AL Forging: 28.0 kN
- Stamped Clamshell: 29.3 kN
- I-Beam w/ tubular flange: 30.7 kN
- Forged Steel: 26.9 kN
Longitudinal Strength – Deformations

Baseline design

Clamshell design

Forged design

I-beam design
Mass Summary

*Notes on steel designs: (1) Enable deletion of bushing bolt/washer. (2) Incorporate a weight-optimized ball joint.*
Clamshell Design – Manufacturing

• Considerations
  – DP780 stamping feasibility
  – Butt welding

• Forming simulations
• Industry welding examples

Industry Example – Butt-Welded FLCA

Forming Simulation – DP780
I-Beam Design – Manufacturing

- Considerations
  - Tube bending
  - Weld fixtures

- Conventional tube bending process
- Simple stamped / blanked components with easily developed trim lines

Industry Examples – Tubes

Gooseneck decklid hinge

IP beam brackets
Forged Design – Manufacturing

- Considerations
  - Aggressive manufacturing target of 3mm minimum gage and associated manufacturing cost

- Industry examples represent current state-of-the-art
- Forging process simulation / optimization required
- Process-based component re-design / optimization

Industry Examples - Forged FLCAs
Cost

- Arm structure only
  - Aluminum FLCA baseline
    - includes washer & bolt, machining
  - Stamped clamshell
  - Fabricated tubular I-beam
  - Steel forging (insufficient data)

- Cost of manufacture only
  - 30k, 100k, and 250k vehicles per year (2 FLCAs per vehicle)
  - 6 year program
Cost

- **Variable costs**
  - Material / coating / E-coat
  - Purchased components
  - Machining labor & burden
  - Overhead
  - Capital
  - SG&A

- **Fixed costs**
  - Tooling (machining, stamping, welding, etc.)

- **Cost**
  - Total $ = variable $ + amortized fixed $

Relative Cost = \frac{\text{Cost}}{\text{Baseline Cost}}

### Assumed material costs

<table>
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<tr>
<th>Material Type</th>
<th>No Coating</th>
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</thead>
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<td>Aluminum</td>
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<td>HSLA 550</td>
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<td>DP 780</td>
<td>$1.31</td>
<td>$1.47</td>
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<tr>
<td>DP 980</td>
<td>$1.42</td>
<td>$1.58</td>
</tr>
</tbody>
</table>
Cost Summary

Costs relative to baseline at 250,000 volume

- Alum baseline
- Clamshell
- I-Beam

Note: Insufficient data for forged design
Summary

- Two (2) sheet steel FLCA and one (1) forged FLCA designs were developed to determine the minimum mass while meeting and/or exceeding the structural performance of the baseline design.
- Manufacturing costs were estimated for each design, except for the forged design which requires a manufacturing feasibility study due to the assumed 3mm minimum gage target.

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Conclusions

- **Equivalent mass to the baseline assembly**
  - Up to 34% cost reduction potential
  - Deemed production feasible based on forming simulations and industry welding examples

- **Highest buckling resistance & high stiffness**
  - Up to 21% cost reduction potential
  - Deemed production feasible based on typical welding process development and industry tube bending examples

- **Highest stiffness & durability performance**
  - Aggressive 3mm minimum gage target
  - Forging industry to evaluate manufacturing feasibility and associated manufacturing costs

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THANK YOU!

Multimatic Engineering
Corrosion

• To maintain OEM corrosion requirements, corrosion protection is applied to components based on material gage

• Sheet steel material gage limit (OEM specific):

  >~2.0mm: E-coat finish

  <~2.0mm: Hot dipped galvanized coating*

  + E-coat

*OEM specific, e.g. Hot Dip G60/G60 or Hot Dip Galvanneal A-40
Baseline Design

Design:
- Min web thickness 5.0 mm
- Flange thickness 10.0 mm
- Flange height 30.0mm (typ)
- Flange to web rads 7.0 mm
- 6° draft

Machined bushing sleeve, T-pin, and BJ housing
Clamshell Design

All components MIG welded (~1.20m weld length)
All components MIG welded (~1.35m weld length)
Forged Design

Design Assumptions:
- Min web thickness 2.8 mm
- Flange thickness 3.0 to 7.8 mm
- Flange height 10.0 to 30.0 mm
- Flange to web rads 3.0 mm
- 5° draft

Machined bushing sleeve and BJ housing

Bushing sleeve

T-pin

Ball joint housing

Section A-A
### Materials

#### Material Stress-Strain Comparison

<table>
<thead>
<tr>
<th>Material</th>
<th>Engineering Stress [MPa]</th>
<th>Engineering Strain</th>
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<tbody>
<tr>
<td>DP980</td>
<td>(σ_y=715MPa, σ_u=1,008 MPa)</td>
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<tr>
<td>T-Pin forging</td>
<td>(σ_y=760MPa, σ_u=1,124 MPa)</td>
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<td>DP780</td>
<td>(σ_y=567MPa, σ_u=846 MPa)</td>
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<tr>
<td>HSLA550</td>
<td>(σ_y=550MPa, σ_u=620 MPa)</td>
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<tr>
<td>AISI 15V24 forging</td>
<td>(σ_y=646MPa, σ_u=878 MPa)</td>
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<tr>
<td>BJ forging</td>
<td>(σ_y=420MPa, σ_u=490 MPa)</td>
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<tr>
<td>DOM1020</td>
<td>(σ_y=414MPa, σ_u=483 MPa)</td>
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<tr>
<td>6082-T6 forged aluminum</td>
<td>(σ_y=310MPa, σ_u=340 MPa)</td>
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# Materials

## A/SP Sheet Material Selection

<table>
<thead>
<tr>
<th>Item</th>
<th>Steel Grade</th>
<th>Thickness (mm)</th>
<th>Grade</th>
<th>Yield (Mpa)</th>
<th>UTS (Mpa)</th>
<th>EL (%)</th>
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<td>1</td>
<td>MIL 160/300</td>
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<td>A60</td>
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<td>8</td>
<td>HSLA 950/40</td>
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<td>10</td>
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<td>A60</td>
<td>260</td>
<td>400</td>
<td>29-36</td>
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</tbody>
</table>

Sources: WorldAutoSteel
Material modeling considerations

- Material fatigue property reduction in the weld HAZ for all steel grades per OEM modeling guidelines (durability load cases only)
- 20% material strength reduction in HAZ zone for high strength AHSS steel grades (e.g. DP980) (strength load cases only)
- AS/P recommendations for gage & grade selection
Longitudinal Strength – Peak Load

- **Baseline design (28.0 kN)**
- **Clamshell design (29.3 kN)**
- **Forged design (26.9 kN)**

**Deflection Magnitude at Balljoint [mm]** vs **Load Magnitude at Balljoint [N]**

- **Target - Longitudinal Buckling (25 kN)**
- **Baseline FLCA**
- **Clamshell Design (tr344)**
- **I-Beam Design (tr485)**
- **Forged Design (tr108)**

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## Performance Summary

<table>
<thead>
<tr>
<th>Design</th>
<th>Baseline AL Forging</th>
<th>Stamped Clamshell</th>
<th>I-Beam w/ tubular flange</th>
<th>Forged Steel</th>
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<tbody>
<tr>
<td>Image - Assembly</td>
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<td></td>
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<tr>
<td>Trial</td>
<td>Base</td>
<td>Tr344</td>
<td>Tr485</td>
<td>Tr108</td>
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<td>Material type</td>
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<td>DP780</td>
<td>SAE 550X, DP 980, DP 780</td>
<td>AISI 15V24</td>
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<td>Stiffness (rigid bushings)</td>
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<td>Direction</td>
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<td>Direction</td>
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<td>Extreme Load / permanent set (nonlinear bushings, nonlinear material &amp; geometry)</td>
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<td>Load Case Name</td>
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*Note: Highly localized issues not considered a design limitation*
# Mass Summary – Detail

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<thead>
<tr>
<th>Design</th>
<th>Baseline AL Forging</th>
<th>Stamped Clamshell</th>
<th>I-Beam w/ tubular flange</th>
<th>Forged Steel</th>
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<tbody>
<tr>
<td><strong>Image - Assembly</strong></td>
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<td>Trial</td>
<td>Base</td>
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<td>Tr485</td>
<td>Tr108</td>
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<td><strong>Material type</strong></td>
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</tr>
<tr>
<td>FLCA w/ BJ housing &amp; bolt</td>
<td>1.65</td>
<td>1.79</td>
<td>1.83</td>
<td>1.91</td>
</tr>
<tr>
<td>Ball joint internals*</td>
<td>0.36</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>FLCA w/ integrated Bj</td>
<td>2.01</td>
<td>2.03</td>
<td>2.06</td>
<td>2.14</td>
</tr>
<tr>
<td>Handling bush (A)</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>Ride bush (B)</td>
<td>0.84</td>
<td>0.84</td>
<td>0.84</td>
<td>0.84</td>
</tr>
<tr>
<td><strong>Complete FLCA Assy</strong></td>
<td>3.07</td>
<td>3.08</td>
<td>3.12</td>
<td>3.20</td>
</tr>
</tbody>
</table>

*Note: Steel designs incorporate a OEM component supplier provided weight optimized ball joint (-0.12kg); re-design of the baseline FLCA ball joint out of the scope of this project.

**Note:**
Steel design enables push-on style ride bushing which does not require 0.07kg bolt for retention.
Cost Summary

Costs relative to baseline at each volume

- Alum baseline
- Clamshell
- I-Beam

Note: Insufficient data for forged design
Clamshell Design – Manufacturing

Stamping Formability

Formability plot (crash form) – 1.90 mm DP780 stamping

Major strain contour plot, contoured to a maximum of 45%

trial 344
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Static Stiffness Analysis Results

- **Baseline AL Forging**: Longitudinal Stiffness: 2.9 kN/mm, Lateral Stiffness: 125 kN/mm
- **Stamped Clamshell**: Longitudinal Stiffness: 3.2 kN/mm, Lateral Stiffness: 125 kN/mm
- **I-Beam w/ tubular flange**: Longitudinal Stiffness: 3.6 kN/mm, Lateral Stiffness: 149 kN/mm
- **Forged Steel**: Longitudinal Stiffness: 3.6 kN/mm, Lateral Stiffness: 189 kN/mm

All values are compared to the Baseline AL Forging, with a requirement of >1.0.