UltraLight Steel Auto Suspension

Engineering Report

An in-depth report of the ULSAS study, undertaken to demonstrate the benefits of steel in designing suspension systems. The report provides detailed information on the design, performance, cost, manufacturing, packaging and mass of the five suspension systems analyzed by the study.

UltraLight Steel Auto Suspension

Research conducted by Lotus Engineering as Commissioned by the UltraLight Steel Auto Suspension Consortium. This report is published by the American Iron and Steel Institute.

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Contents

1. Design 1-1

1.1 Benchmarking 1-2

2. ULSAS Suspension System Types 2-1

2.1 Twistbeam 2-1
2.2 Strut and Links 2-3
2.3 Double Wishbone 2-5
2.4 Multi-Link 2-6
2.5 Lotus Unique 2-7

3. Materials Utilization Summary 3-1

1. Design

The steel industry's search for low-cost, high-performance automotive weight reduction solutions includes auto suspensions. The UltraLight Steel Auto Suspension (ULSAS) study, undertaken by a consortium of the world's largest steel companies, evaluated and developed designs for steel-intensive suspension systems. The resulting designs demonstrate weight and cost improvements over conventional steel and benchmarked aluminum systems.

Through the innovative application of steel and the use of near-reach manufacturing technologies, ULSAS designs achieved:

- Up to 34 percent mass reductions over conventional steel systems.
- Up to 30 percent cost advantages over a benchmarked aluminum system.
- Equal or better performance results.

These results are summarized in Table 1.

Table 1 ULSAS Results Summary - Cost & Mass vs. Targets

Suspension Type	Cost (Savings)		Mass (Savings)	
	Target	Results	Target	Results
Twistbeam	0%	6%	20%	32%
Strut and Links	0%	2%	20%	25%
Double Wishbone	0%	0%	20%	17%
Multi-Link*	20%	30%	0%	3%
Lotus Unique**	0%	22%	20%	34%

*Compared to aluminum benchmark
**Compared to Double Wishbone

Lotus Engineering, a world-class leader in vehicle and chassis engineering and experts in vehicle dynamics, conducted the study under the guidance and supervision of the steel consortium.

ULSAS Design Phase

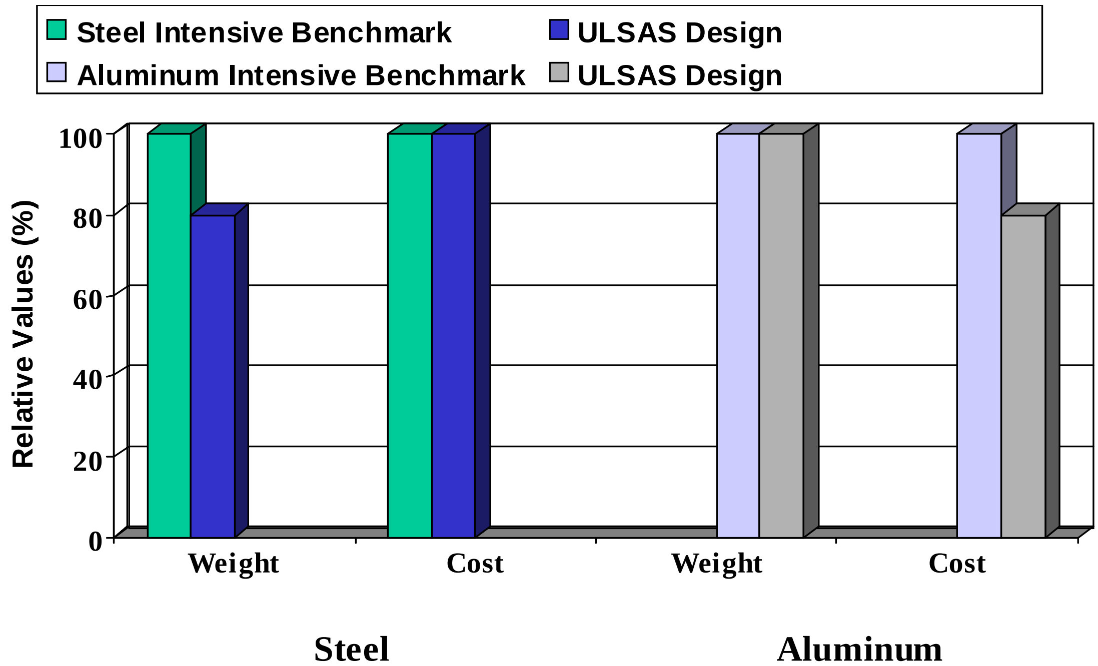
After conducting an extensive benchmarking analysis of several suspension system designs, the steel consortium and Lotus agreed on the design objectives of the program:

Objective #1: Reduce the mass of new steel designs by at least 20 percent over benchmarked conventional steel suspension systems, without a cost penalty (Figure 1).

Objective #2: Match the mass of a benchmarked aluminum system while demonstrating a cost reduction of at least 20 percent (Figure 1).

1.1 Benchmarking

Benchmark versus Design Objectives



Materials Implications

Identified applications for new steels that would contribute to mass savings, cost reductions and enhanced performance with an emphasis on:

- High- and ultra high-strength steels
- Large, thin-wall sections

Manufacturing Implications

Analyzed the manufacturing technologies associated with the production of different suspension designs, including:

- The forming of specific components, assembly, and time estimates for fitting the total system to vehicles.
- The requirements that ensure parts were designed with minimum yield strength.
- The determination of optimal conditions for forging, hydroforming, tailor welded blanks, and welding, including laser.

Packaging Implications

Reviewed the packaging capabilities of each system, to include:

- Underfloor fit
- Interior space requirement
- Trunk space requirements

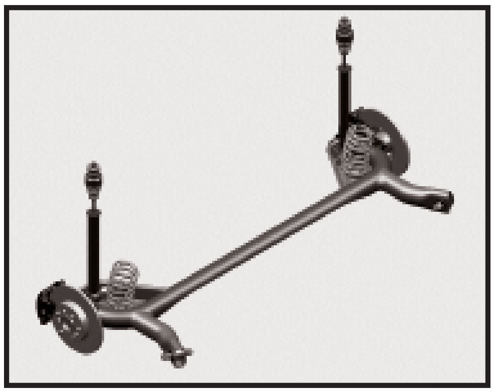
2. ULSAS Suspension System Types

Design for each ULSAS suspension system shared a common approach:

- A thorough ground-up approach to design
- State-of-the-art sub-system components
- Unique design solutions
- System structural analysis
- Cost analysis

Following are summaries of results for each suspension design.

2.1 Twistbeam

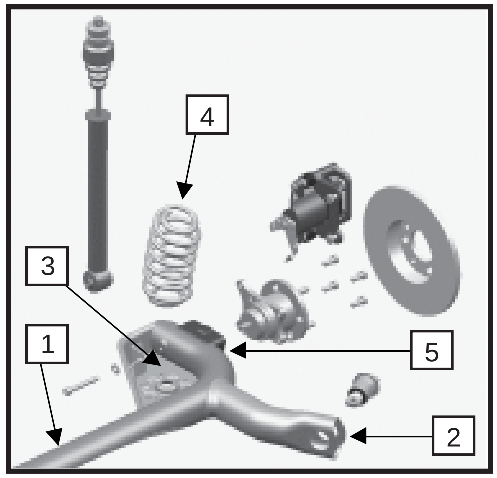


Summary:

- 32 percent mass savings
- 6 percent cost savings
- Improved performance over benchmark
- Potential for broader scope of twistbeam applications

Features:

- Iterative, holistic design.
- Use of high-strength and ultra high-strength steel sheet, tubing, bar, etc.
- Use of innovative manufacturing technologies, such as hydroforming.
- A unique U-shape swept section that provides continuity of structure from hub to hub.
- High-strength constant section thin-wall steel tube, bent through a tight radius at each corner.
- A plasma-cut profile at the center section of the tube to reduce torsional stiffness, thus allowing the twistbeam to twist.
- Two forward facing hydroformed arms that achieve appropriate geometry with the main tube.
- Forged wheel bearing mountings that are MIG welded onto the main tube.
- Hub units that are detachable for ease of service.



Twistbeam Component Details

(Numbers correspond to the text that follows)

1. **Transverse Beam**
   - 600 MPa ultra high-strength steel
   - 2.8 mm to 4.1 mm wall thickness
   - Plasma trimmed cutout
   - 125 mm bend radius using wiper die and ball mandrel

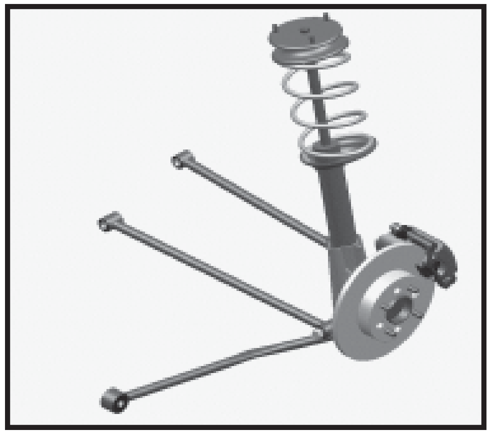
2. **Trailing Arm**
   - 400 MPa high-strength steel
   - 70 mm by 2.0 mm tube
   - MIG welded to twistbeam
   - Could be produced by hydroforming with an end flaring or punch point operation

3. **Spring Pan**
   - 500 MPa ultra high-strength steel blank
   - 3.2 mm to 4.0 mm wall thickness

4. **Springs**
   - 1300 MPa ultra high-strength steel bar
   - Diameter range: 10.04 mm to 11.43 mm

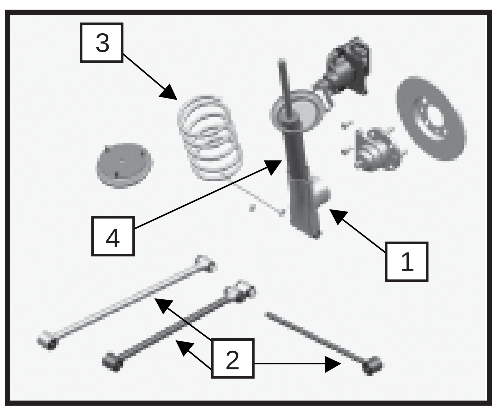
5. **Hub Mounting Plate**
   - 600 MPa ultra high-strength steel

2.2 Strut and Links



Summary:
- 25 percent mass savings
- 2 percent cost savings
- Improved performance over benchmark

Features:
- Two designs developed by using a holistic, iterative design approach that reduces mass through the use of high- and ultra high-strength steels:
- Hybrid knuckle design - for D, E and PNGV class vehicles
- Hydroformed tubular knuckle design - for B and C class vehicles



Strut and Links Component Details

1. **Fabricated knuckle**
   Hybrid knuckle (stamped)
   - 500 MPa high-strength steel
   - 4.0 mm wall thickness
   - Stamped in two halves and laser welded together
     Lower housing: forged 500 MPa high-strength steel
     Lower bracket: blanked and folded from 250 MPa, 4.0 mm-thick high-strength steel
     Hydroformed knuckle (tube)

2.2 Strut and Links (Continued)

- 500 MPa high-strength steel
- 3.5 mm wall thickness

Lower housing: forged from 500 MPa high-strength steel

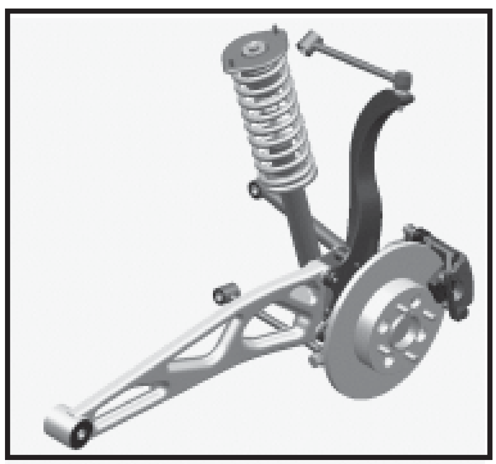
Both knuckles attach to the integral hub bearing unit by "through wall" laser welding, which penetrates the knuckle wall, joining it to the hub.

2. **Forward and rear lateral links**
   - 250 MPa high-strength steel tubes
   - 2.0 mm wall thickness

3. **Springs**
   - 1300 MPa high-strength steel bar
   - Diameter range: 10.6 mm to 12.3 mm

4. **Damper**
   - Fitted with hollow damper rod
   - High-strength steel housing
   - MIG welded to knuckle

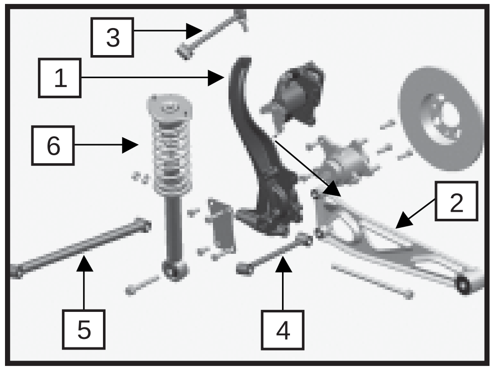
2.3 Double Wishbone



Summary:
- 17 percent mass savings
- No cost penalty
- Improved performance

Features:
- Stamped, high-strength steel fore and aft arm.
- Forged steel upright.
- Steel tubular links. Initial analysis indicated that the optimal solution for the links would be a cigar-shaped tubular member. However, the structural advantages proved to be only marginal and are outweighed by the cost penalty of increased manufacturing complexity.
- Extensive use of CAE techniques led to an optimal solution for the steel fore and aft arm and the forged knuckle.

Double Wishbone Component Details



1. **Forged Knuckle**
   - 600 MPa ultra high-strength steel

2. **Fore and Aft Arm**
   - 500 MPa high-strength steel
   - 3.0 mm-thick stamped steel

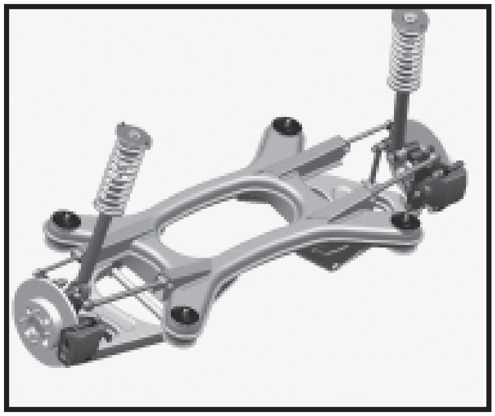
3. **Tubular Upper Link**
   - 250 MPa min.
   - 13 mm diameter by 1.5 mm wall thickness

4. **Tubular Lateral Link**
   - 250 MPa min.
   - 14 mm diameter by 1.5 mm wall thickness

5. **Tubular Lateral Link**
   - 250 MPa min.
   - 25 mm diameter by 3.0 mm wall thickness

6. **Springs**
   - 1300 MPa high-strength steel bar
   - Diameter range: 9.08 mm to 10.91 mm

2.4 MultiLink Component Details



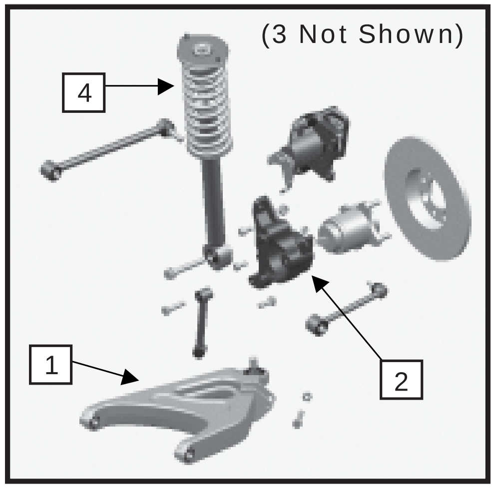
Summary:

- 30 percent cost savings (over benchmarked aluminum system)
- 3 percent mass savings
- Matched all other target criteria

Features:

- Appropriate across the D, E and PNGV classes.
- Large hollow section lower arms, formed by welding together two 2.0 mm-thick 300 MPa high-strength steel clamshell stampings.
- Symmetrical upper and lower stampings.
- Links that use 16 mm by 1.5 mm and 17.5 mm by 1.5 mm diameter, 250 MPa high-strength steel tubes.
- Sub-frame that is a stamped assembly, manufactured with five major components and several reinforcements using steels ranging from 1.2 mm to 2.0 mm and yield strength levels between 200 MPa and 400 MPa.

Multi-Link Component Details



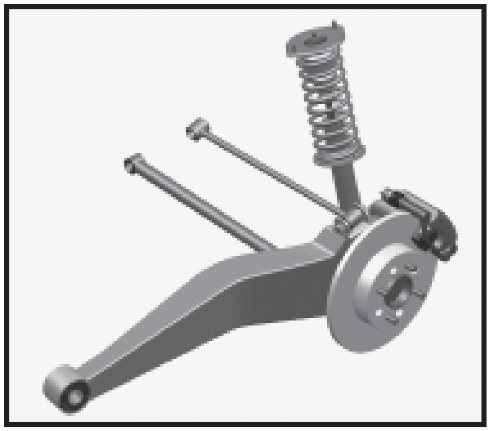
1. **Stamped Control Arm Halves**
   - 300 MPa high-strength steel
   - 2.0 mm gauges
   - Butt welded together by MIG and spot welding

2. **Forged Knuckle**
   - 750 MPa ultra high-strength steel

3. **Stamped Steel Sub-frame**
   - Joined by combination of laser, MIG and spot welding
   - With minor dimensional changes, is easily adaptable to smaller or larger cars

4. **Springs**
   - 1300 MPa high-strength steel bar
   - Diameter range: 10.42 mm to 10.78 mm

2.5 Lotus Unique



Summary:

- 34 percent mass savings (compared to double wishbone)
- 22 percent cost advantage (compared to double wishbone)
- Improved performance (compared to double wishbone)

Features:

- A unique rear suspension design to demonstrate possibilities with the freedom of a "clean sheet" approach and use of the latest range of steel material and manufacturing technologies.
- Minimal parts and optimized materials.
- A large integral fore and aft arm hub carrier comprising inner and outer tailor welded blank stampings. The two stampings represent six different material grade/gauge combinations:

Part	**Trailing Arm Outer Panel**		
Process	Stamped Tailor Welded Blank		
Material Gauge (mm)	1.8	2.7	1.2
Material Grade (MPa)	400	200	200
Part	**Trailing Arm Outer Panel**		
Process	Stamped Tailor Welded Blank		
Material Gauge (mm)	2.3	2.3	1.2
Material Grade (MPa)	500	150	250

- A hub mounting sleeve that is an integral part of the fore-aft arm, consisting of a tubular housing of 3.0 mm with a yield strength of 300 MPa and a stamped outer hub reinforcement of 2.5 mm-thick steel with a yield strength of 400 MPa.

Lotus Unique Component Details

1. **Upper and Lower Links**
   - 250 MPa high-strength steel conventional welded tubing
   - 25 mm diameter; 1.5 mm wall thickness
   - Extreme requirements for combination of high gauge/small diameters may require cold drawn tubing

2. **Gussets, Reinforcements, Mounting Brackets**
   - Material grade range: 150 MPa to 400 MPa high-strength steel
   - Gauge range: 1.7 mm to 3.0 mm

3. **Springs**
   - 1300 MPa high-strength steel bar
   - Diameter range: 8.65 mm to 11.16 mm

3. Materials Utilization Summary

- Sheet Steel
  - Thickness range — 1.2 to 5 mm
  - Strength range — 150 to 500 MPa
- Tubes
  - Thickness range — 1 to 3.5 mm
  - Diameter range — 13 to 70 mm
  - Strength range — 150 to 600 MPa
- Bar & Rod (springs)
  - Diameter range — 8.5 to 12.5 mm
  - Strength — 1300 MPa
- Forgings
  - Strength range — up to 750 MPa

UltraLight Steel Auto Suspension (ULSAS)

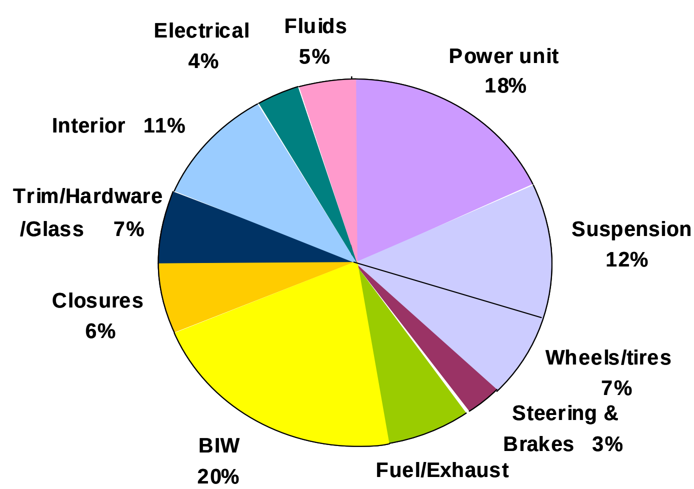
An Innovative Approach to Producing Lightweight and Affordable Suspension Systems

ULSAS Objectives:

- Show the potential for optimized, cost-effective, environmentally friendly and lightweight steel-intensive solutions.
- Explore and promote the full range of steel product and process technologies.
- Develop steel-based design concepts that meet or exceed modern standards of performance, safety and efficiency.
- Assist automakers in meeting the competitive challenges of reducing mass while satisfying a range of technical, safety, environmental and consumer demands.

Program Background:

ULSAS is a companion to the UltraLight Steel Auto Body (ULSAB) study (1998), the UltraLight Steel Auto Closures (ULSAC) study (2000), and the ULSAB-AVC (Advanced Vehicle Concepts) study (2002). The ULSAS consortium commissioned Lotus Engineering to provide design and engineering management for the ULSAS project.



Realizing the potential for applying steel lightweighting solutions to suspension systems, the ULSAS consortium undertook a comprehensive study focusing solely on this area.

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