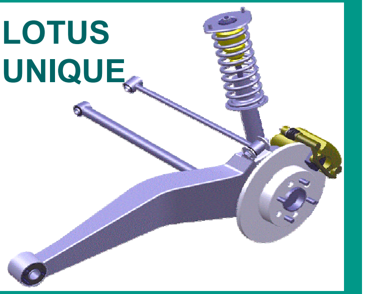
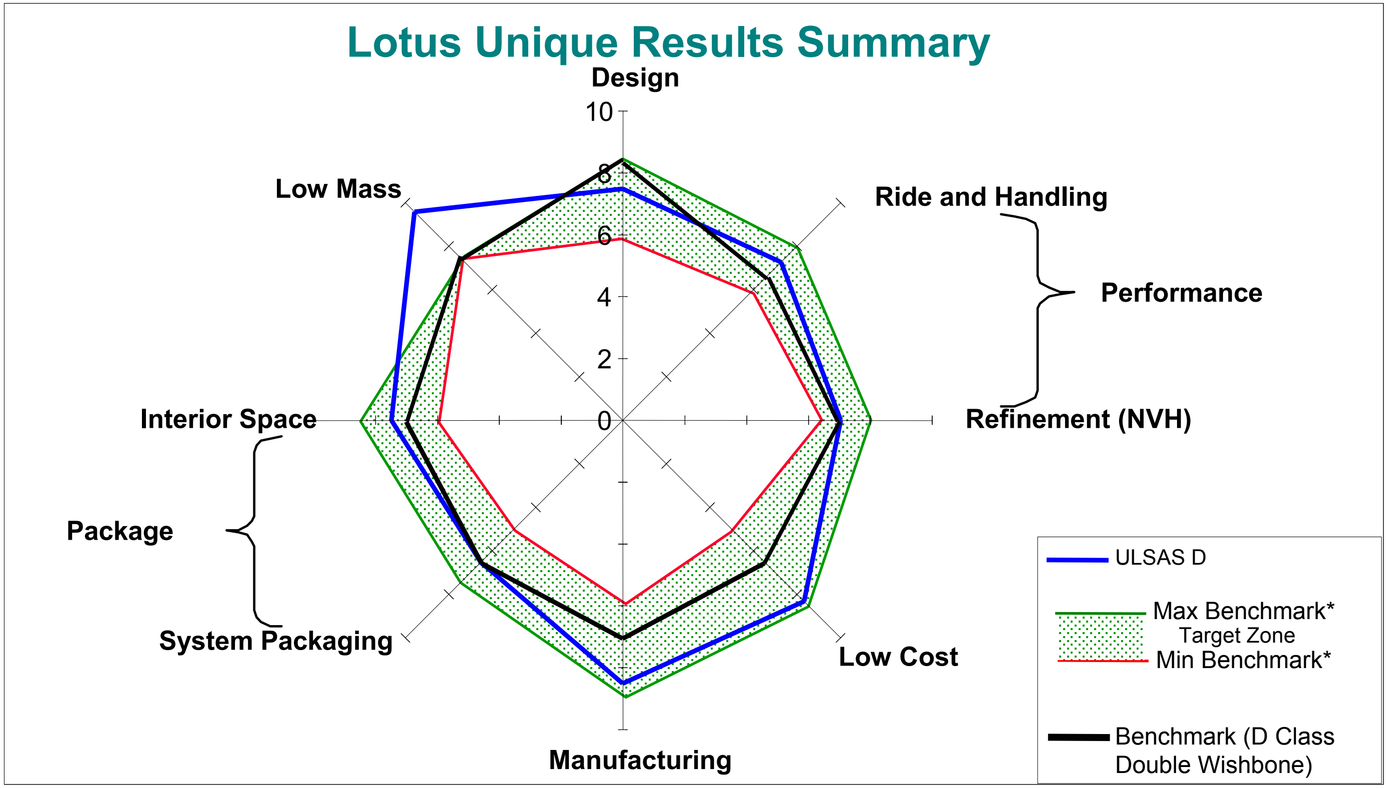
LOTUS UNIQUE: RESULTS SUMMARY

LOTUS UNIQUE





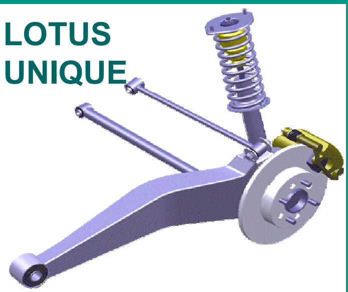
- MASS SAVING
- COST SAVING
- GOOD PERFORMANCE AND IMAGE
- REASONABLE PACKAGE
- EASY ASSEMBLY AND MANUFACTURE

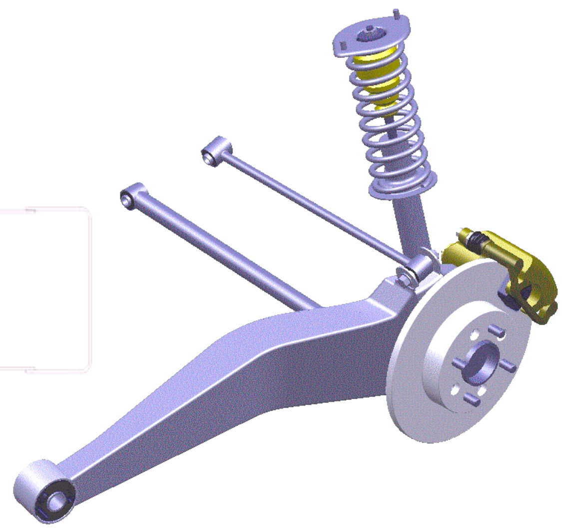
*Maximum and minimum benchmark scores are for all the systems benchmarked

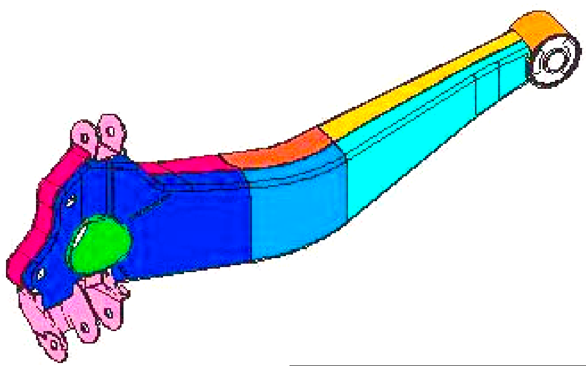
ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE: DESIGN

LOTUS UNIQUE





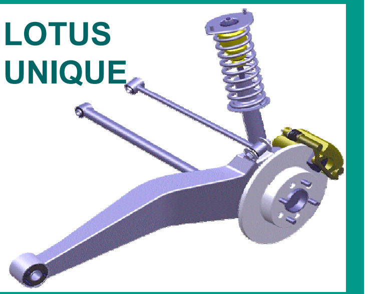


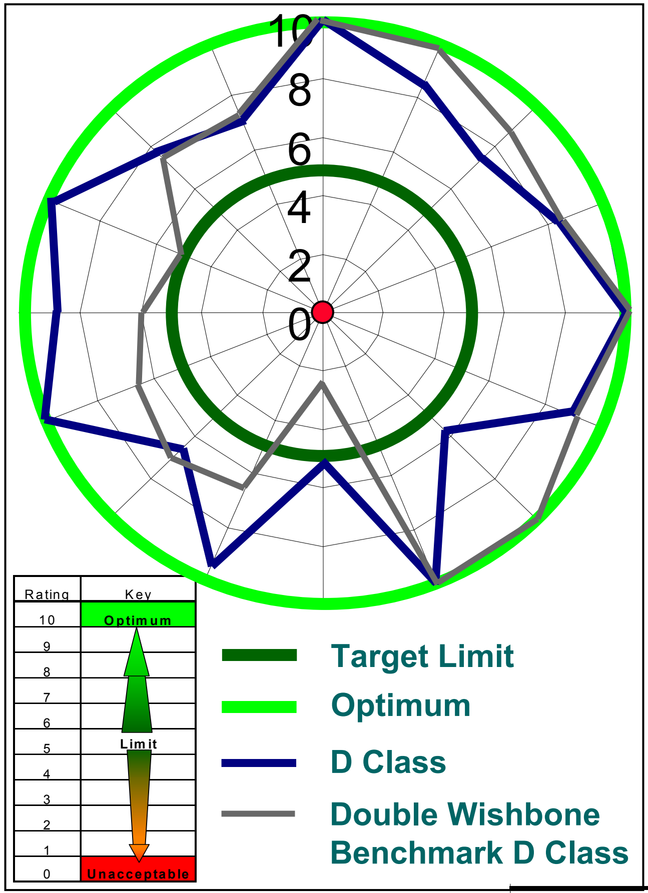
- The Lotus Unique system was evaluated against the same design criteria as the Benchmarking Phase, including:
  - Potential Technical Development
  - Potential for System/Component Integration
  - System Image / Marketability
  - Structural Efficiency & Elegance.
- The ULSAS solution compares well against the Benchmark systems in all areas of design.

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS D	BENCHMARK (D Class, Double Wishbone)
Design	7.5	8.5

LOTUS UNIQUE: PERFORMANCE

LOTUS UNIQUE





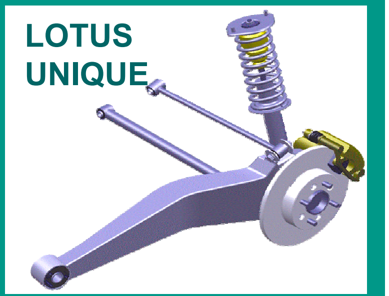
- The Lotus Unique solution demonstrates good levels of performance.
- The performance of the Lotus Unique falls within the target acceptance limits for every criteria.
- Overall score is judged to match the score of the Double Wishbone system.

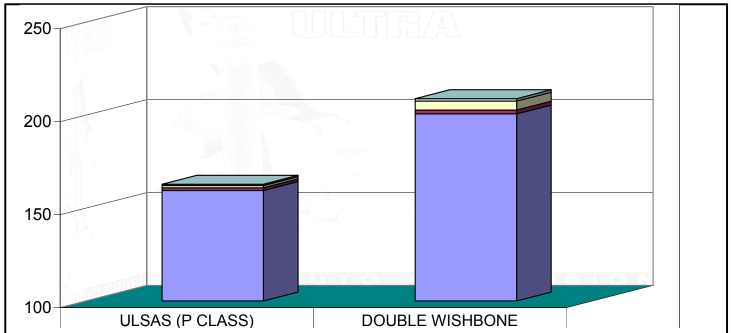
SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS D	BENCHMARK (D Class, Double Wishbone)
Ride and Handling	7.2	6.5
Refinement (NVH)	7.0	7.0

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE: COST

LOTUS UNIQUE





(US$)	Double Wishbone Benchmark D Class	Lotus ULSAS D Class
PIECE COST	**$200.7**	**$159.4**
TOTAL TOOLING COST ($,000)	**$4,192**	**$2,907**
5 YEAR Volume (Assumptions)	2,075,000	2,000,000
TOOLING COST	$2.0	$1.5
TOTAL SYSTEM COST	$202.7	$160.9
SYSTEM ASSY		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Assembly Mins	6.59	1.58
SYSTEM ASSEMBLY COST	$4.83	$1.16
VEHICLE FITTING		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Fitting Mins	1.83	1.01
VEHICLE FITTING COST	$1.34	$0.74

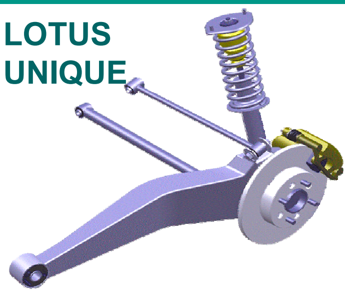
Total Cost ($)	**$208.9**	**$162.8**
Cost Saving($)		$46.1
Cost Saving %		**22%**

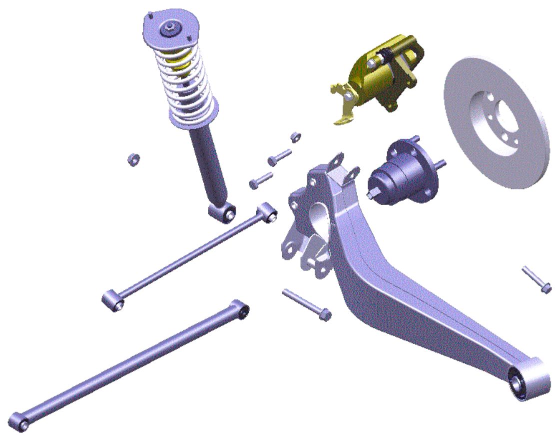
- The cost of the ULSAS solution compares favourably with the benchmarked Double Wishbone suspension.
- Overall score in this area is proportionately higher than the Double Wishbone.
- Reduction in assembly time is due mainly to greater levels of parts integration in the ULSAS design.

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS D	BENCHMARK (D Class, Double Wishbone)
Cost	8.3	6.5

LOTUS UNIQUE: MANUFACTURING

LOTUS UNIQUE





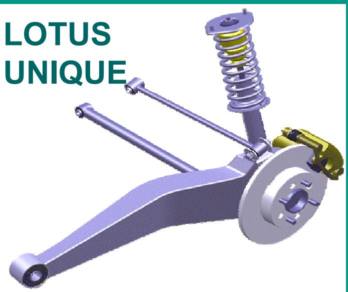
Cost of ULSAS Solutions Vs Benchmark Vehicles		
(US$)	Double Wishbone	Lotus
	Benchmark D Class	ULSAS D Class
SYSTEM ASSY		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Assembly Mins	6.59	1.58
SYSTEM ASSEMBLY COST	$4.83	$1.16
VEHICLE FITTING		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Fitting Mins	1.83	1.01
VEHICLE FITTING COST	$1.34	$0.74
Total Cost ($)	**$6.2**	**$1.9**
Cost Saving($)		$4.3
Cost Saving %		**69%**

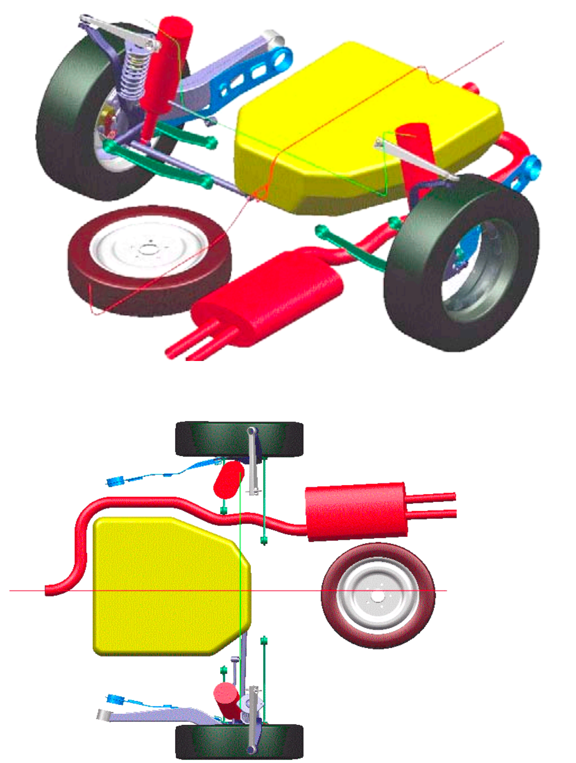
- The ULSAS solution compares favourably with the Benchmarked systems in terms of assembly and fitting times.
- Fewer parts and sub-assemblies have reduced assembly times and costs.
- An appropriate level of manufacturing feasibility has been taken into account.
- Overall score in this area is higher than all the Benchmark Systems other than the Twistbeam.

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS D	BENCHMARK (D Class, Double Wishbone)
Manufacturing	8.5	7.0

LOTUS UNIQUE: PACKAGING

LOTUS UNIQUE





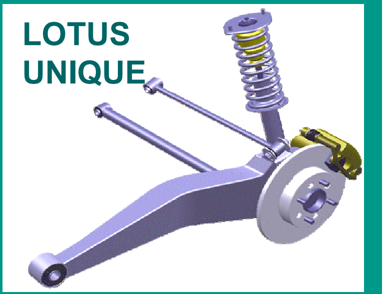
- The ULSAS solution matches the underfloor layout of the Double Wishbone Benchmark vehicle well.
- The interior space package of the ULSAS solution is better than that of the Benchmarked vehicle.
- Overall score for Systems Packaging matches the Benchmark.
- The score for Interior Space is higher than the Benchmark.

SUMMARY OF OVERALL SCORES & RATINGS

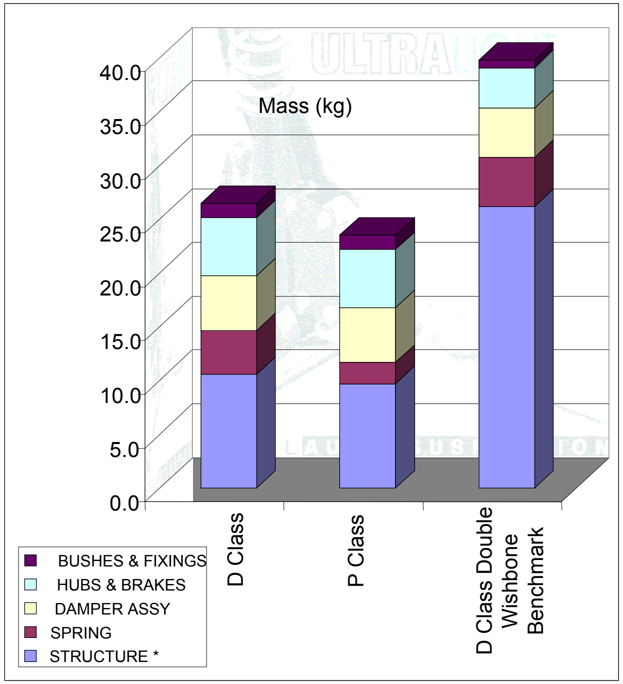
	ULSAS D	BENCHMARK (D Class, Double Wishbone)
System Packaging	6.5	6.5
Interior Space	7.5	7.0

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE



LOTUS UNIQUE: MASS



*** Structure includes knuckle and links**

- The ULSAS solution demonstrates a good mass reduction compared to the Double Wishbone Benchmarked system.
- The mass savings of the structural elements of the system alone are even more pronounced.
- Overall score for system mass is therefore significantly higher than the Double Wishbone Benchmark.

Mass Of ULSAS Solutions vs Benchmark Vehicles

Description	B	C	D	E	PNGV
Benchmark (kg)			**39.84**		
ULSAS Solution (kg)			**26.49**		**23.53**
Saving vs Benchmark			**34%**		

SUMMARY OF OVERALL SCORES & RATINGS

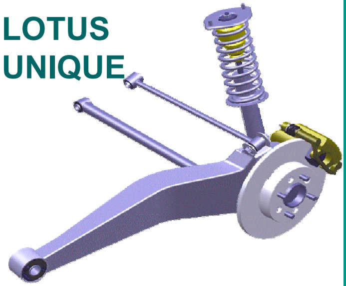
	ULSAS D	BENCHMARK (D Class, Double Wishbone)
Mass	9.5	7.5

STEEL AUTO SUSPENSION

LOTUS UNIQUE: MASS

P Class

LOTUS UNIQUE

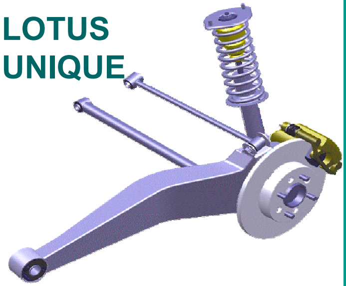


PARTS LIST			P Class			Benchmark D Class		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY LOTUS UNIQUE	2	**23.53**			**39.84**		
2	WELDED ASSEMBLY, RH	1	**4.37**	**4.369**			**DOUBLE WISHBONE**	
3	WELDED ASSEMBLY, LH	1	**4.37**	**4.369**				
4	TRAILING ARM, OUTER	2			1.485			
5	TRAILING ARM, INNER	2			1.593			
6	INTERNAL GUSSET BOTTOM	2			0.022			
7	INTERNAL GUSSET TOP	2			0.054			
8	PIVOT BUSH HOUSING	2			0.263			
9	CRUSH TUBE, CALIPER MOUNTING	4			0.074			
10	HOUSING HUB BEARING UNIT	2			0.292			
11	OUTER HUB REINFORCEMENT	2			0.495			
12	LOWER LINK MOUNTING BRKTS	2			0.091			
13	LATERAL LINK ASSY, LOWER	2	**0.64**	**0.320**				
14	LATERAL LINK ASSY, UPPER	2	**0.37**	**0.185**				
15	BUSH HOUSING, LATERAL LINK	8						
16	LINK, LATERAL LOWER	2						
17	LINK, LATERAL UPPER	2						
18	HUB BEARING UNIT	2	**5.40**	**2.700**				
19	CALIPER, BRAKE	2						
20	BRAKE DISC	2						
21	DAMPER	2	**4.00**	**2.000**				
22	SPRING	2	**1.95**	**0.974**				
23	MOUNT, UPR, SPRING & DAMPER	2	**1.10**	**0.550**				
24	VARIOUS BUSHES AND JOINTS		**0.64**					
25	ASSORTED FIXINGS		**0.69**					

LOTUS UNIQUE: COST

P Class

LOTUS UNIQUE



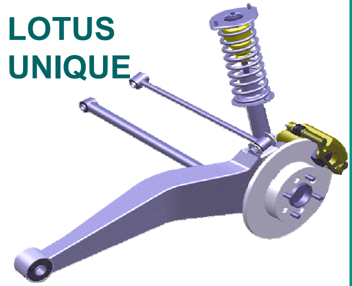
N.B. All Costs in US $ Tooling in US$(,000)

PARTS LIST			P Class			D Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	PART COST (US$)	SYSTEM COST(US$)	TOOLING COST (US$k)	PART COST (US$)	SYSTEM COST(US$)	TOOLING COST (US$k)
1	ASSEMBLY LOTUS UNIQUE	2		159.42	2907.00		200.70	4192.00
2	WELDED ASSEMBLY, RH	1	$4.0	$21.5	$1,127		DOUBLE WISHBONE	
3	WELDED ASSEMBLY, LH	1	$4.0	$21.5				
4	TRAILING ARM, OUTER	2	$5.3		$280			
5	TRAILING ARM, INNER	2	$5.2		$280			
6	INTERNAL GUSSET BOTTOM	2	$0.5		$35			
7	INTERNAL GUSSET TOP	2	$0.5		$35			
8	PIVOT BUSH HOUSING	2	$1.0					
9	CRUSH TUBE, CALIPER MOUNTING	4	$1.5					
10	HOUSING HUB BEARING UNIT	2	$1.0		$150			
11	OUTER HUB REINFORCEMENT	2	$2.0		$140			
12	LOWER LINK MOUNTING BRKTS	2	$0.5		$80			
13	LATERAL LINK ASSY, LOWER	2	$4.3	$8.6	$100			
14	LATERAL LINK ASSY, UPPER	2	$4.0	$8.0	$100			
15	BUSH HOUSING, LATERAL LINK	8						
16	LINK, LATERAL LOWER	2						
17	LINK, LATERAL UPPER	2						
18	HUB BEARING UNIT	2	$19.0	$38.0	$0			
19	CALIPER, BRAKE	2						
20	BRAKE DISC	2						
21	DAMPER	2	$16.0	$32.0	$330			
22	SPRING	2	$5.2	$10.4	$0			
23	MOUNT, UPR, SPRING & DAMPER	2	$1.6	$3.2	$250			
24	VARIOUS BUSHES AND JOINTS			$13.3				
25	ASSORTED FIXINGS			$3.0				

LOTUS UNIQUE: MATERIAL

P Class

LOTUS UNIQUE

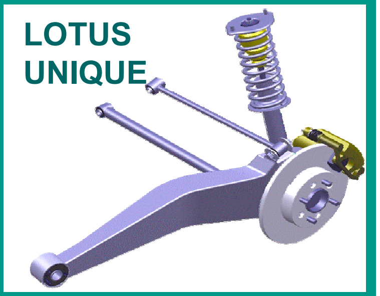


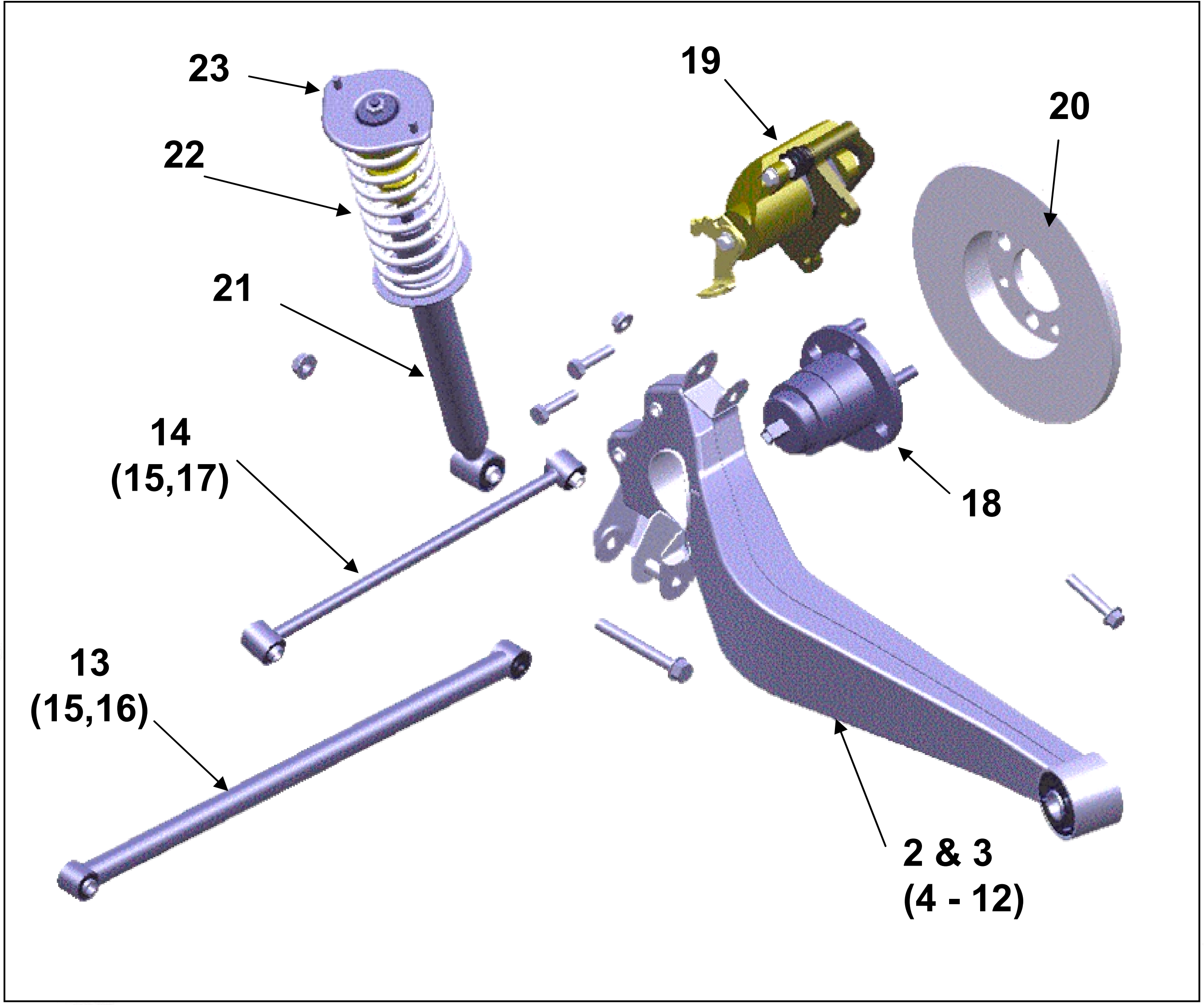
PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPa)
1	ASSEMBLY LOTUS UNIQUE	2	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSEMBLY, RH	1	FABRICATION (items; 4-12)		
3	WELDED ASSEMBLY, LH	1	FABRICATION (items; 4-12)		
4	TRAILING ARM, OUTER	2	PRESSING; TAILOR WELDED BLANK	1.2 - 2.7	200-400
5	TRAILING ARM, INNER	2	PRESSING; TAILOR WELDED BLANK	1.2 - 2.3	150-500
6	INTERNAL GUSSET BOTTOM	2	BLANK & FOLD	1.7	300
7	INTERNAL GUSSET TOP	2	BLANK & FOLD	1.7	300
8	PIVOT BUSH HOUSING	2	TUBE	3	300
9	CRUSH TUBE, CALIPER MOUNTING	4	TUBE	3	150
10	HOUSING HUB BEARING UNIT	2	TUBE	3	300
11	OUTER HUB REINFORCEMENT	2	PRESSING	2.5	400
12	LOWER LINK MOUNTING BRKTS	2	BLANK & FOLD	2.5	400
13	LATERAL LINK ASSY, LOWER	2	FABRICATION (items; 15,16)		
14	LATERAL LINK ASSY, UPPER	2	FABRICATION (items; 15,17)		
15	BUSH HOUSING, LATERAL LINK	8	TUBE		250
16	LINK, LATERAL LOWER	2	TUBE	Ø 25 x 1.5	250
17	LINK, LATERAL UPPER	2	TUBE	Ø 25 x 1.5	250
18	HUB BEARING UNIT	2	GEN 3 WITH ACTIVE ABS SENSOR		
19	CALIPER, BRAKE	2	INTEGRATED HANDBRAKE MECHANISM		
20	BRAKE DISC	2	SOLID, CAST IRON		
21	DAMPER ASSEMBLY	2	INCL SPRING SEAT & BUMP RUBBER	See note	
22	SPRING	2	SHEAR STRESS LIMIT 1300MPa	8.65-11.16	1300
23	MOUNT, UPR, SPRING & DAMPER	2	2 BOLT FIXING TO BIW.		
24	VARIOUS BUSHES AND JOINTS		RUBBER BUSHES & SPHERICAL JOINTS		
25	ASSORTED FIXINGS		NUTS, BOLTS & WASHERS ETC		

Note : Damper Assembly Consists of 4 Main Components

Damper Body:	350 MPa Material
Damper Rod:	Dia 13mm x 3mm tube
Spring Pan:	350 Mpa Material
Bump Stop Rubber:	Polyurethane Material

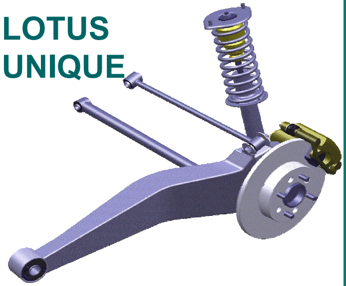
LOTUS UNIQUE: EXPLODED VIEW

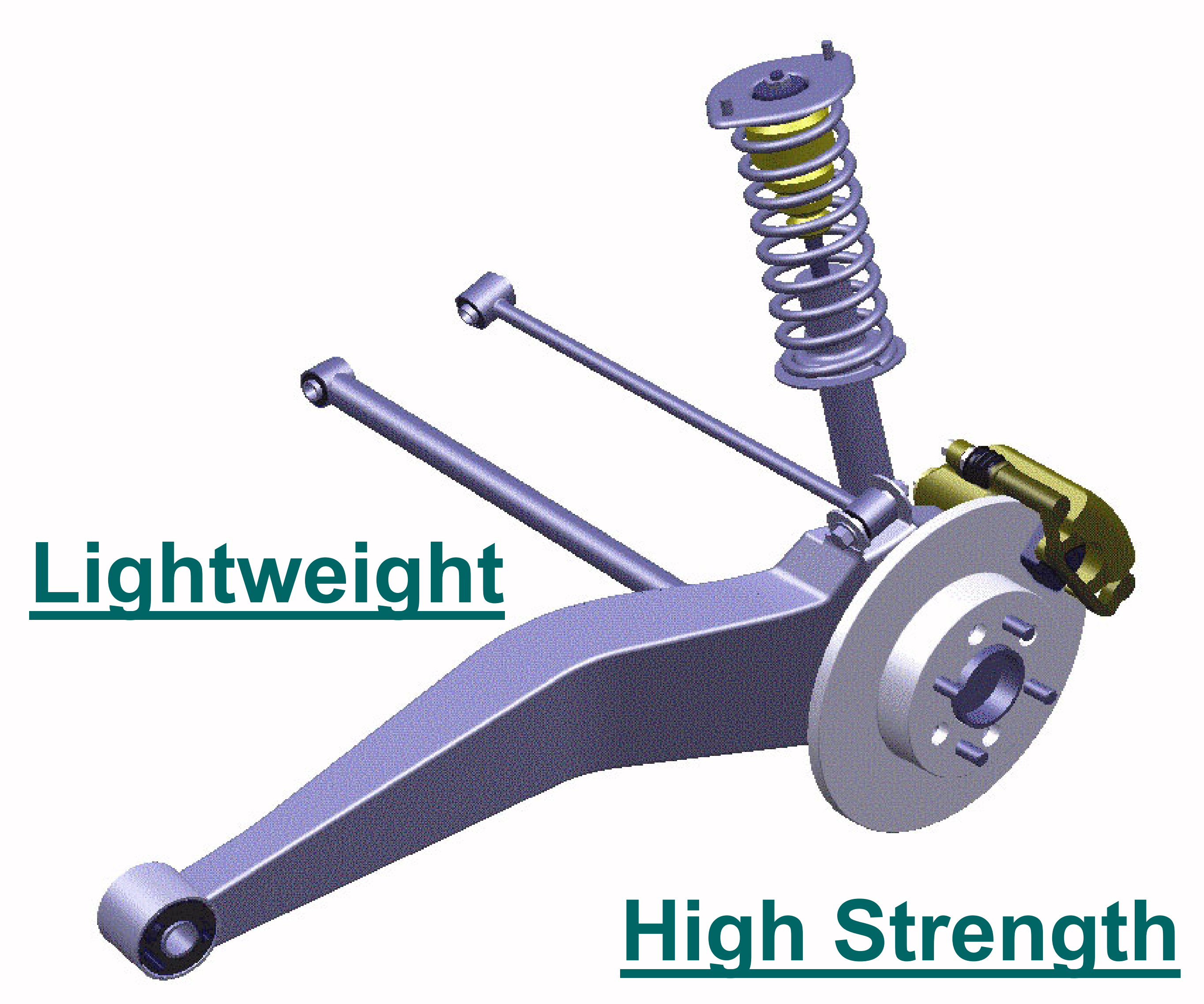




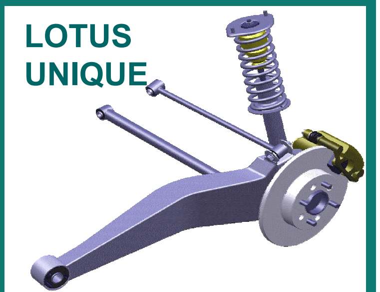
LOTUS UNIQUE: DESIGN & FEA

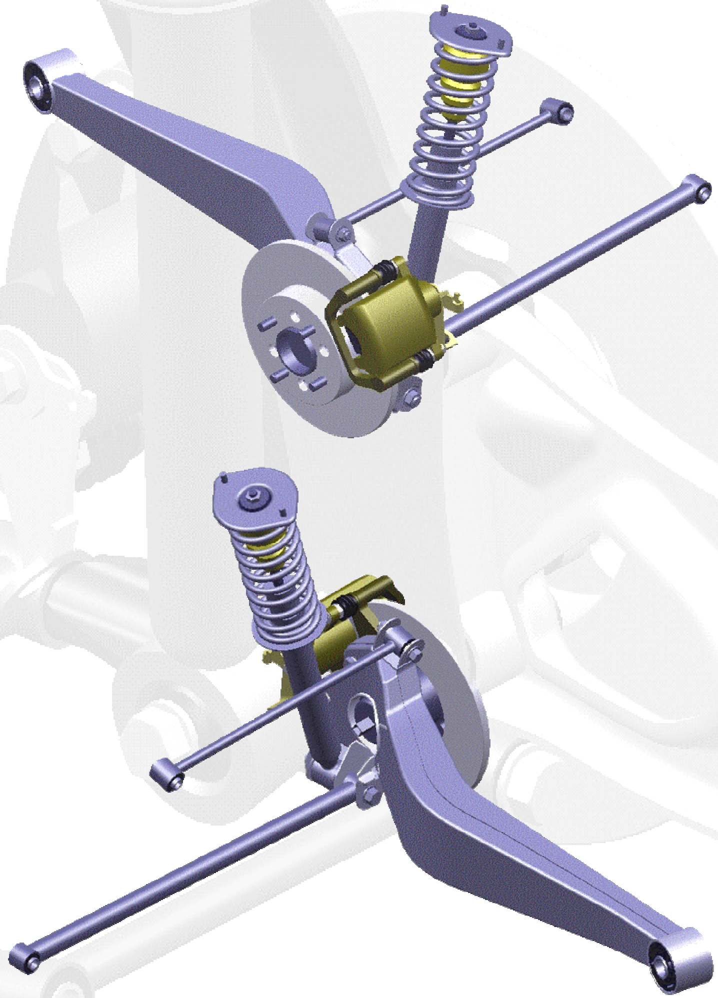
LOTUS UNIQUE





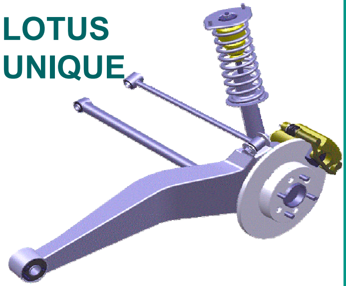
LOTUS UNIQUE: DESIGN & FEA

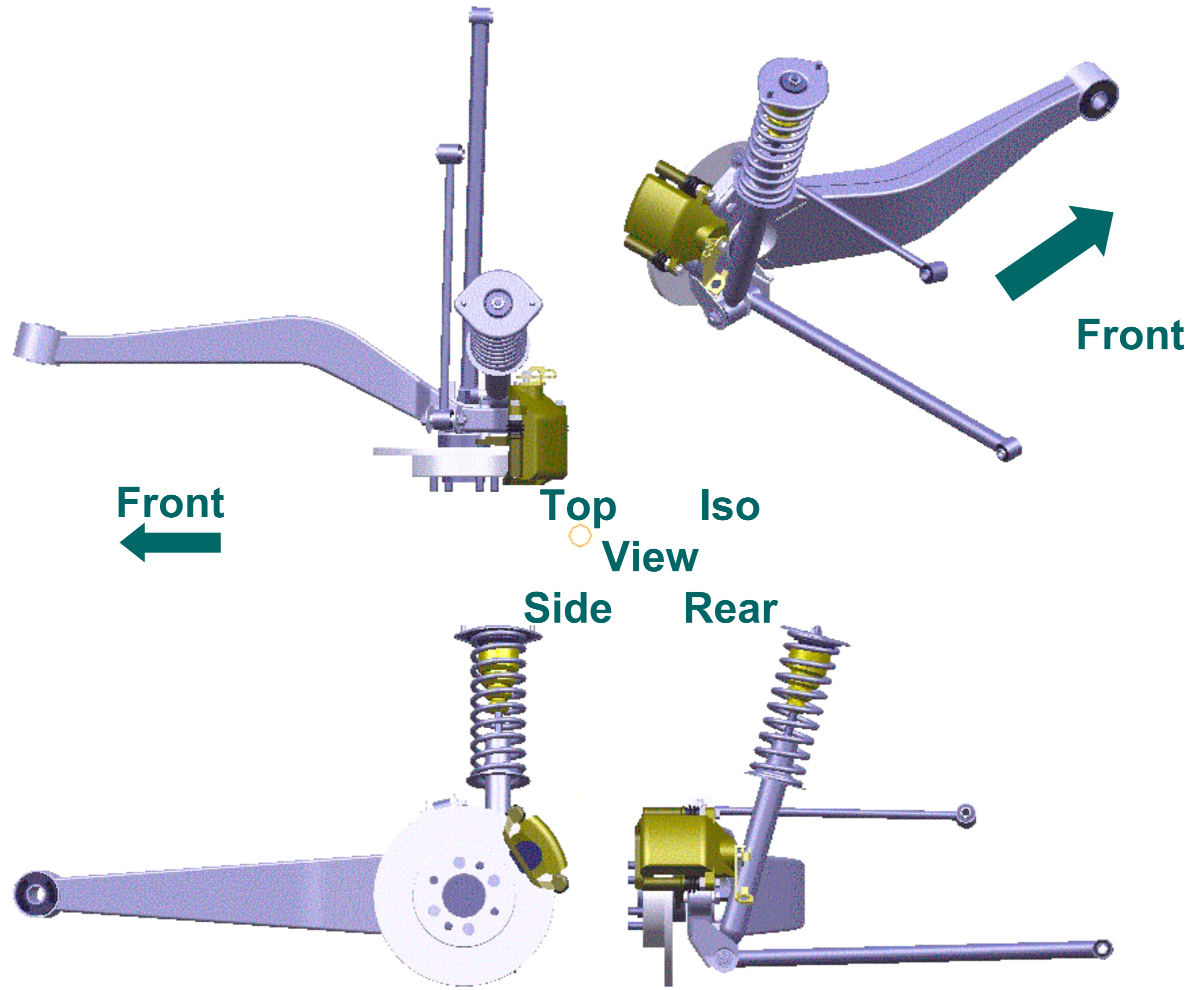




LOTUS UNIQUE: DESIGN & FEA

LOTUS UNIQUE

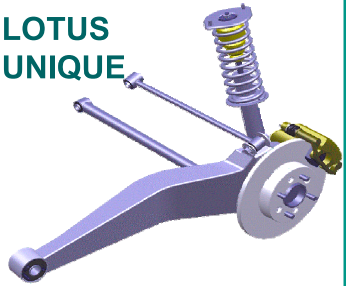




Lightweight Safe Efficient Affordable

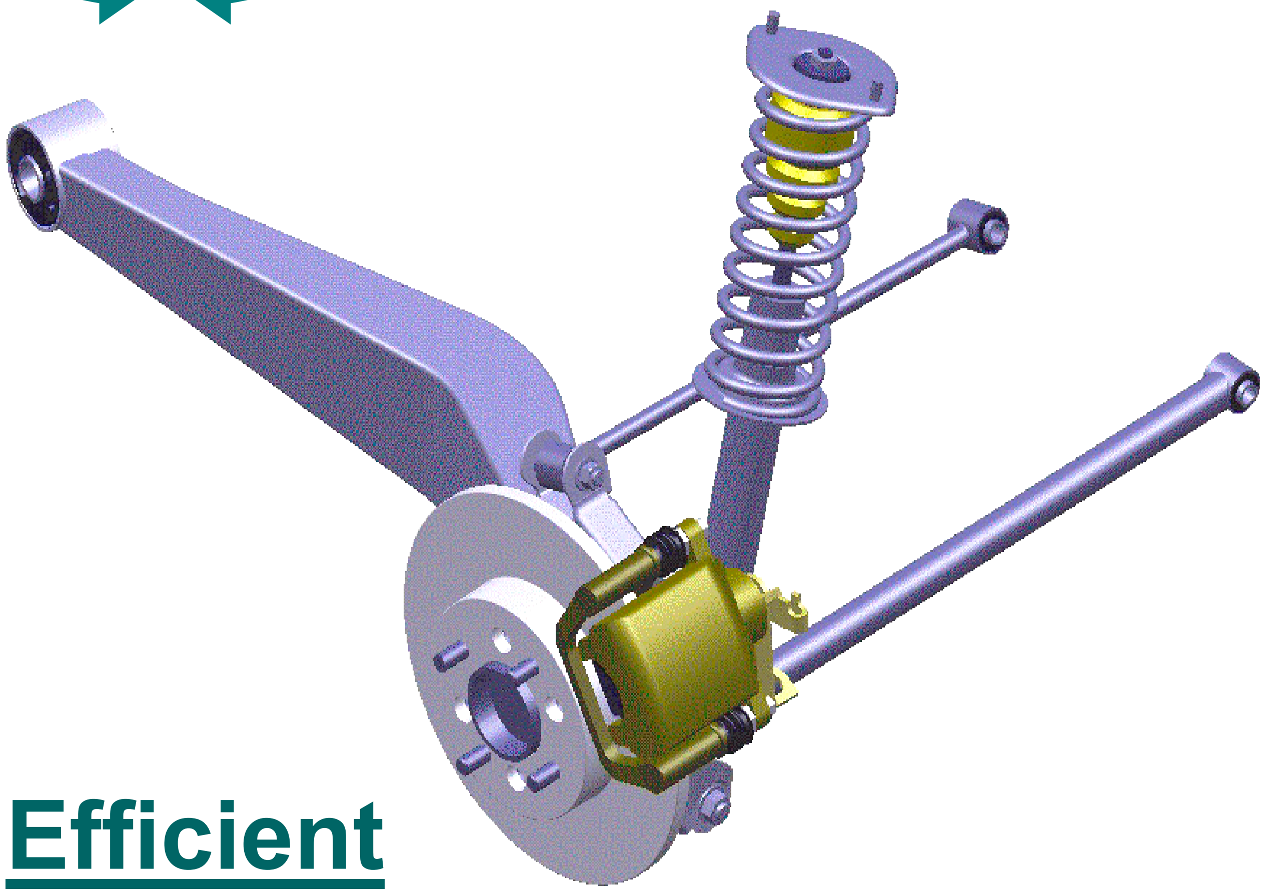
ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE: DESIGN & FEA



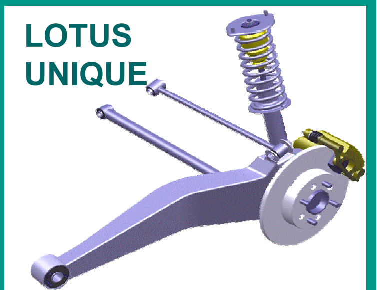
Press to rotate and for details

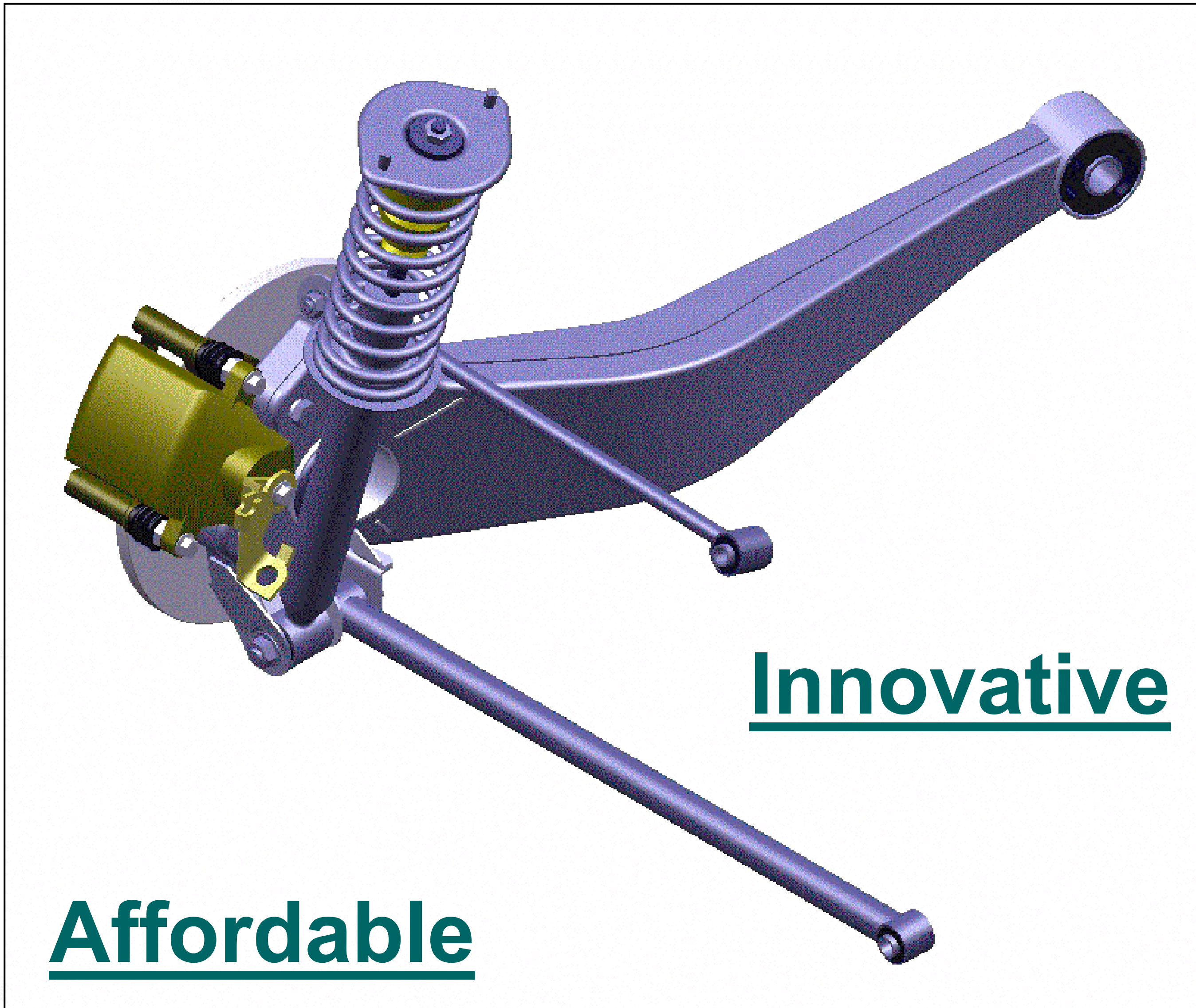
Packagable



Efficient

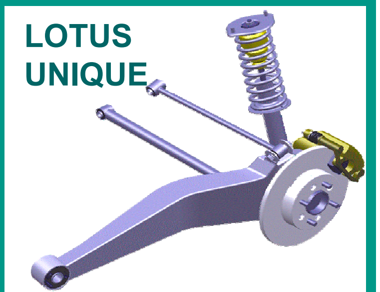
LOTUS UNIQUE: DESIGN & FEA

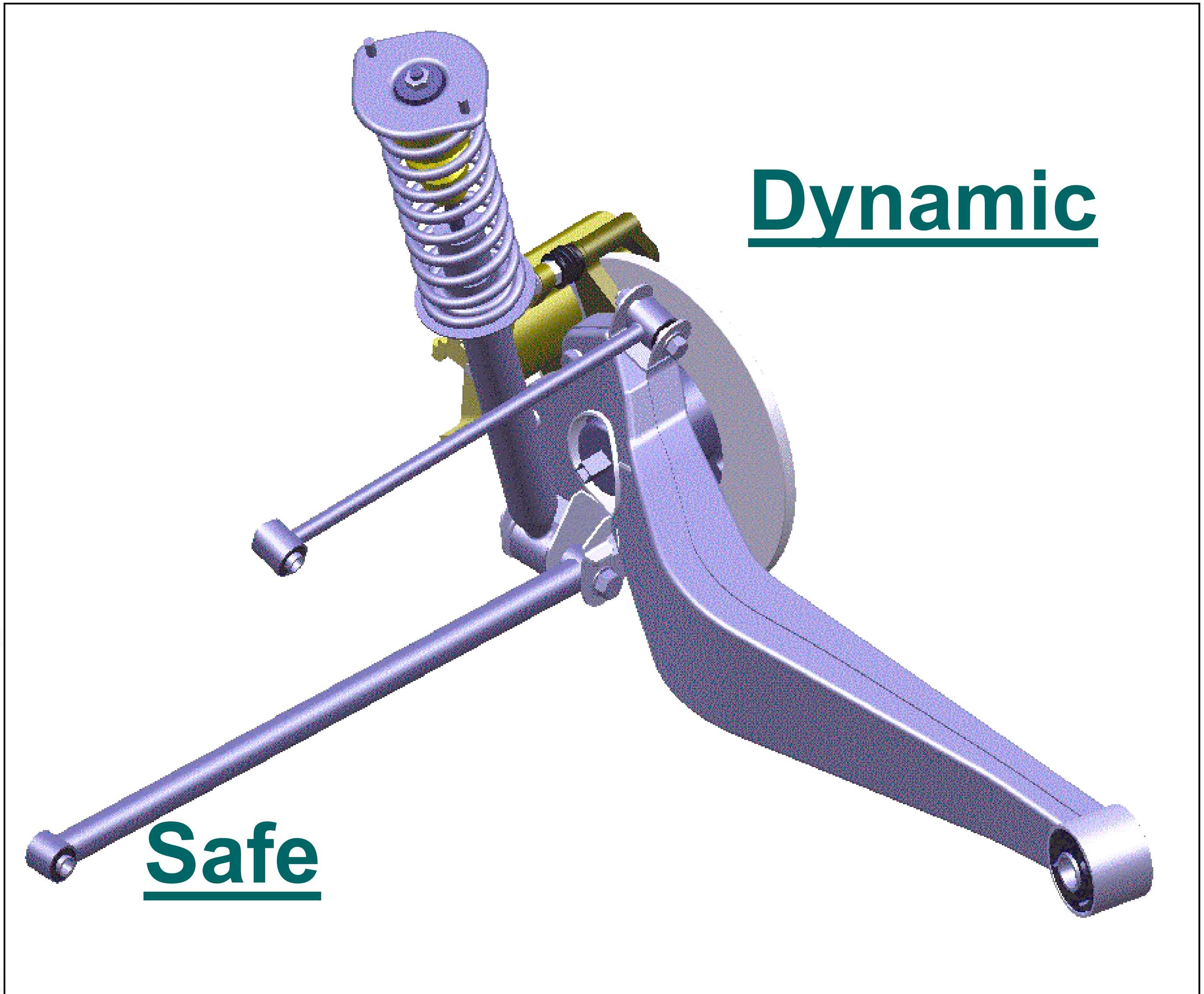




ULTRALIGHT STEEL AUTO SUSPENSION

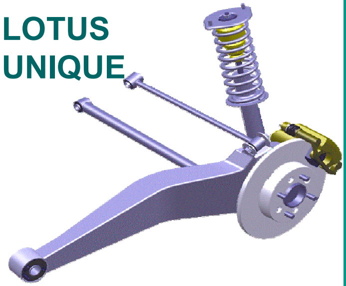
LOTUS UNIQUE: DESIGN & FEA

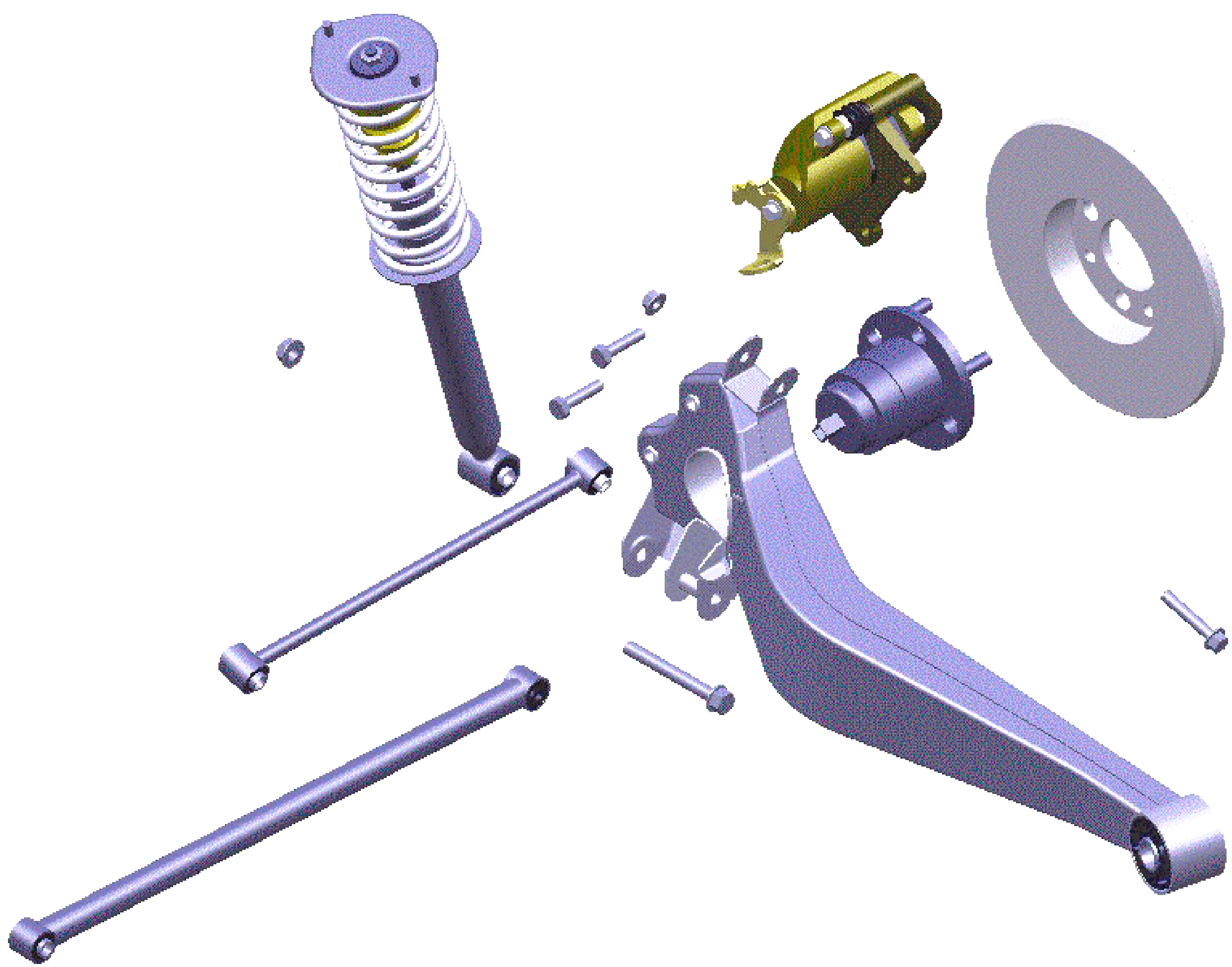


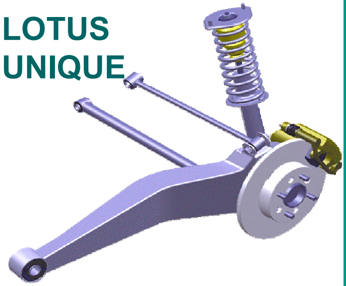


LOTUS UNIQUE: DESIGN

LOTUS UNIQUE





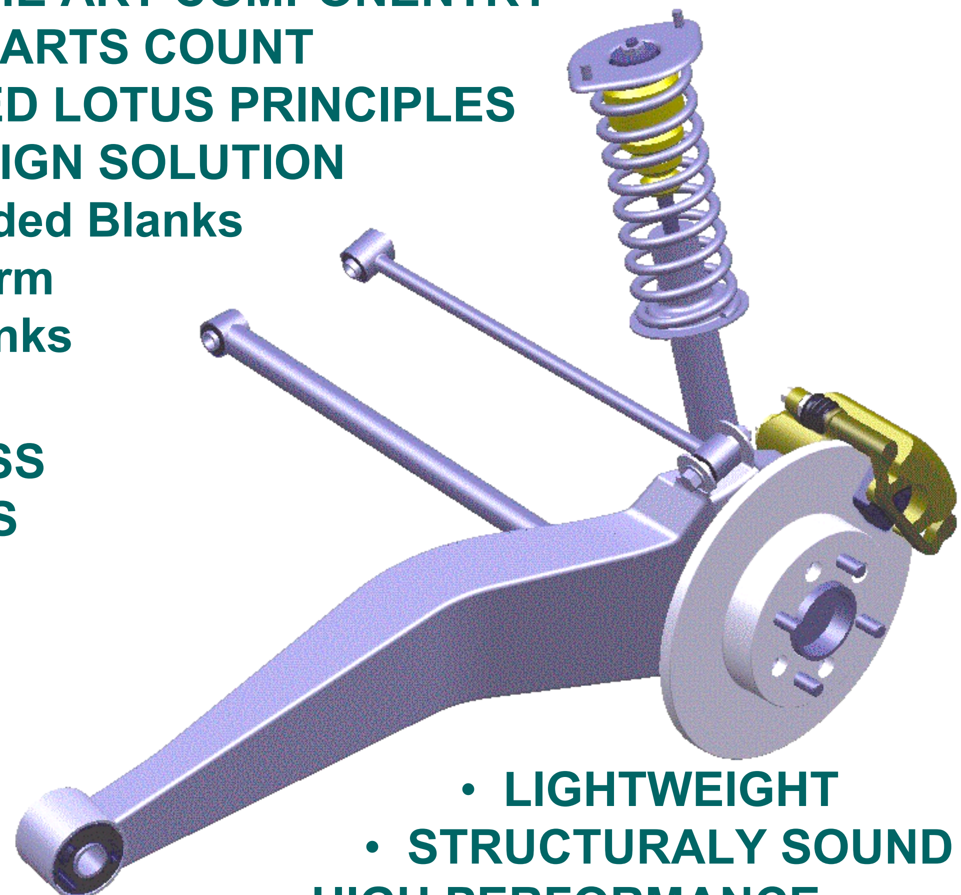


LOTUS UNIQUE: DESIGN

Overview

- STATE OF THE ART COMPONENTRY
- MINIMISED PARTS COUNT
- ESTABLISHED LOTUS PRINCIPLES
- UNIQUE DESIGN SOLUTION
  - Tailor Welded Blanks
  - Pressed Arm
  - Tubular Links

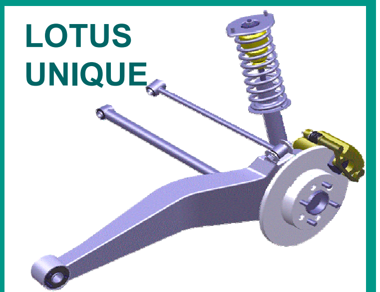
- D & P CLASS SOLUTIONS



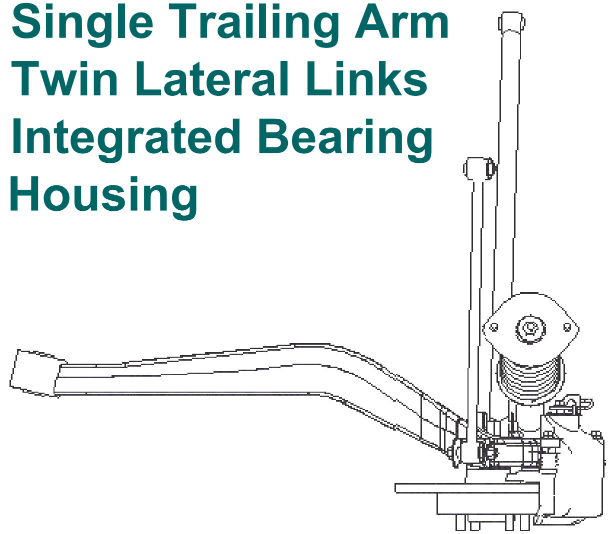
- LIGHTWEIGHT
- STRUCTURALY SOUND
- HIGH PERFORMANCE
- MANUFACTURABLE
- AFFORDABLE

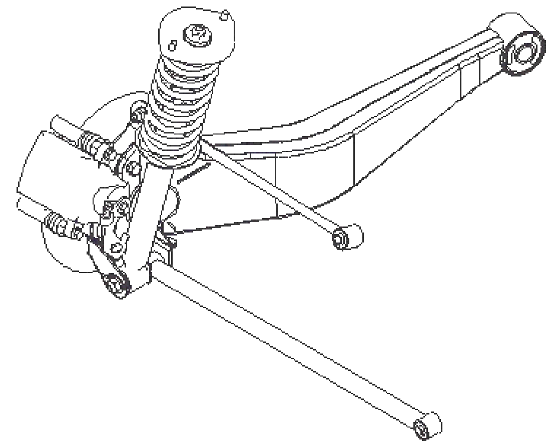
LOTUS UNIQUE: DESIGN

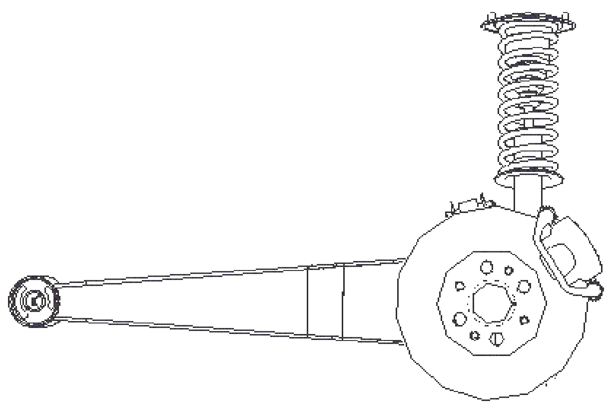
Overview

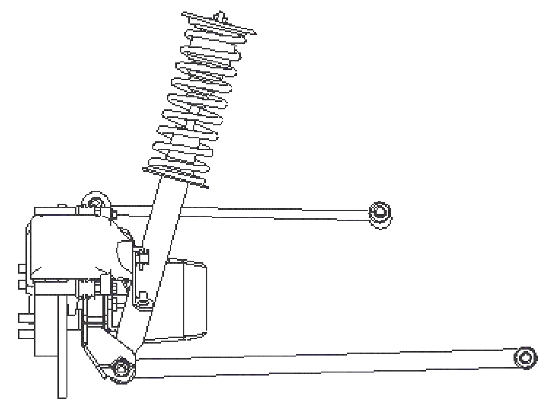


- Co-axial Spring Damper
- Single Trailing Arm
- Twin Lateral Links
- Integrated Bearing Housing





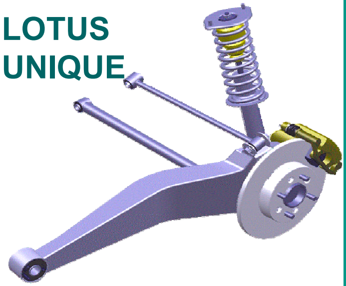




LOTUS UNIQUE: DESIGN

Approach

LOTUS UNIQUE



- The initial package layout was created with 3D models developed in the CAD system. These were based upon sections and shape that exhibit appropriate properties.

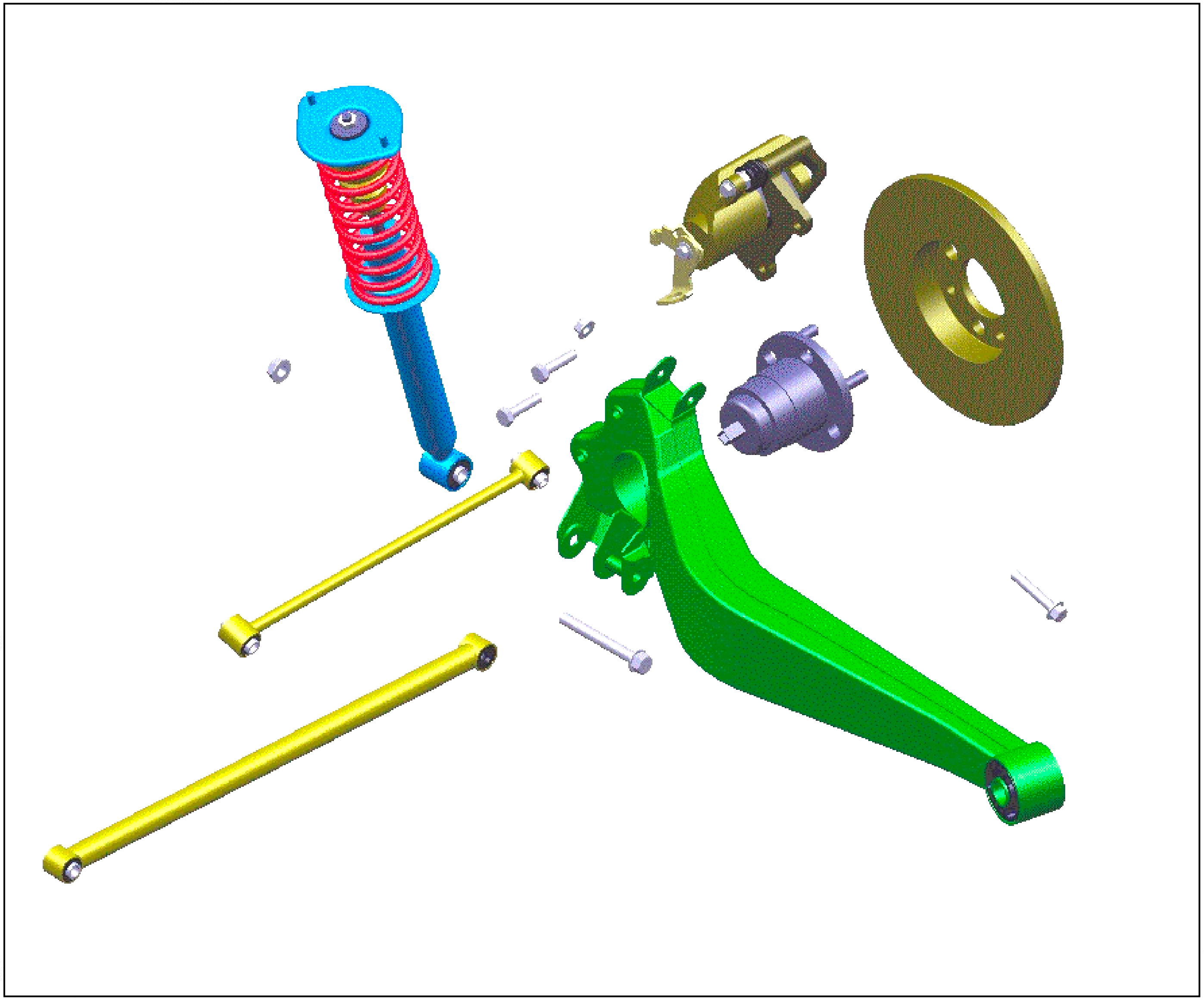
- The designs were refined by close collaboration between CAD & CAE to develop these initial concepts through a series of evolutions and optimisations to the final concept proposal.

- Structural Analysis optimisation techniques were utilised to establish material gauges and grades for each part of the main structural component, so as to meet both the stiffness and structural targets.

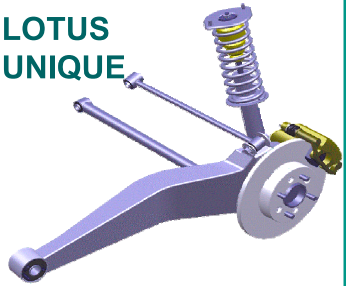
- Further, more detailed analysis (including non-linear in selected areas) was carried out to validate the design. In some cases, even detail design features were fully investigated and validated.

LOTUS UNIQUE: DESIGN

Parts Review

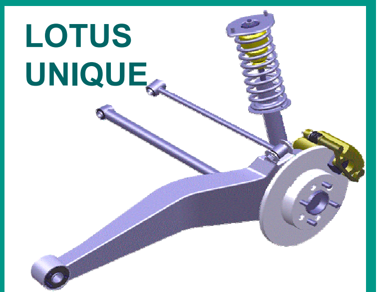


LOTUS UNIQUE

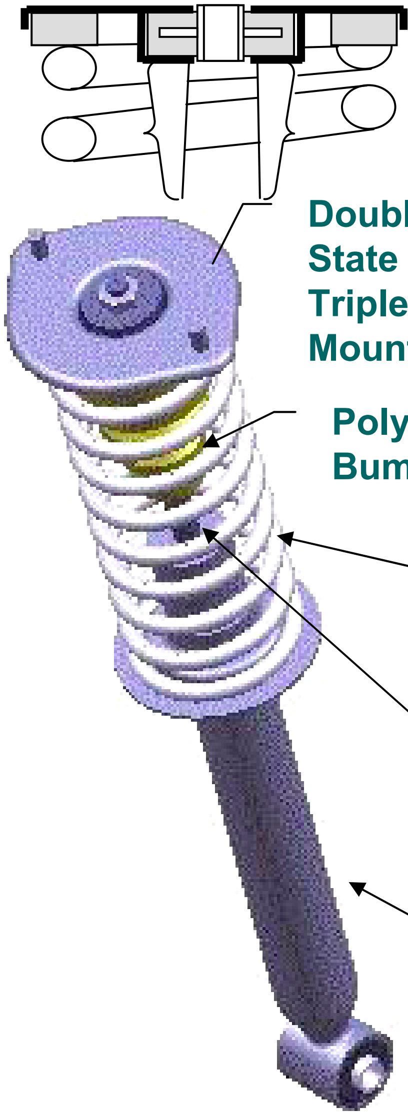


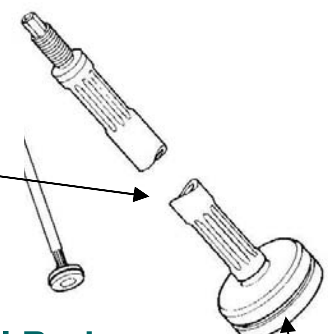
LOTUS UNIQUE: DESIGN

Spring Damper



			D Class	P Class
Outer Diameter	Do	mm	87.32	82.29
Inner diameter	Di	mm	65.00	65.00
Design length	Ld	mm	239.23	222.13
Bump length	Lb	mm	139.23	106.21
Rebound length	Lr	mm	323.23	333.01
Load at Design length	Pd	N	4068.08	2092.41
Number of working coils	n	-	9.42	8.99
Total number of coils	N		10.92	10.49
Maximum Allowable Stress		N/mm^2	1300	1300
Mean coil diameter	D	mm	76.16	73.65
Wire diameter	d	mm	11.16	8.65
Spring rate	**S**	**N/mm**	**36.59**	**15.27**
Wire length	Lw	mm	2627.40	2439.96
Spring mass	m	kg	**2.02**	**1.12**

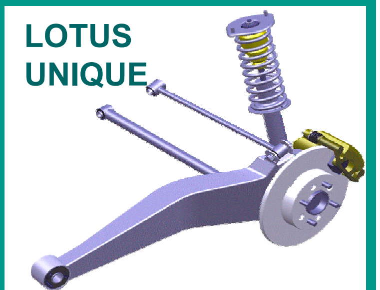




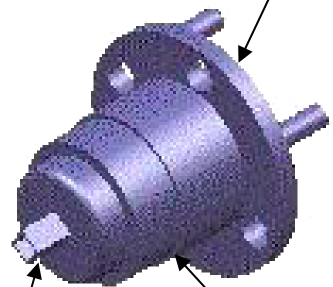
LOTUS UNIQUE: DESIGN

Hub & Bearing Unit

LOTUS UNIQUE



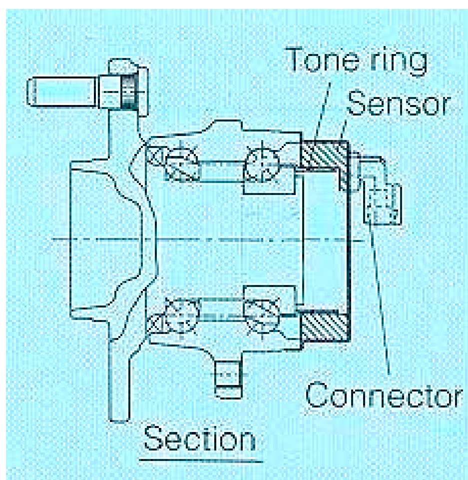
GENERATION 2 TYPE HUB & BEARING UNIT



Integrated Wheel Hub Flange

Integral ABS Sensor (Anti-Lock Brake System)

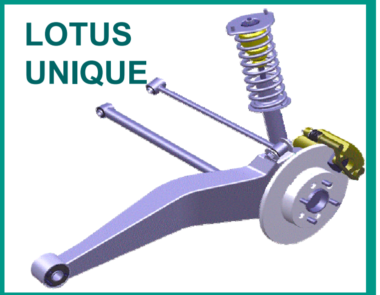
Press fit and retained by a circlip into Main Arm.

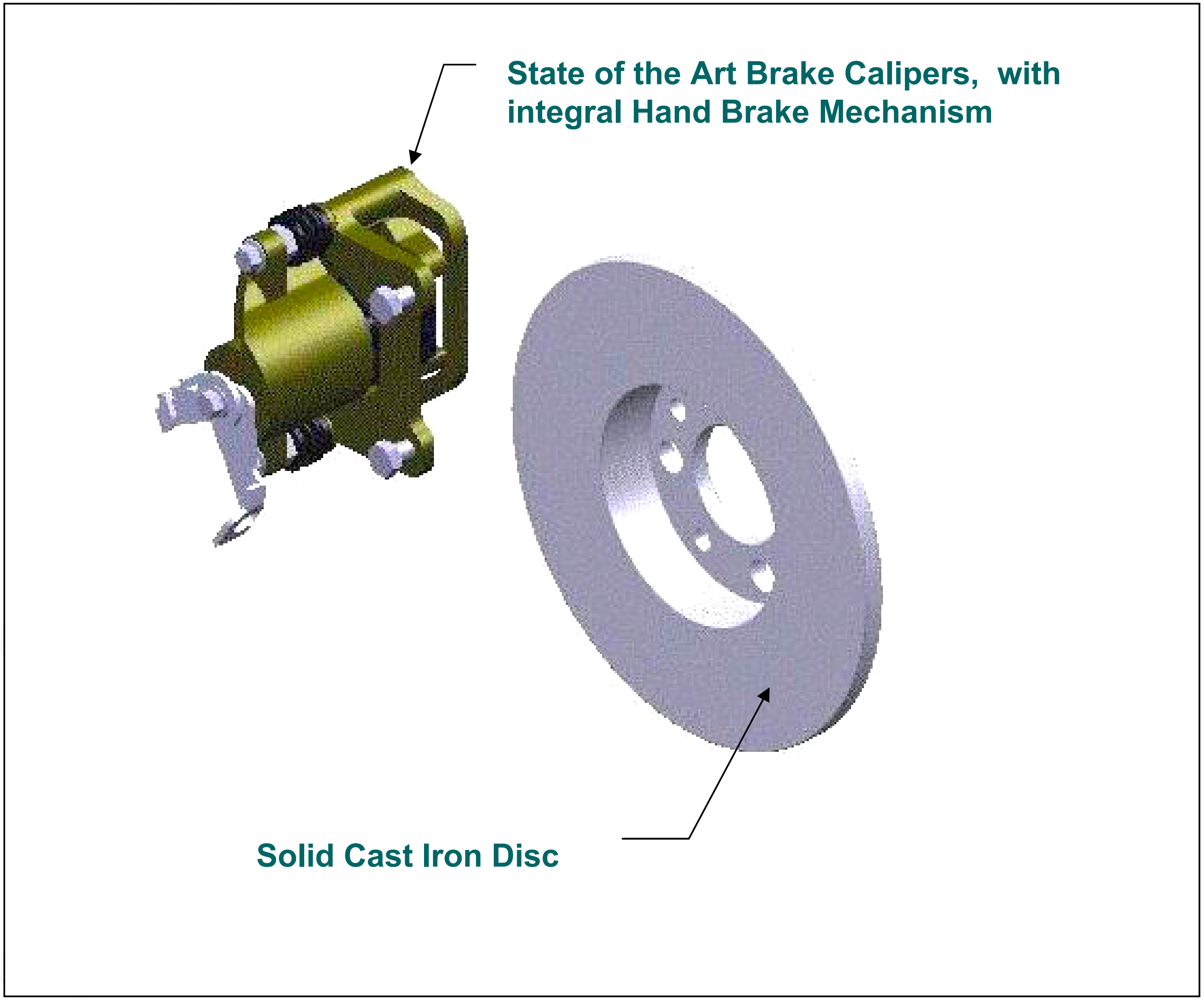


Typical Cross Section of Bearing

LOTUS UNIQUE: DESIGN

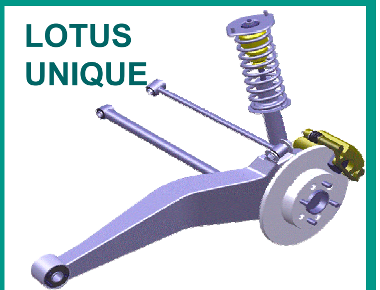
Brakes





LOTUS UNIQUE: DESIGN

Lateral Links

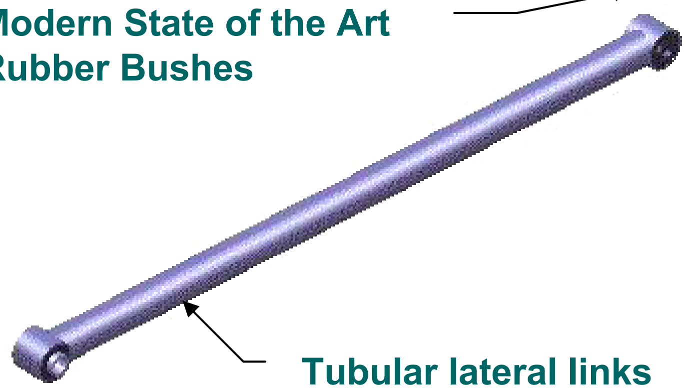


Analysis demonstrated that a ‘cigar’ shaped member holds a marginal structural advantage over a parallel thin walled tube.

However, the manufacturing cost penalty of adopting such a configuration is significant. Therefore the links employed throughout the ULSAS programme are all parallel thin walled tubes.

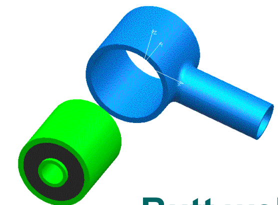
Nevertheless, a variety of compatible end fittings have been considered & employed in the design solutions, examples of which are depicted.

Modern State of the Art Rubber Bushes

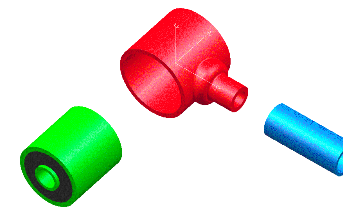


Tubular lateral links
Diameter = 25mm
Thickness = 1.5mm
Minimum Yield = 250 MPa

Alternative End Fixings



Butt welded

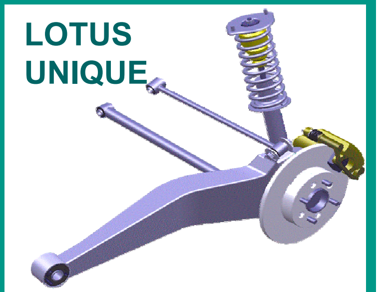


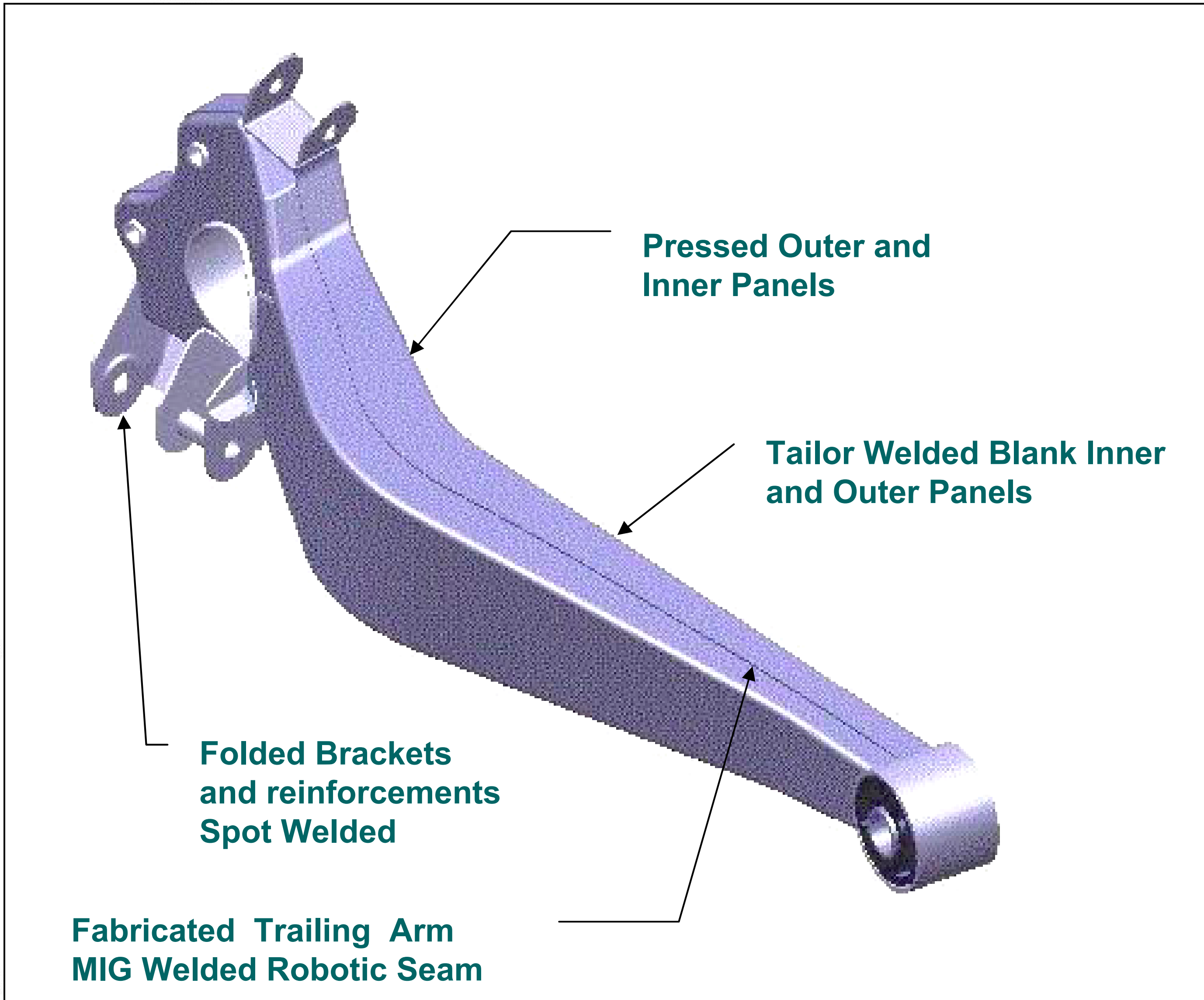
Hydro-formed T Piece clinched or welded

Cold rotary swage

LOTUS UNIQUE: DESIGN

Trailing Arm

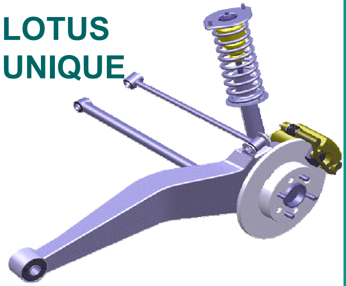




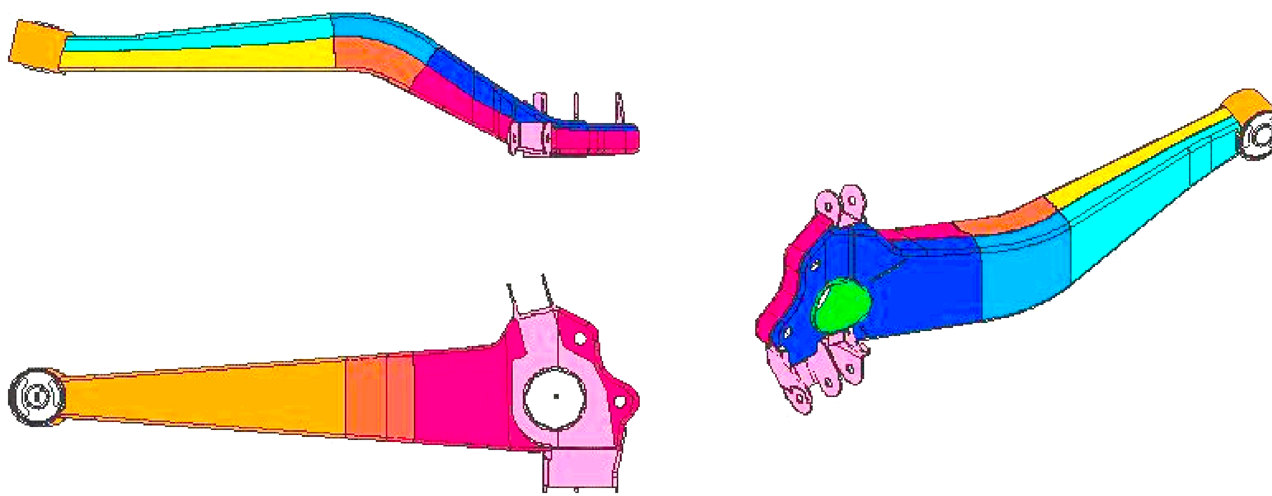
LOTUS UNIQUE: DESIGN

Trailing Arm

LOTUS UNIQUE



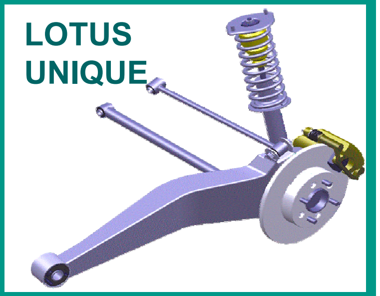
Part	Trailing Arm Outer Panel			Part	Outer Hub Reinforcement	
Process	Pressing Tailor Welded Blank			Process	Pressing	
Material Gauge (mm)	1.8	2.7	1.2	Material Gauge (mm)	2.5	
Material Grade (MPa)	400	200	200	Material Grade (MPa)	400	
Part	Trailing Arm Inner Panel			Part	Housing Hub Bearing Unit	
Process	Pressing Tailor Welded Blank			Process	Machined (Tube)	
Material Gauge (mm)	2.3	2.3	1.2	Material Gauge (mm)	3	
Material Grade (MPa)	500	150	250	Material Grade (MPa)	300	

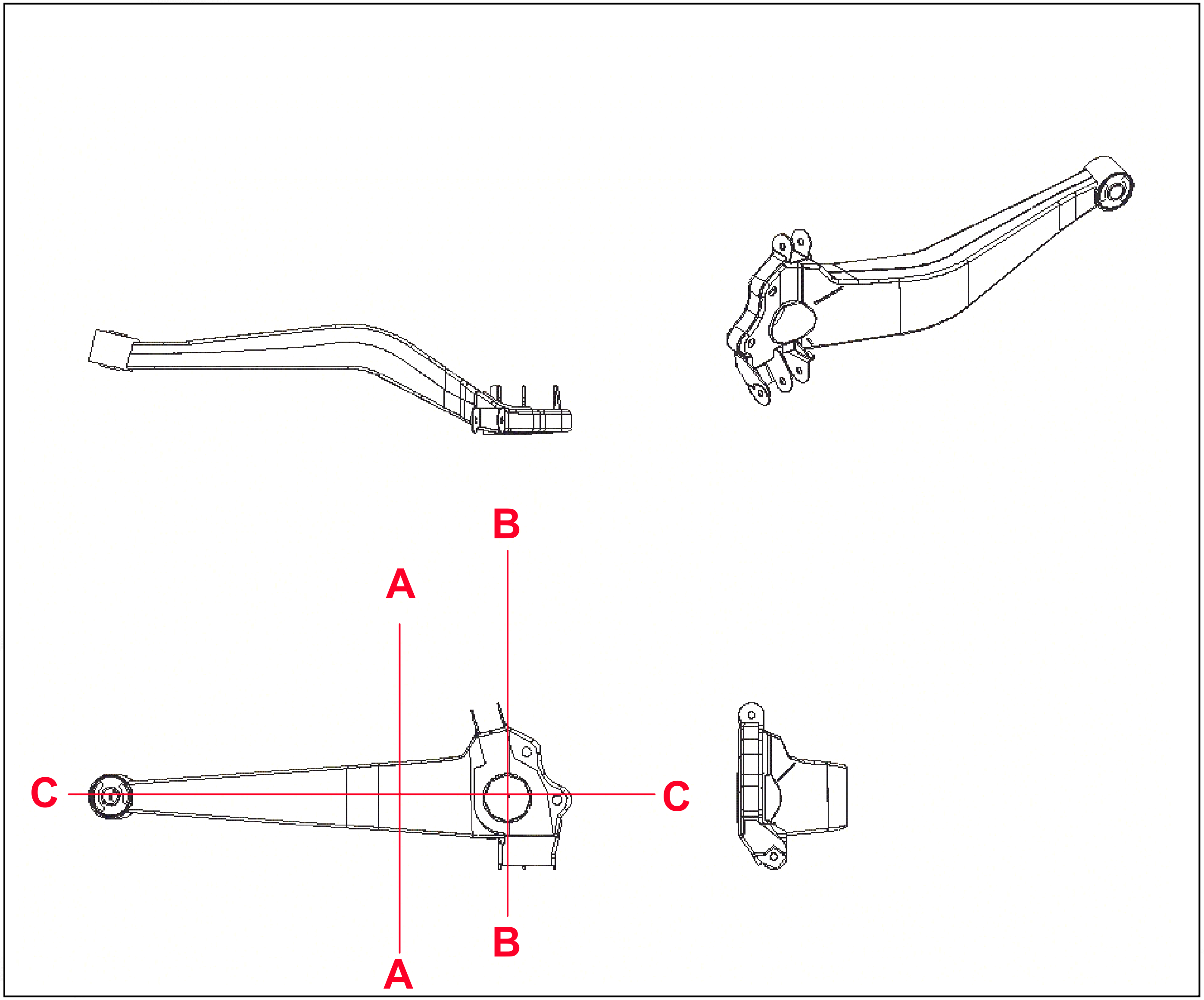


LOTUS UNIQUE: DESIGN

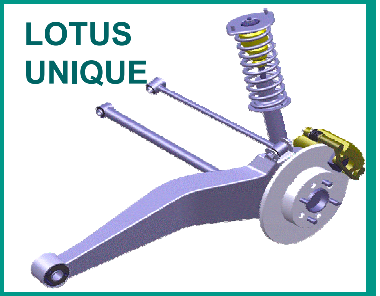
Trailing Arm

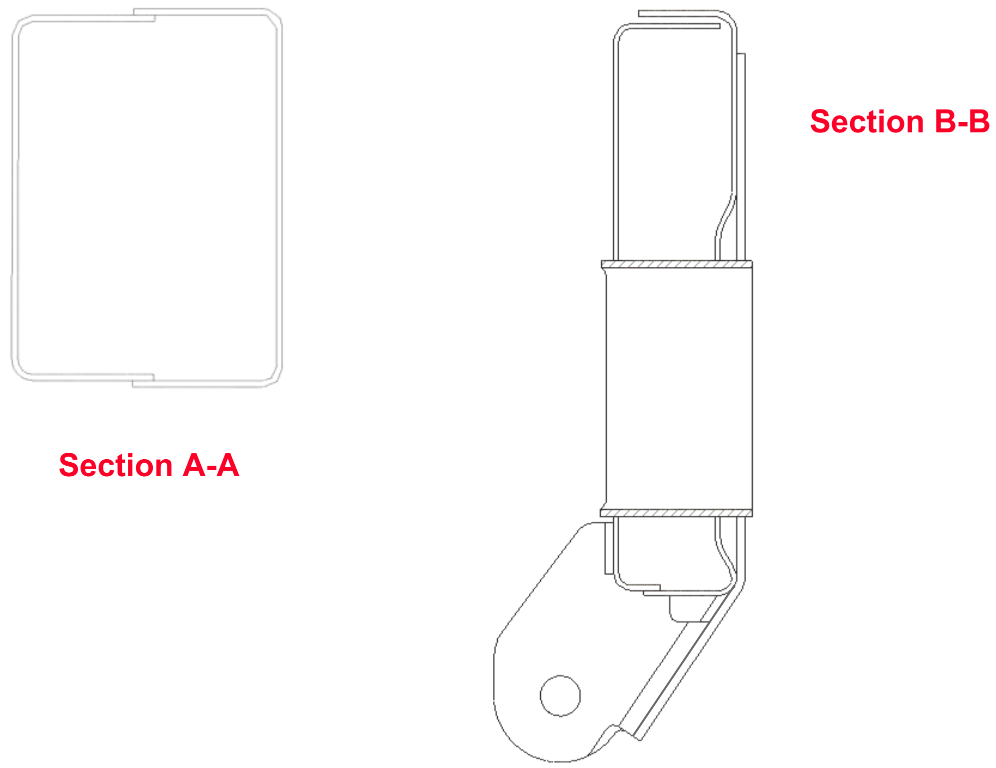
ULTRALIGHT STEEL AUTO SUSPENSION





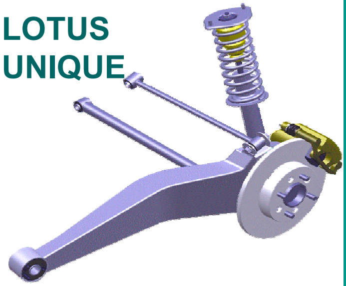
LOTUS UNIQUE: DESIGN
Trailing Arm

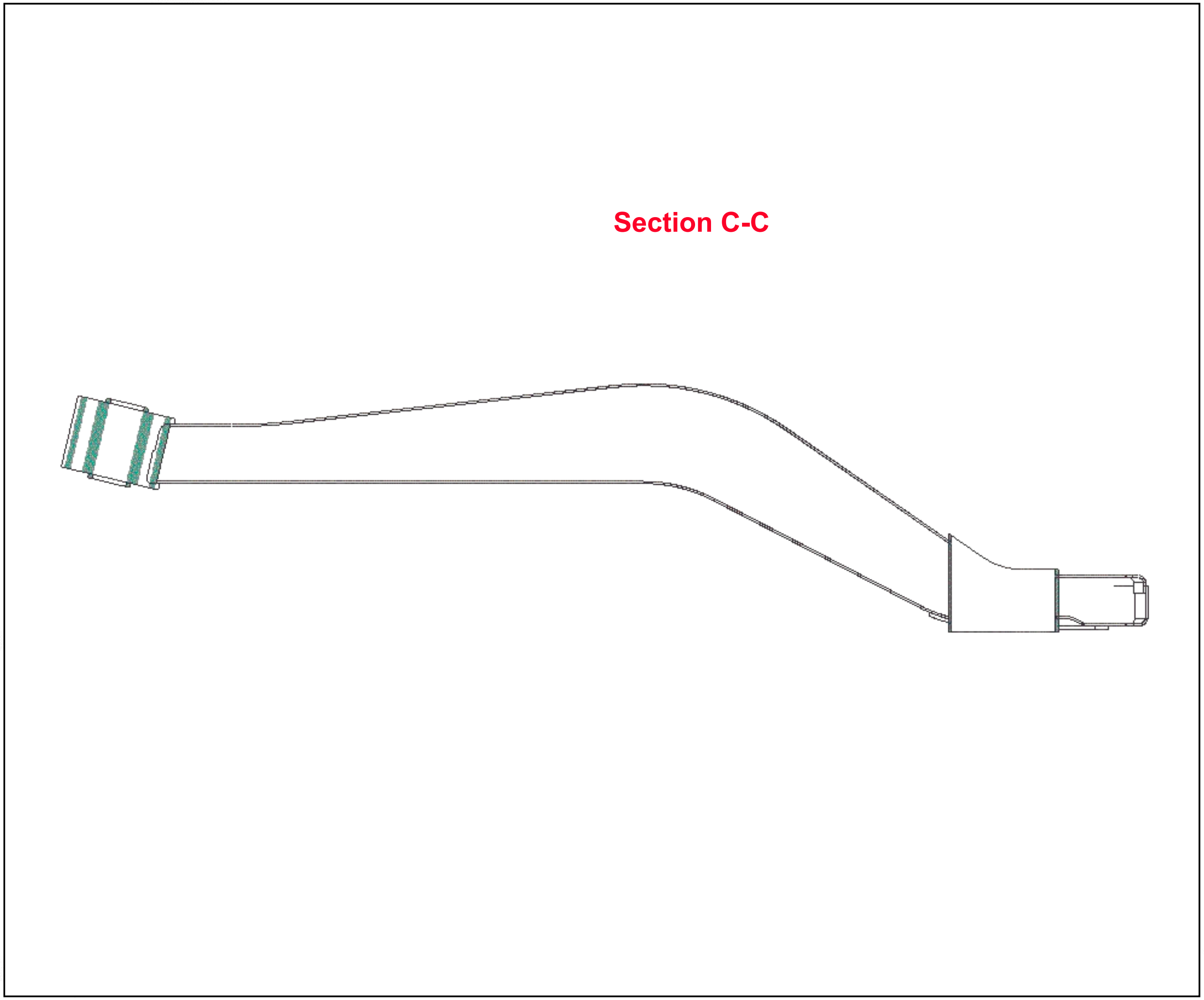




LOTUS UNIQUE: DESIGN

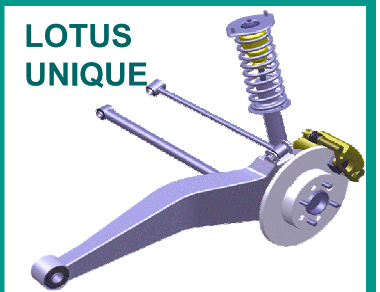
Trailing Arm

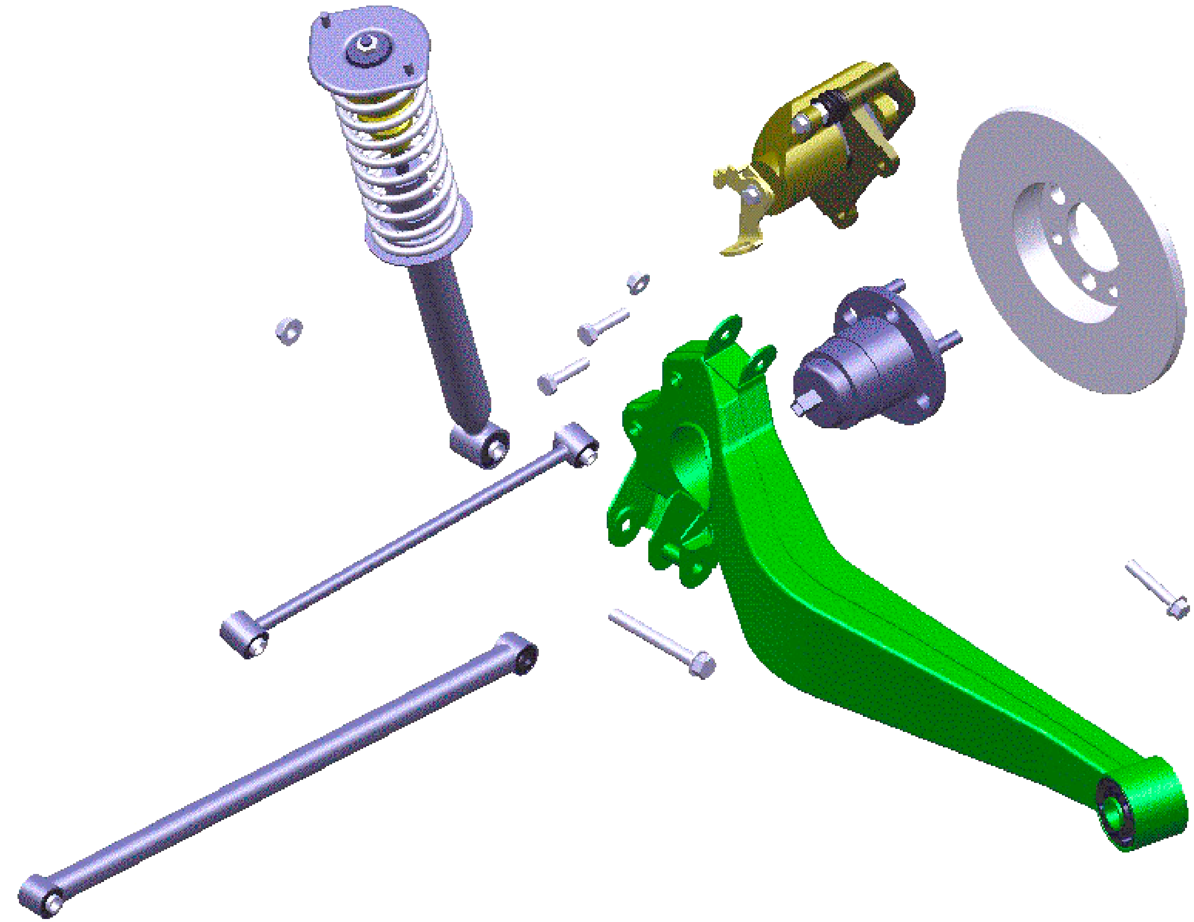


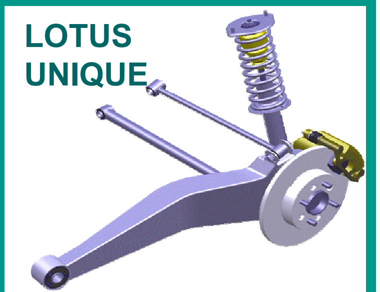


LOTUS UNIQUE

Finite Element Analysis







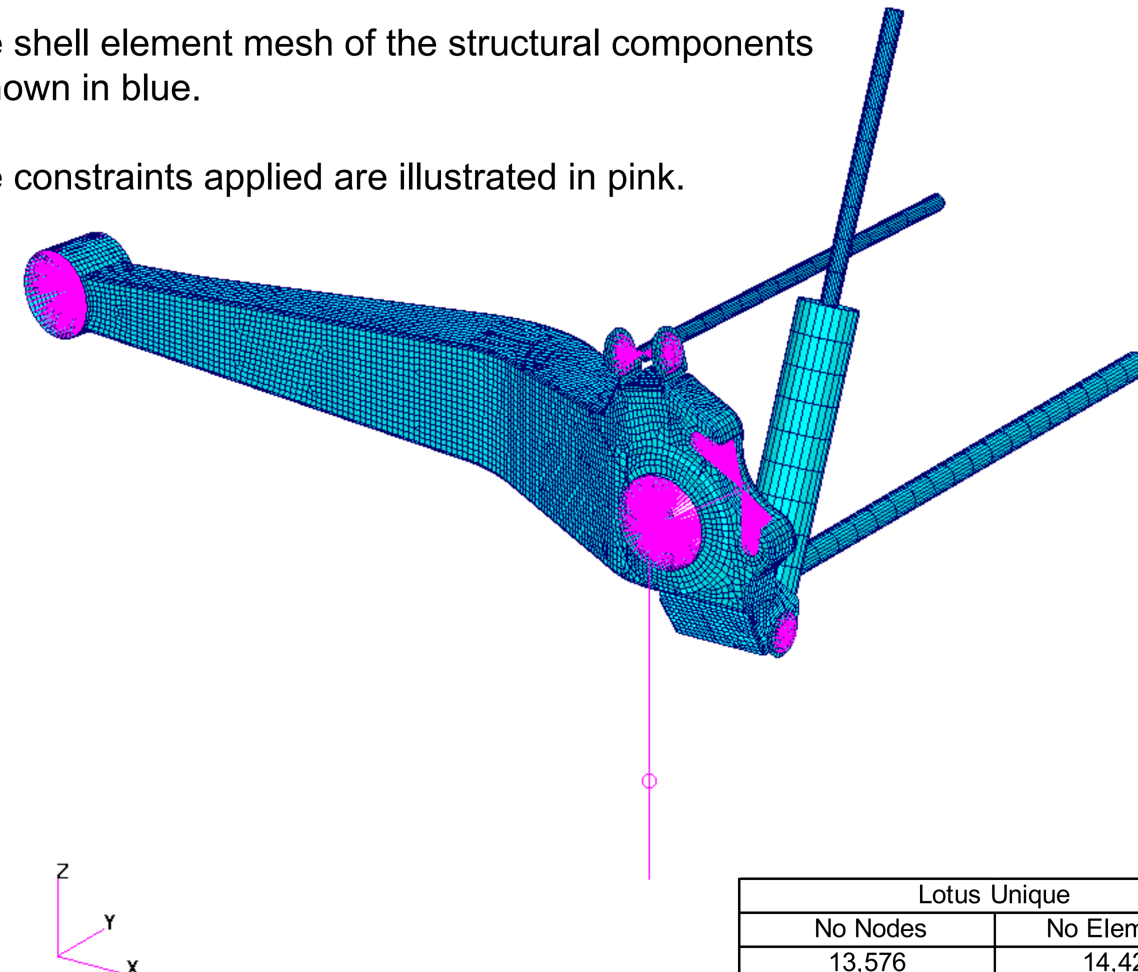
LOTUS UNIQUE

Finite Element Analysis

Finite Element Model of Lotus Unique System:

•The shell element mesh of the structural components is shown in blue.

•The constraints applied are illustrated in pink.

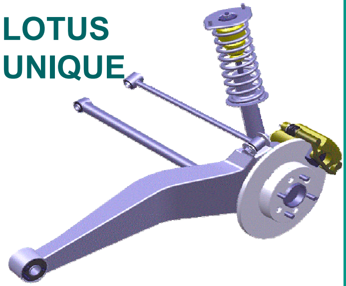


Lotus Unique	
No Nodes	No Elements
13,576	14,426

LOTUS UNIQUE:STRESS RESULTS

D Class

LOTUS UNIQUE

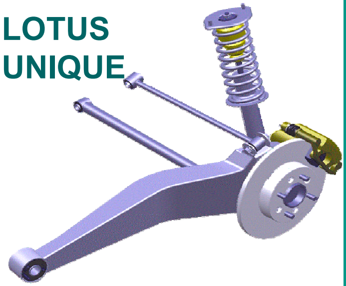


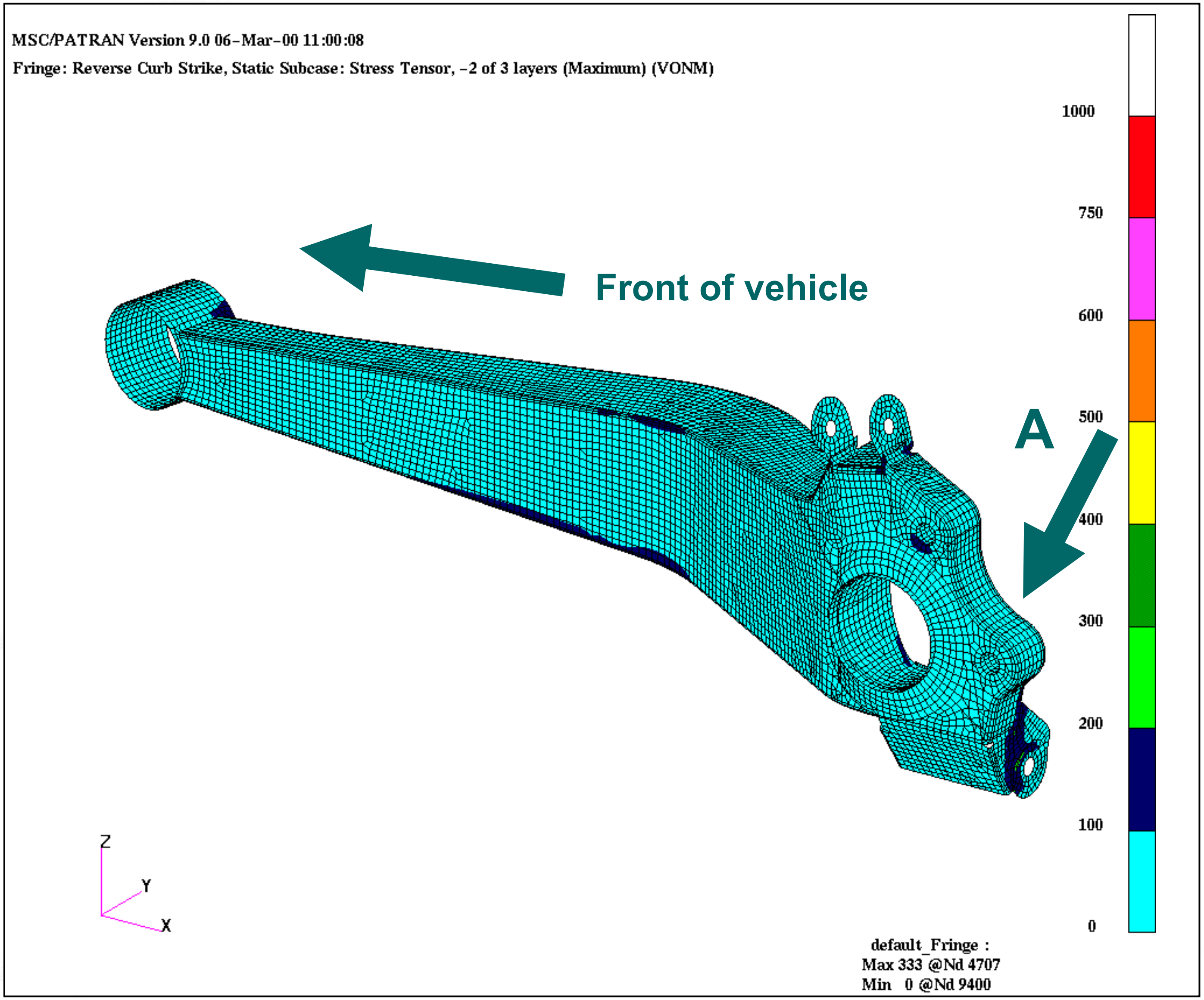
Load Case	Max stress (Von Mises)
Reverse Curb Strike (TCP)	**333 MPa**
Lateral Curb Strike 1 with load transfer	**392 MPa**
Lateral Curb Strike 2 with NO load transfer	**377 MPa**
Vertical Bump (TCP)	**390 MPa**
Forward Braking with ABS (TCP)	**255 MPa**
Combined Bump and Cornering (TCP)	**391 MPa**
Pothole Brake (TCP)	**329 MPa**

LOTUS UNIQUE

Reverse Curb Strike, D Class

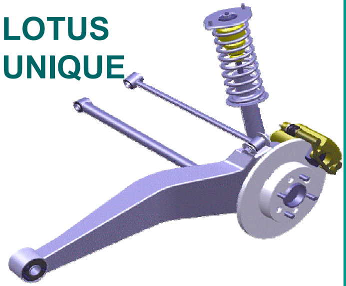
LOTUS UNIQUE

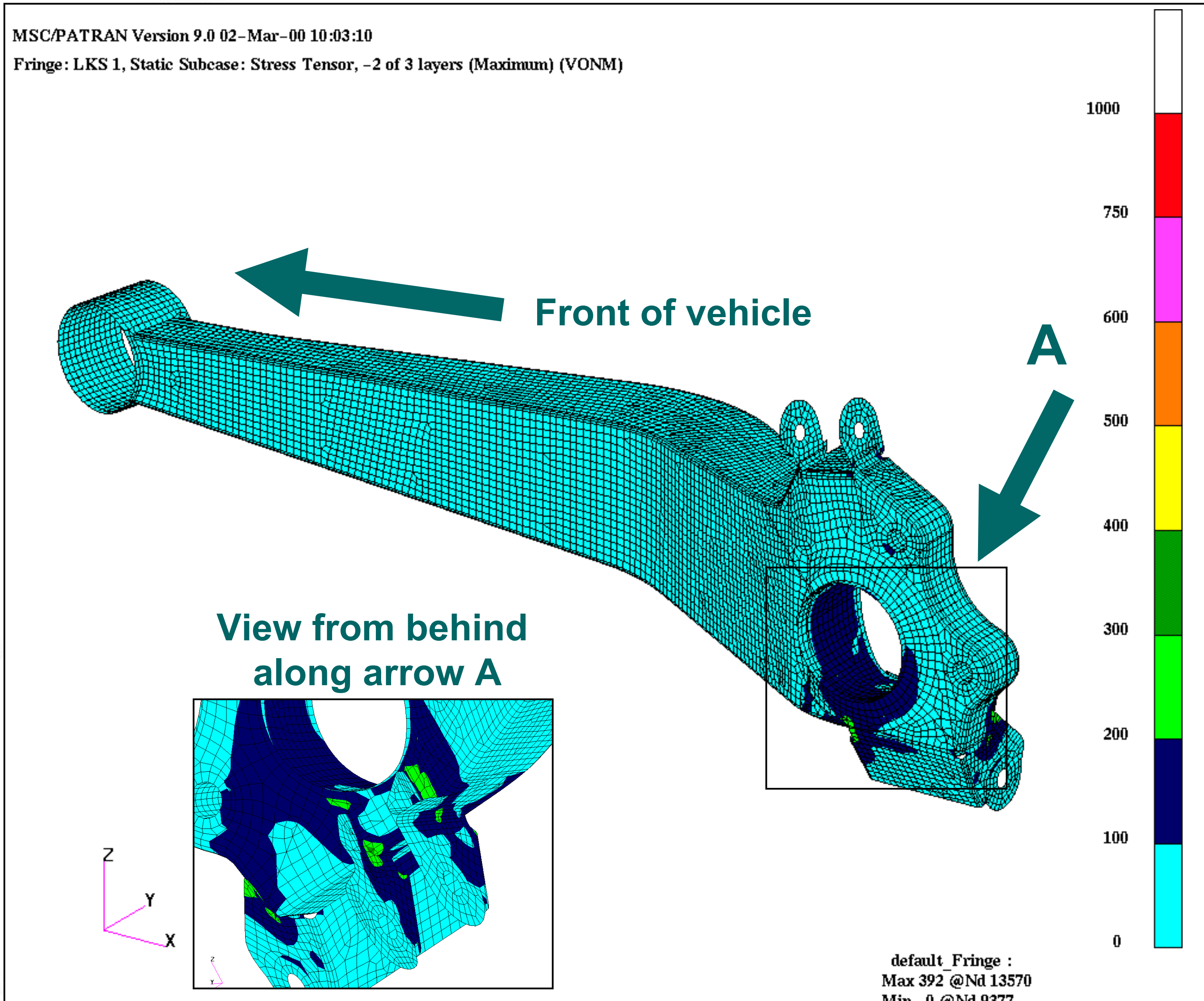




LOTUS UNIQUE
Lateral Curb Strike 1, D Class

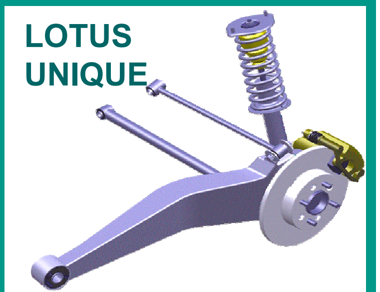
LOTUS
UNIQUE

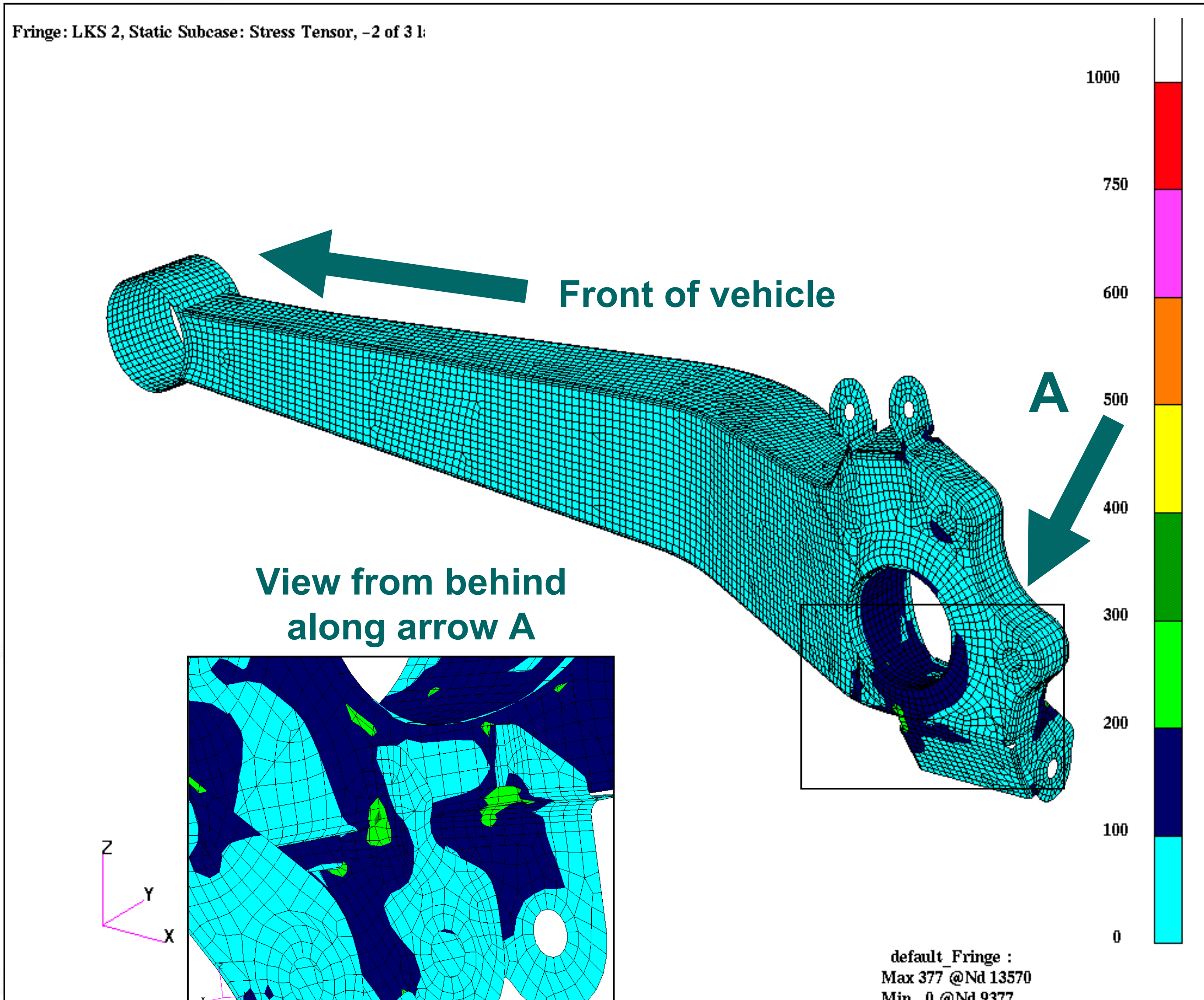




LOTUS UNIQUE

Lateral Curb Strike 2, D Class





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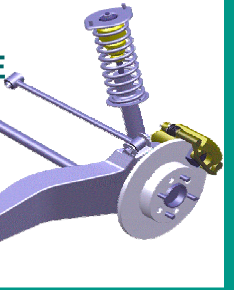
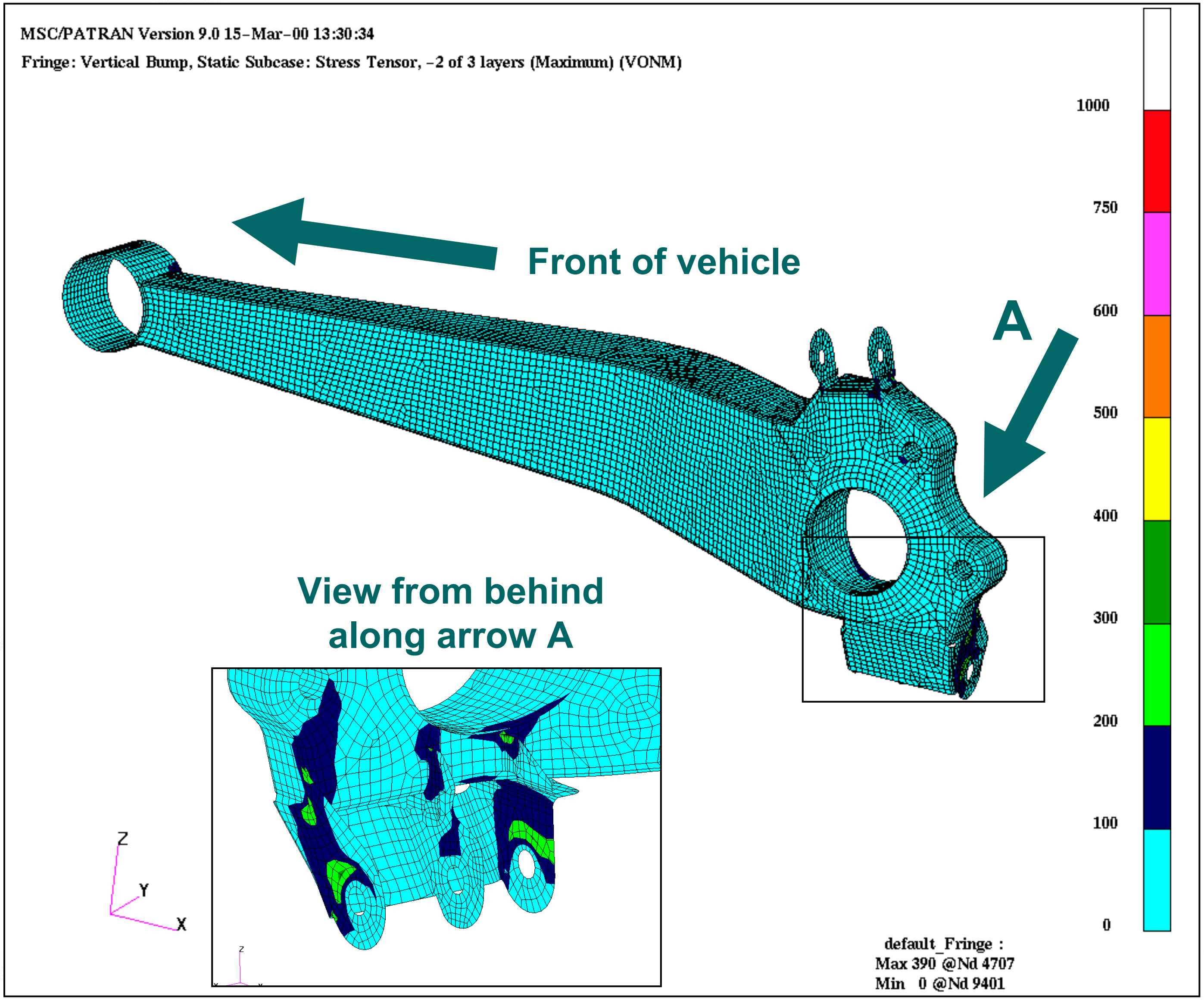


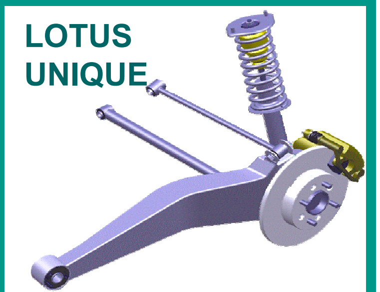
LOTUS UNIQUE

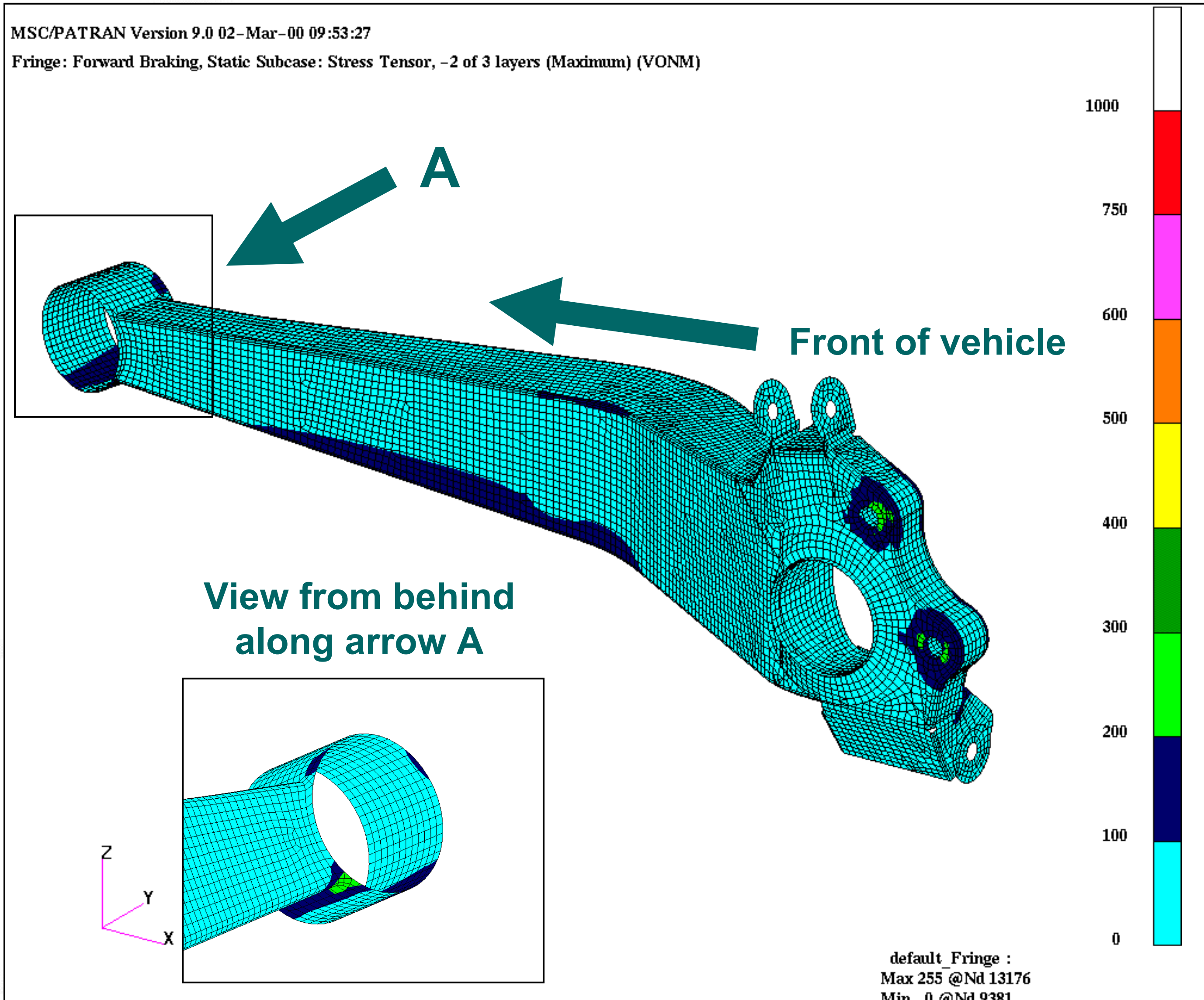
Vertical Bump, D Class



LOTUS UNIQUE

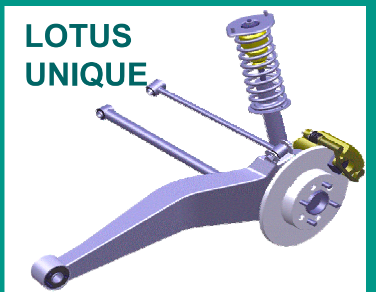
Forward Braking, D Class

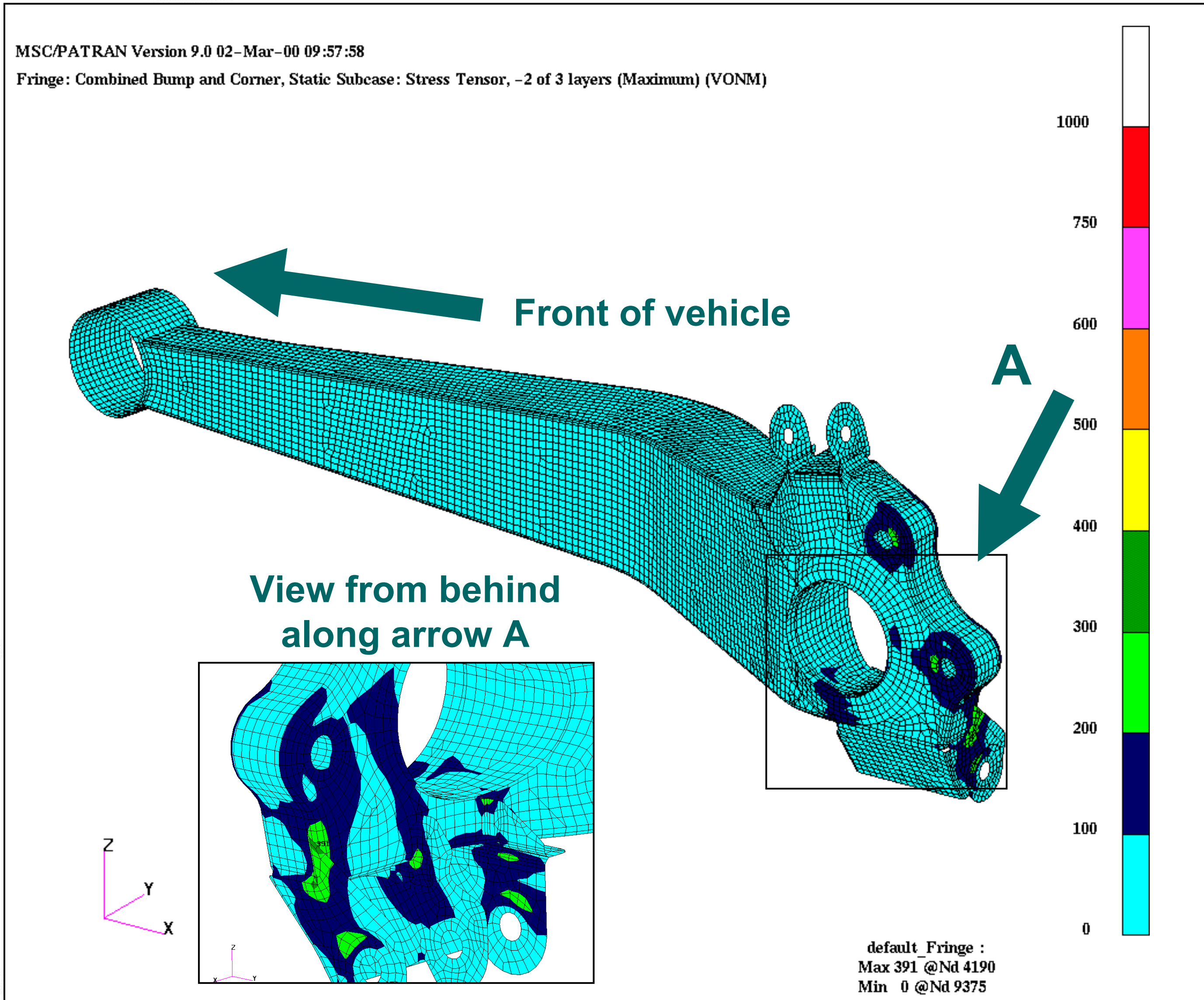




LOTUS UNIQUE

Combined Bump & Corner, D Class

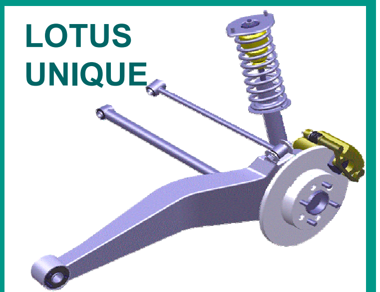


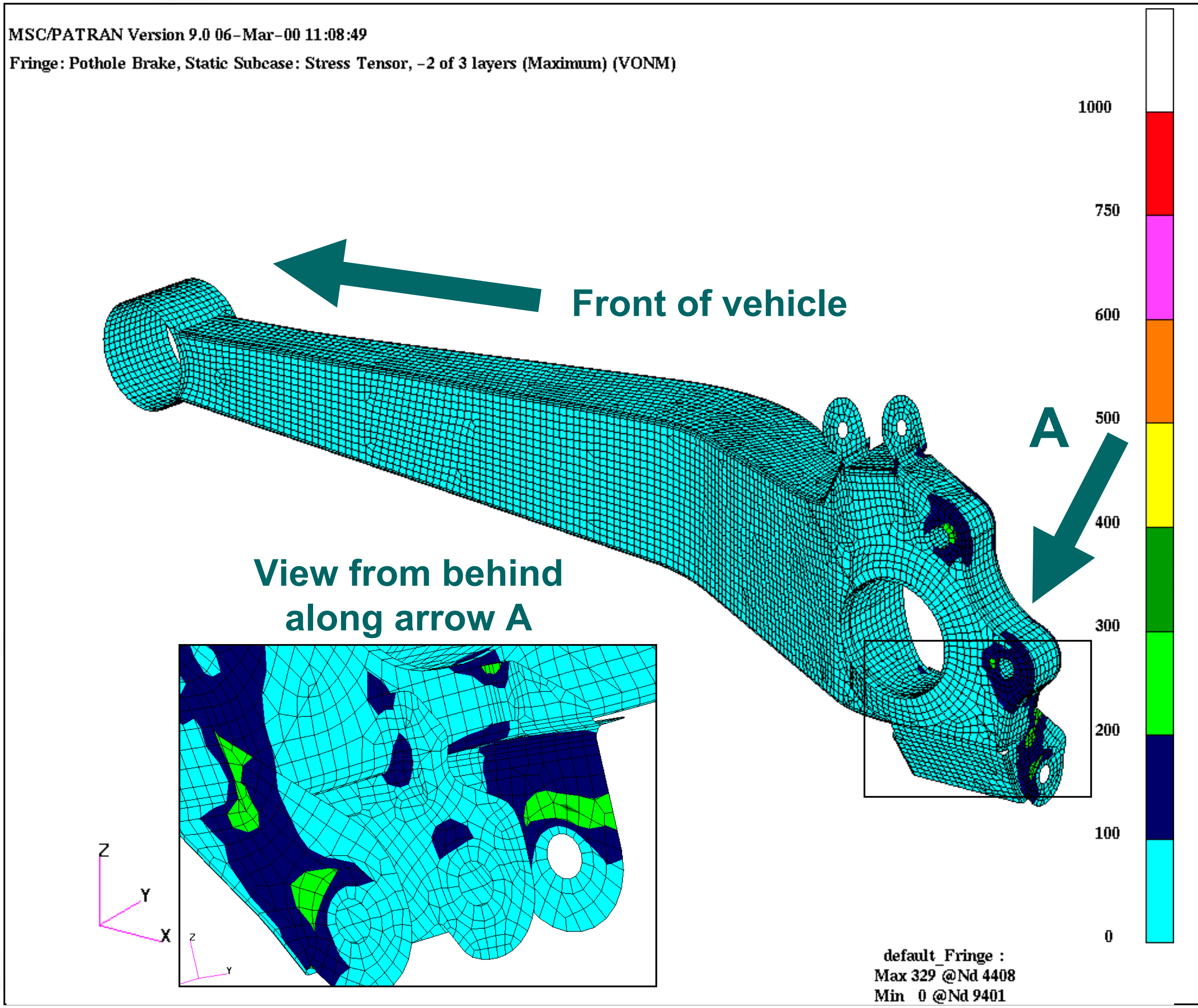


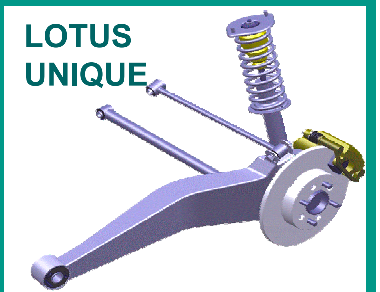
LOTUS UNIQUE

Pothole Brake, D Class

LOTUS UNIQUE

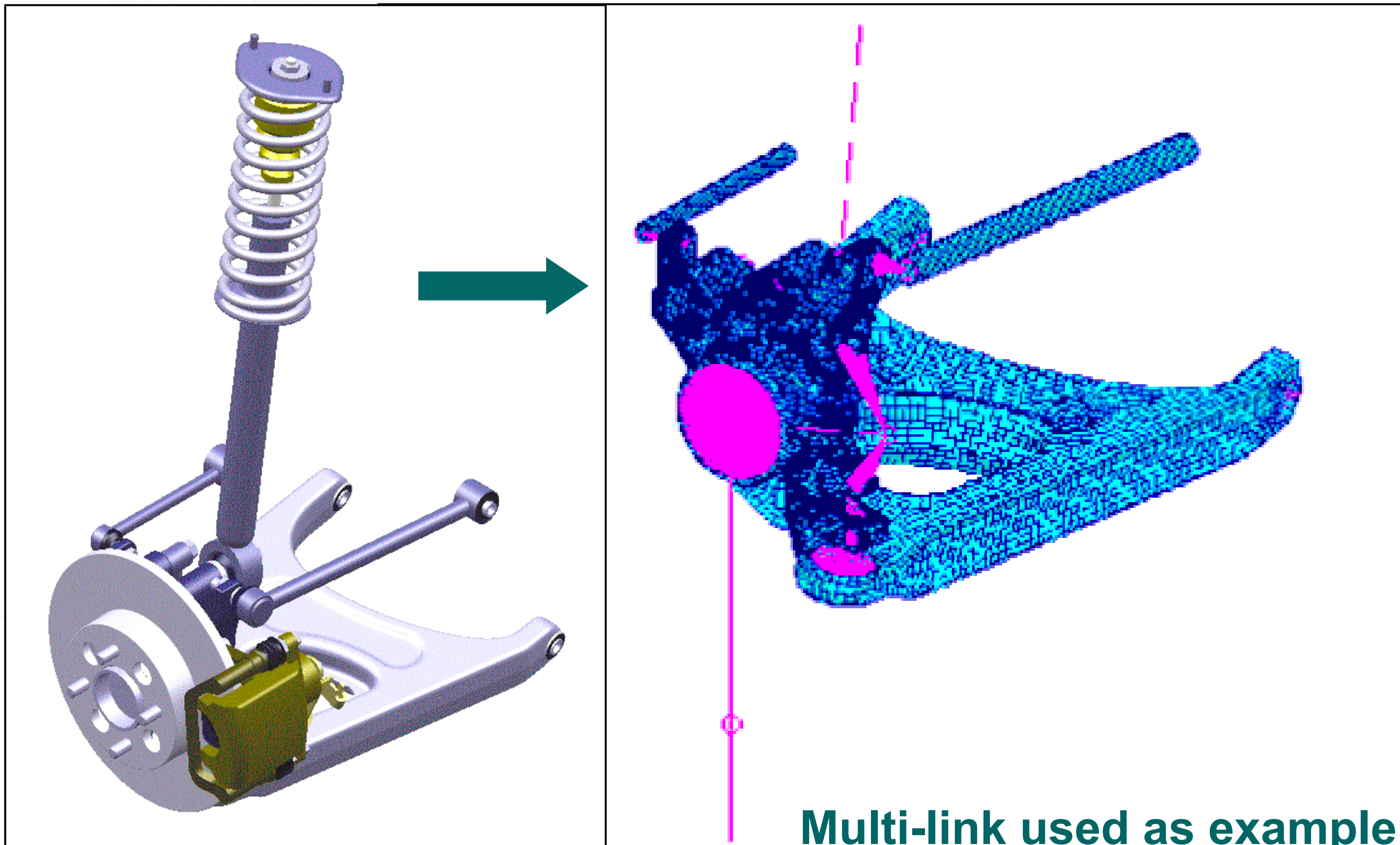






LOTUS UNIQUE: CAE STRUCTURAL APPROACH

Part Physical Geometry

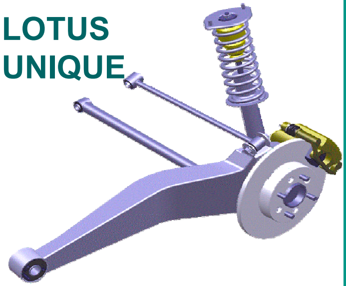


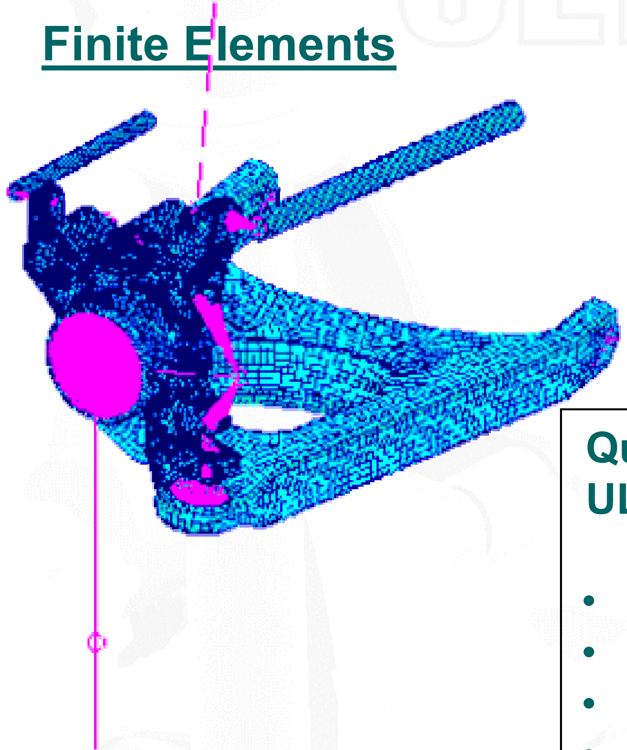
The physical geometry of the parts used to create the finite element model was imported from the CAD environment. Appropriate modifications were then made within the FE environment using the many tools available.

LOTUS UNIQUE: CAE STRUCTURAL APPROACH

Finite Elements

LOTUS UNIQUE





Multi-link used as exam

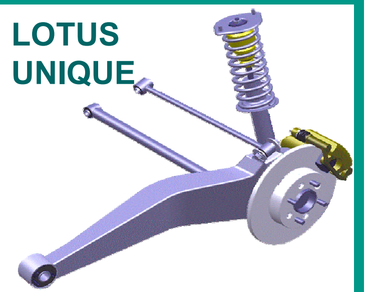
Quality indices adapted throughout the ULSAS Programme for shell elements:

- Aspect Ratio < 5:1
- Warp Angle < 7 degrees
- Skew Angle < 30 degrees
- Taper > 0.8

An FE mesh was created using the imported CAD geometry. This was undertaken by using either manual or auto meshing techniques. Beam, shell or solid elements are used depending upon the underlying geometry. Once the mesh has been created, it is checked for free edges duplicates and normals. The element's quality is also checked for aspect ratio, warp angle, skew angle, and taper. Typical values for these are:

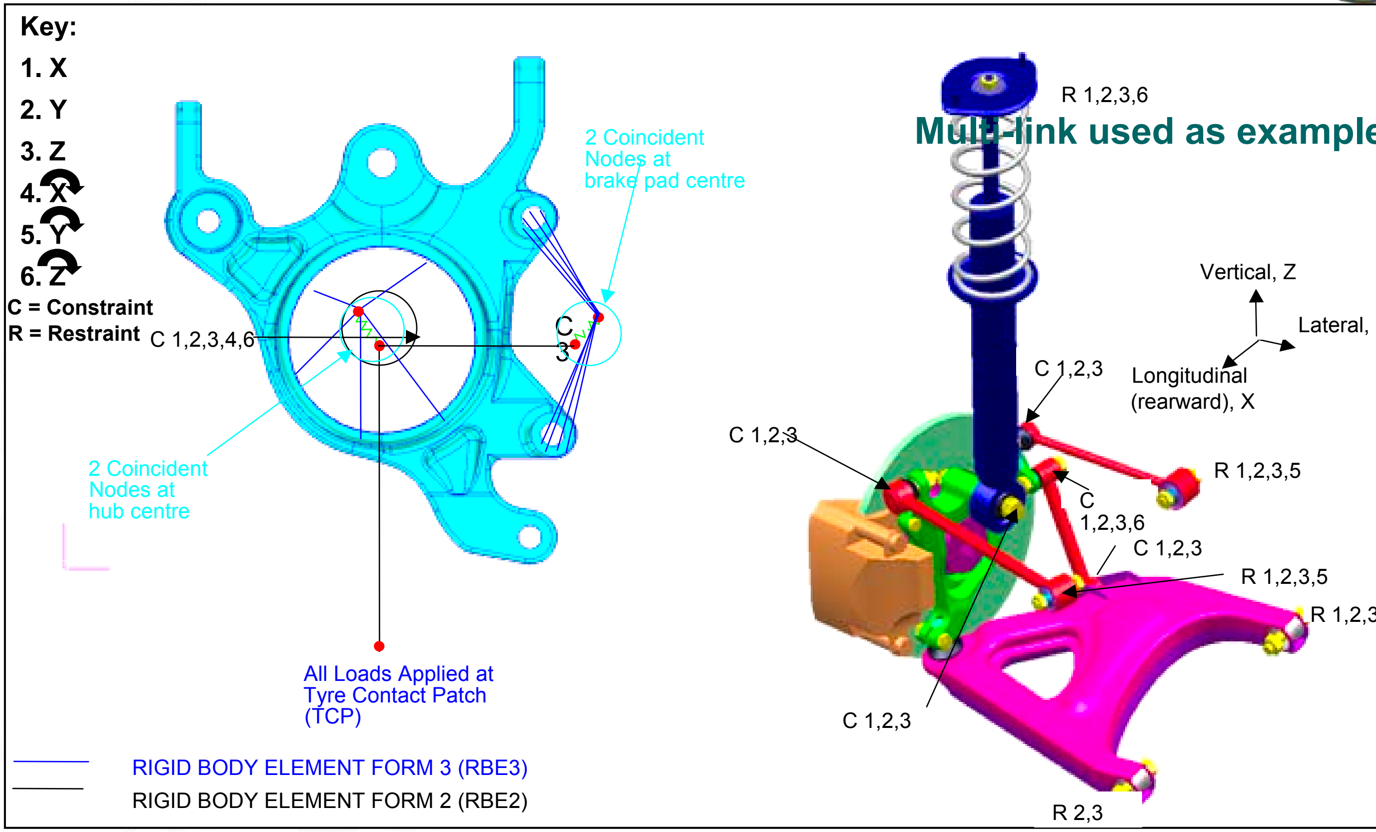
Aspect Ratio	<	5:1.
Warp Angle	<	7 degrees.
Skew Angle	<	30 degrees.
Taper	>	0.8.

These values can be doubled, but for only 10% of the FE model, and only in areas of little concern.



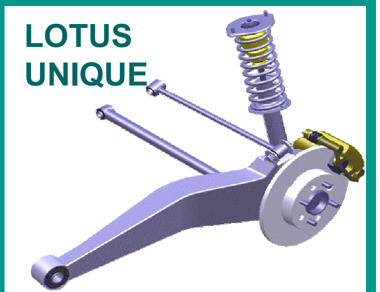
LOTUS UNIQUE: CAE STRUCTURAL APPROACH

Loads and Boundary Conditions



Restraints, constraints and loads are applied to the FE model using appropriate rigid elements and springs, with the necessary degrees of freedom carefully defined. Restraints are normally RBE3s from a hole to a fixing point, and then a spring to ground. Constraints connect two components using RBE3s from holes to a common point, which is joined using springs. Loads are applied through RBE2s and RBE3s to the structure.

NB. RBE3s are defined as the motion at a reference grid point as the weighted average of the motions at a set of other grid points and RBE2s are defined as a rigid body whose independant degrees of freedom are specified at a single grid point and whose dependant degrees of freedom are specified at an arbitrary number of grid points.



LOTUS UNIQUE: CAE STRUCTURAL APPROACH

Materials

Material models are obtained from the FE software database, or else are created explicitly. Linear analysis only requires the elastic modulus and Poisson ratio. A non linear analysis also requires the yield point and a plastic hardening modulus.

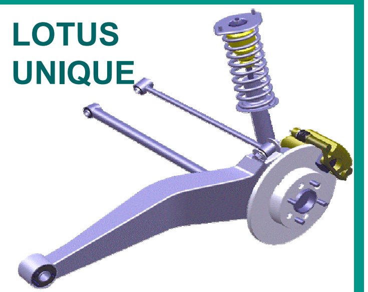
Properties

Spring, beam and shell properties are defined for each type of element. Springs require stiffnesses and degrees of freedom, beams require section properties and orientations, and shells require thicknesses.

LOTUS UNIQUE: CAE STRUCTURAL APPROACH
Load Cases

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE



ULSAS Standard Load Cases

Load Case Description (2)	X direction	Y direction	Z direction (1)	Position of force Application
Reverse Curb Strike	- 0.5 g	0	3 g	Tyre contact patch
Lateral Curb Strike 1	0	(-) 1.5 g (based on axle weight)	1g with weight transfer	Wheel rim lower position
Lateral Curb Strike 2	0	(-) 1.5 g (based on xle weight)	1g with no weight transfer	Wheel rim lower position
Vertical Bump	0	0	4 g	Tyre contact patch
Forward Braking (With ABS)	1.1 g	0	1g with no weight transfer	Tyre contact patch
Combined Bump and Cornering	0.316 g at wheel including yaw and longitudinal	(-) 0.58 g (based on axle weight)	3g with weight transfer	Tyre contact patch
Pot hole	1.5 g	0	4 g	Tyre contact patch

Actual forces are calculated including dynamic effects (e.g. weight transfer for lateral acceleration) unless stated.

Sign Convention:

X =Positive rearward
Y =Positive to the right
Z =Positive upwards

Notes:

(1) Z direction loading includes 1g static load

(2) Loads to be calculated assuming that the vehicle is in the Gross Mass condition.

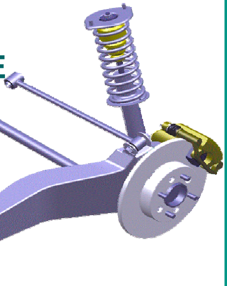
Unit loads are applied to the FE models at the tyre contact patch and any other specific application areas. These are then combined to produce the standard proof load cases for stiffness and strength assessment. The proof load cases are obtained from Lotus' in house software and are as follows:

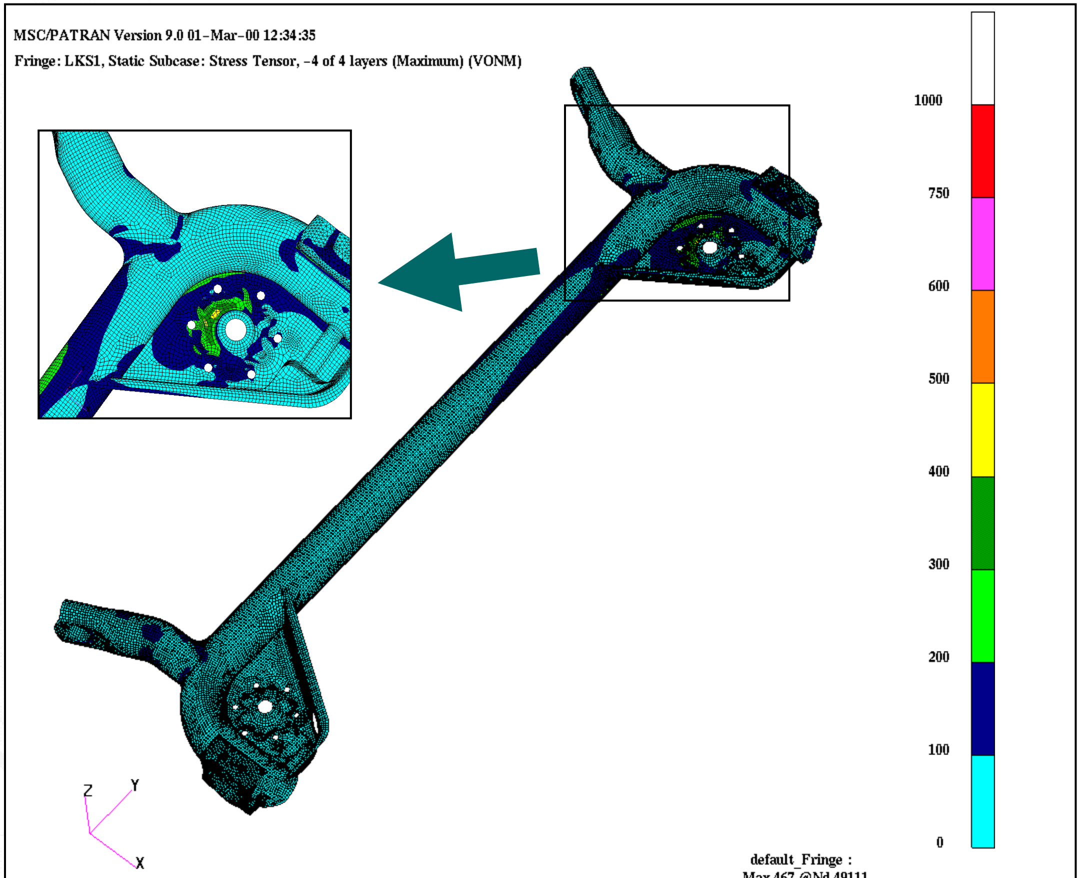
Reverse Curb Strike.
Lateral Curb Strike With Load Transfer.
Lateral Curb Strike Without Load Transfer.
Vertical Bump.
Forward Braking With ABS.
Combined Bump And Cornering.
Pothole Braking.

LOTUS UNIQUE: CAE STRUCTURAL APPROACH

Analysis

LOTUS UNIQUE





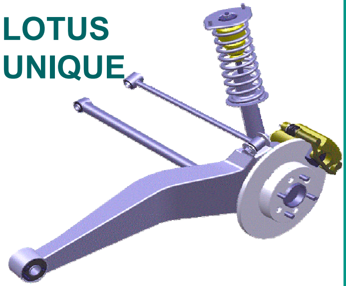
Twistbeam used as example

The two main types of analysis performed are linear static, and nonlinear static. For the nonlinear static analysis the nonlinear material model has to be specified, and the nonlinear load case must also be defined. (It is not possible to combine nonlinear static results.)

LOTUS UNIQUE: CAE STRUCTURAL APPROACH

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE



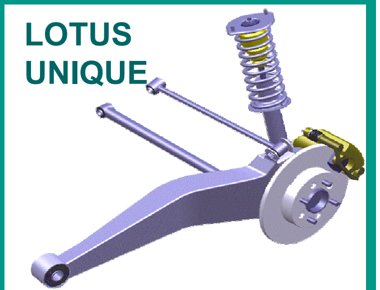
Load Case	Max stress (Von Mises)	Location
Reverse Curb Strike (TCP)	**468 MPa**	Spring pan
Lateral Curb Strike 1 with load transfer	**472 MPa**	Spring pan
Lateral Curb Strike 2 with NO load transfer	**416 MPa**	Knuckle join
Vertical Bump (TCP)	**592 MPa**	Tube
Forward Braking with ABS (TCP)	**355 MPa**	Knuckle join
Combined Bump and Cornering (TCP)	**445 MPa**	Spring pan
Pothole Brake (TCP)	**589 MPa**	Tube

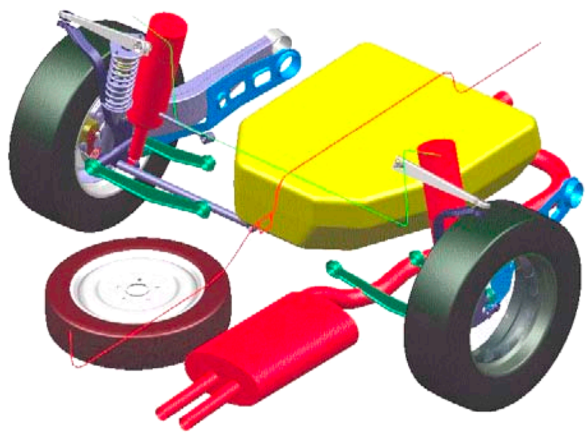
Example of results table.

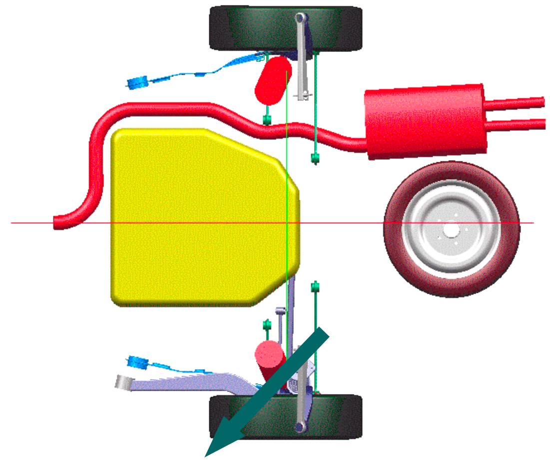
For the linear static analysis, after combining the unit load cases, the deformation of the FE model is checked to make sure the model is behaving correctly, and to obtain any stiffness values. The Von Mises stress value for each load case is then compared against the yield stress of the material. The element averaging definition domain should be compared between all entities and none. This gives an indication as to how good the mesh density and stress convergence is. If the stress value goes above the yield stress for very localised areas, this is acceptable. However, if there are considerable areas above the yield stress, then the part design needs to be redefined. If this is not possible then nonlinear static analysis may be performed to further evaluate the behaviour of the component under stress.

STEEL AUTO SUSPENSION

LOTUS UNIQUE: PACKAGING







An evaluation of the packaging implications of the proposed suspension system was carried out. This compared the ULSAS system to the benchmarked vehicle in the following areas:

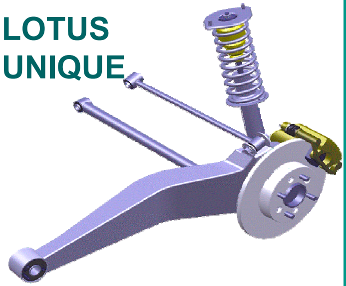
- **Systems Packaging**
- **Interior Space**

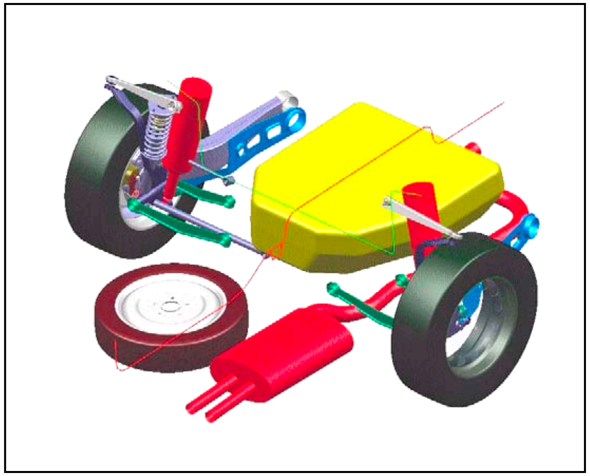
NB. There is no direct comparison for the Lotus Unique System.The Double Wishbone benchmark has been used for illustration purposes.

LOTUS UNIQUE: PACKAGING

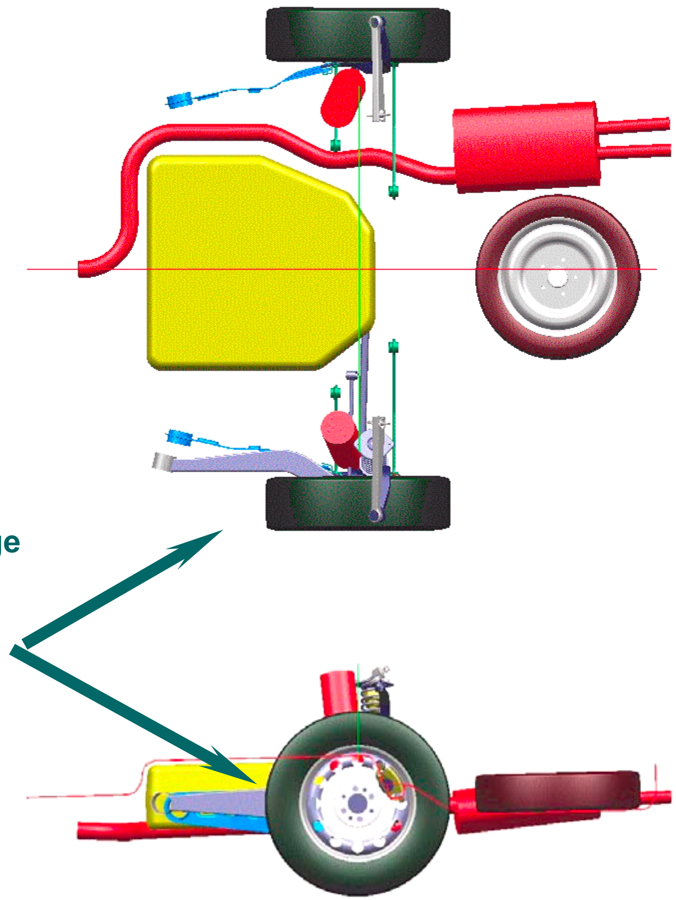
Systems

LOTUS UNIQUE





The ULSAS solution has no package implications upon the fuel tank, spare wheel or the exhaust system. The package of the ULSAS solution almost exactly matches that of the benchmarked system package.



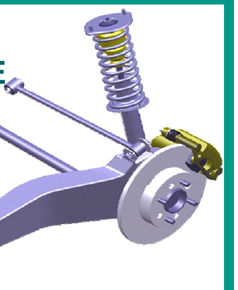
- Benchmark Vehicle
- ULSAS Solution

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE: PACKAGING

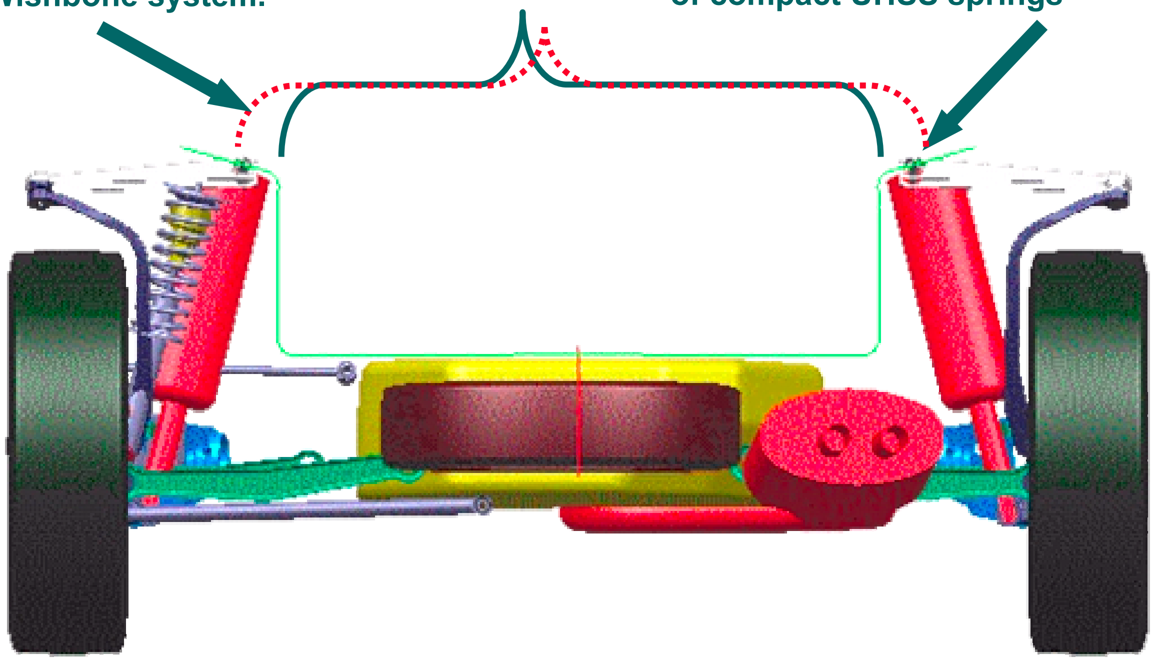
Interior

LOTUS UNIQUE



The ULSAS solution has package advantages over the benchmark system in respect of luggage compartment width. This is evident in the spacing of the damper units which can be seen to be both wider and lower for the Lotus Unique system compared to the Double Wishbone system.

An increase in the damper mount height in the ULSAS design has not proved necessary. The longer stroke dampers which enable good ride comfort have been packaged within a lower and wider envelope than the benchmarked system. This was possible due to the application of compact UHSS springs

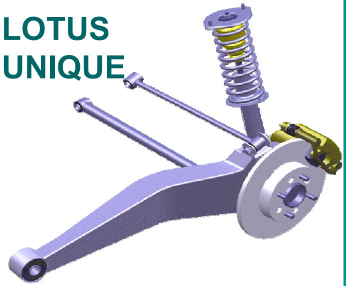


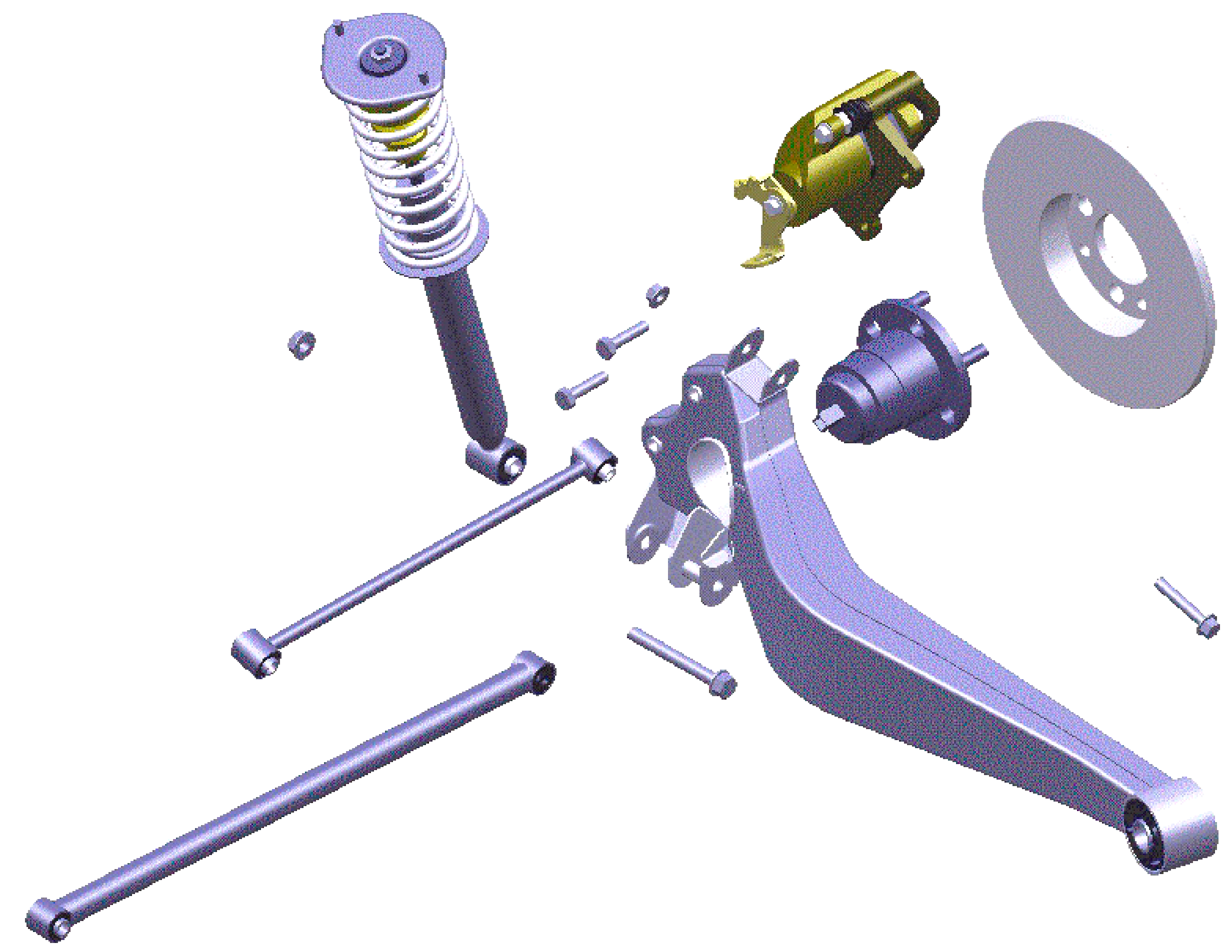
⋯⋯⋯ Luggage compartment with ULSAS Lotus Unique solution.

——— Luggage compartment with Double Wishbone Benchmark.

LOTUS UNIQUE: MANUFACTURING

LOTUS UNIQUE



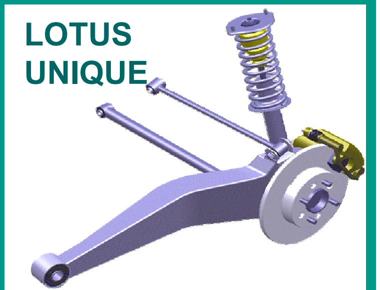


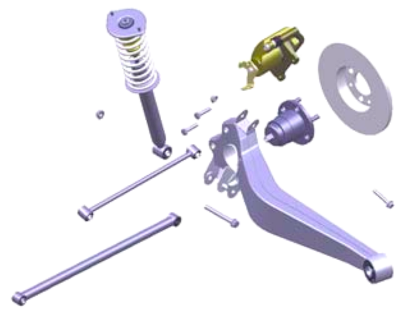
ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE: MANUFACTURING

Sub-Assembly

LOTUS UNIQUE





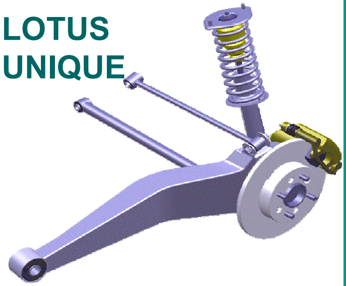
BREAKDOWN OF TIMING FOR SUB-ASSEMBLY OF LOTUS UNIQUE SUSPENSION SYSTEM

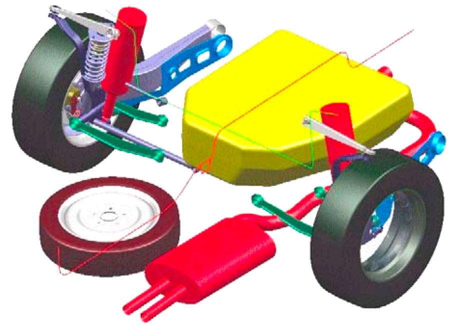
SUB-ASSEMBLY Operation	number	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
LOAD TRAILING ARM	2	FIX2H	0.09	0.09	0.18
FIT BRAKE DISK	2	FIX1H	0.05	0.05	0.10
FIT BRAKE CALIPER	2	FIX1H	0.05	0.05	0.10
FIX CALIPER	4	TFPTN	0.11	0.21	0.32
LOAD LOWER LATERAL LINK	2	FIX1H	0.05	0.05	0.10
LOAD DAMPER	2	FIX1H	0.05	0.05	0.10
LOAD BOLT	2	FITFN	0.07	0.04	0.11
FIX NUT	2	TFPTN	0.11	0.07	0.18
LOAD UPPER LATERAL LINK	2	FIX1H	0.05	0.05	0.10
FIT BOLT	2	FITFN	0.07	0.04	0.11
FIX NUT	2	TFPTN	0.11	0.07	0.18
				TOTAL	1.58

LOTUS UNIQUE: MANUFACTURING

Vehicle Assembly

LOTUS UNIQUE



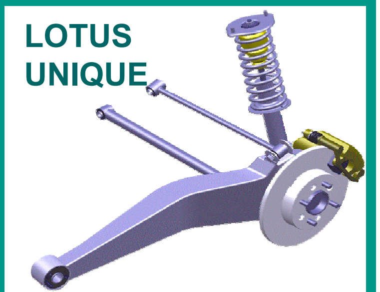


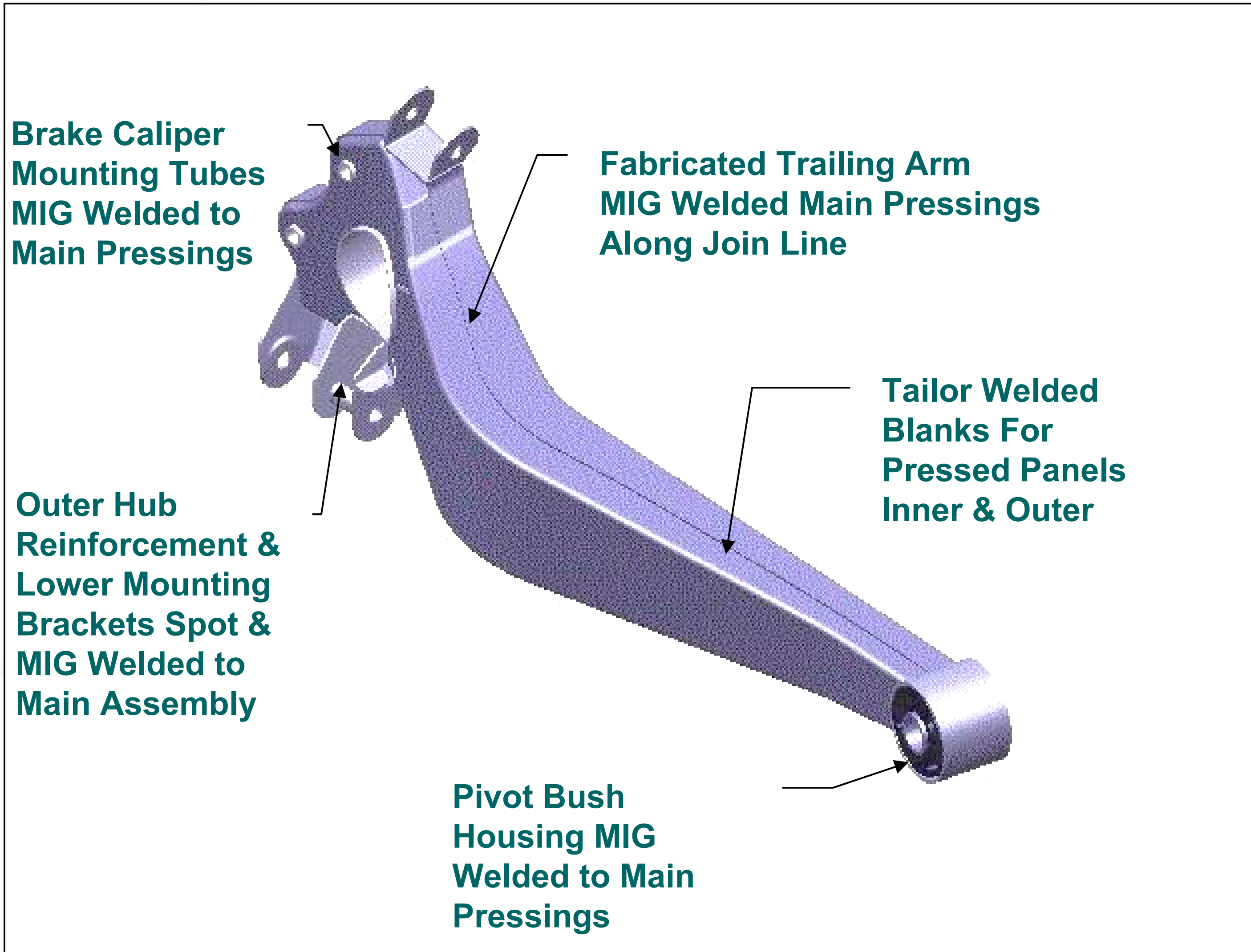
BREAKDOWN OF TIMING FOR FINAL ASSEMBLY OF LOTUS UNIQUE SUSPENSION TO THE VEHICLE

FINAL ASSEMBLY Operation	number	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
FIT TRAILING ARM BOLT	2	FITFN	0.07	0.04	0.11
FIX TRAILING ARM BOLT	2	TFPTN	0.11	0.07	0.18
FIT LOWER LATERAL BOLT	2	FITFN	0.07	0.04	0.11
FIX LOWER LATERAL NUT	2	TFPTN	0.11	0.07	0.18
FIT UPPER LATERAL BOLT	2	FITFN	0.07	0.04	0.11
FIX DAMPER NUT	4	TFPTN	0.11	0.21	0.32
				TOTAL	**1.01**

LOTUS UNIQUE: MANUFACTURING

Feasibility

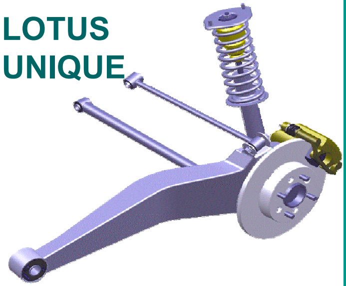




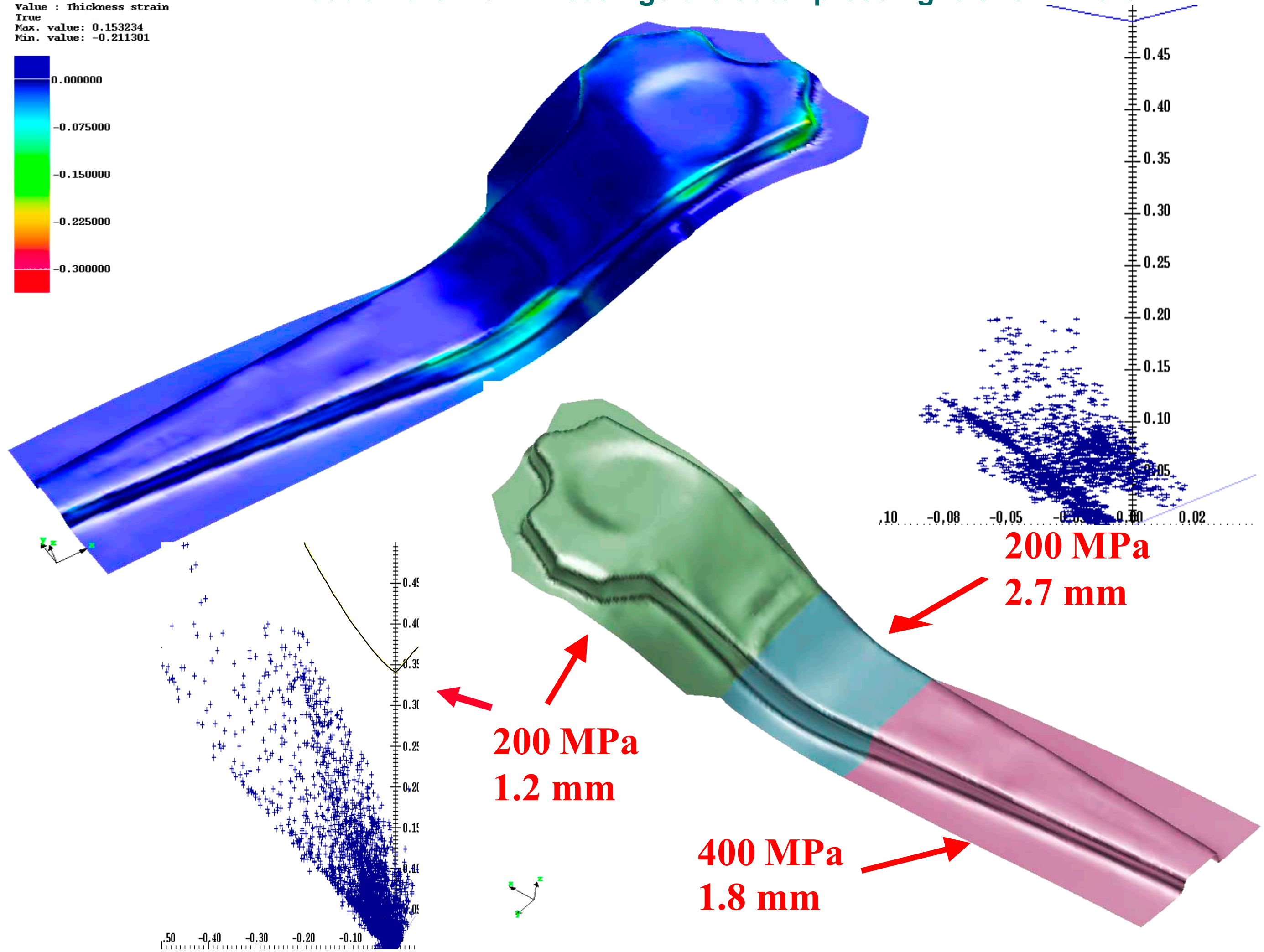
LOTUS UNIQUE: MANUFACTURING

Feasibility

LOTUS UNIQUE



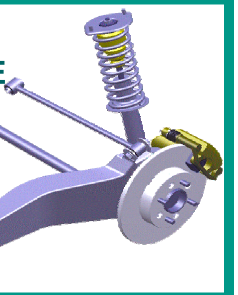
Trailing Arm :- Manufacturing Feasibility was carried out on the main Pressings the outer pressing is shown here.



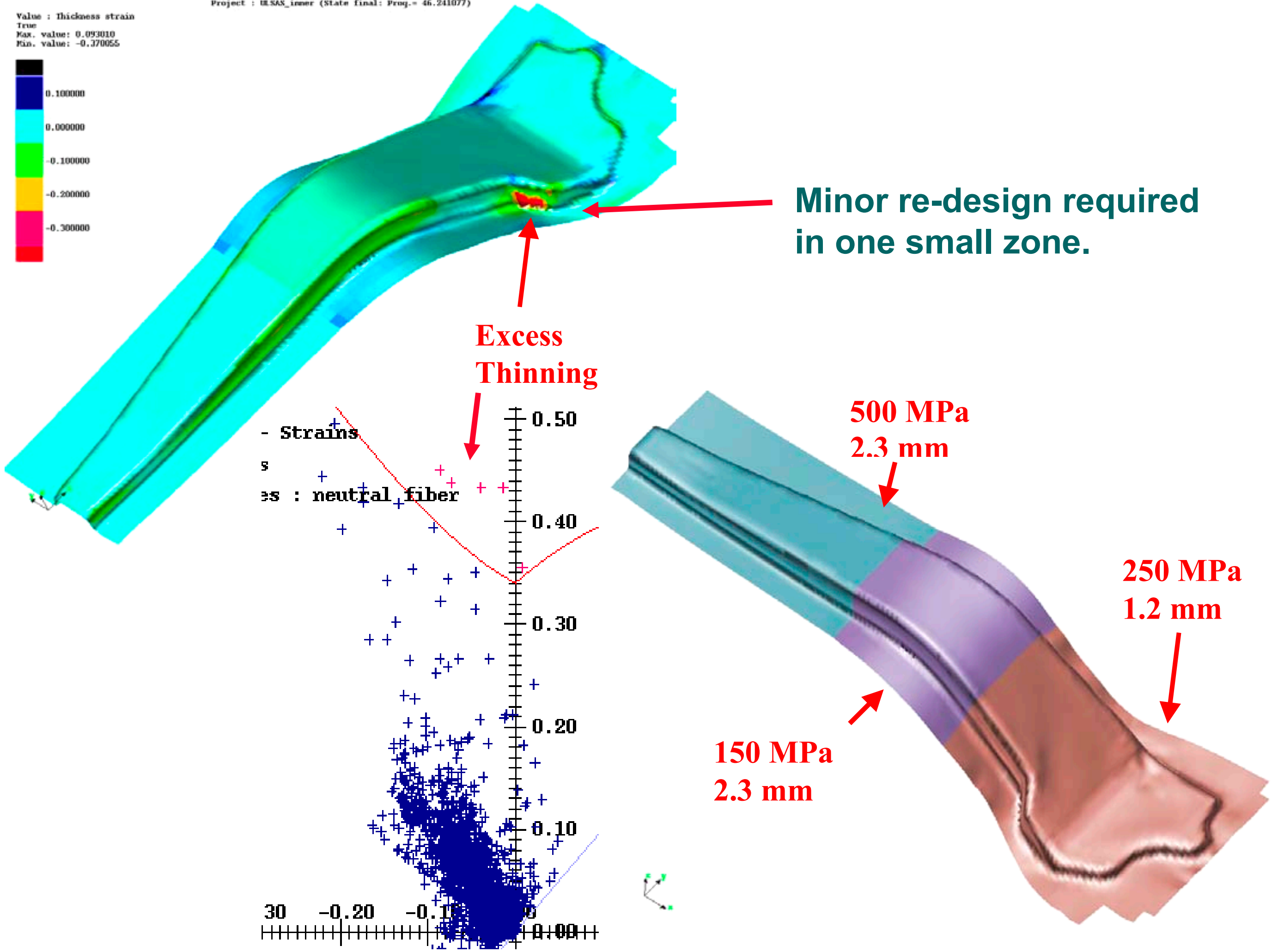
LOTUS UNIQUE: MANUFACTURING

Feasibility

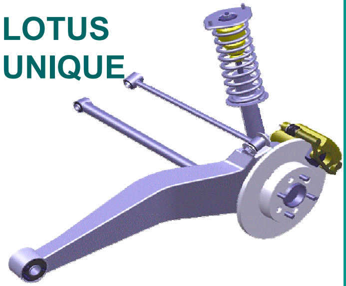
LOTUS UNIQUE



Trailing Arm :- Manufacturing Feasibility was carried out on the main Pressings



LOTUS
UNIQUE



LOTUS UNIQUE: MANUFACTURING APPROACH

ULSAS MANUFACTURING SUPPORT:

- **Manufacturing Feasibility**
- **Material Requirement Analysis**
- **Assembly Analysis**
- **Assembly Time Estimates for input into the Costing Analysis**
- **Consortium Member Input**

Throughout the ULSAS Programme the manufacturing implications of the designs were reviewed. Close liaison between the Lotus design team, manufacturing department and Consortium Members ensured the ULSAS systems are lightweight, safe, affordable and manufacturable.

Reviewing the manufacturing feasibility of the designs is an integral part of the iterative design process. This has resulted in a high level of confidence in the manufacturing feasibility of the ULSAS concept designs.

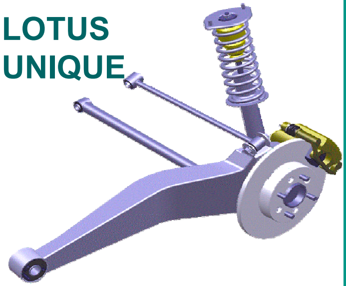
The material requirements of the components were reviewed on an individual basis throughout the design process. Where applicable, i.e. beneficial to mass or cost, high strength near reach materials have been incorporated. Combinations of high and extra high strength steel sheet and forging grades were considered to satisfy perfomance requirements.

The assembly processes and orders for each of the solutions has been considered throughout. This has resulted in estimation of the time taken to assemble the sub-assemblies, assemblies and the fixation to the vehicle. This data has been input into the costing analysis exercise.

Consortium members contributed by attending periodic design reviews and providing details of appropriate near reach materials and technologies. Additional support was available in the form of the latest manufacturing forming simulation techniques, a process utilised on several of the components.

LOTUS UNIQUE: MANUFACTURING APPROACH

LOTUS UNIQUE



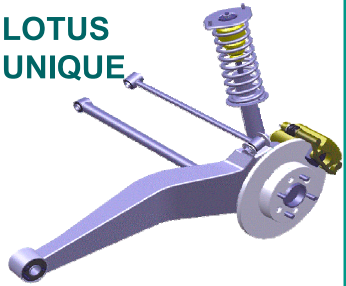
ULSAS MANUFACTURING PROCEDURE:

- **Manufacturing Component Feasibility**
- **Material Requirements**
- **Assembly**
- **Timing Study**
- **Welding**

Feasibility studies of pressed sheet, forged and fabricated components commenced at the earliest possible stage in the design loop and continued on a simultaneous basis throughout the design process. Detailed formability evaluation was carried out in conjunction with forming simulation analysis on selected parts to further enhance manufacturing input into component design. Simplification of component design was considered at all stages to aid ease of manufacture and reduce the associated tooling costs. This was done whilst avoiding, where possible, compromises to the components performance for example non-handed parts. Consideration was also given to commercial availability of grades and target volume requirements.

Detailed finite element analysis (FEA) techniques were used to validate part stiffness properties and structural integrity performance, which provided data to support material requirements, in terms of material properties for the components. Prior to FEA, an estimation of the applicable material properties was made to enable feasibility studies to commence. In addition to structural demands, each unique component was reviewed on an individual basis in order to consider manufacturing requirements based on the component design.

LOTUS UNIQUE



LOTUS UNIQUE: MANUFACTURING APPROACH

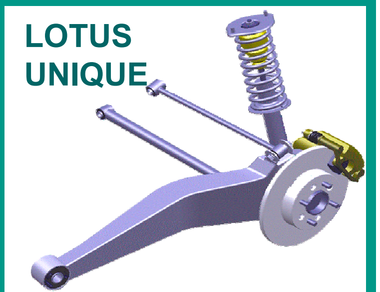
ULSAS MANUFACTURING PROCEDURE:

- **Manufacturing Component Feasibility**
- **Material Requirements**
- **Assembly**
- **Timing Study**
- **Welding**

Detailed drawings of the designs were studied both in hardcopy and on the CAD workstations. This formed the basis of the assembly analysis. The complex multi link system was subjected to a detailed assembly analysis using a industry recognised software package. This has the advantage of linking with the Catia generated design files to ensure assembly feasibility.

The timing study was carried out using the industry recognised manual assembly data manual assembly data system PMTS (Pre Determined Motion Time System). A manual system was used to ensure equality for comparison purposes. A more detailed procedure is available on the following page.

Welding feasibility studies were carried out in conjunction with The Welding Institute Cambridge, UK.



LOTUS UNIQUE: MANUFACTURING APPROACH
ULSAS TIMING STUDY ASSUMPTIONS

During assembly, the largest possible unit is fitted.

- **Torque sensing power tools utilised wherever possible.**
- **No confirmation actions such as paint marking are carried out.**
- **Bolts would be supplied complete with any washers required.**
- **For the fitting operation the unit or units are already lifted in place.**
- **The systems have been assembled on a single site.**
- **All parts and tools are ergonomically situated for optimum performance.**
- **Estimates are for total system including fitment of brakes and calipers.**

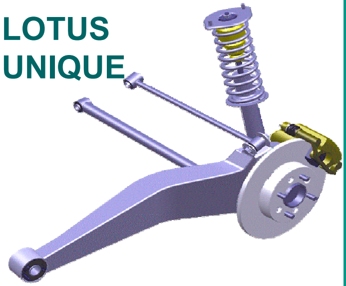
In order to make a labour cost analysis of the systems investigated and to compare this with the benchmarked systems, it was necessary to establish the time taken for fitting and sub assembly.

For the purposes of this investigation Lotus has chosen to use the Integrated Business Controls, Motor Industry Assembly Data system. This system was developed for quick estimating, particularly in pre-production or design office situations. IBC uses data blocks of work that can be described in simple terms, be easily recognised and counted with a known statistical variation. The IBC data blocks look at each individual operation as a whole. Therefore the times quoted include elements such as picking up parts and tools, aligning, fitting together and putting down any tools required.

In order to carry out this study the above assumptions, in common with those used on the benchmark vehicles, have been made.

LOTUS UNIQUE: MANUFACTURING APPROACH
ULSAS MATERIAL SELECTION ASSUMPTIONS

LOTUS UNIQUE



Sheet Grades

Sheet steel grades would be specified to meet the strength requirements as determined by CAE analysis. The nearest available grade with a strength level equal to or higher than the minimum requirement would need to be selected. Commercially available high strength grades would meet many of the requirements for high strength combined with good formability. There are a number of considerations when specifying appropriate sheet grades:

Allowance should be made on parts where springback/shape problems could be an issue following forming. Material influences such as gauge reduction and high yield requirements, in addition to geometrical influences such as open ended panel designs, can promote the susceptibility to panel shape loss through springback. Consideration of these influences should be included in material selection. For example, grades with a lower yield to UTS ratio for a given strength reduce the potential for springback.

Stretched flanges or holes require good edge ductility, an influence not only of the quality of cut edge, but also the edge forming characteristics of the material. Certain grades delivering equal strength can offer superior edge ductility.

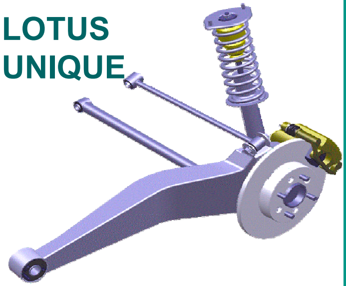
Weight reduction requirements dictate grades of thinner gauge offering high strength characteristics. A consequence of these extremes of grade is the current limited commercial availability. Opportunities exist for availability of such grades to be made more widespread, in line with promoting opportunities for near reach high and ultra-high strength grades.

Specific requirements and commercial availability should be discussed in detail with the appropriate Consortium Member Companies.

NB:All material strength requirements quoted are for minimum yield levels

LOTUS UNIQUE: MANUFACTURING APPROACH
ULSAS MATERIAL SELECTION ASSUMPTIONS

LOTUS UNIQUE



Tube Grades

Tube steel grades would be specified to meet the strength requirements as determined by CAE analysis. The nearest available grade with a strength level equal to or higher than the minimum requirement would need to be selected. Commercially available high strength grades would meet many of the requirements for high strength and good weldability. Specification of appropriate tube grades would be as follows:

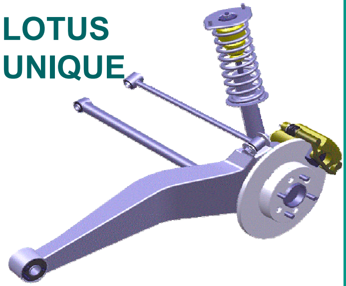
-Tube requirements would primarily be met with conventional welded tube.
-Extreme requirements for combinations of high gauge/small diameters may need to be specified as cold drawn tube.

Specific requirements and commercial availability should be discussed in detail with the appropriate steel supplier(s).

NB: All material strength requirements quoted are for minimum yield level

LOTUS UNIQUE: MANUFACTURING APPROACH
ULSAS MATERIAL SELECTION ASSUMPTIONS

LOTUS UNIQUE



Forging Grades

Forging grades would be specified to meet the strength requirements as determined by CAE analysis. The nearest available grade with a strength level equal to or higher than the minimum requirement would need to be selected. There are a number of considerations when specifying appropriate forging grades:

-Air cooled forging grades are preferable through elimination of secondary heat treatment operations for lower strength requirements.
-The associated increase in carbon content for the higher strength grades could cause weldability issues. Preheat and possibly post weld heat treatment of the components following welding could be carried out in order to achieve higher strength levels, but would be unacceptable on the basis of the volume requirements for these parts.
-Strength levels can vary with the section size of the individual forged components.

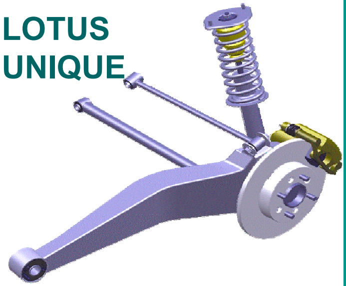
There is ongoing research on air cooled forging steels in the steel industry to offer grades to meet higher strength requirements, while maintaining a lower carbon content to avoid the need for pre/post weld heat treatment.

There is a specific requirement for a high strength forging grade with a minimum yield >750MPa, for the Multi Link configuration. Heat treatment following forging would be required to obtain this strength level. However, for production purposes, it is favourable to avoid post operations such as heat treating. Unfortunately, air cooled grades are not currently commercially available to meet these high strength requirements, signalling a real opportunity for grades of this type to be developed to meet customer needs in the longer term.

These issues would need to be investigated further at the detailed design stage with trials being carried out where necessary to validate fully. All requirements should be discussed in detail with the appropriate steel supplier(s).

LOTUS UNIQUE: MANUFACTURING APPROACH
ULSAS MATERIALCOATING ASSUMPTIONS

LOTUS UNIQUE



Coating/Corrosion Considerations

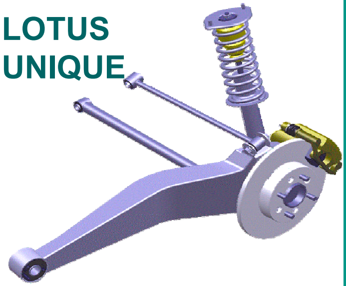
Opportunities exist for extensive use of pre-zinc coated steels. Coated steels will help to meet warranty requirements and place less reliance on protection offered by secondary coatings. Further weight/cost savings may be achieved through avoidance of wax injecting and/or the use of thinner additional coatings.

Organic coating methods such as Electrocoating, are commonly applied to provide a barrier against corrosion. Internal coating of the assembly would require access holes for the in-flow and out-flow of the fluid. The addition of tooling holes (added at the detailed design stage) could also benefit the coating process.

Clearly the type and level of corrosion protection required would be dictated by the manufacturers own corrosion requirements. Allowance for the type and method of corrosion protection to be employed would need to be considered at the detailed design stage.

LOTUS UNIQUE: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS

LOTUS UNIQUE



Laser Welding/Trimming

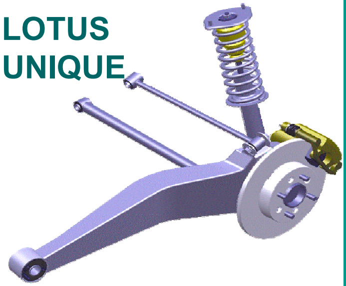
Edge Welding Panels/Blanks
Edge or butt laser welding requires very close control of gap and offset tolerances. As a guide, the requirement for welding panels is as follows (assuming 2mm gauge material):

Offset tolerance 1mm max
Gap tolerance 0.2mm max.

Control to these tolerances when welding together finished panels in volume production is difficult, particularly with application of thinner high strength grades were shape/springback issues increase dimensional inconsistency of parts. It is recommended that MIG welding be used as an alternative for joining butt edges in these instances where appropriate.

Laser welding of sheet/blanks is a well-developed technology, where significantly tighter offset tolerances can be achieved providing accurate edge treatment is carried out prior to welding.

LOTUS UNIQUE: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS



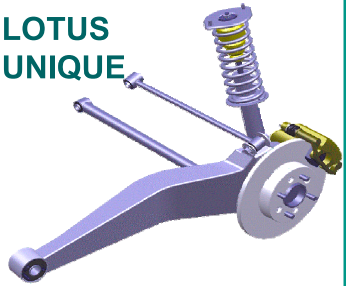
Flange/Lap Welding

Through wall lap welding from one side can be achieved on flanges. Welding can occur just off the radius of the flange where two flat surfaces can be guaranteed. A weld width of 1.0 to 1.5mm should be deposited onto the flange. A gap tolerance between the laps of 0.2mm maximum can be tolerated and is ordinarily achieved by clamping the flange during welding. It is possible to increase this tolerance through the use of feed wire, but this would be at the expense of welding speed and mass. Gauge limitations for laser lap welding are well in excess of normal automotive gauge requirements.

The size of flange is primarily a clamping requirement as opposed to a welding limitation. The force/area required to maintain a flat area within the aforementioned 0.2mm max. tolerance would need to be determined. The required flange width may fall inside that conventionally required for spot welding to the advantage of weight reduction, although trial work would be required to validate this (laser trimming the flange back to the weld would reduce the flange size further - see following passage). This method is further limited by the geometrical design of the component and allowing access for clamp tooling.

LOTUS UNIQUE: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS

LOTUS UNIQUE



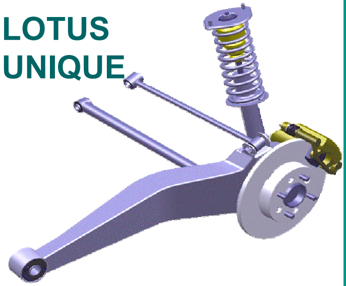
Panel Trimming

Laser trimming of panels is primarily suited to low volume production. However, laser welding offers the design flexibility of producing complex trim conditions and reducing flange sizes. The type of robot (3 or 5-axis) would be determined by the complexity of the trim conditions on the panel designs. A trimmed flange width of 1.5 to 2mm beyond the radius may be achievable, allowing a significant reduction in flange width over that required for conventional spot welding. However, the addition of a laser trim would ultimately come at the expense of higher initial investment, and more significantly, the addition of an extra stage in the process.

Industry studies suggest that significant cost penalties will be associated with this route over more conventional trimming methods. Consideration should be given to the fact that most fabricators do not already possess a laser facility to deal with the projected volumes. It is likely that several laser booths would be required to maintain production throughput on high volume parts. A dedicated automated facility would cater more effectively for high volumes. A detailed study would need to be carried out by the manufacturer to consider investment needs relating to specific manufacturing requirements to assess the overall viability.

LOTUS UNIQUE: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS

LOTUS UNIQUE



MIG Welding

MIG welding with the associated filler requires control of gap and offset tolerances within the following limits (assuming 2mm gauge material):

Offset tolerance is 2mm max
Gap tolerance is 2mm max.
(Total offset and gap tolerances together should not exceed 2mm - i.e. 1mm offset and 1mm gap tolerance is acceptable or any variation as long as the total remains at 2mm or below)

Welding rates for MIG are approximately 0.75 to 1.2m/min, depending on the thickness of the material being welded. Distortion created by welding due to the greater heat input over spot and laser weld is a consideration, particularly where dimensional control is critical. Trials may need to be carried out to fully validate implications.

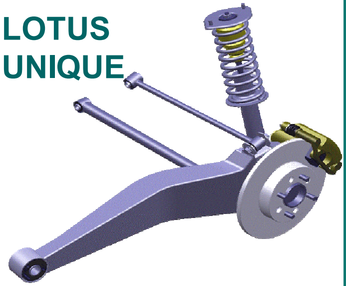
Spot-Welding/Flange Welding

A minimum flange width (typically around 16mm) is required to allow electrode access. Wide variations in gauge thicknesses can be tolerated with spot welding. Ratios of 3:1 are typically used.

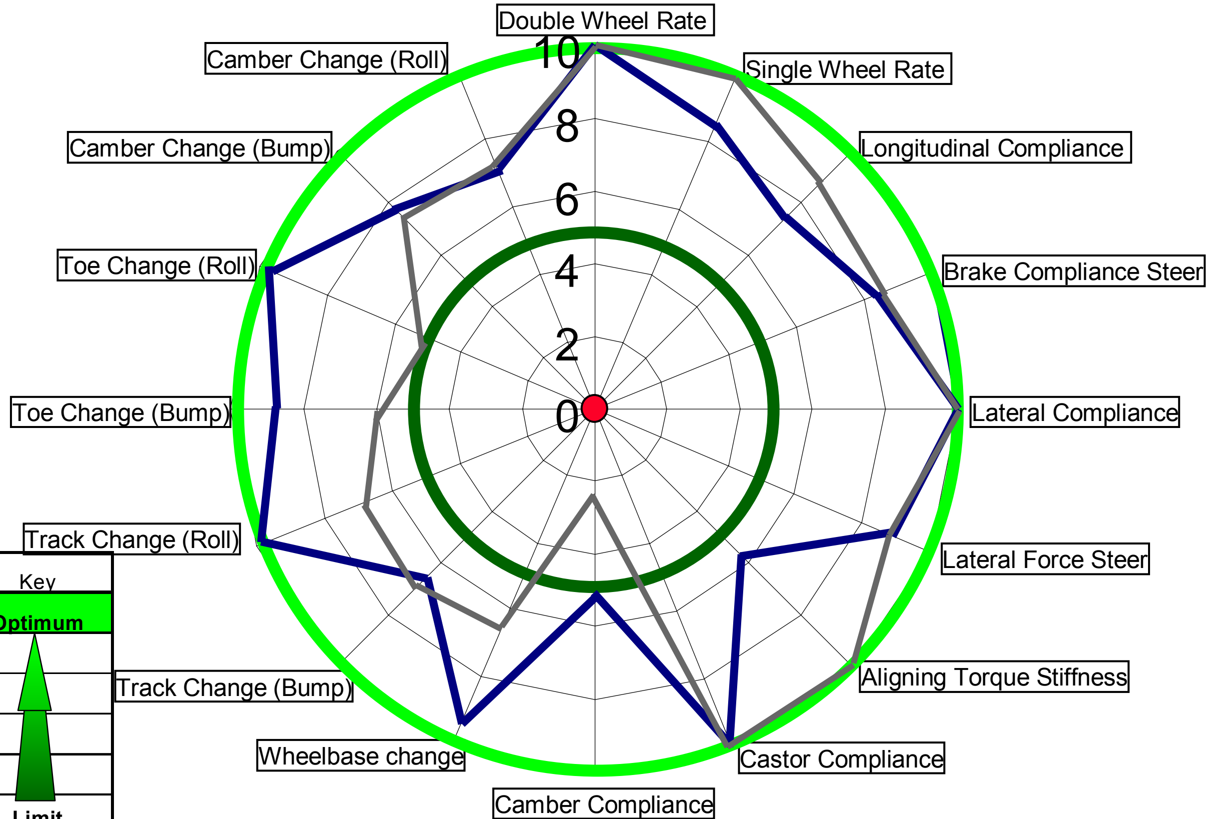
Please note: Welding feasibility studies were carried out in conjunction with The Welding Institute, Cambridge, UK.

LOTUS UNIQUE: Performance

LOTUS UNIQUE



LOTUS UNIQUE SYSTEM PERFORMANCE RATING Vs TARGETS



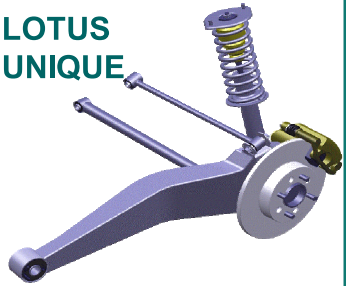
Rating	Key
10	Optimum
9	
8	
7	
6	
5	Limit
4	
3	
2	
1	
0	Unacceptable

- Target Level
- Optimum
- ULSAS D & P Class
- Benchmark D Class Double Wishbone

STEEL AUTO SUSPENSION

ULSAS CAE DYNAMICS APPROACH

LOTUS UNIQUE



Mechanical Dynamics Industries ADAMS software.

- System structural components represented as rigid elements.
- Compliant joints represented by ADAMS Bushing statements.
- Ball joints represented by ADAMS Spherical Joint statements.
- Wheel bearing and strut bending compliances were represented using ADAMS Bushing statements.

The suspension geometries for the ULSAS programme suspensions were developed using Mechanical Dynamics Industries ADAMS software, version 9.1.

System structural components (links, arms, hub carriers, etc.) were represented as rigid elements. Compliant joints (bushes) were represented by ADAMS BUSHING statements.

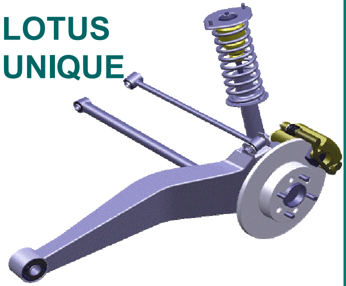
Ball joints were represented by ADAMS SPHERICAL JOINT statements.

Wheel bearing, and where appropriate, strut bending compliances were represented using ADAMS BUSHING statements.

ULTRALIGHT STEEL AUTO SUSPENSION

ULSAS CAE DYNAMICS APPROACH

LOTUS UNIQUE



The models were used to:

- Generate the kinematic characteristics of the suspensions with respect to vertical wheel displacement.
- Establish the contribution of non-structural components of the system to overall system compliance characteristics.
- The system geometry and compliant joint stiffnesses were carefully tuned to obtain a solution which satisfied the programme kinematic and compliance targets.

Analysis results were subsequently converted to predicted ratings (0 to 10) using Lotus in-house algorithms.

The models were used to generate the kinematic characteristics of the suspensions with respect to vertical wheel displacement, and to establish the contribution of non-structural components of the system to overall system compliance characteristics with respect to lateral and longitudinal forces applied at the tyre contact patch centre, and torque applied about a vertical axis through the tyre contact patch centre.

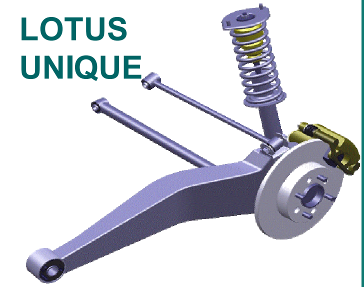
The system geometry and compliant joint stiffnesses were varied to obtain a solution which satisfied the kinematic and compliance targets generated by the target setting process.

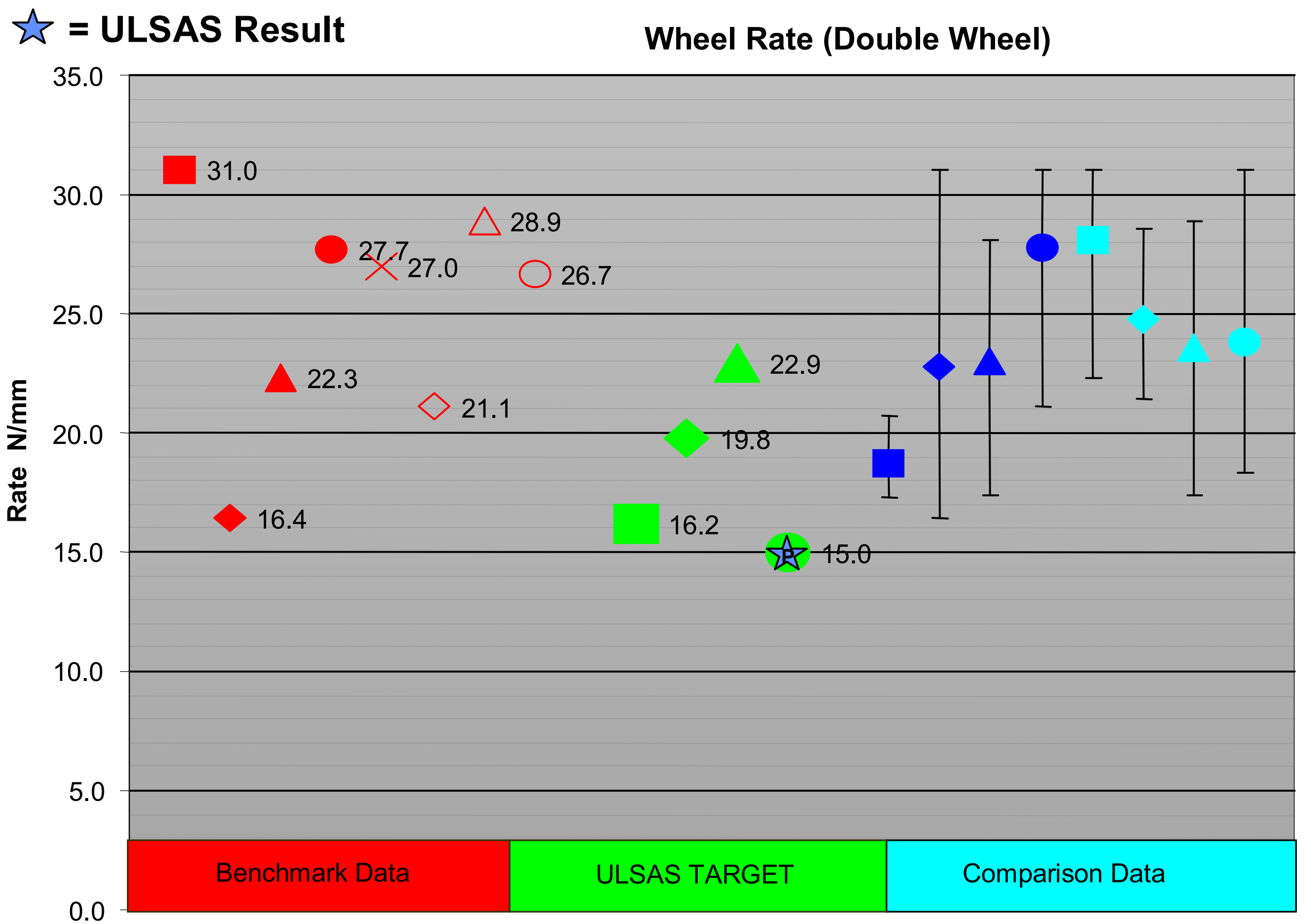
Potential NVH ratings were estimated from the models by considering the relationship between bush stiffnesses, component stiffnesses and body mounting point stiffnesses and positions.

STEEL AUTO SUSPENSION

LOTUS UNIQUE: Performance

LOTUS UNIQUE



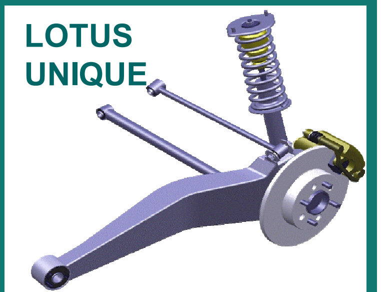


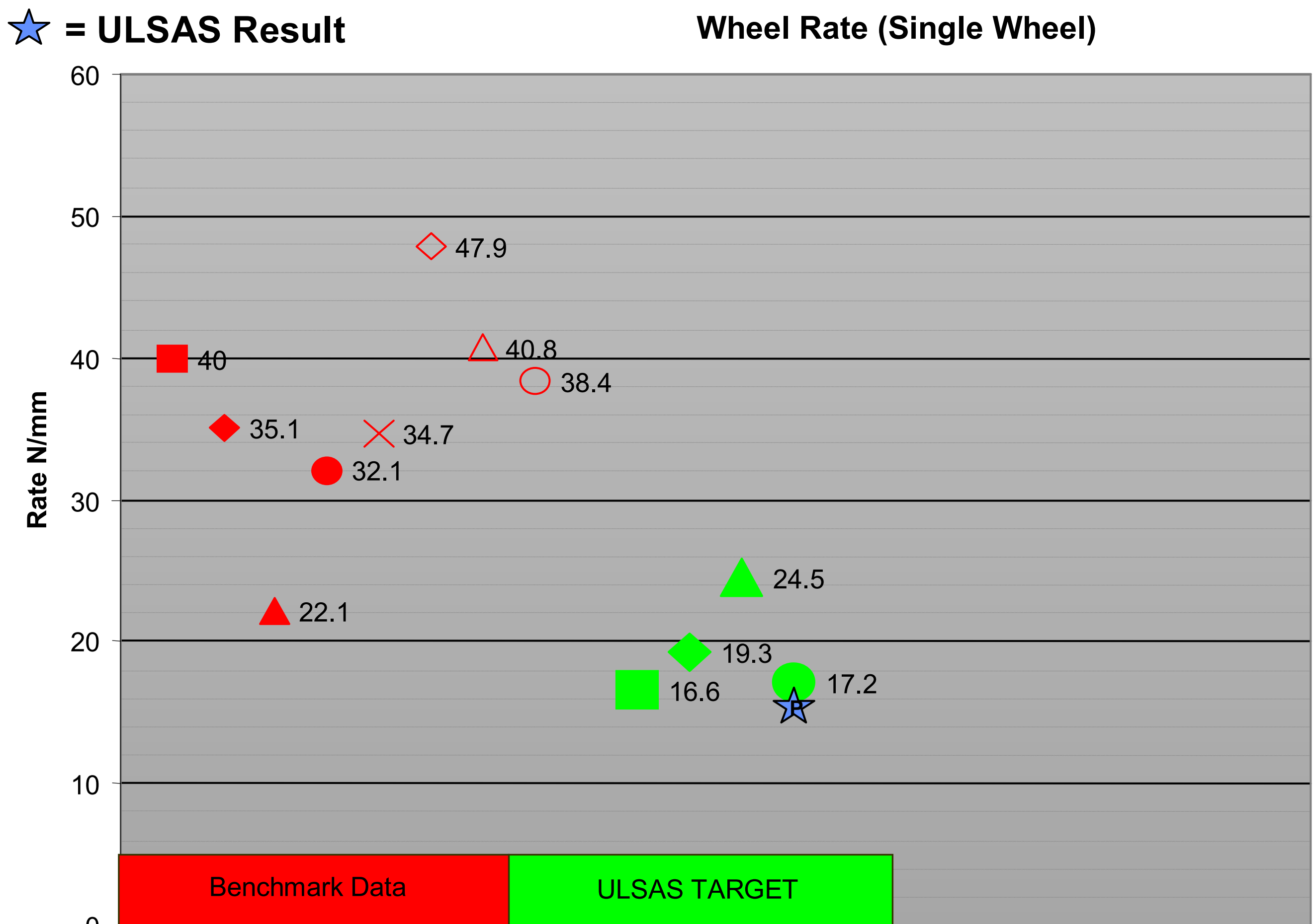
Comments:

Wheel rates have exactly matched targets by a combination of spring design and suspension parasitic rate. The rate for single wheel bump will be the same as for double wheel bump in this independent system.

LOTUS UNIQUE: Performance

LOTUS UNIQUE



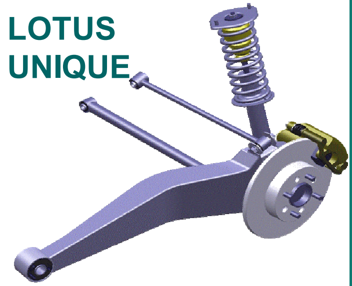


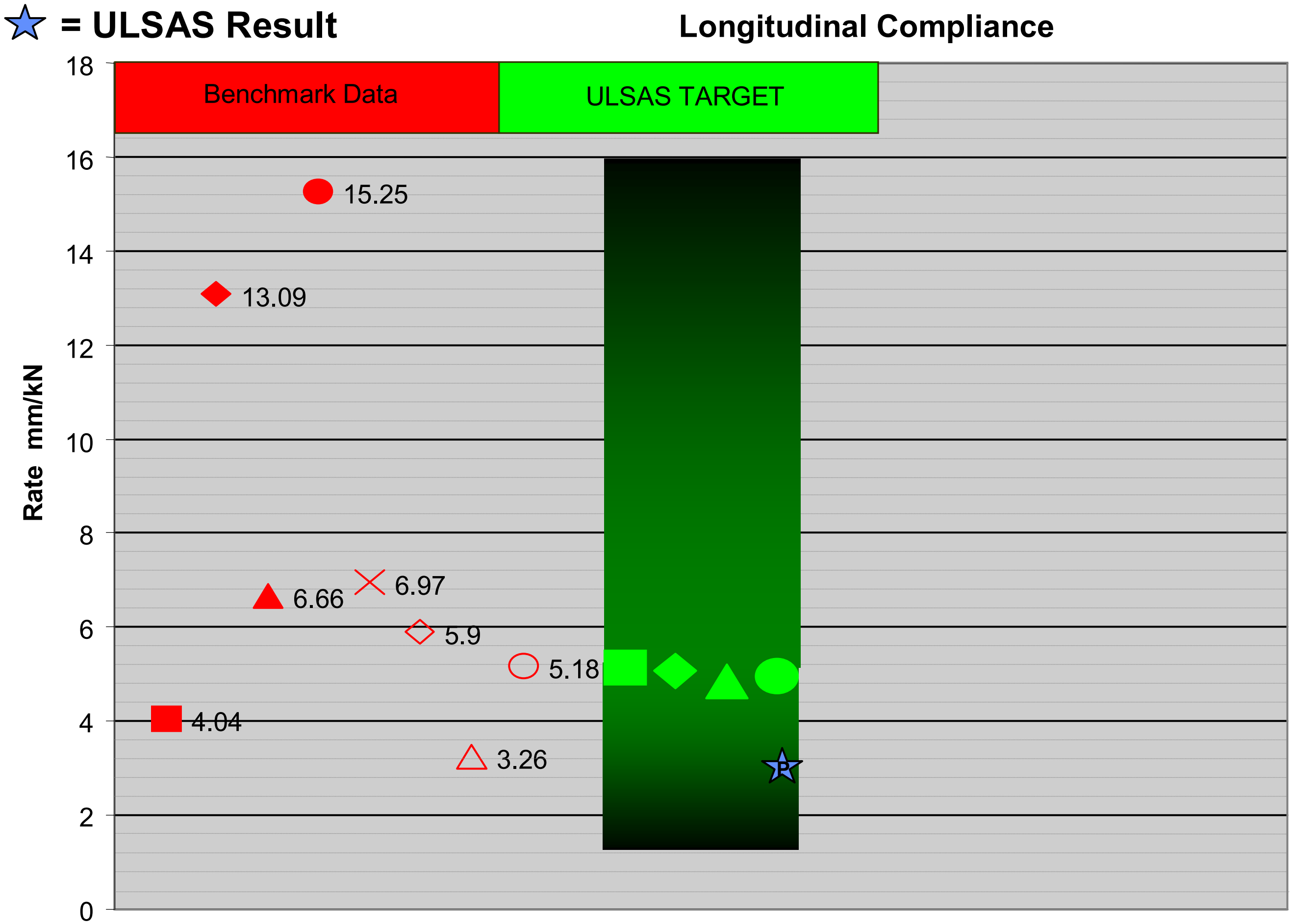
Comments:

Single wheel rate is slightly low therefore an additional anti-roll bar may be required. The additional rate however is fairly small and so many manufacturers would not add an anti-roll bar for reasons of cost and weight whilst others may add one for the purpose of giving some vehicle characterisation.

LOTUS UNIQUE: Performance

LOTUS UNIQUE



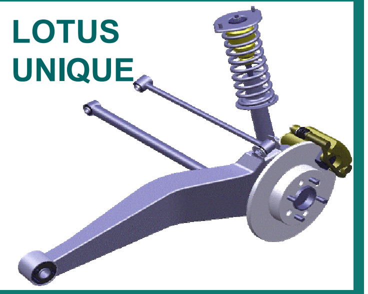


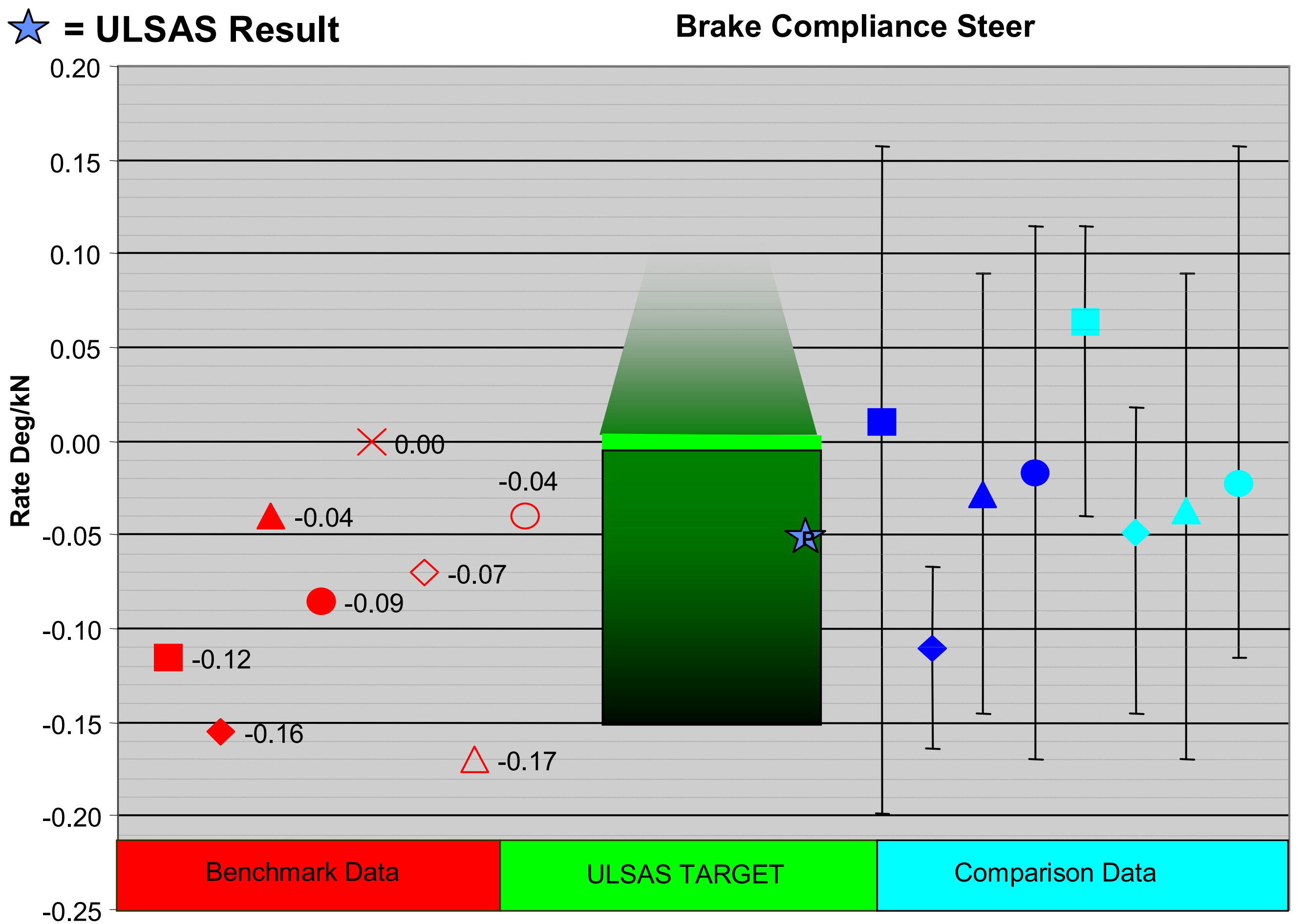
Comments:

The longitudinal compliance achieved is reasonable compared to the target value.

LOTUS UNIQUE: Performance

LOTUS UNIQUE

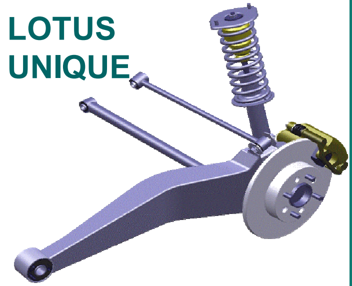


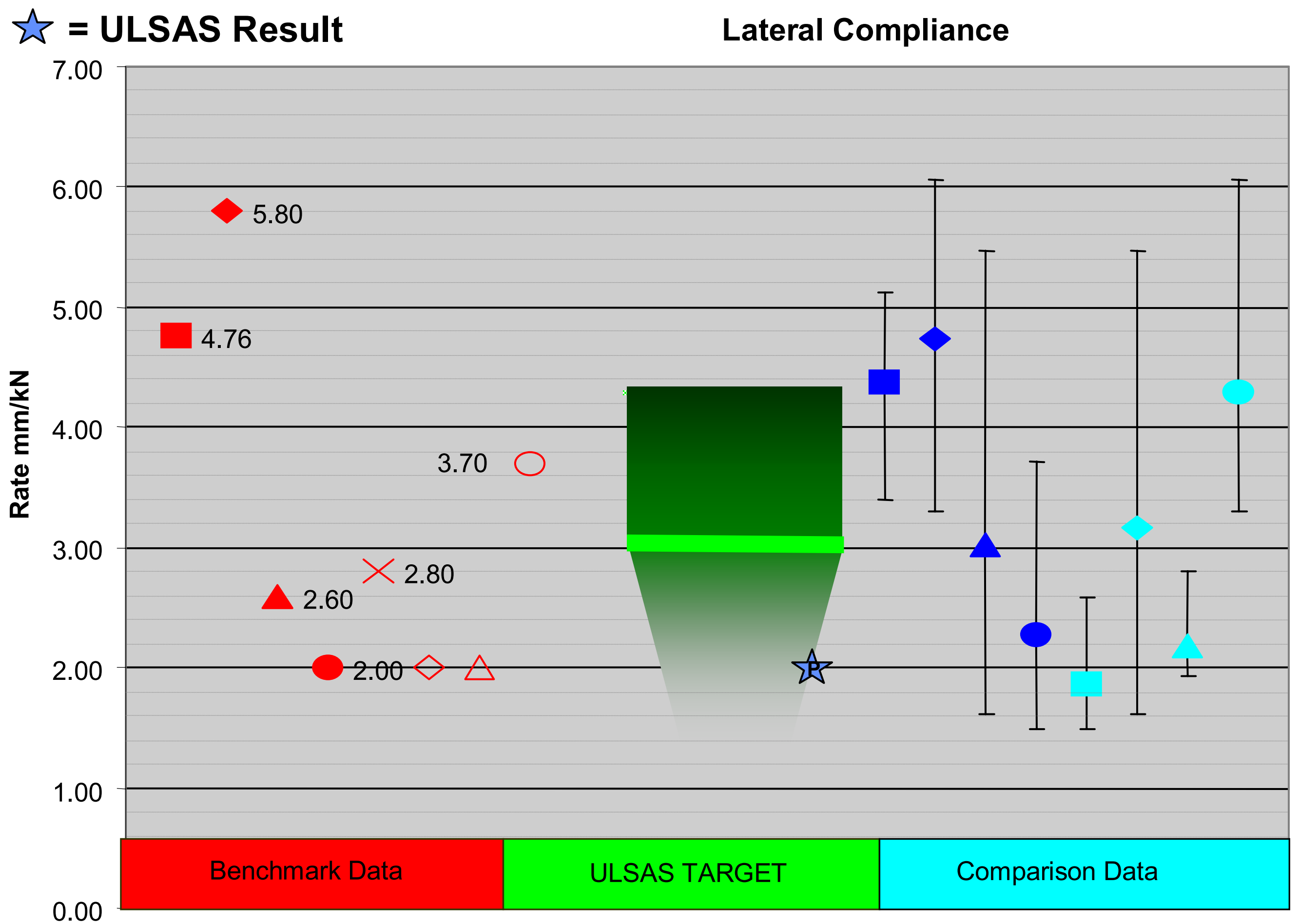


Comments:
A good level of control has been achieved. The final result whilst not ideal, is comparable to the benchmark vehicles.

LOTUS UNIQUE: Performance

LOTUS UNIQUE



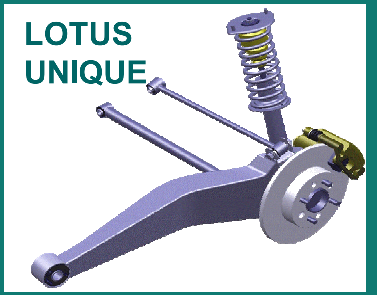


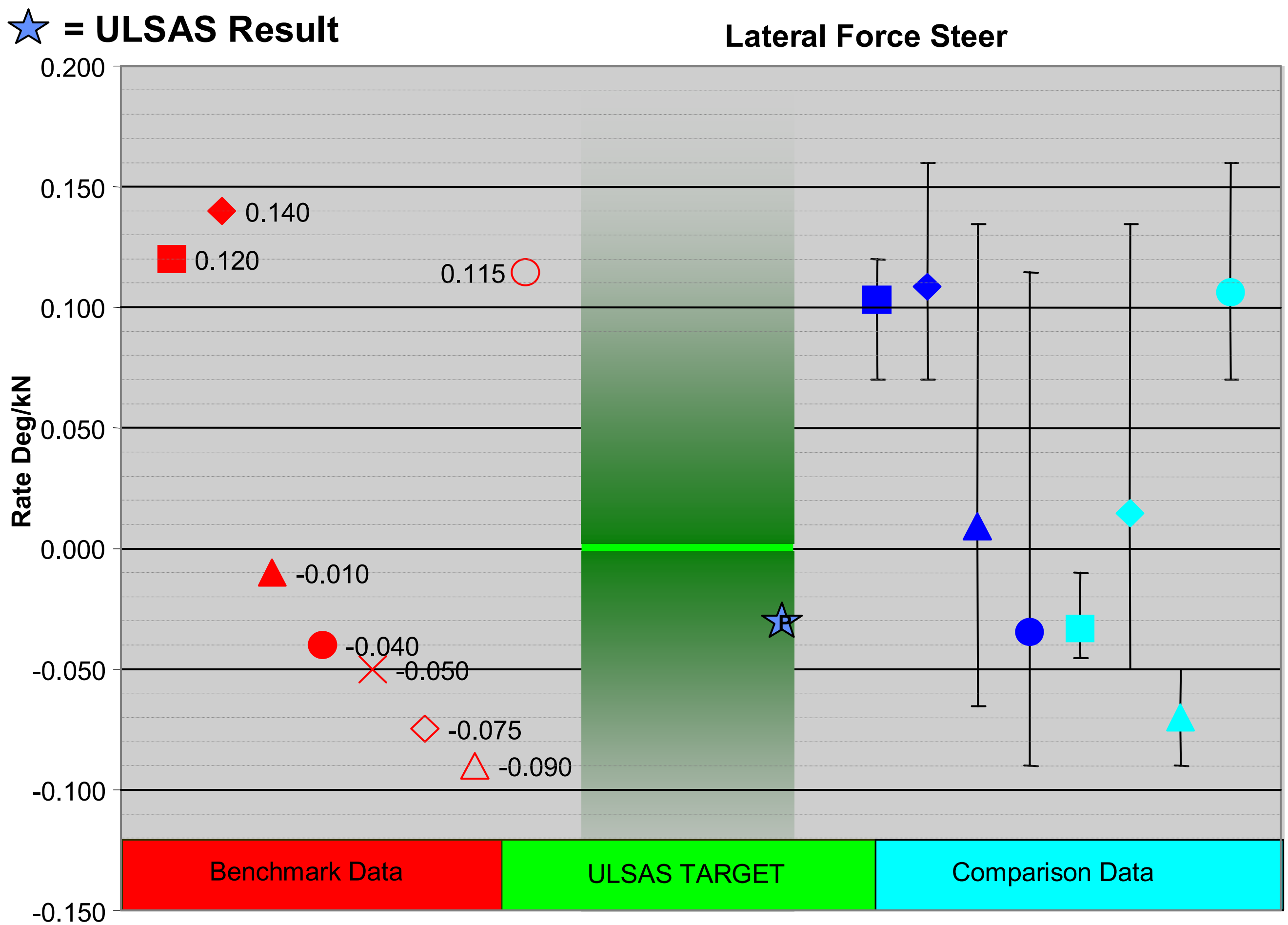
Comments:

Good control has been achieved with a level which exceeds the target value.

LOTUS UNIQUE: Performance

LOTUS UNIQUE

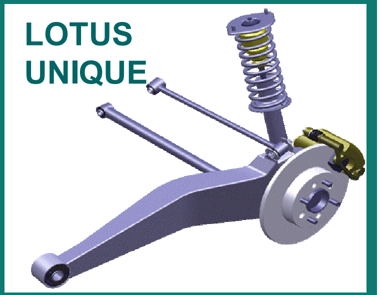


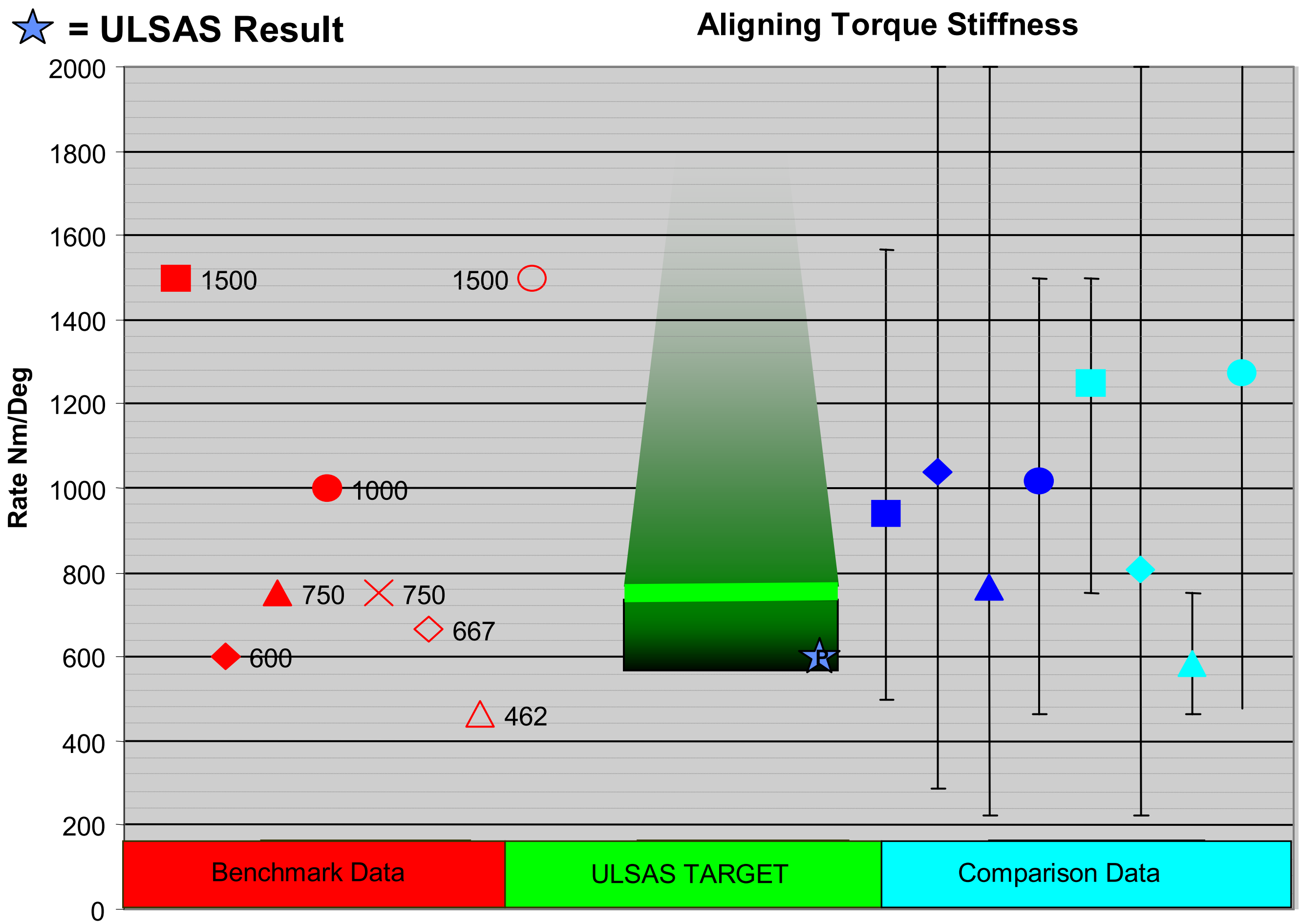


Comments:
Good control has been achieved close to the ideal value.

LOTUS UNIQUE: Performance

LOTUS UNIQUE



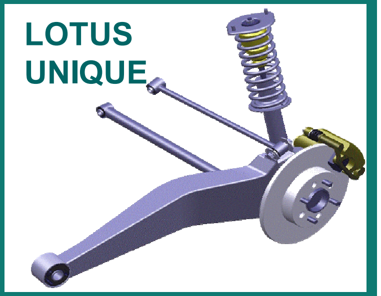


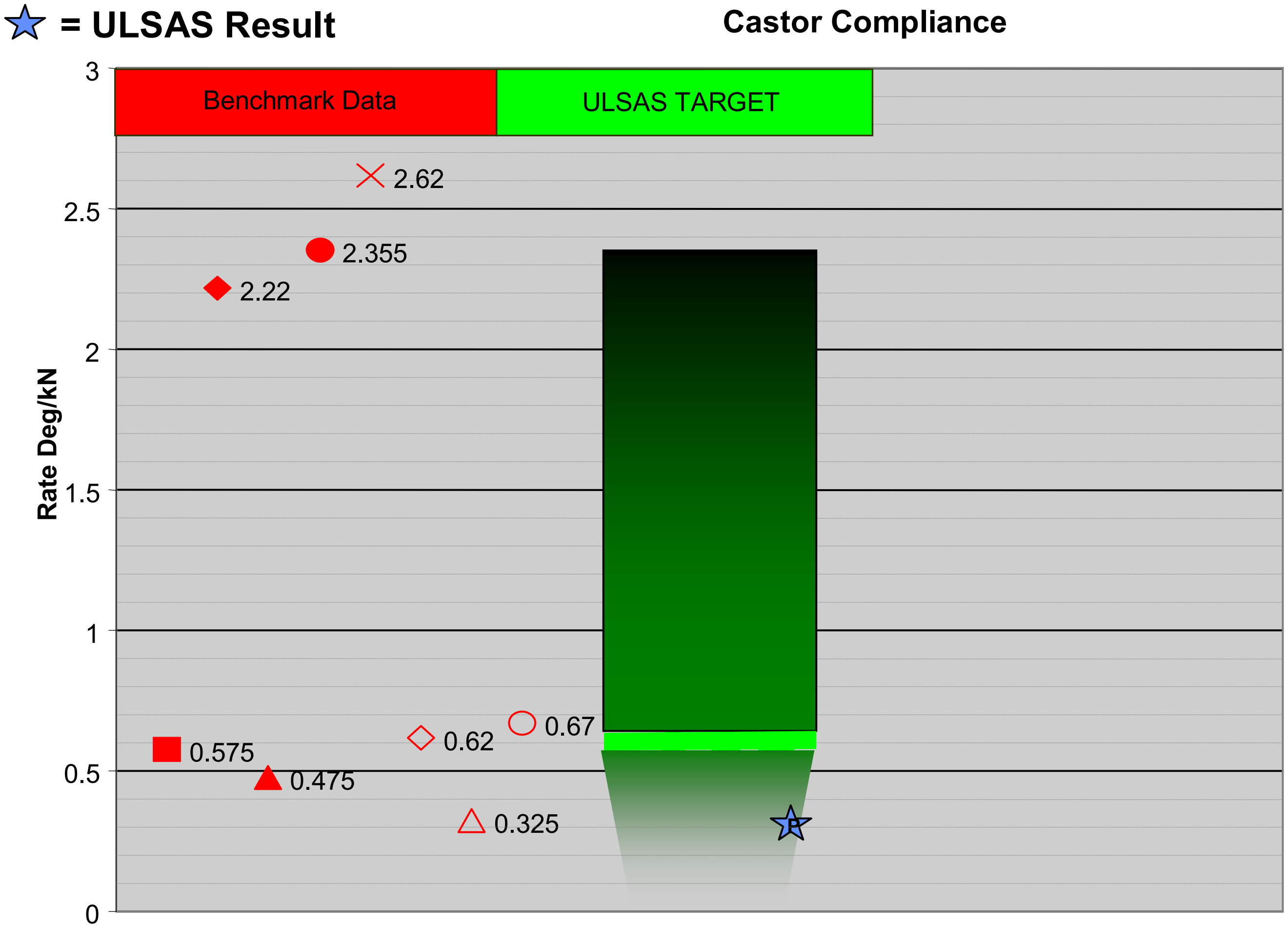
Comments:

The level of stiffness achieved is within the target range for Aligning Torque Stiffness

LOTUS UNIQUE: Performance

LOTUS UNIQUE

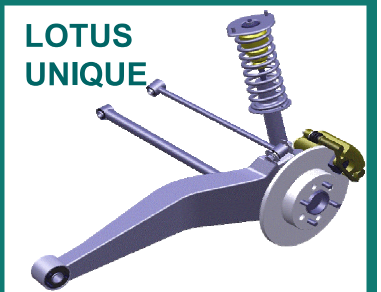


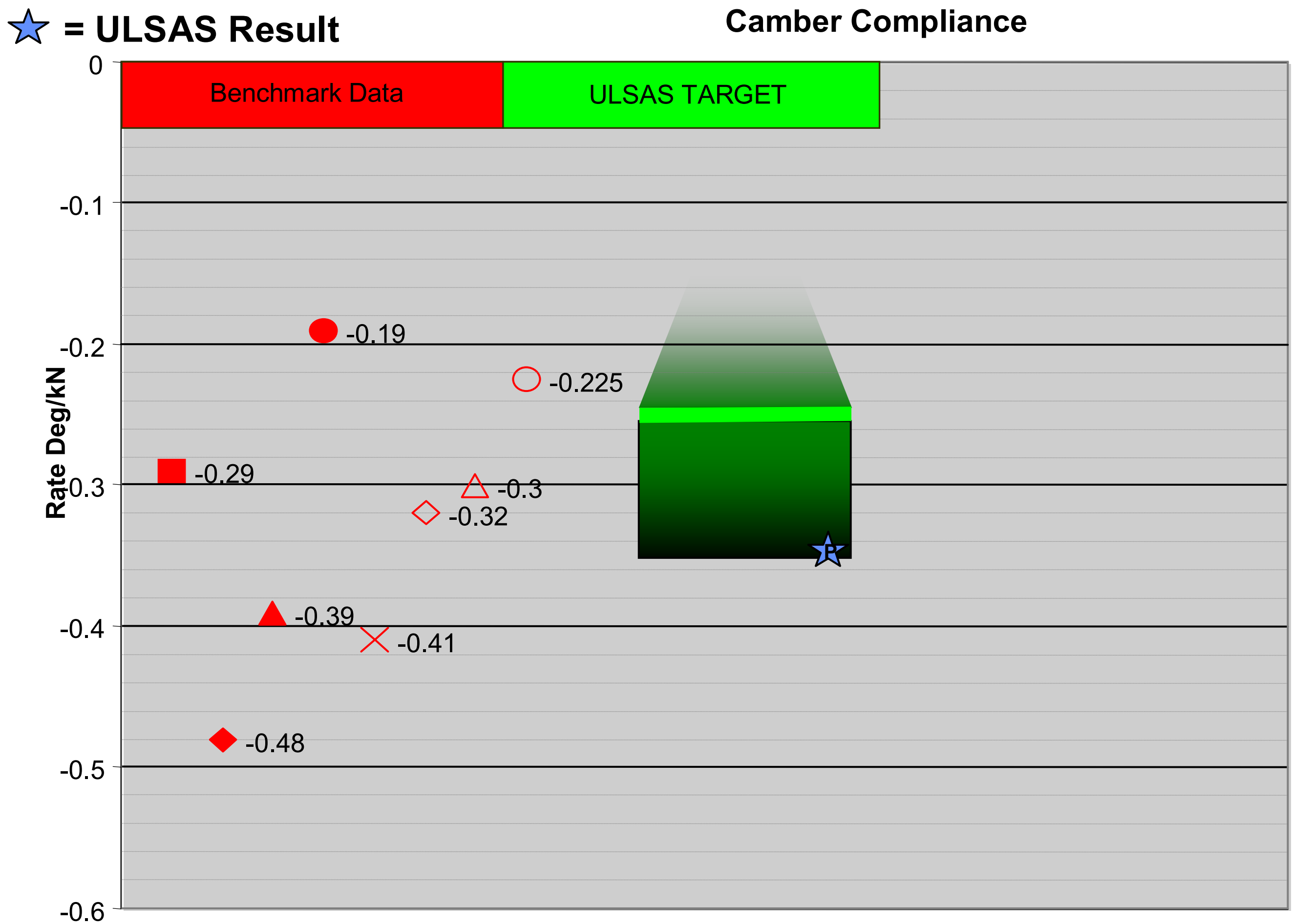


Comments:
The target rate is exceeded by the ULSAS Lotus Unique design.

LOTUS UNIQUE: Performance

LOTUS UNIQUE

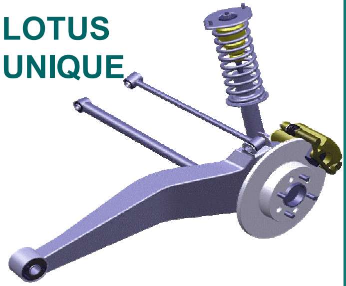


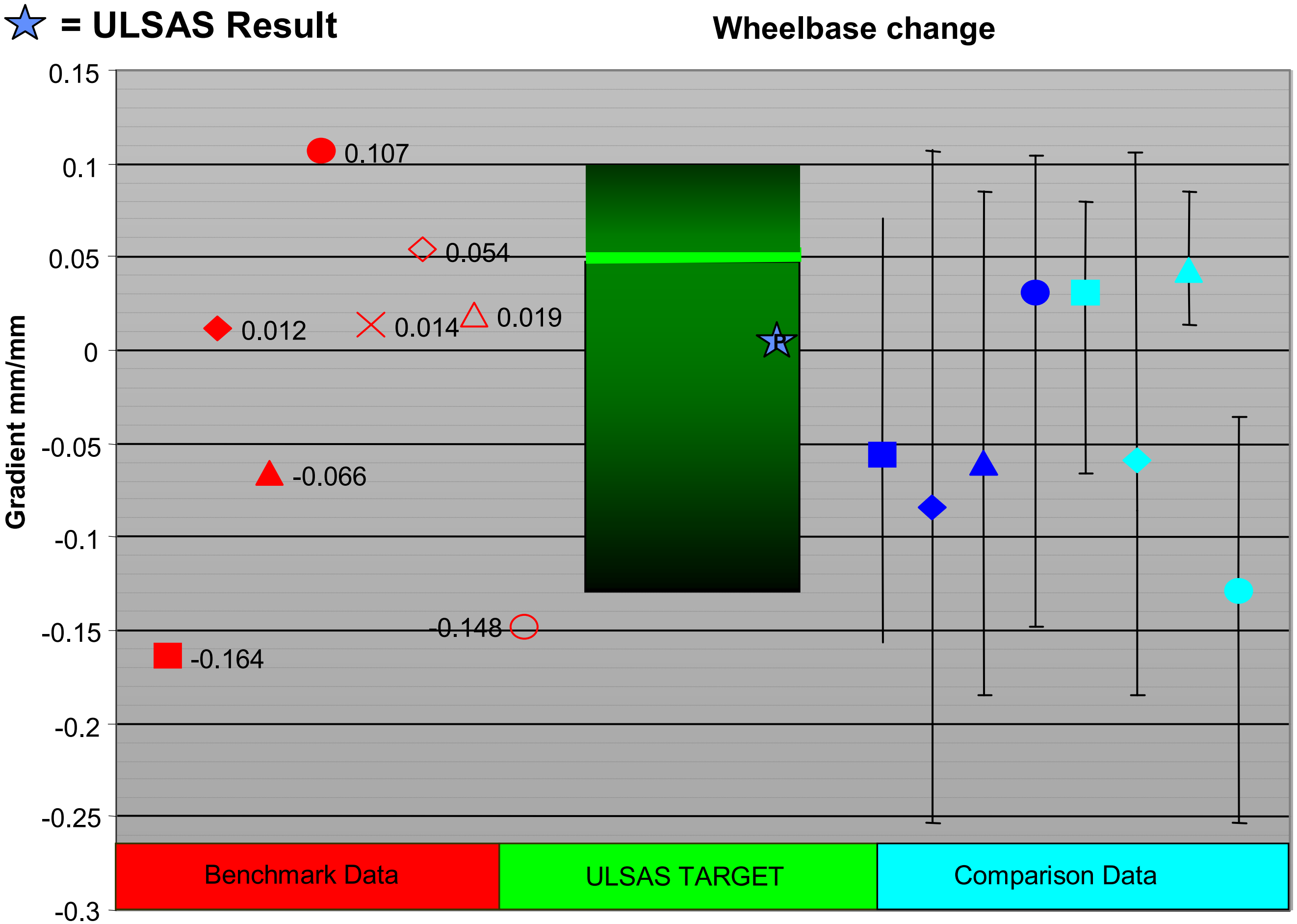


Comments:
Sufficient Camber stiffness has been achieved, within the required tolerance bands.

LOTUS UNIQUE: Performance

LOTUS UNIQUE





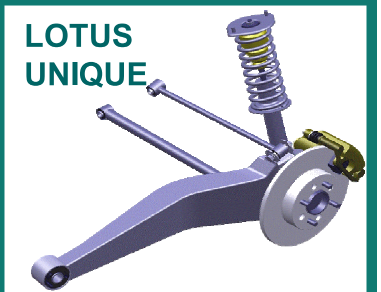
Comments:

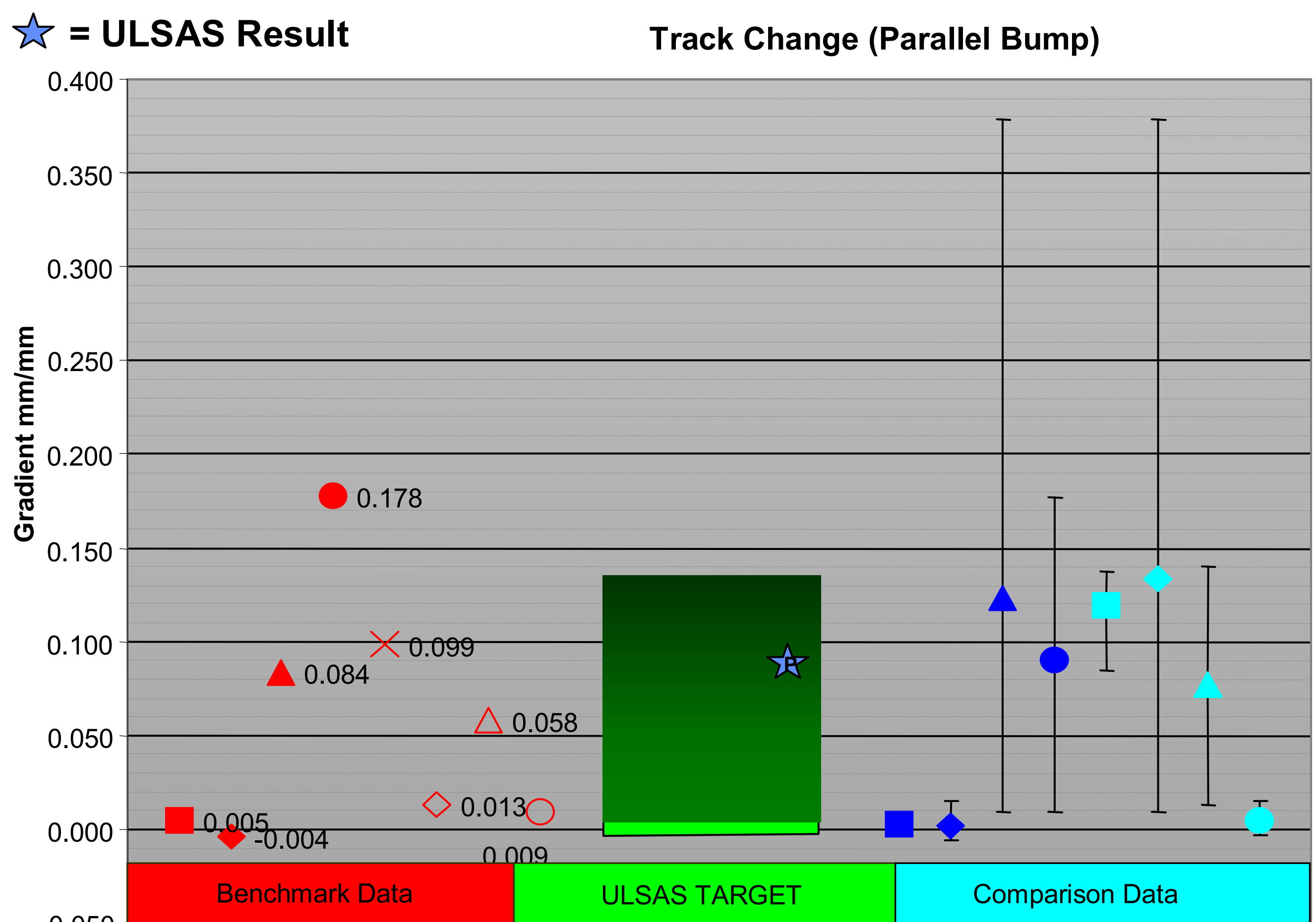
Good characteristics have been achieved close to the ideal targets which will help maximise ride quality.

STEEL AUTO SUSPENSION

LOTUS UNIQUE: Performance

LOTUS UNIQUE



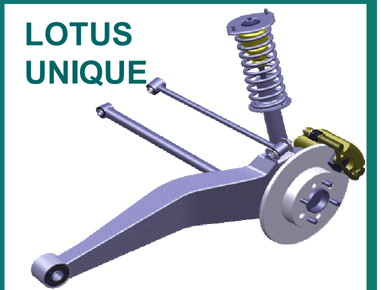


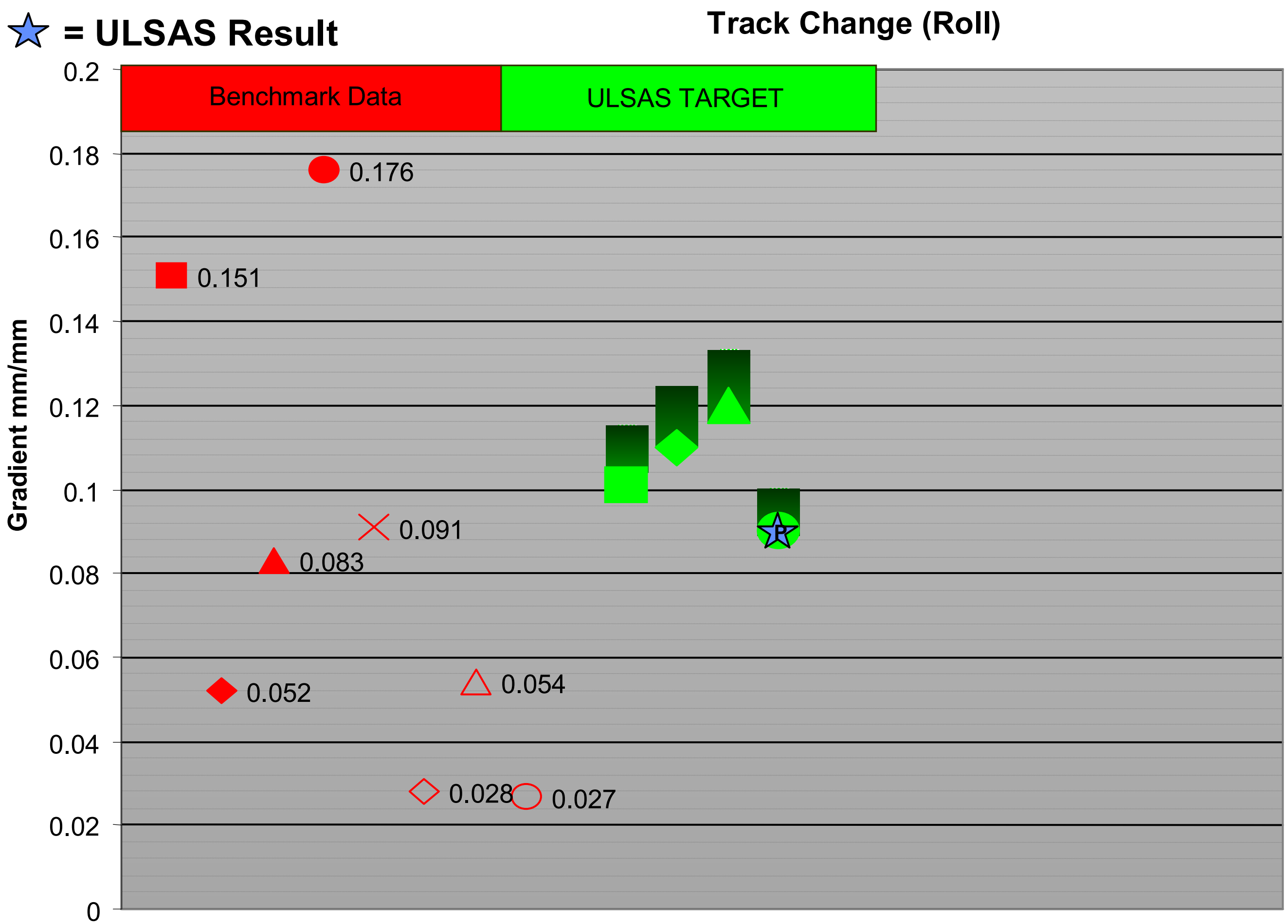
Comments:
Control of track in parallel bump is the same as in roll for the Lotus Unique system. The level achieved is within the required tolerance.

STEEL AUTO SUSPENSION

LOTUS UNIQUE: Performance

LOTUS UNIQUE





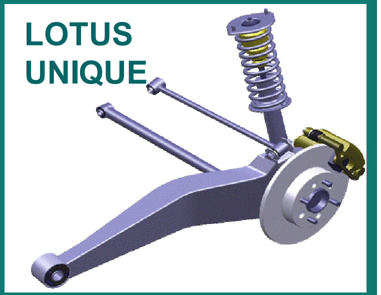
Comments:

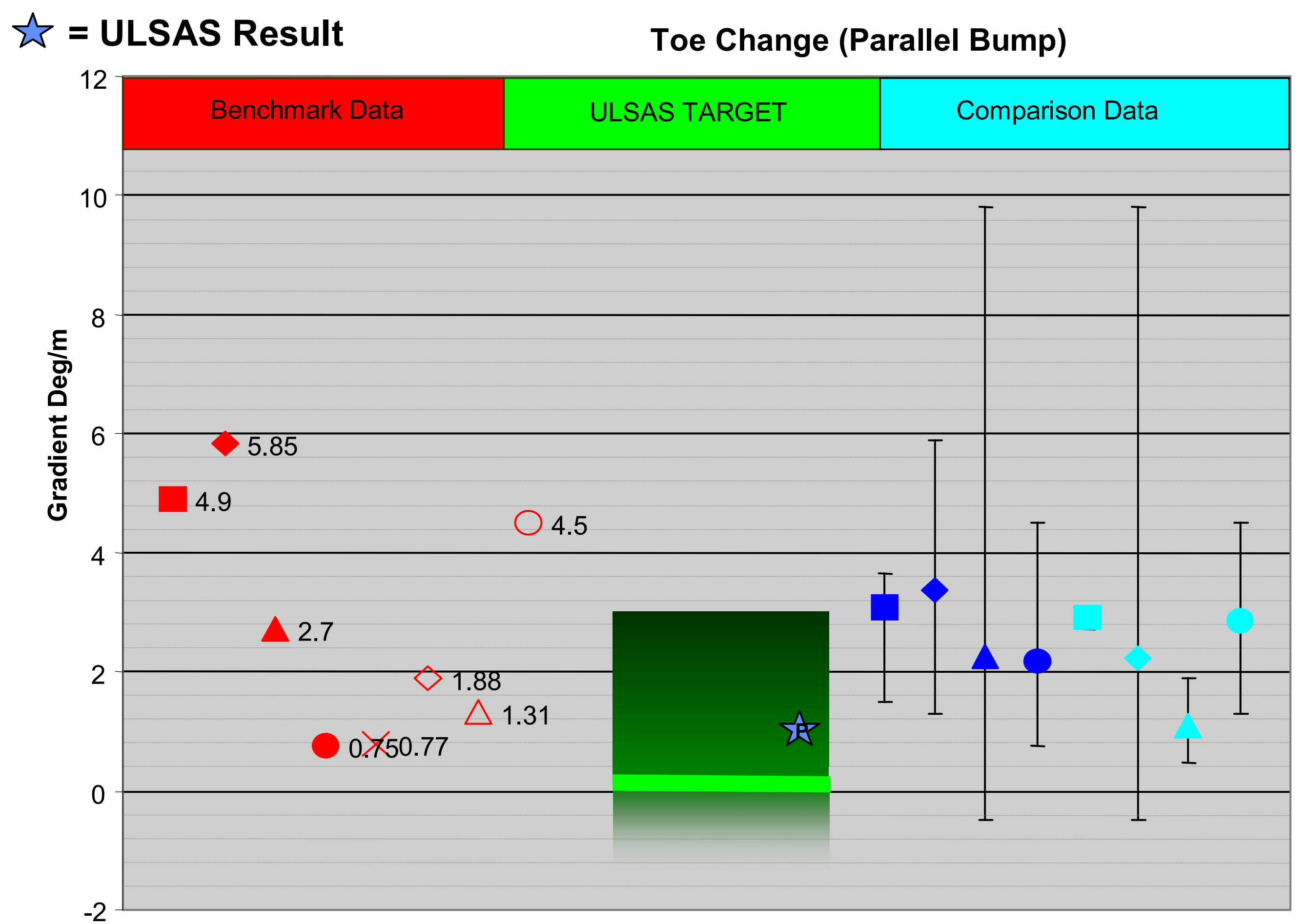
Close tolerances are required to control Roll Centre position. The ideal level of track change control in roll has been achieved.

STEEL AUTO SUSPENSION

LOTUS UNIQUE: Performance

LOTUS UNIQUE



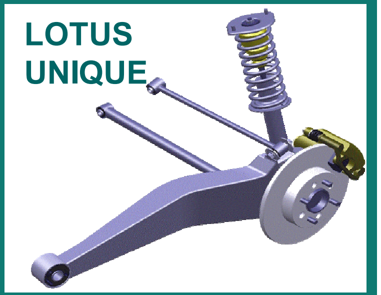


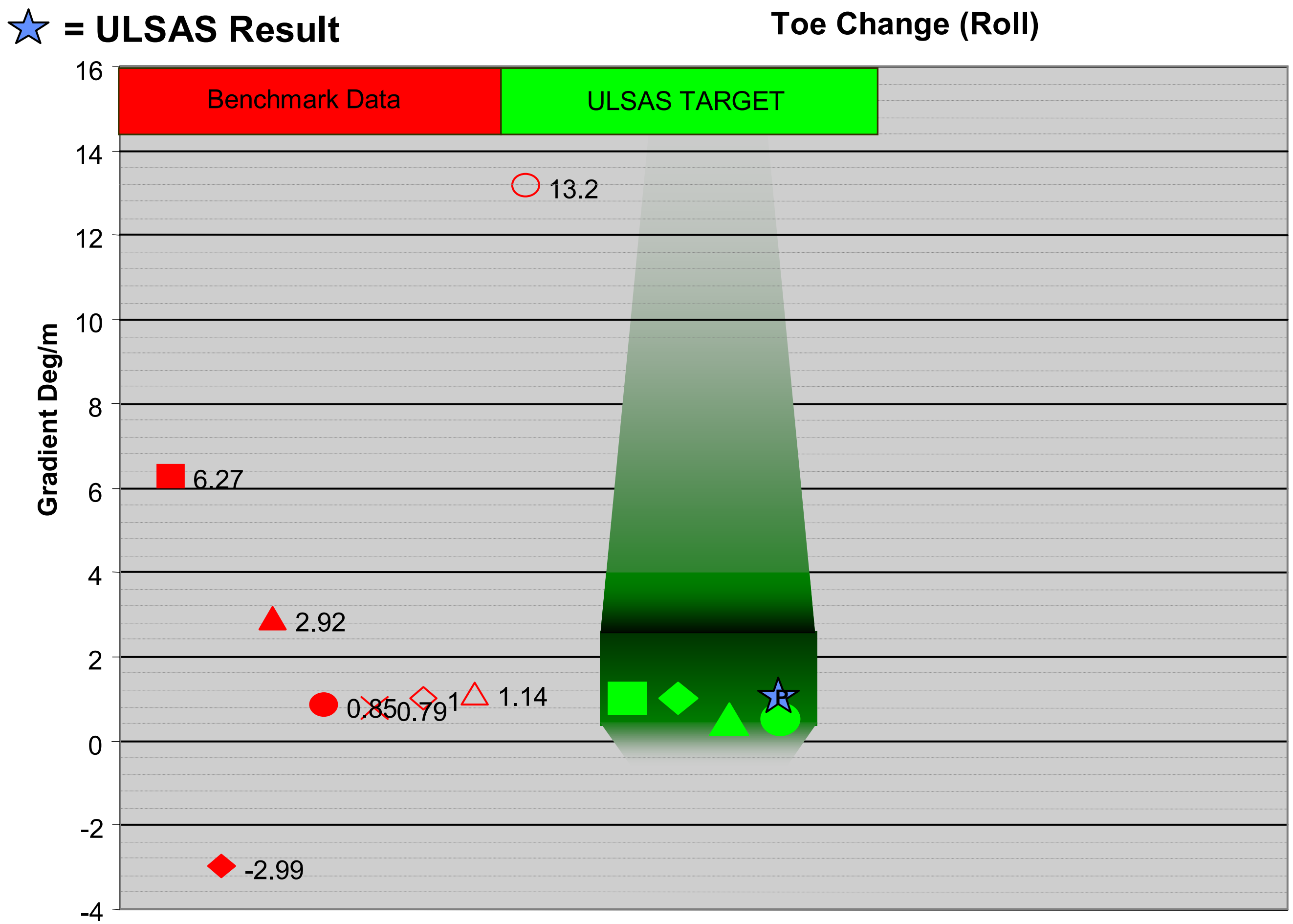
Comments:

Good control has been achieved with a small amount of Toe-in in bump.

LOTUS UNIQUE: Performance

LOTUS UNIQUE

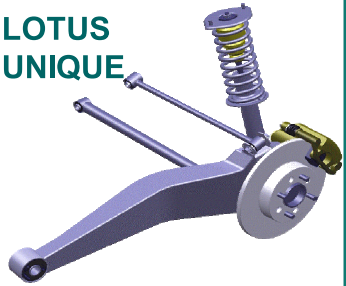


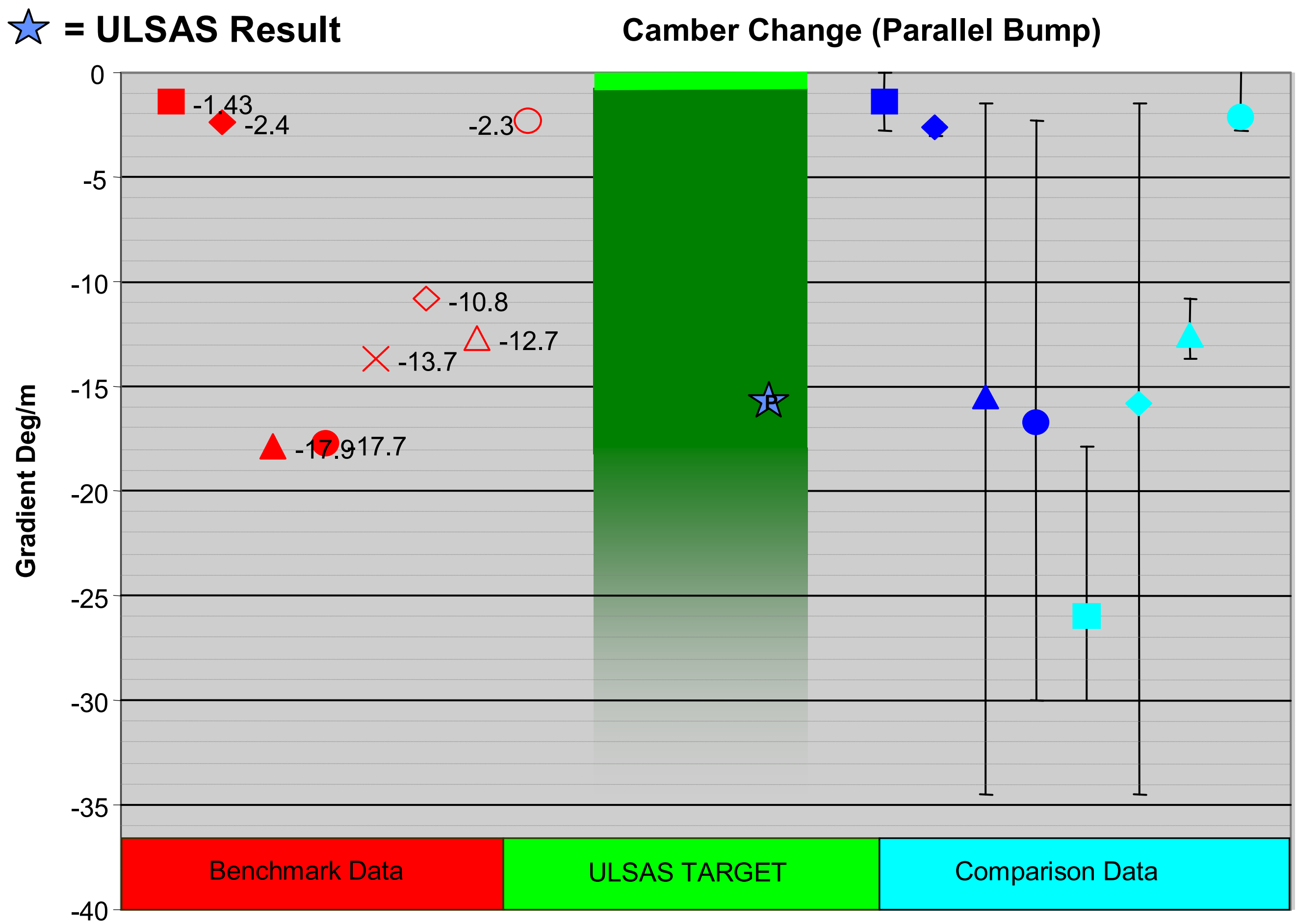


Comments:
Toe change in roll is the same as in parallel bump for the Lotus Unique system. Good balance has been achieved between these two requirements, with both results close to the Targets

LOTUS UNIQUE: Performance

LOTUS UNIQUE



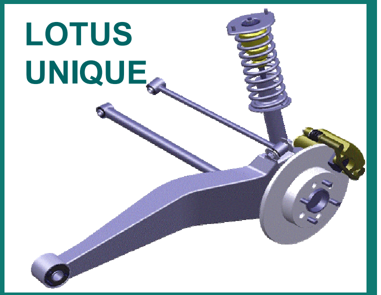


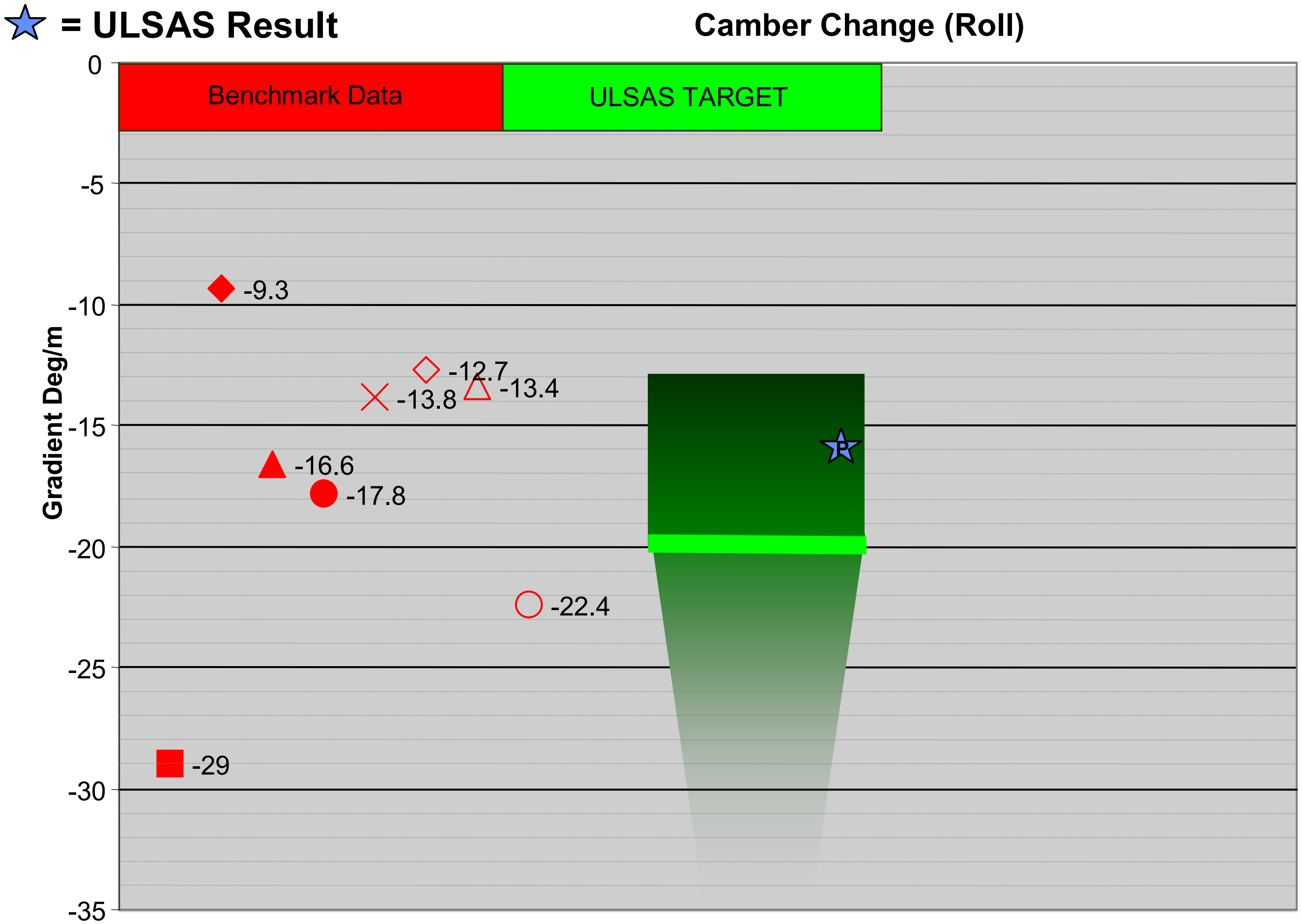
Comments:

The characteristics achieved are within the acceptable levels of the tolerance band. A balance has been achieved with the requirements in roll.

LOTUS UNIQUE: Performance

LOTUS UNIQUE



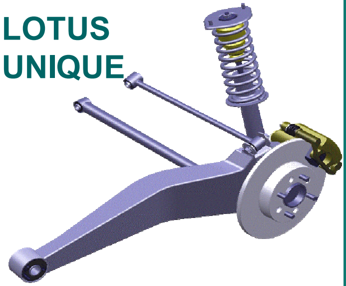


Comments:
Camber change in roll is the same as in parallel bump for the Lotus Unique system. The Camber change in roll will aid cornering performance.

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE: Performance

LOTUS UNIQUE



SYSTEM COMPLIANCES : Detailed Results Breakdown

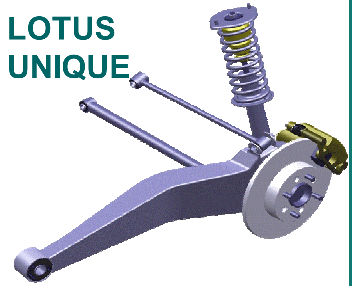
(Bushes Vs Structural Contributions)

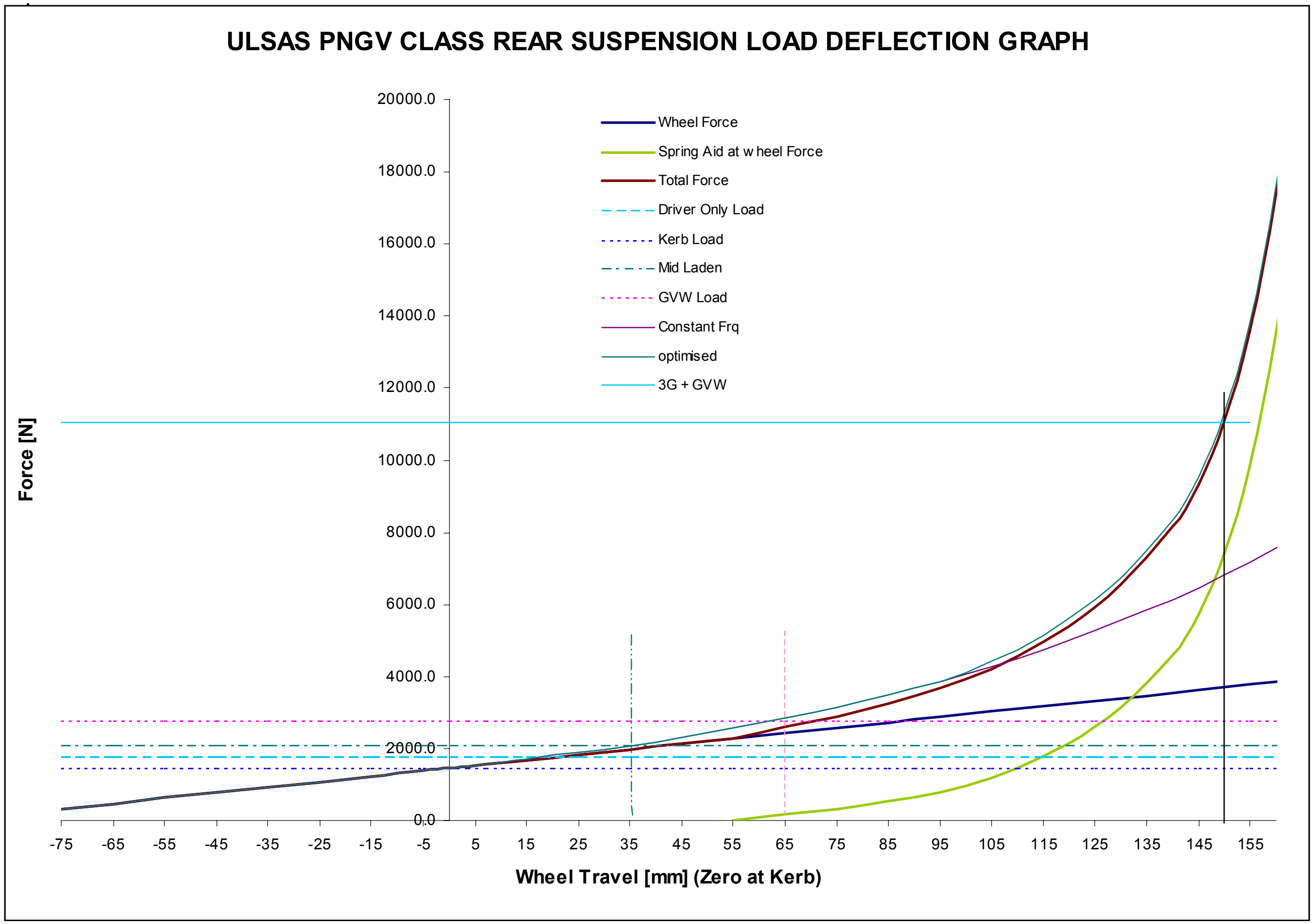
Characteristic	Units	Bush P Class	Structural	TOTAL P Class
Longitudinal Force at TCP				
TCP Longitudinal Compliance	mm/kN	2.673	0.43	3.11
Steer Compliance	deg/kN	0.02	0.02	0.05
Castor Compliance	deg/kN	0.22	0.07	0.30
Lateral Force at TCP				
TCP Lateral Compliance	mm/kN	1.58	0.42	2.00
Steer Compliance	deg/kN	-0.03	-0.004	-0.03
Camber Compliance	deg/kN	0.27	0.08	0.35
Aligning Torque at TCP				
Steer Stiffness	Nm / deg	740.00	3025.00	594.56

STEEL AUTO SUSPENSION

LOTUS UNIQUE: Performance

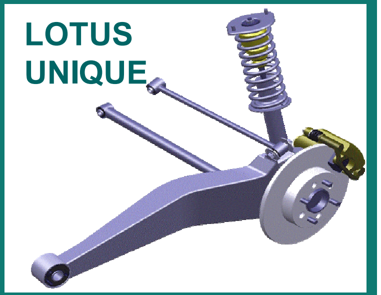
LOTUS UNIQUE

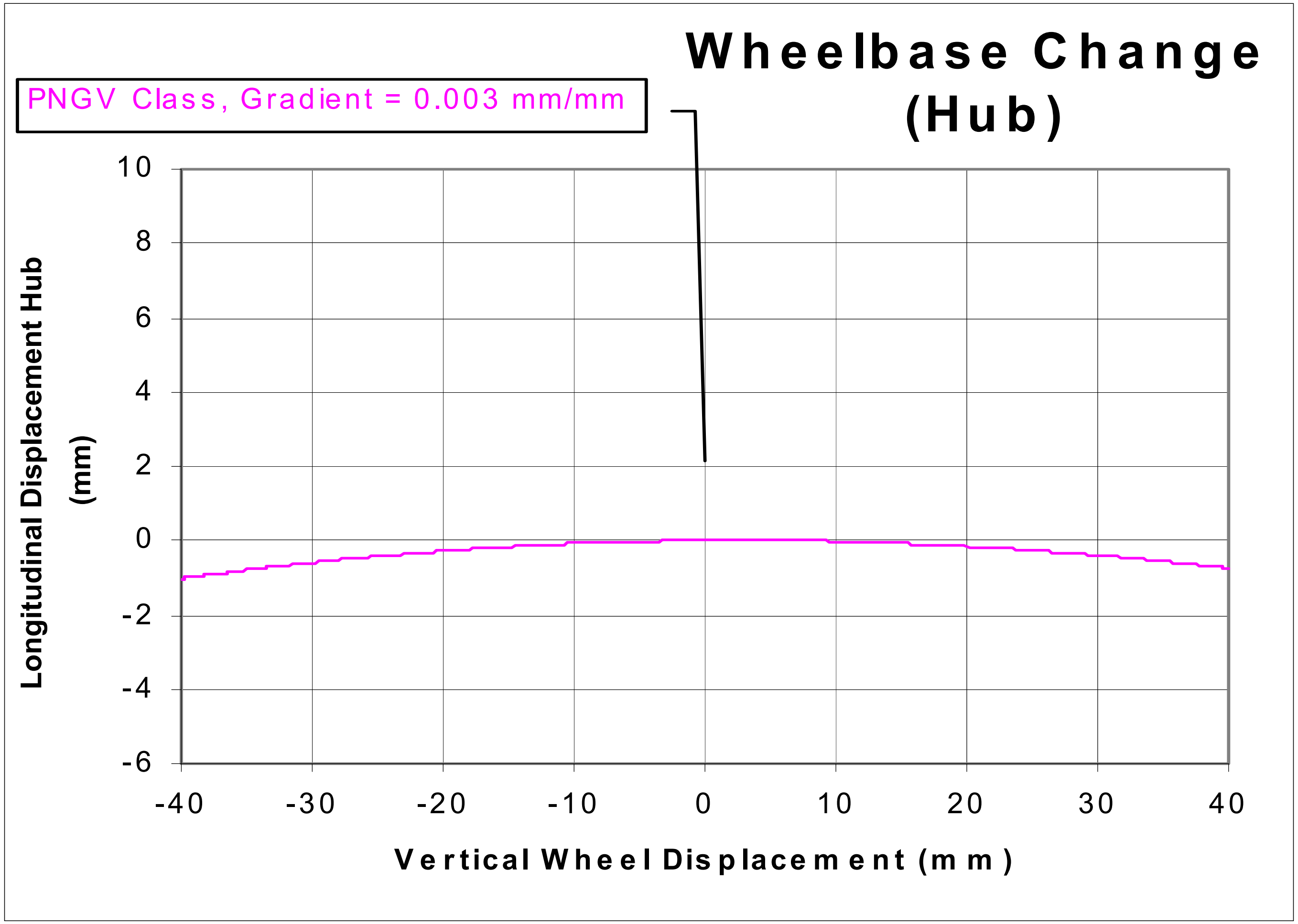




LOTUS UNIQUE: Performance

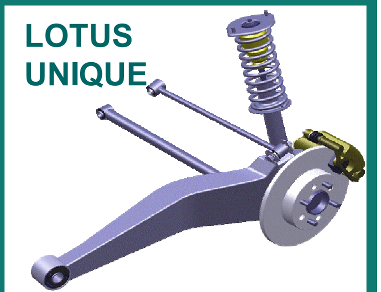
LOTUS UNIQUE

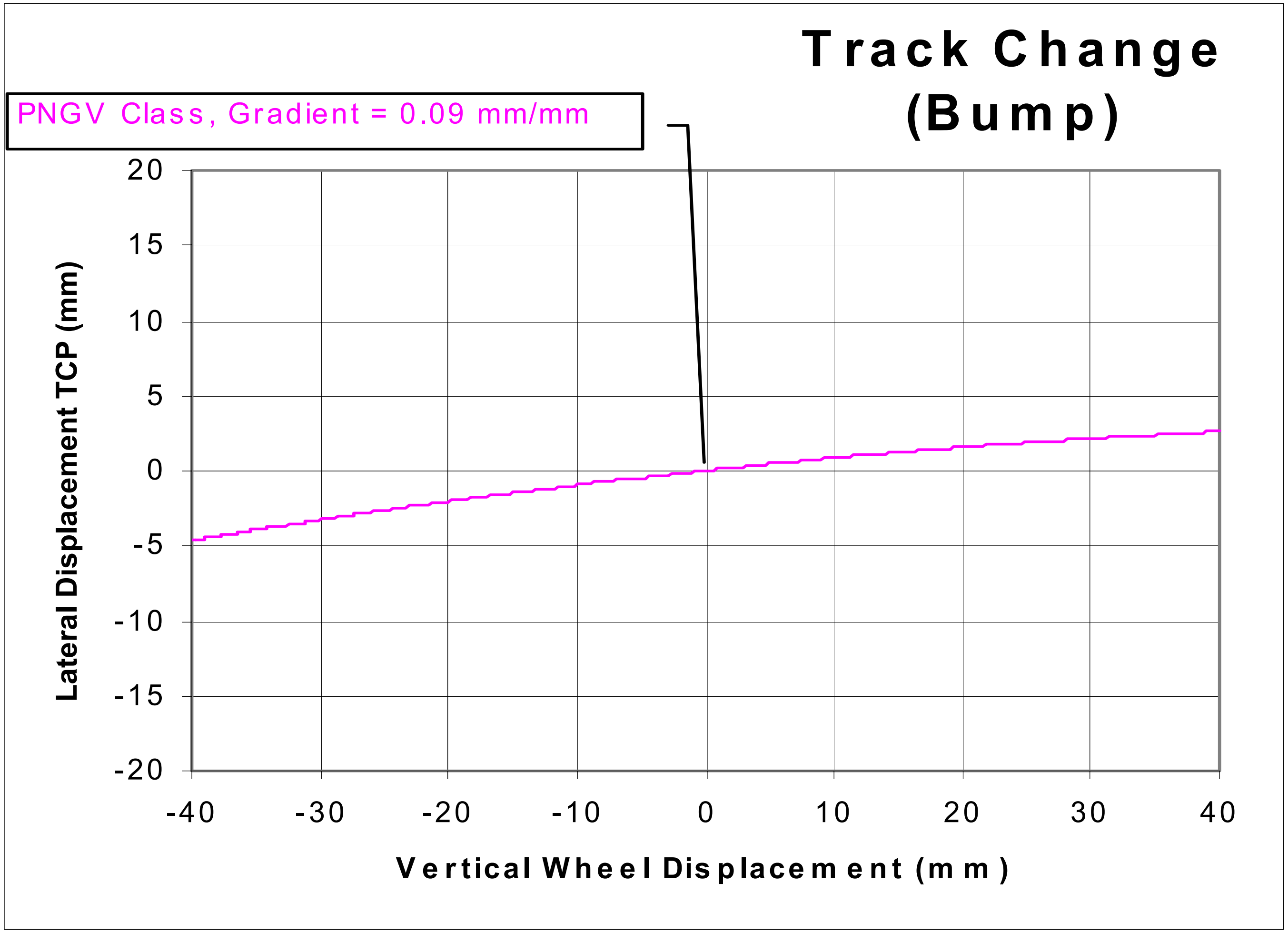




Instantaneous gradient taken at wheel displacement zero

LOTUS UNIQUE: Performance

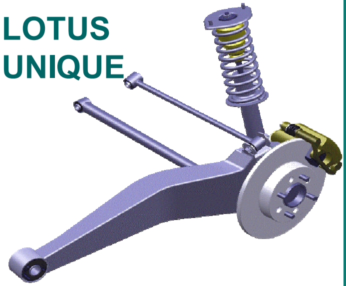


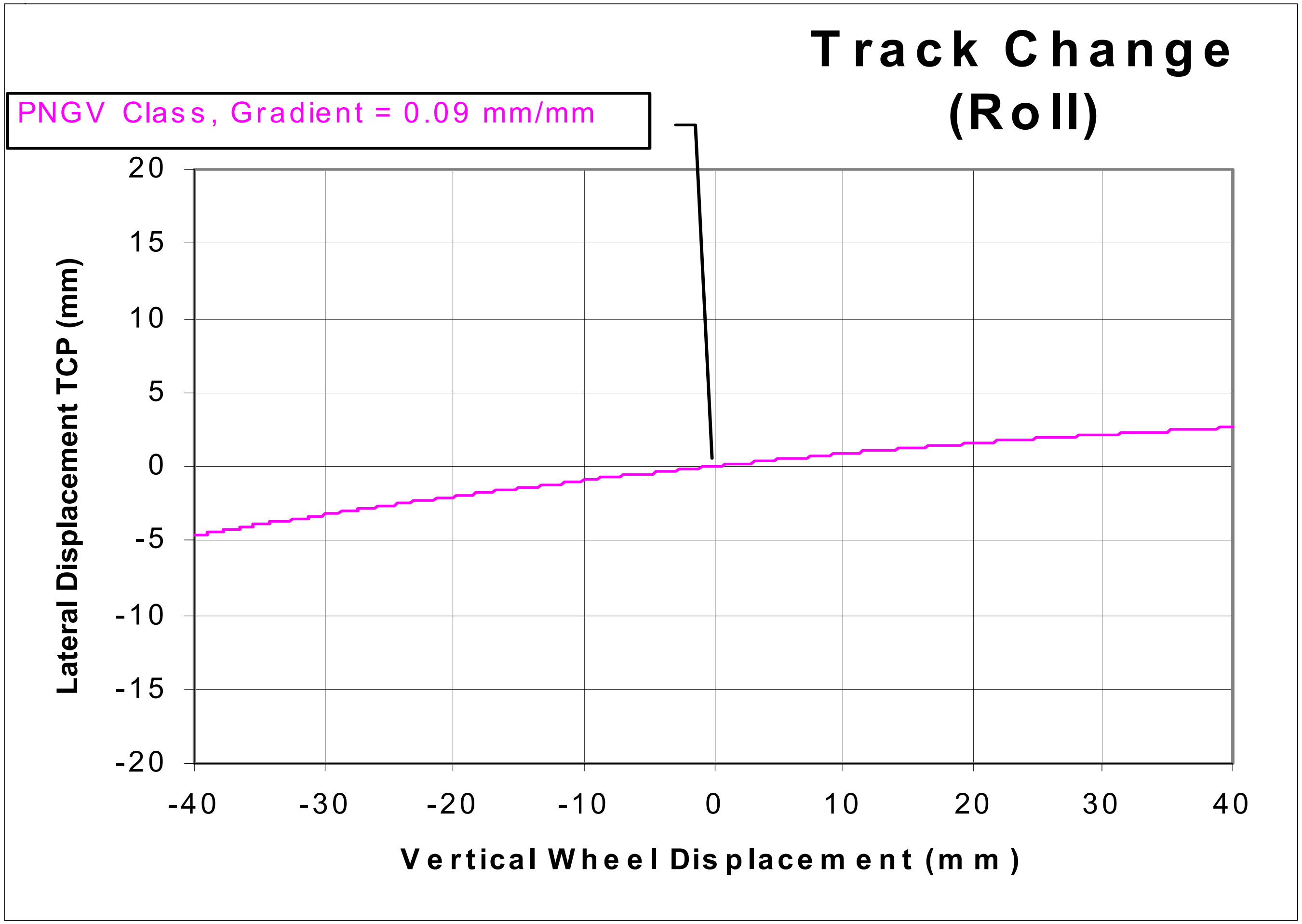


Instantaneous gradient taken at wheel displacement zero

LOTUS UNIQUE: Performance

LOTUS UNIQUE

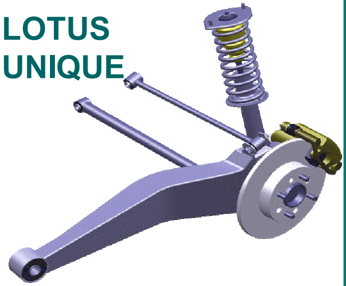


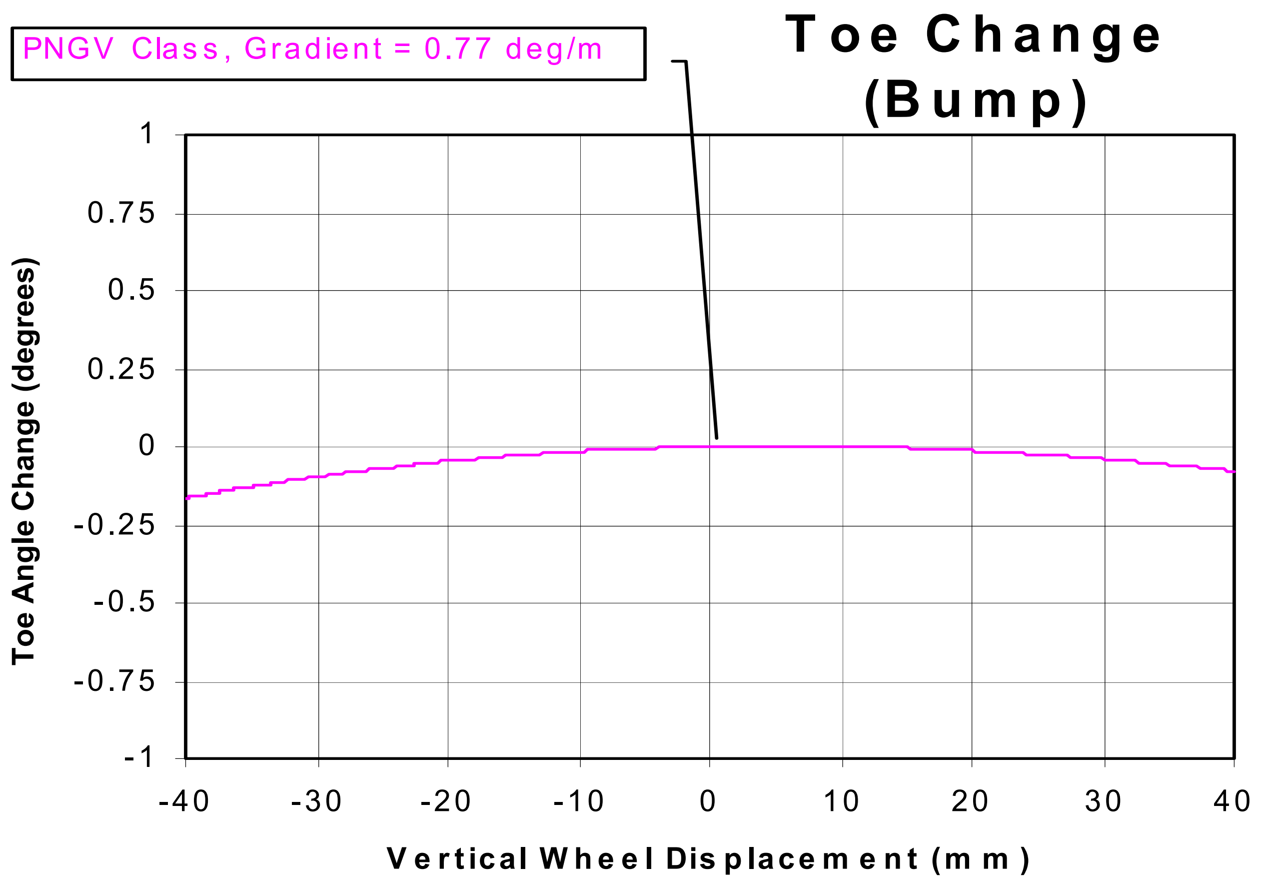


Instantaneous gradient taken at wheel displacement zero

LOTUS UNIQUE: Performance

LOTUS UNIQUE

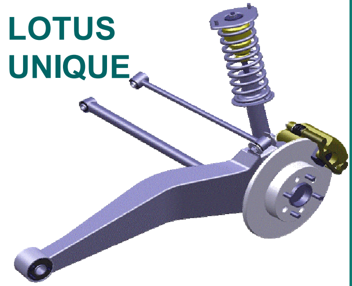


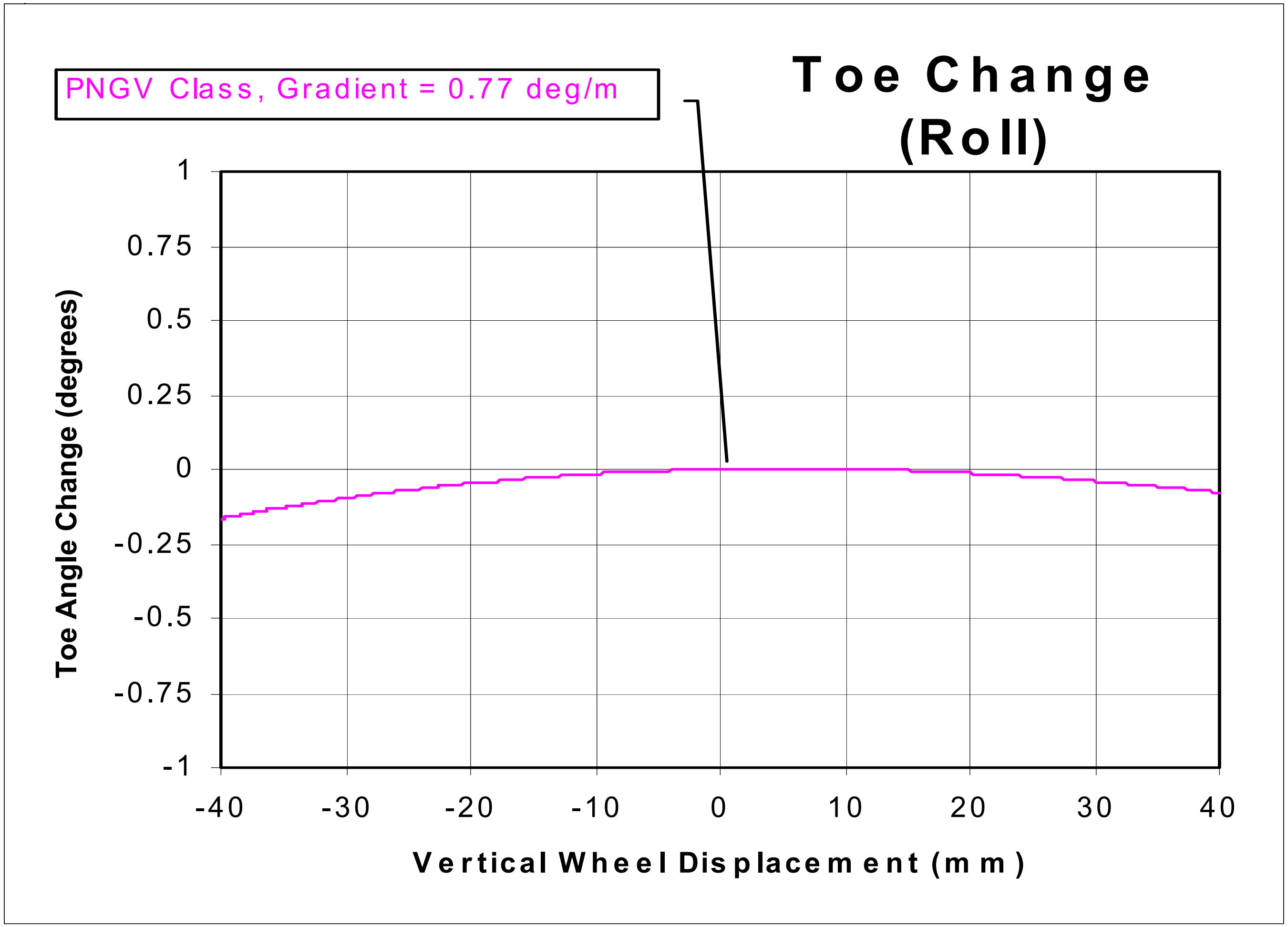


Instantaneous gradient taken at wheel displacement zero

LOTUS UNIQUE: Performance

LOTUS UNIQUE

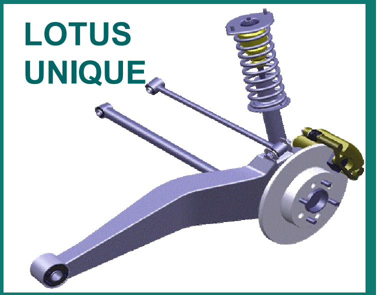


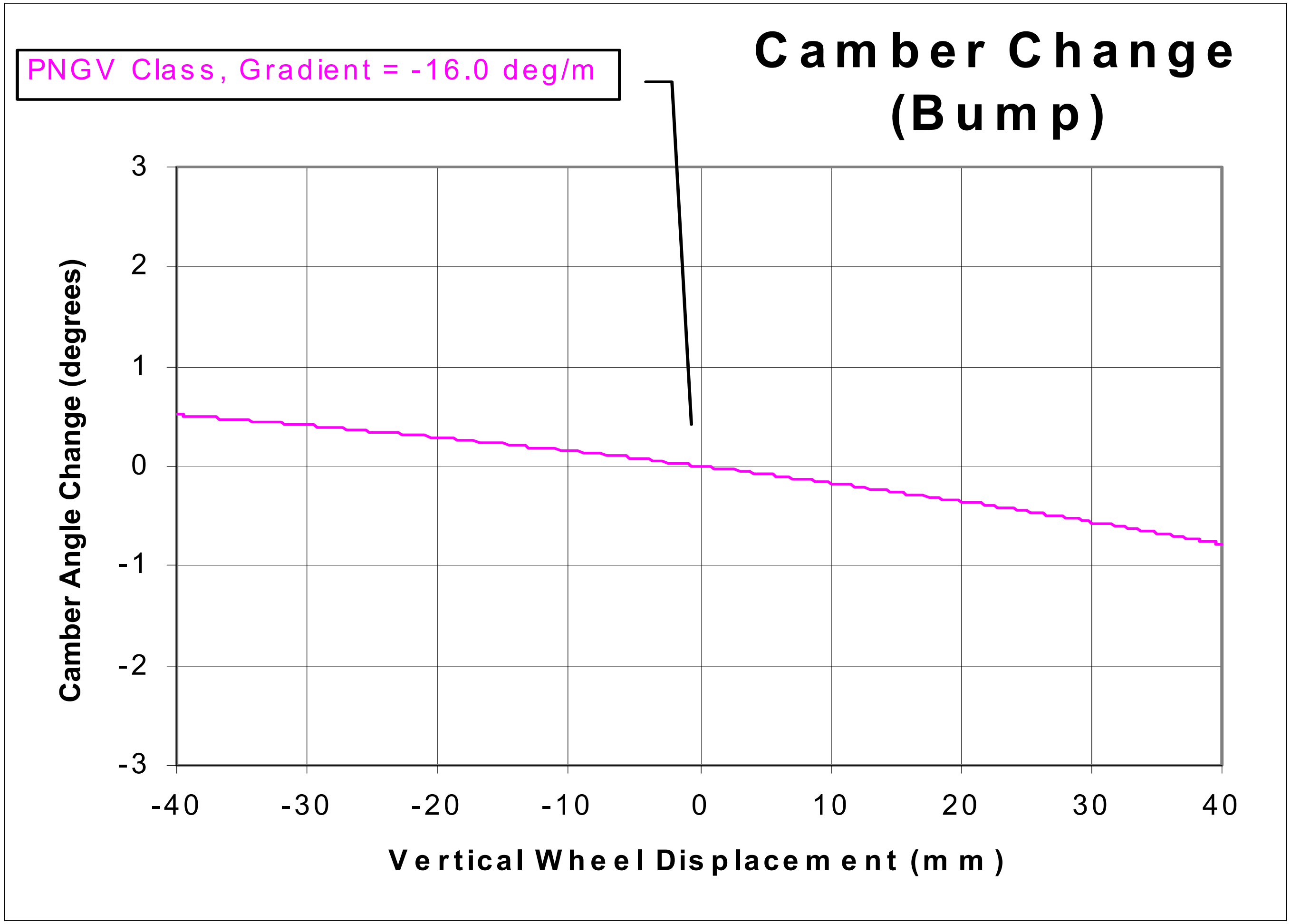


Instantaneous gradient taken at wheel displacement zero

LOTUS UNIQUE: Performance

LOTUS UNIQUE



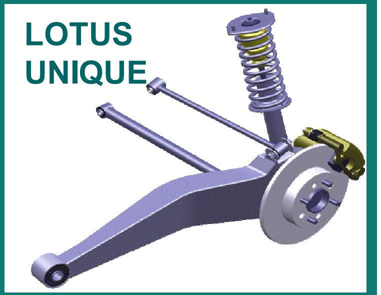


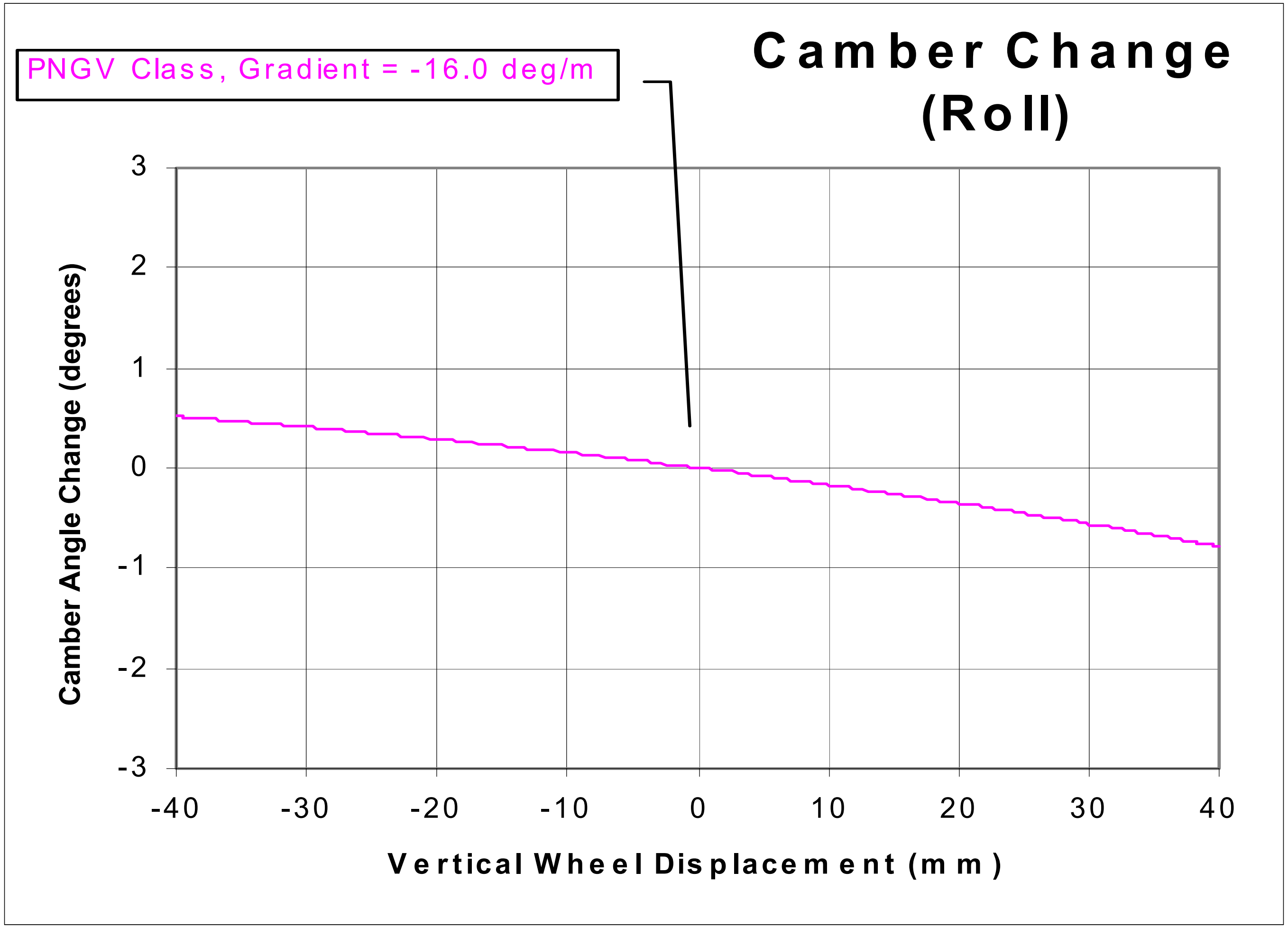
Instantaneous gradient taken at wheel displacement zero

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE: Performance

LOTUS UNIQUE



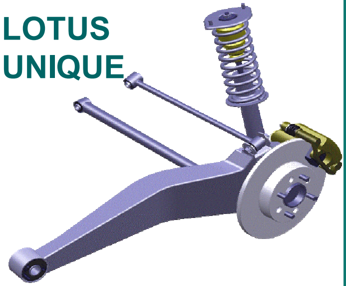


Instantaneous gradient taken at wheel displacement zero

PERFORMANCE RESULTS GRAPHS KEY

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE



Key to Objective Targets Graphs:

Optimum value (ULSAS Target)

= **ULSAS Result**

Tolerance Bands

Min Performance

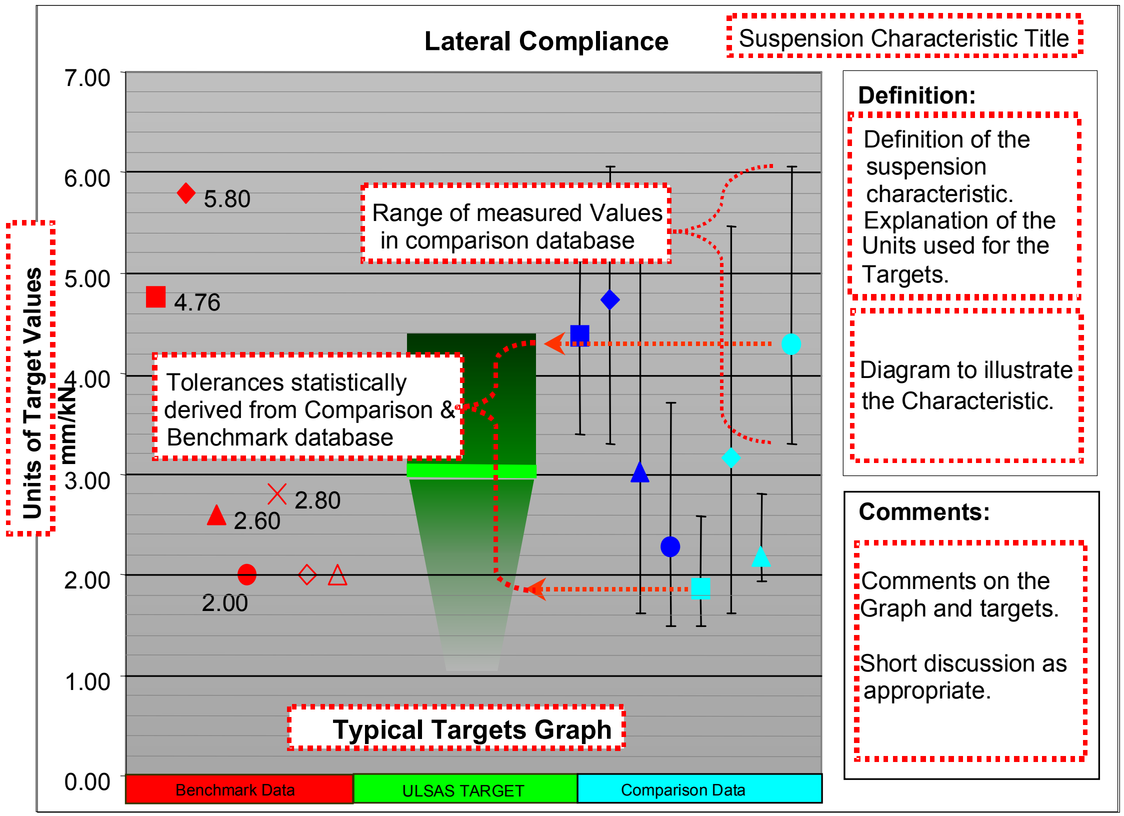
Band showing areas of acceptable Performance. Darker areas show Min Performance levels.

Band showing areas of acceptable Performance. Lighter areas indicate reduced performance levels with no clear minimum.

Low Performance

Diminishing Efficiency

Band showing areas of Performance above the required optimum level. Lighter areas indicate diminishing efficiency, ie: levels of performance that are beyond those required, but at the expense of Mass or Cost.



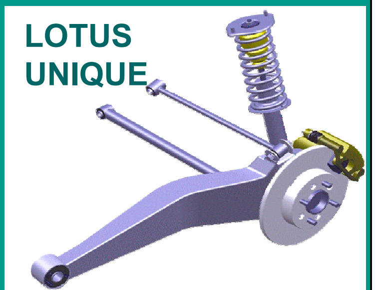
- VW Golf
- Peugeot 306
- Honda Accord
- BMW 528
- Dodge Intrepid
- Ford Taurus
- Chevrolet Lumina
- Audi A6
- ULSAS TARGET B
- ULSAS TARGET C
- ULSAS TARGET D
- ULSAS TARGET PNGV
- B Class Typical
- C Class Typical
- D Class Typical
- E Class Typical
- Double Wishbone Typical
- Multilink Typical
- Struts&Links Typical
- Twistbeam Typical

STEEL AUTO SUSPENSION

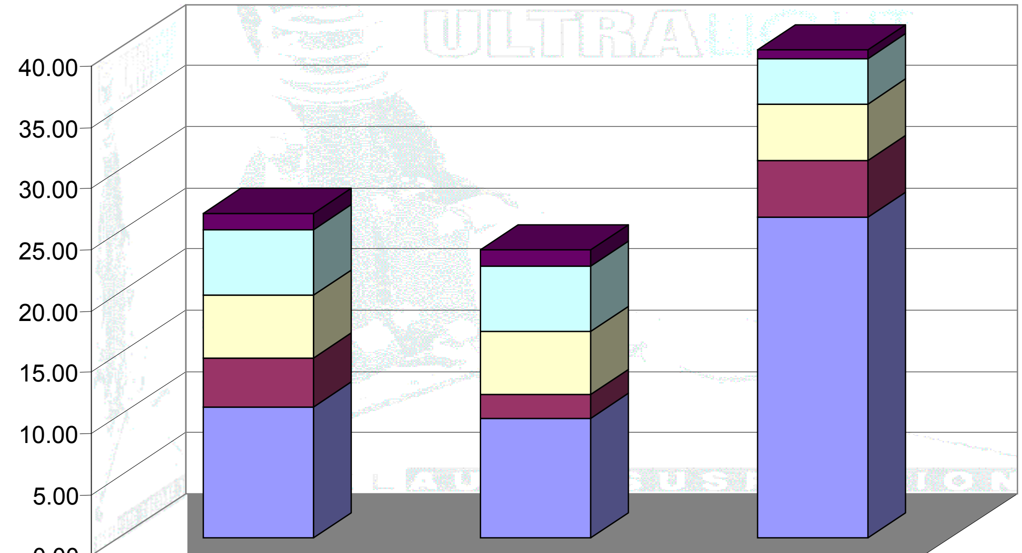
LOTUS UNIQUE: MASS

Comparison

LOTUS UNIQUE



*NB. There is no direct comparison for the Lotus Unique system. The Double Wishbone (D Class) Benchmark mass is used for illustration only.

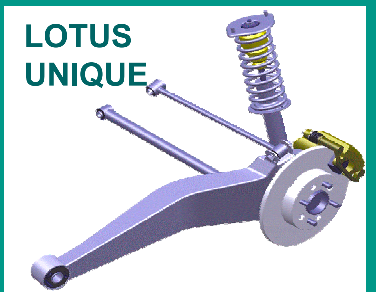


	D Class	P Class	Double Wishbone*
BUSHES & FIXINGS	1.33	1.33	0.72
HUBS	5.40	5.40	3.74
DAMPER ASSY	5.10	5.10	4.56
SPRING	4.04	1.95	4.62
STRUCTURE **	10.62	9.75	26.20
TOTAL SYSTEM	**26.49**	**23.53**	**39.84**

Mass Of ULSAS Solutions Vs Benchmark Vehicles

Description	B	C	D	E	P
Benchmark (kg)			**39.84**		
ULSAS Solution (kg)			**26.49**		**23.53**
Saving vs Benchmark			**34%**		

**** Structure includes knuckle and links**



LOTUS UNIQUE: MASS

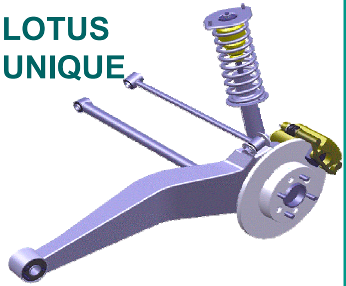
Approach

- Mass estimations were established for:
  - Components
  - Sub-assemblies / Proprietary Parts
- Mass estimates for Lotus designed parts derived from Mass Property Tables in the C.A.D software or the analysis C.A.E software.
- For Proprietary Parts the results were generated using a combination of Lotus experience and judgement supported by confirmation from suppliers and consortium members.
- For other standard parts Indicative quotations were obtained through Lotus relationships with suppliers.

LOTUS UNIQUE: MASS

D & P Class

LOTUS UNIQUE



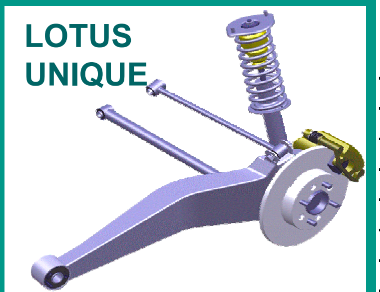
PARTS LIST			P Class			Benchmark D Class		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY LOTUS UNIQUE	2	**23.53**			**39.84**		
2	WELDED ASSEMBLY, RH	1	**4.37**	**4.369**		**DOUBLE WISHBONE**		
3	WELDED ASSEMBLY, LH	1	**4.37**	**4.369**				
4	TRAILING ARM, OUTER	2			1.485			
5	TRAILING ARM, INNER	2			1.593			
6	INTERNAL GUSSET BOTTOM	2			0.022			
7	INTERNAL GUSSET TOP	2			0.054			
8	PIVOT BUSH HOUSING	2			0.263			
9	CRUSH TUBE, CALIPER MOUNTING	4			0.074			
10	HOUSING HUB BEARING UNIT	2			0.292			
11	OUTER HUB REINFORCEMENT	2			0.495			
12	LOWER LINK MOUNTING BRKTS	2			0.091			
13	LATERAL LINK ASSY, LOWER	2	**0.64**	**0.320**				
14	LATERAL LINK ASSY, UPPER	2	**0.37**	**0.185**				
15	BUSH HOUSING, LATERAL LINK	8						
16	LINK, LATERAL LOWER	2						
17	LINK, LATERAL UPPER	2						
18	HUB BEARING UNIT	2	**5.40**	**2.700**				
19	CALIPER, BRAKE	2						
20	BRAKE DISC	2						
21	DAMPER	2	**4.00**	**2.000**				
22	SPRING	2	**1.95**	**0.974**				
23	MOUNT, UPR, SPRING & DAMPER	2	**1.10**	**0.550**				
24	VARIOUS BUSHES AND JOINTS		**0.64**					
25	ASSORTED FIXINGS		**0.69**					

LOTUS UNIQUE: MATERIAL

P Class

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPa)
1	ASSEMBLY LOTUS UNIQUE	2	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSEMBLY, RH	1	FABRICATION (items; 4-12)		
3	WELDED ASSEMBLY, LH	1	FABRICATION (items; 4-12)		
4	TRAILING ARM, OUTER	2	PRESSING; TAILOR WELDED BLANK	1.2 - 2.7	200-400
5	TRAILING ARM, INNER	2	PRESSING; TAILOR WELDED BLANK	1.2 - 2.3	150-500
6	INTERNAL GUSSET BOTTOM	2	BLANK & FOLD	1.7	300
7	INTERNAL GUSSET TOP	2	BLANK & FOLD	1.7	300
8	PIVOT BUSH HOUSING	2	TUBE	3	300
9	CRUSH TUBE, CALIPER MOUNTING	4	TUBE	3	150
10	HOUSING HUB BEARING UNIT	2	TUBE	3	300
11	OUTER HUB REINFORCEMENT	2	PRESSING	2.5	400
12	LOWER LINK MOUNTING BRKTS	2	BLANK & FOLD	2.5	400
13	LATERAL LINK ASSY, LOWER	2	FABRICATION (items; 15,16)		
14	LATERAL LINK ASSY, UPPER	2	FABRICATION (items; 15,17)		
15	BUSH HOUSING, LATERAL LINK	8	TUBE		250
16	LINK, LATERAL LOWER	2	TUBE	Ø 25 x 1.5	250
17	LINK, LATERAL UPPER	2	TUBE	Ø 25 x 1,5	251
18	HUB BEARING UNIT	2	GEN 3 WITH ACTIVE ABS SENSOR		
19	CALIPER, BRAKE	2	INTEGRATED HANDBRAKE MECHANISM		
20	BRAKE DISC	2	SOLID, CAST IRON		
21	DAMPER ASSEMBLY	2	INCL SPRING SEAT & BUMP RUBBER	See note	
22	SPRING	2	SHEAR STRESS LIMIT 1300MPa	8.65-11.16	1300
23	MOUNT, UPR, SPRING & DAMPER	2	2 BOLT FIXING TO BIW.		
24	VARIOUS BUSHES AND JOINTS		RUBBER BUSHES & SPHERICAL JOINTS		
25	ASSORTED FIXINGS		NUTS, BOLTS & WASHERS ETC		

Note : Damper Assembly Consists of 4 Main Components

Damper Body Assumes 350 MPa Material

Damper Rod Assumes Dia 13mm x 3mm tube

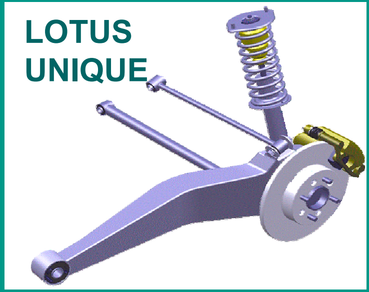
Spring Pan Assumes 350 MPa Material

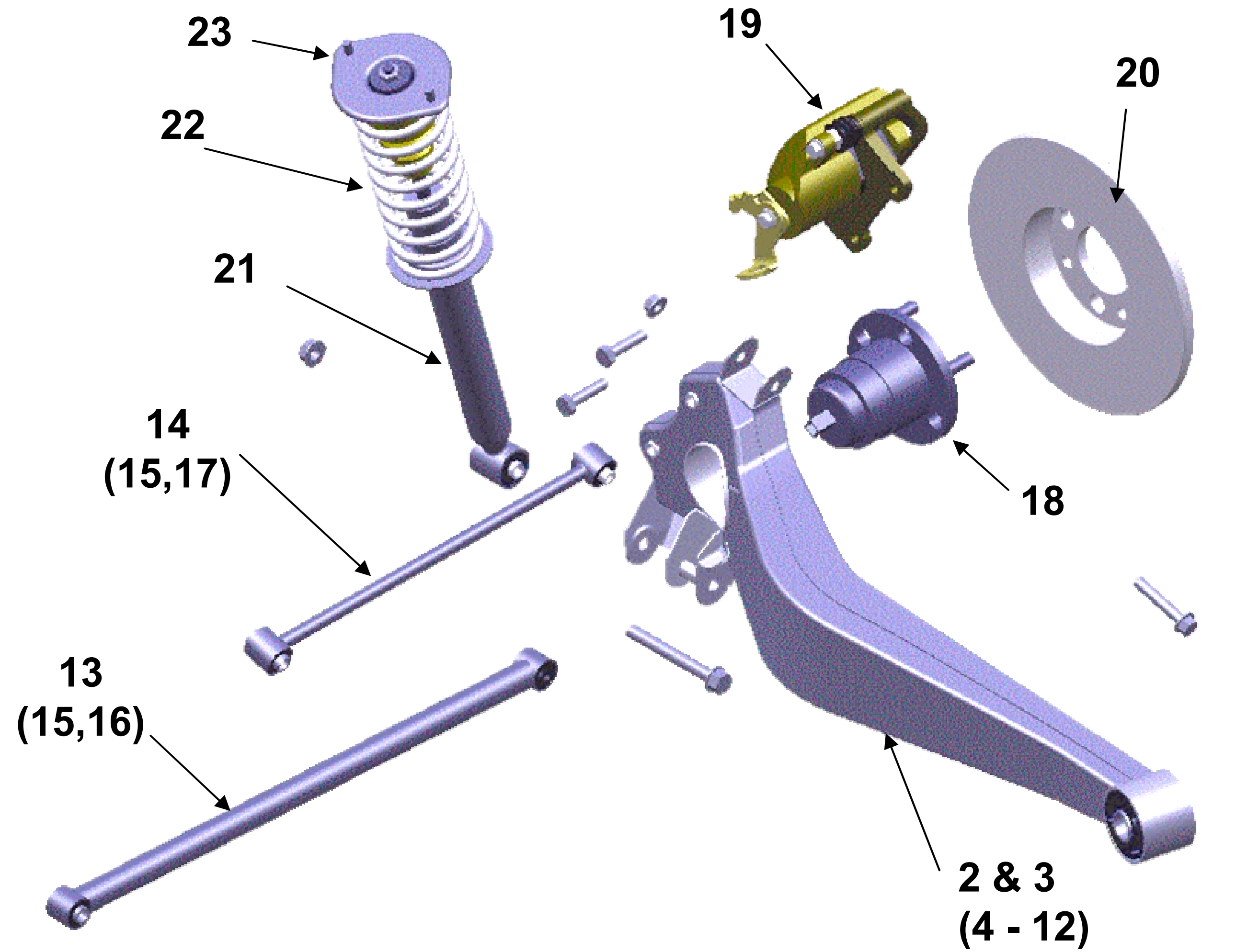
Bump Rubber Assumes Polyurethane Material

STEEL AUTO SUSPENSION

LOTUS UNIQUE: EXPLODED VIEW

LOTUS UNIQUE

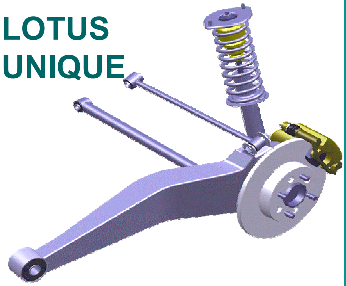




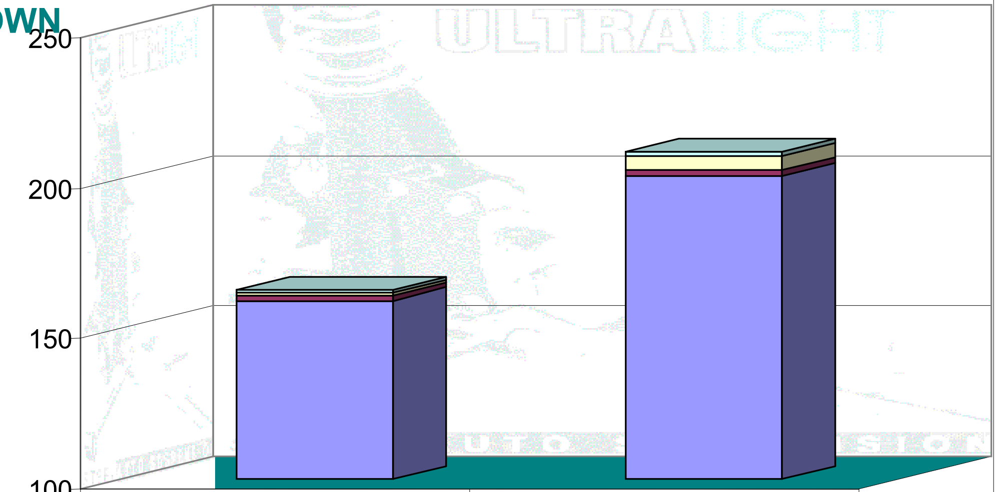
1 = Full Suspension Assembly

LOTUS UNIQUE: COST

LOTUS UNIQUE



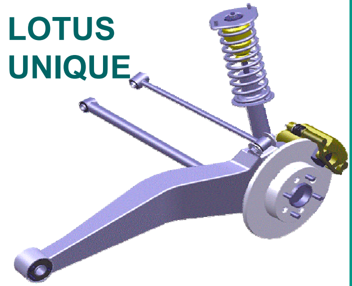
COST BREAKDOWN
LOTUS UNIQUE



	ULSAS (D CLASS)	DOUBLE WISHBONE
VEHICLE FITTING COST	$0.7	$1.3
SYSTEM ASSEMBLY COST	$1.2	$4.8
TOOLING COST	$1.5	$2.0
PIECE COST	$159.4	$200.7
TOTAL COST	**$162.8**	**$208.9**

LOTUS UNIQUE: COST

LOTUS UNIQUE



(US$)	Double Wishbone	Lotus
	Benchmark D Class	ULSAS D Class
COMPONENT COST	**$200.7**	**$159.4**
TOTAL TOOLING COST ($,000)	**$4,192**	**$2,907**
5 YEAR Volume (Assumptions)	2,075,000	2,000,000
TOOLING COST	$2.0	$1.5
TOTAL SYSTEM COST	$202.7	$160.9
SYSTEM ASSY		
Labour Rate (US$/min on $44/Hr	$0.73	$0.73
Assembly Mins	6.59	1.58
SYSTEM ASSEMBLY COST	$4.83	$1.16
VEHICLE FITTING		
Labour Rate (US$/min on $44/Hr	$0.73	$0.73
Fitting Mins	1.83	1.01
VEHICLE FITTING COST	$1.34	$0.74

Total Cost ($)	**$208.9**	**$162.8**
Cost Saving($)		$46.1
Cost Saving %		**22%**

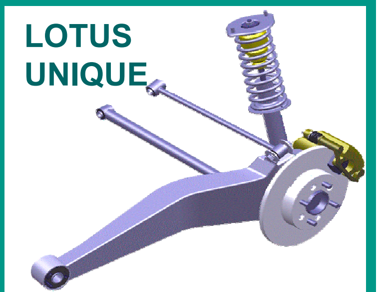
Reduction in assembly time is due mainly to greater levels of parts integration in the ULSAS design.

NB. Nearest benchmark system is the Double Wishbone.

LOTUS UNIQUE: COST

Bill of Materials

LOTUS UNIQUE



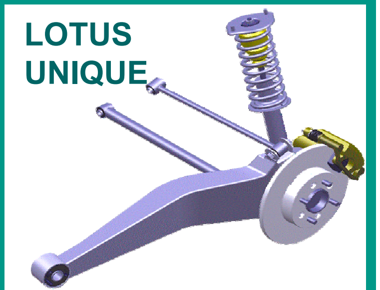
N.B. All Costs in US $ Tooling in US$(,000)

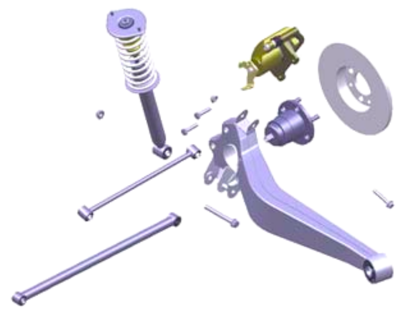
PARTS LIST			ULSAS D Class			D Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	PART COST (US$)	SYSTEM COST(US$)	TOOLING COST (US$k)	PART COST (US$)	SYSTEM COST(US$)	TOOLING COST (US$k)
1	ASSEMBLY LOTUS UNIQUE	2		159.42	2907.00		200.70	4192.00
2	WELDED ASSEMBLY, RH	1	$4.0	$21.5	$1,127	DOUBLE WISHBONE		
3	WELDED ASSEMBLY, LH	1	$4.0	$21.5				
4	TRAILING ARM, OUTER	2	$5.3		$280			
5	TRAILING ARM, INNER	2	$5.2		$280			
6	INTERNAL GUSSET BOTTOM	2	$0.5		$35			
7	INTERNAL GUSSET TOP	2	$0.5		$35			
8	PIVOT BUSH HOUSING	2	$1.0					
9	CRUSH TUBE, CALIPER MOUNTING	4	$1.5					
10	HOUSING HUB BEARING UNIT	2	$1.0		$150			
11	OUTER HUB REINFORCEMENT	2	$2.0		$140			
12	LOWER LINK MOUNTING BRKTS	2	$0.5		$80			
13	LATERAL LINK ASSY, LOWER	2	$4.3	$8.6	$100			
14	LATERAL LINK ASSY, UPPER	2	$4.0	$8.0	$100			
15	BUSH HOUSING, LATERAL LINK	8						
16	LINK, LATERAL LOWER	2						
17	LINK, LATERAL UPPER	2						
18	HUB BEARING UNIT	2	$19.0	$38.0	$0			
19	CALIPER, BRAKE	2						
20	BRAKE DISC	2						
21	DAMPER	2	$16.0	$32.0	$330			
22	SPRING	2	$5.2	$10.4	$0			
23	MOUNT, UPR, SPRING & DAMPER	2	$1.6	$3.2	$250			
24	VARIOUS BUSHES AND JOINTS			$13.3				
25	ASSORTED FIXINGS			$3.0				

LOTUS UNIQUE: TIMING

Sub-Assembly

LOTUS UNIQUE





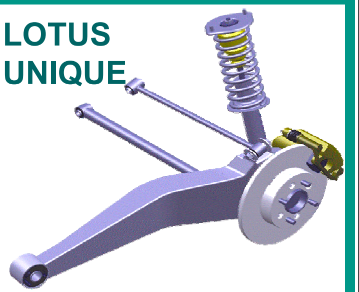
BREAKDOWN OF TIMING FOR SUB-ASSEMBLY OF LOTUS UNIQUE SUSPENSION SYSTEM

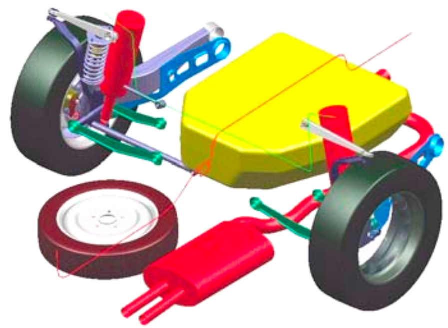
SUB-ASSEMBLY Operation	number	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
LOAD TRAILING ARM	2	FIX2H	0.09	0.09	0.18
FIT BRAKE DISK	2	FIX1H	0.05	0.05	0.10
FIT BRAKE CALIPER	2	FIX1H	0.05	0.05	0.10
FIX CALIPER	4	TFPTN	0.11	0.21	0.32
LOAD LOWER LATERAL LINK	2	FIX1H	0.05	0.05	0.10
LOAD DAMPER	2	FIX1H	0.05	0.05	0.10
LOAD BOLT	2	FITFN	0.07	0.04	0.11
FIX NUT	2	TFPTN	0.11	0.07	0.18
LOAD UPPER LATERAL LINK	2	FIX1H	0.05	0.05	0.10
FIT BOLT	2	FITFN	0.07	0.04	0.11
FIX NUT	2	TFPTN	0.11	0.07	0.18
				TOTAL	1.58

LOTUS UNIQUE: TIMING

Final Vehicle Assembly

LOTUS UNIQUE

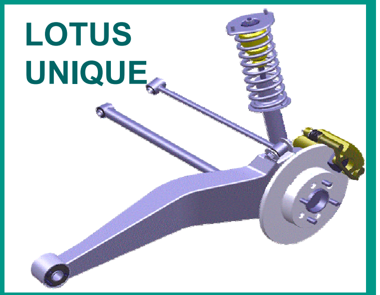




Overlay Comparison with Double Wishbone Benchmark Illustrated.

BREAKDOWN OF TIMING FOR FINAL ASSEMBLY OF LOTUS UNIQUE SUSPENSION TO THE VEHICLE.

FINAL ASSEMBLY Operation	number	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
FIT TRAILING ARM BOLT	2	FITFN	0.07	0.04	0.11
FIX TRAILING ARM BOLT	2	TFPTN	0.11	0.07	0.18
FIT LOWER LATERAL BOLT	2	FITFN	0.07	0.04	0.11
FIX LOWER LATERAL NUT	2	TFPTN	0.11	0.07	0.18
FIT UPPER LATERAL BOLT	2	FITFN	0.07	0.04	0.11
FIX DAMPER NUT	4	TFPTN	0.11	0.21	0.32
				TOTAL	**1.01**



LOTUS UNIQUE: COST

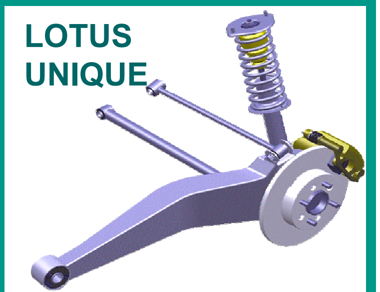
Benchmark Phase

Costing Exercise Deliverables for both the Benchmarking Phase and the Design Phase include:

- Costed Bill of Materials
- Tooling cost estimates for each of the major components and sub-assemblies.

LOTUS UNIQUE: COST

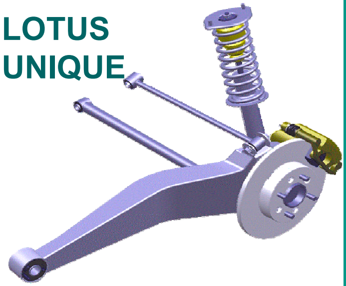
Benchmark Phase



- Results were generated via a combination of Lotus experience supported by cost confirmation from suppliers and consortium members.
- Indicative quotations were obtained through Lotus relationships with suppliers.
- Potential for negotiated preferential supply rates is excluded.
- Variances between ULSAS Benchmark estimates and OEM costs exist - due to the following:
  - » Process variations
  - » Special supplier / manufacturer relationships
  - » Availability of existing tooling and facilities to the manufacturer.

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE



LOTUS UNIQUE: COST

Benchmark Assumptions

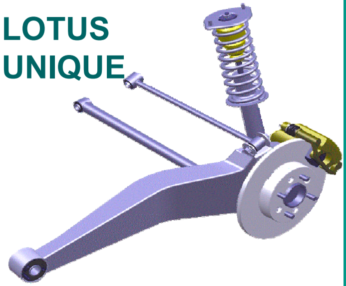
- 1998 economics.
- Costs are shown in US Dollars (US$).
- Ex-works prices for sub-assemblies.
- Tooling recovery over 5 years full production.
- Supplier base cost, not OEM based.
- No capital equipment cost included.
- Component costs are shown fully finished (including coatings etc. where applicable).
- Estimated production volumes:

Manufacturer	Model	Suspension System	Volume	Assumptions
Audi	A6	Twistbeam	110,000	(2)
Ford	Taurus	Strut & Links	380,000	(1)
Honda	Accord	Double Wishbone	415,000	(1)
BMW	5 Series	Multi-link	215,000	(2)

(1)= 1997 North America **(2) = 1997 European**

ULTRALIGHT STEEL AUTO SUSPENSION

LOTUS UNIQUE



LOTUS UNIQUE: COST

Design Phase

Identical Assumptions and similar rationale to the Benchmarking Phase were applied to ensure compatibility.

- 1998 Economics - for consistency with Benchmark data.
- Lotus Manufacturing Engineering costing experience and judgement used throughout for consistency.
- Benchmarking against known costs for components.
- Close collaboration with consortium members.
- Elegance of design reduces cost.
- Optimised tool utilisation reduces cost.
- Costs developed simultaneously with the designs.
- Volume assumptions :

SUSPENSION TYPE	VOLUME (per annum)
Twistbeam	400,000
Strut & Links	400,000
Double Wishbone	400,000
Multi-link	200,000
Lotus Unique	400,000