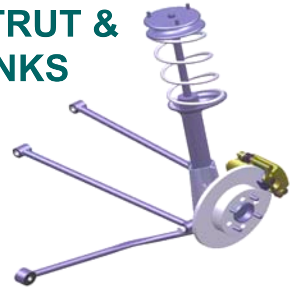
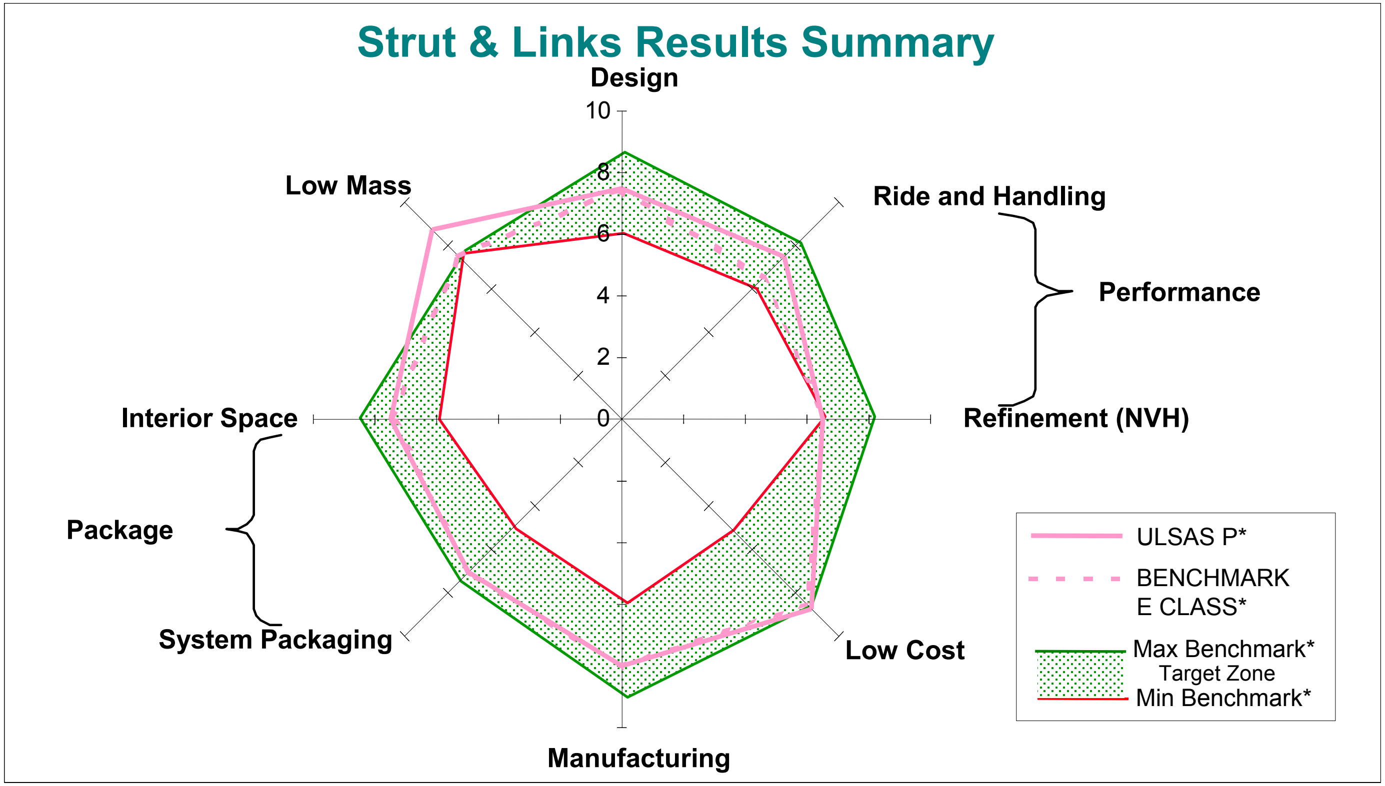
STRUT & LINKS: RESULTS SUMMARY

STRUT & LINKS





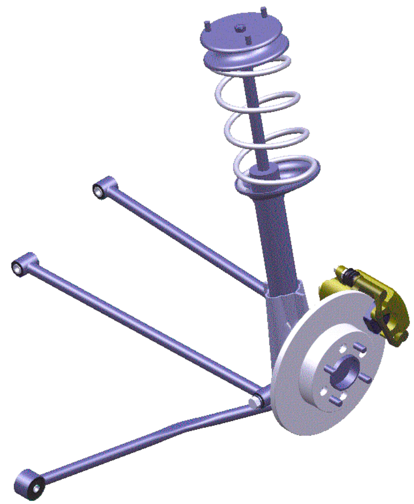
- MASS SAVINGS - NO COST PENALTY
- PERFORMANCE EXCEEDS BENCHMARK
- ALL OTHER AREAS MATCH BENCHMARK

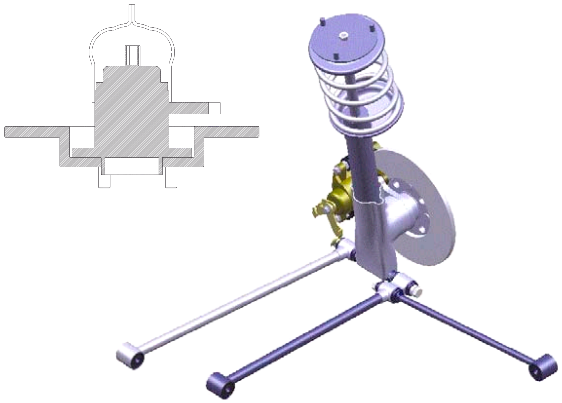
*** Except for the 'Low Mass' category where D Class Benchmark results are depicted as P Class benchmark vehicles are not available**

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

STRUT & LINKS: DESIGN

STRUT & LINKS



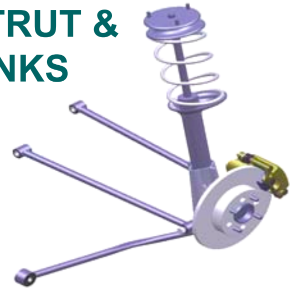


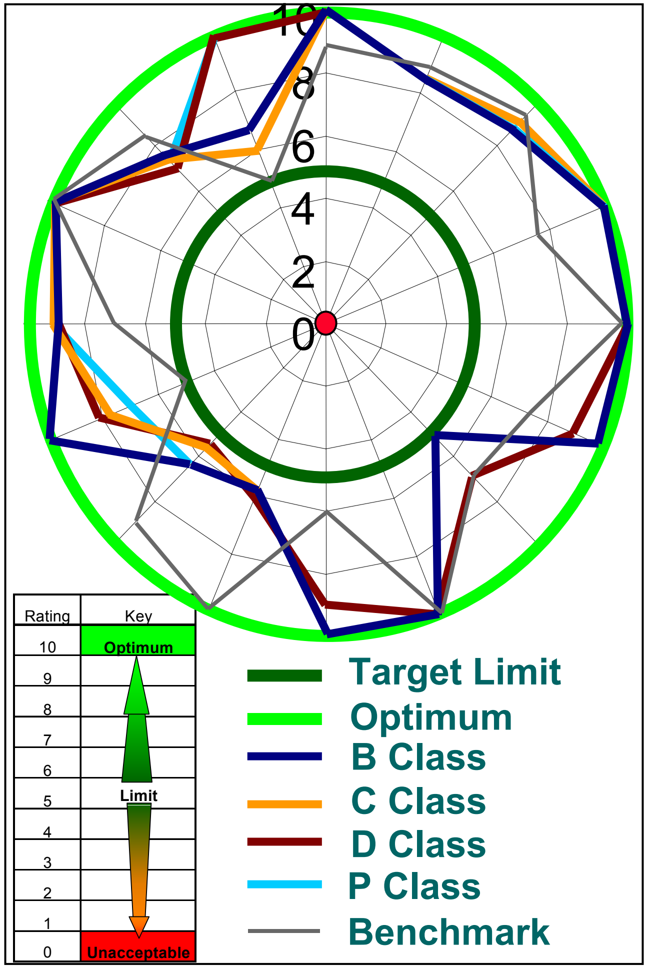
- The Strut & Links system was evaluated against the same design criteria as the Benchmarking Phase, including:
  - Potential Technical Development
  - Potential for System/Component Integration
  - System Image / Marketability
  - Structural Efficiency & Elegance
- The ULSAS solution matches the Benchmark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

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS P	BENCHMARK E CLASS
Design	7.5	7.5

STRUT & LINKS: PERFORMANCE

STRUT & LINKS





- The Strut & Links solution demonstrates good levels of performance.
- The performance of the Strut & Links falls within the target acceptance limits for every criteria.
- Overall score is higher than the Benchmark for Ride & Handling and matches that for NVH.

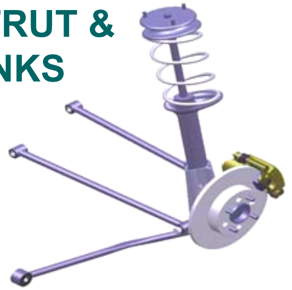
SUMMARY OF OVERALL SCORES & RATINGS

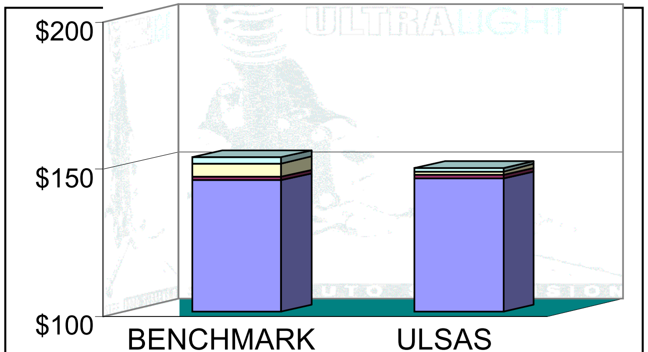
	ULSAS P	BENCHMARK E CLASS
Ride and Handling	7.4	6.5
Refinement (NVH)	6.5	6.5

STRUT & LINKS: COST

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS





(US$)	Struts & Links	
	Benchmark E Class	ULSAS P Class
PIECE COST	**$144.5**	**$145.1**
TOTAL TOOLING COST ($,000)	**$2,180**	**$2,283**
5 YEAR Volume (Assumptions)	2,000,000	2,000,000
TOOLING COST	$1.1	$1.1
TOTAL SYSTEM COST	$145.6	$146.2
SYSTEM ASSY		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Assembly Mins	6.17	1.92
SYSTEM ASSEMBLY COST	$4.52	$1.41
VEHICLE FITTING		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Fitting Mins	2.93	1.33
VEHICLE FITTING COST	$2.15	$0.98

Total Cost ($)	**$152.3**	**$148.6**
Cost Saving($)		$3.7
Cost Saving %		**2%**

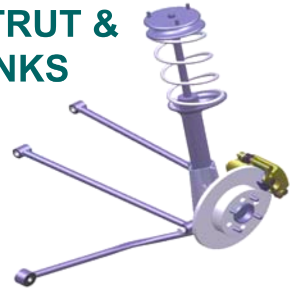
- The cost of the ULSAS solution compares favourably to the Benchmarked suspension.
- For both the ULSAS solution and the Benchmark system, the dominant factor is the piece cost of the components and sub-assemblies.
- Overall score in this area is slightly higher than the Benchmark.
- Reduction in assembly time is due mainly to greater levels of parts integration in the ULSAS design.

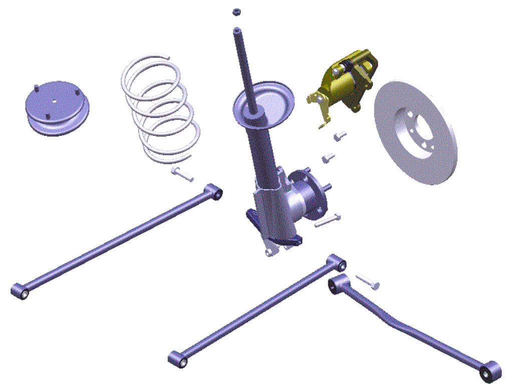
SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS P	BENCHMARK E CLASS
Cost	8.7	8.5

STEEL AUTO SUSPENSION

STRUT & LINKS: MANUFACTURING

STRUT & LINKS





Cost of ULSAS Solutions Vs Benchmark Vehicles		
(US$)	Struts & Links	
	Benchmark E Class	ULSAS P Class
SYSTEM ASSY		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Assembly Mins	6.17	1.92
SYSTEM ASSEMBLY COST	$4.52	$1.41
VEHICLE FITTING		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Fitting Mins	2.93	1.33
VEHICLE FITTING COST	$2.15	$0.98
Total Cost ($)	**$6.7**	**$2.4**
Cost Saving($)		$4.3
Cost Saving %		**64%**

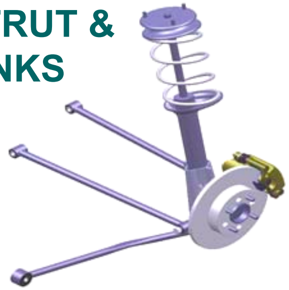
- The ULSAS solution compares favourably with the Benchmarked system in terms of assembly and fitting times.
- An appropriate level of manufacturing feasibility has been taken into account.
- Overall score in this area exceeds the Benchmark.

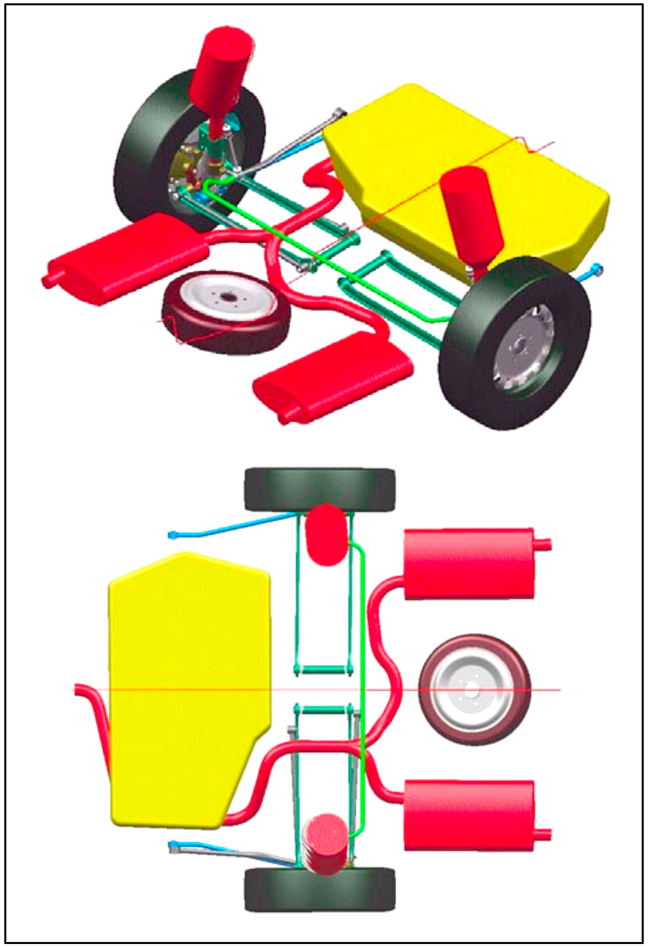
SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS P	BENCHMARK E CLASS
Manufacturing	8.1	8

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS: PACKAGING

STRUT & LINKS



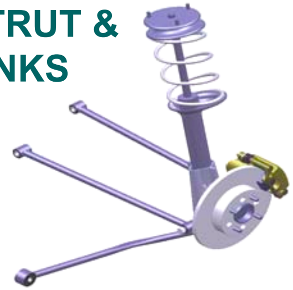


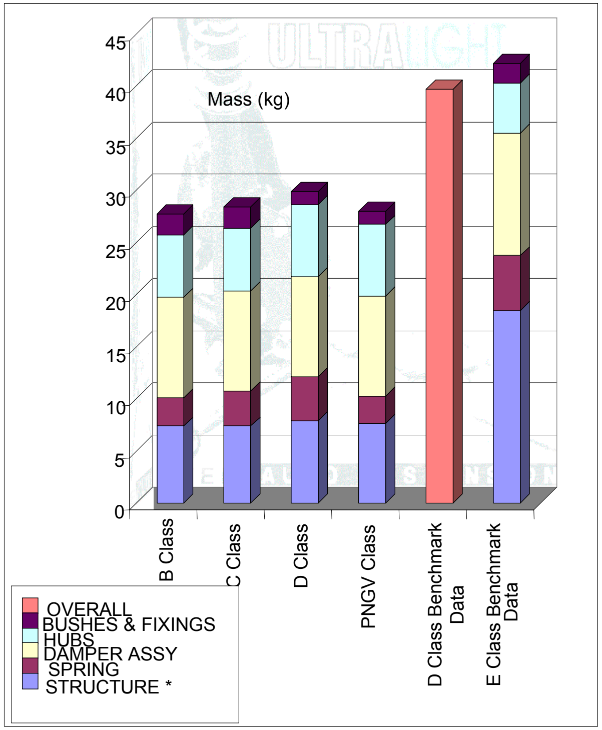
- The ULSAS solution matches the underfloor layout of the Benchmark vehicle well.
- The interior space package of the ULSAS solution is comparable with that of the Benchmarked vehicle.
- Overall score for Systems Packaging matches the Benchmark.
- The score for Interior Space matches the Benchmark.

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS P	BENCHMARK E CLASS
System Packaging	7	7
Interior Space	7.5	7.5

STRUT & LINKS: MASS

STRUT & LINKS





* Structure includes knuckle and links

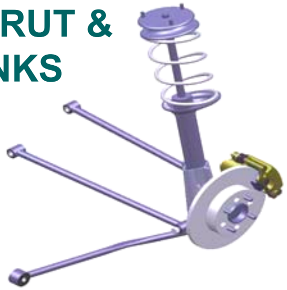
- Both the ULSAS solutions demonstrate a good mass reduction compared to the Benchmarked systems.
- The mass savings of the structural elements of the system alone are even more pronounced.
- Overall score for system mass is therefore significantly higher than the Benchmark value.

Mass Of ULSAS Solutions Vs Benchmark Vehicles					
Description	**B**	**C**	**D**	**E**	**P**
Benchmark (Kg)			**39.70**	**42.10**	
ULSAS Solution (Kg)	**27.77**	**28.37**	**29.87**		**27.97**
Saving vs Benchmark			**25%**		

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS D	BENCHMARK D CLASS
Mass	8.7	7.5

STRUT & LINKS: SYSTEM PHILOSOPHY

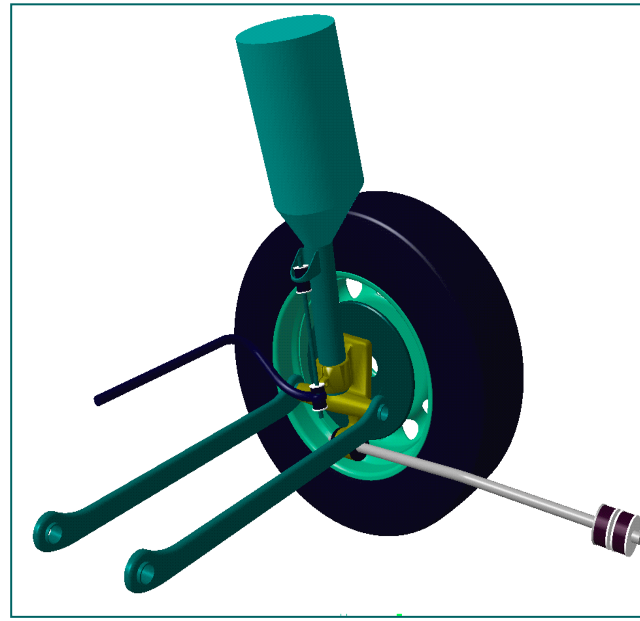
STRUT & LINKS

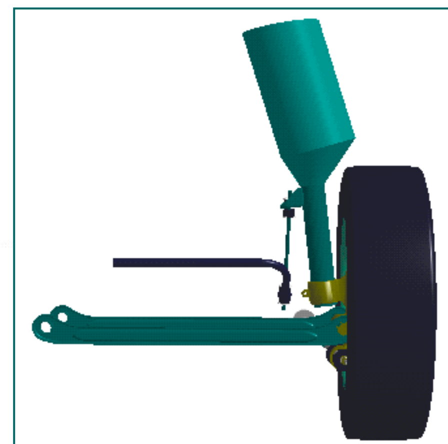


In recent years the market utilisation of independent rear suspension mechanisms has increased. One common system to be employed is referred to as the Strut & Links System. This system utilises a linkage system with a coil spring and damper unit rigidly attached to the hub carrier.

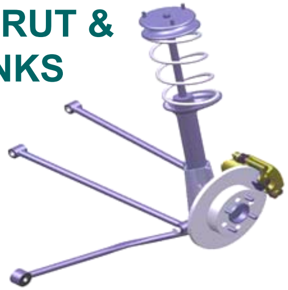
The Strut & Links suspension concept can be engineered in a variety of configurations. Consequently, it is not appropriate to review the designs on a generic basis. Each configuration has its own advantages and disadvantages and specific versions of each configuration can also have different dynamic properties.

The systems encountered during this review comprise longitudinal links, twin lateral links and strut assemblies. This arrangement provides improved flexibility in the design of the static geometry and kinematic behavior of the road wheel when compared with other systems. The locations of the mountings of the lateral links have a strong influence on the camber change, roll centre height and the toe change behavior of the system. The locations of the mountings of the longitudinal links have a strong influence on the bump and rebound motion of the wheel and hence the control of pitch. Compliant bushes are typically used in the attachment of the links to both the strut unit and the body structure.



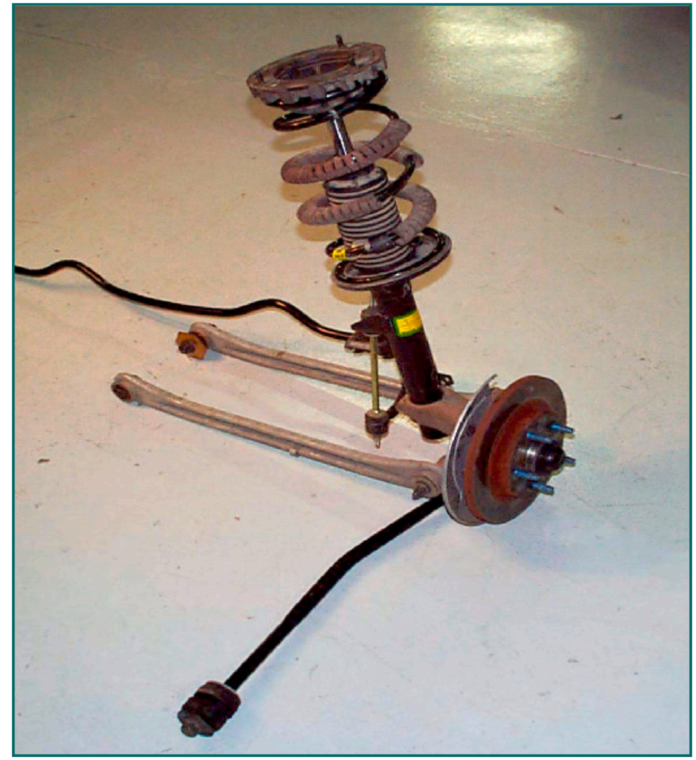


STRUT & LINKS: SYSTEM PHILOSOPHY



The use of a strut unit has a number of advantages. These advantages are most easily demonstrated by considering the load inputs to the wheel in each of the primary directions.

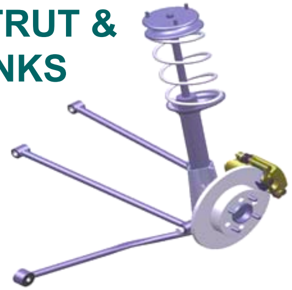
When the system is subjected to vertical load inputs, the loading is transmitted through the wheel and the wheel bearing into the hub carrier and then directly into the spring and damper units. The displacements of the spring and the damper are directly comparable with those of the wheel, providing spring and damper ratios close to one. This avoids load magnification within the system and allows the more refined control of the bump and rebound behavior of the wheel. As a result of the packaging constraints between the strut unit and the tyre, the strut is subjected to bending loads. The bending loads result in the side loading of the damper which increases the friction levels within the damper unit. This can degrade the system NVH and dynamic performance. The magnitude of the side loading can be partially offset by mounting the coil spring at an angle to the damper axis. The load path into the vehicle structure is primarily through the strut top. This removes the need for a substantial structure to support the lateral and longitudinal links.



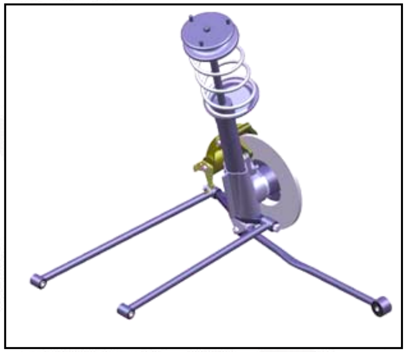
Typical example of a Strut & Links Rear Suspension System

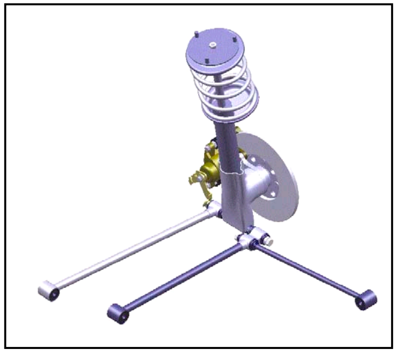
ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS



STRUT & LINKS: SYSTEM PHILOSOPHY





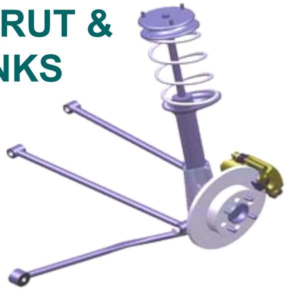
When the system is subjected to longitudinal loading during braking or traction events a torque is applied to the hub carrier. This torque is reacted within the strut assembly. The longitudinal location of the wheel is maintained by the longitudinal link which is subjected to axial tensile and compressive loading. The longitudinal compliance is primarily a function of the stiffness of the mountings attaching the longitudinal link to the body and the link to the strut. The stiffness of the mountings of the lateral links also has an influence on the longitudinal compliance and steer behaviour of the system. When the strut unit moves in the longitudinal direction the outboard ends of the lateral links must also move. If the lateral links form the arms of a parallelogram, i.e. a parallel motion configuration, the steer effect on the strut unit is minimised. If desired the steer behaviour during braking and traction events can be tuned by the adjustment of the relative lengths of the links and the inboard position of the link mounting.

During cornering events, the system and strut unit are subjected to lateral loading. The lateral location of the wheel is maintained by the lateral links. The relative length and loading on each link and the compliance of each link mounting are used to control the lateral compliance steer behaviour of the wheel. The methods used to adjust the relative lengths and inboard locations of the links are varied and include turnbuckle arrangements and cam bolt fixings.

In each of the loading conditions considered the links are primarily subjected to axial tensile and compressive loading. Some bending is experienced, however the bending moments are low and are a function of the torsional deflection and torsional stiffness of the mounting bushes at the ends of each link. This loading regime allows the development of relatively simple and low cost designs for the links. By using relatively long links the interactions between the technical parameters that control the longitudinal and lateral compliance can be minimised. This provides the opportunity to optimise the overall compliance behaviour of the system.

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS



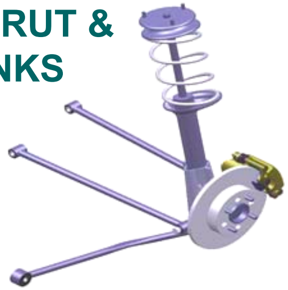
STRUT & LINKS: SYSTEM PHILOSOPHY

In addition to the concerns with the side loading of the damper, the main disadvantages of a multi link and strut system arise from the structural and package requirements. The mounting of a strut unit requires structural elements high in the body. The upper mounting reacts all of the spring, damper and in most cases the bump stop loads. This places considerable demands on the local design of the structure and can also lead to difficulties with the design of the mounting and noise transmission. A benefit from the adoption of a strut based system is the wide spacing of the attachment points of the links to the vehicle. This arrangement allows the lateral and longitudinal loads to be distributed around the body structure. This can be beneficial to the system NVH performance. The high position of the strut top mounting and the packaging of the strut intrudes into the occupant and boot space of the vehicle.

The structure supporting the lateral link to body mounting can be engineered in a number of ways. In its most simple form the brackets supporting the links can be produced as an integral part of the body in white structure. However the manufacturing tolerances associated with bracket positioning have a direct effect on the performance of the suspension mechanism, in particular the compliance and steer behaviour. Consequently length and lateral position adjustment features may be required on the lateral links to ensure consistency of performance from one side of the vehicle to the other and also from one vehicle to the next. The introduction of a subframe structure can reduce the manufacturing variation. The subframe can be either rigidly mounted or resiliently mounted. A rigidly mounted subframe acts as an extension of the body in white. It can be used to modify the stiffness of the body structure and also to re-distribute the suspension loading into the structure. A resiliently mounted subframe provides additional opportunities to tune the noise isolation and compliance behaviour of the suspension system. The primary loading on the subframe system results from the lateral loading on the suspension system. The vertical loading is reacted by the strut unit and the longitudinal loading is reacted by the longitudinal link.

A notable advantage of a multi link and strut based system is the ease with which such a mechanism can be adapted to suit either a driven or a non driven rear axle. The use of a subframe can be advantageous in such instances, as it can provide the necessary additional support features for a differential.

STRUT & LINKS



STRUT & LINKS: SYSTEM PHILOSOPHY

Basic Forces Acting on the Suspension

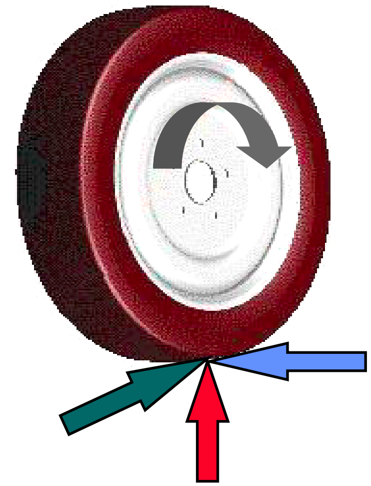
3 primary forces at tyre contact patch

- **Longitudinal**
- **Lateral**
- **Vertical**

Additional Torque Loading

- **From Braking (Combined with a Longitudinal Force**

Also acceleration loadings on RWD



To better understand the complex loading in the suspension system we must first look at the fundamental forces that are generated at the tyre contact patch. These forces act in the three primary directions as shown and there is an additional torque loading from brake reaction, there are also torque's generated about the other two axes due to offset loading, trail, etc but these are of less significance. From these forces we can look at the movements in the suspension system and also examine how the forces are controlled by the suspension system.

Movements

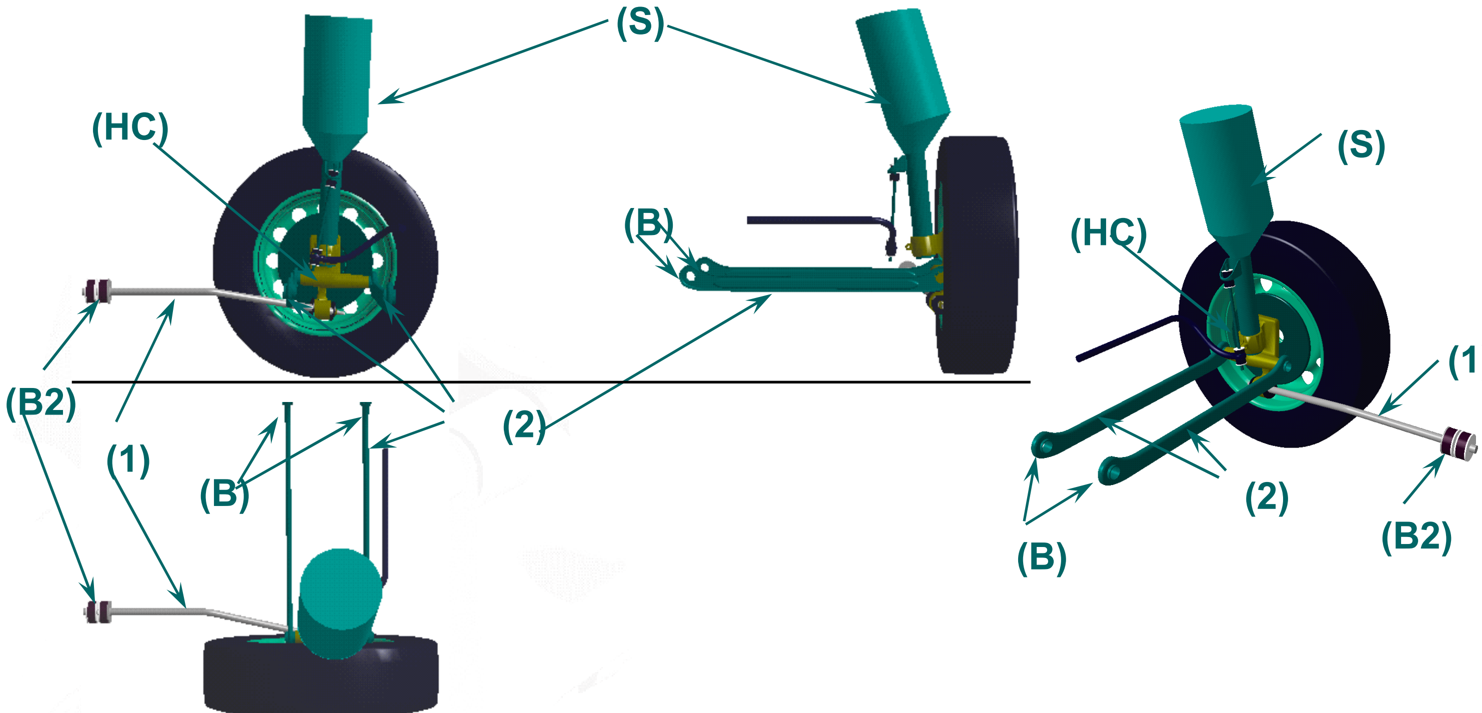
- Longitudinal
- Lateral
- Ride
- Steer
- Camber
- Rolling

Forces

- Longitudinal
- Lateral
- Vertical
- Braking/ Acceleration

STRUT & LINKS: SYSTEM PHILOSOPHY

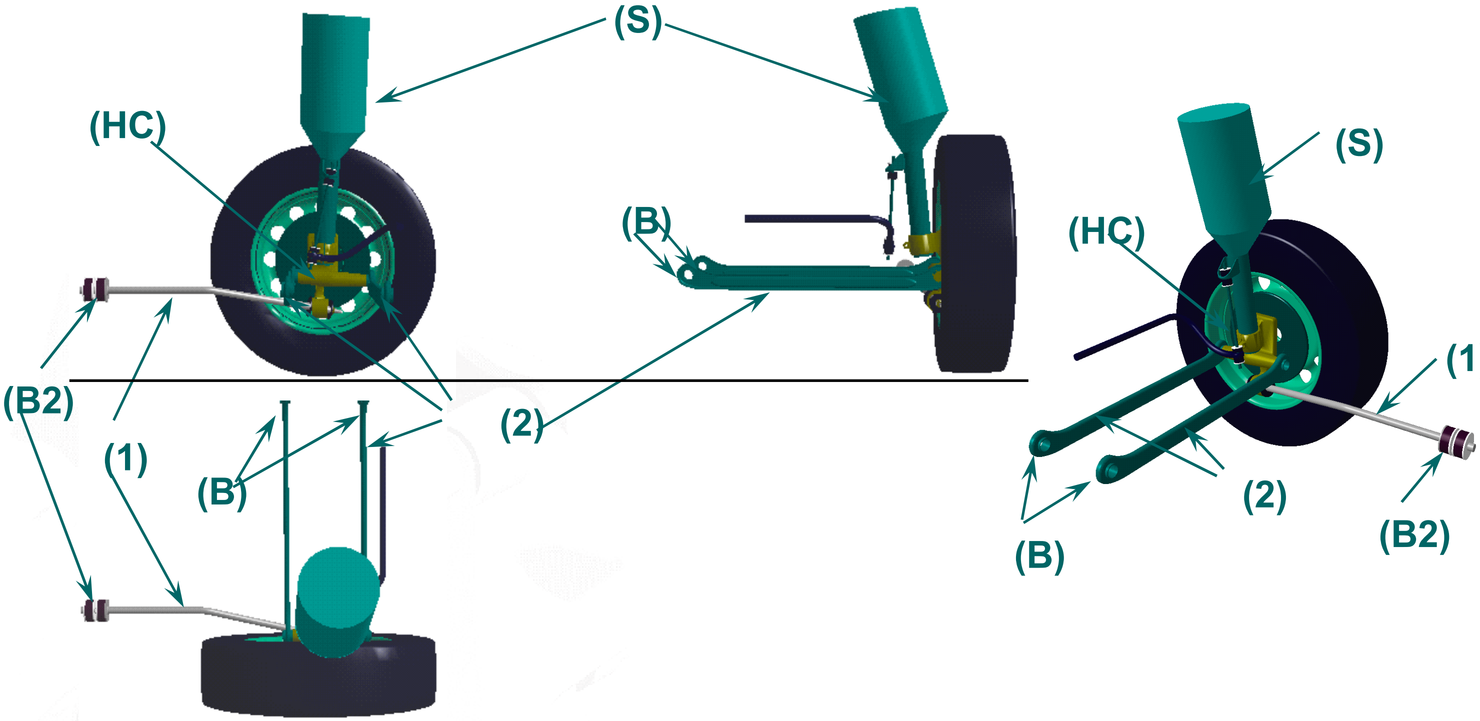
STRUT & LINKS



Movements

Compliance:- Deflection and articulation of bushes (B) and tension in arm (1) with deflection of . bush (B2) allows fore and aft movement of the wheel.
Track:- Radial stiffness of bushes (B) controls track change due to lateral forces. . Interactions of links (2) and sliding action of the strut unit (S) control track change . during suspension travel.
Ride:- The wheel moves vertically by links (1) & (2) rotating about bushes (B) & (B2) and . compressing the strut unit (S).
Steer:- Steer is controlled by the links (2) during changes in suspension travel and . longitudinal forces and by bushes (B) under lateral forces.
Camber:- Camber is controlled by the interactions of links (2) and sliding action of the strut . unit (S) during changes in suspension travel and by bushes (B) under lateral forces.
Rolling:- The wheel is able to rotate on bearings in the hub carrier (HC).

STRUT & LINKS: SYSTEM PHILOSOPHY



Forces

Longitudinal:- Forces are resisted by tension and compression loads in links (1) & (2) and bending in strut unit (S).

Lateral:- Forces are resisted by tension and compression loads in links (2) and bending in the strut unit (S).

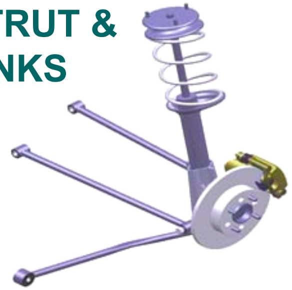
Vertical:- Forces are resisted by loads in the strut unit (S) by tension and compression loads in links (2) and bending in the strut unit (S).

Braking:- Torque is taken by tension in arm (1) and bending in strut unit (S).

STRUT & LINKS: MASS

B & C Class

STRUT & LINKS



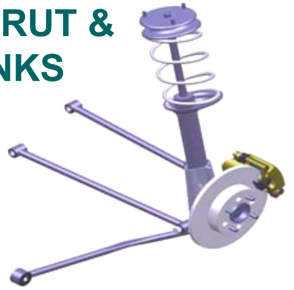
PARTS LIST			ULSAS B Class			ULSAS C Class		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, STRUT & LINKS	1	**27.77**			**28.37**		
2	WELDED ASSY, STRUT UNIT RH	1	**8.40**	**8.397**	8.397	**8.40**	**8.397**	8.397
3	WELDED ASSY, STRUT UNIT LH	1	**8.40**	**8.397**	8.397	**8.40**	**8.397**	8.397
4	KNUCKLE	2			1.331			1.331
5	KNUCKLE FORGING	2			0.266			0.266
6	HUB & BEARING UNIT RH	1			3.000			3.000
7	HUB & BEARING UNIT LH	1			3.000			3.000
8	DAMPER ASSEMBLY	2			3.800			3.800
9	DISC BRAKE	2						
10	CALIPER, BRAKE	2						
11	SPRING	2	**2.75**	**1.373**		**3.34**	**1.672**	
12	UPPER MOUNTING - STRUT	2	**2.00**	**1.000**		**2.00**	**1.000**	
13	ASSY, FORWARD LINK	2	**2.50**	**1.250**	1.250	**2.50**	**1.250**	1.250
14	LONGITUDINAL LINK	2						
15	BUSH HOUSING	2						
16	DOUBLE JOINT ASSY	2						
17	FORWARD LATERAL LINK	2						
18	LATERAL LINK BUSH HOUSING	2						
19	ASSY, REAR LATERAL LINK	2	**1.70**	**0.850**	0.850	**1.70**	**0.850**	0.850
20	REAR LATERAL LINK	2						
21	LATERAL LINK BUSH HOUSING	2						
22	LATERAL LINK OUTER JOINTS	2						
23	VARIOUS BUSHES AND JOINTS	1	**1.56**	**1.556**		**1.56**	**1.556**	
24	ASSORTED FIXINGS	1	**0.48**	**0.477**		**0.48**	**0.477**	

39.7 Ref D Class Mass

STRUT & LINKS: MASS
D Class

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS



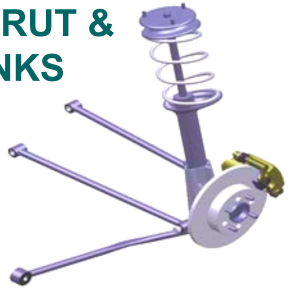
PARTS LIST			ULSAS D Class		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, STRUT & LINKS	1	**29.87**		
2	WELDED ASSY, STRUT UNIT RH	1	**9.41**	**9.408**	9.408
3	WELDED ASSY, STRUT UNIT LH	1	**9.41**	**9.408**	9.408
4	KNUCKLE PRESSING	2			0.700
5	KNUCKLE PRESSING	2			0.700
6	KNUCKLE FORGING	2			0.641
7	LOWER BRACKET	2			0.137
8	HUB & BEARING UNIT RH	1			3.430
9	HUB & BEARING UNIT LH	1			3.430
10	DAMPER ASSEMBLY	2			3.800
11	DISC BRAKE	2			
12	CALIPER, BRAKE	2			
13	SPRING	2	**4.21**	**2.107**	
14	UPPER MOUNTING - STRUT	2	**2.00**	**1.000**	
15	ASSY, LONGITUDINAL LINK	2	**1.05**	**0.524**	0.524
16	LONGITUDINAL LINK	2			0.524
17	BUSH HOUSING	2			
18	BUSH HOUSING	2			
19	ASSY, FORWARD LATERAL LINK	2	**1.29**	**0.643**	0.643
20	FORWARD LATERAL LINK	2			
21	LATERAL LINK BUSH HOUSING	4			
22	ASSY, REAR LATERAL LINK	2	**1.26**	**0.628**	0.628
23	REAR LATERAL LINK	2			
24	LATERAL LINK BUSH HOUSING	4			
25	VARIOUS BUSHES AND JOINTS	1	**0.71**	**0.712**	
26	ASSORTED FIXINGS	1	**0.54**	**0.540**	

THE D CLASS BENCHMARK MASS IS 39.7 Kg

STEEL AUTO SUSPENSION

STRUT & LINKS: MASS
P Class

STRUT & LINKS



PARTS LIST			ULSAS P Class			E Class Benchmark Data		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, STRUT & LINKS	1	27.97			42.10		
2	WELDED ASSY, STRUT UNIT RH	1	9.41	9.408	9.408	10.98	10.980	10.980
3	WELDED ASSY, STRUT UNIT LH	1	9.41	9.408	9.408	10.98	10.980	10.980
4	KNUCKLE PRESSING	2			0.700			4.050
5	KNUCKLE PRESSING	2			0.700			4.050
6	KNUCKLE FORGING	2			0.641			
7	LOWER BRACKET	2			0.137			
8	HUB & BEARING UNIT RH	1			3.430			2.400
9	HUB & BEARING UNIT LH	1			3.430			2.400
10	DAMPER ASSEMBLY	2			3.800			4.530
11	DISC BRAKE	2						
12	CALIPER, BRAKE	2						
13	SPRING	2	2.61	1.303		5.22	2.610	
14	UPPER MOUNTING - STRUT	2	2.00	1.000		2.66	1.330	
15	ASSY, LONGITUDINAL LINK	2	1.06	0.528	0.528	4.20	2.100	
16	LONGITUDINAL LINK	2			0.528			
17	BUSH HOUSING	2						
18	BUSH HOUSING	2						
19	ASSY, FORWARD LATERAL LINK	2	1.08	0.538	0.538	3.10	1.550	
20	FORWARD LATERAL LINK	2						
21	LATERAL LINK BUSH HOUSING	4						
22	ASSY, REAR LATERAL LINK	2	1.17	0.584	0.584	3.10	1.550	
23	REAR LATERAL LINK	2						
24	LATERAL LINK BUSH HOUSING	4						
25	VARIOUS BUSHES AND JOINTS	1	0.71	0.712		1.31	1.305	
26	ASSORTED FIXINGS	1	0.54	0.540		0.55		

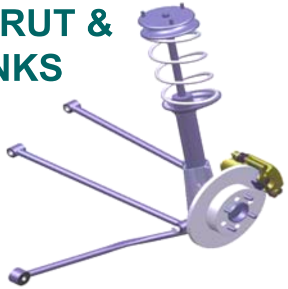
39.7 Ref D Class Mass

STRUT & LINKS: COST

P Class

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

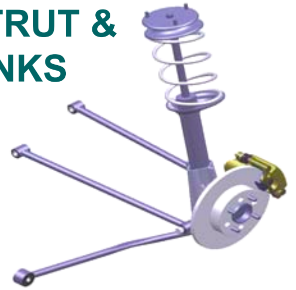
STRUT & LINKS



PARTS LIST			ULSAS P Class			E Class Benchmark Data		
ITEM No.	DESCRIPTION	QTY Veh	PART COST	SYSTEM COST	TOOLING COST	PART COST	SYSTEM COST	TOOLING COST
1	ASSEMBLY, STRUT & LINKS	1		145.08	2283.00		144.50	2180.00
2	WELDED ASSY, STRUT UNIT RH	1	$10.5	$10.5	$750	$22.5	$22.5	$207
3	WELDED ASSY, STRUT UNIT LH	1	$10.5	$10.5	$750	$22.5	$22.5	$207
4	KNUCKLE PRESSING	2						
5	KNUCKLE PRESSING	2						
6	KNUCKLE FORGING	2						
7	LOWER BRACKET	2						
8	HUB & BEARING UNIT RH	1	$19.0	$19.0		$8.0	$8.0	$75
9	HUB & BEARING UNIT LH	1	$19.0	$19.0		$8.0	$8.0	$75
10	DAMPER ASSEMBLY	2	$18.5	$37.0	$330	$24.1	$48.2	$528
11	DISC BRAKE	2						
12	CALIPER, BRAKE	2						
13	SPRING	2	$5.6	$11.2				
14	UPPER MOUNTING - STRUT	2	$2.8	$5.6	$200			
15	ASSY, LONGITUDINAL LINK	2	$4.7	$9.4	$148	$3.1	$6.2	$363
16	LONGITUDINAL LINK	2						
17	BUSH HOUSING	2						
18	BUSH HOUSING	2						
19	ASSY, FORWARD LATERAL LINK	2	$4.2	$8.4	$53	$4.0	$8.0	$363
20	FORWARD LATERAL LINK	2						
21	LATERAL LINK BUSH HOUSING	4						
22	ASSY, REAR LATERAL LINK	2	$4.2	$8.4	$53	$4.0	$8.0	$363
23	REAR LATERAL LINK	2						
24	LATERAL LINK BUSH HOUSING	4						
25	VARIOUS BUSHES AND JOINTS	1		$3.0			$6.7	
26	ASSORTED FIXINGS	1		$3.0			$6.4	

STRUT & LINKS: MATERIAL
B & C Class

STRUT & LINKS



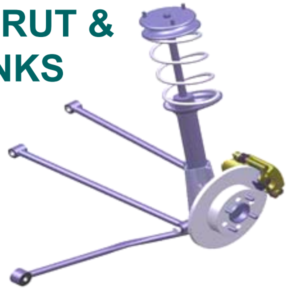
PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPA)
1	ASSEMBLY, STRUT & LINKS	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, STRUT UNIT RH	1	FABRICATION (items 4-10)		
3	WELDED ASSY, STRUT UNIT LH	1	FABRICATION (items 4-10)		
4	KNUCKLE	2	HYDROFORMING	3.5	500
5	KNUCKLE FORGING	2	FORGING	na	500
6	HUB & BEARING UNIT RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
7	HUB & BEARING UNIT LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
8	DAMPER ASSEMBLY	2	INCL SPRING SEAT & BUMP RUBBER	See note	
9	DISC BRAKE	2	SOLID, CAST IRON		
10	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE MECHANISM		
11	SPRING	2	SHEAR STRESS LIMIT 1300MPa	Ø 10.6 (B) Ø 11.4 (C)	1300
12	UPPER MOUNTING - STRUT	2	RUBBER ISOLATED BUSH		
13	ASSY, FORWARD LINK	2	FABRICATION (items 16 - 21)		
14	LONGITUDINAL LINK	2	TUBE	Ø 20 x 2	250
15	BUSH HOUSING	2	TUBE		250
16	DOUBLE JOINT ASSY	2	TWIN SPHERICAL BUSH ASSY		
17	FORWARD LATERAL LINK	2	TUBE	Ø 20 x 2	250
18	LATERAL LINK BUSH HOUSING	2	TUBE		250
19	ASSY, REAR LATERAL LINK	2	FABRICATION (item 23 & 24)		
20	REAR LATERAL LINK	2	TUBE	Ø 20 x 2	250
21	LATERAL LINK BUSH HOUSING	2	TUBE		250
22	LATERAL LINK OUTER JOINTS	2	SPHERICAL BUSH ASSY		
23	VARIOUS BUSHES AND JOINTS	1	RUBBER BUSHES & SPHERICAL JOINTS		
24	ASSORTED FIXINGS	1	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

STRUT & LINKS: MATERIAL
D Class

STRUT & LINKS



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPA)
1	ASSEMBLY, STRUT & LINKS	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, STRUT UNIT RH	1	FABRICATION (items 4-10)		
3	WELDED ASSY, STRUT UNIT LH	1	FABRICATION (items 4-10)		
4	KNUCKLE PRESSING	2	PRESSING	4	500
5	KNUCKLE PRESSING	2	PRESSING	4	500
6	KNUCKLE FORGING	2	FORGING	na	500
7	LOWER BRACKET	2	BLANK & FOLD	4	250
8	HUB & BEARING UNIT RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
9	HUB & BEARING UNIT LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
10	DAMPER ASSEMBLY	2	INCL SPRING SEAT & BUMP RUBBER	See note	
11	DISC BRAKE	2	SOLID, CAST IRON		
12	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE MECHANISM		
13	SPRING	2	SHEAR STRESS LIMIT 1300MPa	Ø 12.30	1300
14	UPPER MOUNTING - STRUT	2	RUBBER ISOLATED BUSH		
15	ASSY, LONGITUDINAL LINK	2	FABRICATION (items 16,17 & 18)		
16	LONGITUDINAL LINK	2	TUBE	Ø 20 x 2	250
17	BUSH HOUSING	2	TUBE		250
18	BUSH HOUSING	2	TUBE		250
19	ASSY, FORWARD LATERAL LINK	2	FABRICATION (item 20 & 21)		
20	FORWARD LATERAL LINK	2	TUBE	Ø 20 x 2	250
21	LATERAL LINK BUSH HOUSING	4	TUBE		250
22	ASSY, REAR LATERAL LINK	2	FABRICATION (item 23 & 24)		
23	REAR LATERAL LINK	2	TUBE	Ø 20 x 2	250
24	LATERAL LINK BUSH HOUSING	4	TUBE		250
25	VARIOUS BUSHES AND JOINTS	1	RUBBER BUSHES & SPHERICAL JOINTS		
26	ASSORTED FIXINGS	1	NUTS, BOLTS & WASHERS ETC		

Note : Damper Assembly Consists of 4 Main Components

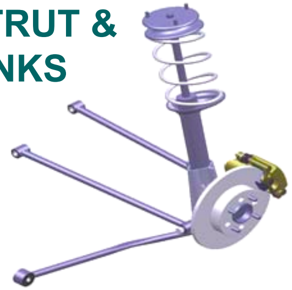
Damper Body:	350 MPa Material
Damper Rod:	Dia 13mm x 3mm tube
Spring Pan:	350 Mpa Material
Bump Stop Rubber:	Polyurethane Material

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS: MATERIAL

P Class

STRUT & LINKS



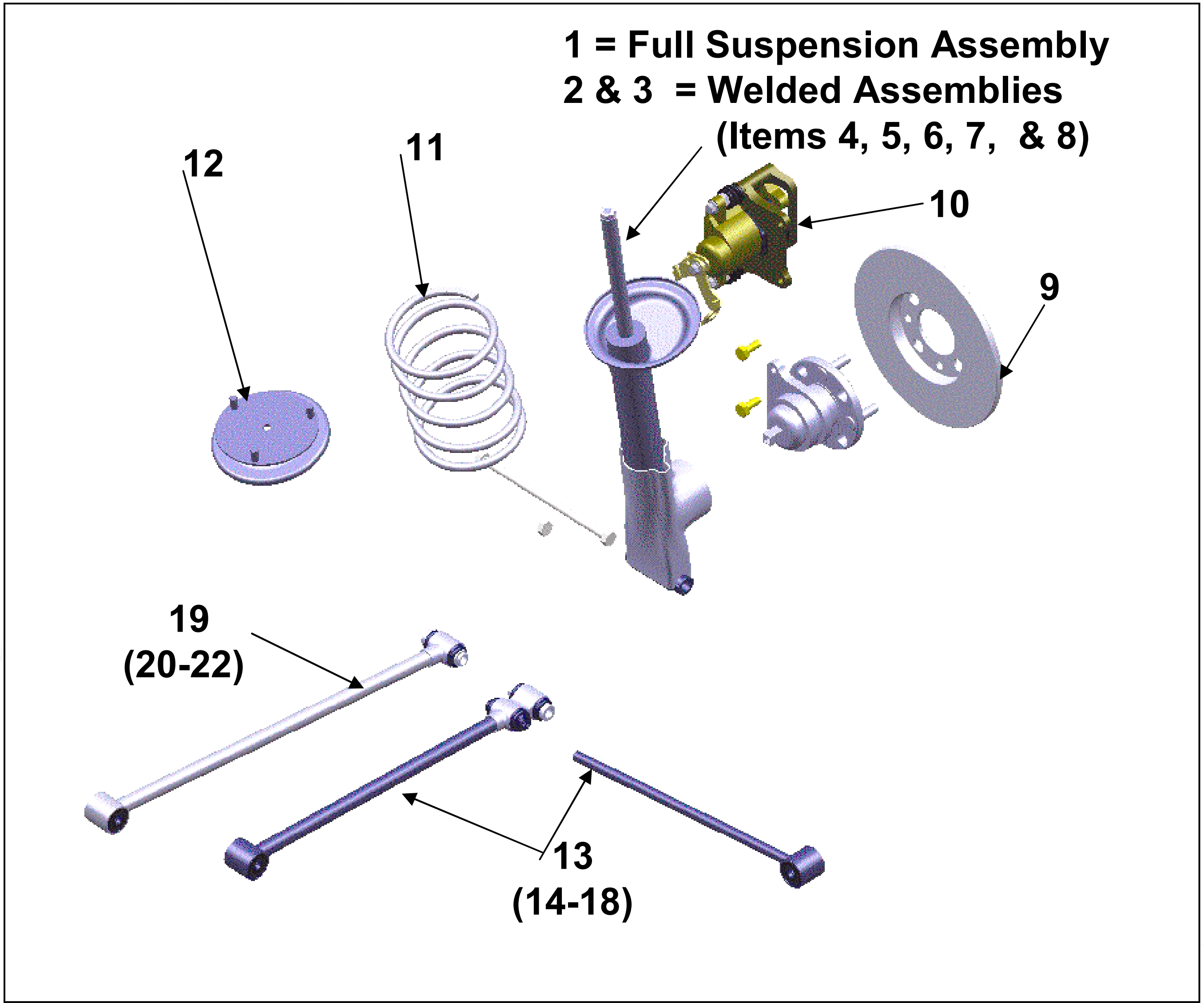
PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPA)
1	ASSEMBLY, STRUT & LINKS	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, STRUT UNIT RH	1	FABRICATION (items 4-10)		
3	WELDED ASSY, STRUT UNIT LH	1	FABRICATION (items 4-10)		
4	KNUCKLE PRESSING	2	PRESSING	4	500
5	KNUCKLE PRESSING	2	PRESSING	4	500
6	KNUCKLE FORGING	2	FORGING	na	500
7	LOWER BRACKET	2	BLANK & FOLD	4	250
8	HUB & BEARING UNIT RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
9	HUB & BEARING UNIT LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
10	DAMPER ASSEMBLY	2	INCL SPRING SEAT & BUMP RUBBER	See note	
11	DISC BRAKE	2	SOLID, CAST IRON		
12	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE MECHANISM		
13	SPRING	2	SHEAR STRESS LIMIT 1300MPa	Ø 10.39	1300
14	UPPER MOUNTING - STRUT	2	RUBBER ISOLATED BUSH		
15	ASSY, LONGITUDINAL LINK	2	FABRICATION (items 16,17 & 18)		
16	LONGITUDINAL LINK	2	TUBE	Ø 20 x 2	250
17	BUSH HOUSING	2	TUBE		250
18	BUSH HOUSING	2	TUBE		250
19	ASSY, FORWARD LATERAL LINK	2	FABRICATION (item 20 & 21)		
20	FORWARD LATERAL LINK	2	TUBE	Ø 20 x 2	250
21	LATERAL LINK BUSH HOUSING	4	TUBE		250
22	ASSY, REAR LATERAL LINK	2	FABRICATION (item 23 & 24)		
23	REAR LATERAL LINK	2	TUBE	Ø 20 x 2	250
24	LATERAL LINK BUSH HOUSING	4	TUBE		250
25	VARIOUS BUSHES AND JOINTS	1	RUBBER BUSHES & SPHERICAL JOINTS		
26	ASSORTED FIXINGS	1	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

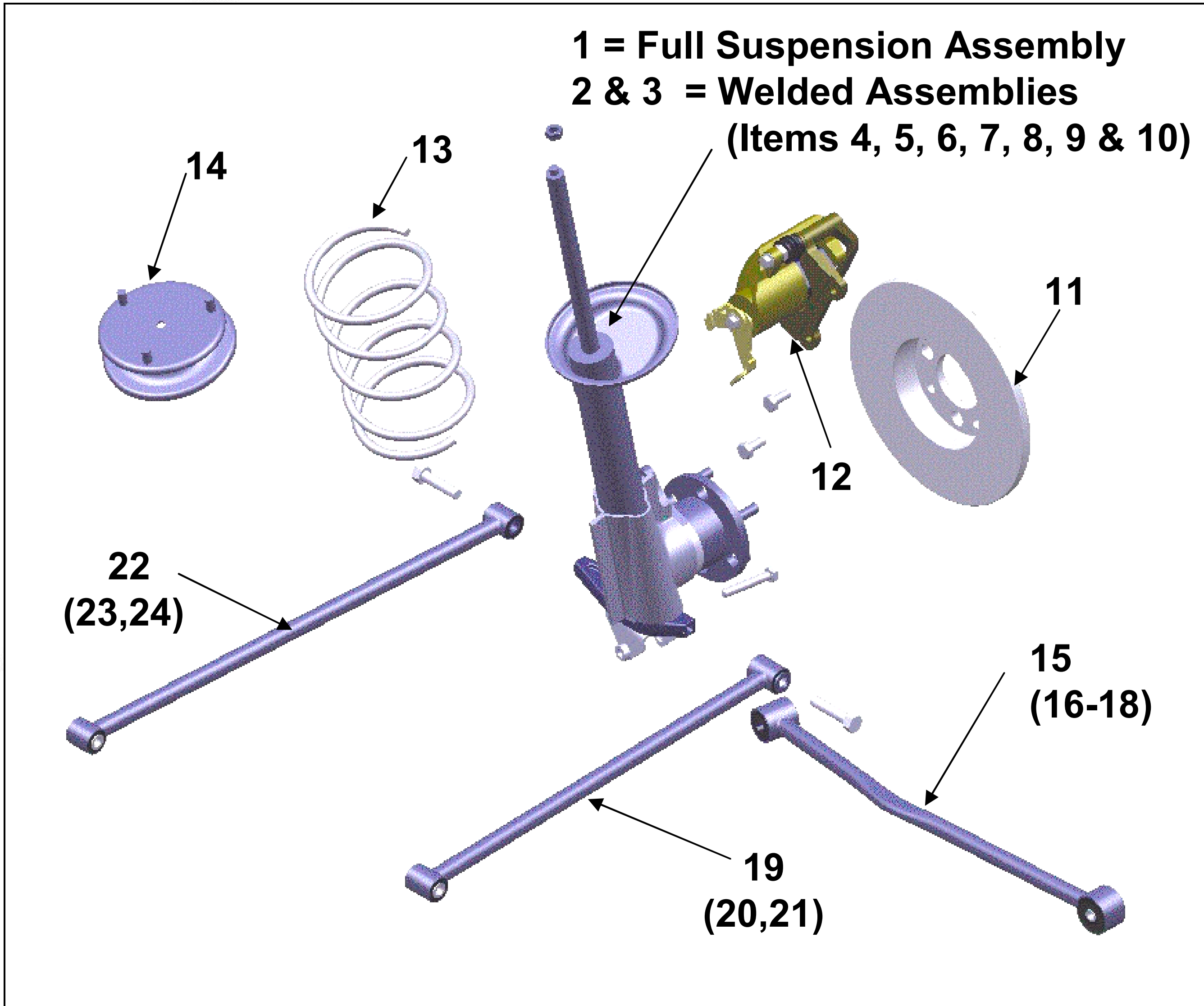
STRUT & LINKS: EXPLODED VIEW

STRUT & LINKS



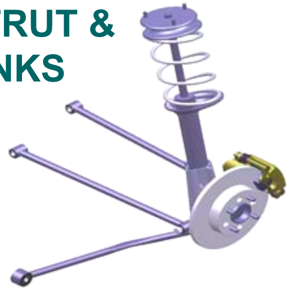
STRUT & LINKS: EXPLODED VIEW

STRUT & LINKS

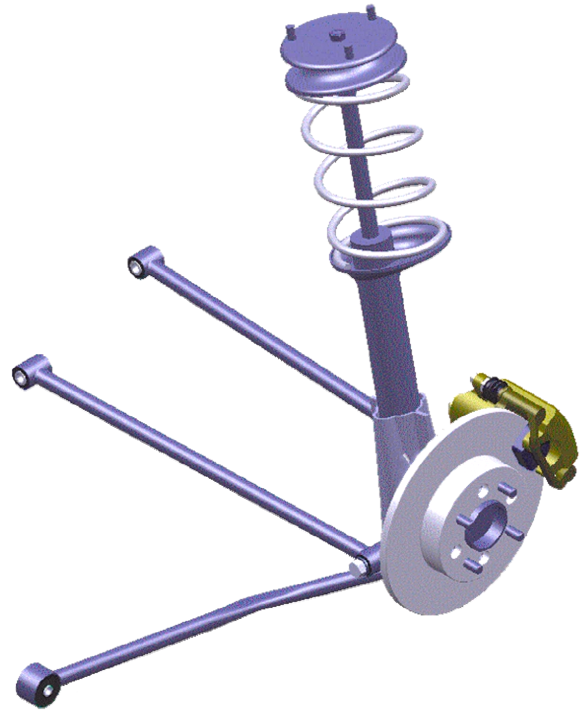


STRUT & LINKS: DESIGN & FEA

STRUT & LINKS



High Strength

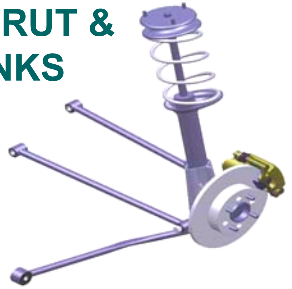


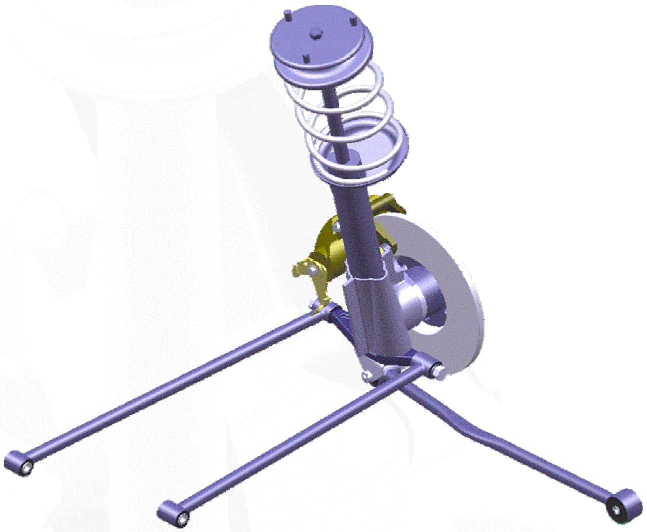
Lightweight

STRUT & LINKS: DESIGN & FEA

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS

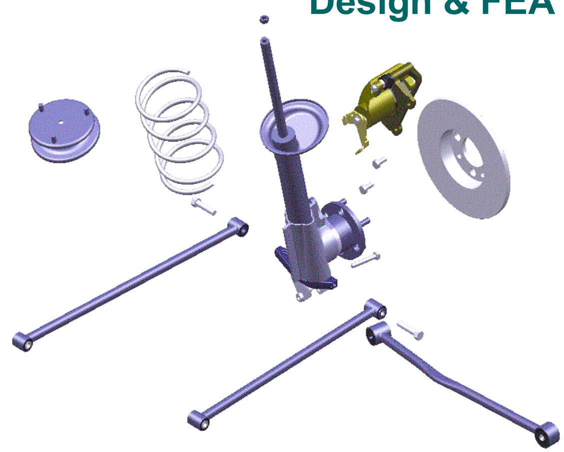




Mass, Cost and Material

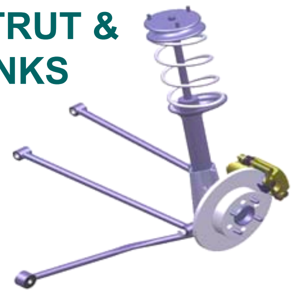
PARTS LIST		
ITEM No.	DESCRIPTION	QTY Veh
1	ASSEMBLY, STRUT & LINKS	1
2	WELDED ASSY, STRUT UNIT RH	1
3	WELDED ASSY, STRUT UNIT LH	1
4	KNUCKLE PRESSING	2
5	KNUCKLE PRESSING	2
6	KNUCKLE FORGING	2

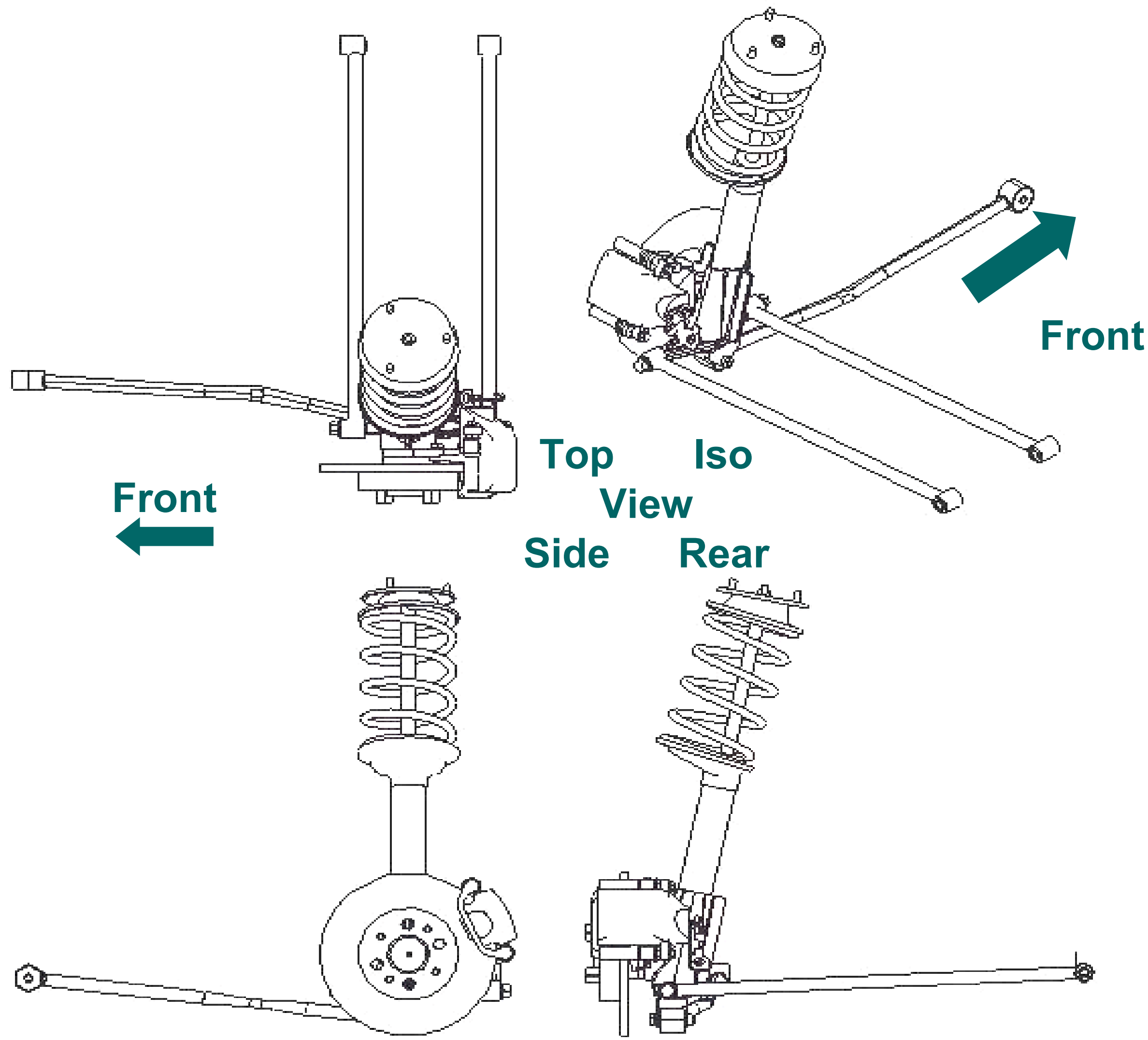
Design & FEA



STRUT & LINKS: DESIGN & FEA

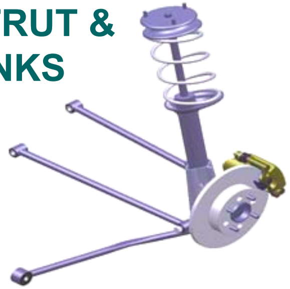
STRUT & LINKS



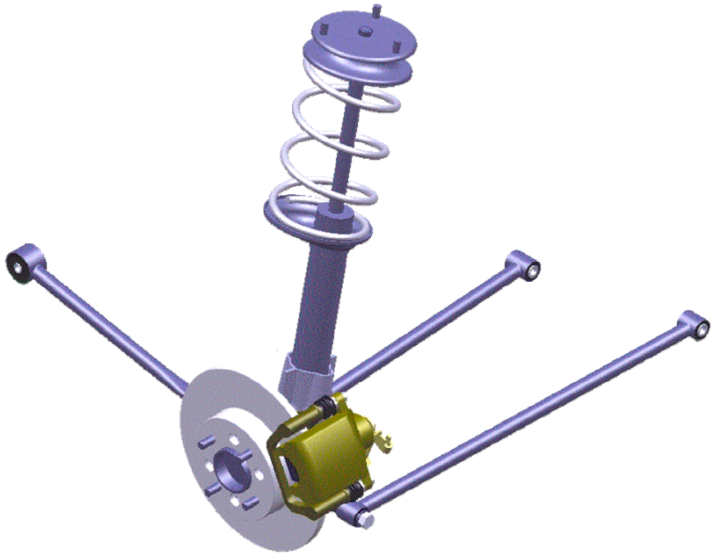


STRUT & LINKS: DESIGN & FEA

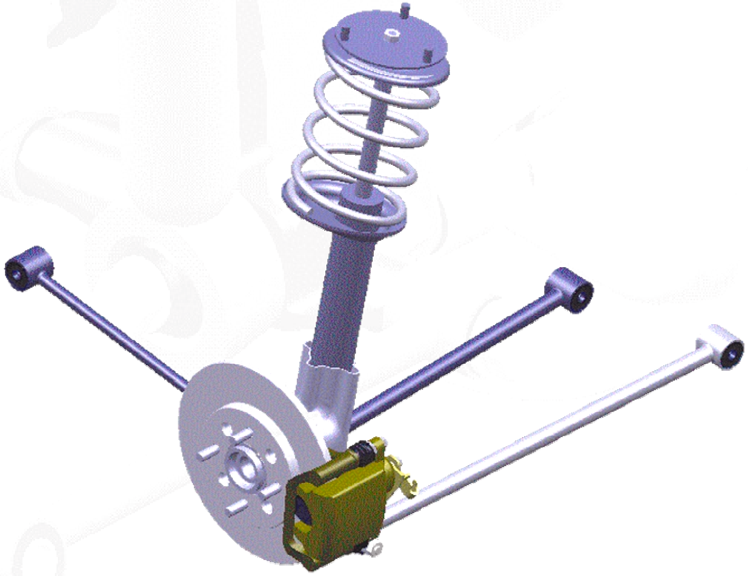
STRUT & LINKS



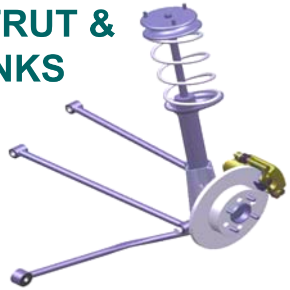
Efficient

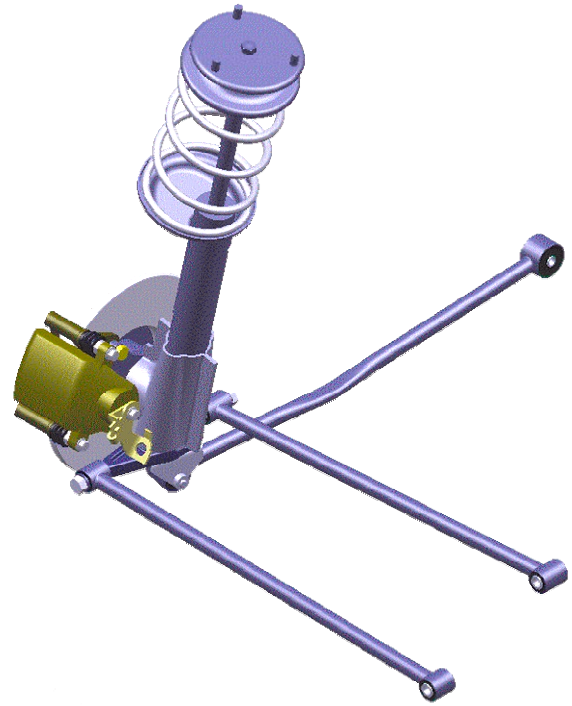


Packagable

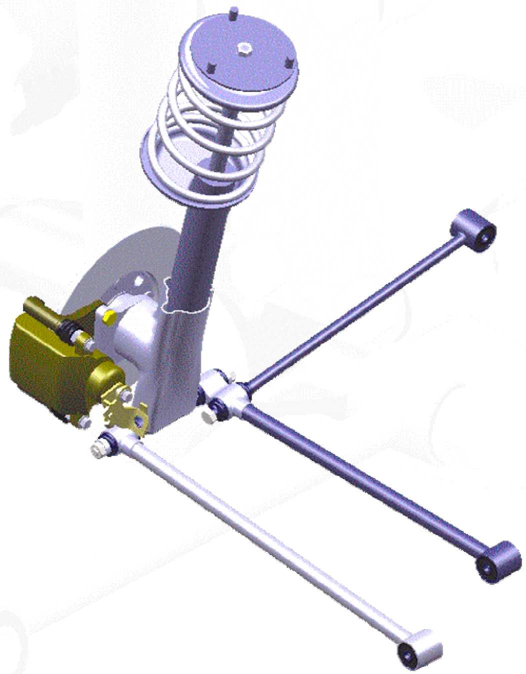


STRUT & LINKS: DESIGN & FEA





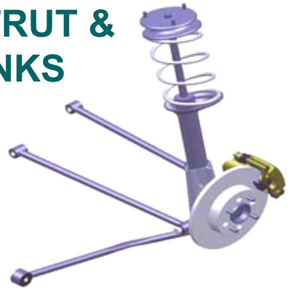
Affordable



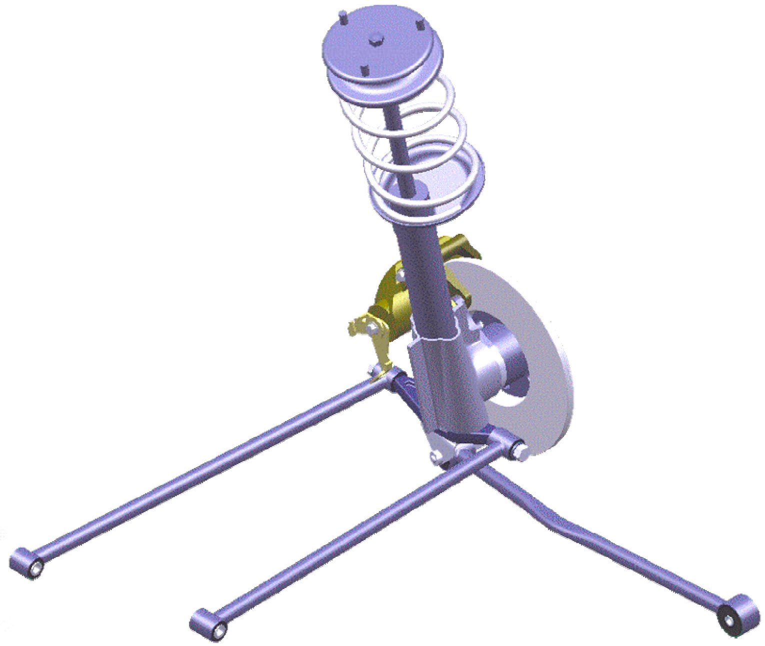
Innovative

STRUT & LINKS: DESIGN & FEA

STRUT & LINKS



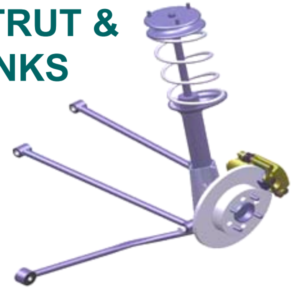
Safe

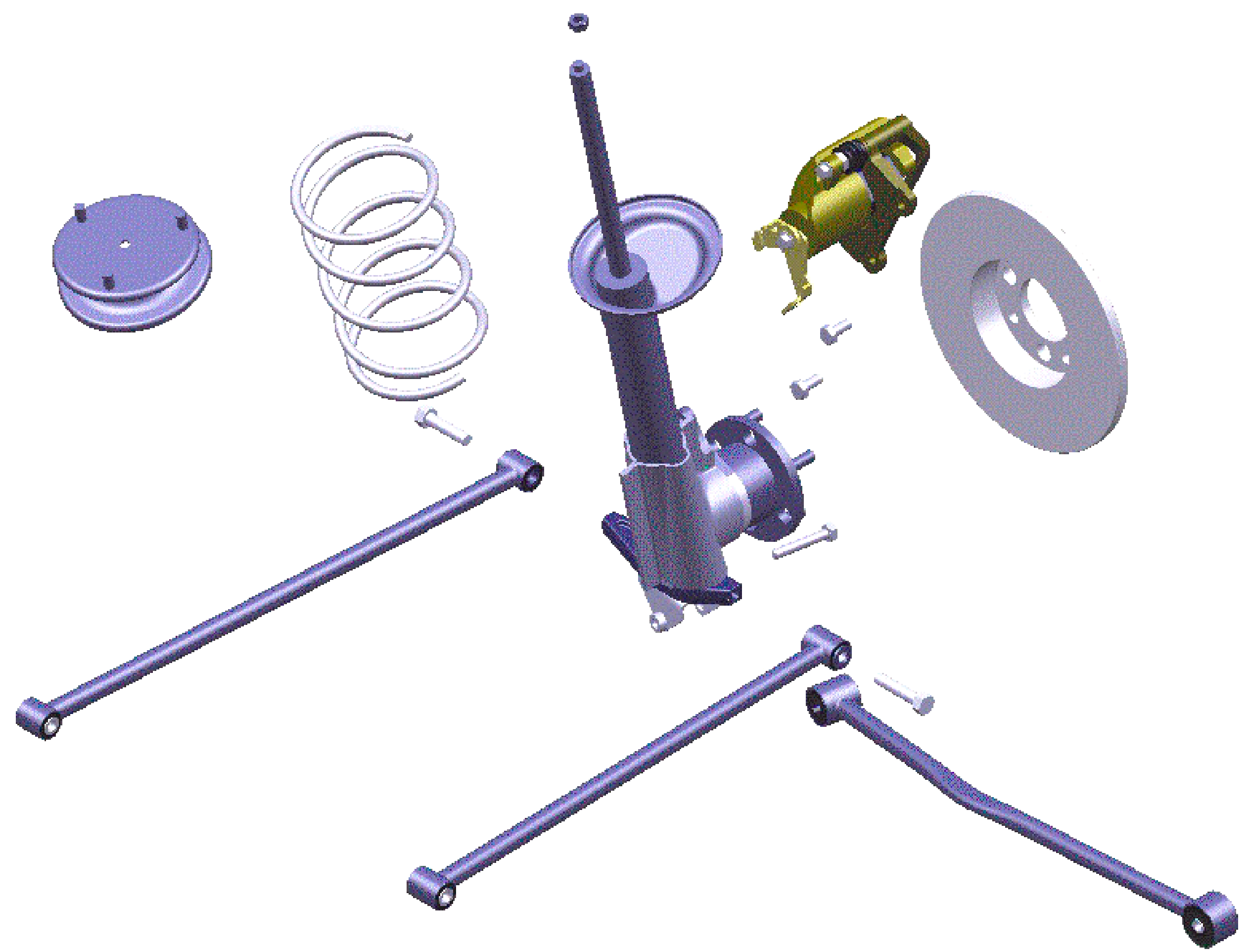


Dynamic

STRUT & LINKS: DESIGN

STRUT & LINKS

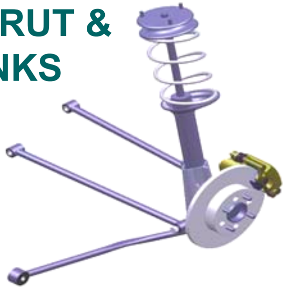




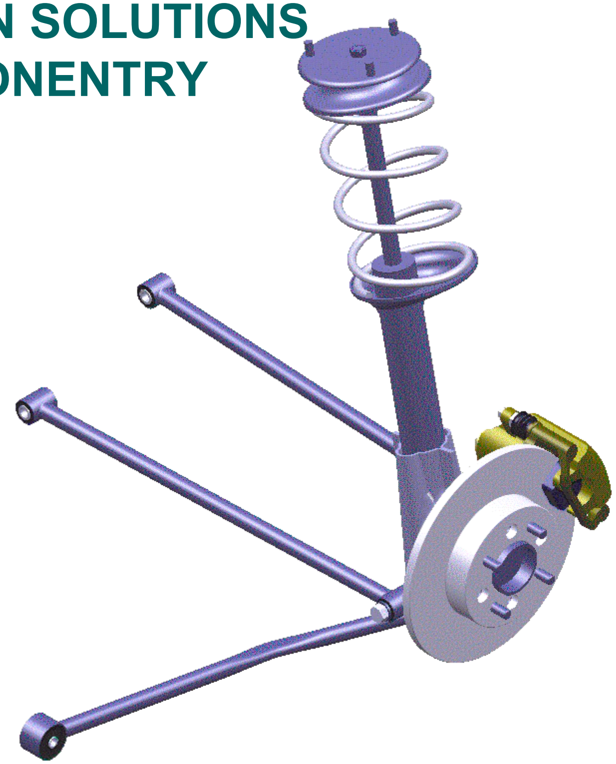
STRUT & LINKS: DESIGN

Overview

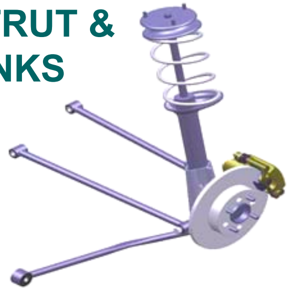
STRUT & LINKS



- TWO ALTERNATIVE DESIGN SOLUTIONS
- STATE OF THE ART COMPONENTRY
- OPTIMISED DESIGNS
  - Hybrid Knuckle
  - Hydroformed Knuckle
  - Tubular Links



- LIGHTWEIGHT
- STRUCTURALLY SOUND
- GOOD PERFORMANCE
- MANUFACTURABLE
- AFFORDABLE



STRUT & LINKS: DESIGN

Overview

Hydroformed

Solution

B Class Solution
C Class Solution

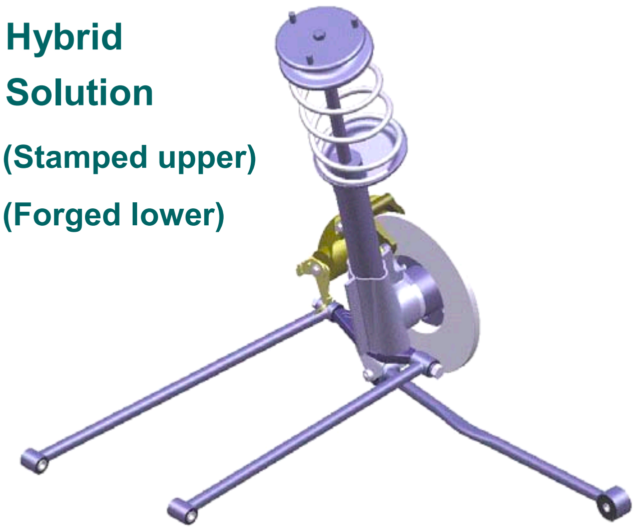
D Class Solution
E Class Solution
P Solution

Hybrid

Solution

(Stamped upper)

(Forged lower)



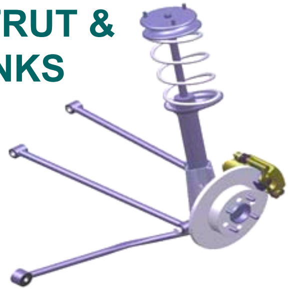
TWO DIFFERENT, BUT SIMILAR, DESIGNS WERE DEVELOPED FOR APPLICATION THROUGHOUT THE DIFFERENT CLASSES OF VEHICLE

THE HYBRID DESIGN IS MORE APPICABLE TO THE LARGER AND HEAVIER VEHICLES BUT IN A DETAIL DESIGN PHASE EITHER SOLUTION COULD BE CONSIDERED FOR ANY CLASS OF VEHICLE

STRUT & LINKS: DESIGN

Approach

STRUT & LINKS

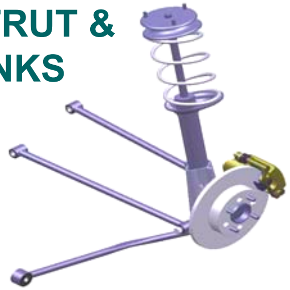


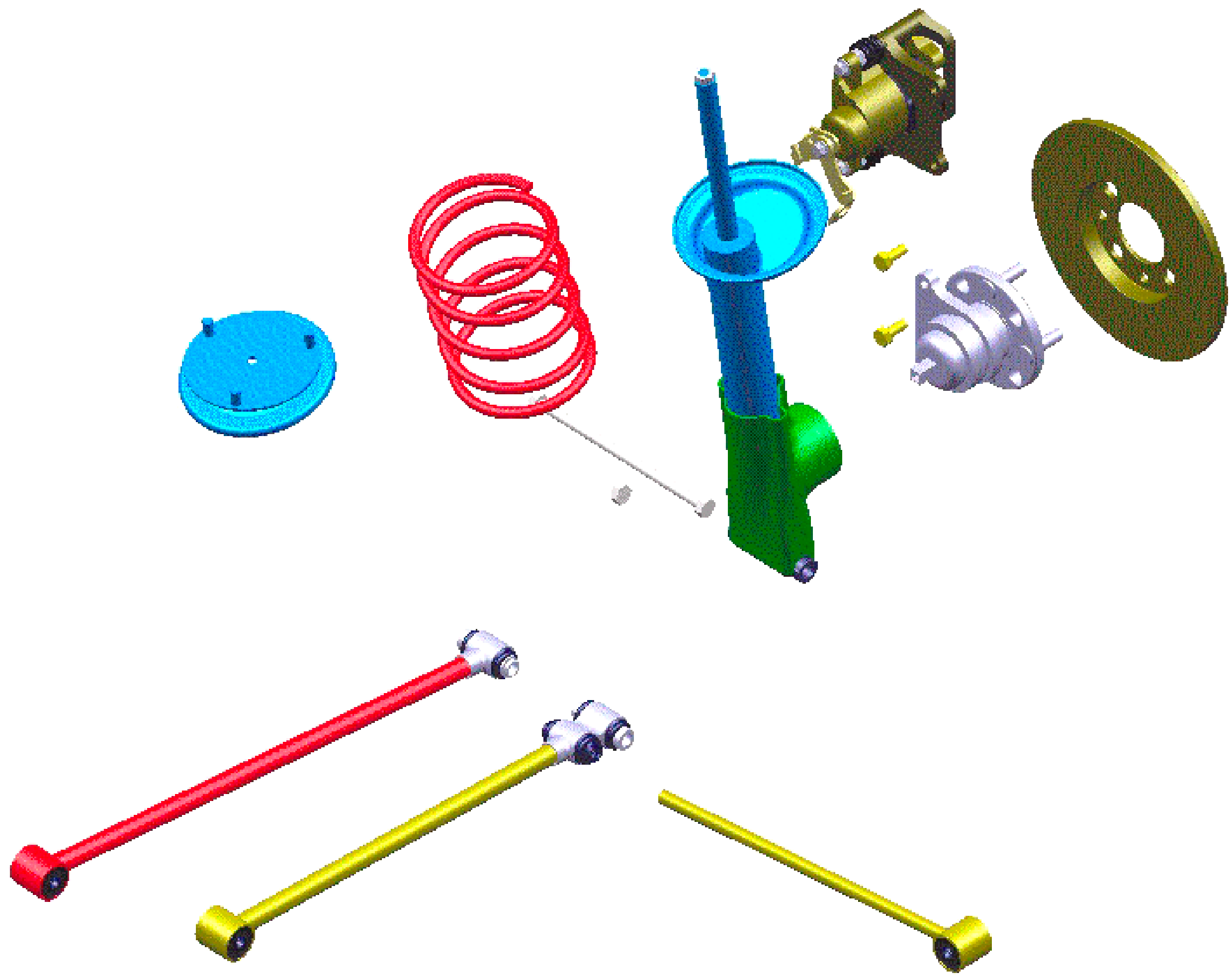
- The initial package layout was created with 3D models developed in the CAD system. These were based upon sections and shape that exhibit appropriate properties.
- The designs were refined by close collaboration between CAD & CAE to develop these initial concepts through a series of evolutions and optimisations 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.

STRUT & LINKS: DESIGN

Parts Review

STRUT & LINKS



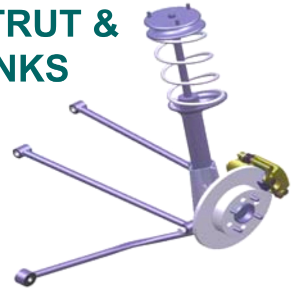


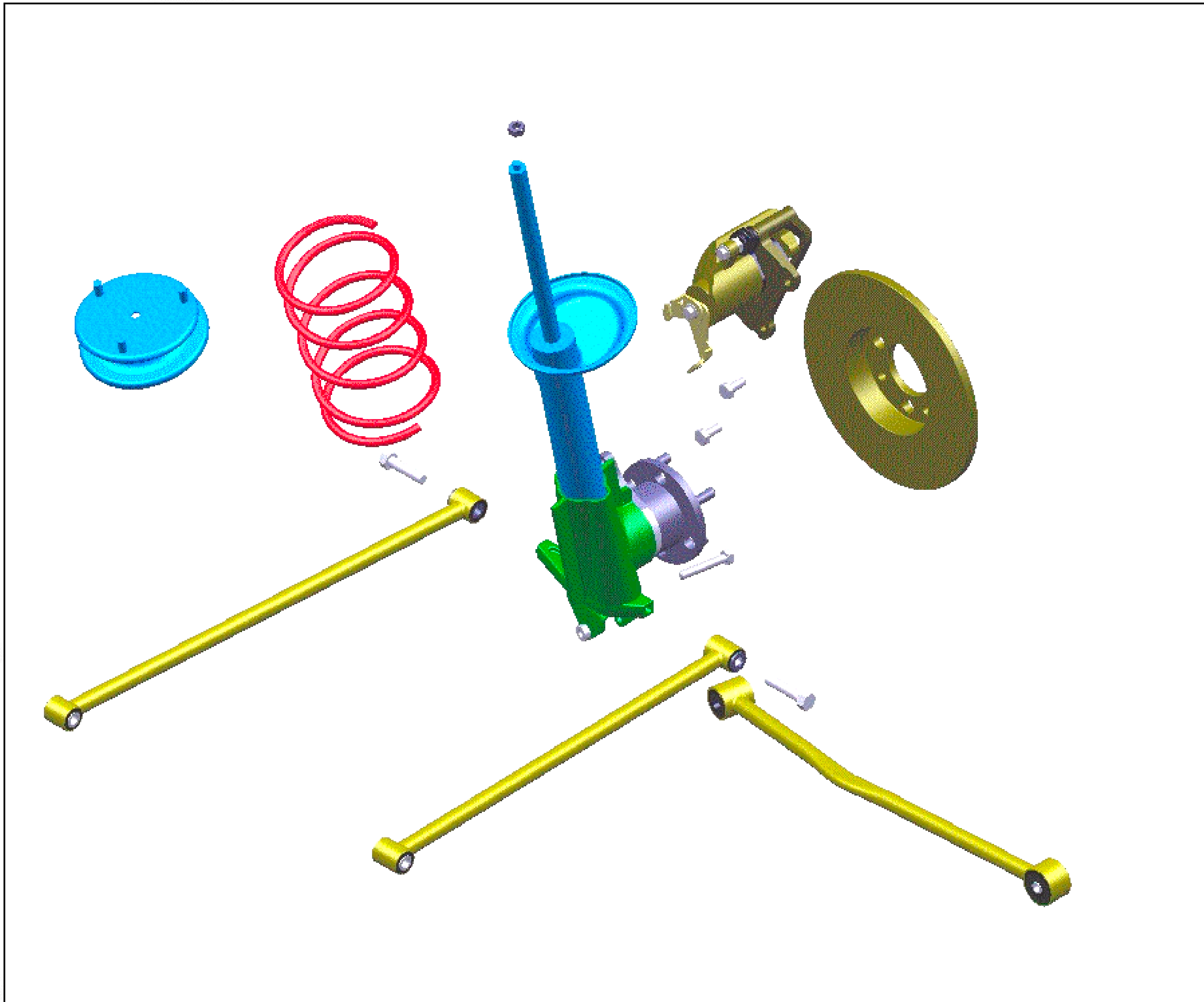
ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS: DESIGN

Parts Review

STRUT & LINKS



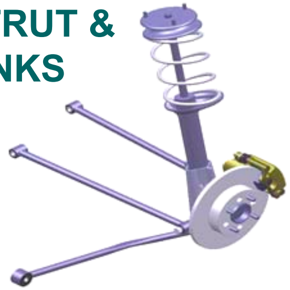


STEEL AUTO SUSPENSION

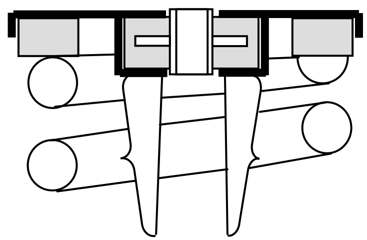
STRUT & LINKS: DESIGN

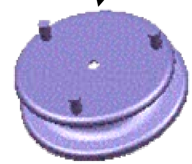
Spring & Top Mounting

STRUT & LINKS

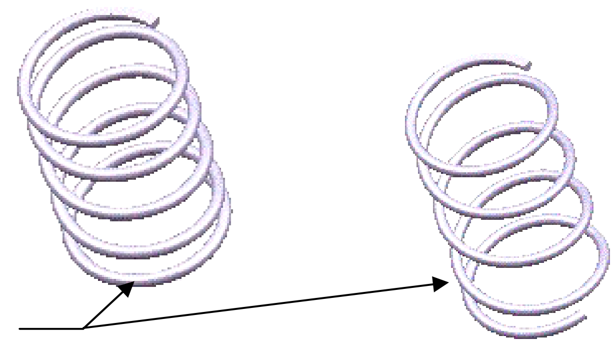


State of the Art Triple Path Top Mounting





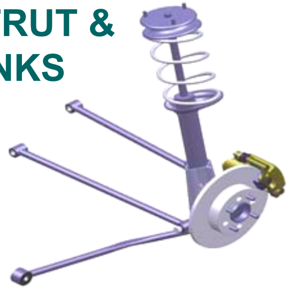
1300 Mpa Spring Material

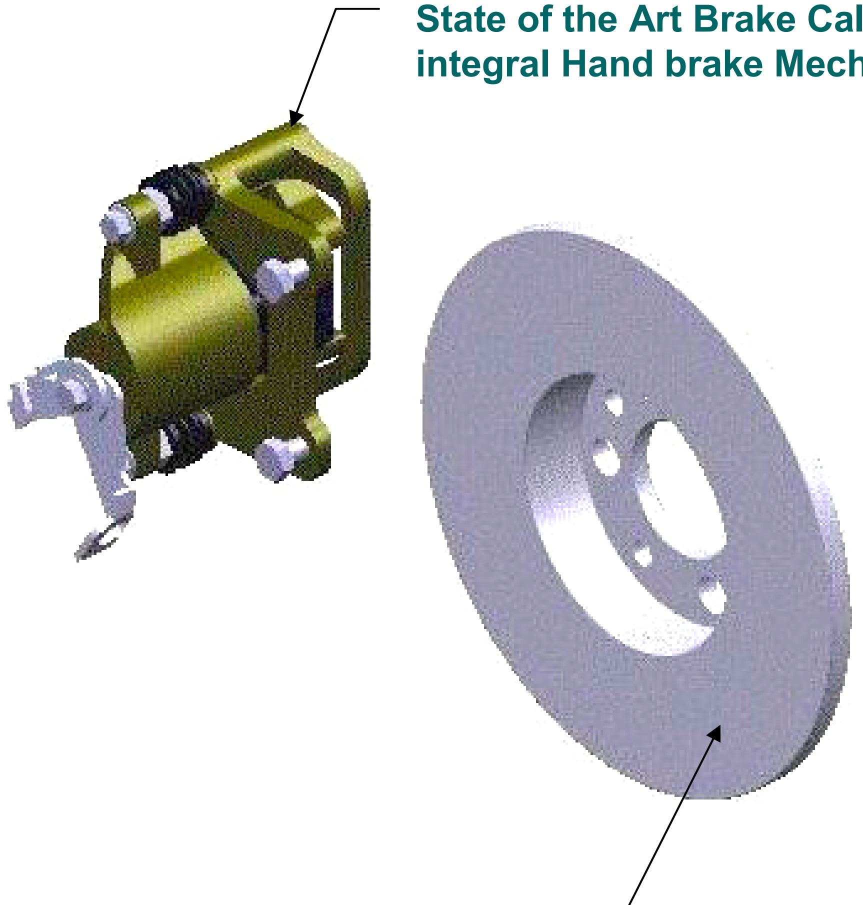


			B Class	C Class	D Class	P Class
Outer Diameter	Do	mm	140.26	141.87	143.59	139.79
Inner diameter	Di	mm	119.00	119.00	119.00	119.00
Design length	Ld	mm	200.00	200.00	239.00	239.00
Bump length	Lb	mm	95.94	95.94	121.38	130.79
Rebound length	Lr	mm	308.79	313.52	337.81	342.51
Load at Design length	Pd	N	2451.46	3007.29	3458.52	2241.39
Number of working coils	n	-	3.29	3.51	3.92	3.23
Total number of coils	N		4.79	5.01	5.42	4.73
Maximum Allowable Stress		Mpa	1300	1300	1300	1300
Mean coil diameter	D	mm	129.63	130.44	131.30	129.39
Wire diameter	d	mm	10.63	11.44	12.30	10.39
Spring rate	**S**	**N/mm**	**17.51**	**21.53**	**25.26**	**16.34**
Wire length	Lw	mm	1970.72	2073.48	2260.74	1956.22
Spring mass	m	kg	**1.37**	**1.67**	**2.11**	**1.30**

STRUT & LINKS: DESIGN

Brakes & Bushes





STRUT & LINKS: DESIGN

Links, D & P Class

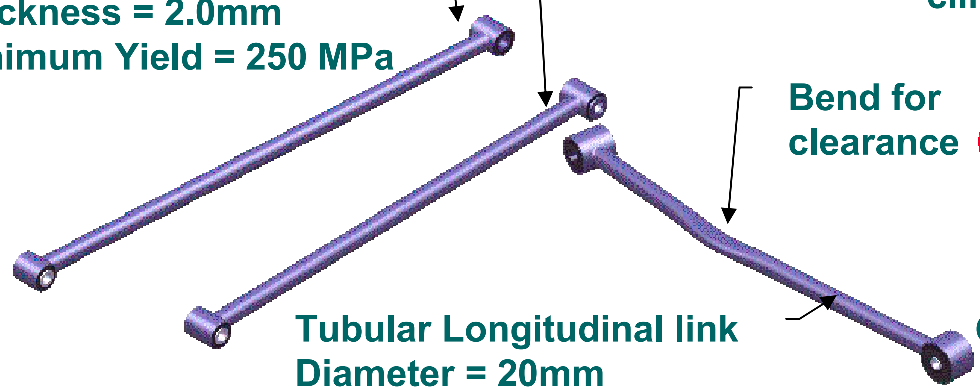
STRUT & LINKS

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.

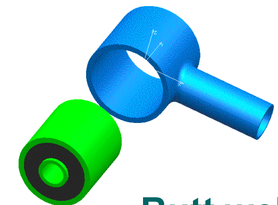
Tubular Lateral Links
Diameter = 20mm
Thickness = 2.0mm
Minimum Yield = 250 MPa



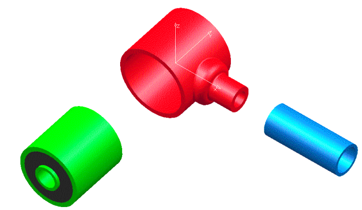
Tubular Longitudinal link
Diameter = 20mm
Thickness = 2.0mm
Minimum Yield = 250 MPa

Bend for clearance

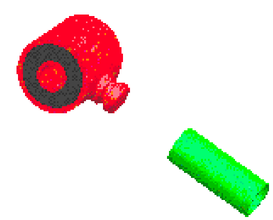
Alternative End fixings



Butt welded



Hydro-formed T Piece clinched or welded

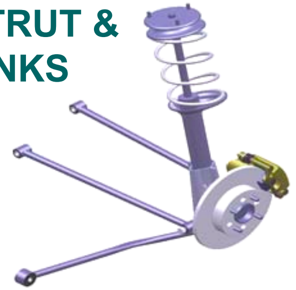


Cold Rotary swage

STRUT & LINKS: DESIGN

Links, B & C Class

STRUT & LINKS



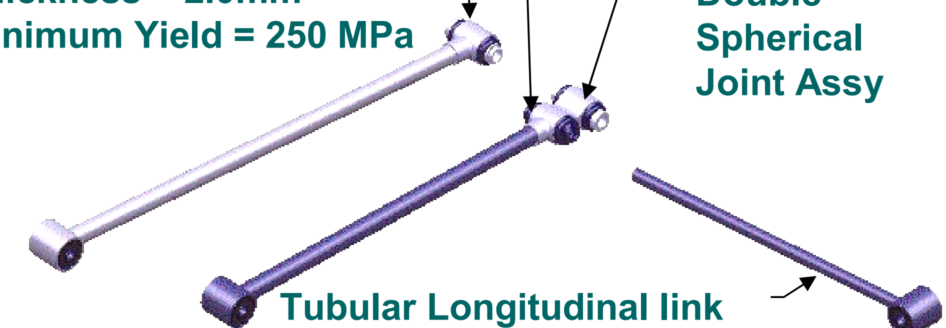
Analysis demonstrated that a ‘cigar’ shaped member holds a marginal structural advantage over a parallel thin walled tube.

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.

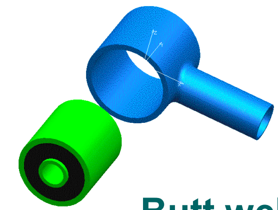
Tubular Lateral Links
Diameter = 20mm
Thickness = 2.0mm
Minimum Yield = 250 MPa

Double Spherical Joint Assy

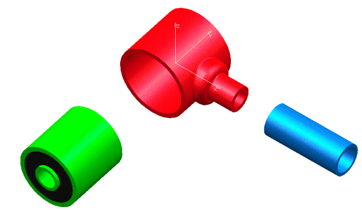


Tubular Longitudinal link
Diameter = 20mm
Thickness = 2.0mm
Minimum Yield = 250 MPa

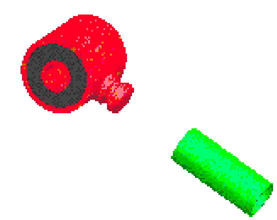
Alternative End fixings



Butt welded



Hydro-formed T Piece clinched or welded

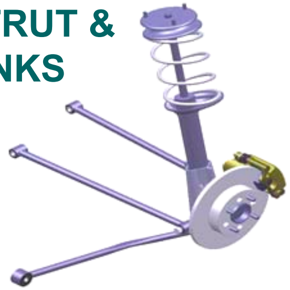


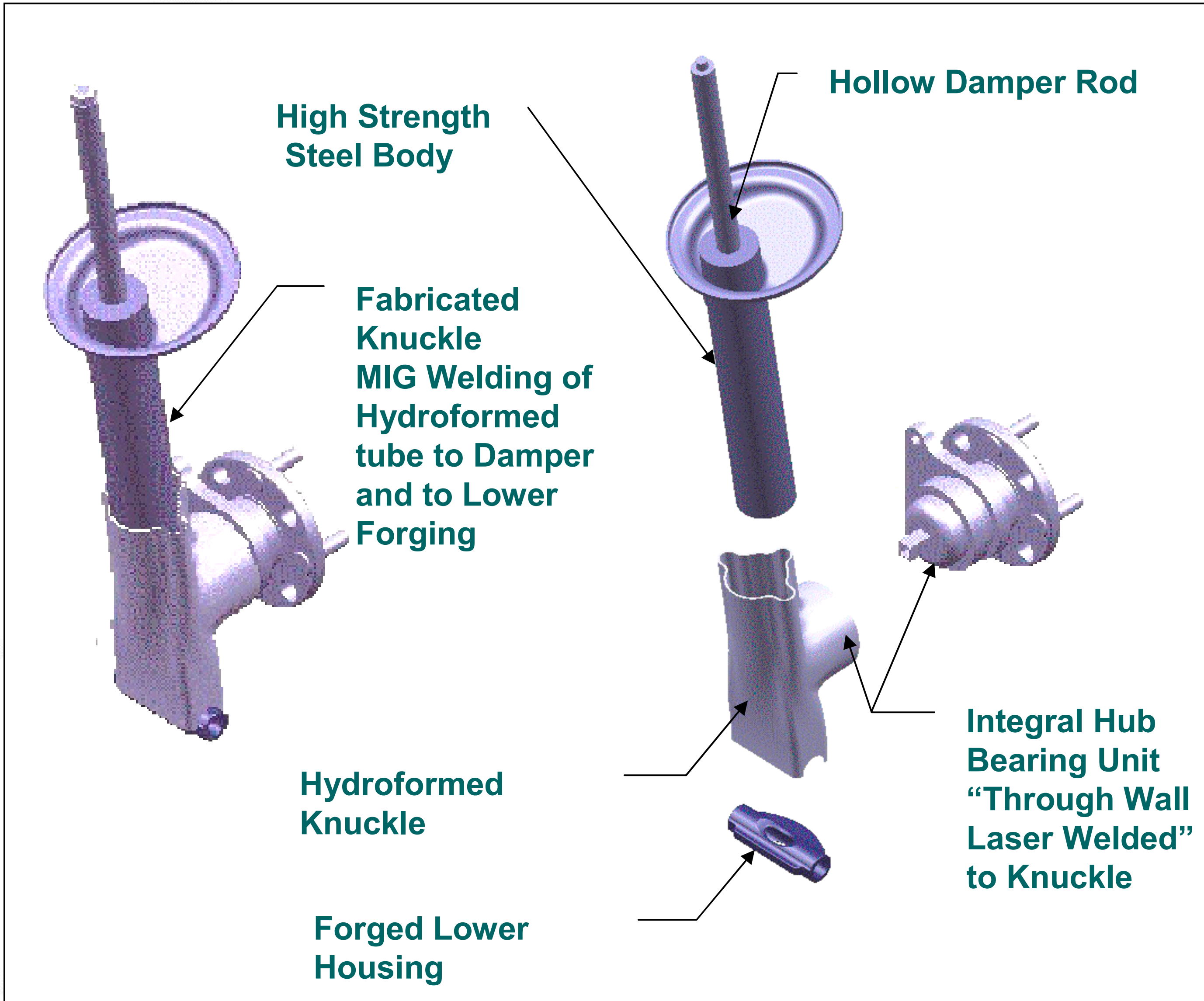
Cold Rotary swage

STRUT & LINKS: DESIGN

Hydroformed Knuckle

STRUT & LINKS



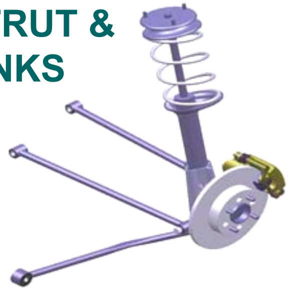


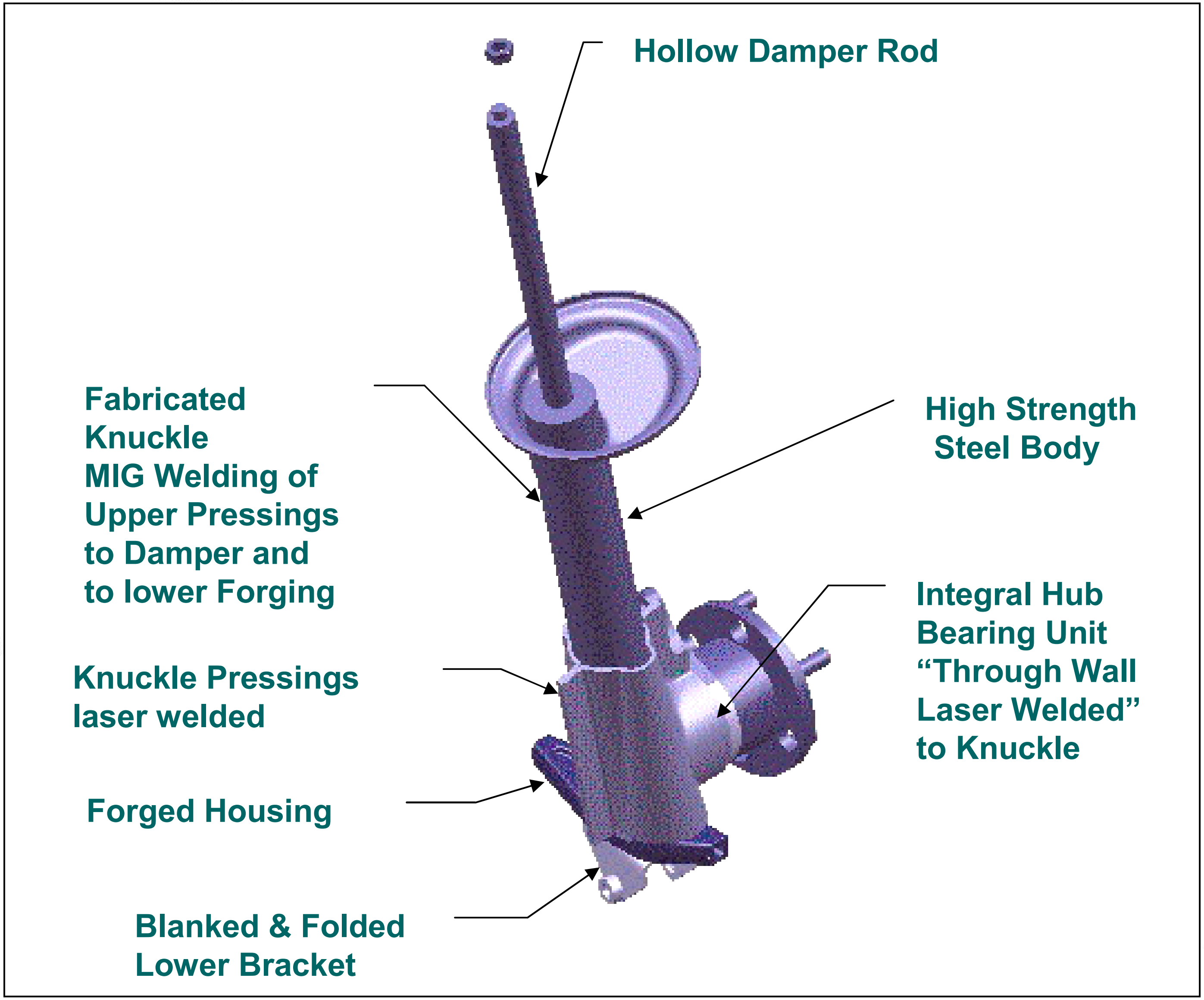
ULTRALIGHT STEEL AUTO SUSPENSION

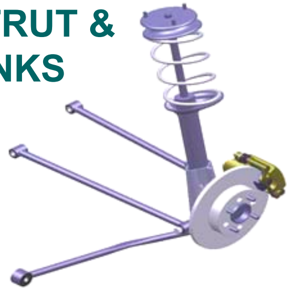
STRUT & LINKS: DESIGN

Hybrid Knuckle

STRUT & LINKS



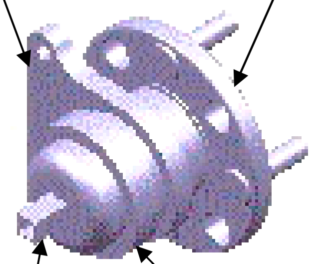




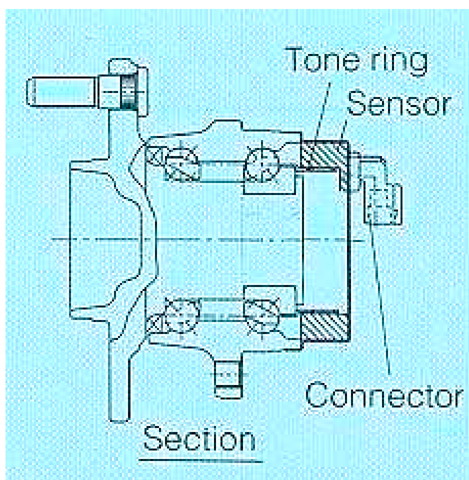
STRUT & LINKS: DESIGN

Hub & Bearing Unit

GENERATION 3 TYPE HUB & BEARING UNIT



Bearing Unit is through wall laser welded to the knuckle. This process allows a finished integrated Hub Bearing Unit to be welded directly to the suspension knuckle

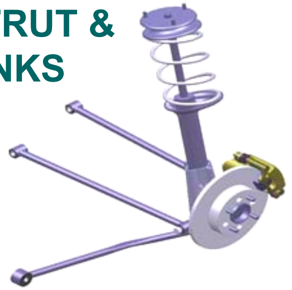


Typical Cross Section of Bearing

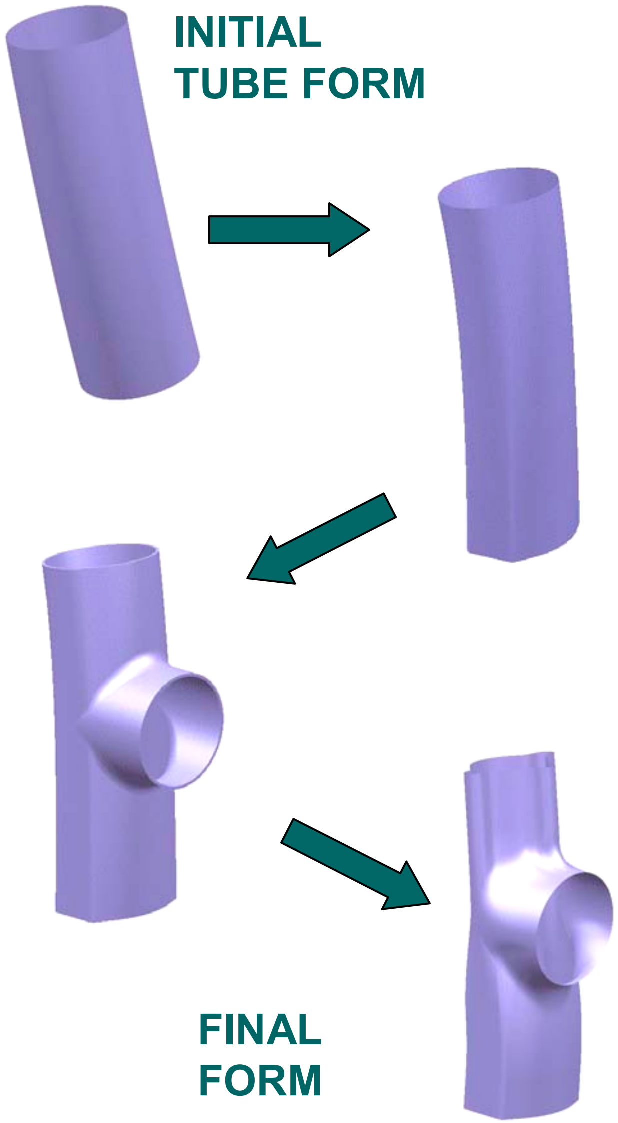
STRUT & LINKS: DESIGN

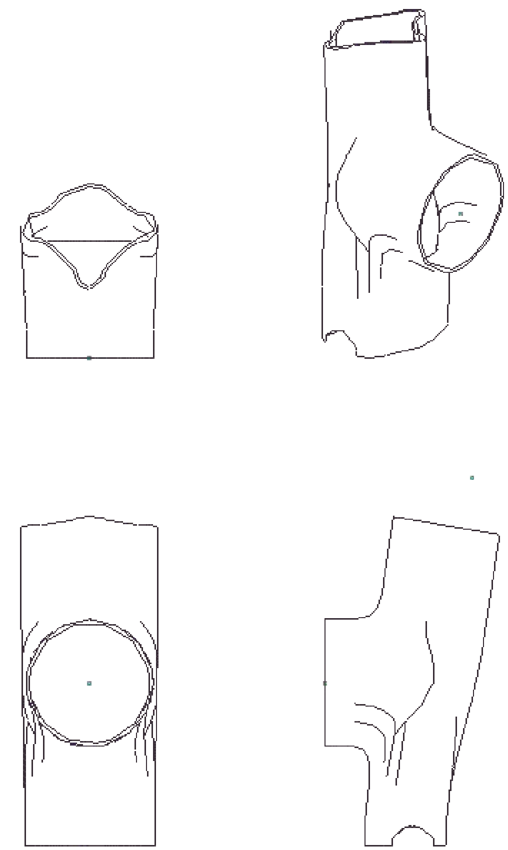
Hydroformed Knuckle

STRUT & LINKS



Part	Hydroformed Knuckle		
Process	Hydroforming		
	B	C	
Material Gauge (mm)	3.5	3.5	
Material Grade (Mpa)	500	500	
Mass (kg)	1.33	1.33	



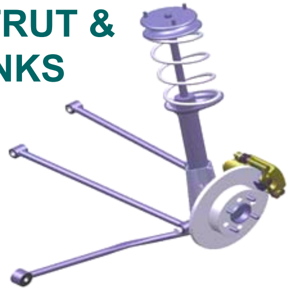


ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS: DESIGN

Knuckle Pressing

STRUT & LINKS

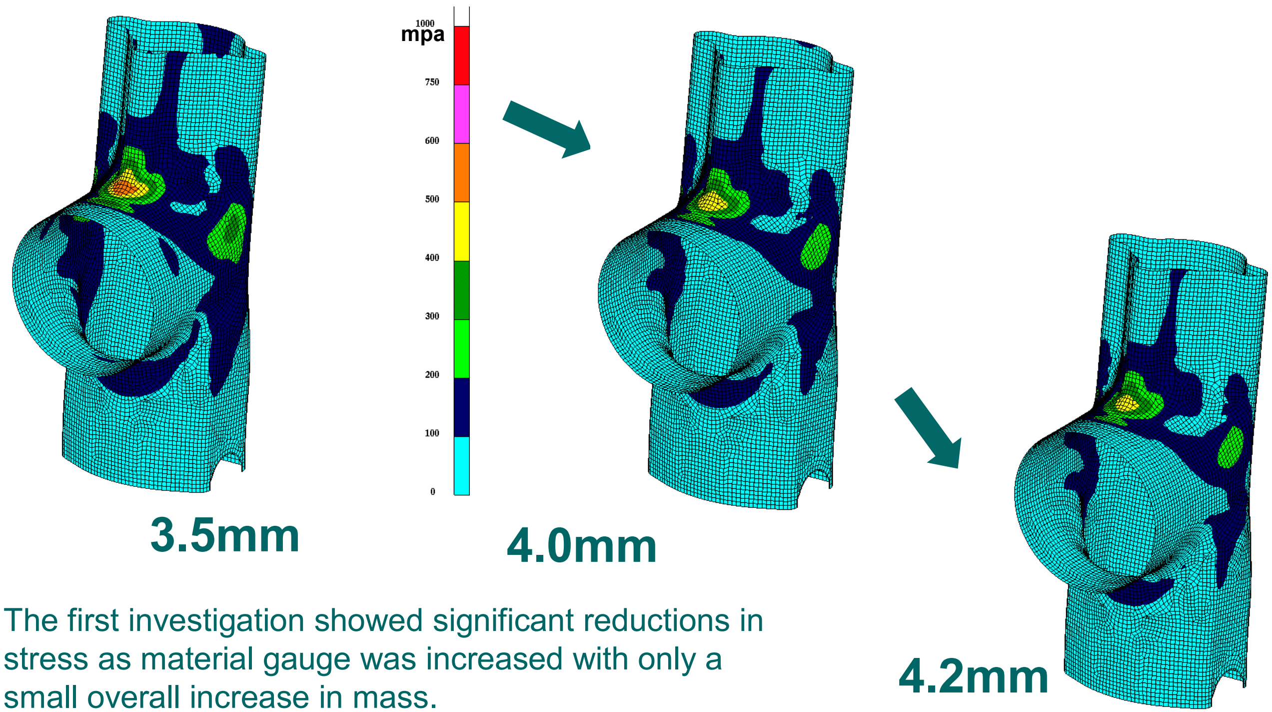


Further, more detailed analysis was carried out on the knuckle pressing to assess the local areas of high stress.

Two avenues were explored, firstly alternative material gauges were assessed.

Secondly Non-Linear stress analysis was utilised to gain a more detailed understanding of the stress.

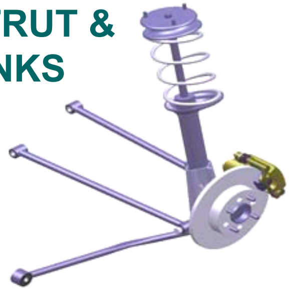
Part	Hydroformed Knuckle		
Process	Hydroforming		
Class	B	C	
Material Gauge (mm)	3.5	3.5	
Material Grade (MPa)	500	500	
Mass (kg)	1.33	1.33	



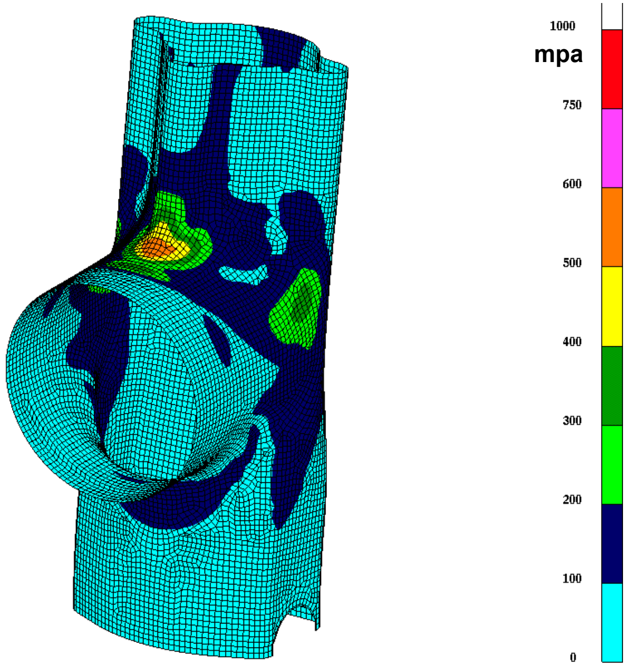
The first investigation showed significant reductions in stress as material gauge was increased with only a small overall increase in mass.

STRUT & LINKS: DESIGN
Knuckle Pressing

STRUT & LINKS

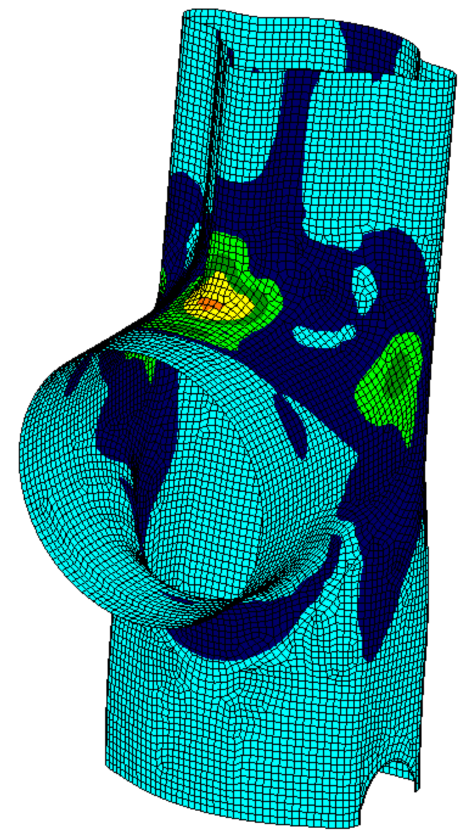


Part	Hydroformed Knuckle		
Process	Hydroforming		
Class	B	C	
Material Gauge (mm)	3.5	3.5	
Material Grade (MPa)	500	500	
Mass (kg)	1.33	1.33	

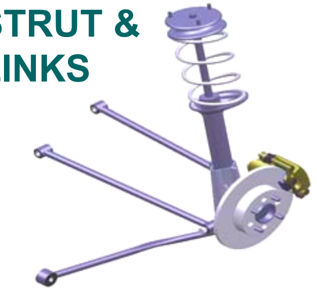


3.5mm Linear Analysis

The second investigation showed significant areas of reduced stress when the non-linear material properties of the material above yield were taken into account. The resulting areas of high stress would also benefit from revised local shape changes during detail design. It is apparent from this that a robust solution is possible based on this concept, with little or no increase in the overall system mass.



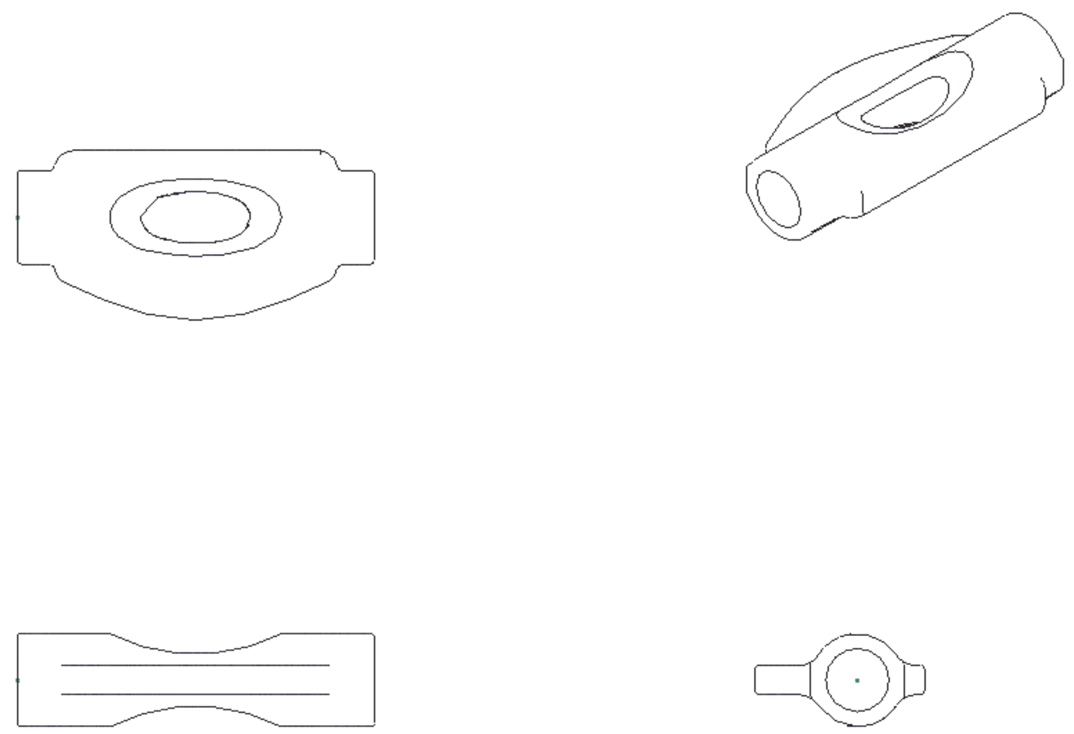
3.5mm Non-Linear Analysis

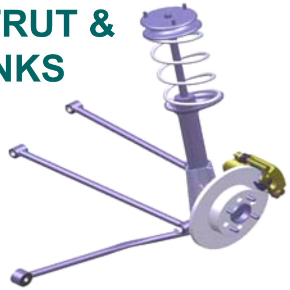


STRUT & LINKS: DESIGN

Knuckle Forging B & C Class

Part	Knuckle Forging		
Process	Forged		
Class	B	C	
Material Gauge (mm)	na	na	
Material Grade (MPa)	500	500	
Mass (kg)	0.266	0.266	

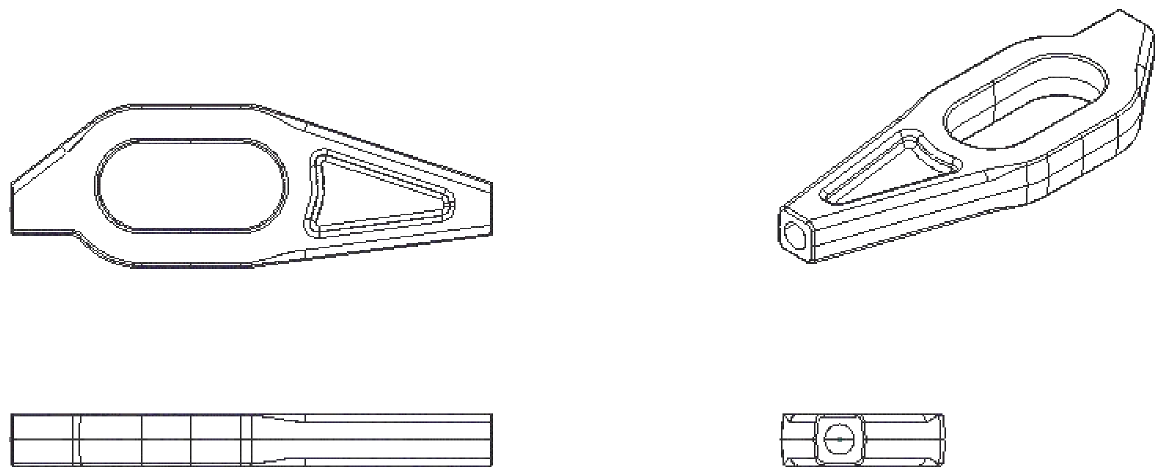




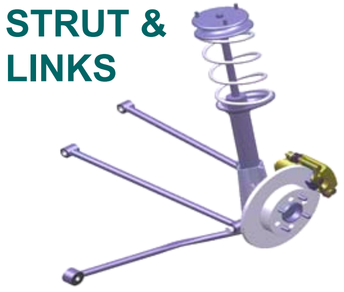
STRUT & LINKS: DESIGN

Knuckle Forging D & P Class

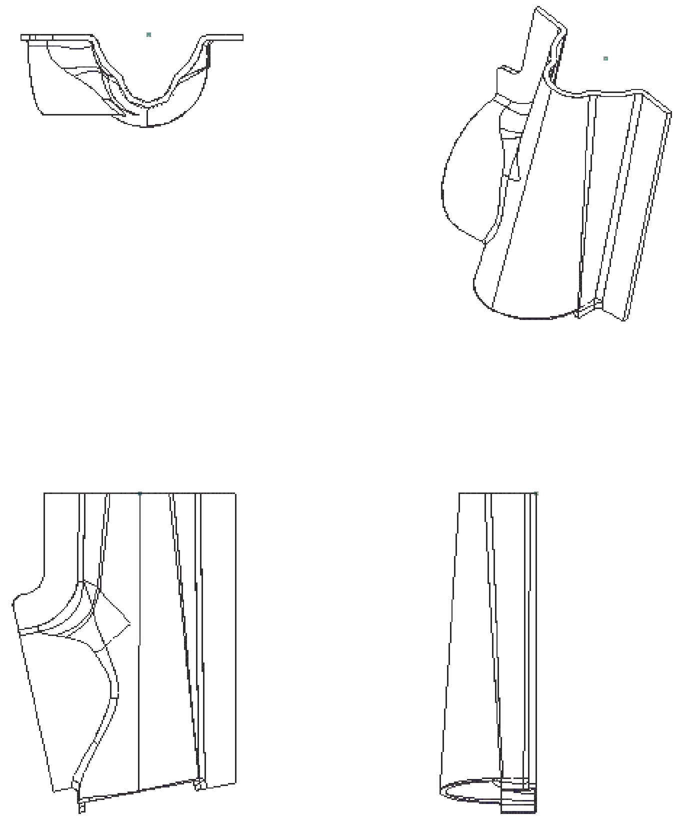
Part	Knuckle Forging		
Process	Forged		
Class	D	P	
Material Gauge (mm)	na	na	
Material Grade (MPa)	500	500	
Mass (kg)	0.641	0.641	



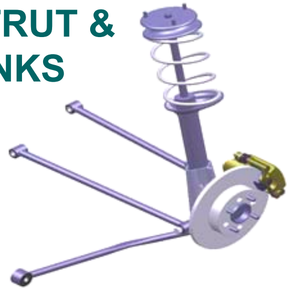
STRUT & LINKS: DESIGN
Knuckle Pressing



Part	Knuckle Pressing		
Process	Pressing		
Class	D	P	
Material Gauge (mm)	4	4	
Material Grade (MPa)	500	500	
Mass (kg)	0.7	0.7	



STRUT & LINKS: DESIGN
Knuckle Pressing

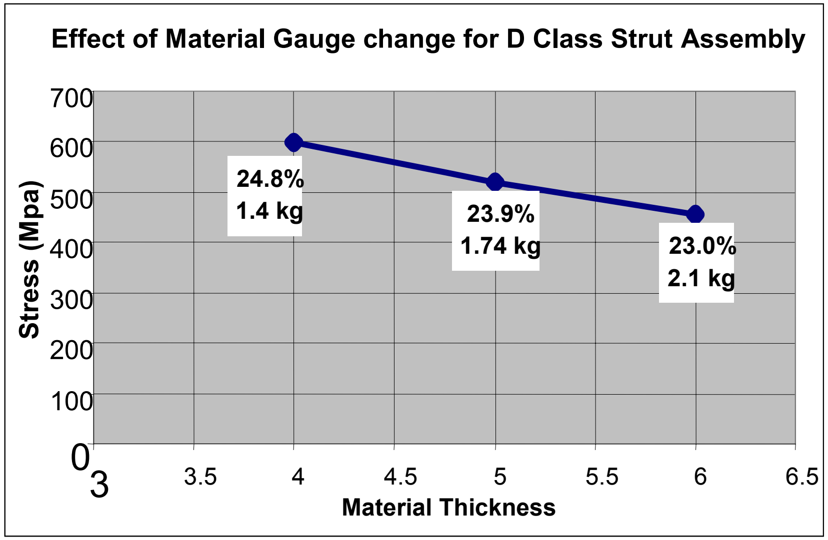


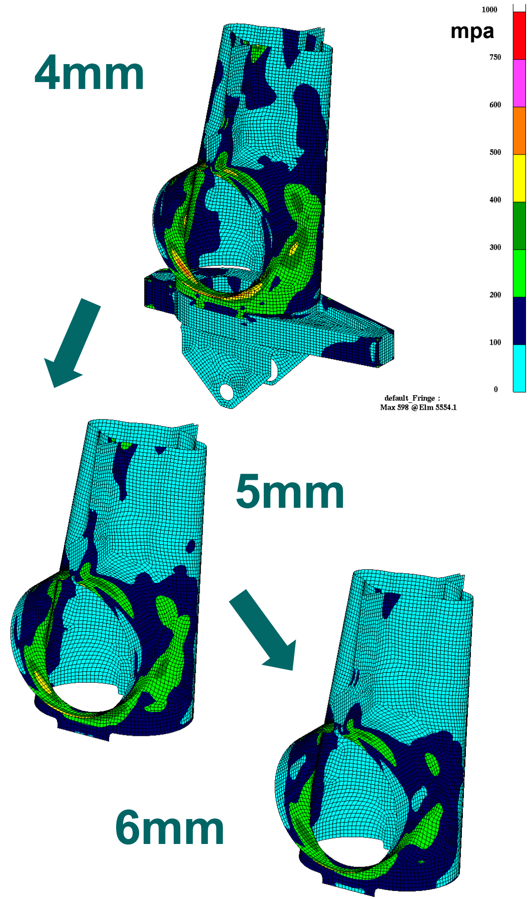
Further, more detailed analysis was carried out on the knuckle pressing to assess the local areas of high stress.

Two avenues were explored, firstly alternative material gauges were assessed, and the weight penalty quantified.

Secondly Non-Linear stress analysis was utilised to gain a more detailed understanding of the stress.

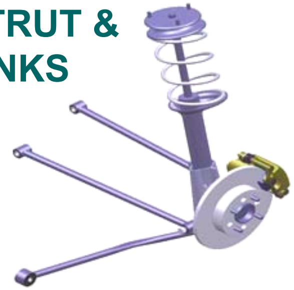
Part	Knuckle Pressing		
Process	Pressing		
Class	D	P	
Material Gauge (mm)	4	4	
Material Grade (MPa)	500	500	
Mass (kg) Each Part	0.7	0.7	





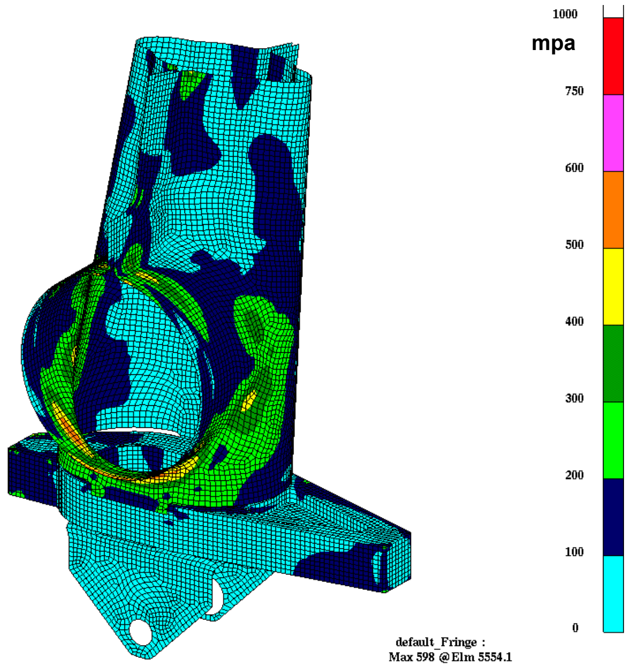
The first investigation showed significant reductions in stress as material gauge was increased with only a small overall increase in mass.

STRUT & LINKS



STRUT & LINKS: DESIGN

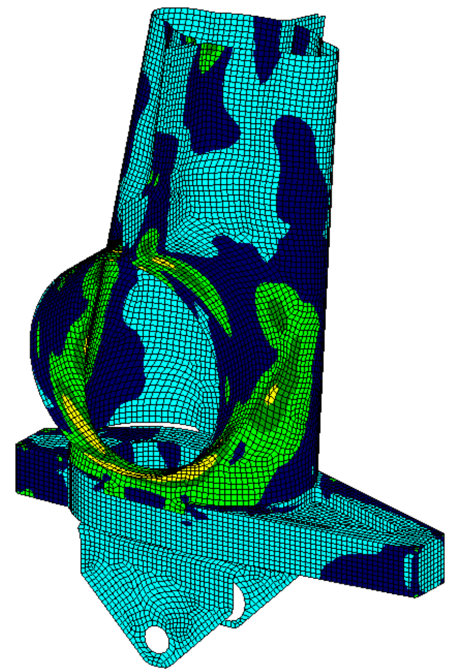
Knuckle Pressing



Part	Knuckle Pressing	
Process	Pressing	
Class	D	P
Material Gauge (mm)	4	4
Material Grade (MPa)	500	500
Mass (kg)	0.7	0.7

4mm Linear Analysis

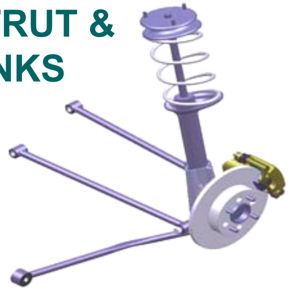
The second investigation showed significant areas of reduced stress when the non-linear material properties of the material above yield were taken into account. The resulting areas of high stress would also benefit from revised local shape changes during detail design. It is apparent from this that a robust solution is possible based on this concept, with little or no increase in the overall system mass.

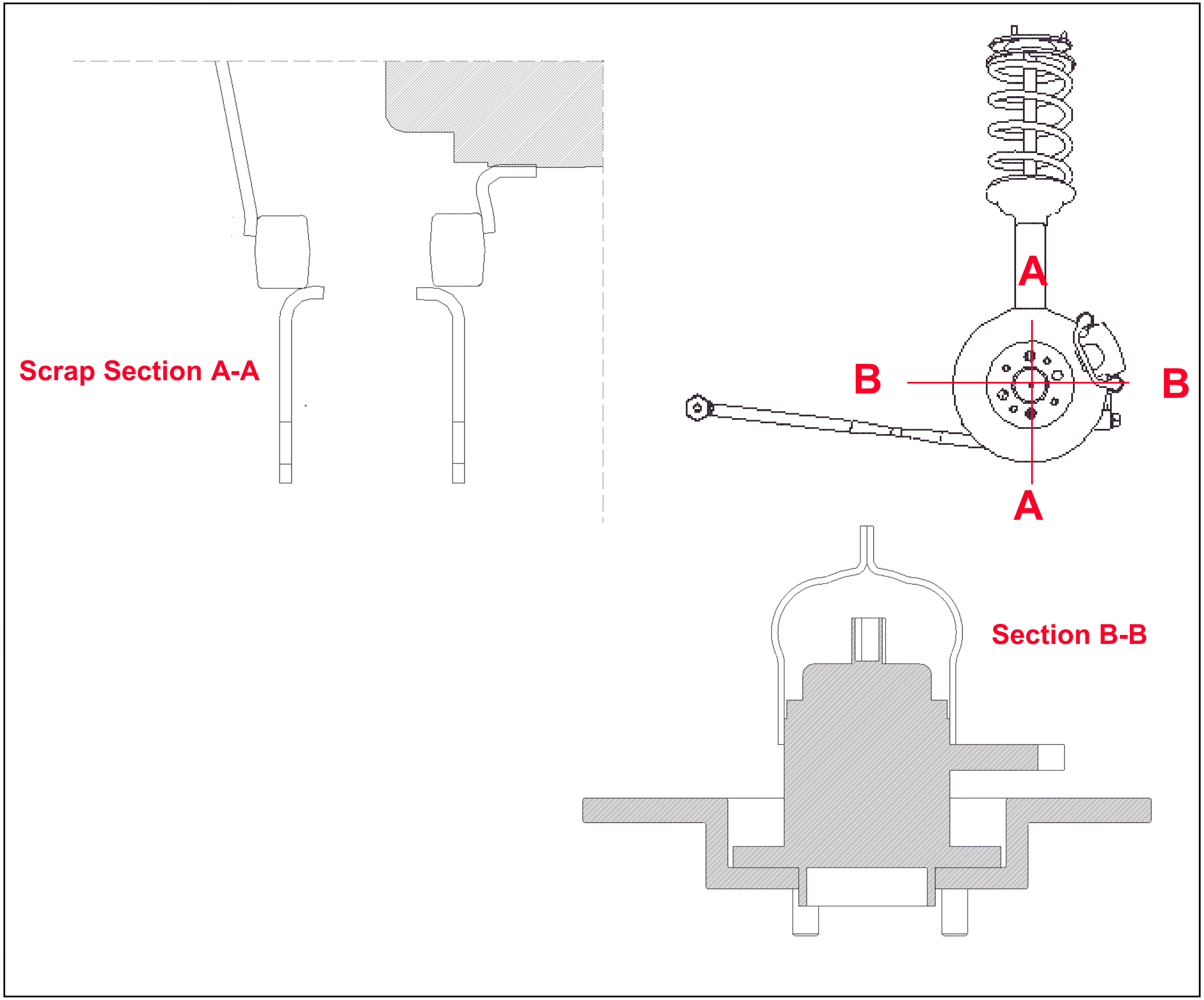


4mm Non-Linear Analysis

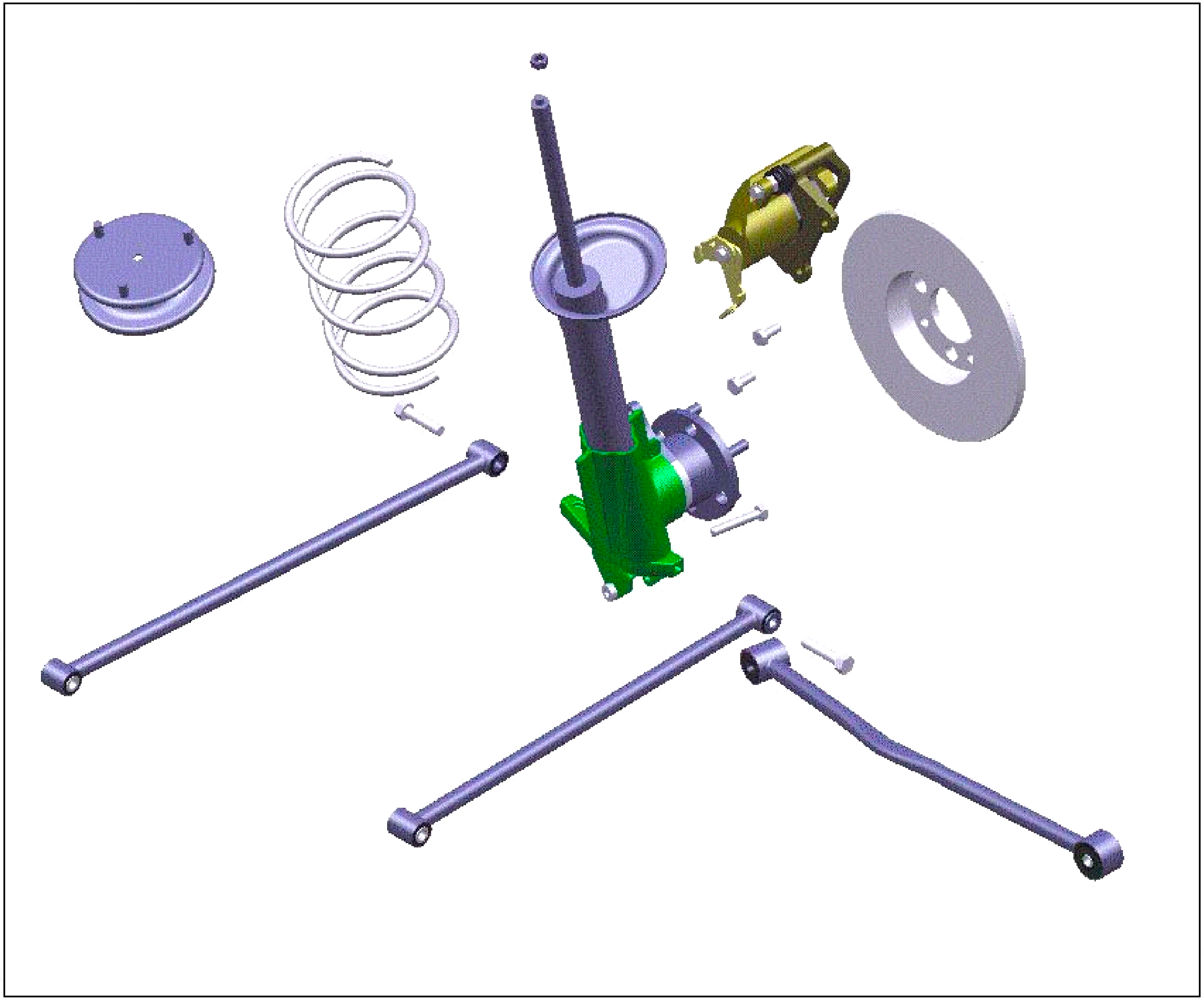
STRUT & LINKS: DESIGN

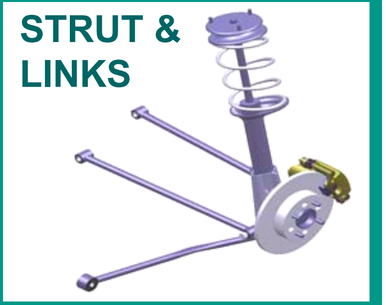
Hybrid Knuckle



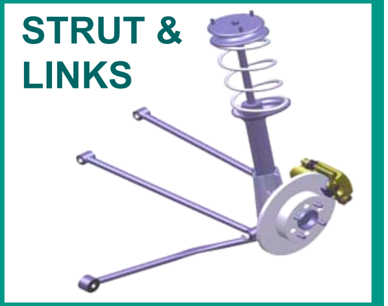


STRUT & LINKS
Finite Element Analysis





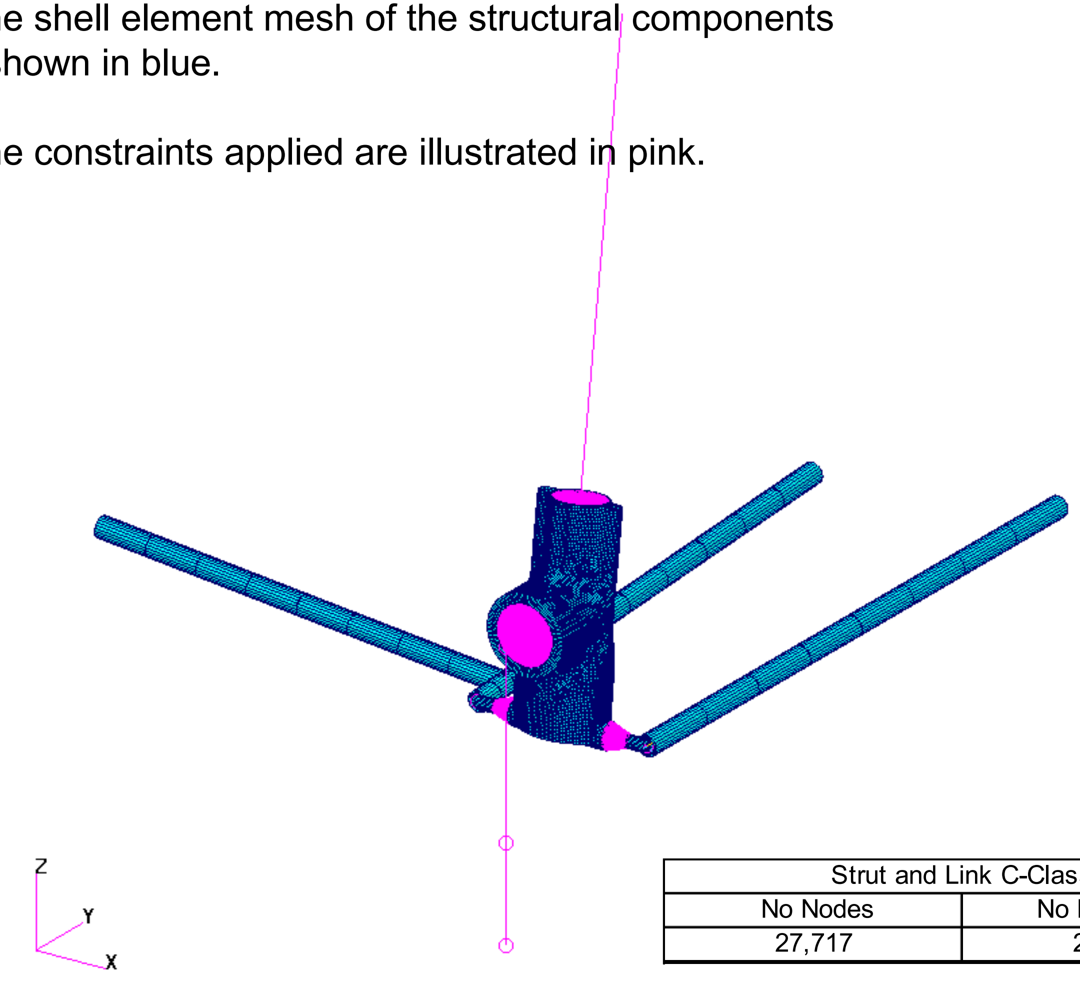
STRUT & LINKS
Finite Element Analysis



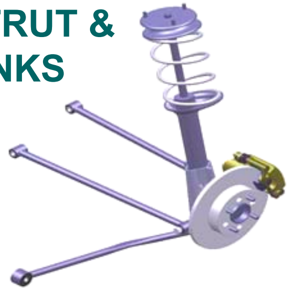
Finite Element Model of Strut & links System:

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

•The constraints applied are illustrated in pink.



Strut and Link C-Class	
No Nodes	No Elements
27,717	24,335



STRUT & LINKS
Finite Element Analysis

Finite Element Model of Strut & links System:

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

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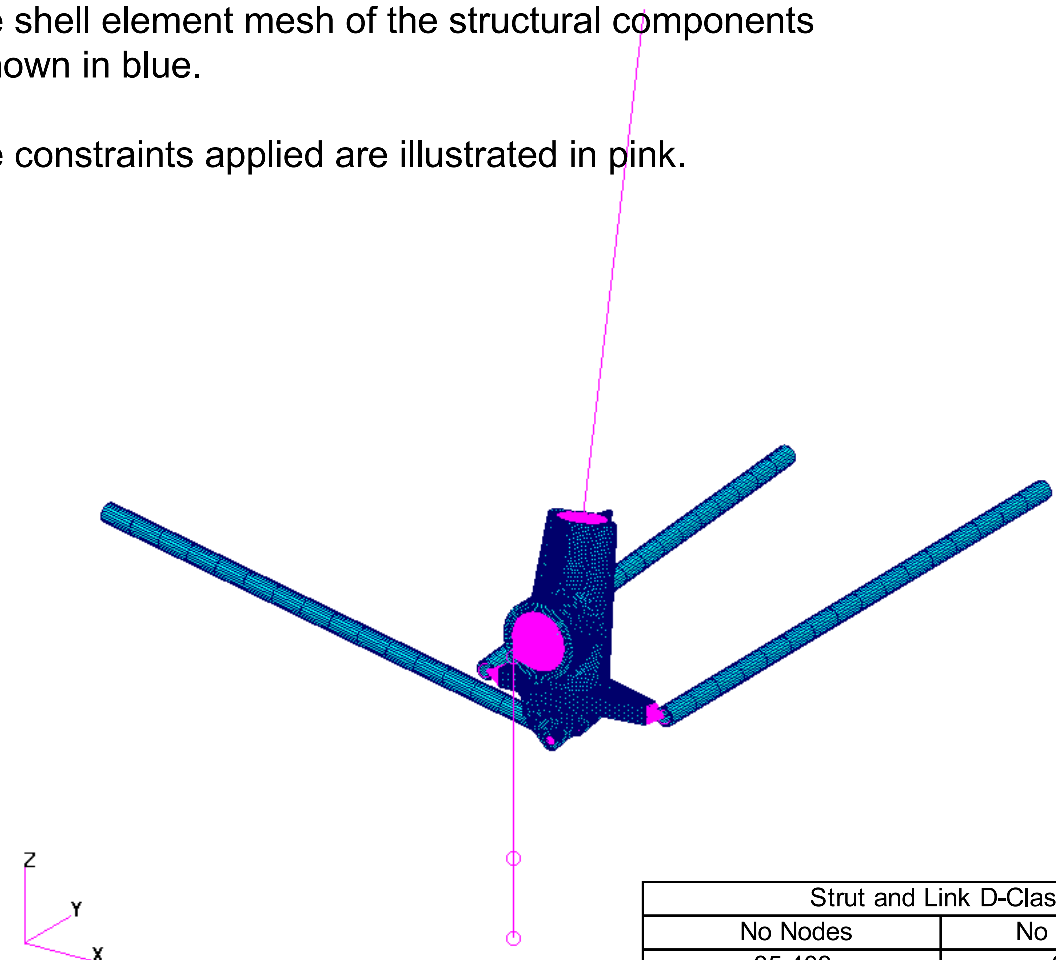
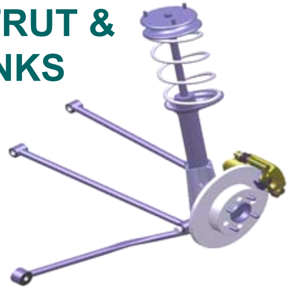


Strut and Link D-Class	
No Nodes	No Elements
35,403	31,396

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS: STRESS RESULTS
C Class

STRUT & LINKS



Load Case	Max stress (Von Mises)
Reverse Curb Strike (TCP)	469 MPa
Lateral Curb Strike 1 with load transfer	517 MPa
Lateral Curb Strike 2 with NO load transfer	564 MPa
Vertical Bump (TCP)	586 MPa
Forward Braking with ABS (TCP)	281 MPa
Combined Bump and Cornering (TCP)	267 MPa
Pothole Brake (TCP)	513 MPa

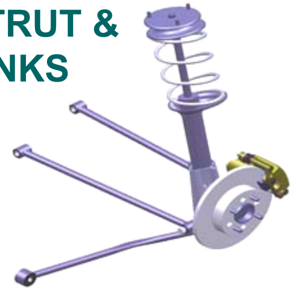
Click on result to view details

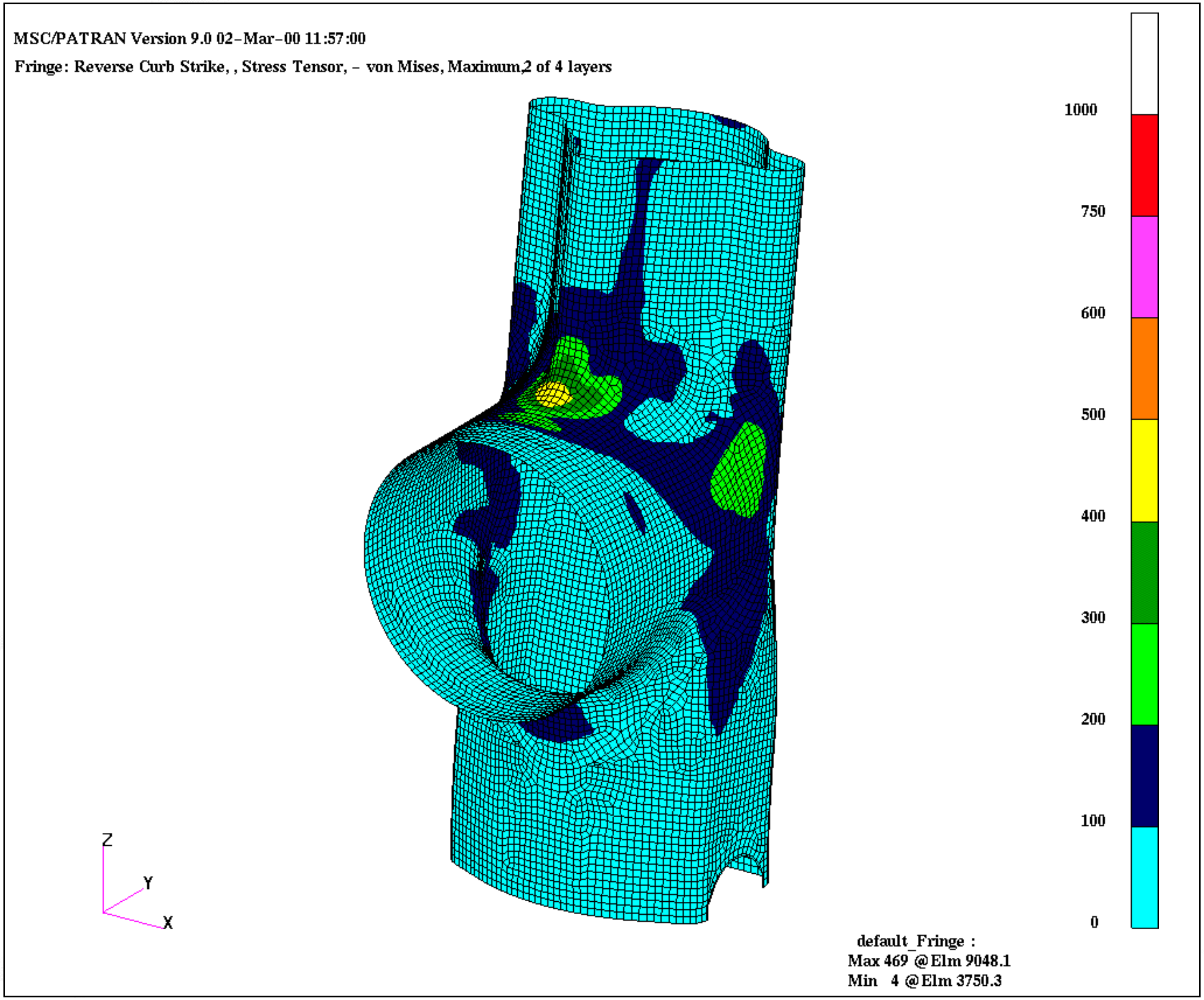
STEEL AUTO SUSPENSION

STRUT & LINKS: KNUCKLE

Reverse Curb Strike, C Class

STRUT & LINKS

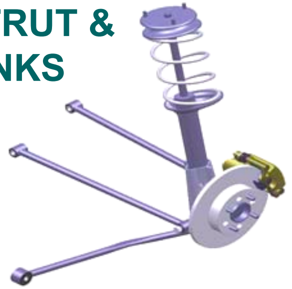


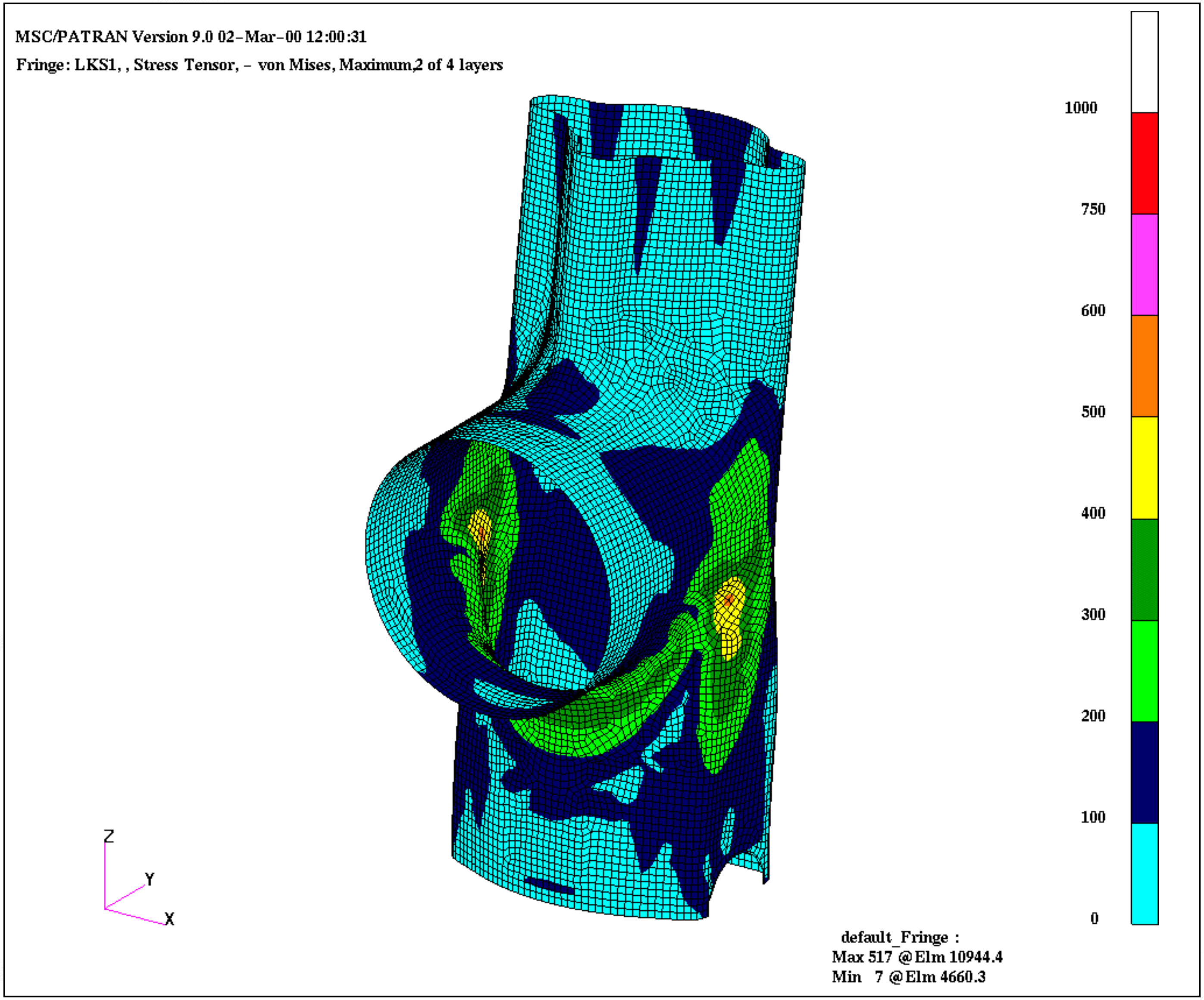


STRUT & LINKS: KNUCKLE

Lateral Curb Strike 1, C Class

STRUT & LINKS

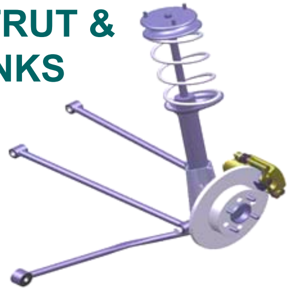


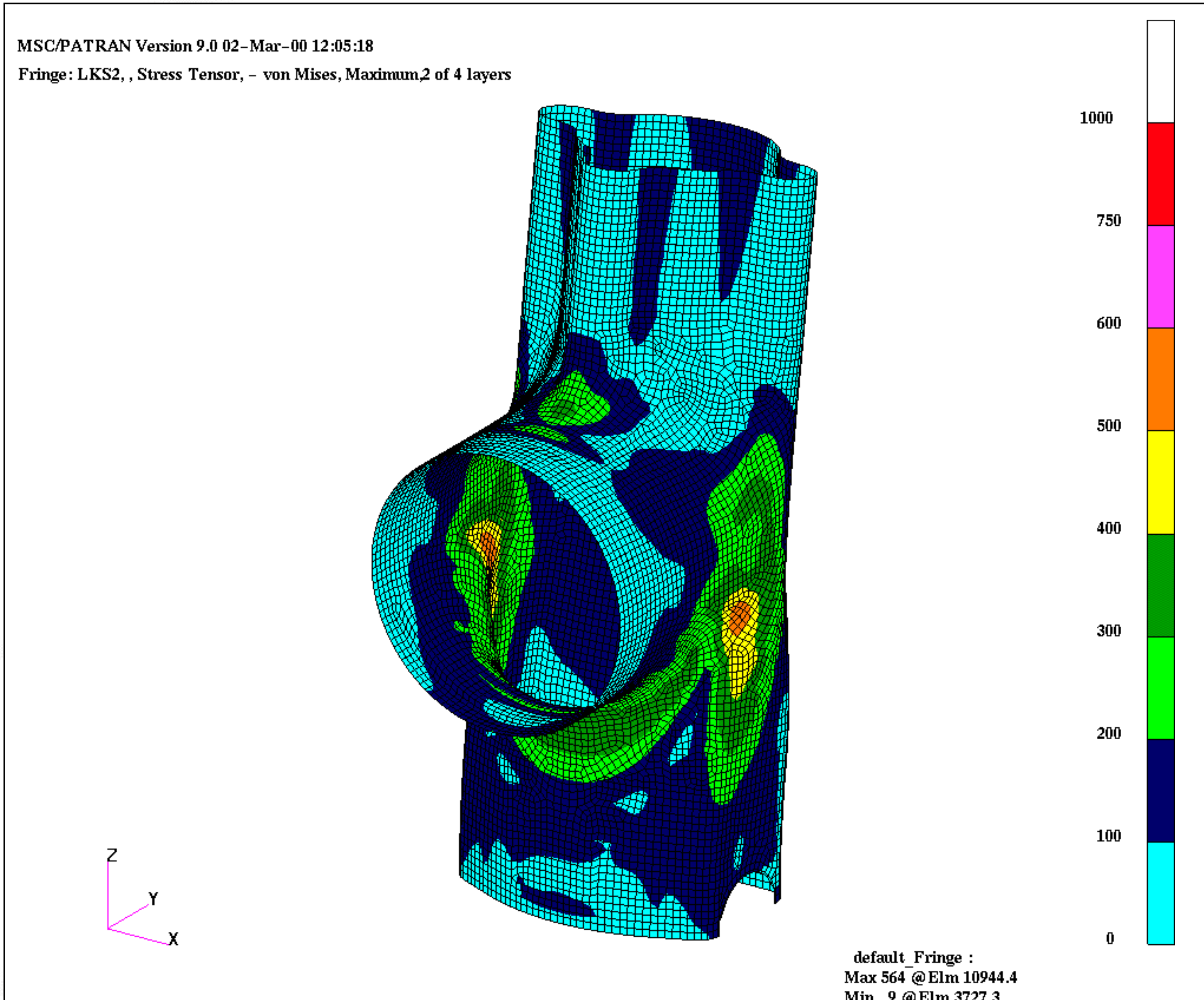


STRUT & LINKS: KNUCKLE

Lateral Curb Strike 2, C Class

STRUT & LINKS

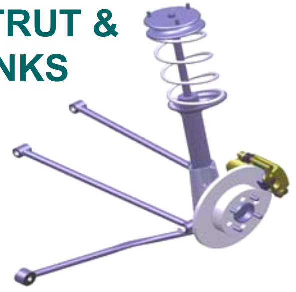


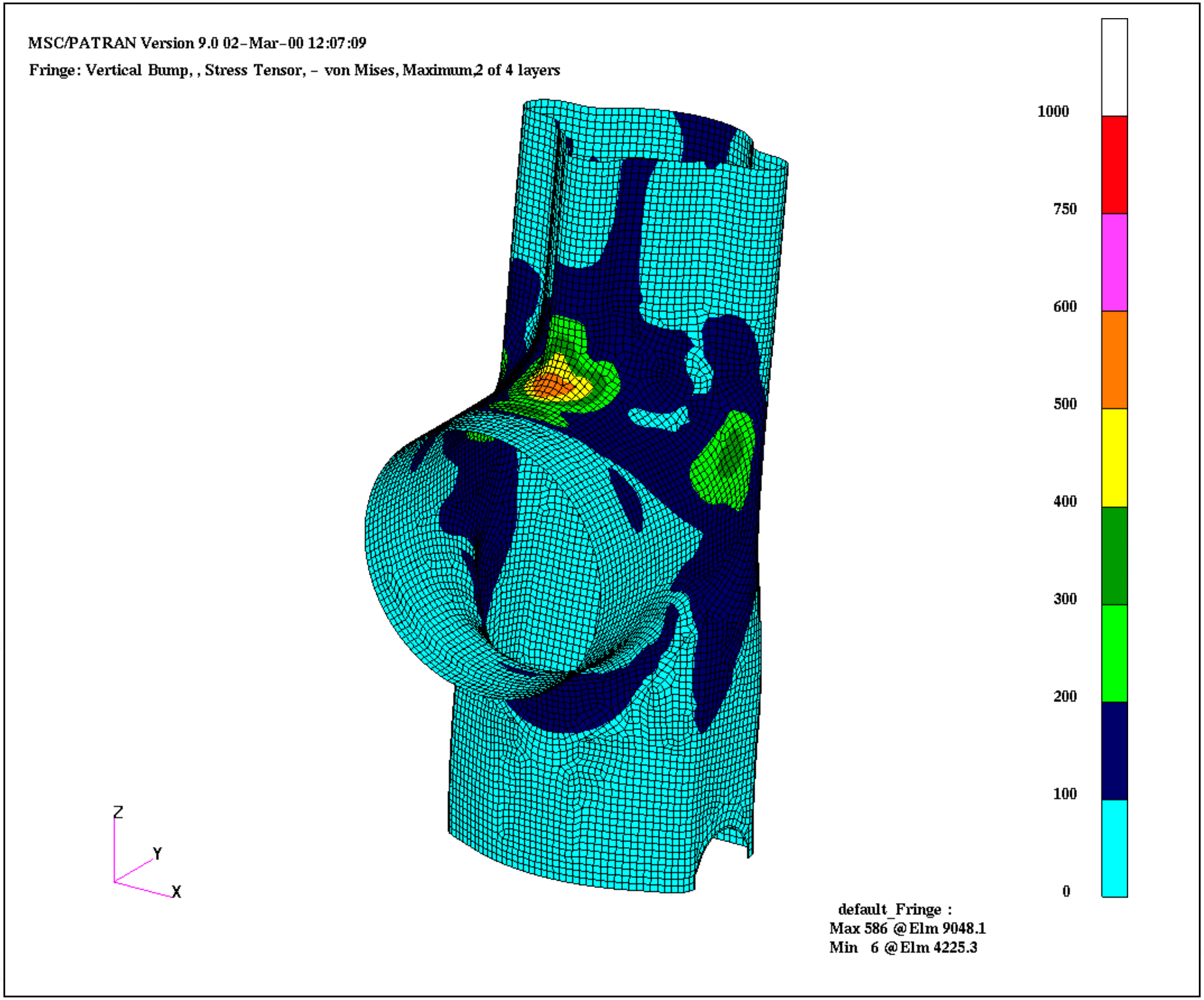


STRUT & LINKS: KNUCKLE
Vertical Bump, 586MPa Max. Stress, C Class

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS

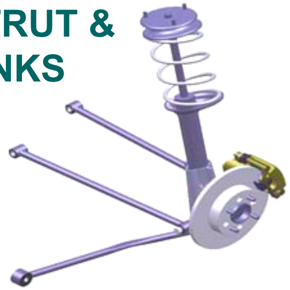


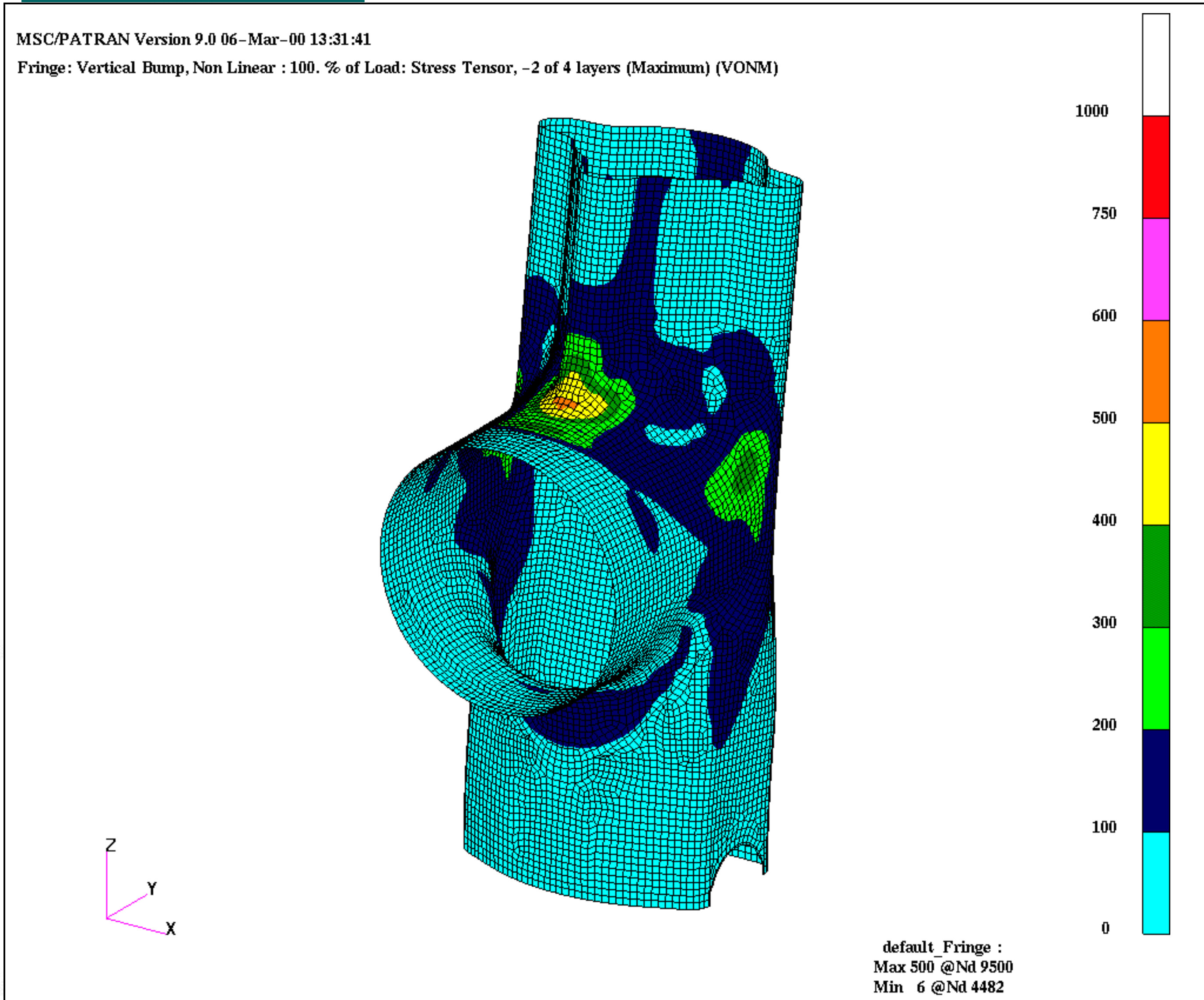


STRUT & LINKS: KNUCKLE

Vertical Bump, 500MPa Max. Stress, Non-linear analysis, C Class

STRUT & LINKS



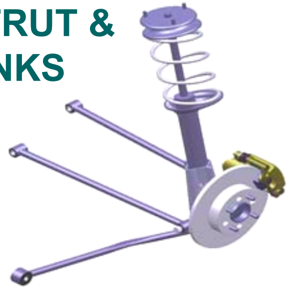


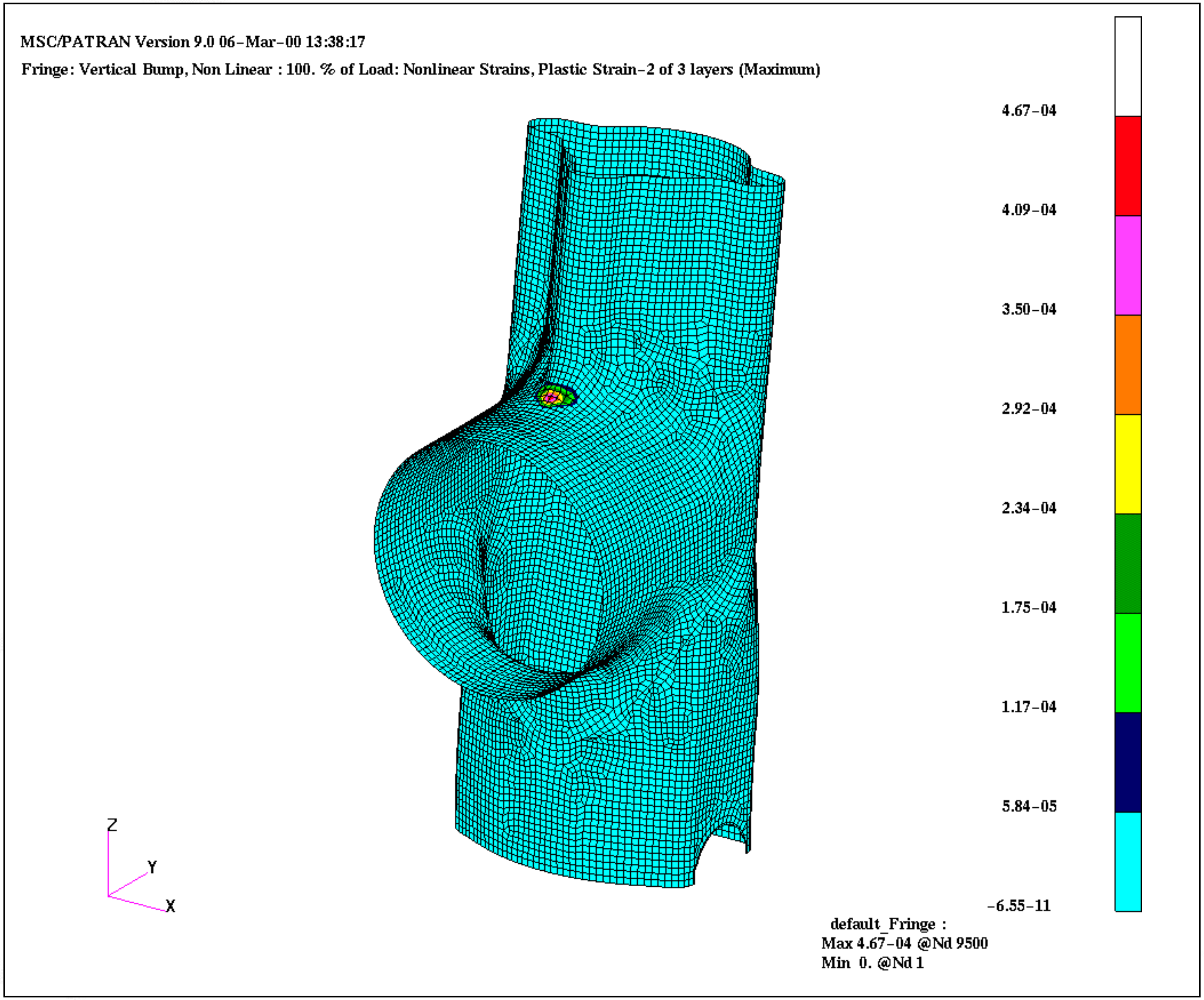
STRUT & LINKS: KNUCKLE

Vertical Bump, 500MPa Max. Stress, Non-linear analysis, Plastic Strain, C Class

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS



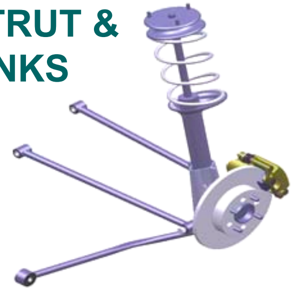


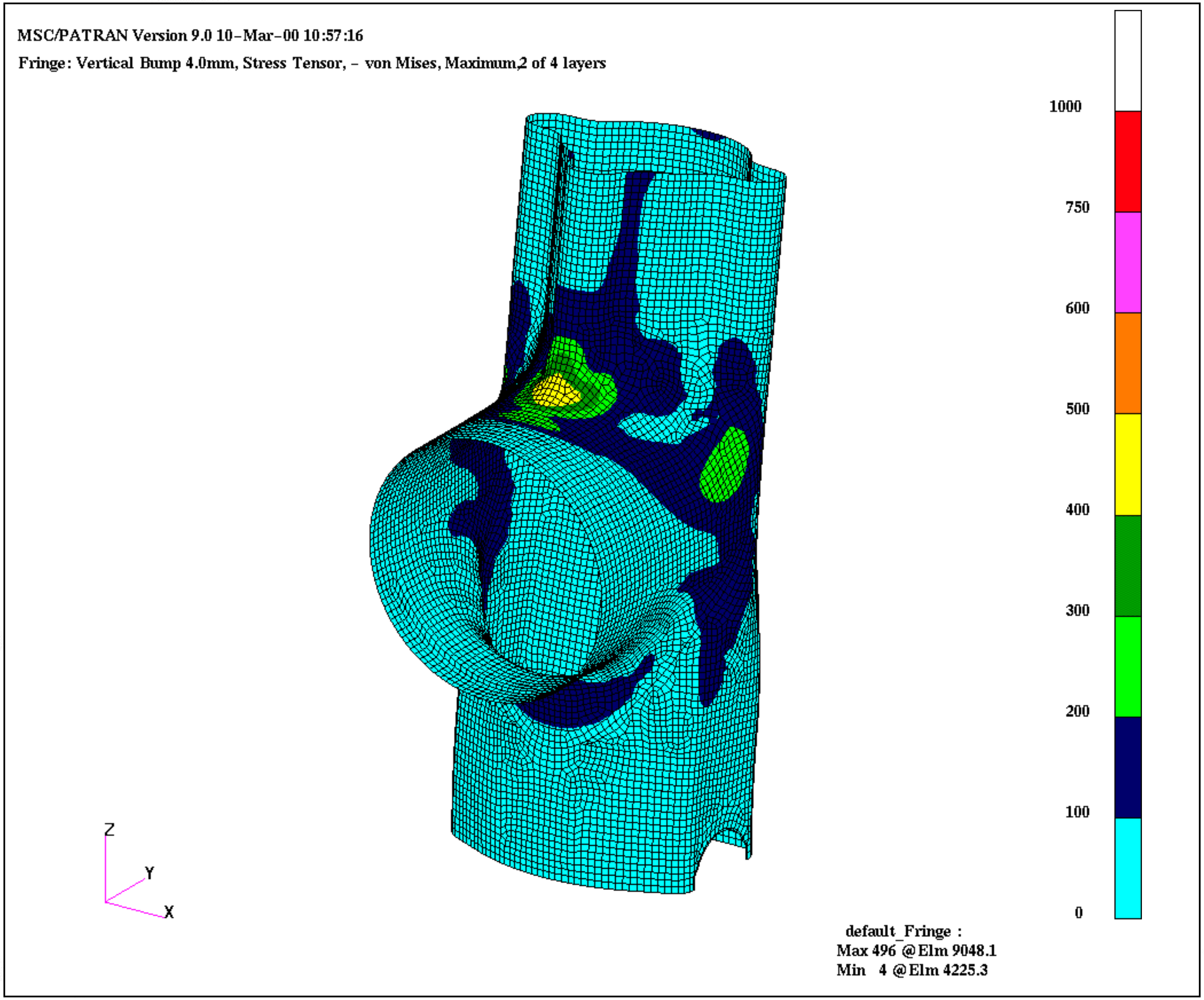
STRUT & LINKS: KNUCKLE

Vertical Bump, 496MPa Max. Stress, C Class

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS

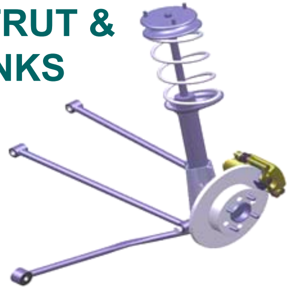


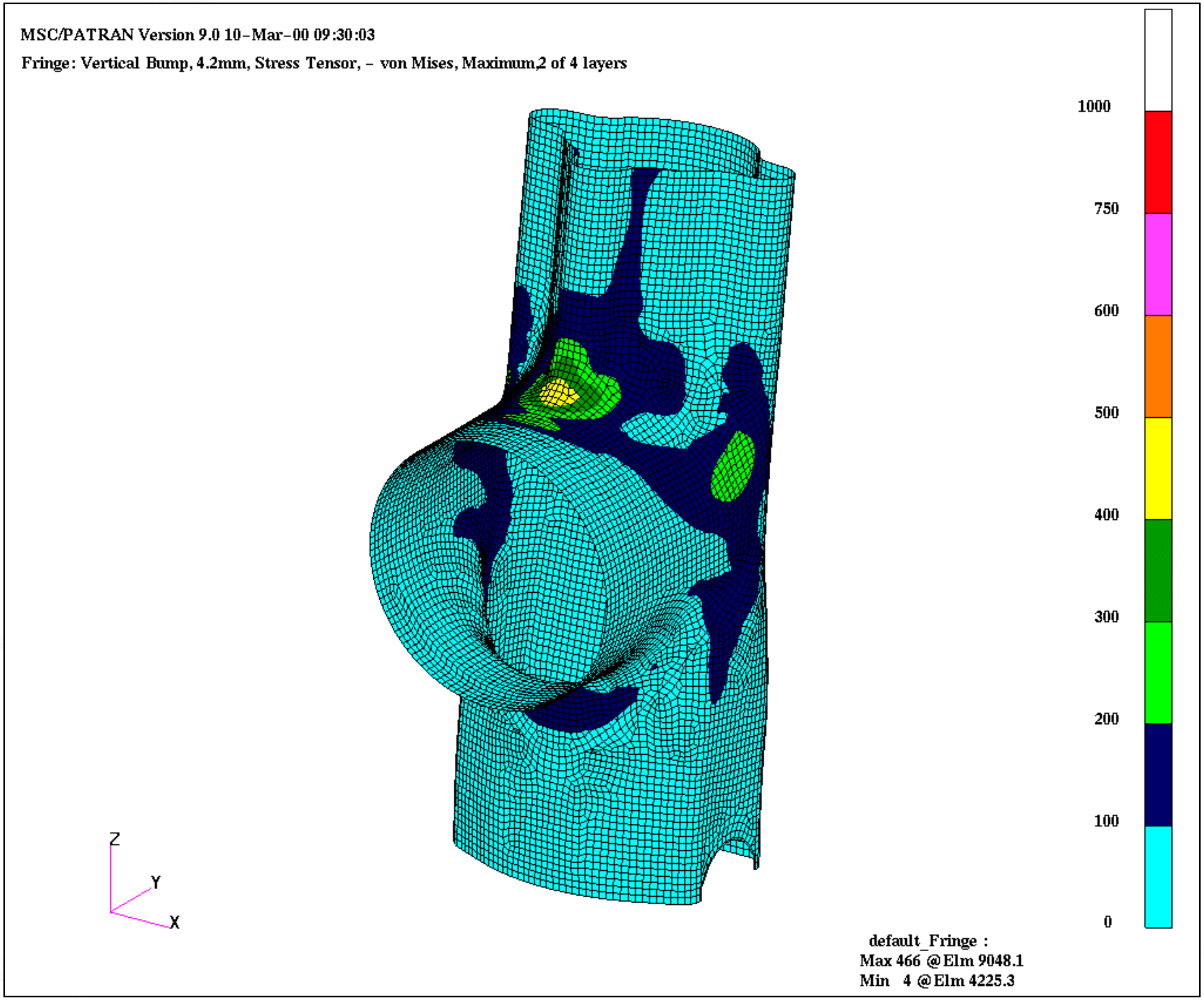


STRUT & LINKS: KNUCKLE

Vertical Bump, 466MPa Max. Stress, C Class

STRUT & LINKS

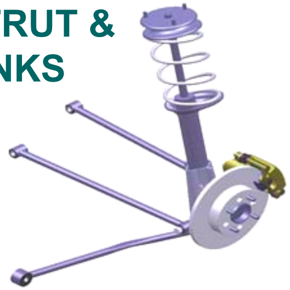


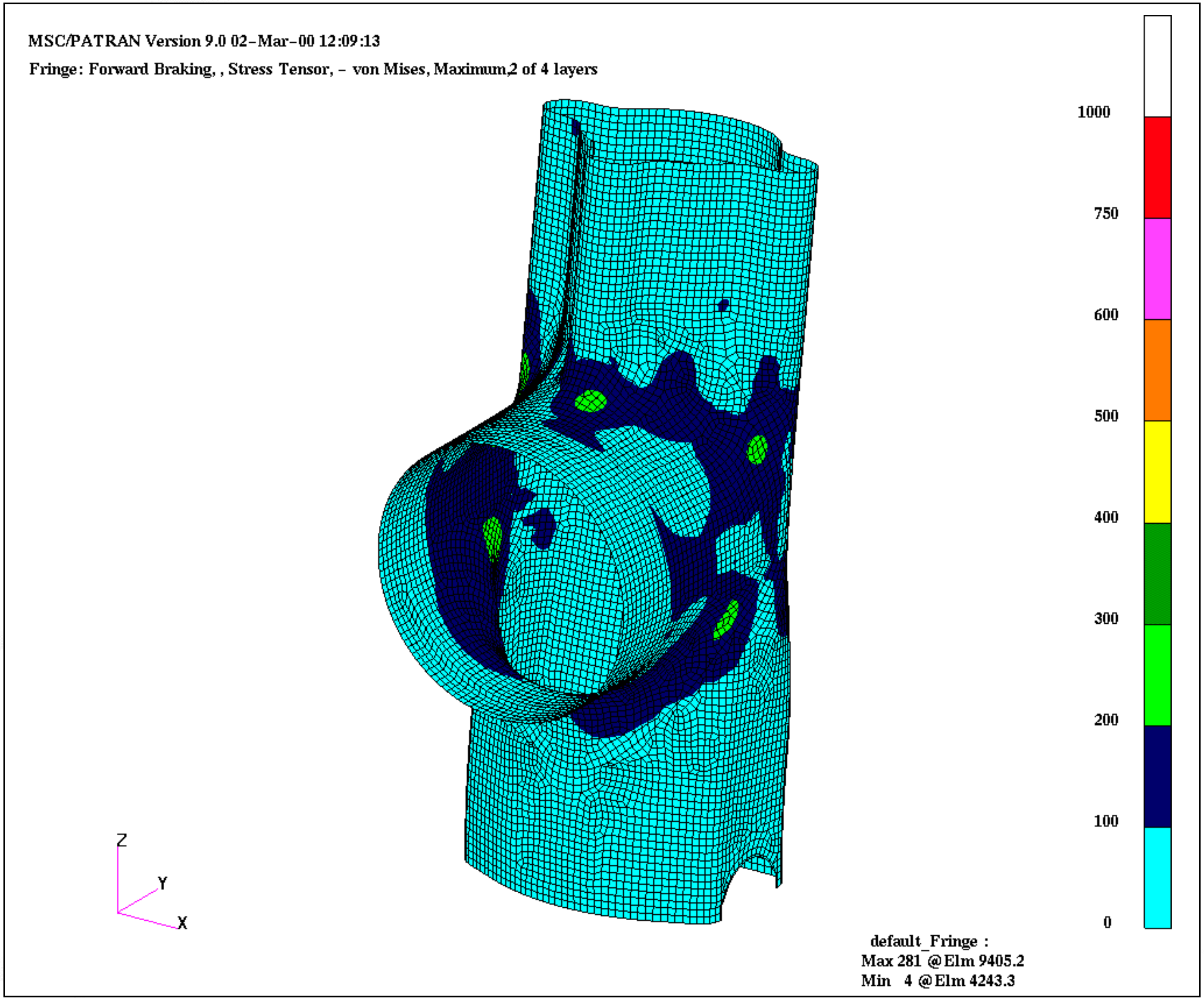


STRUT & LINKS: KNUCKLE

Forward Braking, C Class

STRUT & LINKS

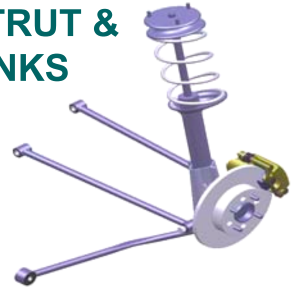


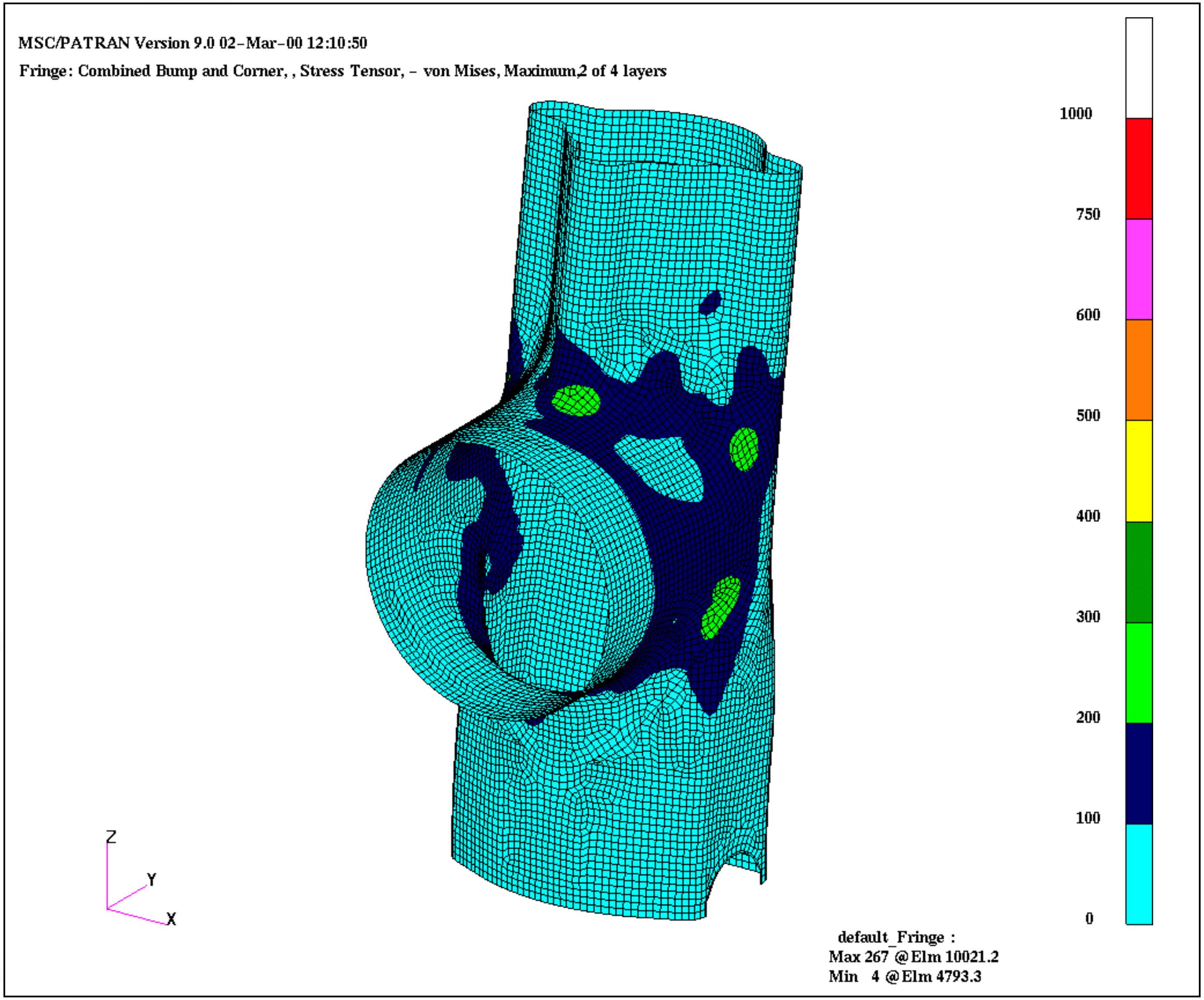


STRUT & LINKS: KNUCKLE

Combined Bump & Corner, C Class

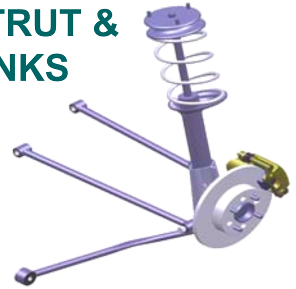
STRUT & LINKS

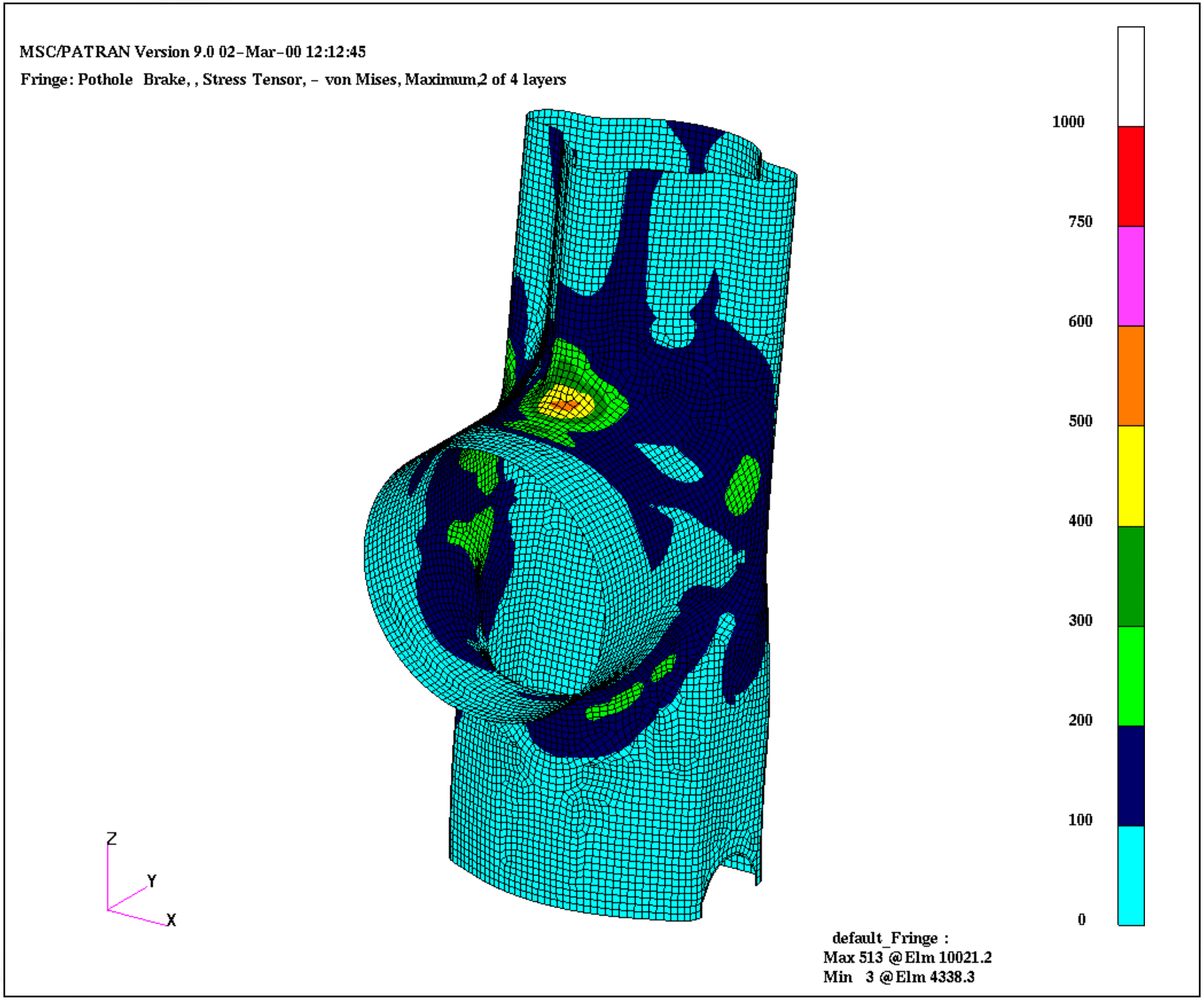


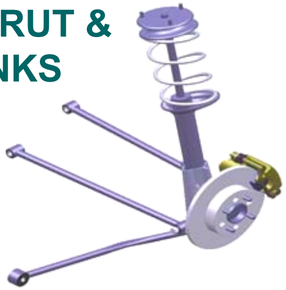


STRUT & LINKS: KNUCKLE
Pothole Brake, C Class

STRUT & LINKS







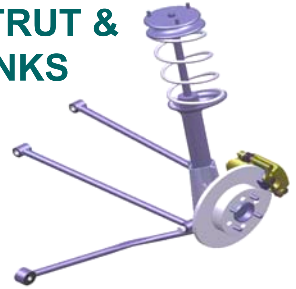
STRUT & LINKS: STRESS RESULTS

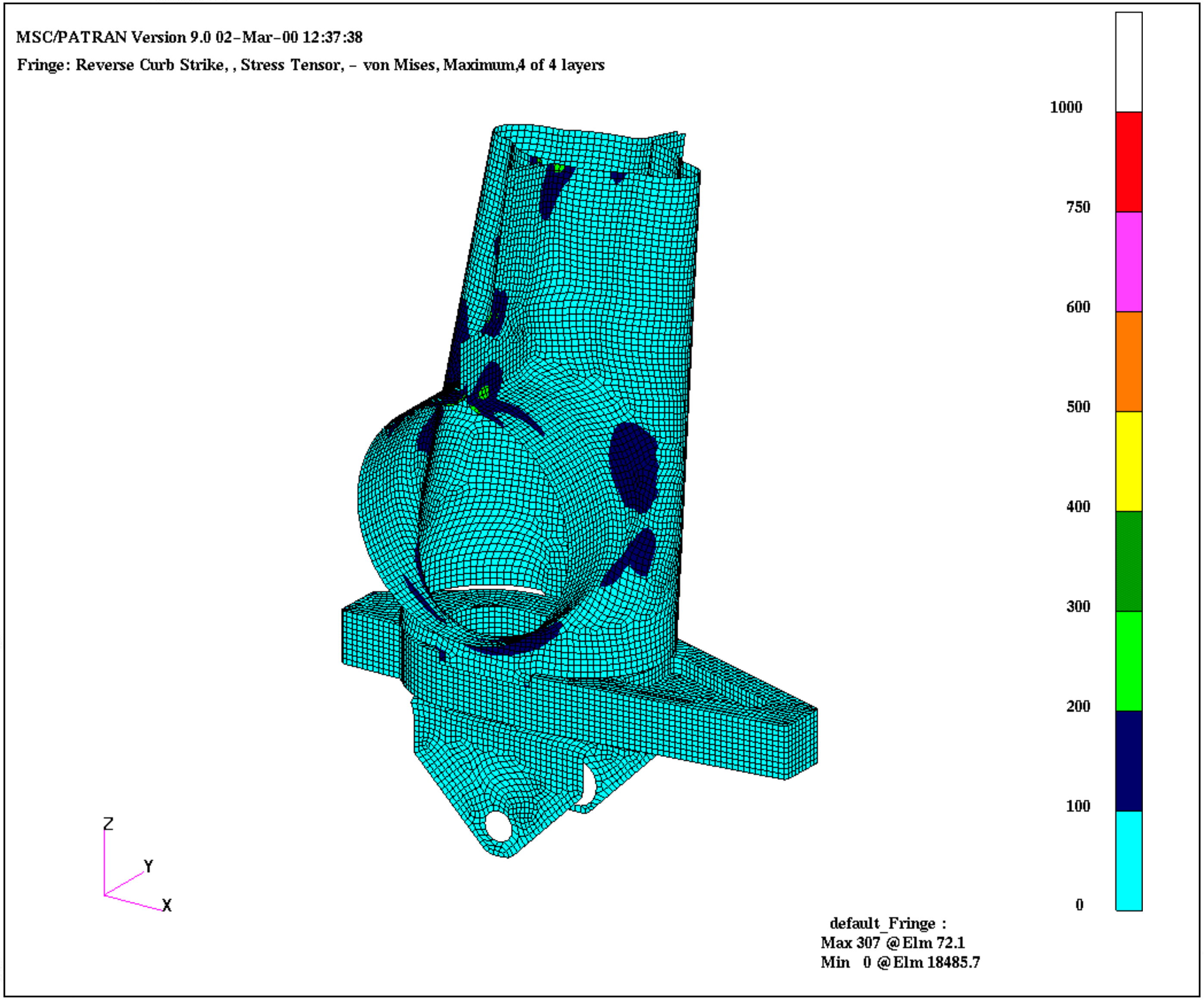
D Class

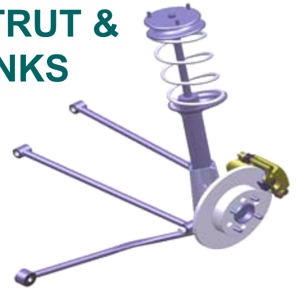
Load Case	Max stress (Von Mises)
Reverse Curb Strike (TCP)	307 MPa
Lateral Curb Strike 1 with load transfer	577 MPa
Lateral Curb Strike 2 with NO load transfer	598 MPa
Vertical Bump (TCP)	361 MPa
Forward Braking with ABS (TCP)	436 MPa
Combined Bump and Cornering (TCP)	371 MPa
Pothole Brake (TCP)	377 MPa

STRUT & LINKS: KNUCKLE
Reverse Curb Strike, D Class

STRUT & LINKS

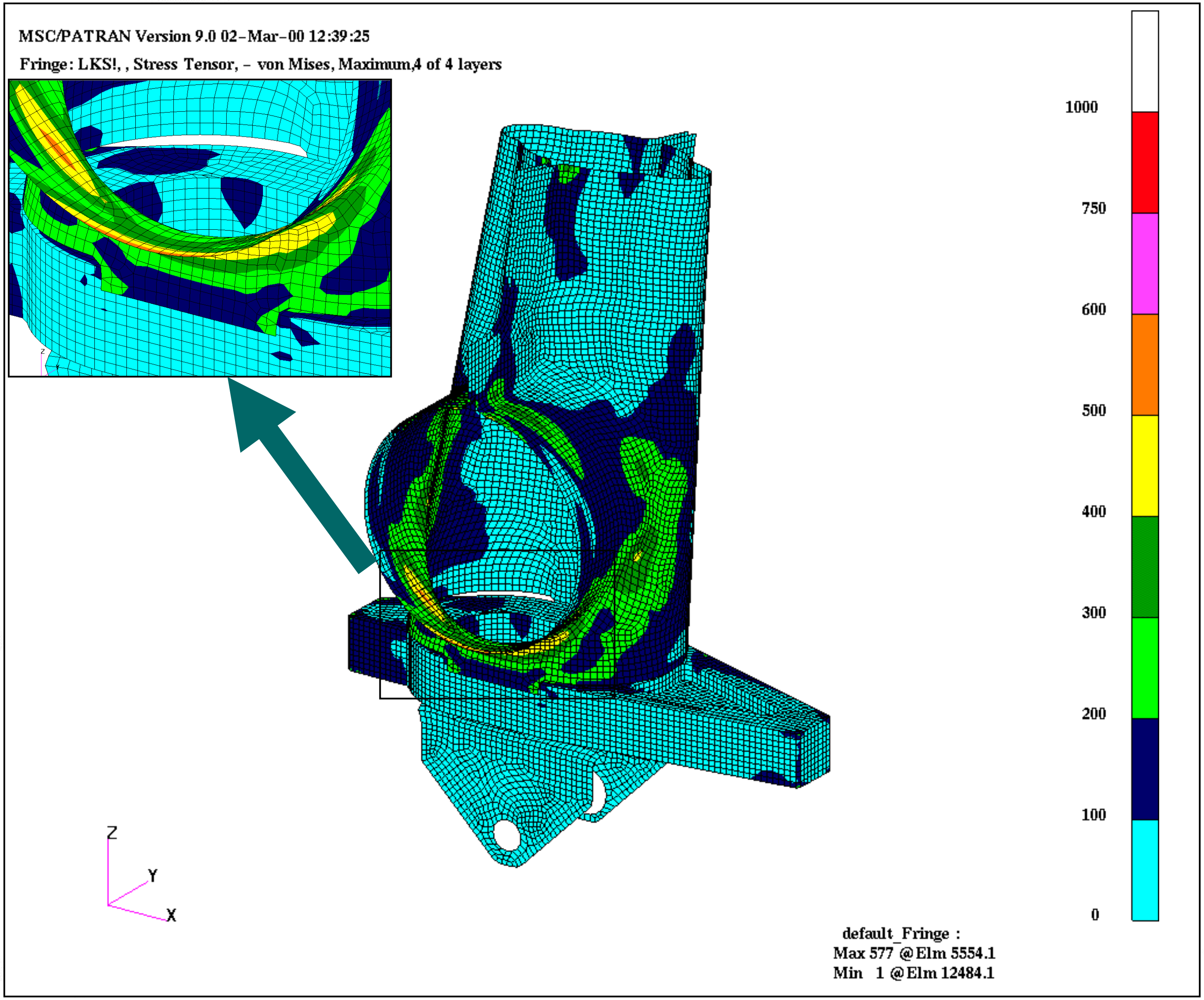






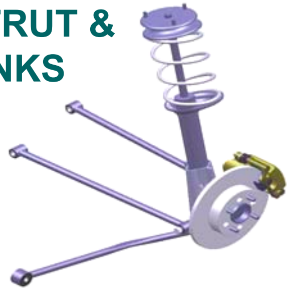
STRUT & LINKS: KNUCKLE

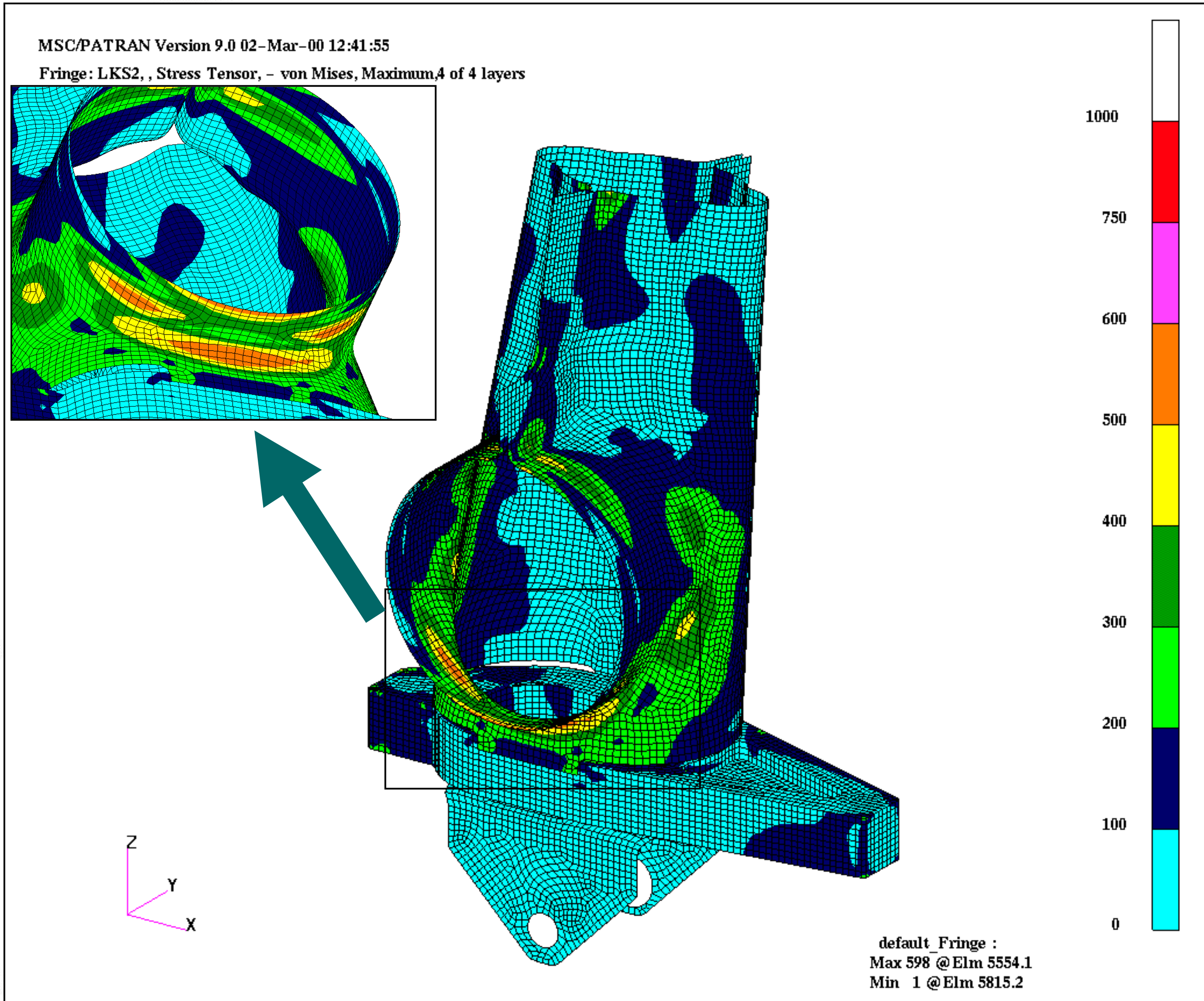
Lateral Curb Strike 1, D Class



STRUT & LINKS: KNUCKLE

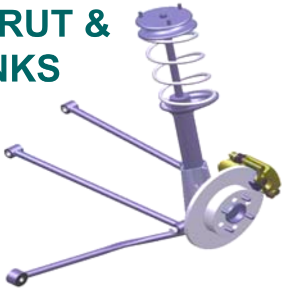
Lateral Curb Strike 2, 598MPa Max. Stress, D Class

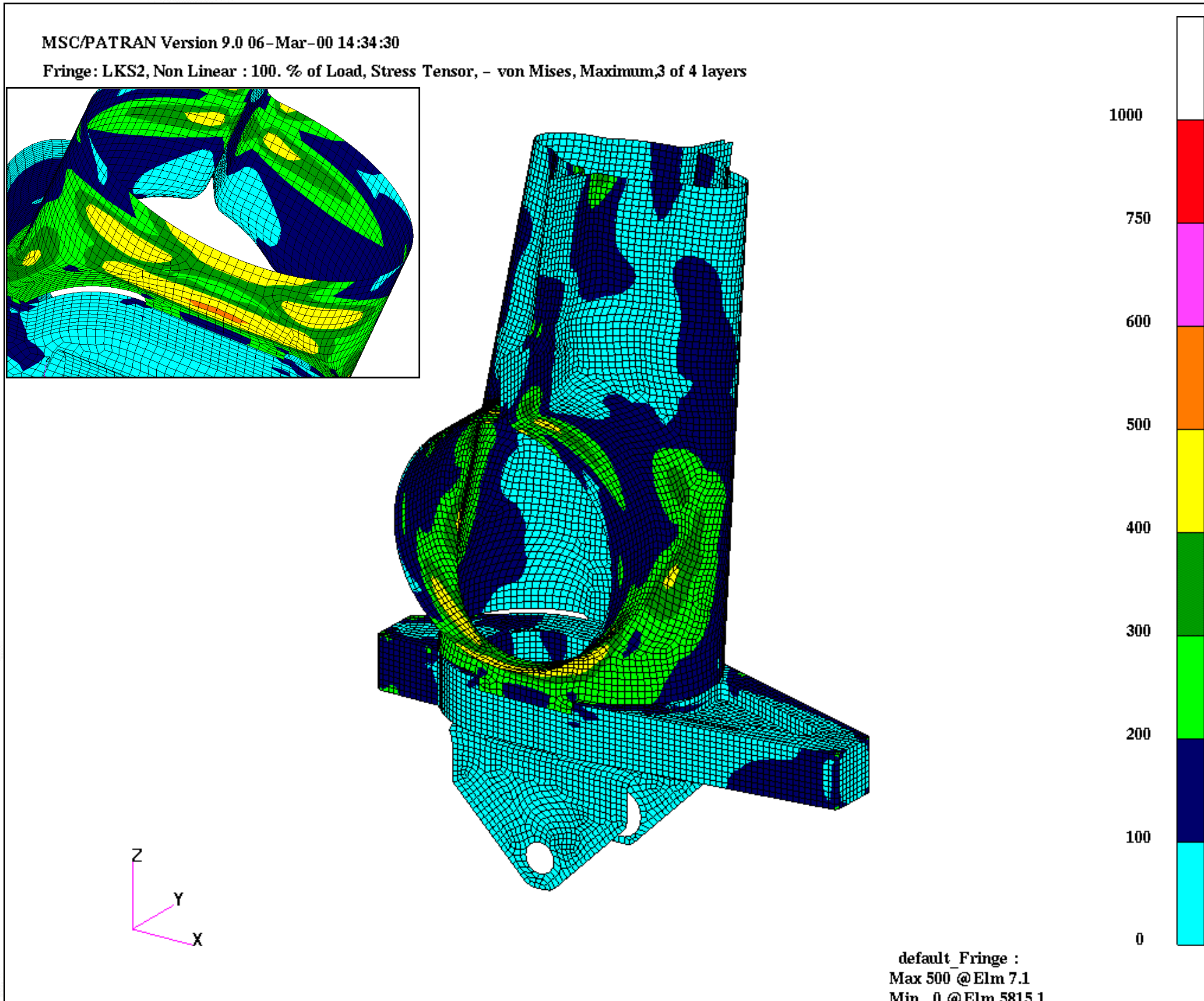




STRUT & LINKS: KNUCKLE

Lateral Curb Strike 2, 500MPa Max. Stress, Non-linear analysis, D Class

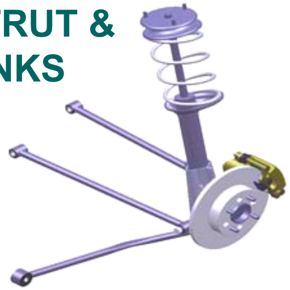


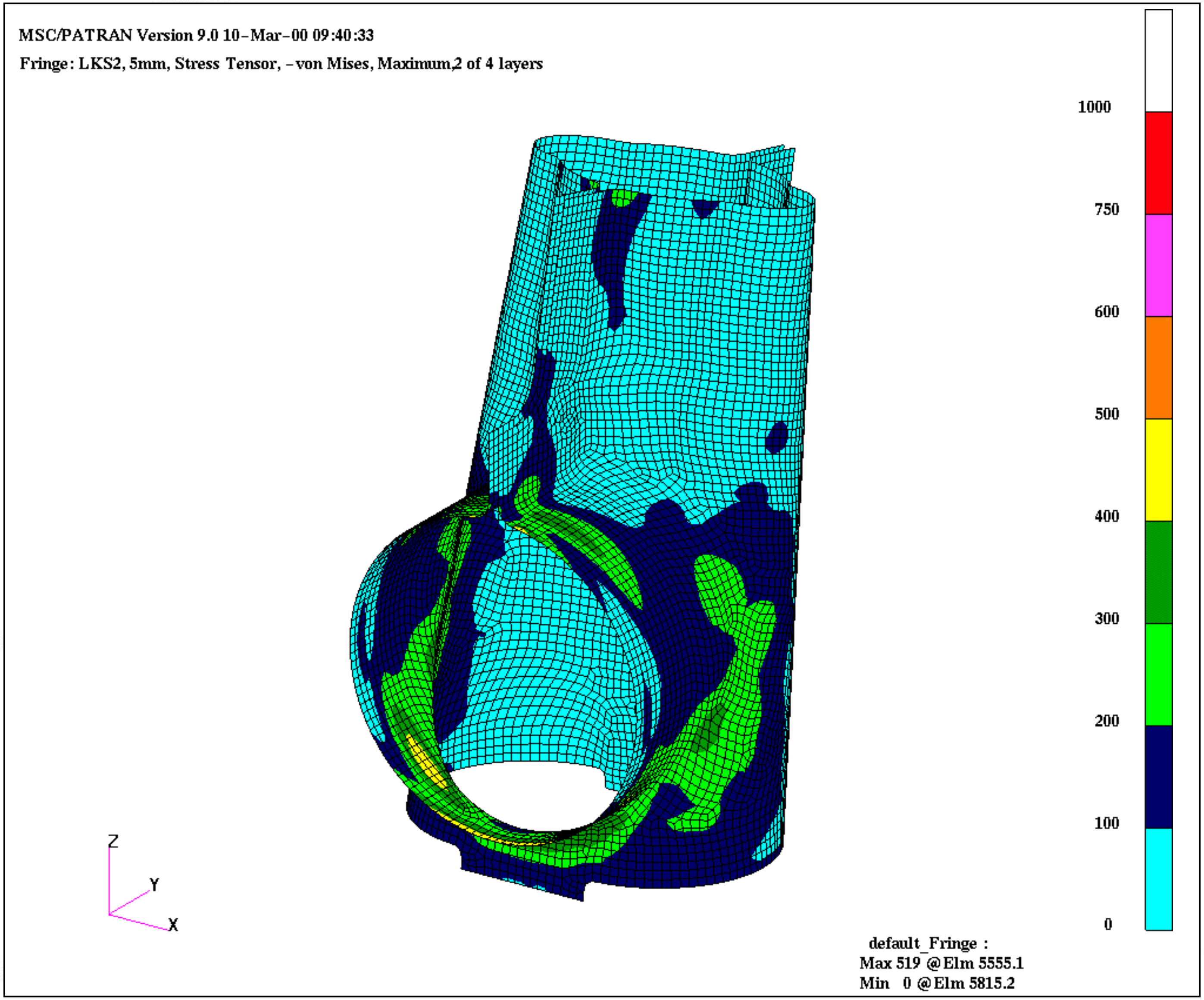


STRUT & LINKS: KNUCKLE
Lateral Curb Strike 2, 519MPa Max. Stress, D Class

ULTRALIGHT STEEL AUTO SUSPENSION

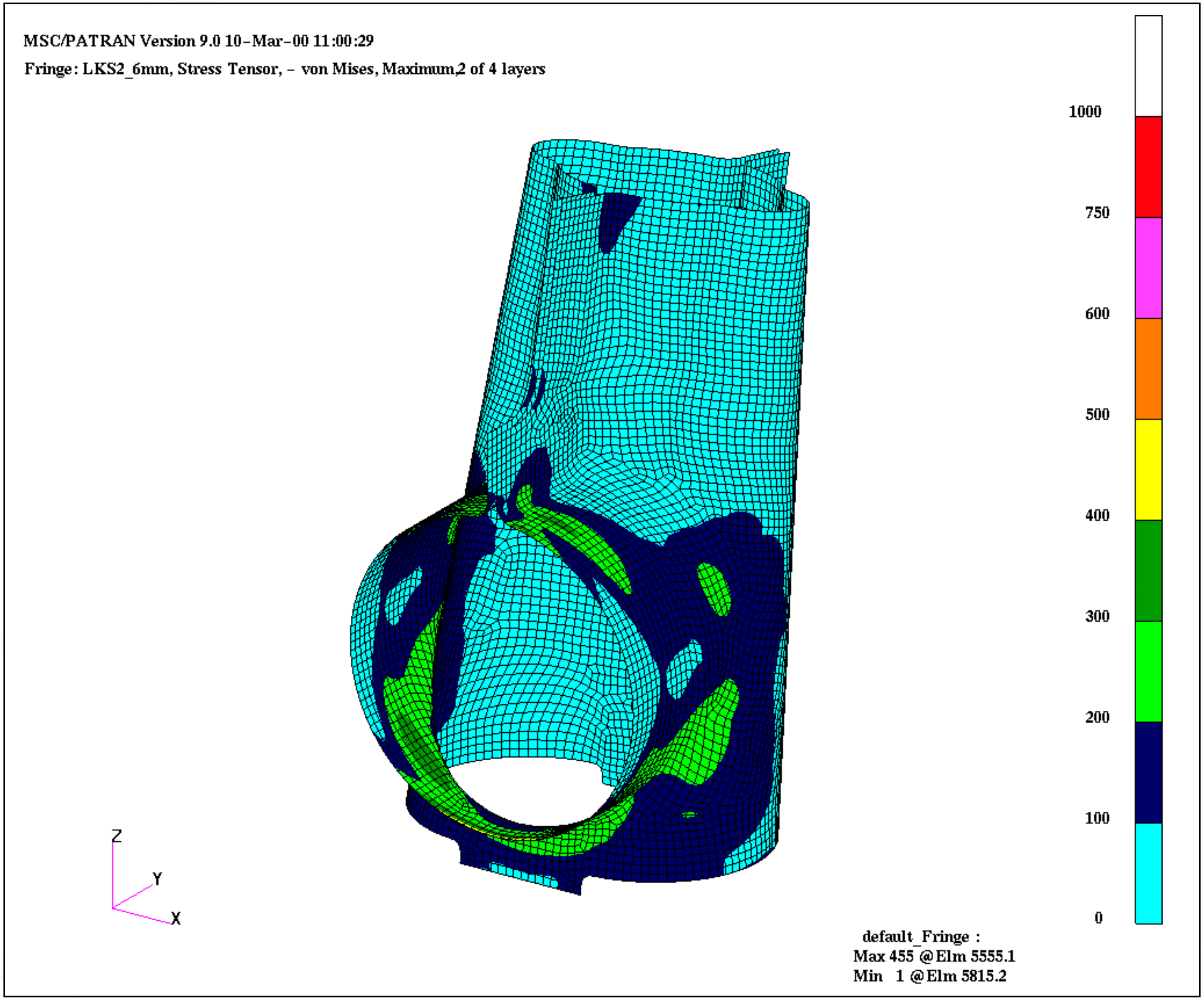
STRUT & LINKS



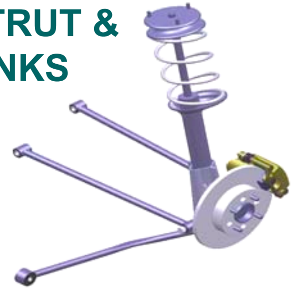


STRUT & LINKS: KNUCKLE

Lateral Curb Strike 2, 455MPa Max. Stress, D Class



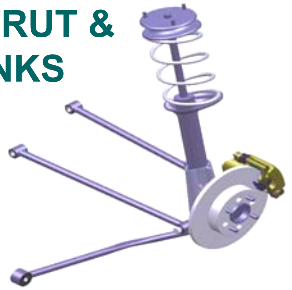
STRUT & LINKS

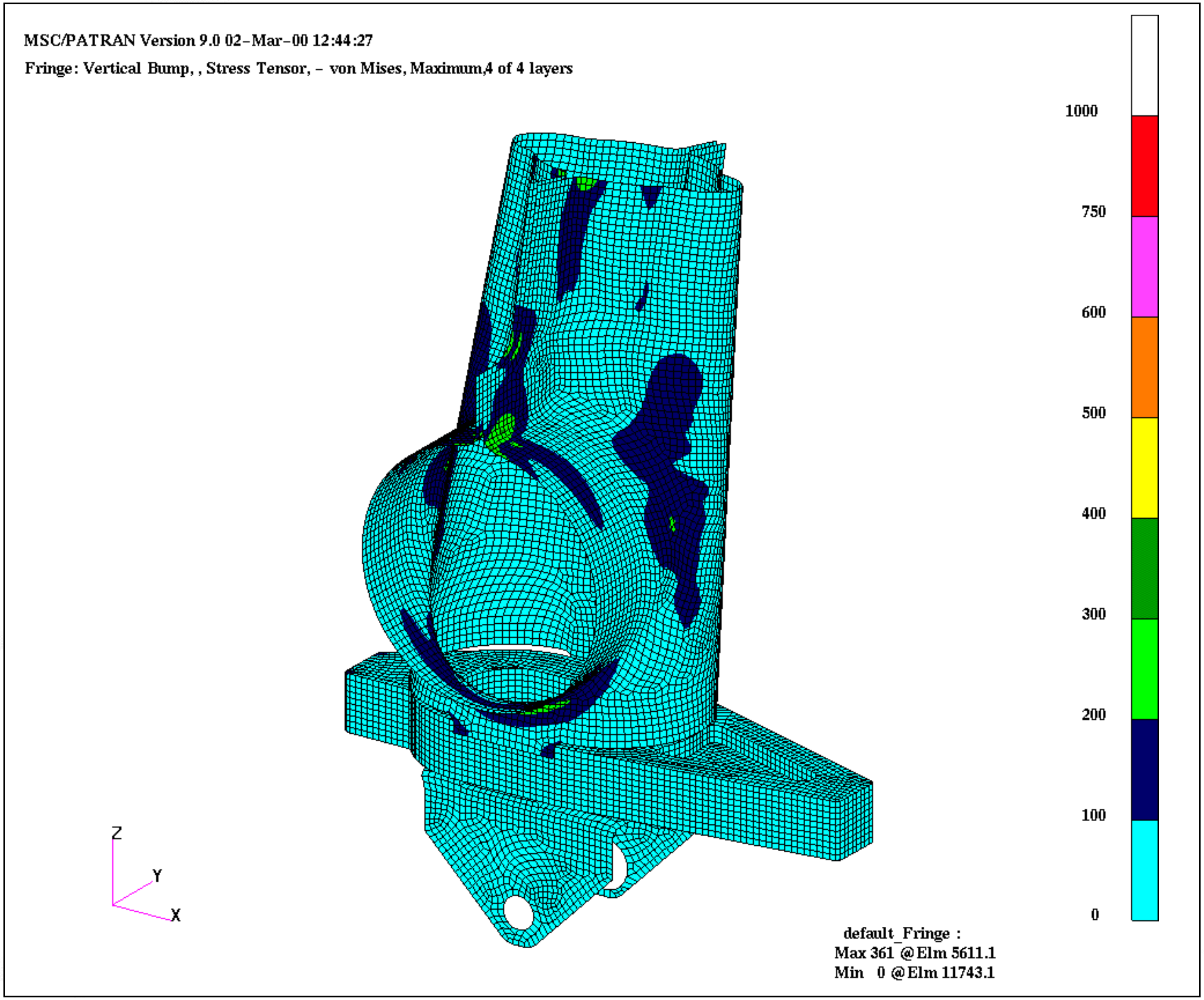


STRUT & LINKS: KNUCKLE

Vertical Bump, 361MPa Max. Stress, D Class

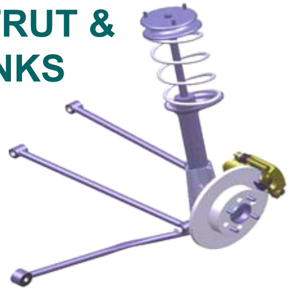
STRUT & LINKS

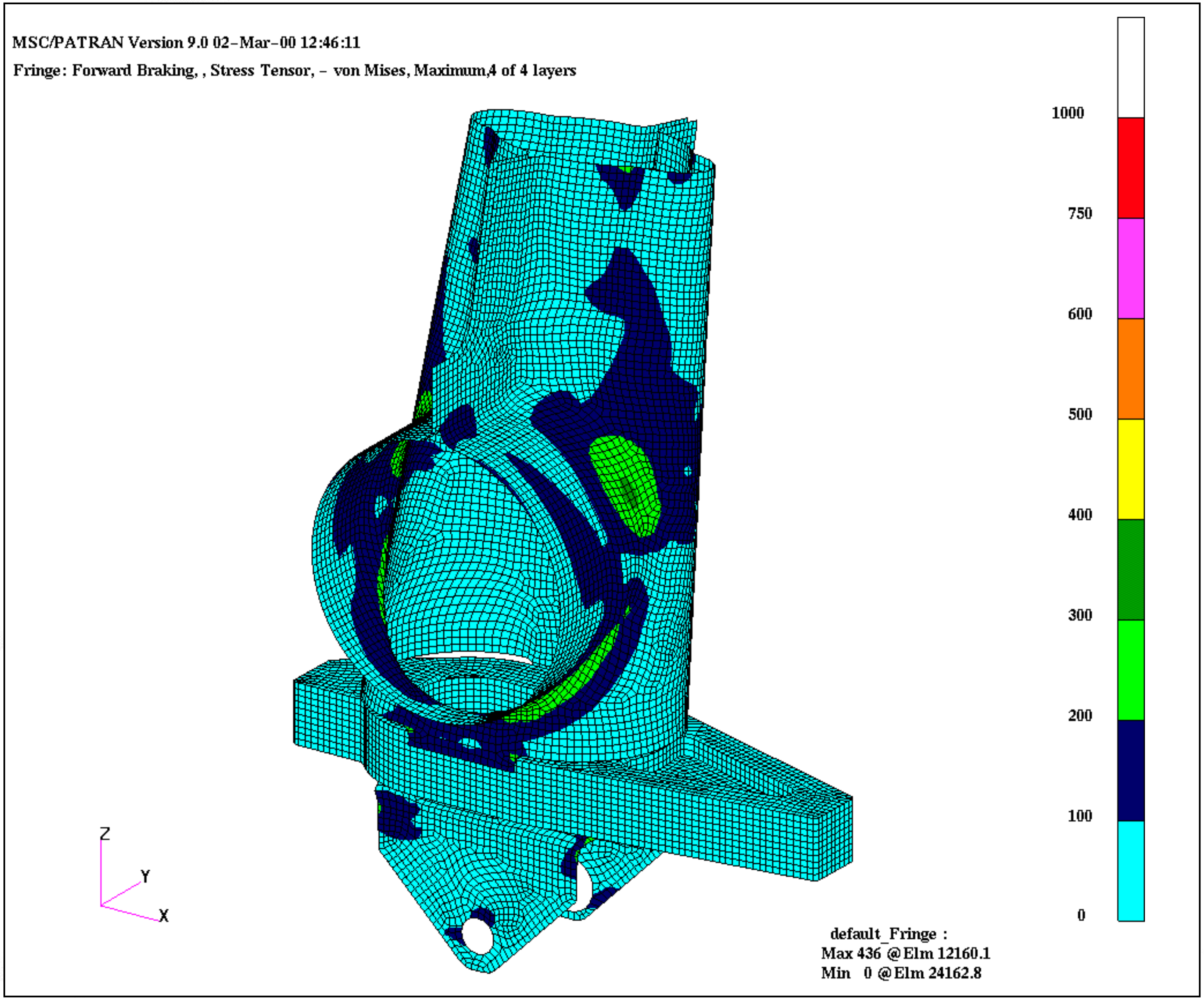




STRUT & LINKS: KNUCKLE
Forward Braking, D Class

STRUT & LINKS

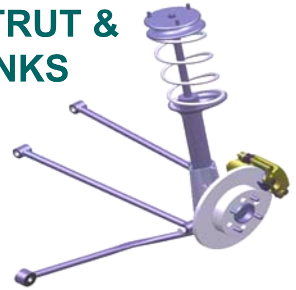


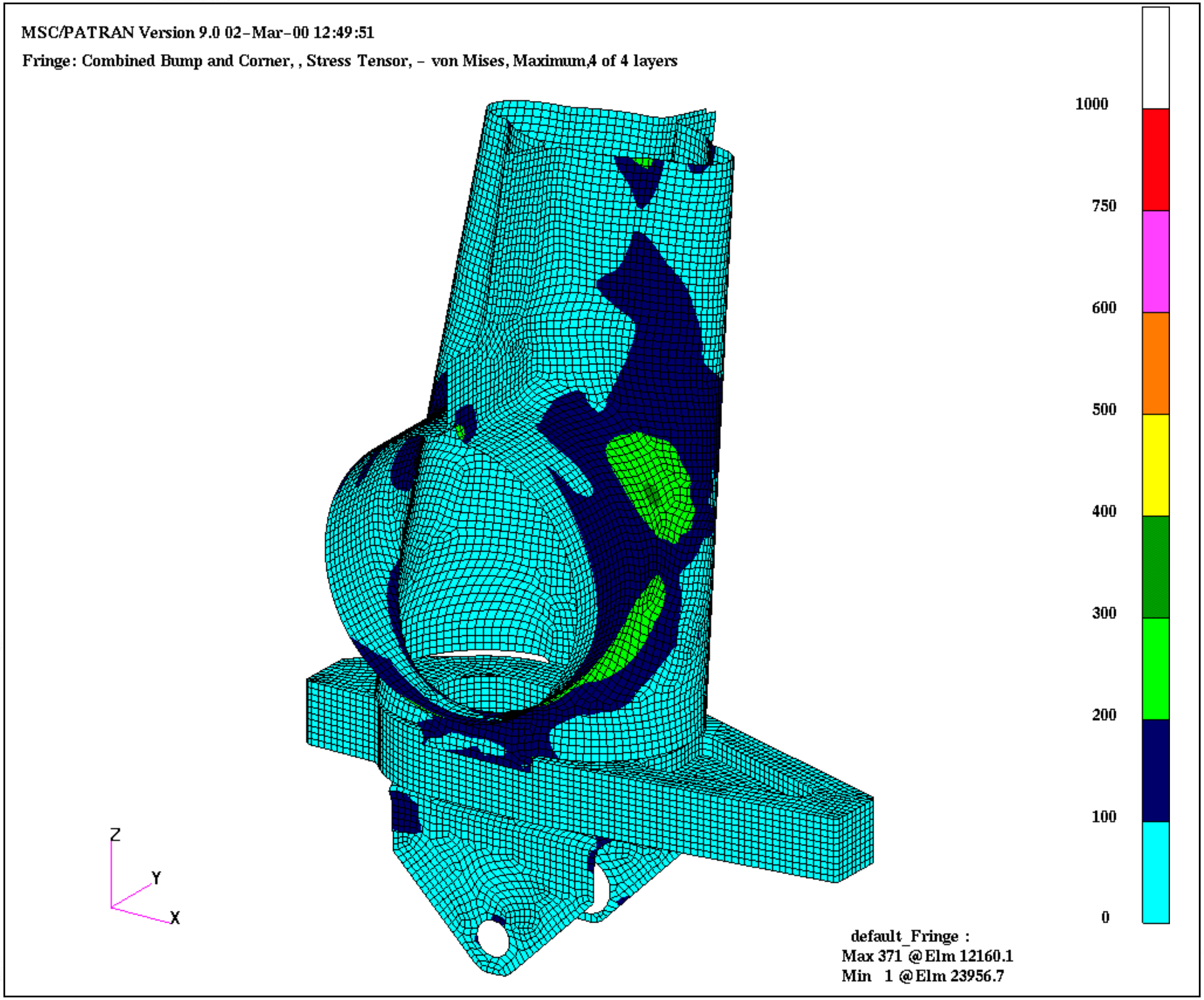


STRUT & LINKS: KNUCKLE
Combined Bump & Corner, D Class

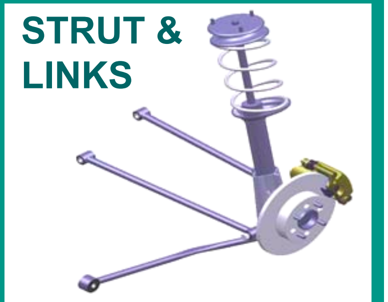
ULTRALIGHT STEEL AUTO SUSPENSION

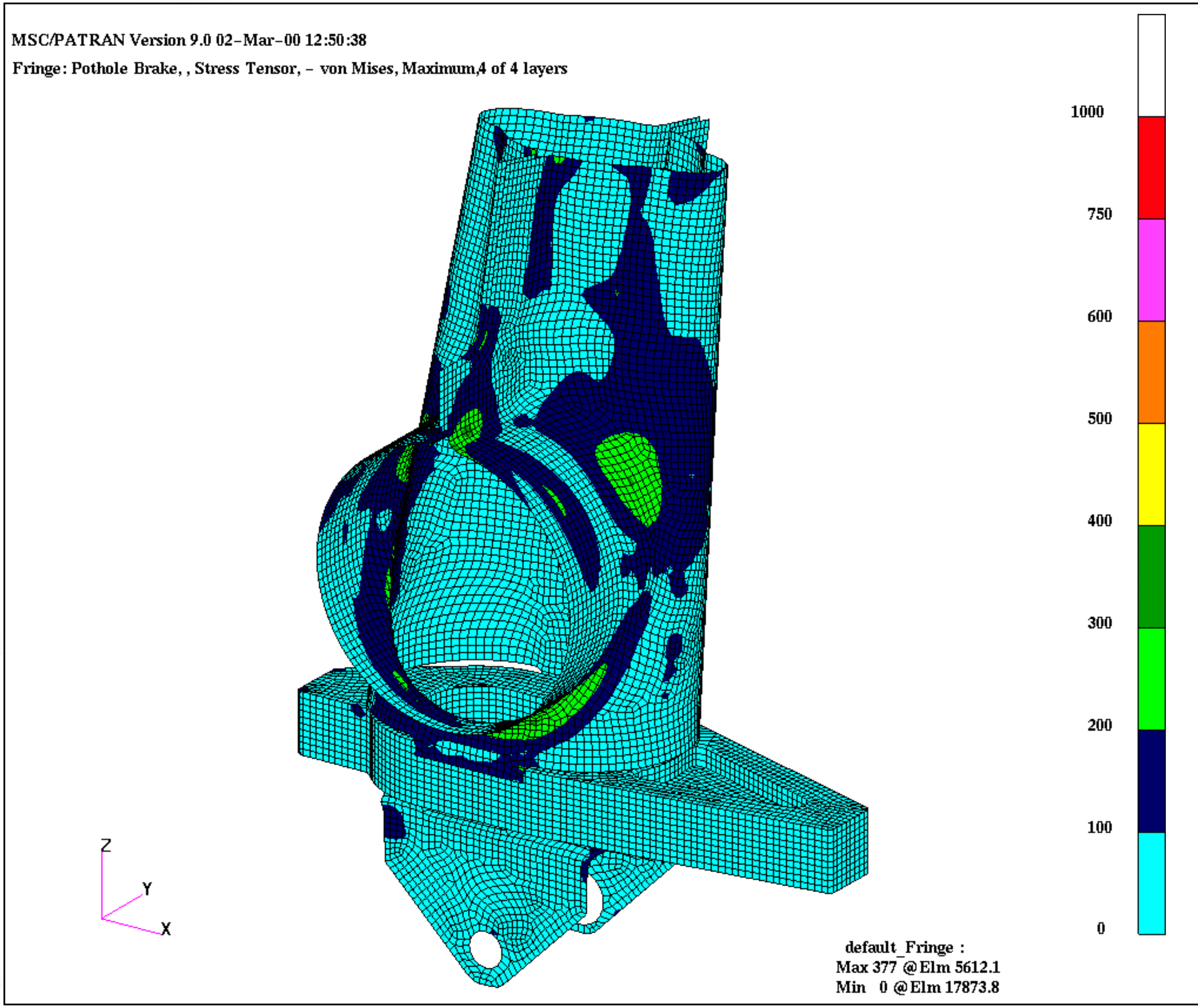
STRUT & LINKS

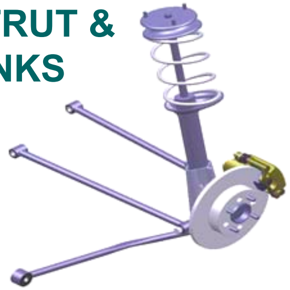




STRUT & LINKS: KNUCKLE
Pothole Brake, D Class

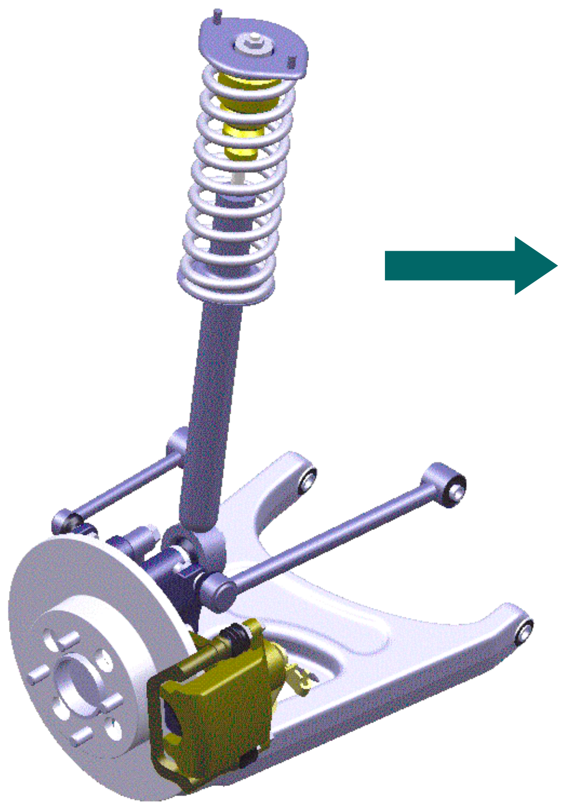


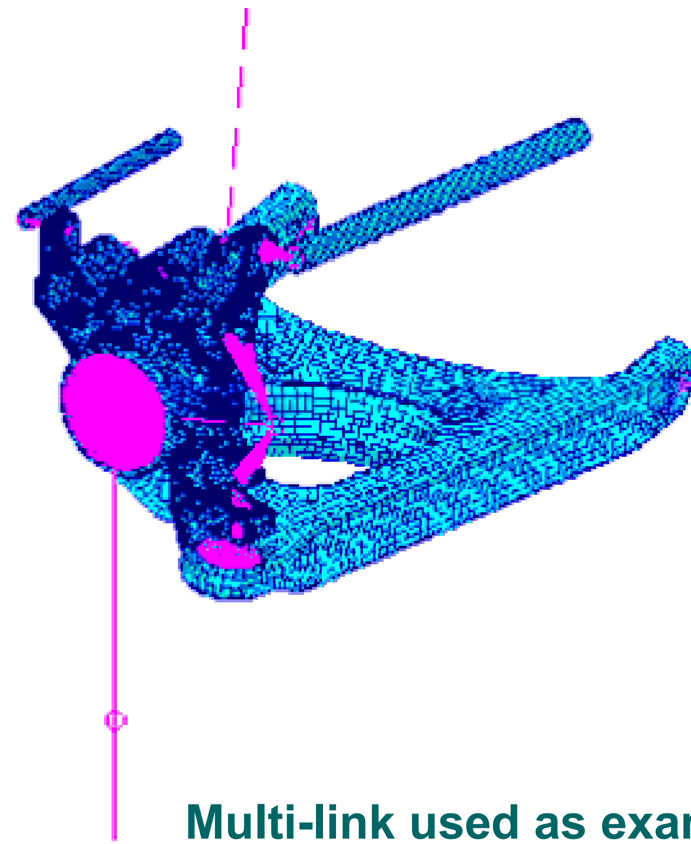




STRUT & LINKS: CAE STRUCTURAL APPROACH

Part Physical Geometry

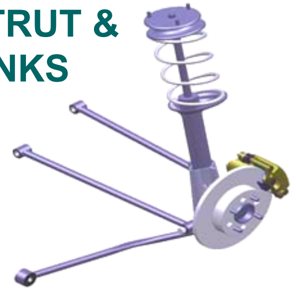




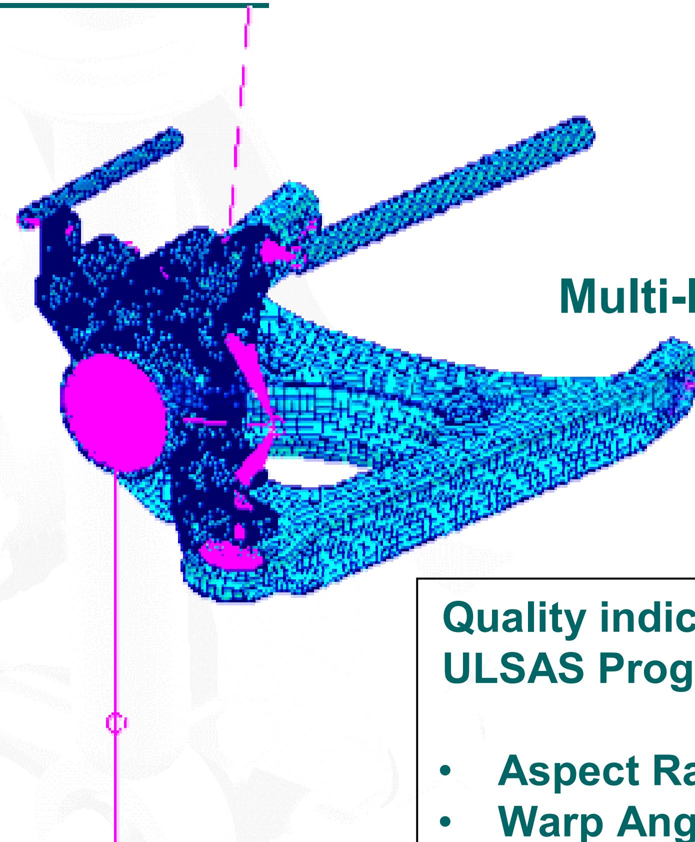
Multi-link used as example

The physical geometry of the parts used to create the finite element model was imported from the CAD environment. This was modified within the FE environment using the many tools available.

STRUT & LINKS: CAE STRUCTURAL APPROACH



Finite Elements



Multi-link used as example

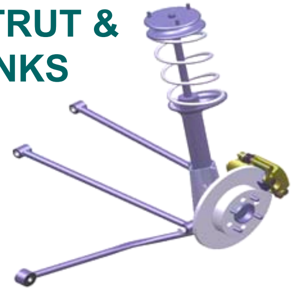
Quality indices adapted throughout the ULSAS Programme for shell elements :

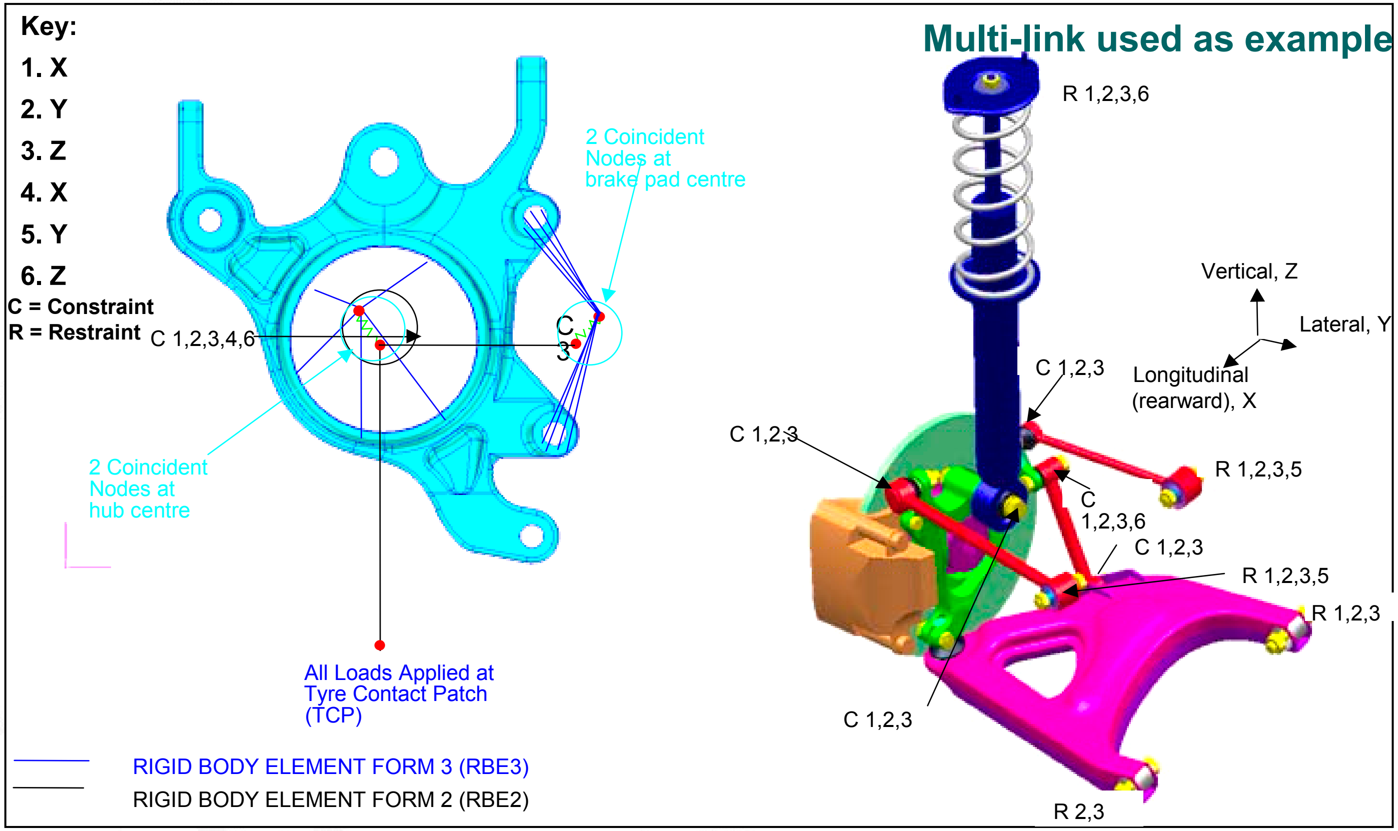
• Aspect Ratio	<	5:1
• Warp Angle	<	7 degrees
• Skew Angle	<	30 degrees
• Taper	>	0.8

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

STRUT & LINKS: CAE STRUCTURAL APPROACH

Loads and Boundary Conditions

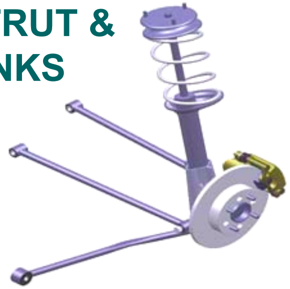




Restraints, constraints and loads are applied to the FE model using appropriate rigid elements and springs, with the necessary degrees of freedom carefully defined. Restraints are normally RBE3s from a hole to a fixing point, and then a spring to ground. Constraints connect two components using RBE3s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

STRUT & LINKS



STRUT & LINKS: CAE STRUCTURAL APPROACH

Materials

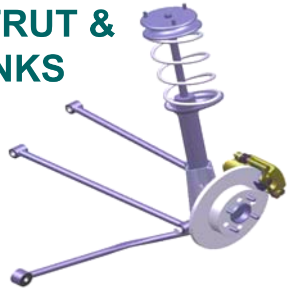
Material models are obtained from the FE software database, or else are created explicitly. Linear analysis only requires the elastic modulus and Poisson ratio. A non linear analysis also requires the yield point and a plastic hardening modulus.

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.

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS



STRUT & LINKS: CAE STRUCTURAL APPROACH

Load Cases

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:

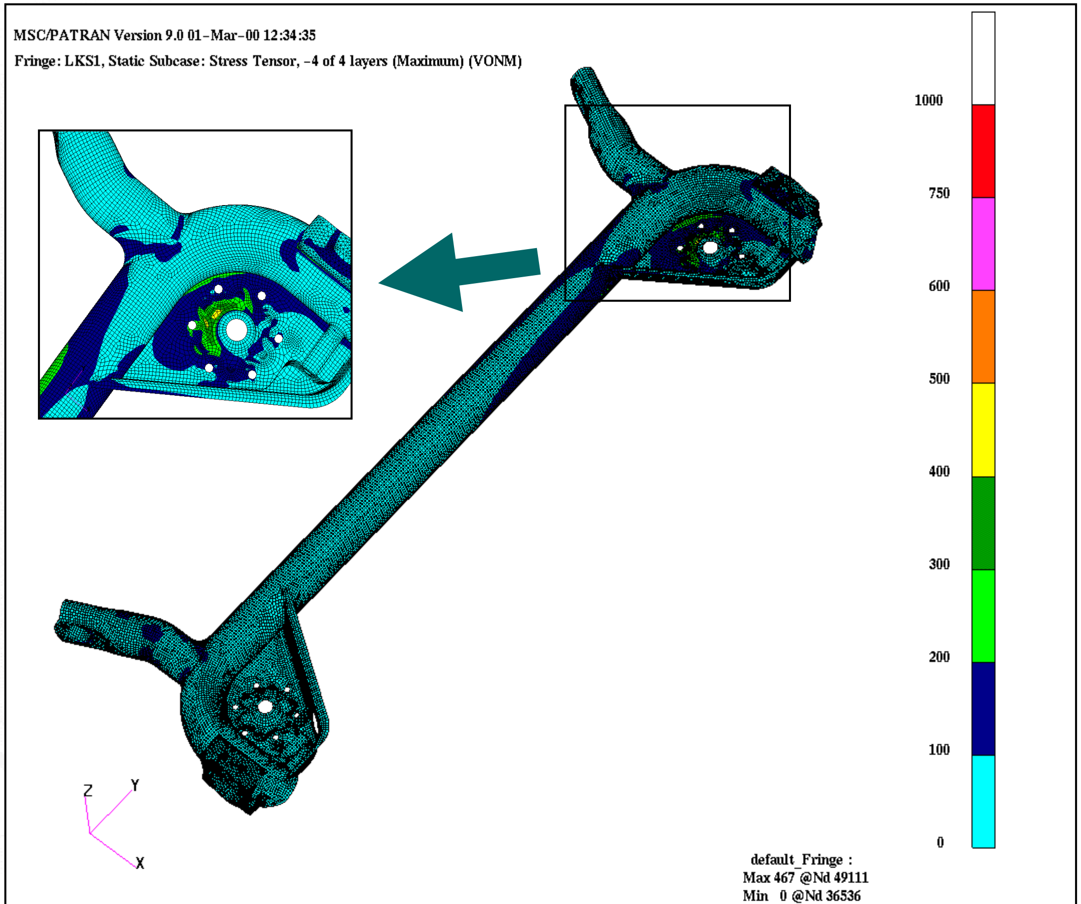
X =Positive rearward
Y =Positive to the right
Z =Positive upwards

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 indicated above.

STRUT &LINKS: CAE STRUCTURAL APPROACH

Analysis

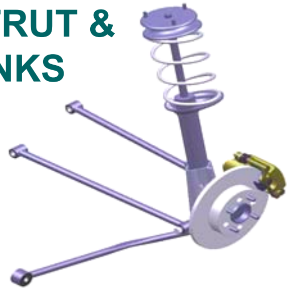


Twistbeam used as example

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.)

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS



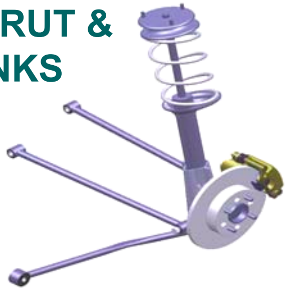
STRUT & LINKS: CAE STRUCTURAL APPROACH

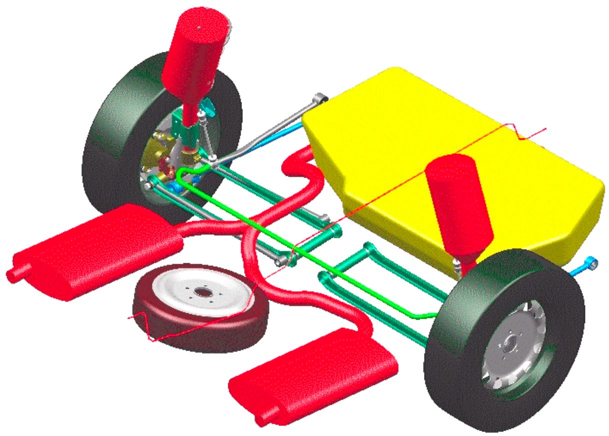
Load Case	Max stress (Von Mises)	Location
Reverse Curb Strike (TCP)	468 MPa	Spring pan
Lateral Curb Strike 1 with load transfer	472 MPa	Spring pan
Lateral Curb Strike 2 with NO load transfer	416 MPa	Knuckle join
Vertical Bump (TCP)	592 MPa	Tube
Forward Braking with ABS (TCP)	355 MPa	Knuckle join
Combined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

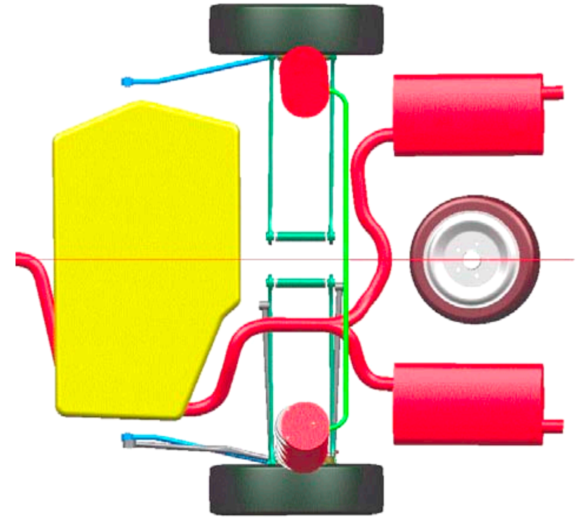
Example of Results Table

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 a the part design needs to be redefined. If this is not possible then nonlinear static analysis may be performed to further evaluate the behavior of the component under.

STRUT & LINKS: PACKAGING





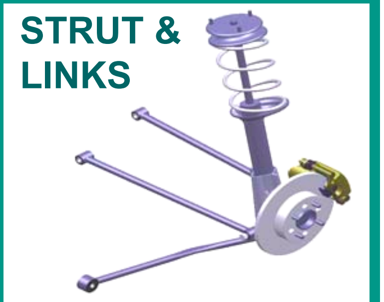


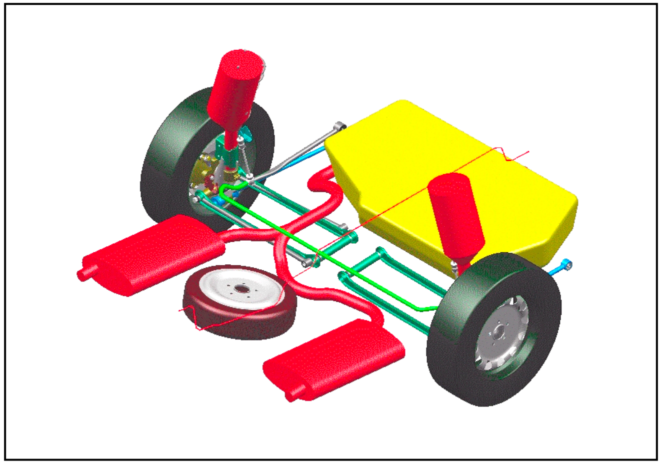
An evaluation of the packaging implications of the proposed suspension system was carried out. This compared the ULSAS system to the benchmarked vehicle in the following areas:

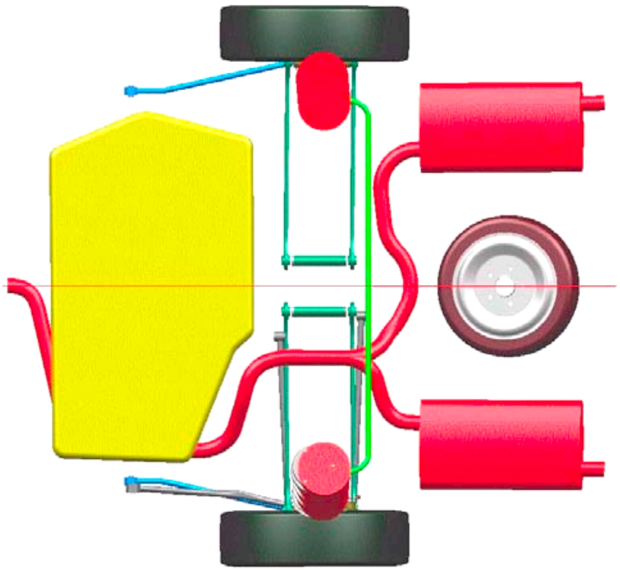
- **Systems Packaging**
- **Interior Space**

STRUT & LINKS: PACKAGING

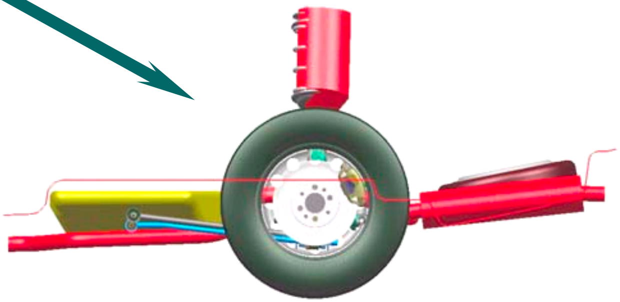
Systems







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



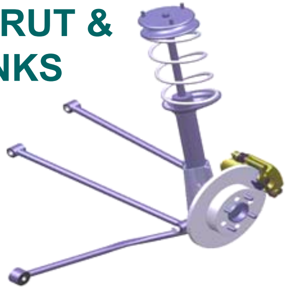
Benchmark Vehicle (E Class)

ULSAS Solution (P Class)

STRUT & LINK: PACKAGING

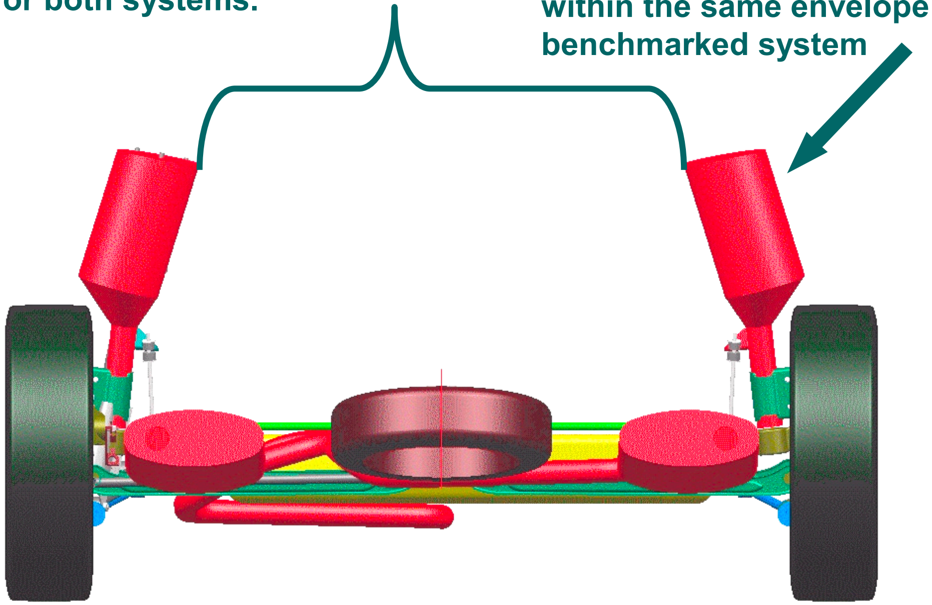
Interior

STRUT & LINKS



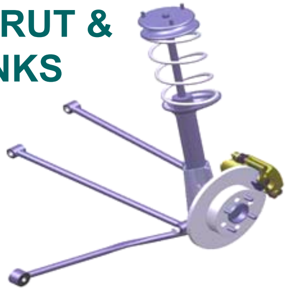
The ULSAS solution has no package disadvantages over the benchmark system in respect of luggage compartment width. This is best illustrated in the spacing of the damper units which is virtually identical for both systems.

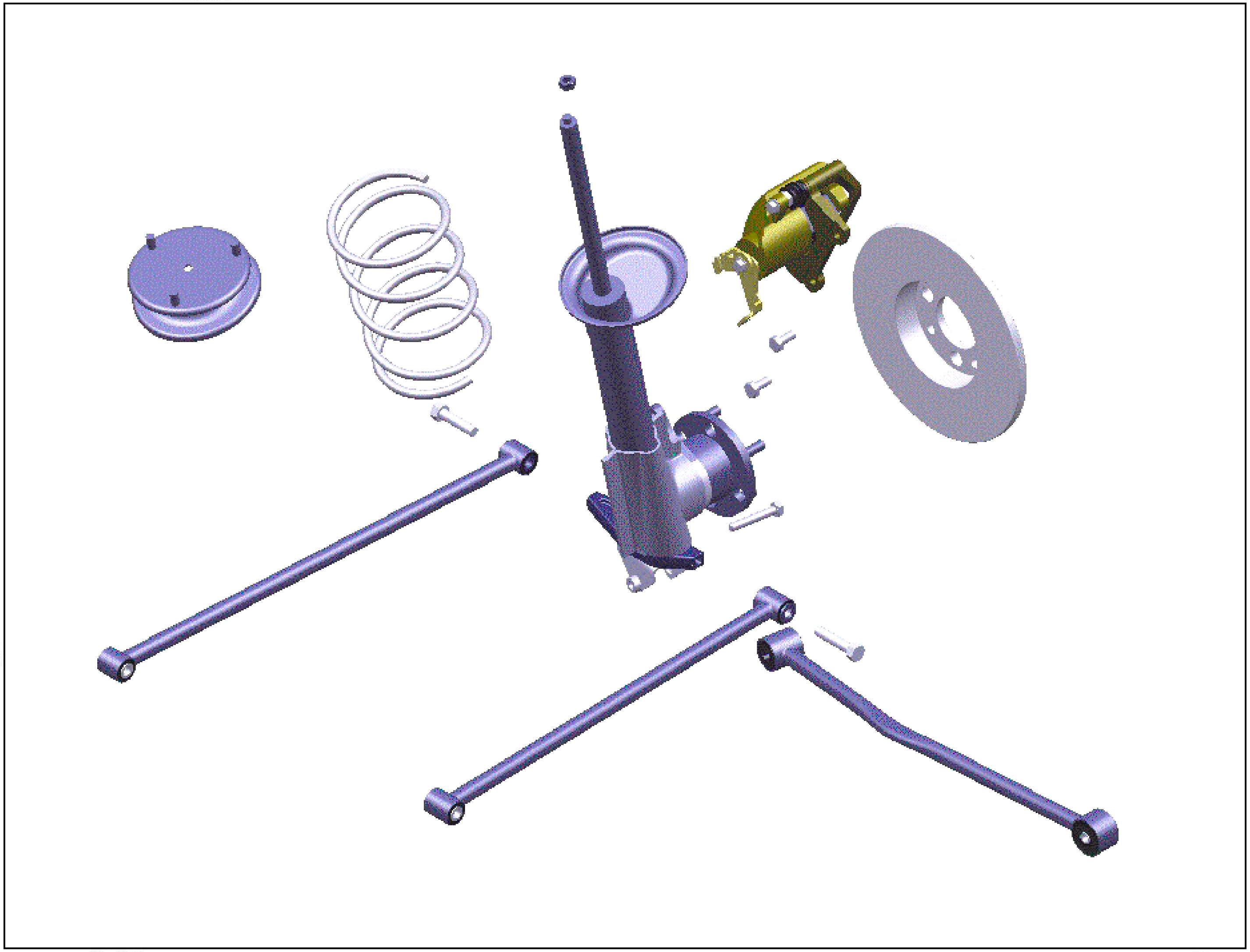
An increase to the damper mount height in the ULSAS design has not proved necessary due to the application of compact UHSS springs. The longer stroke dampers specified have been packaged within the same envelope as the benchmarked system



STRUT & LINKS: MANUFACTURING

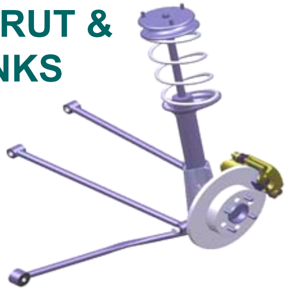
STRUT & LINKS

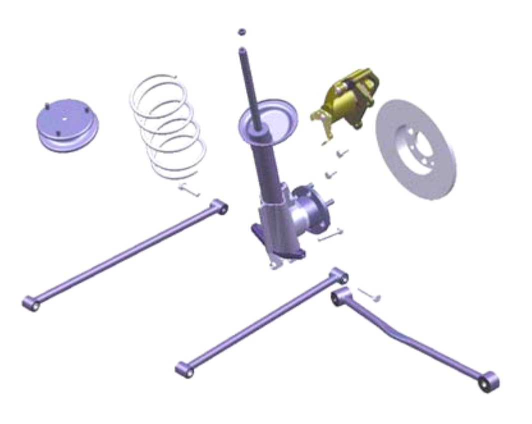




STRUT & LINKS: MANUFACTURING

Sub-Assembly





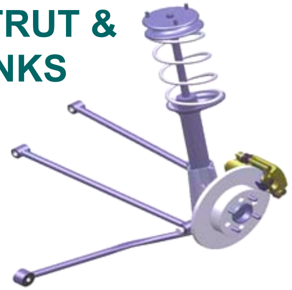
BREAKDOWN OF TIMING FOR SUB-ASSEMBLY OF STRUT & LINKS SUSPENSION SYSTEM

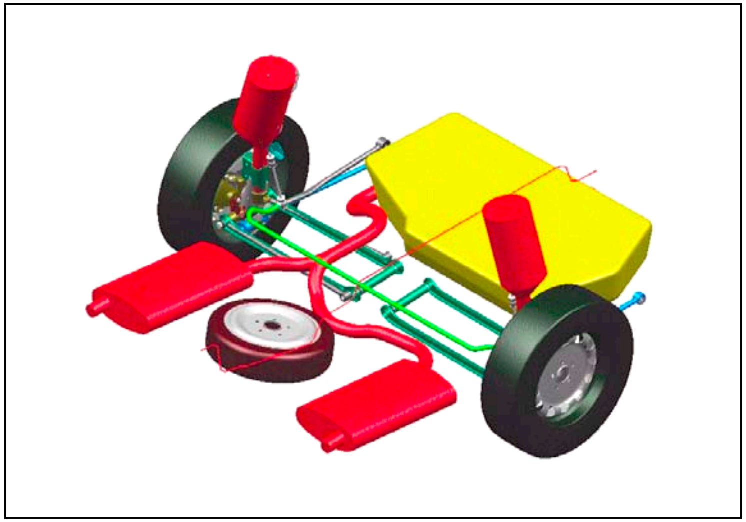
SUB-ASSEMBLY Operation	Number	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
FIT TRAIL ARM	2	FIT1H	0.19	0.13	0.32
FIX TRAIL ARM NUT	2	TFPTN	0.11	0.07	0.18
FIT DAMPER ASSY	2	FIX1H	0.05	0.05	0.10
FIT TRAIL ARM ASSY	2	FIX1H	0.05	0.05	0.10
FIT RWD LATERAL LINK	2	FIX1H	0.05	0.05	0.10
FIT LATERAL LINK BOLT	2	FITFN	0.07	0.04	0.11
FIX LATERAL LINK NUT	2	TFPTN	0.11	0.07	0.18
FIT BRAKE DISK	2	FIT1H	0.19	0.13	0.32
FIT BRAKE CALIPER	2	FIT1H	0.19	0.13	0.32
FIX BRAKE CALIPER BOLTS	4	TFPTN	0.07	0.12	0.19
				TOTAL	**1.92**

STRUT & LINKS: MANUFACTURING

Vehicle Assembly

STRUT & LINKS





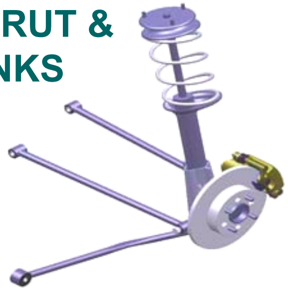
BREAKDOWN OF TIMING FOR FINAL ASSEMBLY OF STRUT & LINKS SUSPENSION TO THE VEHICLE

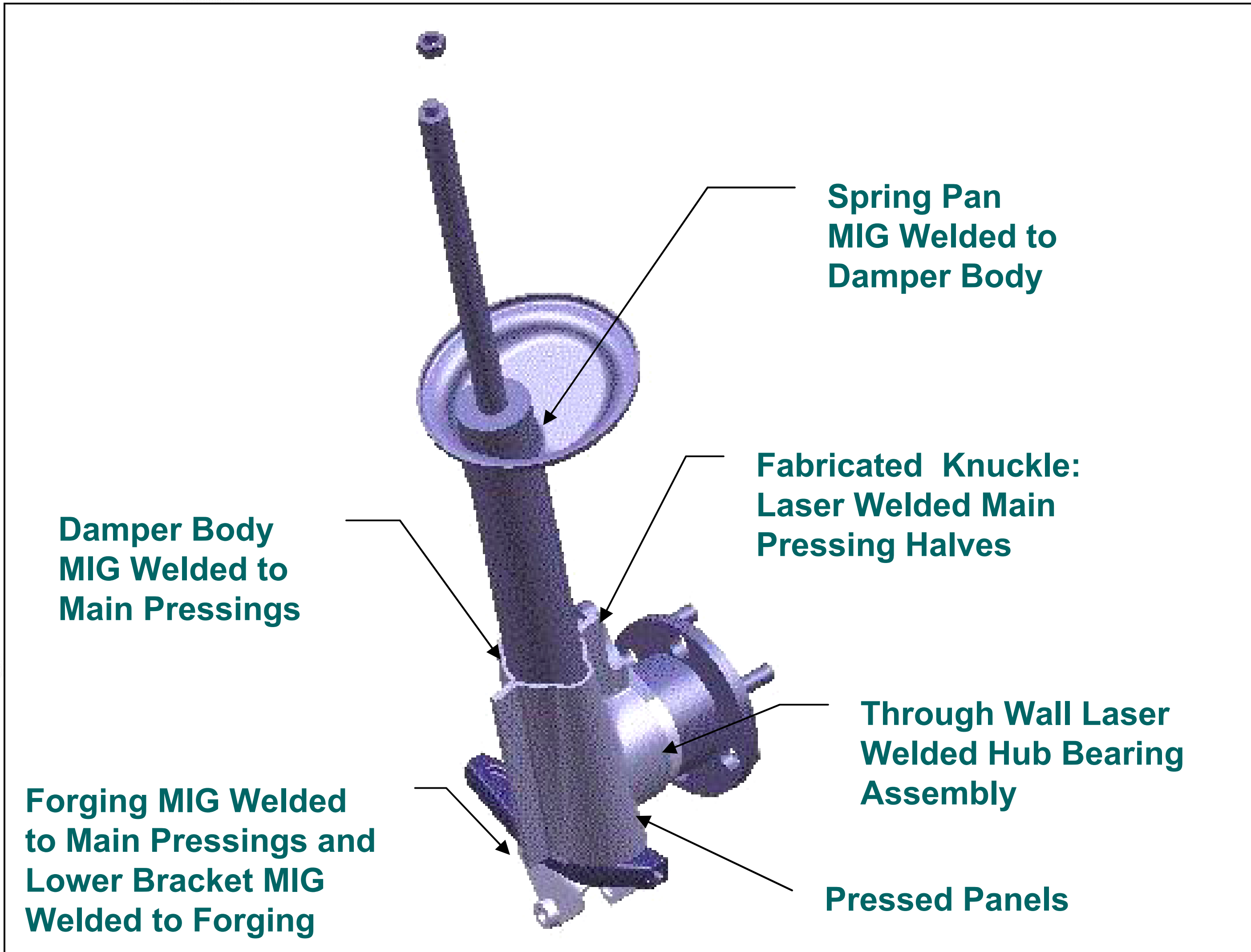
FINAL ASSEMBLY Operation	Number	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
FIT FWD LATERAL LINK BOLT	2	FITFN	0.07	0.04	0.11
FIT RWD LATERAL LINK BOLT	2	FITFN	0.07	0.04	0.11
FIX FWD LATERAL LINK NUT	2	TFPTN	0.11	0.07	0.18
FIX RWD LATERAL LINK NUT	2	TFPTN	0.11	0.07	0.18
FIT TRAILINIG ARM BOLT	2	FITFN	0.07	0.04	0.11
FIX TRAILING ARM NUT	2	TFPTN	0.11	0.07	0.18
FIX DAMPER NUT	6	TFPTN	0.11	0.35	0.46
				TOTAL	**1.33**

STRUT & LINKS: MANUFACTURING

Feasibility

STRUT & LINKS

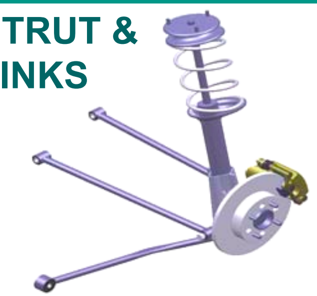




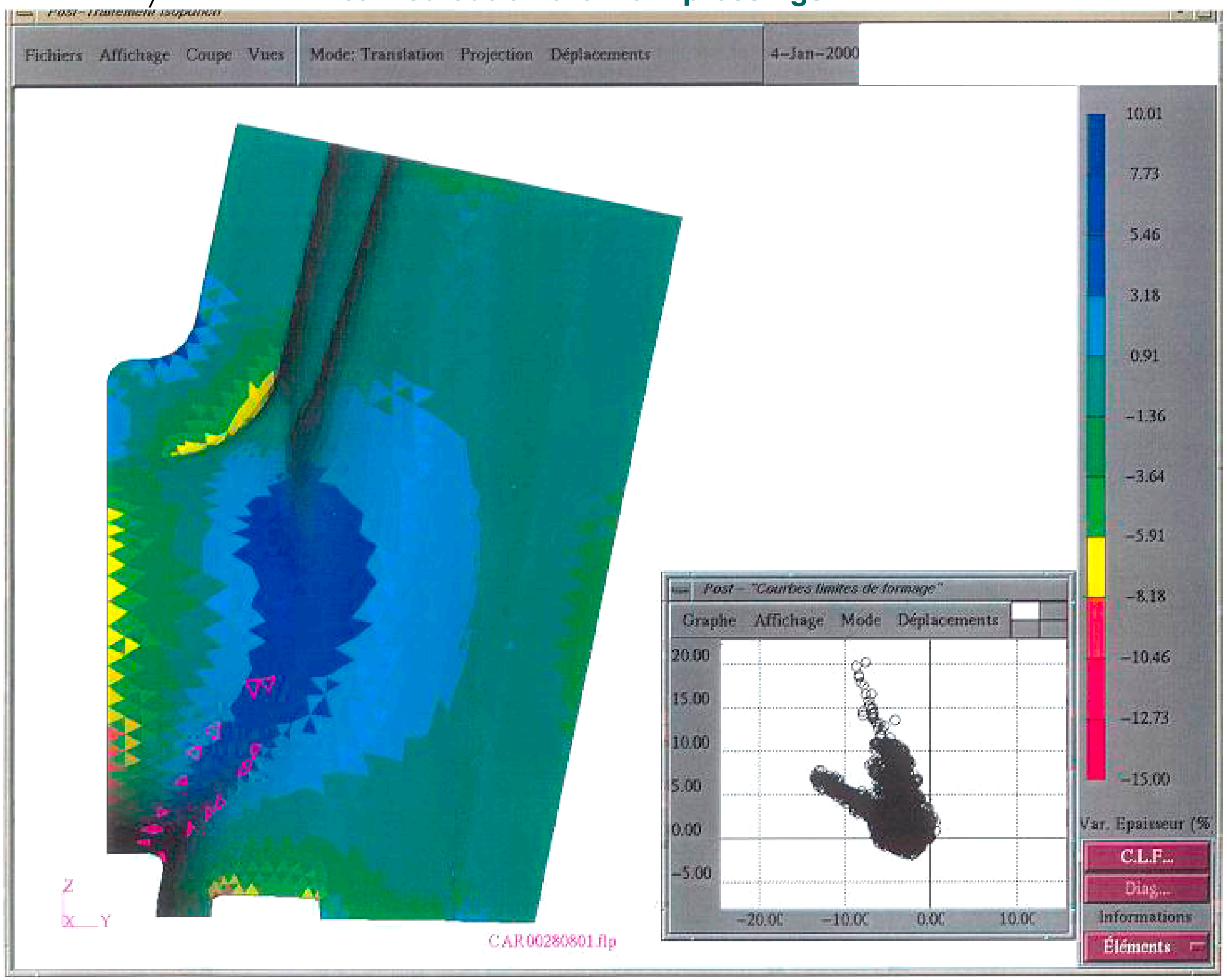
STRUT & LINKS: MANUFACTURING

Feasibility

STRUT & LINKS



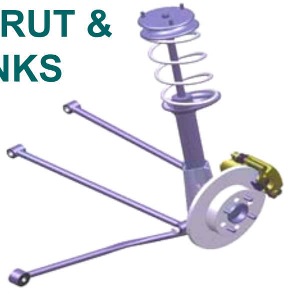
Knuckle Pressing :- Manufacturing feasibility was carried out on the main pressings



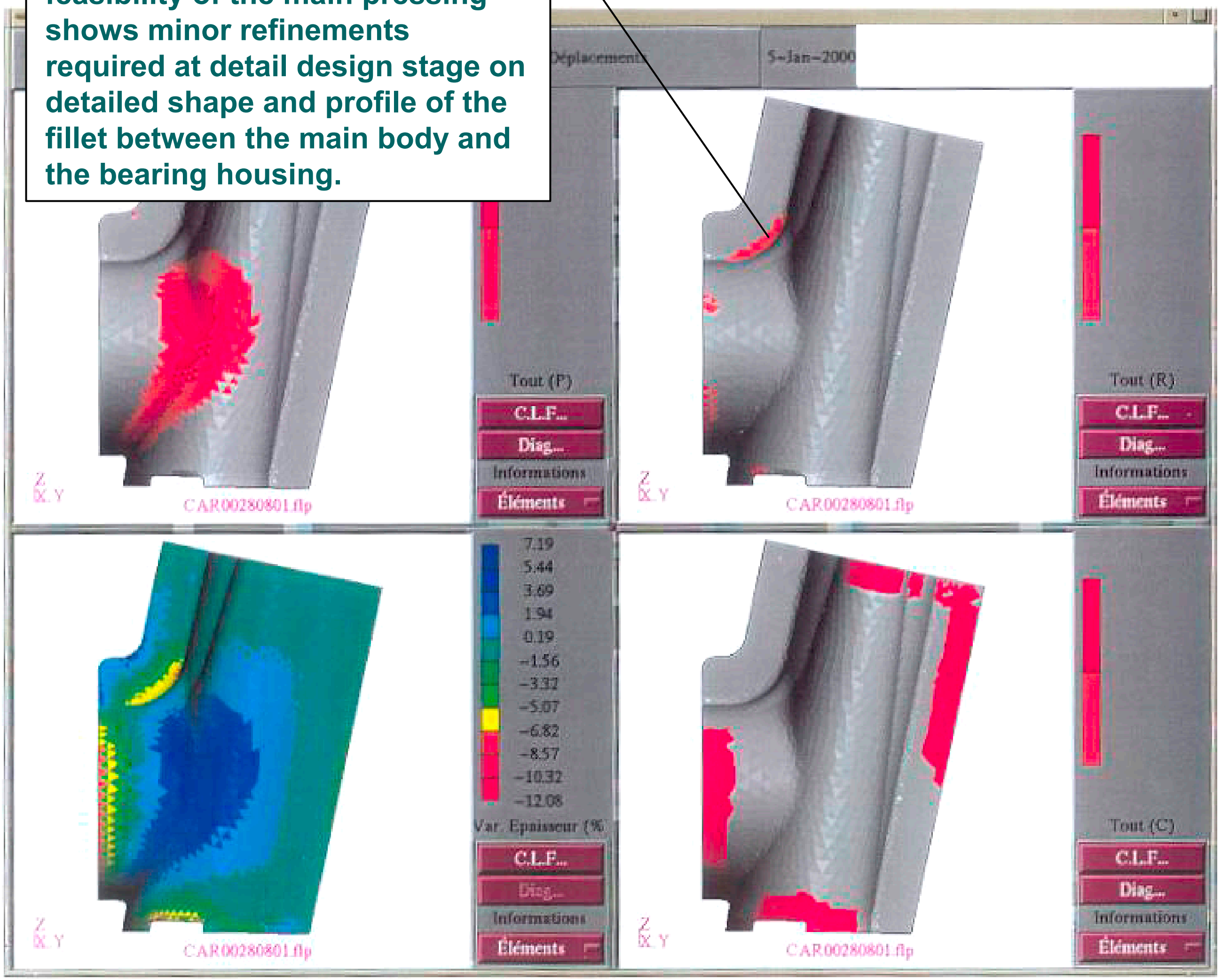
STRUT & LINKS: MANUFACTURING

Feasibility

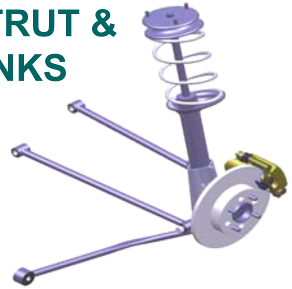
STRUT & LINKS



Knuckle :- Manufacturing feasibility of the main pressing shows minor refinements required at detail design stage on detailed shape and profile of the fillet between the main body and the bearing housing.



STRUT & LINKS



STRUT & LINKS: 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.

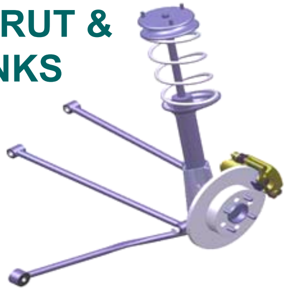
The material requirements of the components were reviewed on an individual basis throughout the design process. Where applicable, i.e. beneficial to mass or cost, high strength near reach materials have been incorporated. Combinations of high and extra high strength steel sheet and forging grades were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

STRUT & LINKS: MANUFACTURING APPROACH

STRUT & LINKS



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.

STRUT & LINKS: MANUFACTURING APPROACH

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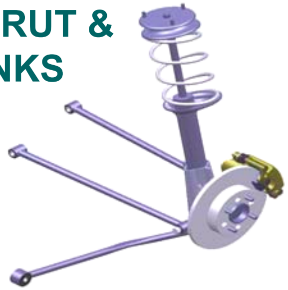


ULSAS MANUFACTURING PROCEDURE:

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

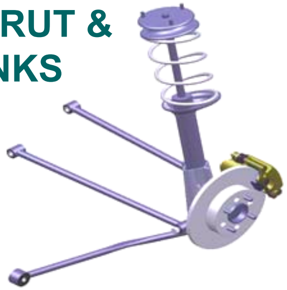
Detailed drawings of the designs were studied both in hardcopy and on the CAD workstations. This formed the basis of the assembly analysis. The complex multi link system was subjected to a detailed assembly analysis using a industry recognised software package. This has the advantage of linking with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

STRUT & LINKS: MANUFACTURING APPROACH

STRUT & LINKS



ULSAS TIMING STUDY ASSUMPTIONS:

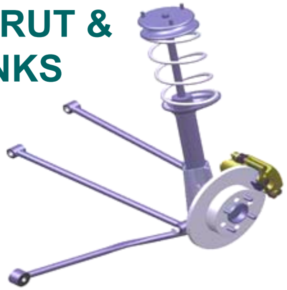
- During assembly, the largest possible unit is fitted.
- Torque sensing power tools utilised wherever possible.
- No confirmation actions such as paint marking are carried out.
- Bolts would be supplied complete with any washers required.
- For the fitting operation the unit or units are already lifted 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.

STRUT & LINKS: MANUFACTURING APPROACH
ULSAS MATERIAL SELECTION ASSUMPTIONS



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.

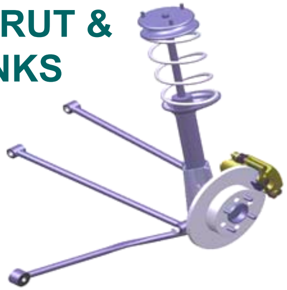
Stretched flanges or holes require good edge ductility, an influence not only of the quality of cut edge, but also the edge forming characteristics of the material. Certain grades delivering equal strength can offer superior edge ductility.

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

STRUT & LINKS: MANUFACTURING APPROACH
ULSAS MATERIAL SELECTION ASSUMPTIONS



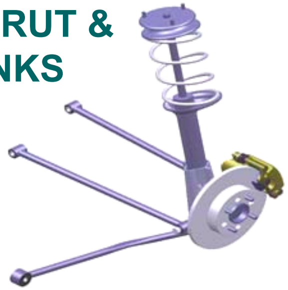
Tube Grades

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



STRUT & LINKS: MANUFACTURING APPROACH
ULSAS MATERIAL SELECTION ASSUMPTIONS

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.

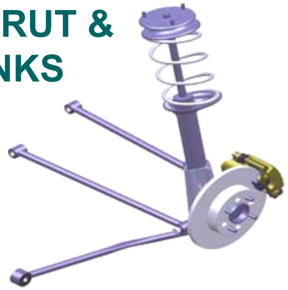
There is ongoing research on air cooled forging steels in the steel industry to offer grades to meet higher strength requirements, while maintaining a lower carbon content to avoid the need for pre/post weld heat treatment.

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).

STRUT & LINKS: MANUFACTURING APPROACH
ULSAS MATERIAL COATING ASSUMPTIONS

STRUT & LINKS



Coating/Corrosion Considerations

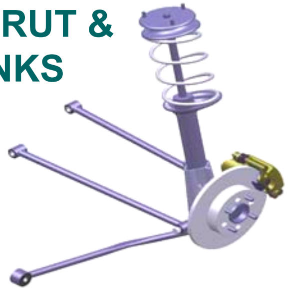
Opportunities exist for extensive use of pre-zinc coated steels. Coated steels will help to meet warranty requirements and place less reliance on protection offered by secondary coatings. Further weight/cost savings may be achieved through avoidance of wax injecting and/or the use of thinner additional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

STRUT & LINKS: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS

STRUT & LINKS



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):

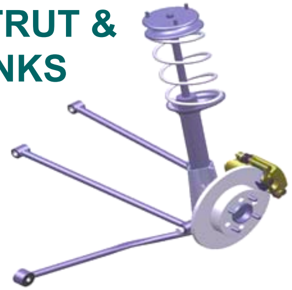
Offset tolerance 1mm max

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.

STRUT & LINKS: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS



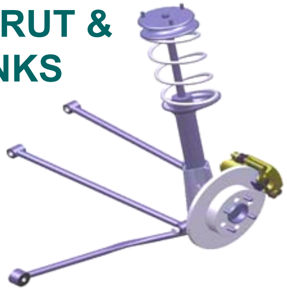
Flange/Lap Welding

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.

STRUT & LINKS: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS

STRUT & LINKS



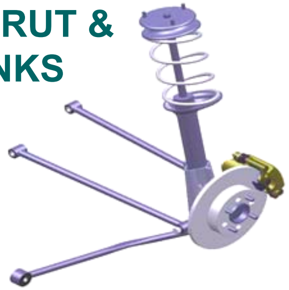
Panel Trimming

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.

STRUT & LINKS: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS

STRUT & LINKS



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

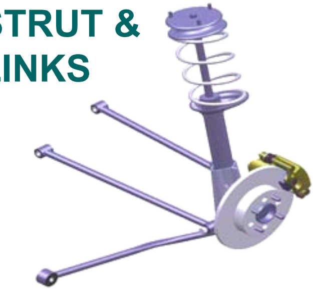
A minimum flange width (typically around 16mm) is required to allow electrode access. Wide variations in gauge thicknesses can be tolerated with spot welding. Ratios of 3:1 are typically used.

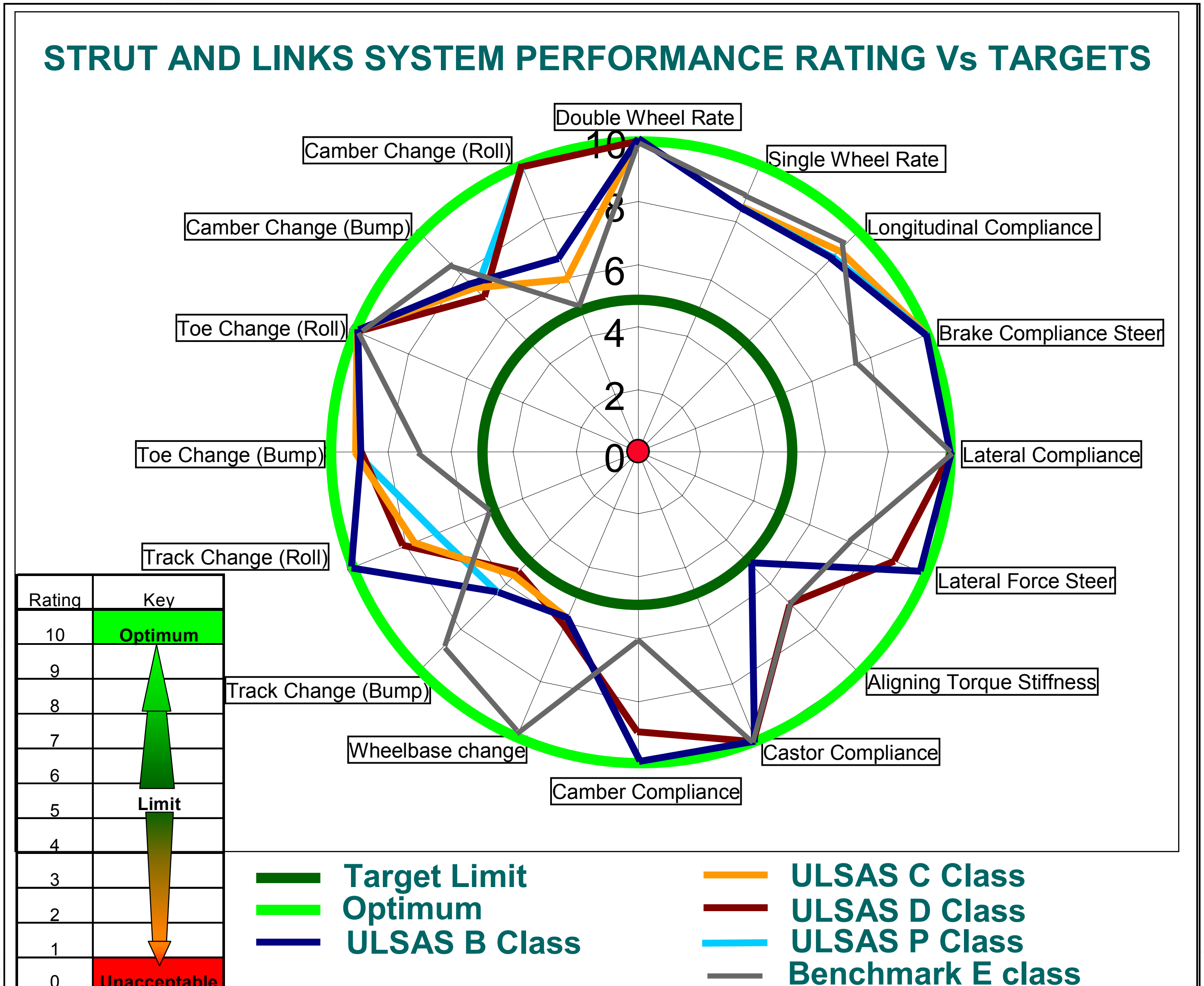
Please note: Welding feasibility studies were carried out in conjunction with The Welding Institute, Cambridge, UK.

STRUT & LINKS: Performance

ULTRALIGHT STEEL AUTO SUSPENSION

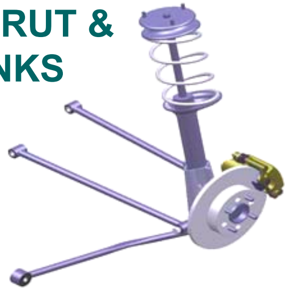
STRUT & LINKS





ULSAS CAE DYNAMICS APPROACH

STRUT & LINKS



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.

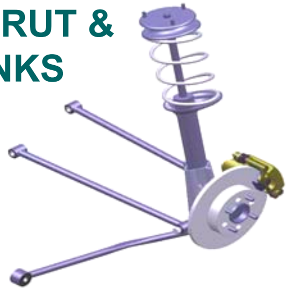
Compliant joints (bushes) were represented by ADAMS BUSHING statements.

Ball joints were represented by ADAMS SPHERICAL JOINT statements.

Wheel bearing, and where appropriate strut bending, compliance's were represented using ADAMS BUSHING statements.

ULSAS CAE DYNAMICS APPROACH

STRUT & LINKS



The models were used to:

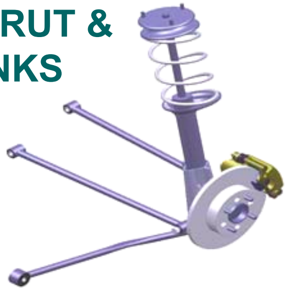
- Generate the kinematic characteristics of the suspensions with respect to vertical wheel displacement.
- Establish the contribution of non-structural components of the system to overall system compliance characteristics.
- The system geometry and compliant joint stiffnesses were carefully tuned to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

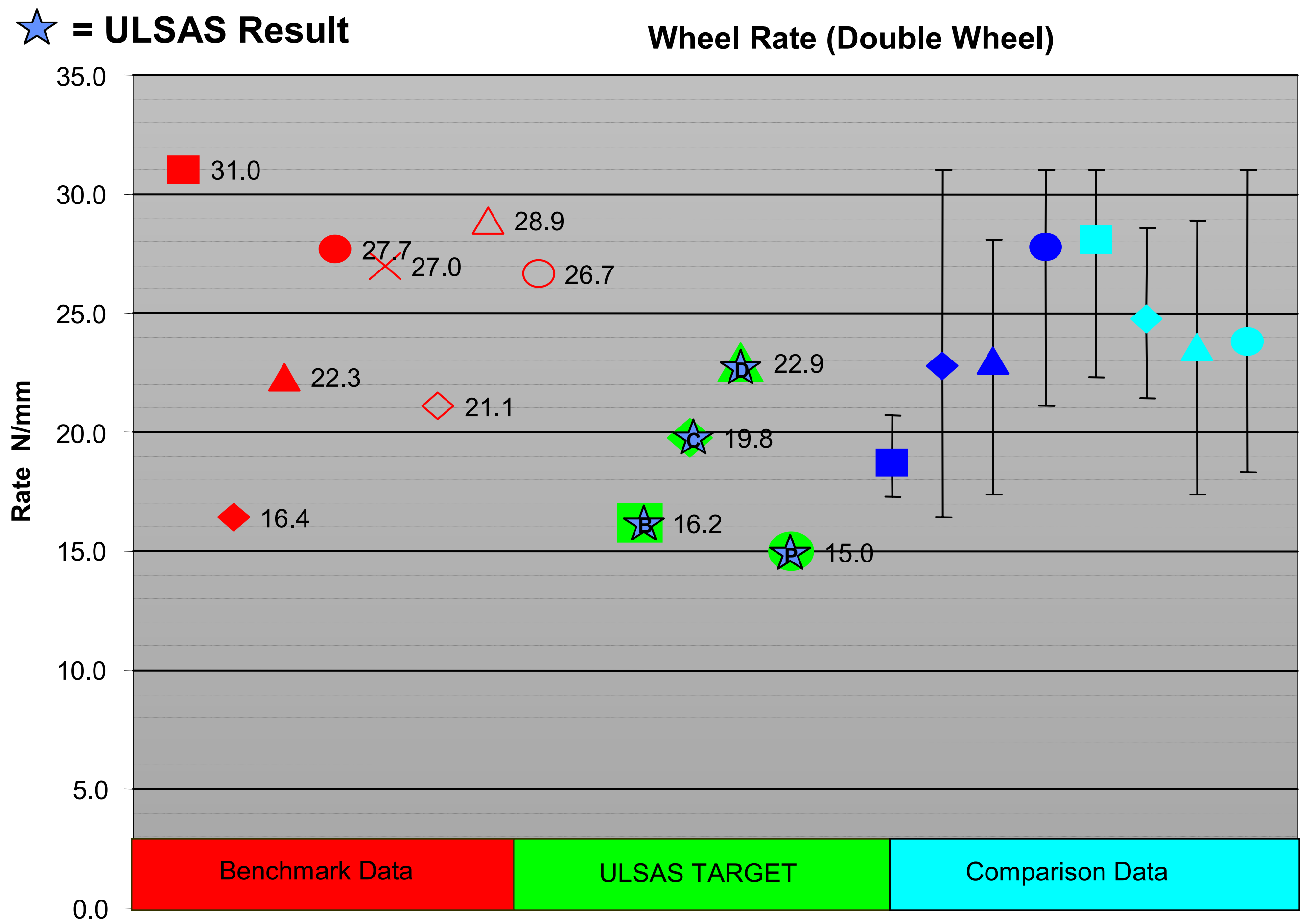
The models were used to generate the kinematic characteristics of the suspensions with respect to vertical wheel displacement, and to establish the contribution of non-structural components of the system to overall system compliance characteristics with respect to lateral and longitudinal forces applied 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.



STRUT AND LINKS: Performance

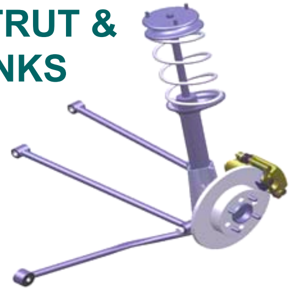


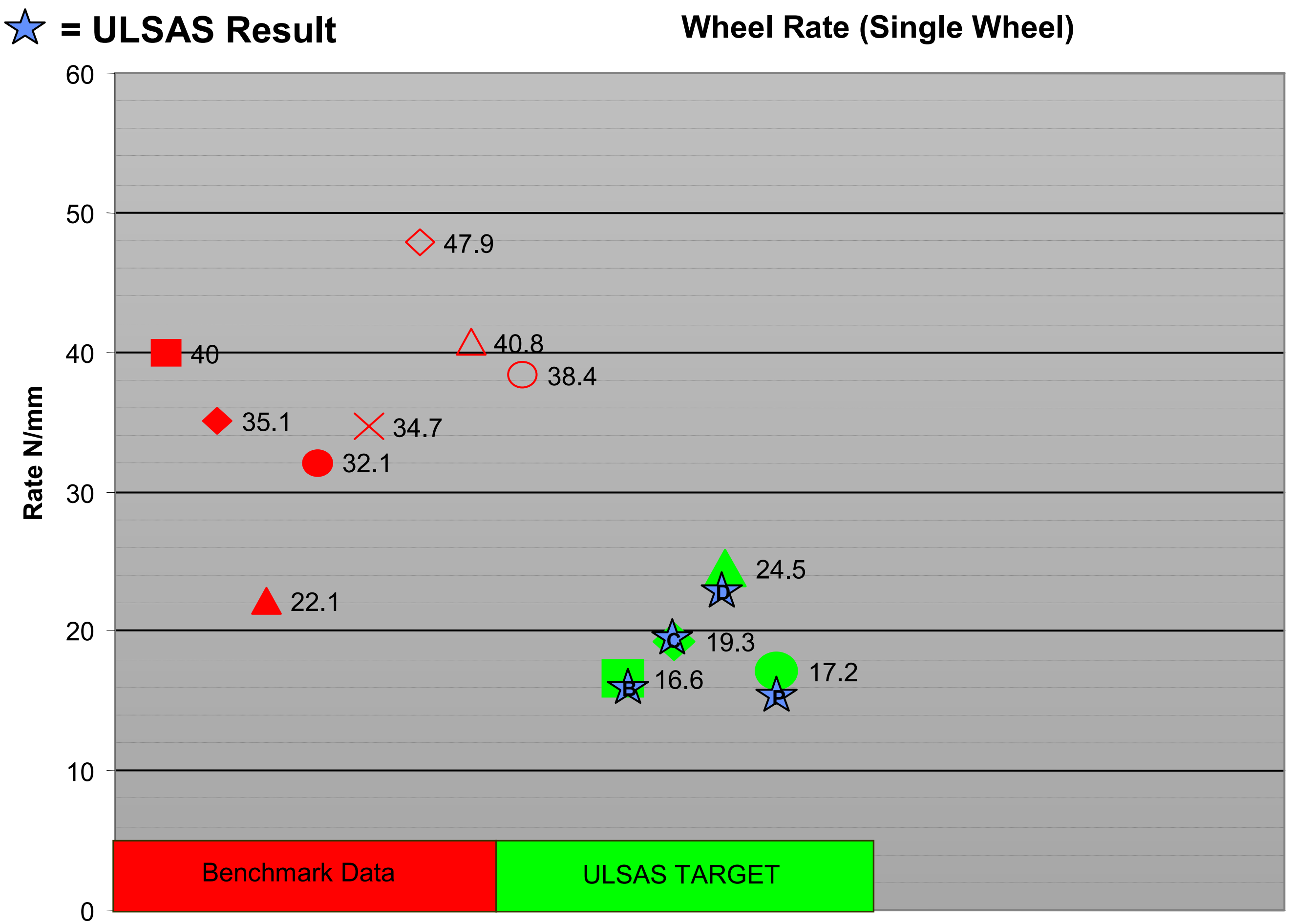
Comments:

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.

STRUT AND LINKS: Performance

STRUT & LINKS



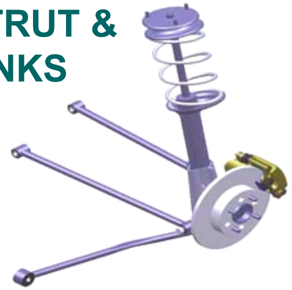


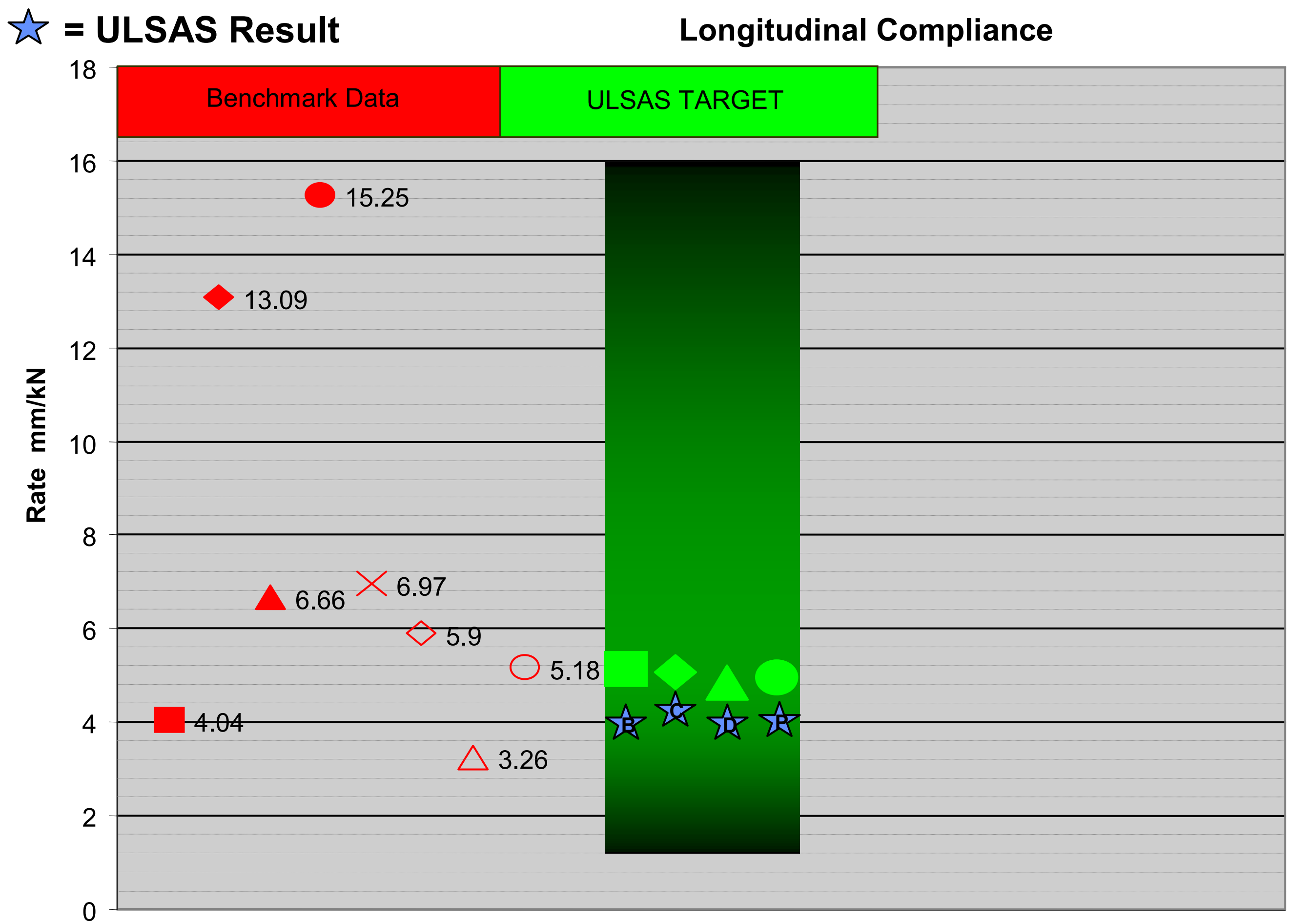
Comments:

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.

STRUT AND LINKS: Performance

STRUT & LINKS



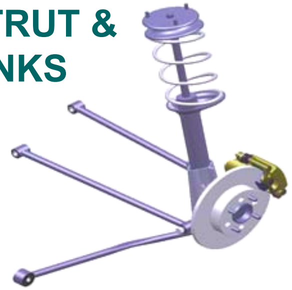


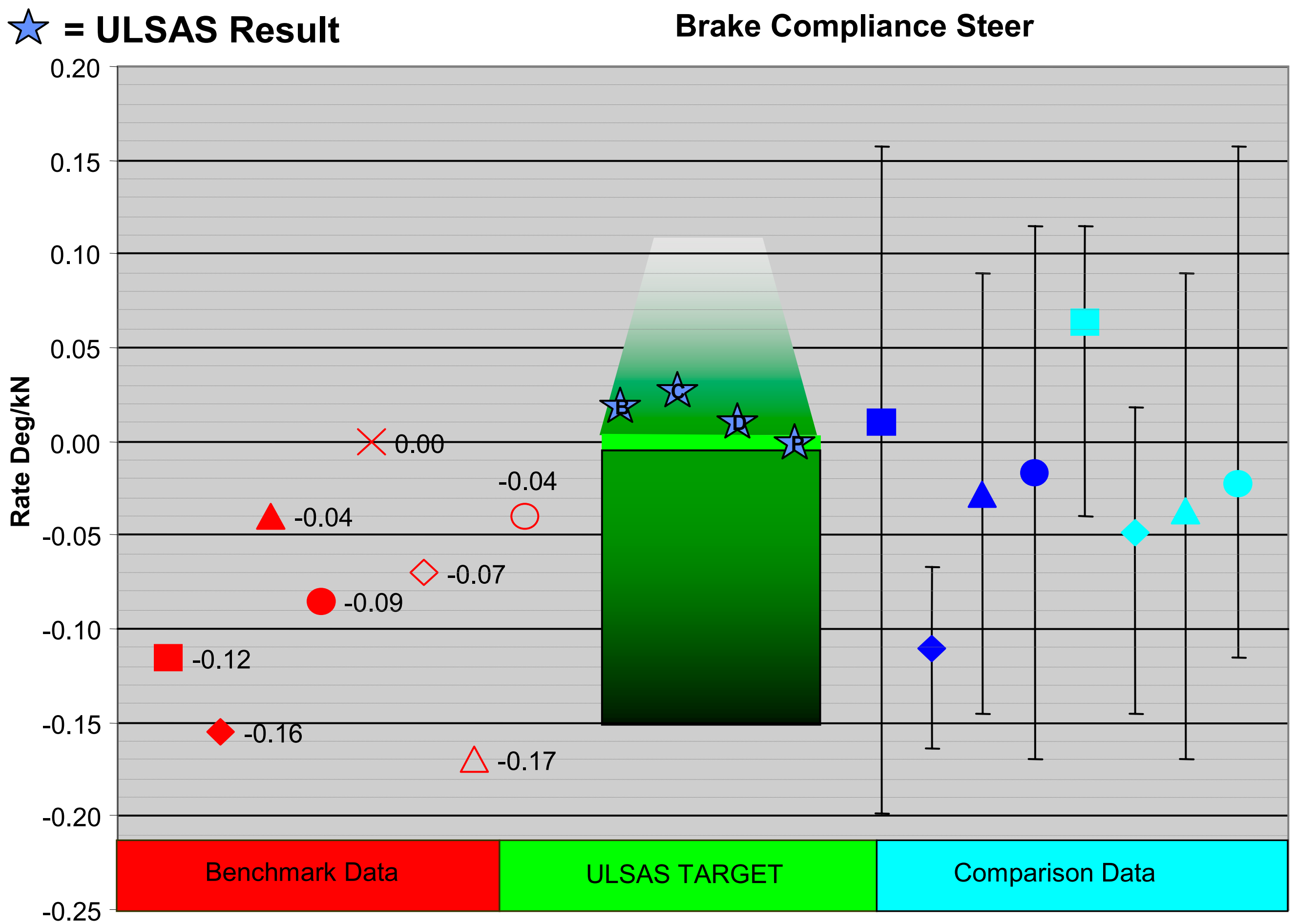
Comments:
The longitudinal compliance achieved is close to the ideal value and within the tolerance band.

STEEL AUTO SUSPENSION

STRUT AND LINKS: Performance

STRUT & LINKS



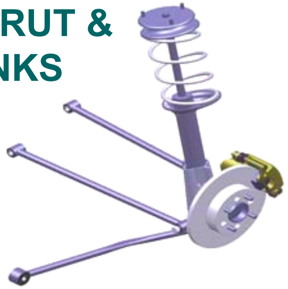


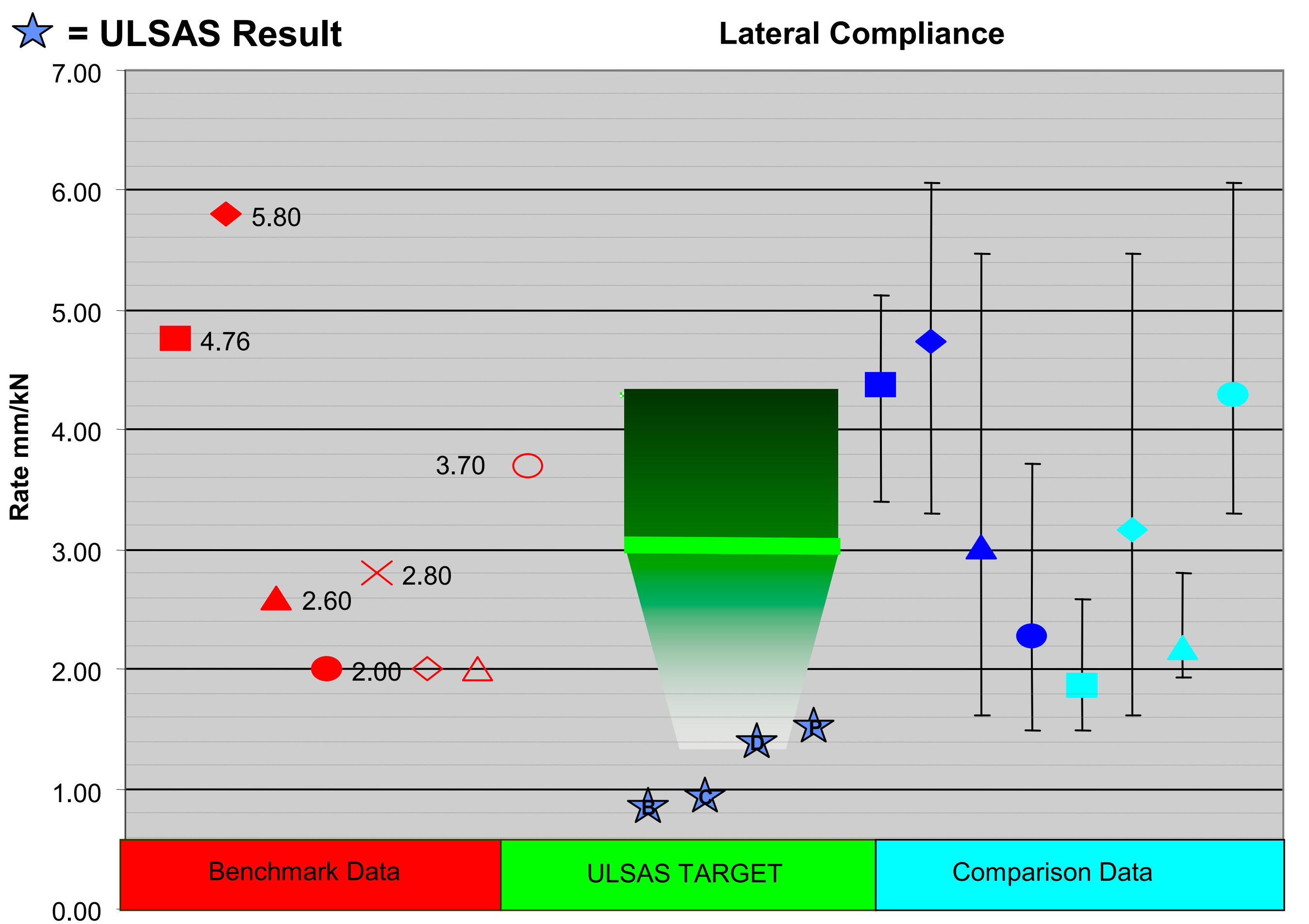
Comments:
All the ULSAS Strut and Links designs have exceeded the ideal value for brake steer.

STRUT AND LINKS: Performance

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS





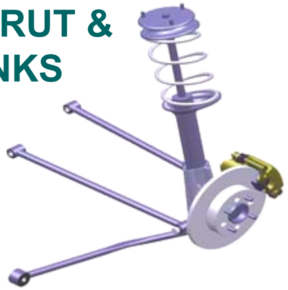
Comments:

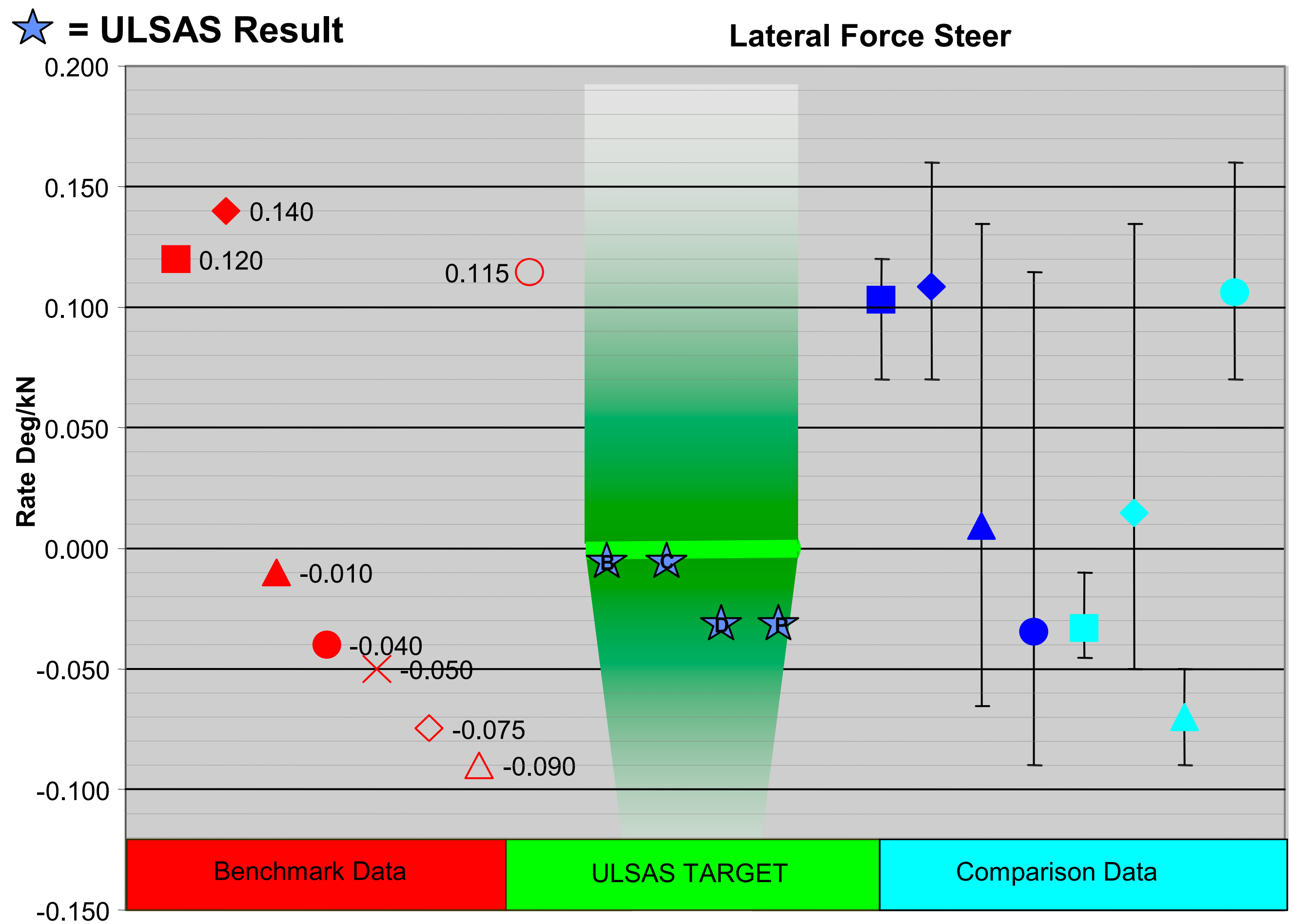
A high degree of control has been achieved with a level which exceeds the target value.

STEEL AUTO SUSPENSION

STRUT AND LINKS: Performance

STRUT & LINKS

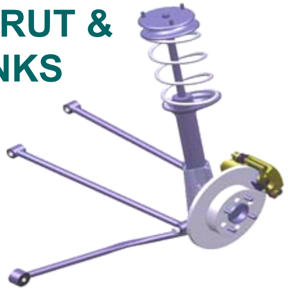


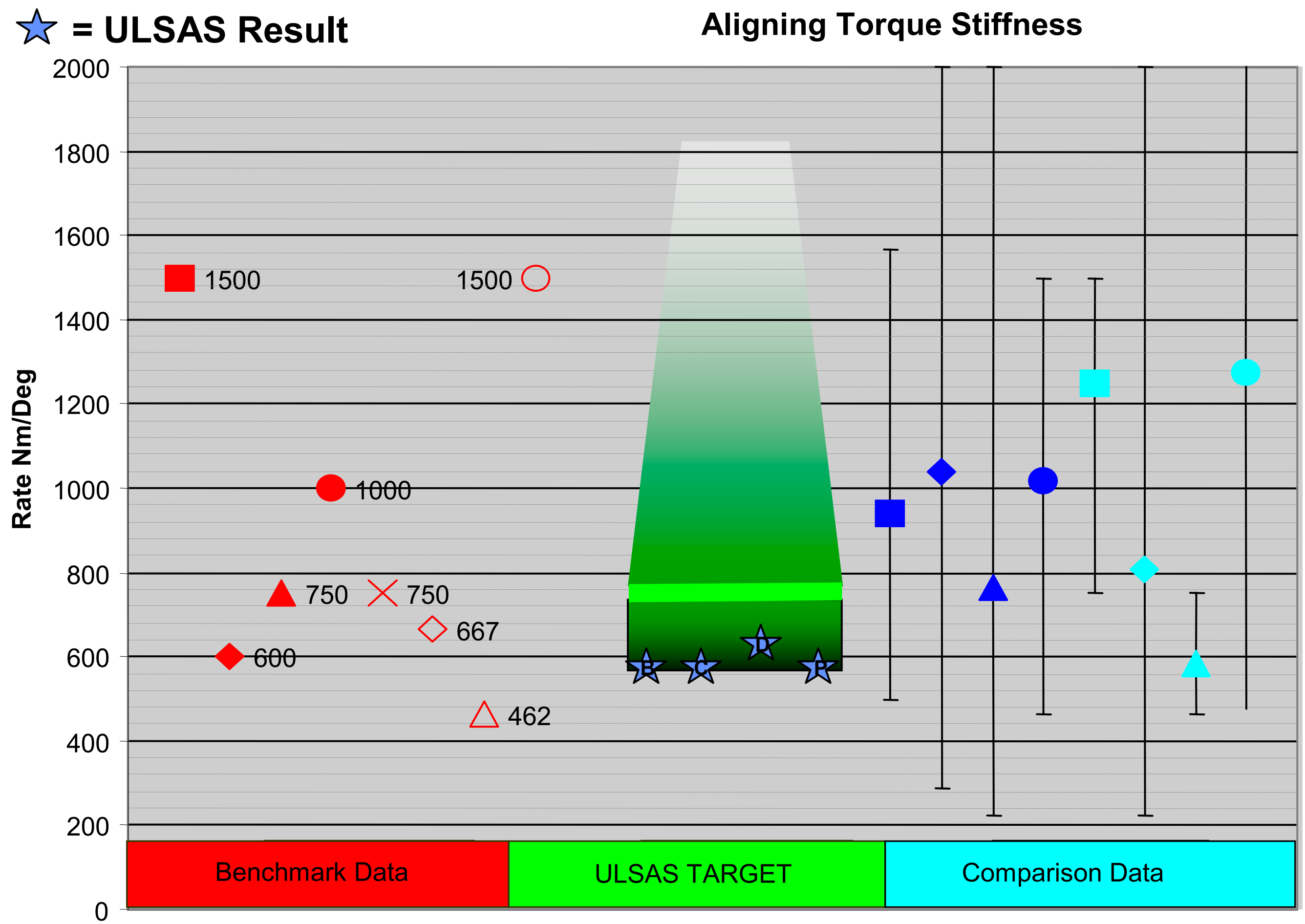


Comments:
The ULSAS Strut and Links designs have achieved a good level of lateral force steer control with slight understeer.

STRUT AND LINKS: Performance

STRUT & LINKS



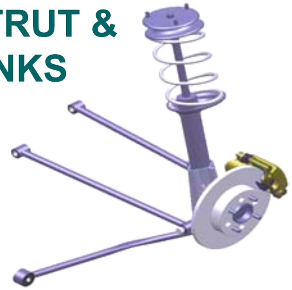


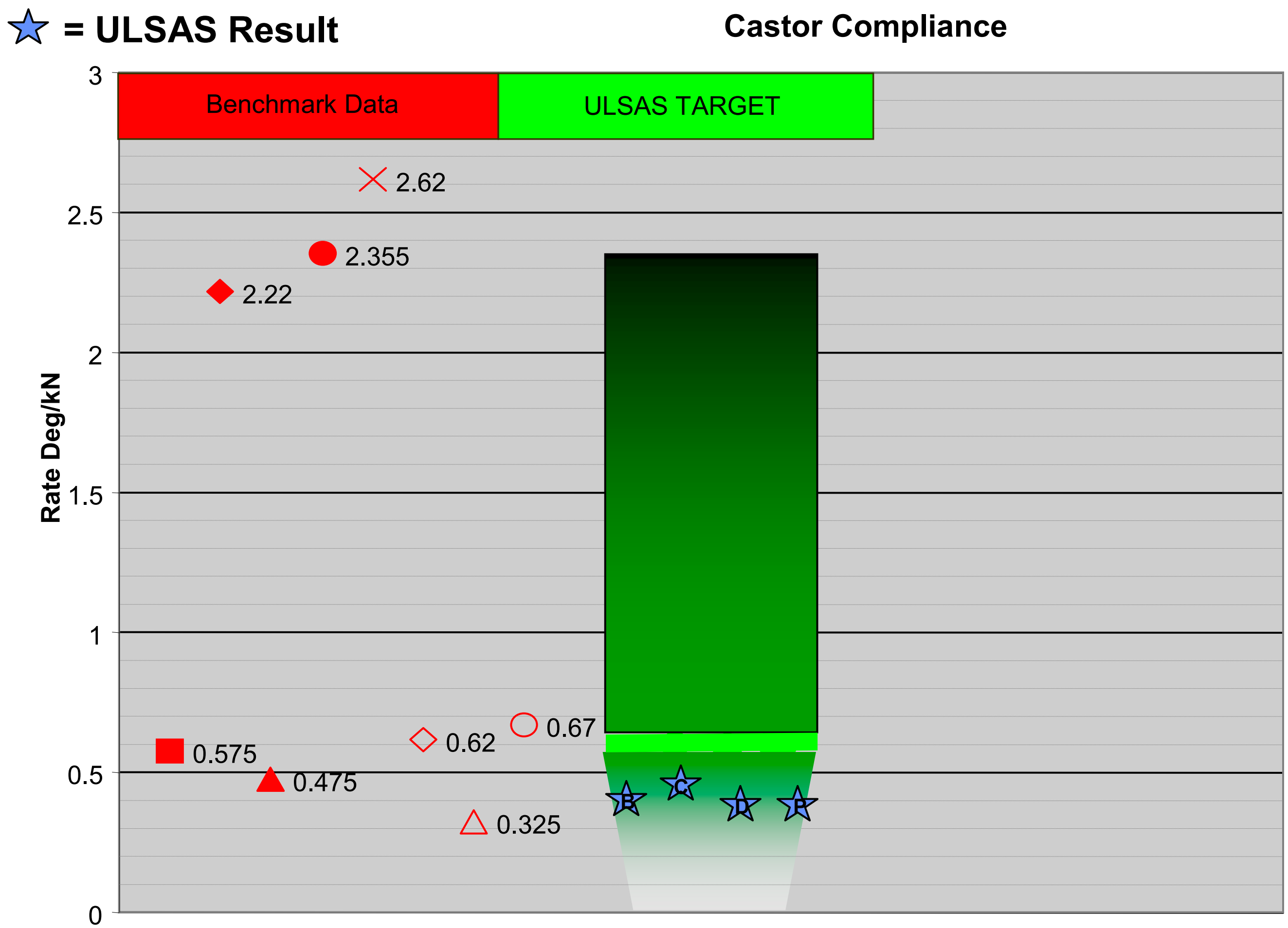
Comments:
The ULSAS Strut and Link designs have achieved a level of aligning torque stiffness within the target range.

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT AND LINKS: Performance

STRUT & LINKS



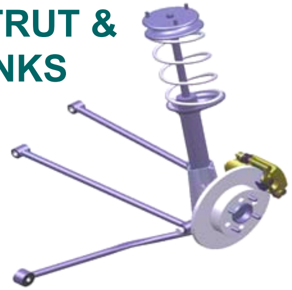


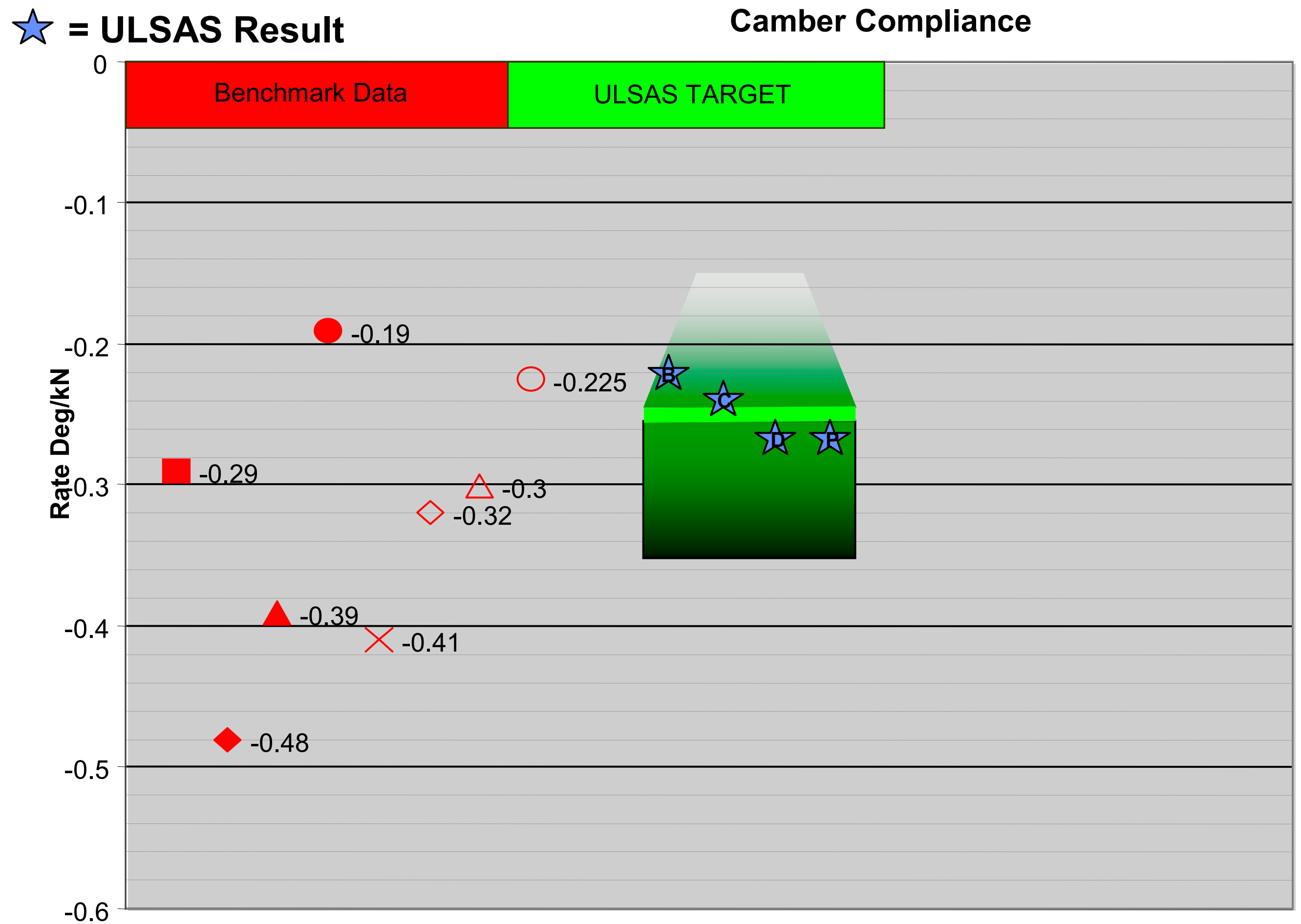
Comments:
The target rate is exceeded by the ULSAS Strut and Links designs.

STEEL AUTO SUSPENSION

STRUT AND LINKS: Performance

STRUT & LINKS

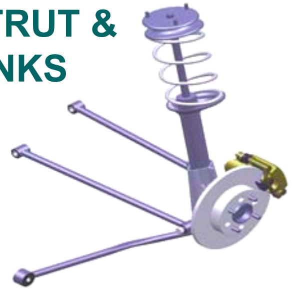


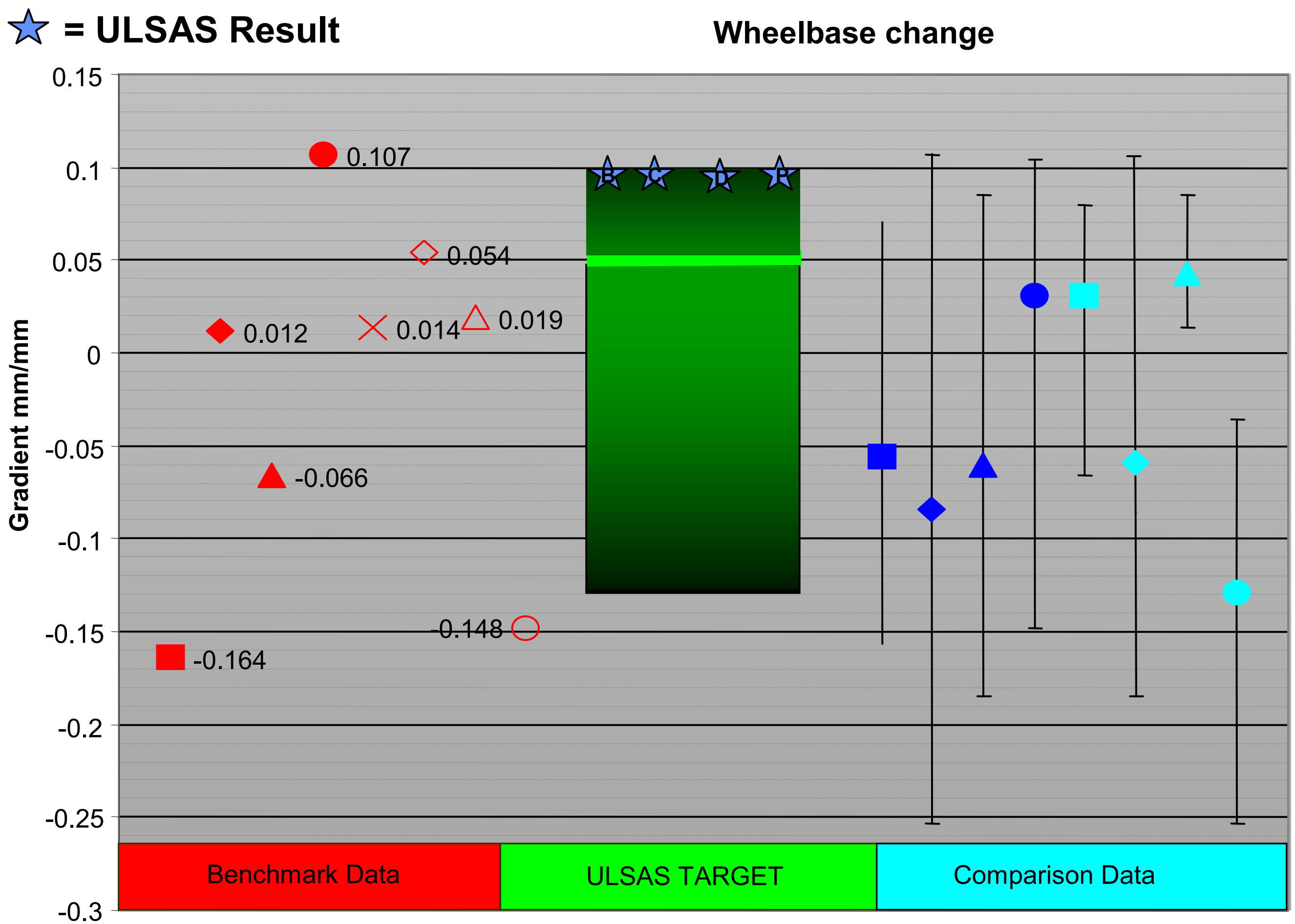


Comments:
A good level of Camber stiffness has been achieved for all the ULSAS Strut and Links designs, with the B and C Class designs exceeding the ideal target value.

STRUT AND LINKS: Performance

STRUT & LINKS



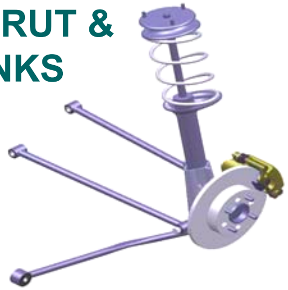


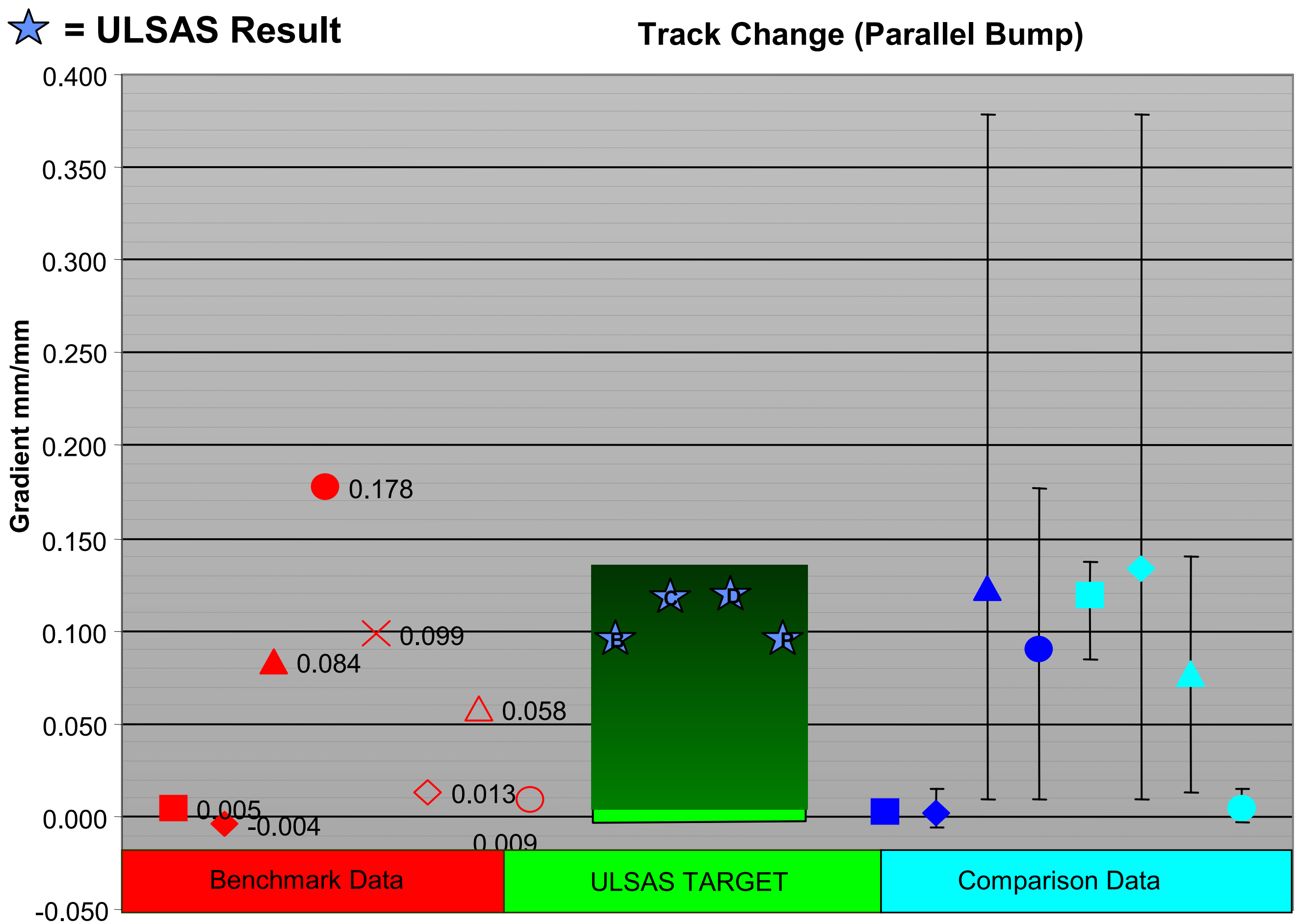
Comments:

Good characteristics have been achieved with rearward hub centre motion in bump, which will help maximise ride quality.

STRUT AND LINKS: Performance

STRUT & LINKS



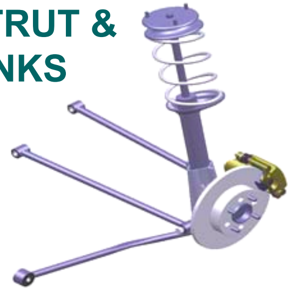


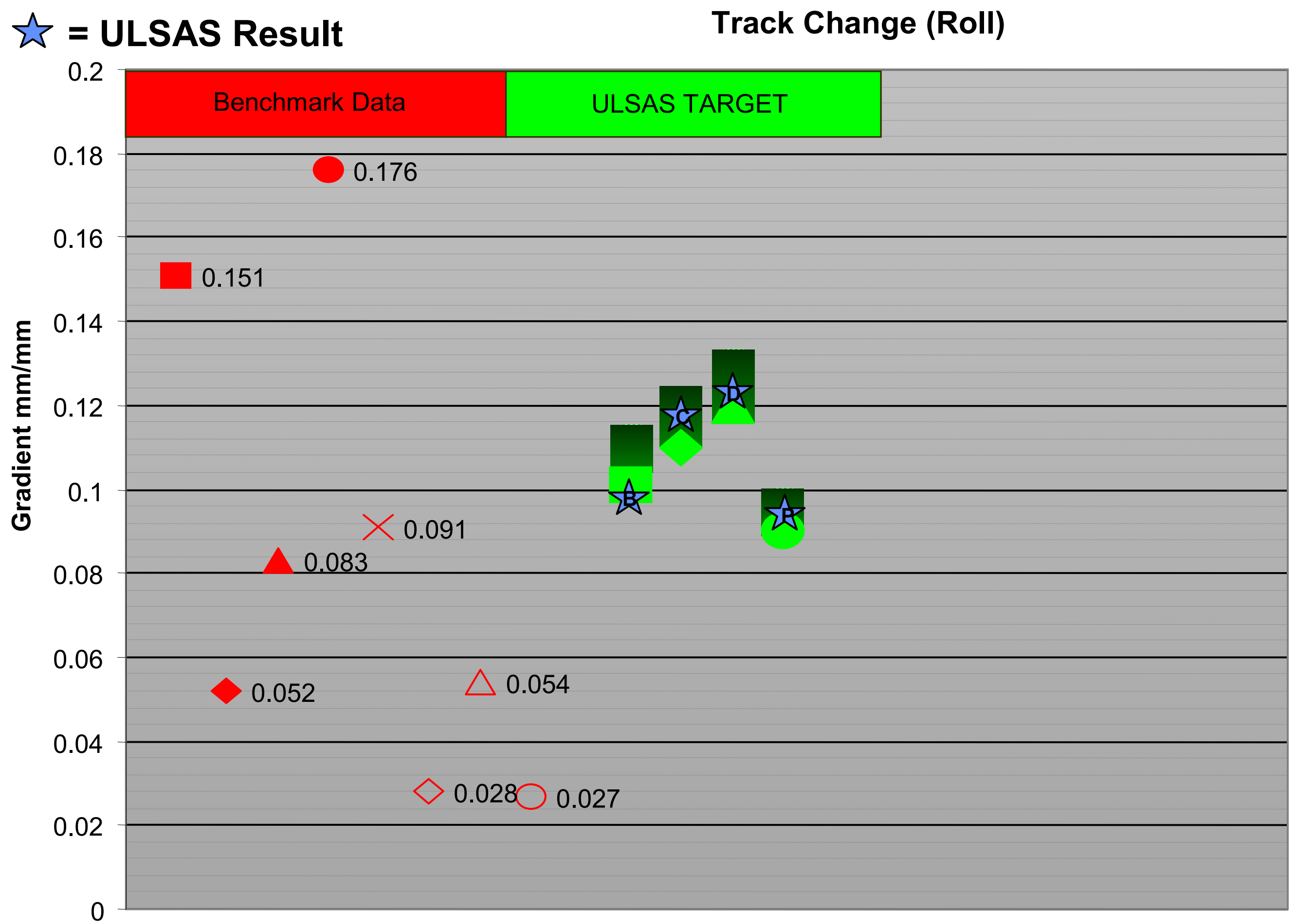
Comments:

Control of track in parallel bump is the same as in roll for the Strut and Links system. The levels achieved are within the required tolerance.

STRUT AND LINKS: Performance

STRUT & LINKS



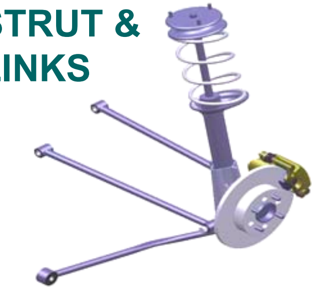


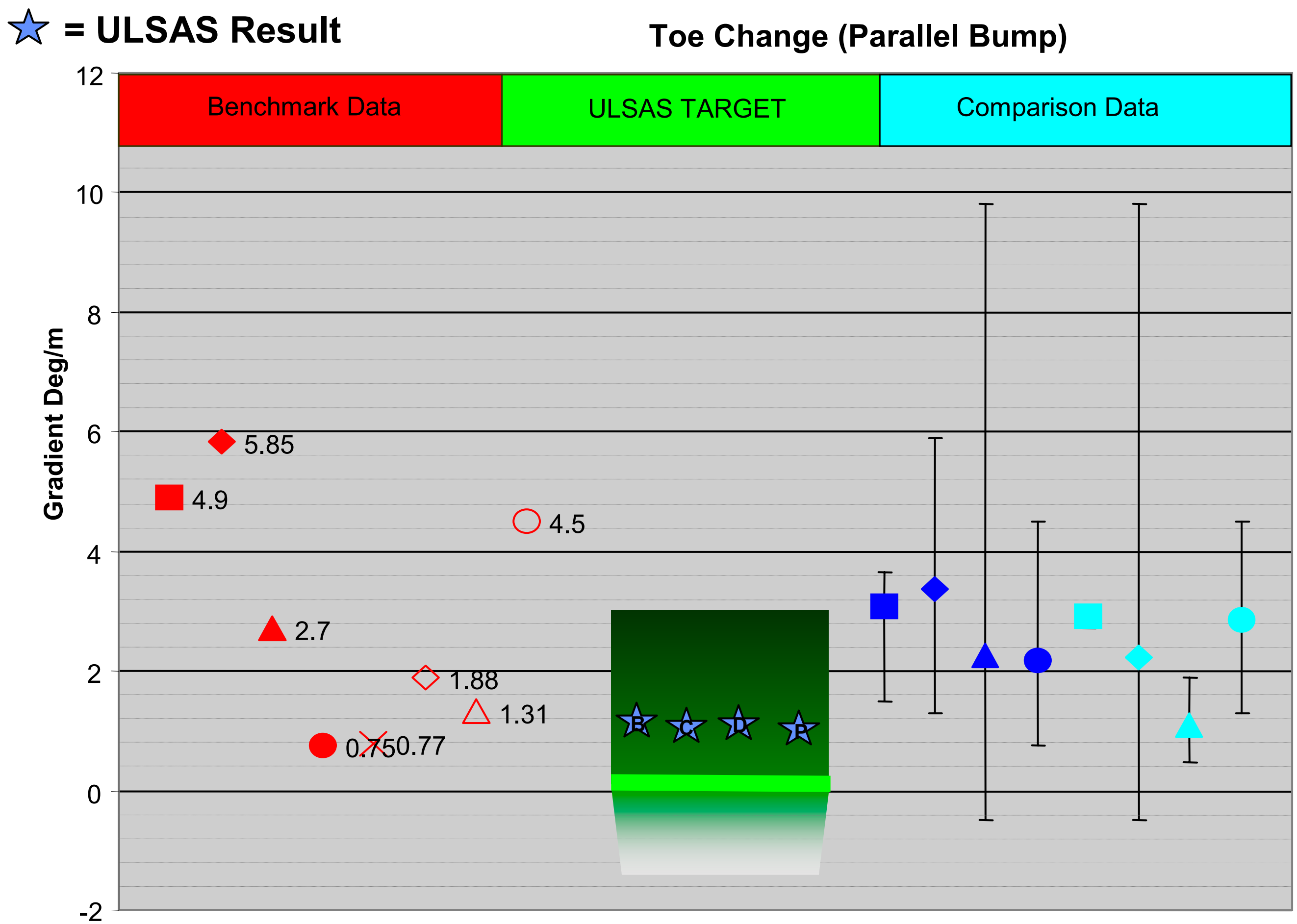
Comments:
Close tolerances are required to control Roll Centre position. The level of track change control in roll is within the desired target range for all ULSAS Strut and Links designs.

STRUT AND LINKS: Performance

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS





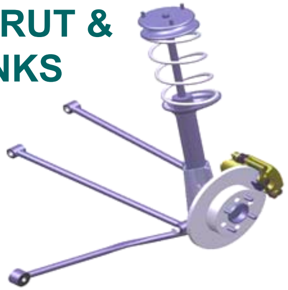
Comments:
Good control has been achieved with a small amount of Toe-in in bump.

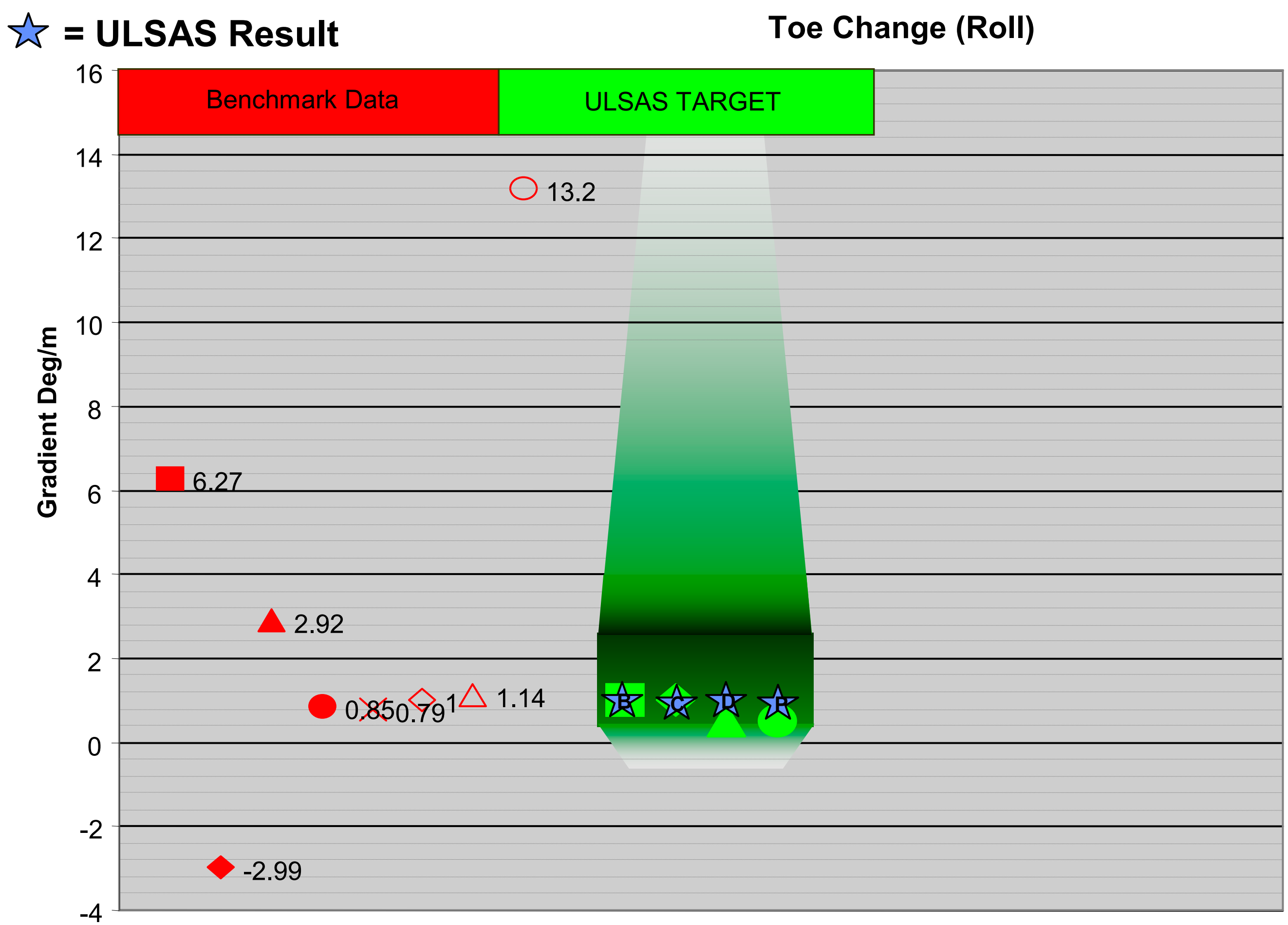
STEEL AUTO SUSPENSION

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT AND LINKS: Performance

STRUT & LINKS



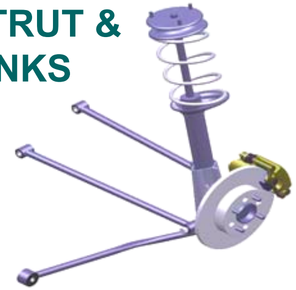


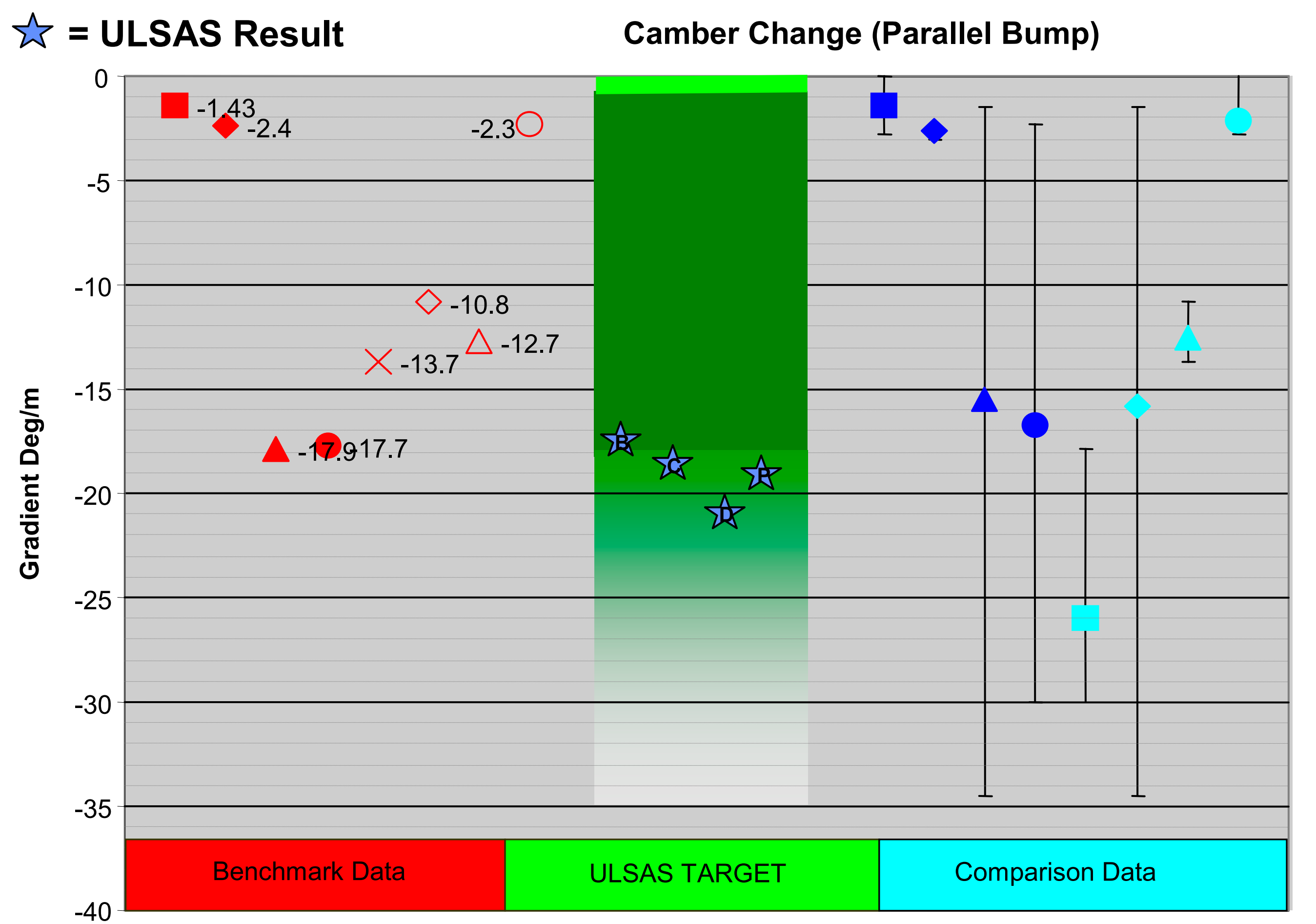
Comments:

Toe change in roll is the same as in parallel bump for the Strut and Links system. Good balance has been achieved between these two requirements, with both results close to the ideal Targets

STRUT AND LINKS: Performance

STRUT & LINKS



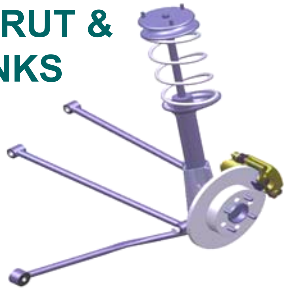


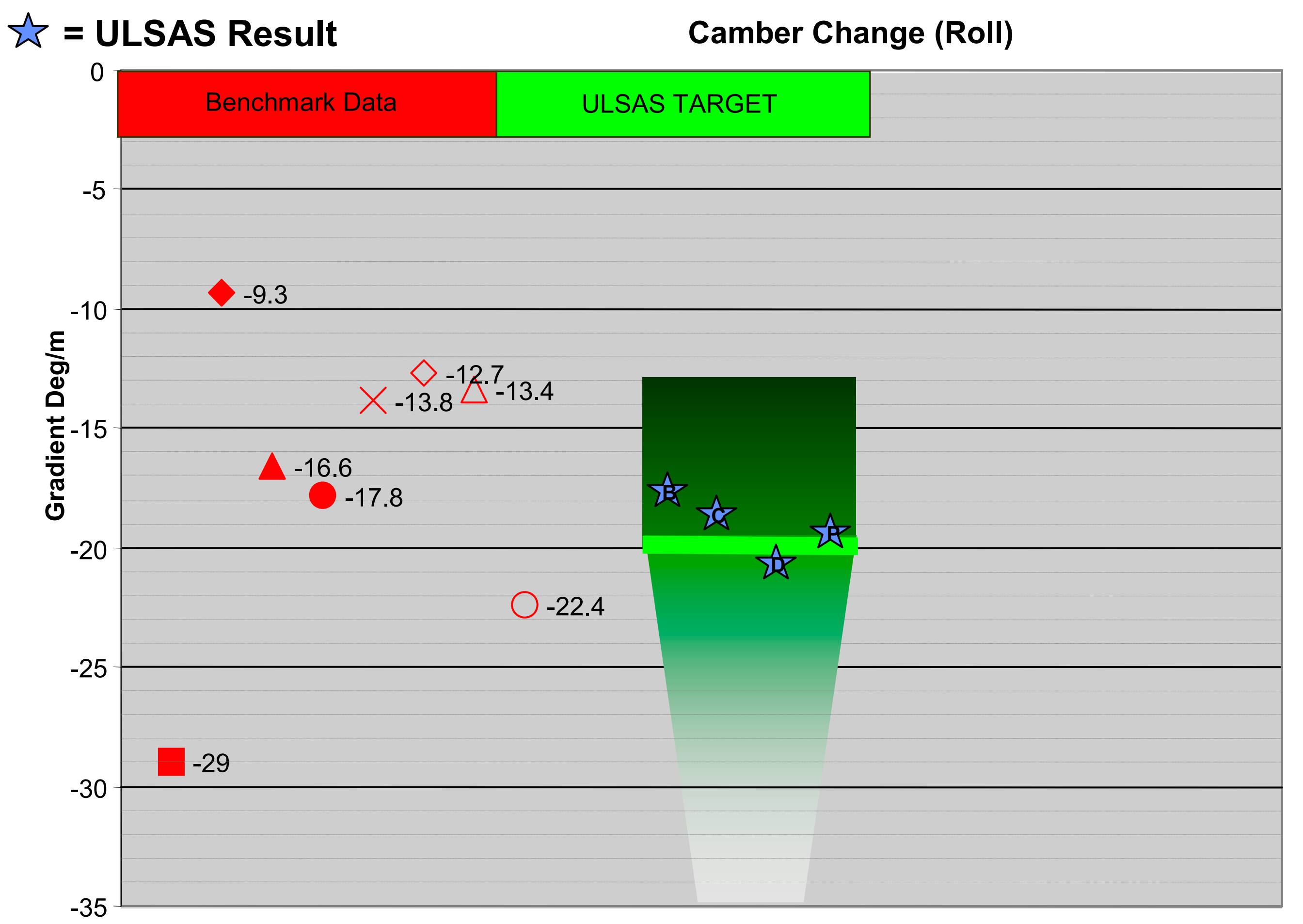
Comments:

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

STRUT AND LINKS: Performance

STRUT & LINKS

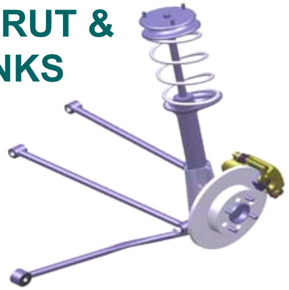




Comments:
Camber change in roll is the same as in parallel bump for the Strut and Links system. The ULSAS designs have all produced gradients within the tolerance band.

STRUT AND LINKS: Performance

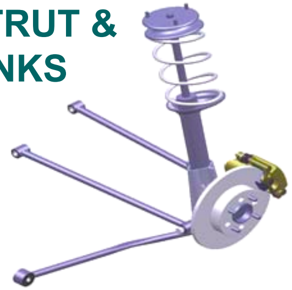
STRUT & LINKS



SYSTEM COMPLIANCES : Detailed Results Breakdown (Bushes Vs Structural Contributions)

Characteristic	Units	Bush B Class	Bush C Class	Structural	TOTAL B Class	TOTAL C Class
Longitudinal Force at TCP						
TCP Longitudinal Compliance	mm/kN	3.43	3.68	0.61	4.04	4.29
Steer Compliance	deg/kN	0.01	0.02	0.01	0.02	0.03
Castor Compliance	deg/kN	0.34	0.37	0.07	0.41	0.44
Lateral Force at TCP						
TCP Lateral Compliance	mm/kN	0.58	0.69	0.27	0.86	0.96
Steer Compliance	deg/kN	-0.006	-0.006	0.001	-0.005	-0.005
Camber Compliance	deg/kN	0.15	0.16	0.06	0.21	0.22
Aligning Torque at TCP						
Steer Stiffness	Nm / deg	854.00	848.00	1781.00	577.22	574.47

STRUT & LINKS



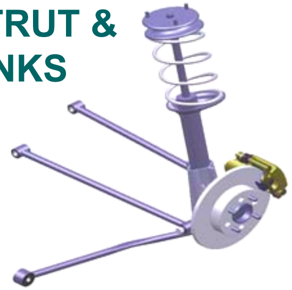
STRUT AND LINKS: Performance

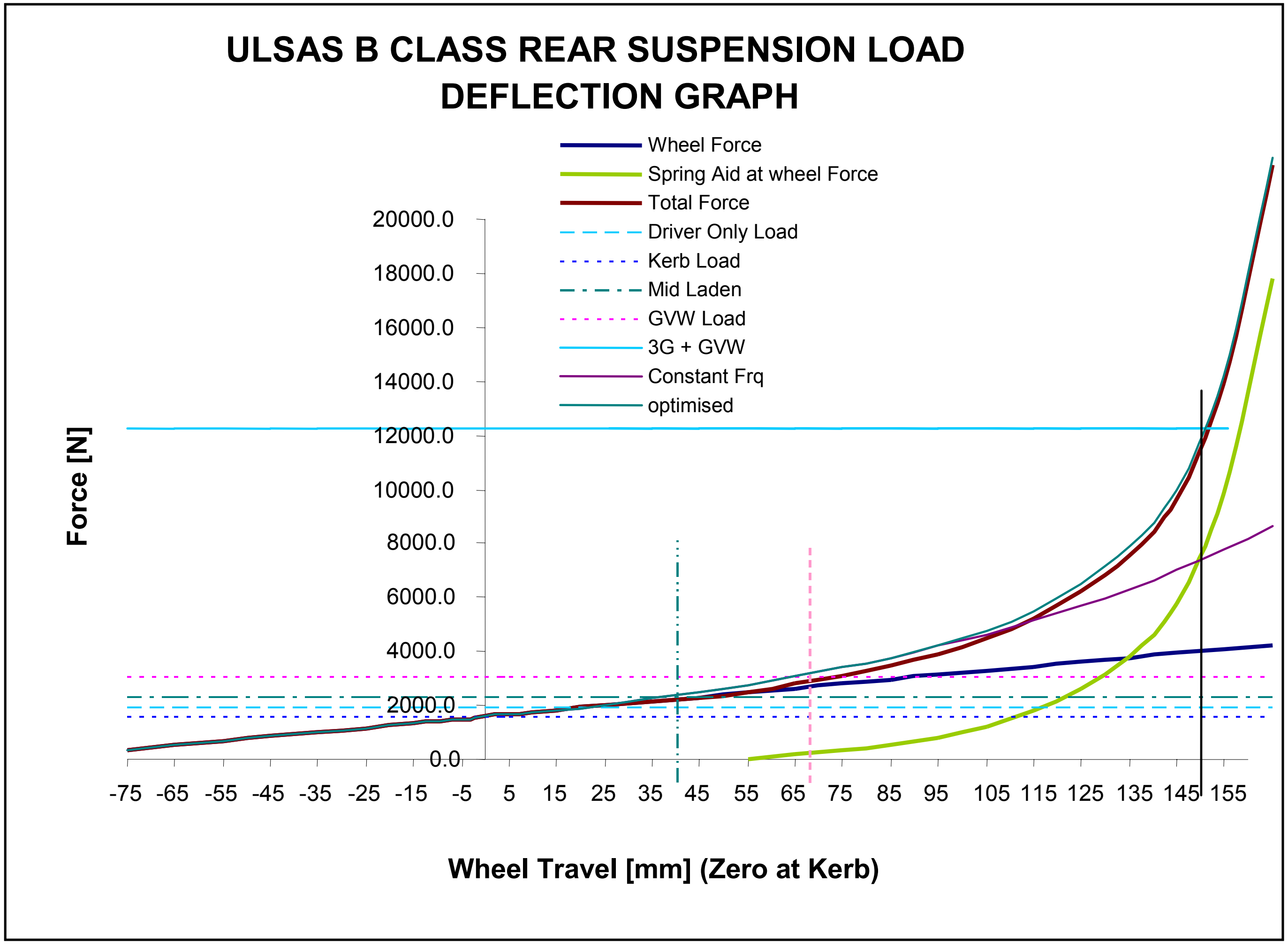
SYSTEM COMPLIANCES : Detailed Results Breakdown (Bushes Vs Structural Contributions)

Characteristic	Units	Bush D Class	Bush P Class	Structural	TOTAL D Class	TOTAL P Class
Longitudinal Force at TCP						
TCP Longitudinal Compliance	mm/kN	3.84	3.89	0.21	4.05	4.10
Steer Compliance	deg/kN	0.01	0.00	-0.01	0.01	0.00
Castor Compliance	deg/kN	0.34	0.34	0.04	0.38	0.38
Lateral Force at TCP						
TCP Lateral Compliance	mm/kN	1.08	1.15	0.35	1.43	1.50
Steer Compliance	deg/kN	-0.03	-0.03	0.00	-0.03	-0.03
Camber Compliance	deg/kN	0.20	0.20	0.07	0.27	0.27
Aligning Torque at TCP						
Steer Stiffness	Nm / deg	859.00	752.00	2458.00	636.55	575.83

STRUT AND LINKS: Performance

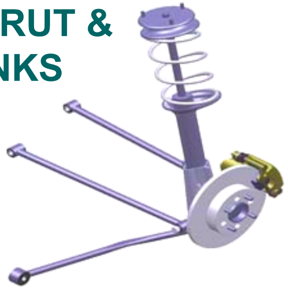
STRUT & LINKS

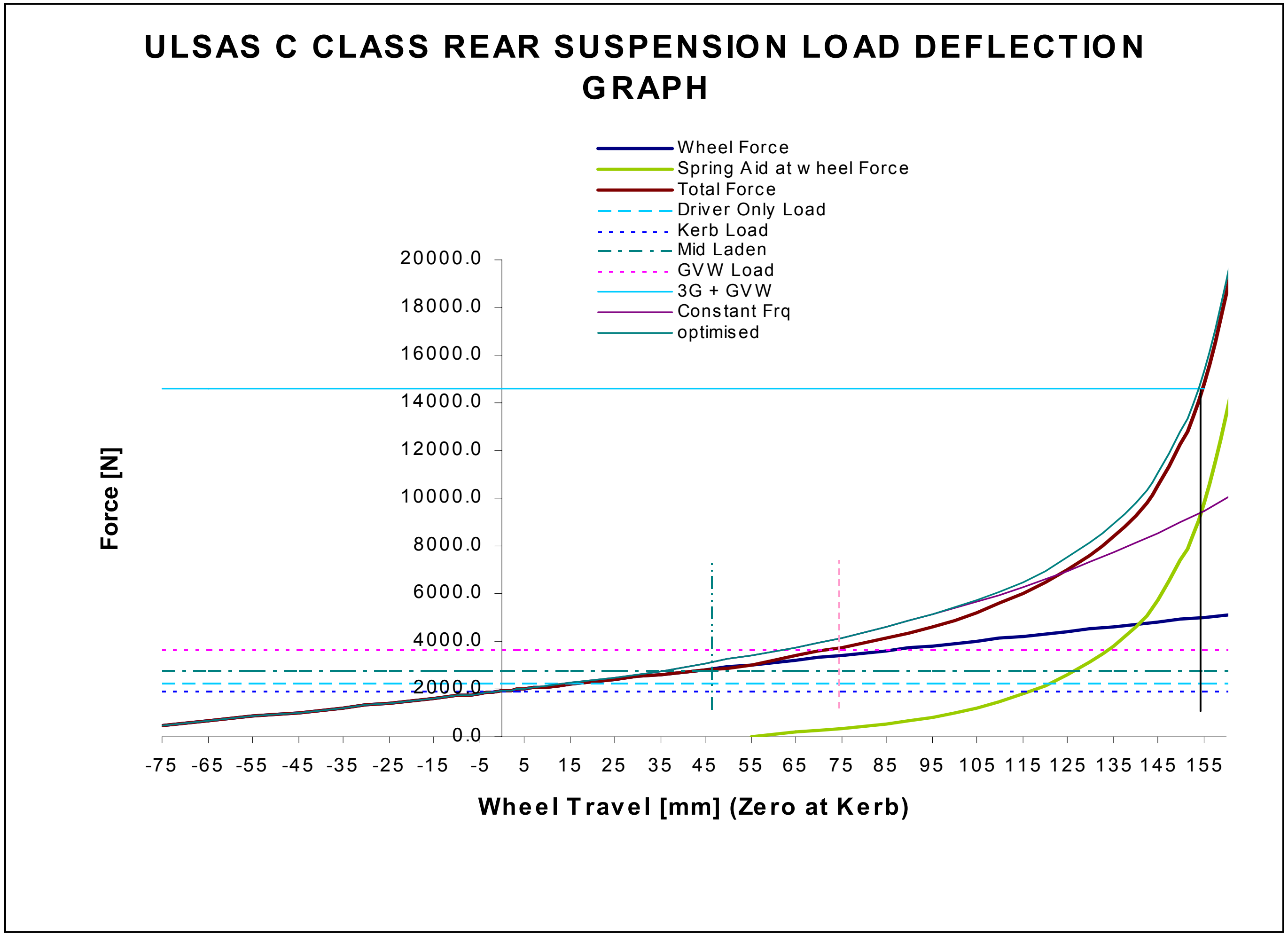




STRUT AND LINKS: Performance

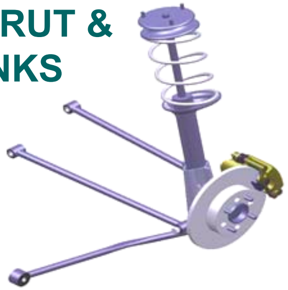
STRUT & LINKS

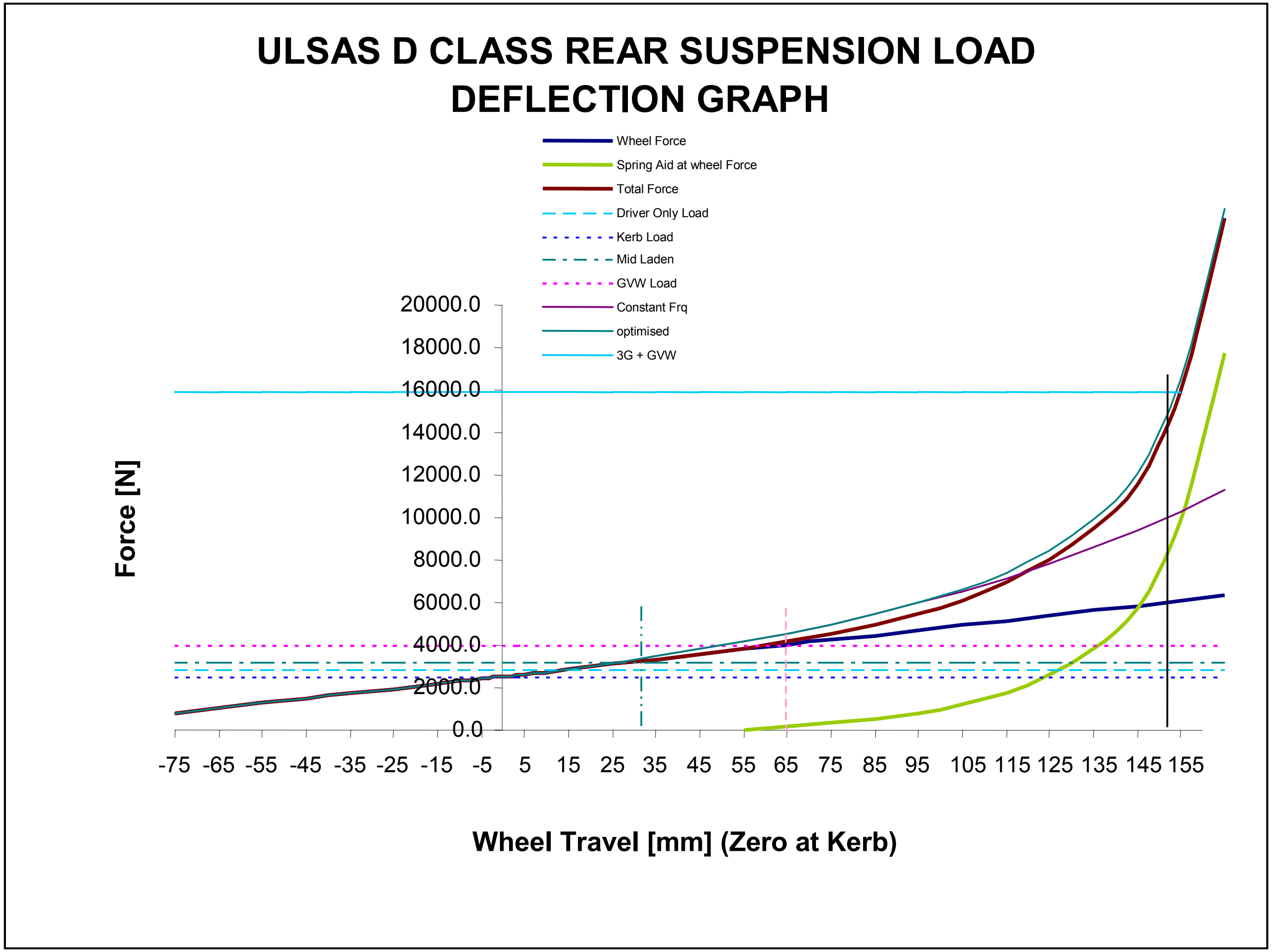




STRUT AND LINKS: Performance

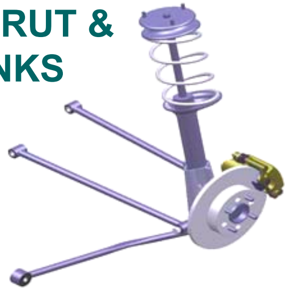
STRUT & LINKS

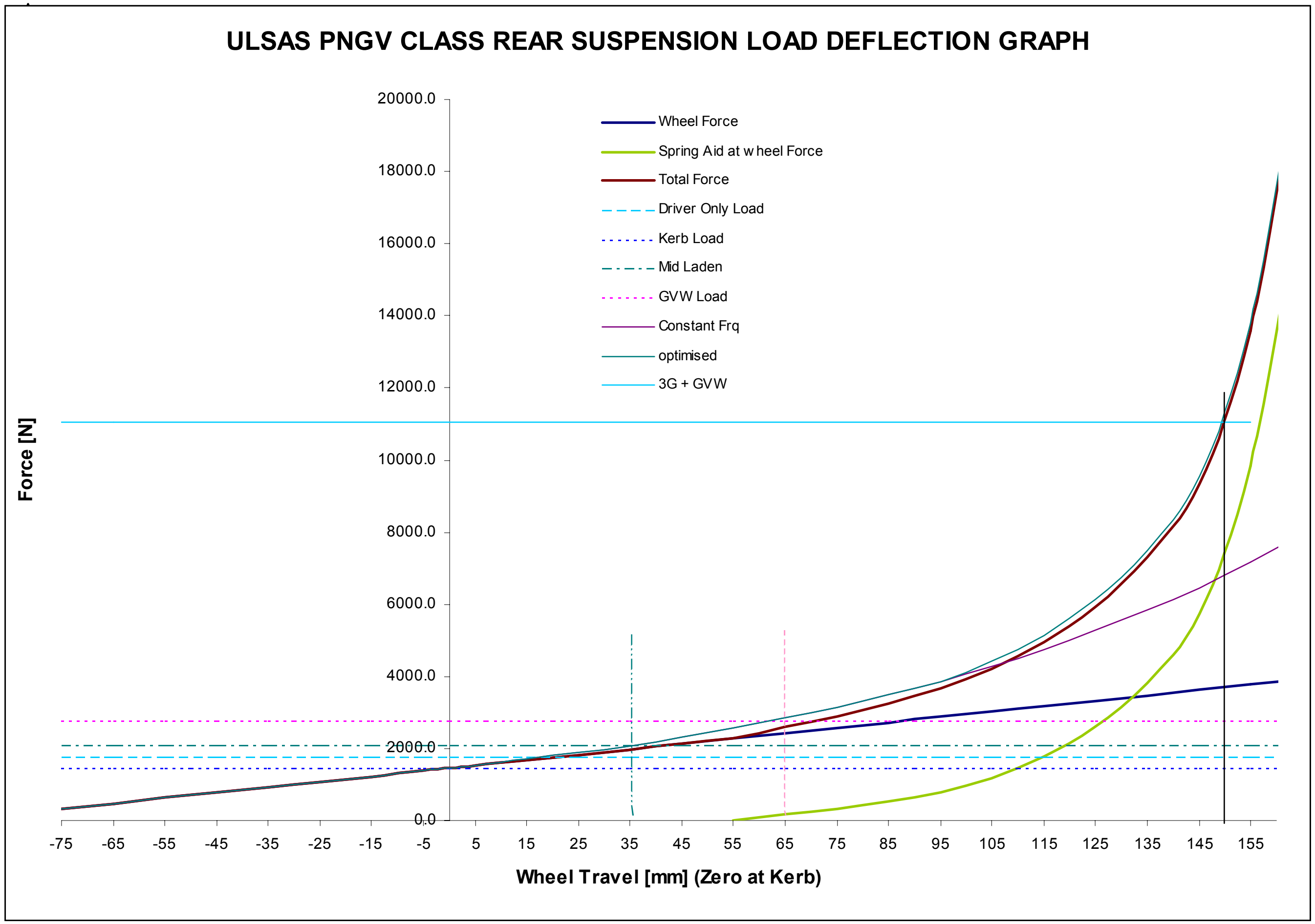




STRUT AND LINKS: Performance

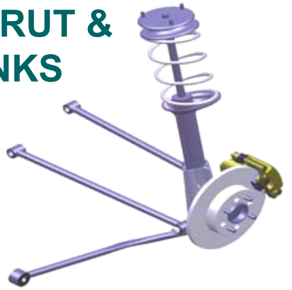
STRUT & LINKS

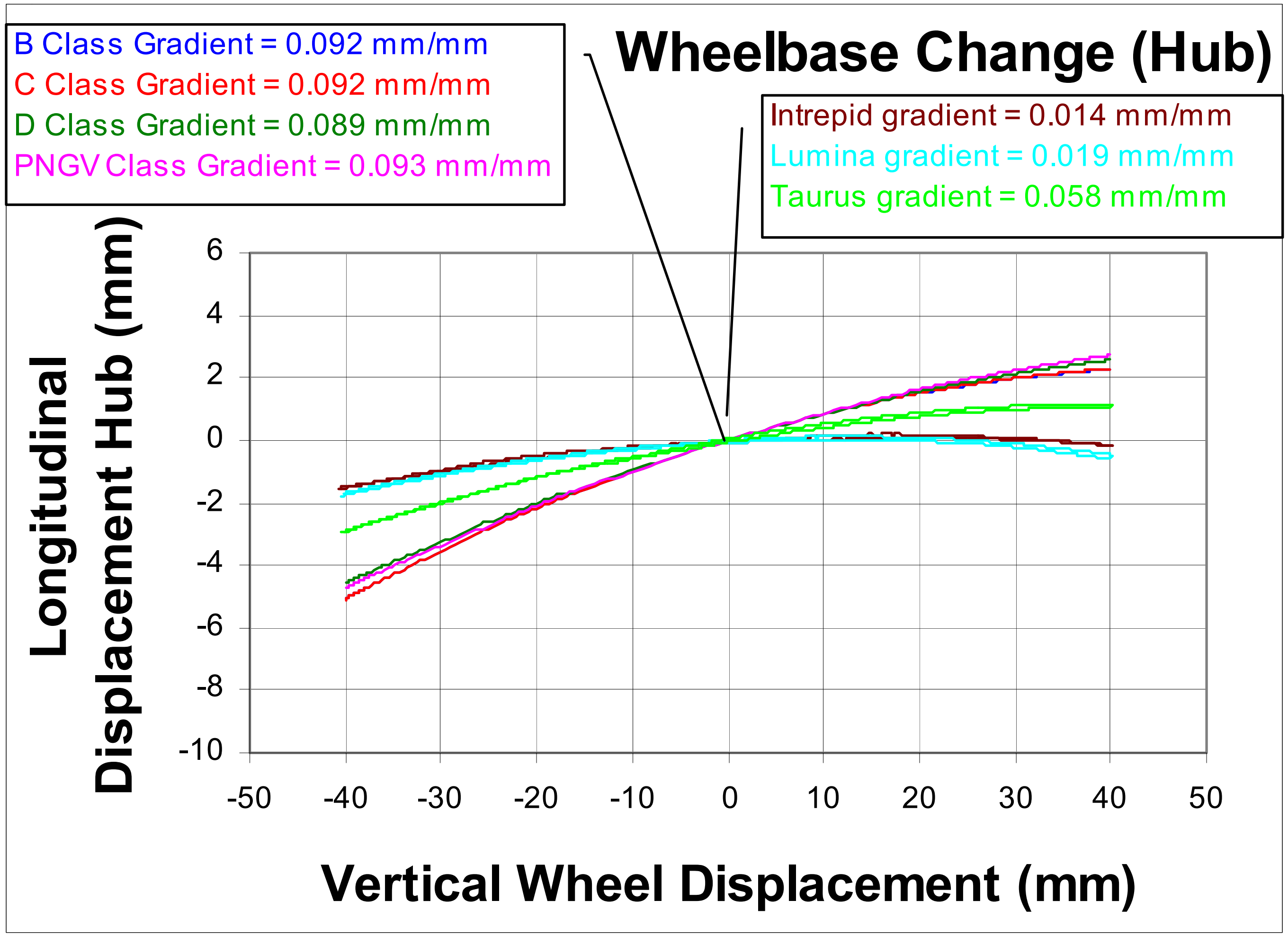




STRUT AND LINKS: Performance

STRUT & LINKS

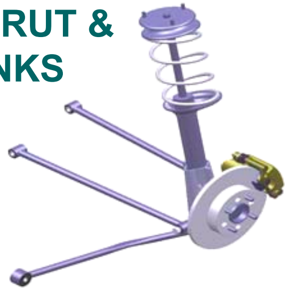


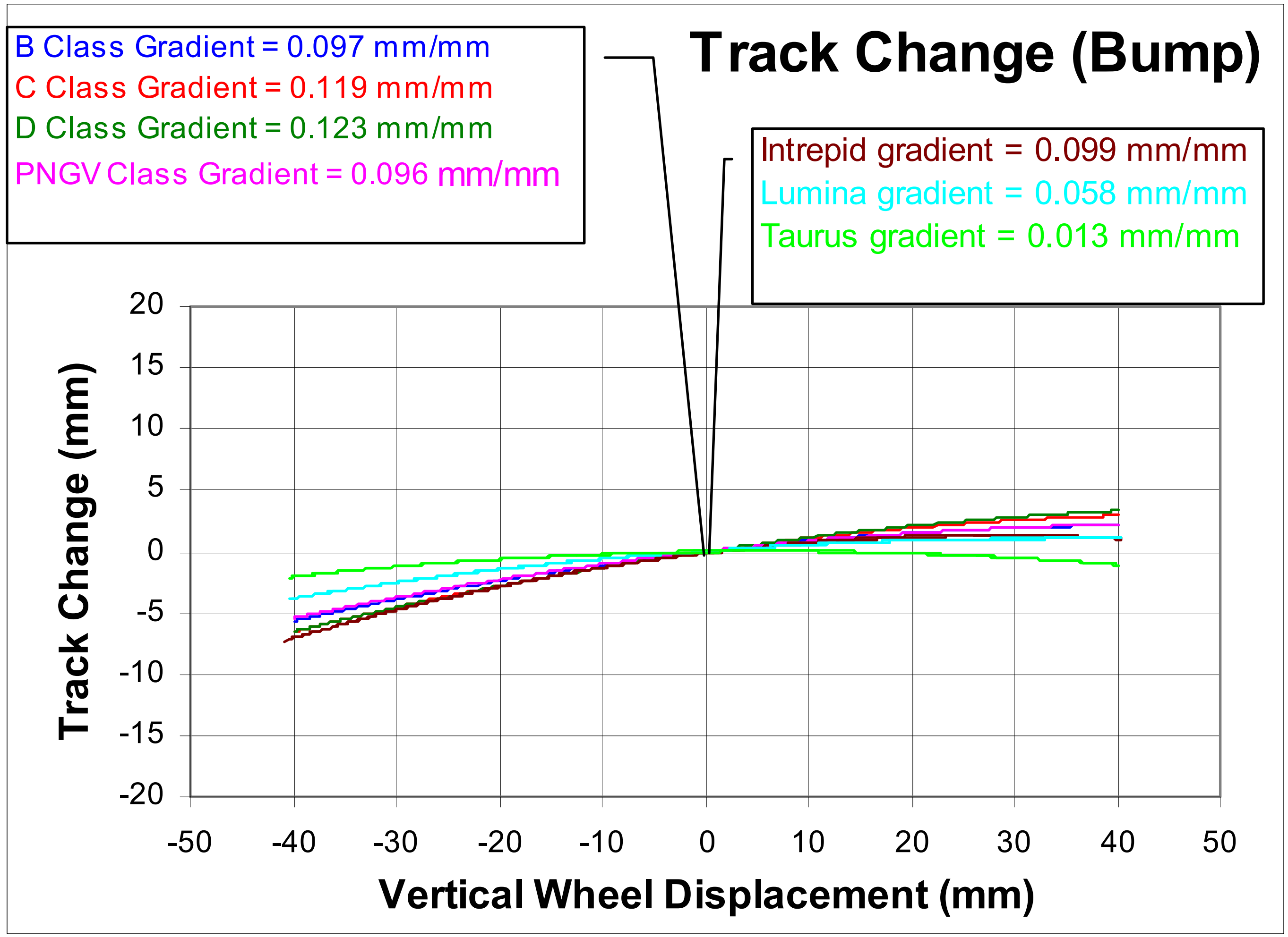


Instantaneous gradient taken at wheel displacement zero

STRUT AND LINKS: Performance

STRUT & LINKS

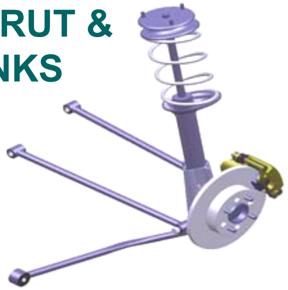


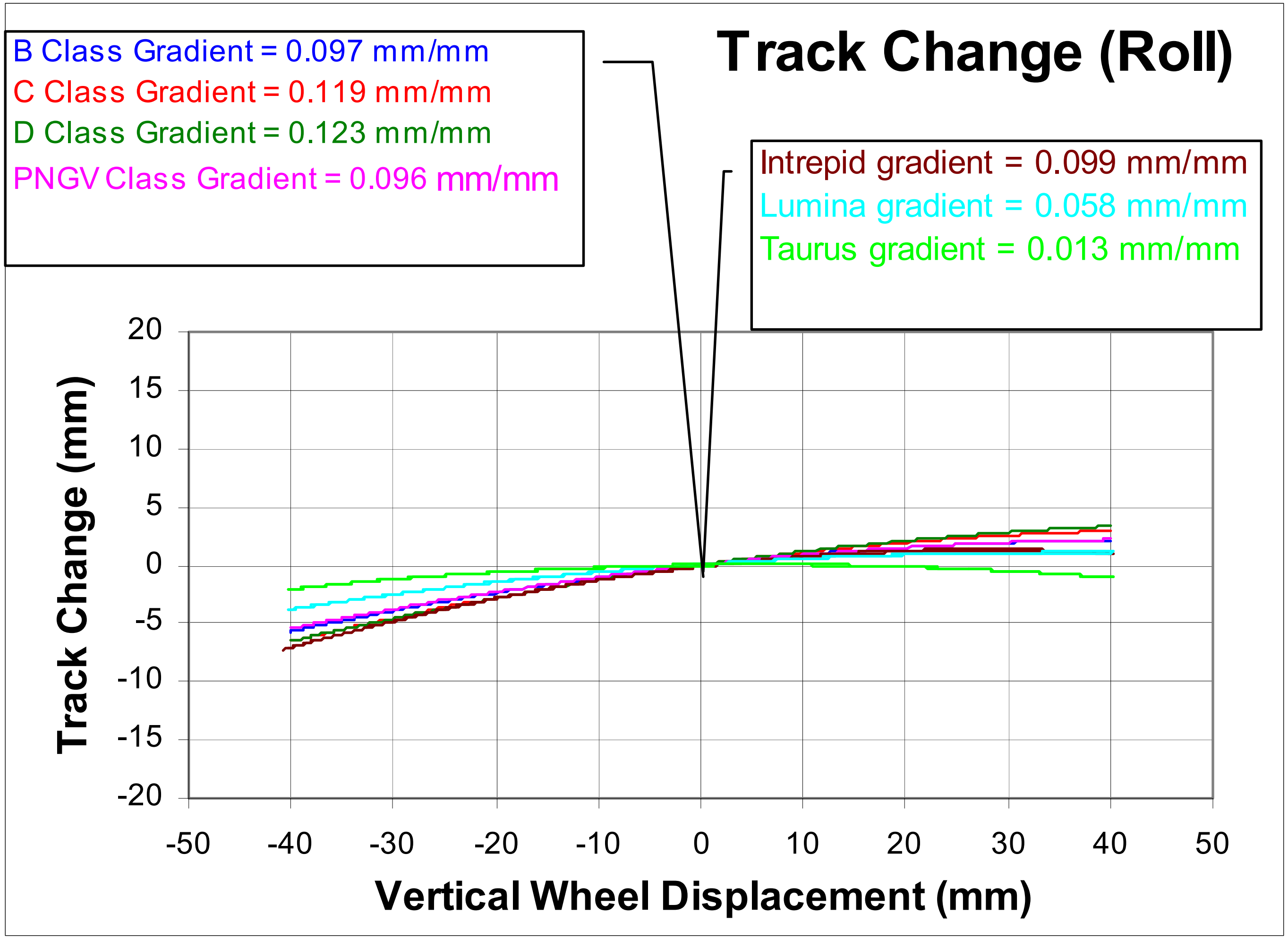


Instantaneous gradient taken at wheel displacement zero

STRUT AND LINKS: Performance

STRUT & LINKS

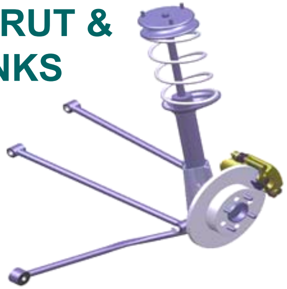


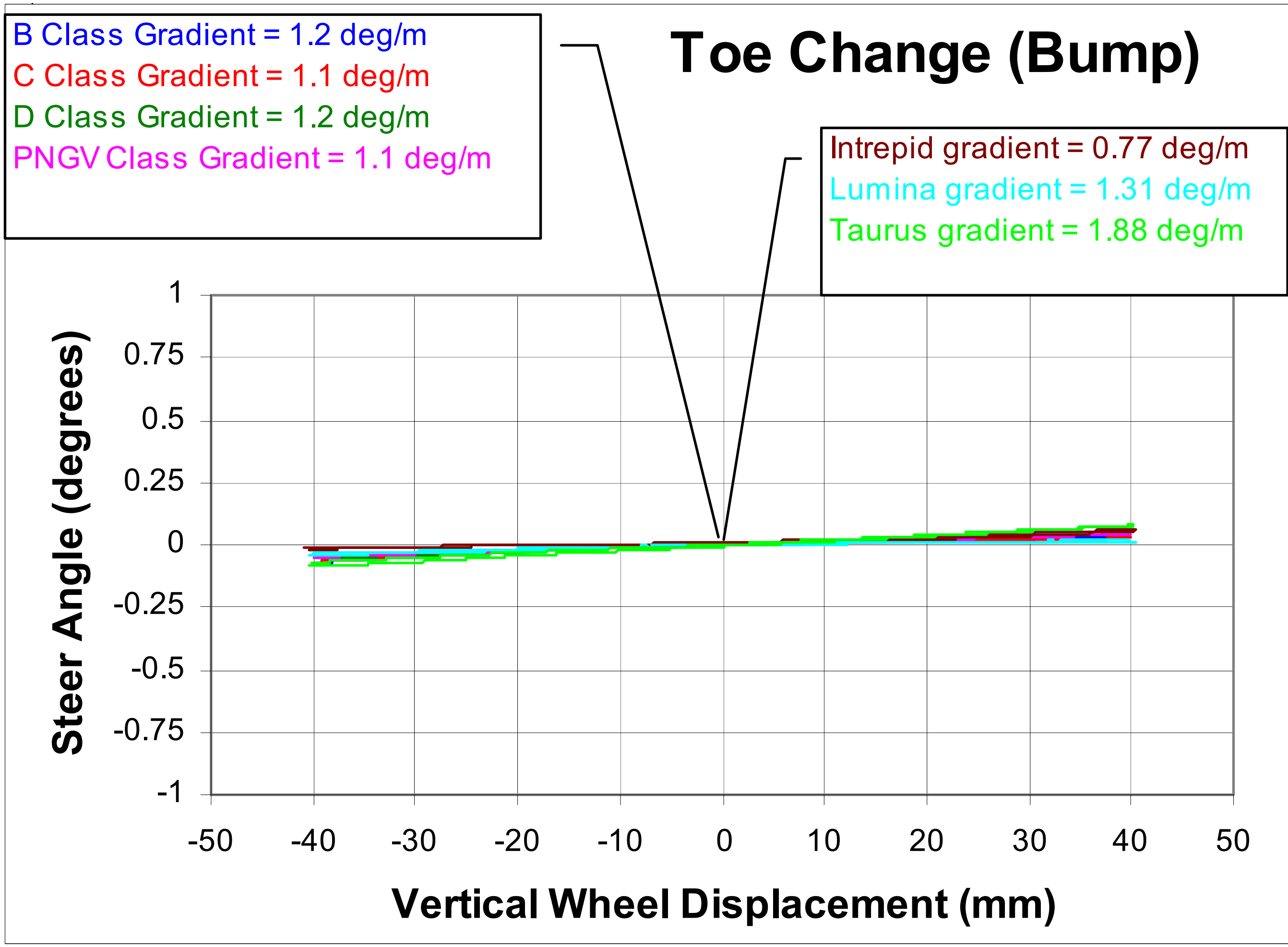


Instantaneous gradient taken at wheel displacement zero

STRUT AND LINKS: Performance

STRUT & LINKS

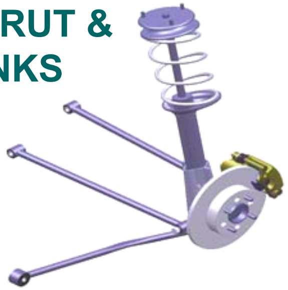


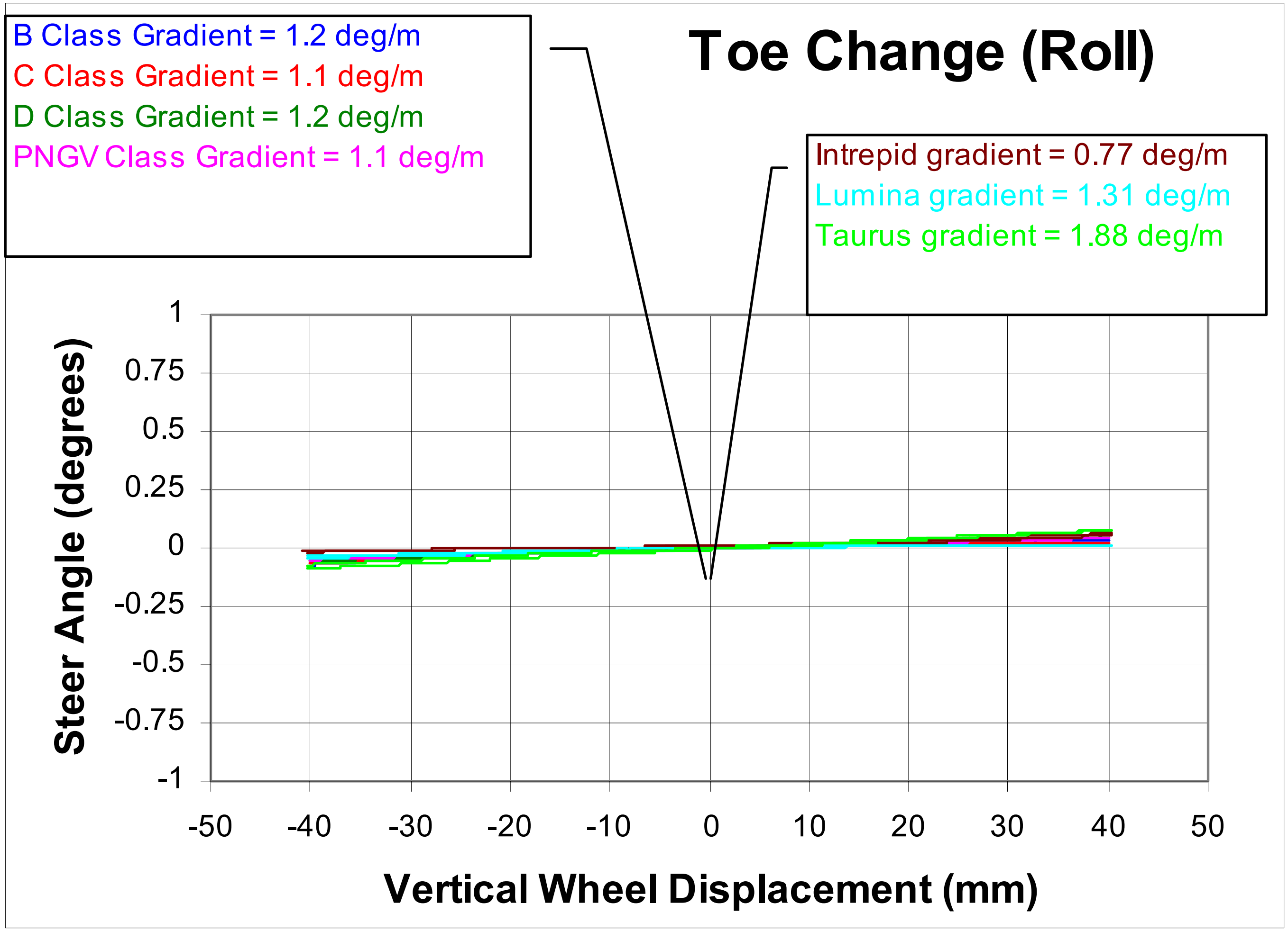


Instantaneous gradient taken at wheel displacement zero

STRUT AND LINKS: Performance

STRUT & LINKS

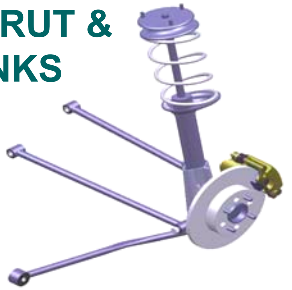


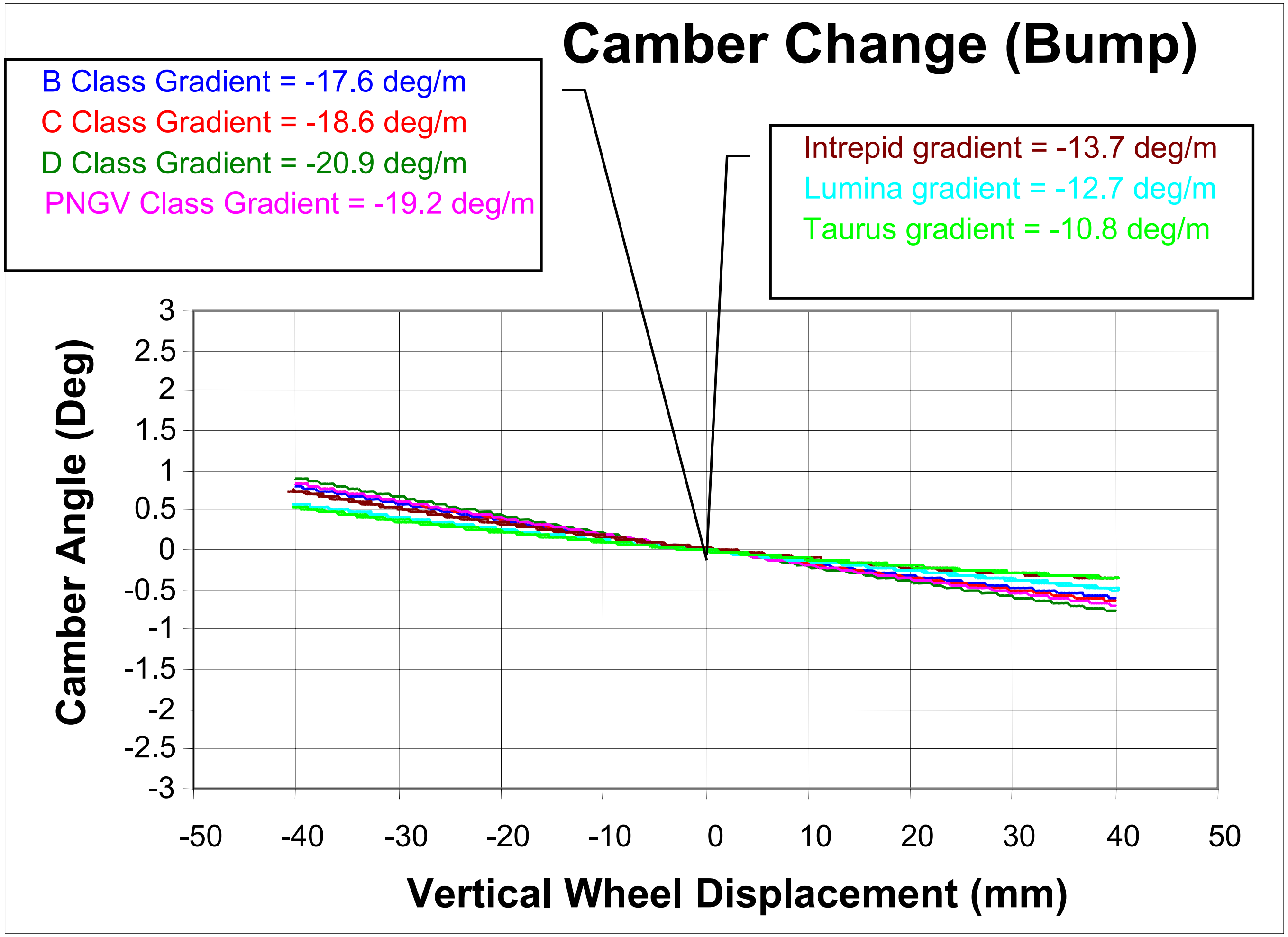


Instantaneous gradient taken at wheel displacement zero

STRUT AND LINKS: Performance

STRUT & LINKS

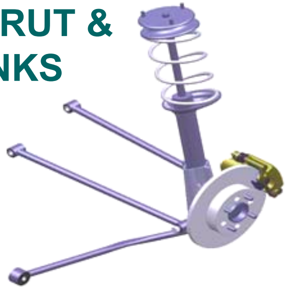


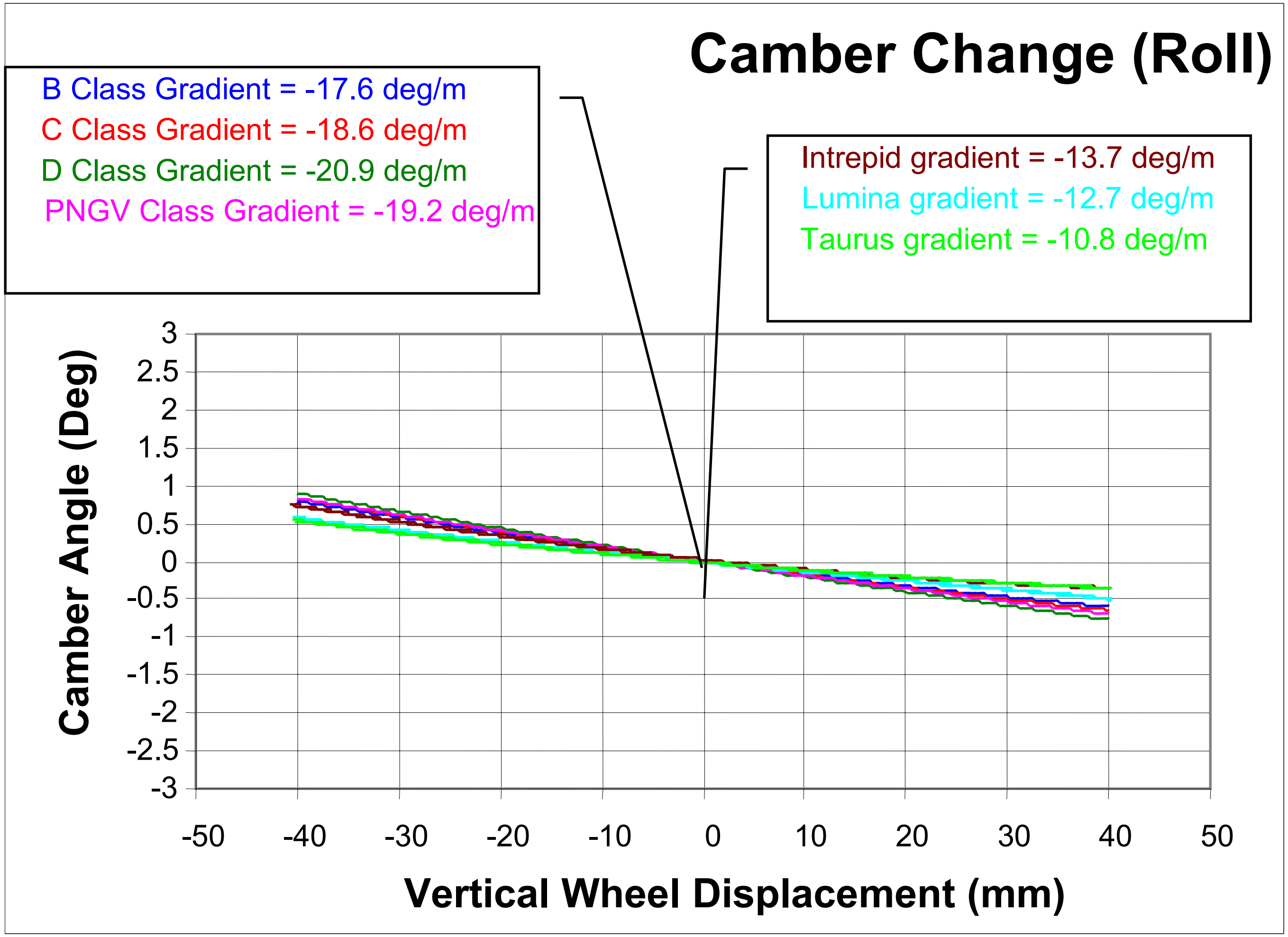


Instantaneous gradient taken at wheel displacement zero

STRUT AND LINKS: Performance

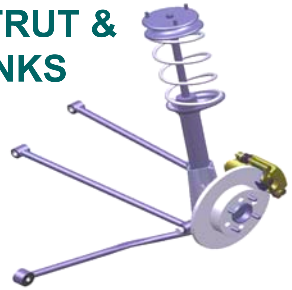
STRUT & LINKS





PERFORMANCE RESULTS GRAPHS KEY

STRUT & LINKS



Key to Objective Targets Graphs:

Optimum value (ULSAS Target)

★ = ULSAS Result

Tolerance Bands

Min Performance

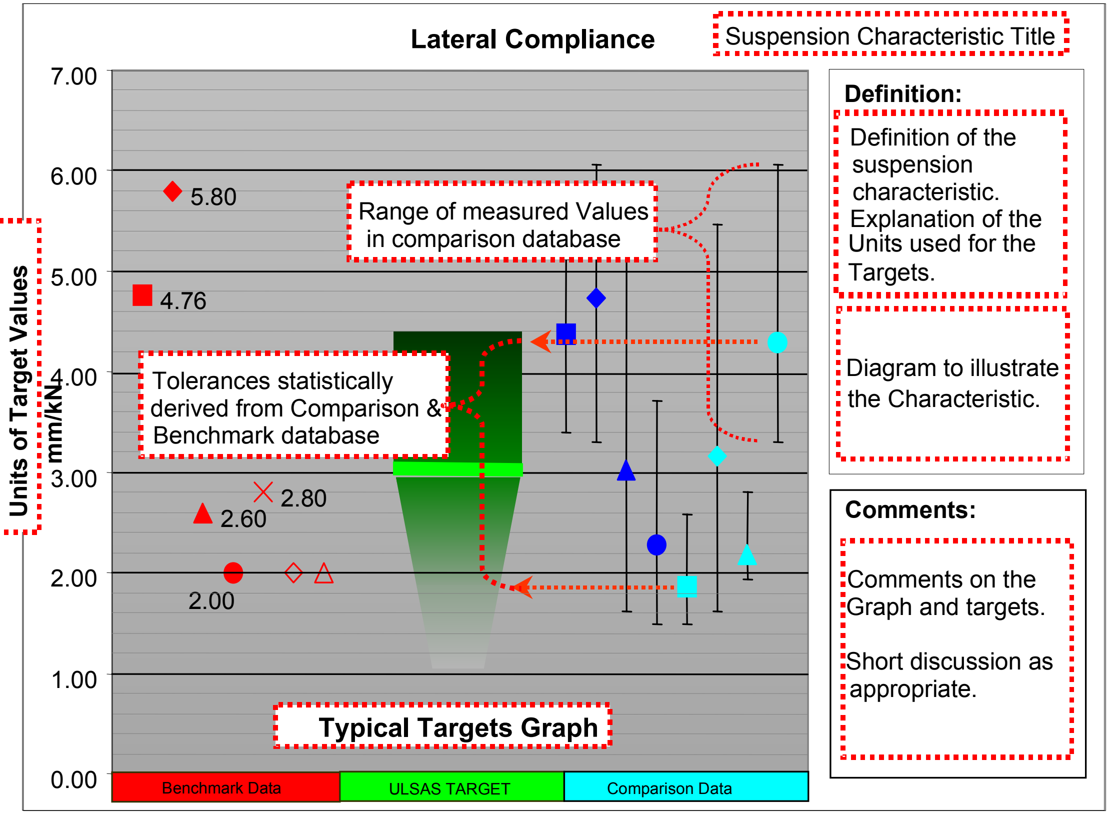
Band showing areas of acceptable Performance. Darker areas show Min Performance levels.

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.

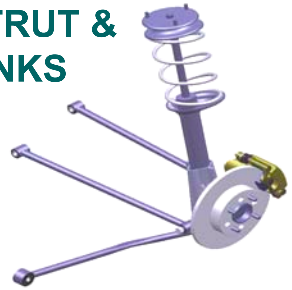


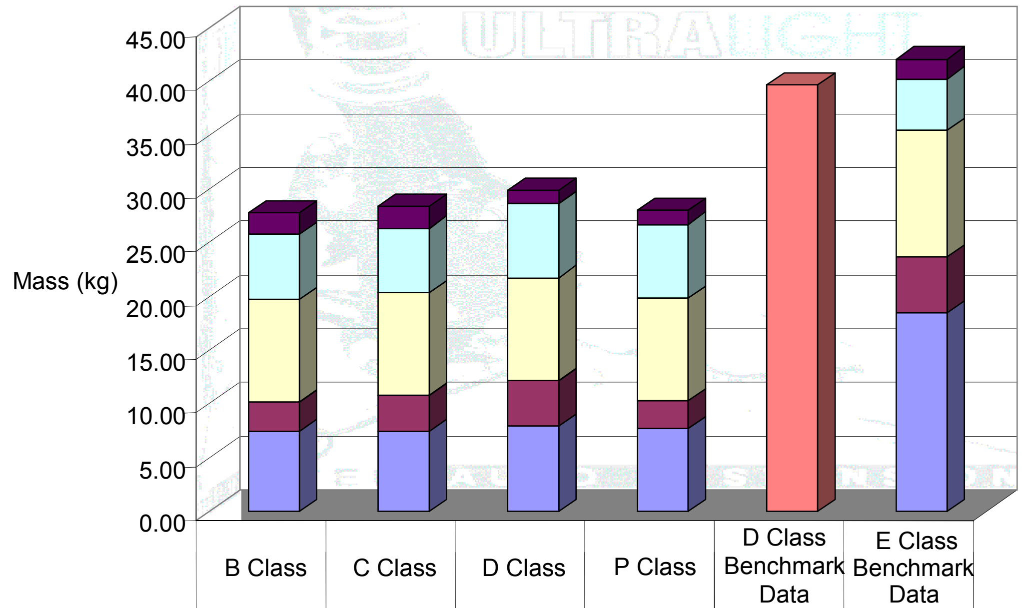
- VW Golf
- Peugeot 306
- Honda Accord
- BMW 528
- Dodge Intrepid
- Ford Taurus
- Chevrolet Lumina
- Audi A6
- ULSAS TARGET B
- ULSAS TARGET C
- ULSAS TARGET D
- ULSAS TARGET PNGV
- B Class Typical
- C Class Typical
- D Class Typical
- E Class Typical
- Double Wishbone Typical
- Multilink Typical
- Struts&Links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

STRUT & LINKS: MASS

Comparison

STRUT & LINKS





	B Class	C Class	D Class	P Class	D Class Benchmark Data	E Class Benchmark Data
OVERALL					39.70	
BUSHES & FIXINGS	2.03	2.03	1.25	1.25		1.86
HUBS	6.00	6.00	6.86	6.86		4.80
DAMPER ASSY	9.60	9.60	9.60	9.60		11.72
SPRING	2.75	3.34	4.21	2.61		5.22
STRUCTURE *	7.39	7.39	7.95	7.66		18.50
SYSTEM	**27.77**	**28.37**	**29.87**	**27.97**	39.70	42.10

Mass Of ULSAS Solutions Vs Benchmark Vehicles

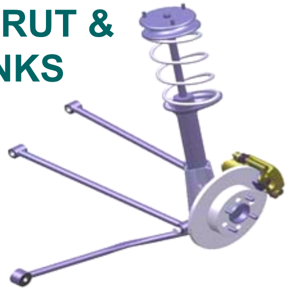
Description	B	C	D	E	P
Benchmark (Kg)			39.70	42.10	
ULSAS Solution (Kg)	27.77	28.37	29.87		27.97
Saving vs Benchmark			25%		

*** Structure includes knuckle and links**

STRUT & LINKS: MASS

Approach

STRUT & LINKS



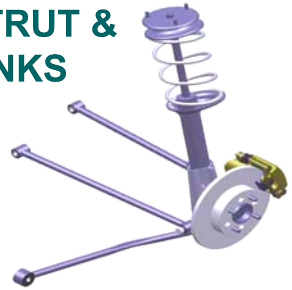
- Mass estimations were established for:
  - Components
  - Sub-assemblies / Proprietary Parts
- Mass estimates for Lotus designed parts derived from Mass Property Tables in the C.A.D software or the analysis C.A.E software.
- For Proprietary Parts the results were generated using a combination of Lotus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

STRUT & LINKS: MASS

B & C Class

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS



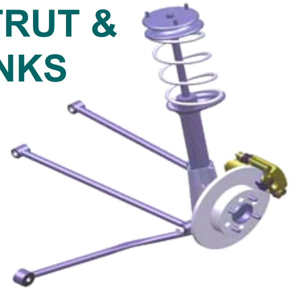
PARTS LIST			ULSAS B Class			ULSAS C Class		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, STRUT & LINKS	1	**27.77**			**28.37**		
2	WELDED ASSY, STRUT UNIT RH	1	**8.40**	**8.397**	8.397	**8.40**	**8.397**	8.397
3	WELDED ASSY, STRUT UNIT LH	1	**8.40**	**8.397**	8.397	**8.40**	**8.397**	8.397
4	KNUCKLE	2			1.331			1.331
5	KNUCKLE FORGING	2			0.266			0.266
6	HUB & BEARING UNIT RH	1			3.000			3.000
7	HUB & BEARING UNIT LH	1			3.000			3.000
8	DAMPER ASSEMBLY	2			3.800			3.800
9	DISC BRAKE	2						
10	CALIPER, BRAKE	2						
11	SPRING	2	**2.75**	**1.373**		**3.34**	**1.672**	
12	UPPER MOUNTING - STRUT	2	**2.00**	**1.000**		**2.00**	**1.000**	
13	ASSY, FORWARD LINK	2	**2.50**	**1.250**	1.250	**2.50**	**1.250**	1.250
14	LONGITUDINAL LINK	2						
15	BUSH HOUSING	2						
16	DOUBLE JOINT ASSY	2						
17	FORWARD LATERAL LINK	2						
18	LATERAL LINK BUSH HOUSING	2						
19	ASSY, REAR LATERAL LINK	2	**1.70**	**0.850**	0.850	**1.70**	**0.850**	0.850
20	REAR LATERAL LINK	2						
21	LATERAL LINK BUSH HOUSING	2						
22	LATERAL LINK OUTER JOINTS	2						
23	VARIOUS BUSHES AND JOINTS	1	**1.56**	**1.556**		**1.56**	**1.556**	
24	ASSORTED FIXINGS	1	**0.48**	**0.477**		**0.48**	**0.477**	

39.7 Ref D Class Mass

STEEL AUTO SUSPENSION

STRUT & LINKS: MASS
D Class

STRUT & LINKS



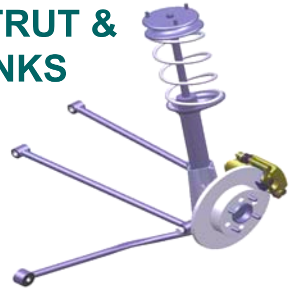
PARTS LIST			ULSAS D Class		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, STRUT & LINKS	1	29.87		
2	WELDED ASSY, STRUT UNIT RH	1	9.41	9.408	9.408
3	WELDED ASSY, STRUT UNIT LH	1	9.41	9.408	9.408
4	KNUCKLE PRESSING	2			0.700
5	KNUCKLE PRESSING	2			0.700
6	KNUCKLE FORGING	2			0.641
7	LOWER BRACKET	2			0.137
8	HUB & BEARING UNIT RH	1			3.430
9	HUB & BEARING UNIT LH	1			3.430
10	DAMPER ASSEMBLY	2			3.800
11	DISC BRAKE	2			
12	CALIPER, BRAKE	2			
13	SPRING	2	4.21	2.107	
14	UPPER MOUNTING - STRUT	2	2.00	1.000	
15	ASSY, LONGITUDINAL LINK	2	1.05	0.524	0.524
16	LONGITUDINAL LINK	2			0.524
17	BUSH HOUSING	2			
18	BUSH HOUSING	2			
19	ASSY, FORWARD LATERAL LINK	2	1.29	0.643	0.643
20	FORWARD LATERAL LINK	2			
21	LATERAL LINK BUSH HOUSING	4			
22	ASSY, REAR LATERAL LINK	2	1.26	0.628	0.628
23	REAR LATERAL LINK	2			
24	LATERAL LINK BUSH HOUSING	4			
25	VARIOUS BUSHES AND JOINTS	1	0.71	0.712	
26	ASSORTED FIXINGS	1	0.54	0.540	

THE D CLASS BENCHMARK MASS IS 39.7 Kg

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS: MASS
P Class

STRUT & LINKS



PARTS LIST			ULSAS P Class			E Class Benchmark Data		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, STRUT & LINKS	1	27.97			42.10		
2	WELDED ASSY, STRUT UNIT RH	1	9.41	9.408	9.408	10.98	10.980	10.980
3	WELDED ASSY, STRUT UNIT LH	1	9.41	9.408	9.408	10.98	10.980	10.980
4	KNUCKLE PRESSING	2			0.700			4.050
5	KNUCKLE PRESSING	2			0.700			4.050
6	KNUCKLE FORGING	2			0.641			
7	LOWER BRACKET	2			0.137			
8	HUB & BEARING UNIT RH	1			3.430			2.400
9	HUB & BEARING UNIT LH	1			3.430			2.400
10	DAMPER ASSEMBLY	2			3.800			4.530
11	DISC BRAKE	2						
12	CALIPER, BRAKE	2						
13	SPRING	2	2.61	1.303		5.22	2.610	
14	UPPER MOUNTING - STRUT	2	2.00	1.000		2.66	1.330	
15	ASSY, LONGITUDINAL LINK	2	1.06	0.528	0.528	4.20	2.100	
16	LONGITUDINAL LINK	2			0.528			
17	BUSH HOUSING	2						
18	BUSH HOUSING	2						
19	ASSY, FORWARD LATERAL LINK	2	1.08	0.538	0.538	3.10	1.550	
20	FORWARD LATERAL LINK	2						
21	LATERAL LINK BUSH HOUSING	4						
22	ASSY, REAR LATERAL LINK	2	1.17	0.584	0.584	3.10	1.550	
23	REAR LATERAL LINK	2						
24	LATERAL LINK BUSH HOUSING	4						
25	VARIOUS BUSHES AND JOINTS	1	0.71	0.712		1.31	1.305	
26	ASSORTED FIXINGS	1	0.54	0.540		0.55		

39.7 Ref D Class Mass

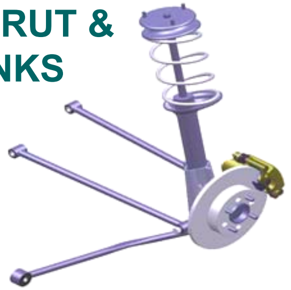
STEEL AUTO SUSPENSION

ULTRALIGHT STEEL AUTO SUSPENSION

STRUT & LINKS: MATERIAL

B & C Class

STRUT & LINKS



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPA)
1	ASSEMBLY, STRUT & LINKS	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, STRUT UNIT RH	1	FABRICATION (items 4-10)		
3	WELDED ASSY, STRUT UNIT LH	1	FABRICATION (items 4-10)		
4	KNUCKLE	2	HYDROFORMING	3.5	500
5	KNUCKLE FORGING	2	FORGING	na	500
6	HUB & BEARING UNIT RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
7	HUB & BEARING UNIT LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
8	DAMPER ASSEMBLY	2	INCL SPRING SEAT & BUMP RUBBER	See note	
9	DISC BRAKE	2	SOLID, CAST IRON		
10	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE MECHANISM		
11	SPRING	2	SHEAR STRESS LIMIT 1300MPa	Ø 10.6 (B) Ø 11.4 (C)	1300
12	UPPER MOUNTING - STRUT	2	RUBBER ISOLATED BUSH		
13	ASSY, FORWARD LINK	2	FABRICATION (items 16 - 21)		
14	LONGITUDINAL LINK	2	TUBE	Ø 20 x 2	250
15	BUSH HOUSING	2	TUBE		250
16	DOUBLE JOINT ASSY	2	TWIN SPHERICAL BUSH ASSY		
17	FORWARD LATERAL LINK	2	TUBE	Ø 20 x 2	250
18	LATERAL LINK BUSH HOUSING	2	TUBE		250
19	ASSY, REAR LATERAL LINK	2	FABRICATION (item 23 & 24)		
20	REAR LATERAL LINK	2	TUBE	Ø 20 x 2	250
21	LATERAL LINK BUSH HOUSING	2	TUBE		250
22	LATERAL LINK OUTER JOINTS	2	SPHERICAL BUSH ASSY		
23	VARIOUS BUSHES AND JOINTS	1	RUBBER BUSHES & SPHERICAL JOINTS		
24	ASSORTED FIXINGS	1	NUTS, BOLTS & WASHERS ETC		

Note : Damper Assembly Consists of 4 Main Components

Damper Body Assumes 350 MPa Material

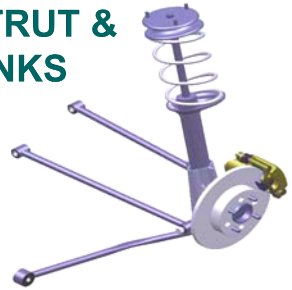
Damper Rod Assumes Dia 22mm x 3mm Tube

Spring Pan Assumes 350 MPa Material

Bump Rubber Assumes Polyurethane Material

STRUT & LINKS: MATERIAL
D Class

STRUT & LINKS



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPA)
1	ASSEMBLY, STRUT & LINKS	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, STRUT UNIT RH	1	FABRICATION (items 4-10)		
3	WELDED ASSY, STRUT UNIT LH	1	FABRICATION (items 4-10)		
4	KNUCKLE PRESSING	2	PRESSING	4	500
5	KNUCKLE PRESSING	2	PRESSING	4	500
6	KNUCKLE FORGING	2	FORGING	na	500
7	LOWER BRACKET	2	BLANK & FOLD	4	250
8	HUB & BEARING UNIT RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
9	HUB & BEARING UNIT LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
10	DAMPER ASSEMBLY	2	INCL SPRING SEAT & BUMP RUBBER	See note	
11	DISC BRAKE	2	SOLID, CAST IRON		
12	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE MECHANISM		
13	SPRING	2	SHEAR STRESS LIMIT 1300MPa	Ø 12.30	1300
14	UPPER MOUNTING - STRUT	2	RUBBER ISOLATED BUSH		
15	ASSY, LONGITUDINAL LINK	2	FABRICATION (items 16,17 & 18)		
16	LONGITUDINAL LINK	2	TUBE	Ø 20 x 2	250
17	BUSH HOUSING	2	TUBE		250
18	BUSH HOUSING	2	TUBE		250
19	ASSY, FORWARD LATERAL LINK	2	FABRICATION (item 20 & 21)		
20	FORWARD LATERAL LINK	2	TUBE	Ø 20 x 2	250
21	LATERAL LINK BUSH HOUSING	4	TUBE		250
22	ASSY, REAR LATERAL LINK	2	FABRICATION (item 23 & 24)		
23	REAR LATERAL LINK	2	TUBE	Ø 20 x 2	250
24	LATERAL LINK BUSH HOUSING	4	TUBE		250
25	VARIOUS BUSHES AND JOINTS	1	RUBBER BUSHES & SPHERICAL JOINTS		
26	ASSORTED FIXINGS	1	NUTS, BOLTS & WASHERS ETC		

Note : Damper Assembly Consists of 4 Main Components

Damper Body Assumes 350 MPa Material

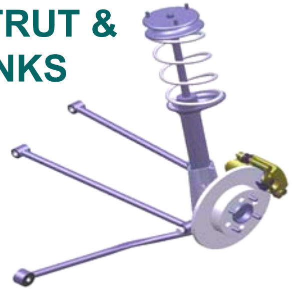
Damper Rod Assumes Dia 22mm x 3mm Tube

Spring Pan Assumes 350 MPa Material

Bump Rubber Assumes Polyurethane Material

STRUT & LINKS: MATERIAL
P Class

STRUT & LINKS



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPA)
1	ASSEMBLY, STRUT & LINKS	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, STRUT UNIT RH	1	FABRICATION (items 4-10)		
3	WELDED ASSY, STRUT UNIT LH	1	FABRICATION (items 4-10)		
4	KNUCKLE PRESSING	2	PRESSING	4	500
5	KNUCKLE PRESSING	2	PRESSING	4	500
6	KNUCKLE FORGING	2	FORGING	na	500
7	LOWER BRACKET	2	BLANK & FOLD	4	250
8	HUB & BEARING UNIT RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
9	HUB & BEARING UNIT LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
10	DAMPER ASSEMBLY	2	INCL SPRING SEAT & BUMP RUBBER	See note	
11	DISC BRAKE	2	SOLID, CAST IRON		
12	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE MECHANISM		
13	SPRING	2	SHEAR STRESS LIMIT 1300MPa	Ø 10.39	1300
14	UPPER MOUNTING - STRUT	2	RUBBER ISOLATED BUSH		
15	ASSY, LONGITUDINAL LINK	2	FABRICATION (items 16,17 & 18)		
16	LONGITUDINAL LINK	2	TUBE	Ø 20 x 2	250
17	BUSH HOUSING	2	TUBE		250
18	BUSH HOUSING	2	TUBE		250
19	ASSY, FORWARD LATERAL LINK	2	FABRICATION (item 20 & 21)		
20	FORWARD LATERAL LINK	2	TUBE	Ø 20 x 2	250
21	LATERAL LINK BUSH HOUSING	4	TUBE		250
22	ASSY, REAR LATERAL LINK	2	FABRICATION (item 23 & 24)		
23	REAR LATERAL LINK	2	TUBE	Ø 20 x 2	250
24	LATERAL LINK BUSH HOUSING	4	TUBE		250
25	VARIOUS BUSHES AND JOINTS	1	RUBBER BUSHES & SPHERICAL JOINTS		
26	ASSORTED FIXINGS	1	NUTS, BOLTS & WASHERS ETC		

Note : Damper Assembly Consists of 4 Main Components

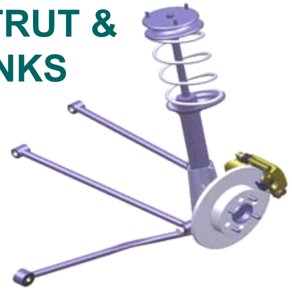
Damper Body Assumes 350 MPa Material

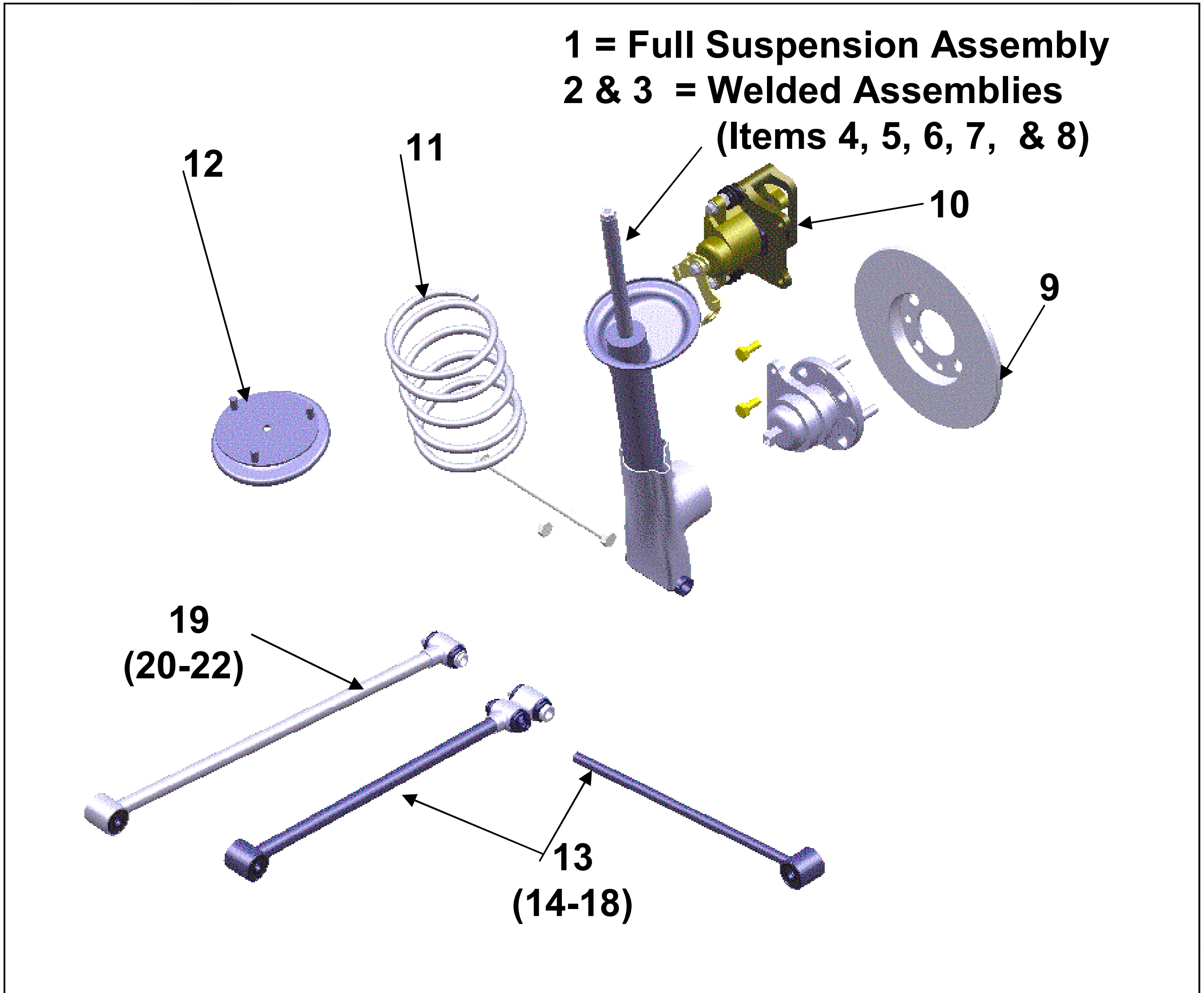
Damper Rod Assumes Dia 22mm x 3mm Tube

Spring Pan Assumes 350 MPa Material

Bump Rubber Assumes Polyurethane Material

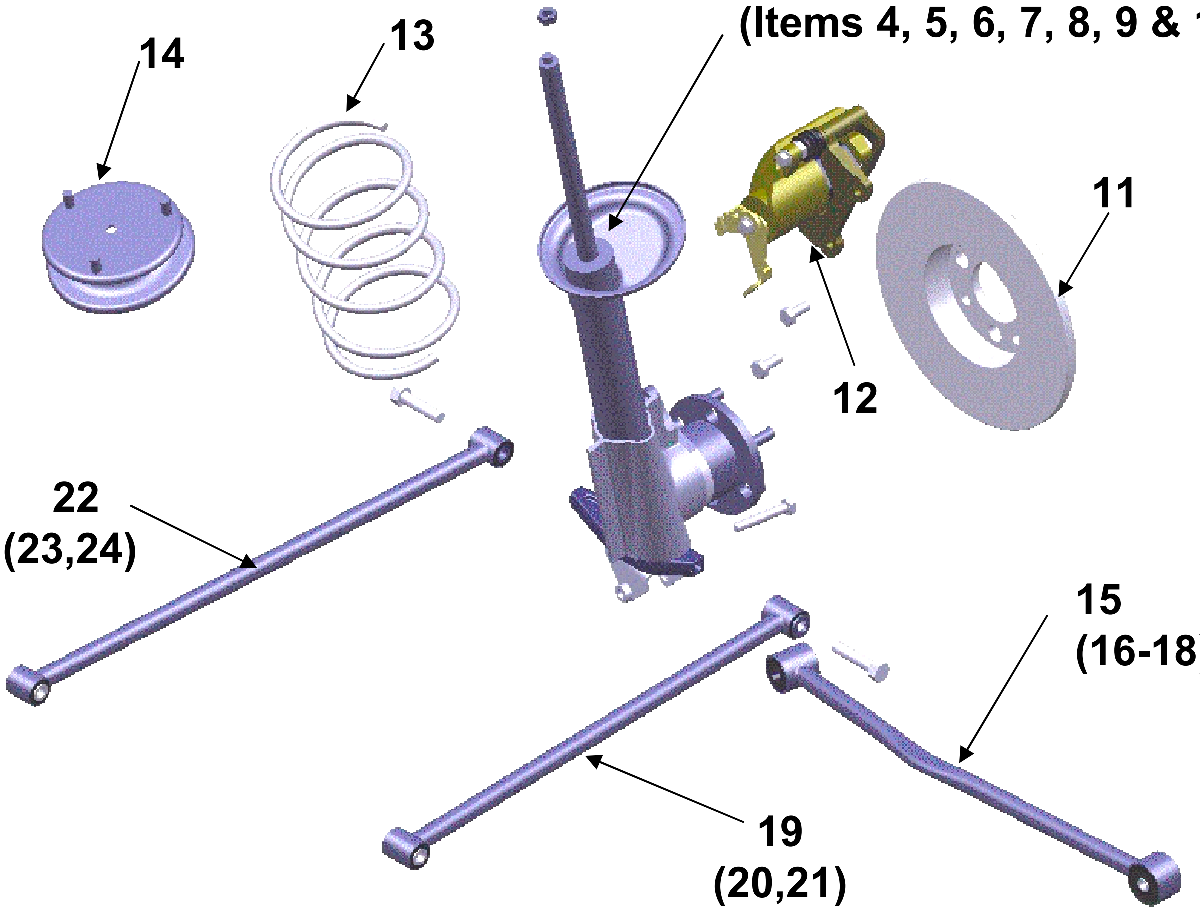
STRUT & LINKS: EXPLODED VIEW





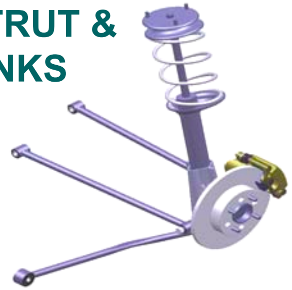
STRUT & LINKS: EXPLODED VIEW

STRUT & LINKS

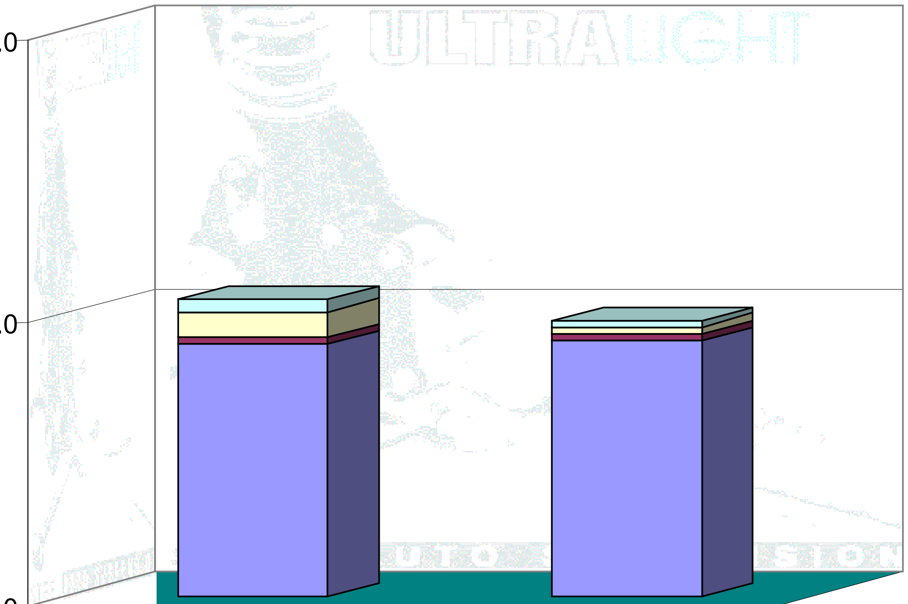


STRUT & LINKS: COST

STRUT & LINKS



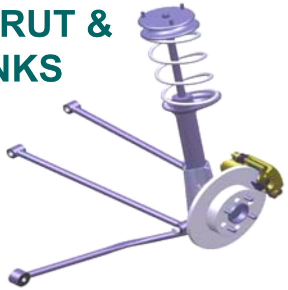
COST BREAKDOWN STRUT & LINKS



	BENCHMARK (E Class)	ULSAS P Class
VEHICLE FITTING COST	$2.1	$1.0
SYSTEM ASSEMBLY COST	$4.5	$1.3
TOOLING COST	$1.1	$1.1
PIECE COST	$144.5	$145.1
TOTAL COST	**$152.3**	**$148.6**

STRUT & LINKS: COST

STRUT & LINKS



(US$)	Strut & Links	
	Benchmark E Class	ULSAS P Class
COMPONENT COST	**$144.5**	**$145.1**
TOTAL TOOLING COST ($,000)	**$2,180**	**$2,283**
5 YEAR Volume (Assumptions)	2,000,000	2,000,000
TOOLING COST	$1.1	$1.1
TOTAL SYSTEM COST	$145.6	$146.2
SYSTEM ASSY		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Assembly Mins	6.17	1.92
SYSTEM ASSEMBLY COST	$4.52	$1.41
VEHICLE FITTING		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Fitting Mins	2.93	1.33
VEHICLE FITTING COST	$2.15	$0.98

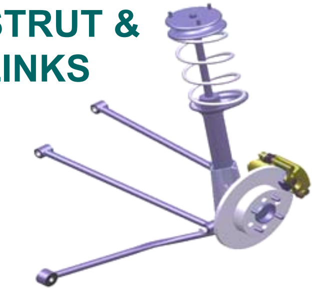
Total Cost ($)	**$152.3**	**$148.6**
Cost Saving($)	$3.7	
Cost Saving %		**2%**

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

STRUT & LINKS: COST

Bill of Materials

STRUT & LINKS



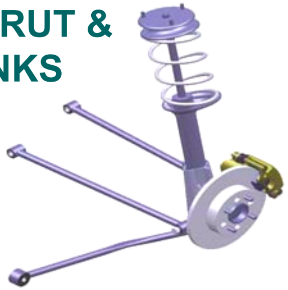
N.B. All Costs in US $ Tooling in US$(,000)

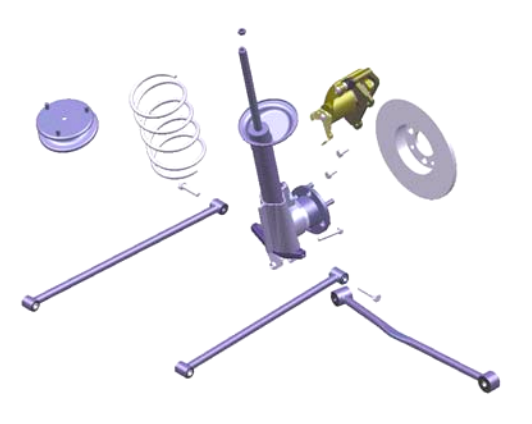
PARTS LIST			ULSAS P Class			E Class Benchmark Data		
ITEM No.	DESCRIPTION	QTY Veh	PART COST	SYSTEM COST	TOOLING COST	PART COST	SYSTEM COST	TOOLING COST
1	ASSEMBLY, STRUT & LINKS	1		145.08	2283.00		144.50	2180.00
2	WELDED ASSY, STRUT UNIT RH	1	$10.5	$10.5	$750	$22.5	$22.5	$207
3	WELDED ASSY, STRUT UNIT LH	1	$10.5	$10.5	$750	$22.5	$22.5	$207
4	KNUCKLE PRESSING	2						
5	KNUCKLE PRESSING	2						
6	KNUCKLE FORGING	2						
7	LOWER BRACKET	2						
8	HUB & BEARING UNIT RH	1	$19.0	$19.0		$8.0	$8.0	$75
9	HUB & BEARING UNIT LH	1	$19.0	$19.0		$8.0	$8.0	$75
10	DAMPER ASSEMBLY	2	$18.5	$37.0	$330	$24.1	$48.2	$528
11	DISC BRAKE	2						
12	CALIPER, BRAKE	2						
13	SPRING	2	$5.6	$11.2				
14	UPPER MOUNTING - STRUT	2	$2.8	$5.6	$200			
15	ASSY, LONGITUDINAL LINK	2	$4.7	$9.4	$148	$3.1	$6.2	$363
16	LONGITUDINAL LINK	2						
17	BUSH HOUSING	2						
18	BUSH HOUSING	2						
19	ASSY, FORWARD LATERAL LINK	2	$4.2	$8.4	$53	$4.0	$8.0	$363
20	FORWARD LATERAL LINK	2						
21	LATERAL LINK BUSH HOUSING	4						
22	ASSY, REAR LATERAL LINK	2	$4.2	$8.4	$53	$4.0	$8.0	$363
23	REAR LATERAL LINK	2						
24	LATERAL LINK BUSH HOUSING	4						
25	VARIOUS BUSHES AND JOINTS	1		$3.0			$6.7	
26	ASSORTED FIXINGS	1		$3.0			$6.4	

STRUT & LINKS: TIMING

Sub-Assembly

STRUT & LINKS



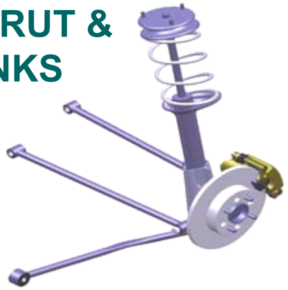


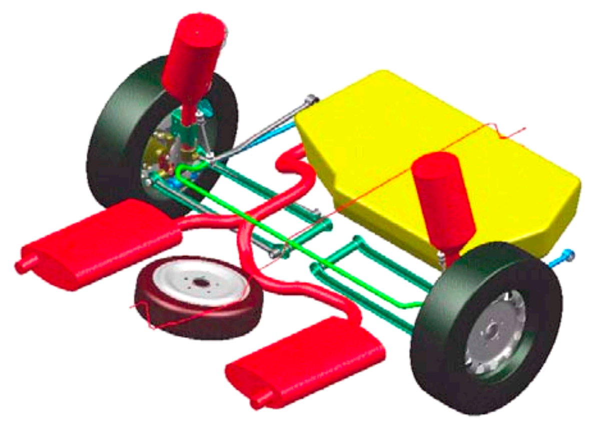
BREAKDOWN OF TIMING FOR SUB-ASSEMBLY OF STRUT & LINKS SUSPENSION SYSTEM

SUB-ASSEMBLY Operation	Number	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
FIT TRAIL ARM	2	FIT1H	0.19	0.13	0.32
FIX TRAIL ARM NUT	2	TFPTN	0.11	0.07	0.18
FIT DAMPER ASSY	2	FIX1H	0.05	0.05	0.10
FIT TRAIL ARM ASSY	2	FIX1H	0.05	0.05	0.10
FIT RWD LATERAL LINK	2	FIX1H	0.05	0.05	0.10
FIT LATERAL LINK BOLT	2	FITFN	0.07	0.04	0.11
FIX LATERAL LINK NUT	2	TFPTN	0.11	0.07	0.18
FIT BRAKE DISK	2	FIT1H	0.19	0.13	0.32
FIT BRAKE CALIPER	2	FIT1H	0.19	0.13	0.32
FIX BRAKE CALIPER BOLTS	4	TFPTN	0.07	0.12	0.19
				TOTAL	1.92

STRUT & LINKS: TIMING
Final Vehicle Assembly

STRUT & LINKS

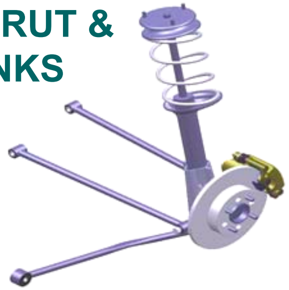




BREAKDOWN OF TIMING FOR FINAL ASSEMBLY OF STRUT & LINKS SUSPENSION TO THE VEHICLE

FINAL ASSEMBLY Operation	Number	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
FIT FWD LATERAL LINK BOLT	2	FITFN	0.07	0.04	0.11
FIT RWD LATERAL LINK BOLT	2	FITFN	0.07	0.04	0.11
FIX FWD LATERAL LINK NUT	2	TFPTN	0.11	0.07	0.18
FIX RWD LATERAL LINK NUT	2	TFPTN	0.11	0.07	0.18
FIT TRAILINIG ARM BOLT	2	FITFN	0.07	0.04	0.11
FIX TRAILING ARM NUT	2	TFPTN	0.11	0.07	0.18
FIX DAMPER NUT	6	TFPTN	0.11	0.35	0.46
				TOTAL	1.33

STRUT & LINKS



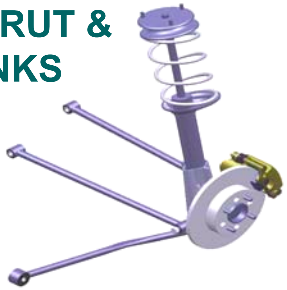
STRUT & LINKS: COST

Benchmarking 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.

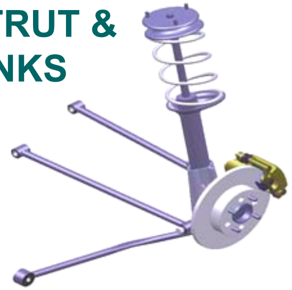
STRUT & LINKS



STRUT & LINKS: COST

Benchmarking 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.



STRUT & LINKS: COST

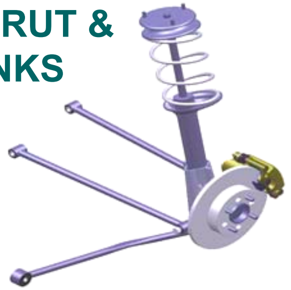
Benchmarking Assumptions

- 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**

STRUT & LINKS



STRUT & LINKS: COST

Design Phase

Identical assumptions and similar rationale to the Benchmarking Phase 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.
- Optimising tool utilisation of 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