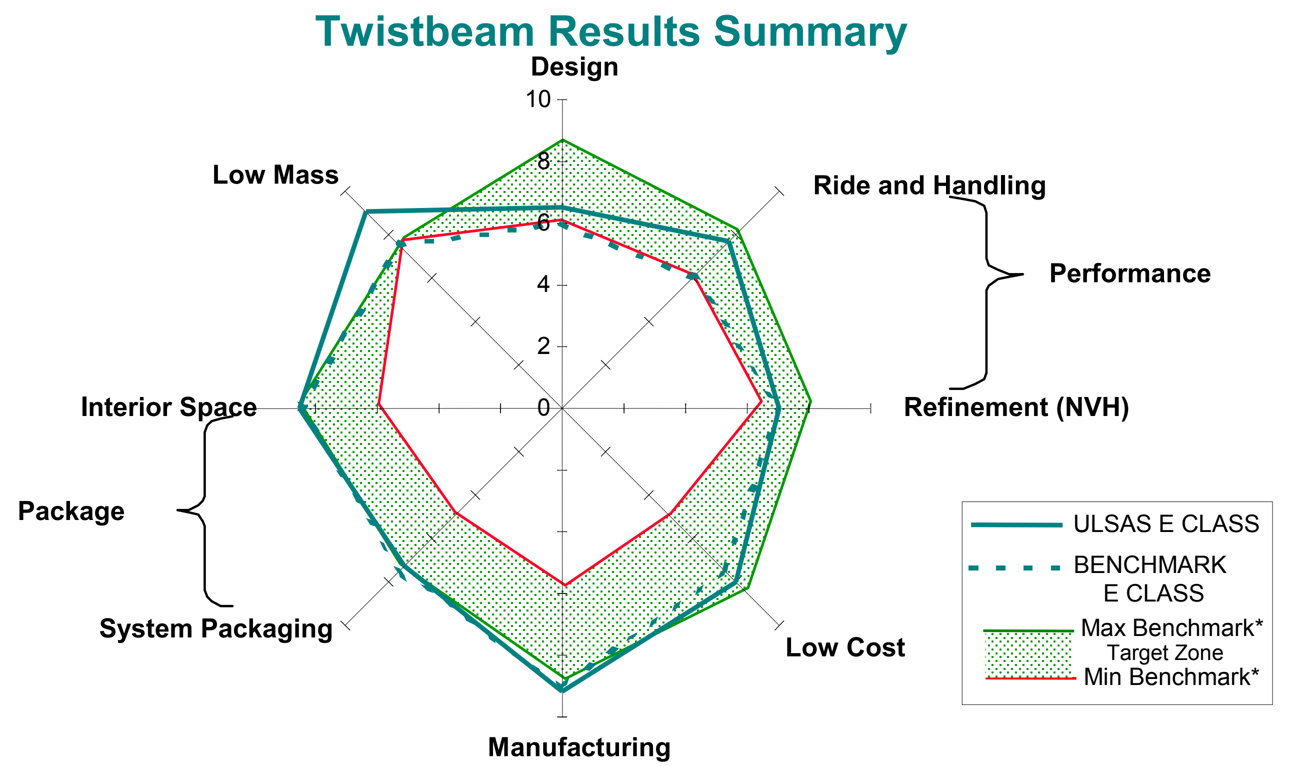
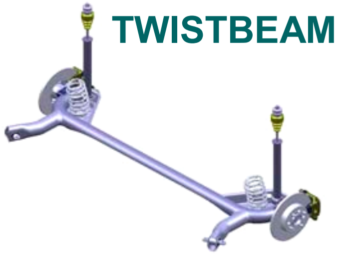
TWISTBEAM: RESULTS SUMMARY

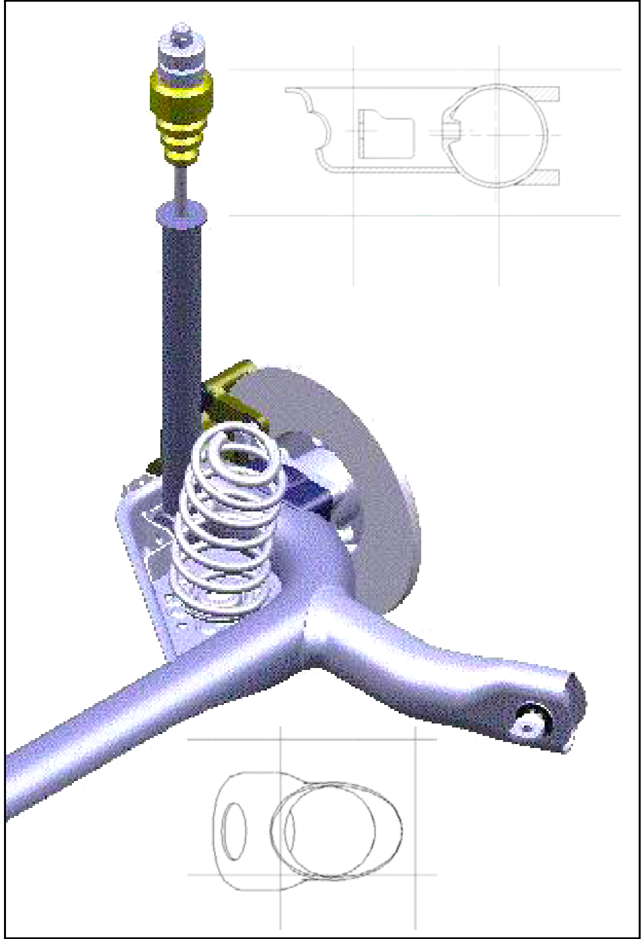


- SIGNIFICANT MASS SAVINGS - NO COST PENALTY
- DESIGN AND PERFORMANCE EXCEED BENCHMARK
- MANUFACTURING AND PACKAGE MATCH BENCHMARK

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

TWISTBEAM: DESIGN



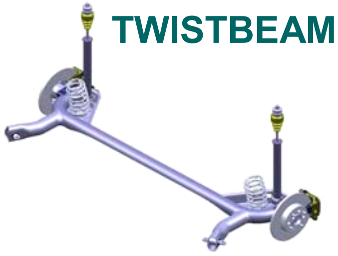


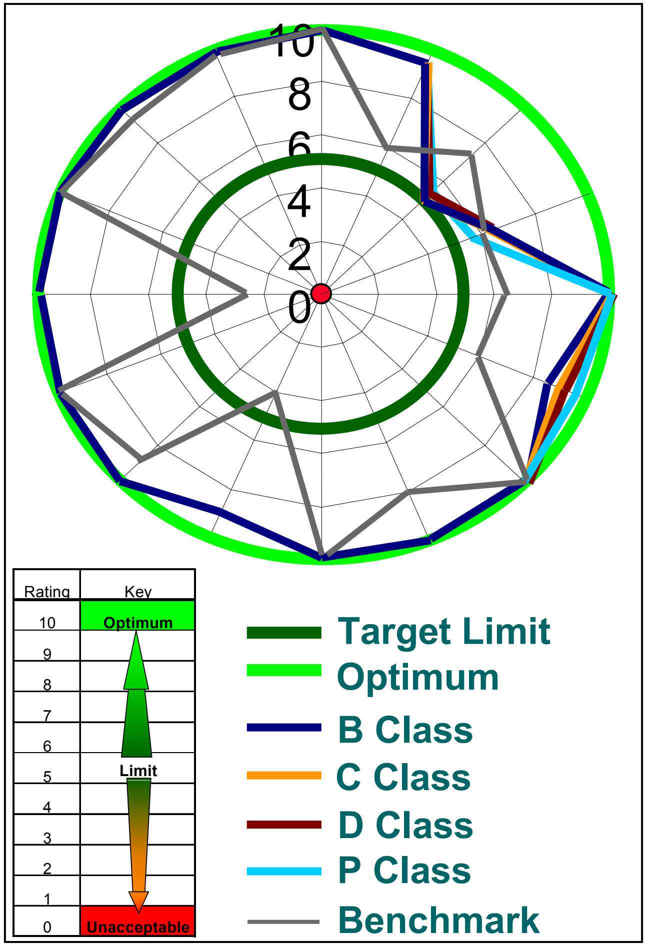
- The Twistbeam was evaluated against the same design criteria as the Benchmarking Phase, including:
  - Potential Technical Development
  - Potential for System/Component Integration
  - System Image / Marketability
  - Structural Efficiency & Elegance
- The ULSAS solution matches or exceeds the standards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

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS E CLASS	BENCHMARK E CLASS
Design	6.5	6

TWISTBEAM: PERFORMANCE

TWISTBEAM



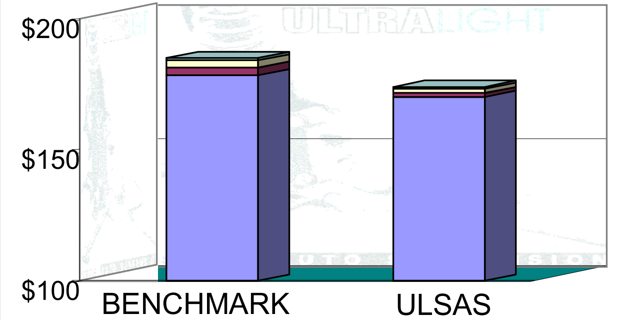


- The Twistbeam solution demonstrates very good levels of performance.
- The performance of the Twistbeam generally meet the optimum target levels set. All of the characteristics fall within the target acceptance limits.
- Overall score is higher than the Benchmark score for Ride & Handling and matches that for NVH.

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS E CLASS	BENCHMARK E CLASS
Ride and Handling	7.6	6.0
Refinement (NVH)	7.0	7.0

TWISTBEAM: COST

TWISTBEAM



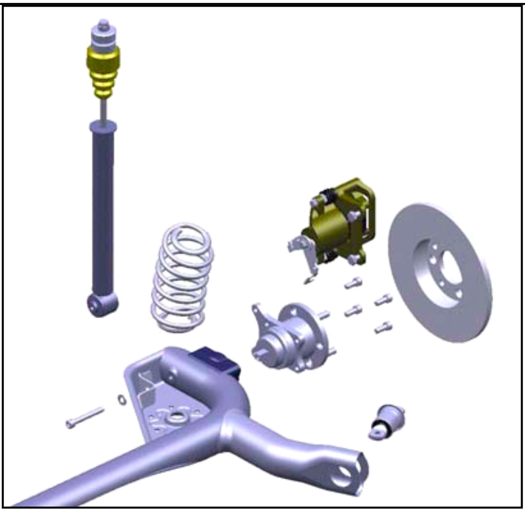
(US$)	Twistbeam	
	Benchmark E Class	ULSAS E CLASS
PIECE COST	$178.3	$169.9
TOTAL TOOLING COST ($,000)	$5,611	$2,965
5 YEAR Volume (Assumptions)	2,000,000	2,000,000
TOOLING COST	$2.8	$1.5
TOTAL SYSTEM COST	$181.1	$171.4
SYSTEM ASSY		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Assembly Mins	3.86	2.42
SYSTEM ASSEMBLY COST	$2.83	$1.77
VEHICLE FITTING		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Fitting Mins	1.21	0.93
VEHICLE FITTING COST	$0.89	$0.68
Total Cost ($)	$184.8	$173.9
Cost Saving($)		$11.0
Cost Saving %		6%

- The cost of the ULSAS solution compares favourably to the Benchmarked suspensions.
- For both the ULSAS solution and the Benchmark system, the dominant factor is the piece cost of the components and sub-assemblies.
- Overall a 6% cost saving was identified.
- Overall score in this area is proportionately higher than the Benchmark value.
- Reduction in assembly time is due mainly to greater levels of parts integration in the ULSAS design.

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS E CLASS	BENCHMARK E CLASS
Cost	7.9	7.5

TWISTBEAM: MANUFACTURING

TWISTBEAM



Assembly of ULSAS Solutions Vs Benchmark

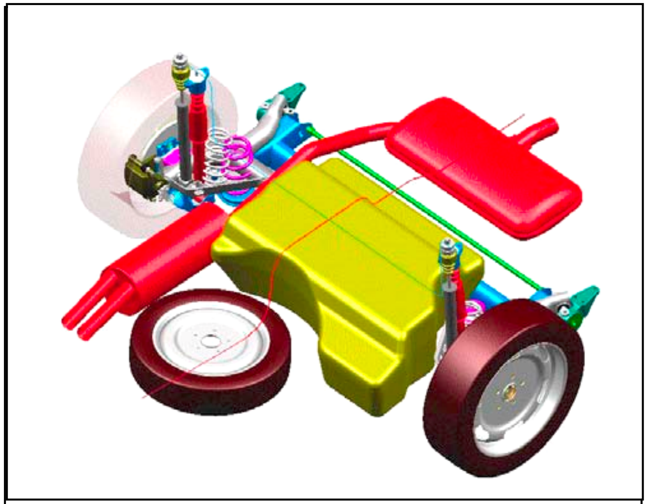
(US$)	Twistbeam	
	Benchmark E Class	ULSAS E Class
SYSTEM ASSY		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Assembly Mins	3.86	2.42
SYSTEM ASSEMBLY COST	$2.83	$1.77
VEHICLE FITTING		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Fitting Mins	1.21	0.93
VEHICLE FITTING COST	$0.89	$0.68
Total Cost ($)	**$3.7**	**$2.5**
Cost Saving($)		$1.3
Cost Saving %		**34%**

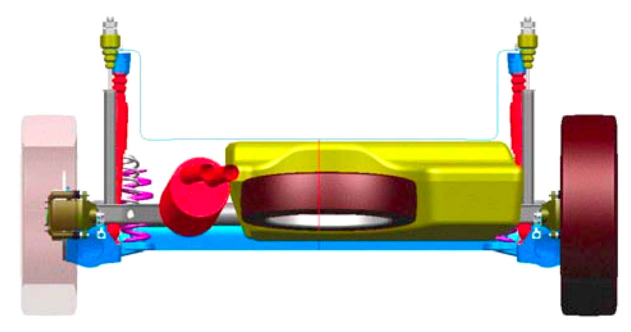
- The ULSAS solution compares favourably well with the Benchmarked system in terms of assembly and fitting times.
- Fewer parts and sub-assemblies have reduced assembly times and costs.
- An appropriate level of manufacturing feasibility has been taken into account.
- The simplified nature of the Twistbeam system is beneficial for manufacturing.
- Overall score in this area surpasses the Benchmark.

SUMMARY OF OVERALL SCORES & RATINGS

	ULSAS E CLASS	BENCHMARK E CLASS
Manufacturing	9.1	9

TWISTBEAM: PACKAGING



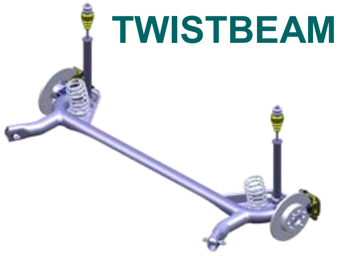


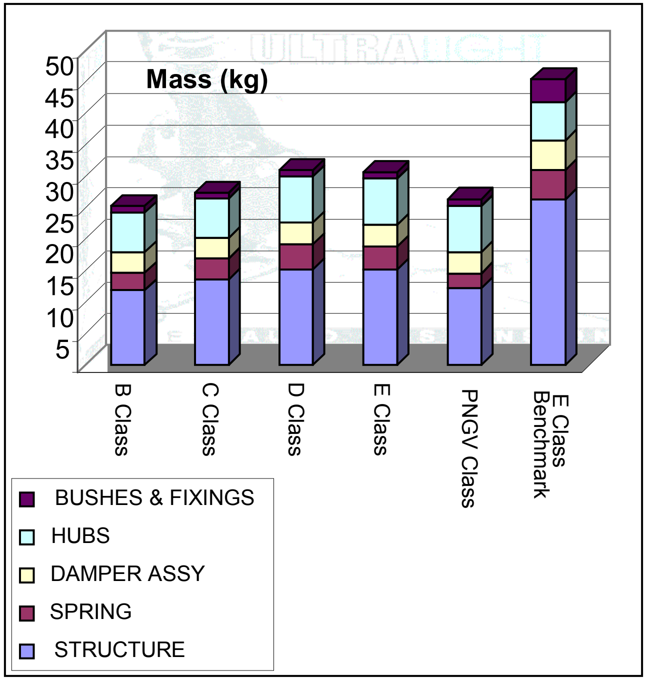
- The ULSAS solution suits a more commonly encountered underfloor layout than that of the benchmark vehicle.
- The interior space package of the ULSAS solution is comparable with that of the benchmarked vehicle.
- Overall score for systems packaging is slightly lower than benchmark.
- The score for interior space matches the benchmark.

SUMMARY OF OVERALL SCORES & RATINGS		
	ULSAS E CLASS	BENCHMARK E CLASS
System Packaging	7.2	7.5
Interior Space	8.5	8.5

TWISTBEAM: MASS

TWISTBEAM





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

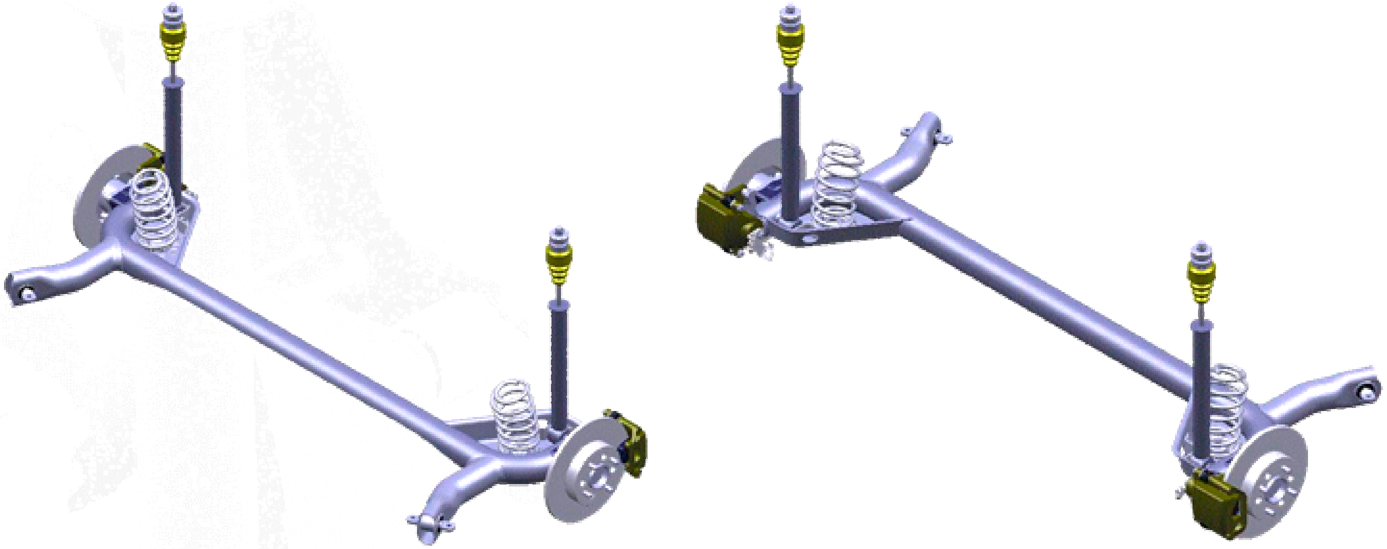
Mass Of ULSAS Solutions Vs Benchmark Vehicles

Description	B	C	D	E	P
Benchmark (Kg)		33.40		45.35	
ULSAS Solution (Kg)	25.12	27.30	30.97	30.63	26.31
Saving vs Benchmark		18%		32%	

SUMMARY OF OVERALL SCORES & RATINGS

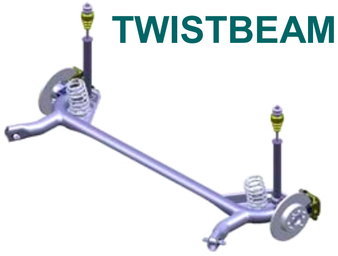
	ULSAS E CLASS	BENCHMARK E CLASS
Mass	9.0	7.5

TWISTBEAM: SYSTEM PHILOSOPHY



TWISTBEAM: SYSTEM PHILOSOPHY

TWISTBEAM



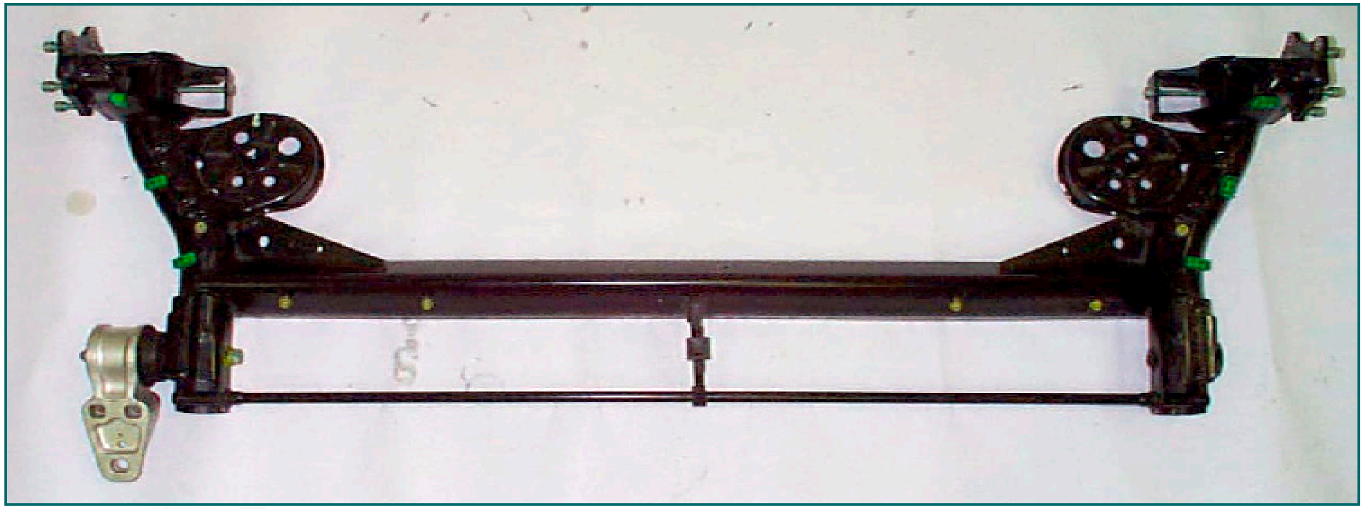
The TwistBeam suspension concept is a semi-independent type. The use of the concept in a volume production vehicle was pioneered by Volkswagen and has subsequently become increasingly popular on small front wheel drive cars.

The system comprises an assembly of two trailing arms that are interconnected by a transverse beam. The connections between the beam and the trailing arms are rigid. The longitudinal position of the beam is a design variable. However, generally the system takes the form of a 'H' shaped frame. There are no other links within the system. The forward mounting of the frame is pivoted with respect to the vehicle body using a compliant mounting and bracket arrangement. Coil springs are regarded as the most appropriate springing media for use with this suspension concept. The system is not regarded as being suitable for rear wheel drive vehicles.

Three basic configurations of the system can be considered. With the transverse beam attached to the trailing arms in line with the pivot axis the system behaviour is very much like a pure trailing arm system. The next arrangement has the transverse beam attached part way between the bushings and the wheel centre. This configuration is the most common encountered. The third configuration has the transverse beam mounted in line with the wheel centres. This design requires additional linkage arrangements to control the system lateral forces and deflections, e.g. Panhard rod.

The twist beam system combines some of the performance features of a pure trailing arm system with those of a semi trailing arm system. During two wheel bump events the system pivots about an axis through the body mountings like a hinge with a behaviour similar to that of a pure trailing arm system. To accommodate the requirements of single wheel inputs and vehicle roll, the system undergoes large elastic deformation within the structural parts of the assembly . The performance of the system during these events is analogous to a semi trailing arm system.

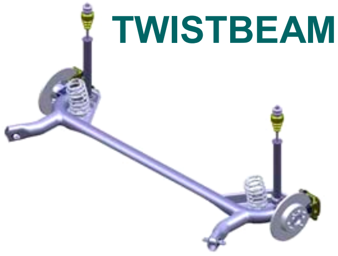
TWISTBEAM: SYSTEM PHILOSOPHY



Typical example of a TwistBeam Rear Suspension System

TWISTBEAM: SYSTEM PHILOSOPHY

TWISTBEAM



The longitudinal location of the transverse beam and the position of the flexural centre of the beam have an influence on the system characteristics. The instantaneous roll centre height is a function of the location of the beam flexural centre. The flexural centre lies on a plane section through the beam that experiences zero twist. It is the point on that section through which a transverse load can be applied without causing the section to twist. Rearwards movement of the beam raises the height of the roll centre. With the beam flexural centre above the bushings roll understeer is obtained. With the flexural centre below the bushings roll oversteer is obtained. The packaging requirements of vehicles often lead to installations where the flexural centre of the beam is below the bushings. This limits the potential to use the system structure to induce roll understeer characteristics.

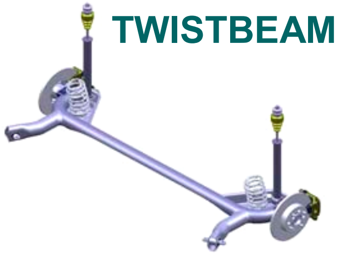
The performance characteristics of a twist beam system can be summarised as follows:

For parallel two wheel inputs:

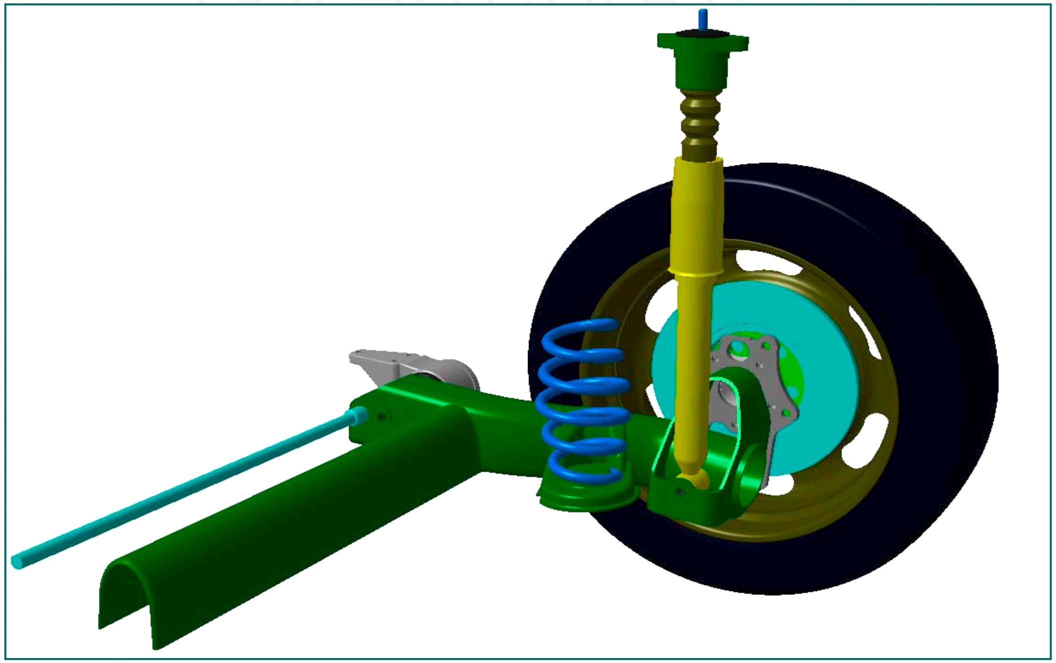
There is no camber change with wheel travel
There is no toe change with wheel travel. (Toe change may occur on some systems where a lateral link is used. In such cases the level of toe change is a function of the mounting locations of the link.)

For single wheel inputs and vehicle roll:

The roll centre height changes with system articulation. The roll centre height can be tuned by changing the longitudinal position of the transverse beam. Applying a lateral force at the tyre contact patch produces pivot deflections and trailing arm bending that induce toe out, e.g. an over steer characteristic. The positioning and design of the mounting bushes can be used to modify this characteristic. A very small camber change also takes place due to torsion and bending in the twistbeam structure.



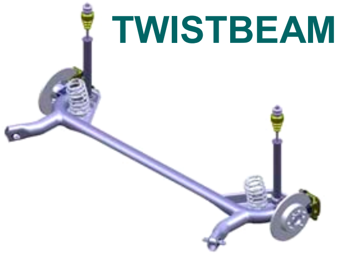
TWISTBEAM: SYSTEM PHILOSOPHY

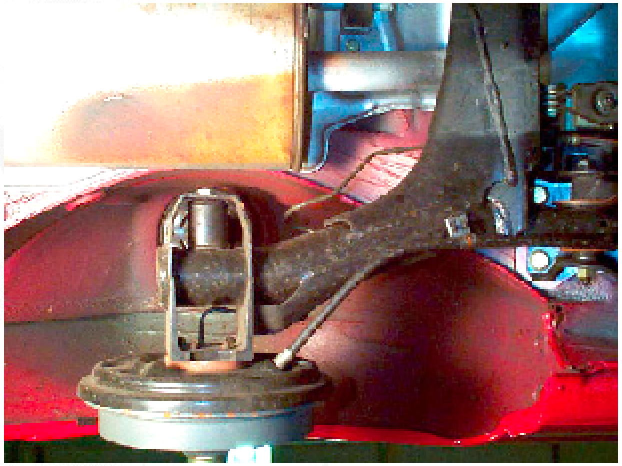


The twist beam concept has a minimal number of paths to transmit the wheel input loads through to the vehicle structure. Typically the pivot mounting bushes react all of the longitudinal and lateral loads and share the vertical loading with the suspension spring medium. The trailing arms connect the wheel hubs to the pivot mounting bushes and are linked together by the crossbeam. The loading experienced by the trailing arms and crossbeam is complex and is described later.

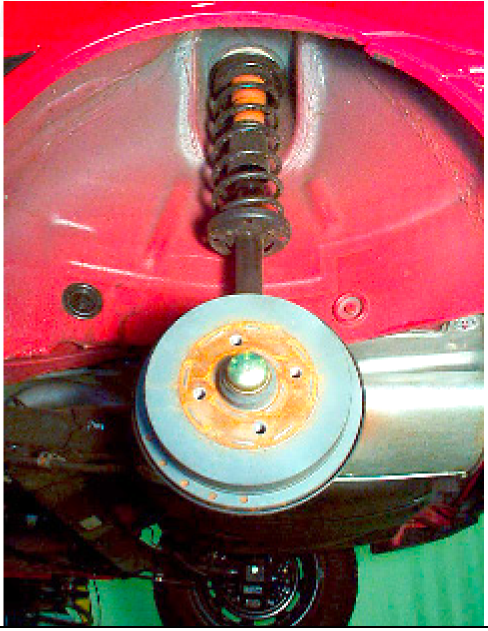
The location of the suspension spring with respect to the pivot axis has a significant effect on the design of the trailing arm. One target for the system designer is to obtain spring and damper displacements that are comparable with those of the wheel. Typically the spring ratios and damper ratios should be close to one. Such an arrangement avoids load magnification and allows the more refined control of the wheel motion when compared to a system with lower ratios. Spring and damper ratios close to one can be achieved by attaching the springs and dampers to the free ends of the trailing arm, close to the axle centre line. The vertical bending loading experienced by the trailing arm is minimised with this type of installation. However, the packaging of such an arrangement requires careful consideration and must be assessed with respect to the resulting different design requirements for the trailing arm.

TWISTBEAM: SYSTEM PHILOSOPHY





VW GOLF TWISTBEAM



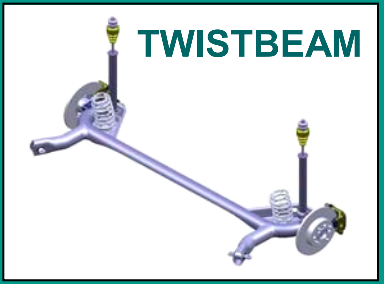
There are generally two approaches to the design of an installation that permits the attachment of the springs and dampers to the ends of the trailing arms. The first to be considered requires that the spring media upper mountings be located high in the vehicle. The VW Golf provides an example of this arrangement. This allows the longitudinal torsional loading on the arm to be minimised but requires a robust body structure. The second approach provides a low position for the upper spring media mounting, but generally requires the spring media components to be mounted a distance inboard of the wheel. This is to avoid foul conditions between the tyre and the coil spring. Such an arrangement is undesirable as it increases the longitudinal torsion loading applied to the trailing arm and also results in considerable intrusion into the boot area.

The separation of the spring and damper components provides a compromise solution. This arrangement can reduce the requirements for structural mounting points high in the body and can also allow the spring to be mounted to a more robust part of the trailing arm. The arrangement requires that the designer compromises on the targets for the spring and the damper ratios. The maintenance of damper ratio has the higher priority. The Vauxhall Astra and Audi A6 utilise this type of arrangement.

The transverse beam is a key element of a twist beam system. It is subjected to a complex regime of loading.

TWISTBEAM: SYSTEM PHILOSOPHY

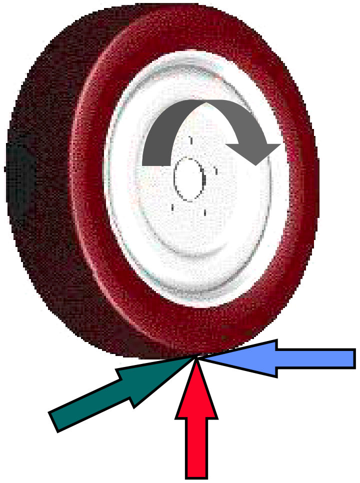
Basic Forces Acting on the Suspension



TWISTBEAM

- 3 primary forces at tyre contact patch
  - **Longitudinal**
  - **Lateral**
  - **Vertical**

- Additional Torque Loading
  - **From Braking (Combined with a Longitudinal Force)**



To better understand the complex loadings in the twistbeam 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 also torques generated about the other two axes due to offset loadings, 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

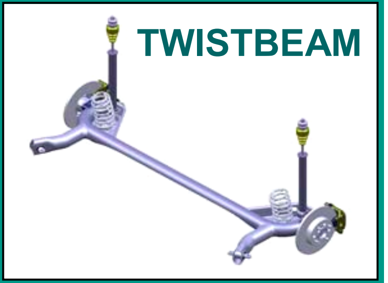
- Longitudinal
- Lateral
- Ride
- Steer
- Camber
- Rolling

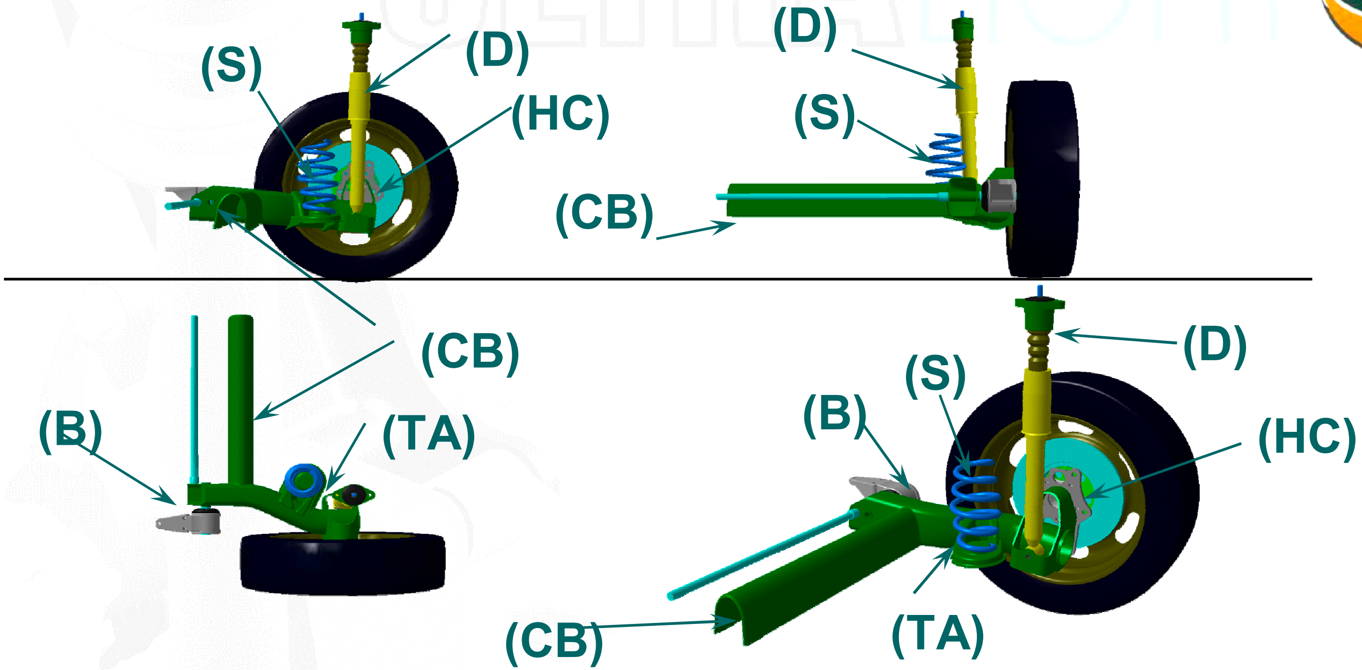
Forces

- Longitudinal
- Lateral
- Vertical

- Braking/ Acceleration

TWISTBEAM: SYSTEM PHILOSOPHY





TWISTBEAM: SYSTEM PHILOSOPHY

TWISTBEAM

MOVEMENTS

Longitudinal:- Deflection of bushes (B) allows fore and aft movement of the wheel.

Lateral:- No significant change in track is possible as track is controlled by the fixed width of the twist beam assembly and could only be achieved by bending of trailing arm (TA).

Ride:- Rotation about bushes (B) and twisting of the cross beam (CB).

Steer:- Steer can only be achieved by the whole frame moving by deflection of bushes (B) and by bending in trailing arm (TA).

Camber:- No significant change in camber is possible as it is fixed by the design of the twist beam assembly and could only be achieved by twisting of the trailing arm (TA) and bending of the cross beam (CB).

Rolling:- The wheel is able to rotate on bearings in the hub carrier (HC).

FORCES

Longitudinal:- Forces are resisted by tension and compression loads in trailing arm (TA) and . bending in the cross beam (CB).

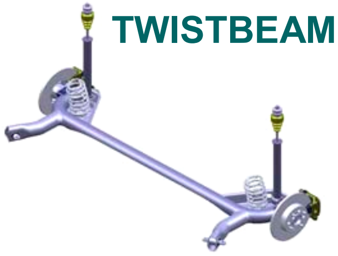
Lateral:- Forces are resisted by bending and torsion in the trailing arm (TA) and . bending in the cross beam (CB).

Vertical:- Forces are resisted by loads in the spring (S) and damper (D) and by bending . and torsion in the trailing arm (TA) and also by torsion in the cross beam (CB) . during roll.

Braking:- Torque is taken by bending in trailing arm (TA).

TWISTBEAM: MASS

B Class

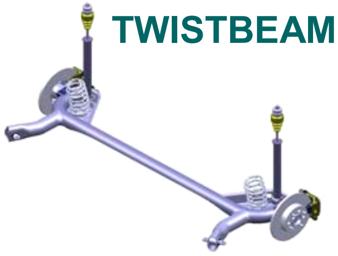


PARTS LIST			B Class			C Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	25.12			33.40		
2	WELDED ASSY, TWIST BEAM	1	11.86	11.860	11.860	20.37	20.370	20.37
3	TRAILING ARM	2			0.788			
4	TRANSVERSE BEAM	1			6.720			
5	HUB MOUNTING PLATE	2			0.510			
6	SPRING PLATFORM RH	1			1.160			
7	SPRING PLATFORM LH	1			1.160			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	2.67	1.336			2.820	1.410
10	SPRING ISOLATOR	4	0.30	0.074	0.074			
11	DAMPER UNIT	2	2.76	1.380	1.380		4.924	2.462
12	BUMP STOP	2	0.30	0.150	0.150		0.296	0.148
13	BOLT - DAMPER	2	0.10	0.049	0.049		0.118	0.059
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	3.10	3.100			1.024	1.024
16	HUB & BEARING UNIT, LH	1	3.10	3.100			1.024	1.024
17	BOLT - HUB	8	0.27	0.034	0.034		0.212	0.106
18	BOLT - CALIPER	4	0.12	0.030	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	0.54	0.272			2.610	1.305

TWISTBEAM: MASS

C Class

TWISTBEAM

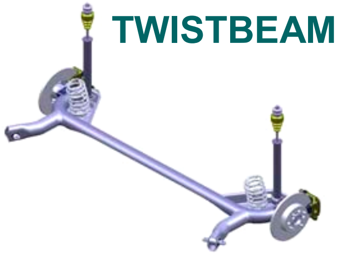


PARTS LIST			C Class			C Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	**27.30**			**33.40**		
2	WELDED ASSY, TWIST BEAM	1	**13.48**	13.475	13.475	**20.37**	**20.370**	20.37
3	TRAILING ARM	2			0.788			
4	TRANSVERSE BEAM	1			8.055			
5	HUB MOUNTING PLATE	2			0.510			
6	SPRING PLATFORM RH	1			1.300			
7	SPRING PLATFORM LH	1			1.300			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	**3.29**	**1.646**			**2.820**	1.410
10	SPRING ISOLATOR	4	**0.30**	**0.074**	0.074			
11	DAMPER UNIT	2	**2.76**	**1.380**	1.380		**4.924**	2.462
12	BUMP STOP	2	**0.30**	**0.150**	0.150		**0.296**	0.148
13	BOLT - DAMPER	2	**0.10**	**0.049**	0.049		**0.118**	0.059
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	**3.10**	**3.100**			**1.024**	1.024
16	HUB & BEARING UNIT, LH	1	**3.10**	**3.100**			**1.024**	1.024
17	BOLT - HUB	8	**0.22**	**0.027**	0.027		**0.212**	0.106
18	BOLT - CALIPER	4	**0.12**	**0.030**	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	**0.54**	**0.272**			**2.610**	1.305

TWISTBEAM: MASS

D Class

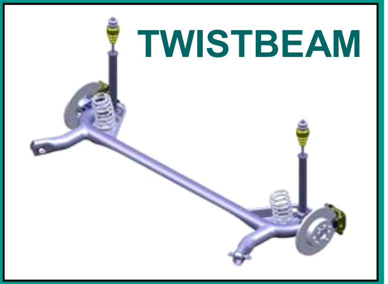
TWISTBEAM



PARTS LIST			D Class			E Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	**30.97**			**45.35**		
2	WELDED ASSY, TWIST BEAM	1	**15.09**	15.086	15.086	**26.20**	**26.200**	26.2
3	TRAILING ARM	2			0.942			
4	TRANSVERSE BEAM	1			9.174			
5	HUB MOUNTING PLATE	2			0.532			
6	SPRING PLATFORM RH	1			1.370			
7	SPRING PLATFORM LH	1			1.370			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	**4.06**	**2.030**	2.030		**4.740**	2.370
10	SPRING ISOLATOR	4	**0.36**	**0.090**	0.090		**0.358**	0.179
11	DAMPER UNIT	2	**2.76**	**1.380**	1.380		**3.994**	1.997
12	BUMP STOP	2	**0.30**	**0.150**	0.150		**0.300**	0.150
13	BOLT - DAMPER	2	**0.10**	**0.049**	0.049		**0.126**	0.063
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	**3.63**	**3.630**			**3.040**	3.040
16	HUB & BEARING UNIT, LH	1	**3.63**	**3.630**			**3.040**	3.040
17	BOLT - HUB	8	**0.22**	**0.028**	0.028		**0.240**	
18	BOLT - CALIPER	4	**0.12**	**0.030**	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	**0.71**	**0.353**			**3.310**	1.655

TWISTBEAM: MASS

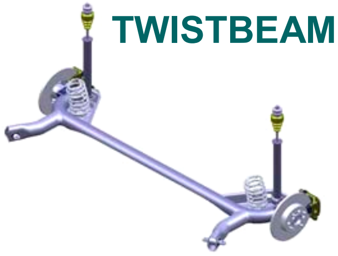
E Class



PARTS LIST			E Class			E Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	**30.63**			**45.35**		
2	WELDED ASSY, TWIST BEAM	1	**15.02**	15.022	15.022	**26.20**	**26.200**	26.2
3	TRAILING ARM	2			0.942			
4	TRANSVERSE BEAM	1			9.350			
5	HUB MOUNTING PLATE	2			0.532			
6	SPRING PLATFORM RH	1			1.250			
7	SPRING PLATFORM LH	1			1.250			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	**3.78**	**1.889**	1.202		**4.740**	2.370
10	SPRING ISOLATOR	4	**0.36**	**0.090**	0.090		**0.358**	0.179
11	DAMPER UNIT	2	**2.76**	**1.380**	1.380		**3.994**	1.997
12	BUMP STOP	2	**0.30**	**0.150**	0.150		**0.300**	0.150
13	BOLT - DAMPER	2	**0.10**	**0.049**	0.049		**0.126**	0.063
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	**3.63**	**3.630**			**3.040**	3.040
16	HUB & BEARING UNIT, LH	1	**3.63**	**3.630**			**3.040**	3.040
17	BOLT - HUB	8	**0.22**	**0.028**	0.028		**0.240**	
18	BOLT - CALIPER	4	**0.12**	**0.030**	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	**0.71**	**0.353**			**3.310**	1.655

TWISTBEAM: MASS

P Class


TWISTBEAM

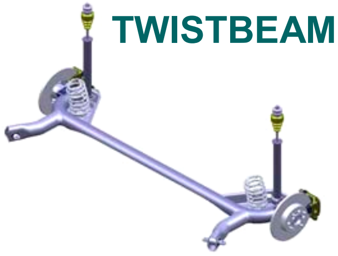
PARTS LIST			P Class			E Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	**26.31**			**45.35**		
2	WELDED ASSY, TWIST BEAM	1	**12.07**	12.074	12.074	**26.20**	**26.200**	26.2
3	TRAILING ARM	2			0.942			
4	TRANSVERSE BEAM	1			6.720			
5	HUB MOUNTING PLATE	2			0.532			
6	SPRING PLATFORM RH	1			1.091			
7	SPRING PLATFORM LH	1			1.091			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	**2.40**	**1.202**	1.202		**4.740**	2.370
10	SPRING ISOLATOR	4	**0.36**	**0.090**	0.090		**0.358**	0.179
11	DAMPER UNIT	2	**2.76**	**1.380**	1.380		**3.994**	1.997
12	BUMP STOP	2	**0.30**	**0.150**	0.150		**0.300**	0.150
13	BOLT - DAMPER	2	**0.10**	**0.049**	0.049		**0.126**	0.063
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	**3.63**	**3.630**			**3.040**	3.040
16	HUB & BEARING UNIT, LH	1	**3.63**	**3.630**			**3.040**	3.040
17	BOLT - HUB	8	**0.22**	**0.028**	0.028		**0.240**	
18	BOLT - CALIPER	4	**0.12**	**0.030**	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	**0.71**	**0.353**			**3.310**	1.655

TWISTBEAM: COST

E Class

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

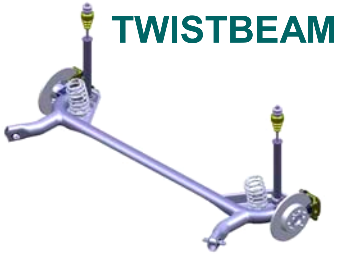
TWISTBEAM



PARTS LIST			E Class			Benchmark E Class Data		
ITEM No.	DESCRIPTION	QTY Veh	PART COST	SYSTEM COST	TOOLING COST	PART COST	SYSTEM COST	TOOLING COST
1	ASSEMBLY, TWIST BEAM	1		**169.94**	**2965**		**178.34**	**5611**
2	WELDED ASSY, TWIST BEAM	1	$25.0	$25.0	$850	$69.3	$69.3	$4,950
3	TRAILING ARM	2	$3.2	$6.4	$600			
4	TRANSVERSE BEAM	1	$10.0	$10.0	$450			
5	HUB MOUNTING PLATE	2	$8.5	$17.0	$300			
6	SPRING PLATFORM RH	1	$3.4	$3.4	$350			
7	SPRING PLATFORM LH	1	$3.4	$3.4				
8	DAMPER BRACKET	2	$0.5	$1.0	$85			
9	SPRING	2	$5.5	$11.0		$4.1	$8.2	$0
10	SPRING ISOLATOR	4	$0.8	$3.2				
11	DAMPER UNIT	2	$16.5	$33.0	$330	$16.5	$33.0	$330
12	BUMP STOP	2						
13	BOLT - DAMPER	2		$1.0				
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	$19.0	$38.0	$0	$19.0	$38.0	$0
16	HUB & BEARING UNIT, LH	1						
17	BOLT - HUB	8		$2.0				
18	BOLT - CALIPER	4		$2.5				
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	$6.5	$13.0	$0	$14.9	$29.8	$331

TWISTBEAM: MATERIAL

B Class



TWISTBEAM

PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	**REMARKS**	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	3.1	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	3.4	500
7	SPRING PLATFORM LH	1	PRESSING	3.4	500
8	DAMPER BRACKET	2	BLANK & FOLD	3.2	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 10.04	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

Note : Damper Assembly Consists of 2 Main Components

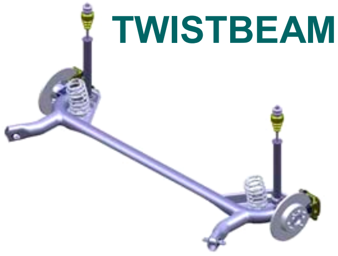
Damper Body: 350 MPa Material

Damper Rod: Dia 13mm x 3 mm Tube

TWISTBEAM: MATERIAL

C Class

TWISTBEAM



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	3.6	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	3.8	500
7	SPRING PLATFORM LH	1	PRESSING	3.8	500
8	DAMPER BRACKET	2	BLANK & FOLD	3.2	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 10.81	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

Note : Damper Assembly Consists of 2 Main Components

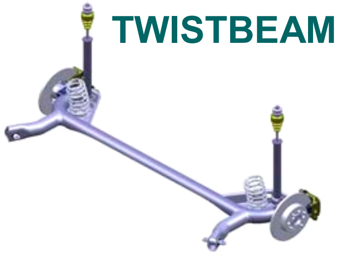
Damper Body: 350 MPa Material

Damper Rod: Dia 13mm x 3 mm Tube

TWISTBEAM: MATERIAL

D Class

TWISTBEAM



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	4	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	4	500
7	SPRING PLATFORM LH	1	PRESSING	4	500
8	DAMPER BRACKET	2	BLANK & FOLD	3.2	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 11.34	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

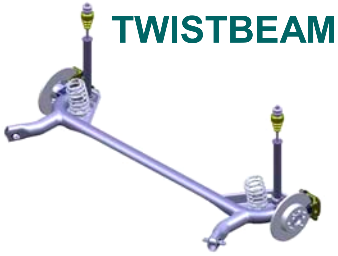
Note : Damper Assembly Consists of 2 Main Components

Damper Body:	350 MPa Material
Damper Rod:	Dia 13mm x 3 mm Tube

TWISTBEAM: MATERIAL

E Class

TWISTBEAM



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	4.1	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	3.7	500
7	SPRING PLATFORM LH	1	PRESSING	3.7	500
8	DAMPER BRACKET	2	BLANK & FOLD	3.2	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 11	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

Note : Damper Assembly Consists of 2 Main Components

Damper Body:	350 MPa Material
Damper Rod:	Dia 13mm x 3 mm Tube

TWISTBEAM: MATERIAL

P Class

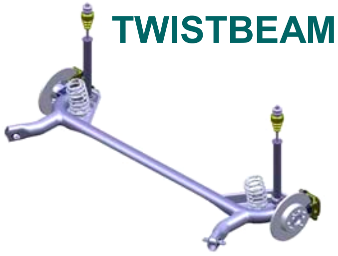
TWISTBEAM

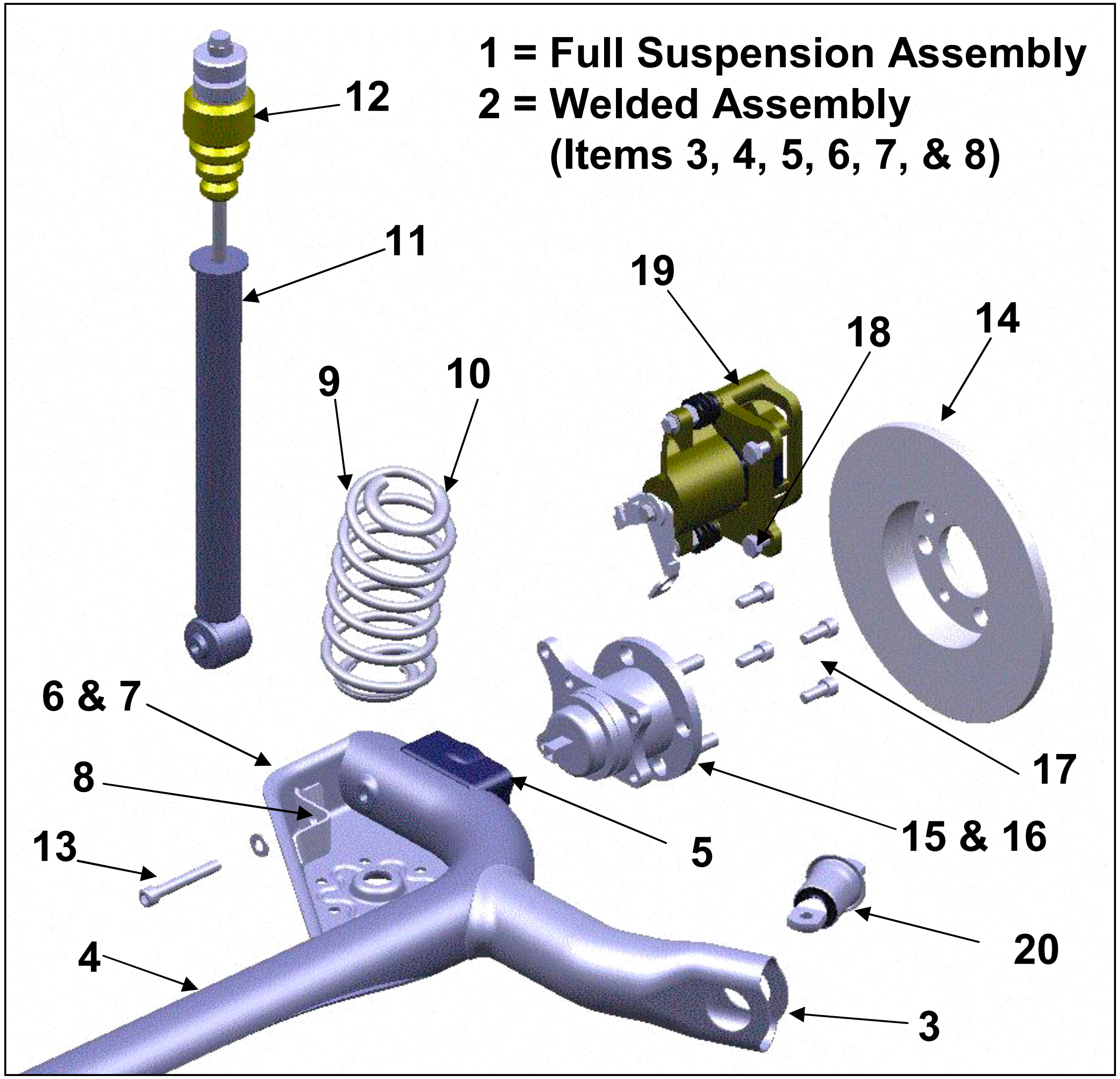
PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	2.8	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	3.2	500
7	SPRING PLATFORM LH	1	PRESSING	3.2	500
8	DAMPER BRACKET	2	BLANK & FOLD	3	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 9.52	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

Note : Damper Assembly Consists of 2 Main Components

Damper Body:	350 MPa Material
Damper Rod:	Dia 13mm x 3 mm Tube

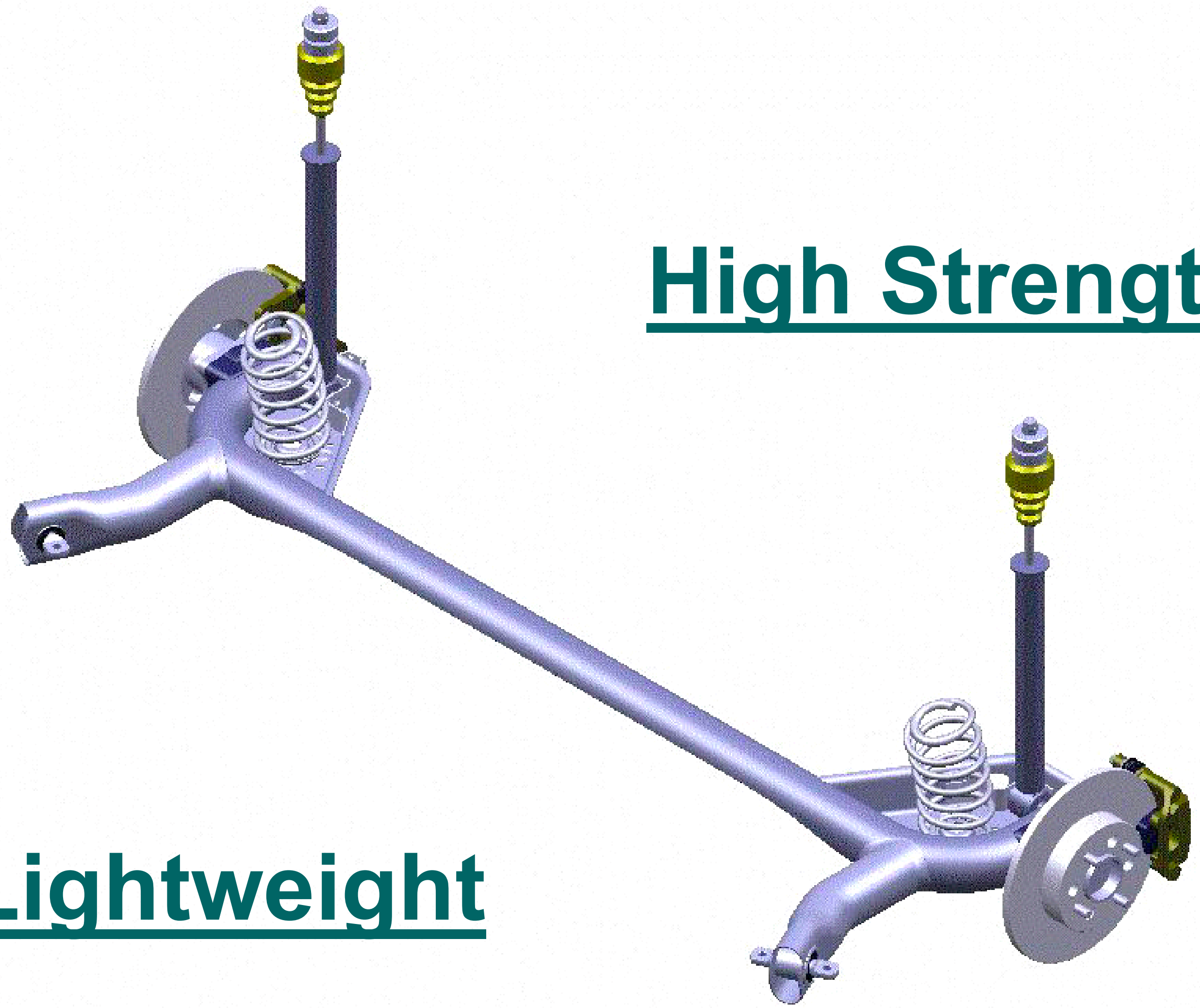
TWISTBEAM: EXPLODED VIEW





1 = Full Suspension Assembly
2 = Welded Assembly
(Items 3, 4, 5, 6, 7, & 8)

TWISTBEAM: DESIGN & FEA

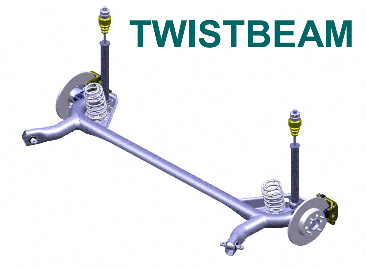


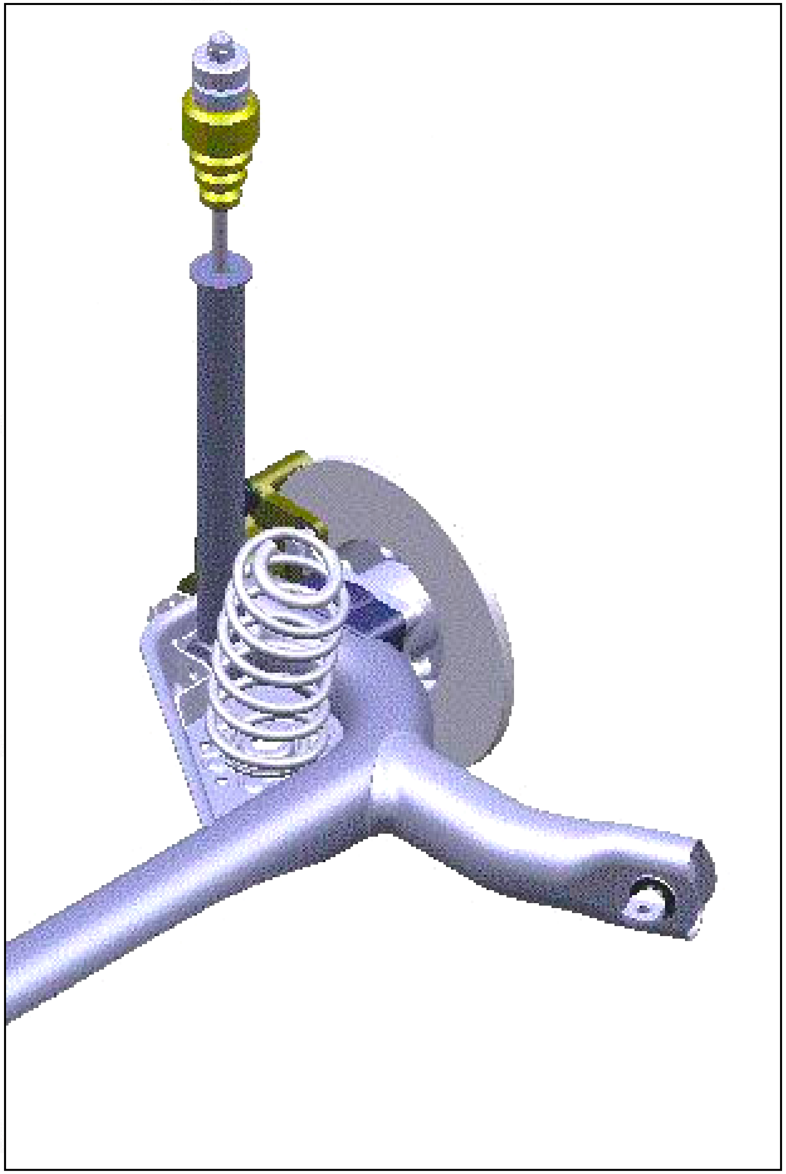
High Strength

Lightweight

ULTRALIGHT
STEEL
AUTO SUSPENSION

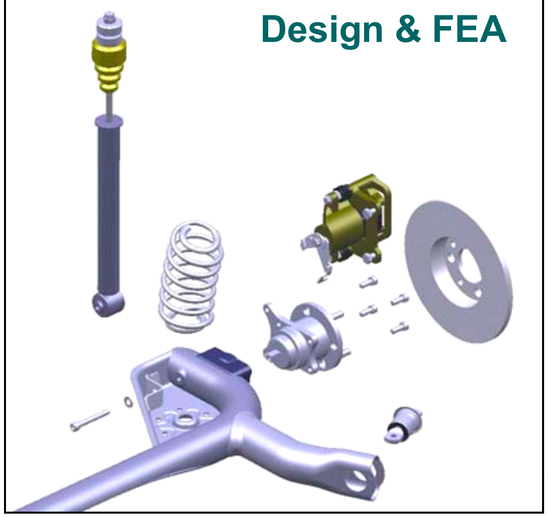
TWISTBEAM: DESIGN & FEA



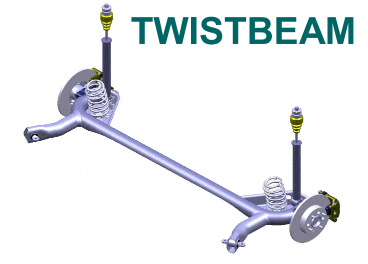


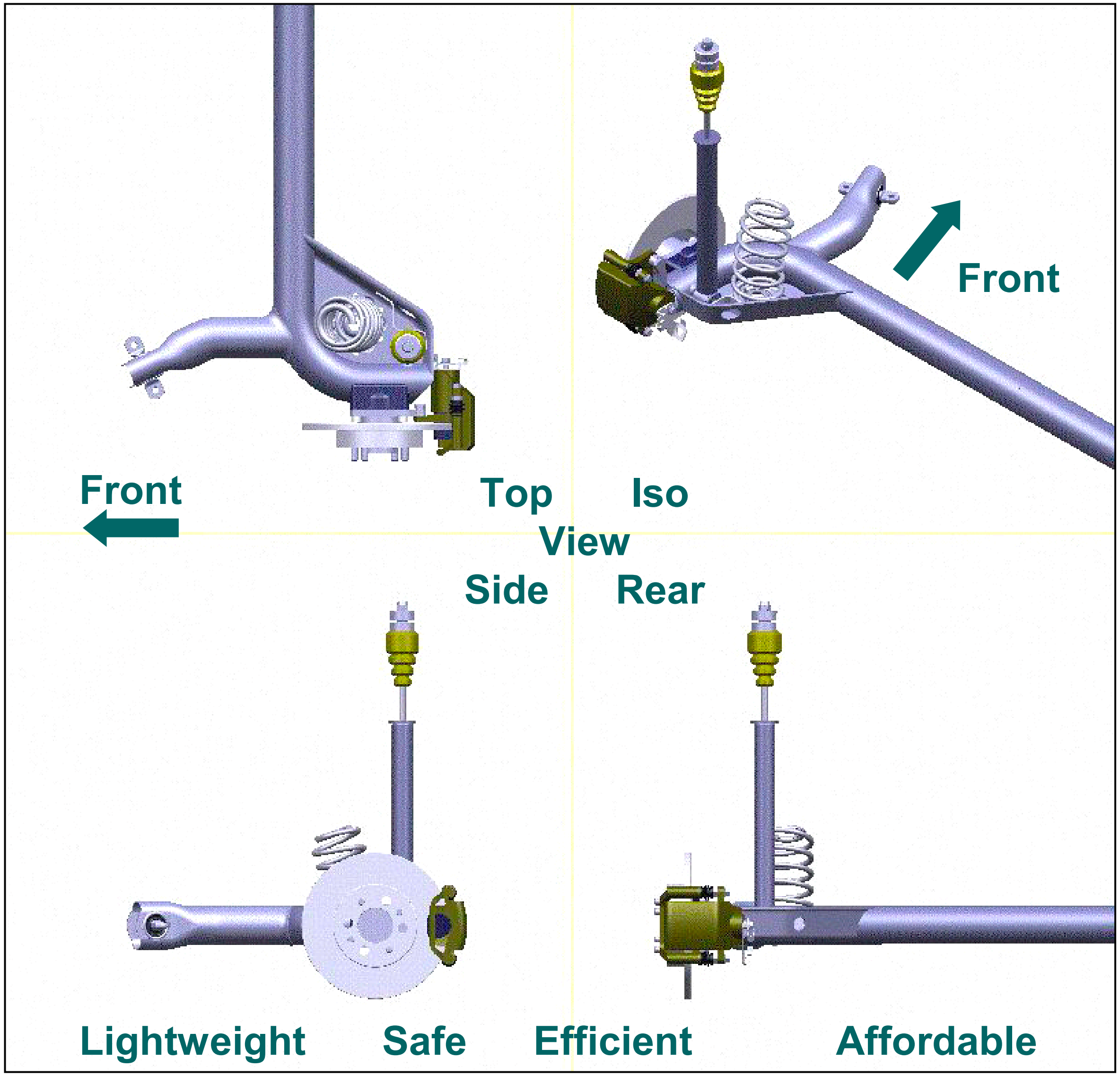
Mass, Cost and Material

ITEM No.	DESCRIPTION	QTY Veh
1	ASSEMBLY, TWIST BEAM	1
2	WELDED ASSY, TWIST BEAM	1
3	TRAILING ARM	2
4	TRANSVERSE BEAM	1
5	HUB MOUNTING PLATE	2
6	SPRING PLATFORM RH	1
7	SPRING PLATFORM LH	1
8	DAMPER BRACKET	2
9	SPRING	2



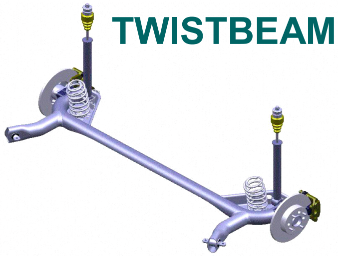
TWISTBEAM: DESIGN & FEA

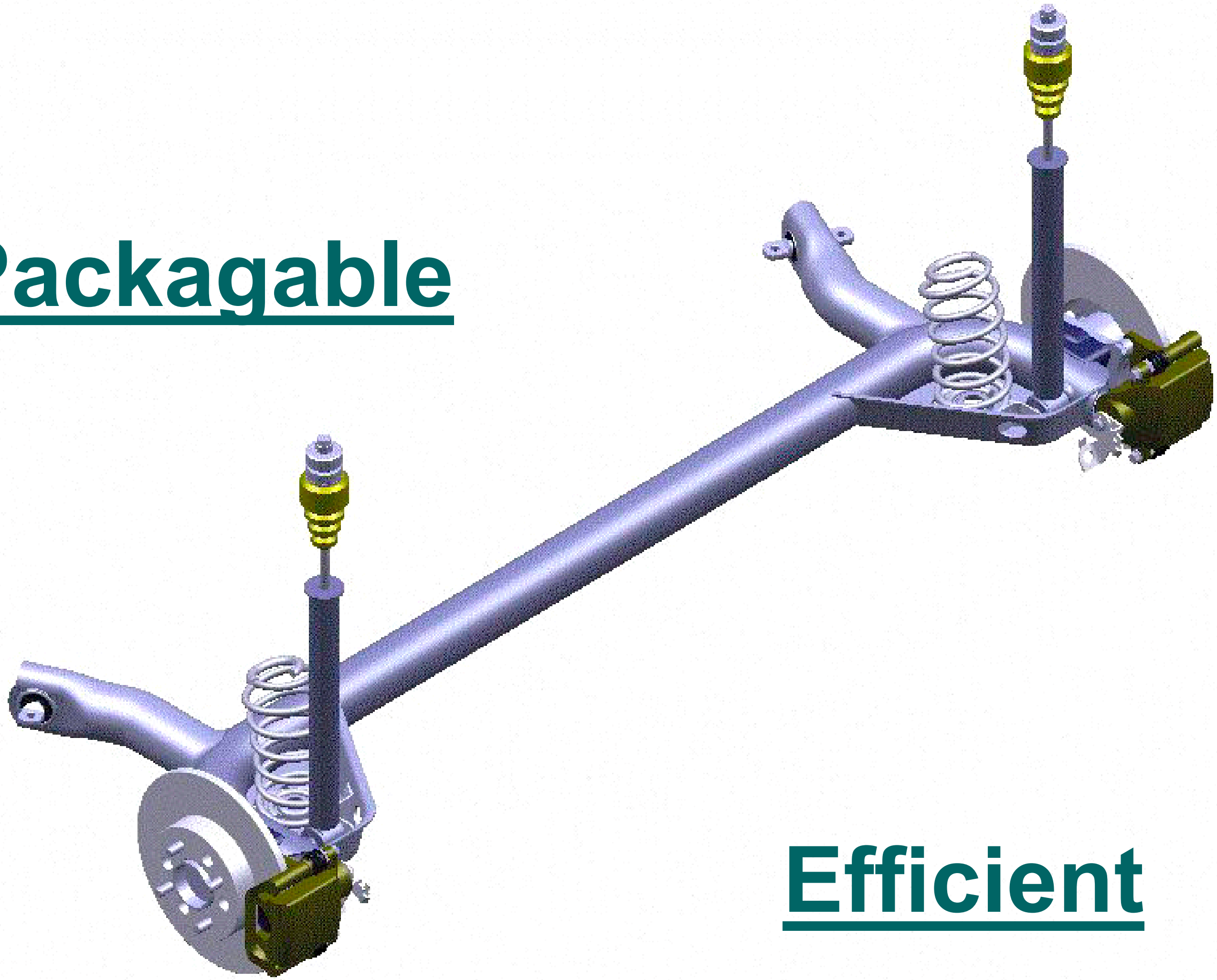




Lightweight Safe Efficient Affordable

TWISTBEAM: DESIGN & FEA

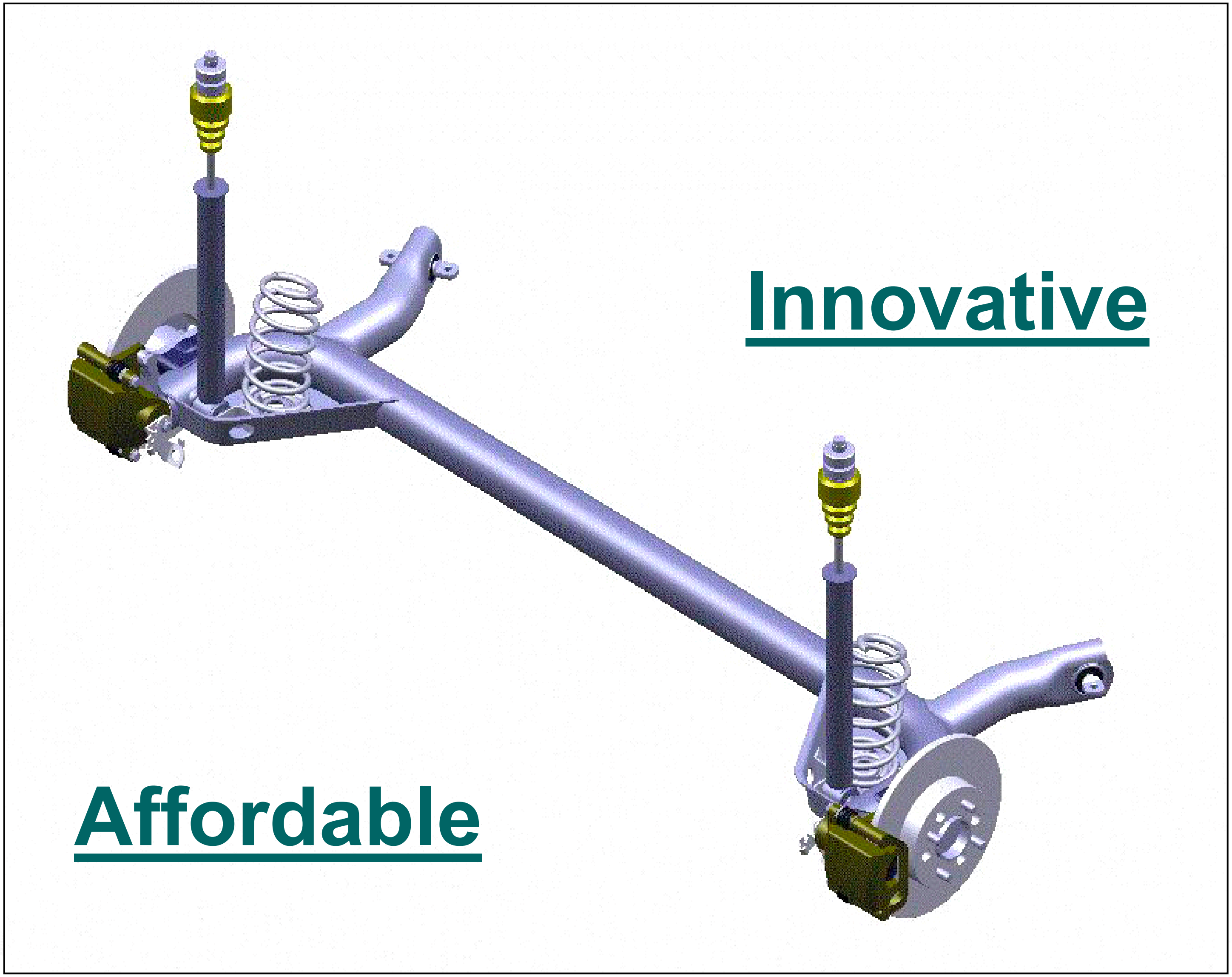




Packagable

Efficient

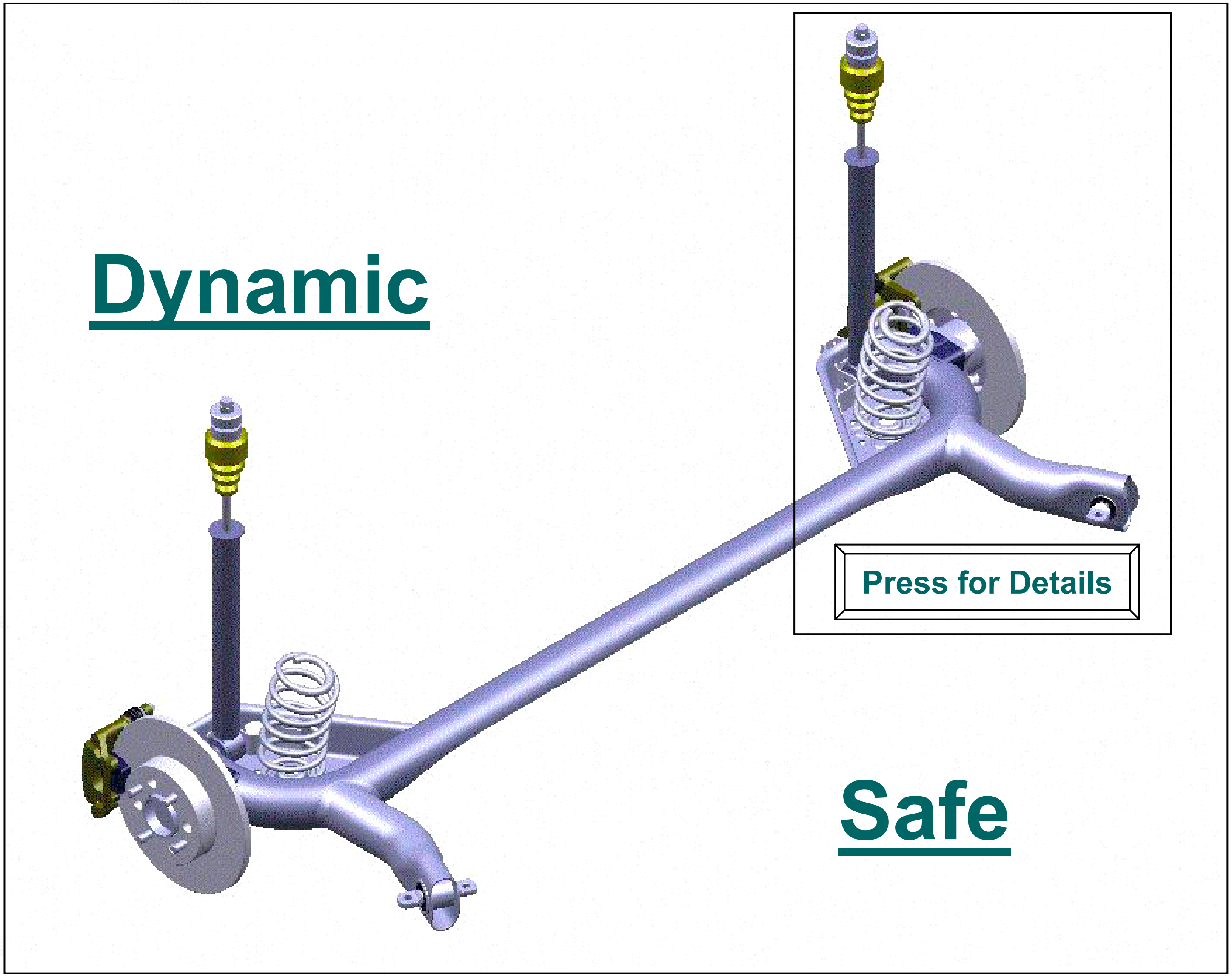
TWISTBEAM: DESIGN & FEA



Innovative

Affordable

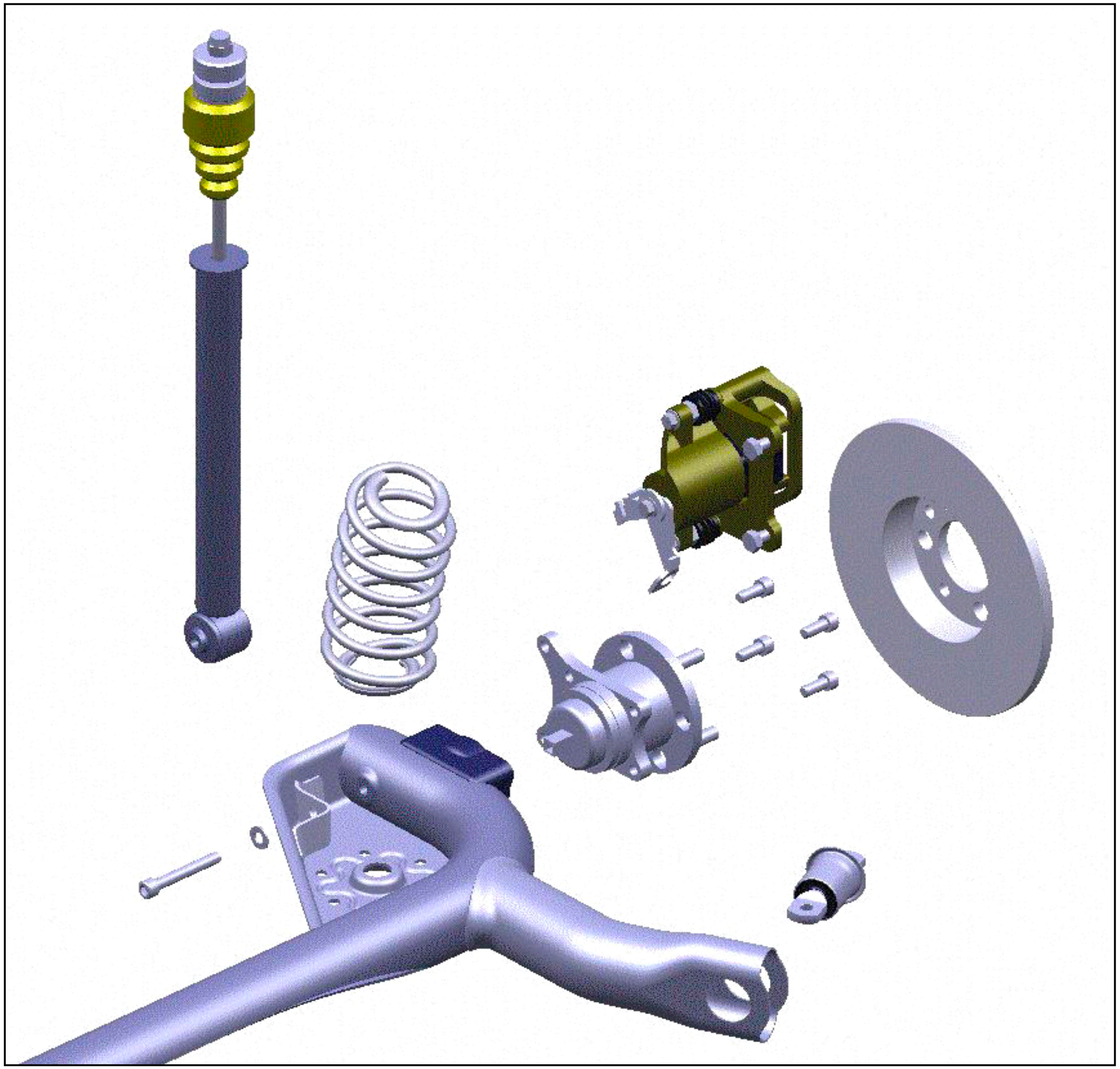
TWISTBEAM: DESIGN & FEA



Dynamic

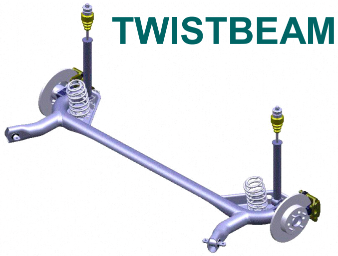
Safe

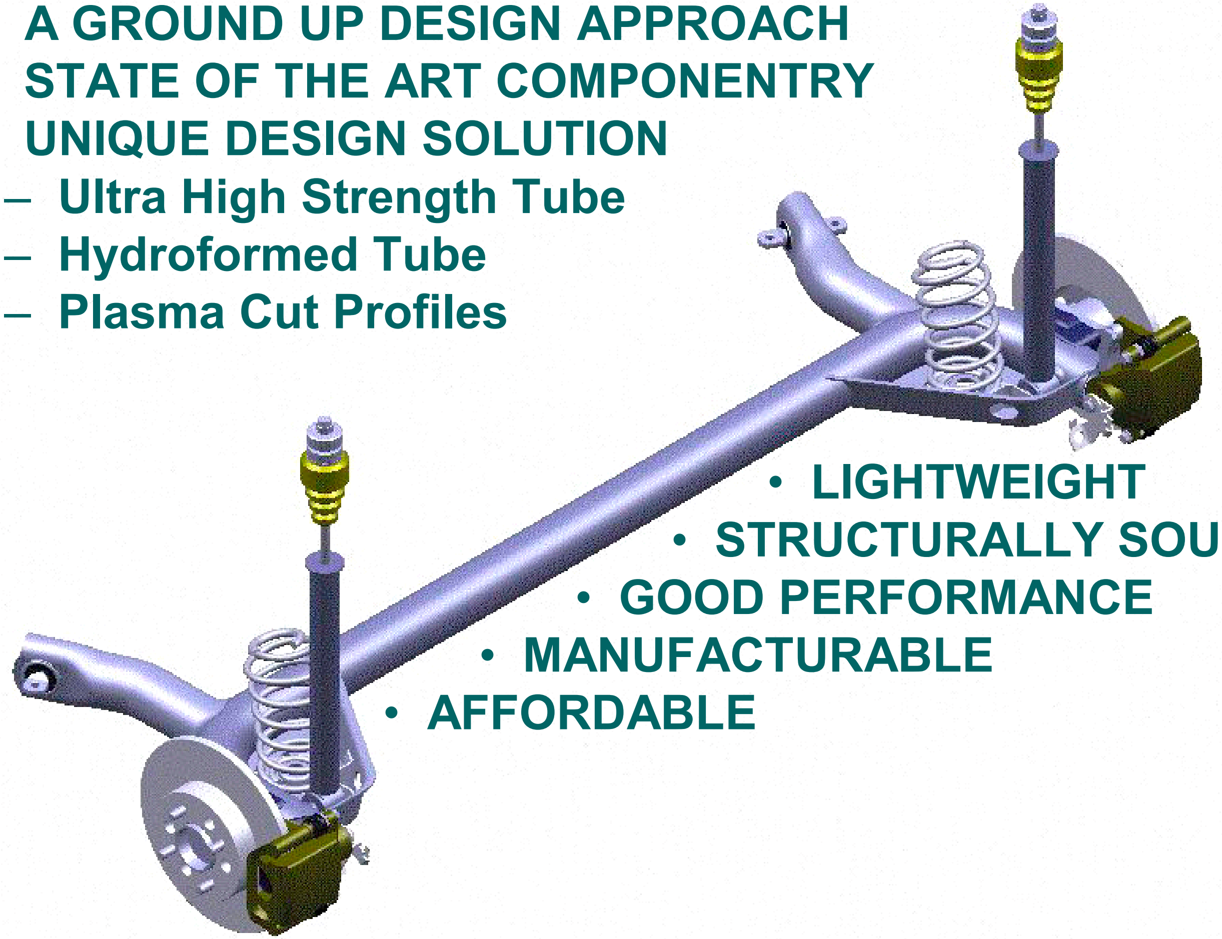
TWISTBEAM: DESIGN



TWISTBEAM: DESIGN

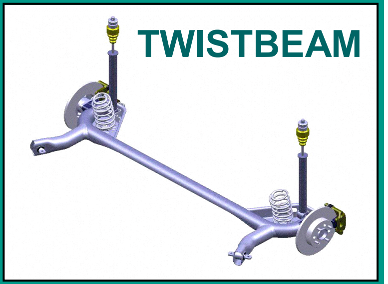
Overview





- A GROUND UP DESIGN APPROACH
- STATE OF THE ART COMPONENTRY
- UNIQUE DESIGN SOLUTION
  - Ultra High Strength Tube
  - Hydroformed Tube
  - Plasma Cut Profiles

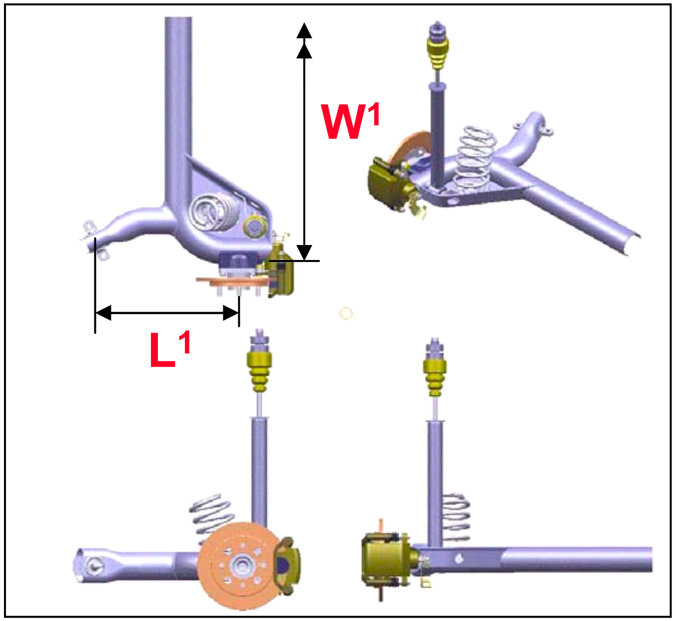
- LIGHTWEIGHT
- STRUCTURALLY SOUND
- GOOD PERFORMANCE
- MANUFACTURABLE
- AFFORDABLE



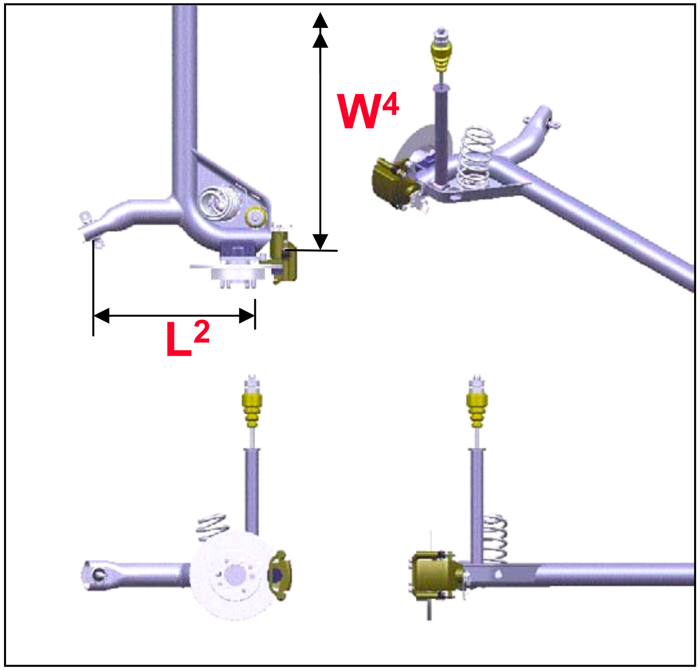
TWISTBEAM: DESIGN

Overview

B Class Solution



B Class Solution
C Class Solution
D Class Solution
E Class Solution
P Class Solution



P Class Solution

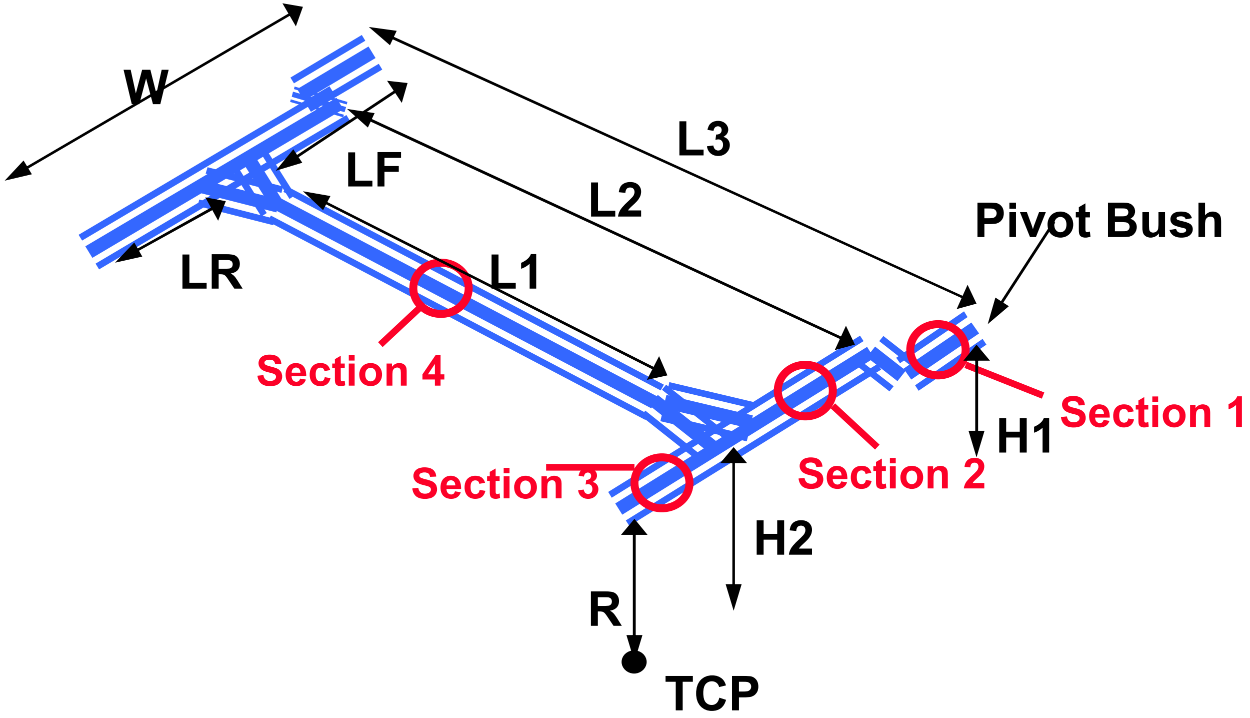
EVOLUTION OF THE DESIGN WAS POSSIBLE THROUGHOUT THE DIFFERENT CLASSES OF VEHICLE WITH VARIATIONS IN MATERIAL GAUGE AND CHANGES IN THE BASIC OVERALL DIMENSIONS

B Class	L1	W1
C Class	L1	W2
D Class	L2	W3
E Class	L2	W4
P Class	L2	W4

TWISTBEAM: DESIGN

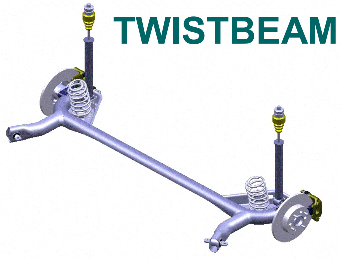
Approach

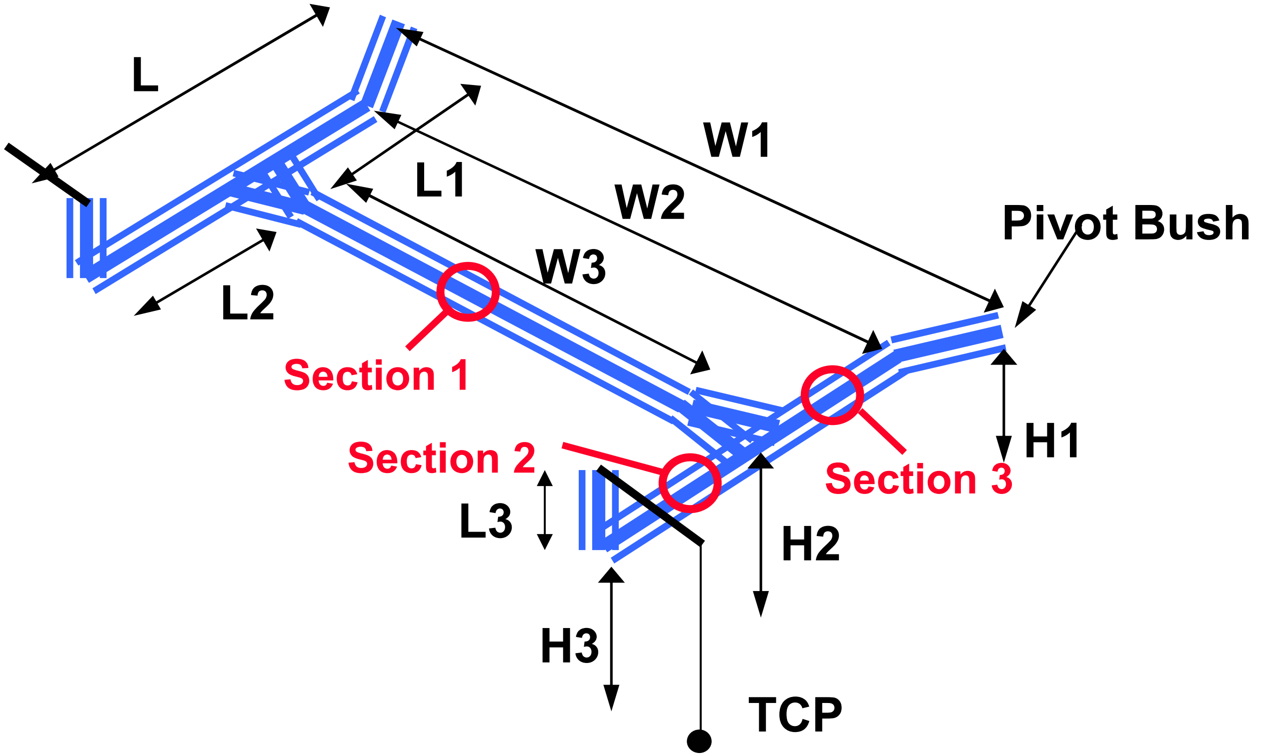
- A Ground up approach was adopted for the design of the Twistbeam System
- Structural stiffness proposals were evaluated utilising Twistbeam design optimisation software



TWISTBEAM: DESIGN

Approach





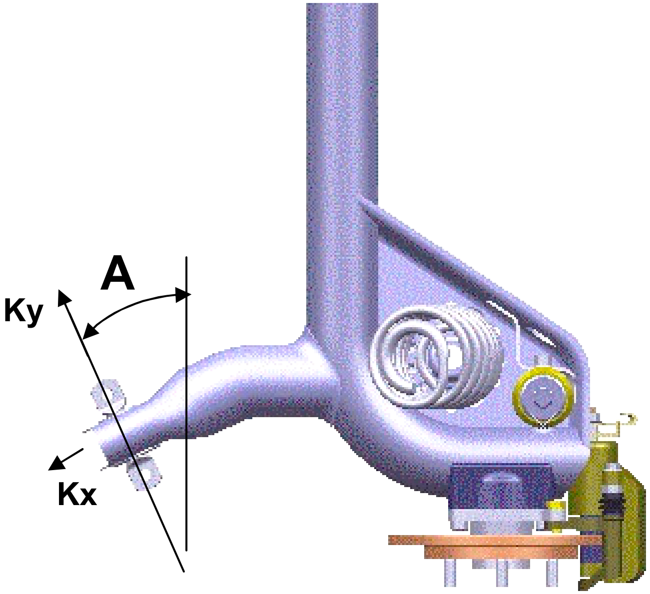
Variables include:

Sections
1) Crossbeam
2) Rear trailing arm
3) Front trailing arm

Length
Position of the crossbeam L1 and L2.
Height of hub drop link L3

TWISTBEAM: DESIGN

Approach

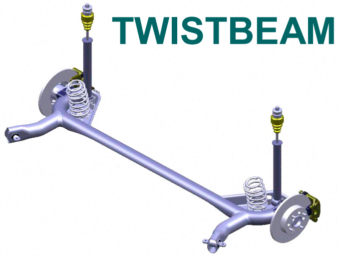


CHASSIS BUSH ORIENTATION

The chassis bushes can be orientated at an angle A in the plan view to minimise lateral force compliance “toe out”. To Achieve this, a high stiffness ratio of Kx/Ky is required. This has the detrimental effect of reducing longitudinal hub compliance. Also large angles have the detrimental effect of generating “toe out” during split ‘mn’ braking. An analysis model was generated to account for all these effects so that the optimum stiffness ratio and bush angle could be generated to give the best compromise for the required characteristics by the automatic investigation of all bush angles from 0 to 90 degrees together with all feasible bush stiffness ratios.

TWISTBEAM: DESIGN

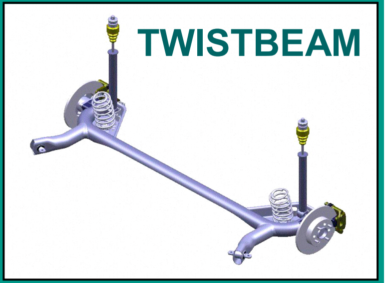
Approach

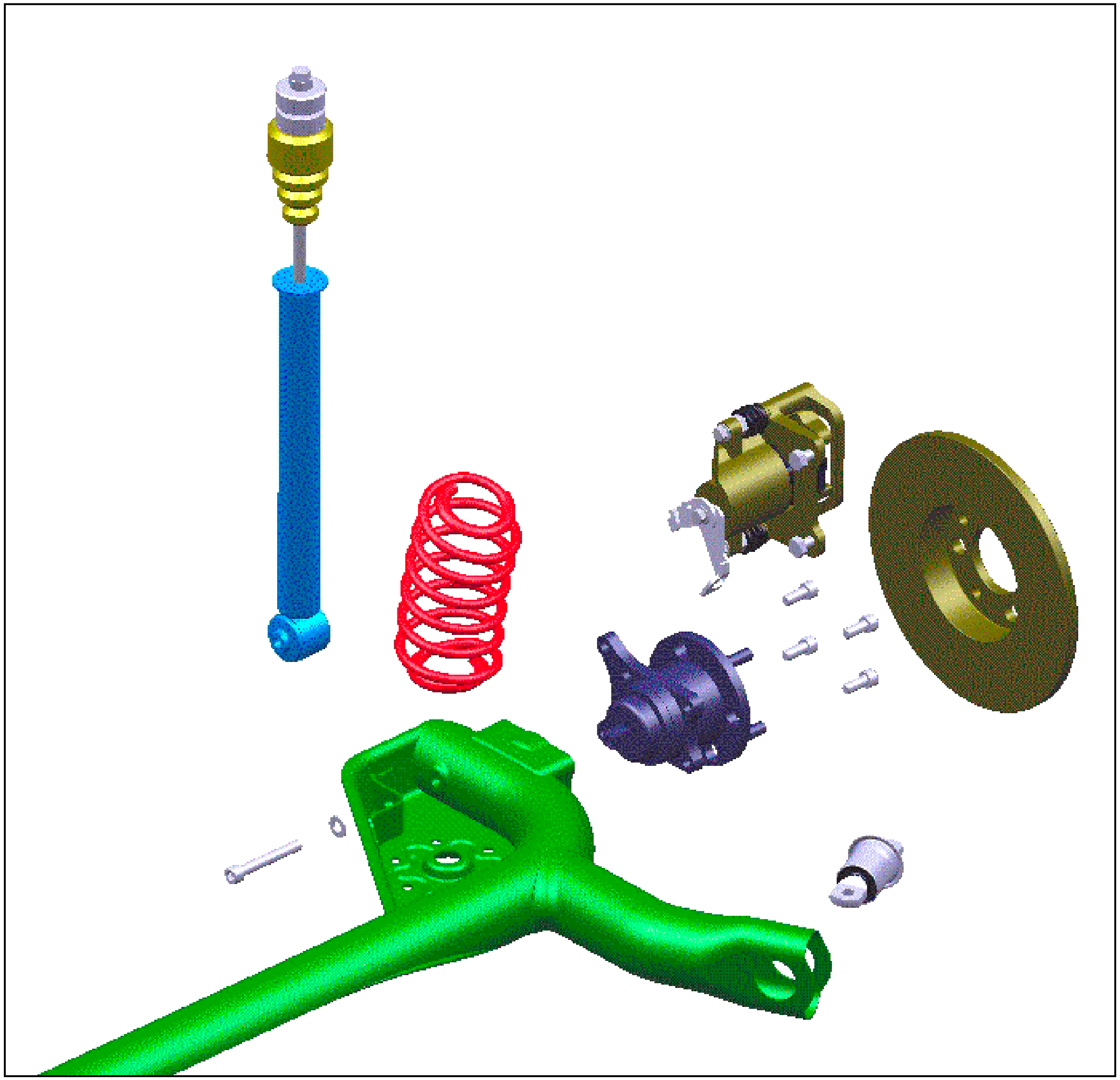


- The optimised layout and sectional properties were passed into CAD to develop the concept design proposals
- The CAD working in conjunction with the Structural Analysis developed the initial concepts through a series of evolutions and optimisations to the final concept proposals
- Structural analysis optimisation techniques were utilised to establish idealised material gauges for each of the main structural components, so as to meet both stiffness and strength requirements.
- More detailed analysis was carried out to validate the design. This included accounting for bush effects plus non-linear effects of geometry and material. Some individual design features which significantly influenced peak stresses were identified and further refined.

TWISTBEAM: DESIGN

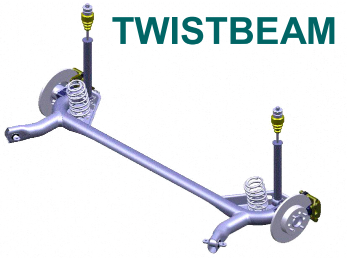
Parts Review

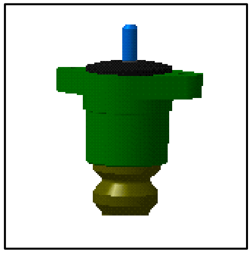




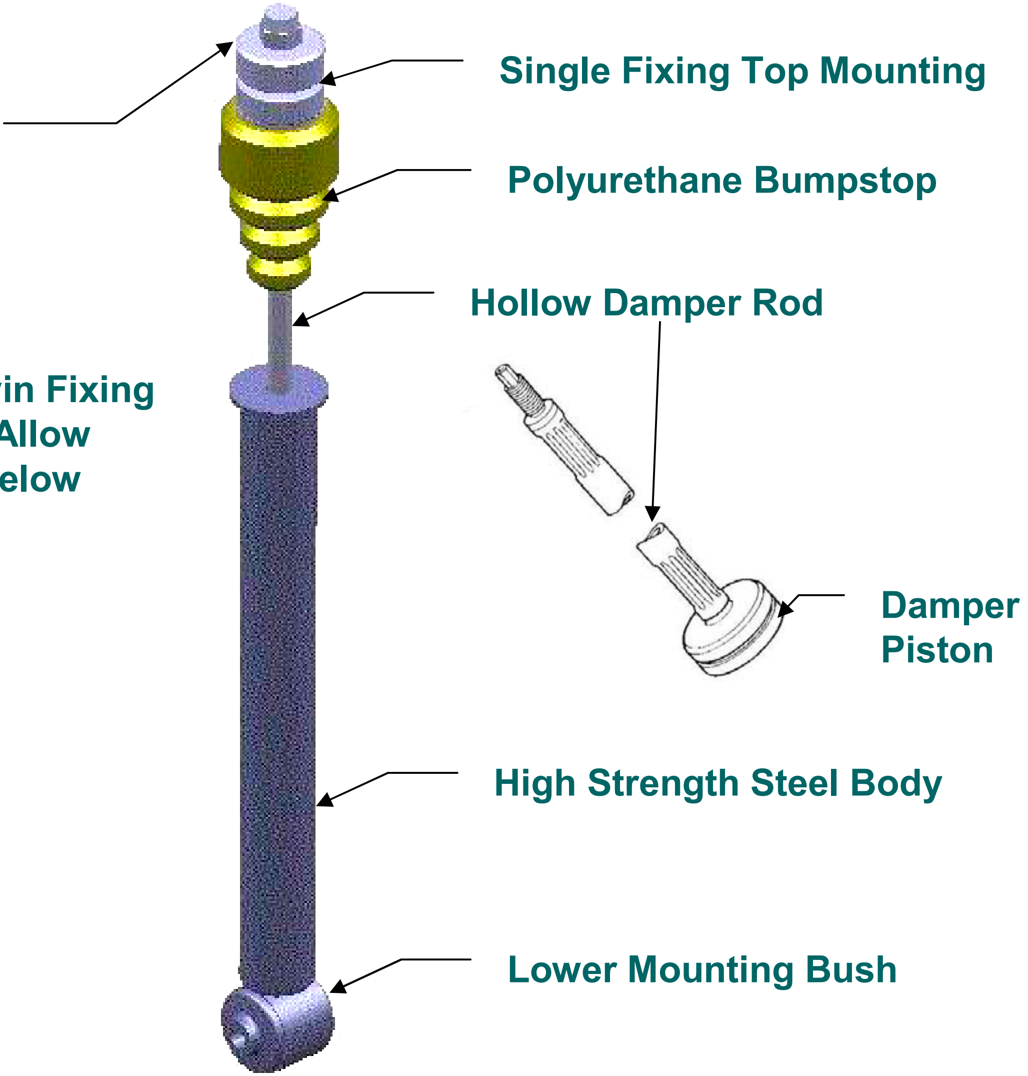
TWISTBEAM: DESIGN

Damper





Alternative Twin Fixing Mounting, To Allow Fixing From Below



Single Fixing Top Mounting

Polyurethane Bumpstop

Hollow Damper Rod

Damper Piston

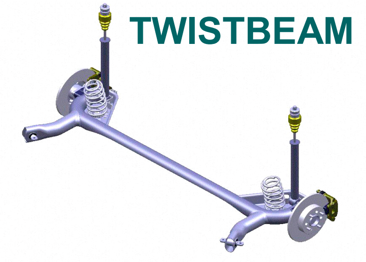
High Strength Steel Body

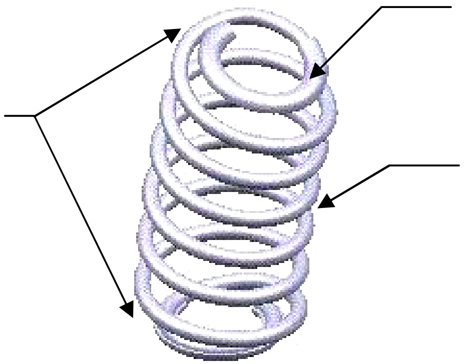
Lower Mounting Bush

TWISTBEAM: DESIGN

Spring

TWISTBEAM





Optimised Angles Top & Bottom To Eliminate Spring Buckling

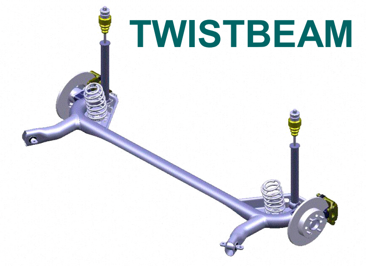
Rubber Spring Isolators Top & Bottom

1300 Mpa Spring Material

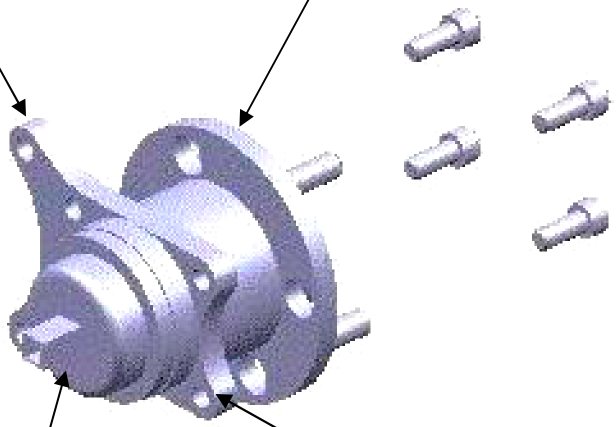
			B Class	**C Class**	**D Class**	**E Class**	**P Class**
Outer Diameter	Do	mm	102.00	102.00	102.00	102.00	97.99
Inner diameter	Di	mm	81.91	80.37	79.33	80.00	78.96
Design length	Ld	mm	190.00	200.70	233.59	215.00	192.71
Bump length	Lb	mm	94.30	103.90	121.94	112.29	90.00
Rebound length	Lr	mm	280.85	294.30	323.63	309.33	287.04
Load at Design length	Pd	N	2760.81	3427.59	3740.77	3748.10	2424.31
Number of working coils	n	-	5.89	6.42	7.44	7.31	6.19
Total number of coils	N		7.39	7.92	8.94	8.81	7.69
Maximum Allowable Stress		N/mm^2	1300	1300	1300	1300	1300
Mean coil diameter	D	mm	91.96	91.19	90.66	91.00	88.48
Wire diameter	d	mm	10.04	10.81	11.34	11.00	9.52
Spring rate	**S**	**N/mm**	**21.83**	**27.58**	**29.20**	**26.08**	**18.76**
Wire length	Lw	mm	2147.20	2282.17	2563.08	2532.32	2151.85
Spring mass	m	kg	**1.34**	**1.65**	**2.03**	**1.89**	**1.20**
Buckling Check			OK	OK	OK	OK	OK

TWISTBEAM: DESIGN

Hub & Bearing Unit



GENERATION 3 TYPE HUB & BEARING UNIT



Wheel Hub Flange

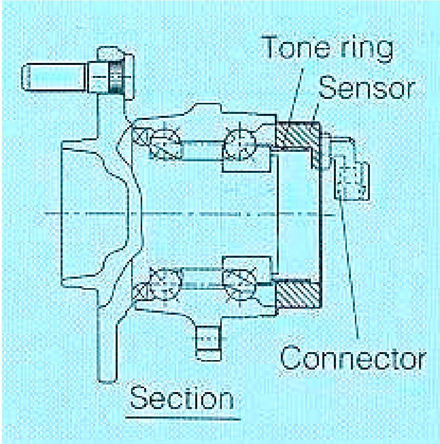
Integral Brake Caliper Mountings

4 Bolt Attachment

Integral ABS Sensor (Anti-Lock Brake System)

Flange to Bolt Bearing Unit to Twistbeam.

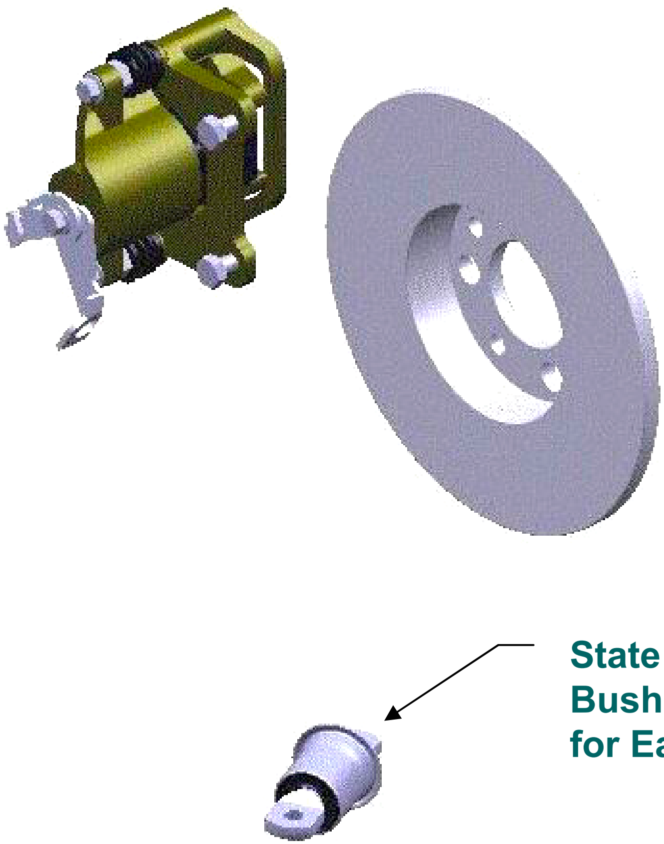
(Due to the large size & cost of the Twistbeam Assembly to minimise replacement costs the hub units are of the bolt on variety for this application.)



Typical Cross Section of Bearing

TWISTBEAM: DESIGN

Brakes & Bushes



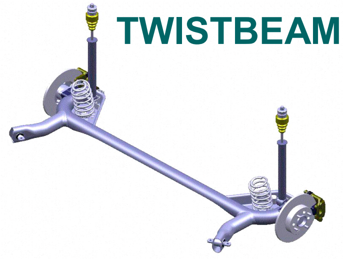
State of the Art Brake Calipers, with integral Hand Brake Mechanism

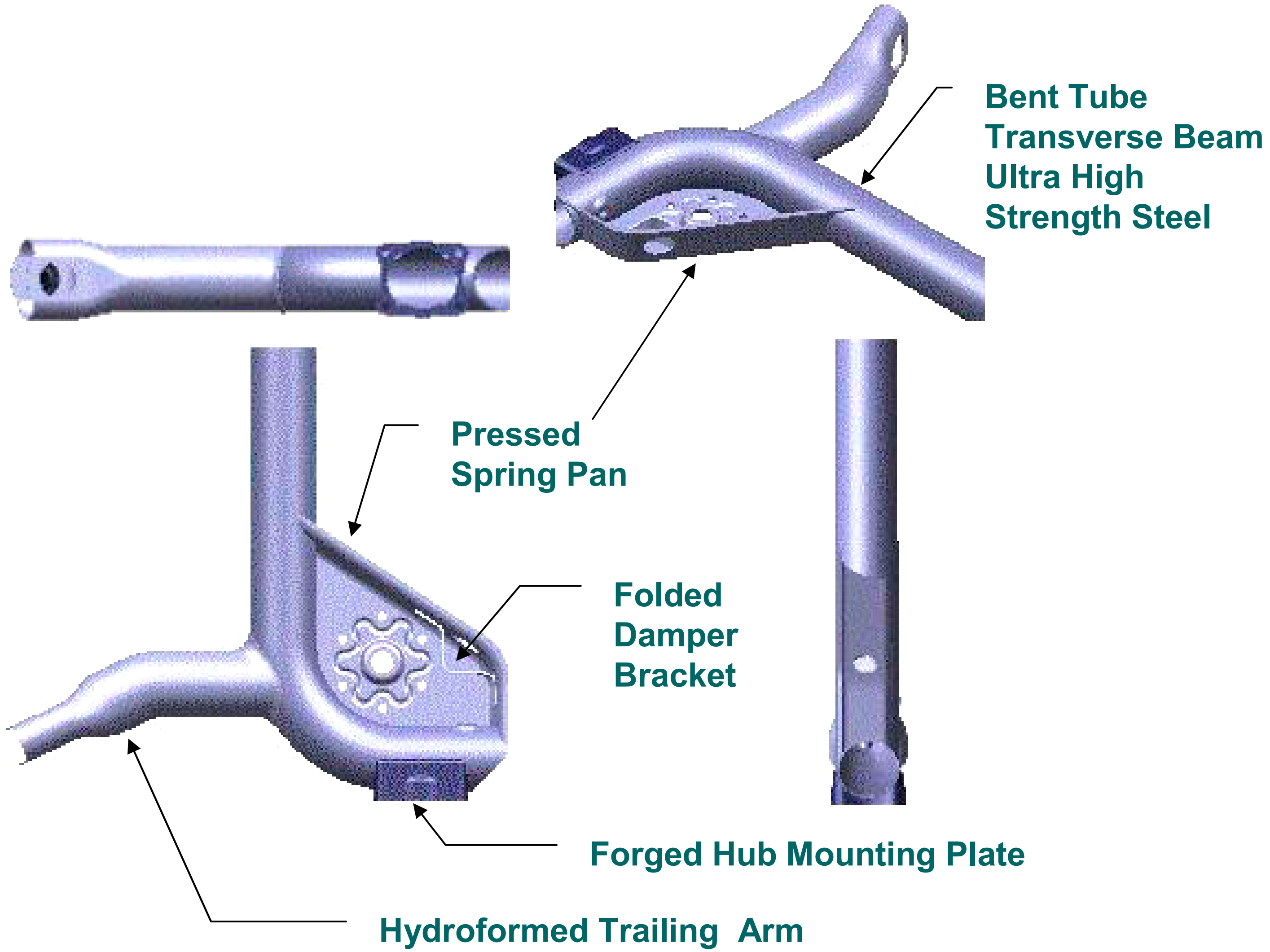
Solid Cast Iron Disc

State of the Art Mounting Bushes with Vertical Fixings for Ease of Vehicle Fitment

TWISTBEAM: DESIGN

Twistbeam Structure





Bent Tube Transverse Beam Ultra High Strength Steel

Pressed Spring Pan

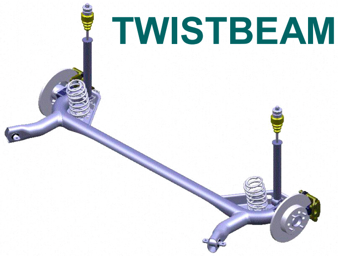
Folded Damper Bracket

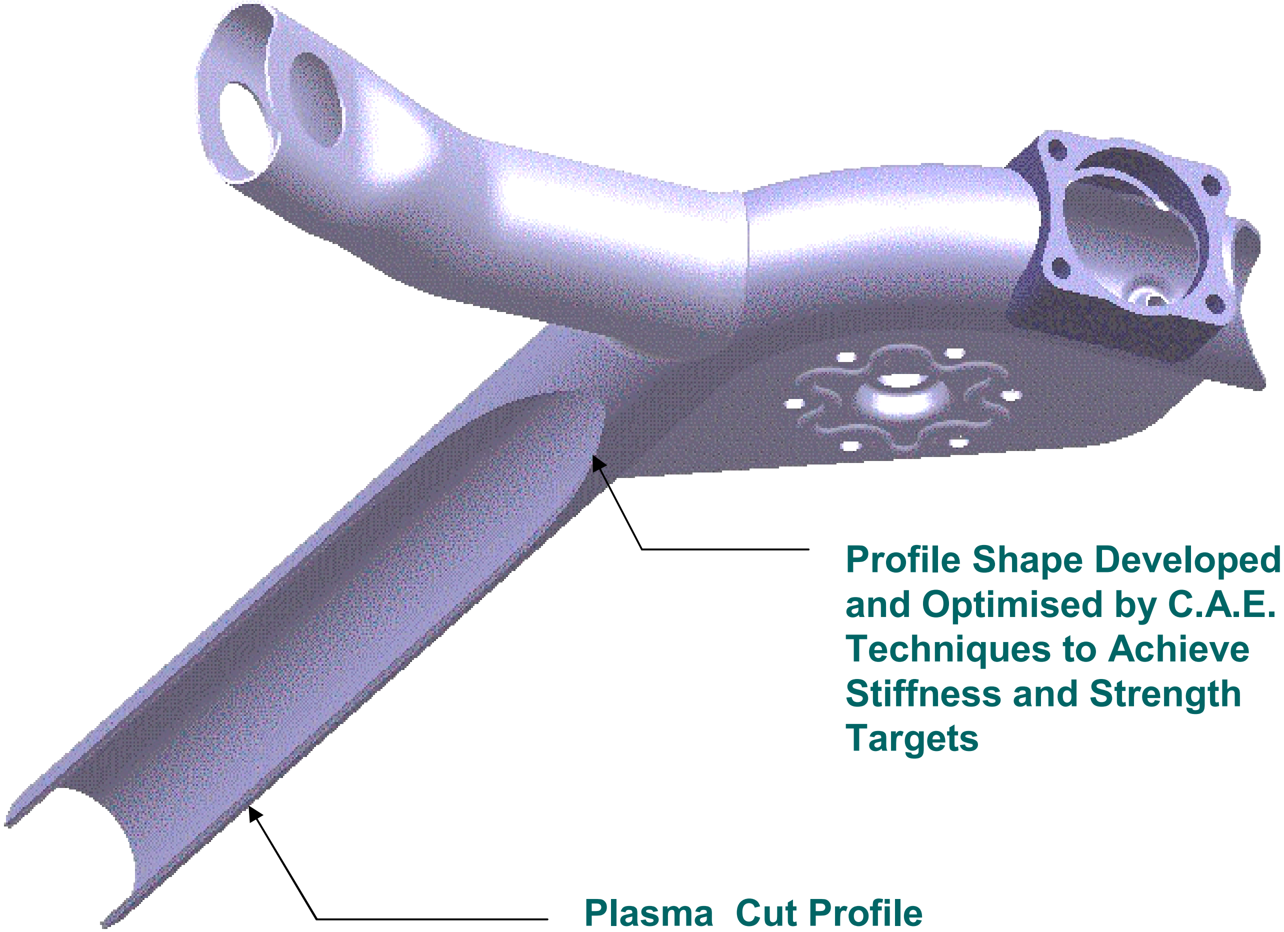
Forged Hub Mounting Plate

Hydroformed Trailing Arm

TWISTBEAM: DESIGN

Twistbeam Structure



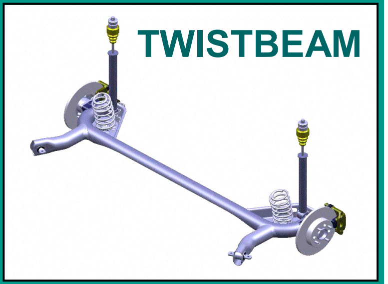


Profile Shape Developed and Optimised by C.A.E. Techniques to Achieve Stiffness and Strength Targets

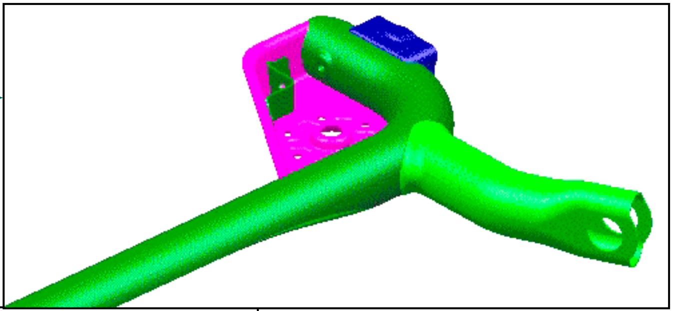
Plasma Cut Profile

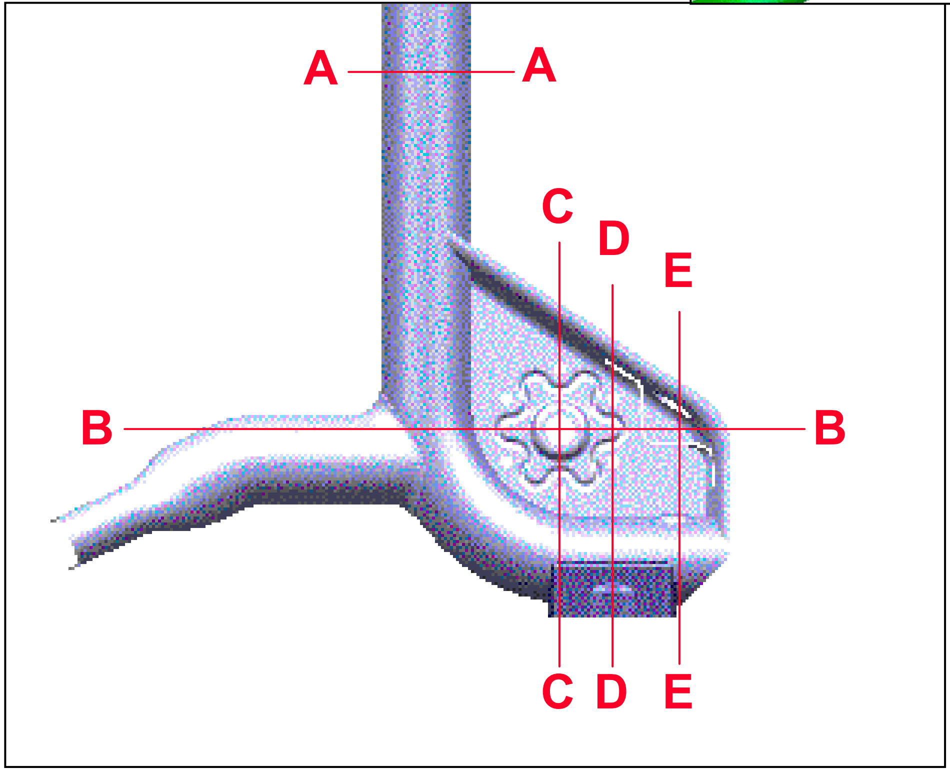
TWISTBEAM: DESIGN

Twistbeam Structure



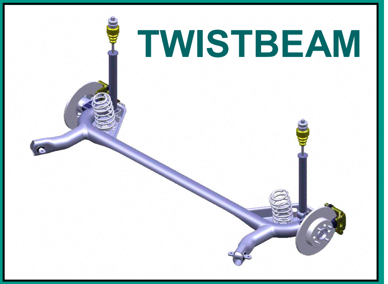
SELECT PART OR SECTION

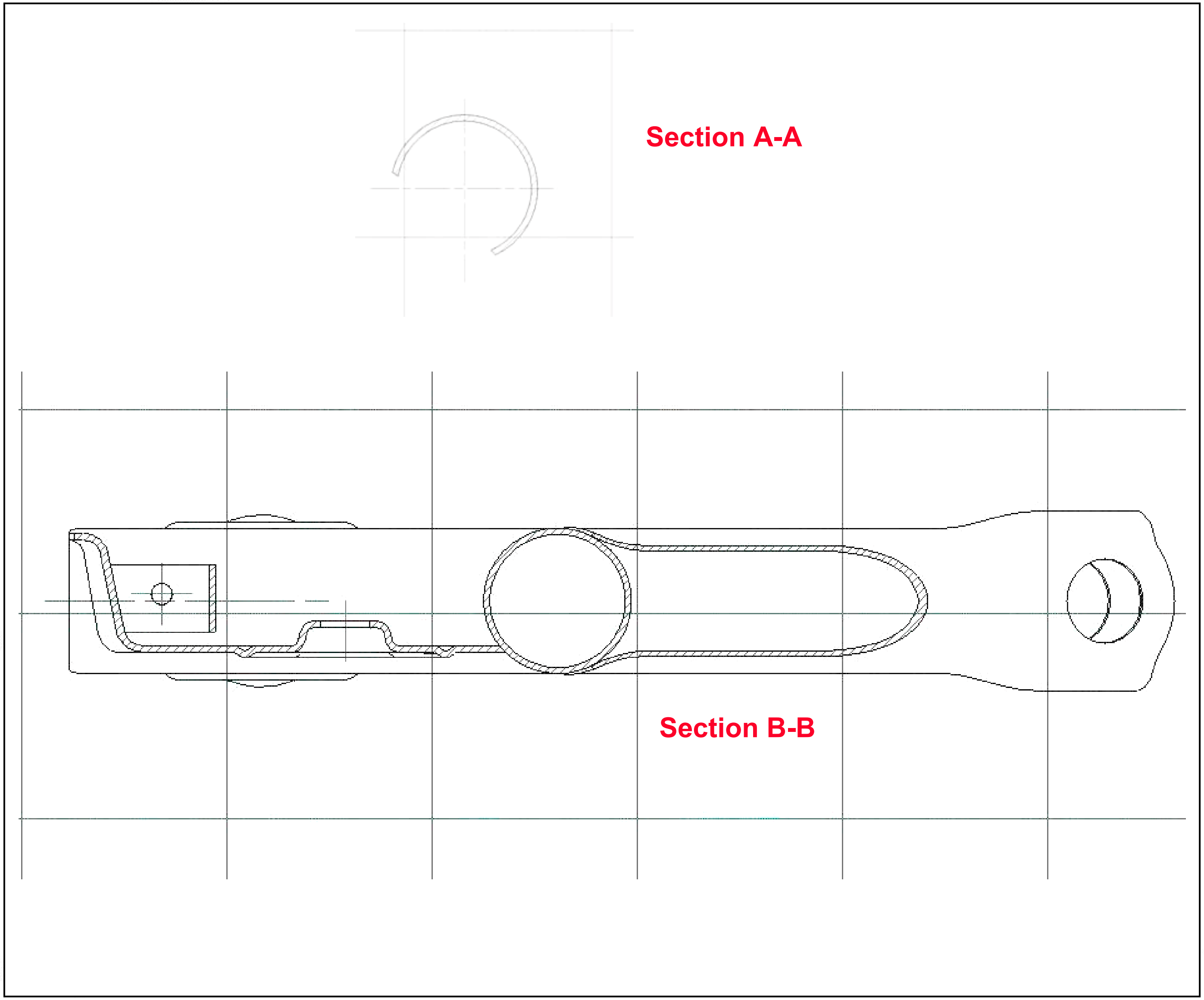




TWISTBEAM: DESIGN

Twistbeam Structure

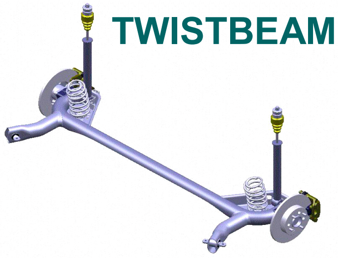


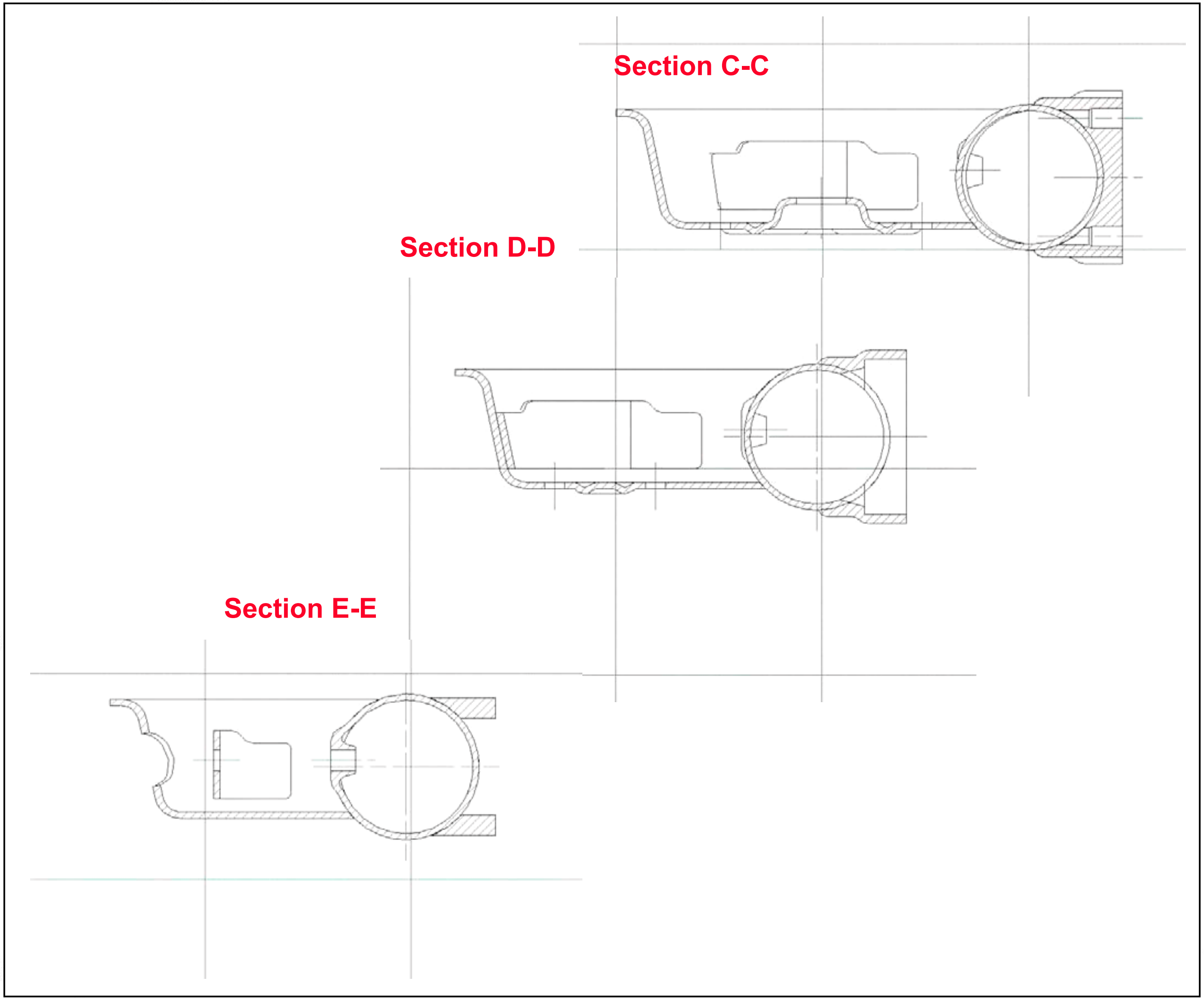


TWISTBEAM: DESIGN

Twistbeam Structure

TWISTBEAM

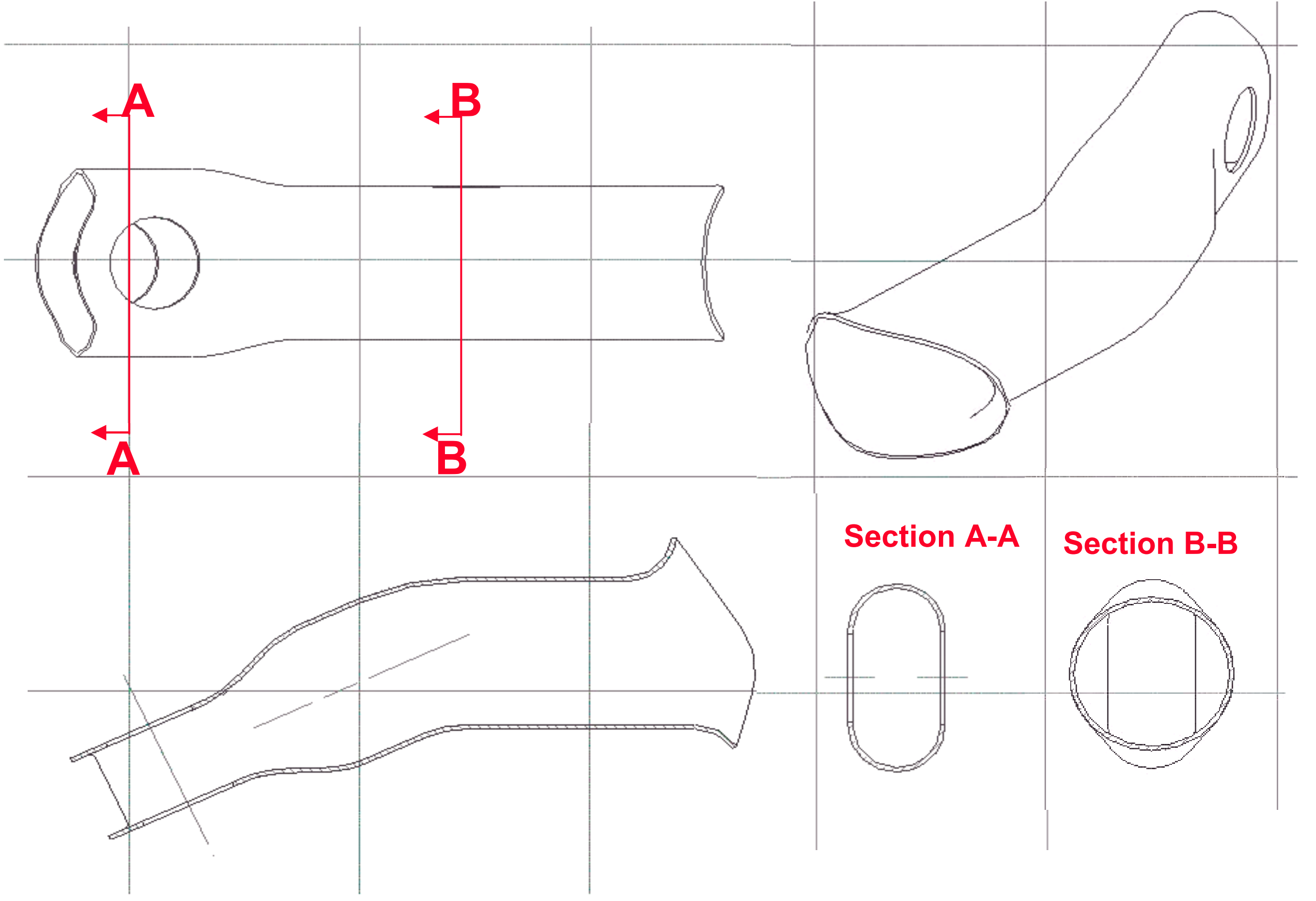




TWISTBEAM: DESIGN

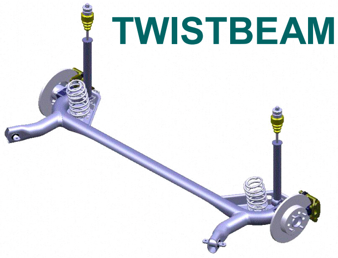
Twistbeam Structure

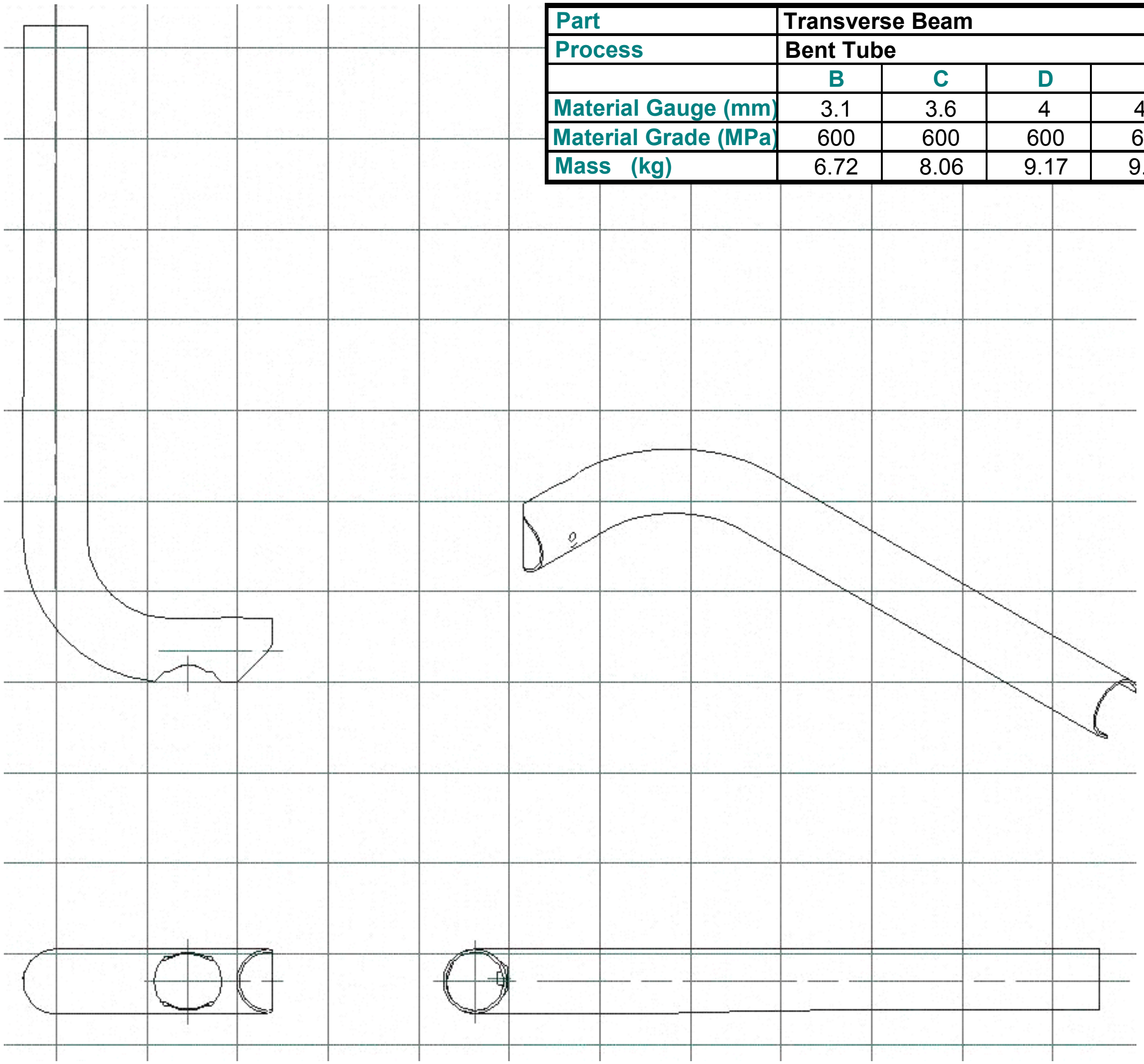
Part	Trailing arm				
Process	Hydro-Formed				
	B	C	D	E	P
Material Gauge (mm)	2	2	2	2	2
Material Grade (Mpa)	400	400	400	400	400
Mass (kg)	0.788	0.788	0.942	0.942	0.942



TWISTBEAM: DESIGN

Twistbeam Structure



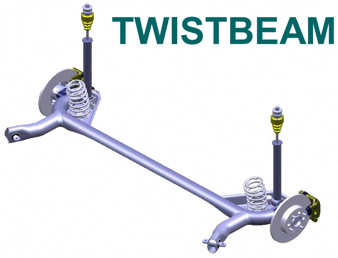


Part	Transverse Beam				
Process	Bent Tube				
	B	C	D	E	P
Material Gauge (mm)	3.1	3.6	4	4.1	2.8
Material Grade (MPa)	600	600	600	600	600
Mass (kg)	6.72	8.06	9.17	9.35	6.72

TWISTBEAM: DESIGN

Twistbeam Structure

TWISTBEAM

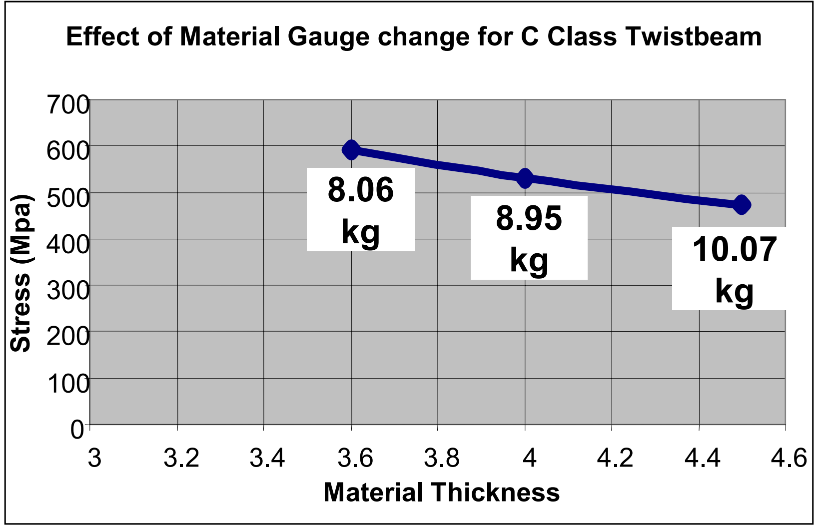


Further, more detailed, analysis was carried out on the C Class Transverse Beam to assess the local areas of high stress which were most significant on this variant.

Part	Transverse Beam				
Process	Bent Tube				
	B	C	D	E	P
Material Gauge (mm)	3.1	3.6	4	4.1	2.8
Material Grade (MPa)	600	600	600	600	600
Mass (kg)	6.72	8.06	9.17	9.35	6.72

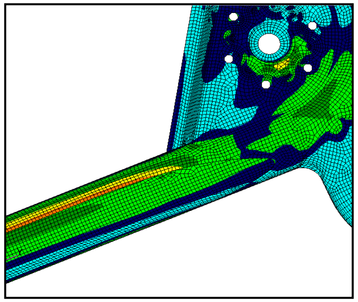
Two avenues were explored, firstly alternative material gauges were assessed, and the weight penalty quantified.

Secondly further analysis was undertaken to explore alternative detail shape changes.

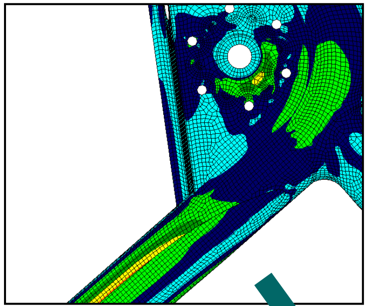


The first investigation showed significant reductions in stress as material gauge was increased but with a proportionate increase in the part mass.

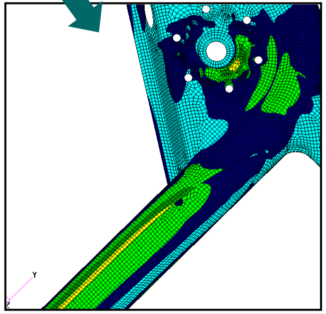
3.6mm



4.0mm

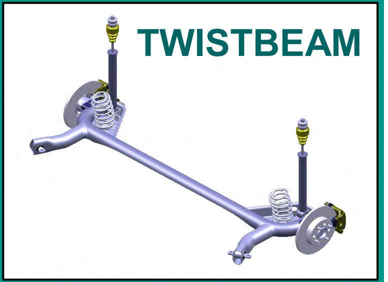


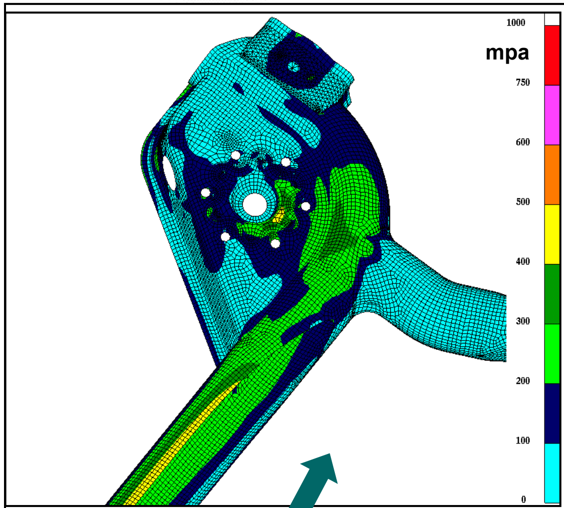
4.5mm



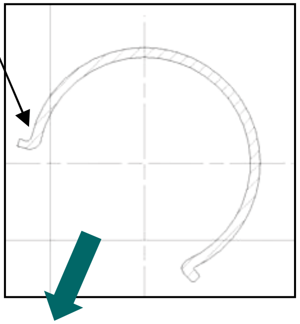
TWISTBEAM: DESIGN

Twistbeam Structure

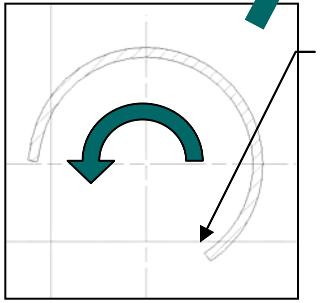




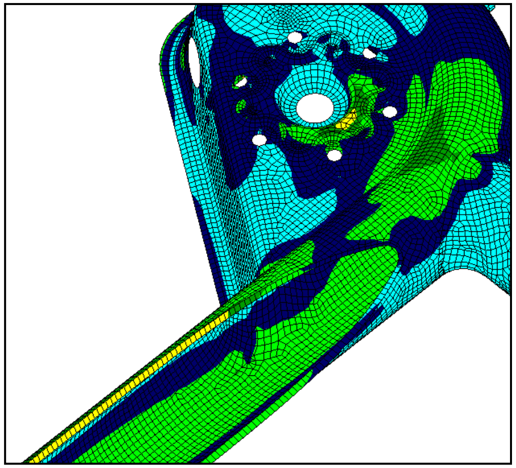
Part	Transverse Beam				
Process	Bent Tube				
	B	C	D	E	P
Material Gauge (mm)	3.1	3.6	4	4.1	2.8
Material Grade (MPa)	600	600	600	600	600
Mass (kg)	6.72	8.06	9.17	9.35	6.72



Bent Tube Transverse Beam with Cut out Profile Revised by Adding a Small Lip Flange Around Edge



Bent Tube Transverse Beam with Cut out Profile Repositioned by a 5 Deg Rotation

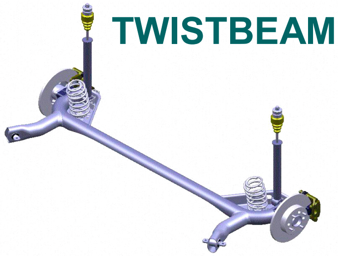


The second investigation looked at alternative detail design changes to the shape of the edge of the cutout profile. These changes both resulted in significant areas of reduced stress. It is apparent from this that a robust solution is possible based on this concept, with little or no increase in the overall system mass.

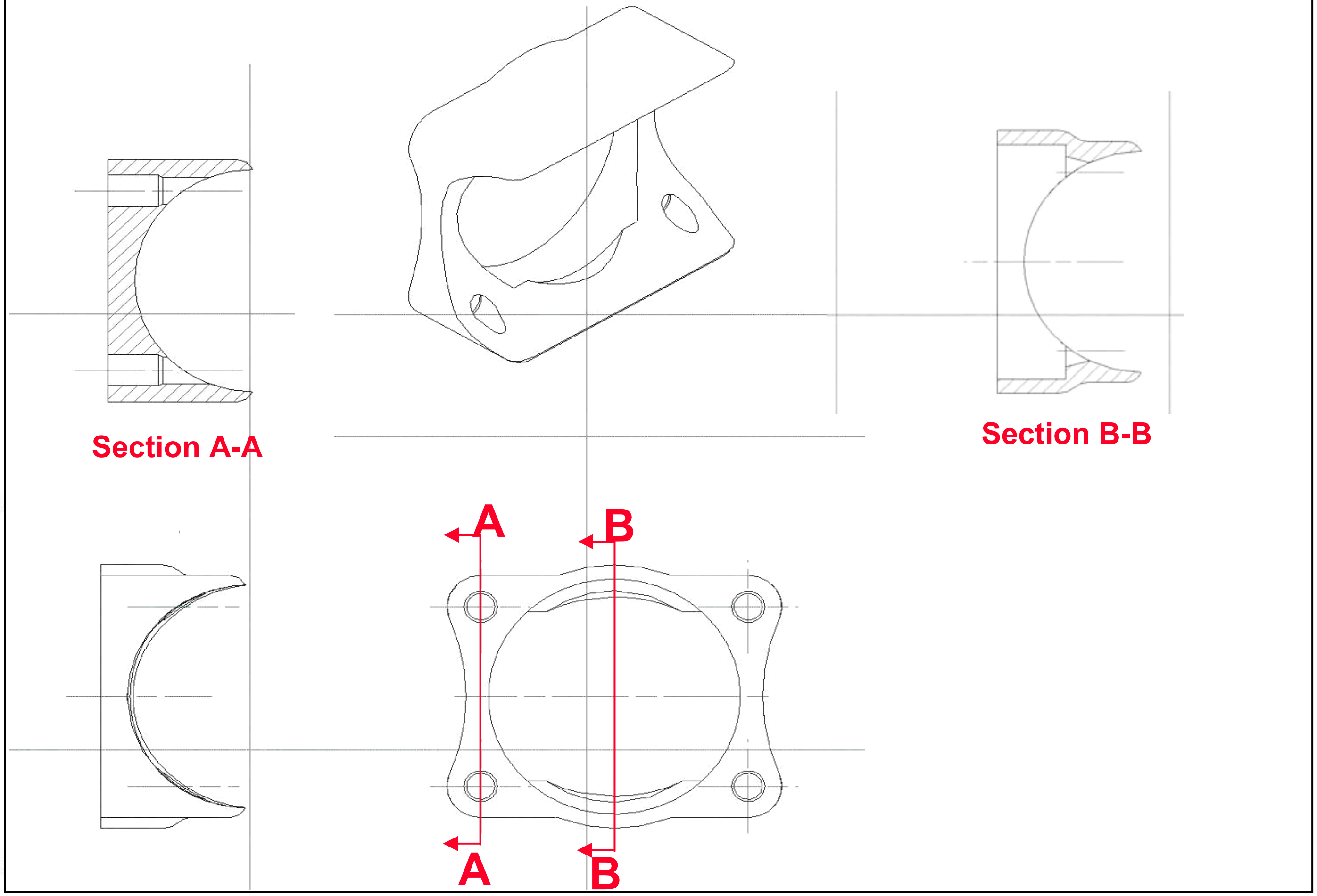
TWISTBEAM: DESIGN

Twistbeam Structure

TWISTBEAM



Part	Hub Mounting Plate				
Process	Forged				
	B	C	D	E	P
Material Gauge (mm)					
Material Grade (Mpa)	600	600	600	600	600
Mass (kg)	0.51	0.51	0.532	0.532	0.532



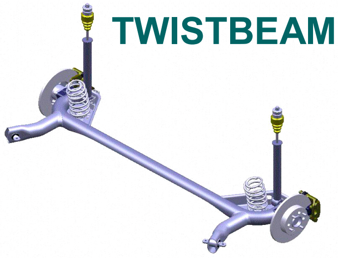
Section A-A

Section B-B

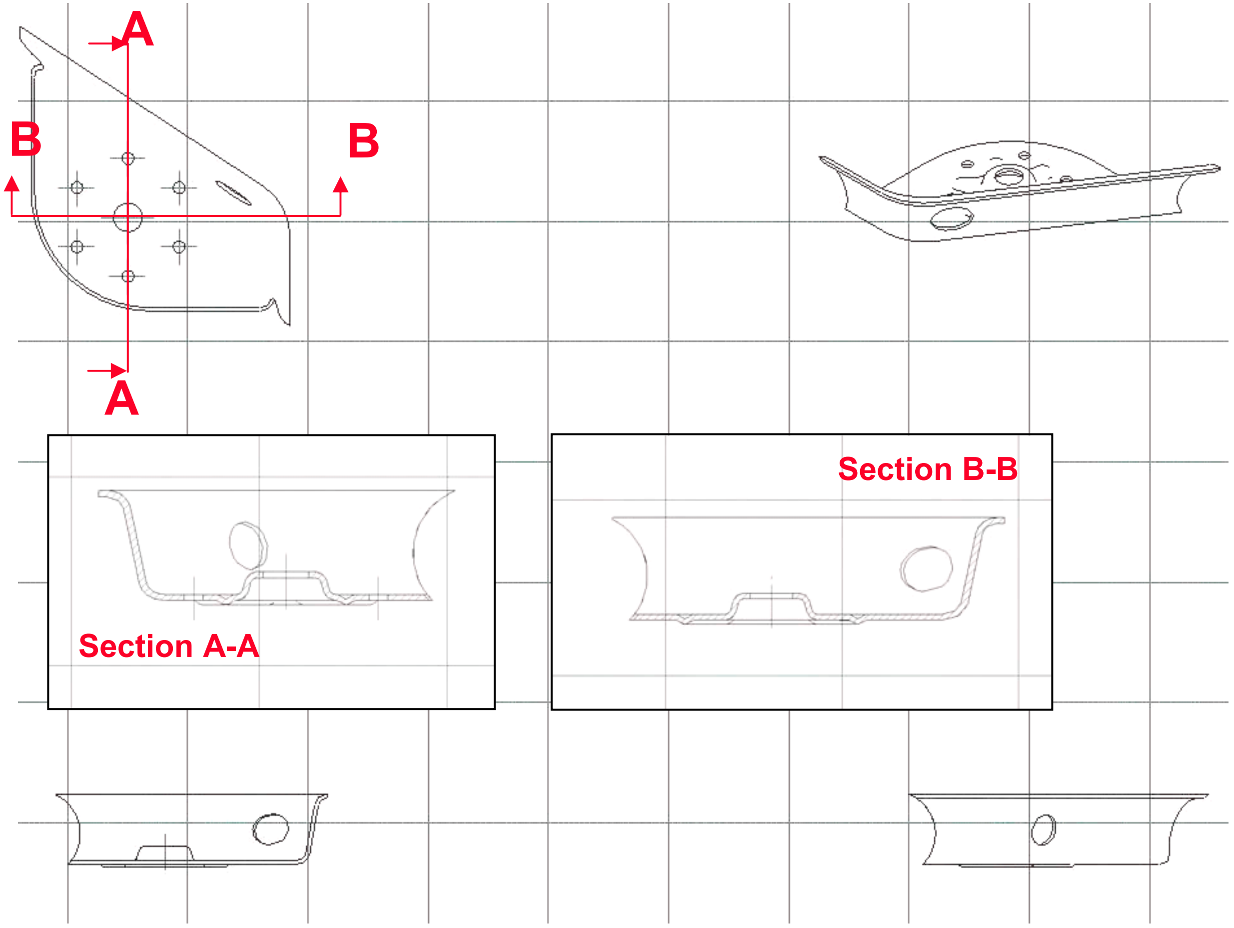
TWISTBEAM: DESIGN

Twistbeam Structure

TWISTBEAM

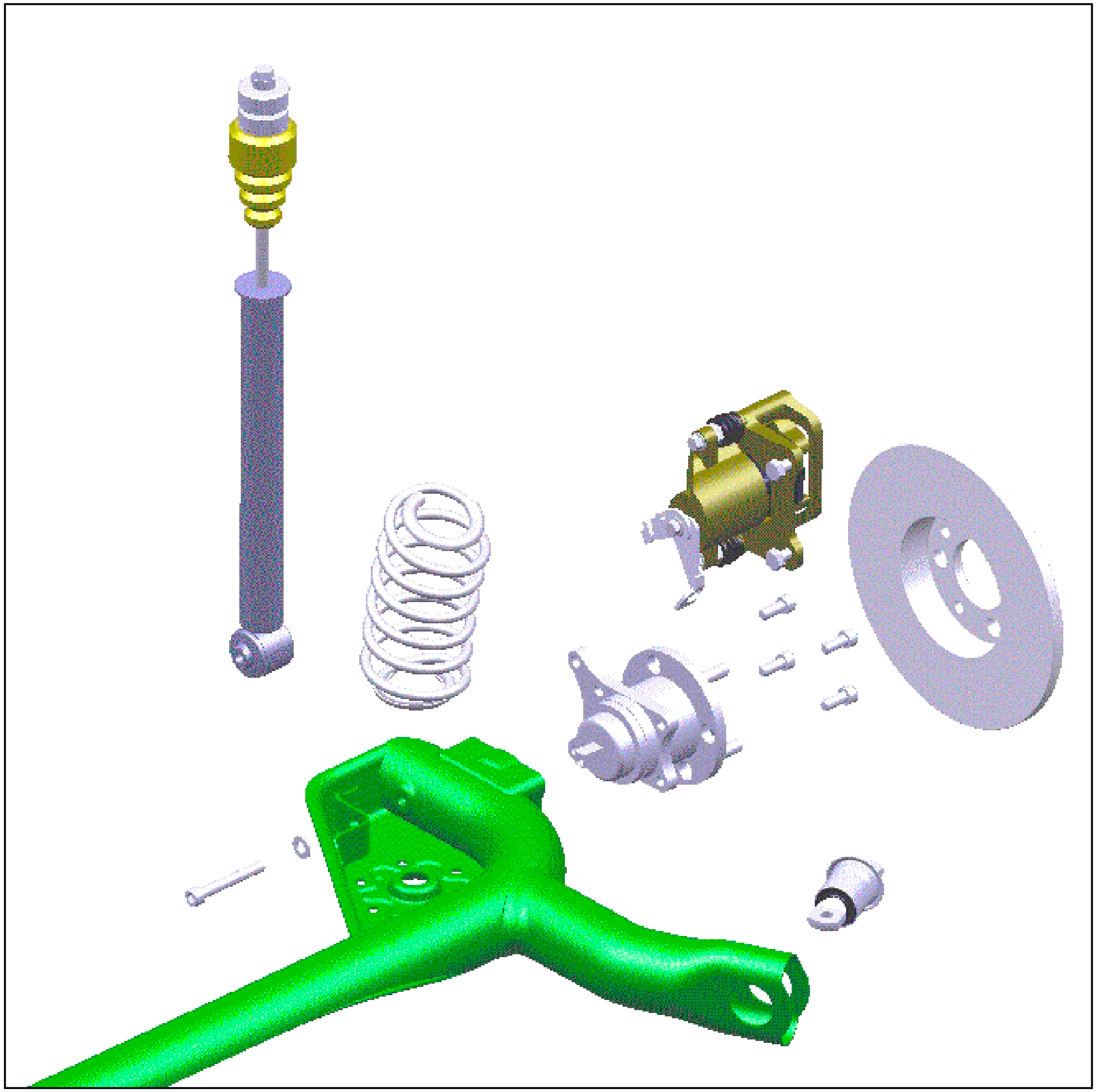


Part	Spring Platform				
Process	Pressing				
	B	C	D	E	P
Material Gauge (mm)	3.4	3.8	4	3.7	3.2
Material Grade (Mpa)	500	500	500	500	500
Mass (kg)	1.16	1.3	1.37	1.25	1.09



TWISTBEAM

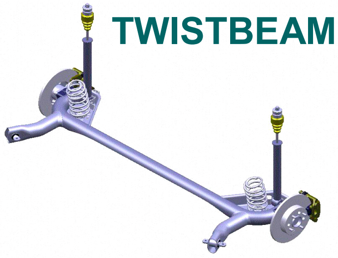
Finite Element Analysis



TWISTBEAM

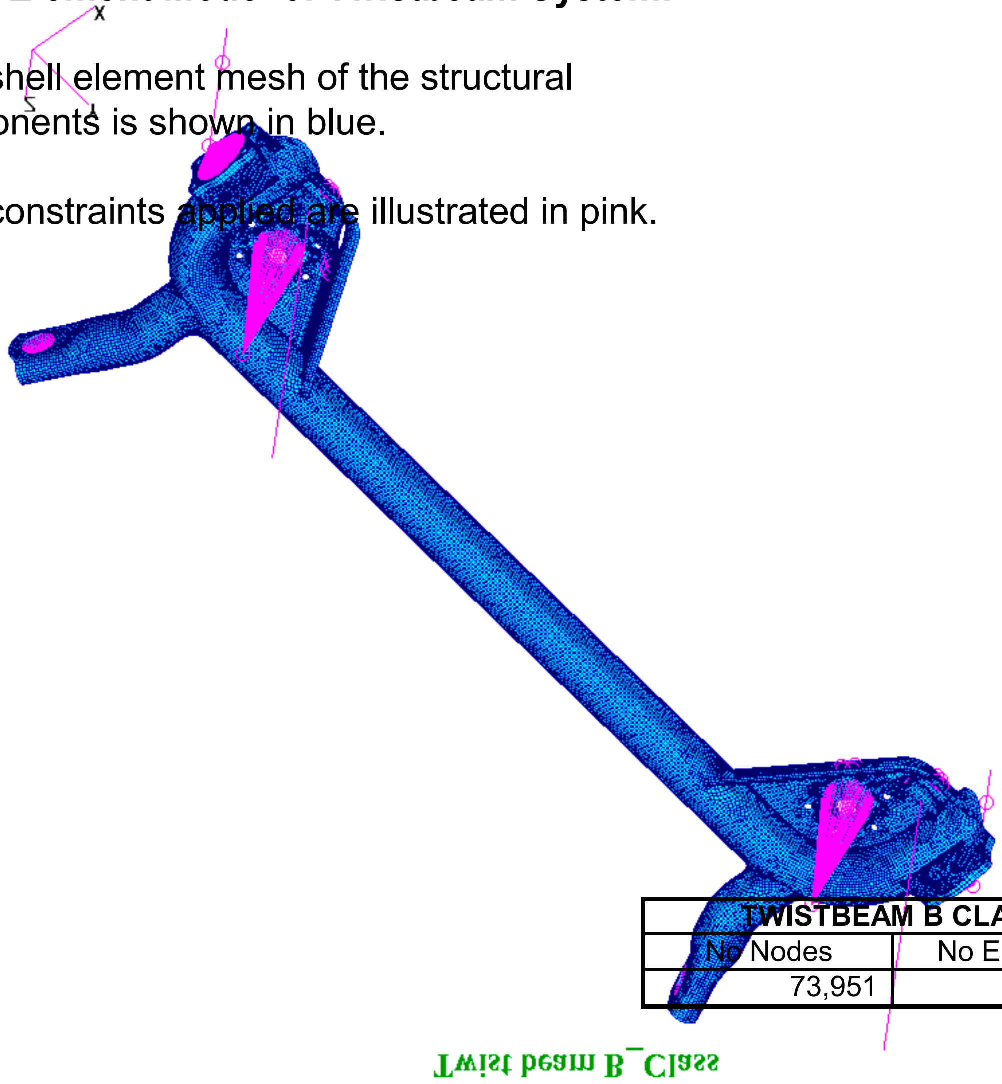
Finite Element Analysis

TWISTBEAM



Finite Element Model of Twistbeam System:

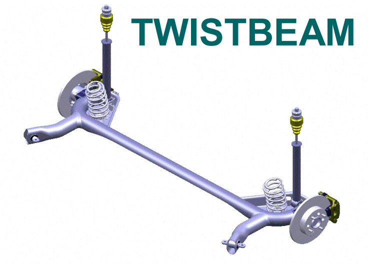
- The shell element mesh of the structural components is shown in blue.
- The constraints applied are illustrated in pink.



TWISTBEAM B CLASS	
No Nodes	No Elements
73,951	56,536

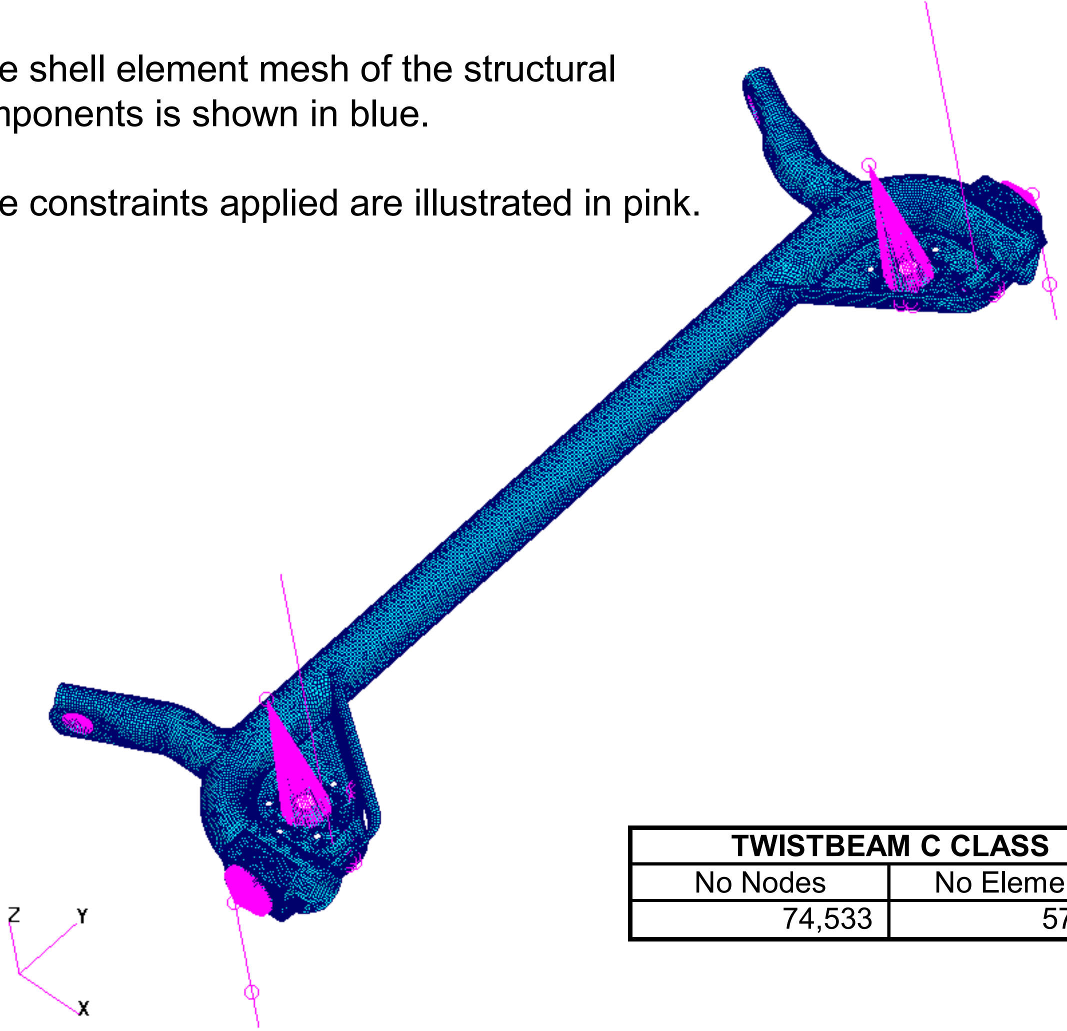
TWISTBEAM

Finite Element Analysis



Finite Element Model of Twistbeam System:

- The shell element mesh of the structural components is shown in blue.
- The constraints applied are illustrated in pink.



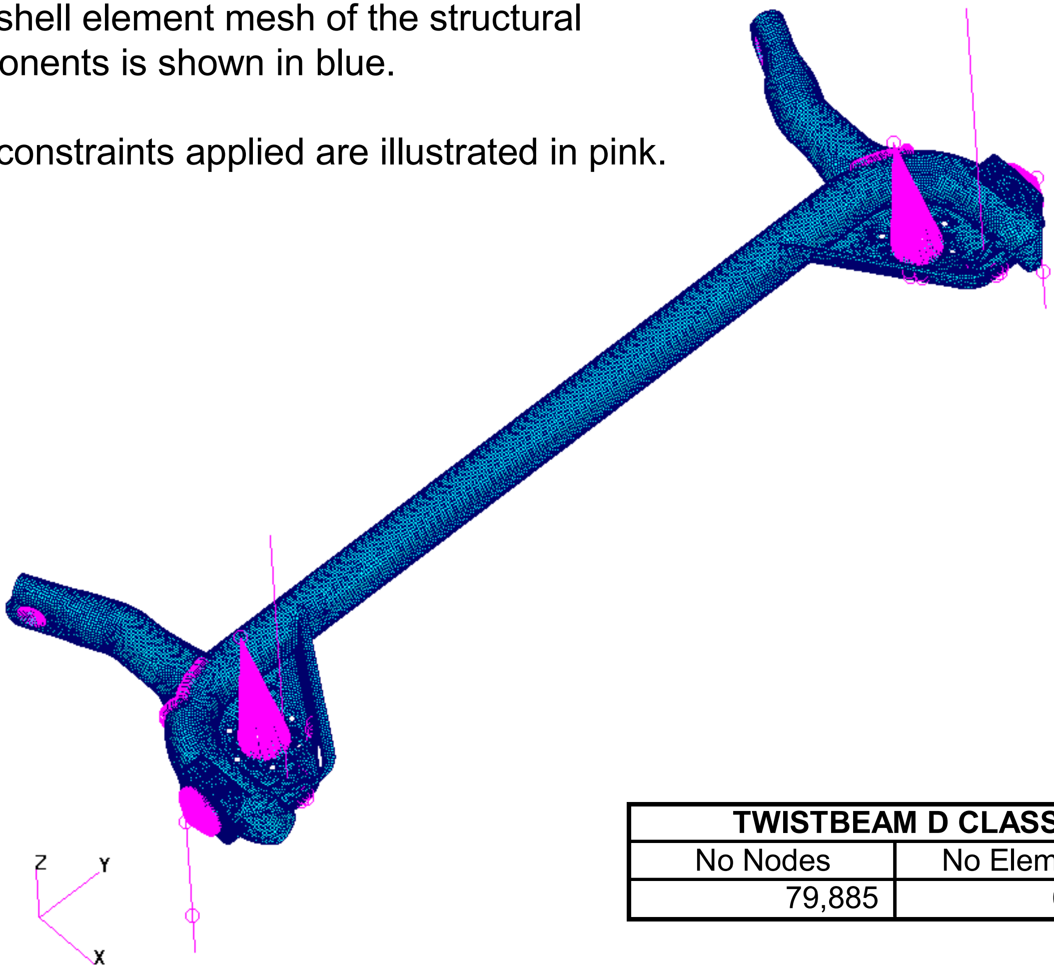
TWISTBEAM C CLASS	
No Nodes	No Elements
74,533	57,096

TWISTBEAM

Finite Element Analysis

Finite Element Model of Twistbeam System:

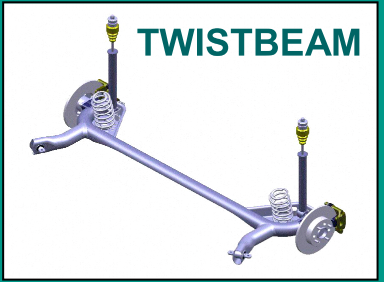
- The shell element mesh of the structural components is shown in blue.
- The constraints applied are illustrated in pink.



TWISTBEAM D CLASS	
No Nodes	No Elements
79,885	62,108

TWISTBEAM

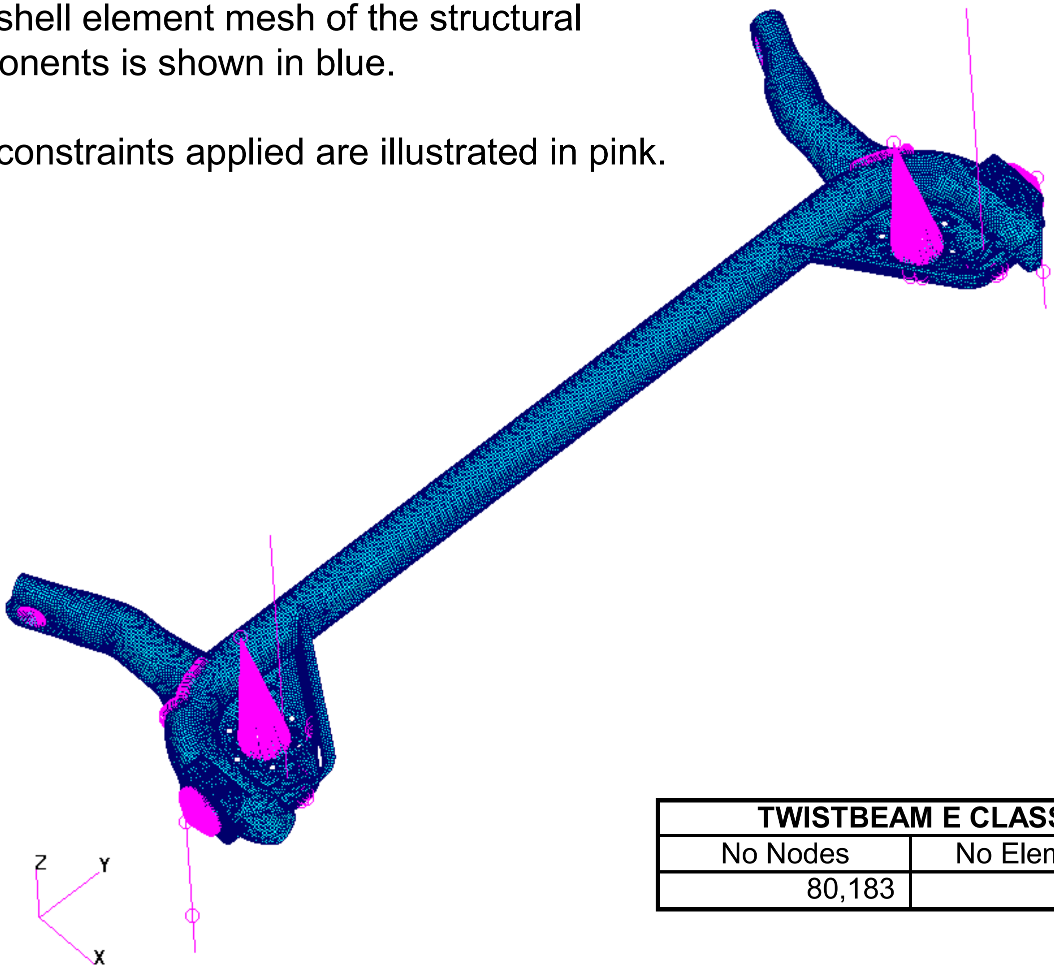
Finite Element Analysis



Finite Element Model of Twistbeam System:

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

- The constraints applied are illustrated in pink.



TWISTBEAM E CLASS	
No Nodes	No Elements
80,183	62,402

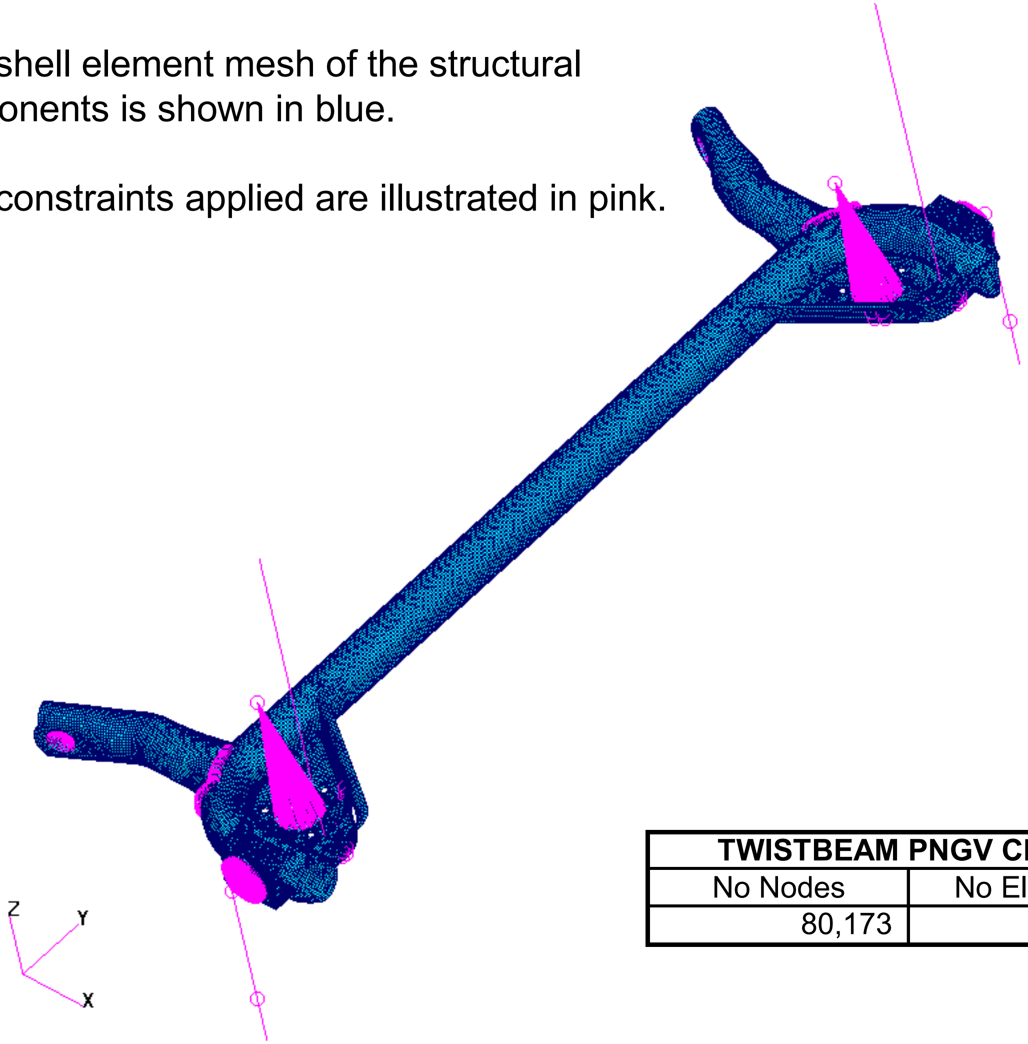
TWISTBEAM

Finite Element Analysis

Finite Element Model of Twistbeam System:

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

- The constraints applied are illustrated in pink.

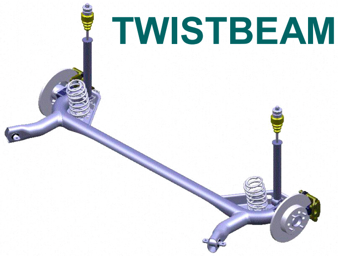


TWISTBEAM PNGV CLASS	
No Nodes	No Elements
80,173	62,388

TWISTBEAM: STRESS RESULTS

B Class with Bushes

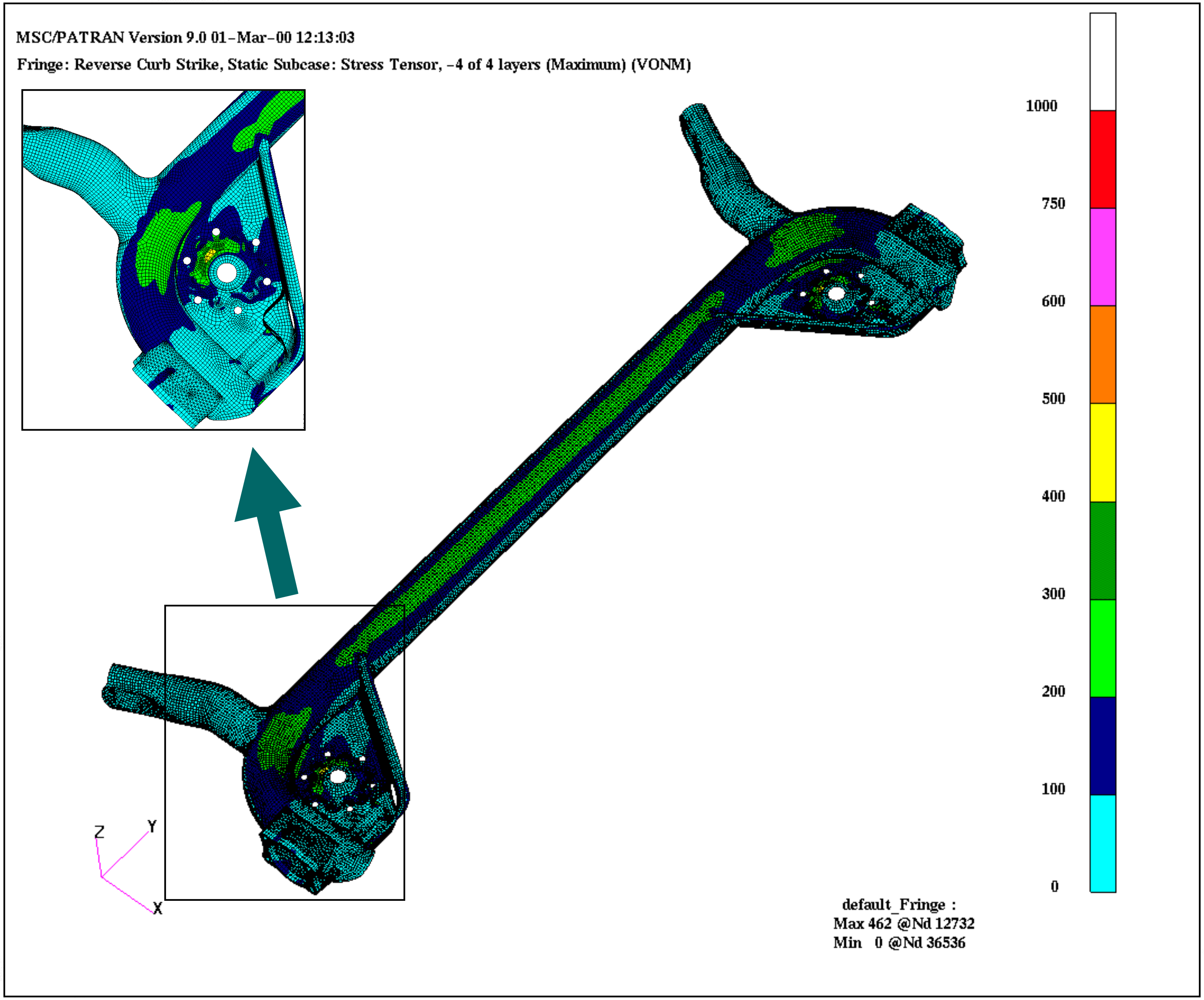
TWISTBEAM



Load Case	Max stress (Von Mises)	Location
Reverse Curb Strike (TCP)	462 MPa	Spring pan
Lateral Curb Strike 1 with load transfer	467 MPa	Spring pan
Lateral Curb Strike 2 with NO load transfer	412 MPa	Spring pan
Vertical Bump (TCP)	577 MPa	Tube
Forward Braking with ABS (TCP)	366 MPa	Spring pan
Combined Bump and Cornering (TCP)	445 MPa	Spring pan
Pothole Brake (TCP)	578 MPa	Tube

TWISTBEAM: TRANSVERSE BEAM

Reverse Curb Strike, B Class

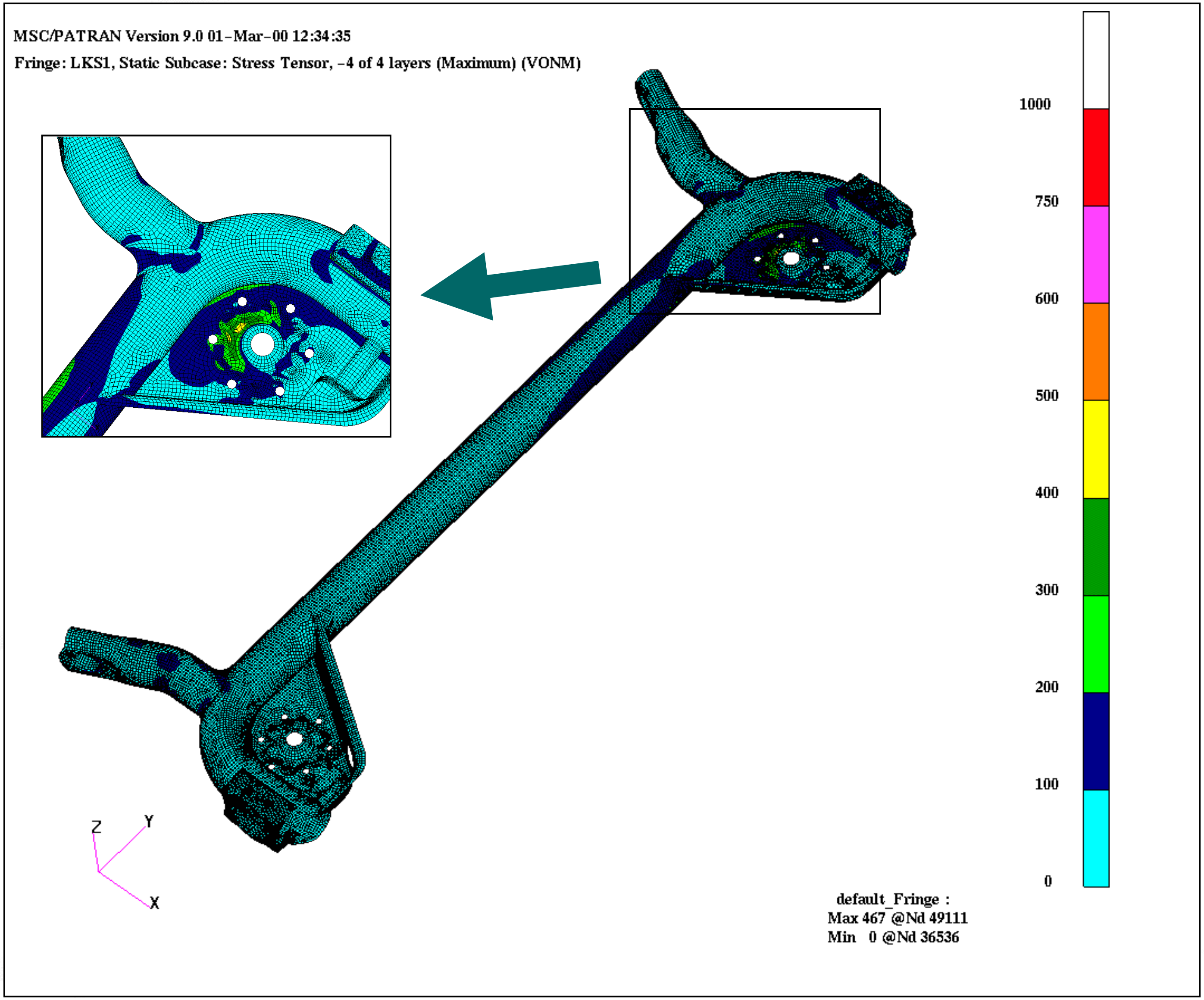

MSC/PATRAN Version 9.0 01-Mar-00 12:13:03
Fringe: Reverse Curb Strike, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

default_Fringe :
Max 462 @Nd 12732
Min 0 @Nd 36536

TWISTBEAM: TRANSEVERSE BEAM

Lateral Curb Strike 1, B Class

TWISTBEAM



MSC/PATRAN Version 9.0 01-Mar-00 12:34:35

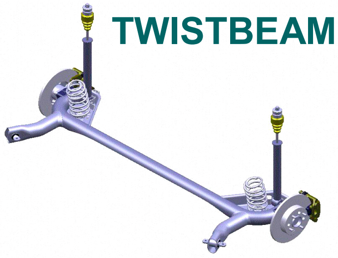
Fringe: LKS1, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

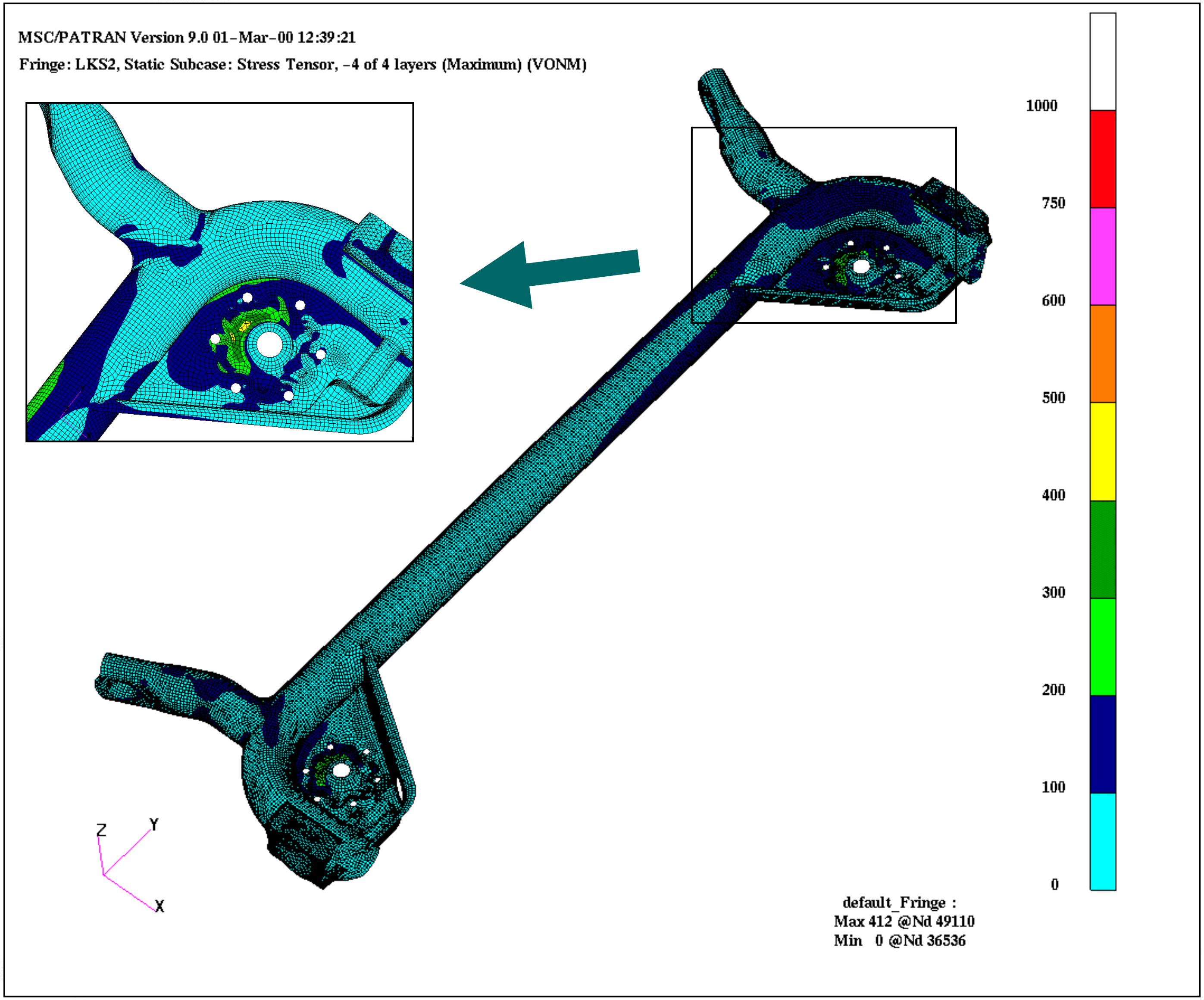
default_Fringe :
Max 467 @Nd 49111
Min 0 @Nd 36536

TWISTBEAM: TRANSVERSE BEAM

Lateral Curb Strike 2, B Class

TWISTBEAM





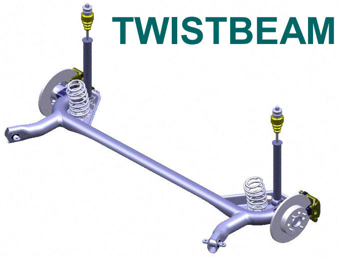
MSC/PATRAN Version 9.0 01-Mar-00 12:39:21

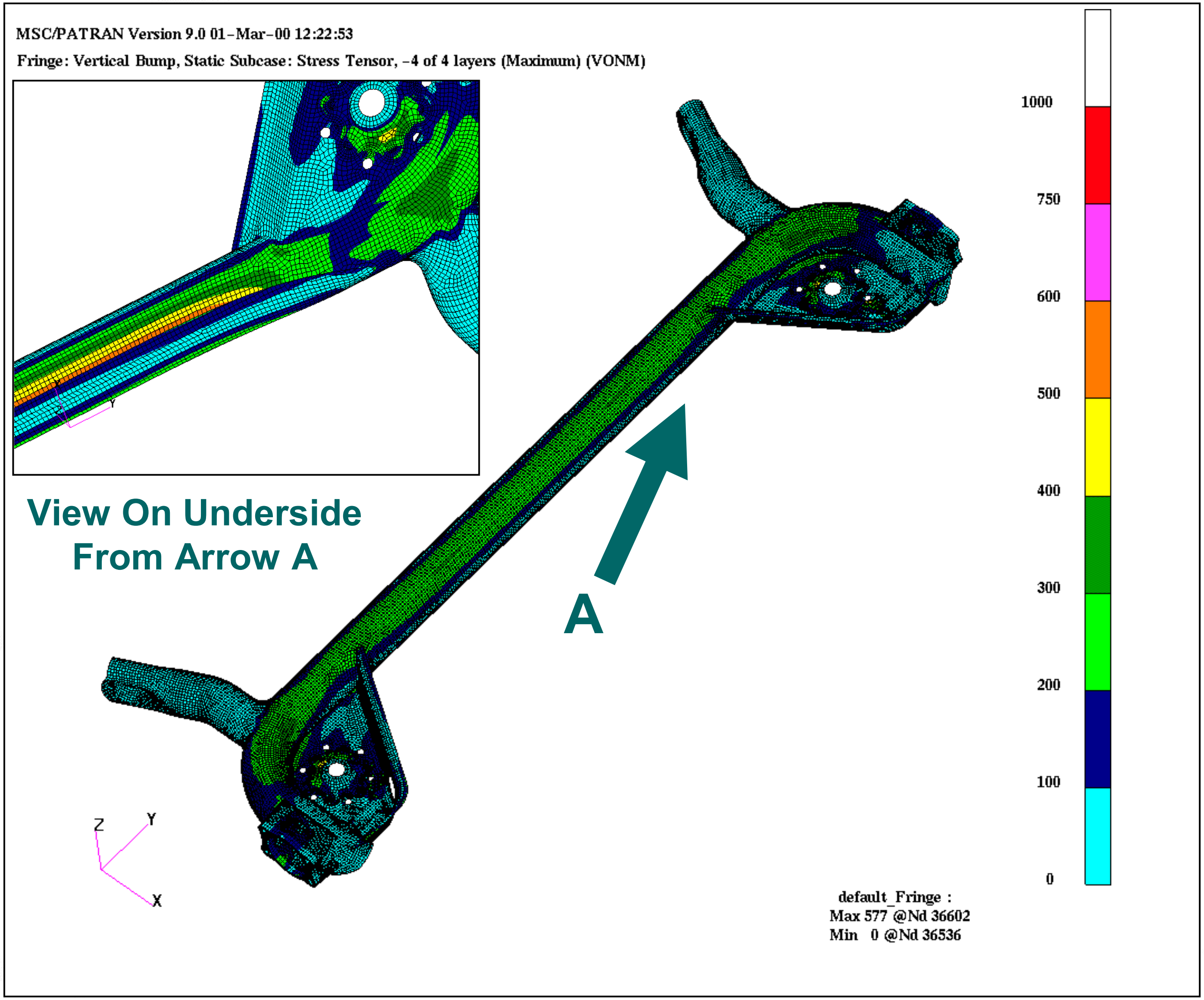
Fringe: LKS2, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

default_Fringe :
Max 412 @Nd 49110
Min 0 @Nd 36536

TWISTBEAM: TRANSVERSE BEAM

Vertical Bump, B Class





MSC/PATRAN Version 9.0 01-Mar-00 12:22:53

Fringe: Vertical Bump, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

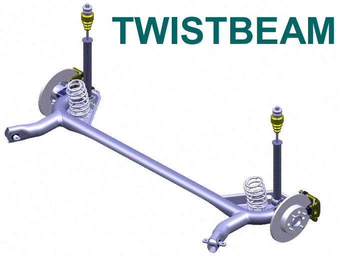
View On Underside From Arrow A

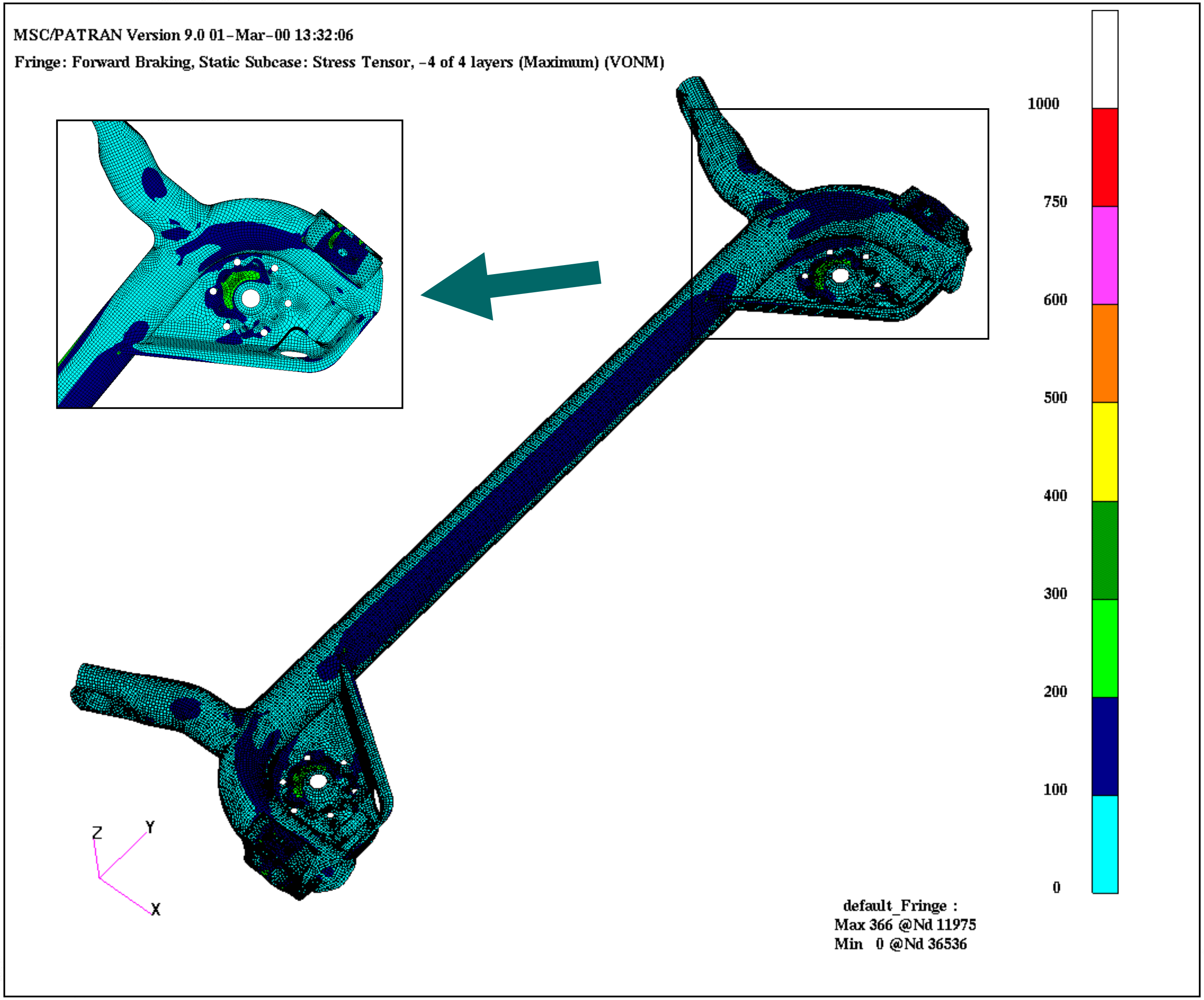
default_Fringe :
Max 577 @Nd 36602
Min 0 @Nd 36536

TWISTBEAM: TRANSVERSE BEAM

Forward Braking, B Class

TWISTBEAM





MSC/PATRAN Version 9.0 01–Mar–00 13:32:06

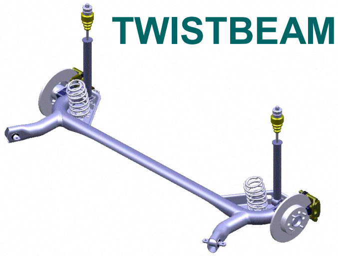
Fringe: Forward Braking, Static Subcase: Stress Tensor, –4 of 4 layers (Maximum) (VONM)

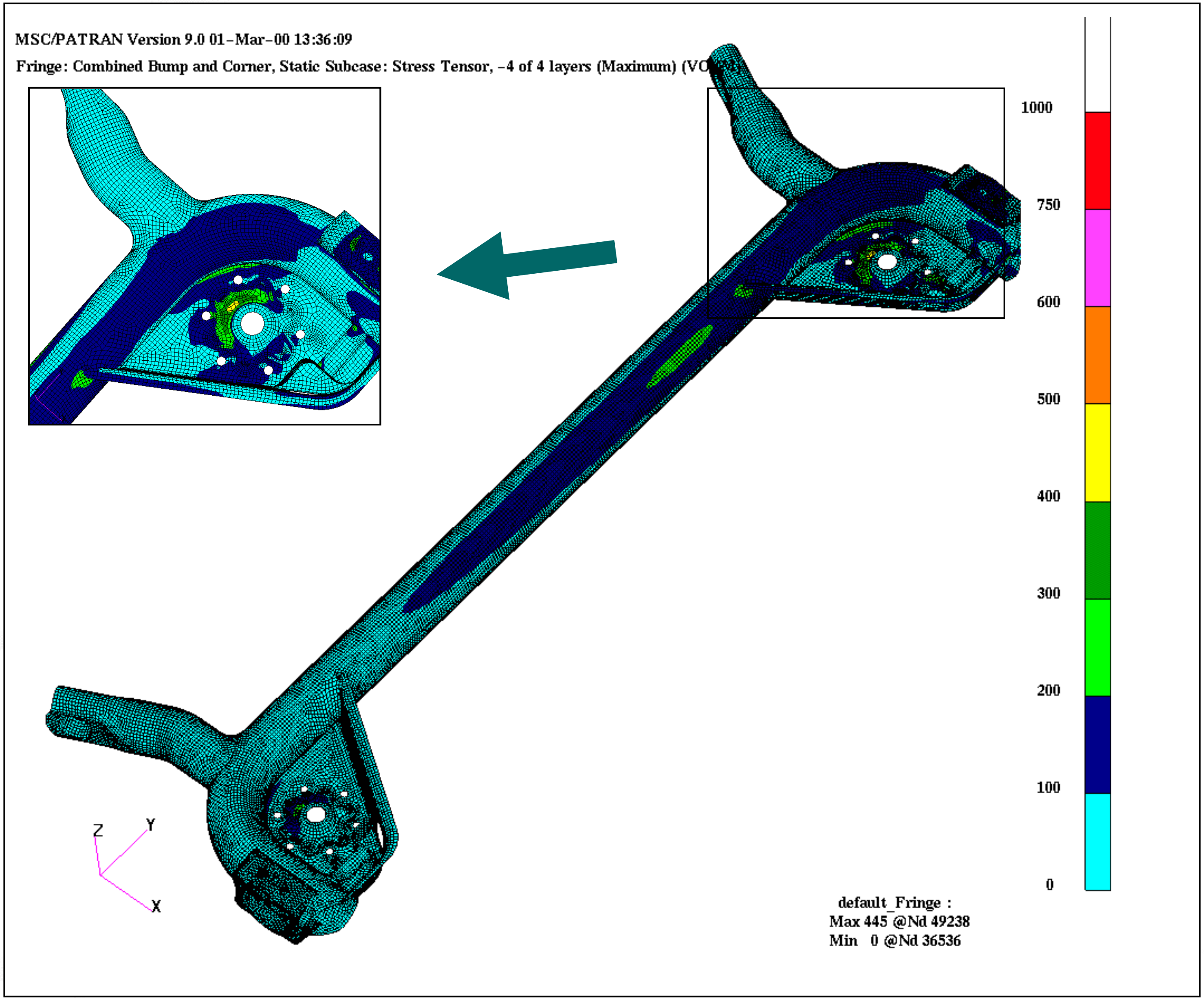
default_Fringe :
Max 366 @Nd 11975
Min 0 @Nd 36536

TWISTBEAM: TRANSVERSE BEAM

Combined Bump & Corner, B Class

TWISTBEAM





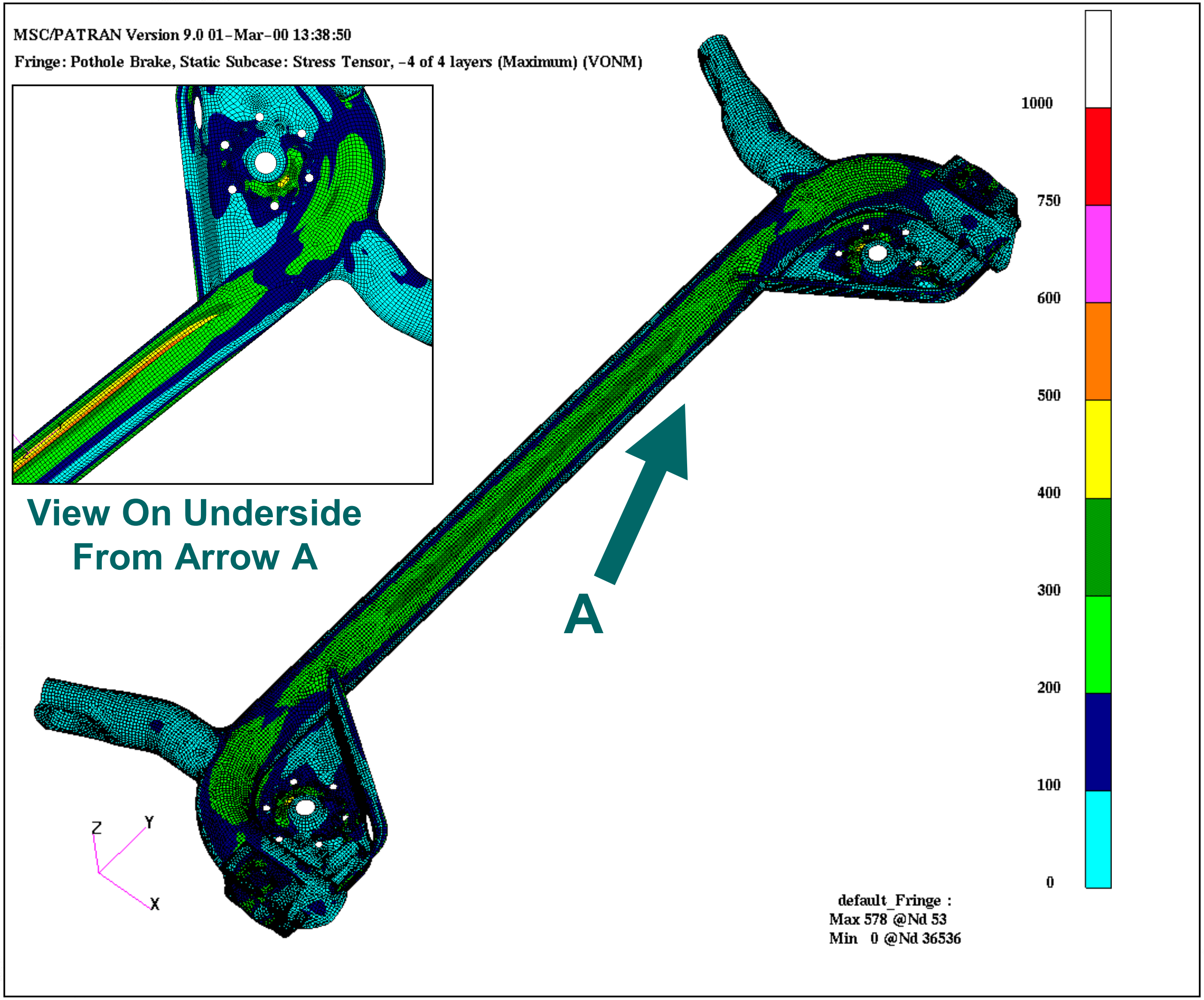
MSC/PATRAN Version 9.0 01-Mar-00 13:36:09

Fringe: Combined Bump and Corner, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VO

default_Fringe :
Max 445 @Nd 49238
Min 0 @Nd 36536

TWISTBEAM: TRANSVERSE BEAM

Pothole Brake, B Class


MSC/PATRAN Version 9.0 01-Mar-00 13:38:50

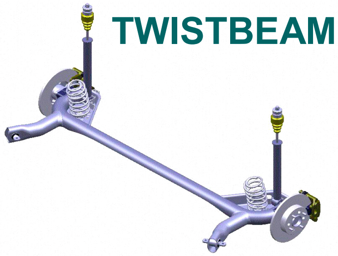
Fringe: Pothole Brake, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

View On Underside From Arrow A

default_Fringe :
Max 578 @Nd 53
Min 0 @Nd 36536

TWISTBEAM: STRESS RESULTS

C Class with Bushes

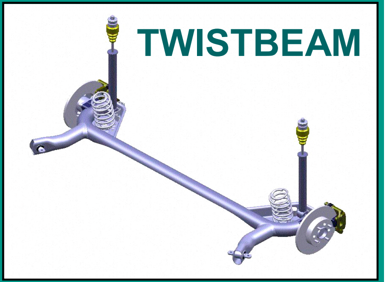


TWISTBEAM

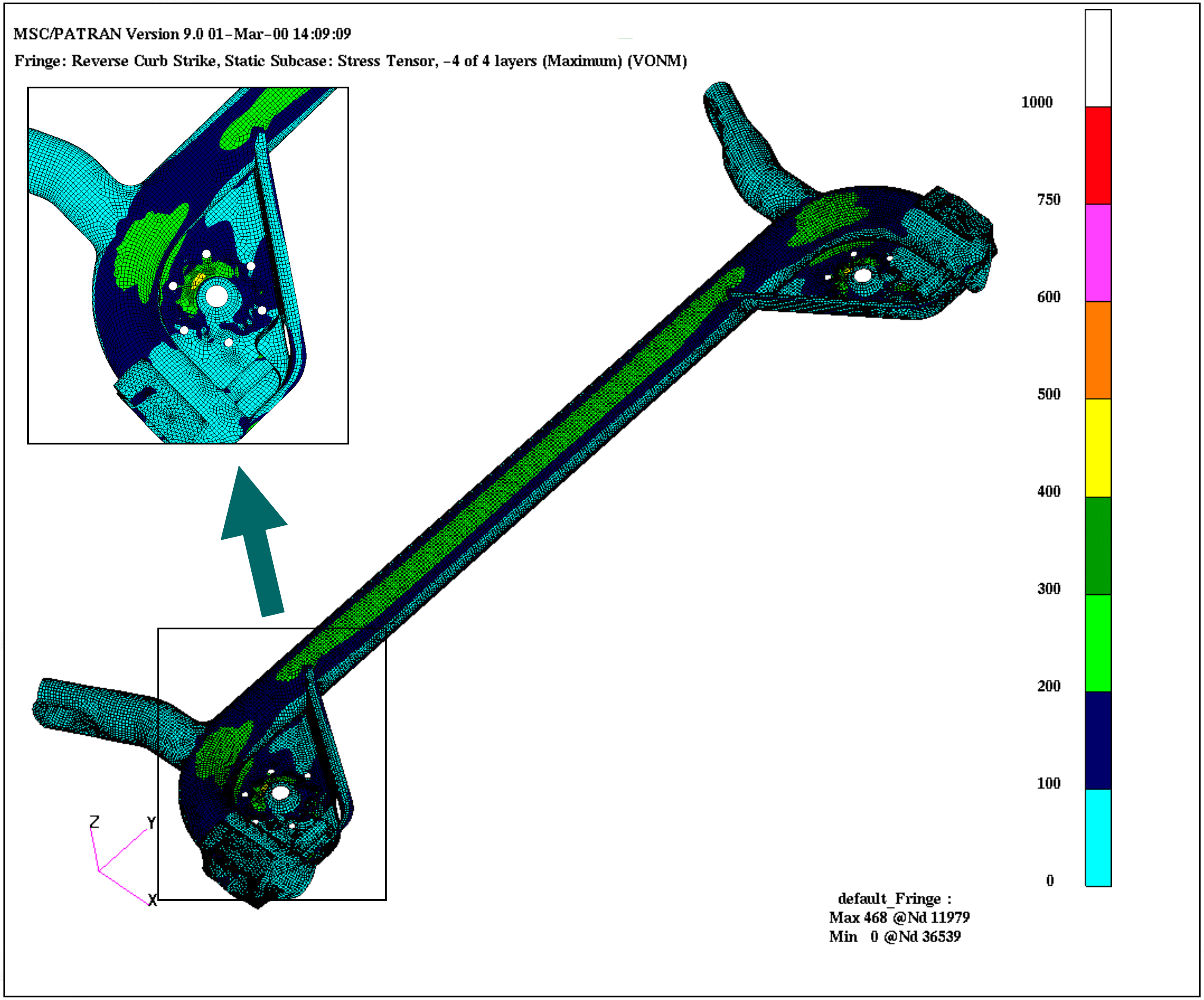
Load Case	Max stress (Von Mises)	Location
Reverse Curb Strike (TCP)	468 MPa	Spring pan
Lateral Curb Strike 1 with load transfer	472 MPa	Spring pan
Lateral Curb Strike 2 with NO load transfer	416 MPa	Knuckle join
Vertical Bump (TCP)	592 MPa	Tube
Forward Braking with ABS (TCP)	355 MPa	Knuckle join
Combined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

TWISTBEAM: TRANVERSE BEAM

Reverse Curb Strike, C Class



TWISTBEAM



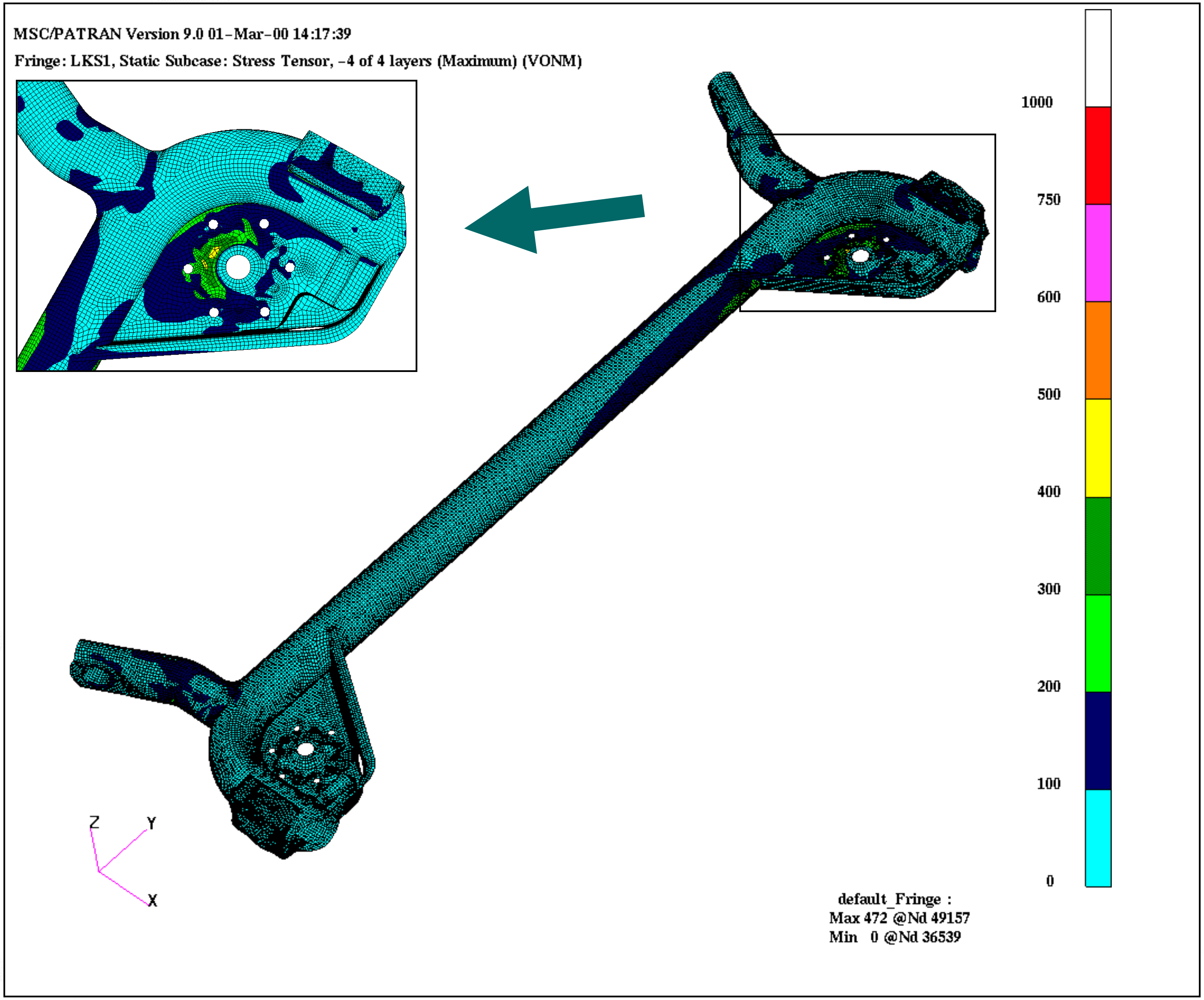
MSC/PATRAN Version 9.0 01-Mar-00 14:09:09

Fringe: Reverse Curb Strike, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

default_Fringe :
Max 468 @Nd 11979
Min 0 @Nd 36539

TWISTBEAM: TRANSVERSE BEAM

Lateral Curb Strike 1, C Class



MSC/PATRAN Version 9.0 01-Mar-00 14:17:39

Fringe: LKS1, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

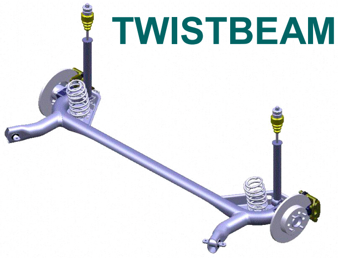
default_Fringe :
Max 472 @Nd 49157
Min 0 @Nd 36539

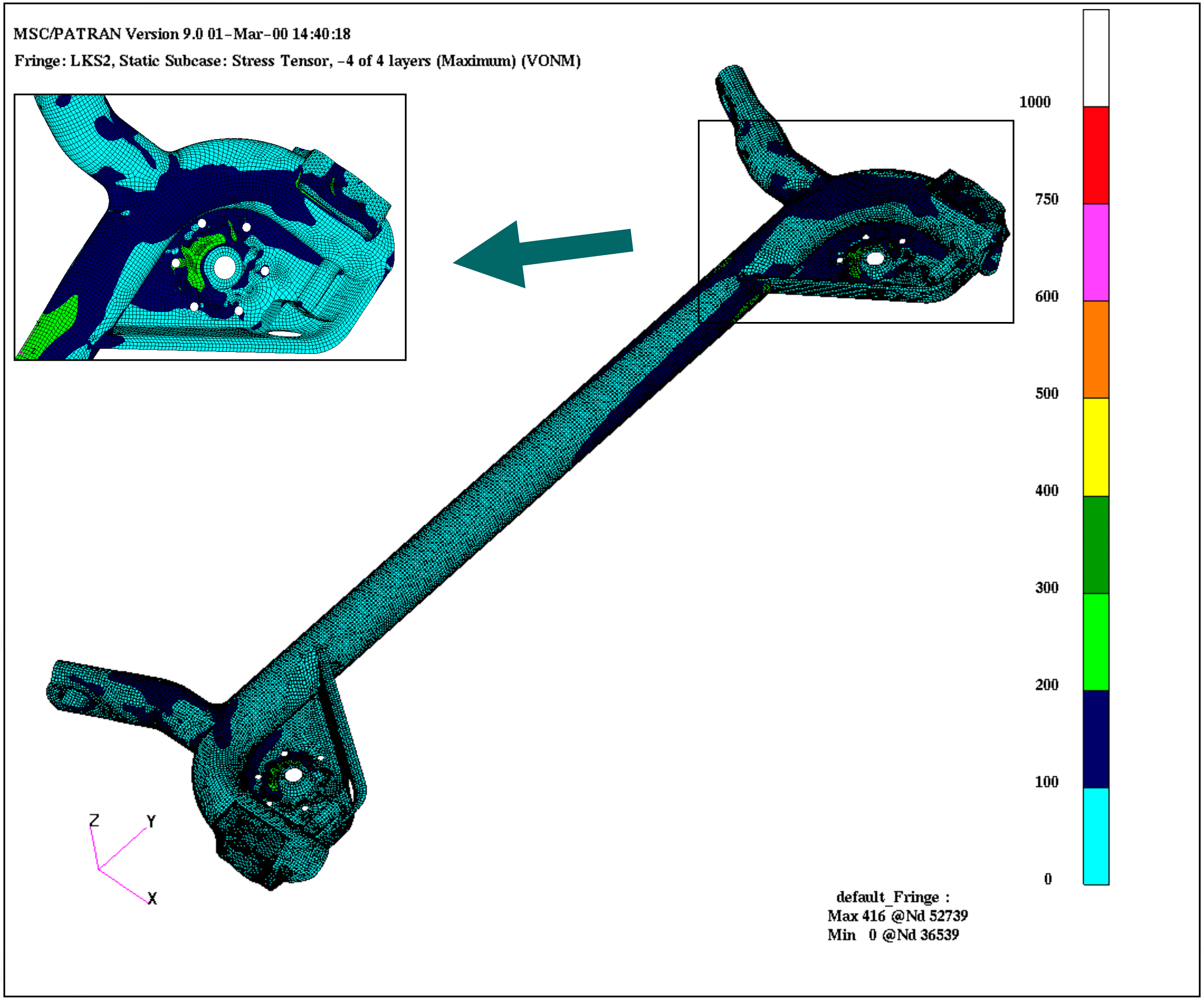
ULTRALIGHT
STEEL
AUTO SUSPENSION

TWISTBEAM: TRANSVERSE BEAM

Lateral Curb Strike 2, C Class

TWISTBEAM



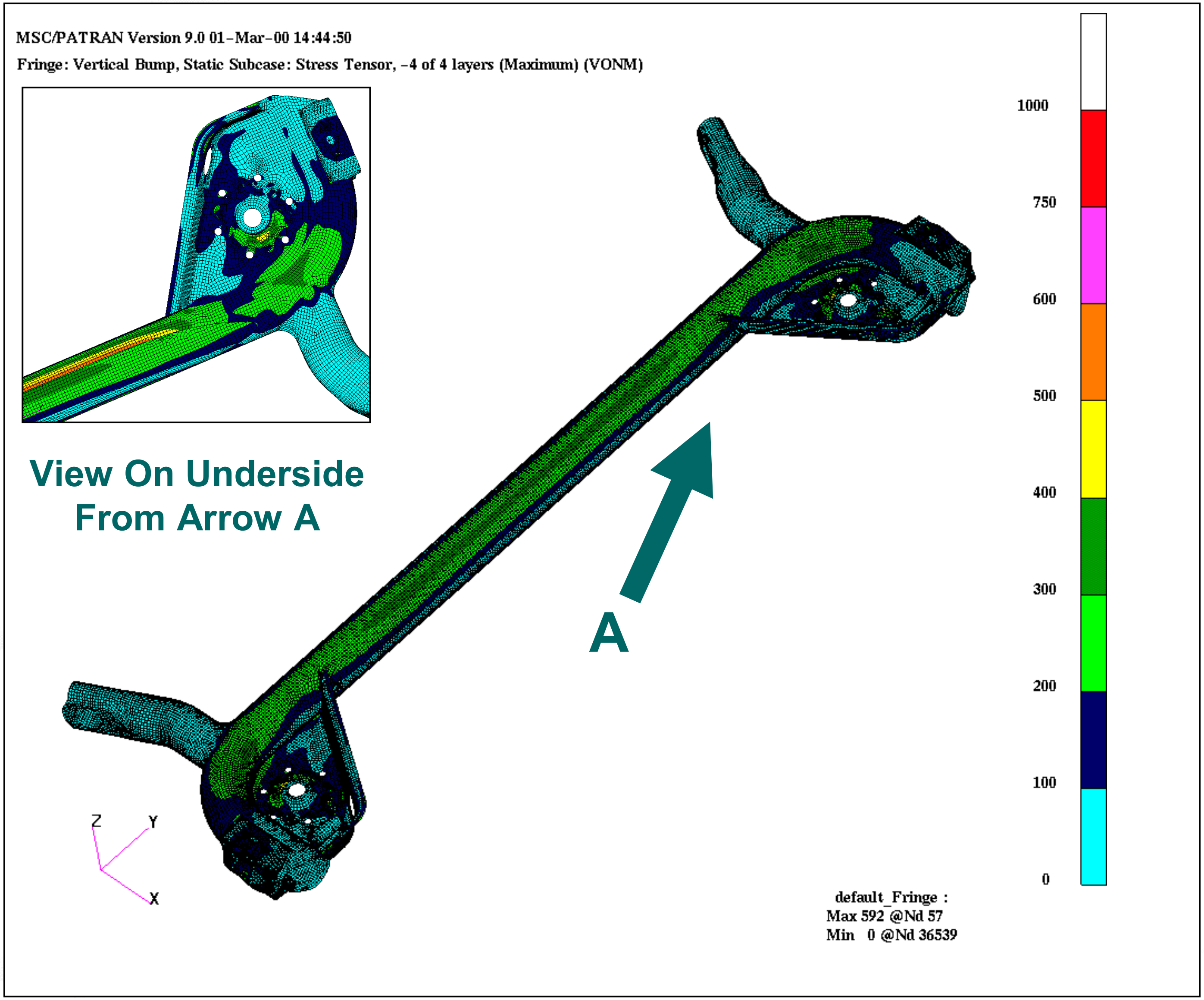


MSC/PATRAN Version 9.0 01-Mar-00 14:40:18
Fringe: LKS2, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

default_Fringe :
Max 416 @Nd 52739
Min 0 @Nd 36539

TWISTBEAM: TRANSVERSE BEAM

Vertical Bump, C Class



MSC/PATRAN Version 9.0 01-Mar-00 14:44:50

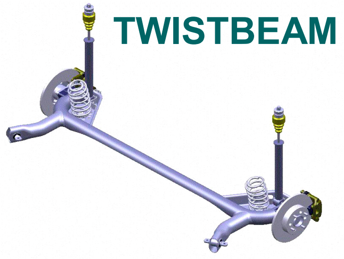
Fringe: Vertical Bump, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

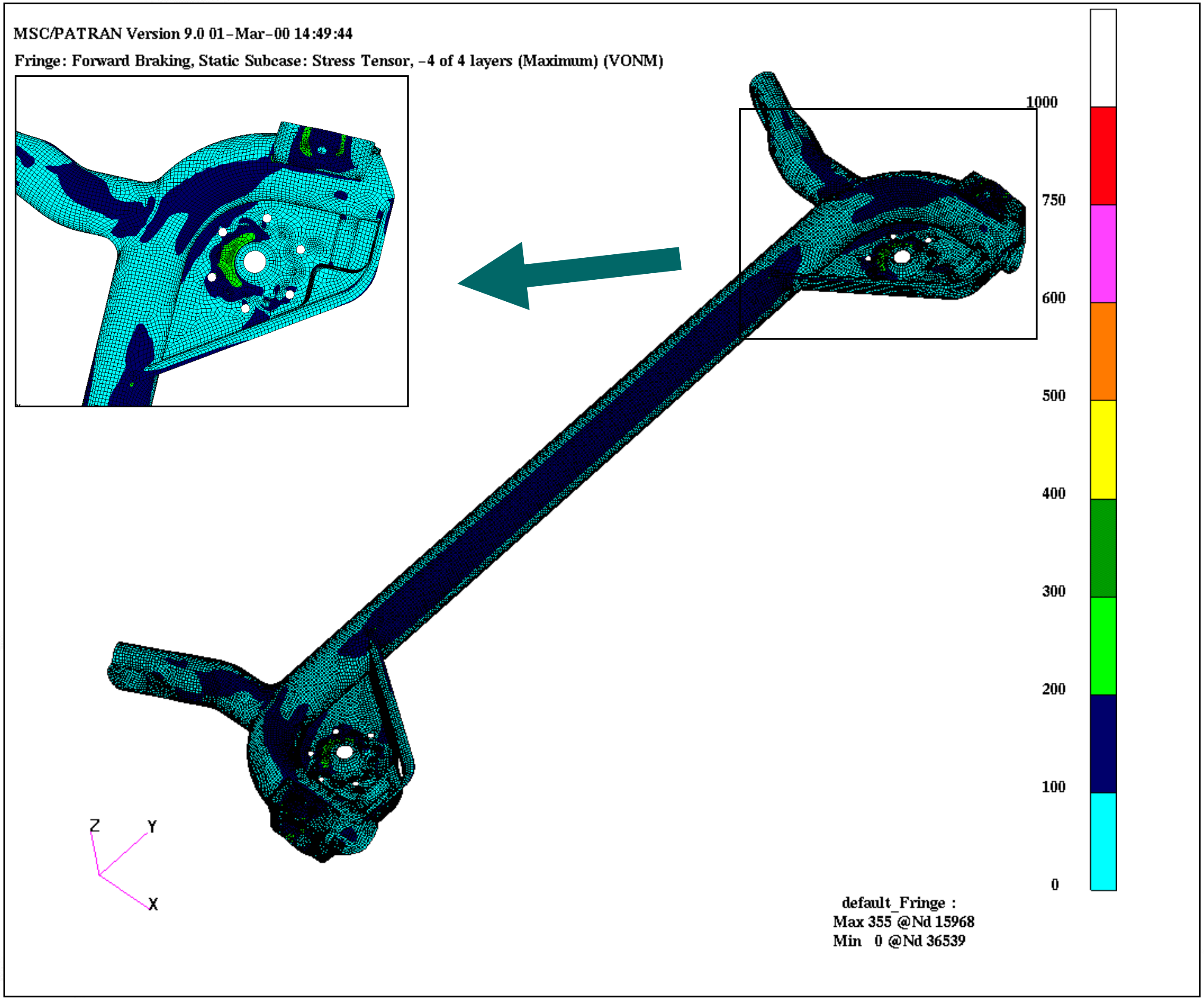
View On Underside From Arrow A

default_Fringe :
Max 592 @Nd 57
Min 0 @Nd 36539

TWISTBEAM: TRANSVERSE BEAM

Forward Braking, C Class




MSC/PATRAN Version 9.0 01-Mar-00 14:49:44

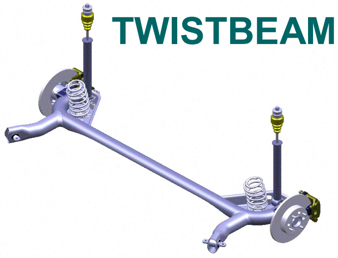
Fringe: Forward Braking, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

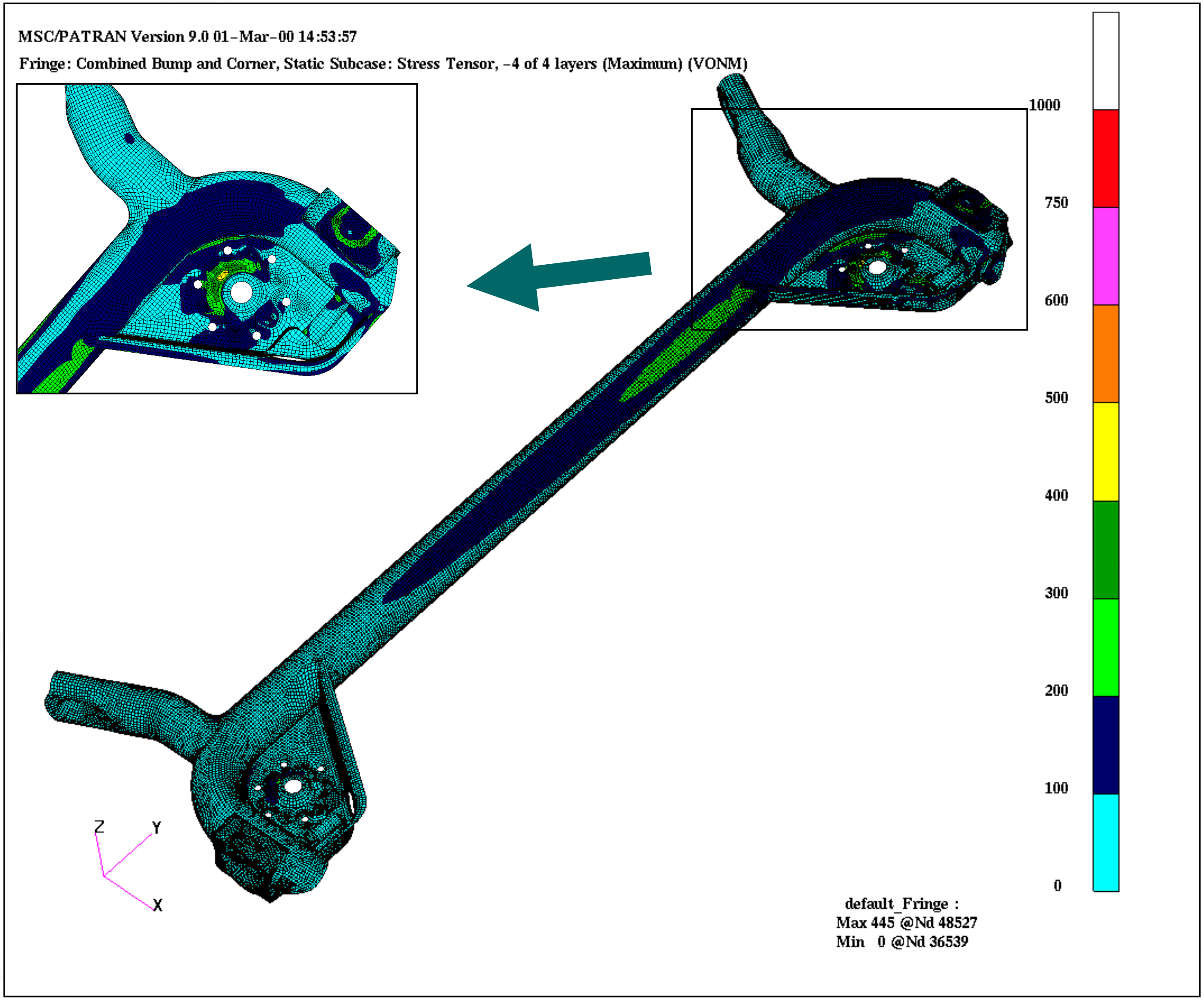
default_Fringe :
Max 355 @Nd 15968
Min 0 @Nd 36539

TWISTBEAM: TRANSVERSE BEAM

Combined Bump & Corner, C Class

TWISTBEAM





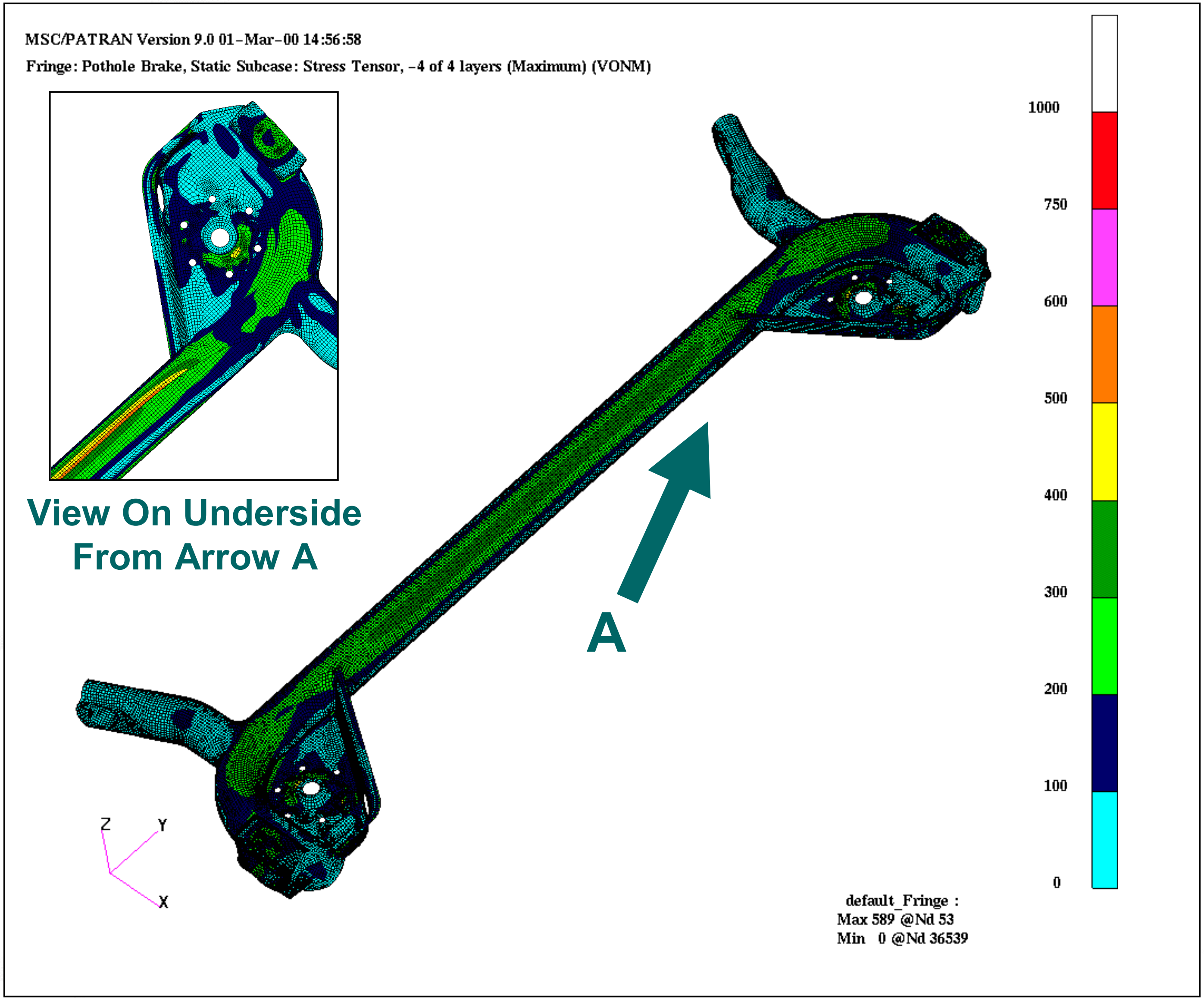
MSC/PATRAN Version 9.0 01-Mar-00 14:53:57

Fringe: Combined Bump and Corner, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

default_Fringe :
Max 445 @Nd 48527
Min 0 @Nd 36539

TWISTBEAM: TRANSVERSE BEAM

Pothole Brake, C Class



MSC/PATRAN Version 9.0 01-Mar-00 14:56:58

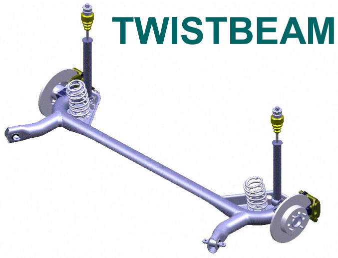
Fringe: Pothole Brake, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

View On Underside From Arrow A

default_Fringe :
Max 589 @Nd 53
Min 0 @Nd 36539

TWISTBEAM: STRESS RESULTS

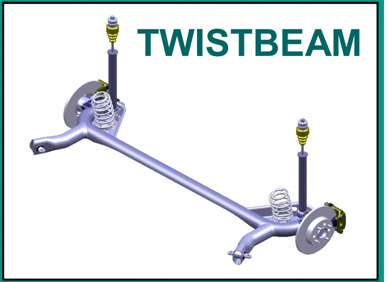
D Class with Bushes

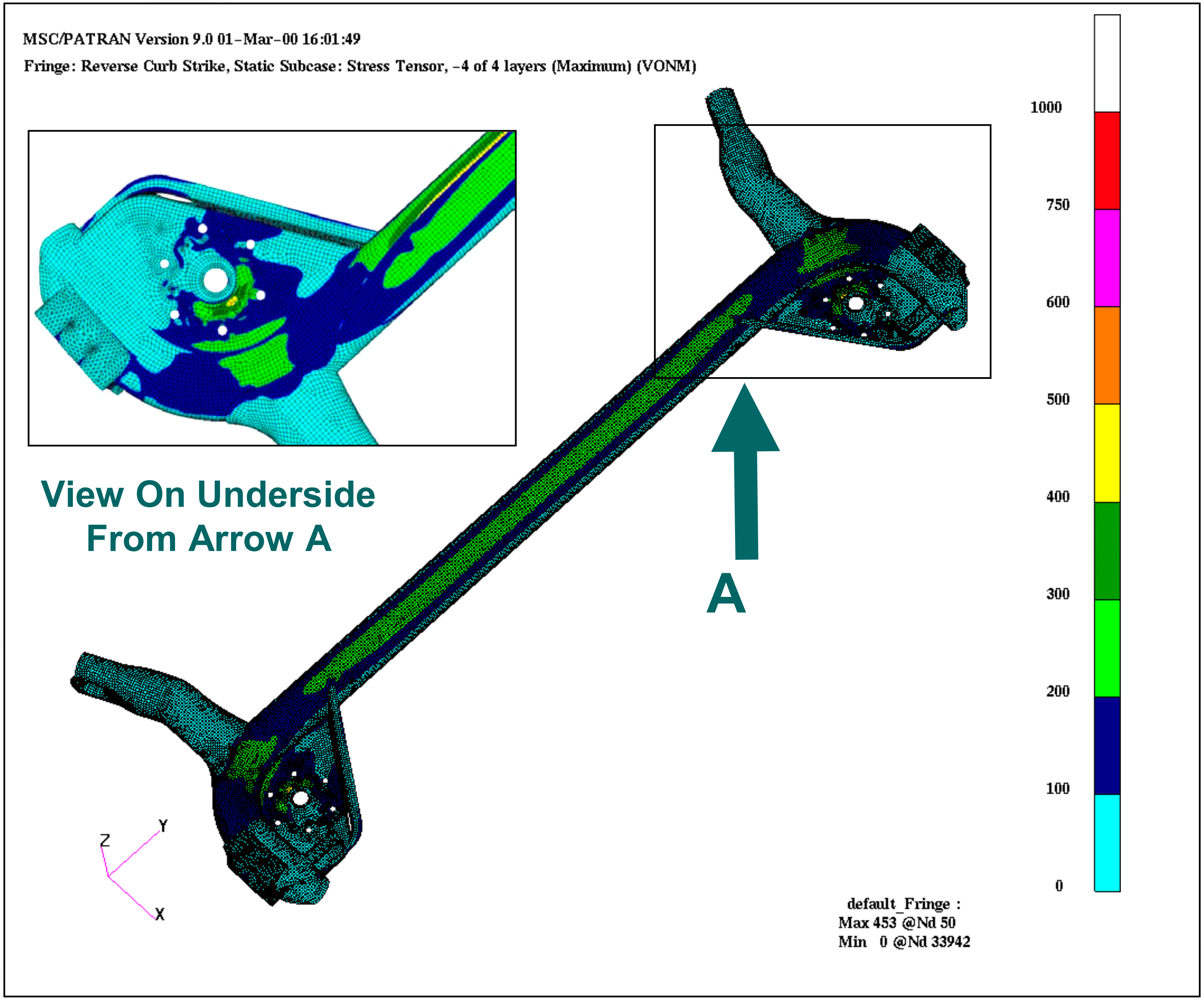


Load Case	Max stress (Von Mises)	Location
Reverse Curb Strike (TCP)	453 MPa	Tube
Lateral Curb Strike 1 with load transfer	474 MPa	Spring pan
Lateral Curb Strike 2 with NO load transfer	528 MPa	Knuckle join
Vertical Bump (TCP)	577 MPa	Tube
Forward Braking with ABS (TCP)	391 MPa	Knuckle join
Combined Bump and Cornering (TCP)	422 MPa	Spring pan
Pothole Brake (TCP)	574 MPa	Tube

TWISTBEAM: TRANSVERSE BEAM

Reverse Curb Strike, D Class





MSC/PATRAN Version 9.0 01-Mar-00 16:01:49

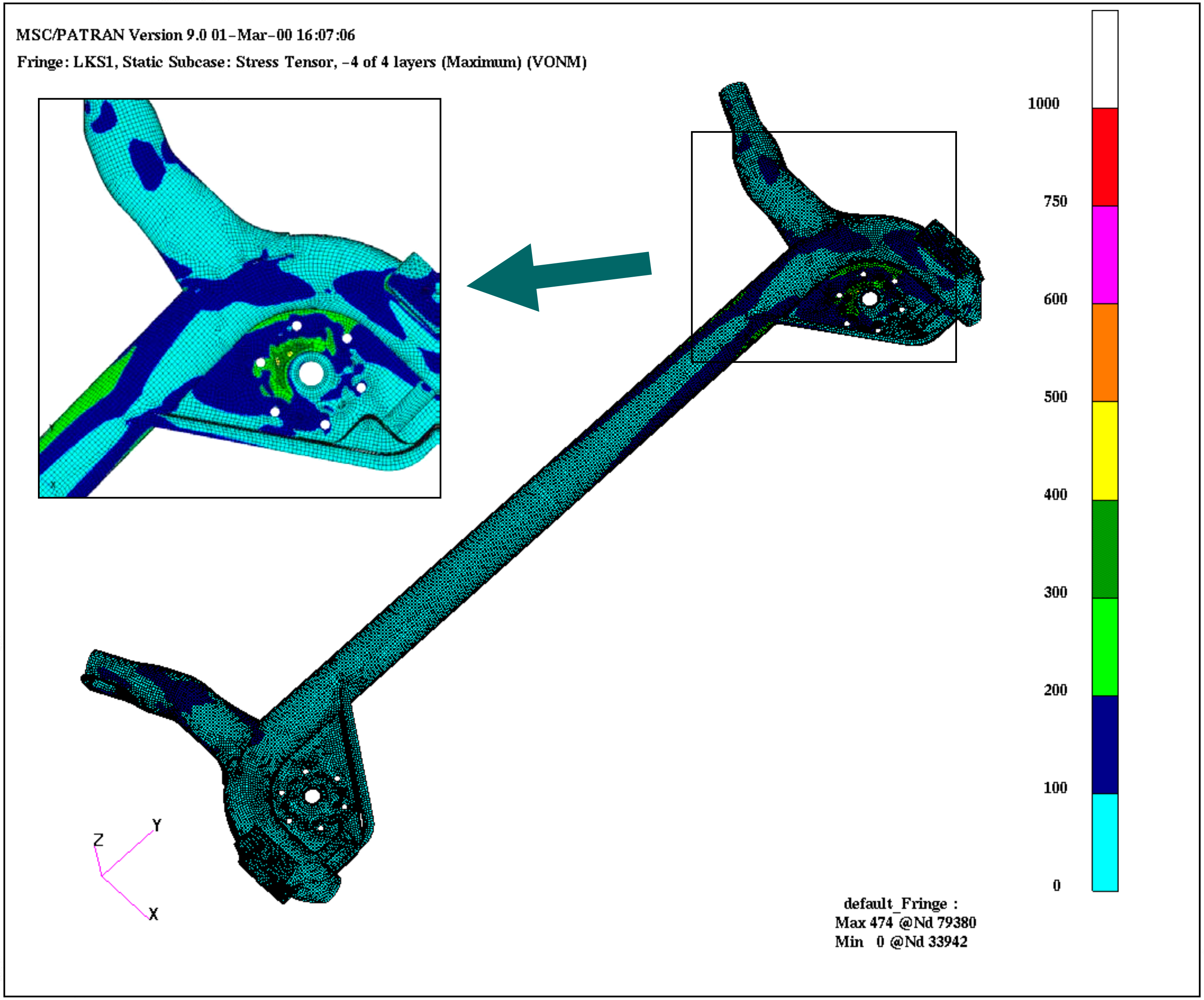
Fringe: Reverse Curb Strike, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

View On Underside From Arrow A

default_Fringe :
Max 453 @Nd 50
Min 0 @Nd 33942

TWISTBEAM: TRANSVERSE BEAM

Lateral Curb Strike 1, D Class


MSC/PATRAN Version 9.0 01-Mar-00 16:07:06

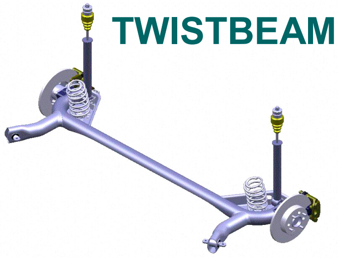
Fringe: LKS1, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

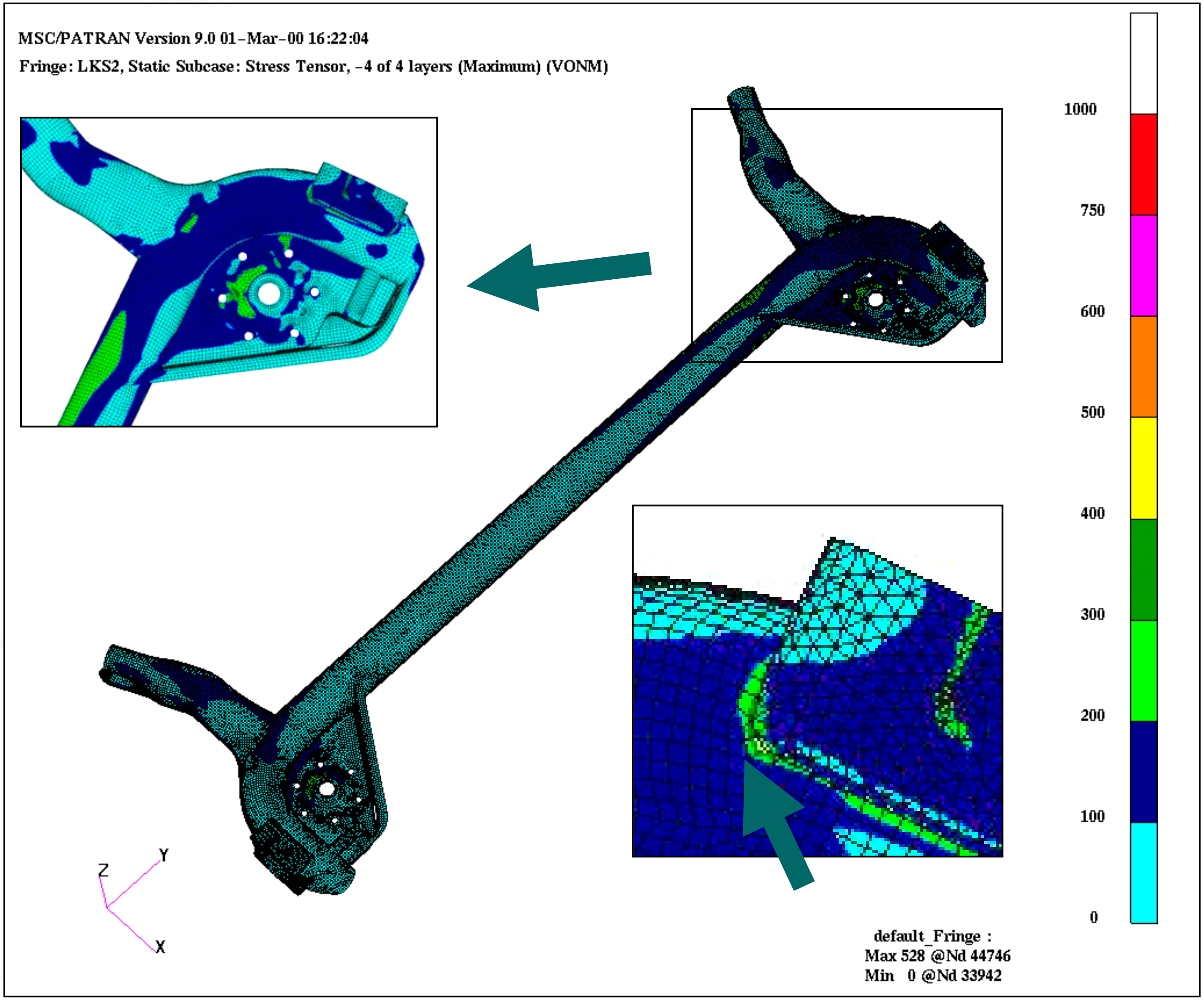
default_Fringe :
Max 474 @Nd 79380
Min 0 @Nd 33942

TWISTBEAM: TRANSVERSE BEAM

Lateral Curb Strike 2, D Class

TWISTBEAM





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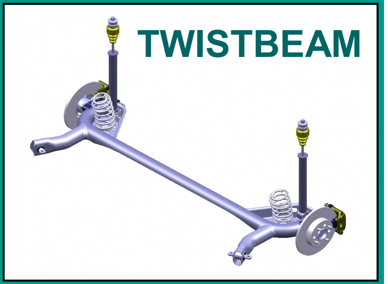
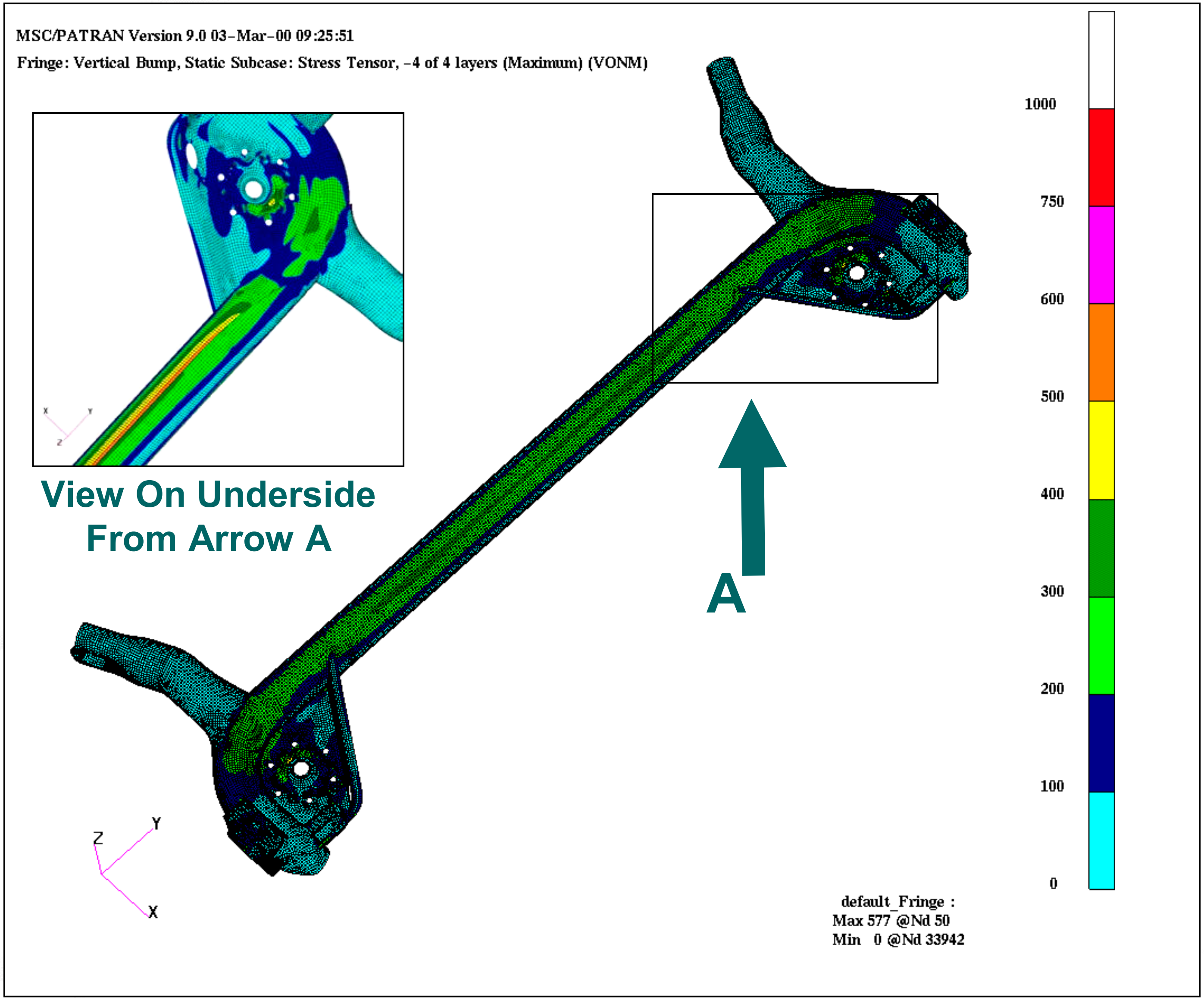
MSC/PATRAN Version 9.0 01-Mar-00 16:22:04
Fringe: LKS2, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)
```

```
default_Fringe :
Max 528 @Nd 44746
Min   0 @Nd 33942
```

TWISTBEAM: TRANSVERSE BEAM

Vertical Bump, D Class





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MSC/PATRAN Version 9.0 03-Mar-00 09:25:51
Fringe: Vertical Bump, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)
```
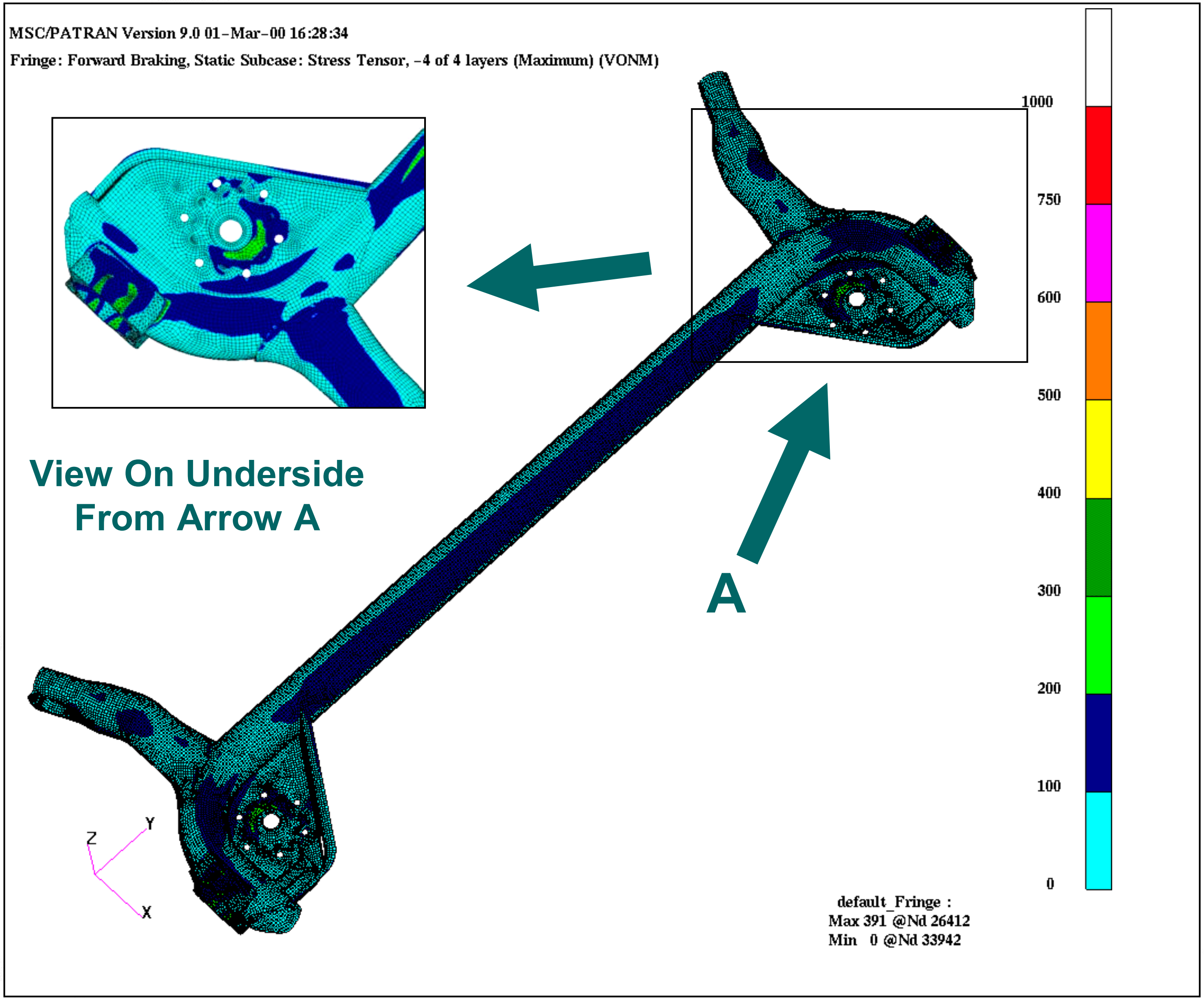

View On Underside From Arrow A

```
default_Fringe :
Max 577 @Nd 50
Min   0 @Nd 33942
```

TWISTBEAM: TRANSVERSE BEAM

Forward Braking, D Class



MSC/PATRAN Version 9.0 01-Mar-00 16:28:34

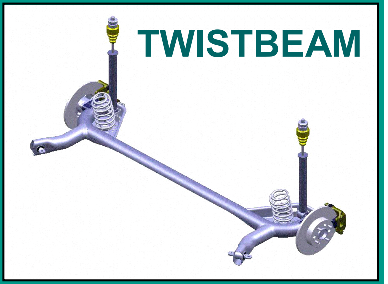
Fringe: Forward Braking, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

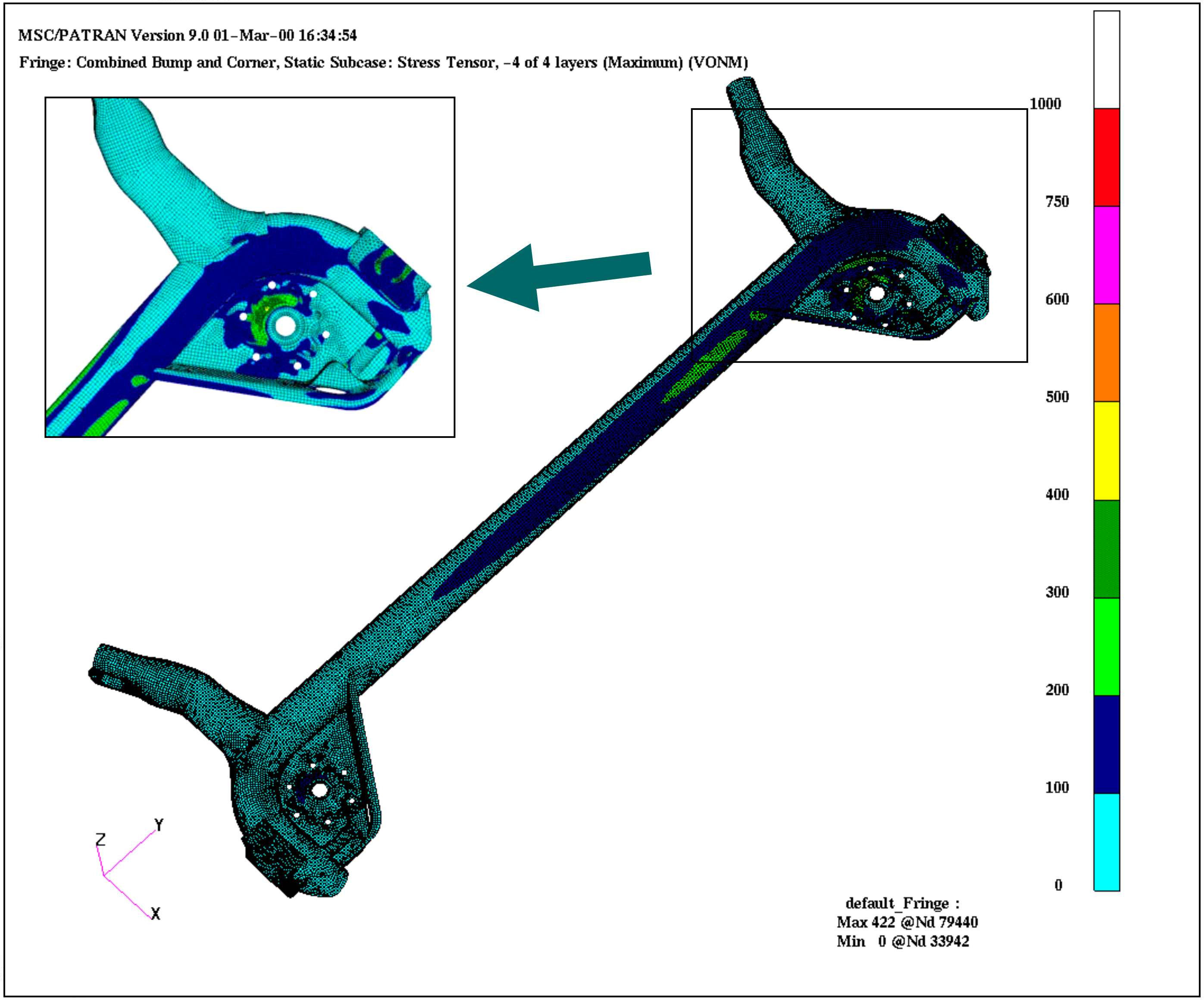
View On Underside From Arrow A

default_Fringe :
Max 391 @Nd 26412
Min 0 @Nd 33942

TWISTBEAM: TRANSVERSE BEAM

Combined Bump & Corner, D Class



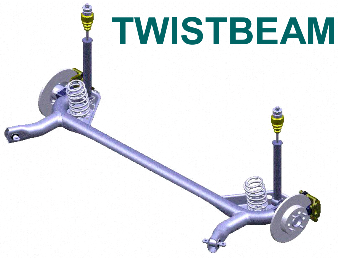

MSC/PATRAN Version 9.0 01-Mar-00 16:34:54

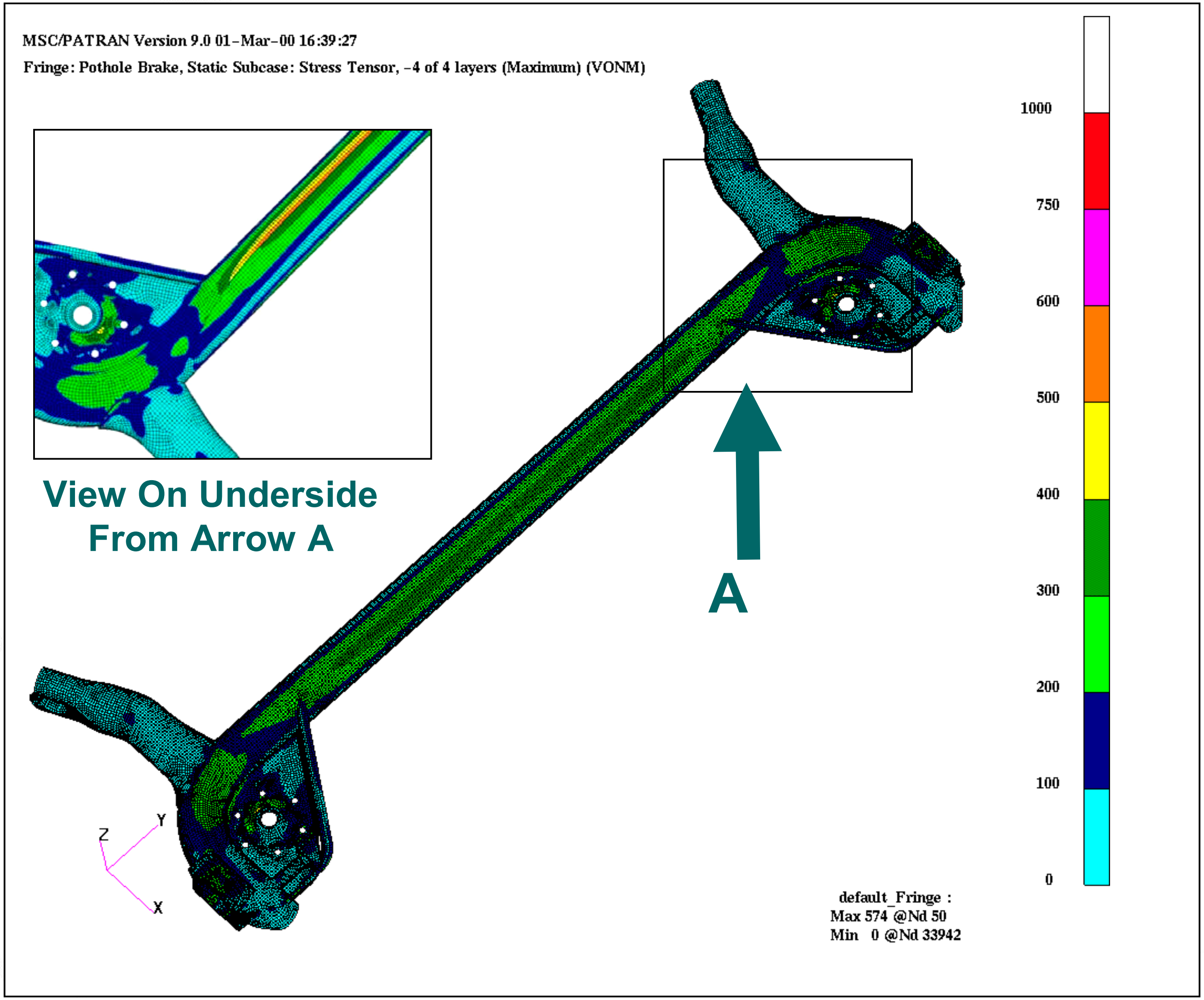
Fringe: Combined Bump and Corner, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

default_Fringe :
Max 422 @Nd 79440
Min 0 @Nd 33942

TWISTBEAM: TRANSVERSE BEAM

Pothole Brake, D Class




MSC/PATRAN Version 9.0 01-Mar-00 16:39:27

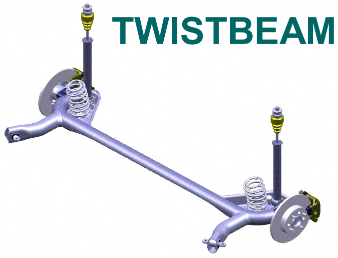
Fringe: Pothole Brake, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

View On Underside From Arrow A

default_Fringe :
Max 574 @Nd 50
Min 0 @Nd 33942

TWISTBEAM: STRESS RSULTS

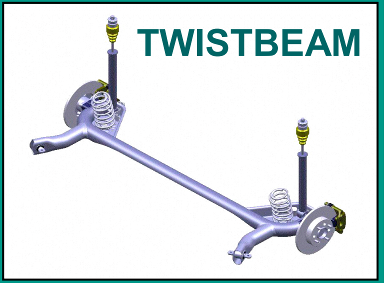
E Class with Bushes

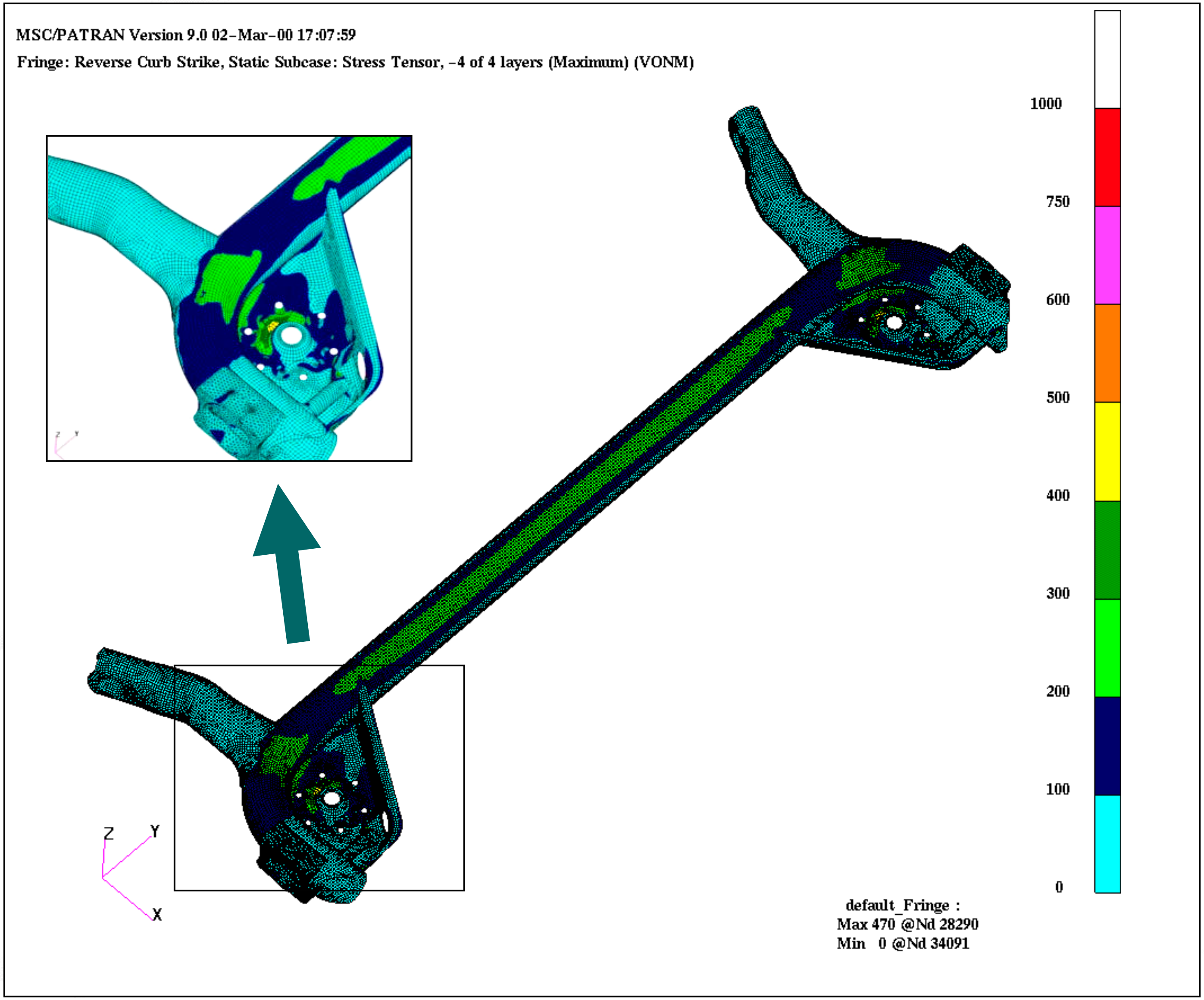


Load Case	Max stress (Von Mises)	Location
Reverse Curb Strike (TCP)	**470 MPa**	Spring pan
Lateral Curb Strike 1 with load transfer	**504 MPa**	Spring pan
Lateral Curb Strike 2 with NO load transfer	**535 MPa**	Knuckle join
Vertical Bump (TCP)	**575 MPa**	Tube
Forward Braking with ABS (TCP)	**417 MPa**	Knuckle join
Combined Bump and Cornering (TCP)	**445 MPa**	Spring pan
Pothole Brake (TCP)	**571 MPa**	Tube

TWISTBEAM: TRANSVERSE BEAM

Reverse Curb Strike, E Class





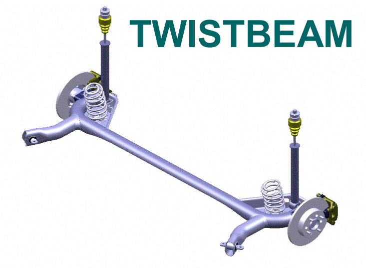
MSC/PATRAN Version 9.0 02-Mar-00 17:07:59

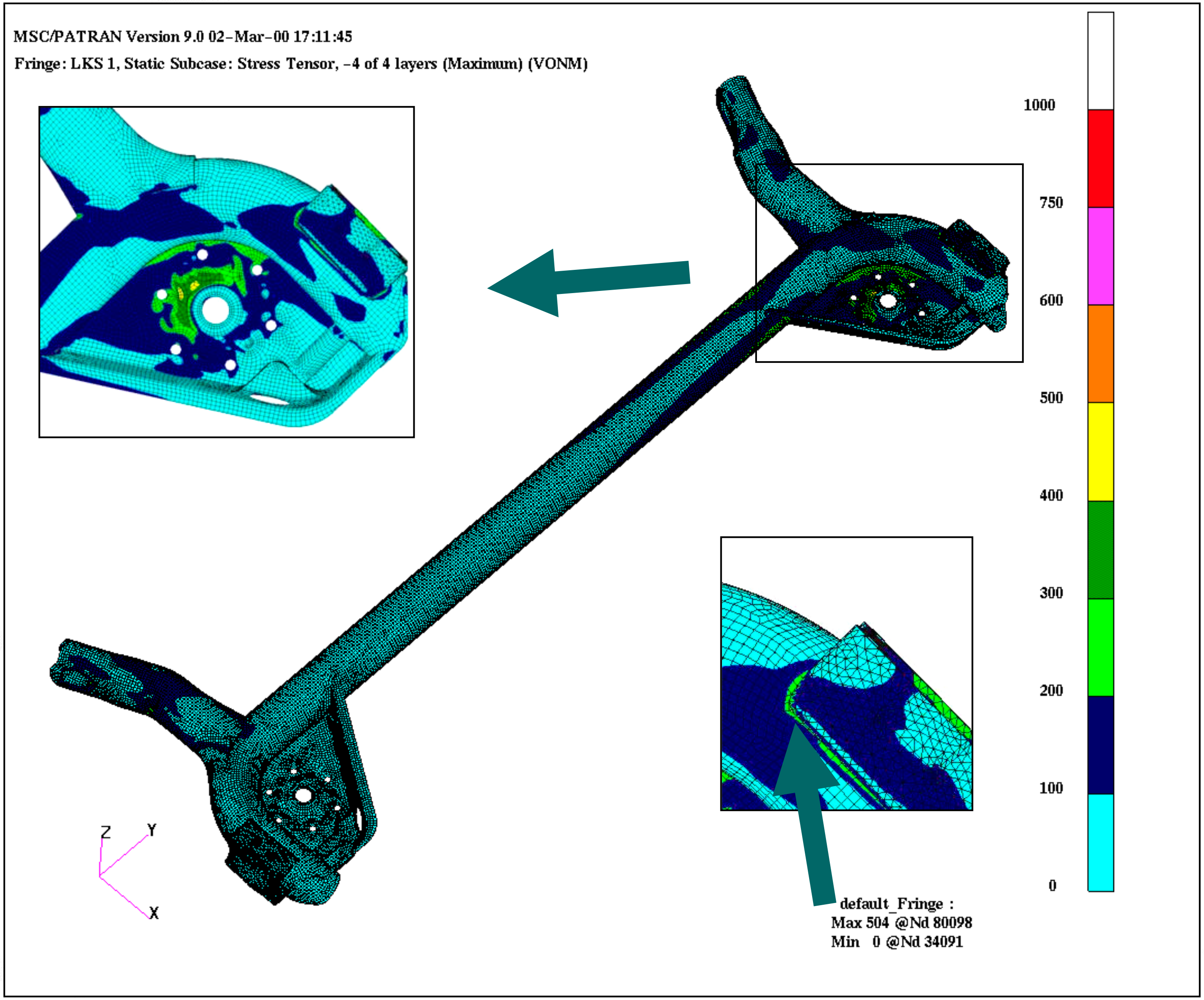
Fringe: Reverse Curb Strike, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

default_Fringe :
Max 470 @Nd 28290
Min 0 @Nd 34091

TWISTBEAM: TRANSVERSE BEAM

Lateral Curb Strike 1, E Class





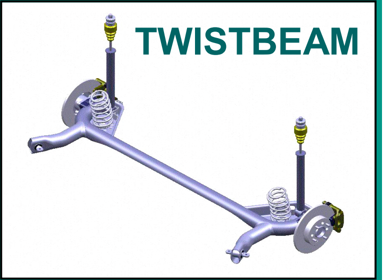
MSC/PATRAN Version 9.0 02-Mar-00 17:11:45

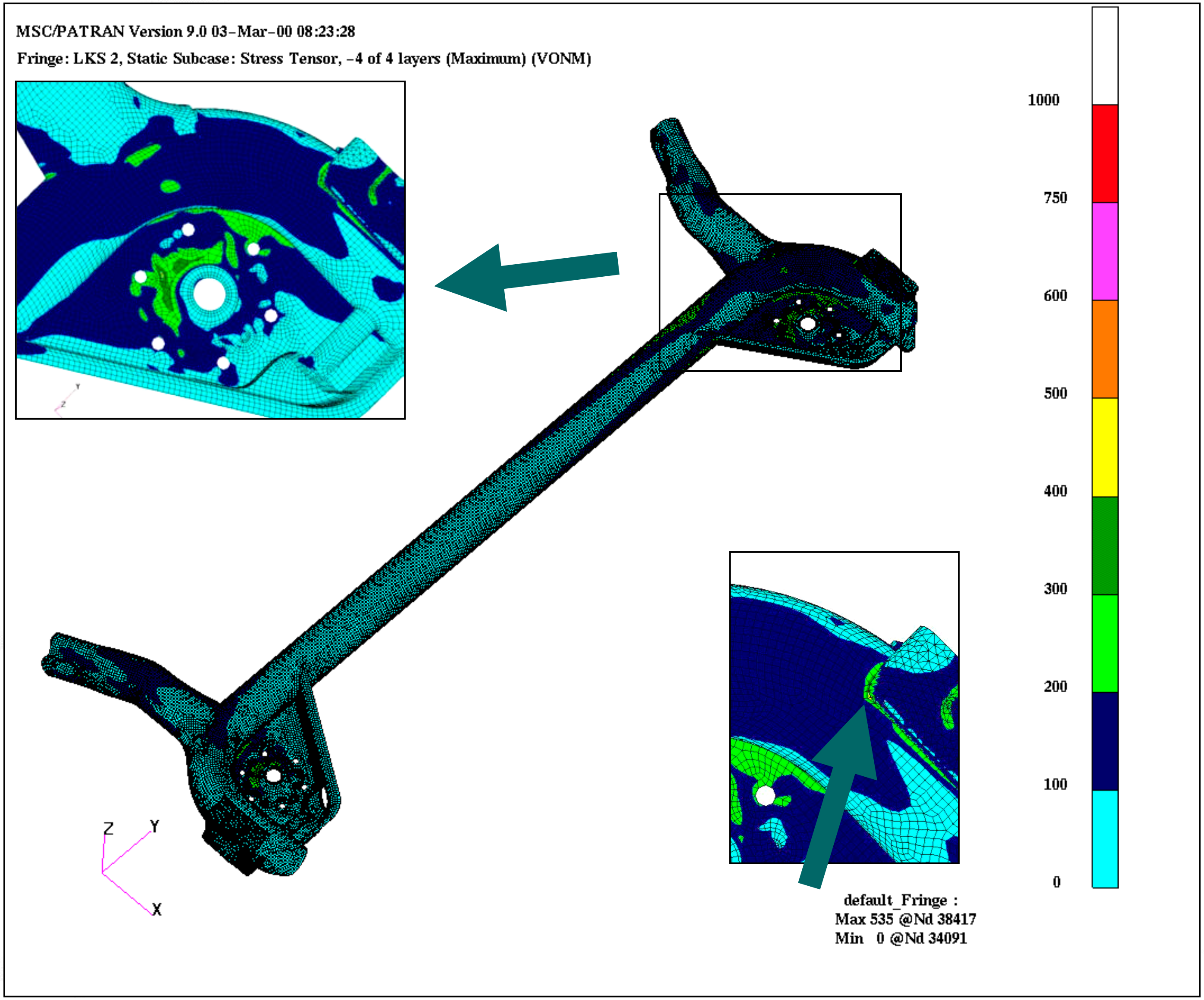
Fringe: LKS 1, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

default_Fringe :
Max 504 @Nd 80098
Min 0 @Nd 34091

TWISTBEAM: TRANSVERSE BEAM

Lateral Curb Strike 2, E Class




MSC/PATRAN Version 9.0 03–Mar–00 08:23:28

Fringe: LKS 2, Static Subcase: Stress Tensor, –4 of 4 layers (Maximum) (VONM)

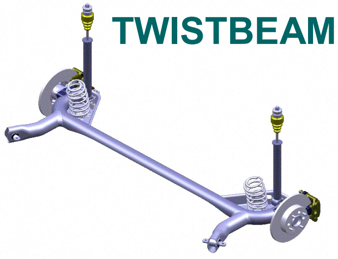
default_Fringe :
Max 535 @Nd 38417
Min 0 @Nd 34091

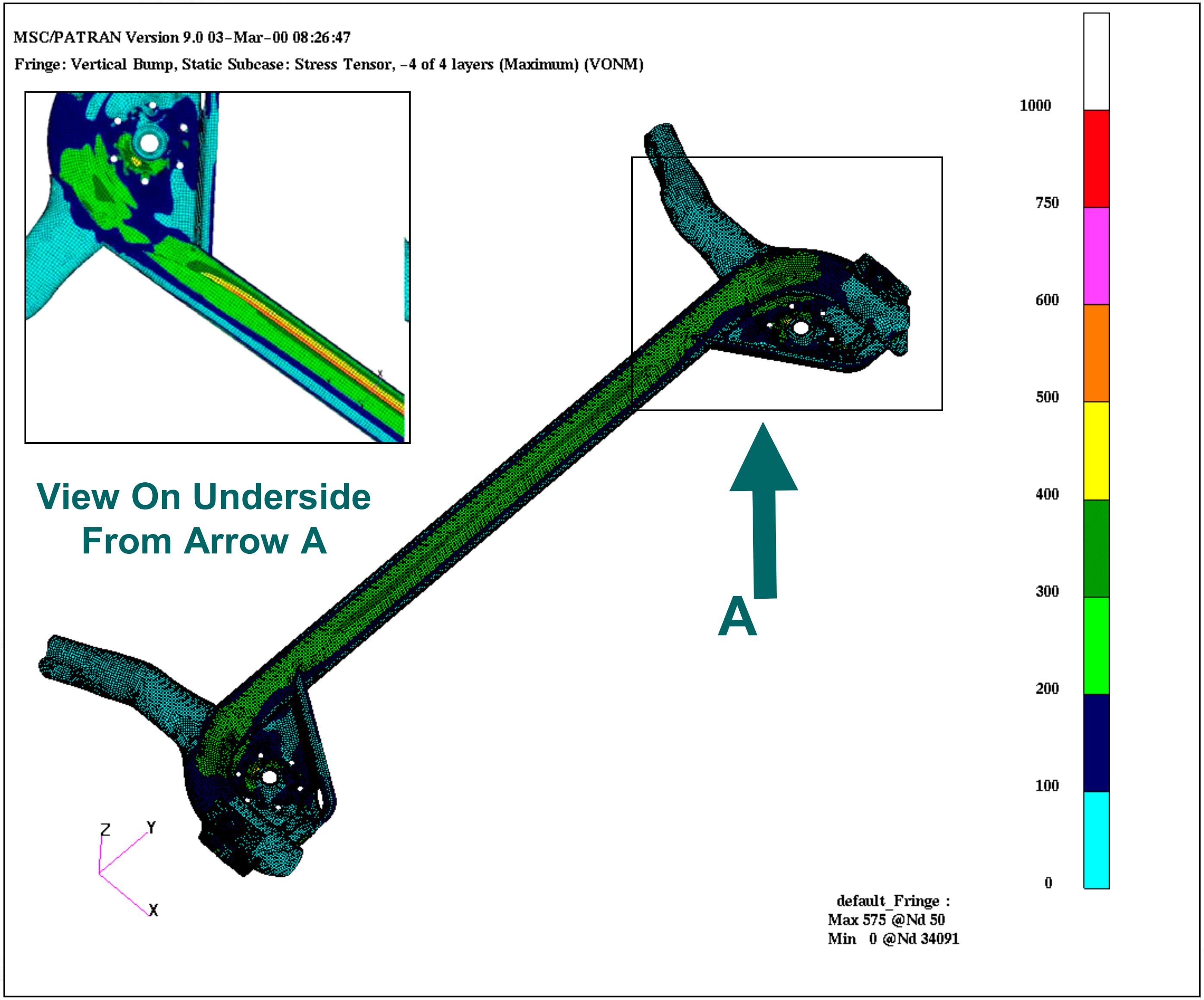
ULTRALIGHT
STEEL
AUTO SUSPENSION

TWISTBEAM: TRANSVERSE BEAM

Vertical Bump, E Class

TWISTBEAM





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MSC/PATRAN Version 9.0 03-Mar-00 08:26:47
Fringe: Vertical Bump, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)
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View On Underside From Arrow A

A

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default_Fringe :
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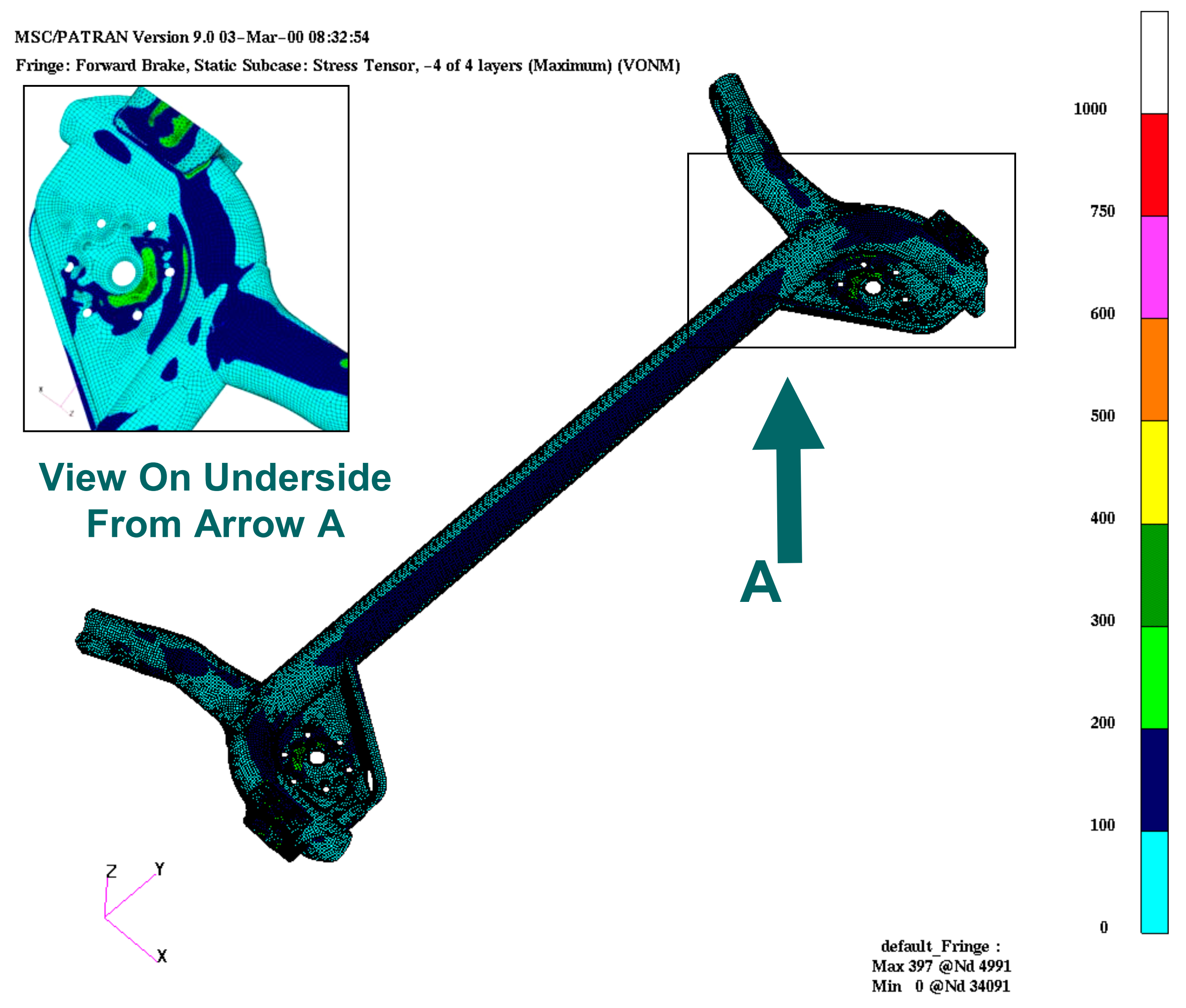
TWISTBEAM: TRANSVERSE BEAM

Forward Braking, E Class



MSC/PATRAN Version 9.0 03-Mar-00 08:32:54

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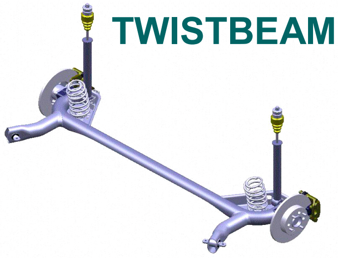
Min 0 @Nd 34091

View On Underside
From Arrow A

A

TWISTBEAM: TRANSVERSE BEAM

Combined Bump & Corner, E Class



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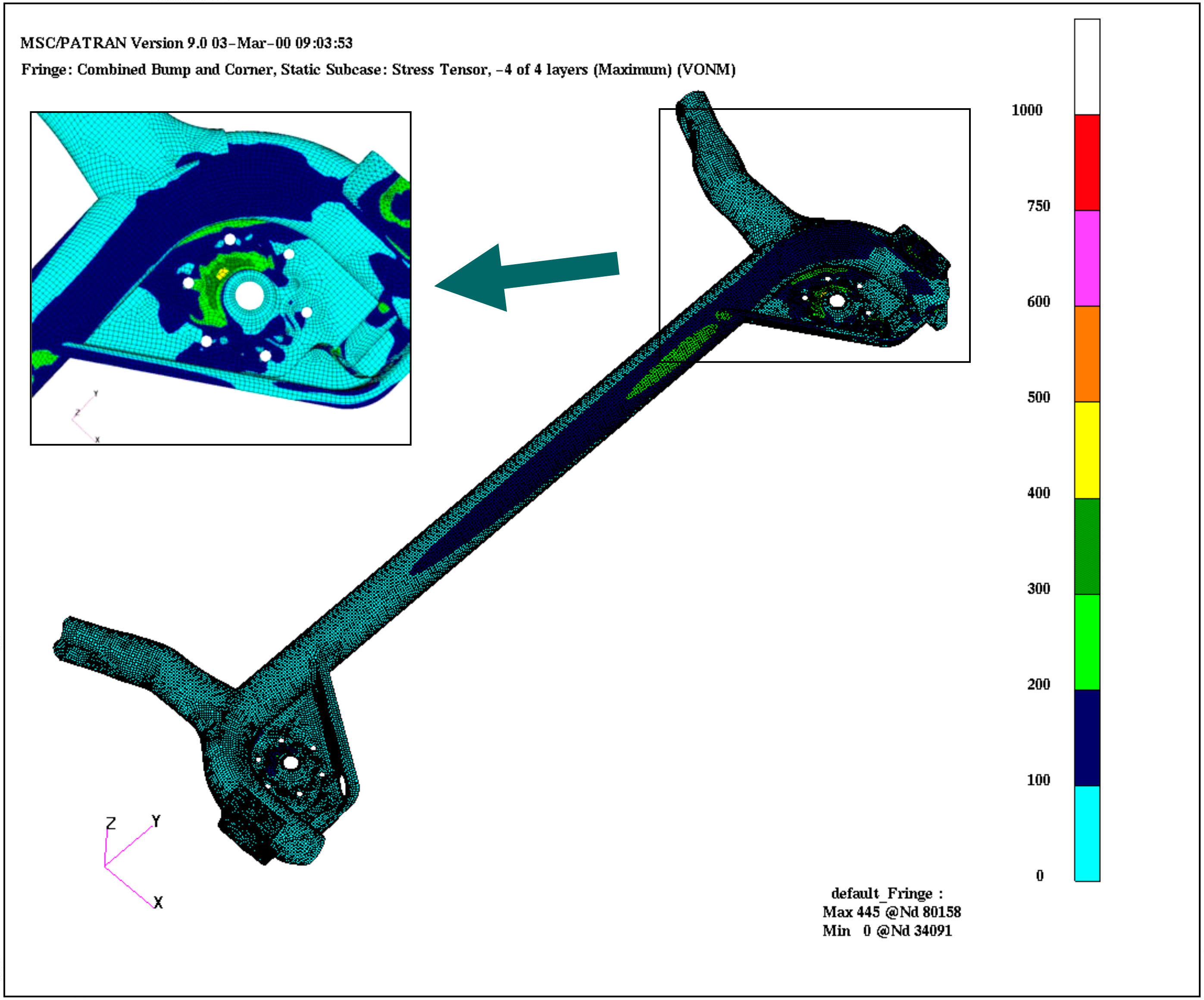

MSC/PATRAN Version 9.0 03-Mar-00 09:03:53

Fringe: Combined Bump and Corner, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

default_Fringe :
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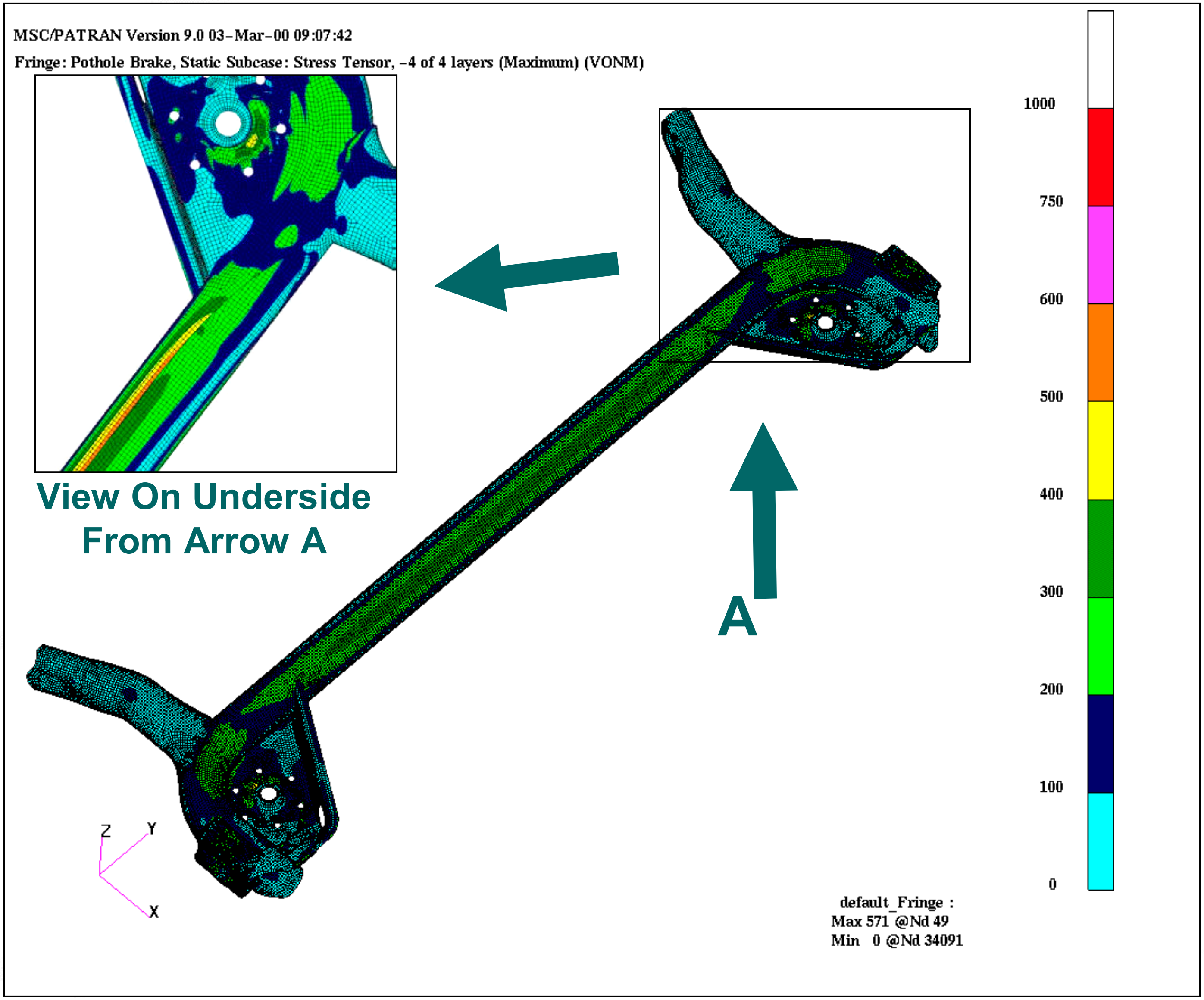
Min 0 @Nd 34091

TWISTBEAM: TRANSVERSE BEAM

Pothole Brake, E Class


MSC/PATRAN Version 9.0 03-Mar-00 09:07:42

Fringe: Pothole Brake, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

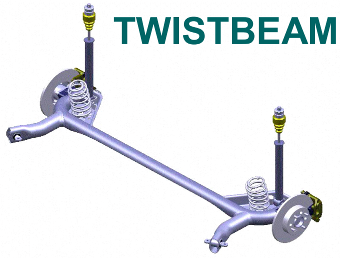
View On Underside From Arrow A

A

default_Fringe :
Max 571 @Nd 49
Min 0 @Nd 34091

TWISTBEAM: STRESS RESULTS

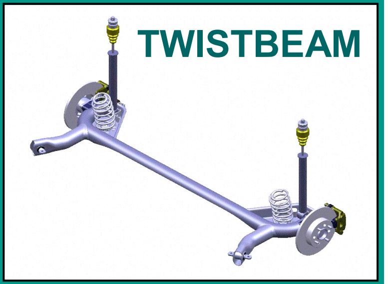
P Class with Bushes

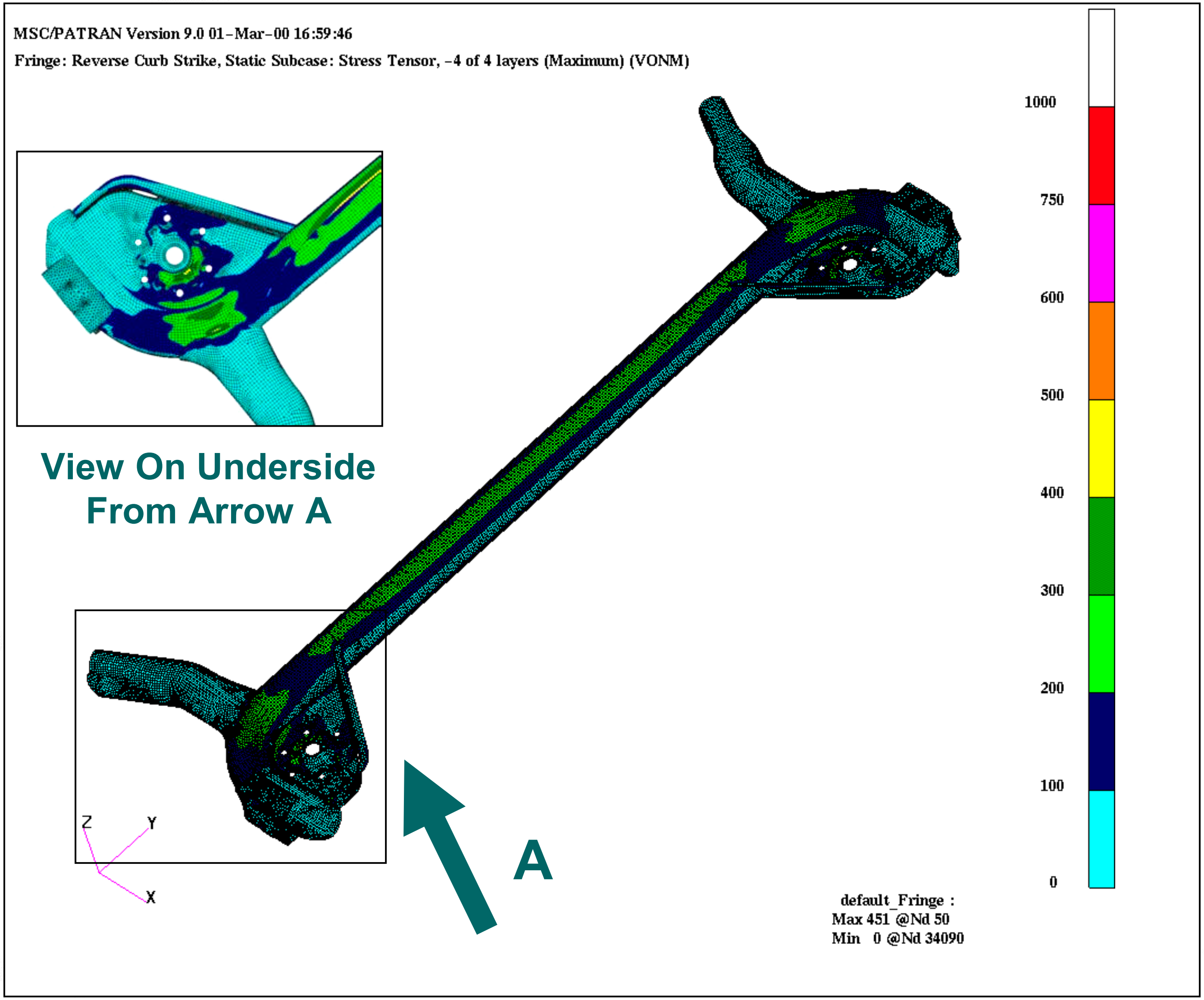


Load Case	Max stress (Von Mises)	Location
Reverse Curb Strike (TCP)	**451 MPa**	Tube
Lateral Curb Strike 1 with load transfer	**506 MPa**	Knuckle join
Lateral Curb Strike 2 with NO load transfer	**572 MPa**	Knuckle join
Vertical Bump (TCP)	**575 MPa**	Tube
Forward Braking with ABS (TCP)	**449 MPa**	Knuckle join
Combined Bump and Cornering (TCP)	**460 MPa**	Knuckle join
Pothole Brake (TCP)	**572 MPa**	Tube

TWISTBEAM: TRANSVERSE BEAM

Reverse Curb Strike, P Class




MSC/PATRAN Version 9.0 01-Mar-00 16:59:46

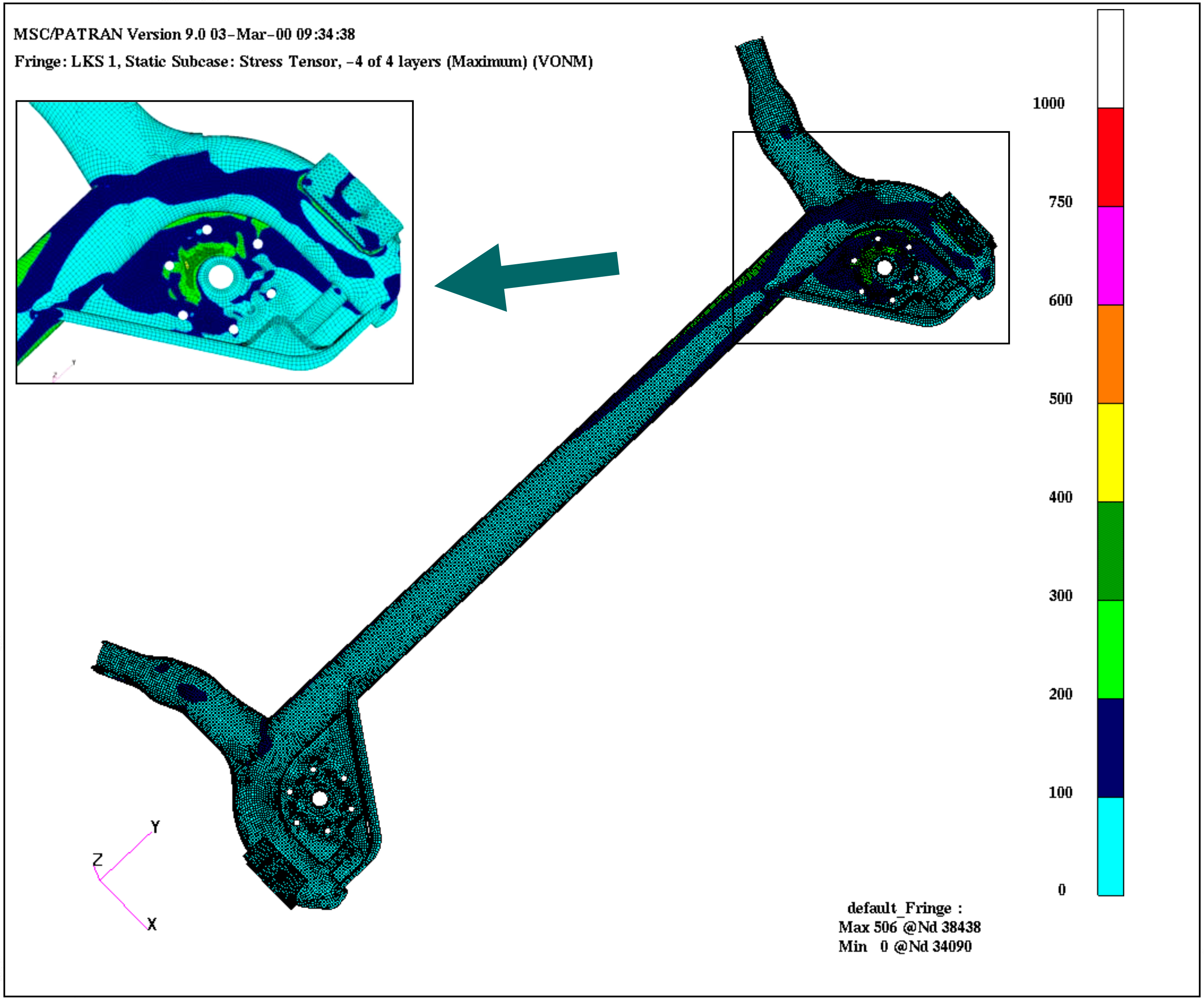
Fringe: Reverse Curb Strike, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

View On Underside From Arrow A

default_Fringe :
Max 451 @Nd 50
Min 0 @Nd 34090

TWISTBEAM: TRANSVERSE BEAM

Lateral Curb Strike 1, P Class


MSC/PATRAN Version 9.0 03-Mar-00 09:34:38

Fringe: LKS 1, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

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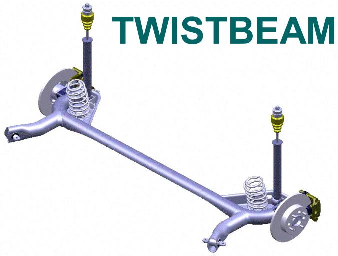
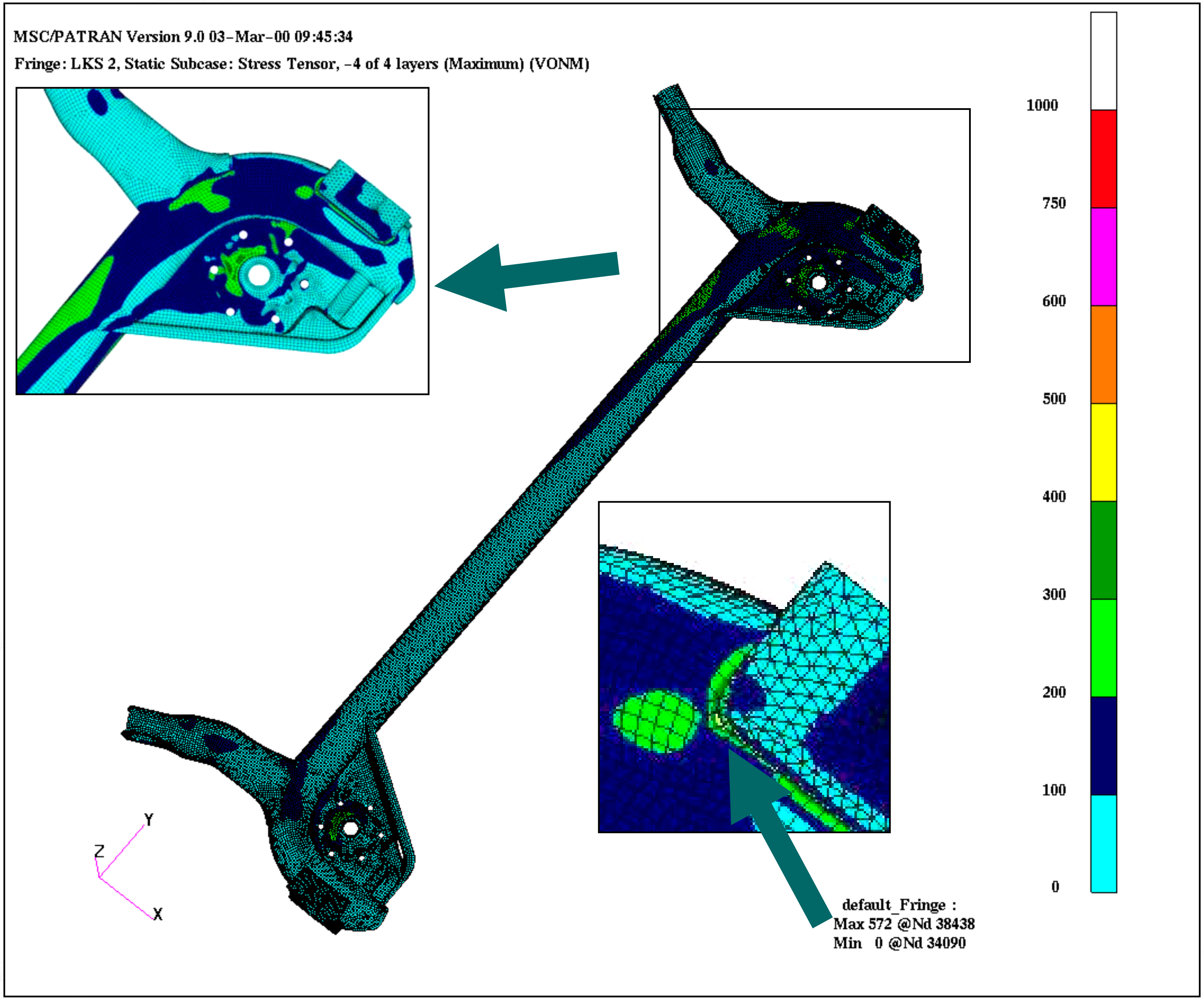
Max 506 @Nd 38438
Min 0 @Nd 34090

TWISTBEAM: TRANSVERSE BEAM

Lateral Curb Strike 2, P Class

TWISTBEAM





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Min  0 @Nd 34090
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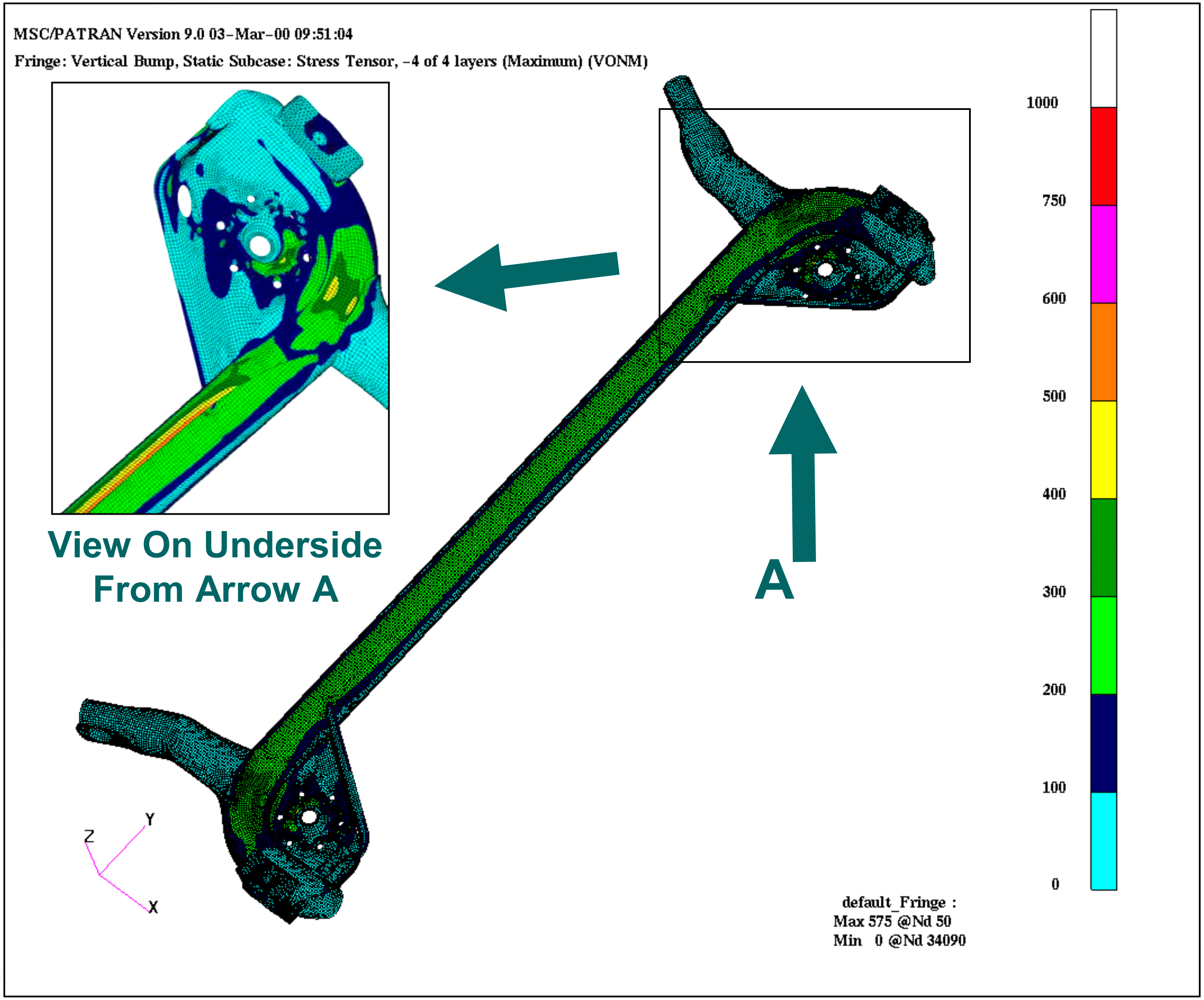
TWISTBEAM: TRANSVERSE BEAM

Vertical Bump, P Class



MSC/PATRAN Version 9.0 03-Mar-00 09:51:04

Fringe: Vertical Bump, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

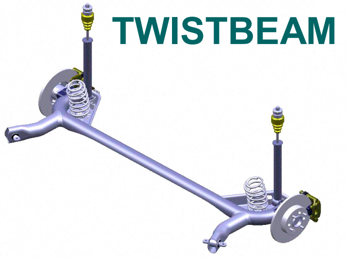
View On Underside From Arrow A

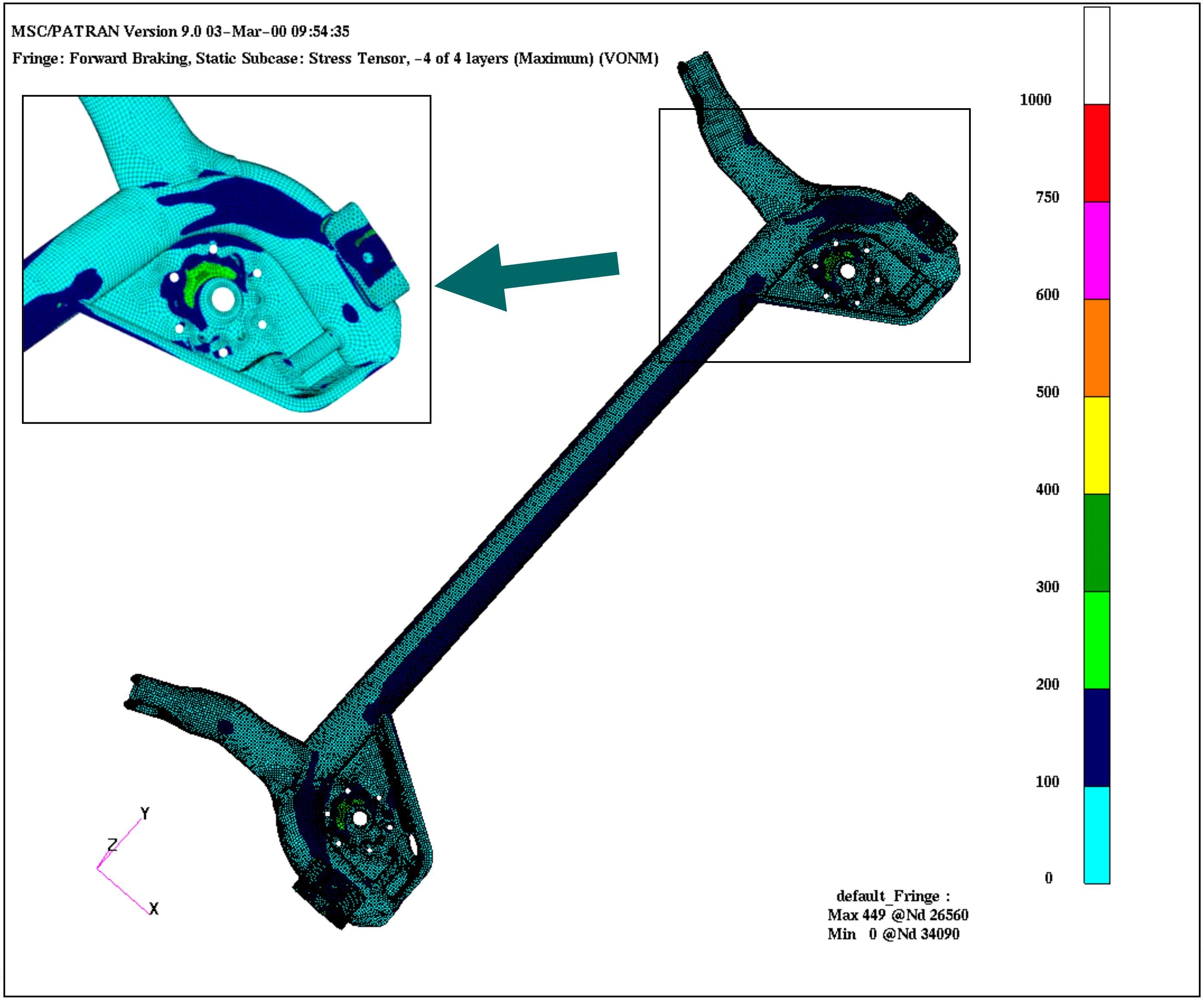
default_Fringe :
Max 575 @Nd 50
Min 0 @Nd 34090

TWISTBEAM: TRANSVERSE BEAM

Forward Braking, P Class

TWISTBEAM





MSC/PATRAN Version 9.0 03-Mar-00 09:54:35

Fringe: Forward Braking, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

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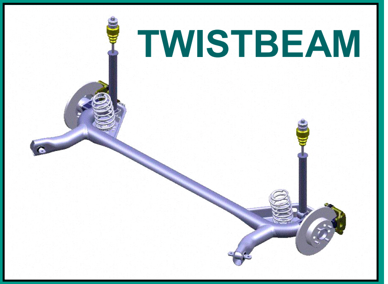
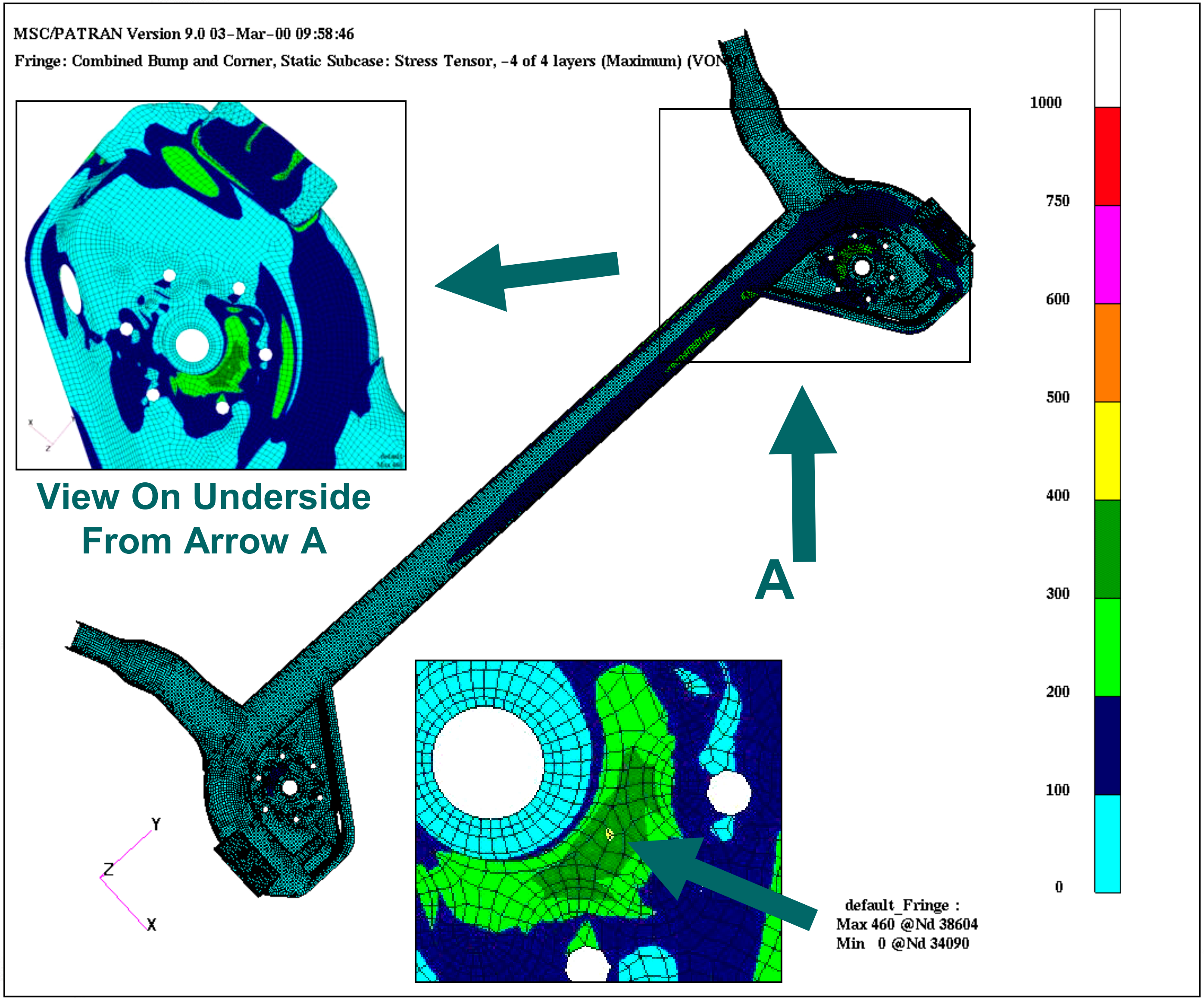
Min 0 @Nd 34090

TWISTBEAM: TRANSVERSE BEAM

Combined Bump & Corner, P Class





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MSC/PATRAN Version 9.0 03-Mar-00 09:58:46
Fringe: Combined Bump and Corner, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VON
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View On Underside From Arrow A

A

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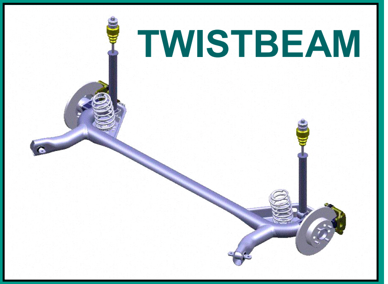
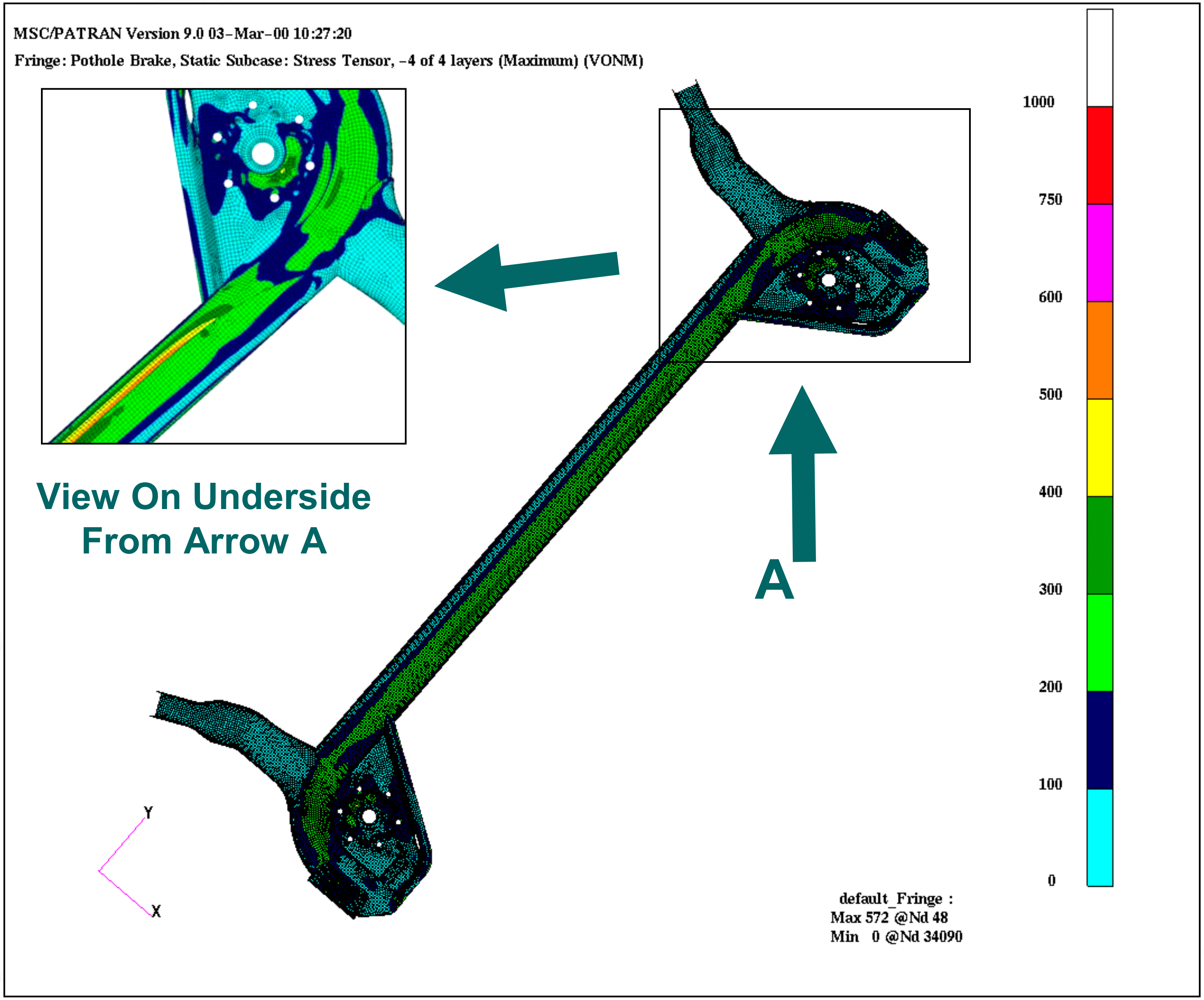
TWISTBEAM: TRANSVERSE BEAM

Pothole Brake, P Class




MSC/PATRAN Version 9.0 03-Mar-00 10:27:20

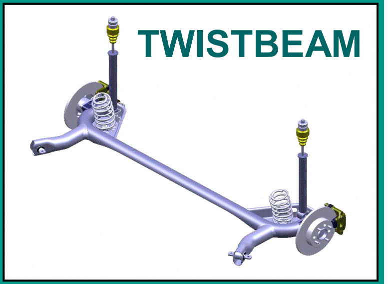
Fringe: Pothole Brake, Static Subcase: Stress Tensor, -4 of 4 layers (Maximum) (VONM)

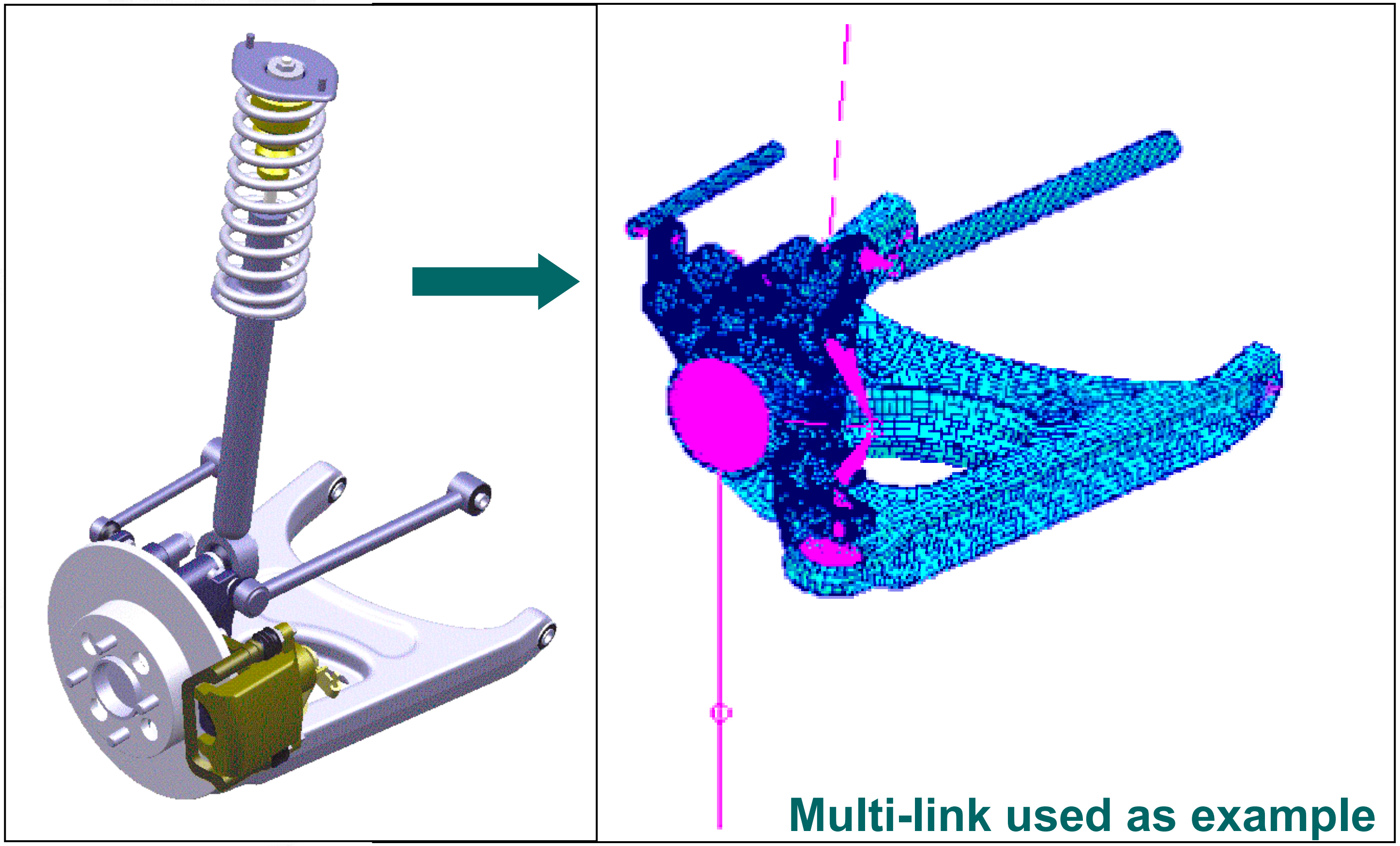
View On Underside
From Arrow A

default_Fringe :
Max 572 @Nd 48
Min 0 @Nd 34090

TWISTBEAM: CAE STRUCTURAL APPROACH

Part Physical Geometry



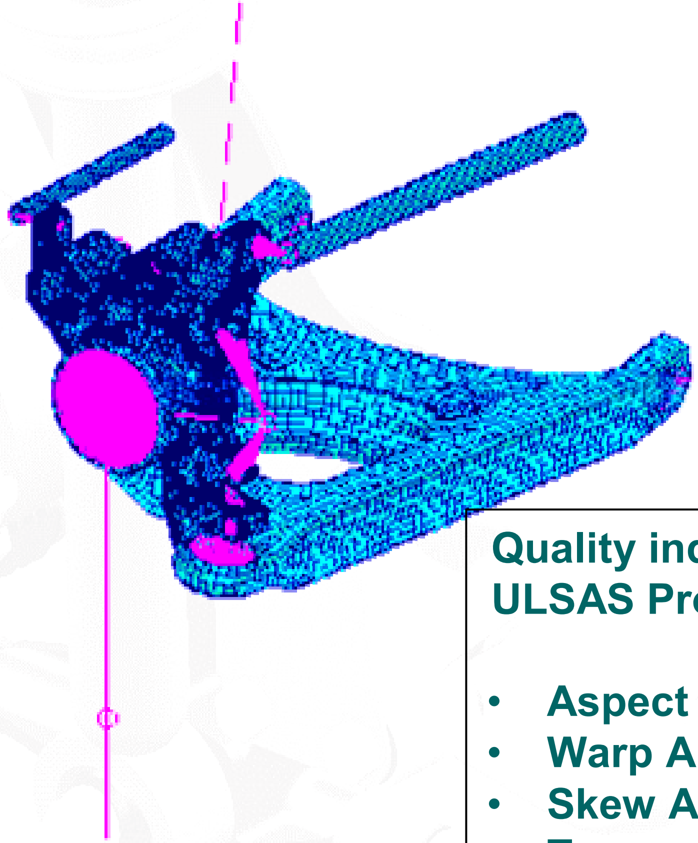


Multi-link used as example

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

TWISTBEAM: CAE STRUCTURAL APPROACH

Finite Elements



Multi-link used as example

Quality indices adapted throughout the ULSAS Programme for shell elements :

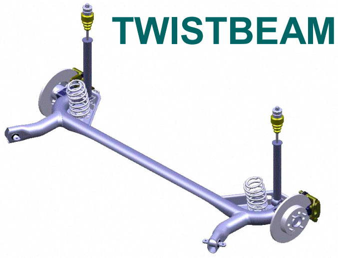
- **Aspect Ratio < 5:1**
- **Warp Angle < 7 degrees**
- **Skew Angle < 30 degrees**
- **Taper > 0.8**

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

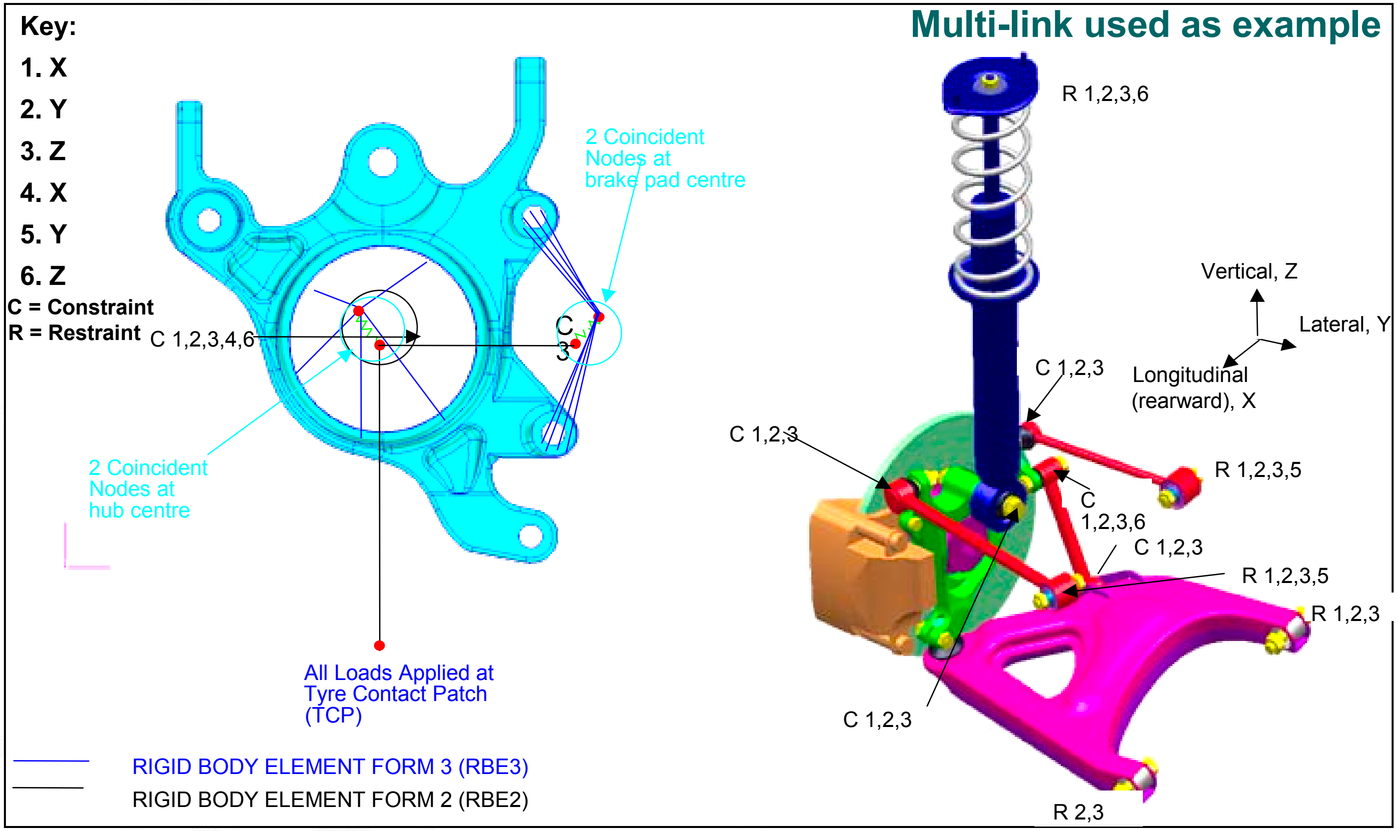
TWISTBEAM: CAE STRUCTURAL APPROACH

Loads and Boundary Conditions

TWISTBEAM



Multi-link used as example



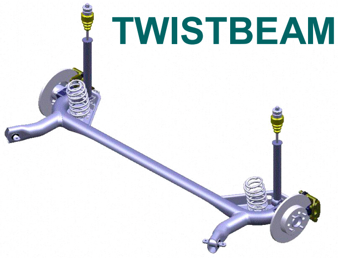
Key:
1. X
2. Y
3. Z
4. X
5. Y
6. Z
C = Constraint
R = Restraint

RIGID BODY ELEMENT FORM 3 (RBE3)
RIGID BODY ELEMENT FORM 2 (RBE2)

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.

TWISTBEAM: CAE STRUCTURAL APPROACH



TWISTBEAM

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.

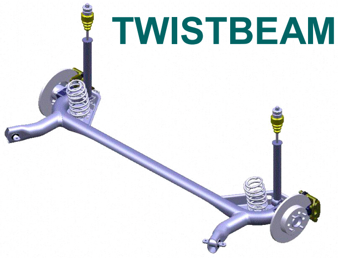
Properties

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.

TWISTBEAM: CAE STRUCTURAL APPROACH

Load Cases

TWISTBEAM



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

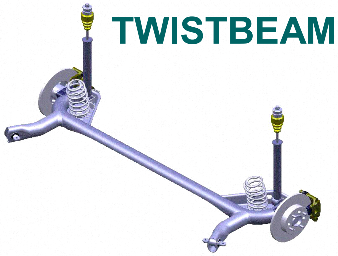
(2) Loads to be calculated assuming that the vehicle is in the Gross Mass condition.

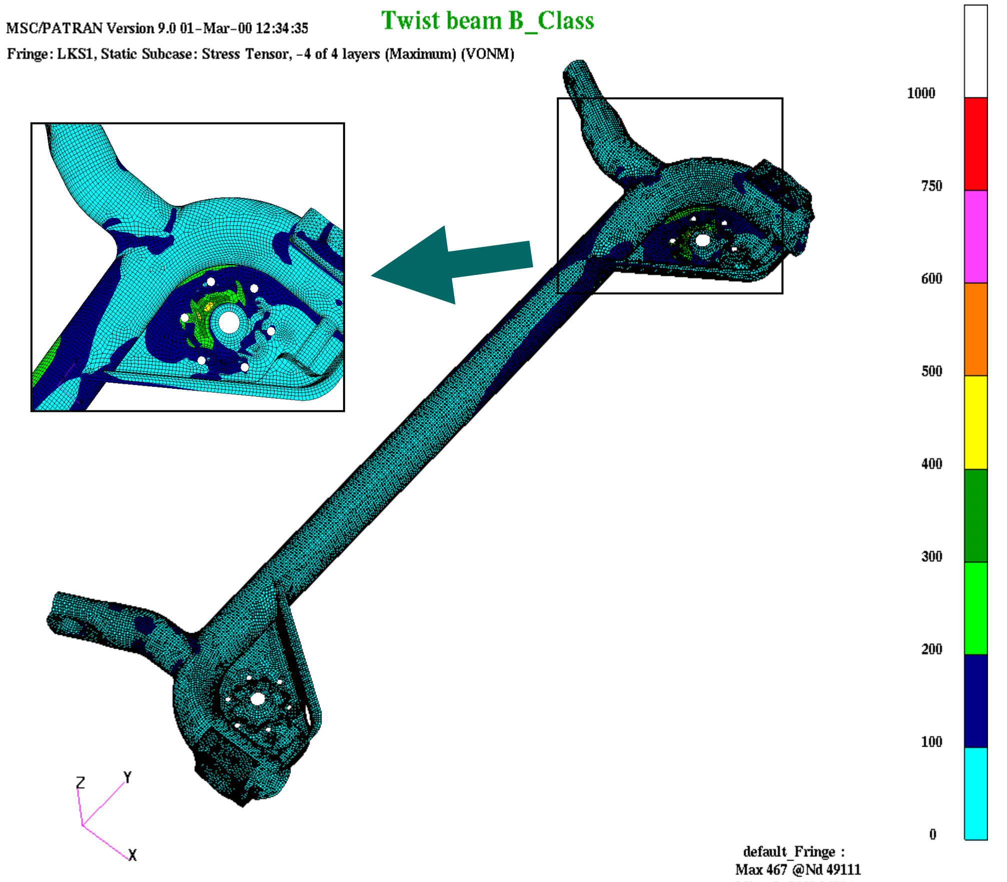
Unit loads are applied to the FE models at the tyre contact patch and any other specific application areas. These are then combined to produce the standard proof load cases for stiffness and strength assessment. The proof load cases are obtained from Lotus' in house software and are as indicated in the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

TWISTBEAM: CAE STRUCTURAL APPROACH

Analysis

TWISTBEAM

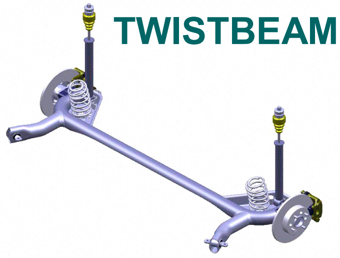




Twistbeam used as example

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.)

TWISTBEAM: CAE STRUCTURAL APPROACH

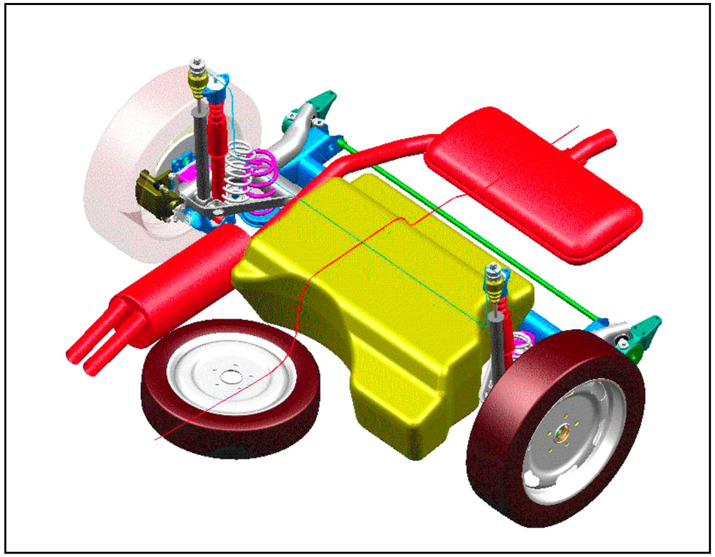


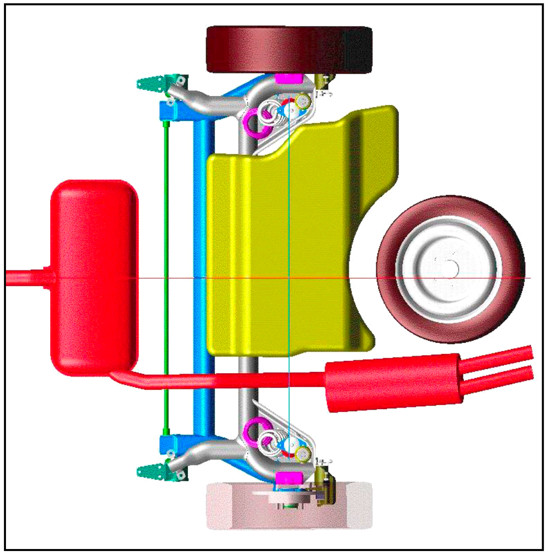
Load Case	Max stress (Von Mises)	Location
Reverse Curb Strike (TCP)	468 MPa	Spring pan
Lateral Curb Strike 1 with load transfer	472 MPa	Spring pan
Lateral Curb Strike 2 with NO load transfer	416 MPa	Knuckle join
Vertical Bump (TCP)	592 MPa	Tube
Forward Braking with ABS (TCP)	355 MPa	Knuckle join
Combined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

TWISTBEAM: PACKAGING



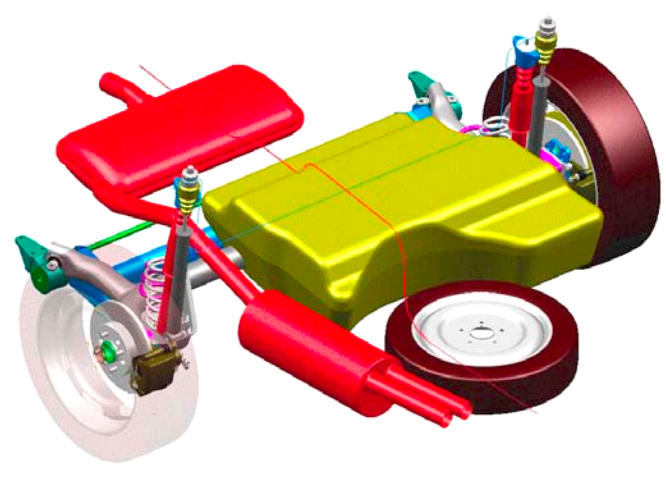


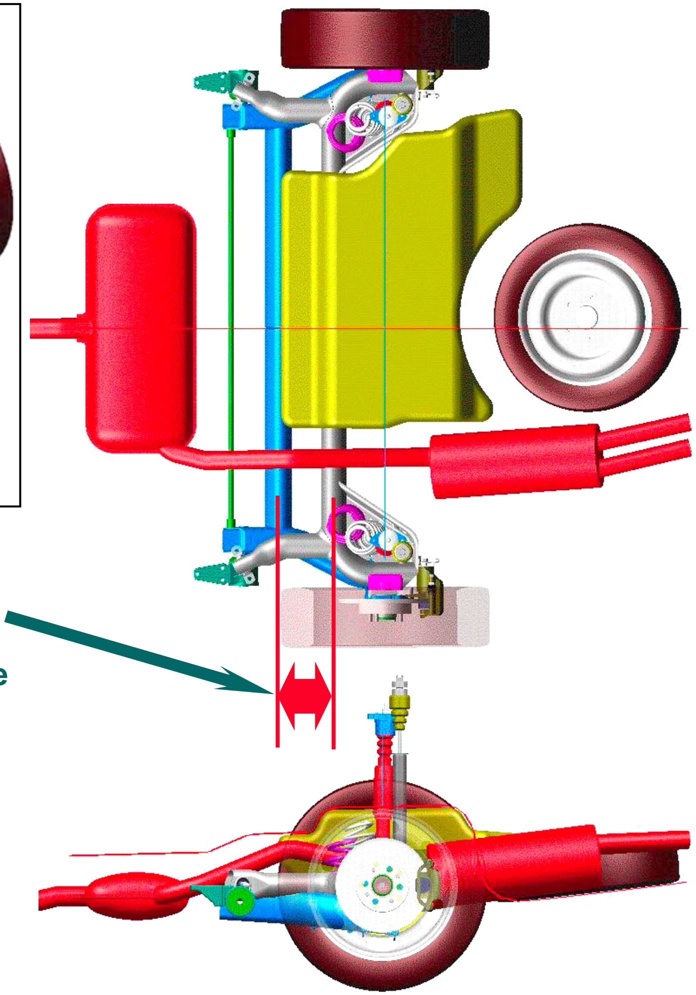
An evaluation of the packaging implications of the proposed suspension system was carried out. This compared the ULSAS system to the benchmarked vehicle in the following areas:

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

TWISTBEAM: PACKAGING

Systems





Revised position of the crossbeam on the ULSAS solution has package implications on the fuel tank and the exhaust system. These implications are minor and only require a revision to the underfloor layout to resolve the issue.

Show Revised Layout

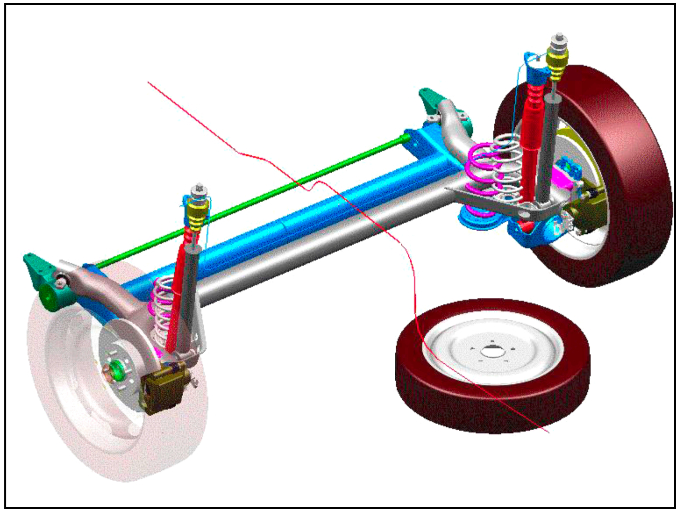
🟦 **Benchmark Vehicle**

⬛ **ULSAS Solution**

TWISTBEAM: PACKAGING

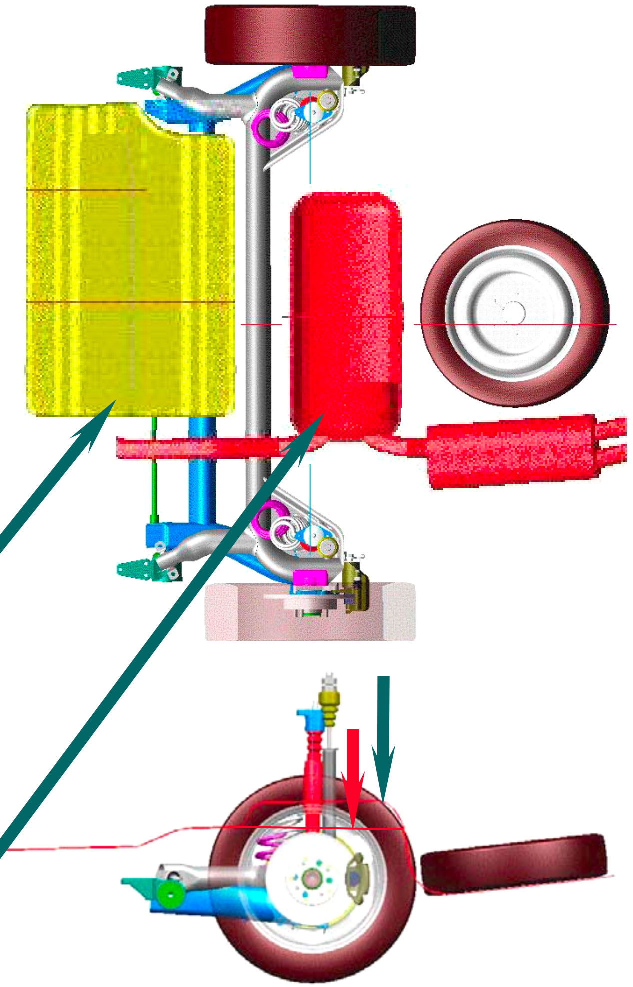
Systems


TWISTBEAM



A revised underfloor layout to a more commonly encountered arrangement would resolve the issues;

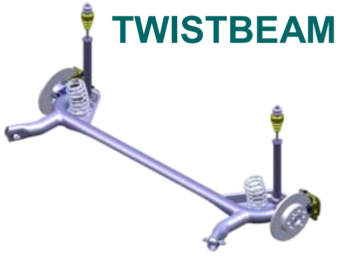
- Fuel Tank moved lower and forward ahead of axle, under rear seat, similar to VW Golf. This will move a major mass to within the wheelbase as well as lower the center of gravity height slightly. Both being of potential benefit.
- Exhaust system moved to rear of axle.
- Luggage compartment floor lowered with revised fuel tank location.



🟦 Benchmark Vehicle

⬛ ULSAS Solution

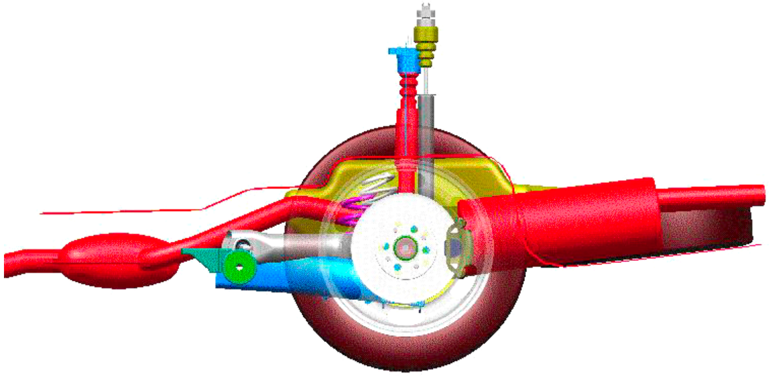
TWISTBEAM



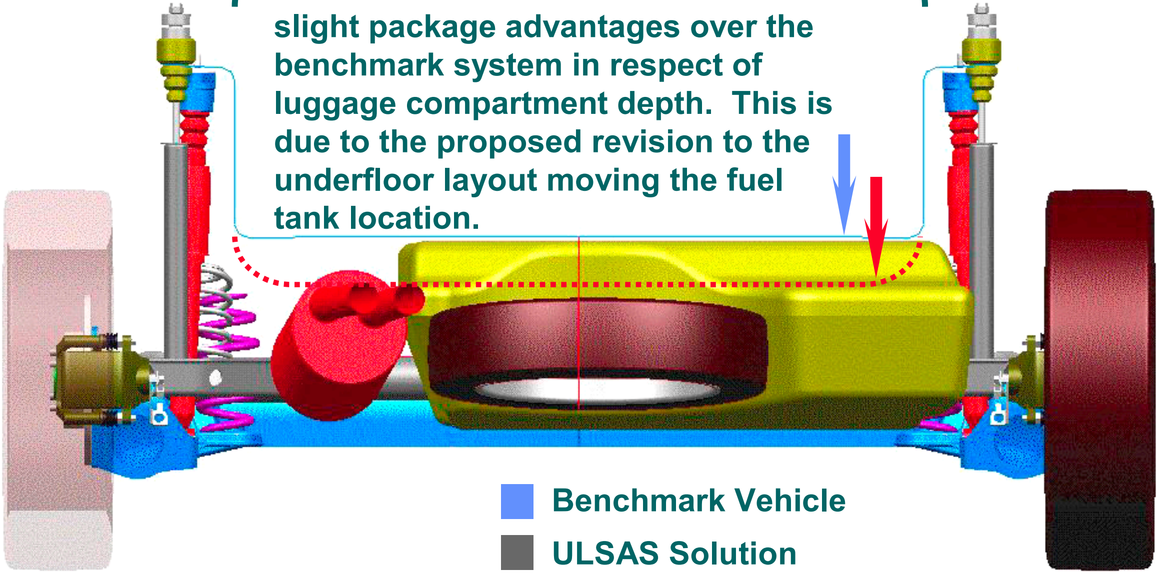
TWISTBEAM: PACKAGING

Interior

The ULSAS solution has slight package advantages over the benchmark system in respect of luggage compartment width. This is due to the wider spacing of the damper units, although this is traded off slightly by the increased height. The required increase in height is due to the larger wheel travels allowed in the ULSAS design to give good ride comfort.



The ULSAS solution also has a slight package advantages over the benchmark system in respect of luggage compartment depth. This is due to the proposed revision to the underfloor layout moving the fuel tank location.

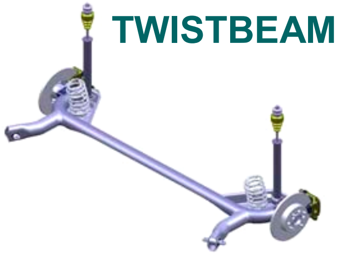


🟦 Benchmark Vehicle

⬛ ULSAS Solution

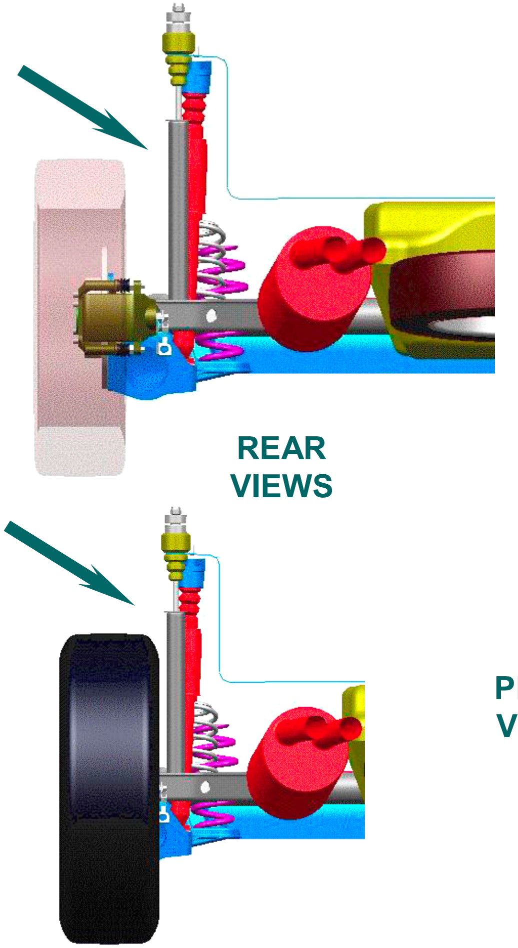
TWISTBEAM: PACKAGING

Interior



TWISTBEAM

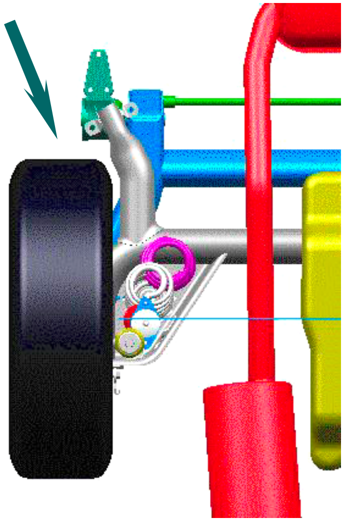
There appears to be a large clearance here between the damper and the wheel. However the ULSAS solution for the PNGV class has a narrower track than the Benchmark Vehicle.



REAR VIEWS

The ULSAS solution is much more tightly packaged, giving a neat compact solution.

The ULSAS solution is also compact and neatly packaged around the front edge of the tyre.



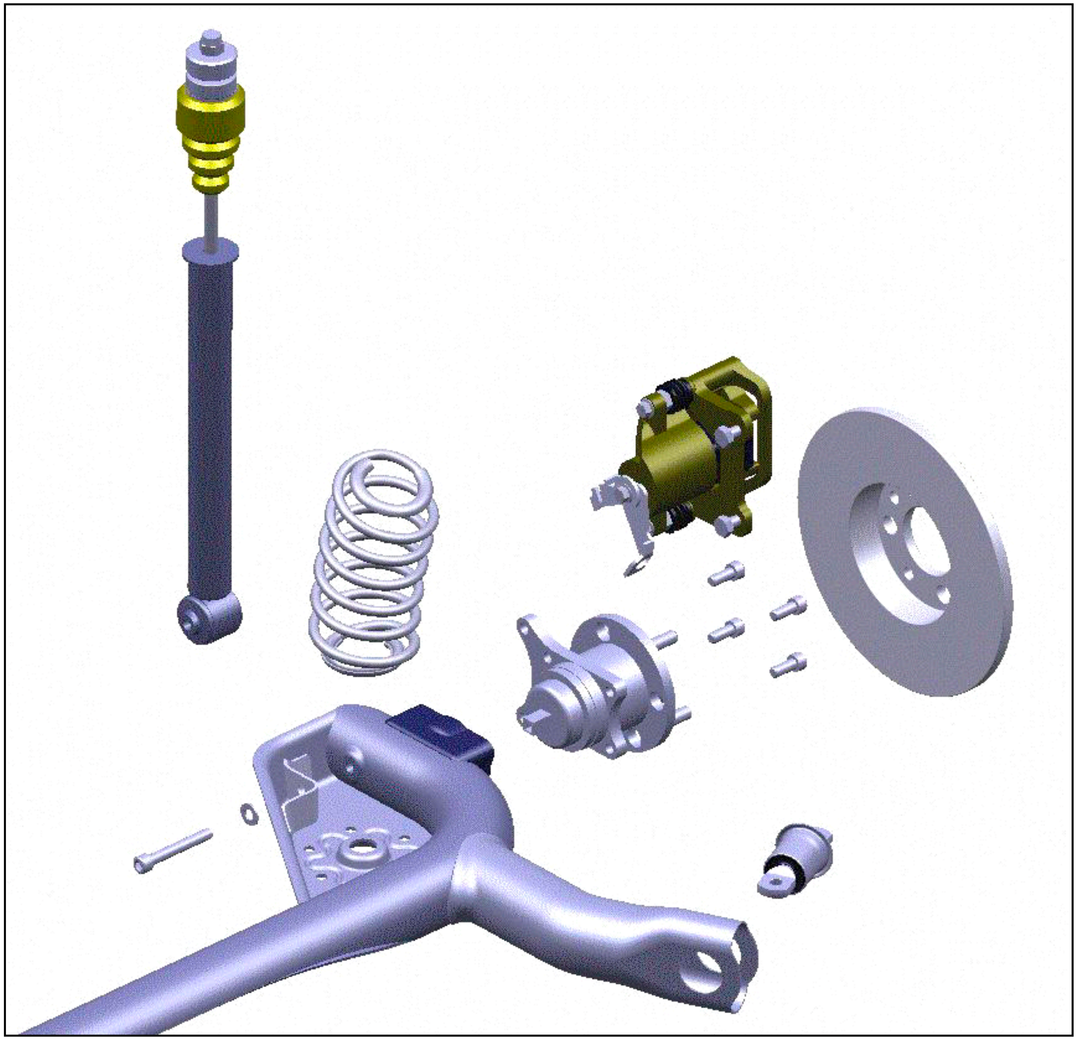
PLAN VIEW

🟦 Benchmark Vehicle

⬛ ULSAS Solution

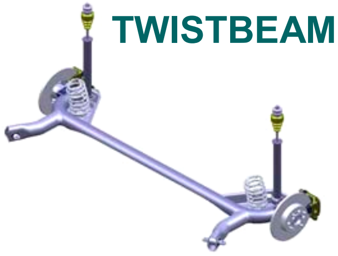
TWISTBEAM: MANUFACTURING

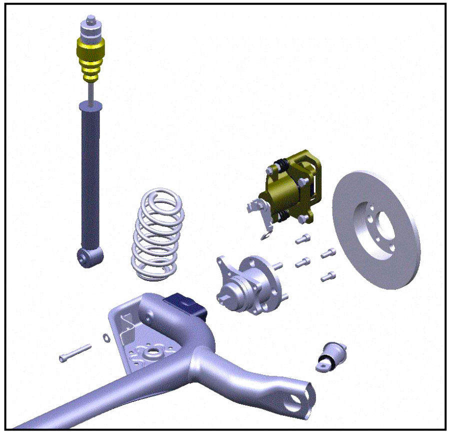
TWISTBEAM



TWISTBEAM: MANUFACTURING

Sub-Assembly



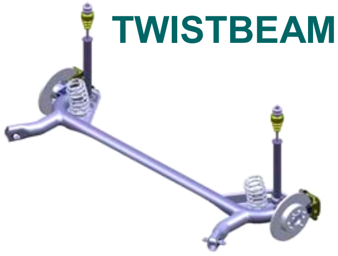


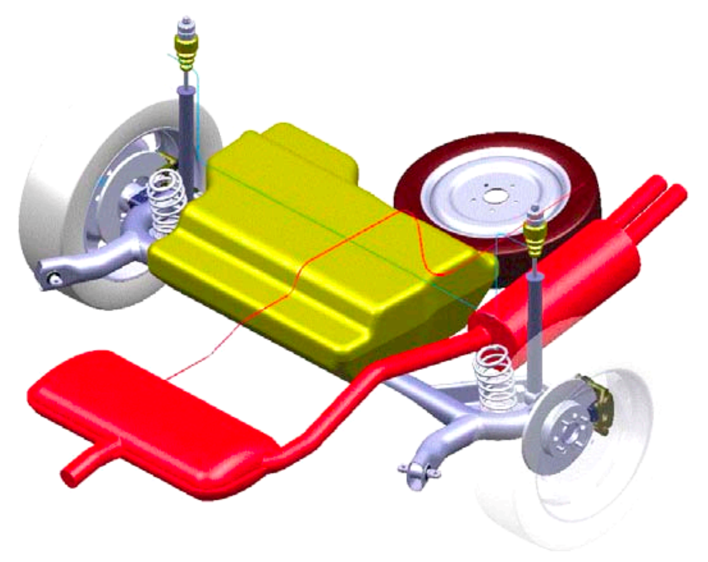
BREAKDOWN OF TIMING FOR SUB-ASSEMBLY OF TWISTBEAM SUSPENSION SYSTEM PARTS

SUB-ASSEMBLY Operation	No.	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
LOAD TORSION BEAM	1	FIXLG	0.6		0.6
LOAD HUB	2	FIX1H	0.05	0.05	0.1
FIX HUB	8	TFPTN	0.11	0.49	0.6
LOAD BRAKE DISK	2	FIX1H	0.05	0.05	0.1
FIX BRAKE DISK	2	FIT1H	0.19	0.13	0.32
LOAD BRAKE CALIPER	2	FIX1H	0.05	0.05	0.1
FIX BRAKE CALIPER	4	TFPTN	0.11	0.21	0.32
LOAD DAMPER	2	FIX1H	0.05	0.05	0.1
FIX DAMPER	2	TFPTN	0.11	0.07	0.18
				TOTAL	2.42

TWISTBEAM: MANUFACTURING

Vehicle Assembly

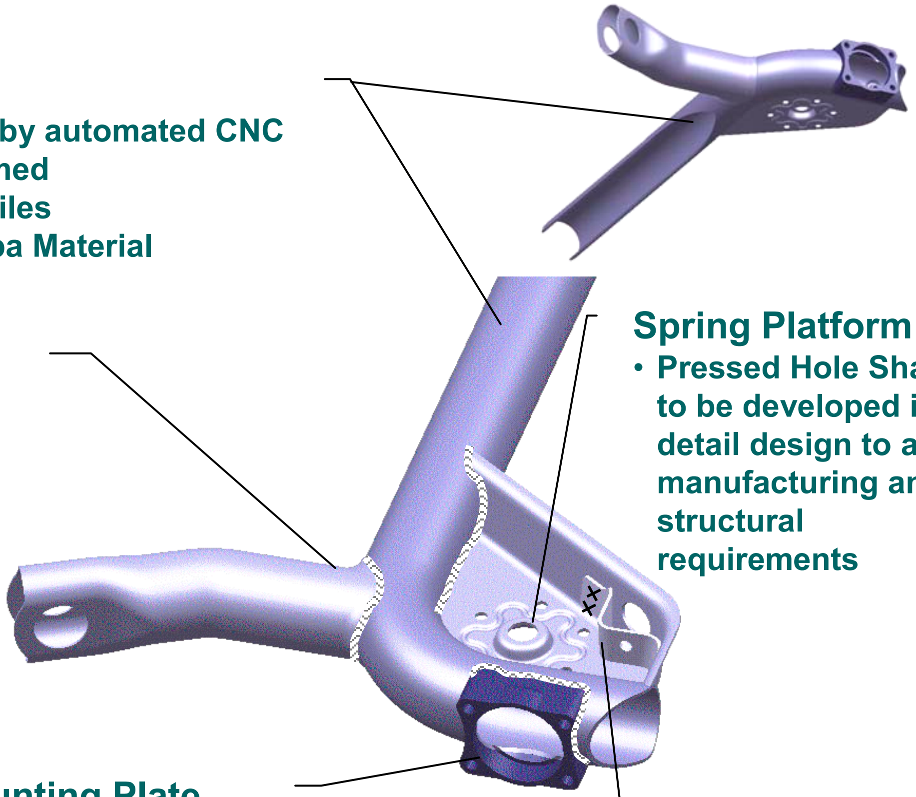




BREAKDOWN OF TIMING FOR FINAL ASSEMBLY OF TWISTBEAM SUSPENSION TO THE VEHICLE

FINAL ASSEMBLY			First Time	Subsequent	Total Time
Operation	No.	Code	(man minutes)	(man minutes)	(man minutes)
load spring	2	FIT1H	0.19	0.13	0.32
fix bolt	4	TFPTN	0.11	0.21	0.32
fit buffer	2	FITFN	0.07	0.04	0.11
fix nut	2	TFPTN	0.11	0.07	0.18
				TOTAL	0.93

TWISTBEAM: MANUFACTURING Feasibility



Transverse Beam
- Bent Tube Produced by automated CNC
- Cut-Out plasma trimmed
- Machine cut end profiles
- High Strength 600 Mpa Material

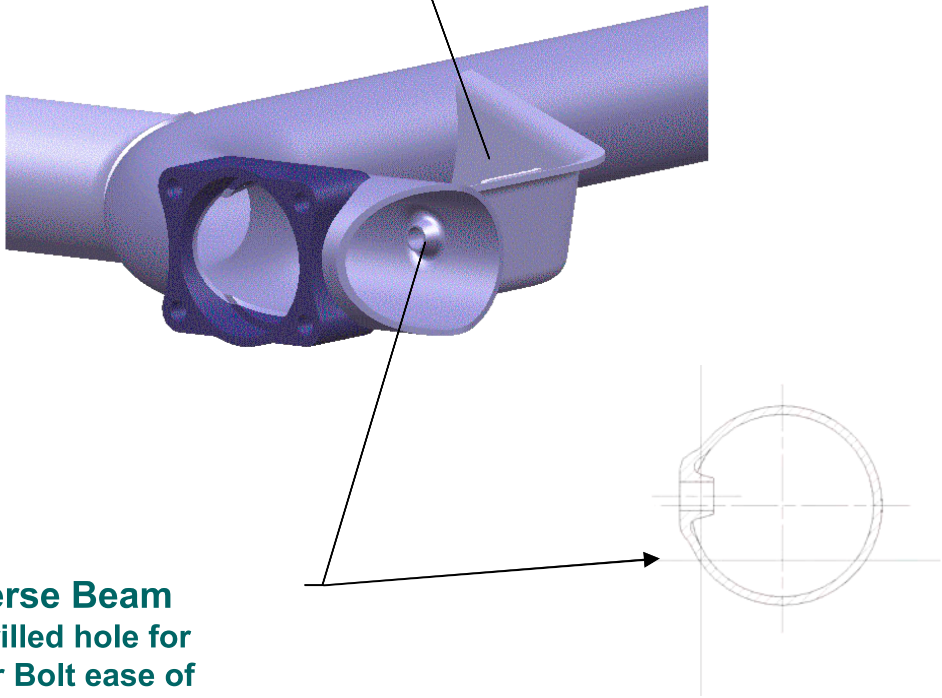
Trailing Arm
- Hydroformed Tube
- Tube end mating profile swaged and plasma trimmed prior to MIG welding

Spring Platform
- Pressed Hole Shape to be developed in detail design to aid manufacturing and structural requirements

Hub Mounting Plate
- Forged and Machined
- MIG welded to Transverse Beam
- Hole finish machined after welding

Damper Bracket
- Blanked and Folded
- Spot welded to Spring Pan

TWISTBEAM: MANUFACTURING Feasibility



Spring Platform

- Pressed Panel- Potential to produce as a pan 4 off resulting in 2 RH & 2 LH panels from one panel
- MIG welded to Transverse Beam

Transverse Beam

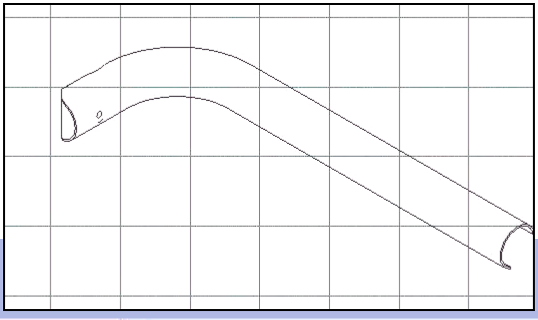
- Flow drilled hole for Damper Bolt ease of Assembly

TWISTBEAM: MANUFACTURING Feasibility

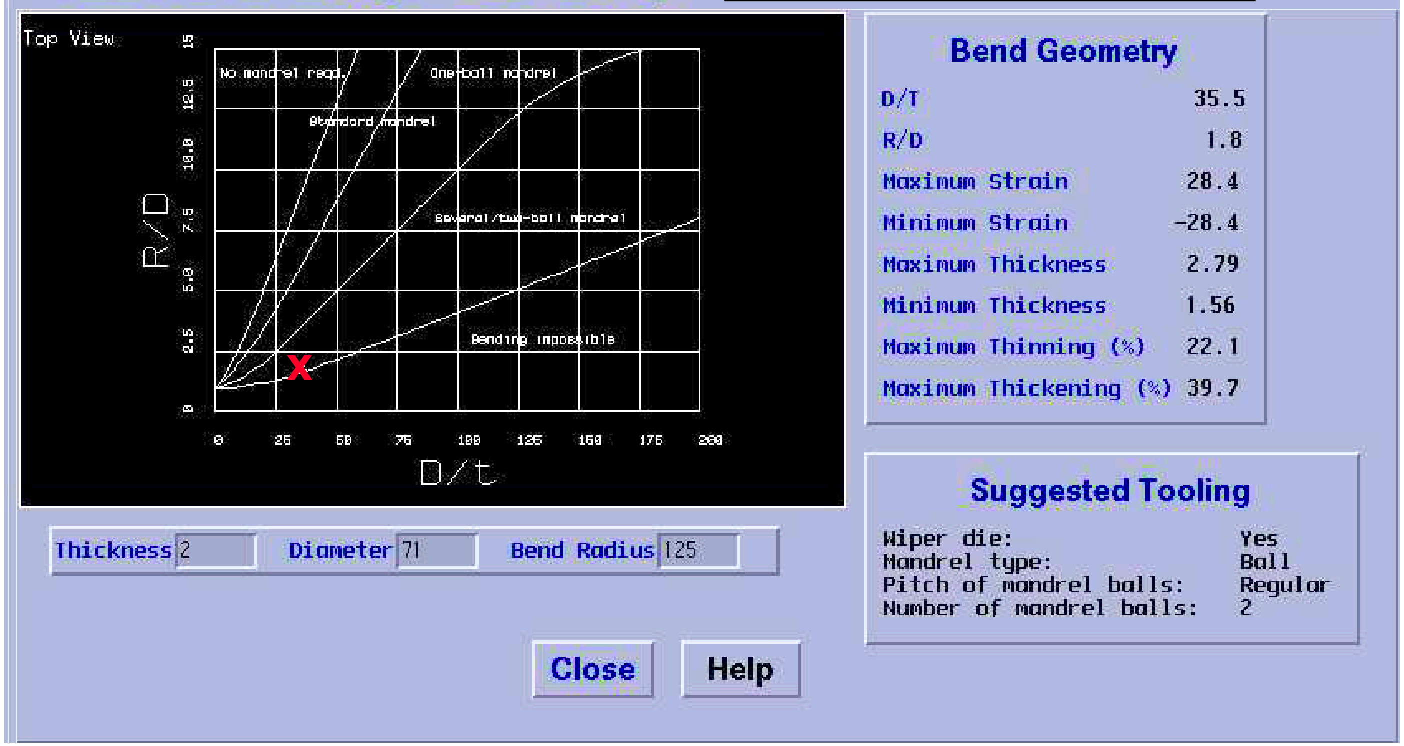
TWISTBEAM

Transverse Beam

- Manufacturing Feasibility was carried out. This Confirms that the main Bend of the Transverse Beam part is manufacturable



Tube Bending Feasibility



Bend Geometry

D/T	35.5
R/D	1.8
Maximum Strain	28.4
Minimum Strain	-28.4
Maximum Thickness	2.79
Minimum Thickness	1.56
Maximum Thinning (%)	22.1
Maximum Thickening (%)	39.7

Suggested Tooling

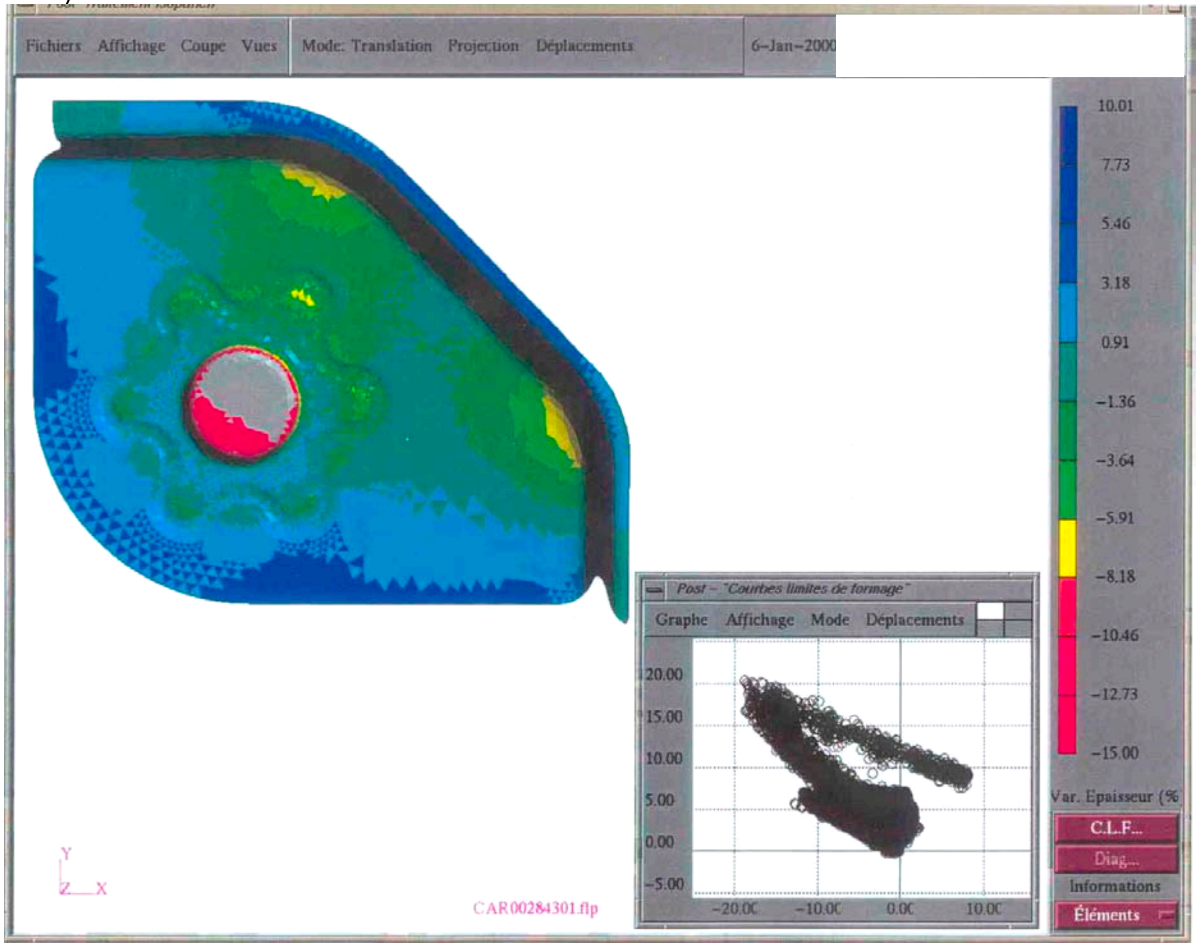
Wiper die:	Yes
Mandrel type:	Ball
Pitch of mandrel balls:	Regular
Number of mandrel balls:	2

Thickness 2
Diameter 71
Bend Radius 125

TWISTBEAM: MANUFACTURING Feasibility

ULTRALIGHT STEEL AUTO SUSPENSION

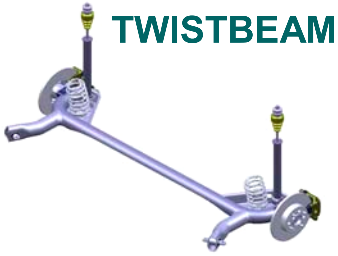
Spring Pan:- Manufacturing feasibility was carried out on the main pressing

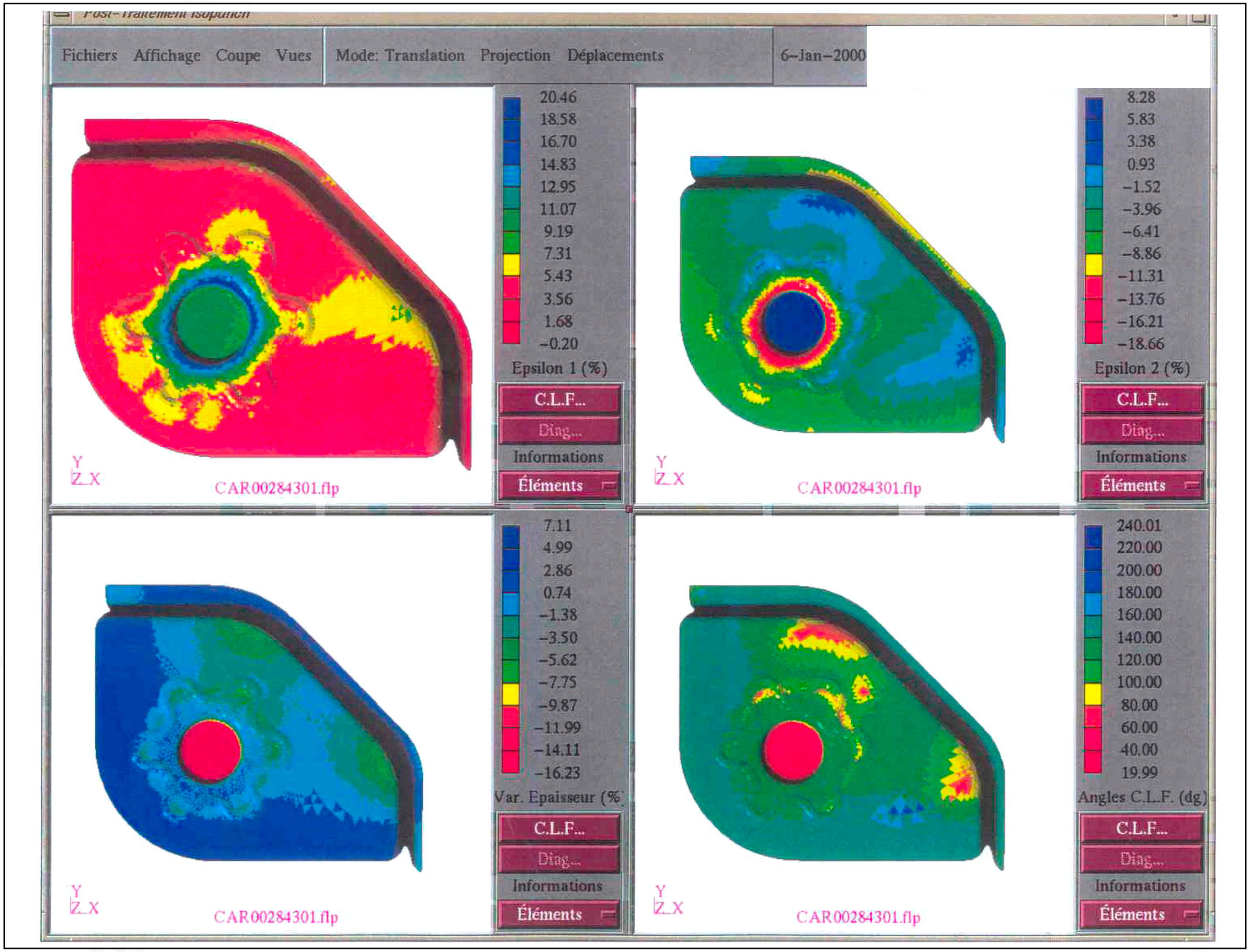


STEEL AUTO SUSPENSION

TWISTBEAM: MANUFACTURING Feasibility

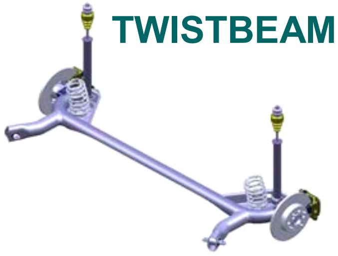
TWISTBEAM

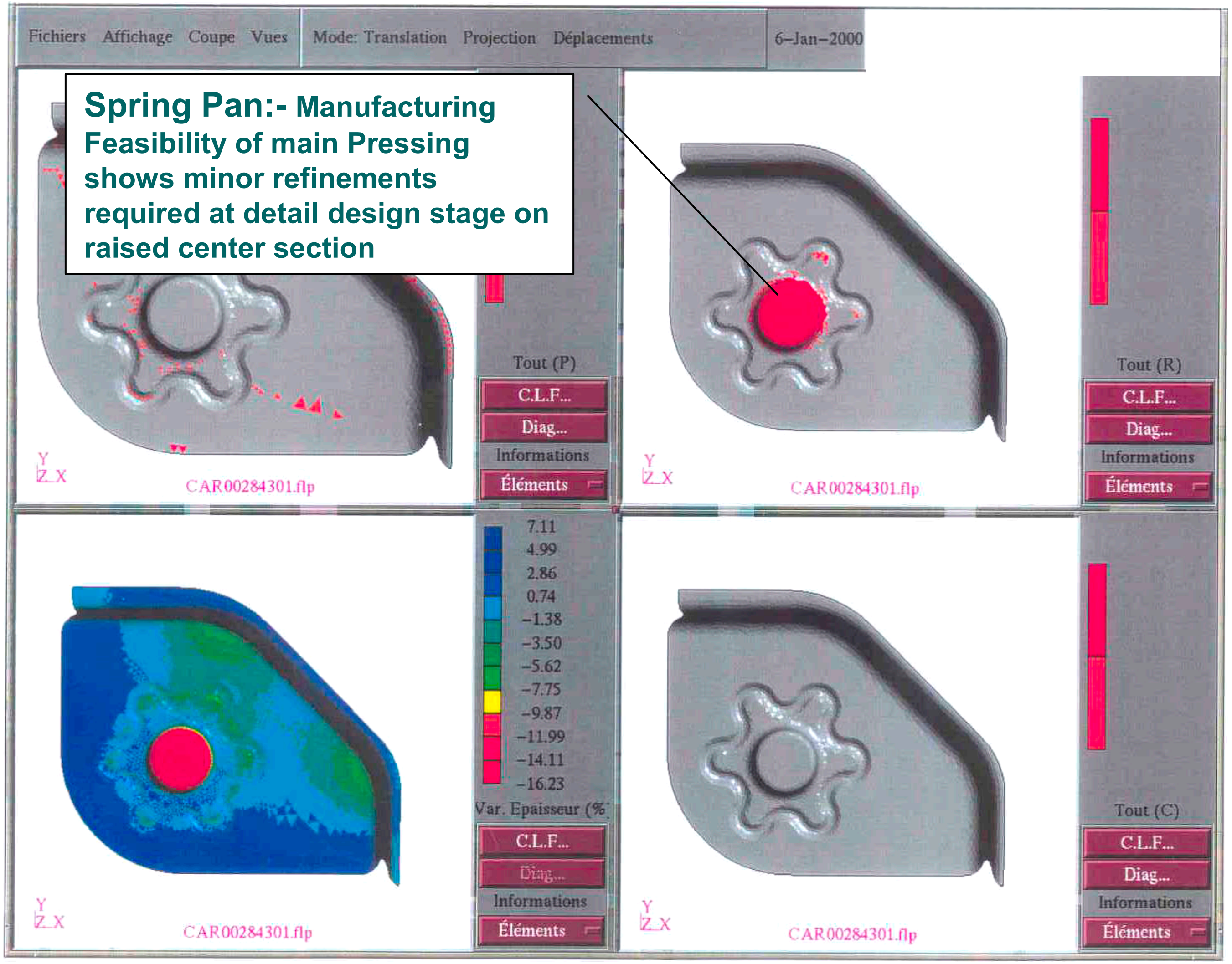




TWISTBEAM: MANUFACTURING Feasibility

TWISTBEAM

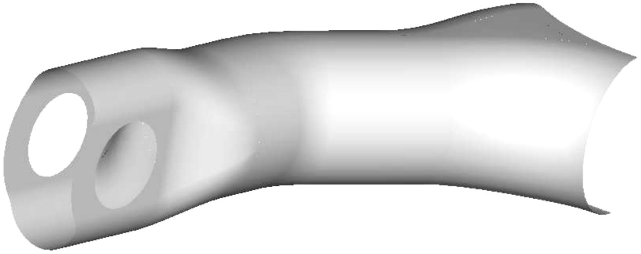


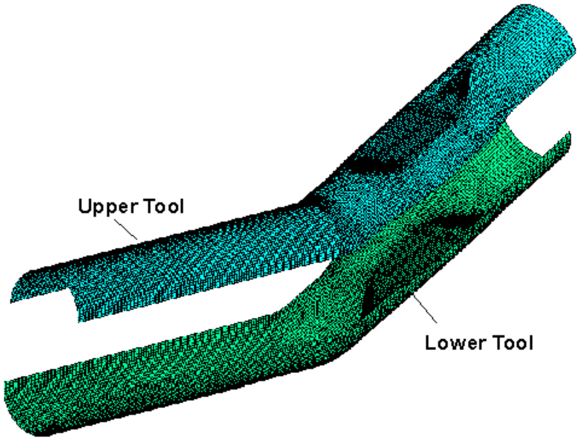


Spring Pan:- Manufacturing Feasibility of main Pressing shows minor refinements required at detail design stage on raised center section

TWISTBEAM: MANUFACTURING Feasibility

Front Arm Hydroforming:





DISCUSSION

The results have indicated that the component can be manufactured using the hydroforming process since there are no severe global or local expansions, which would cause splitting problems. However, wrinkling problems could be encountered which could impair performance. To avoid the development of wrinkling, during pre-form/ hydroform tool closure, pre-bending is necessary or alternatively the use of pre-forming with an internal support. Pre-bending would require multiple ball mandrel tooling for the particular diameter to thickness ratio and bend radius. This is evident from the results of the analyses conducted using a ‘plug’ mandrel, which does not provide adequate support to the inside of the bend. Pre-bending would also avoid possible problems encountered with deformation to the tube ends during the tool closure.

CONCLUSIONS

FEA of the Torsion beam component geometry demonstrated that a satisfactory component may be produced from a 71 mm x 2.0 mm tube blank made of 350 Mpa (min yield) using the tube hydroforming process. However, to produce the full design geometry, an end flaring or punch point operation would be required.

TWISTBEAM: MANUFACTURING APPROACH

- 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.

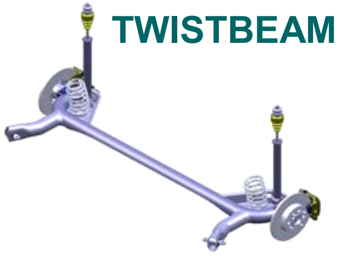
Reviewing the manufacturing feasibility of the designs is an integral part of the iterative design process. This has resulted in a high level of confidence in the manufacturing feasibility of the ULSAS concept designs.

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.

TWISTBEAM: MANUFACTURING APPROACH



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

ULSAS MANUFACTURING PROCEDURE:

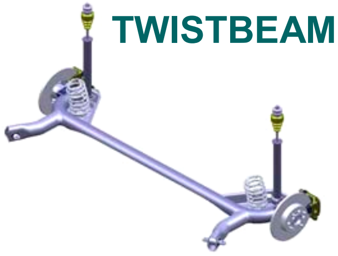
- Manufacturing Component Feasibility
- Material Requirements
- Assembly
- Timing Study
- Welding

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.

TWISTBEAM: MANUFACTURING APPROACH



ULSAS TIMING STUDY ASSUMPTIONS:

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

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

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

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

TWISTBEAM: MANUFACTURING APPROACH
ULSAS MATERIAL SELECTION ASSUMPTIONS

TWISTBEAM

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.

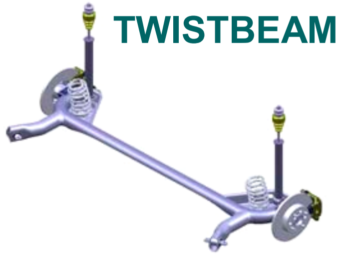
Stretched flanges or holes require good edge ductility, an influence not only of the quality of cut edge, but also the edge forming characteristics of the material. Certain grades delivering equal strength can offer superior edge ductility.

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

TWISTBEAM: 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:

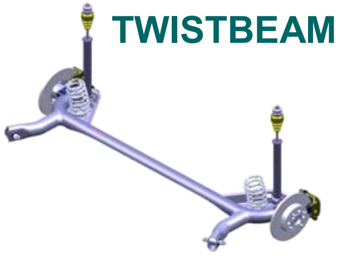
-Tube requirements would primarily be met with conventional welded tube.
-Extreme requirements for combinations of high gauge/small diameters may need to be specified as cold drawn tube.

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

TWISTBEAM: 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).

TWISTBEAM: MANUFACTURING APPROACH
ULSAS MATERIAL COATING ASSUMPTIONS

TWISTBEAM

Coating/Corrosion Considerations

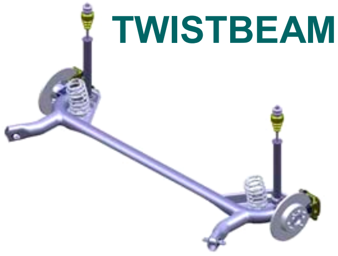
Opportunities exist for extensive use of pre-zinc coated steels. Coated steels will help to meet warranty requirements and place less reliance on protection offered by secondary coatings. Further weight/cost savings may be achieved through avoidance of wax injecting and/or the use of thinner additional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

TWISTBEAM: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS

TWISTBEAM



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):

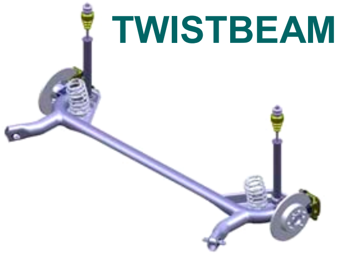
Offset tolerance 1mm max
Gap tolerance 0.2mm max.

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.

TWISTBEAM: 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.

TWISTBEAM: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS

TWISTBEAM

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.

TWISTBEAM: MANUFACTURING APPROACH
ULSAS WELDING ASSUMPTIONS

TWISTBEAM

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.

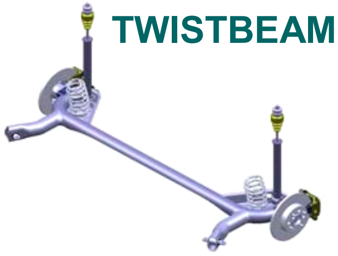
Spot-Welding/Flange Welding

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.

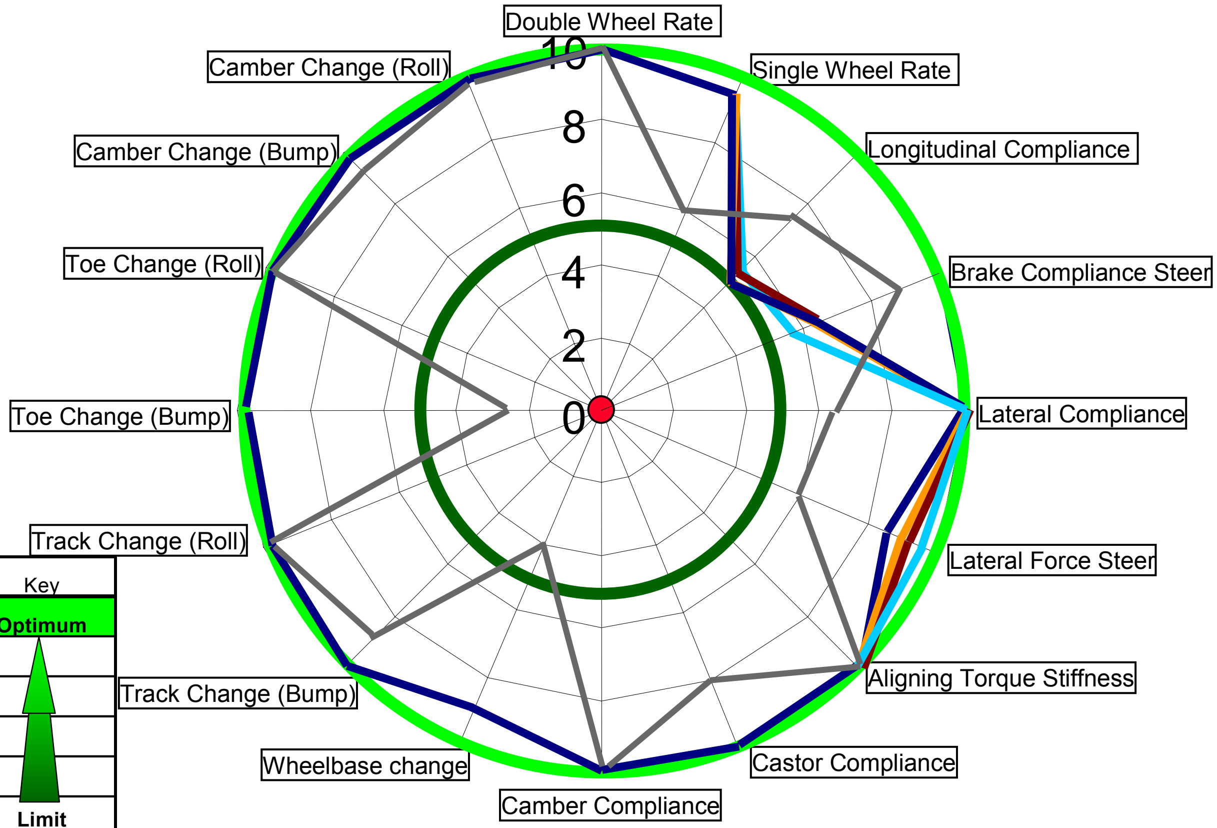
Please note: Welding feasibility studies were carried out in conjunction with The Welding Institute, Cambridge, UK.

TWISTBEAM :   Performance

TWISTBEAM



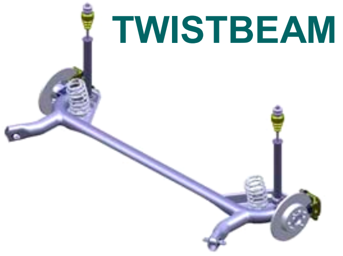
TWISTBEAM SYSTEM PERFORMANCE RATING Vs TARGETS



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

Target Limit
Optimum
ULSAS B Class
ULSAS C Class
ULSAS D Class
ULSAS P Class
Benchmark E Class

ULSAS CAE DYNAMICS APPROACH


TWISTBEAM

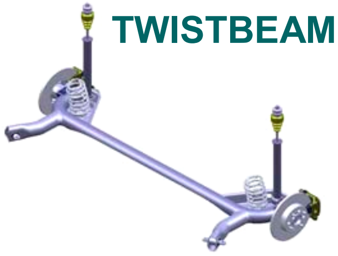
Models were used to:

- Generate the overall characteristics of the suspensions with respect to vertical wheel displacement.
- Establish the contribution of both the structural and non-structural components of the system to the overall system compliance characteristics.
- The system geometry, stiffness of components and compliant joint stiffness 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.

ULSAS CAE DYNAMICS APPROACH

TWISTBEAM



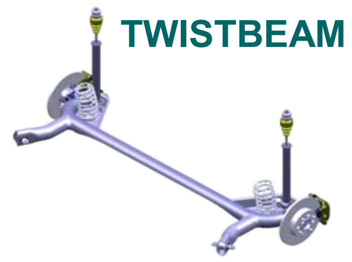
Models were used to generate the compliance and kinematic characteristics of the suspensions with respect to vertical wheel displacement, and to establish the contribution of all of the components of the overall system performance. The system characteristics were established with respect to lateral and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

To obtain the maximum level of accuracy in the prediction of wheel displacements and rotations with vertical wheel displacement, the ULSAS Twistbeam has been simulated by Abaqus non-linear F.E. analysis.

In general, ADAMS is used to analyse suspension systems, where at the concept stage the main suspension components are represented as rigid bodies, with bushes represented as linear characteristics. ADAMS generates a correct representation of the geometry changes during suspension system motion.

Structural compliance can be incorporated into an ADAMS model by using ADAMS beams. This is satisfactory at a basic concept level, but does not accurately model complex geometry. Alternatively, linear compliance of the parts can be included, if required, by using ADAMS F.E. This allows the rigid parts in ADAMS to be replaced by F.E models. These F.E. models are generated using an external code (Nastran etc.).

ULSAS CAE DYNAMICS APPROACH


TWISTBEAM

Systems that require the structural compliance to be included can be modelled directly using F.E. analysis. Twistbeams fall into this category. If non-linear geometry effects are to be calculated (as they should be) non-linear F.E. analysis should be used (ABAQUS etc.) This type of analysis can also be used to represent a pseudo-kinematic system, with bushes and joints – and will give identical kinematic and compliant results to ADAMS F.E., where structural deflection of parts is small.

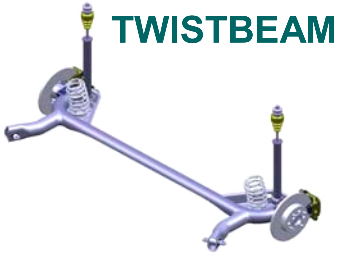
For twistbeams, structural compliance generates non-linear geometry changes. ADAMS F.E. would not produce the correct answer over large deflections (such as roll simulation). ADAMS can only support linear structural compliance, valid only for small deflections. For large structural deflections, as in a twistbeam kinematic analysis, non-linear structural compliance must be represented for accurate results, was achieved using a non-linear F.E. tool. As F.E. models already existed (for stress results etc.), Abaqus was used to analyse the Kinematic and Compliant characteristics. An ADAMS model could have be created in addition, but would have been of no benefit.

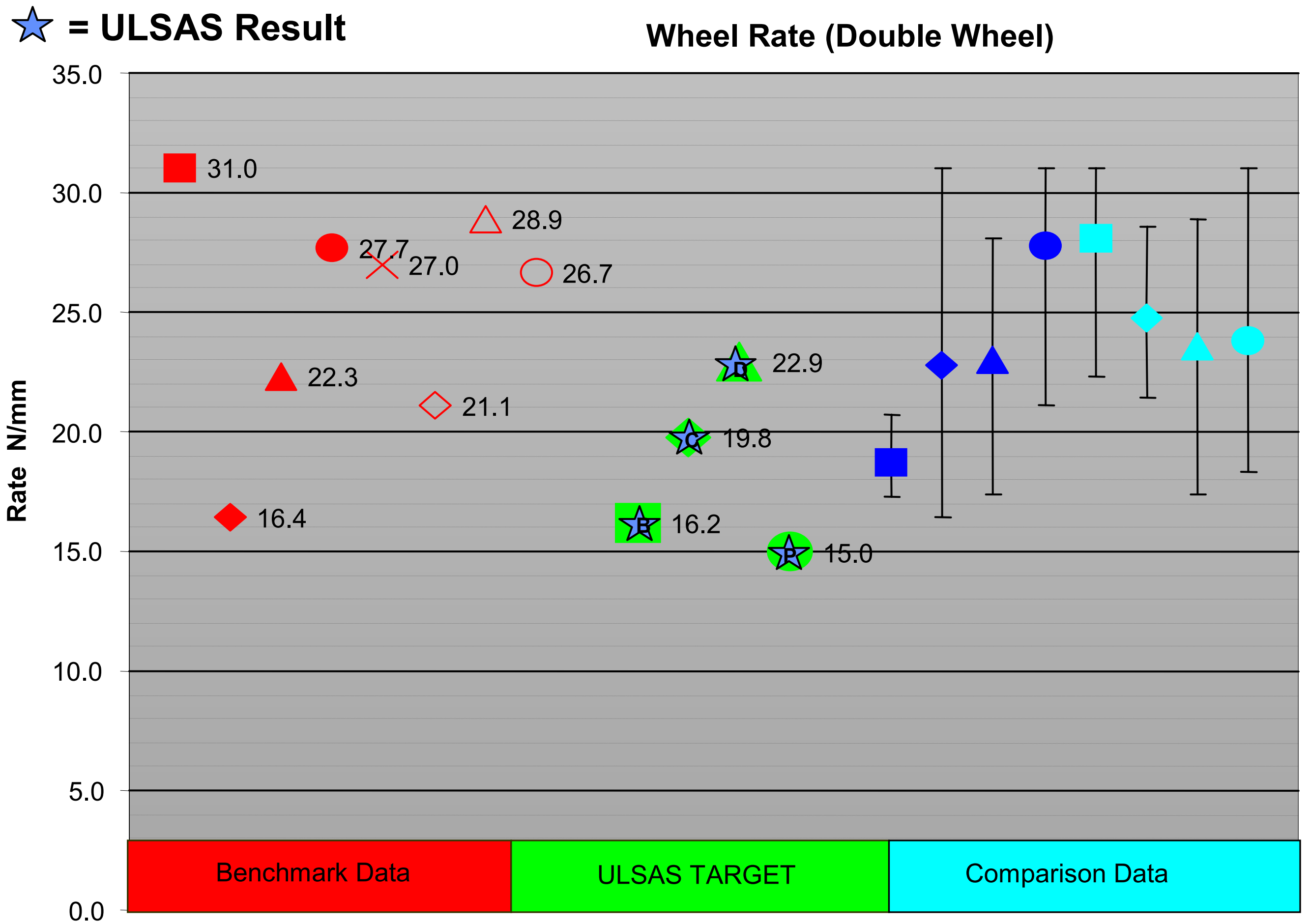
The system geometry, component stiffness and compliant joint stiffness were all varied to obtain a solution which satisfied the kinematic and compliance targets generated by the target setting process.

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

TWISTBEAM: Performance

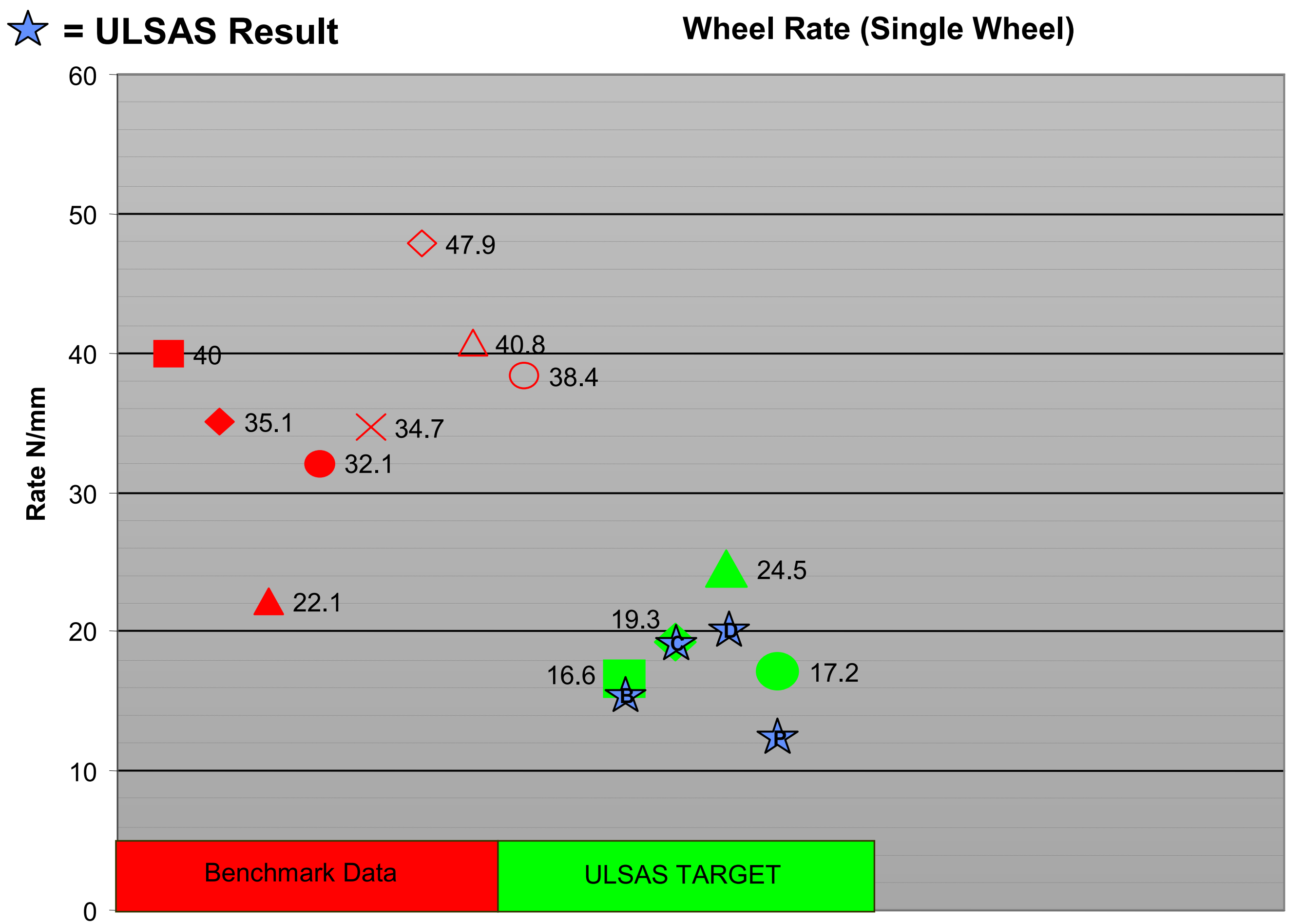
TWISTBEAM





Comments:
Wheel rates have exactly matched targets by a combination of spring design and suspension parasitic rate.

TWISTBEAM: Performance



Comments:

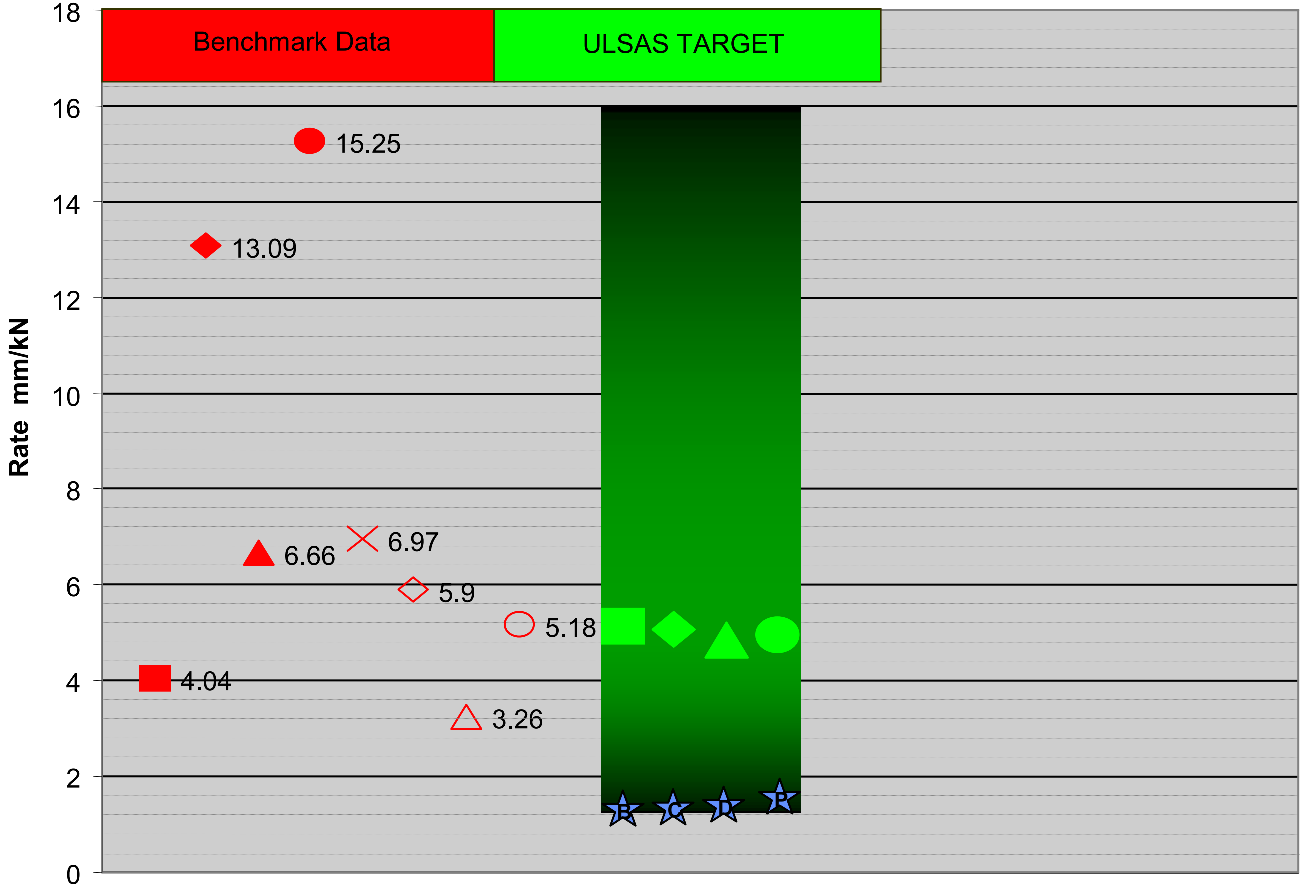
Single wheel rate is slightly low therefore an additional anti-roll bar may be required. However, the high track change in roll achieved with the ULSAS twistbeam designs reduces the requirement for single wheel rate compared to independent suspensions.

TWISTBEAM: Performance

TWISTBEAM

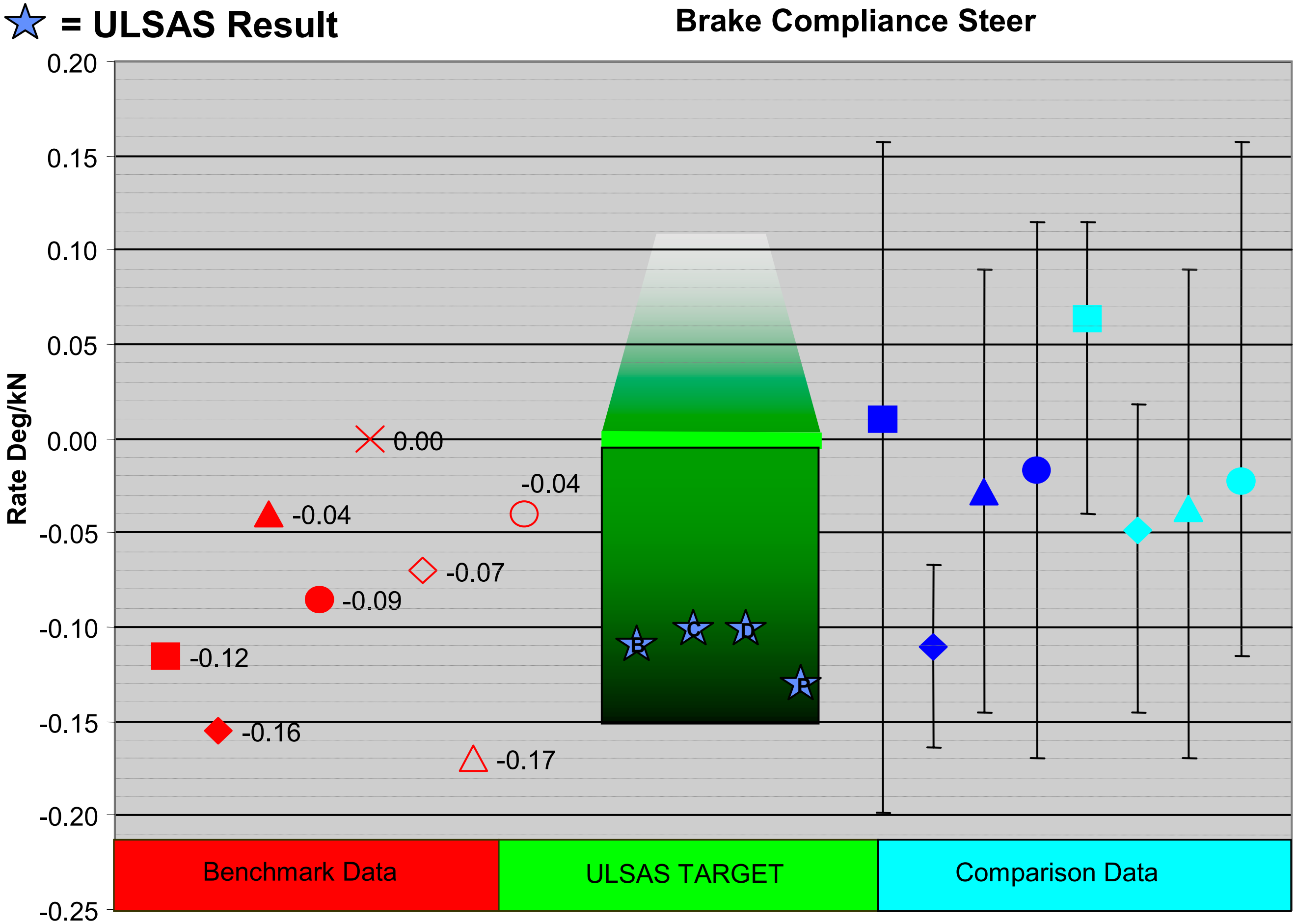
★ **= ULSAS Result**

Longitudinal Compliance



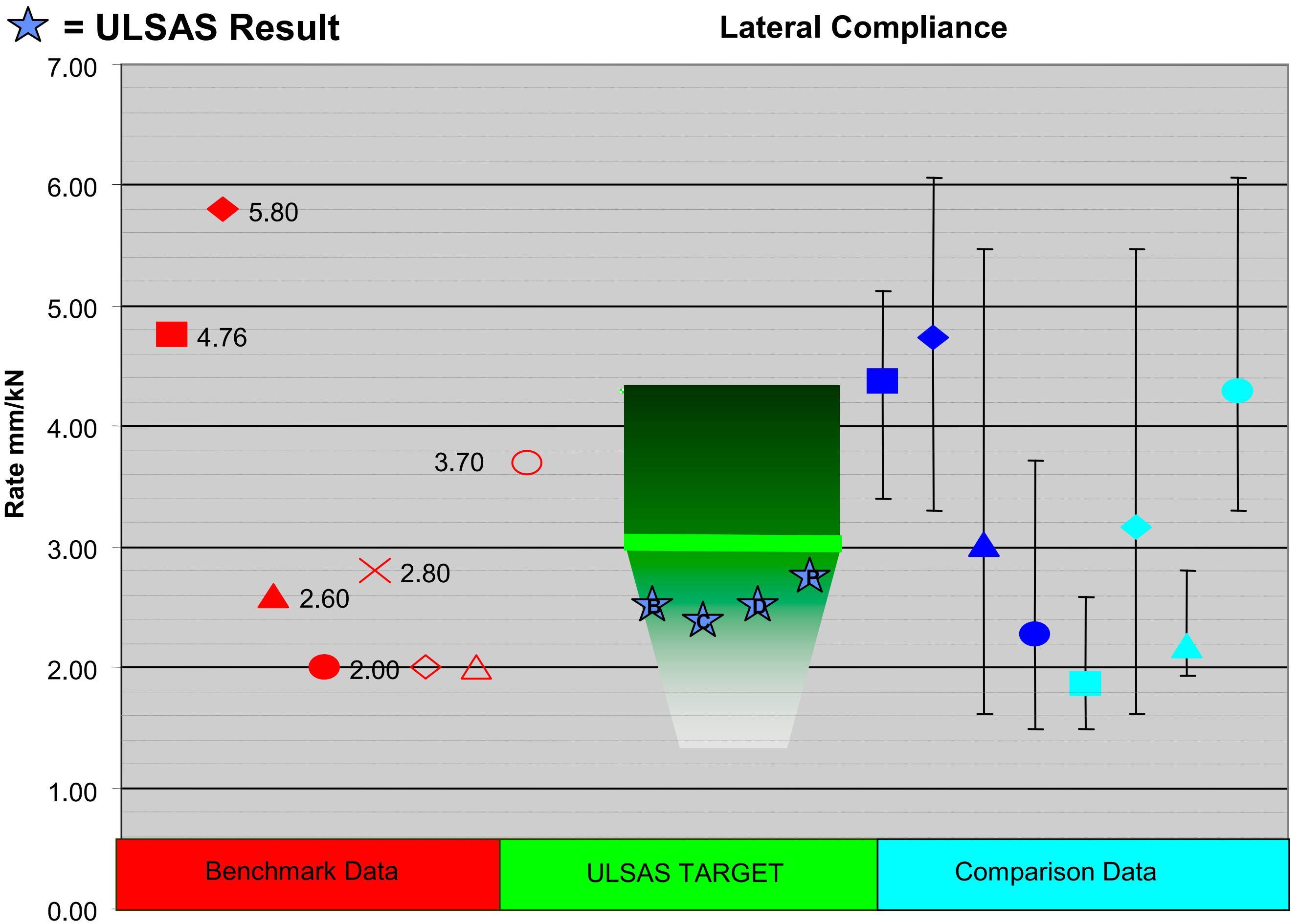
Comments:
The longitudinal compliance is lower than target, this is due to the high level of castor stiffness achieved, which allows much lower longitudinal compliance at the tyre contact patch for the desired longitudinal axle location stiffness.

TWISTBEAM: Performance



Comments:
The levels of brake steer compliance control achieved are typical for twistbeam suspensions.

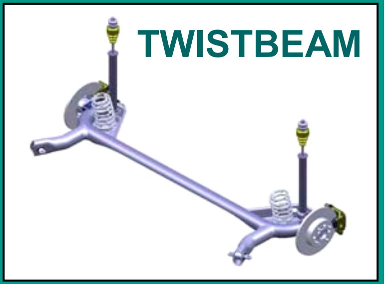
TWISTBEAM: Performance

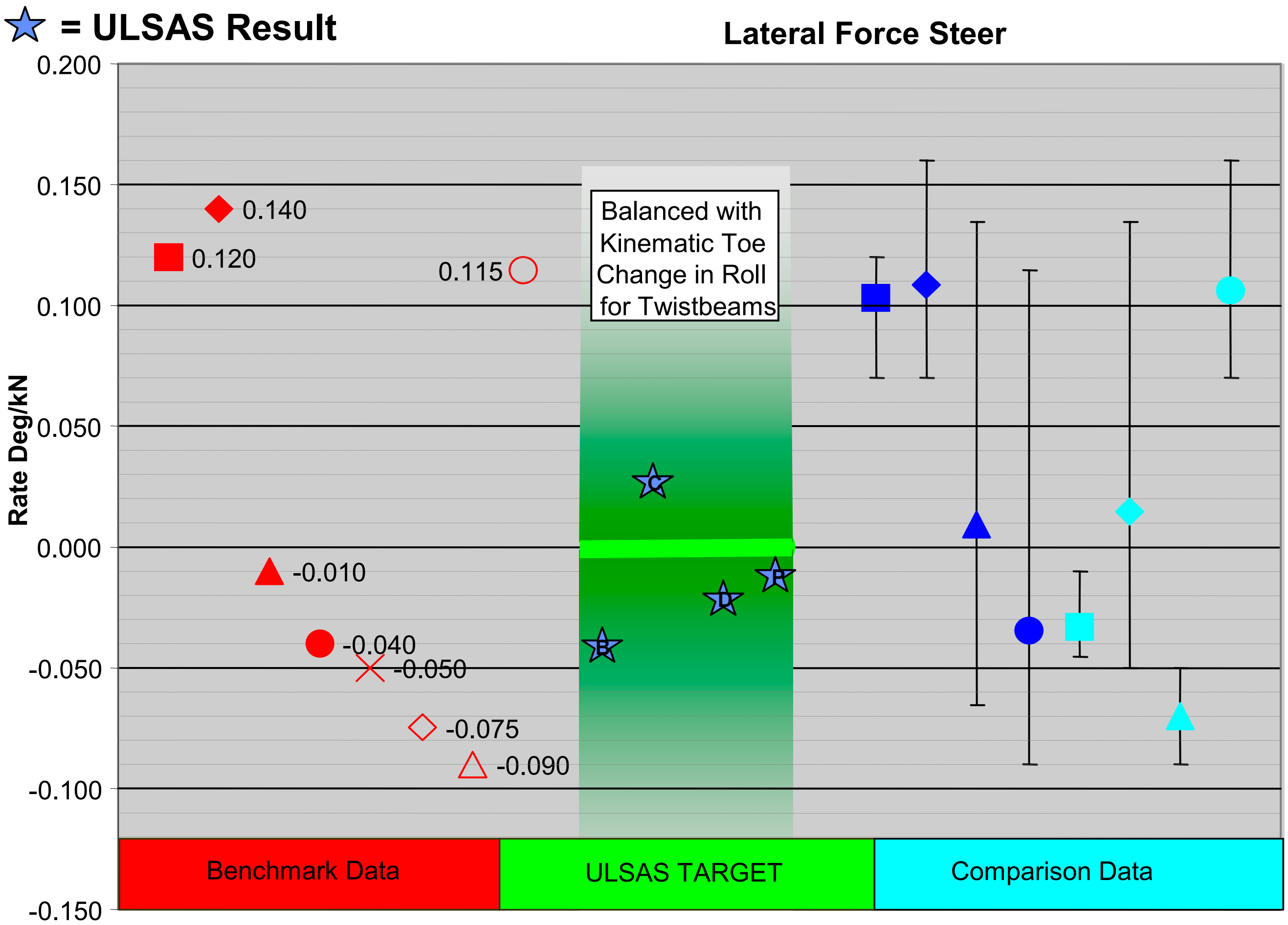


Comments:

Good control has been achieved with performance exceeding the requirement.

TWISTBEAM: Performance

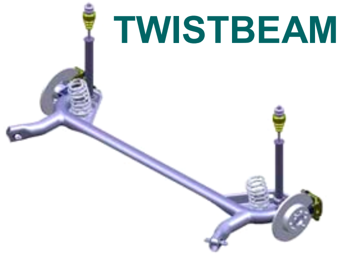


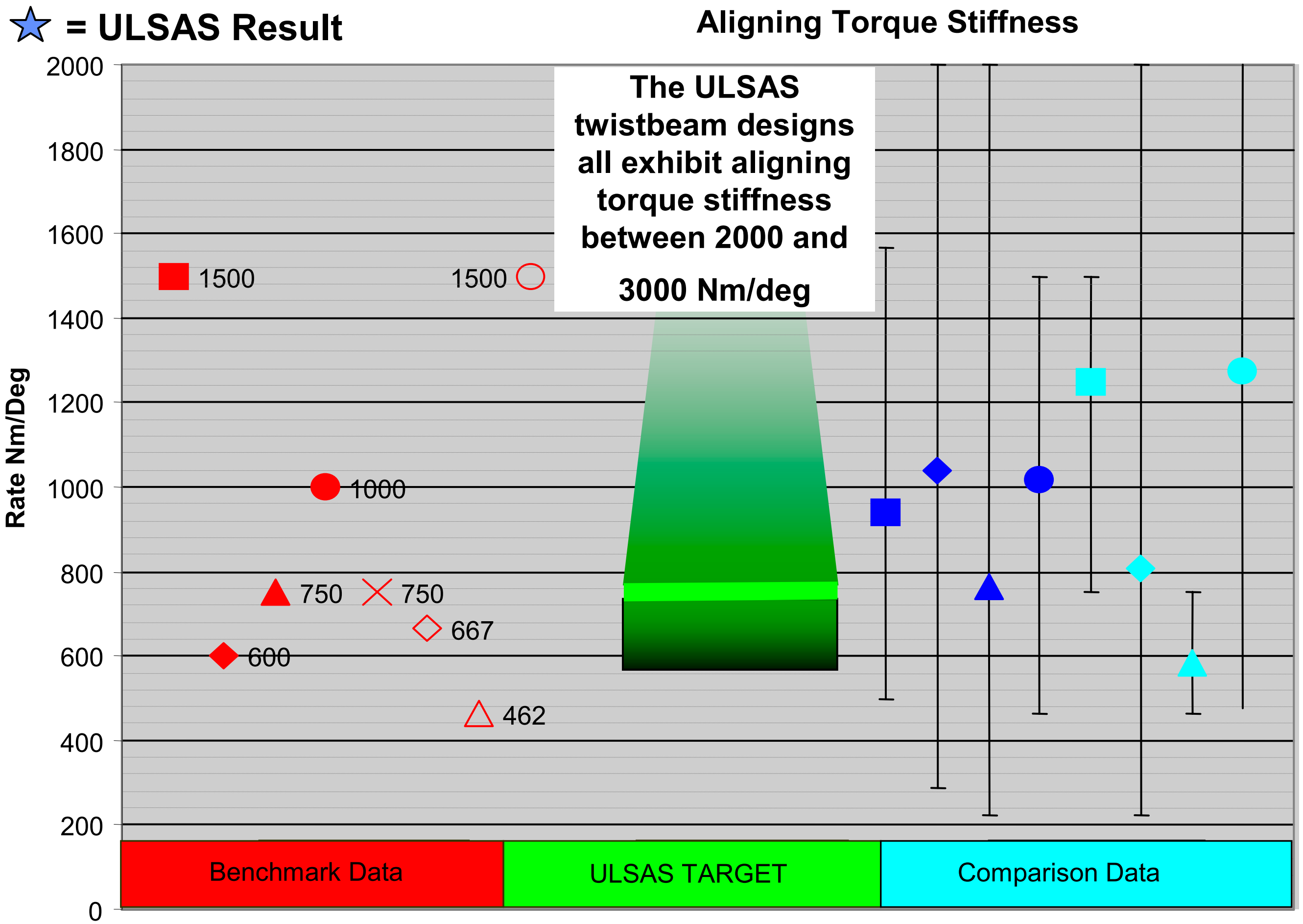


Comments:
A good level of control of lateral force steer compliance has been achieved for the ULSAS twistbeam suspensions.

TWISTBEAM: Performance

TWISTBEAM



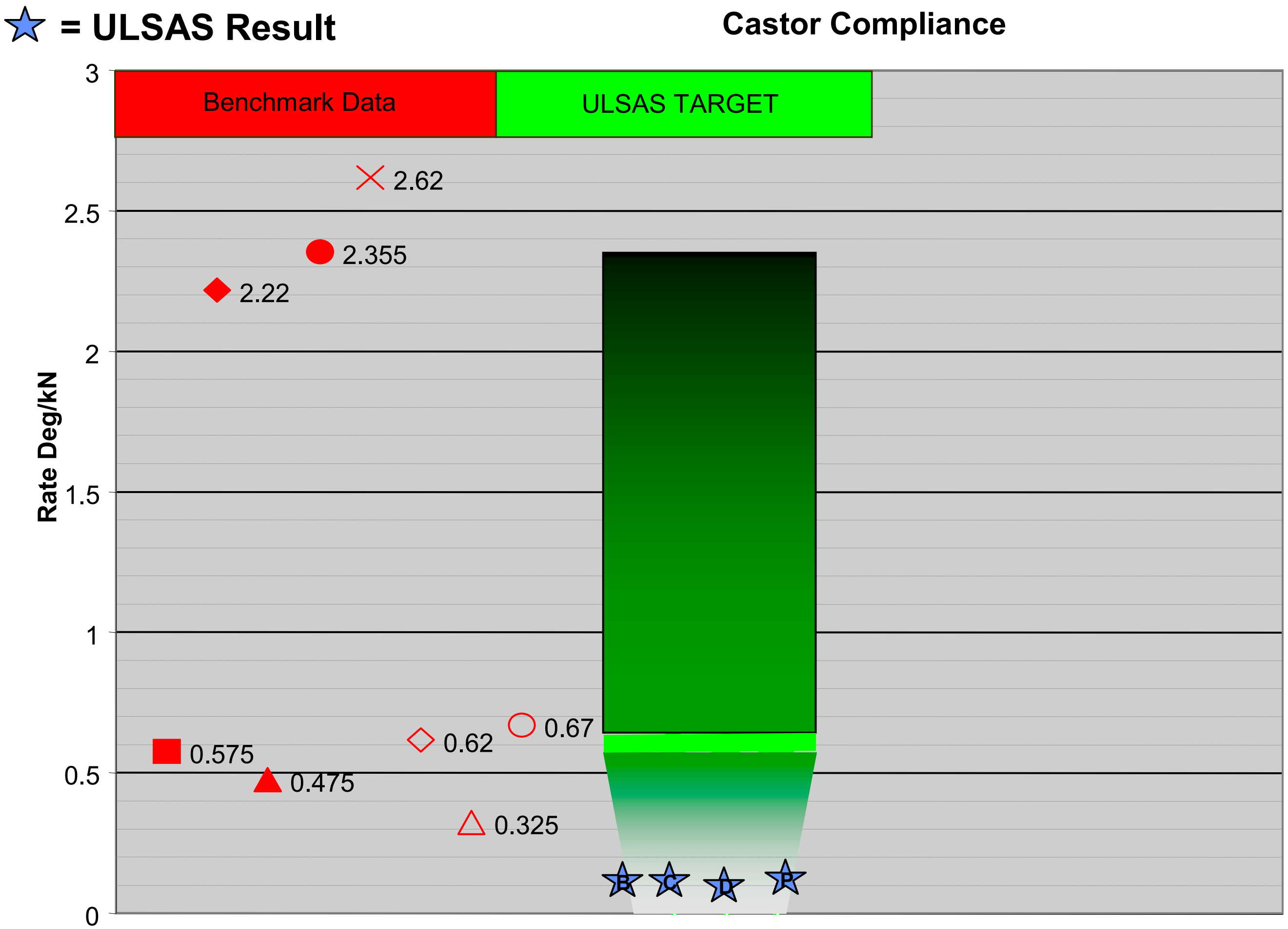


The ULSAS twistbeam designs all exhibit aligning torque stiffness between 2000 and 3000 Nm/deg

Comments:

The ULSAS twistbeam designs have all achieved a value of aligning torque stiffness significantly better than target.

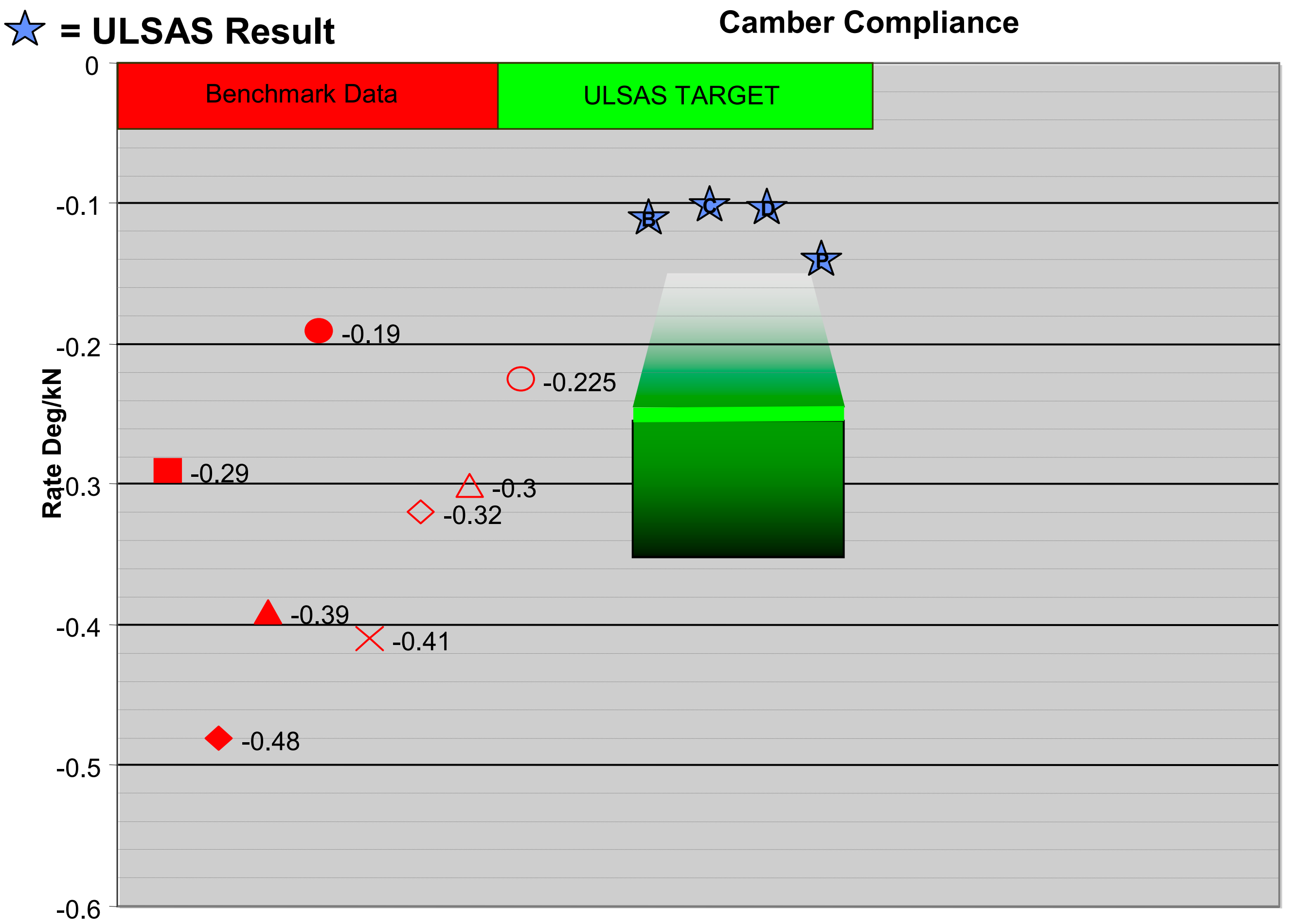
TWISTBEAM : Performance



Comments:
The ULSAS twistbeam designs have all achieved a low level of castor compliance. These exceed the performance target for this characteristic.

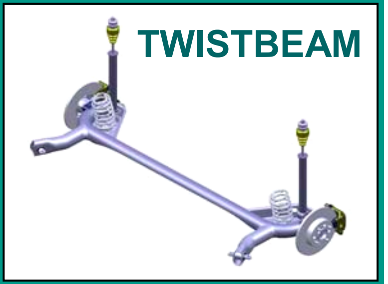
TWISTBEAM : Performance

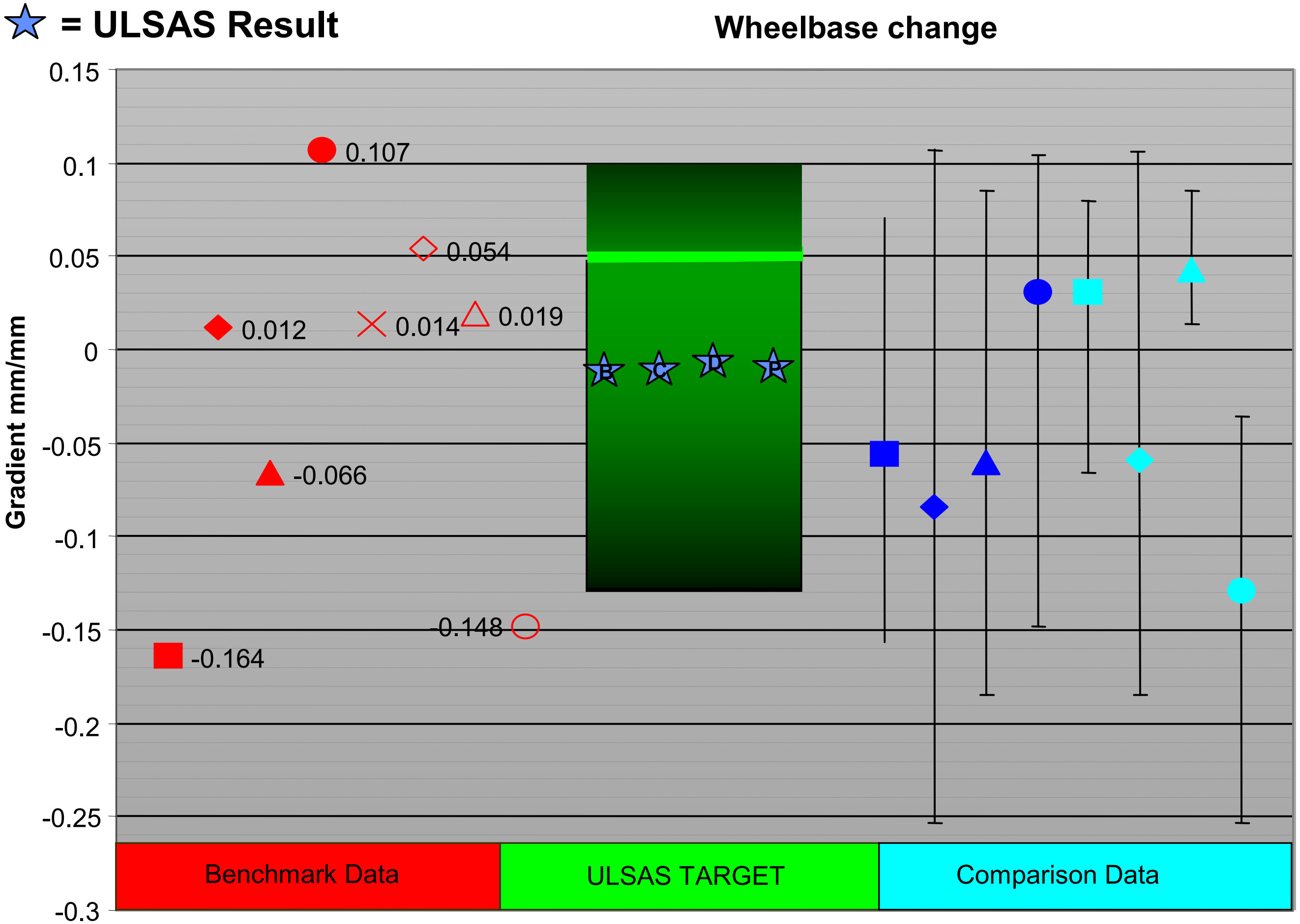
TWISTBEAM



Comments:
Good levels of camber stiffness have been achieved, exceeding the performance target requirements.

TWISTBEAM : Performance

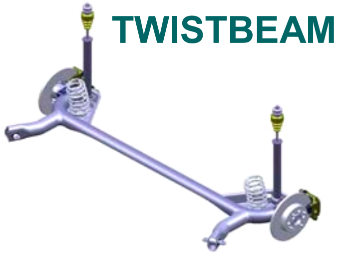


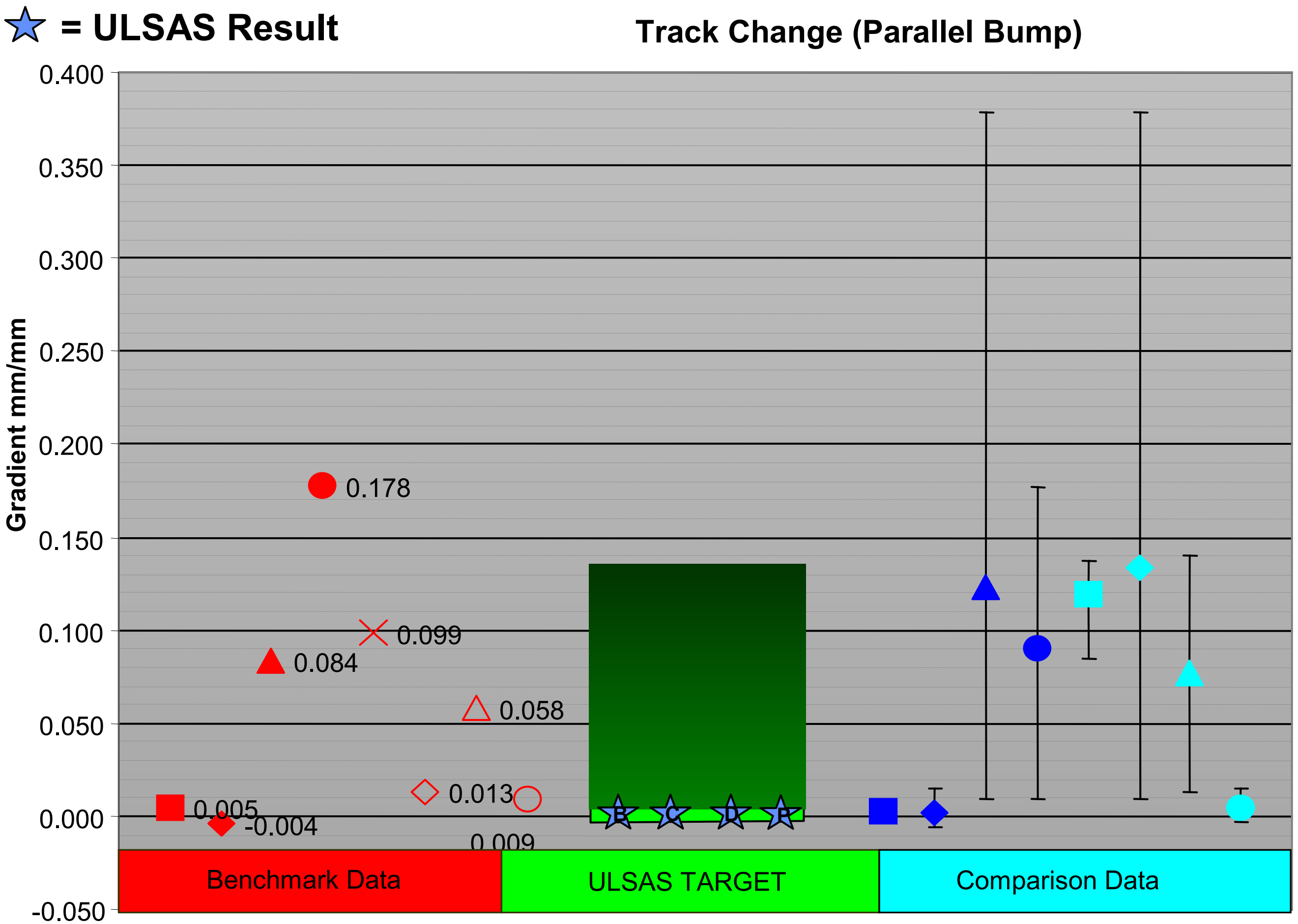


Comments:
Good characteristics have been achieved close to the optimum which will help maximise ride quality. On the Audi A6 and VW Golf the rear wheel actually moves forward in bump This is detrimental to ride.

TWISTBEAM : Performance

TWISTBEAM

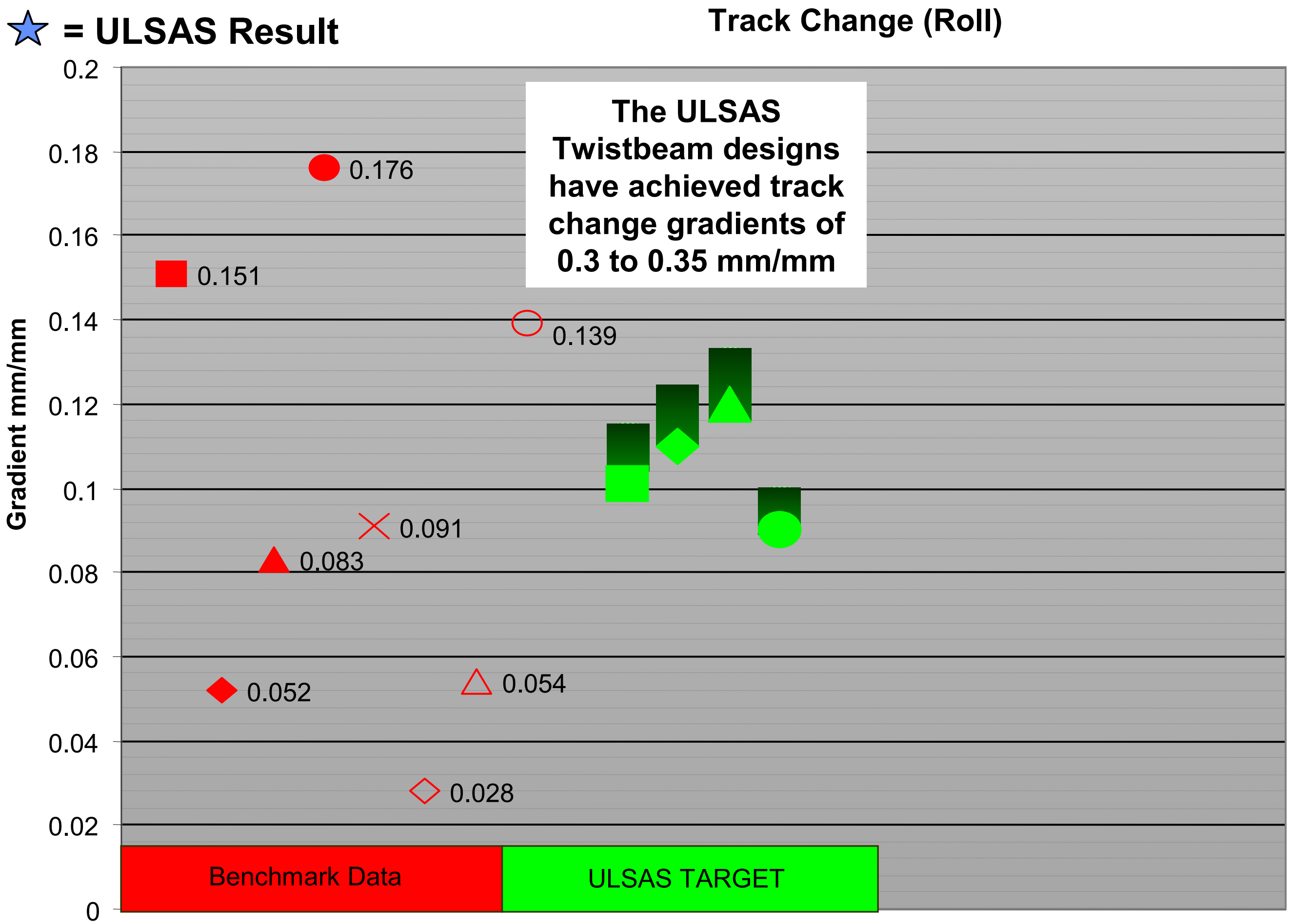




Comments:
For a twistbeam system, track change in parallel bump is independent of track change in roll. All the ULSAS twistbeam designs achieve the ideal target of zero.

TWISTBEAM : Performance

TWISTBEAM

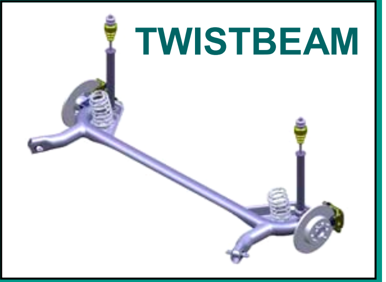


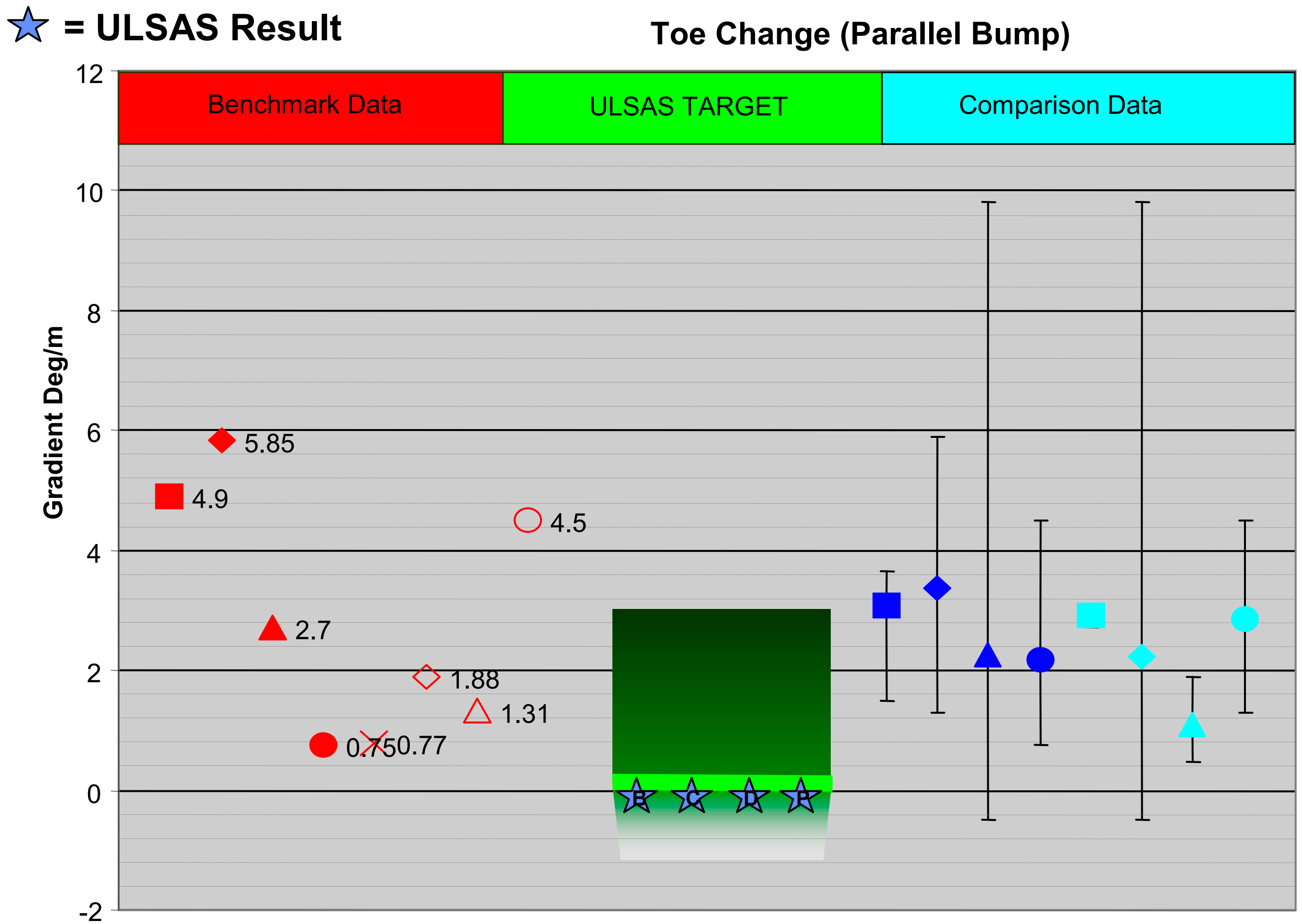
The ULSAS Twistbeam designs have achieved track change gradients of 0.3 to 0.35 mm/mm

Comments:

Twistbeam suspensions are able to generate high track change gradients in roll without the detrimental effects associated with high track change in independent suspensions. The high track change gradient in roll achieved, benefits handling by reducing the roll moment reacted by the suspension springs during cornering.

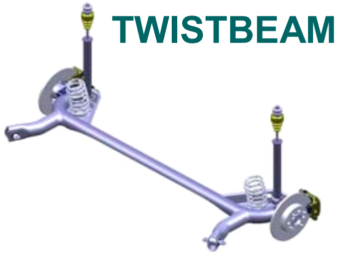
TWISTBEAM : Performance



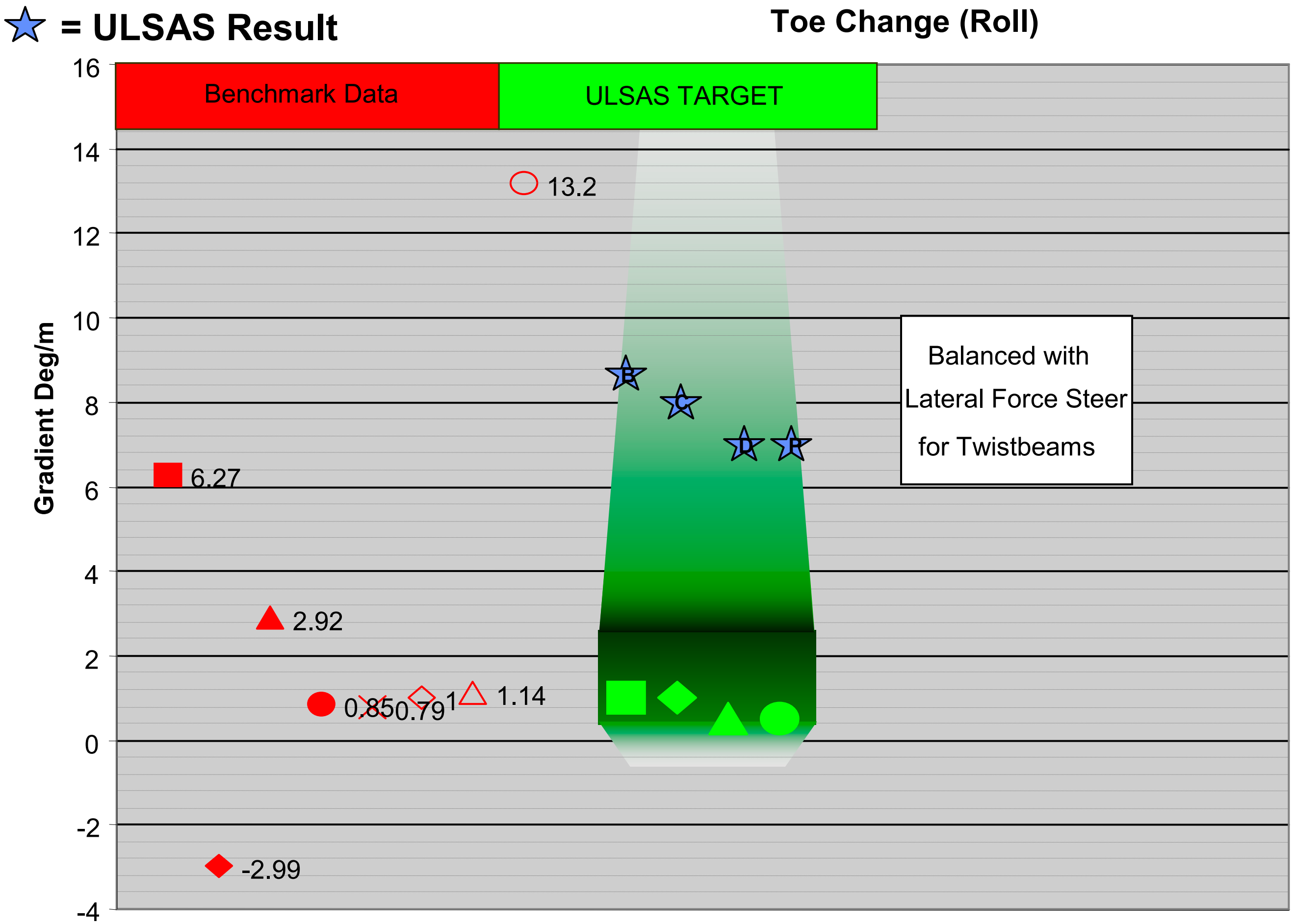


Comments:
With a twistbeam suspension, toe change in parallel bump results only from static camber (at the suspension's ride position) translating into toe as the hub carrier rotates about a lateral axis (castor change). Static camber is set as part of a vehicle's final development tuning.

TWISTBEAM : Performance



TWISTBEAM



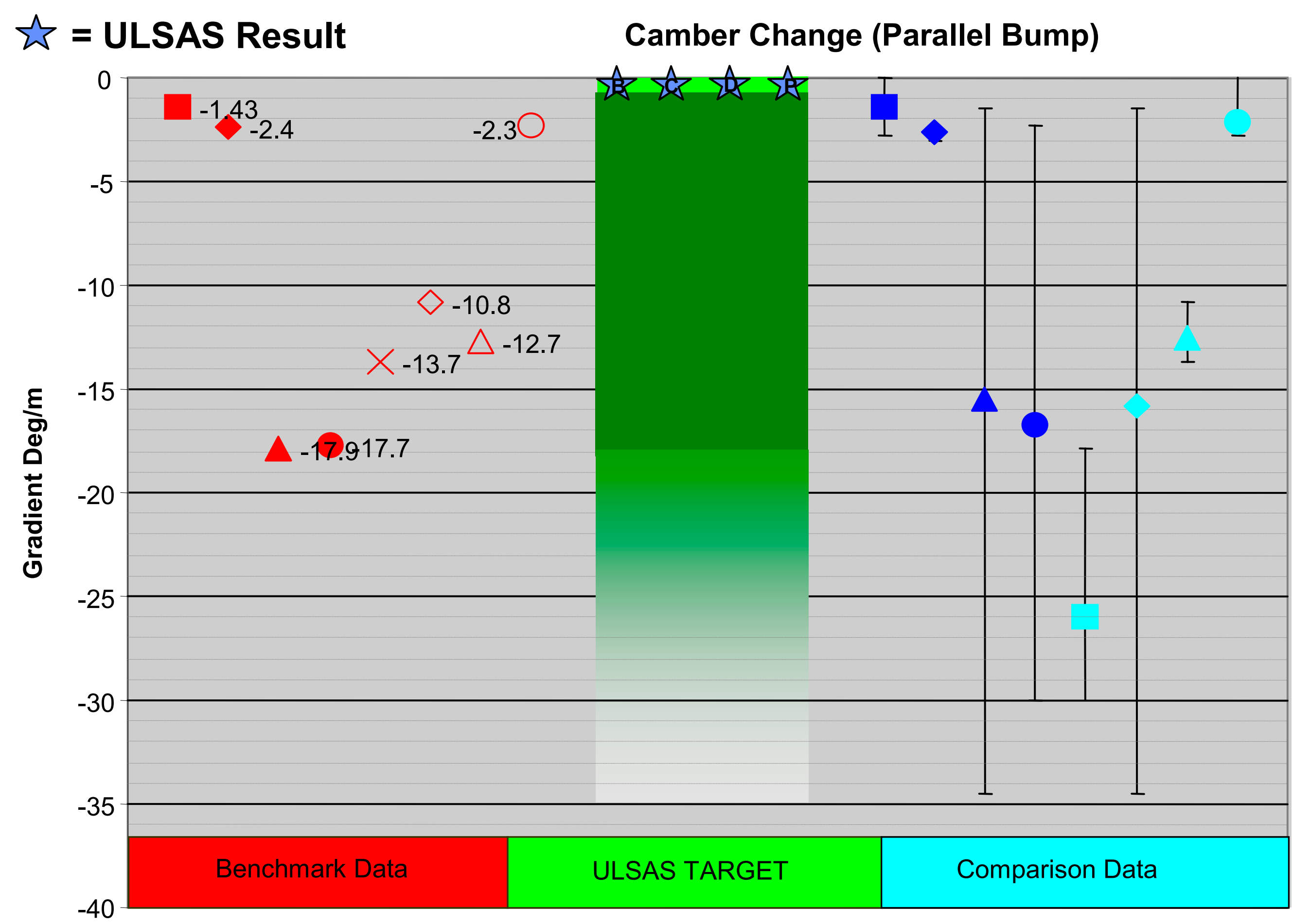
Balanced with Lateral Force Steer for Twistbeams

Comments:

The ULSAS twistbeam designs show Toe Change comparable with the benchmark vehicle’s. Values are significantly less than those of the Audi A6 to balance with the reduced level of lateral force steer compliance achieved.

TWISTBEAM : Performance

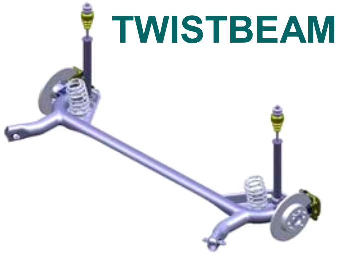
TWISTBEAM

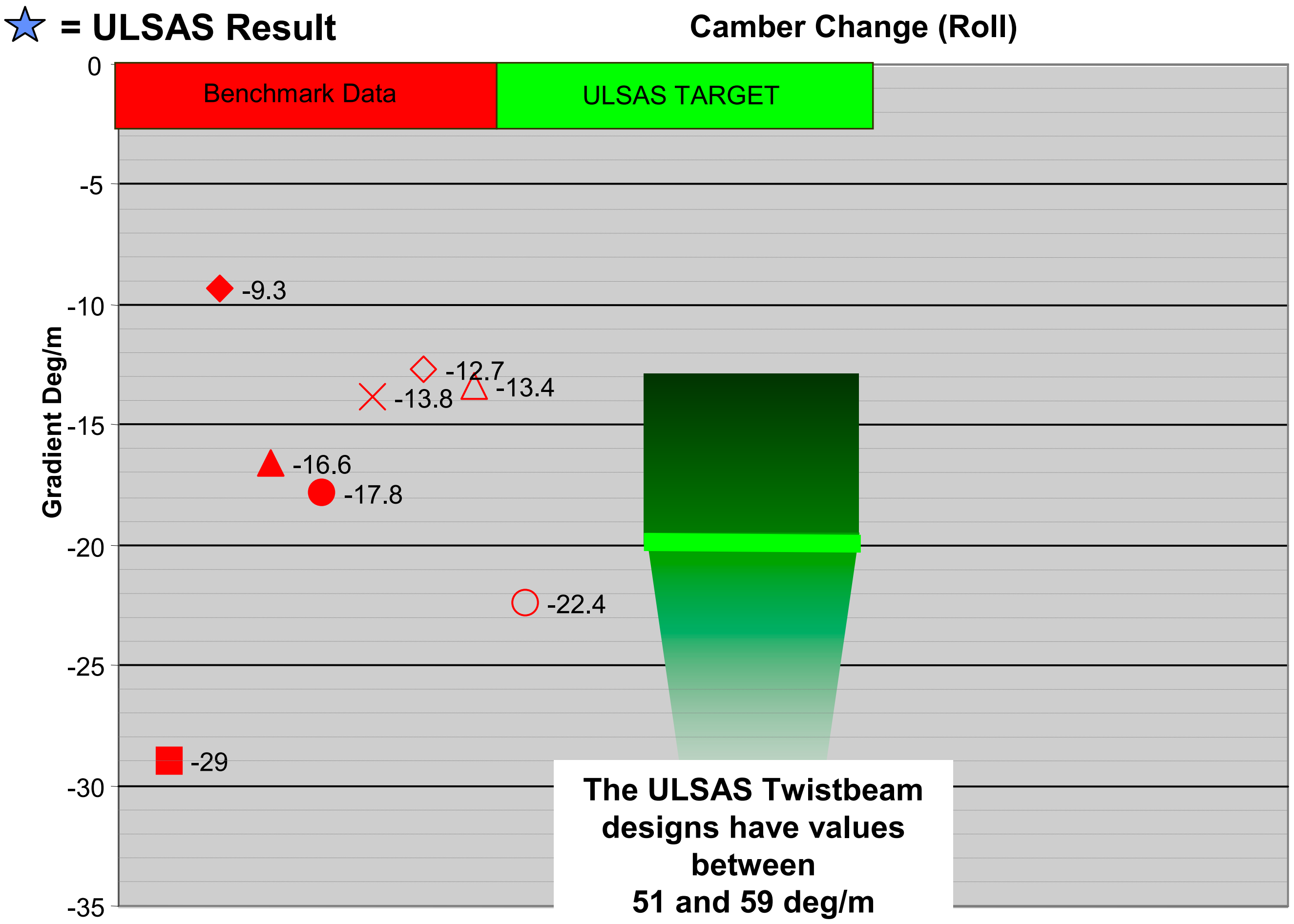


Comments:
With a twistbeam suspension, camber change in parallel bump results only from static toe (at the suspension's ride position) translating into camber as the hub carrier rotates about a lateral axis (castor change). Static toe is set as part of a vehicle's final development tuning.

TWISTBEAM : Performance

TWISTBEAM





The ULSAS Twistbeam designs have values between 51 and 59 deg/m

Comments:

Twistbeam suspensions are able to generate high levels of camber change in roll, without the detrimental effect of high camber change in parallel bump. High camber change in roll aids cornering by increasing the rear axle lateral force capability.

TWISTBEAM : Performance

TWISTBEAM

SYSTEM COMPLIANCES : B CLASS

Detailed Results Breakdown (Bushes Vs Structural Contributions)

Characteristic	Units	Bush	Structural	TOTAL
Longitudinal Force at TCP				
TCP Longitudinal Compliance	mm/kN	0.97	0.40	1.37
Steer Compliance	deg/kN	-0.07	-0.04	-0.11
Castor Compliance	deg/kN	0.04	0.07	0.11
Lateral Force at TCP				
TCP Lateral Compliance	mm/kN	1.77	0.71	2.47
Steer Compliance	deg/kN	-0.05	0.01	-0.04
Camber Compliance	deg/kN	0.00	0.11	0.11
Aligning Torque at TCP				
Steer Stiffness	Nm / deg	6493.00	3815.00	2403.07

TWISTBEAM : Performance

SYSTEM COMPLIANCES : C CLASS

Detailed Results Breakdown (Bushes Vs Structural Contributions)

Characteristic	Units	Bush	Structural	TOTAL
Longitudinal Force at TCP				
TCP Longitudinal Compliance	mm/kN	0.98	0.38	1.36
Steer Compliance	deg/kN	-0.07	-0.03	-0.10
Castor Compliance	deg/kN	0.04	0.07	0.11
Lateral Force at TCP				
TCP Lateral Compliance	mm/kN	1.75	0.64	2.39
Steer Compliance	deg/kN	0.02	0.01	0.03
Camber Compliance	deg/kN	0.00	0.10	0.10
Aligning Torque at TCP				
Steer Stiffness	Nm / deg	7413.00	4289.00	2717.00

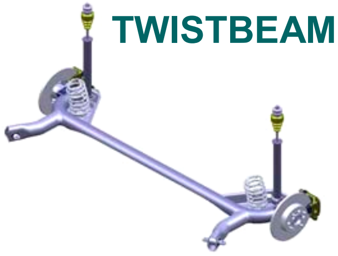
TWISTBEAM : Performance

SYSTEM COMPLIANCES : D CLASS

Detailed Results Breakdown (Bushes Vs Structural Contributions)

Characteristic	Units	Bush	Structural	TOTAL
Longitudinal Force at TCP				
TCP Longitudinal Compliance	mm/kN	1.02	0.41	1.43
Steer Compliance	deg/kN	-0.07	-0.03	-0.10
Castor Compliance	deg/kN	0.04	0.06	0.10
Lateral Force at TCP				
TCP Lateral Compliance	mm/kN	1.76	0.75	2.51
Steer Compliance	deg/kN	-0.04	0.01	-0.02
Camber Compliance	deg/kN	0.00	0.10	0.10
Aligning Torque at TCP				
Steer Stiffness	Nm / deg	7884.00	4580.00	2897.04

TWISTBEAM : Performance

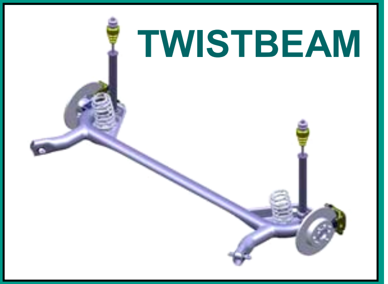


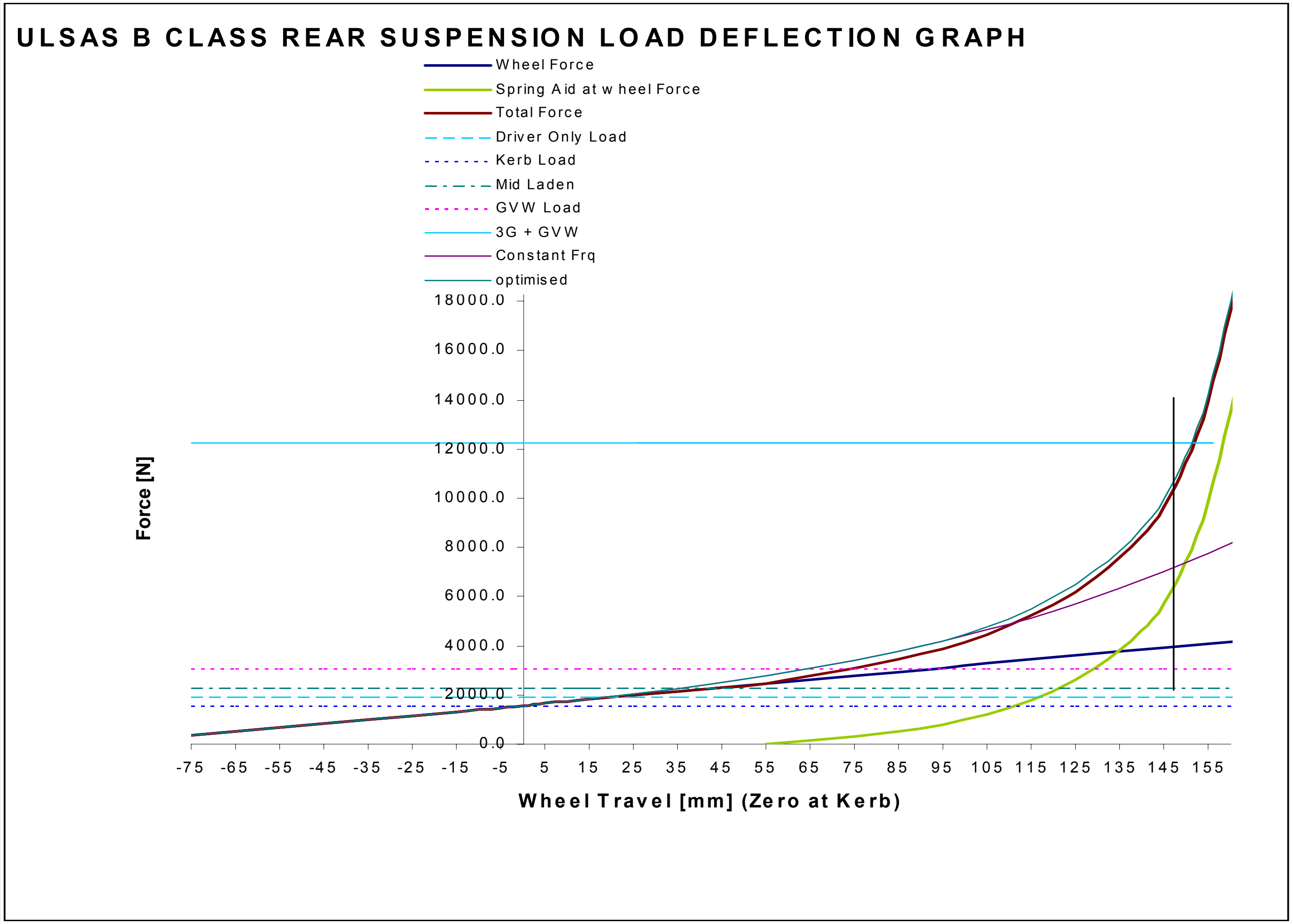
SYSTEM COMPLIANCES : P CLASS

Detailed Results Breakdown (Bushes Vs Structural Contributions)

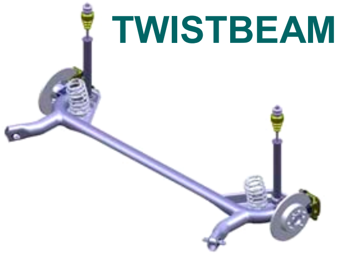
Characteristic	Units	Bush	Structural	TOTAL
Longitudinal Force at TCP				
TCP Longitudinal Compliance	mm/kN	1.15	0.49	1.64
Steer Compliance	deg/kN	-0.09	-0.04	-0.13
Castor Compliance	deg/kN	0.04	0.08	0.12
Lateral Force at TCP				
TCP Lateral Compliance	mm/kN	1.73	1.05	2.78
Steer Compliance	deg/kN	-0.03	0.01	-0.01
Camber Compliance	deg/kN	0.00	0.14	0.14
Aligning Torque at TCP				
Steer Stiffness	Nm / deg	8432.00	3054.00	2241.98

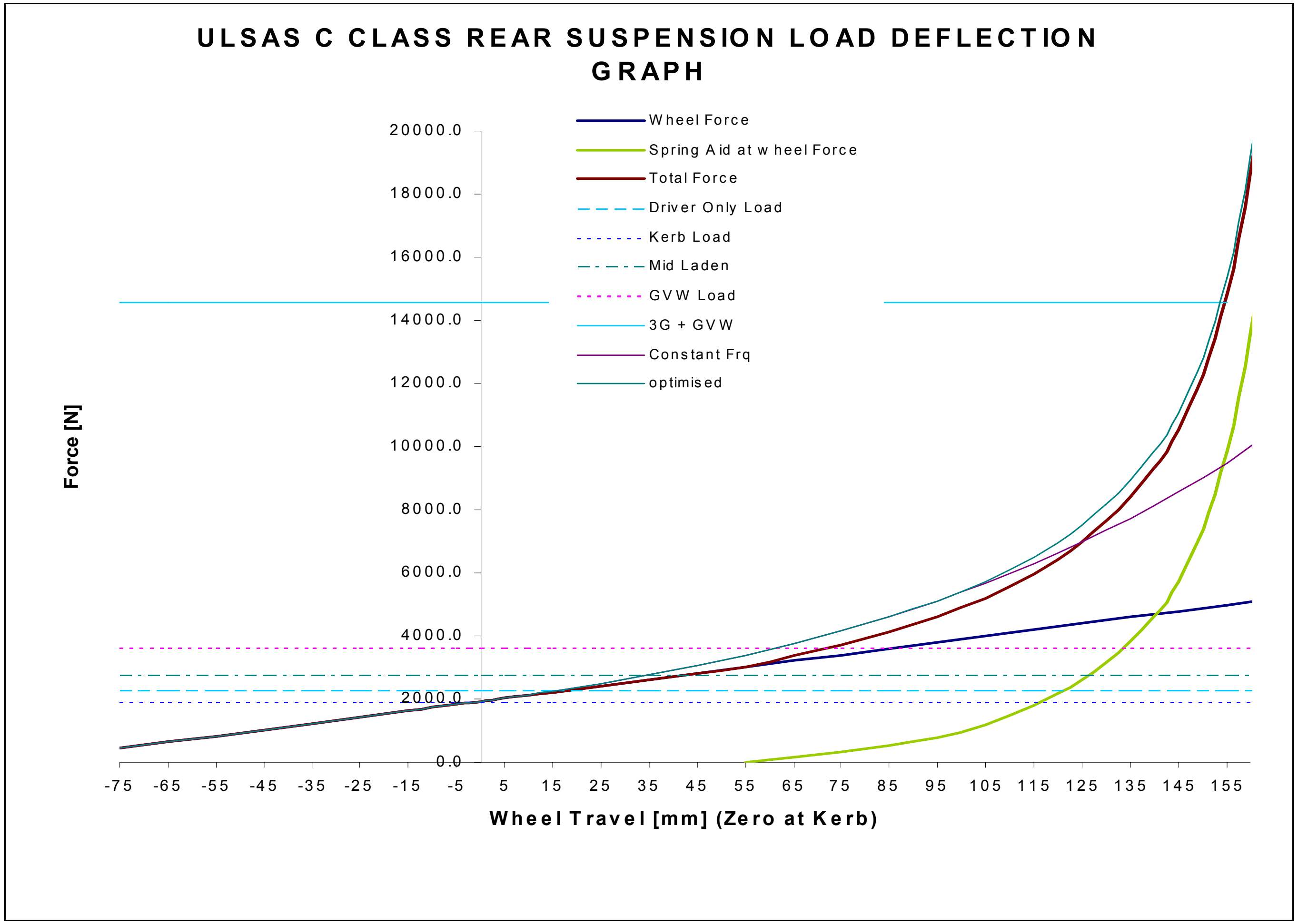
TWISTBEAM : Performance





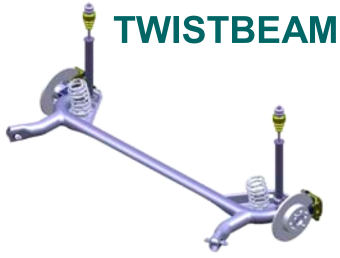
TWISTBEAM : Performance

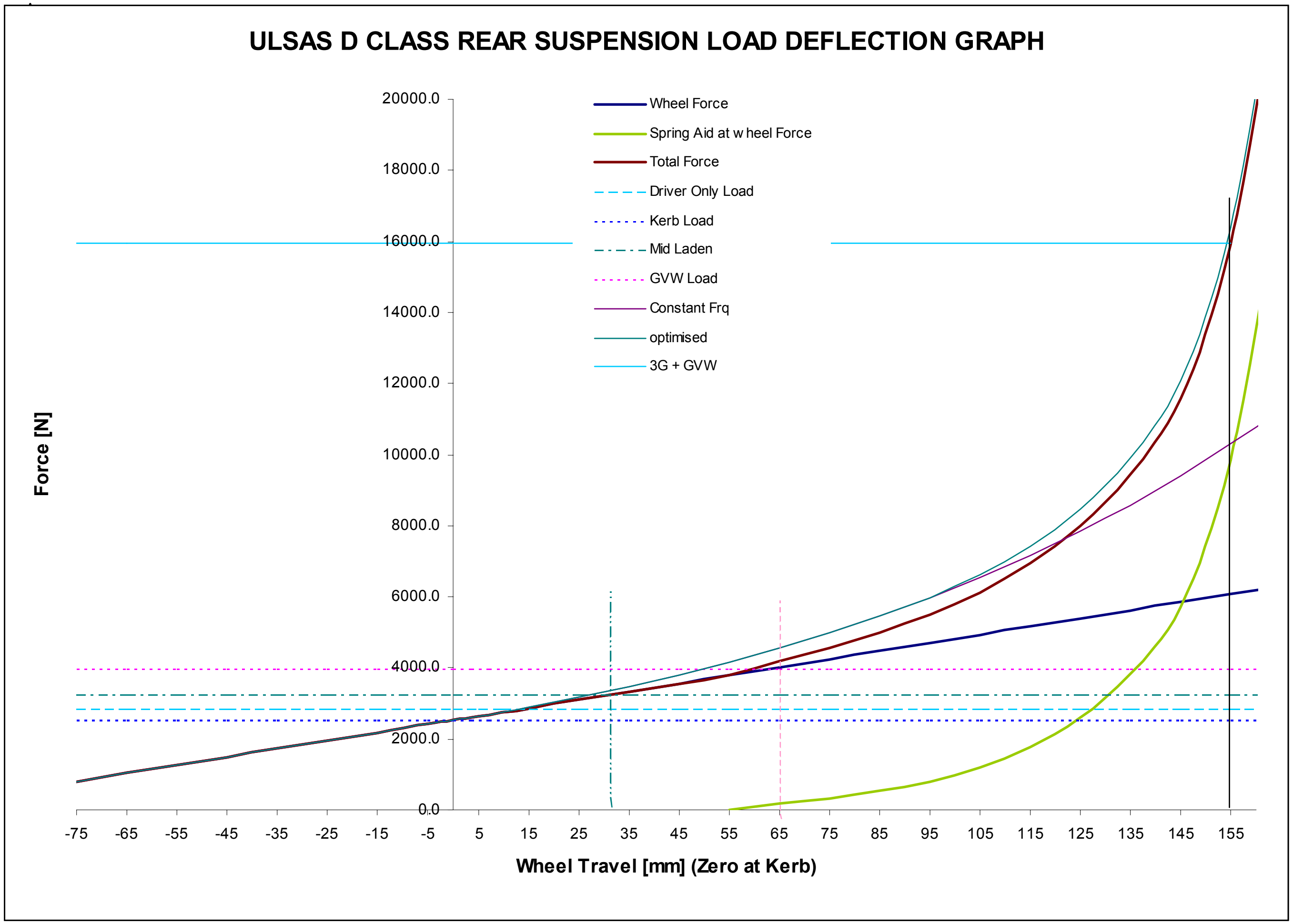



ULSAS C CLASS REAR SUSPENSION LOAD DEFLECTION GRAPH

ULTRALIGHT
STEEL
AUTO SUSPENSION

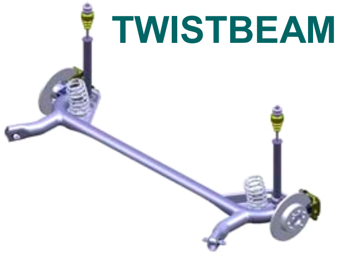
TWISTBEAM : Performance


TWISTBEAM

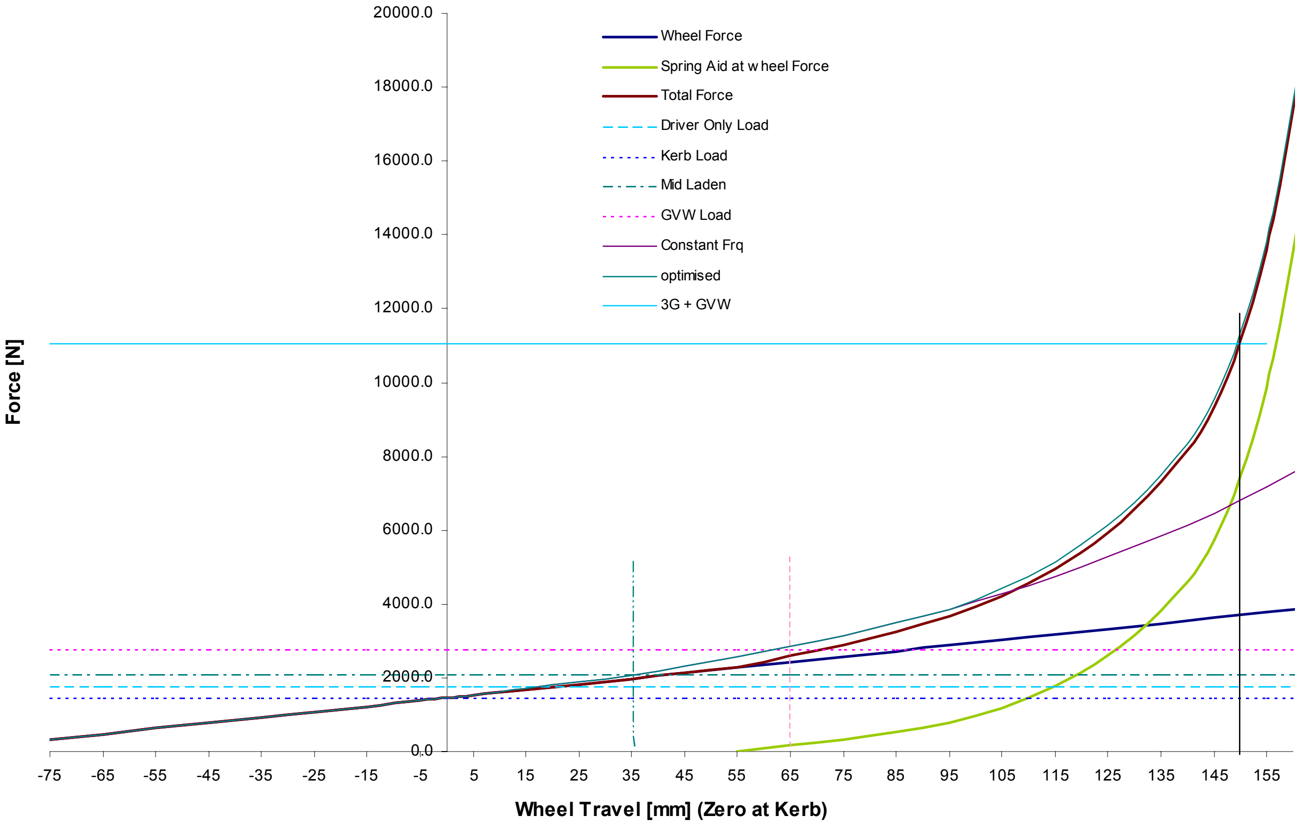

ULSAS D CLASS REAR SUSPENSION LOAD DEFLECTION GRAPH

TWISTBEAM : Performance

TWISTBEAM

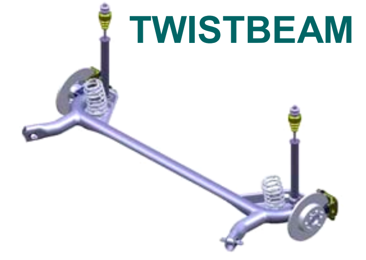


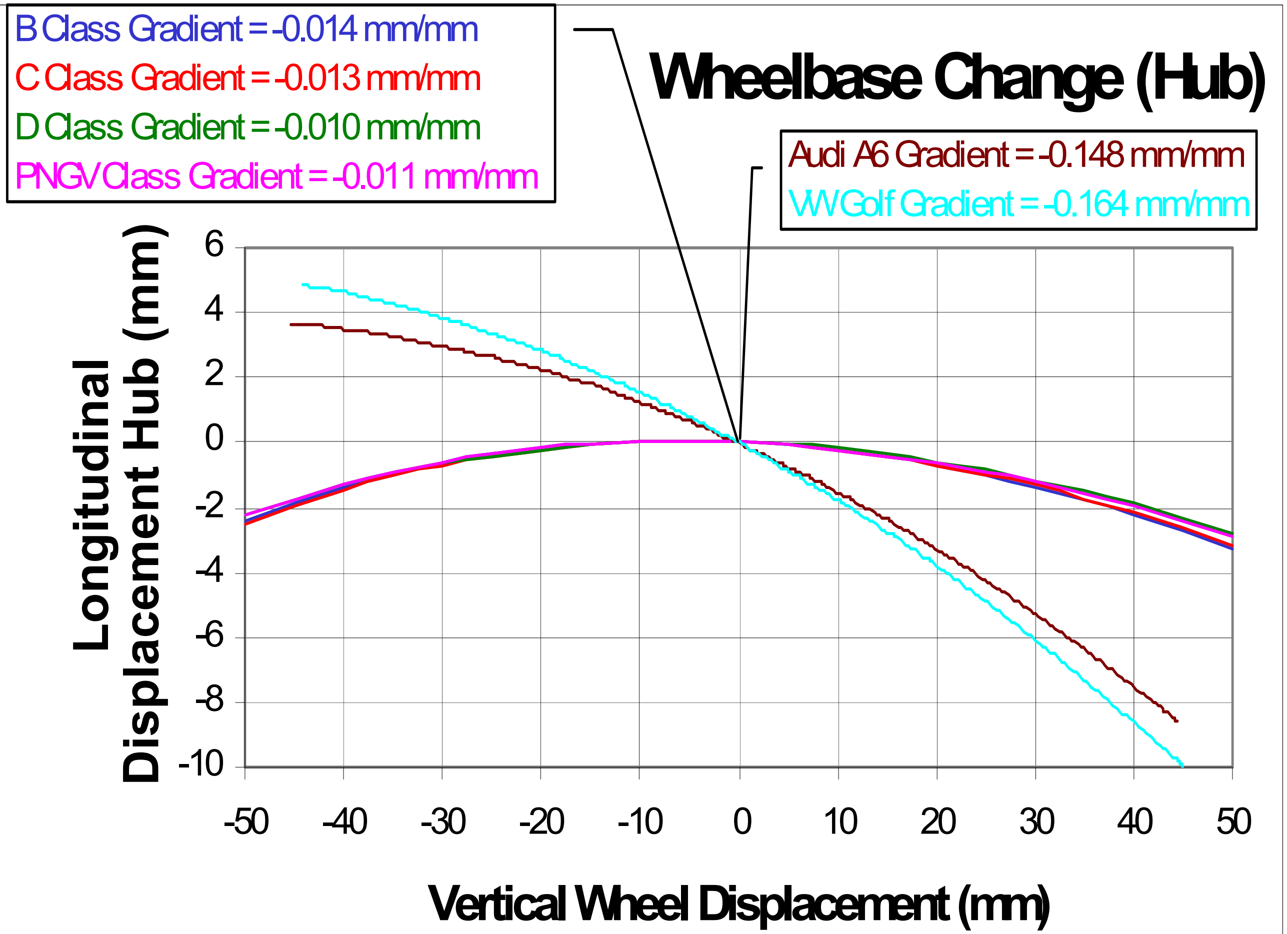
ULSAS PNGV CLASS REAR SUSPENSION LOAD DEFLECTION GRAPH



ULTRALIGHT STEEL AUTO SUSPENSION

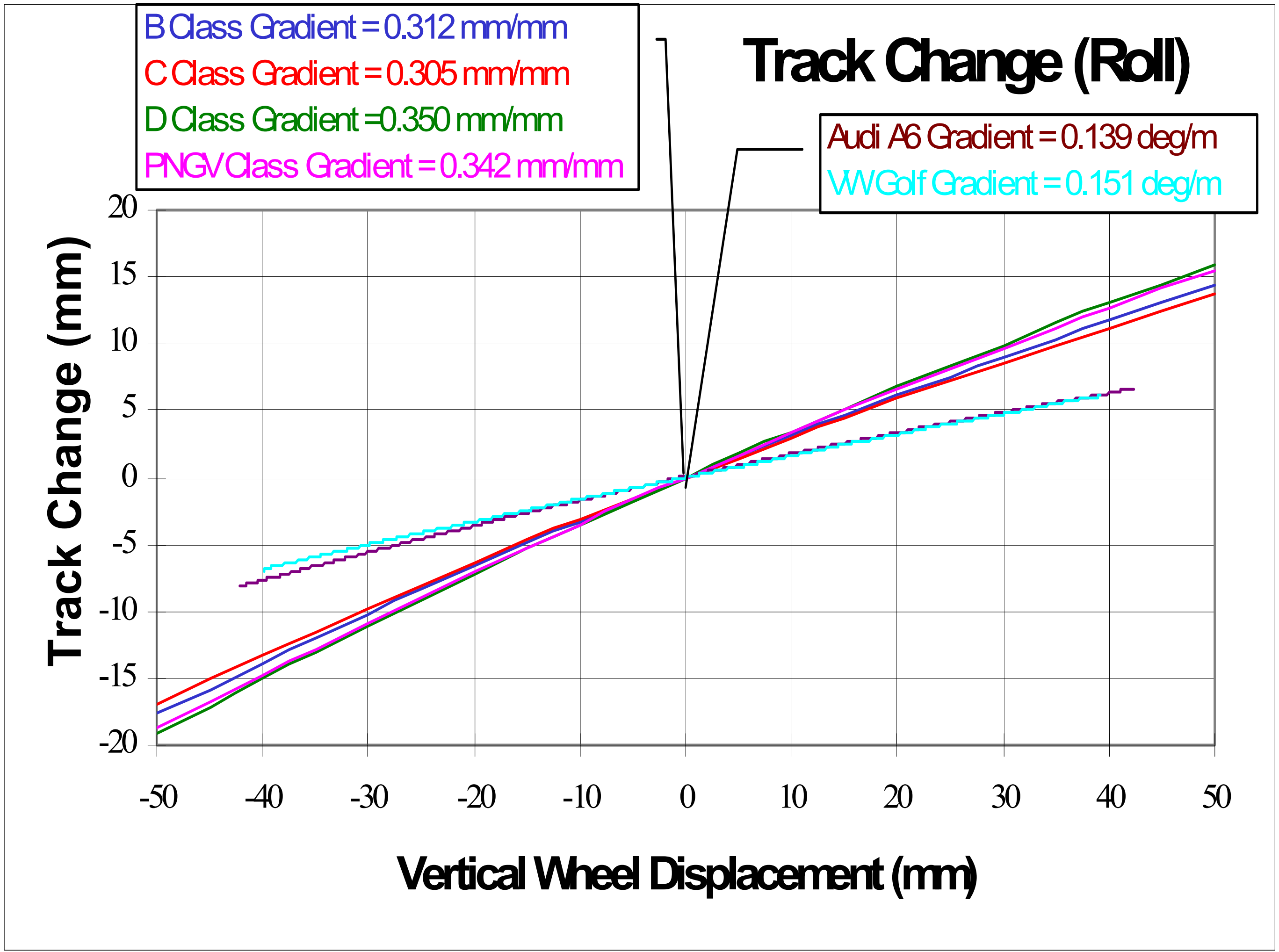
TWISTBEAM : Performance





Instantaneous gradient taken at wheel displacement zero

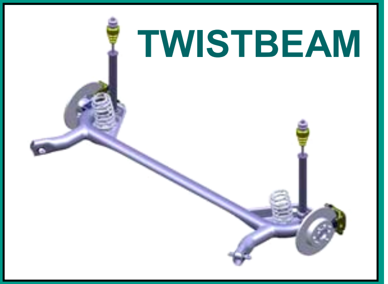
TWISTBEAM : Performance

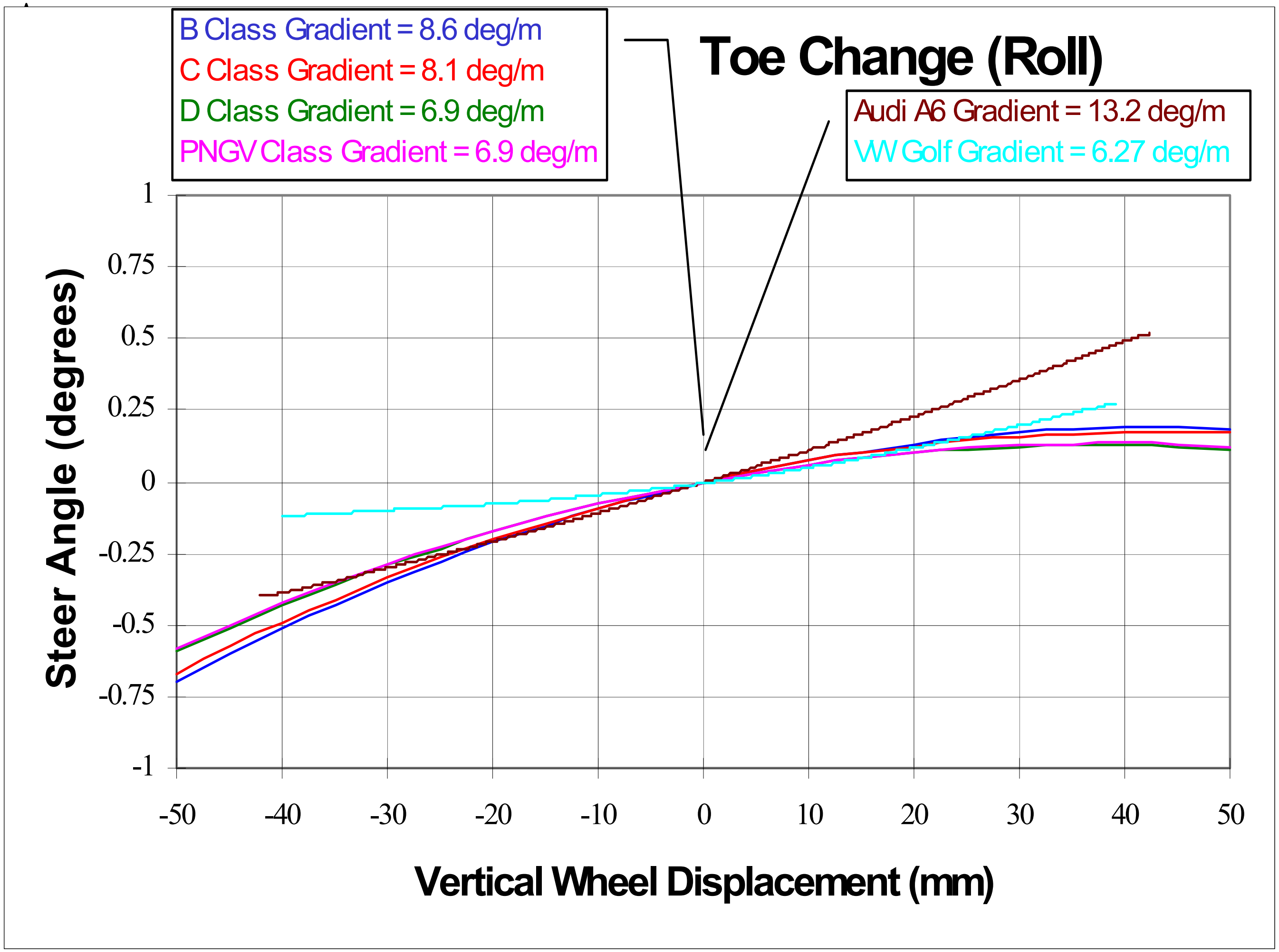


Instantaneous gradient taken at wheel displacement zero

ULTRALIGHT
STEEL
AUTO SUSPENSION

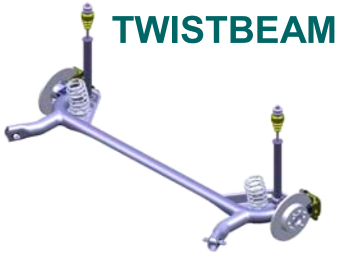
TWISTBEAM : Performance

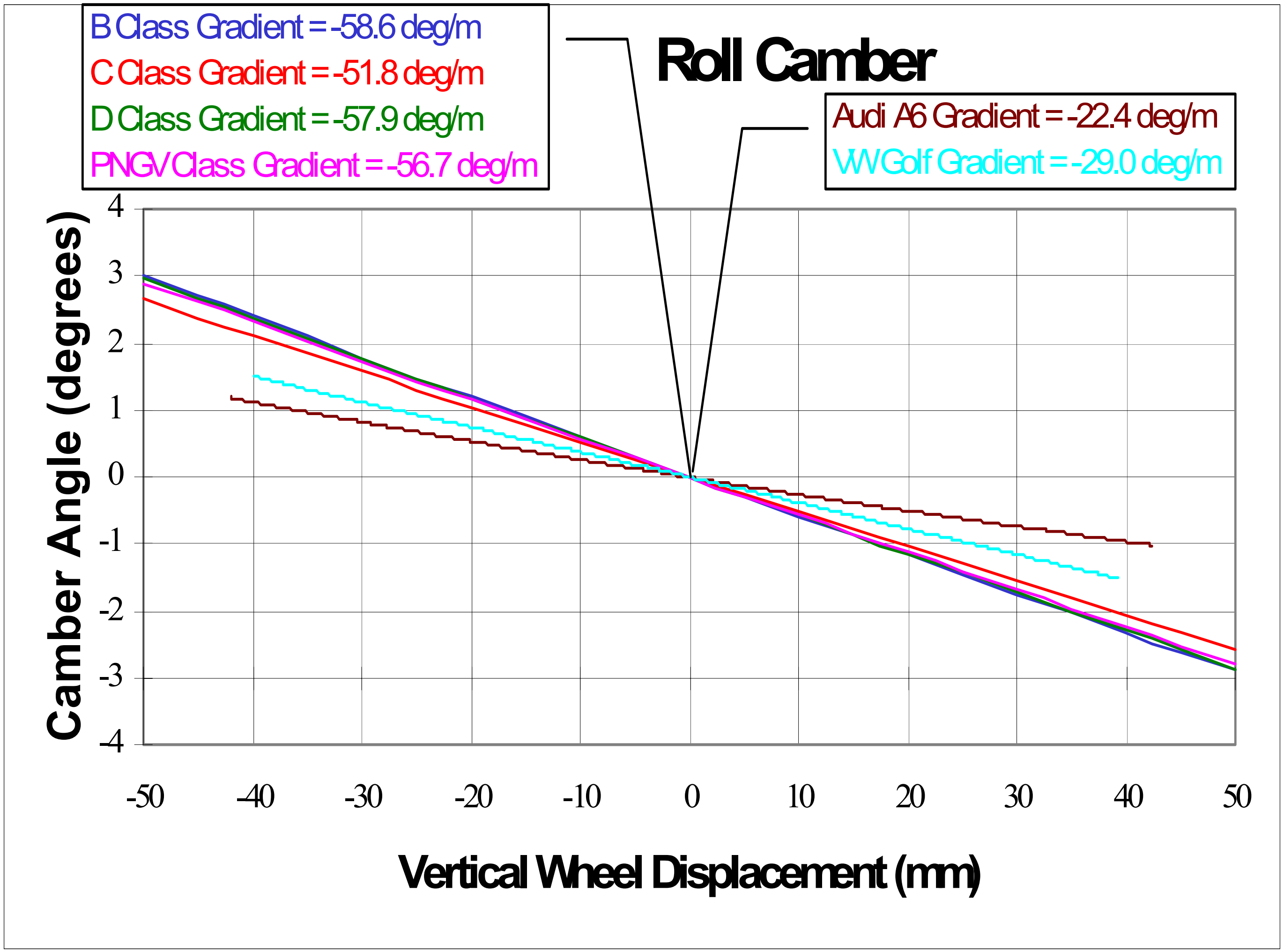




Instantaneous gradient taken at wheel displacement zero

TWISTBEAM : Performance





Instantaneous gradient taken at wheel displacement zero

ULTRALIGHT STEEL AUTO SUSPENSION

PERFORMANCE RESULTS GRAPHS KEY

TWISTBEAM

Key to Objective Targets Graphs:

▬ Optimum value (ULSAS Target)

☆ = ULSAS Result

Tolerance Bands

🟩 Min Performance

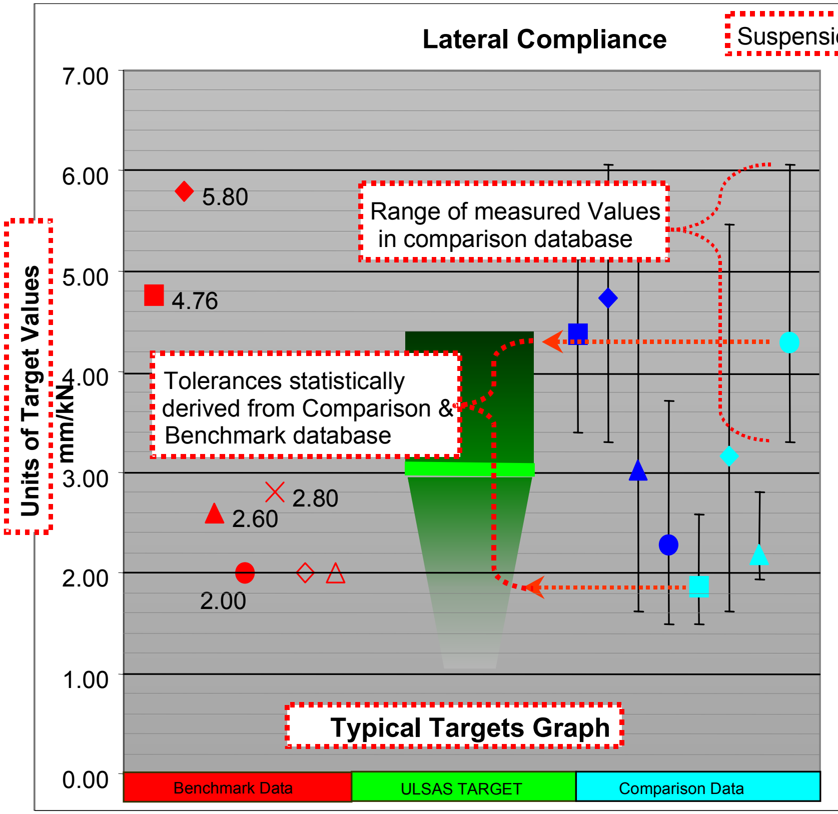
Band showing areas of acceptable Performance. Darker areas show Min Performance levels.

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.



Suspension Characteristic Title

Range of measured Values in comparison database

Tolerances statistically derived from Comparison & Benchmark database

Typical Targets Graph

Definition:

Definition of the suspension characteristic. Explanation of the Units used for the Targets.

Diagram to illustrate the Characteristic.

Comments:

Comments on the Graph and targets.

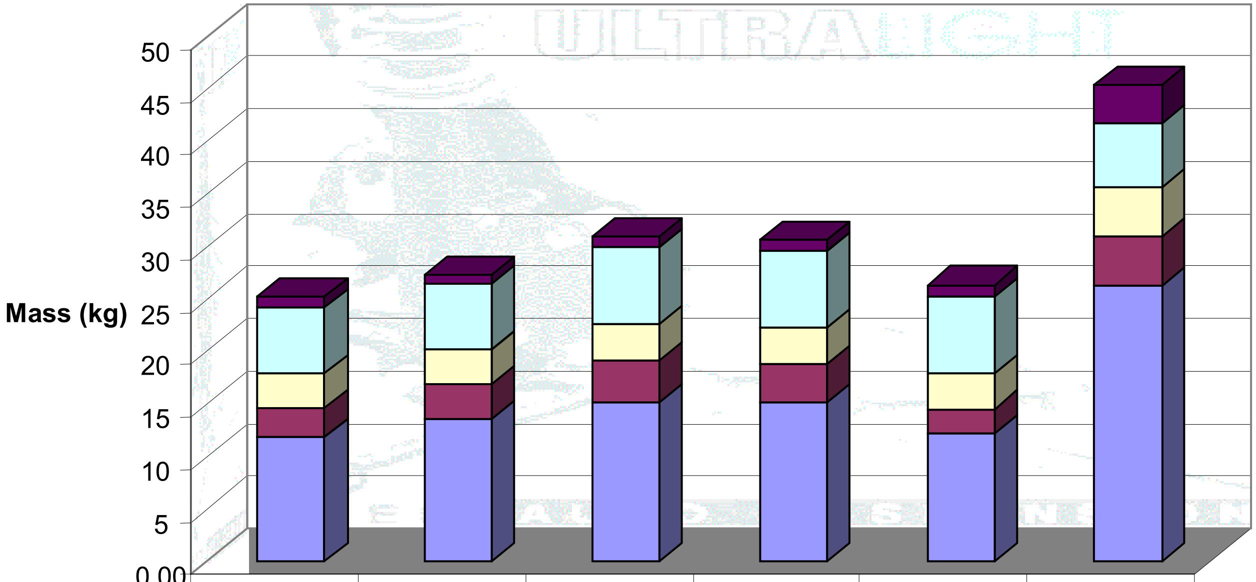
Short discussion as appropriate.

- ■ 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

TWISTBEAM: MASS

Comparison

TWISTBEAM



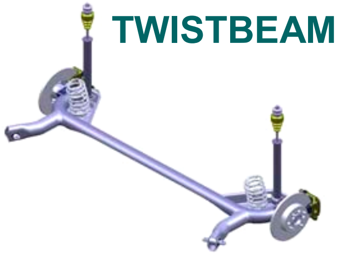
	B Class	C Class	D Class	E Class	P Class	E Class Benchmark
■ BUSHES & FIXINGS	1.03	0.98	1.15	1.15	1.15	3.68
☐ HUBS	6.20	6.20	7.26	7.26	7.26	6.08
☐ DAMPER ASSY	3.36	3.36	3.42	3.42	3.42	4.65
■ SPRING	2.67	3.29	4.06	3.78	2.40	4.74
■ STRUCTURE	11.86	13.48	15.09	15.02	12.07	26.20
TOTAL SYSTEM	25.12	27.30	30.97	30.63	26.31	45.35

Mass Of ULSAS Solutions Vs Benchmark Vehicles

Description	B	C	D	E	P
Benchmark (Kg)		33.40		45.35	
ULSAS Solution (Kg)	25.12	27.30	30.97	30.63	26.31
Saving vs Benchmark		18%		32%	

TWISTBEAM: MASS

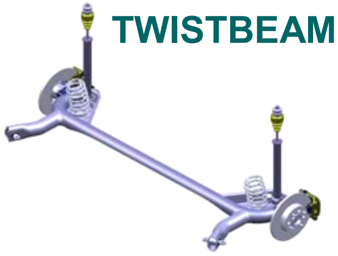
Approach



- Mass estimations were established for:
  - Components
  - Sub-assemblies / Proprietary Parts
- Mass estimates for Lotus designed parts derived from Mass Property Tables in the design 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.

TWISTBEAM: MASS

B Class



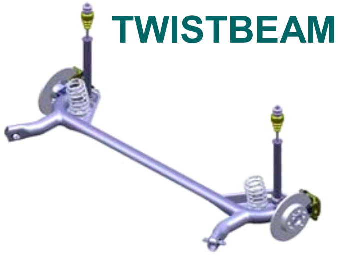
TWISTBEAM

PARTS LIST			B Class			C Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	**25.12**			**33.40**		
2	WELDED ASSY, TWIST BEAM	1	**11.86**	**11.860**	11.860	**20.37**	**20.370**	20.37
3	TRAILING ARM	2			0.788			
4	TRANSVERSE BEAM	1			6.720			
5	HUB MOUNTING PLATE	2			0.510			
6	SPRING PLATFORM RH	1			1.160			
7	SPRING PLATFORM LH	1			1.160			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	**2.67**	**1.336**			**2.820**	1.410
10	SPRING ISOLATOR	4	**0.30**	**0.074**	0.074			
11	DAMPER UNIT	2	**2.76**	**1.380**	1.380		**4.924**	2.462
12	BUMP STOP	2	**0.30**	**0.150**	0.150		**0.296**	0.148
13	BOLT - DAMPER	2	**0.10**	**0.049**	0.049		**0.118**	0.059
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	**3.10**	**3.100**			**1.024**	1.024
16	HUB & BEARING UNIT, LH	1	**3.10**	**3.100**			**1.024**	1.024
17	BOLT - HUB	8	**0.27**	**0.034**	0.034		**0.212**	0.106
18	BOLT - CALIPER	4	**0.12**	**0.030**	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	**0.54**	**0.272**			**2.610**	1.305

TWISTBEAM: MASS

C Class

TWISTBEAM

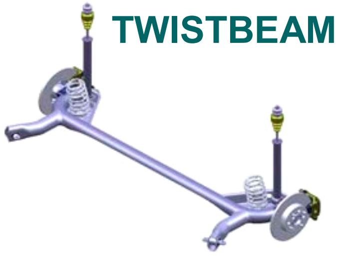


PARTS LIST			C Class			C Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	**27.30**			**33.40**		
2	WELDED ASSY, TWIST BEAM	1	**13.48**	13.475	13.475	**20.37**	**20.370**	20.37
3	TRAILING ARM	2			0.788			
4	TRANSVERSE BEAM	1			8.055			
5	HUB MOUNTING PLATE	2			0.510			
6	SPRING PLATFORM RH	1			1.300			
7	SPRING PLATFORM LH	1			1.300			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	**3.29**	**1.646**			**2.820**	1.410
10	SPRING ISOLATOR	4	**0.30**	**0.074**	0.074			
11	DAMPER UNIT	2	**2.76**	**1.380**	1.380		**4.924**	2.462
12	BUMP STOP	2	**0.30**	**0.150**	0.150		**0.296**	0.148
13	BOLT - DAMPER	2	**0.10**	**0.049**	0.049		**0.118**	0.059
14	DISC BRAKE	2						
~~15~~	~~HUB & BEARING UNIT, RH~~	~~1~~	~~**3.10**~~	~~**3.100**~~			~~**1.024**~~	~~1.024~~
16	HUB & BEARING UNIT, LH	1	**3.10**	**3.100**			**1.024**	1.024
17	BOLT - HUB	8	**0.22**	**0.027**	0.027		**0.212**	0.106
18	BOLT - CALIPER	4	**0.12**	**0.030**	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	**0.54**	**0.272**			**2.610**	1.305

TWISTBEAM: MASS

D Class

TWISTBEAM

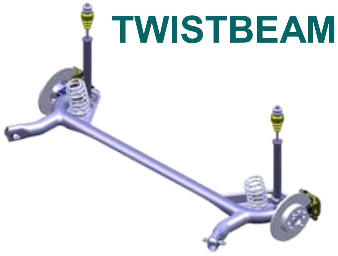


PARTS LIST			D Class			E Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	**30.97**			**45.35**		
2	WELDED ASSY, TWIST BEAM	1	**15.09**	15.086	15.086	**26.20**	**26.200**	26.2
3	TRAILING ARM	2			0.942			
4	TRANSVERSE BEAM	1			9.174			
5	HUB MOUNTING PLATE	2			0.532			
6	SPRING PLATFORM RH	1			1.370			
7	SPRING PLATFORM LH	1			1.370			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	**4.06**	**2.030**	2.030		**4.740**	2.370
10	SPRING ISOLATOR	4	**0.36**	**0.090**	0.090		**0.358**	0.179
11	DAMPER UNIT	2	**2.76**	**1.380**	1.380		**3.994**	1.997
12	BUMP STOP	2	**0.30**	**0.150**	0.150		**0.300**	0.150
13	BOLT - DAMPER	2	**0.10**	**0.049**	0.049		**0.126**	0.063
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	**3.63**	**3.630**			**3.040**	3.040
16	HUB & BEARING UNIT, LH	1	**3.63**	**3.630**			**3.040**	3.040
17	BOLT - HUB	8	**0.22**	**0.028**	0.028		**0.240**	
18	BOLT - CALIPER	4	**0.12**	**0.030**	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	**0.71**	**0.353**			**3.310**	1.655

TWISTBEAM: MASS

E Class

TWISTBEAM

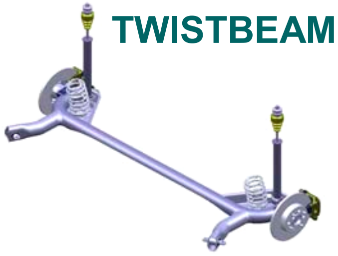


PARTS LIST			E Class			E Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	**30.63**			**45.35**		
2	WELDED ASSY, TWIST BEAM	1	**15.02**	15.022	15.022	**26.20**	**26.200**	26.2
3	TRAILING ARM	2			0.942			
4	TRANSVERSE BEAM	1			9.350			
5	HUB MOUNTING PLATE	2			0.532			
6	SPRING PLATFORM RH	1			1.250			
7	SPRING PLATFORM LH	1			1.250			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	**3.78**	**1.889**	1.202		**4.740**	2.370
10	SPRING ISOLATOR	4	**0.36**	**0.090**	0.090		**0.358**	0.179
11	DAMPER UNIT	2	**2.76**	**1.380**	1.380		**3.994**	1.997
12	BUMP STOP	2	**0.30**	**0.150**	0.150		**0.300**	0.150
13	BOLT - DAMPER	2	**0.10**	**0.049**	0.049		**0.126**	0.063
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	**3.63**	**3.630**			**3.040**	3.040
16	HUB & BEARING UNIT, LH	1	**3.63**	**3.630**			**3.040**	3.040
17	BOLT - HUB	8	**0.22**	**0.028**	0.028		**0.240**	
18	BOLT - CALIPER	4	**0.12**	**0.030**	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	**0.71**	**0.353**			**3.310**	1.655

TWISTBEAM: MASS

P Class

TWISTBEAM

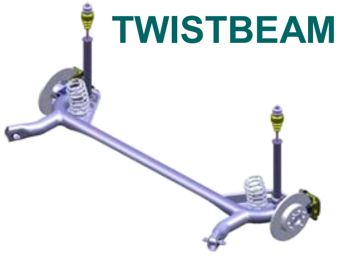


PARTS LIST			P Class			E Class Benchmark		
ITEM No.	DESCRIPTION	QTY Veh	System (kg)	Sub Assy (kg)	Parts (kg)	System (kg)	Sub Assy (kg)	Parts (kg)
1	ASSEMBLY, TWIST BEAM	1	26.31			45.35		
2	WELDED ASSY, TWIST BEAM	1	**12.07**	12.074	12.074	**26.20**	**26.200**	26.2
3	TRAILING ARM	2			0.942			
4	TRANSVERSE BEAM	1			6.720			
5	HUB MOUNTING PLATE	2			0.532			
6	SPRING PLATFORM RH	1			1.091			
7	SPRING PLATFORM LH	1			1.091			
8	DAMPER BRACKET	2			0.112			
9	SPRING	2	**2.40**	**1.202**	1.202		**4.740**	2.370
10	SPRING ISOLATOR	4	**0.36**	**0.090**	0.090		**0.358**	0.179
11	DAMPER UNIT	2	**2.76**	**1.380**	1.380		**3.994**	1.997
12	BUMP STOP	2	**0.30**	**0.150**	0.150		**0.300**	0.150
13	BOLT - DAMPER	2	**0.10**	**0.049**	0.049		**0.126**	0.063
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	**3.63**	**3.630**			**3.040**	3.040
16	HUB & BEARING UNIT, LH	1	**3.63**	**3.630**			**3.040**	3.040
17	BOLT - HUB	8	**0.22**	**0.028**	0.028		**0.240**	
18	BOLT - CALIPER	4	**0.12**	**0.030**	0.030			
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	**0.71**	**0.353**			**3.310**	1.655

TWISTBEAM: MATERIAL

B Class

TWISTBEAM



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	**REMARKS**	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	3.1	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	3.4	500
7	SPRING PLATFORM LH	1	PRESSING	3.4	500
8	DAMPER BRACKET	2	BLANK & FOLD	3.2	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 10.04	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

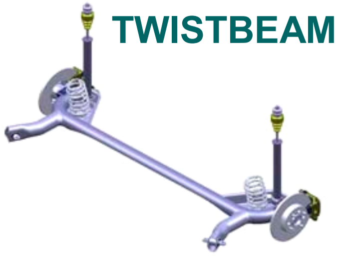
Note : Damper Assembly Consists of 2 Main Components

Damper Body Assumes 350 MPa Material

Damper Rod Assumes Dia 13mm x 3 mm Tube

TWISTBEAM: MATERIAL

C Class



TWISTBEAM

PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	3.6	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	3.8	500
7	SPRING PLATFORM LH	1	PRESSING	3.8	500
8	DAMPER BRACKET	2	BLANK & FOLD	3.2	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 10.81	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

Note : Damper Assembly Consists of 2 Main Components

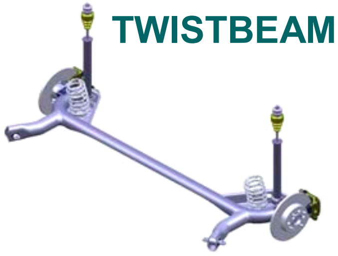
Damper Body Assumes 350 MPa Material

Damper Rod Assumes Dia 13mm x 3 mm Tube

TWISTBEAM: MATERIAL

D Class

TWISTBEAM



PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	REMARKS	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	4	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	4	500
7	SPRING PLATFORM LH	1	PRESSING	4	500
8	DAMPER BRACKET	2	BLANK & FOLD	3.2	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 11.34	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

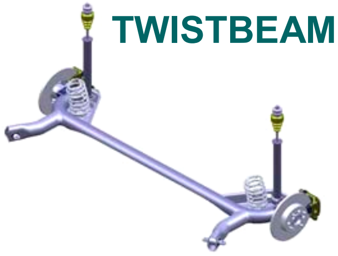
Note : Damper Assembly Consists of 2 Main Components

Damper Body Assumes 350 MPa Material

Damper Rod Assumes Dia 13mm x 3 mm Tube

TWISTBEAM: MATERIAL

E Class



TWISTBEAM

PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	**REMARKS**	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	4.1	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	3.7	500
7	SPRING PLATFORM LH	1	PRESSING	3.7	500
8	DAMPER BRACKET	2	BLANK & FOLD	3.2	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 11	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

Note : Damper Assembly Consists of 2 Main Components

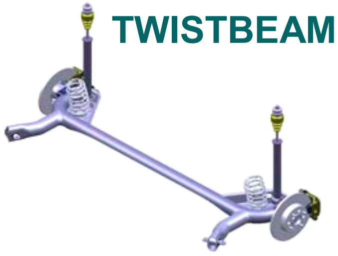
Damper Body Assumes 350 MPa Material

Damper Rod Assumes Dia 13mm x 3 mm Tube

TWISTBEAM: MATERIAL

P Class

TWISTBEAM



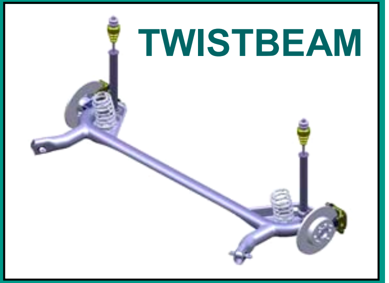
PARTS LIST				MATERIAL	
ITEM No.	DESCRIPTION	QTY Veh	**REMARKS**	Gauge (mm)	Grade (MPa)
1	ASSEMBLY, TWIST BEAM	1	FULL SUSPENSION ASSEMBLY		
2	WELDED ASSY, TWIST BEAM	1	FABRICATION. (ITEMS 3 - 8)		
3	TRAILING ARM	2	HYDRO-FORMED TUBE - NON HANDED	2	400
4	TRANSVERSE BEAM	1	FORMED TUBE - NON HANDED PART	2.8	600
5	HUB MOUNTING PLATE	2	FORGED/ MACHINED PART	na	600
6	SPRING PLATFORM RH	1	PRESSING	3.2	500
7	SPRING PLATFORM LH	1	PRESSING	3.2	500
8	DAMPER BRACKET	2	BLANK & FOLD	3	500
9	SPRING	2	SHEAR STRESS 1300 MPa	Ø 9.52	1300
10	SPRING ISOLATOR	4	MOULDED RUBBER		
11	DAMPER UNIT	2	HOLLOW ROD, HIGH STRENGTH STEEL	See note	
12	BUMP STOP	2	POLYURETHANE		
13	BOLT - DAMPER	2	M10 GRADE 10.9 LENGTH 60mm		
14	DISC BRAKE	2	SOLID, CAST IRON		
15	HUB & BEARING UNIT, RH	1	GEN 3 WITH ACTIVE ABS SENSOR		
16	HUB & BEARING UNIT, LH	1	GEN 3 WITH ACTIVE ABS SENSOR		
17	BOLT - HUB	8	M10 GRADE 10.9 LENGTH 24mm		
18	BOLT - CALIPER	4	M10 GRADE 10.9 LENGTH 22mm		
19	CALIPER, BRAKE	2	INTEGRATED HAND BRAKE		
20	BUSH -TRAILING ARM	2	TWIN BOLT FIXING		

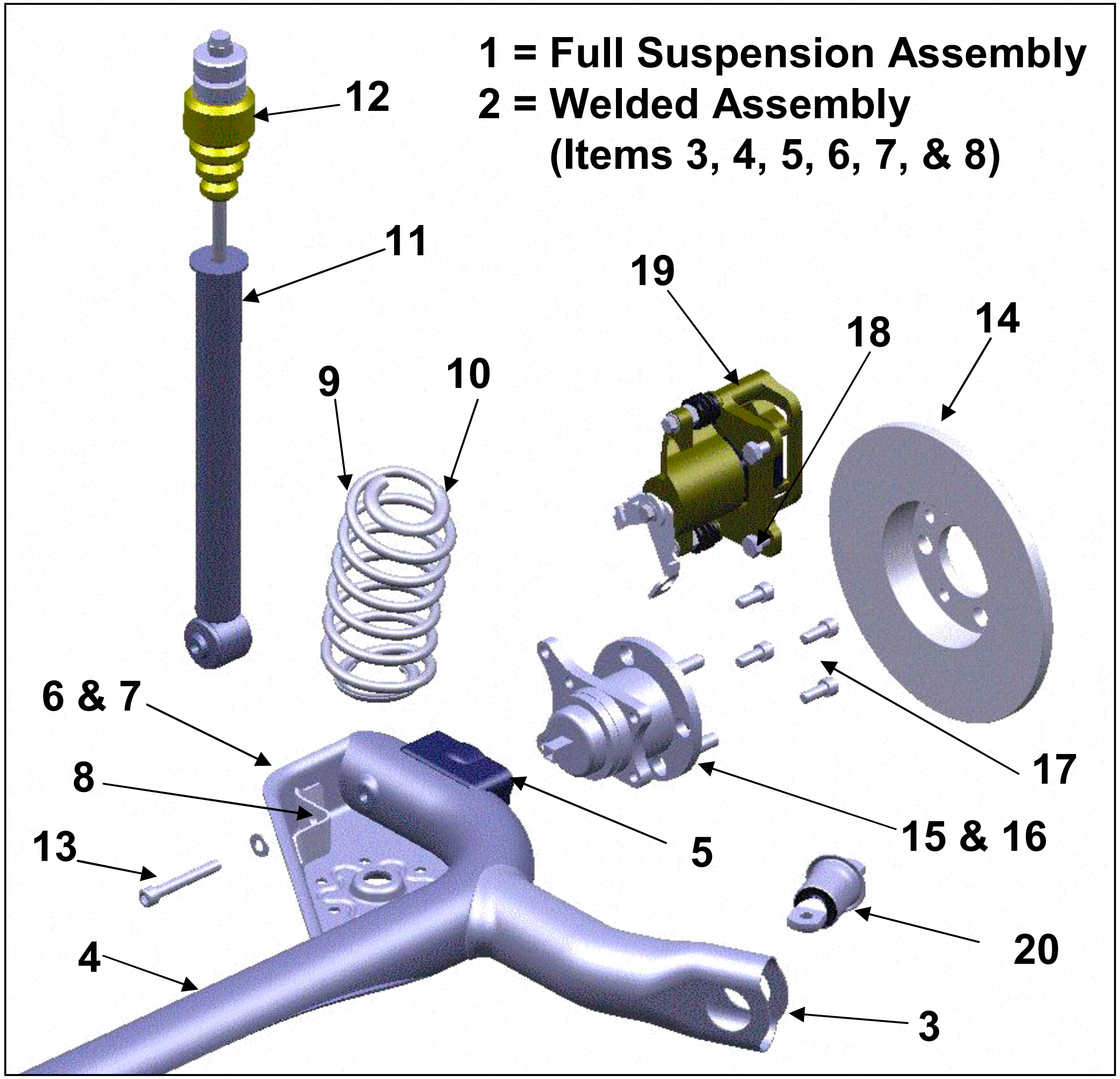
Note : Damper Assembly Consists of 2 Main Components

Damper Body Assumes 350 MPa Material

Damper Rod Assumes Dia 13mm x 3 mm Tube

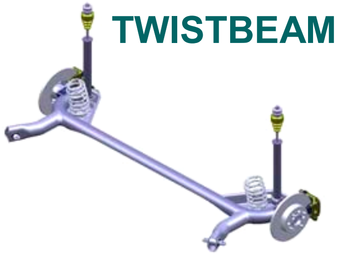
TWISTBEAM: EXPLODED VIEW





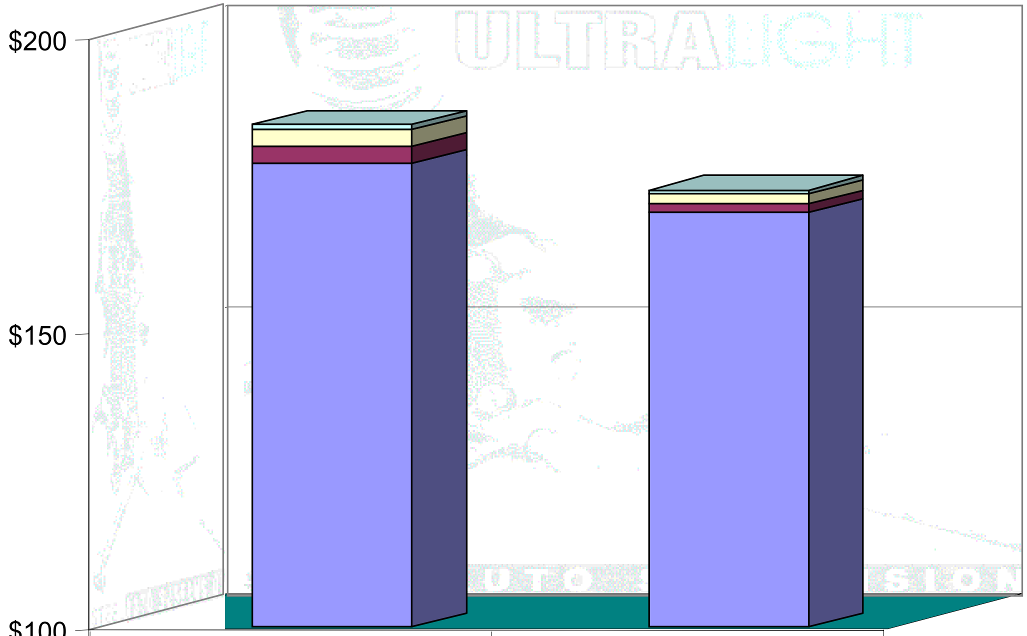
1 = Full Suspension Assembly
2 = Welded Assembly
(Items 3, 4, 5, 6, 7, & 8)

TWISTBEAM: COST



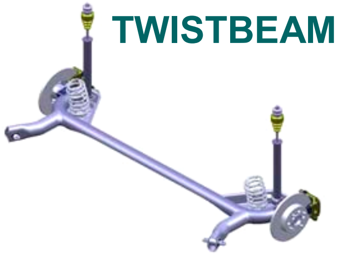
TWISTBEAM

COST BREAKDOWN TWISTBEAM



	BENCHMARK (E Class)	ULSAS E Class
▢ VEHICLE FITTING COST	$0.9	$0.7
🟨 SYSTEM ASSEMBLY COST	$2.8	$1.8
🟥 TOOLING COST	$2.8	$1.5
🟦 PIECE COST	$178.3	$169.9
TOTAL COST	**$184.8**	**$173.9**

TWISTBEAM: COST



(US$)	Twistbeam	
	Benchmark E Class	ULSAS E Class
COMPONENT COST	**$178.3**	**$169.9**
TOTAL TOOLING COST ($,000)	**$5,611**	**$2,965**
5 YEAR Volume (Assumptions)	2,000,000	2,000,000
TOOLING COST	$2.8	$1.5
TOTAL SYSTEM COST	$181.1	$171.4
SYSTEM ASSY		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Assembly Mins	3.86	2.42
SYSTEM ASSEMBLY COST	$2.83	$1.77
VEHICLE FITTING		
Labour Rate (US$/min on $44/Hr)	$0.73	$0.73
Fitting Mins	1.21	0.93
VEHICLE FITTING COST	$0.89	$0.68

Total Cost ($)	**$184.8**	**$173.9**
Cost Saving($)		$11.0
Cost Saving %		**6%**

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

TWISTBEAM: COST

Bill of Materials

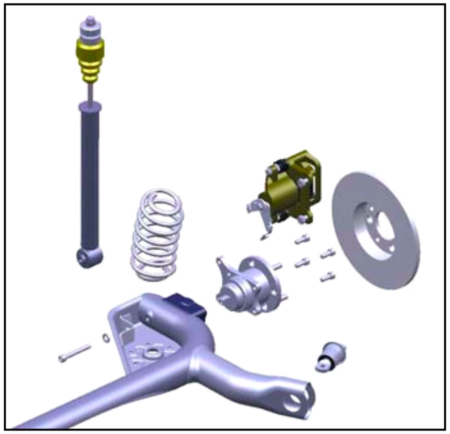
TWISTBEAM

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

PARTS LIST			E Class			Benchmark E Class Data		
ITEM No.	DESCRIPTION	QTY Veh	PART COST	SYSTEM COST	TOOLING COST	PART COST	SYSTEM COST	TOOLING COST
1	ASSEMBLY, TWIST BEAM	1		**169.94**	**2965**		**178.34**	**5611**
2	WELDED ASSY, TWIST BEAM	1	$25.0	$25.0	$850	$69.3	$69.3	$4,950
3	TRAILING ARM	2	$3.2	$6.4	$600			
4	TRANSVERSE BEAM	1	$10.0	$10.0	$450			
5	HUB MOUNTING PLATE	2	$8.5	$17.0	$300			
6	SPRING PLATFORM RH	1	$3.4	$3.4	$350			
7	SPRING PLATFORM LH	1	$3.4	$3.4				
8	DAMPER BRACKET	2	$0.5	$1.0	$85			
9	SPRING	2	$5.5	$11.0		$4.1	$8.2	$0
10	SPRING ISOLATOR	4	$0.8	$3.2				
11	DAMPER UNIT	2	$16.5	$33.0	$330	$16.5	$33.0	$330
12	BUMP STOP	2						
13	BOLT - DAMPER	2		$1.0				
14	DISC BRAKE	2						
15	HUB & BEARING UNIT, RH	1	$19.0	$38.0	$0	$19.0	$38.0	$0
16	HUB & BEARING UNIT, LH	1						
17	BOLT - HUB	8		$2.0				
18	BOLT - CALIPER	4		$2.5				
19	CALIPER, BRAKE	2						
20	BUSH -TRAILING ARM	2	$6.5	$13.0	$0	$14.9	$29.8	$331

TWISTBEAM: TIMING

Sub-Assembly

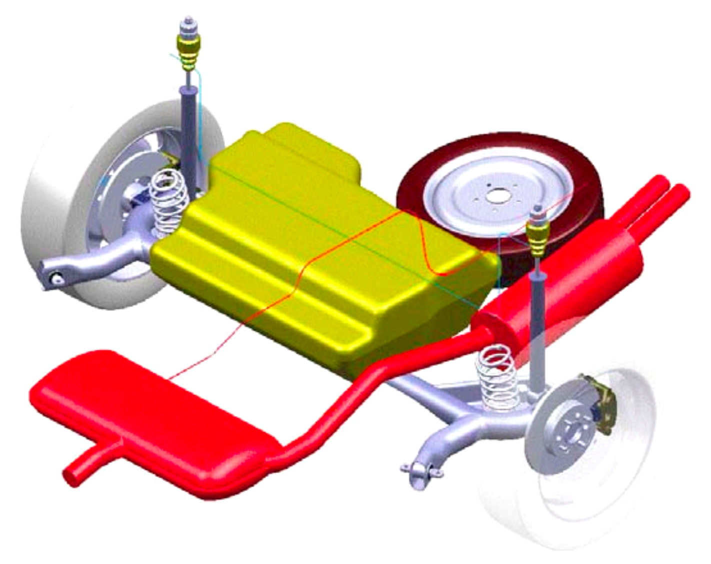


BREAKDOWN OF TIMING FOR SUB-ASSEMBLY OF TWISTBEAM SUSPENSION SYSTEM

SUB-ASSEMBLY Operation	No.	Code	First Time (man minutes)	Subsequent (man minutes)	Total Time (man minutes)
LOAD TORSION BEAM	1	FIXLG	0.6		0.6
LOAD HUB	2	FIX1H	0.05	0.05	0.1
FIX HUB	8	TFPTN	0.11	0.49	0.6
LOAD BRAKE DISK	2	FIX1H	0.05	0.05	0.1
FIX BRAKE DISK	2	FIT1H	0.19	0.13	0.32
LOAD BRAKE CALIPER	2	FIX1H	0.05	0.05	0.1
FIX BRAKE CALIPER	4	TFPTN	0.11	0.21	0.32
LOAD DAMPER	2	FIX1H	0.05	0.05	0.1
FIX DAMPER	2	TFPTN	0.11	0.07	0.18
				TOTAL	2.42

TWISTBEAM: TIMING

Final Vehicle Assembly



BREAKDOWN OF TIMING FOR FINAL ASSEMBLY OF TWISTBEAM SUSPENSION TO THE VEHICLE

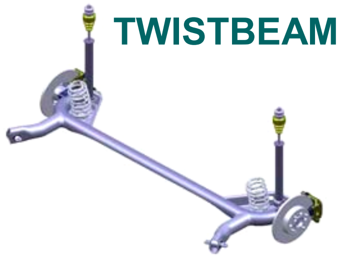
FINAL ASSEMBLY			First Time	Subsequent	Total Time
Operation	No.	Code	(man minutes)	(man minutes)	(man minutes)
load spring	2	FIT1H	0.19	0.13	0.32
fix bolt	4	TFPTN	0.11	0.21	0.32
fit buffer	2	FITFN	0.07	0.04	0.11
fix nut	2	TFPTN	0.11	0.07	0.18
				TOTAL	**0.93**

Twistbeam: 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.

Twistbeam: 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.

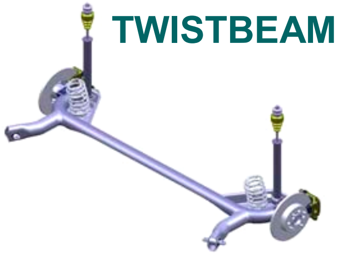
Twistbeam: COST

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**


TWISTBEAM

Twistbeam: 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 the utilisation of tooling 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