

2021

# Analysing and improving the structural stiffness of the Triumph Vitesse

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Jones, C. (2021) 'Analysing and improving the structural stiffness of the Triumph Vitesse', The Plymouth Student Scientist, 14(1), pp. 246-285.

<http://hdl.handle.net/10026.1/17331>

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The Plymouth Student Scientist  
University of Plymouth

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## Appendices

### Appendix 1: - Hand Calculations

Solid Section				
Parameter	Symbol	Value	Unit	Source
Beam Depth	A	0.085	m	Set Variable
Beam Width	B	0.08	m	Set Variable
Internal Depth	a	0.0425	m	Calculated
Internal Width	b	0.04	m	Calculated
Shape Constant	k	6.468E-06	m <sup>4</sup>	Calculated
Torque	T	2000	Nm	Set Variable
Length	L	2	m	Set Variable
Shear Modulus	G	8.00E+10	Nm <sup>-2</sup>	Solidworks Material
beta	β	0.141	-	Shigley
alpha	α	0.208	-	Shigley
Roark Twist	θ <sub>Roark</sub>	0.443	°	Calculated
Roark Shear	τ <sub>Roark</sub>	17.320	MPa	Calculated
Shigley Twist	θ <sub>Shigley</sub>	0.467	°	Calculated
Shigley Shear	τ <sub>Shigley</sub>	17.258	MPa	Calculated
	θ	0.450	°	Measured
Averaged FEA	-	2%	-	Calculated
	τ	18.88	MPa	Measured
	-	8%	-	Calculated

Solid (Shigley)

$$\theta = \frac{TL}{\beta bt^3 G}$$

$$\tau_{max} = \frac{T}{abt^2}$$

Solid Section (Roarks)

$$\theta = \frac{TL}{kG}$$

$$k = ab^3 \left[ 5.33 - 3.36 \frac{b}{a} \left( 1 - \frac{b^4}{12a^4} \right) \right]$$

$$\tau_{max} = \frac{3T}{8ab^2} \left[ 1 + 0.6095 \frac{b}{a} + 0.8865 \frac{b^2}{a} - 1.8023 \frac{b^3}{a} + 0.9100 \frac{b^4}{a} \right]$$

Open Section					
Parameter	Symbol	Open	w. 10mm	Unit	Source
Beam Depth	A	0.085	0.085	m	Set Variable
Beam Width	B	0.08	0.08	m	Set Variable
Wall Thickness	t	0.002	0.002	m	Set Variable
Median Lenth	l <sub>m</sub>	0.239	0.259	m	Calculated
Shape Constant	k	6.438E-10	7.090E-10	m <sup>4</sup>	Calculated
ShapeConstant1	k <sub>1</sub>	1.100E-10	2.331E-11	m <sup>4</sup>	Calculated
ShapeConstant2	k <sub>2</sub>	2.063E-10	3.662E-12	m <sup>4</sup>	Calculated
Alpha	α	0.108	0.108	-	Calculated
	a	0.0425	0.01	m	Set Variable
	b	0.002	0.002	m	Set Variable
	D	0.00269	0.00269	m	Set Variable
	c	0.078	0.002	m	Set Variable
	r	0.001	0.001	m	Set Variable
Beta	β	0.3333	0.333	-	Shigley
Length	L	2	2	m	Set Variable
Torque	T	1	1	Nm	Set Variable
Shear Modulus	G	8.00E+10	8.00E+10	Nm <sup>-2</sup>	Solidworks Material
Roark Twist	θ <sub>Roark</sub>	2.225	2.020	°	Calculated
Roark Shear	τ <sub>Roark</sub>	3.154	2.909	MPa	Calculated
Shigley Twist	θ <sub>Shigley</sub>	2.247	2.074	°	Calculated
Shigley Shear	τ <sub>Shigley</sub>	3.138	2.896	MPa	Calculated
	θ	2.032	1.923	°	Measured
Averaged FEA	-	-9%	-5%	-	Calculated
	τ	2.995	2.896	MPa	Measured
	-	-5%	0%	-	Calculated

Closed Section				
Parameter	Symbol	Value	Unit	Source
Beam Depth	A	0.085	m	Set Variable
Beam Width	B	0.08	m	Set Variable
Wall Thickness	t	0.002	m	Set Variable
MeridianPerimeter	l <sub>m</sub>	0.322	m	Calculated
AreainsideMeridian	A <sub>m</sub>	0.006474	m <sup>2</sup>	Calculated
2nd MomentofArea	J	7.480E-07	m <sup>4</sup>	Calculated
Shape Constant	k	1.041E-06	m <sup>4</sup>	Calculated
Length	L	2	m	Set Variable
Torque	T	2000	Nm	Set Variable
Shear Modulus	G	8.00E+10	Nm <sup>-2</sup>	Solidworks Material
Roark Twist (j)	θ <sub>Roark(j)</sub>	3.830	°	Calculated
Roark Shear (j)	τ <sub>Roark(j)</sub>	77.232	MPa	Calculated
Roark Twist (k)	θ <sub>Roark(k)</sub>	2.751	°	Calculated
Roark Shear (k)	τ <sub>Roark(k)</sub>	77.232	MPa	Calculated
Shigley Twist	θ <sub>Shigley</sub>	2.751	°	Calculated
Shigley Shear	τ <sub>Shigley</sub>	77.232	MPa	Calculated
	θ	2.884	°	Measured
Averaged FEA	-	5%	-	Calculated
	τ	85	MPa	Measured
	-	9%	-	Calculated

Open Section (Roarks)

$$\theta = \frac{TL}{kG}$$

$$k = k_1 + k_2 + \alpha D^4$$

$$k_1 = ab^3 \left[ 0.33 - 0.21 \frac{b}{a} \left( 1 - \frac{b^4}{12a^4} \right) \right]$$

$$k_2 = cd^3 \left[ 0.333 - 0.105 \frac{d}{c} \left( 1 - \frac{d^4}{192c^4} \right) \right]$$

$$\alpha = \frac{a}{b} \left( 0.07 + 0.076 \frac{r}{b} \right)$$

$$D = 2[d + b + 3r - \sqrt{2(2r + b)(2r + d)}]$$

$$\tau_{max} = T \frac{3l_m + 1.8t}{l_m^2 t^2}$$

Open (Shigley)

$$\theta = \frac{\tau L}{Gt}$$

$$\tau_{max} = \frac{3T}{l_m t^2}$$

Closed (Shigley)

$$\theta = \frac{LTl_m}{4GA_m^2 t}$$

$$\tau_{max} = \frac{T}{2A_m t}$$

Closed Section (Roarks)

$$\theta = \frac{TL}{kG}$$

$$k = \frac{2t^2(a-t)^2(b-t)^2}{at + bt - 2t^2}$$

$$\tau_{Average} = \frac{T}{2t(a-t)(b-t)}$$

**Bending Beam Study - (Simply supported beam, centrally applied load)**

Parameter	Symbol	Solid Section	Closed Section	Open Section C	Open Section U	Unit	Source
Beam Length	L	2	2	2	2	m	Set Variable
Beam Depth	d	0.085	0.08	0.08	0.085	m	Set Variable
Beam Width	b	0.08	0.085	0.085	0.08	m	Set Variable
Wall Thickness	t	N/A	0.002	0.002	0.002	m	Set Variable
Applied Force	F	1000	1000	1000	1000	N	Set Variable
Youngs Modulus	E	2.05E+11	2.05E+11	2.05E+11	2.05E+11	Pa	Solidworks Material
Reaction Force	R	500	500	500	500	N	Calculated
Bending Moment	M	500	500	500	500	Nm	Calculated
2ndMomentArea	I	4.09E-06	6.64E-07	6.17E-07	3.78E-07	m <sup>4</sup>	Calculated
Dist to NA	Y	0.0425	0.04	0.0400	0.0290	m	Calculated
Bending Stress	σ	5.190	30.140	32.434	38.363	MPa	Calculated
Deflection	δ	0.20	1.23	1.32	2.15	mm	Calculated
		5.155	28.8	28.59	36.62	Mpa	Measured
		-0.68%	-4.65%	-13.44%	-4.76%	-	Calculated
Averaged FEA	δ	0.2004	1.265	4.51	2.125	mm	Measured
		0.91%	3.15%	70.77%	-1.21%	-	Calculated

(Hibbeler)

$$\sigma_{max} = \frac{mY}{I}$$

$$I = \frac{bd^3}{12} \text{ (rectangle)}$$

$$\delta_{max} = \frac{FL^3}{48EI} \text{ (Simply Supported, Point Load)}$$

2nd Moment of Area U-Section				2nd Moment of Area C-Section			
	A	B	C		A	B	C
Area	0.000166	0.00016	0.000166	Area	0.00016	0.000166	0.000166
Y	0.0425	0.084	0.0425	Y	0.04	0.079	0.001
AY	7.06E-06	1.34E-05	7.06E-06	AY	6.4E-06	1.31E-05	1.66E-07
d	0	0.0413	0	d	0	0.04	0.04
Ad <sup>2</sup>	0	2.79E-07	0	Ad <sup>2</sup>	0	2.66E-07	2.656E-07
I	1.02E-07	5.2E-11	5.2E-11	I	8.53E-08	5.53E-11	5.53E-11

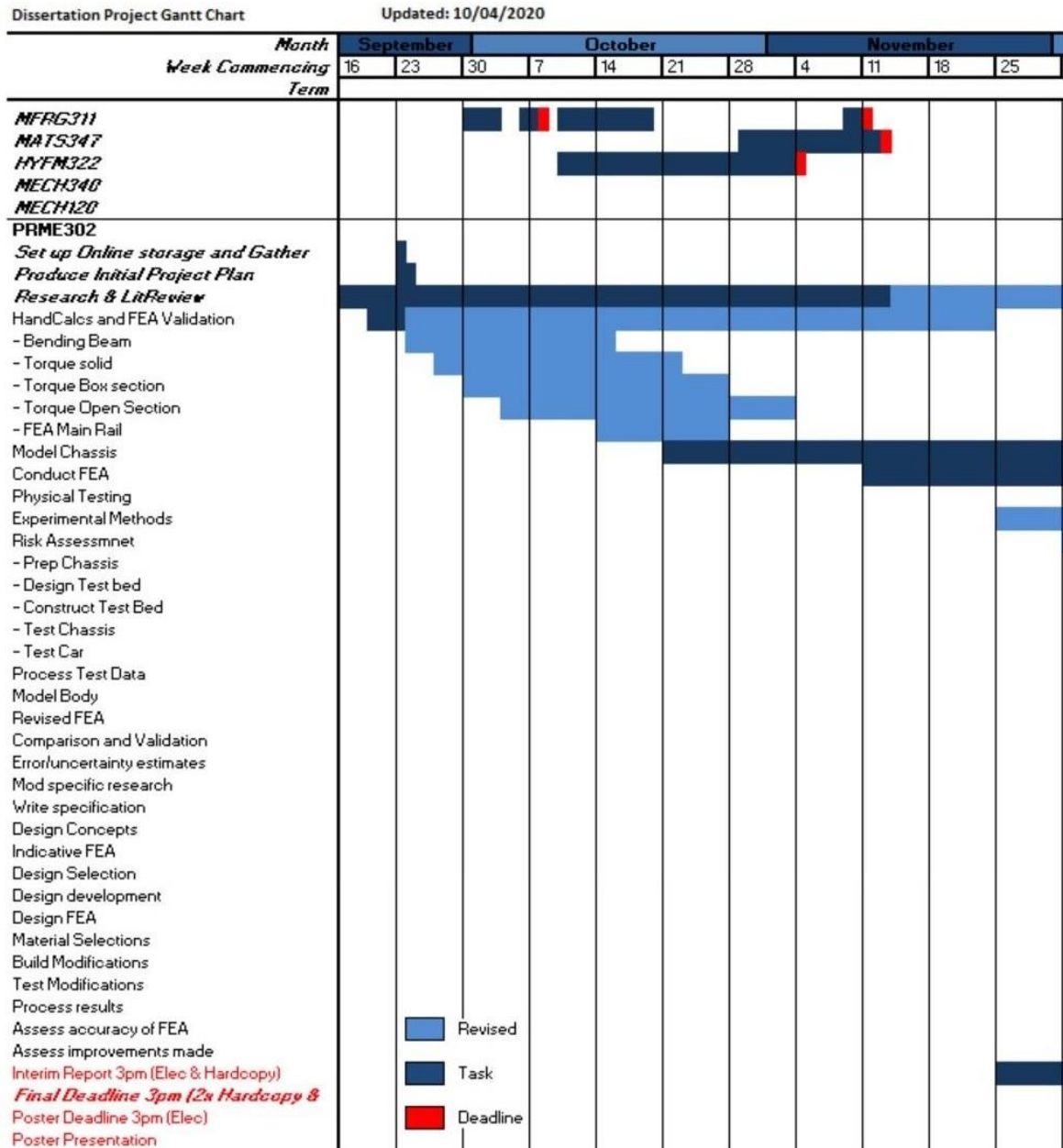
**Main Rail Section**

Twist	θ	3.431	*	Measured (SW)
% Difference Box	-	16%	-	Calculated
Shear	τ	89.75	MPa	Measured (SW)
% Difference Box	-	14%	-	Calculated
Equip.Box Depth	A	0.092	m	Solver Derived
Equip.Box Width	B	0.065	m	Solver Derived
Twist	θ	3.43	*	Solver Target
	-	0%	-	Calculated
Stress	τ	88.51	MPa	Calculated
	-	-1%	-	Calculated
Equip.Box Depth	A	0.092	m	Solver Derived
Equip.Box Width	B	0.064	m	Solver Derived
Twist	θ	3.505	*	Calculated
	-	2%	-	Calculated
Stress	τ	89.75	MPa	Solver Target
	-	-1%	-	Calculated

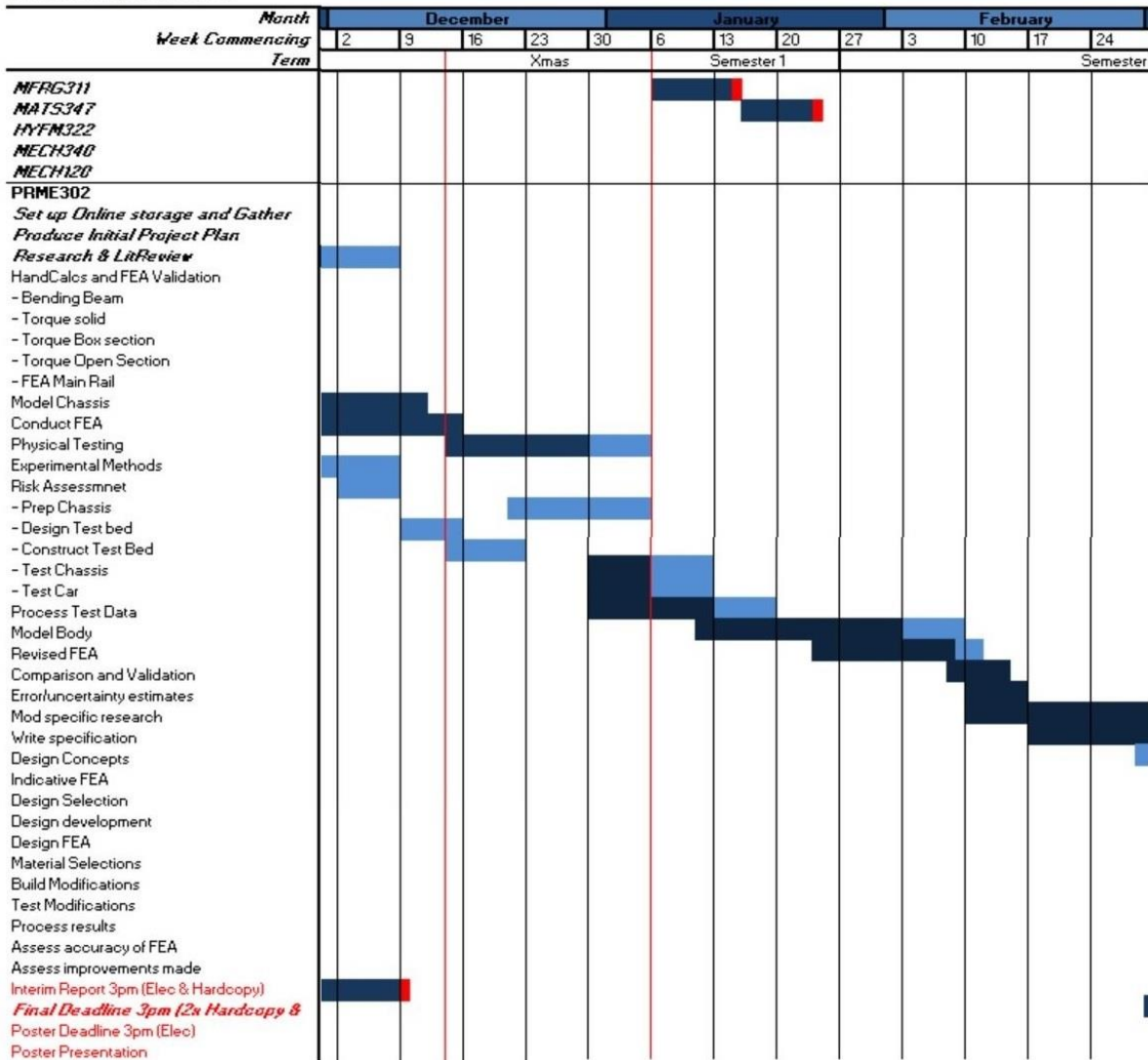
**MainRail**

Parameter	Symbol	Value	Unit	Source
Stress	σ	45.45	Mpa	Measured
%Diff-Closed	-	33.69%	-	Calculated
Deflection	δ	1.128	mm	Measured
%Diff-Closed	-	-8.62%	-	Calculated
EquipBoxDepth	A	0.063	m	Solver Derived
EquipBoxWidth	B	0.075	m	Solver Derived
Stress	σ	45.45	mpa	Solver Taret
Deflection	δ	2.36	mm	Calculated
EquipBoxDepth	A	0.077	m	Solver Derived
EquipBoxWidth	B	0.105	m	Solver Derived
Stress	σ	26.716	mpa	Calculated
Deflection	δ	1.13	mm	Solver Target
EquipBoxDepth	A	0.092	m	Taken from torque study
EquipBoxWidth	B	0.064	m	Taken from torque study
Stress	σ	30.85	mpa	Calculated
Deflection	δ	1.09	mm	Calculated

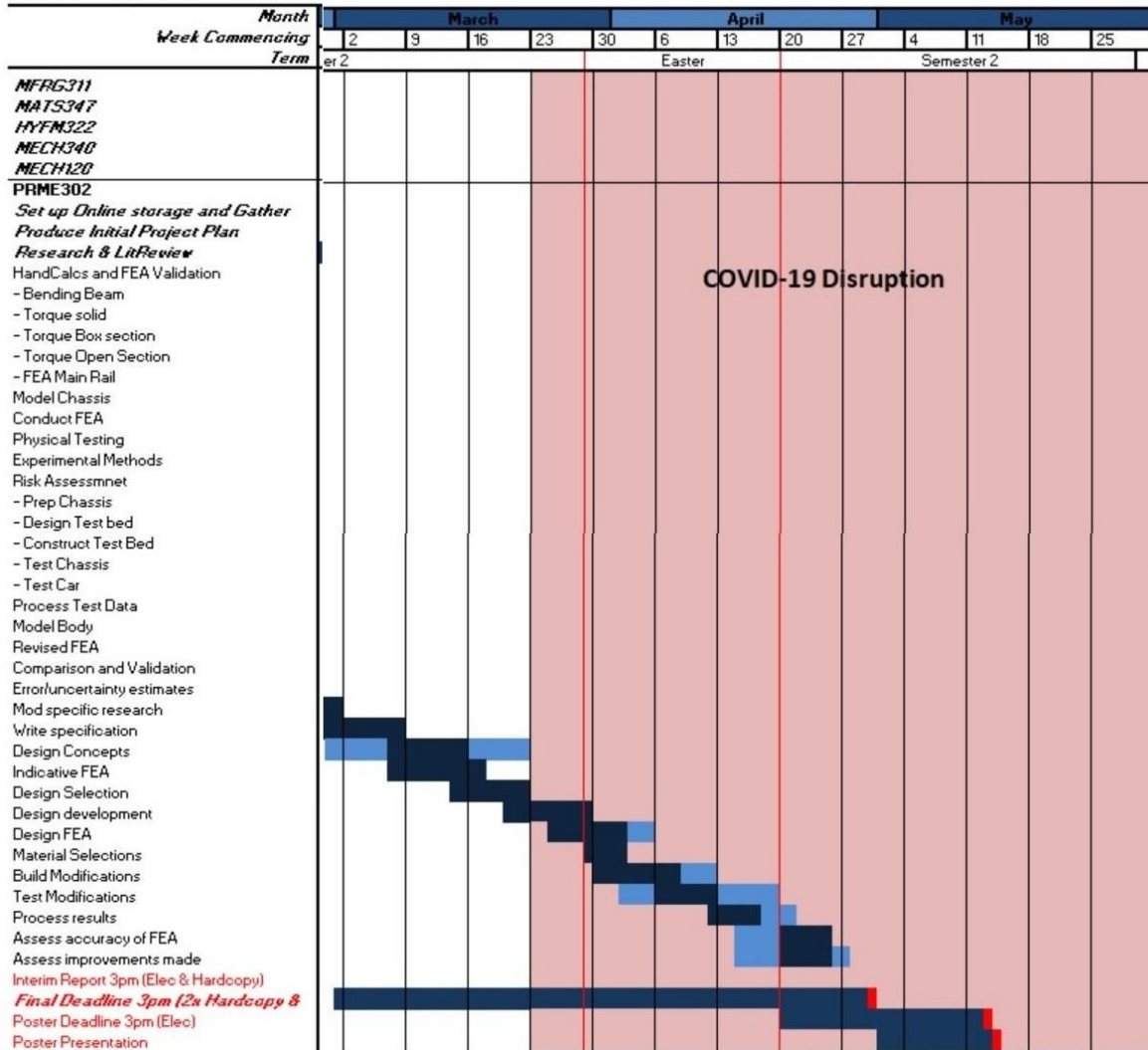
## Appendix 2: - Gantt Chart



Dissertation Project Gantt Chart



Dissertation Project Gantt Chart



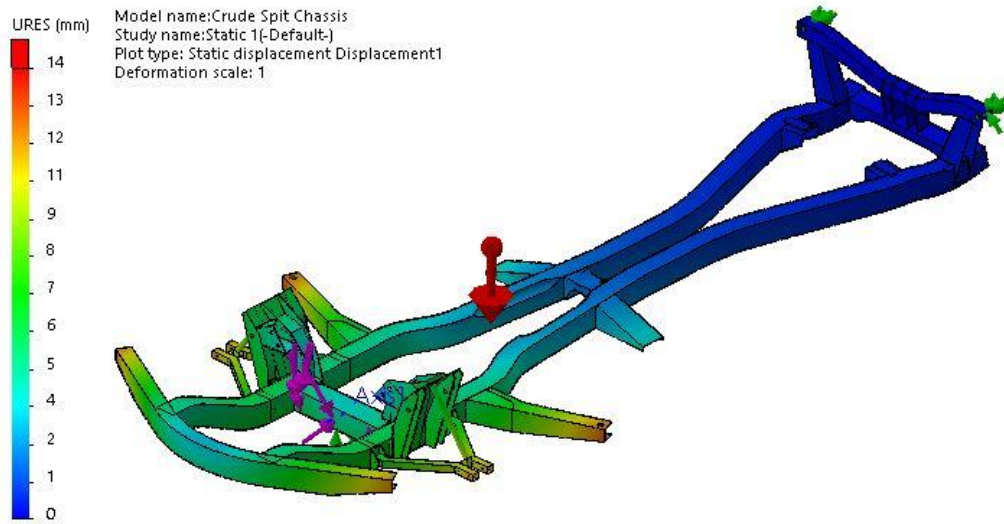
### Appendix 3: - Roll Stiffness Calculations

#### Triumph Vitesse: - Roll Stiffness

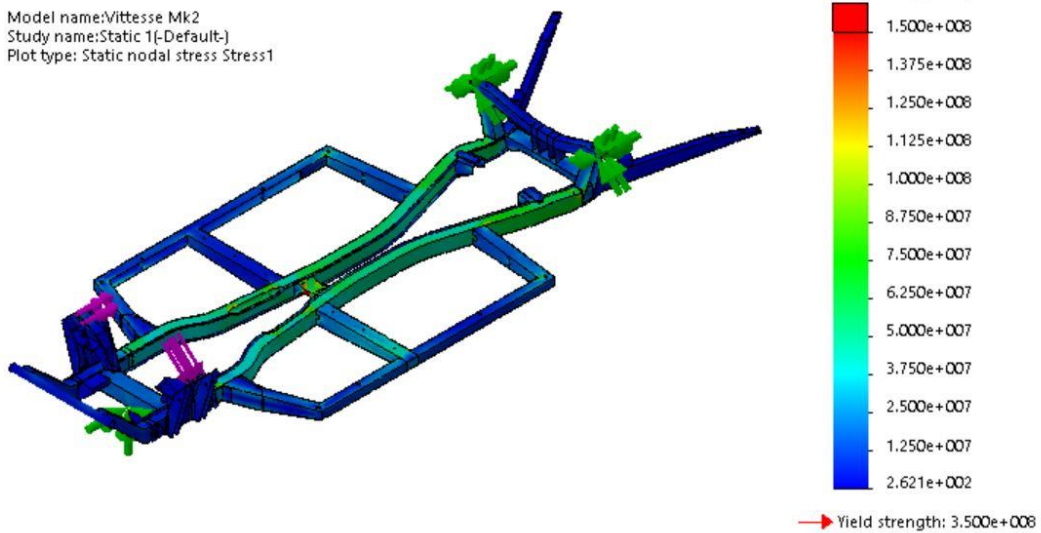
Based on Geithner, P. (2013) Triumph Spitfire & GT6 Spring Rates and resultant Wheel Rates and Roll Stiffnesses. Available at: [http://auskellian.com/paul/links\\_files/springs.htm](http://auskellian.com/paul/links_files/springs.htm) (Accessed: 29/11/2019)

Front	Standard	Current	500Nm	Unit	Source
Track	48.96	48.96	48.96	in	Measured
Free Length	10.5	10.5	10.5	in	Measured
Spring Rate	229	350	550	lbf/in	Manufacturer
Wheel Rate Factor	0.56	0.56	0.56	-	Reference value
Wheel Rate	128.24	196	308	lbf/in	Calculated
Roll Stiffness	<b>223.56</b>	<b>341.69</b>	<b>536.95</b>	lbf/deg	Calculated
ARB Stiffness	39	39	39	lbf/deg	Reference value
Front Total	262.56	380.69	575.95	lbf/deg	Calculated
<b>Rear</b>					
Spring Type	Fixed	Fixed	Fixed	-	Manufacturer
Spring Width	41.4	41.4	41.4	in	Measured
Track Width	48.96	48.96	48.96	in	Measured
Wheel Rate Factor	0.72	0.72	0.72	-	Calculated
Spring Rate	270	270	270	lbf/in	Manufacturer
Spring Rate/Side	135	135	135	lbf/in	Calculated
Wheel Rate	96.53	96.53	96.53	lbf/deg	Calculated
Roll Stiffness	<b>168.28</b>	<b>168.28</b>	<b>168.28</b>	lbf/deg	Calculated
Total Rear Wheel Rate	193.06	193.06	193.06	lbf/in	Calculated
Total Front Wheel Rate	256.48	392.00	616.00	lbf/in	Calculated
Total Vertical Stiffness	449.54	585.06	809.06	lbf/in	Calculated
	<b>609.57</b>	<b>793.33</b>	<b>1097.08</b>	Nm/deg	Calculated
Front%	57%	67%	76%	-	Calculated
Rear%	43%	33%	24%	-	Calculated
<b>Total Vehicle Roll</b>	430.84	548.97	744.23	lbf/deg	Calculated
	<b>584.23</b>	<b>744.41</b>	<b>1009.17</b>	Nm/deg	Calculated
Front%	61%	69%	77%	-	Calculated
Rear%	39%	31%	23%	-	Calculated

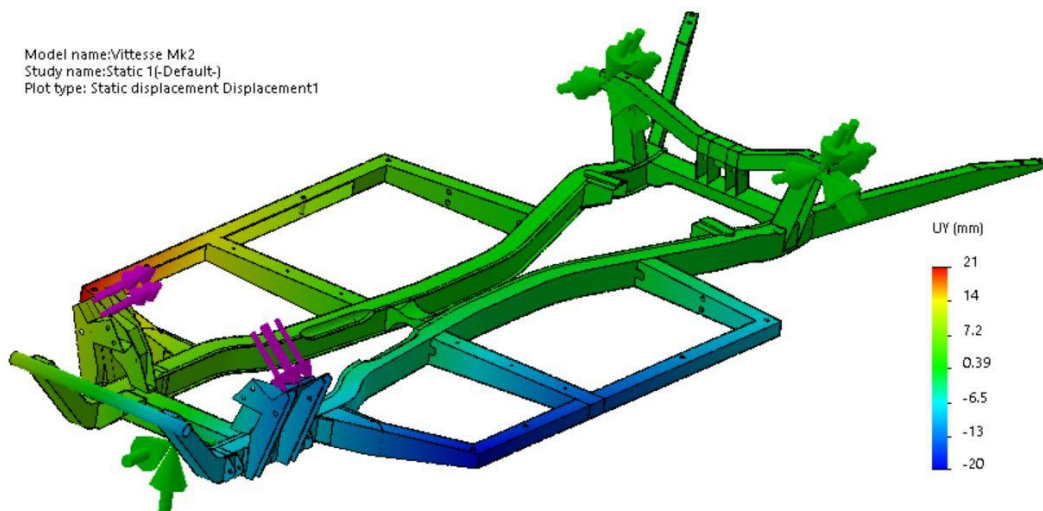
## Appendix 4: - FEA Images



Model name:Vitesse Mk2  
 Study name:Static 1(-Default-)  
 Plot type: Static nodal stress Stress1



Model name:Vitesse Mk2  
 Study name:Static 1(-Default-)  
 Plot type: Static displacement Displacement1





## Appendix 5: - FEA Log Spitfire Chassis

Spit/GT6 Chassis

Run#	Mesh		Disp.		I mm	L m	T Nm	θ °	Kθ Nm/Deg	1225 %	Change Log
	Type	mm	mm	mm							
1	Standard	20mm	5.706	5.82	360	2.45	1000	1.83	1336.03	8.31%	shelled. Torque about front Xmember. Fixed geometry at damper mounts.
2	Standard	15mm	6.852	6.823	360	2.45	1000	2.18	1126.23	-8.77%	Changed fixture to allow rotation
3	Standard	15mm	7.108	7.086	360	2.45	1000	2.26	1085.09	-12.89%	Added gaerbox reliefs in main rails
4	Standard	15mm	4.694	4.711	360	2.45	1000	1.50	1637.14	25.17%	Removed front outriggers (Had shelled holes into main rails)
5	Standard	15mm	5.715	5.598	360	2.45	1000	1.80	1361.17	10.00%	Reduced main rails to 65mm narrow
6	Standard	15mm	12.97	11.12	360	2.45	1000	3.83	639.96	-91.42%	Reduced main rails to 77.1mm long
7	Standard	15mm	9.588	6.982	360	2.45	1000	2.64	929.67	-31.77%	Increased back to 80mm
8	Standard	15mm	8.52	6.4	360	2.45	1000	2.37	1032.35	-18.66%	added double skin tofront rails
9	Standard	15mm	8.081	5.897	360	2.45	1000	2.22	1101.84	-11.18%	added bumper
10	Standard	15mm	6.077	8.069	360	2.45	1000	2.25	1088.77	-12.51%	rail back to 70mm short
11	Standard	15mm	5.668	7.799	360	2.45	1000	2.14	1143.61	-7.12%	unshelled rear upright
12	Standard	15mm	6.106	8.331	360	2.45	1000	2.30	1066.85	-14.82%	rebuilt rear structure
13	Standard	15mm	5.801	8.091	360	2.45	1000	2.21	1108.66	-10.49%	reduced open shell face
14	Standard	15mm	5.237	7.903	360	2.45	1000	1.99	1228.07	0.25%	increased wall thickness to 2.2mm
15	Standard	15mm	5.696	4.834	360	2.45	1000	1.68	1462.32	16.23%	rebuilt rear structure
16	Standard	15mm	5.323	6.233	360	2.45	1000	1.84	1332.56	8.07%	wall thickness back to 2mm
17	Standard	15mm	5.583	6.445	360	2.45	1000	1.91	1280.31	4.32%	reduce shell faces
18	Standard	15mm	5.561	6.446	360	2.45	1000	1.91	1282.54	4.49%	rebuilt crossmembers to remove shelled openings
19	Standard	15mm	5.88	6.736	360	2.45	1000	2.01	1220.68	-0.35%	rebuilt rear crossmember
20	Standard	15mm	5.855	6.763	360	2.45	1000	2.01	1220.49	-0.37%	Added diff mounts. Supressed bumper to run.
21	Standard	15mm	5.849	6.747	360	2.45	1000	2.00	1222.62	-0.19%	further diff mounting
22	Standard	15mm	5.415	6.332	360	2.45	1000	1.87	1310.91	6.55%	Added front outriggers. Repaired bumper.
23	Curvature	15mm	5.88	6.213	360	2.45	1000	1.92	1273.43	3.80%	bumper curvature and relief pressings added
24	Curvature	15mm	5.894	6.233	360	2.45	1000	1.93	1269.86	3.53%	full bumper and added turret mounts
25	Curvature	15mm	4.708	8.327	360	2.45	1000	2.07	1181.48	-3.68%	rebuilt rear beam
26	Curvature	15mm	4.697	7.955	360	2.45	1000	2.01	1217.21	-0.64%	added lower wishbone mounts and corrected double skin
26.1	Curvature	15mm	3.732	3.87	360	2.45	1000	1.21	2025.27	39.51%	Config 26. fixed at diff mounts. 1000Nm about front xmember
26.2	Curvature	15mm	3.694	3.834	360	2.45	1000	1.20	2045.17	40.10%	rerun with gearbox mount plate
27	Curvature	15mm	6.75	5.544	360	2.45	1000	1.96	1252.63	2.21%	Added forward suspension turrets
28	Curvature	15mm	4.13	4.096	360	2.45	1073.72	1.31	2009.67	39.04%	Added Lower Wishbones and Dampers. Applied 1000N opposing at Wishbone
29	Curvature	12.5mm	4.225	4.224	360	2.45	1073.72	1.34	1956.64	37.39%	added extra fixture at front. Mesh reduced
30	Curvature	12.5mm	4.007	4.007	360	2.45	1000	1.28	1921.18	36.24%	rerun with 1000nm torque about xmember
31	Curvature	12.5mm	4.011	4.011	360	2.45	1000	1.28	1919.27	36.17%	Spaced off the wishbones and lower damper mount
32	Curvature	12.5mm	4.011	4.011	360	2.45	1000	1.28	1919.27	36.17%	removed wishbone brace
33	Curvature	12.5mm	4.012	4.012	360	2.45	1000	1.28	1918.79	36.16%	Removed damper
34	Curvature	12.5mm	4.012	4.011	360	2.45	1000	1.28	1919.03	36.17%	Shelled wishbone 1.5mm
35	Curvature	12.5mm	4.007	4.007	360	2.45	1000	1.28	1921.18	36.24%	supressed wishbones and dampers
36	Curvature	12.5mm	6.51	6.507	360	2.45	1000	2.07	1183.11	-3.54%	removed front fixture
37	Curvature	12.5mm	6.508	6.508	360	2.45	1000	2.07	1183.20	-3.53%	modify fixture. Fixed vertically only
38	Curvature	12.5mm	6.203	6.205	360	2.45	1000	1.97	1241.13	1.30%	Unsupressed wishbones and dampers
39	Curvature	12.5mm	4.238	4.238	360	2.45	1073.72	1.35	1950.41	37.19%	loaded wishbones 1000N opposing
40	Curvature	12.5mm	6.203	6.205	360	2.45	1000	1.97	1241.13	1.30%	returned to torque abou xmember
41	Curvature	12.5mm	4.23	4.23	360	2.45	1073.72	1.35	1954.10	37.31%	removed rearmost wishbone bolt
42	Curvature	12.5mm	4.225	4.225	360	2.45	1073.72	1.34	1956.41	37.39%	removed front wishbone bolt
43	Curvature	12.5mm	4.237	4.238	360	2.45	1073.72	1.35	1950.64	37.20%	reduced damper diameter. Added bolts
44	Curvature	12.5mm	4.239	4.238	360	2.45	1073.72	1.35	1950.18	37.19%	reduced diameters
45	Curvature	12.5mm	4.219	4.219	360	2.45	1073.72	1.34	1959.19	37.47%	Rebuilt bumper- raised and moved forward
46	Curvature	12.5mm	6.468	6.468	360	2.45	1000	2.06	1190.51	-2.90%	supressed wishboones and dampers. back to torque about Xmember
47	Curvature	12.5mm	6.146	6.147	360	2.45	1000	1.96	1252.73	2.21%	added intermediate outrigger stumps
48	Curvature	12.5mm	6.472	6.472	360	2.45	1000	2.06	1189.77	-2.96%	included wishbones etc
49	Curvature	12.5mm	6.278	6.278	360	2.45	1000	2.00	1226.51	0.12%	removed gearbox mount plate
50	Curvature	12.5mm	6.273	6.283	360	2.45	1000	2.00	1226.51	0.12%	Added Gravity

## Appendix 6: - FEA Log Vitesse Chassis

Vitesse Chassis

↓ Percentage change from previous iteration

Run#	Mesh		Disp.		I	L	T	θ	Kθ	%	Change Log
	Type	mm	mm	mm							
1	Standard	15mm	6.886	6.96	360	2.45	1000	2.20	1112.335	-	shelled. Torque about front Xmember. Fixed geometry at damper mounts.
2	Standard	15mm	4.151	4.062	360	2.45	1000	1.31	1874.647	40.66%	reshelled(without holes intomain rails). Ditto above
3	Curvature	15mm	3.695	3.718	360	2.45	1073.72	1.18	2230.00	15.94%	Spit Chassis #28 converted to side rails and outriggers. Not front bumper.
4	Curvature	12.5mm	3.779	3.821	360	2.45	1073.72	1.21	2175.14	-2.52%	bumper and rack mounts
5	Curvature	12.5mm	3.719	3.736	360	2.45	1073.72	1.19	2217.44	1.91%	tweaked bumper irons and rack mounts
6	Curvature	12.5mm	3.784	3.813	360	2.45	1073.72	1.21	2176.00	-1.90%	Added Boot Riggers
7	Curvature	12.5mm	3.742	3.743	360	2.45	1073.72	1.19	2208.55	1.47%	repaired fixture
8	Curvature	12.5mm	3.751	3.747	360	2.45	1073.72	1.19	2204.72	-0.17%	increased gap between turret and chassis rails. 0.5mm
9	Curvature	12.5mm	14.99	15	360	2.45	4294.88	4.76	2209.64	0.22%	Increased Load to 4000N each
10	Curvature	12.5mm	3.828	3.752	360	2.45	1073.72	1.21	2180.88	-1.32%	Added Engine mass 777N x2. 195Nm engine mounts. 750N gearbox
11	Curvature	12.5mm	7.037	7.035	360	2.45	1000	2.24	1094.49	-99.26%	using torque about xmember
12	Curvature	12.5mm	7.164	7.162	360	2.45	1000	2.28	1075.10	-1.80%	removed gearbox mount plate
13	Curvature	12.5mm	7.16	7.162	360	2.45	1000	2.28	1075.40	0.03%	added star plates to front outrigger armpit
14	Curvature	12.5mm	4.794	4.792	360	2.45	1000	1.53	1606.24	33.05%	remove rack mounts
15	Curvature	12.5mm	4.716	4.714	360	2.45	1000	1.50	1632.80	1.63%	Added Gearbox Mount
16	Curvature	12.5mm	3.275	3.274	360	2.45	1000	1.04	2350.82	30.54%	Added Fixtures at diff mount
17	Curvature	12.5mm	3.232	3.311	360	2.45	1000	1.04	2352.97	0.09%	Added Engine and Gearbox
18	Curvature	12.5mm	4.681	4.763	360	2.45	1000	1.50	1630.38	-44.32%	Removed diff fixtures
19	Curvature	12.5mm	1.998	2.034	360	2.45	1000	0.64	3818.07	57.30%	added 'spring' as link between turrets. Ditched gravity
20	Curvature	12.5mm	0.872	0.887	360	2.45	1000	0.28	8751.52	56.37%	added 'springs' turret to gearbox mount
21	Curvature	12.5mm	0.469	0.476	360	2.45	1000	0.15	16289.78	46.28%	added 'springs' as differential fixtures
22	Curvature	12.5mm	2.704	2.714	360	2.45	1000	0.86	2841.45	42.54%	changed spring stiffnesses to v1 calc values
23	Curvature	12.5mm	4.252	4.337	360	2.45	1000	1.37	1792.61	8.91%	suppressed engine springs
24	Curvature	12.5mm	2.896	2.908	360	2.45	1000	0.92	2652.50	38.44%	unsuppress engine. Suppress diff
25	Curvature	12.5mm	4.6812	4.763	360	2.45	1000	1.50	1630.35	-0.15%	engine mass effects
26	Curvature	12.5mm	4.715	4.713	360	2.45	1000	1.50	1633.15	0.02%	engine without gearbox load
27	Curvature	12.5mm	4.731	4.742	360	2.45	1000	1.51	1625.39	-	bare chassis with gravity supported as per and torque about xmember
28	Curvature	12.5mm	4.7	4.7	360	2.45	1000	1.50	1638.01	-	singlepoint front fixture. Cut out corners of siderails
29	Curvature	12.5mm	5.5	5.5	360	2.45	1000	1.75	1399.87	-	reduced all thickness 2mm to 1.6mm 16 gauge
30	Curvature	12mm	5.62349	5.62246	360	2.45	1000	1.79	1369.28	-	reduced siderail and outrigger thickness from 2mm to 1.6mm
31	Curvature	12mm	5.555	5.555	360	2.45	1000	1.77	1386.02	-	Reintroduced steering rack mounts
32	Curvature	12mm	6.9	6.9	360	2.45	1000	2.20	1116.04	-	Changed loading to spring/damper positions on turrets 1500N each.

## Appendix 7: - FEA Log Vitesse Body

Vitesse Chassis and Body Assembly

↓ Percentage change from previous iteration

Run#	Mesh		Disp.		I	L	T	θ	Kθ	%	Change Log
	Type	mm	mm	mm							
1	Curvature	12	4.797	4.797	360	2.45	1000	1.53	1604.904	-	@Vit26 - bare chassis torque about front xmember
2	Curvature	12	4.802	4.791	360	2.45	1000	1.53	1605.071	0.01%	added gravity
3	Curvature	12	3.7623	3.7624	360	2.45	1082	1.20	2213.845	27.50%	fixed at damper mounts. Bare chassis with pinned wishbones. Double links as dampers
4	Curvature	12	3.763	3.763	360	2.45	1082	1.20	2213.463	-0.02%	single link wishbones
5	Curvature	12/3	3.828	3.828	360	2.45	1082	1.22	2175.889	-1.73%	refined wishbone mesh 3mm
6	Curvature	12	4.798	4.797	360	2.45	1000	1.53	1604.737	-35.59%	removed wishbones. Engine and diff in place. Torque about xmember.
7	Curvature	12	3.76	3.76	360	2.45	1000	1.20	2047.346	21.62%	@Vit30 - front tub and chassis as single part 12 2.4 30 1.5
8	Blend	100	0.9215	0.9208	360	2.45	1000	0.29	8355.826	75.50%	front and rear tub joint removed. Very crude mesh
9	Curvature	12	2.52262	2.52201	360	2.45	1000	0.80	3051.723	-173.81%	12/2.4/36/1.6 FFEPlus 30 mins <b>Body and Chassis as solid part</b>
10	Curvature	12	2.69225	2.69162	360	2.45	1000	0.86	2859.458	-6.72%	12/2.4/36/1.6 FFEPlus 20hrs?? Removed some upper structure under screen
11	Curvature	12	2.69402	2.69326	360	2.45	1000	0.86	2857.649	-0.06%	12/2.4/36/1.6 FFEPlus made midoutrigger bodymount into 3 smaller ones
12	Curvature	12	2.70356	2.70291	360	2.45	1000	0.86	2847.507	-0.36%	reduced a pillar wall thickness
13	Curvature	12	2.72578	2.72517	360	2.45	1000	0.87	2824.275	-0.82%	cut back front body mounts from lip
14	Curvature	12	2.75882	2.75819	360	2.45	1000	0.88	2790.462	-1.21%	reduced radius of b pillar gusset
15	Curvature	12	2.80924	2.80858	360	2.45	1000	0.89	2740.396	-1.83%	reduced sill flange and rear body mounts
16	Attempted assembly study. Meshed with previous settings. Set up contact sets - no penetration. Ran for 10+ hours (18% complete, 30% through solving contact sets)										
17	Attempted assembly study. Meshed with previous settings. Removed contact settings - added bolted connections. Ran for 6 hours stuck on 9.1% and 58% iterations. Saved results showed body passed through chassis										
18	Curvature	12	2.7294	2.73005	360	2.45	1000	0.87	2819.878	2.82%	previous changes embodied into new solid part. reduced body mounts.
19	Curvature	12	2.78048	2.78126	360	2.45	1000	0.89	2768.024	-1.87%	reduced 'sill' flange to 10mm
20	Curvature	12	2.78076	2.78145	360	2.45	1000	0.89	2767.79	-0.01%	split 'sill' flange at front rear joint
21	Curvature	12	2.84186	2.8427	360	2.45	1000	0.90	2708.228	-2.20%	removed second boot body mounts and shelled tunnel mounts
22	Curvature	12	2.85873	2.85952	360	2.45	1000	0.91	2692.274	-0.59%	cut back upper a pillar and reduced bulkhead thickness
23	Curvature	12	2.9911	2.9917	360	2.45	1000	0.95	2573.247	-4.63%	<b>reduced body mounts to bolt diameter</b>
24	Curvature	12	2.48851	2.48909	360	2.45	1000	0.79	3092.813	16.80%	added 'doors'
25	Curvature	12	2.51637	2.5169	360	2.45	1000	0.80	3058.609	-1.12%	reduced 'door' contact patch
26	Curvature	12	2.91314	2.91363	360	2.45	1000	0.93	2642.141	-15.76%	removed cross brace of door bars
27	Curvature	12	2.87226	2.87276	360	2.45	1000	0.91	2679.731	1.40%	added shorter crossbrace
28	Curvature	12	2.46461	2.46401	360	2.45	1000	0.78	3123.545	14.21%	longer cross brace
29	Curvature	12	2.48858	2.48917	360	2.45	1000	0.79	3092.72	-1.00%	thinner bars
30	Curvature	12	2.63661	2.63701	360	2.45	1000	0.84	2919.229	-5.94%	brace to 950mm
31	Curvature	12	2.77803	2.77863	360	2.45	1000	0.88	2770.554	-5.37%	<b>brace to 850mm</b>

## Appendix 8: - Experiment Procedure

Experimental method is to be carried out by no less than two people and in accordance with the attached risk assessment.

### Prepare vehicle

In accordance with the Haynes Manual:

1. Remove Seatbelts (chassis mounts) and Gearbox Tunnel
2. Undo lower section of steering column
3. Crack off wheel nuts
4. Raise the rear of the vehicle using a jack and prop on axel stands
5. Remove Exhaust and Prop Shaft
6. Remove spring and differential IAW Haynes manual. Leave rear uprights in place.
7. Bolt fixtures to the car and floor Fig.B
8. Raise front of vehicle and fit front fixture. Bolt to floor
9. Undo steering rack and anti roll bar. Remove front upright and hubs, make calliper safe without compromising hydraulics.
10. Replace lower Wishbone bushes with aluminium and swap spring/damper assembly for rigid brace.
11. Support engine on blocks and jack
12. Undo engine mounts and raise assembly clear of chassis

### Remove Body

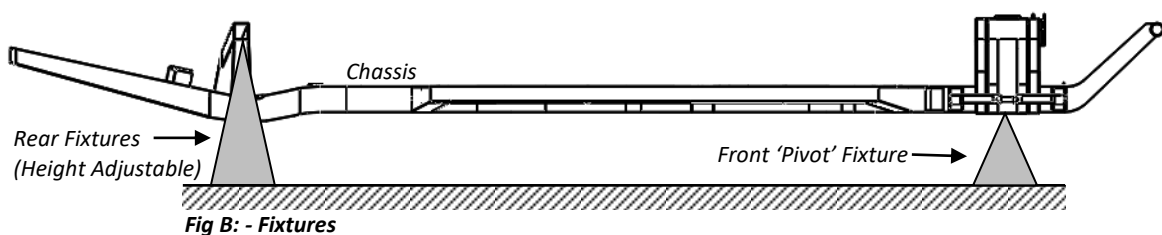
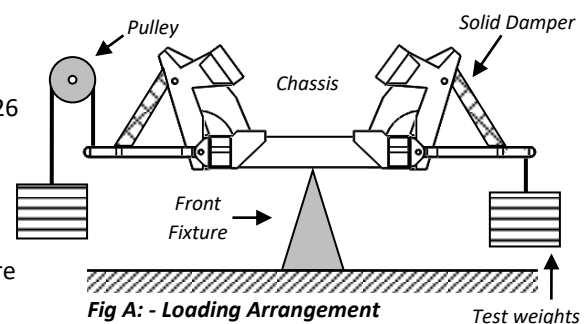
13. Loosen all body mounts
14. Prop body on blocks and scissor jacks at 4 positions
15. Remove body mounts and raise body clear of the chassis
16. Visually confirm chassis is clear, and not contacting other vehicle components

### Test

17. Set up pulley frame and weights Fig.A
18. Measure off and mark positions/stations on chassis
19. Number all weights with paint pen. Weigh each separately and record exact weight
- 20. Measure zero angle at each station and record**
- 21. Add 33kg weight to each side**
- 22. Measure angle of twist at each station and record**
- 23. Visually confirm degree of twist and that the chassis remains clear**
- 24. Add weights and repeat measurements**
- 25. Reverse the process until the chassis is unloaded**
- 26. Visually confirm stability of fixtures and mounts**
27. Remount engine and gearbox, repeat steps 20 to 26
28. Remount Body and Repeat steps 20 to 26

### Reassemble

29. Rebuild vehicle and remove from fixtures  
Replacement is a reversal of the removal procedure



## Appendix 9: - Experiment Risk Assessment

Risk Assessment - Manufacture and Test		Assessed Risk					Mitigating Action					Mitigated Risk				
Risk	Severity	Probability	Risk Factor	Severity	Probability	Risk Factor	Mitigating Action	Severity	Probability	Risk Factor	Severity	Probability	Risk Factor			
Fire	4	3	12	4	1	4	Remove flammable materials prior to work. Fire extinguisher in reach. Use PPE	4	1	4	4	1	4			
Electrocution	4	2	8	4	1	4	Check electrical equipment prior to use. Use in conjunction with appropriate trips etc	4	1	4	4	1	4			
Angle Grinder	4	2	8	3	3	3	Inspect before use. Operate with two hands. Use handle. Do not remove guard. Use PPE	3	3	3	3	1	3			
Machine malfunction	3	2	6	2	2	2	Inspect before use. Use appropriate PPE	2	2	2	2	1	2			
Pulled into machine	3	2	6	2	2	2	Ensure no loose clothing etc. Functioning E-Stop Button	2	2	2	2	1	2			
Machining Debris	4	2	8	4	1	4	Ensure appropriate guards are fitted and used. Use appropriate PPE	4	1	4	4	1	4			
Trips and Slips	3	3	9	3	3	3	Work tidy, coil cables when not in use, route extensions sensibly	3	3	3	3	1	3			
Cuts	3	2	6	2	2	2	Wear gloves during fabrication. Well stocked first aid kit in workshop.	2	2	2	2	1	2			
Burns	3	2	6	2	2	2	Wear gloves during fabrication, be aware of hot materials. Well stocked first aid kit	2	2	2	2	1	2			
Chemical Exposure	3	2	6	3	3	3	Use chemicals in well ventilated area and wear gloves where appropriate. Observe MSDS	3	3	3	3	1	3			
Falling Objects	3	2	6	2	2	2	Plan every lift. Two man lift anything over 25kg. Wear steel toe caps and gloves.	2	2	2	2	1	2			
Manual Handling	3	2	6	3	3	3	Plan each lift. No heavier than 25kg per person. Lift between two or more.	3	3	3	3	1	3			
Car Falls From Fixtures	4	2	8	3	3	3	Use ppe. Increase SF and number of props. Ensure stood at safe distance where possible	3	3	3	3	1	3			
Car Falls During Lift	4	3	12	3	3	3	Use PPE. Ensure equipment is rated appropriately. Maintain a safe distance if possible	3	3	3	3	1	3			
Fuel/oil spill	2	4	8	1	3	3	Take care when working on fluid systems. Keep a rag handy to mop up.	1	3	3	3	1	3			
Test piece failure	3	1	3	3	3	3	Calculate safety factors and inspect test piece before use. Use PPE	3	3	3	3	1	3			
Test fixture failure	4	2	8	4	4	4	Calculate safety factors and inspect fixtures before use. Use PPE	4	4	4	4	1	4			
Restricted height injury	2	2	4	2	1	2	Wear a woolly hat under the vehicle	1	1	2	2	2	2			
Pulley Cable failure	4	2	8	4	4	4	Calculate correct cable spec. Stand clear of cable whilst under load.	4	4	4	4	1	4			

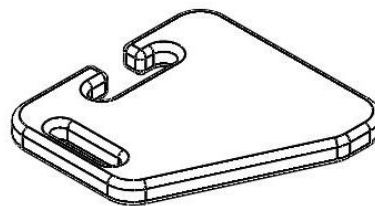
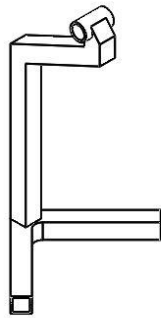
Likelihood	Severity				
	V.Low	Low	Medium	High	V.High
Probable	5	10	15	20	25
V.Likely	4	8	12	16	20
Likely	3	6	9	12	15
Possible	2	4	6	8	10
Not Likely	1	2	3	4	5

Severity	Description
V.high	Multiple fatalities, permanent environmental damage
High	Single fatality or multiple serious injuries, Temporary environmental damage
Medium	RIDDOR reportable injury, Minor environmental damage
Low	Minor injury
V.low	Reportable near miss

## Appendix 10: - Experiment Equipment

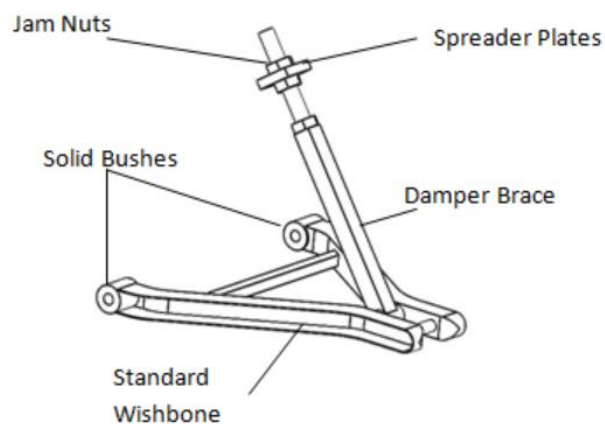
Tractor weights were used as test loads and so custom weight hangers were fabricated to allow level and accessible positioning in the available space. Nominally 33kg the weights were individually marked and weighed and found to be  $\pm 1$ kg, the weight hangers were also weighed and marked:



Tractor Weights	
Number	kg
#A	1.4
#B	1.73
#1	32.4
#2	32.36
#3	32.02
#4	33.13
#5	32.67
#6	32.08
#7	32.5
#8	32.57
#9	31.77
#10	31.68

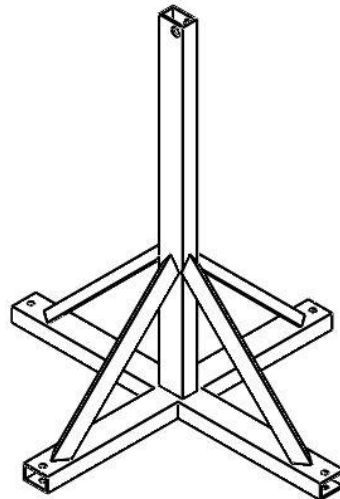
The front spring and damper assemblies were replaced with a rigid brace adjustable via an M16 screw thread; standard lower wishbones were used though the rubber bushes were replaced with solid aluminium.

The LH hanger was fixed directly to the wishbone to impart a downward force, whilst the RH hanger was connected via a pulley to induce an upward force.

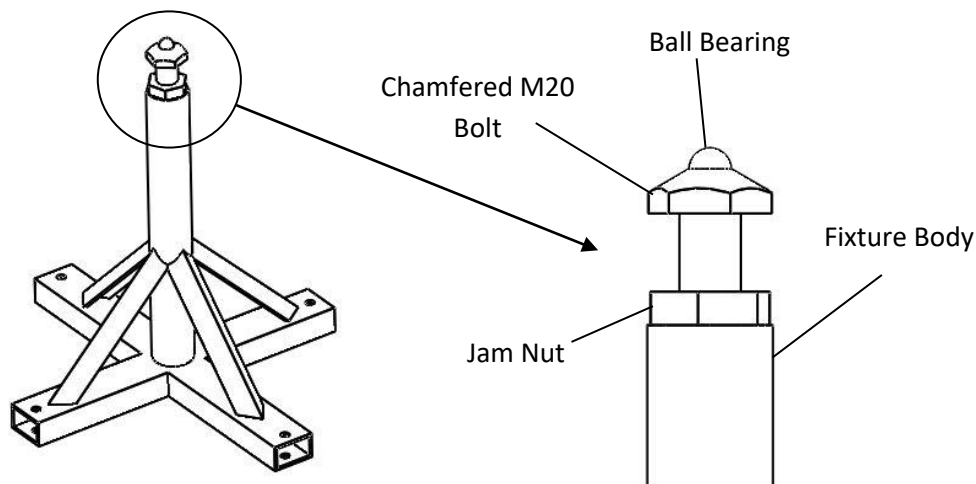


Three fixtures were fabricated to support the chassis at the rear damper mounts and in the centre of the front cross member – all fixtures bolt to the concrete floor in 4 positions. The fixtures use 50x30x3mm mild steel box, braced with 25x25x2mm angle and were MIG welded.

The rear fixtures bolt to the chassis with the original shouldered damper bolts. The shoulder prevents over tightening and allows the rear fixtures to rotate about the bolts. The fixture stands 695mm from base to hole centre, and 600mm across the base.



The front fixture is adjustable for height via an M20 thread and jam nut. The fixture interfaces to the chassis with an 18mm ball bearing locating positively in a pip on a 10mm plate clamped to the front cross member flange. This ball bearing was lubricated with lith-moly grease and allows the test structure to pivot whilst fixing it vertically, laterally and longitudinally.



## Appendix 11: - Experiment Photographs









### Appendix 12: - Experimental Data

Looking from Rear of car. L/R.

LH = Left High  
LL = Left Low

LH RH  
(1) 32.46 / 32.08  
(2) 32.36 / 32.25

Pos.	diff from mm	Zero	LH	RH	LH	RH
1	0	0.37 LH	0.71 LH	0.54 LH	0.50 LH	0.54 LH
2		0.63 LH	0.51 LH	0.64 LH	0.66 LH	0.57 LH
3		0.71 LH	0.62 LH	0.70 LH	0.70 LH	0.62 LH
4		1.08 LH	1.02 LH	1.02 LH	1.01 LH	0.95 LH
5		1.02 LH	1.07 LH	1.03 LH	1.04 LH	0.91 LH
6		0.41 LH	0.44 LH	0.42 LH	0.41 LH	0.21 LH
7		0.30 LH	0.27 LH	0.30 LH	0.30 LH	0.26 LH
8		0.21 LH	0.26 LH	0.25 LH	0.26 LH	0.26 LH
9		0.25 LH	0.30 LH	0.30 LH	0.30 LH	0.26 LH
10		0.50 LH	0.48 LH	0.51 LH	0.54 LH	0.26 LH
11		0.61 LH	0.63 LH	0.61 LH	0.64 LH	0.26 LH

Fixed parts added to chassis as Driven After this test

26/12/19

Chassis twist analysis

TEST: Chassis only  
DATE: 29.12.19

Weights

Station	0	1	2	3	4	5	6	7	8	9	10	11
Rear LH	0	0	32.46 #1	32.36 #2	32.02 #3	32.57 #4	33.13 #5	31.77 #6				
Rear RH	0	0	32.65 #1	32.5 #2	32.57 #3	31.77 #4	31.77 #5	31.77 #6				
Front LH	0	0	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Front RH	0	0	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41

TEST: Chassis only  
DATE: 29.12.19

Weights

Station	0	1	2	3	4	5	6	7	8	9	10	11
Rear LH	0	0	32.46 #1	32.36 #2	32.02 #3	32.57 #4	33.13 #5	31.77 #6				
Rear RH	0	0	32.65 #1	32.5 #2	32.57 #3	31.77 #4	31.77 #5	31.77 #6				
Front LH	0	0	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Front RH	0	0	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41

Handing as seen from the rear of the car looking forward

1064 between wishbone left ctrs.

1250

1660

unloaded 3+2H  
3+2H

**Chassis twist analysis**

TEST: Chassis + Control Deck  
DATE: 30/12/19

Station	Weights										
	0	1	2	3	4	3	2	1	0		
LH	#1	#1	#2	#3	#4	#3	#2	#1			
RH	#8	#5	#6	#7	#8	#7	#6	#5			
1	0.44	0.43	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35	0.34
2	0.48	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.39	0.38
3	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.42
4	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.48	0.47	0.46
5	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.51	0.50
6	0.64	0.63	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.54
7	0.68	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.58
8	0.72	0.71	0.70	0.69	0.68	0.67	0.66	0.65	0.64	0.63	0.62
9	0.76	0.75	0.74	0.73	0.72	0.71	0.70	0.69	0.68	0.67	0.66
10	0.80	0.79	0.78	0.77	0.76	0.75	0.74	0.73	0.72	0.71	0.70
11	0.84	0.83	0.82	0.81	0.80	0.79	0.78	0.77	0.76	0.75	0.74

TEST: Chassis + Control Deck + Box w. doors & seat.  
DATE: 30/12/19

Station	Weights										
	0	1	2	3	4	3	2	1	0		
LH											
RH											
1	0.41	0.40	0.39	0.38	0.37	0.36	0.35	0.34	0.33	0.32	0.31
2	0.45	0.44	0.43	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35
3	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.39
4	0.53	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.43
5	0.57	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.48	0.47
6	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.51
7	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55
8	0.69	0.68	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.59
9	0.73	0.72	0.71	0.70	0.69	0.68	0.67	0.66	0.65	0.64	0.63
10	0.77	0.76	0.75	0.74	0.73	0.72	0.71	0.70	0.69	0.68	0.67
11	0.81	0.80	0.79	0.78	0.77	0.76	0.75	0.74	0.73	0.72	0.71

seen from the rear of the car looking forward

2/1/2020 (1)

**Chassis twist analysis**

TEST: Chassis + Body including seat belt mounts.  
DATE: 2/1/2020

Station	Weights										
	0	1	2	3	4	5	4	3	2		
LH	#1	#1	#2	#3	#4	#5	#4	#3	#2		
Rear	#8	#5	#6	#7	#8	#9	#8	#7	#6		
1	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.39	0.38	0.37
2	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.42	0.41
3	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45
4	0.59	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.49
5	0.63	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.53
6	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.58	0.57
7	0.71	0.70	0.69	0.68	0.67	0.66	0.65	0.64	0.63	0.62	0.61
8	0.75	0.74	0.73	0.72	0.71	0.70	0.69	0.68	0.67	0.66	0.65
9	0.79	0.78	0.77	0.76	0.75	0.74	0.73	0.72	0.71	0.70	0.69
10	0.83	0.82	0.81	0.80	0.79	0.78	0.77	0.76	0.75	0.74	0.73
11	0.87	0.86	0.85	0.84	0.83	0.82	0.81	0.80	0.79	0.78	0.77

cont'd

TEST: Doors open & hood down.  
DATE: 2/1/2020

Station	Weights										
	1	0	1	2	3	4	5	4	3		
LH	#1		#1	#2	#3	#4	#5	#4	#3		
Rear	#5		#5	#6	#7	#8	#9	#8	#7		
1	0.44	0.43	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35	0.34
2	0.48	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.40	0.39	0.38
3	0.52	0.51	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.42
4	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.48	0.47	0.46
5	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.51	0.50
6	0.64	0.63	0.62	0.61	0.60	0.59	0.58	0.57	0.56	0.55	0.54
7	0.68	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.58
8	0.72	0.71	0.70	0.69	0.68	0.67	0.66	0.65	0.64	0.63	0.62
9	0.76	0.75	0.74	0.73	0.72	0.71	0.70	0.69	0.68	0.67	0.66
10	0.80	0.79	0.78	0.77	0.76	0.75	0.74	0.73	0.72	0.71	0.70
11	0.84	0.83	0.82	0.81	0.80	0.79	0.78	0.77	0.76	0.75	0.74

standing as seen from the rear of the car looking forward

2/1/2020 (2)

**Chassis twist analysis**

TEST: Rears open, head down  
DATE: 2/1/2020

Station	Weights									
	2	1	0	3	4	3	2	1	0	
LH										
RH ^										
Rear 1	0.41+	0.41+	0.42+	0.42+	0.43+	0.43+				
2	0.43+	0.44+	0.45+	0.45+	0.45+	0.46+				
3	0.56+	0.56+	0.61+	0.62+	0.59+	0.61+				
4	0.45+	0.68+	0.71+	0.70+	0.74+	0.74+				
5	0.63+	0.62+	0.71+	0.68+	0.70+	0.70+				
6	0.14-	0.15-	0.08+	0.06+	0.27+	0.30+				
7	0.34-	0.34-	0.00	0.00	0.08+	0.08+				
8	0.59-	0.61-	0.28-	0.28-	0.14+	0.14+				
9	0.53-	0.61-	0.25-	0.26-	0.26+	0.26+				
10	0.52-	0.52-	0.13-	0.16-						
Front 11	0.34-	0.32-	0.05-	0.00	0.44+	0.46+				

TEST: \_\_\_\_\_  
DATE: \_\_\_\_\_

Station	Weights									
	0	1	2	3	4	3	2	1	0	
LH										
RH ^										
Rear 1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
Front 11										

Handing as seen from the rear of the car looking forward

Net Spring twist on weight table from rear head end

**Chassis twist analysis**

TEST: Rears down + Rears closed  
DATE: 2/1/20

Station	Weights									
	0	1	2	3	4	5	4	3	2	
LH										
RH ^										
Rear 1	0.43+	0.44+	0.44+	0.44+	0.43+	0.41+	0.41+	0.41+	0.41+	0.41+
2	0.44+	0.45+	0.47+	0.45+	0.45+	0.47+	0.44+	0.41+	0.41+	0.43+
3	0.50+	0.63+	0.63+	0.60+	0.57+	0.61+	0.56+	0.59+	0.51+	0.52+
4	0.75+	0.71+	0.70+	0.71+	0.71+	0.68+	0.61+	0.70+	0.69+	0.64+
5	0.76+	0.78+	0.71+	0.69+	0.68+	0.66+	0.64+	0.68+	0.57+	0.57+
6	0.30+	0.34+	0.19+	0.21+	0.05+	0.04+	0.10-	0.12-	0.27-	0.26-
7	0.30+	0.34+	0.13+	0.14+	0.08-	0.09-	0.26-	0.31-	0.51-	0.48-
8	0.13+	0.18+	0.08+	0.09+	0.33-	0.31-	0.58-	0.57-	0.81-	0.81-
9	0.20+	0.26+	0.08+	0.09+	0.33-	0.31-	0.58-	0.57-	0.81-	0.81-
10	0.30+	0.31+	0.05+	0.05+	0.26-	0.21-	0.48-	0.48-	0.77-	0.76-
Front 11	0.51+	0.52+	0.25+	0.22+	0.08-	0.12-	0.31-	0.32-	0.62-	0.62-

TEST: \_\_\_\_\_  
DATE: \_\_\_\_\_

Station	Weights									
	1	0	2	3	4	3	2	1	0	
LH										
RH ^										
Rear 1	0.43+	0.43+	0.42+	0.45+						
2	0.48+	0.48+	0.45+	0.48+						
3	0.59+	0.59+	0.59+	0.62+						
4	0.75+	0.71+	0.75+	0.76+						
5	0.68+	0.68+	0.76+	0.77+						
6	0.12+	0.12+	0.30+	0.30+						
7	0.04+	0.05+	0.30+	0.30+						
8	0.21+	0.21+	0.11+	0.12+						
9	0.19+	0.19+	0.13+	0.16+						
10	0.08+	0.07+	0.30+	0.30+						
Front 11	0.06+	0.08+	0.47+	0.51+						

Handing as seen from the rear of the car looking forward

\* door gaps "bottomed"?  
\*\* nope! big movement.  
xxx  
- middle air riser not welded round.  
- Rear air riser & c' switch welded.

Door gaps feel bad.  
LH Top air trim strip bottomed (5-5).  
LH bottom - envelope.  
RH Top air trim strip bottomed.  
RH bottom b. trim + 10.6 stick air (low top).

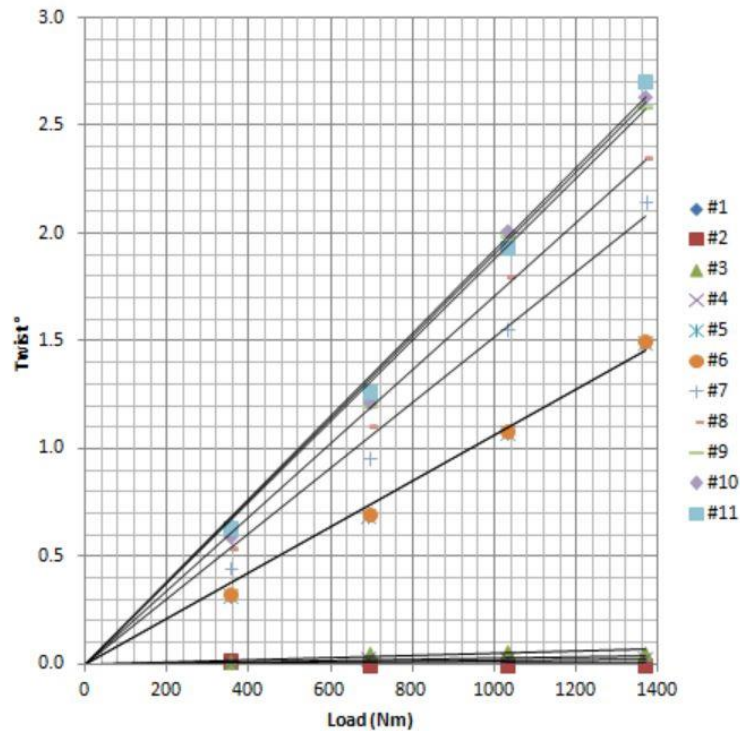
## Appendix 13: - Experiment Tables/Graphs

+Engine - Averaged Twist Angle					+Engine - Corrected Twist Angle								
Posn #	Twist Angle ( $\pm 0.1^\circ$ ) at Load (Nm)				xcoefficient	Twist Angle ( $^\circ$ ) $\pm 4.5\%$ at Load (Nm)							
	352.85	691.35	1028.44	1367.15		-	400	600	800	1000	1200	1400	1600
1	0.02	0.02	0.03	0.01	3.479E-06	0.001	0.002	0.003	0.003	0.004	0.005	0.006	
2	0.03	0.01	0.00	0.00	1.708E-05	0.007	0.010	0.014	0.017	0.020	0.024	0.027	
3	0.01	0.06	0.06	0.05	2.626E-05	0.011	0.016	0.021	0.026	0.032	0.037	0.042	
4	0.01	0.03	0.03	0.03	4.863E-05	0.019	0.029	0.039	0.049	0.058	0.068	0.078	
5	0.11	0.16	0.25	0.33	0.0002382	0.095	0.143	0.191	0.238	0.286	0.333	0.381	
6	0.33	0.70	1.08	1.50	0.0010644	0.426	0.639	0.852	1.064	1.277	1.490	1.703	
7	0.45	0.96	1.56	2.16	0.0015224	0.609	0.913	1.218	1.522	1.827	2.131	2.436	
8	0.54	1.11	1.81	2.36	0.0017097	0.684	1.026	1.368	1.710	2.052	2.394	2.735	
9	0.60	1.24	1.96	2.52	0.0018478	0.739	1.109	1.478	1.848	2.217	2.587	2.956	
10	0.60	1.22	2.02	2.64	0.0019088	0.764	1.145	1.527	1.909	2.291	2.672	3.054	
11	0.64	1.27	1.94	2.71	0.001923	0.769	1.154	1.538	1.923	2.308	2.692	3.077	

\*Data collated from experimental loading data. Used to plot graph of Twist vs Load

\*Values calculated from trendline coefficients to find 'accurate' twist angles

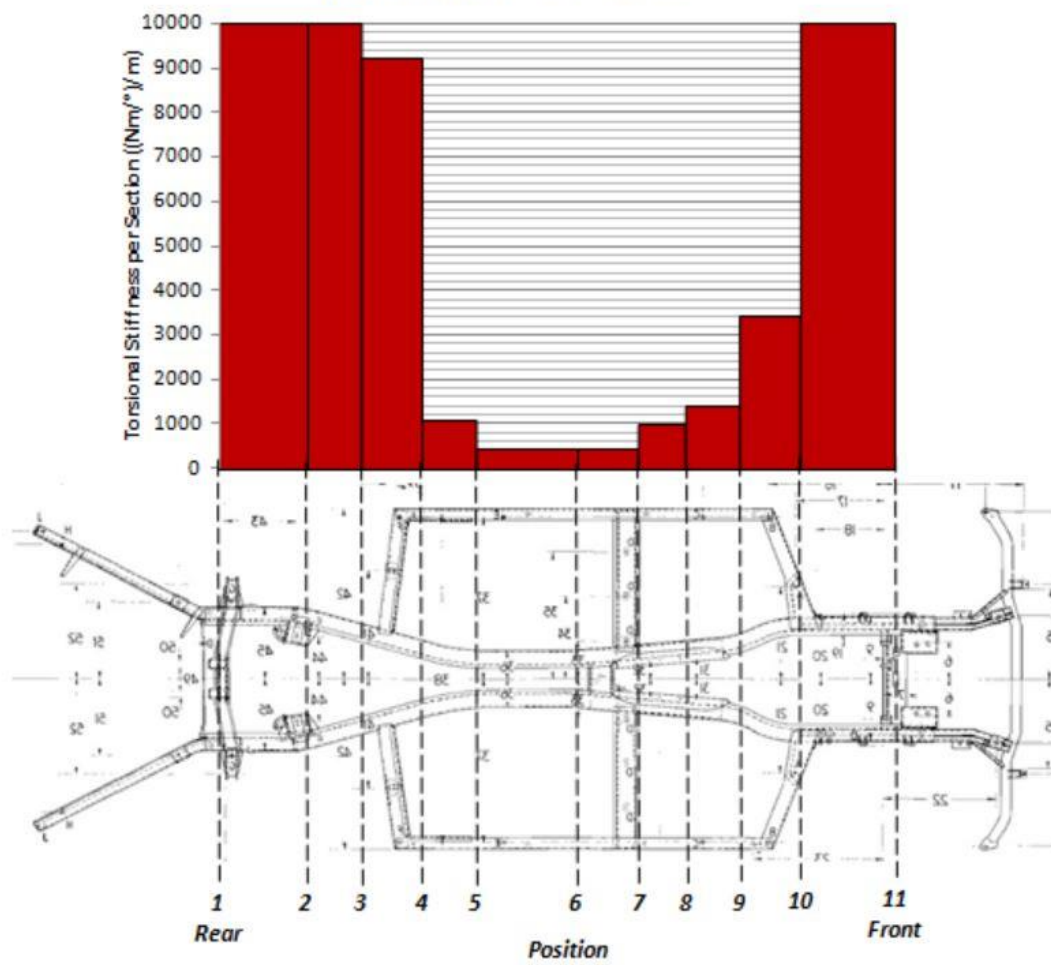
### Load vs Twist Angle



+Engine - Calculated Torsional Stiffness per Section										
Posn #	Section Length(mm)	Torsional Stiffness ((Nm/ $^\circ$ )/m) at Load (Nm)								Average
		400	600	800	1000	1200	1400	1600		
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	336	24710.61	24710.61	24710.61	24710.61	24710.61	24710.61	24710.61	24710.61	10000.00
3	204	22212.06	22212.06	22212.06	22212.06	22212.06	22212.06	22212.06	22212.06	10000.00
4	207	9254.00	9254.00	9254.00	9254.00	9254.00	9254.00	9254.00	9254.00	9254.00
5	207	1092.22	1092.22	1092.22	1092.22	1092.22	1092.22	1092.22	1092.22	1092.22
6	372	450.22	450.22	450.22	450.22	450.22	450.22	450.22	450.22	450.22
7	202	441.03	441.03	441.03	441.03	441.03	441.03	441.03	441.03	441.03
8	190	1014.68	1014.68	1014.68	1014.68	1014.68	1014.68	1014.68	1014.68	1014.68
9	192	1390.17	1390.17	1390.17	1390.17	1390.17	1390.17	1390.17	1390.17	1390.17
10	210	3440.87	3440.87	3440.87	3440.87	3440.87	3440.87	3440.87	3440.87	3440.87
11	340	23975.07	23975.07	23975.07	23975.07	23975.07	23975.07	23975.07	23975.07	10000.00
Overall	2460	1279.24	1279.24	1279.24	1279.24	1279.24	1279.24	1279.24	1279.24	1279.24

\*Values calculated from calculated twist to generate accurate stiffness values  
Averaged stiffness capped at 10000 (Nm/ $^\circ$ )/m to improve chart resolution

**Chart of Stiffness & Angle of Twist per Section - '+Engine'**



**+Body - Averaged Twist Angle**

Posn #	Twist Angle (±0.1°) at Load (Nm)				
	352.85	691.35	1028.44	1367.15	1702.99
1	0.00	0.00	0.00	0.00	0.01
2	0.03	0.03	0.01	0.00	0.02
3	0.00	0.04	0.06	0.03	0.04
4	0.03	0.06	0.09	0.12	0.13
5	0.06	0.11	0.17	0.22	0.25
6	0.10	0.33	0.55	0.75	0.96
7	0.21	0.51	0.79	1.05	1.36
8	0.28	0.59	0.88	1.22	1.50
9	0.28	0.62	0.94	1.31	1.76
10	0.28	0.66	0.98	1.35	1.84
11	0.27	0.67	0.96	1.36	1.79

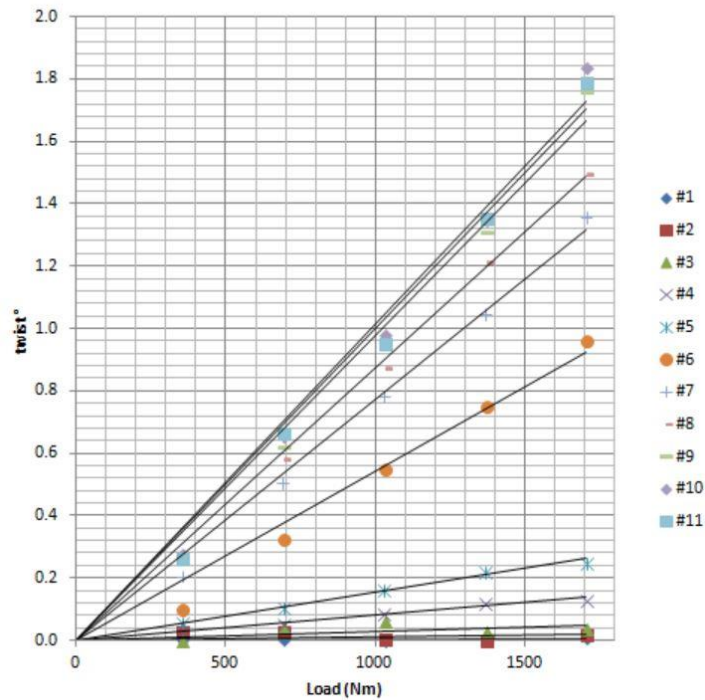
\*Data collated from experimental loading data.  
Used to plot graph of Twist vs Load

**+Body - Corrected Twist Angle**

xcoefficient	Twist Angle (°) ±8% at Load (Nm)						
	400	600	800	1000	1200	1400	1600
-	0.001	0.002	0.003	0.003	0.004	0.005	0.006
3.4608E-06	0.004	0.007	0.009	0.011	0.013	0.015	0.018
0.00	0.011	0.017	0.023	0.028	0.034	0.040	0.046
8.11074E-05	0.032	0.049	0.065	0.081	0.097	0.114	0.130
0.000153976	0.062	0.092	0.123	0.154	0.185	0.216	0.246
0.000542171	0.217	0.325	0.434	0.542	0.651	0.759	0.867
0.000773558	0.309	0.464	0.619	0.774	0.928	1.083	1.238
0.000873629	0.349	0.524	0.699	0.874	1.048	1.223	1.398
0.000976333	0.391	0.586	0.781	0.976	1.172	1.367	1.562
0.001014328	0.406	0.609	0.811	1.001	1.217	1.420	1.623
0.001001062	0.400	0.601	0.801	1.014	1.201	1.401	1.602

\*Values calculated from trendline coefficients to find 'accurate' twist angles

**Twist vs Load**



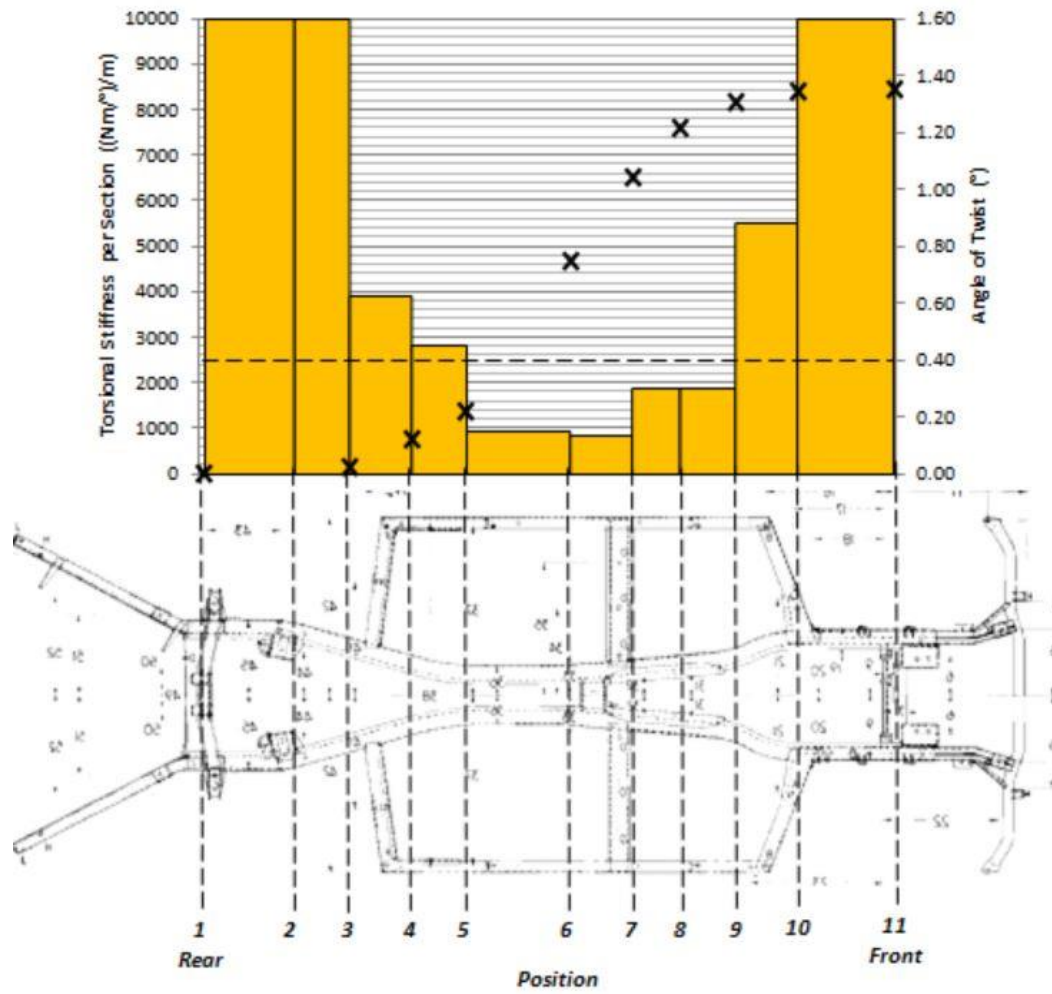
**+Body - Calculated Torsional Stiffness per Section**

Posn #	Section Length(mm)	Torsional Stiffness ((Nm/°)/m) at Load (Nm)							Average
		400	600	800	1000	1200	1400	1600	
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	336	44747.50	44747.50	44747.50	44747.50	44747.50	44747.50	44747.50	10000.00
3	204	11646.69	11646.69	11646.69	11646.69	11646.69	11646.69	11646.69	10000.00
4	207	3933.71	3933.71	3933.71	3933.71	3933.71	3933.71	3933.71	3933.71
5	207	2840.73	2840.73	2840.73	2840.73	2840.73	2840.73	2840.73	2840.73
6	372	958.28	958.28	958.28	958.28	958.28	958.28	958.28	958.28
7	202	873.00	873.00	873.00	873.00	873.00	873.00	873.00	873.00
8	190	1898.64	1898.64	1898.64	1898.64	1898.64	1898.64	1898.64	1898.64
9	192	1869.46	1869.46	1869.46	1869.46	1869.46	1869.46	1869.46	1869.46
10	210	5527.01	5527.01	5527.01	8513.26	5527.01	5527.01	5527.01	5527.01
11	340	22666.67	-25630.59	-25630.59	26153.85	-25630.59	-25630.59	-25630.59	10000.00
<b>Overall</b>	<b>2460</b>	<b>2457.39</b>	<b>2457.39</b>	<b>2457.39</b>	<b>2426.04</b>	<b>2457.39</b>	<b>2457.39</b>	<b>2457.39</b>	<b>2457.39</b>

\*Values calculated from calculated twist to generate accurate stiffness values

Averaged stiffness capped at 10000 (Nm/°)/m to improve chart resolution

**Chart of Stiffness & Angle of Twist per Section - '+Body'**





**+Doors - Averaged Twist Angle**

Posn #	Twist Angle (±0.1°) at Load (Nm)				
	352.85	691.35	1028.44	1367.15	1702.99
1	0.01	0.02	0.01	0.03	0.03
2	0.03	0.03	0.01	0.00	0.03
3	0.00	0.04	0.06	0.06	0.10
4	0.01	0.02	0.04	0.04	0.07
5	0.07	0.10	0.11	0.17	0.20
6	0.12	0.28	0.43	0.59	0.74
7	0.19	0.41	0.61	0.82	1.02
8	0.07	0.48	0.73	0.97	1.50
9	0.23	0.54	0.81	1.07	1.34
10	0.26	0.54	0.79	1.07	1.33
11	0.28	0.62	0.83	1.14	1.43

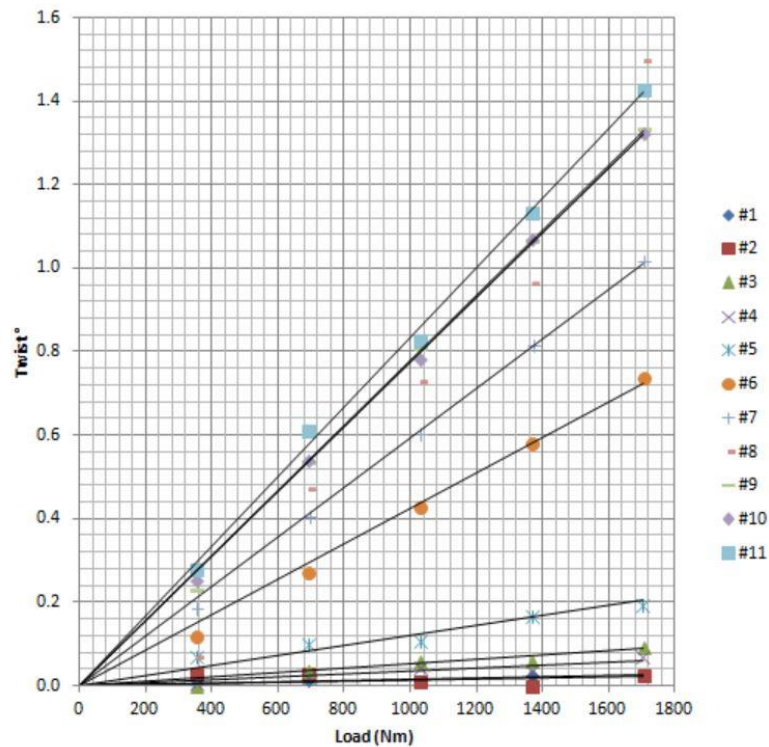
\*Data collated from experimental loading data.  
Used to plot graph of Twist vs Load

**+Doors - Corrected Twist Angle**

xcoefficient	Twist Angle (°) ±9% at Load (Nm)							
	400	600	800	1000	1200	1400	1600	1800
-	0.000013094	0.005	0.008	0.010	0.013	0.016	0.018	0.021
	0.000015425	0.006	0.009	0.012	0.015	0.019	0.022	0.025
	0.000035607	0.014	0.021	0.028	0.036	0.043	0.050	0.057
	0.000051820	0.021	0.031	0.041	0.052	0.062	0.073	0.083
	0.000119989	0.048	0.072	0.096	0.120	0.144	0.168	0.192
	0.000425340	0.170	0.255	0.340	0.425	0.510	0.595	0.681
	0.000593950	0.238	0.356	0.475	0.594	0.713	0.832	0.950
	0.000774196	0.310	0.465	0.619	0.774	0.929	1.084	1.239
	0.000776111	0.310	0.466	0.621	0.776	0.931	1.087	1.242
	0.000779786	0.312	0.468	0.624	0.780	0.936	1.092	1.248
	0.000834379	0.334	0.501	0.668	0.834	1.001	1.168	1.335

\*Values calculated from trendline coefficients to find 'accurate' twist angles

**Twist vs Load**



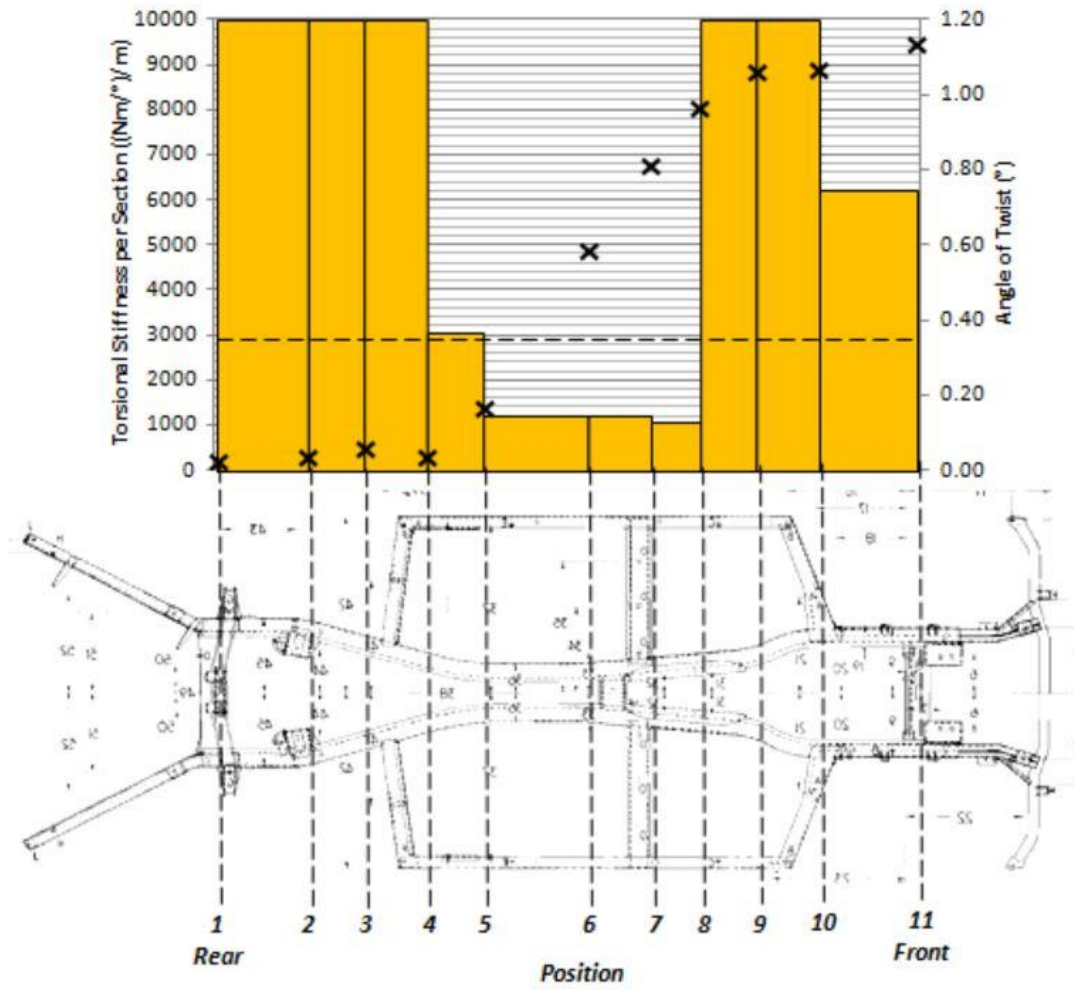
**+Doors - Calculated Torsional Stiffness per Section**

Posn #	Section Length(mm)	Torsional Stiffness ((Nm/°)/m) at Load (Nm)							Average
		400	600	800	1000	1200	1400	1600	
1	N/A	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
2	336	144137.96	144137.96	144137.96	144137.96	144137.96	144137.96	144137.96	10000.00
3	204	10108.07	10108.07	10108.07	10108.07	10108.07	10108.07	10108.07	10000.00
4	207	12767.22	12767.22	12767.22	12767.22	12767.22	12767.22	12767.22	10000.00
5	207	3036.57	3036.57	3036.57	3036.57	3036.57	3036.57	3036.57	3036.57
6	372	1218.27	1218.27	1218.27	1218.27	1218.27	1218.27	1218.27	1218.27
7	202	1198.03	1198.03	1198.03	1198.03	1198.03	1198.03	1198.03	1198.03
8	190	1054.11	1054.11	1054.11	1054.11	1054.11	1054.11	1054.11	1054.11
9	192	100297.76	100297.76	100297.76	100297.76	100297.76	100297.76	100297.76	10000.00
10	210	57145.97	57145.97	57145.97	57145.97	57145.97	57145.97	57145.97	10000.00
11	340	22666.67	6227.86	6227.86	6227.86	6227.86	6227.86	6227.86	6227.86
Overall	2460	2948.30	2948.30	2948.30	2948.30	2948.30	2948.30	2948.30	2948.30

\*Values calculated from cacluated twist to generate accurate stiffness values

Averaged stiffness capped at 10000 (Nm/°)/m to improve chart resolution

### Chart of Stiffness & Angle of Twist per Section - '+Doors'



**+Roof - Averaged Twist Angle**

Posn #	Twist Angle ( $\pm 0.1^\circ$ ) at Load (Nm)			
	352.85	691.35	1028.44	1367.15
1	0.01	0.02	0.01	0.01
2	0.03	0.01	0.01	0.03
3	0.02	0.03	0.06	0.06
4	0.07	0.08	0.07	0.09
5	0.03	0.04	0.10	0.13
6	0.05	0.18	0.34	0.48
7	0.13	0.28	0.46	0.71
8	0.20	0.42	0.64	0.86
9	0.20	0.45	0.66	0.94
10	0.16	0.40	0.59	0.89
11	0.21	0.46	0.72	0.96

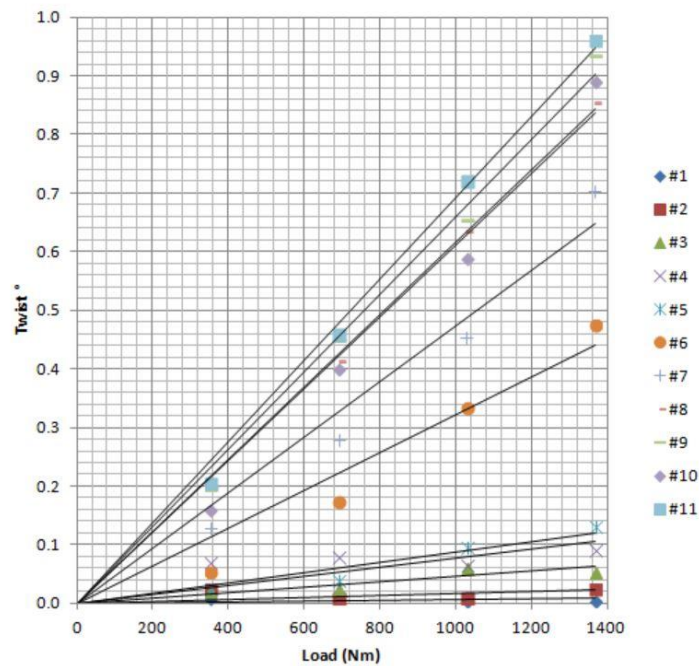
\*Data collated from experimental loading data.  
Used to plot graph of Twist vs Load

**+Roof - Corrected Twist Angle**

xcoefficient	Twist Angle ( $^\circ$ ) $\pm 4.5\%$ at Load (Nm)						
	400	600	800	1000	1200	1400	1600
-	0.003	0.004	0.006	0.007	0.009	0.010	0.012
1.70568E-05	0.007	0.010	0.014	0.017	0.020	0.024	0.027
4.56868E-05	0.018	0.027	0.037	0.046	0.055	0.064	0.073
0.000076475	0.031	0.046	0.061	0.076	0.092	0.107	0.122
8.83775E-05	0.035	0.053	0.071	0.088	0.106	0.124	0.141
0.000321404	0.129	0.193	0.257	0.321	0.386	0.450	0.514
0.000473536	0.189	0.284	0.379	0.474	0.568	0.663	0.758
0.000611047	0.244	0.367	0.489	0.611	0.733	0.855	0.978
0.000617539	0.247	0.371	0.494	0.618	0.741	0.865	0.988
0.000660714	0.264	0.396	0.529	0.661	0.793	0.925	1.057
0.000692298	0.277	0.415	0.554	0.692	0.831	0.969	1.108

\*Values calculated from trendline coefficients to find 'accurate' twist angles

**Twist vs Load**



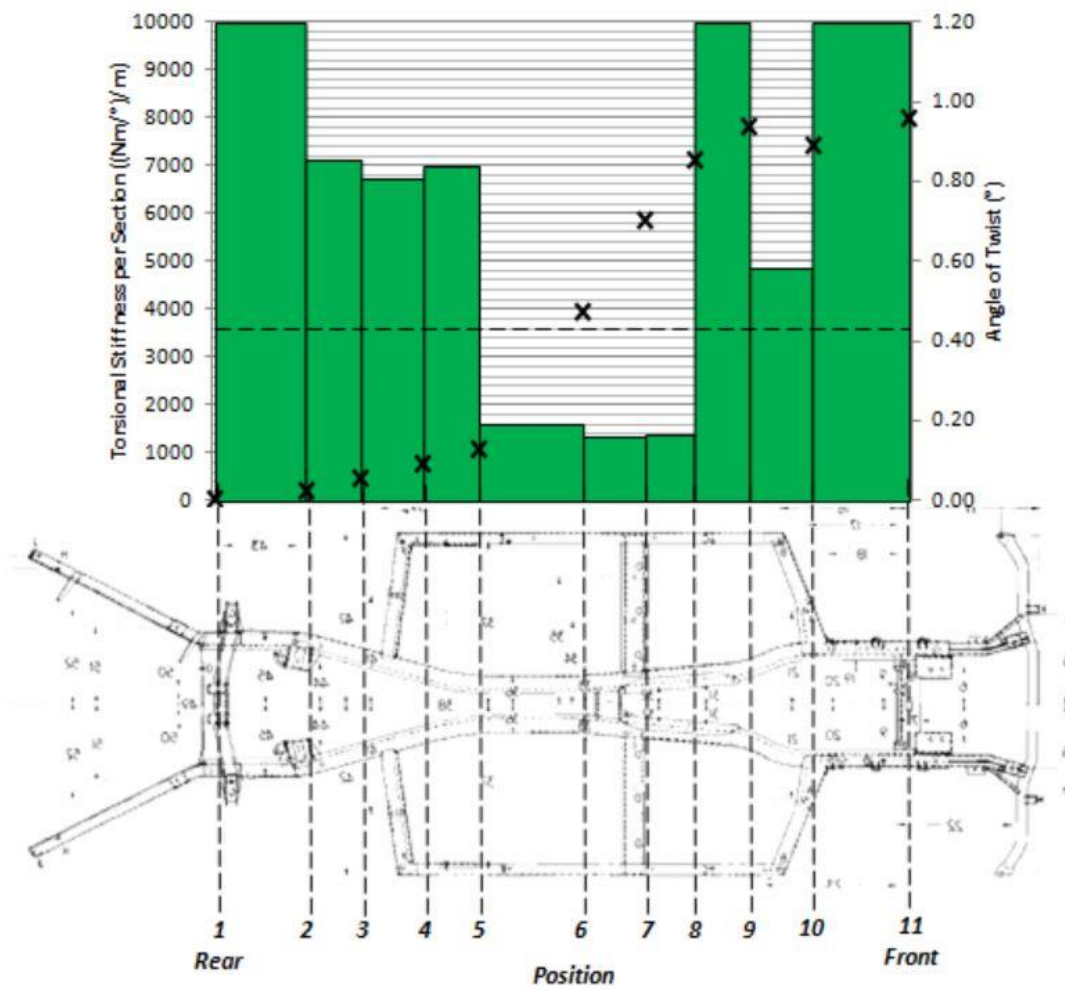
**+Engine - Calculated Torsional Stiffness per Section**

Posn #	Section length(mm)	Torsional Stiffness ((Nm/°)/m) at Load (Nm)							Average
		400	600	800	1000	1200	1400	1600	
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	336	34551.19	34551.19	34551.19	34551.19	34551.19	34551.19	34551.19	10000.00
3	204	7125.39	7125.39	7125.39	7125.39	7125.39	7125.39	7125.39	7125.39
4	207	6723.36	6723.36	6723.36	6723.36	6723.36	6723.36	6723.36	6723.36
5	207	17391.30	17391.30	17391.30	17391.30	17391.30	17391.30	17391.30	7000.00
6	372	1596.38	1596.38	1596.38	1596.38	1596.38	1596.38	1596.38	1596.38
7	202	1327.79	1327.79	1327.79	1327.79	1327.79	1327.79	1327.79	1327.79
8	190	1381.71	1381.71	1381.71	1381.71	1381.71	1381.71	1381.71	1381.71
9	192	29572.58	29572.58	29572.58	29572.58	29572.58	29572.58	29572.58	10000.00
10	210	4863.98	4863.98	4863.98	4863.98	4863.98	4863.98	4863.98	4863.98
11	340	10764.81	10764.81	10764.81	10764.81	10764.81	10764.81	10764.81	10000.00
<b>Overall</b>	<b>2460</b>	<b>3553.38</b>	<b>3553.38</b>	<b>3553.38</b>	<b>3553.38</b>	<b>3553.38</b>	<b>3553.38</b>	<b>3553.38</b>	<b>3553.38</b>

\*Values calculated from cacluated twist to generate accurate stiffness values

Averaged stiffness capped at 10000 (Nm/°)/m to improve chart resolution

**Chart of Stiffness & Angle of Twist per Section - '+Roof'**



+SeatBelt Mounts- Averaged Twist Angle

Posn #	Twist Angle (±0.1°) at Load (Nm)				
	352.85	691.35	1028.44	1367.15	1702.99
1	0.03	0.04	0.04	0.04	0.02
2	0.03	0.03	0.01	0.04	0.05
3	0.03	0.04	0.06	0.11	0.11
4	0.01	0.06	0.07	0.11	0.11
5	0.05	0.09	0.11	0.16	0.21
6	0.04	0.23	0.34	0.52	0.66
7	0.08	0.30	0.49	0.67	0.84
8	0.20	0.43	0.63	0.84	1.05
9	0.20	0.48	0.67	0.90	1.11
10	0.15	0.41	0.64	0.88	1.10
11	0.21	0.48	0.78	0.99	1.22

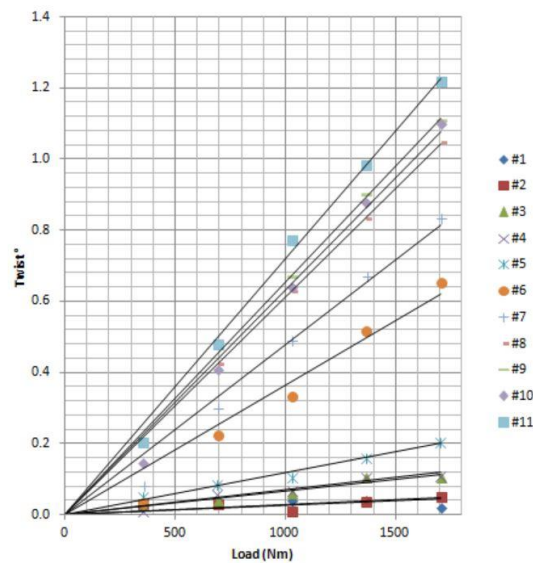
\*Data collated from experimental loading data.  
Used to plot graph of Twist vs Load

+SeatBelt Mounts - Corrected Twist Angle

xcoefficient	Twist Angle (°) ±10% at Load (Nm)							
	400	600	800	1000	1200	1400	1600	
-	0.010	0.015	0.020	0.026	0.031	0.036	0.041	
0.000027158	0.011	0.016	0.022	0.027	0.033	0.038	0.043	
6.54097E-05	0.026	0.039	0.052	0.065	0.078	0.092	0.105	
0.000069661	0.028	0.042	0.056	0.070	0.084	0.098	0.111	
0.000117001	0.047	0.070	0.094	0.117	0.140	0.164	0.187	
0.000363766	0.146	0.218	0.291	0.364	0.437	0.509	0.582	
0.000478668	0.191	0.287	0.383	0.479	0.574	0.670	0.766	
0.000606226	0.242	0.364	0.485	0.606	0.727	0.849	0.970	
0.000632903	0.253	0.380	0.506	0.633	0.759	0.886	1.013	
0.000654611	0.262	0.393	0.524	0.655	0.786	0.916	1.047	
0.000719429	0.288	0.432	0.576	0.719	0.863	1.007	1.151	

\*Values calculated from trendline coefficients to find 'accurate' twist angles

Twist vs Load

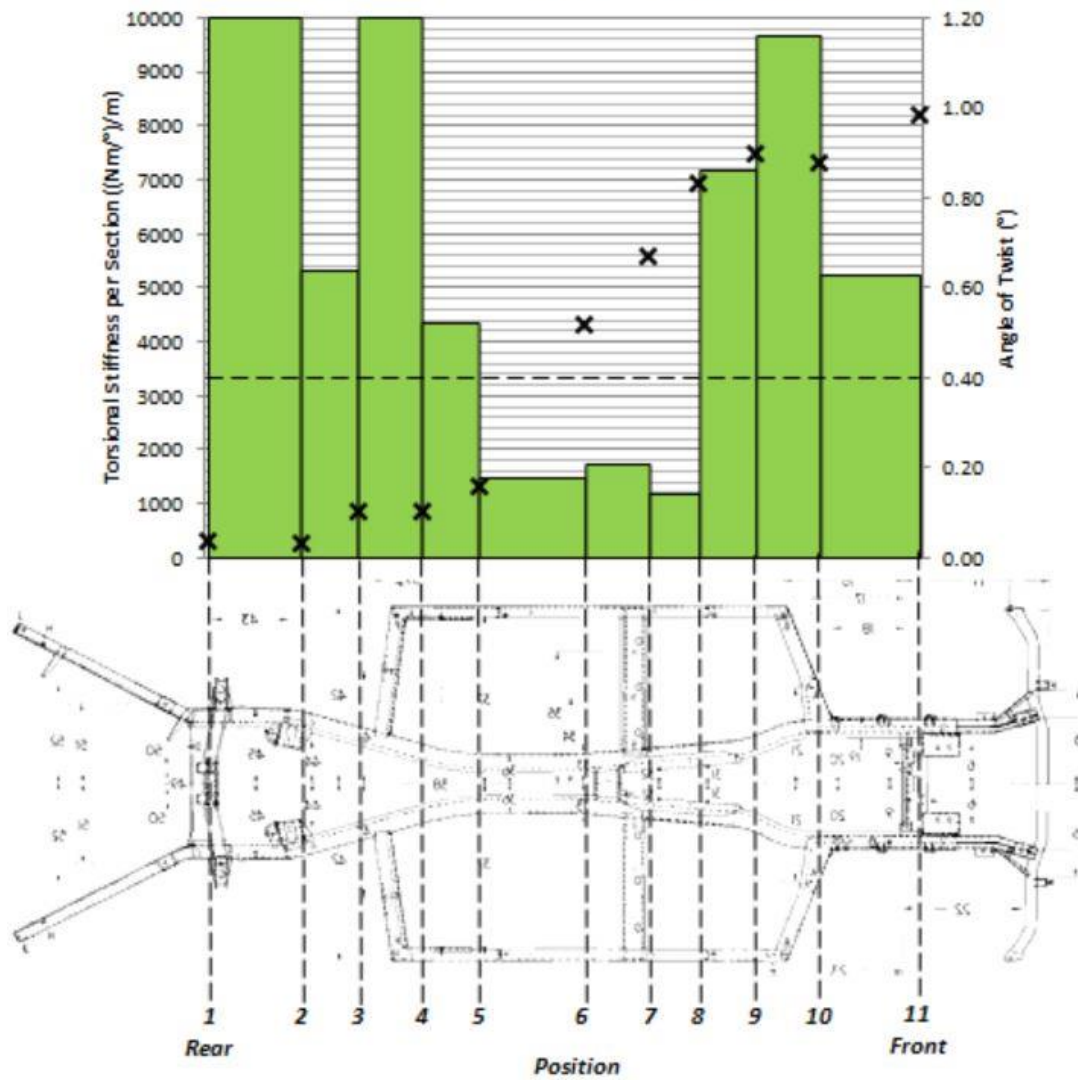


+Seatbelt Mounts - Calculated Torsional Stiffness per Section

Posn #	Section Length(mm)	Torsional Stiffness ((Nm/°)/m) at Load (Nm)								Average
		400	600	800	1000	1200	1400	1600		
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	336	217250.74	217250.74	217250.74	217250.74	217250.74	217250.74	217250.74	217250.74	10000.00
3	204	5333.10	5333.10	5333.10	5333.10	5333.10	5333.10	5333.10	5333.10	5333.10
4	207	48690.99	48690.99	48690.99	48690.99	48690.99	48690.99	48690.99	48690.99	10000.00
5	207	4372.61	4372.61	4372.61	4372.61	4372.61	4372.61	4372.61	4372.61	4372.61
6	372	1507.51	1507.51	1507.51	1507.51	1507.51	1507.51	1507.51	1507.51	1507.51
7	202	1758.03	1758.03	1758.03	1758.03	1758.03	1758.03	1758.03	1758.03	1758.03
8	190	1489.51	1489.51	1489.51	1489.51	1489.51	1489.51	1489.51	1489.51	1201.68
9	192	7197.21	7197.21	7197.21	7197.21	7197.21	7197.21	7197.21	7197.21	7197.21
10	210	9673.81	9673.81	9673.81	9673.81	9673.81	9673.81	9673.81	9673.81	9673.81
11	340	5245.44	5245.44	5245.44	5245.44	5245.44	5245.44	5245.44	5245.44	5245.44
<b>Overall</b>	<b>2460</b>	<b>3419.38</b>	<b>3419.38</b>	<b>3419.38</b>	<b>3419.38</b>	<b>3419.38</b>	<b>3419.38</b>	<b>3419.38</b>	<b>3419.38</b>	<b>3419.38</b>

\*Values calculated from cacluated twist to generate accurate stiffness values  
Averaged stiffness capped at 10000 (Nm/°)/m to improve chart resolution

**Chart of Stiffness & Angle of Twist per Section - '+Seatbelt Mounts'**



## **Appendix 14: - Modification Design Specification**

This specification is for modifications to enhance the structural stiffness of the **Triumph Vitesse Mk2 Convertible** for road use.

### **1.0 Target Outcomes**

1.1 Target Stiffness 7000Nm/degree

1.2 Target Weight Increase of no more than 50kg

1.3 Stress concentrations must be assessed and where they are altered by modifications further analysis is required to ensure the affected structure can sustain this loading. If this is not the case mitigating actions must be proposed to ensure fatigue strength is maintained.

1.4 Where multiple bolt on features are proposed the effects of removing one or the other must be assessed in terms of stress concentrations.

### **2. Practicality**

2.1 Proposed modifications must not restrict the practical use of the vehicle i.e. all seats must remain fitted and useable with modifications installed.

2.2 The modification must not obstruct the use of the convertible roof.

### **3. Corrosion**

3.1 The material selection should consider corrosion where practical – particularly galvanic corrosion

3.2 Coatings should be applied where appropriate for example zinc-rich weld-through primers, paint and wax coatings.

3.3 Component design should minimise collection of moisture and road dirt. Close box sections, especially facing direction of travel.

3.4 Where appropriate include drains with filler compounds to maintain the correct level. Seal joints where practical.

### **4. Safety**

4.1 Modifications may not have sharp projections in the cockpit/cabin or on the vehicle exterior.

4.2 Where component failure may cause injury or death the safety factor must be 5

### **5. Maintenance**

5.1 Must not prevent efficient maintenance or require excessive extra maintenance

5.2 Where they must be removed for access, they must be easily removable without excessive dismantling.

### **6. Manufacture**

6.1 Should be possible to manufacture in a work shop proficient in welding, fabrication and basic machining.

6.2 Where appropriate the tolerances of the original vehicle should be considered and allowed for.

### **7. Legal**

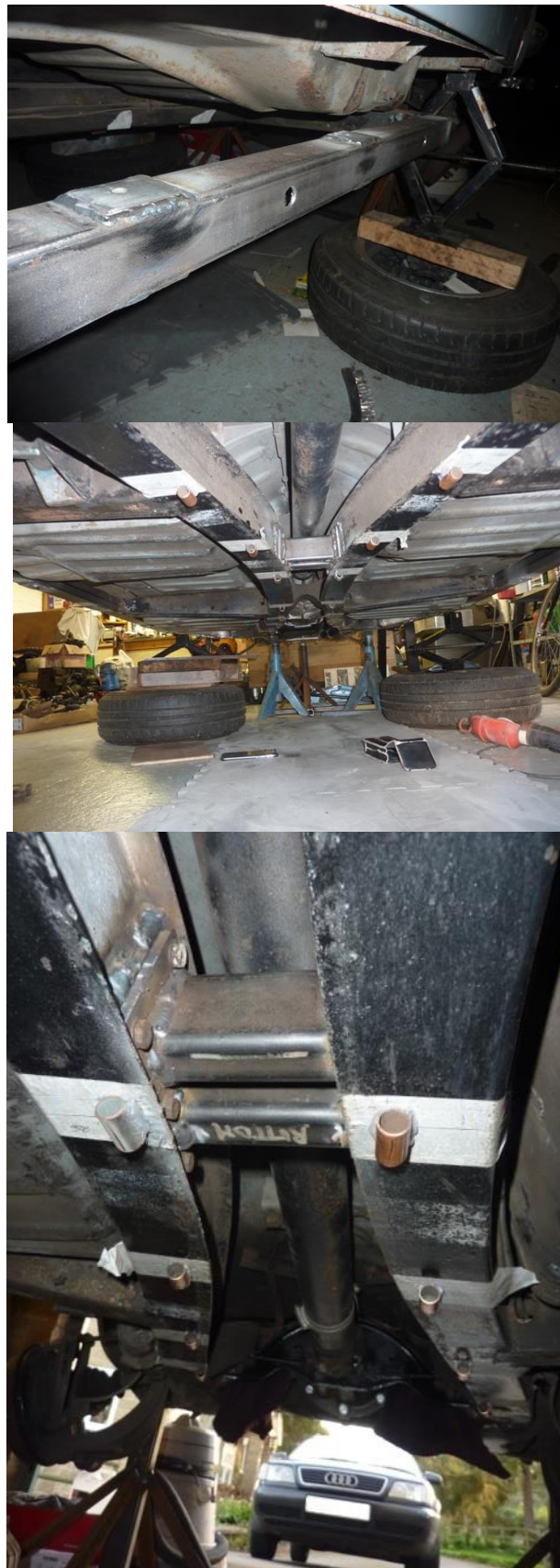
In order to avoid classing as radically altered and require reregistering the vehicle “Chassis, monocoque bodyshell or frame - original or new and unmodified”

[www.gov.uk/vehicle-registration/radically-altered-vehicles](http://www.gov.uk/vehicle-registration/radically-altered-vehicles) (Accessed 10/01/2020)

7.1 The separate backbone chassis may have repairs and bolt on modifications.

7.2 The body shell is not legally considered part of the load bearing structure and so may be structurally modified.

**Appendix 15: - Modification Experiment Photographs**





### Appendix 16: - Modification Experiment Data

7/3/20 Chassis only New Sidebars

Chassis twist analysis

TEST: NEW SIDE BAR  
DATE: \_\_\_\_\_

Station	Weights																		
	0	1	2	3	4	3	2	1	0										
LH																			
RH ^		#1 + #5	2 + 6	3 + 7	4 + 8														
Rear	1	0.43	0.44	0.41	0.44	0.41	0.41	0.43	0.43	0.41	0.41	0.41	0.41	0.42	0.41	0.42	0.47	0.47	0.46
	2	0.30	0.52	0.50	0.48	0.48	0.46	0.47	0.44	0.44	0.45	0.48	0.44	0.45	0.44	0.45	0.47	0.61	0.60
	3	0.61	0.63	0.61	0.62	0.57	0.62	0.61	0.59	0.62	0.59	0.62	0.59	0.59	0.57	0.61	0.71	0.71	0.70
	4	0.71	0.73	0.75	0.74	0.76	0.74	0.75	0.75	0.74	0.74	0.74	0.71	0.71	0.71	0.71	0.92	0.96	0.95
	5	1.00	1.01	0.98	0.94	0.88	0.91	0.91	0.88	0.91	0.91	0.88	0.88	0.91	0.91	0.91	0.92	0.90	0.90
	6	0.30	0.30	0.30	0.30	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
	7	0.30	0.30	0.30	0.30	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
	8	0.14	0.16	0.18	0.19	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	9	0.21	0.23	0.23	0.26	0.21	0.21	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
	10	0.30	0.31	0.31	0.34	0.31	0.31	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Front	11	0.56	0.56	0.55	0.55	0.41	0.47	0.46	0.48	0.55	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.51

0.54 after shake

TEST: NEW SIDE BAR + CENTRE REAR X-MEMBER  
DATE: \_\_\_\_\_

Station	Weights																		
	0	1	2	3	4	3	2	1	0										
LH																			
RH ^																			
Rear	1	0.42	0.41	0.41	0.41	0.42	0.41	0.43	0.41	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
	2	0.48	0.47	0.46	0.45	0.45	0.45	0.41	0.40	0.37	0.38	0.37	0.39	0.39	0.39	0.40	0.43	0.45	0.47
	3	0.64	0.59	0.52	0.51	0.50	0.48	0.44	0.41	0.39	0.40	0.41	0.41	0.43	0.43	0.50	0.52	0.57	0.57
	4	0.69	0.69	0.69	0.67	0.51	0.52	0.44	0.44	0.40	0.40	0.41	0.41	0.43	0.43	0.50	0.52	0.57	0.57
	5	0.90	0.87	0.76	0.76	0.62	0.65	0.57	0.59	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
	6	0.30	0.30	0.30	0.30	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
	7	0.30	0.29	0.28	0.25	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
	8	0.14	0.14	0.15	0.15	0.15	0.15	1.01	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
	9	0.28	0.22	0.19	0.20	0.58	0.60	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
	10	0.31	0.30	0.10	0.09	0.48	0.51	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Front	11	0.50	0.46	0.46	0.46	0.32	0.30	0.48	0.48	0.55	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.50

Handling as seen from the rear of the car looking forward

DIFF + Rear Fronts

0.54 after shake

Chassis twist analysis

TEST: NEW CHASSIS, X-MEMBER + REAR  
DATE: 7/3/20

Station	Weights																		
	0	1	2	3	4	3	2	1	0										
LH																			
RH ^																			
Rear	1	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
	2	0.48	0.47	0.46	0.45	0.45	0.45	0.41	0.40	0.41	0.41	0.41	0.43	0.43	0.44	0.45	0.45	0.45	0.46
	3	0.64	0.59	0.52	0.51	0.50	0.48	0.44	0.41	0.39	0.40	0.41	0.41	0.43	0.43	0.50	0.52	0.57	0.57
	4	0.69	0.69	0.69	0.67	0.51	0.52	0.44	0.44	0.40	0.40	0.41	0.41	0.43	0.43	0.50	0.52	0.57	0.57
	5	0.90	0.87	0.76	0.76	0.62	0.65	0.57	0.59	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
	6	0.30	0.30	0.30	0.30	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
	7	0.30	0.29	0.28	0.25	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
	8	0.14	0.14	0.15	0.15	0.15	0.15	1.01	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
	9	0.28	0.22	0.19	0.20	0.58	0.60	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
	10	0.31	0.30	0.10	0.09	0.48	0.51	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Front	11	0.50	0.46	0.46	0.46	0.32	0.30	0.48	0.48	0.55	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.48	0.50

Handling as seen from the rear of the car looking forward

0.54 after shake

NEW SIDE BAR ONLY

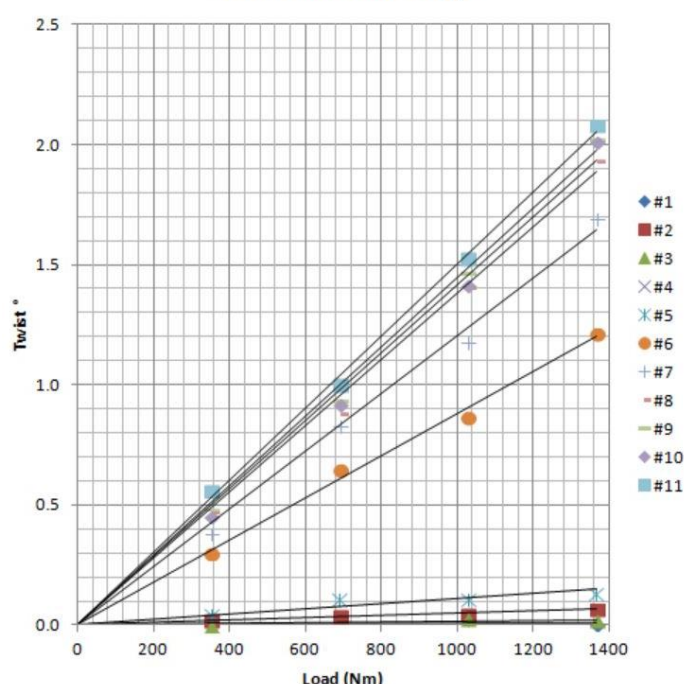
## Appendix 17: - Modification Experiment Tables/Graphs

Mod_Siderails - Averaged Twist Angle					Mod_Siderails - Corrected Twist Angle							
Posn #	Twist Angle ( $\pm 0.1^\circ$ ) at Load (Nm)				xcoefficient	Twist Angle ( $^\circ$ ) $\pm 6\%$ at Load (Nm)						
	352.85	691.35	1028.44	1367.15		400	600	800	1000	1200	1400	1600
1	0.01	-0.01	0.03	0.01	0.000007763	0.003	0.005	0.006	0.008	0.009	0.011	0.012
2	0.02	0.04	0.05	0.07	1.40532E-05	0.006	0.008	0.011	0.014	0.017	0.020	0.022
3	0.00	-0.01	0.03	0.02	2.72826E-05	0.011	0.016	0.022	0.027	0.033	0.038	0.044
4	-0.03	-0.03	-0.03	-0.03	4.81279E-05	0.019	0.029	0.039	0.048	0.058	0.067	0.077
5	0.04	0.11	0.11	0.13	0.000108461	0.043	0.065	0.087	0.108	0.130	0.152	0.174
6	0.30	0.65	0.87	1.21	0.000877134	0.351	0.526	0.702	0.877	1.053	1.228	1.403
7	0.39	0.83	1.18	1.70	0.001201542	0.481	0.721	0.961	1.202	1.442	1.682	1.922
8	0.48	0.89	1.41	1.94	0.001381307	0.553	0.829	1.105	1.381	1.658	1.934	2.210
9	0.49	0.94	1.47	2.03	0.001416674	0.567	0.850	1.133	1.417	1.700	1.983	2.267
10	0.46	0.92	1.42	2.01	0.001445429	0.578	0.867	1.156	1.445	1.735	2.024	2.313
11	0.56	1.00	1.53	2.08	0.001502014	0.601	0.901	1.202	1.502	1.802	2.103	2.403

\*Data collated from experimental loading data. Used to plot graph of Twist vs Load

\*Values calculated from trendline coefficients to find 'accurate' twist angles

### Load vs Twist Angle

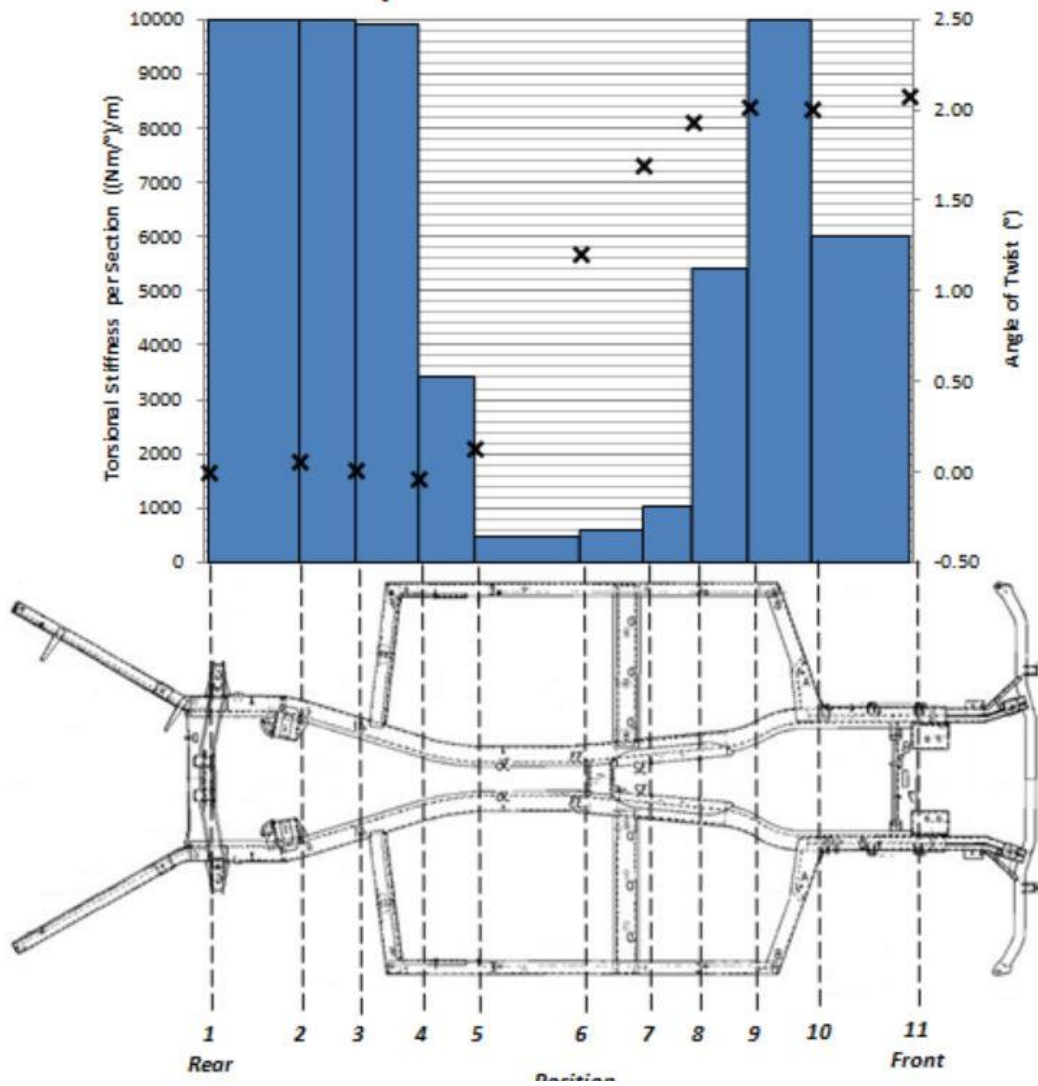


### Mod\_Siderails - Calculated Stiffness per Section

Posn #	Section Length(mm)	Torsional Stiffness ((Nm/°)/m) at Load (Nm)								Average
		400	600	800	1000	1200	1400	1600		
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	336	53416.43	53416.43	53416.43	53416.43	53416.43	53416.43	53416.43	53416.43	10000.00
3	204	15420.20	15420.20	15420.20	15420.20	15420.20	15420.20	15420.20	15420.20	10000.00
4	207	9930.30	9930.30	9930.30	9930.30	9930.30	9930.30	9930.30	9930.30	9930.30
5	207	3430.98	3430.98	3430.98	3430.98	3430.98	3430.98	3430.98	3430.98	3430.98
6	372	483.95	483.95	483.95	483.95	483.95	483.95	483.95	483.95	483.95
7	202	622.67	622.67	622.67	622.67	622.67	622.67	622.67	622.67	622.67
8	190	1056.93	1056.93	1056.93	1056.93	1056.93	1056.93	1056.93	1056.93	1056.93
9	192	5428.82	5428.82	5428.82	5428.82	5428.82	5428.82	5428.82	5428.82	5428.82
10	210	7303.05	7303.05	7303.05	7303.05	7303.05	7303.05	7303.05	7303.05	10000.00
11	340	6008.67	6008.67	6008.67	6008.67	6008.67	6008.67	6008.67	6008.67	6008.67
<b>Overall</b>	<b>2460</b>	<b>1637.80</b>	<b>1637.80</b>	<b>1637.80</b>	<b>1637.80</b>	<b>1637.80</b>	<b>1637.80</b>	<b>1637.80</b>	<b>1637.80</b>	<b>1637.80</b>

\*Values calculated from calculated twist to generate accurate stiffness values  
Averaged stiffness capped at 10000 (Nm/°)/m to improve chart resolution

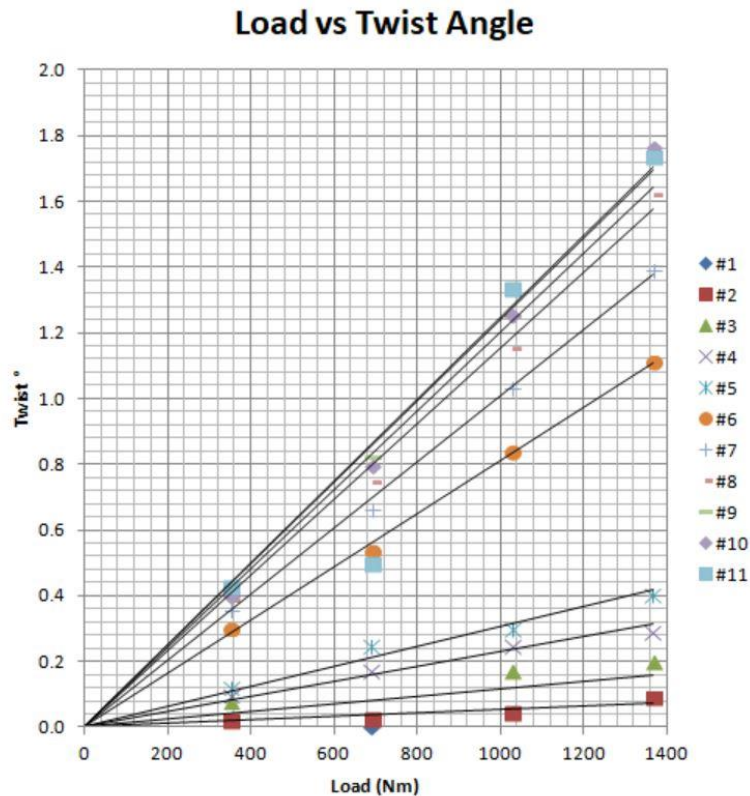
**Chart of Stiffness & Angle of Twist per Section - Siderails**



Mods_2nd Xmember - Average Twist Angle					Mods_2nd Xmember - Corrected Twist Angle								
Posn #	Twist Angle ( $\pm 0.1^\circ$ ) at Load (Nm)				xcoefficient	Twist Angle ( $^\circ$ ) $\pm 7.5\%$ at Load (Nm)							
	352.85	691.35	1028.44	1367.15		-	400	600	800	1000	1200	1400	1600
1	-0.01	0.00	-0.01	-0.01	0.00000137	0.001	0.001	0.001	0.001	0.002	0.002	0.002	
2	0.02	0.03	0.05	0.09	5.48739E-05	0.022	0.033	0.044	0.055	0.066	0.077	0.088	
3	0.08	-0.11	0.18	0.20	0.000115901	0.046	0.070	0.093	0.116	0.139	0.162	0.185	
4	0.10	0.18	0.25	0.29	0.000229469	0.092	0.138	0.184	0.229	0.275	0.321	0.367	
5	0.13	0.25	0.31	0.41	0.000307236	0.123	0.184	0.246	0.307	0.369	0.430	0.492	
6	0.30	0.54	0.84	1.11	0.000809563	0.324	0.486	0.648	0.810	0.971	1.133	1.295	
7	0.36	0.67	1.04	1.40	0.001008254	0.403	0.605	0.807	1.008	1.210	1.412	1.613	
8	0.39	0.75	1.16	1.63	0.001151969	0.461	0.691	0.922	1.152	1.382	1.613	1.843	
9	0.43	0.83	1.26	1.73	0.001202059	0.481	0.721	0.962	1.202	1.442	1.683	1.923	
10	0.40	0.80	1.26	1.77	0.001240475	0.496	0.744	0.992	1.240	1.489	1.737	1.985	
11	0.43	0.50	1.34	1.74	0.001246136	0.498	0.748	0.997	1.246	1.495	1.745	1.994	

\*Data collated from experimental loading data. Used to plot graph of Twist vs Load

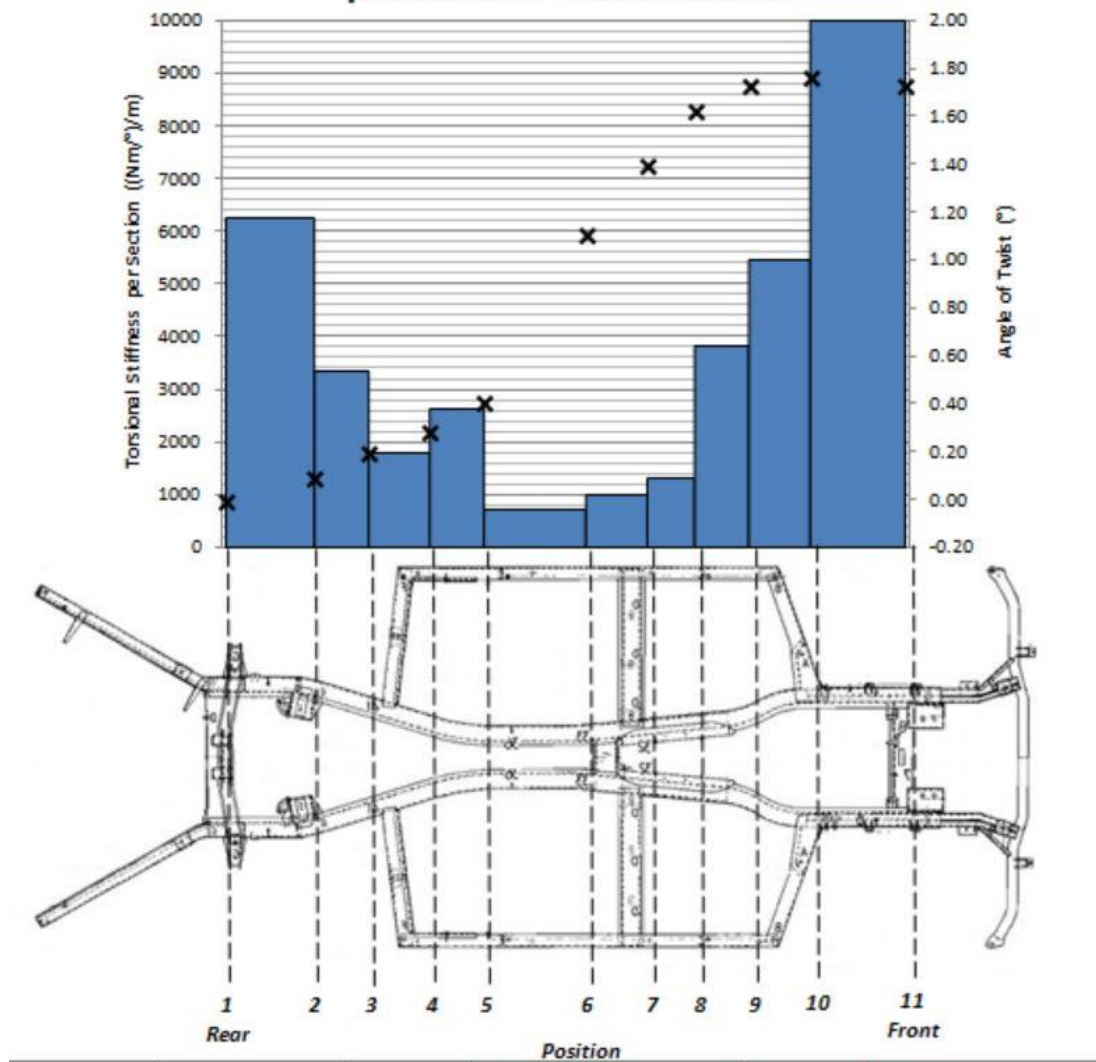
\*Values calculated from trendline coefficients to find 'accurate' twist angles



Mods_2nd Xmember - Calculated Stiffness per Section									
Posn #	Section .length(mm)	Torsional Stiffness ((Nm/°)/m) at Load (Nm)							Average
		400	600	800	1000	1200	1400	1600	
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	336	6279.92	6279.92	6279.92	6279.92	6279.92	6279.92	6279.92	6279.92
3	204	3342.79	3342.79	3342.79	3342.79	3342.79	3342.79	3342.79	3342.79
4	207	1822.69	1822.69	1822.69	1822.69	1822.69	1822.69	1822.69	1822.69
5	207	2661.80	2661.80	2661.80	2661.80	2661.80	2661.80	2661.80	2661.80
6	372	740.55	740.55	740.55	740.55	740.55	740.55	740.55	740.55
7	202	1016.66	1016.66	1016.66	1016.66	1016.66	1016.66	1016.66	1016.66
8	190	1322.06	1322.06	1322.06	1322.06	1322.06	1322.06	1322.06	1322.06
9	192	3833.06	3833.06	3833.06	3833.06	3833.06	3833.06	3833.06	3833.06
10	210	5466.54	5466.54	5466.54	5466.54	5466.54	5466.54	5466.54	5466.54
11	340	60054.76	60054.76	60054.76	60054.76	60054.76	60054.76	60054.76	10000.00
Overall	2460	1974.10	1974.10	1974.10	1974.10	1974.10	1974.10	1974.10	1974.10

\*Values calculated from cacluated twist to generate accurate stiffness values  
 Averaged stiffness capped at 10000 (Nm/°)/m to improve chart resolution

**Chart of Stiffness & Angle of Twist per Section - 2nd Xmember**

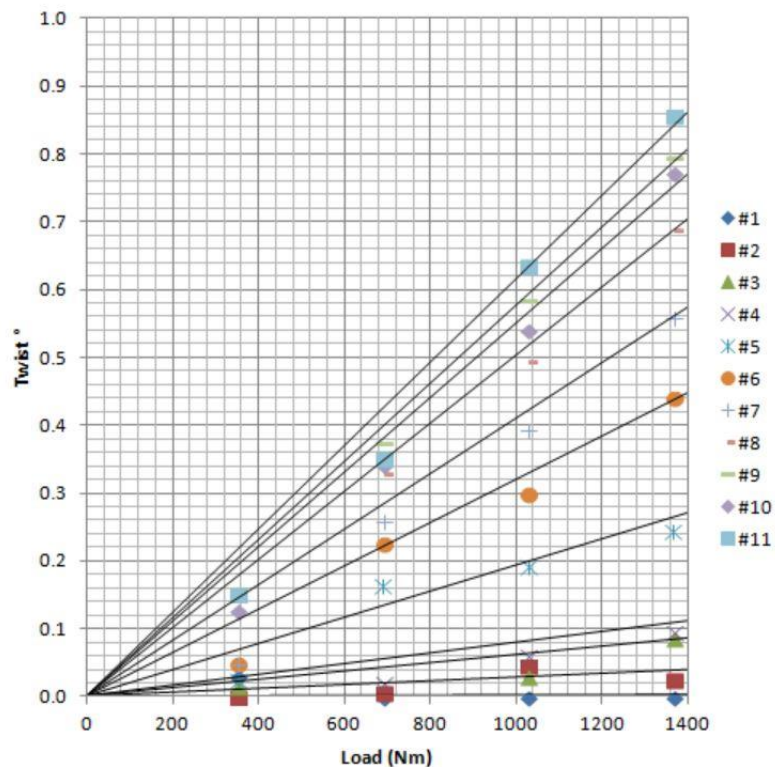


All Mods - Average Twist Angle						All Mods - Corrected Twist Angle								
Posn #	Twist Angle ( $\pm 0.1^\circ$ ) at Load (Nm)					xcoefficient	Twist Angle ( $^\circ$ ) $\pm 14\%$ at Load (Nm)							
	352.85	691.35	1028.44	1367.15	1702.99		-	400	600	800	1000	1200	1400	1600
1	0.03	0.00	0.00	0.00	0.00	1.6464E-06	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.003
2	0.00	0.01	0.05	0.03	0.06	2.89442E-05	0.012	0.017	0.023	0.029	0.035	0.041	0.046	0.046
3	0.02	-0.01	0.03	0.09	0.15	6.23522E-05	0.025	0.037	0.050	0.062	0.075	0.087	0.100	0.100
4	-0.01	0.02	0.06	0.10	0.18	0.000170103	0.068	0.102	0.136	0.170	0.204	0.238	0.272	0.272
5	0.03	0.17	0.20	0.25	0.35	0.000193785	0.078	0.116	0.155	0.194	0.233	0.271	0.310	0.310
6	0.05	0.23	0.30	0.44	0.57	0.000319466	0.128	0.192	0.256	0.319	0.383	0.447	0.511	0.511
7	0.05	0.26	0.40	0.56	0.75	0.000410295	0.164	0.246	0.328	0.410	0.492	0.574	0.656	0.656
8	0.16	0.33	0.50	0.69	0.88	0.000503256	0.201	0.302	0.403	0.503	0.604	0.705	0.805	0.805
9	0.16	0.38	0.59	0.80	1.00	0.000576603	0.231	0.346	0.461	0.577	0.692	0.807	0.923	0.923
10	0.13	0.34	0.54	0.77	0.97	0.000550458	0.220	0.330	0.440	0.550	0.661	0.771	0.881	0.881
11	0.15	0.35	0.64	0.86	1.08	0.000615312	0.246	0.369	0.492	0.615	0.738	0.861	0.984	0.984

\*Data collated from experimental loading data.  
Used to plot graph of Twist vs Load

\*Values calculated from trendline coefficients to find 'accurate' twist angles

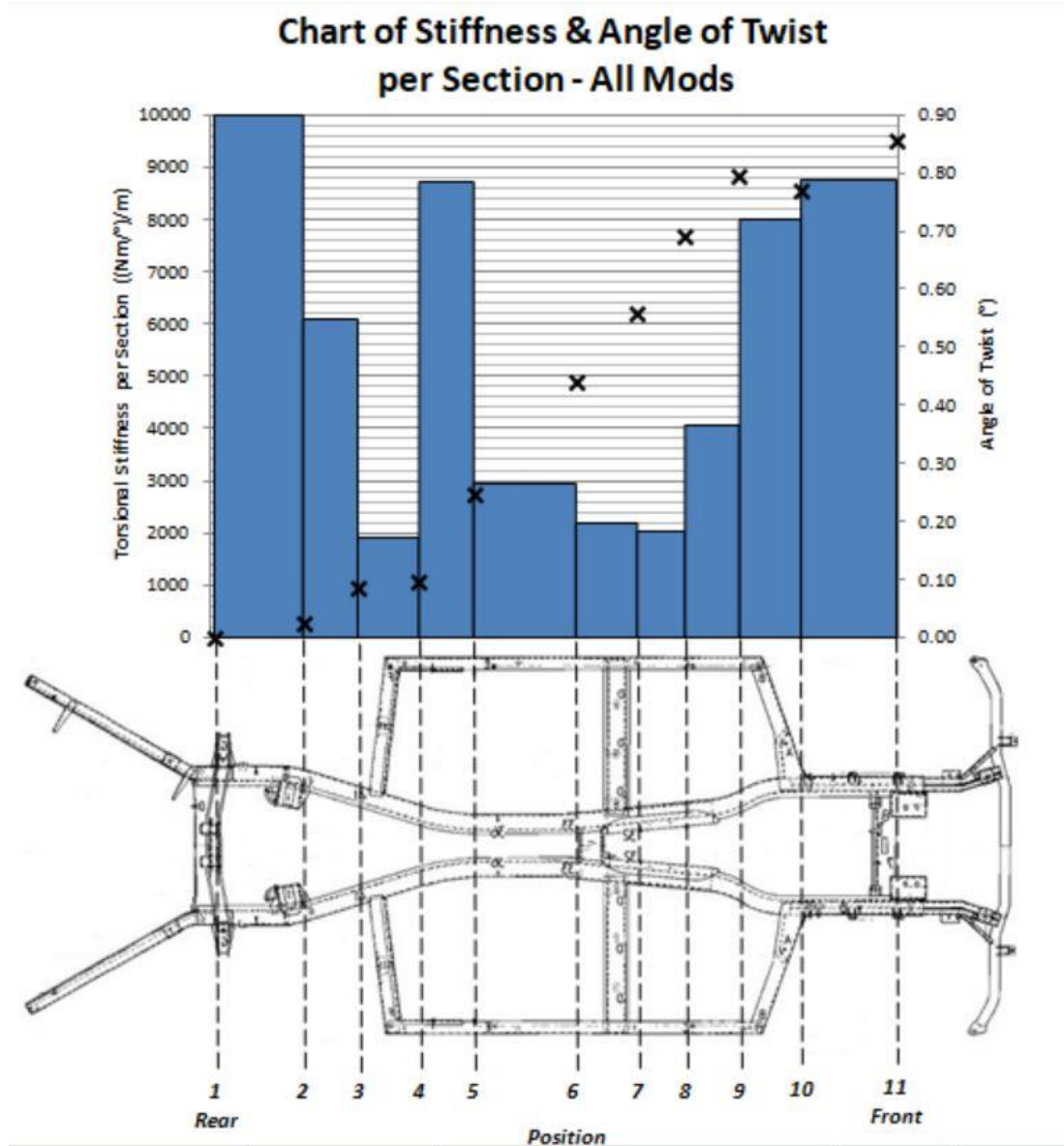
### Load vs Twist Angle



### All Mods - Calculated Stiffness per section

Posn #	Section .length(mm)	Torsional Stiffness ((Nm/°)/m) at Load (Nm)							Average
		400	600	800	1000	1200	1400	1600	
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	336	12308.68	12308.68	12308.68	12308.68	12308.68	12308.68	12308.68	10000.00
3	204	6106.32	6106.32	6106.32	6106.32	6106.32	6106.32	6106.32	6106.32
4	207	1921.11	1921.11	1921.11	1921.11	1921.11	1921.11	1921.11	1921.11
5	207	8740.78	8740.78	8740.78	8740.78	8740.78	8740.78	8740.78	8740.78
6	372	2959.88	2959.88	2959.88	2959.88	2959.88	2959.88	2959.88	2959.88
7	202	2223.95	2223.95	2223.95	2223.95	2223.95	2223.95	2223.95	2223.95
8	190	2043.87	2043.87	2043.87	2043.87	2043.87	2043.87	2043.87	2043.87
9	192	4067.59	4067.59	4067.59	4067.59	4067.59	4067.59	4067.59	4067.59
10	210	8032.22	8032.22	8032.22	8032.22	8032.22	8032.22	8032.22	8032.22
11	340	8783.44	8783.44	8783.44	8783.44	8783.44	8783.44	8783.44	8783.44
<b>Overall</b>	<b>2460</b>	<b>3997.97</b>	<b>3997.97</b>	<b>3997.97</b>	<b>3997.97</b>	<b>3997.97</b>	<b>3997.97</b>	<b>3997.97</b>	<b>3997.97</b>

\*Values calculated from cacluated twist to generate accurate stiffness values  
Averaged stiffness capped at 10000 (Nm/°)/m to improve chart resolution



## Appendix 18: - FEA Log Chassis Modifications

Vitesse Chassis Modification Trials

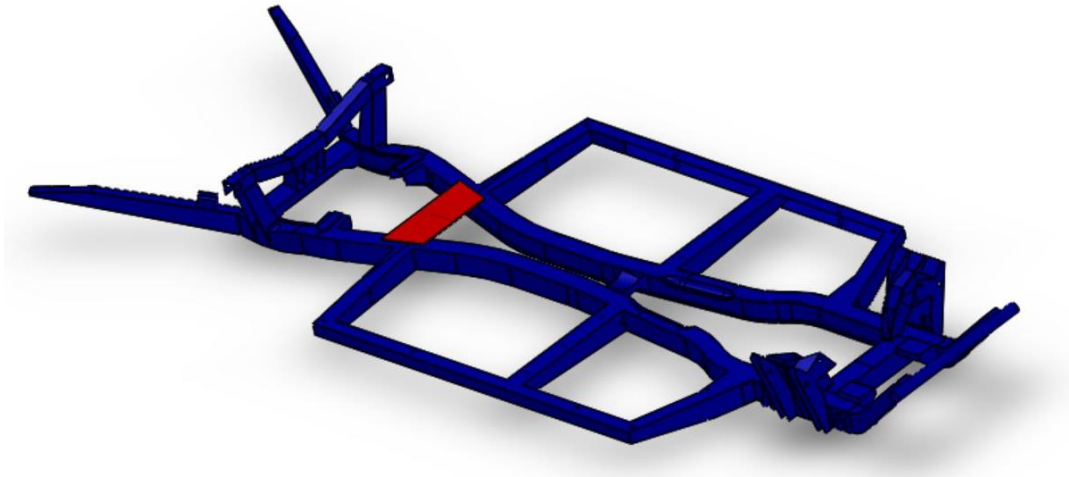
Run#	Mesh Type	mm	Disp. mm	I mm	L m	Percentage change from baseline ↓				↓ Percentage change from baseline		Change Log	
						T Nm	θ °	KB Nm/Deg	%	weight kg	%		
1	Curvature	12mm	5.62349	5.62246	360	2.45	1000	1.79	1369.28	-	74.89	-	bare vitesse chassis (Vit30)
2	Curvature	12mm	5.27686	5.2774	360	2.45	1000	1.68	1458.96	6.15%	-	-	removed old siderails. Added 2.5mm box 50x50 and boxed ends
3	Curvature	12mm	5.07472	5.07501	360	2.45	1000	1.61	1517.07	9.74%	-	-	boxed outriggers (2mm plate)
4	Curvature	12mm	3.96029	3.96072	360	2.45	1000	1.26	1943.73	29.55%	-	-	added second middle xmember between #4 and #5 2mm box 80x80
5	Curvature	12mm	4.55073	4.55086	360	2.45	1000	1.45	1691.69	19.06%	-	-	tried t shirt plate on rear. 3mm on bottom surface. REMOVED 2nd MIDXMEMBER
6	Curvature	12mm	4.83318	4.83331	360	2.45	1000	1.54	1592.87	14.04%	-	-	tshirt plate on top surface (removed bottom)
7	Curvature	12mm	4.7746	4.77507	360	2.45	1000	1.52	1612.35	15.08%	-	-	front t shirt plate between 8 and 9. 3mm bottom. Removed rear plate
8	Curvature	12mm	5.55322	5.55232	360	2.45	1000	1.77	1386.58	1.25%	-	-	removed all mods. Added brace under middle outrigger 2.5mm wall
9	Curvature	12mm	5.3276	5.32825	360	2.45	1000	1.70	1445.06	5.24%	-	-	Just Siderails. 60x40x2 (60 Vertical)
10	Curvature	12mm	5.21958	5.22009	360	2.45	1000	1.66	1474.96	7.17%	-	-	just siderails 75x50x3 (75 vertical)
11	Curvature	12mm	5.19472	5.19423	360	2.45	1000	1.65	1482.16	7.62%	80.24	6.67%	just siderails 75x50x2 (50 vertical)
12	Curvature	12mm	5.0309	5.03041	360	2.45	1000	1.60	1530.40	10.53%	82.24	8.94%	above siderail with boxed outriggers
13	Curvature	12mm	4.06398	4.06356	360	2.45	1000	1.29	1894.35	27.72%	82.64	9.38%	above mods with second mid xmember scalloped
14	Curvature	12mm	4.85555	4.85472	360	2.45	1000	1.55	1585.70	13.65%	75.31	0.56%	extra xmember only 80x80x2mm box 100mm (front edge) from rear edge of midxmember
15	Curvature	12mm	4.6995	4.69874	360	2.45	1000	1.50	1638.32	16.42%	75.31	0.56%	as above 200mm back
16	Curvature	12mm	4.62128	4.62048	360	2.45	1000	1.47	1666.04	17.81%	75.31	0.56%	as above 300mm
17	Curvature	12mm	4.62924	4.62841	360	2.45	1000	1.47	1663.19	17.67%	75.36	0.62%	400mm
18	Curvature	12mm	4.62736	4.62656	360	2.45	1000	1.47	1663.86	17.70%	75.52	0.83%	500mm
19	Curvature	12mm	4.88164	4.88045	360	2.45	1000	1.55	1577.28	13.19%	75.25	0.48%	xmember to 300mm max scallop and central rib 2mm
20	Curvature	12mm	5.47516	5.47439	360	2.45	1000	1.74	1406.32	2.63%	75.76	1.15%	t shirt plate plain 2mm in line with rear outriggers bottom
21	Curvature	12mm	5.37019	5.36976	360	2.45	1000	1.71	1433.75	4.50%	75.81	1.21%	as above with pressed ribs 4mm
22	Curvature	12mm	5.24161	5.24115	360	2.45	1000	1.67	1468.90	6.78%	75.62	0.97%	as above moved to 500mm from mid x member
23	Curvature	12mm	5.03637	5.0355	360	2.45	1000	1.60	1528.79	10.43%	75.51	0.82%	moved to 400mm
24	Curvature	12mm	4.91057	4.90954	360	2.45	1000	1.56	1567.97	12.67%	75.46	0.76%	moved to 300mm
25	Curvature	12mm	5.4017	5.40139	360	2.45	1000	1.72	1425.37	3.94%	75.46	0.76%	as above but flipped to top surface
26	Curvature	12mm	4.91931	4.91945	360	2.45	1000	1.57	1565.00	12.51%	75.32	0.57%	Tshirt plate removed. two 8mm webs 250mm from mid xmember and 450mm (Scalloped)
27	Curvature	12mm	4.97563	4.97627	360	2.45	1000	1.58	1547.21	11.50%	75.32	0.57%	8mm 300mm and 400mm
28	Curvature	12mm	5.0484	5.04849	360	2.45	1000	1.61	1525.01	10.21%	75.32	0.57%	8mm250 and 350
29	Curvature	12mm	4.94002	4.94074	360	2.45	1000	1.57	1558.35	12.13%	75.32	0.57%	8mm 200 and 450
30	Curvature	12mm	4.96908	4.96969	360	2.45	1000	1.58	1549.26	11.62%	75.22	0.44%	6mm webs 250mm from mid xmember and 450mm
31	Curvature	12mm	4.87938	4.88006	360	2.45	1000	1.55	1577.71	13.21%	76.05	1.53%	8mm webs 250 and 450 w.horizontal brace and cutouts
32	Curvature	12mm	5.29759	5.29795	360	2.45	1000	1.69	1453.28	5.78%	76.07	1.55%	50mm diam 2mm wall tube as side rails no other mods
33	Curvature	12mm	5.25885	5.25923	360	2.45	1000	1.67	1463.97	6.47%	77.67	3.58%	as above 2.5mm wall
34	Curvature	12mm	5.24417	5.24471	360	2.45	1000	1.67	1468.05	6.73%	79.37	5.64%	as above 60mm diam
35	Curvature	12mm	5.22291	5.22325	360	2.45	1000	1.66	1474.05	7.11%	77.43	3.28%	as above 2mm wall
36	Curvature	12mm	6.9	6.9	360	2.45	1000	2.20	1116.04	-	75.73	0.00%	Baseline chassis Vit32. Loading turrets 1500N each. Measuring bottom inside corner of rails
37	Curvature	12mm	5.9391	5.9391	360	2.45	1000	1.89	1296.44	13.92%	76.24	1.77%	second x member 300mm from mid xmember. 2mm wall thickness 80x75
38	Curvature	12mm	5.75335	5.75335	360	2.45	1000	1.83	1338.27	16.61%	78.96	4.09%	removed 2nd xmember. replaced side rails with box - 50x50x2mm
39	Curvature	12mm	5.56573	5.56573	360	2.45	1000	1.77	1383.35	19.32%	79.8	5.10%	boxed front outrigger 2mm plate
40	Curvature	12mm	5.31	5.31	360	2.45	1000	1.69	1449.93	23.03%	80.86	6.34%	boxed middle outrigger 2mm plate
41	Curvature	12mm	4.629	4.629	360	2.45	1000	1.47	1663.12	32.89%	81.37	6.93%	combined boxed siderail and outriggers and 2nd xmember
42	Curvature	12mm	6.7	6.7	360	2.45	1000	2.13	1149.32	2.90%	79.2	4.38%	removed all mods. Added a 4mm tshirt plate on top surface in line with rear outriggers.
43	Curvature	12mm	5.249	5.249	360	2.45	1000	1.67	1466.77	23.91%	104.75	27.70%	Bolt on sill(sheetmetal construction on 6mm angle bar and 6x gussets. 1.2mm steel
44	Curvature	12mm	6.12772	6.12772	360	2.45	1000	1.95	1256.56	11.18%	77.86	2.74%	bolt in x member as tested physically
45	Curvature	12mm	4.87789	4.87789	360	2.45	1000	1.55	1578.30	29.29%	82.41	8.11%	siderails and xmember as tested
46	Curvature	12mm	4.77327	4.77327	360	2.45	1000	1.52	1612.88	30.80%	-	-	added springs to act as a diff.
47	Curvature	12mm	4.18545	4.18545	360	2.45	1000	1.33	1839.30	39.32%	82.41	8.11%	run 45 recalculated using position 10.
48	Curvature	12mm	4.82	4.82	360	2.45	1000	1.53	1597.25	30.13%	79.8	5.10%	run 39 recalculated using position 10
49	Curvature	12mm	4.7724	4.7724	360	2.45	1000	1.52	1613.17	30.82%	-	-	siderail mod and xmember as solid (Not Bolted)
50	Curvature	12mm	4.76686	4.76686	360	2.45	1000	1.52	1615.05	30.90%	-	-	added boxed mid outrigger



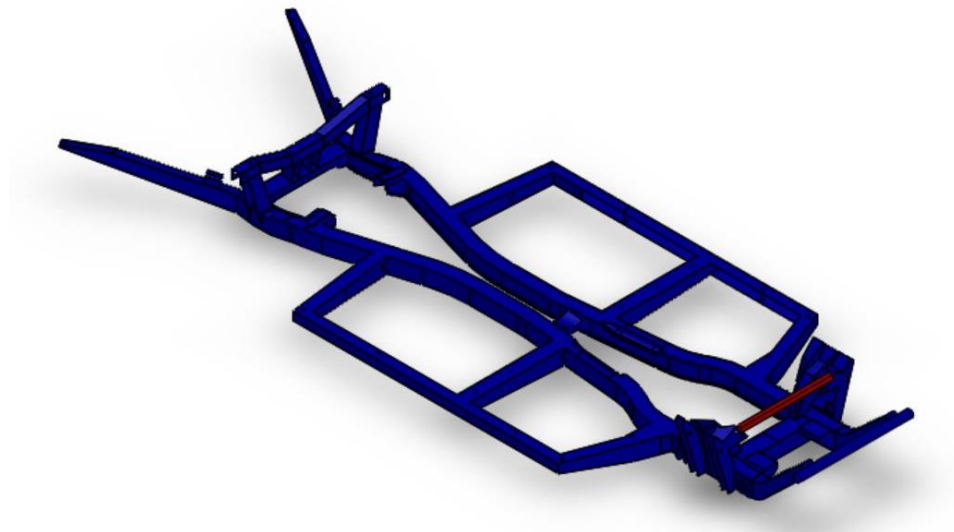
## Appendix 19: - FEA Log Body Modifications

Run#	Mesh Type	mm	mm	Disp. mm	I mm	L m	T Nm	θ °	Percentage change from baseline ↓			↓ Percentage change from baseline			Change Log
									Kθ Nm/Deg	%	Weight Kg	%			
1	Curvature	12	2.9911	2.9917	360	2.45	1000	0.95	2573.247	-	188.4262	-	@Assy23 - Unmodified stiffness (No Doors)		
2	Curvature	12	2.77803	2.77863	360	2.45	1000	0.88	2770.554	-	-	-	@Assy31 - Unmodified stiffness (With Doors)		
3	Curvature	12	2.96619	2.96679	360	2.45	1000	0.94	2594.851	0.83%	188.7796	0.19%	Added US spec rear body mounts No doors		
4	Curvature	12	2.94859	2.94925	360	2.45	1000	0.94	2610.308	1.42%	189.0517	0.33%	added second bolt to rear sill body mount and added body mount in middle of sill		
5	Curvature	12	2.24304	2.24359	360	2.45	1000	0.71	3431.217	25.00%	192.0654	1.89%	added sills. 6 mount points 1.2mm wall		
6	Curvature	12	2.13973	2.14035	360	2.45	1000	0.68	3596.785	28.46%	193.7296	2.74%	added integral x member with 2 extra mount points 1.2mm		
7	Curvature	12	2.12387	2.12438	360	2.45	1000	0.68	3623.732	28.99%	194.5626	3.15%	reinforced b pillar		
8	Curvature	12	2.0331	2.03361	360	2.45	1000	0.65	3785.482	32.02%	195.0489	3.40%	added gussets/braces inside sill. Added returns to b pillar stiffener/lightening holes		
9	Curvature	12	2.01764	2.01807	360	2.45	1000	0.64	3814.558	32.54%	198.1792	4.92%	added diagonalweb to sill length		
10	Curvature	12	1.98086	1.98138	360	2.45	1000	0.63	3885.283	33.77%	200.2101	5.89%	mid outrigger boxed above body		
11	Curvature	12	2.78579	2.78634	360	2.45	1000	0.89	2762.863	6.86%	-	-	removed all mods: Added 4mm thick tunnel cover. Bolted in stanard ish positions		
12	Curvature	10	1.91914	1.91992	360	2.45	1000	0.61	4009.937	35.83%	-	-	unsuppressed all mods - removed tunnel cover. Added rigid link between floor x members		
13	Curvature	10	1.90967	1.91036	360	2.45	1000	0.61	4029.911	36.15%	-	-	added structure into bulkhead possible turret brace mount and tunnel cover support		
14	Curvature	10	2.00549	2.00611	360	2.45	1000	0.64	3837.482	32.94%	-	-	shortened floor box members from 60 deep to 30mm		
15	Curvature	12	1.90616	1.90663	360	2.45	1000	0.61	4037.563	36.27%	202.9245	7.14%	added 'cosmetic' sill removed bulkhead structure and boxed mid xmember		
16	Curvature	12	1.90934	1.90788	360	2.45	1000	0.61	4032.878	36.19%	200.0469	5.81%	removed diagonal sill brace. added mount points in vertical sill faces		
17	Curvature	12	1.96948	1.9681	360	2.45	1000	0.62	3975.015	35.26%	-	-	sill mod only. Widened the sill base		
18	Curvature	12	1.93698	1.93581	360	2.45	1000	0.62	3975.015	35.26%	-	-	added simple h frame full height 6mm		
19	Curvature	12	1.95707	1.9556	360	2.45	1000	0.62	3934.503	34.60%	-	-	removed h frame added dash brace15 x 30mm		
20	Curvature	12	1.70828	1.70716	360	2.45	1000	0.54	4507.257	42.91%	-	-	added vertical brace to dash support and h frame		
21	Curvature	12	1.69096	1.68977	360	2.45	1000	0.54	4553.53	43.49%	-	-	added more structure to dash area - moved further back		
22	Curvature	12	1.66762	1.66633	360	2.45	1000	0.53	4617.419	44.27%	-	-	wider base to h frame -front to back		
23	Curvature	12	1.7771	1.77675	360	2.45	1000	0.57	4331.726	40.60%	201.4625	6.47%	tunnel cover built into tub. Not fixed to chassis		
24	Curvature	12	2.78132	2.78177	360	2.45	1000	0.89	2767.352	7.01%	192.0022	1.86%	tunnel cover only (1.2mm)		
25	Curvature	12	2.69371	2.69422	360	2.45	1000	0.86	2857.304	9.94%	192.1313	1.93%	tunnel cover built into tub and bolted into chassis in 12 places		
26	Curvature	12	1.62858	1.62874	360	2.45	1000	0.52	4726.04	45.55%	207.9733	9.40%	unsuppressed rear/member, sills, bpillarbraces, tunnelcover. + box bolted to outrigger		
27	Curvature	12	1.50636	1.50643	360	2.45	1000	0.48	5109.604	49.64%	-	-	added big dash structure		
28	Curvature	13	1.15898	1.15898	360	2.45	1000	0.37	6641.192	61.25%	-	-	diagonal braces - a to b pillar		

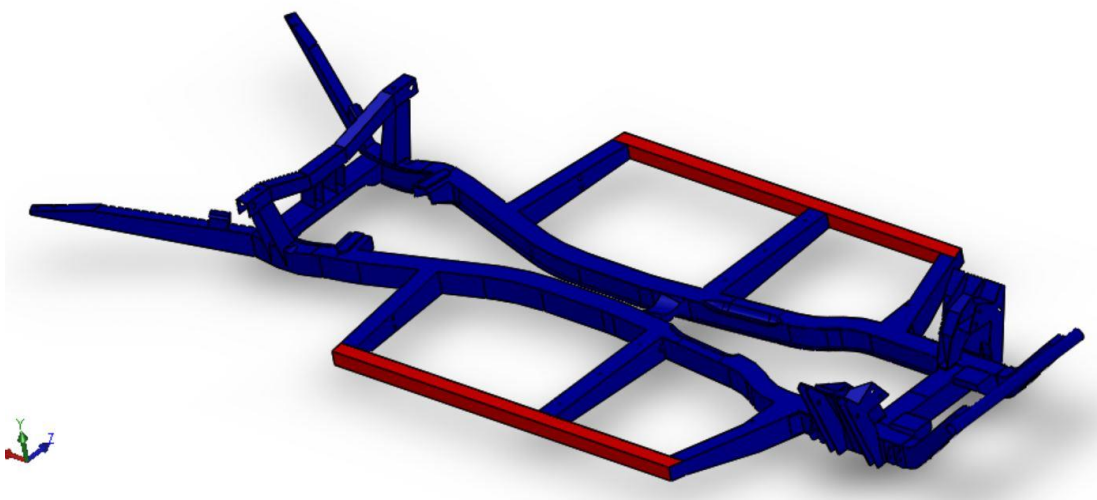
## Appendix 20: - Modification Models



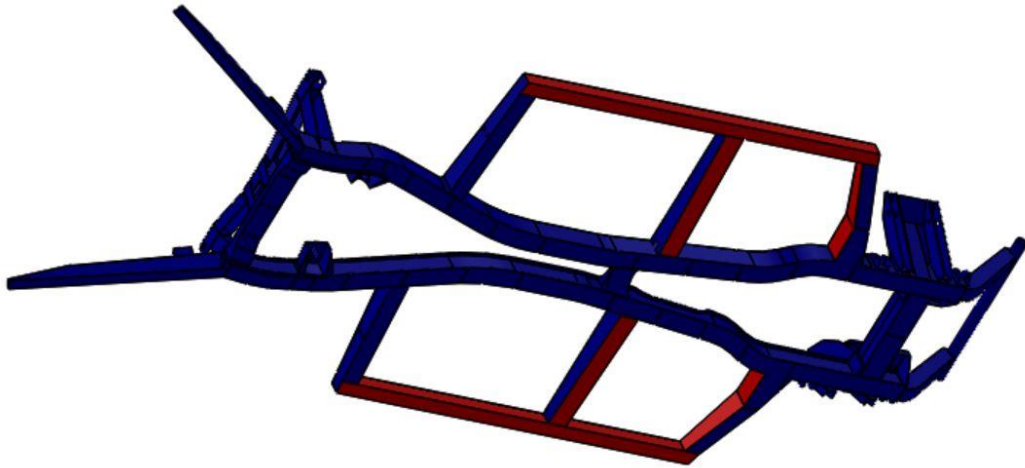
'T-Shirt' Plate – tested above and below main rails and at multiple distances



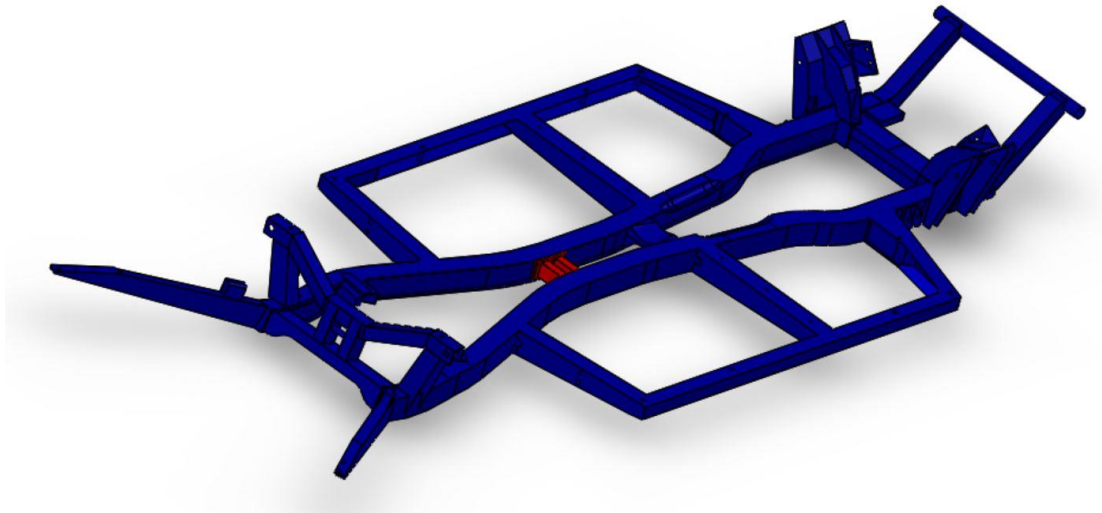
Front suspension turret brace



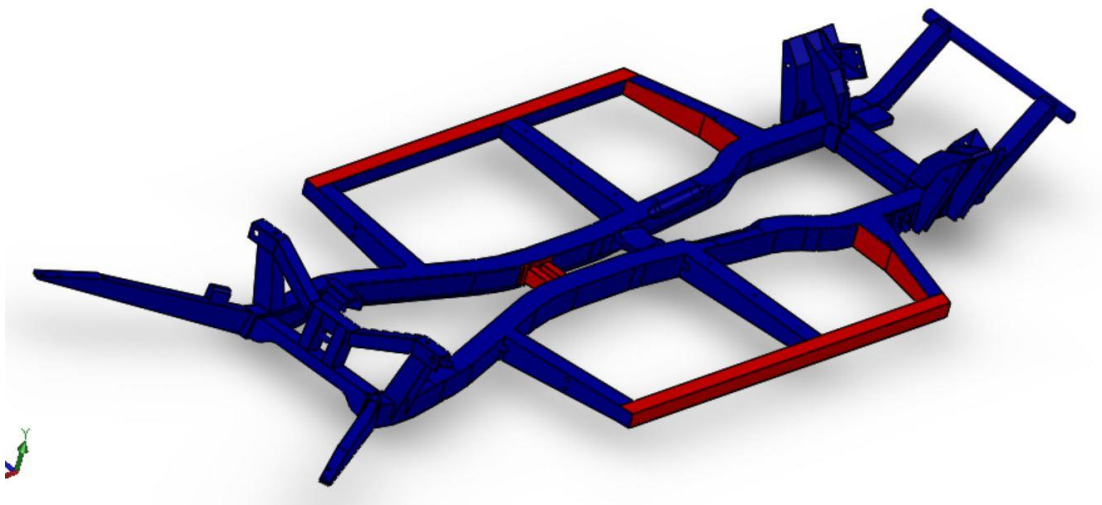
Side-rails replaced with 2.5mm box section



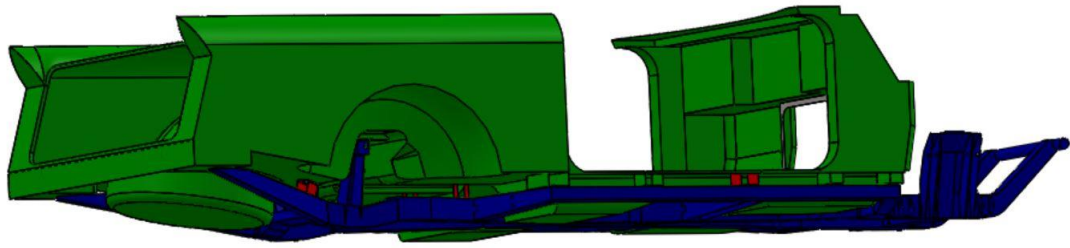
Boxed side-rails and outriggers



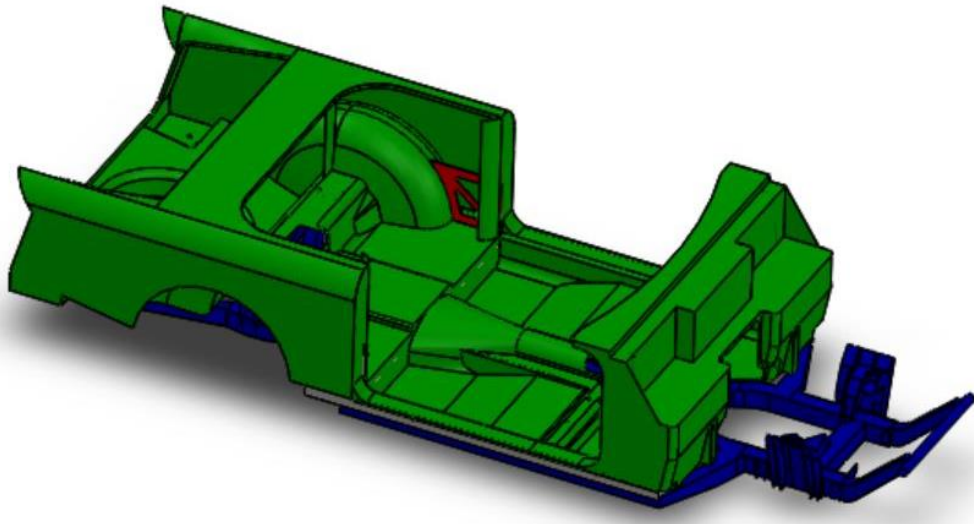
Additional bolt in cross-member



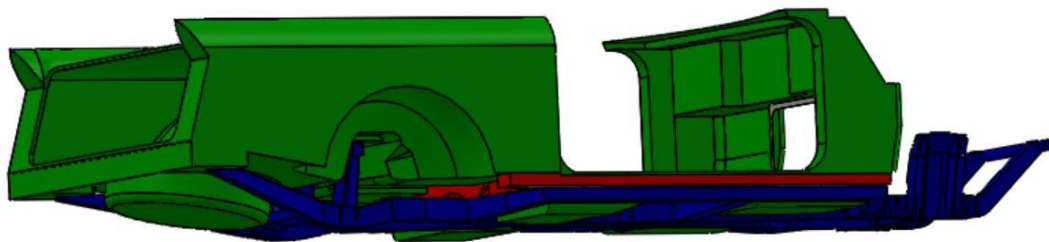
Boxed siderails and front outrigger with second crossmember as tested



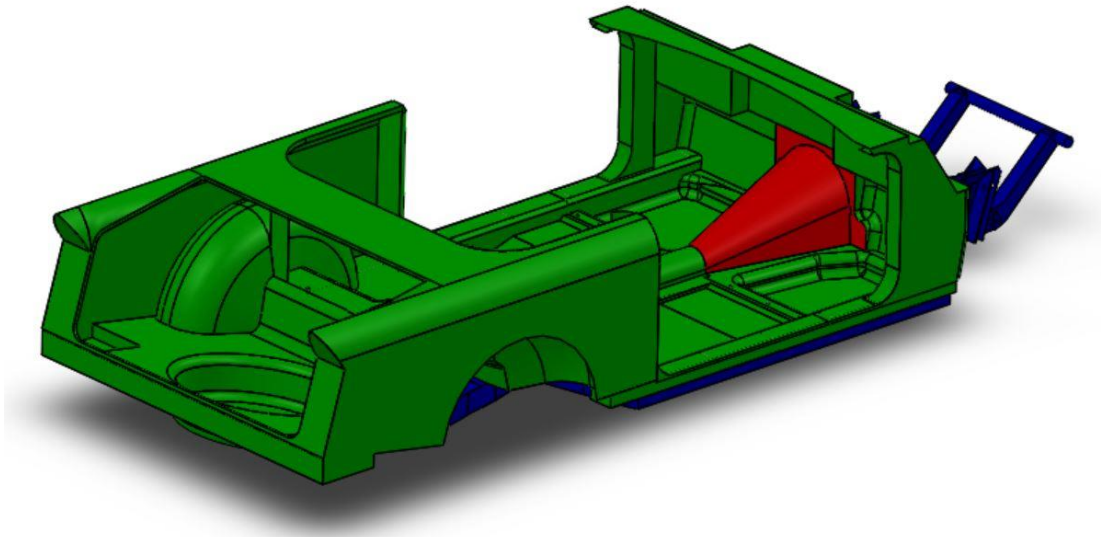
Extra Body mounts 'bolted' to chassis



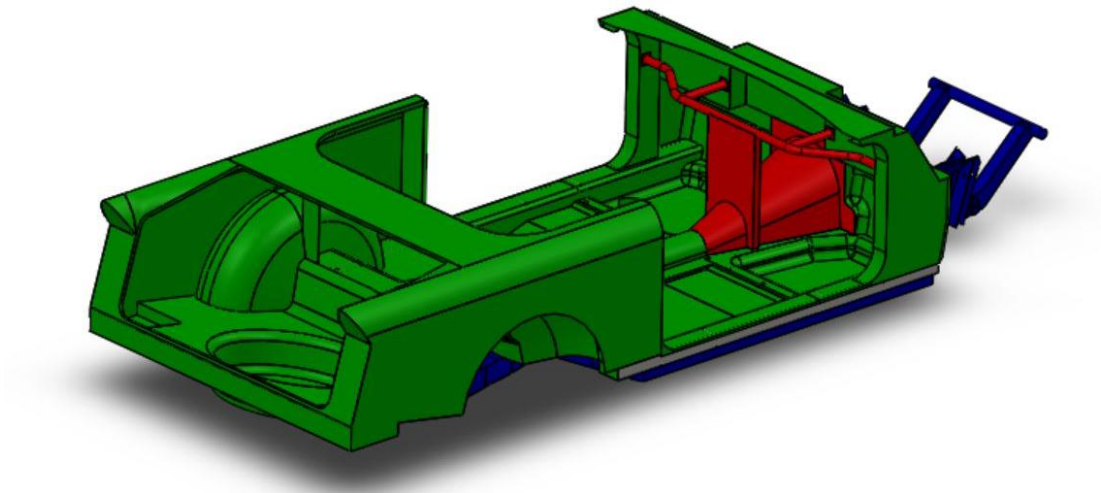
B-Pillar braces



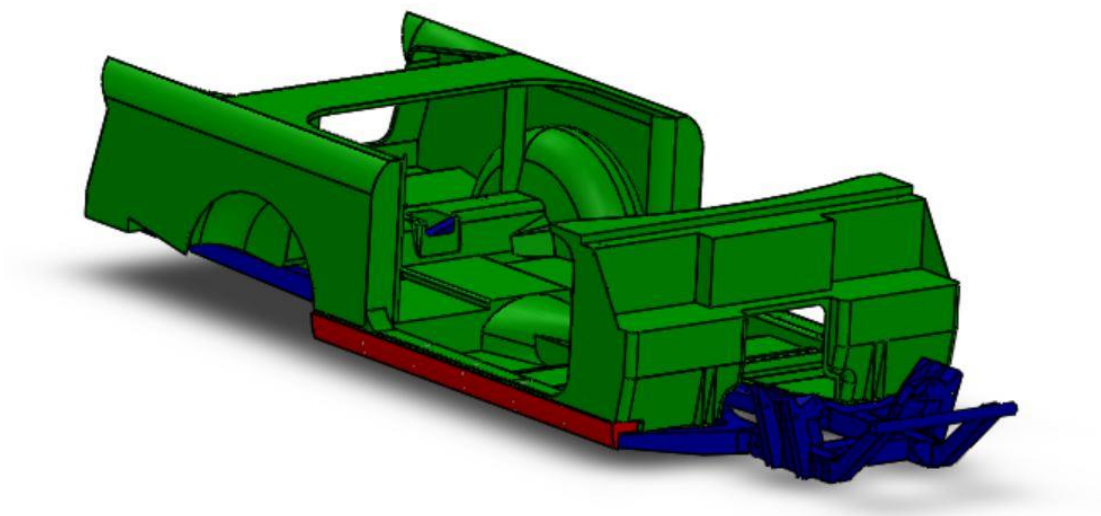
Rear Cross-member and sill structure integral to body (Similar to Spitfire body structure)



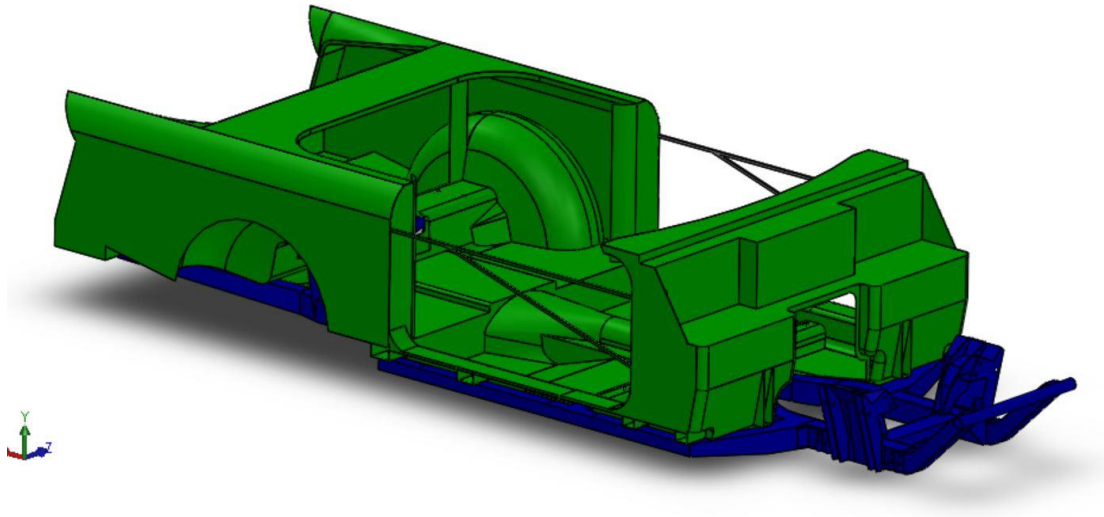
Tunnel cover integral to body – 1.6mm steel



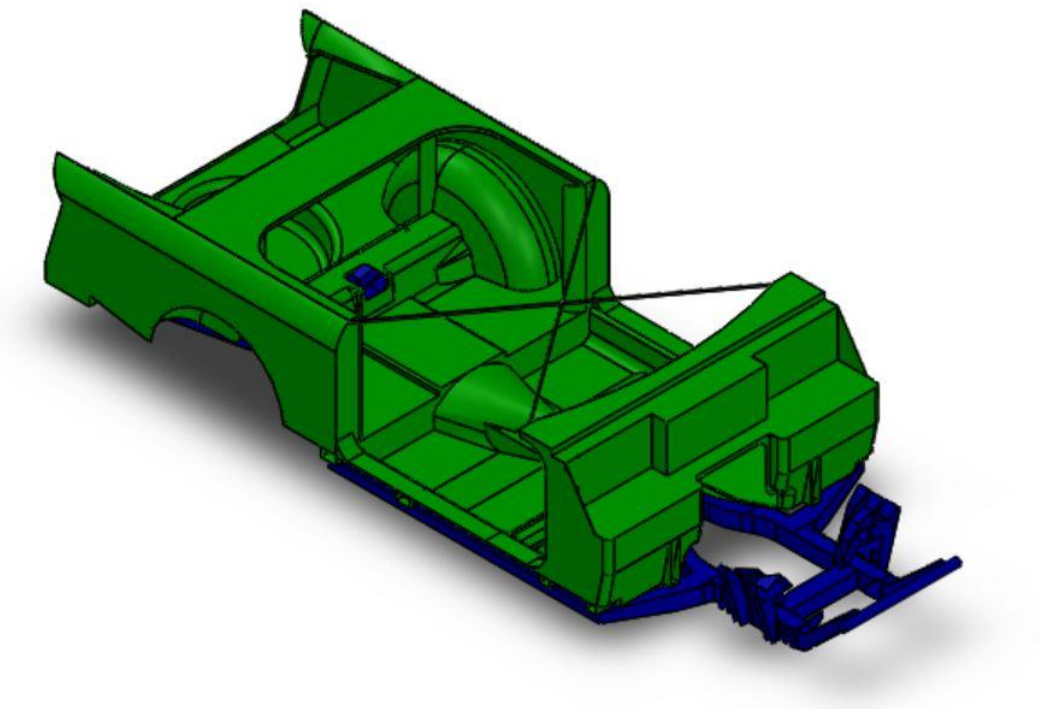
Tunnel cover and 'H-Frame' with additional dashboard structure



Structural sill replacing original cosmetic panel



Brace structure tuned to represent the stiffness contribution of the doors



Pseudo roll cage – bracing A and B pillars across the car