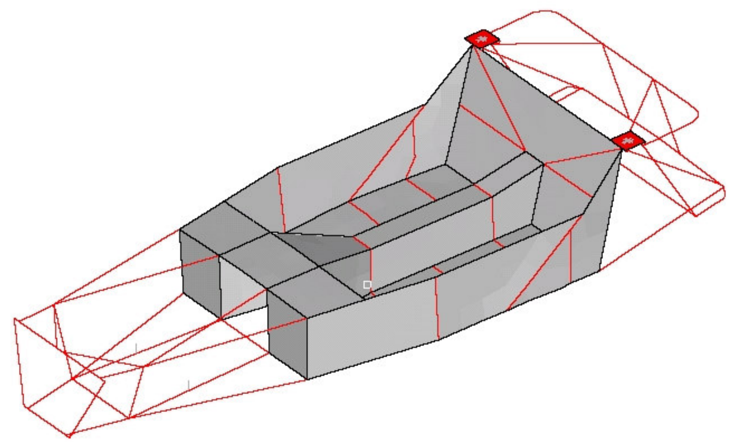


Characterisation and Optimisation of a Lightweight Spaceframe using CAE Methods

Invensys Engineering Limited
5 Blyth Close, Cawston,
Warwickshire, CV22 7GY
Registered in England No. : 5752125

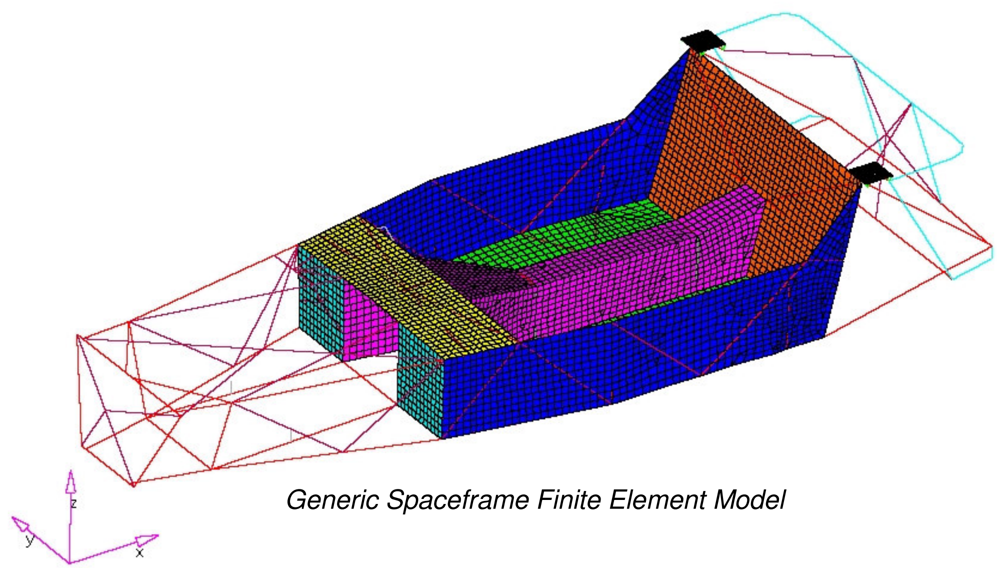
Tel: 01788 522528 / 07780 865096
Enquiries@invensysengineering.co.uk
www.invensysengineering.co.uk

Introduction

In the highly competitive specialist sports car market, there are a number derivatives of the classic ‘Sevenesque’ spaceframe design. This study investigates and develops the generic design using Computer Aided Engineering (CAE) tools, with the purpose of maximising structural performance for least mass and cost.

This particular study is focused on global stiffness and modal characteristics, important for handling, ride and basic NVH, whilst also considering local attachment point stiffness development to improve structure borne noise & vibration.

Merely considering global static stiffness could lead to unrealistic perceived mass saves. Whilst not considering all requirements, this study aims to take a more holistic view of potential performance enhancements and weight reductions.

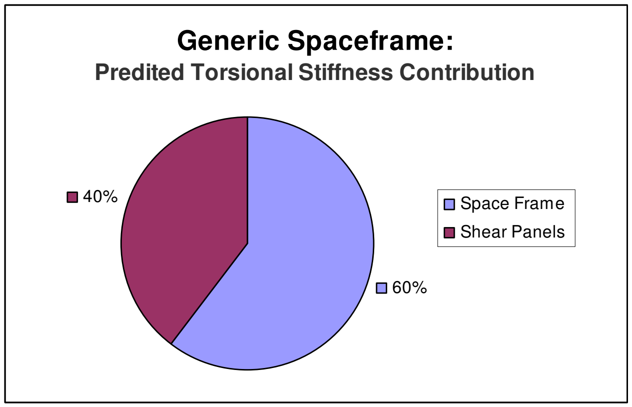


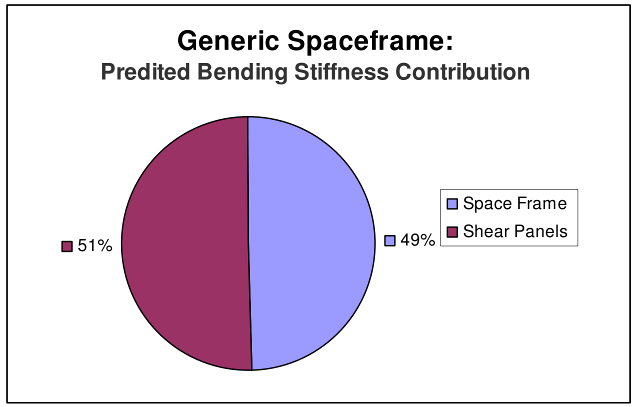
Generic Spaceframe Finite Element Model

Nonetheless, information contained within this document is aimed at a theoretical perspective, to demonstrate the value of CAE toolsets, and as such should not be considered as detailed design guidance. Detailed studies would however provide such guidance.

Characterisation: Shear Panel Stiffness Contribution

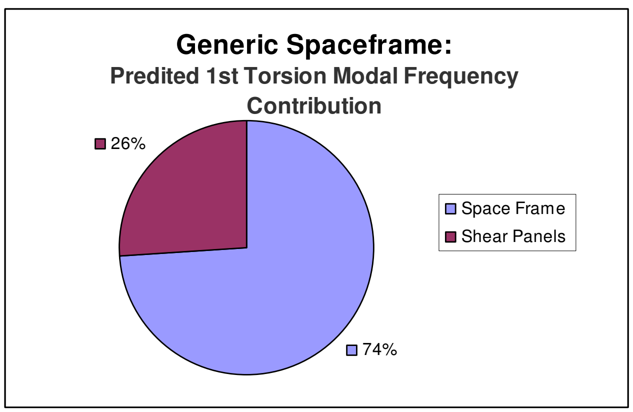
Assuming a nominal 2mm wall thickness for all structural members, a contribution analysis shows that the inclusion of sheet Aluminium shear panels can add 40 – 50% to torsion and bending stiffness even at a gauge of only 1mm. Any optimisation of the structure should therefore be completed as a panelled chassis in order to maximise sheet contribution for least mass.

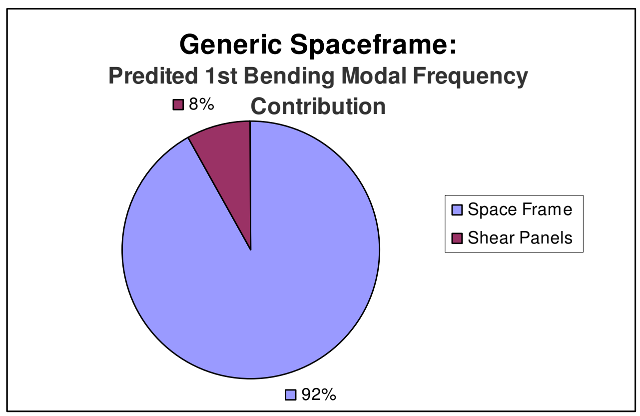




Static Stiffness

- Substantial contribution of sheet to overall static torsion and bending stiffness.





Normal Modes

- Effect of shear panel stiffness increase is degraded by additional weight, hence contribution to modal performance is reduced.
- Optimisation required to balance static gain against mass increase.

Invensys Engineering Limited
5 Blyth Close, Cawston,
Warwickshire, CV22 7GY
Registered in England No. : 5752125

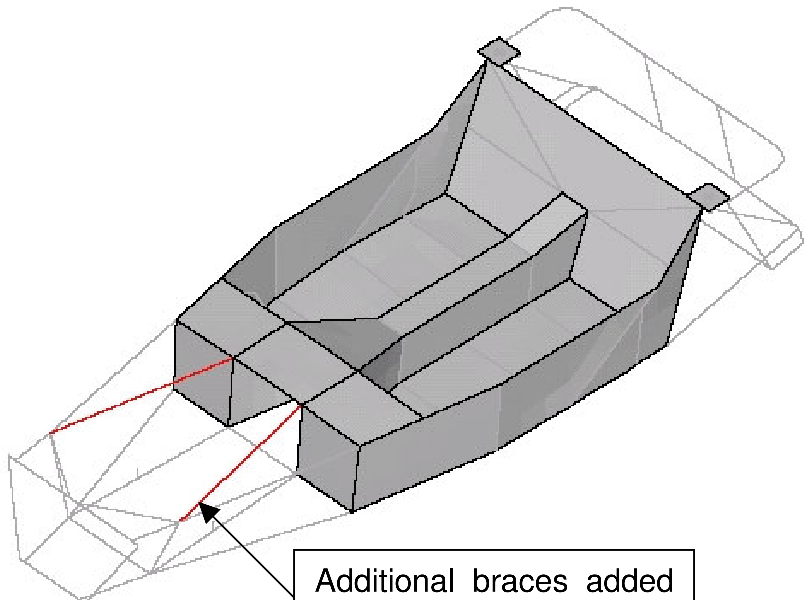
Tel: 01788 522528 / 07780 865096
Enquiries@invensysengineering.co.uk
www.invensysengineering.co.uk

Characterisation: Additional Loadpaths

Animation of static and modal loadcases indicates a stiffness discontinuity between the front end and front bulkhead. Inclusion of a pair of new diagonal members provides a substantial improvement to both static and modal performance for only a 2.1kg mass increase.

With a more developed structure, in terms of loadpaths, an increased opportunity to reduce overall mass should be found.

Attribute	Effect of Braces
Mass	3%
Static Kt	154%
Static Kb	18%
1st Torsion Mode	11%
1st Vertical Bend Mode	7%



Additional braces added to improve global and local stiffness

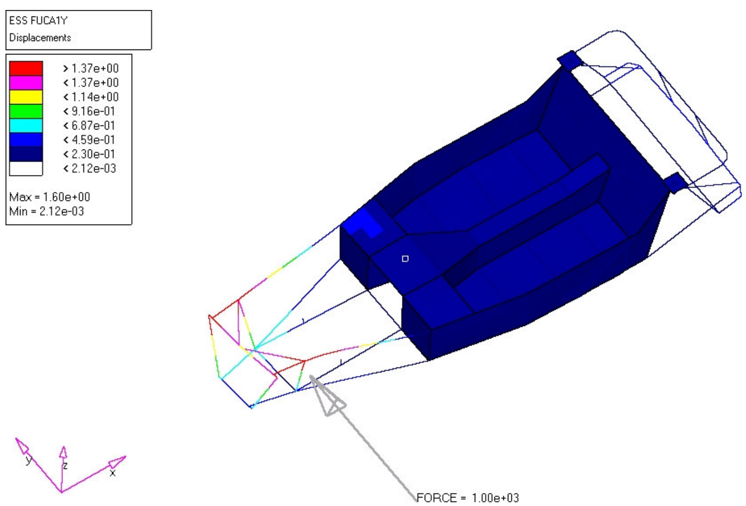
Whilst global static stiffness and fundamental modes are important, local attachment point stiffness should also be considered.

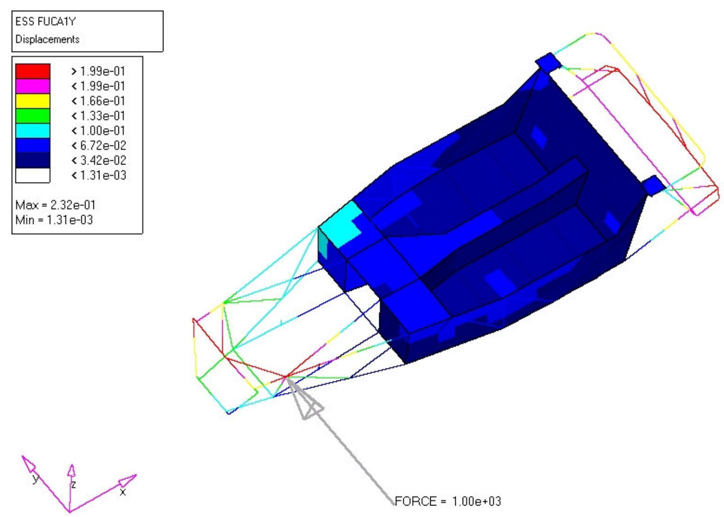
Invensys Engineering Limited
5 Blyth Close, Cawston,
Warwickshire, CV22 7GY
Registered in England No. : 5752125

Tel: 01788 522528 / 07780 865096
Enquiries@invensysengineering.co.uk
www.invensysengineering.co.uk

Characterisation: Local Static Stiffness

The addition of new loadpaths yields significant improvements in global stiffness. Further improvements can also be seen when monitoring chassis suspension arm attachment point stiffness'. Using inertia relief, the application of a lateral load to upper control arm rear mount location quantifies the improvement in local stiffness. This improvement in stiffness should translate as an improvement in steering feel and chassis dynamics.





Base Condition:

Considerable deformation of upper member due to lack of resistive loadpaths:

Ky = 0.74kN/mm

Modified Condition:

Additional braces carry load effectively to surround parts of the spaceframe resulting in a significant increase in stiffness:

Ky = 4.3kN/mm

Invensys Engineering Limited
5 Blyth Close, Cawston,
Warwickshire, CV22 7GY
Registered in England No. : 5752125

Tel: 01788 522528 / 07780 865096
Enquiries@invensysengineering.co.uk
www.invensysengineering.co.uk

Optimisation - Overview

Parameters:

• Base structure with additional load paths used as optimisation basis.

• Each individual member section properties varied (18-40mm RHS 1-2mm thickness).

• Shear panel thickness varied (1-2mm).

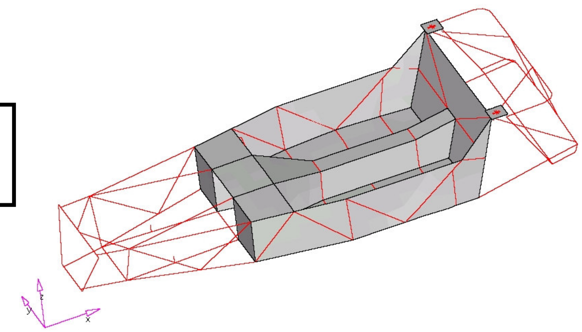
Responses:

• Objective - minimise mass

• Constrained Kt & Kb.

• Constrained front suspension attachment point stiffness – static and dynamic.

Frame mass optimised to 41.8kg



Comparison of Base and Optimised Structures

Attribute	Metric	Units	Base	Optimised	Benefit
Mass	Frame mass	kg	62	**41.8**	-20.2kg
	Sheet mass	kg	8.9	**8.9**	-
	Total Structural Mass	kg	70.9	**50.7**	-20.2kg
Global Stiffness	Static Kt	kNm/deg	1.2	**4.8**	298%
	Static Kb	kN/mm	8.5	**21.5**	154%
BIW Modes	Torsion Mode	Hz	46.3	**52.3**	13%
	Bending Mode	Hz	49.2	**54.5**	11%
Frt Susp Equiv Static Stiffness	Frt Susp Mnt ESS Kx	kN/mm	7.2	**26.1**	263%
	Frt Susp Mnt ESS Ky	kN/mm	1.0	**5.0**	421%
	Frt Susp Mnt ESS Kz	kN/mm	0.6	**2.5**	317%
Frt Susp Dynamic Stiffness 56-177Hz	Frt Susp Mnt RMS Kx	kN/mm	6.7	**17.8**	166%
	Frt Susp Mnt RMS Ky	kN/mm	0.7	**5.4**	671%
	Frt Susp Mnt RMS Kz	kN/mm	0.6	**1.9**	217%
Frt Susp Dynamic Stiffness 177-280Hz	Frt Susp Mnt RMS Kx	kN/mm	23.5	**46.7**	99%
	Frt Susp Mnt RMS Ky	kN/mm	1.2	**2.6**	117%
	Frt Susp Mnt RMS Kz	kN/mm	4.7	**6.1**	30%

Key Findings:

• Structural mass reduced by 20kg

• Global Kt increased by 300%

• Suspension mounting stiffness dramatically improved.

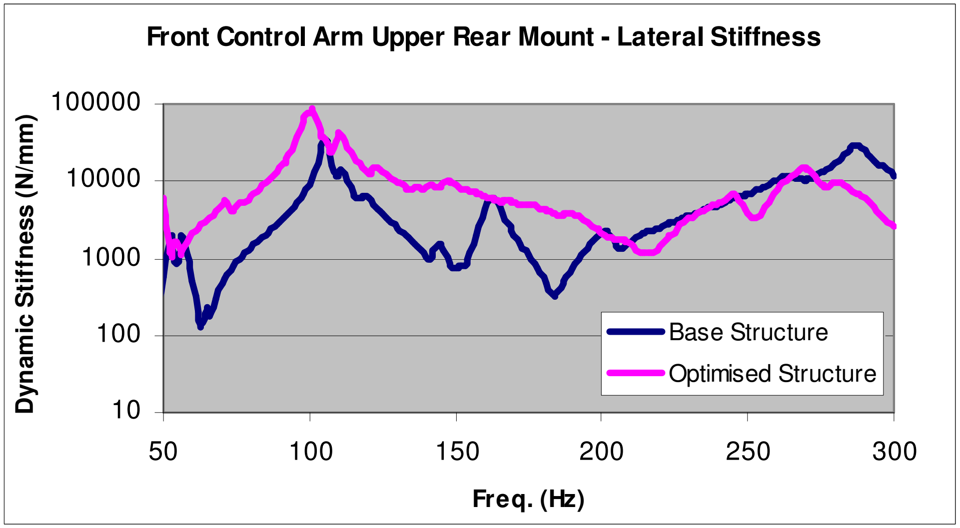
NB. Multiple standard square sections used with varying standard gauges, therefore building complexity increased to improve mass and performance.

Invensys Engineering Limited
5 Blyth Close, Cawston,
Warwickshire, CV22 7GY
Registered in England No. : 5752125

Tel: 01788 522528 / 07780 865096
Enquiries@invensysengineering.co.uk
www.invensysengineering.co.uk

Optimisation – Local Dynamic Stiffness

Improved attachment point dynamic stiffness' leads to better bush isolation and increased attenuation. This in turn results in reduced unwanted structure borne road and powertrain induced noise, vibration and harshness. Poor dynamic stiffness can often be attributed to dominant modal content – a presence of a mode will detract from the underlying dynamic stiffness level. Body structure primary modes are inevitable but careful placement on these modes and the avoidance of higher frequency high energy modes is key to delivering a robust a neutral structure to deliver handling and refinement. The ultimate aim is to generate a flat stiffness response over the frequency domain, at as higher level as is practicably possible (Five times bush stiffness is a good target).



- Low frequency stiffness greatly increased through addition of braces and optimisation.
- Stiffness 'Drop outs' at 150Hz and 180Hz are eliminated.
- Response beyond primary modes (80Hz onwards) is generally flat.
- Performance post 200Hz could be improved at the expense of mass.

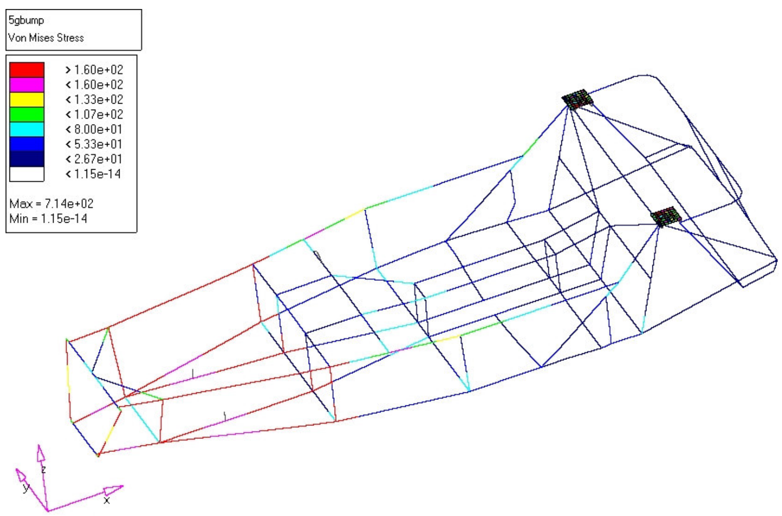
Invensys Engineering Limited
5 Blyth Close, Cawston,
Warwickshire, CV22 7GY
Registered in England No. : 5752125

Tel: 01788 522528 / 07780 865096
Enquiries@invensysengineering.co.uk
www.invensysengineering.co.uk

Optimisation – Simplified Abuse Load Case

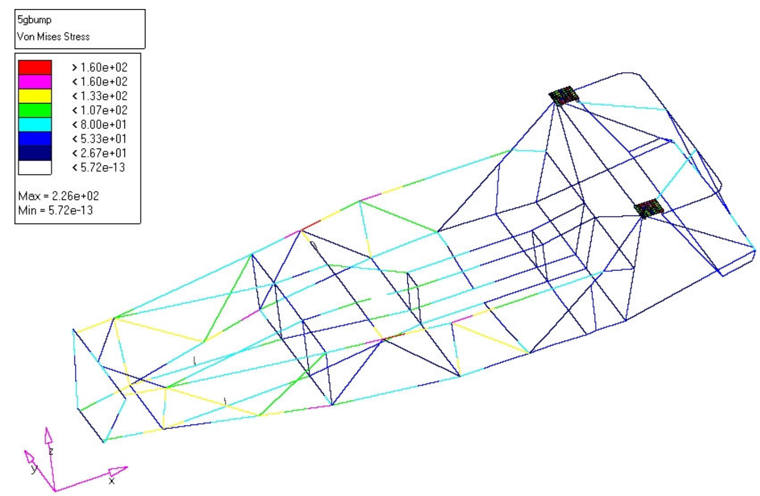
To verify that the strength of the frame hasn't been compromised through section and gauge optimisation, a simplified abuse load case has been analysed.

A 32kN load (5g bump) was applied as 16kN to front suspension mounting points and 16kN to rear suspension mounting points. Member forces and resulting Von Mises stresses were then compared for the baseline frame against the optimised condition. As this is a simplified load case conducted on a simplified model, results are not absolute and are only for a basic comparison. A detailed finite element model and analysis would be required.



Base Frame:

Member stresses in front structure exceed yield by a considerable margin. Loads are non transmitted throughout the structure effectively.



Optimised Frame:

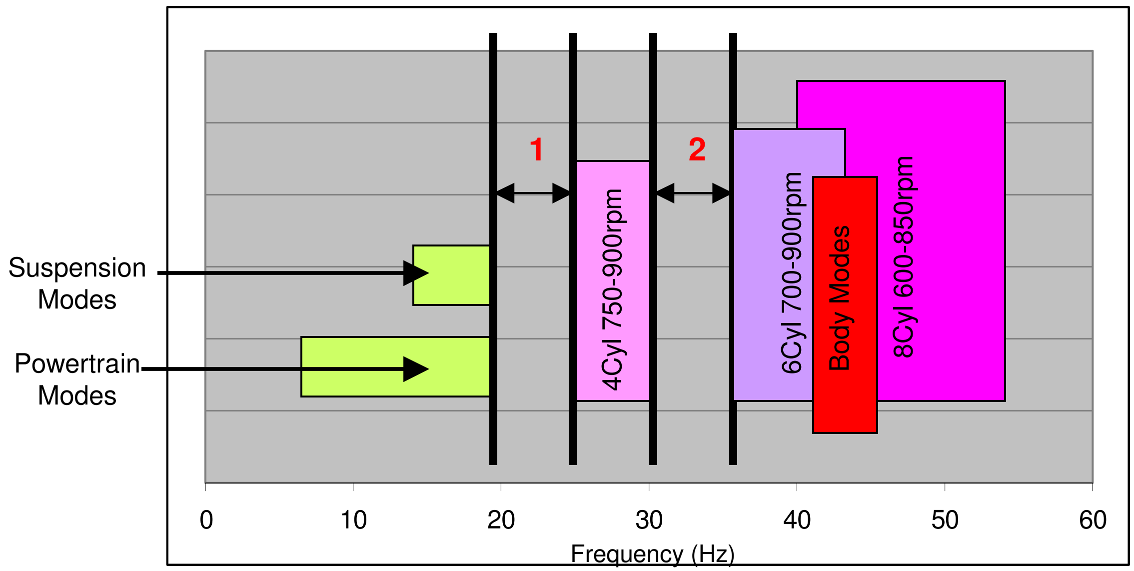
Despite being 20kg lighter, improved load paths and efficient use of sections has dramatically improved the member forces and stresses. Forces are more evenly distributed through the structure.

Invensys Engineering Limited
5 Blyth Close, Cawston,
Warwickshire, CV22 7GY
Registered in England No. : 5752125

Tel: 01788 522528 / 07780 865096
Enquiries@invensysengineering.co.uk
www.invensysengineering.co.uk

Other Considerations: Vehicle Modes

A sound modal alignment strategy is key to delivering a vehicle with high perceived quality. Specialist vehicles often accept a wide range of powertrain installations whether they be 4, 6 or 8 cylinder units.Coupled with dominant firing orders, a wide spread in idle engine speeds also poses problems. Body modes also need to be positioned above powertrain bounce and suspension primary & secondary modes.



Modal Alignment Chart

Modal Drop Off:

From a basic trimmed body analysis, modal drop off from bare structure to a trimmed condition, is estimated to be 13Hz for torsion and 10Hz for bending.

With the stiffened structure, body modes are predicted to sit in a window of 37-45Hz, dependent on trim content.

Idle vibration issues are therefore likely with V6 & V8 installed powertrains.

Base structure modes are predicted to be between 35 & 40Hz, potentially conflicting with 6 cylinder engine idle (3EO).

The two clear windows that exist (20-25Hz (1) and 30-35Hz (2)) would normally be populated with body modes of conventional sports and saloon vehicles. Due to the analysed structure being of a very low structural mass for relatively high static stiffness, coupled with a very low amount of additional non-structural mass, placing body modes in these windows is not practicable. With a predicted modal drop off of only 10-13Hz, compared with typical car drops of 20-25Hz, coincidence of modes with V6 & V8 idle is virtually unavoidable. However, idle refinement for 4 cylinder powered cars should be good.

Conclusions

The techniques applied in this study provide an opportunity to rapidly characterise and improve a vehicle's structure. The net result of the study is a lighter, stiffer structure that should deliver improved vehicle dynamics, NVH and durability.

The toolsets used can equally be applied to more complex body structures to optimise other cost features such as joining (spotwelds, rivets, adhesive). A greater breadth of analysis metrics can also be studied including predicted vibration levels at seat rail and steering wheel and also interior noise at occupant ear positions (fixed roof vehicles).

CAE tools are also very well suited to optimising the design of individual components. Rapid and cost effective improvements in component design can be achieved through detailed optimisation techniques.

Please feel free to contact us to understand more about the services we offer:

Invensys Engineering Ltd.

Email: Enquiries@invensysengineering.co.uk

Web: www.invensysengineering.co.uk