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Ride Improvement of a North American Pick Up Truck

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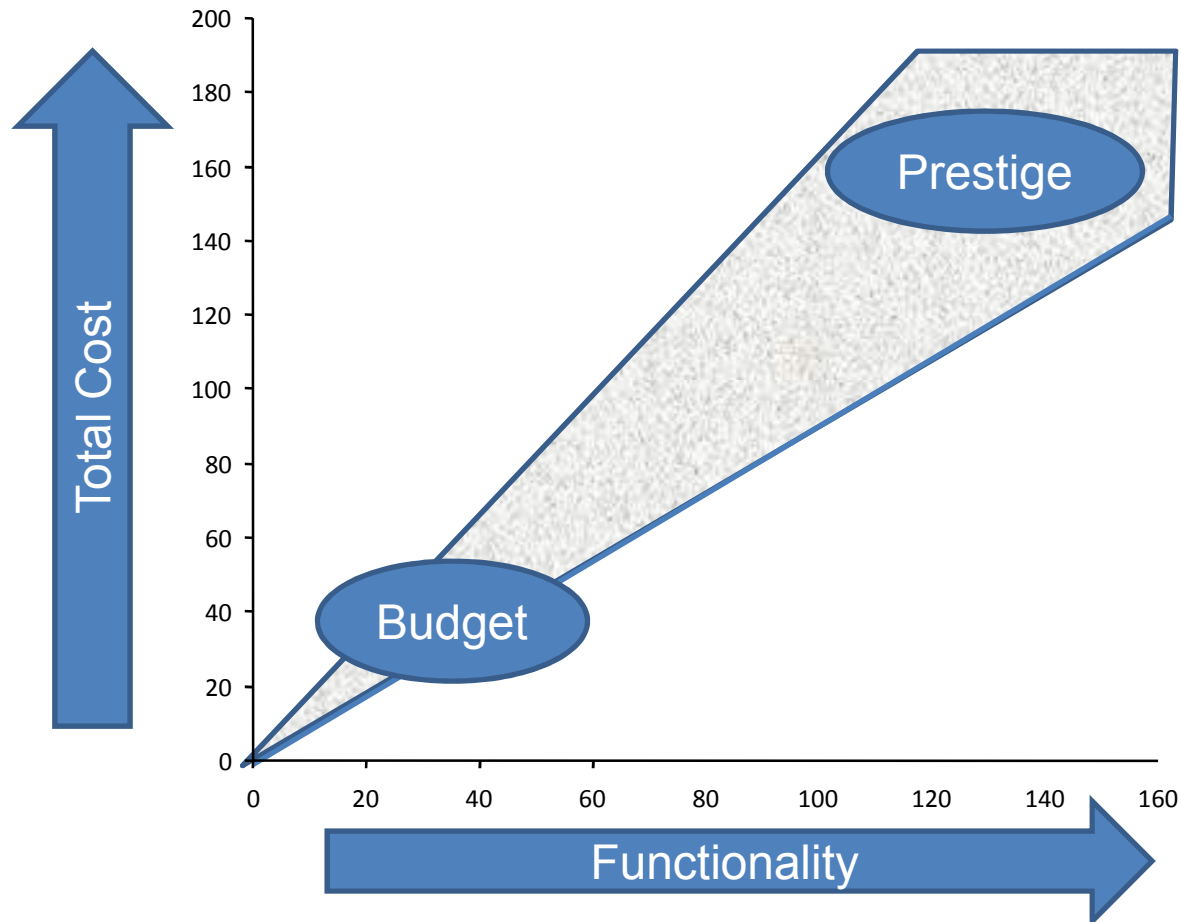
Introduction

- Requirement to understand the ride limitations of large US pick up trucks
- High volume competitive vehicle
- Decision drivers for truck chassis
 - Direction from suppliers
 - Perception from the customers
 - Performance
- Current trends
 - Fuel efficiency
 - Lower cost
- Do we understand the cause of the ride deficiencies?



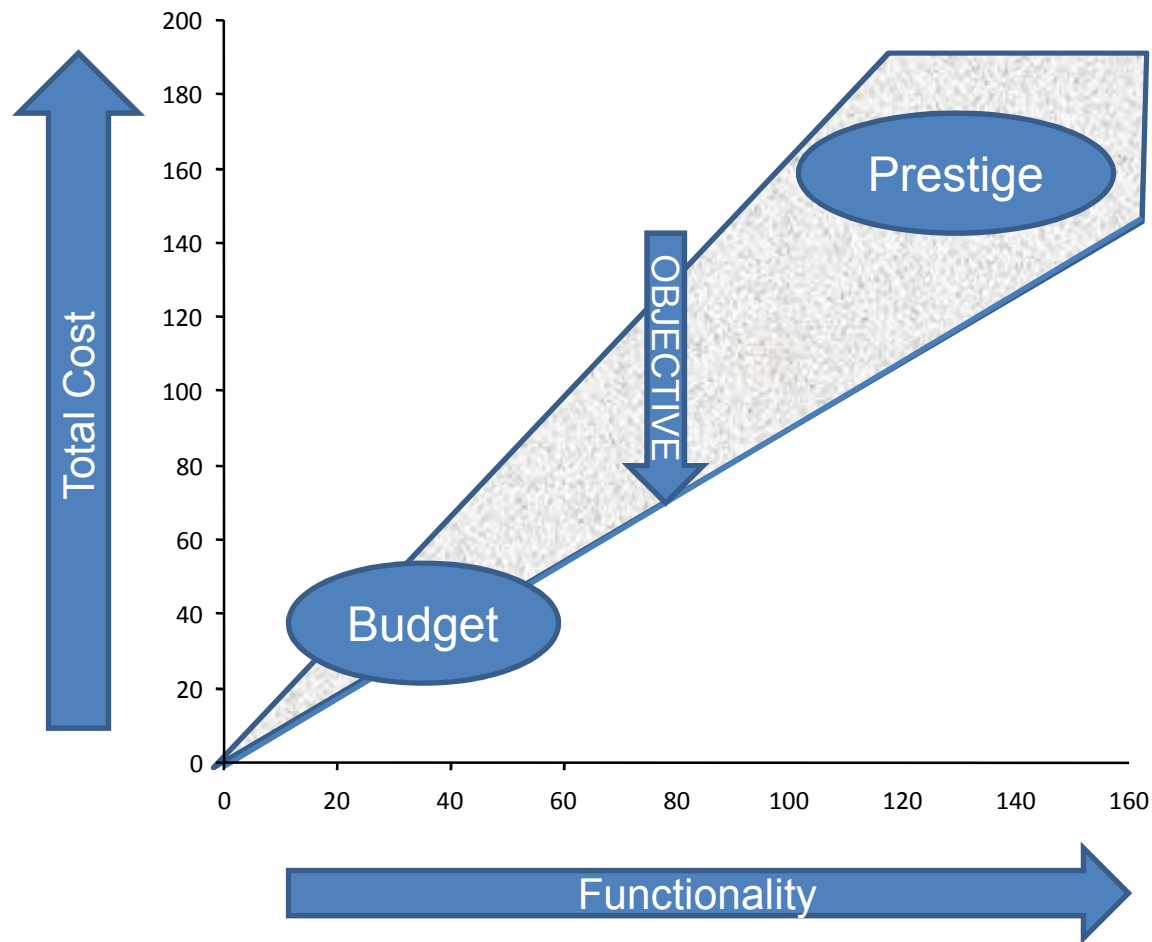
Where are the opportunities

- Two ways to gain financial advantage
 - Better product for same money
 - Same product for less money



What is our direction

- Our aim was to match the competition for less money
 - Understand the system
 - Do not just follow the crowd.



Vehicle Selection

	REAR SUSPENSION	BODY STYLE
Donor Vehicle *	Leaf Spring (Hotchkiss)	Body on frame
Target Vehicle	Link Coil (Solid Axle)	Body on frame with integrated cargo
V1	Leaf Spring (Hotchkiss)	Body on frame
V2	Leaf Spring (Hotchkiss)	Body on frame
V3	Coil Link Blade Independent	Monocoque
V4	Coil Link	Body on frame SUV

Pick ups

* Donor Vehicle:
Target Vehicle:

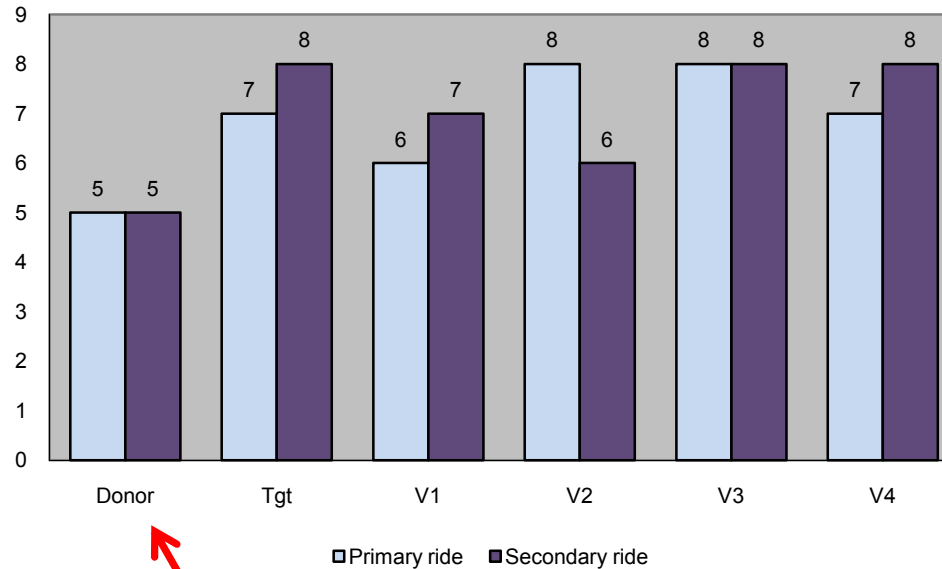
Selected Vehicle to be improved
Selected Vehicle with a target performance

Subjective Assessment Ratings

1	2	3	4	5	6	7	8	9	10
Danger to operator/passenger(s) or others – not suitable for further evaluation as is	Suitable for research/motorsport purposes only with trained operators – not suitable for use on public roads	Suitable for research with untrained operators – use on public roads only with caution	Obstacle to sales (legal issue or likely to discourage customer from purchase decision)	Return to dealer – perceived as a fault with the vehicle	Criticised by most customers	Noted by critical customers (e.g. Journalists)	Noted only by expert assessors	Not discernible	No improvement practicably possible
Prototypes only			Lemons		Mainstream			Cost Reduction Opportunities	

-
- Primary and Secondary ride
 - Handling
 - On-centre behaviour
 - Off-centre behaviour
 - Steering

Subjective Assessment Results



Main Assessors' comments on Donor Vehicle

- "Extremely rebound under damped"
- "Lightly damped shake from rear axle"
- "Shake become much worse at lower speed (30 mph)"
- "Seats too soft and couples with primary pitch"
- "Wallowy" and underdamped takes several cycles to recover after a bump
- "Poor primary becomes *ALMOST NO* primary control when laden"
- "Lots of primary pitch results in tiring head motion"
- "Bizarre diagonal kick"
- "Poor shake from rear axle/frame"

Primary Ride Investigation

ω_r/ω_f k^2/ab

1.06	0.75
1.12	0.91
1.16	0.76
1.17	0.81
1.3	0.96
0.83	1.0

Donor \square

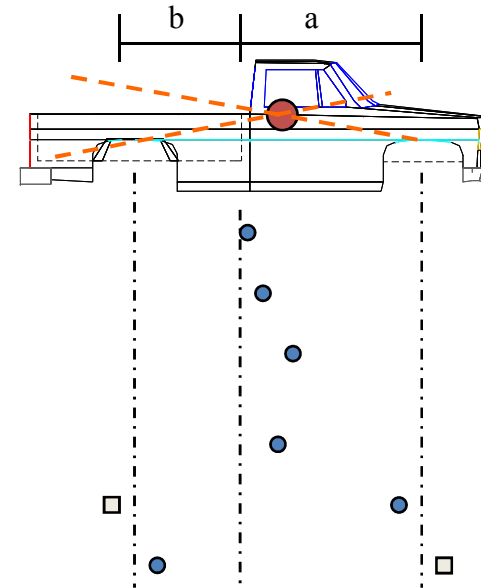
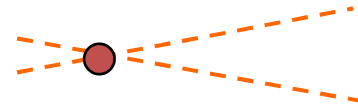
Target

V1

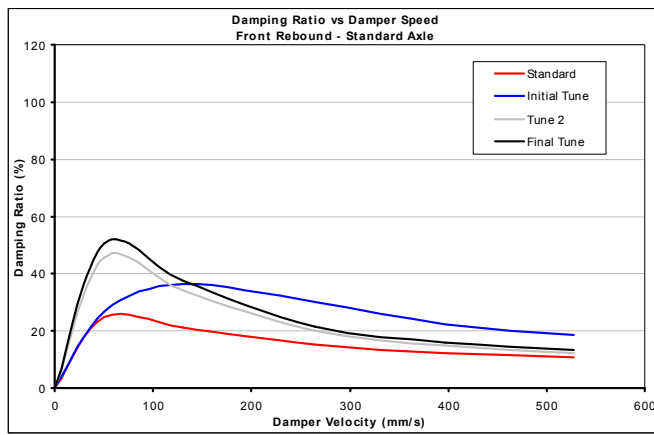
V2

V3

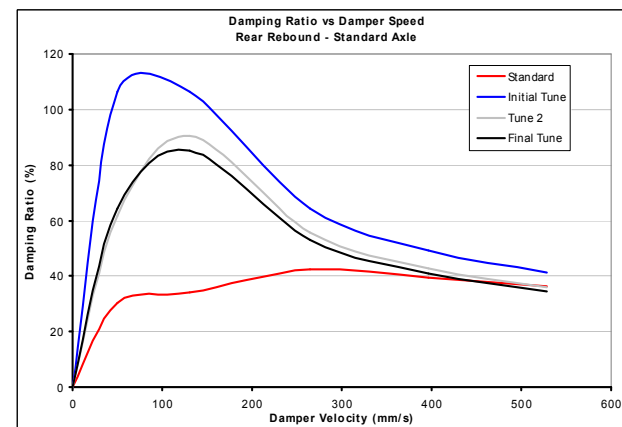
V4



- Ride pitch centre
- Ride bounce centre



Donor Vehicle
Front suspension rebound tune



Donor Vehicle
Rear suspension rebound tune

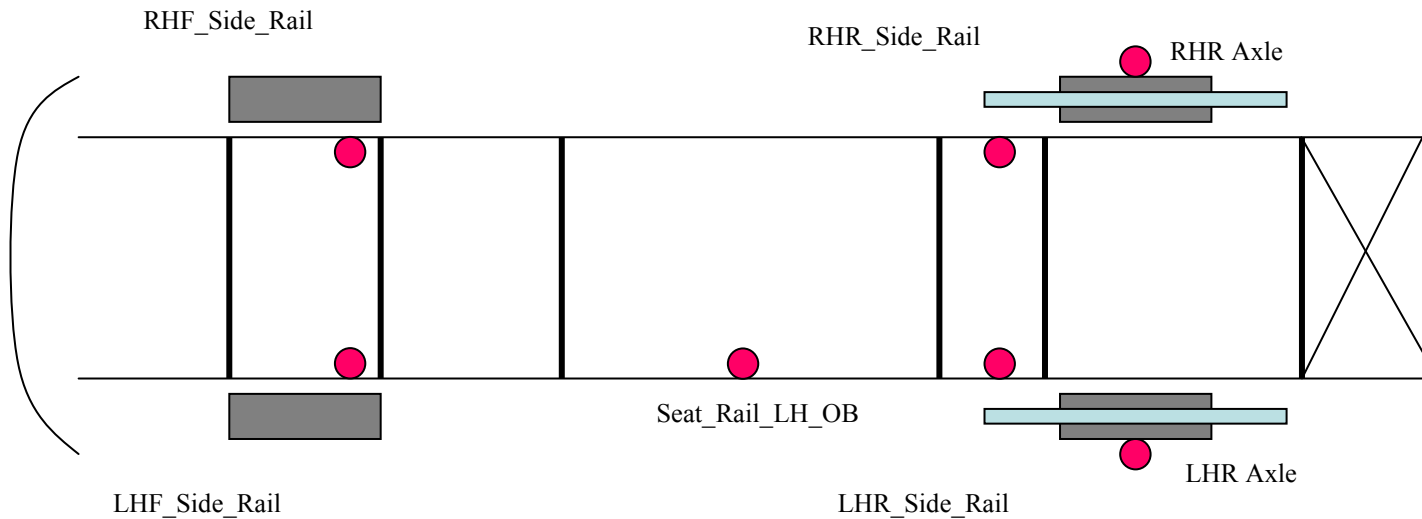
Secondary Ride Investigation

- We need to observe:

Axle acceleration
Seat Rail Acceleration
Frame & Axle Shape

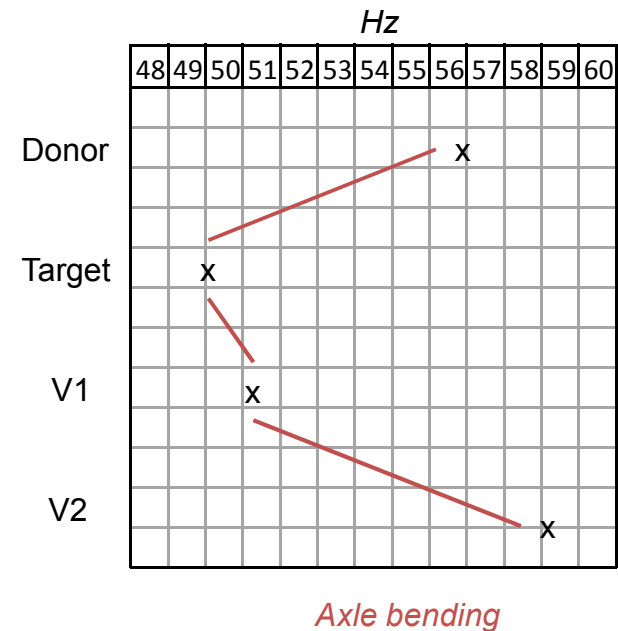
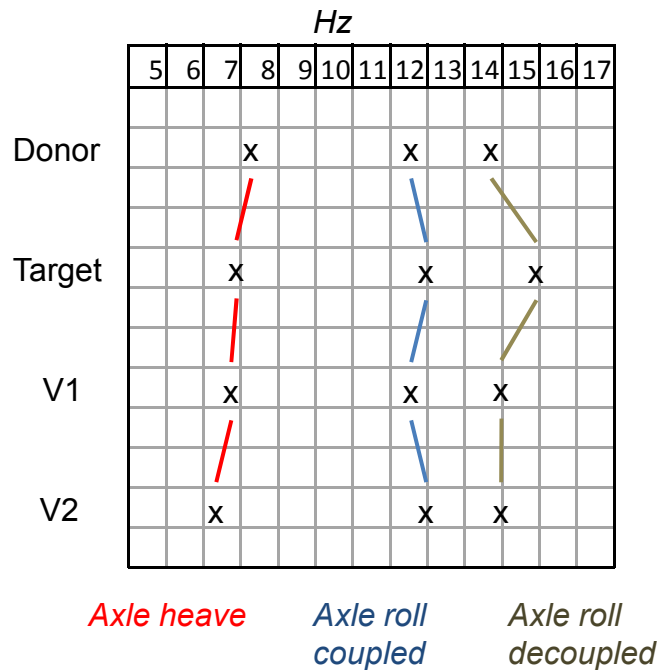


Axle Bounce ("Hop")
Axle Roll in phase ("Tramp 1")
Axle Roll out-of-phase with frame ("Tramp 2")



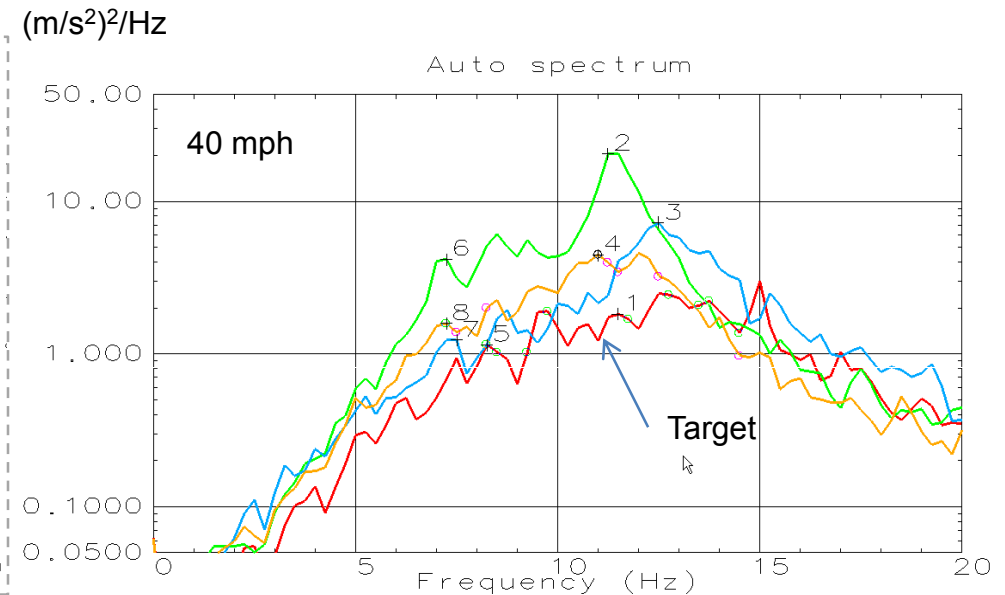
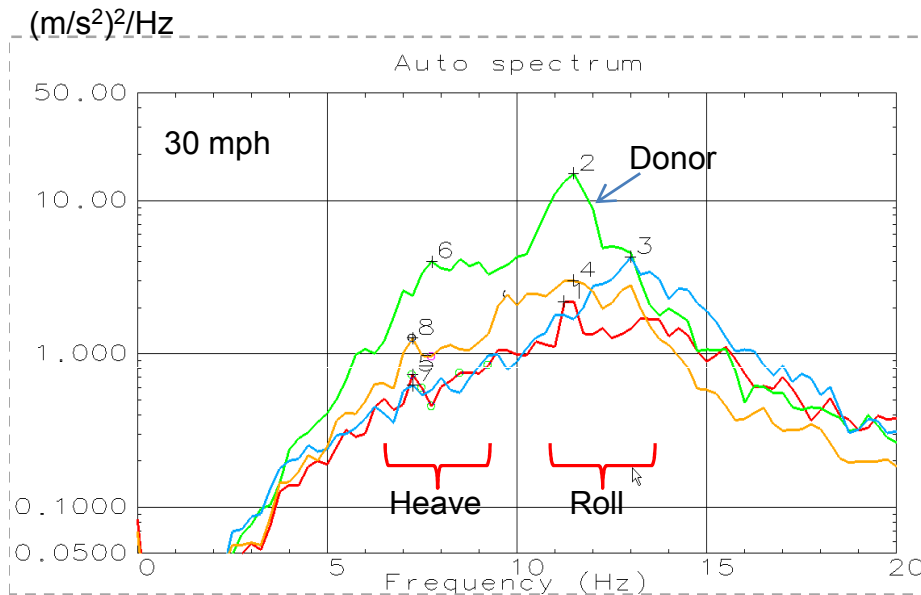
Vehicle Instrumentation

Modal Frequencies



- Axle bending frequency clearly not contributory
- Reposition of chassis modal behaviour impractical
 - Below 6 Hz to separate axle heave
 - Above 15 Hz to separate axle roll
- One vehicle attempted to lower chassis frequency
 - Subjective appraisal notes persistent shake

Secondary Ride (Rear Axle)



- Operating shape analysis confirms similarity
 - Modal position of vehicle very similar
 - Amplitude of donor vehicle significantly higher than benchmark

Solution is to understand cause of higher amplitude..!

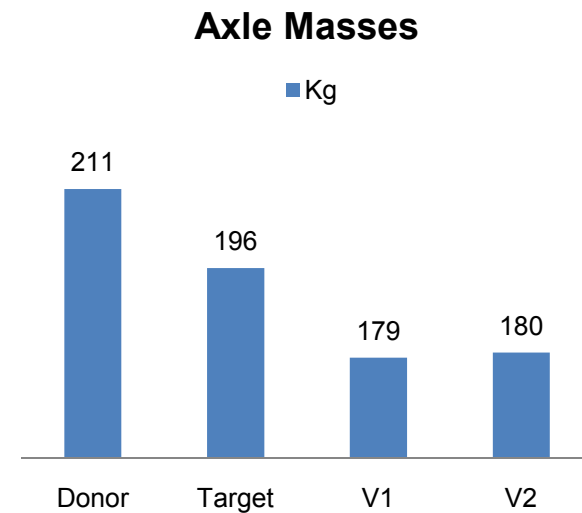
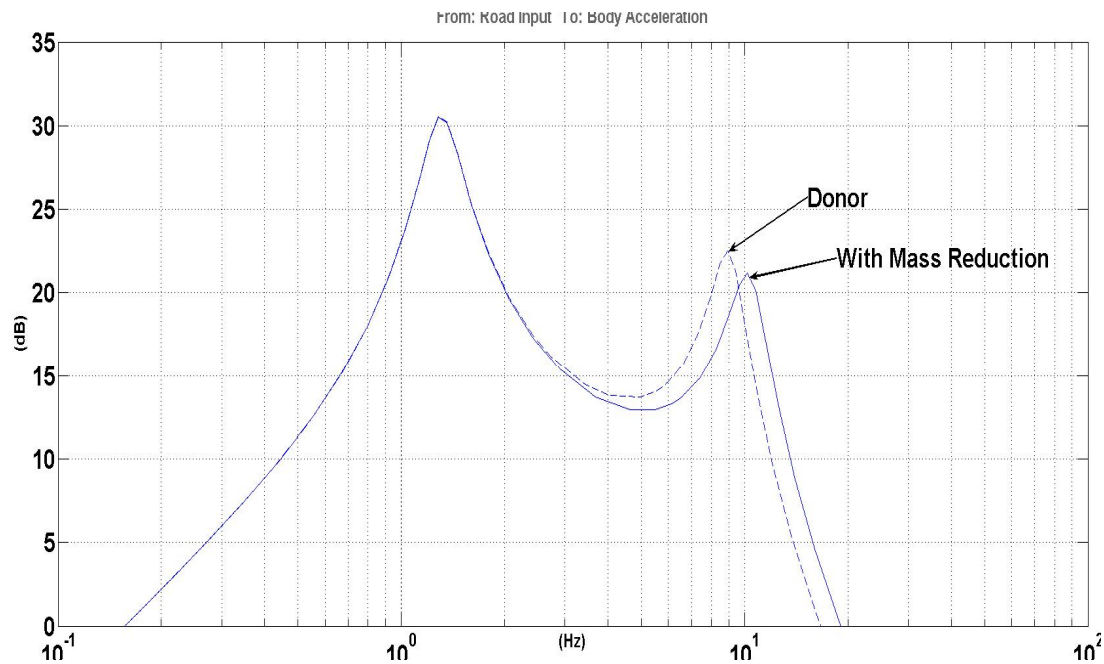
Secondary ride main difference

Modal decoupling is not cost effective

Lower axle mode to low

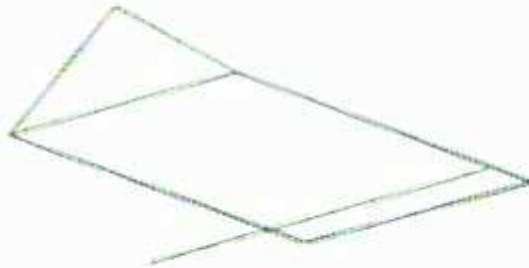
Higher axle mode to high

Reducing donor vehicle axle mass will reduce excitation energy

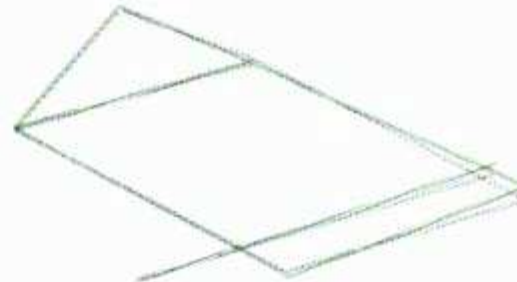


Frame condition

Donor
Mode 11.50 Hz 30 mph



V2
Mode 9.75 Hz 30 mph

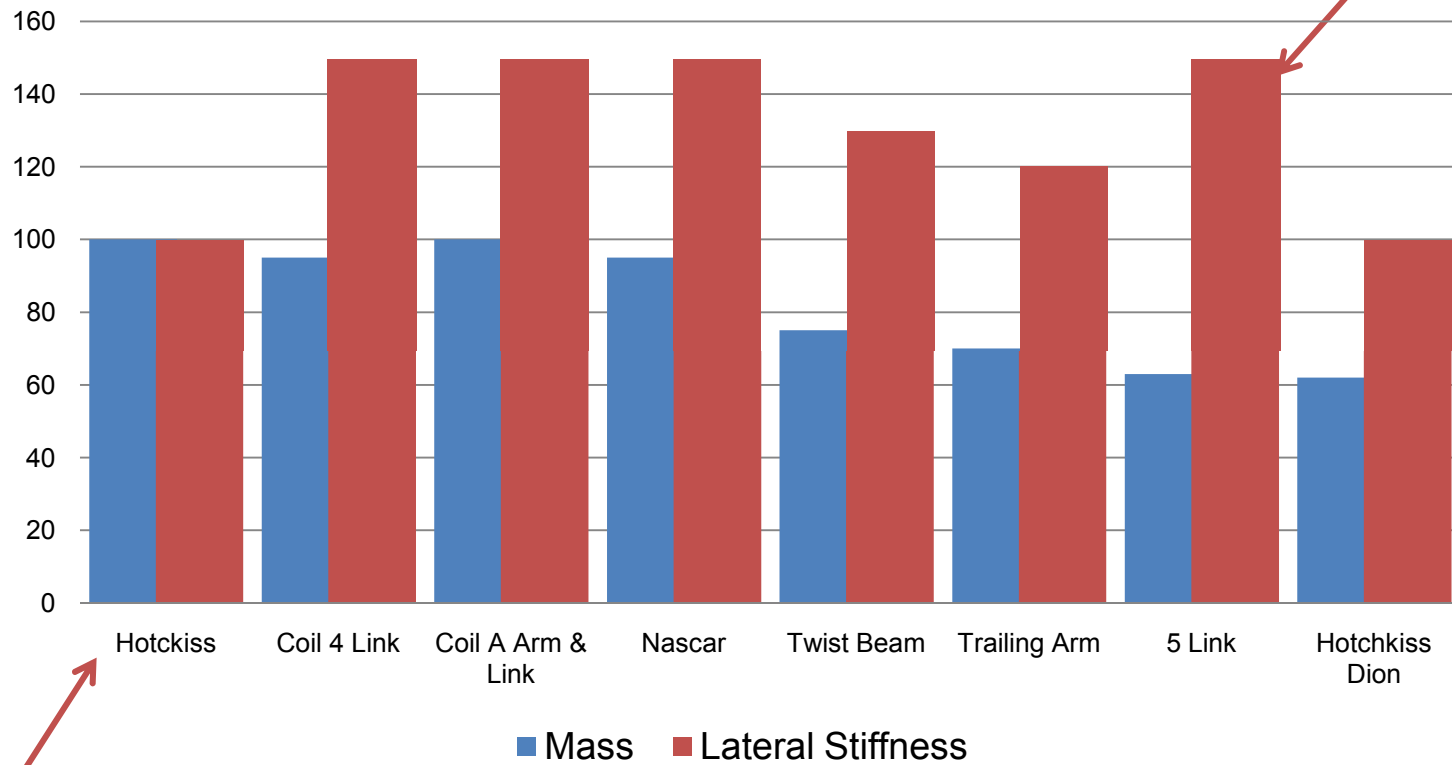


Design Avenues

- Wheelbase reduction to increase dynamic index
- Modify front suspension
- Redesign the frame
- Damping Calibration
- Unsprung mass reduction
- Not under our control
- Does not seem to be the problem
- Does not seem to be the problem
- Feasible
- Different Suspension Concept

Suspension Analysis

Suspension Qualitative Analysis

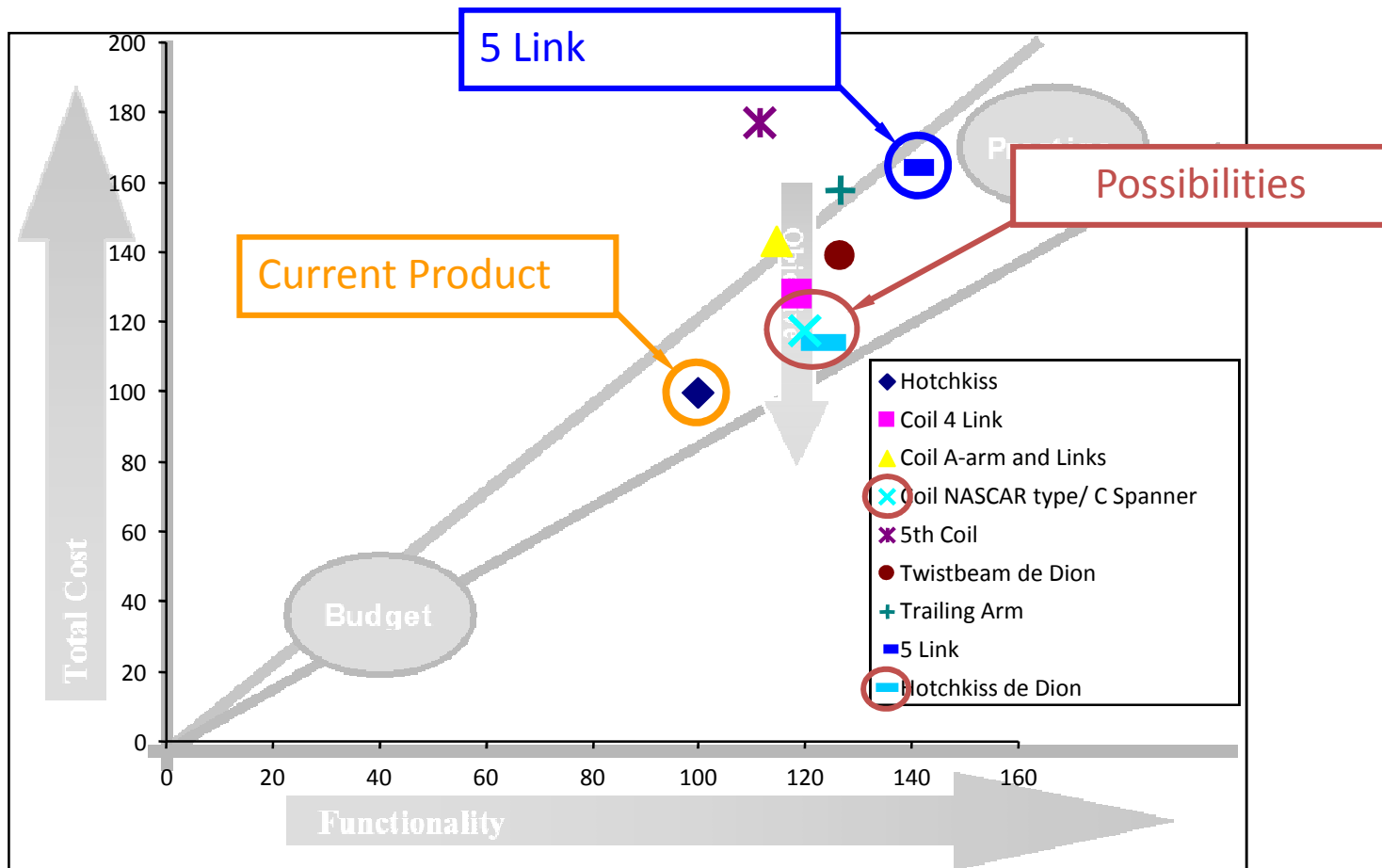


5 Link is the best performer

Everything is better than Hotchkiss for Ride

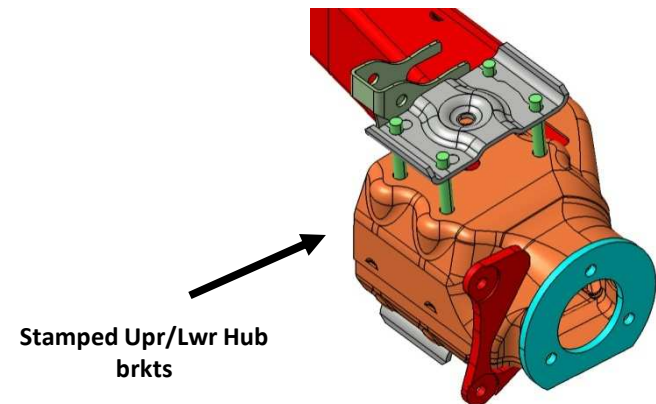
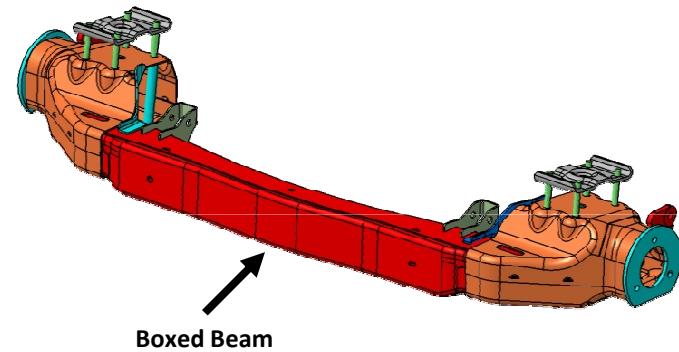
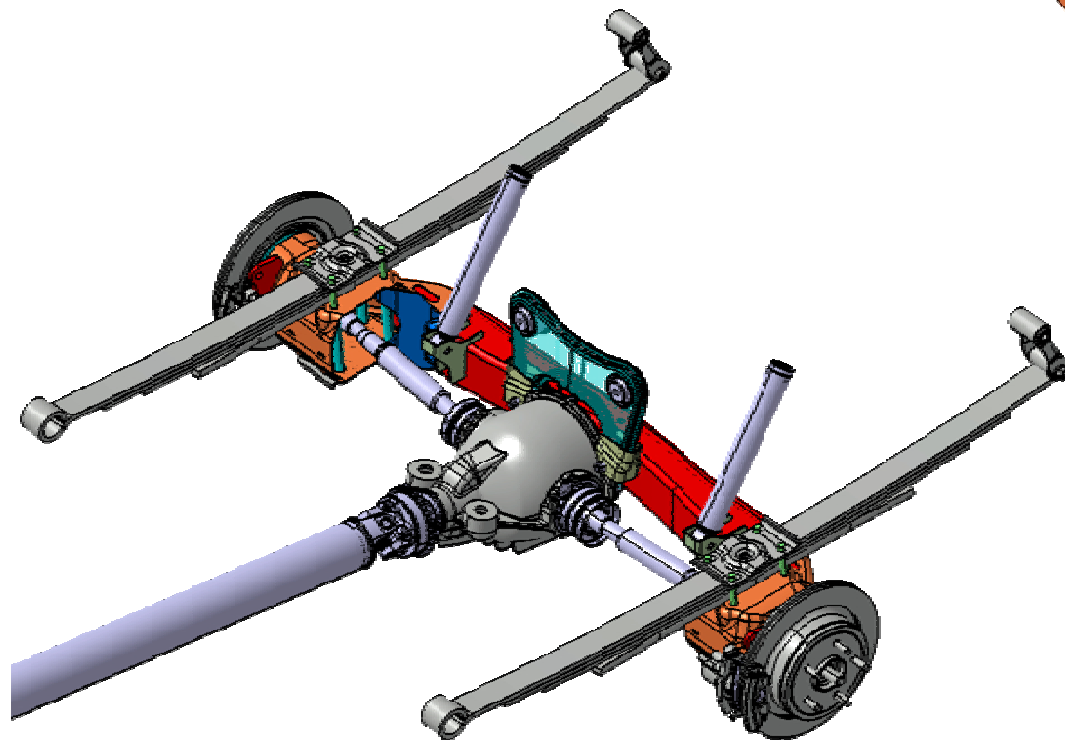
Suspensions Analysis

- Cost-Performance

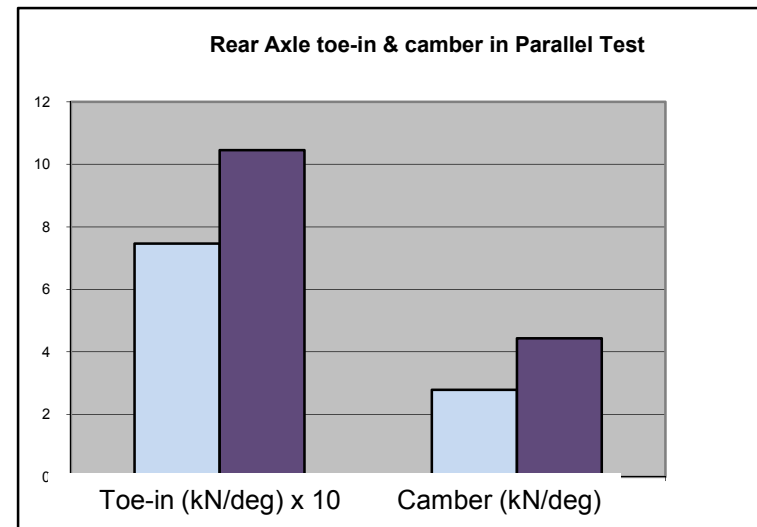
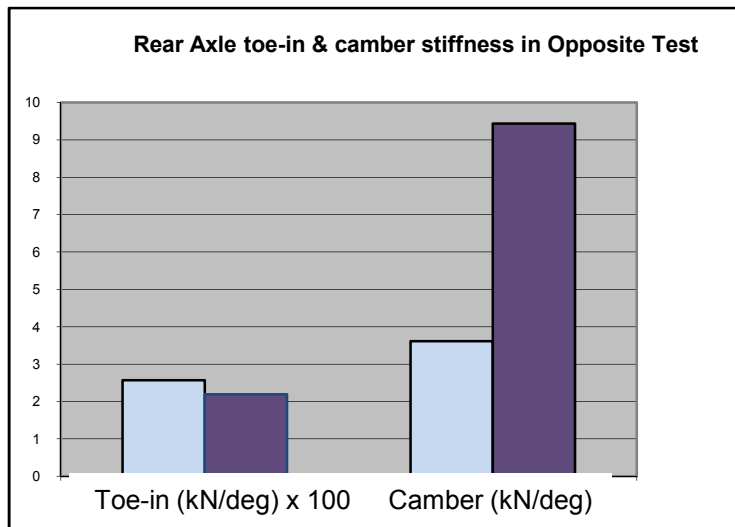
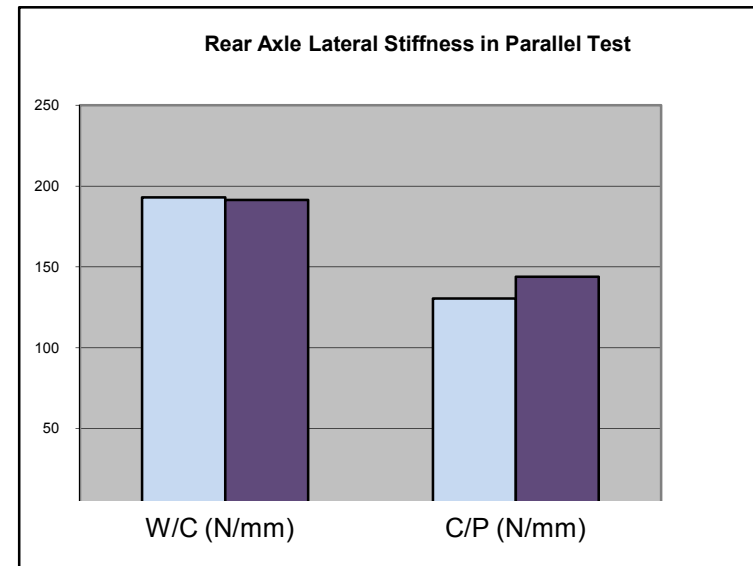
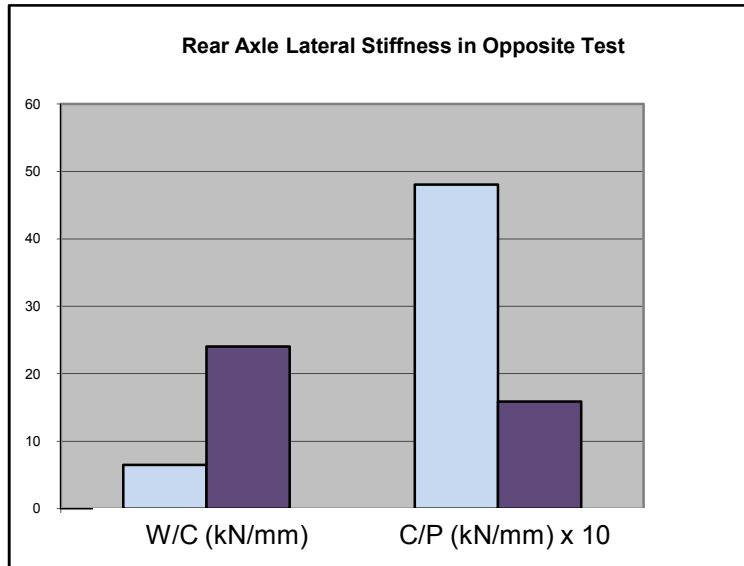


Prototype Solution

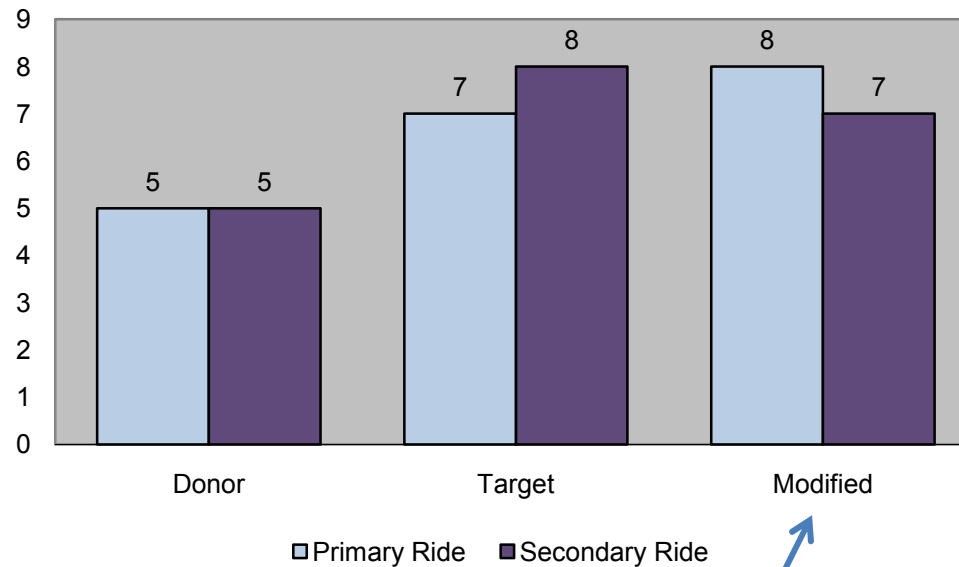
- Beam axle no longer carries differential mass
- 25% reduction of unsprung mass
- Excitation energy reduced by 3 db
- Improved camber and toe stiffness
- Reduce weight, large section beam pressing



K&C Modified vs Donor



Subjective Assessment

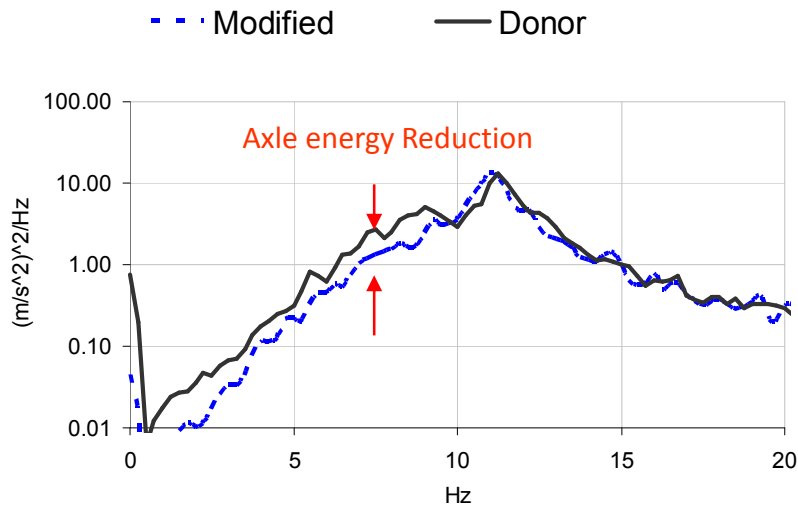


Main Assessors' comments on Modified vehicle.

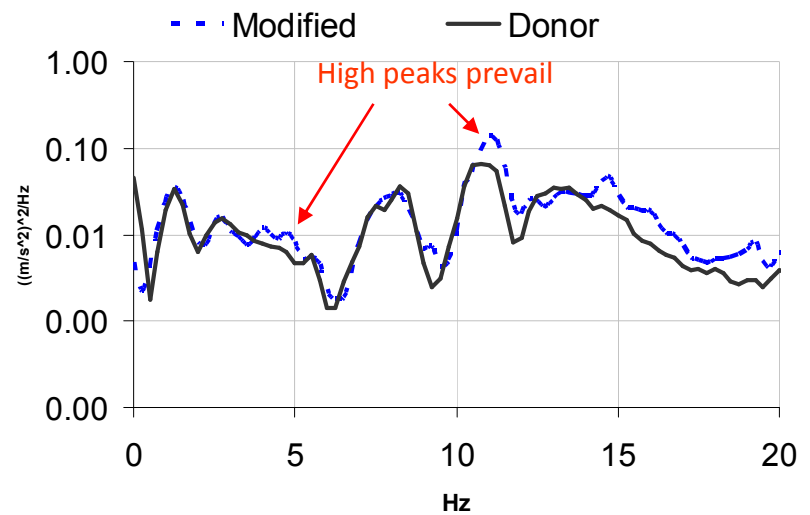
- "Primary ride very well controlled without being harshness"
- "Nicely matched front to rear with plenty of tendency to breathe"
- "Shake well controlled over smooth roads"
- "Input bump quickly dissipated"
- "Roll from side to side occasionally after bumps at low speeds"
- "No obvious roll rock at high speeds"
- "Lot of vibration and a bit of noise on motorway"
- "Rear shake no longer a problem"
- "Front heel board vibration no evident"
- "Smooth flowing feel with no obvious flaws"
- "Shake persistence improves but amplitude remains"

Objective Analysis

Rear Axle Response @ 30 mph



Seat Rail Response @ 30 mph

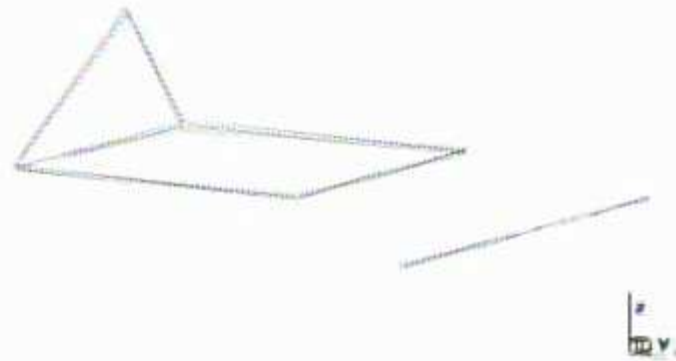


Further Research

Geometry
Mode 13.00 Hz Std. Donor (2006)



Geometry
Mode 14.75 Hz Modified (2007)



Further Research

- The rear shake was resolved at the expense of more harshness, possible causes are the closer proximity of front and rear unsprung frequencies
- The improvement made in rear shake reduction can be masked by the sprung weight distribution although can be reduced by further mass optimization.
- Rear suspension design was not enough to meet target vehicle performance, further refinement is needed in other systems

Conclusions

- Primary ride compromise by poor inertia mass relationship
 - It can be improved in limited sense by damping
- Axle activity and modal behaviour of chassis not realistically separable.
- Secondary ride subjectively improved by reduced mass axle.
- Simple solution represents cost effective fix.
- The rear shake was resolved at the expense of more harshness, possible causes are the closer proximity of front and rear unsprung frequencies
- The improvement made in rear shake reduction can be masked by the sprung weight distribution although can be reduced by further mass optimization.
- Rear suspension design was not enough to meet target vehicle performance, further refinement is needed in other systems

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