Unsprung Mass "The Myths and Realities – Closing the Circle"

A study into the dynamic implications and opportunities of an unsprung-mounted drivetrain.

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Protean Electric Company Overview

- Protean Electric is a leading clean technology company that designs, develops and manufactures the Protean Drive™, the most advanced in-wheel electric drive system for hybrid and battery electric vehicles.

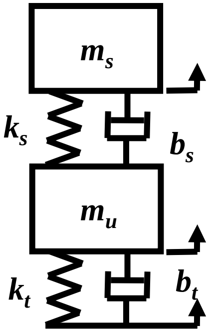
- Protean Drive™ stands alone in matching the performance of traditionally powered vehicles and is a no compromise solution for the development of 2 and 4-wheel drive, commercial vehicles, pickup trucks, SUVs and family size passenger cars; all vehicles customers prefer and all profitable for OEMs.

- Offering a compelling combination of packaging advantages, new vehicle design opportunities and vehicle cost savings, Protean Drive™ is strategically positioned to dominate the hybrid and electric vehicle market.

Introduction

- **The perceived problems regarding wheelmotors ... the "myths":**
  - Grip – "Adding wheelmotors will cause a substantial loss of grip over anything but billiard-table smooth surfaces"
  - Ride – "Adding wheelmotors will lead to considerably greater sprung mass vertical accelerations, and consequently very poor occupant comfort"

- **Two independent approaches for the investigation ... the "realities":**
  - Flexible, wide ranging computer modelling study
    Damian Harty, Dunamos Ltd
  - Subjective, objective and CAE analyses of a mid-size
    Ford Focus hatchback – Lotus Engineering
  - 6 month project Completing Nov 2010



Conclusions – "The Realities"

- **No obvious "break point" for safety, ride or refinement**
- **Analysis indicates that road surface variation and tyre quality are greater factors than unsprung mass**
- **Maintaining wheel hop frequency above 10hz with stock tyres will limit the effects of adding unsprung mass**
- **Tuning is containable with normal development techniques for the average customer perception.**
  - e.g. tyres, bushes, springs, dampers, arb's and top mounts
- **The opportunities far outweigh the slight negative changes to vehicle character**
- **Lotus quotes:**
  - "The understanding gained from this study has led Lotus to believe that the small performance deficit could be largely recovered through design changes to suspension compliance bushings, top mounts, PAS characteristics, springs, arb's and damping, all part of a typical new vehicle tuning program"
  - "Add the powerful benefits of active torque control and Lotus's findings make a strong argument for the vehicle dynamic benefits of hub motors as an EV drivetrain"

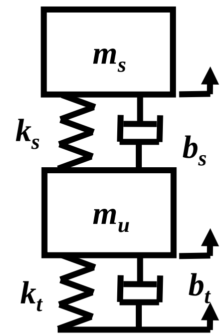
Vehicle Performance and the Integrated Studies

Rather than being obsessive over single performance measures, a 'best practice' balanced scorecard approach was used, focusing on subjective assessment, objective measurements and predictive analysis to review the impact on dynamic performance with increased unsprung mass against:

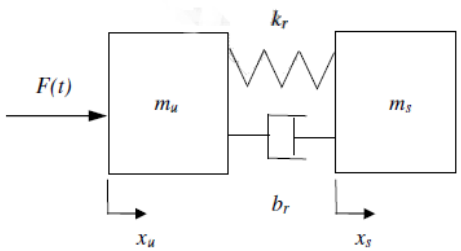
- **Ride** – the ability of the vehicle to absorb distortions
- **Refinement** – the ability of the vehicle to attenuate noise and vibration
- **Active Safety** – the ability of the vehicle to stop and steer in emergency situations
- **Driveability** – the response of the vehicle to the driver's inputs (handwheel, brake and accelerator pedals) in normal situations

Predictive Modelling – Damian Harty, Dunamos Ltd

- **Vertical quarter-car model**
  - Primary ride - RMS sprung accel 0-3hz vertical
  - Secondary ride - RMS sprung accel 3hz+ vertical
  - Grip - RMS tyre normal load variation
    - In response to a random road input – “rough” or “smooth” scaling



- **Longitudinal quarter-car model**
  - Refinement - RMS sprung accel fore-aft
    - In response to a ballistic input



- **Driveability**
  - Lateral – Absolute dynamic index change
  - Longitudinal – Torque rise time change

- **Model parameters**
  - Axle mass range: **720kg – 2300kg**
  - Unsprung mass range: **50 to 80kg per corner (5% to 25%)** i.e. no addition through to +30kgs
  - Primary ride frequencies: **0.8hz – 2.5hz**
  - Damping ratios: **3% - 180%**

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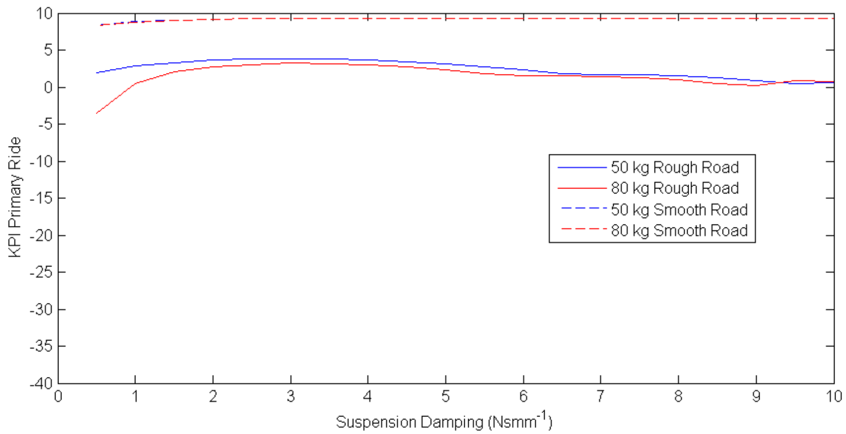
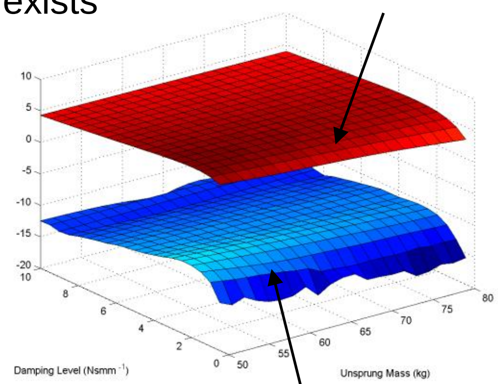
Predictive Ride & Grip

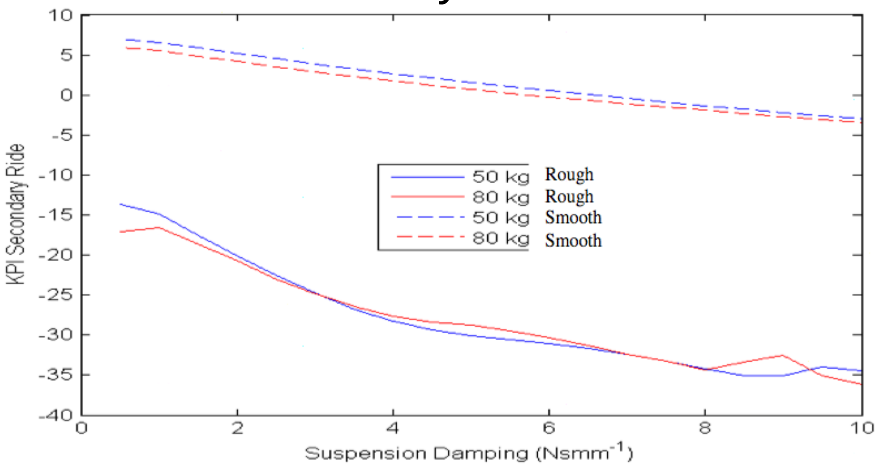
Primary ride < 3hz



- Springs : softer is better
- Dampers: optimum exists
- Unsprung mass: low sensitivity
- **Road roughness: large sensitivity**



Secondary Ride >3hz



- Springs : low sensitivity
- Dampers: softer is better
- Unsprung mass: low sensitivity
- **Road roughness: enormous sensitivity**
- Secondary scores are systematically lower than primary

Ride & Grip are more impacted by road surface and tyre quality than by increasing the unsprung mass!

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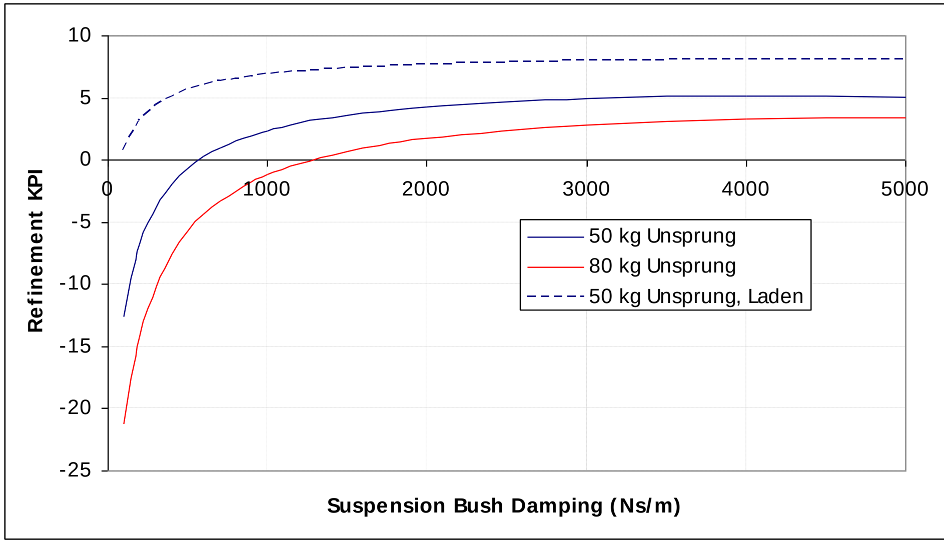
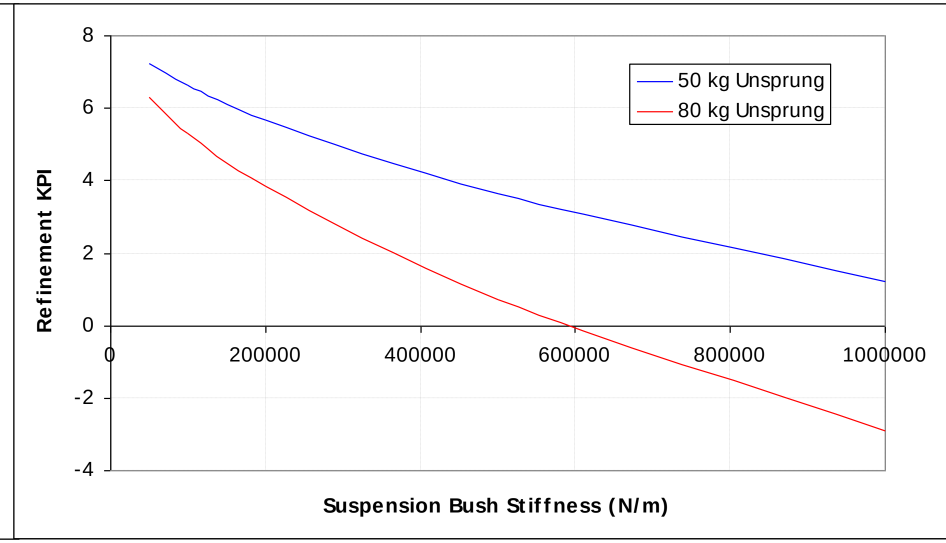
Predictive Refinement

Increased damping vs initial force spike into body:



Decreased stiffness vs lower freq + wheel alignment:



- Increasing the unsprung mass does degrade refinement, especially over rough surfaces.
- Bush stiffness: less is better, and can replace the lost refinement.
- Care must be taken since the fore-aft resonant frequency will go from around 18Hz to around 10Hz. Possible since no suspended powertrain modes to couple with.
- Bush damping: more is better
- Conflict between initial force spike and requirement for high damping drives more complex solutions (e.g. hydrobush)

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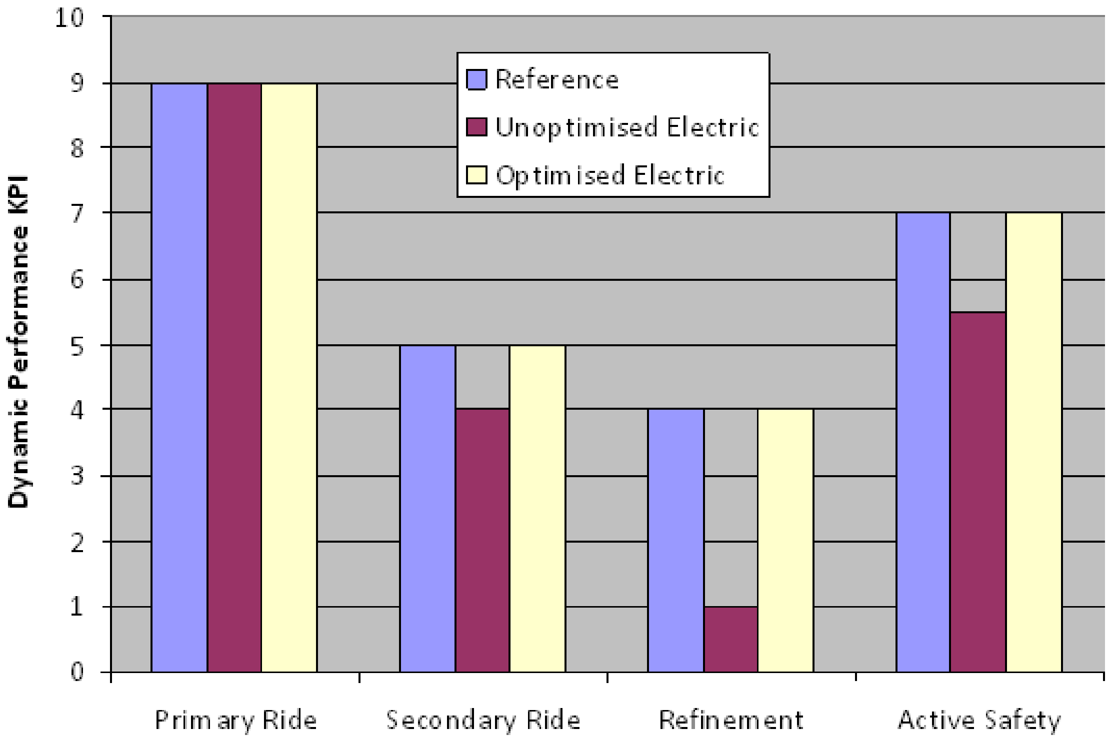
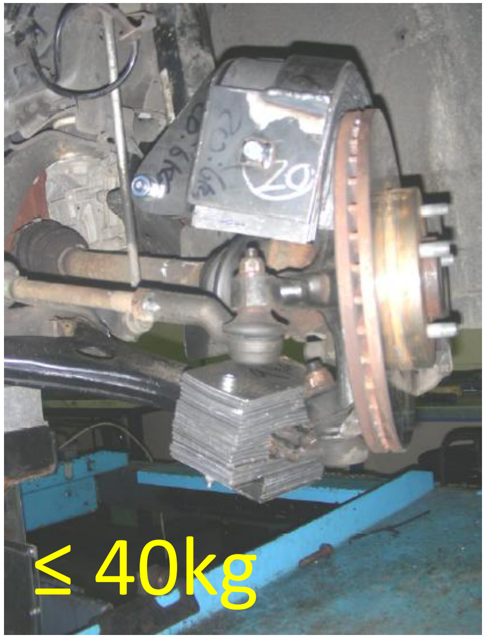
Predictive Modelling Conclusions



Development Tasks

- Nothing “out of the ordinary”
- Tyres and road surfaces ~10x greater effect on grip compared to +30kg unsprung mass
- Slightly stiffer dampers than normal to recover grip and secondary ride
- Longitudinal stiffness reduction whilst maintaining damping – “hydrobushes”

Lotus Engineering – Phase 1 The test vehicle



- 2007 Ford Focus 1.6 "Style"
  - Well damped European hatchback
  - Top-of-class handling, stock condition
  - Unsprung mass addition up to 40kg
- Phase 1 Baseline & Measure Effects
- Phase 2 Recovery towards stock vehicle

	Front	Rear
Wheel Rate (N/mm)	25.3	23.4
Suspension Rate (N/mm)	30.0	25.5
Ride Frequency (Hertz)	1.28	1.49

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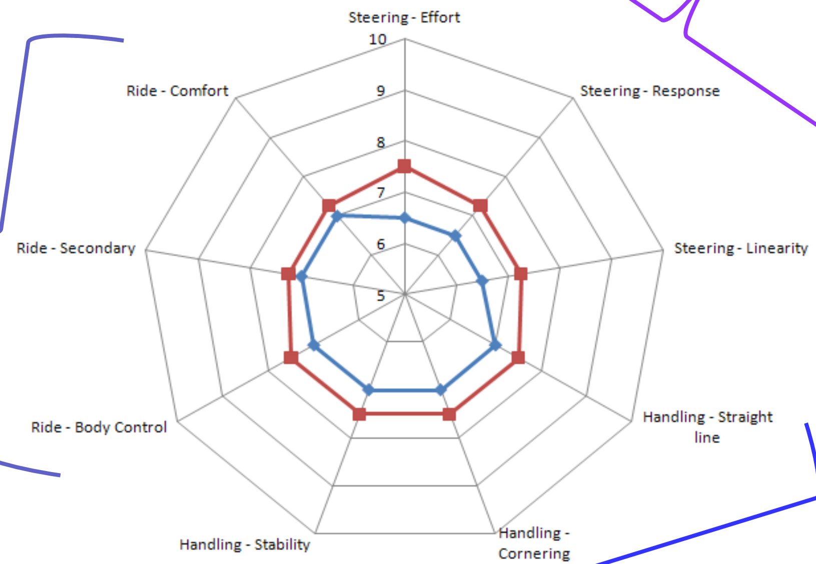
Lotus Engineering – Subjective Results

- Standard
- + 30kg – Typical 18" Protean Motor

Ability for the vehicle to soak up road imperfections:

No impressions described as irrecoverable, merely in need of attention to return the vehicle to standard performance



Ability for the operator to feel connected to the vehicle:

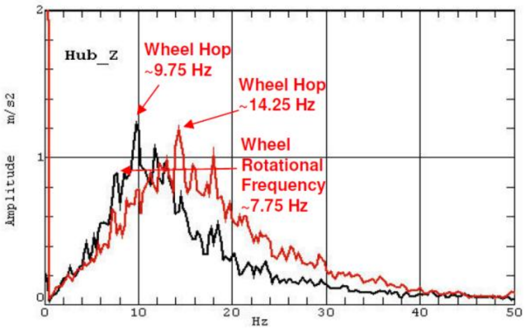
Observed small deficits in the modified vehicle except heavier steering effort

Ability for the vehicle to remain stable and usable:

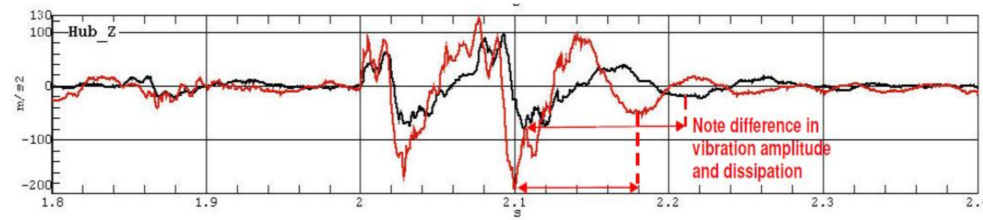
Noted as being rather similar to the base vehicle

Lotus commented "performance is no worse than that which may be expected in the middle of a normal development program and gives no particular cause for disquiet"

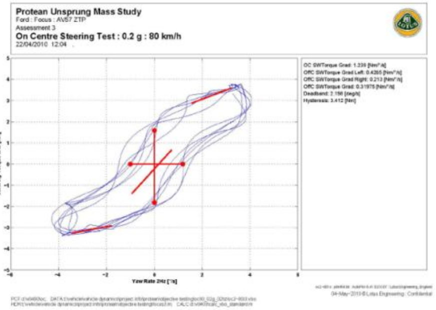
Lotus Engineering – Objective Results



Wheel hop freq lowered as expected (shake road) and no substantial change in level of response, no evidence that vibrations at 10Hz are any more or less evident than at 14Hz, thus ride behavior is not substantially altered.



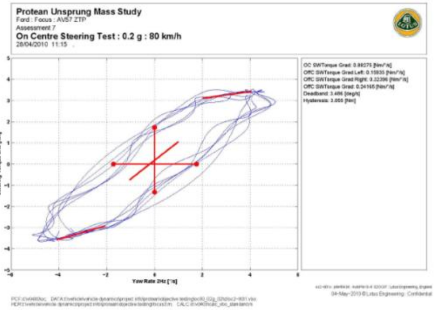
Single bump amplitude and dissipation gives a measurably poorer result, dropping a single VER point:



+30kg Unsprung

On-centre steering torque/yaw rate increases

Non-linear phase relationship more noticeable



Standard

Steering Torque vs Yaw Rate was consistent with the expert driver subjective results. While some differences are measurable using sophisticated engineering techniques, none are beyond normal deviations in a normal vehicle development program.

Lotus Engineering Phase 1 – Conclusions

- Any lost performance can be recovered through normal development tuning
- General small reduction in agility
- Increased unsprung mass improves high frequency isolation
- Separating wheel hop and any powertrain frequencies would restore much subjective secondary ride performance (Note - no vehicle tuning so far)
- Flexibility and opportunity offered through wheel motors gives great dynamic advantages

Lotus Engineering Phase 2 – Suspension Improvements

- The objective was to show if the Vehicle Dynamics performance of the standard Focus could be improved from the Phase 1 level by fitting suspension components from a Focus ST

- The re-tuned vehicle was then tested as follows
  - Subjective Assessment
  - Objective ride and handling tests
  - On-road unsprung mass shake measurements
  - 2-post shaker rig measurements

Lotus Engineering Phase 2 – Suspension Improvements

Subjective Evaluations

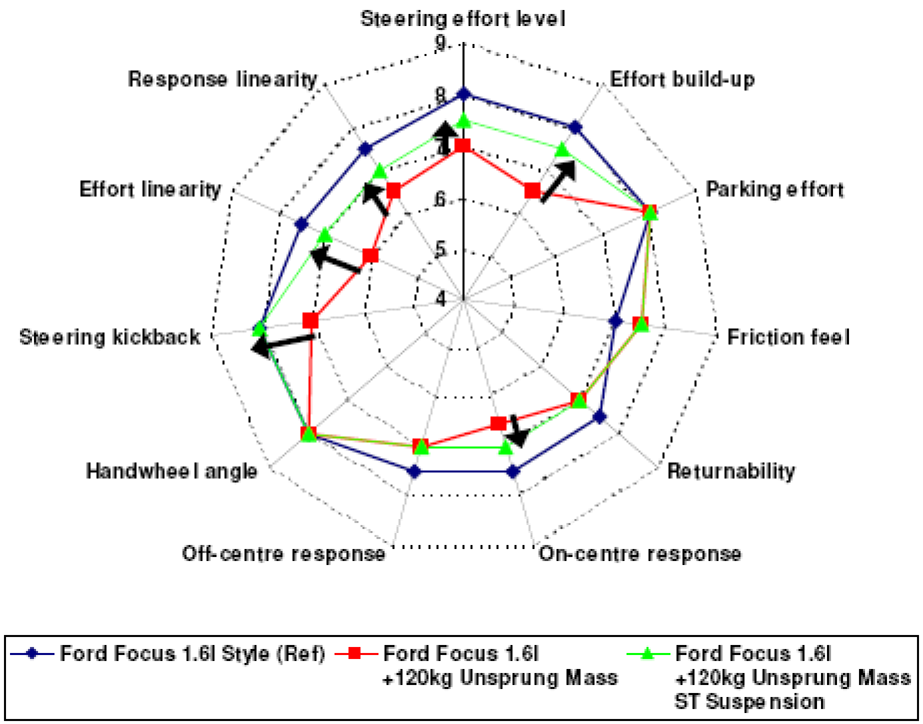
- Three vehicle set-ups are compared:
  - Ford Focus 1.6l as delivered (reference)
  - Ford Focus 1.6l with +120Kg of unsprung mass
  - Ford Focus 1.6l with +120Kg of unsprung mass and Focus ST suspension

- The intention is to demonstrate that degradation in Ride & Handling characteristics by adding 120Kg of unsprung mass to the standard car is within a range which may be remedied by suspension tuning.

- The Focus ST suspension set-up was chosen because it represents the direction (increase spring rate and damping) recommended in Phase 1. It is not a final tune to match the performance of the reference vehicle, but rather intended to demonstrate trends.

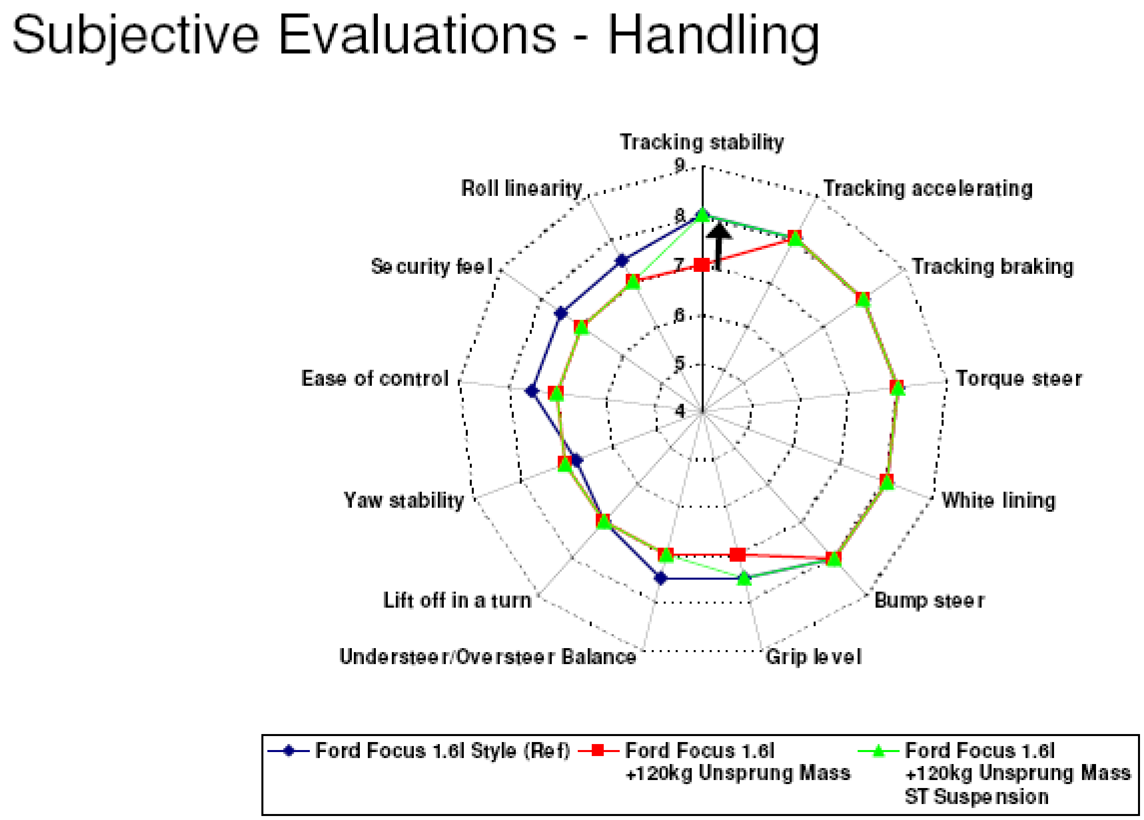
Lotus Engineering Phase 2 – Suspension Improvements

Subjective Evaluations - Steering



- Steering feel and steering response characteristics with additional unsprung mass tend back towards reference when ST suspension is fitted.
- Steering kickback is reduced to reference level with ST suspension.

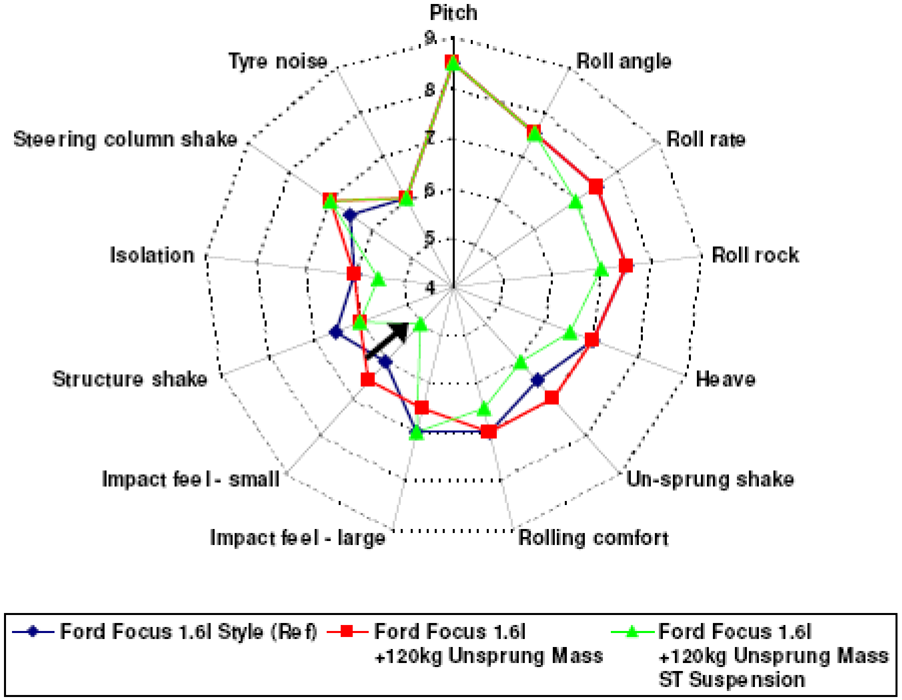
Lotus Engineering Phase 2 – Suspension Improvements



- Improved on-centre response gain characteristics with ST suspension bring straight ahead tracking stability back to reference level.

Lotus Engineering Phase 2 – Suspension Improvements

Subjective Evaluations - Ride



- Some items of ride comfort deteriorate slightly with the ST suspension.
- Impact feel on small impacts is the most noticeable deterioration.

Lotus Engineering Phase 2 – Suspension Improvements

Subjective Evaluations – Conclusions

- Steering items were subjectively degraded most by adding 120Kg of unsprung mass to the vehicle when compared with the as delivered condition.
- Fitting the ST suspension to the vehicle with the increased unsprung mass improved steering items and the trend in all cases was back towards the reference vehicle (all items returned within ½ VER point of the reference).
- Handling items were not degraded further by fitting ST suspension with the 120Kg of additional unsprung mass, and on-centre tracking stability improved back to the reference.
- Some ride comfort items deteriorated slightly by fitting the ST suspension. This is not surprising considering the sporting bias of the ST; a tuning exercise could take greater account of ride comfort relative to the reference during development.
- Fitting the ST suspension demonstrated that the deficiencies resulting from increasing the unsprung mass by 120Kg can be affected by parts included in a typical R&H suspension tuning programme.
- The exercise increased confidence further that the degradation in R&H performance from adding 120Kg of unsprung mass is recoverable by tuning standard items.

Conclusions – "The Realities"

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Questions

Motor Wheel 1931

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