ENGINEERING

Dynamics of Vehicles With In-wheel Motors

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Background

- Traditionally Vehicle Designers seek to reduce Unsprung Mass , notionally to improve ride comfort.
- The introduction of the additional mass of In-wheel electric motors would seem to work against this and produce worse dynamics.
- Protean makes such motors and were keen to understand if simple countermeasures could compensate for this perceived issue.
- As Part of this investigation Protean commissioned Lotus Engineering to carry out two phases of work: -
  - **Phase 1**
    - Subjective and objective assessment of a Ford Focus before and after adding unsprung mass.
  - **Phase 2**
    - Modification of certain suspension components to regain the lost performance.

  - ***Both phases were supported by CAE analysis*.**
- This paper presents some of the main findings of that work

Outline

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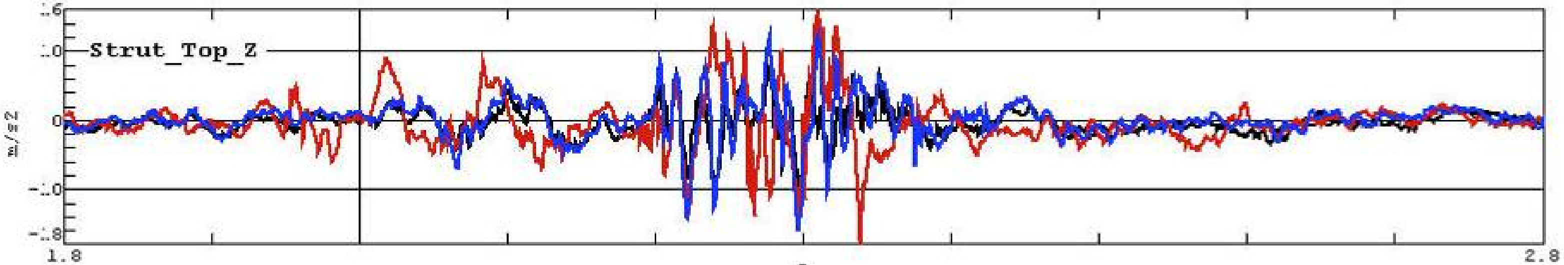


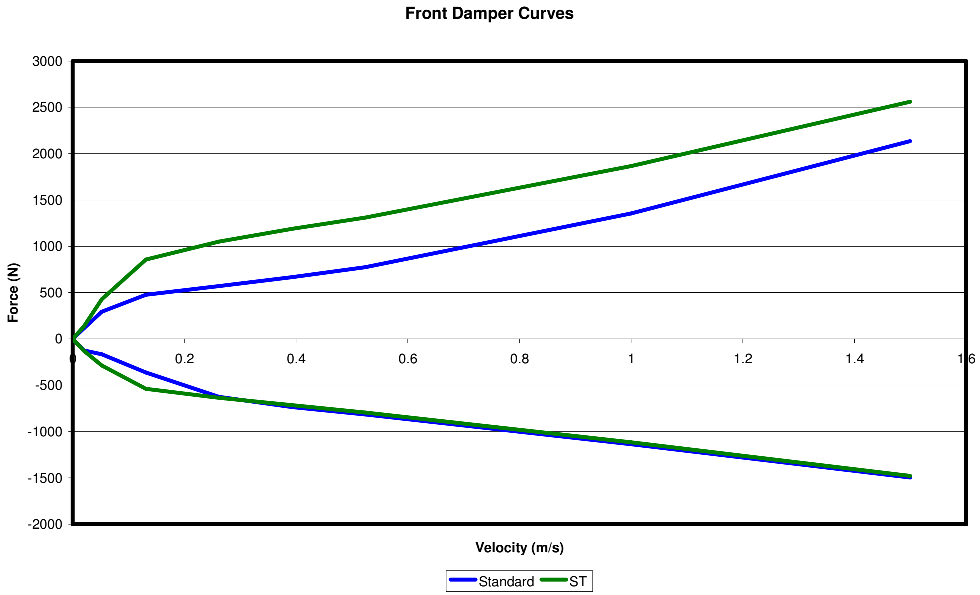
- **Test vehicle and modifications**
- **Vehicle tests**
- **Results**
  - **Subjective**
  - **Objective**
  - **CAE**
- **Conclusion**
- **Acknowledgements**

The Test Vehicle

- 2007 Ford Focus 1.6 “Style”
  - Well damped European hatchback
- Unsprung mass addition of 30 Kg per corner

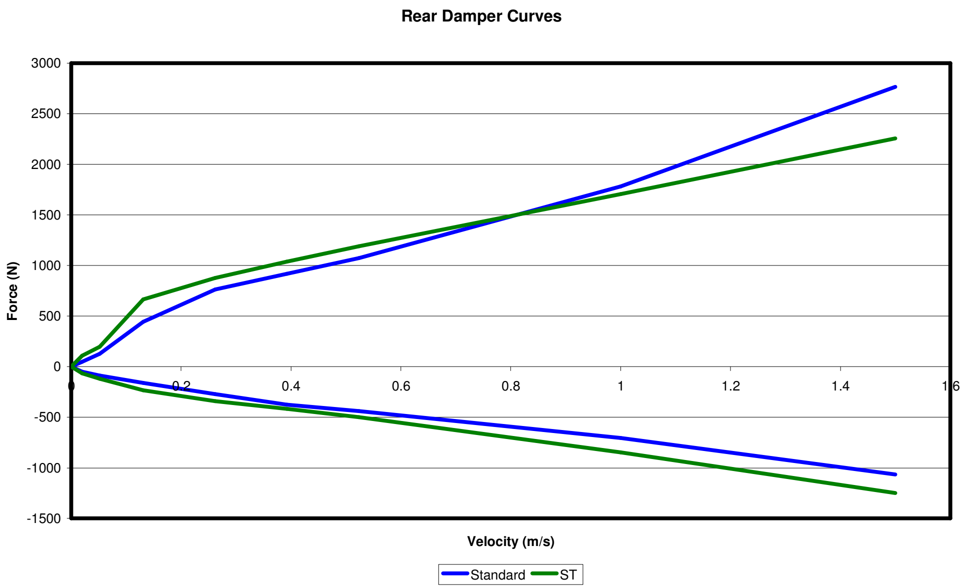
Ride Frequency Hz	Front	Rear
Standard	1.24	1.49
Standard + 30kg	1.29	1.53
Modified + 30kg	1.55	1.71

The Modifications



The changes made to the standard Ford Focus suspension were confined to the springs, dampers and rear anti-roll bar.

	Standard Specification (measured)	ST Specification (measured)
Front Spring	20.2N/mm	30.5N/mm
Rear Spring	22.4N/mm	23.5N/mm
Rear Anti-Roll Bar Dia.	20.0mm	21.2mm



Vehicle Tests – Subjective & Objective

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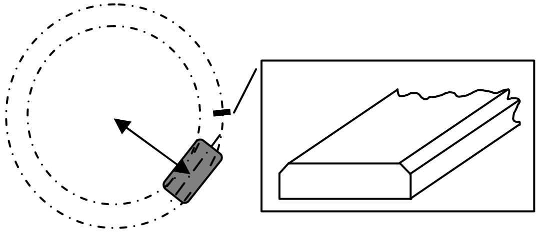
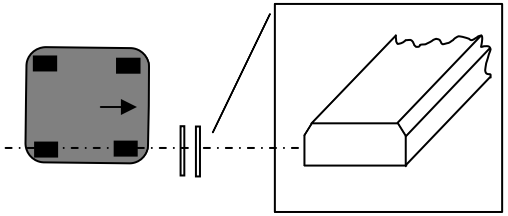
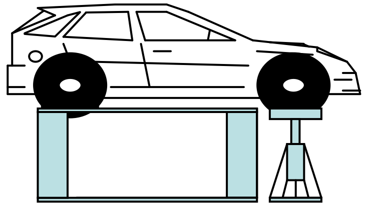
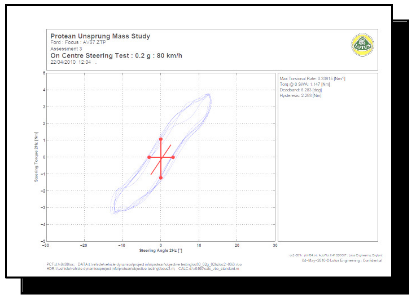






- Shake road 50 km/h
- Bump in Turning circle
- Straight line bumps 50 km/h
- Straight line bump 80 km/h
- Two Post Shaker Rig
- On Centre Steering assessment



Subjective Evaluations - Steering

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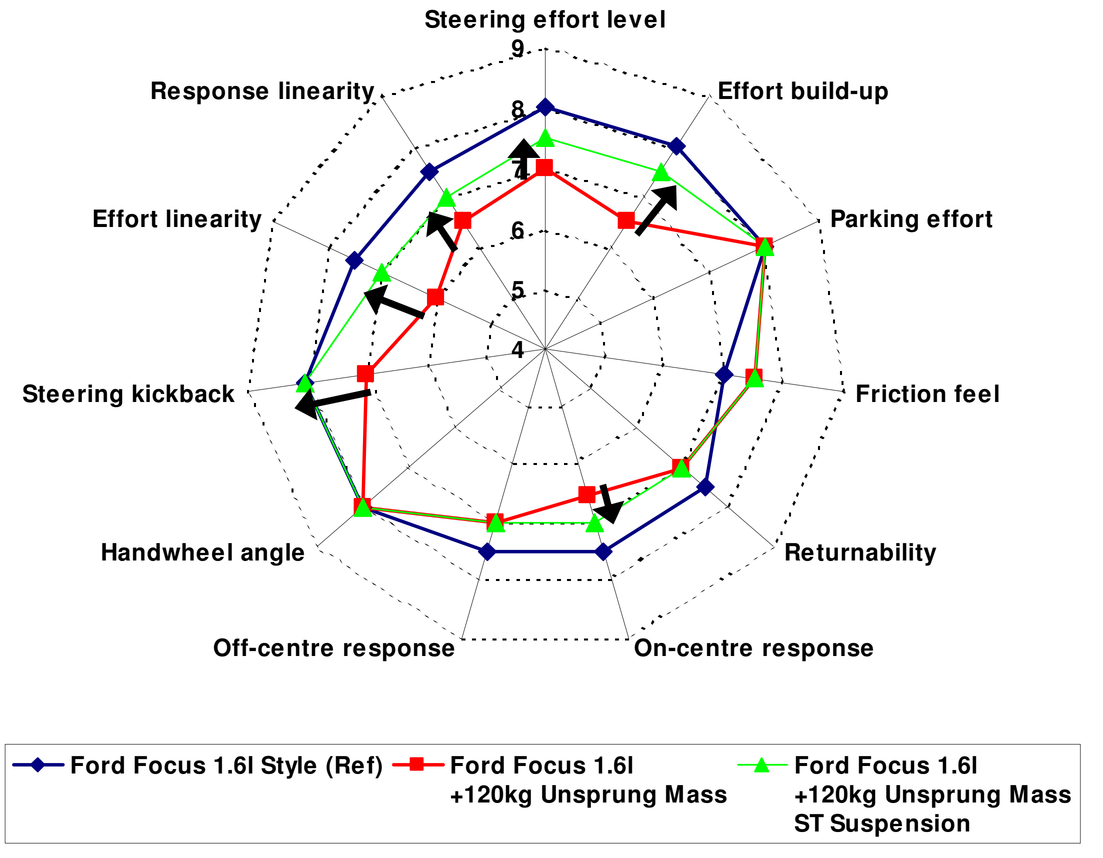

- Steering feel and response characteristics with the additional unsprung mass tend back towards reference when ST suspension is fitted.
- Steering kickback is reduced to reference level with ST suspension.

Subjective Evaluations - Handling

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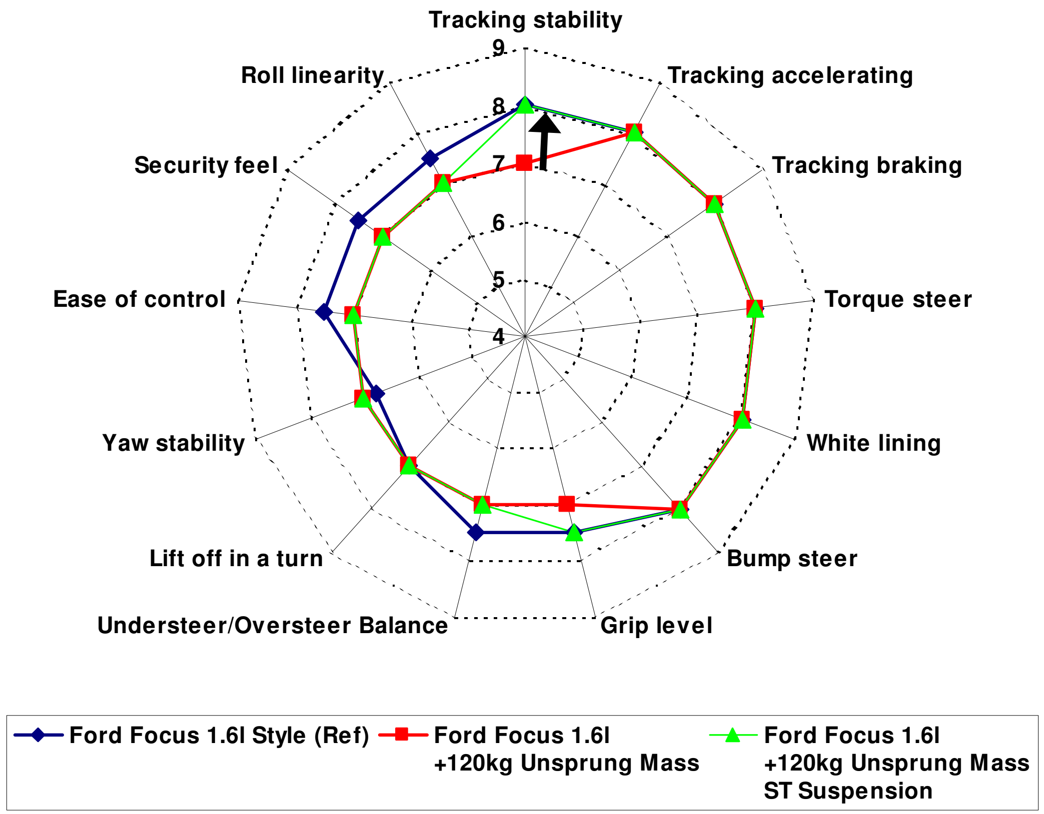

- Improved on-centre response gain characteristics with ST suspension bring straight ahead tracking stability back to reference level.

Subjective Evaluations - Ride

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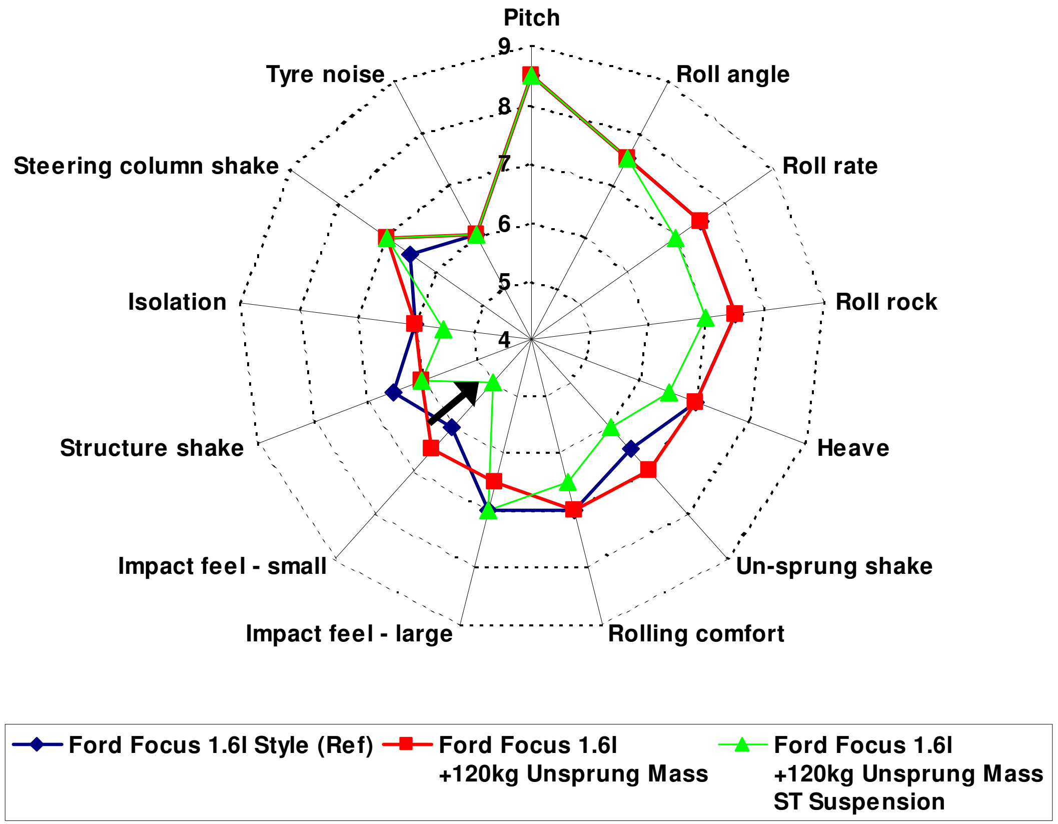

- Some items of ride comfort deteriorate slightly with the ST suspension.
- Impact feel on small impacts is most noticeable deterioration.

Subjective Assessment Results Summary

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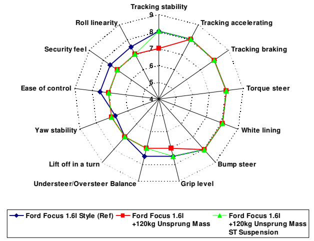
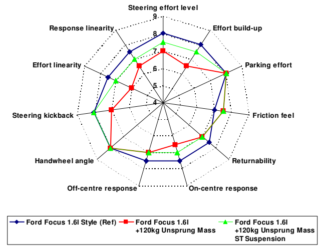
- Subjectively - Steering items were the most degraded by adding unsprung mass.

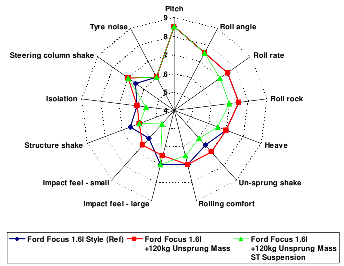


- Stiffer suspension improved steering items to within ½ VER point of the reference

- Handling and agility was degraded with extra mass but not degraded further by stiffer suspension and on-centre tracking stability improved back to the reference.

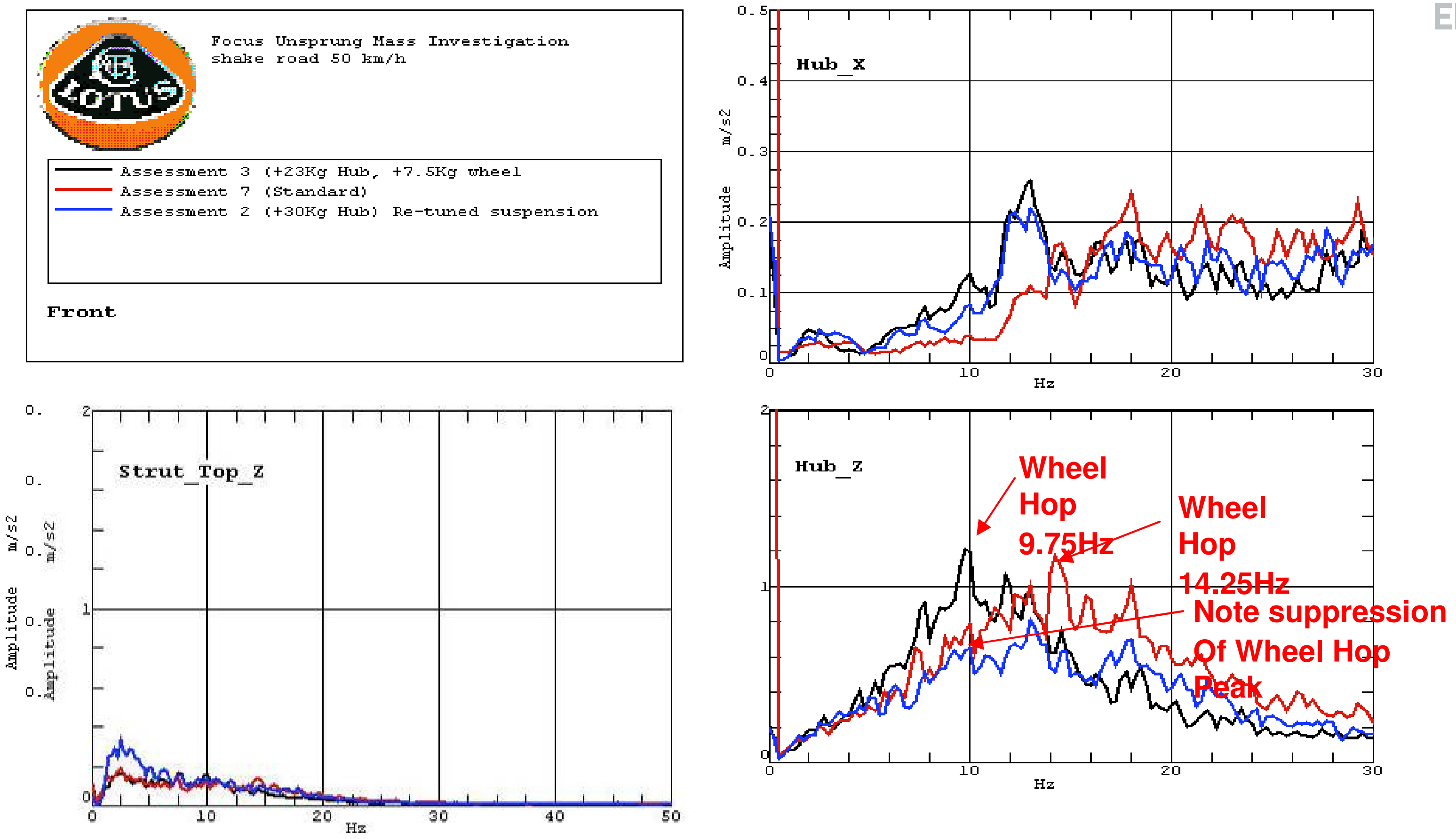


- Some ride comfort items deteriorated slightly by fitting the stiffer suspension but this was not optimised for ride comfort. High frequency isolation was improved.



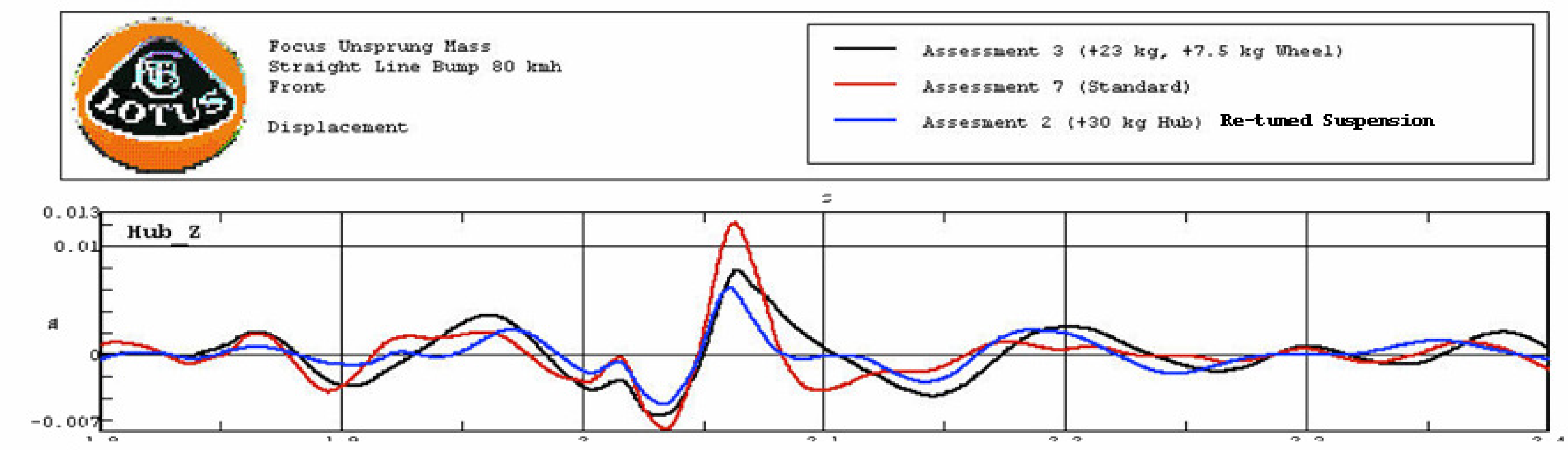
- The deficiencies resulting from increasing the unsprung mass could be largely counteracted by parts included in a typical R&H suspension tuning programme.

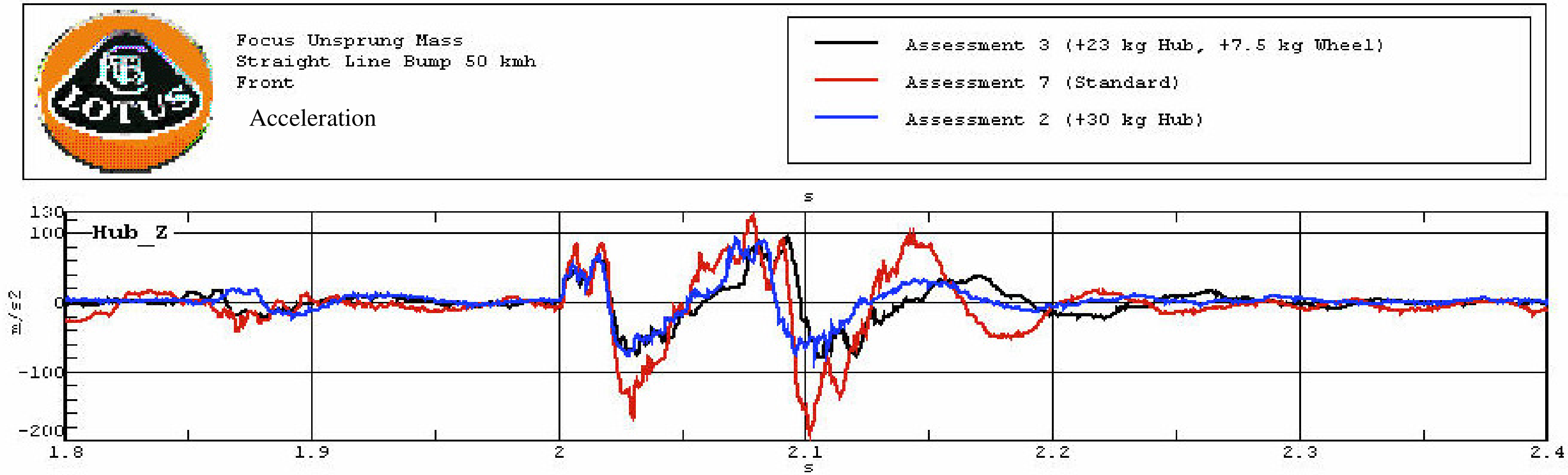
Results - Objective Ride Shake



- Greater unsprung mass reduces wheel hop frequency but increases amplitude.
- Stiffer suspension suppresses wheel hop amplitude but increases body acceleration.

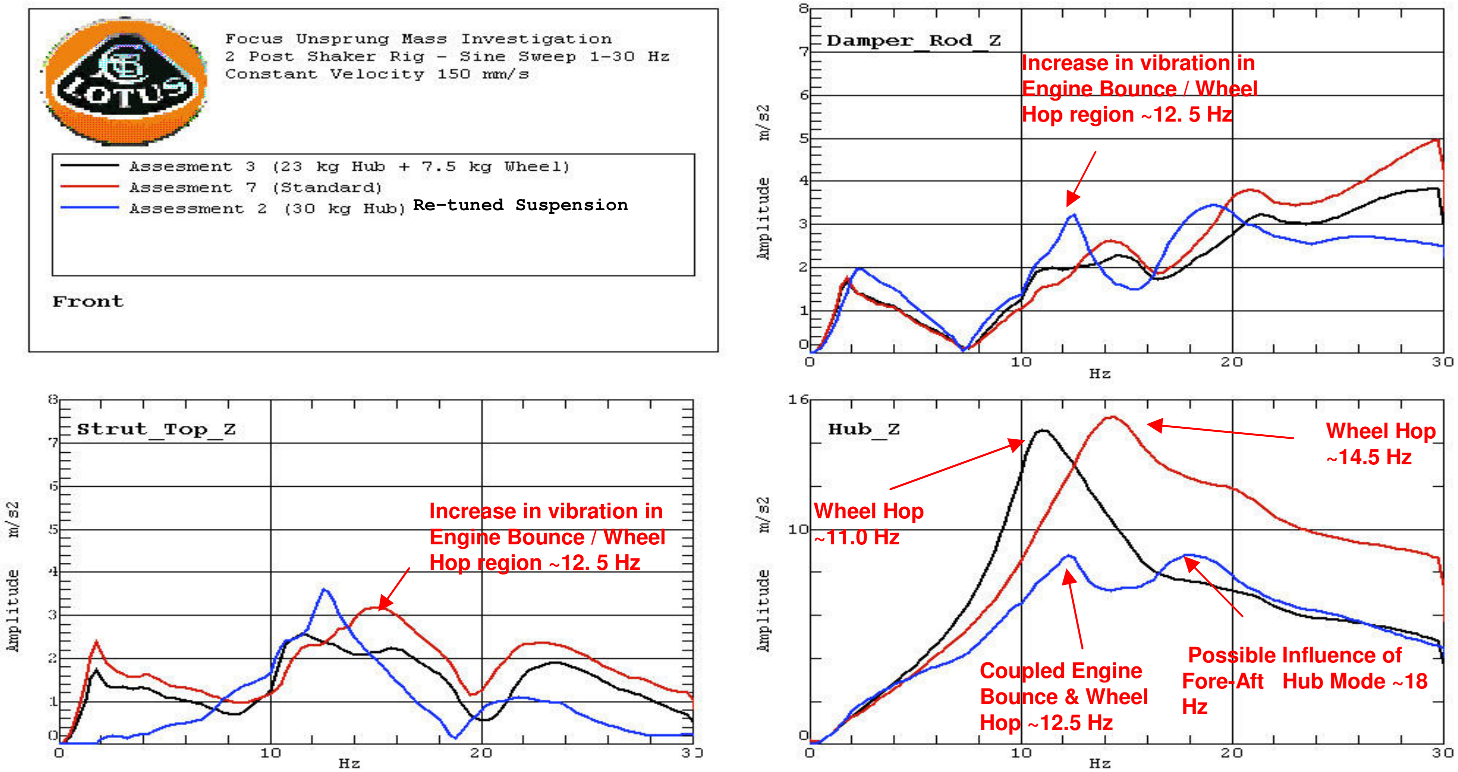
Results – Bump Test Hub Z





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

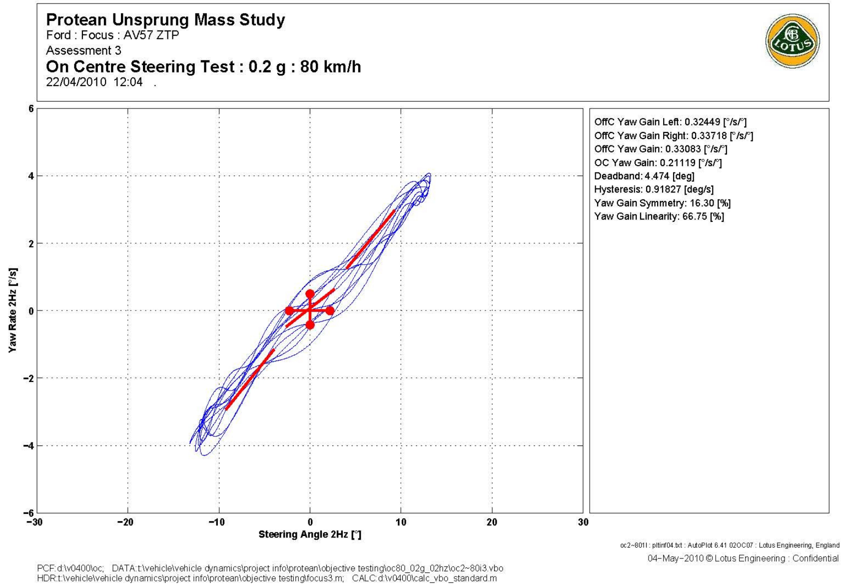
Results Shaker Rig



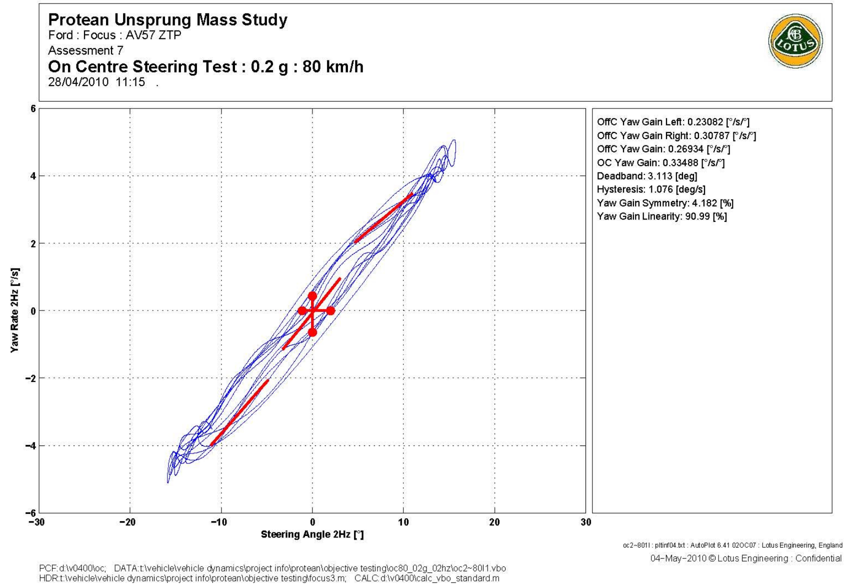
- Engine Z vibration showed that the engine bounce mode was strongly coupled with wheel hop with the increased unsprung mass .
- Re-tuning the suspension resulted in a significant reduction in hub vibration, but the amplitude of the engine bounce mode increased. And would require tuning of the engine mounts
- (If this was an Full EV engine mode would be absent)

Objective Results - Steering Response

– Off centre Yaw Rate gain increased
– On centre connection decreased



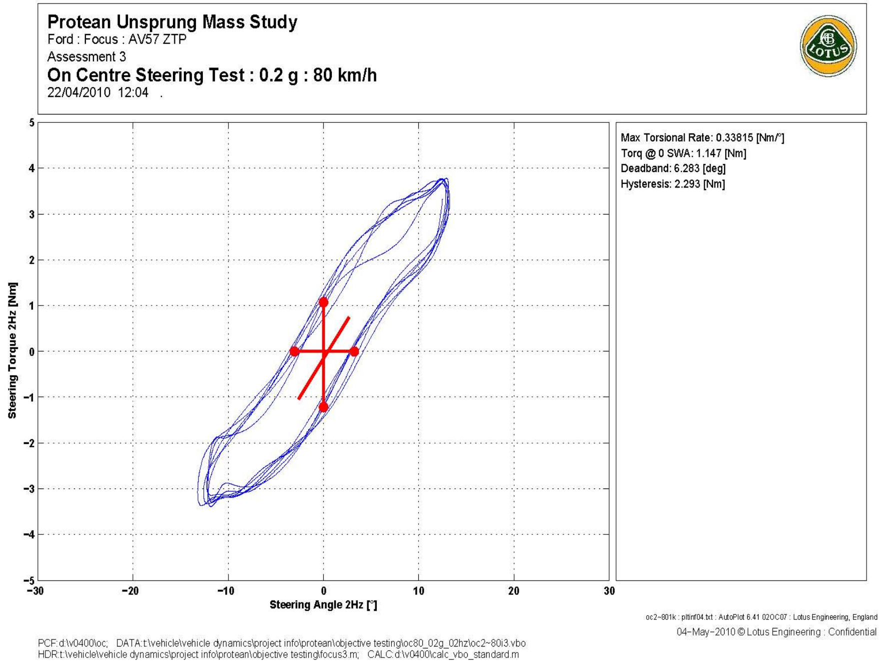
+30kg Unsprung



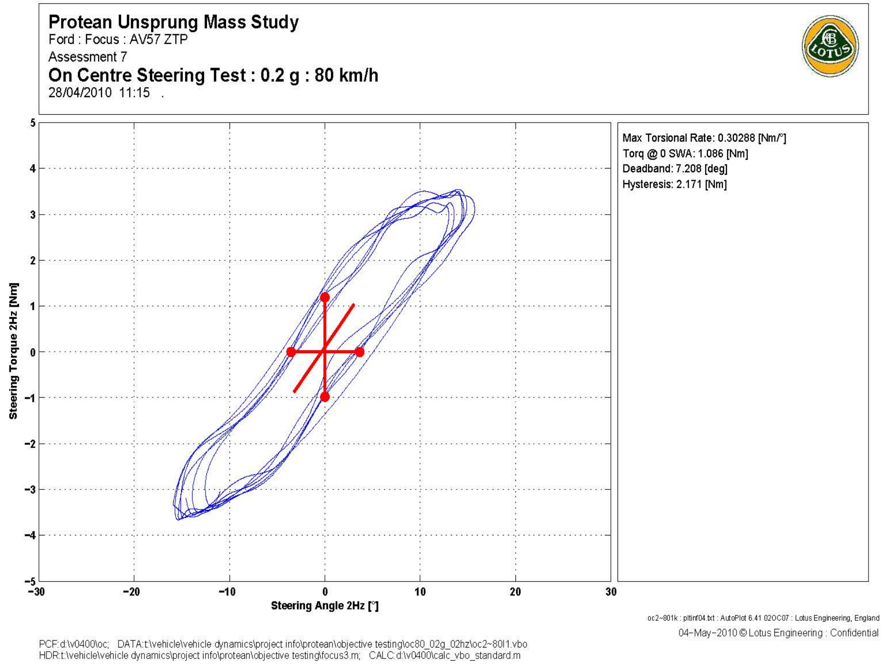
Standard

Objective Results - Steering Effort

– Steering effort level increased by up to 10%
– Steering Hysteresis increased
– Phase relationship diminished with increased unsprung mass



+30kg Unsprung mass

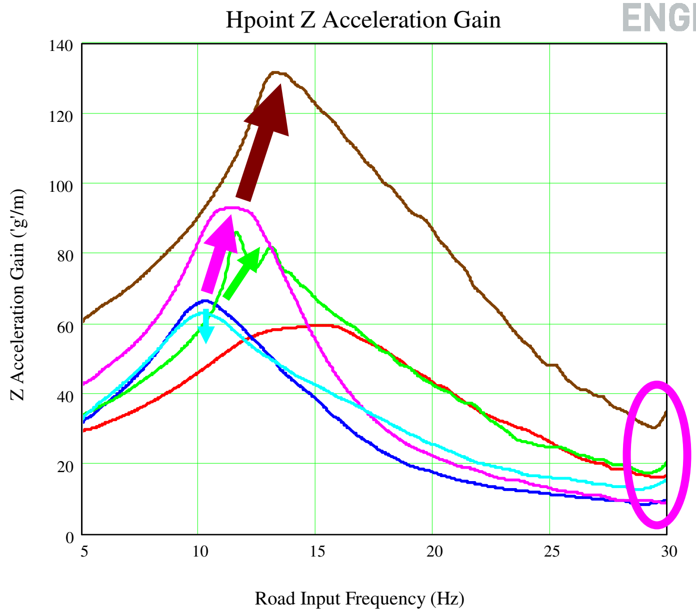


Standard

CAE Analysis

Analysis

- Non–linear parameterised dynamic vehicle model populated from K&C measurements
- Full non-linear kinematic wheel motion characteristics
- 24 dynamic compliant degrees of freedom



Red = std

Blue = + 33 kg

Green = +33 kg + **2 x tyre stiffness**

Magenta = +33 kg + **2 x damper forces**

Cyan = + 33 kg + **2 x top mount stiffness**

Brown = +33 kg **with all changes**

Conclusions

- Stiffer suspension helps hub control and high frequency Isolation but hurts lower frequency ride.
- Tuning Top mounts is a promising countermeasure
- Biggest challenge is lowered wheel hop frequency coupling with Engine bounce -(this would not be an issue with a pure EV + hub motors)
- Limitation on tyre stiffness may limit scope for tuneability

Conclusions

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- The resulting performance – even without Optimisation - can produce a customer acceptable driving experience
- The Negative Effects of Adding Unsprung Mass could be significantly compensated by Traditional Chassis and Powertrain Design and Tuning measures
- Limitations may exist in the availability of suitable tyres – which may need development to better suit the overall system performance
- Further challenges to be addressed will be the ability of the suspension to absorb traction torque reaction without loss of isolation or kinematic control.

Acknowledgements

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Thank You

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