WHERE INSPIRATION AND INNOVATION COMBINE

prodrive

low bandwidth active toe – the next steps

Matthew Taylor - Principal Engineer Vehicle Dynamics

introduction

- Modern vehicles – what is the scope for true improvement?
- Can we sell real improvements in the market place?
- What is the real ‘performance’ that customers want?
  - Brand identification
  - Daily enjoyment
  - Pleasure of ownership
- How do we achieve a competitive advantage?
  - Should we leap ahead of the competition?
  - Should we match the competition but sell for less money?
- What is the appropriate engineering approach?

the benefit of perceived performance

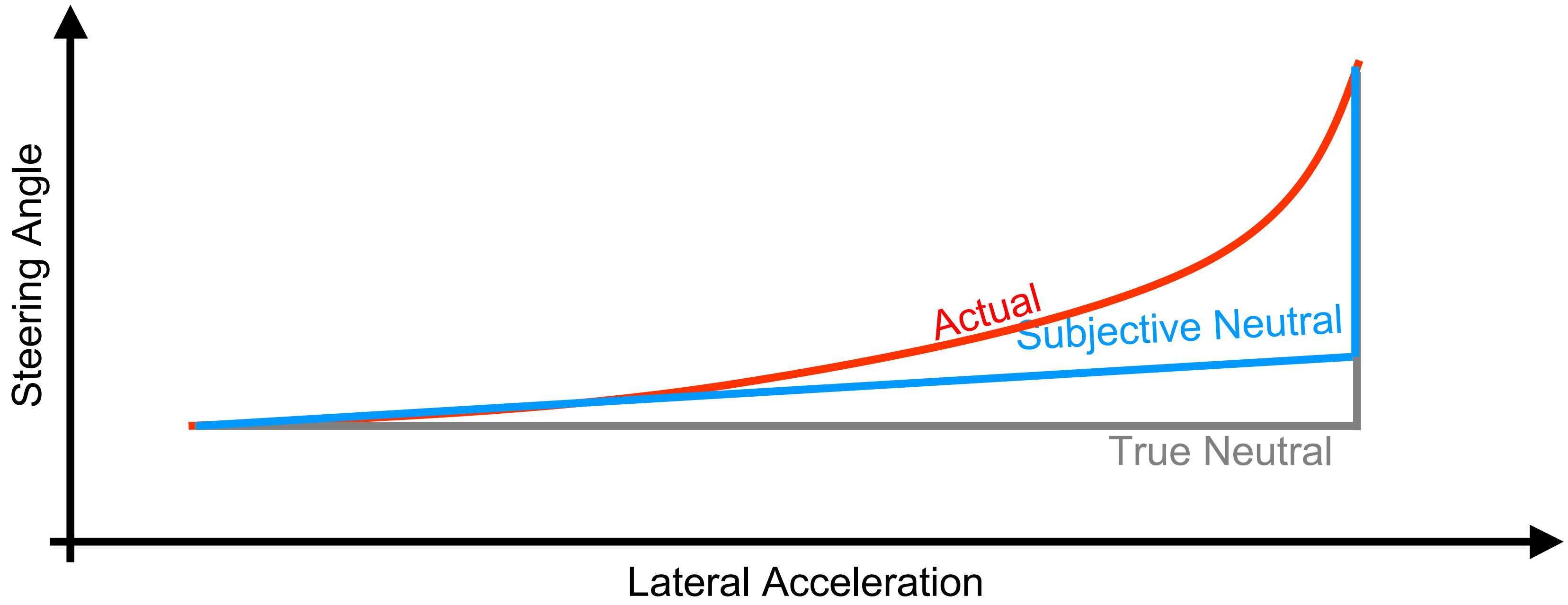
- Strong brand benefits all range but there are further opportunities for the image conscious customer
  - ‘Sport’ sector of market is strong and complementary to performance sector
  - customers look for ‘personality’ and ‘feel’ in pursuit of ‘sportiness’
  - ‘Sport’ models deliver important attributes with much smaller engineering costs

is performance feel easier to sell than performance?

- Non-saleable benefits are of little interest
- Current market place is more cost-driven than ever
- First-to-market is significant gamble for most OEMs
- It is not strategically sensible to ‘leap frog’ competitors
- The aim is to influence the car in a way which the customer appreciates

modern drivers – what do they perceive?

- ‘Linear’ map based on behaviour of the car at low demand and extrapolated
- Perception is more influential to the driver than reality
- Concept is easily investigated and reacted to
  - subjective understeer is an excellent example



low bandwidth active toe

- Many genuine improvements simply cannot be justified in the current market place

- Rear steer – limitations and benefits
  - rear steer has appeared periodically throughout the decades
  - still has a number of applications today
  - dynamic benefit is undeniable
  - high cost is unarguable!

- Rear suspension system requirements
  - rear suspension systems have become increasingly expensive
  - current environmental legislation requires engineering budget to be diverted to endeavours which will ultimately improve drive cycle performance
  - Active Toe offers an opportunity to reduce rear suspension costs and directly influence drive cycle performance of a vehicle

active toe concept

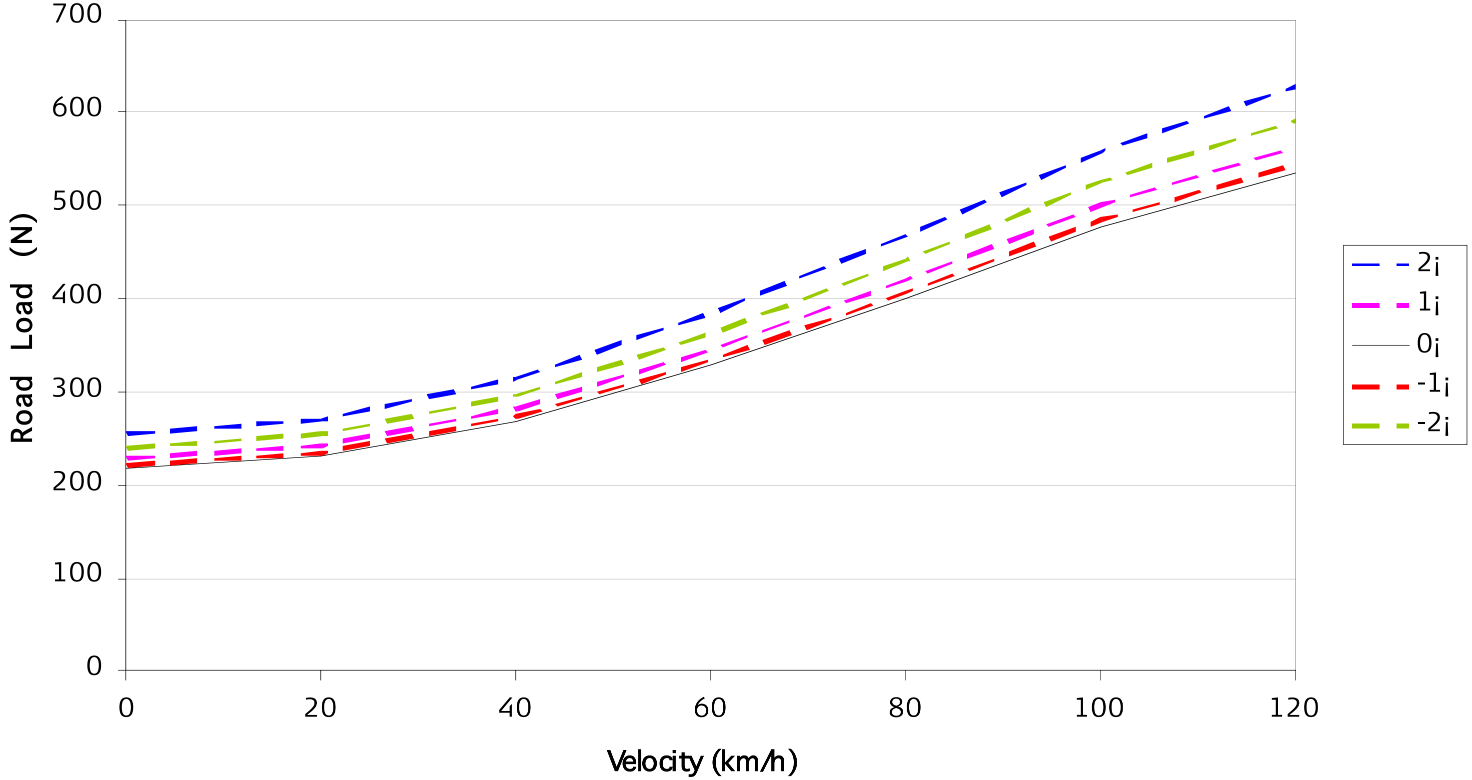
- Prodrive's active toe concept is designed to yield some benefits of active rear steer but for a significantly reduced cost
  - principle is, essentially, to provide adaptable geometry
- Rear toe geometry directly influences
  - yaw rate gain and yaw rate / lateral acceleration phasing
  - coast down performance

active toe concept - demonstrator

- Prodrive has partnered with a Tier One supplier to build a number of demonstrator vehicles for proof of concept
- Data in this presentation was taken from a BMW E60 530i
  - simple modification of rear axle possible
  - excellent chassis yields conservative conclusions

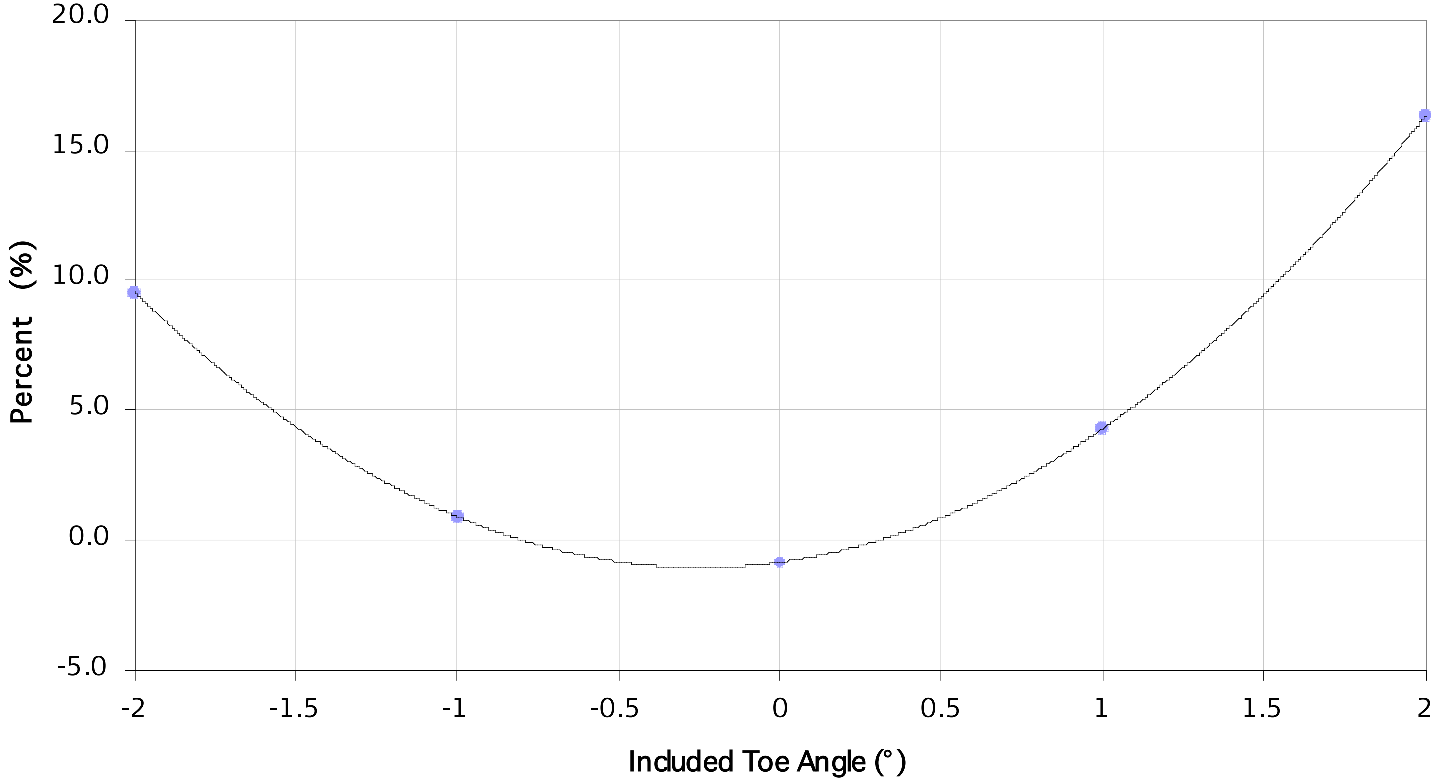
rear geometry effect on coast down performance

- Coast down tests performed with a range of rear geometry settings
  - range arguably greater because of potential to change during use
- Curves determined using the Rolling/Total resistance ratio as defined in Appendix 3 of 70/220/EEC



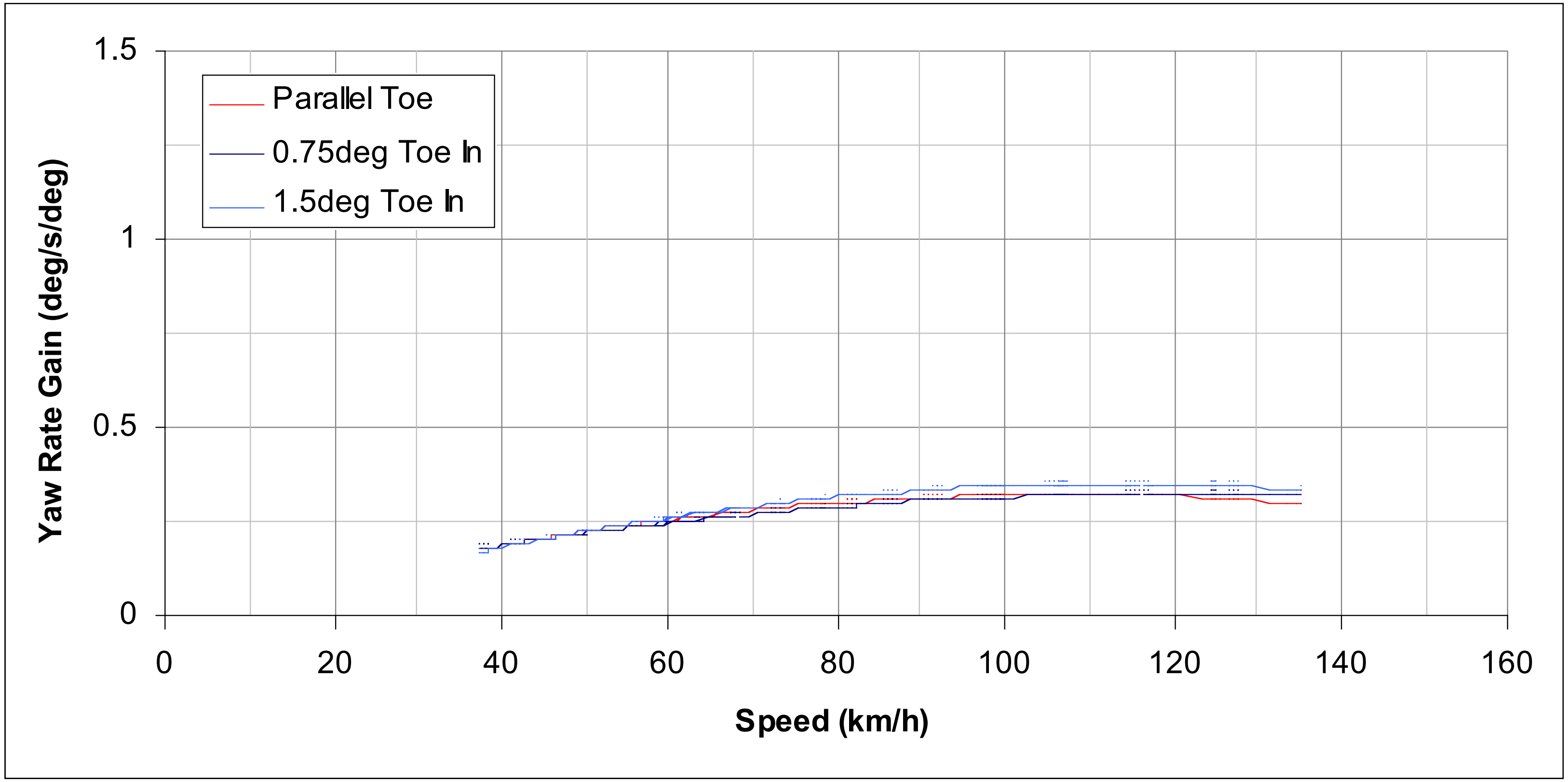
rear geometry effect on coast down performance

- Coast down tests performed with a range of rear geometry settings
  - range arguably greater because of potential to change during use
- Expressed as percentage – range is clearer
  - initial surprise that parallel is not least resistant – compensation for camber



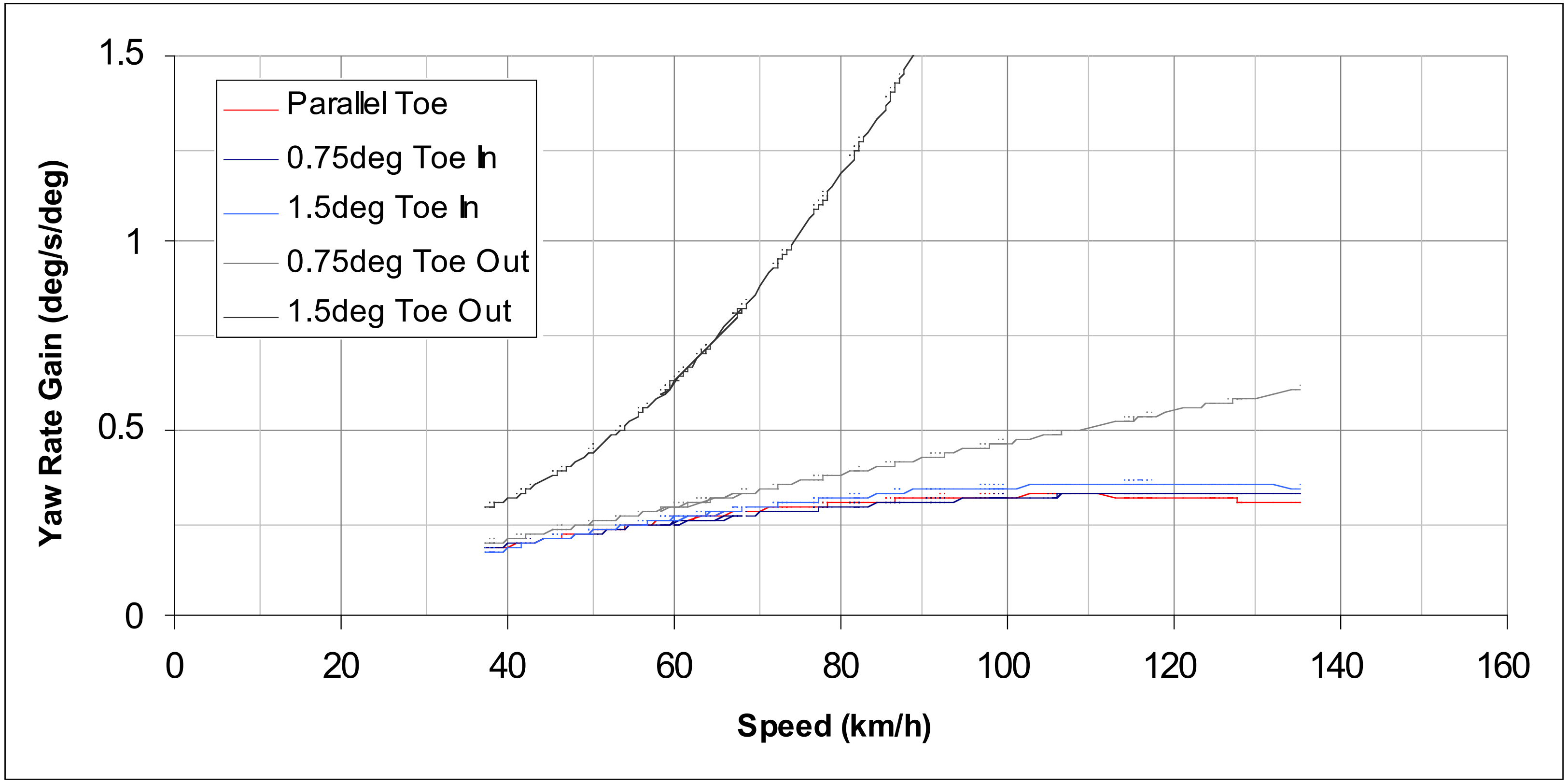
rear geometry effect on yaw rate gain

- Similar testing carried out to confirm effect of toe change on yaw rate gain
- Swept sign test executed at discrete speeds
  - parallel toe to toe-in yields surprisingly small change



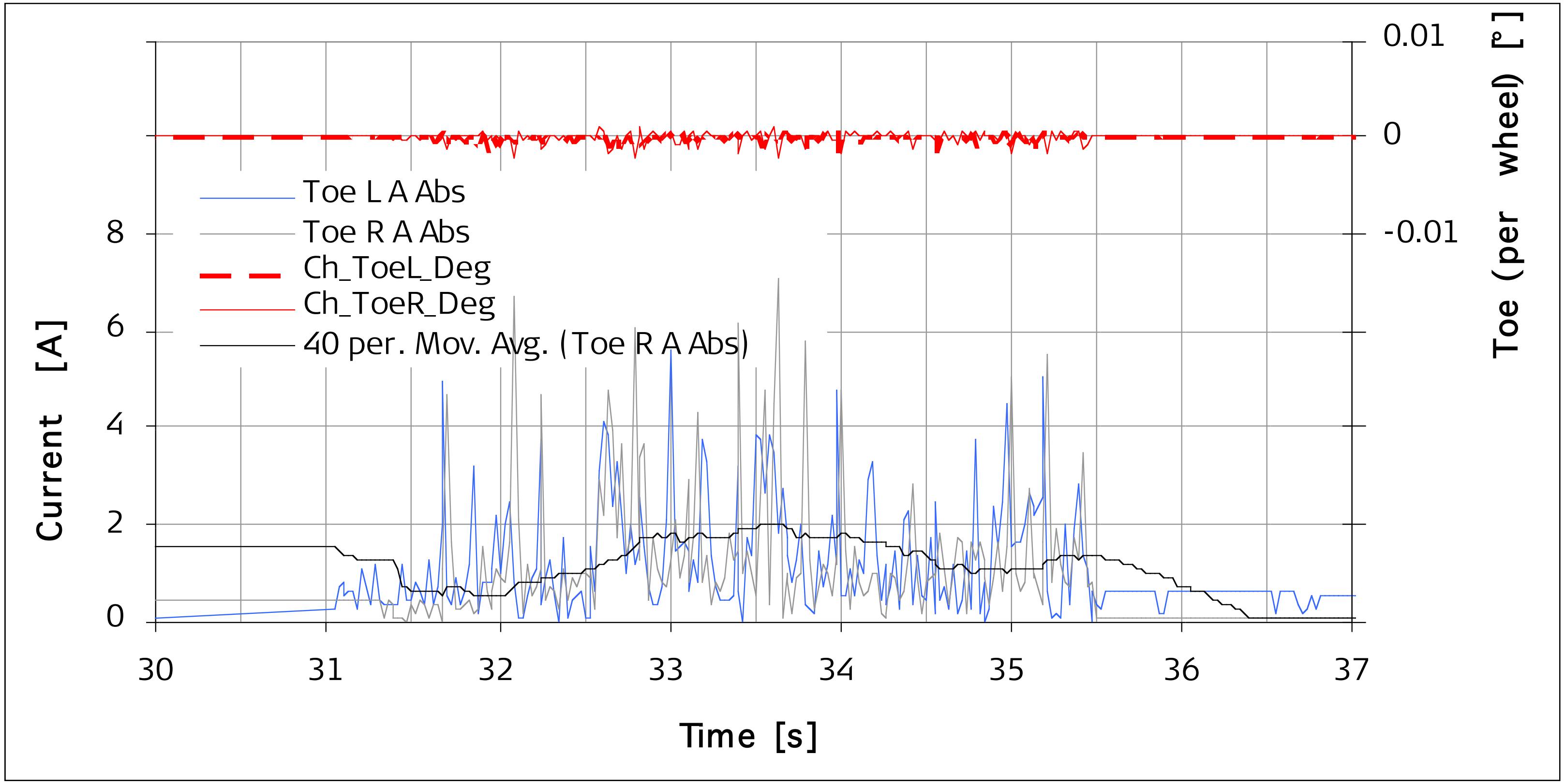
rear geometry effect on yaw rate gain

- Similar testing carried out to confirm effect of toe change on yaw rate gain
- Swept sign test carried out at discrete speeds
  - parallel toe to toe-in yields surprisingly small change
  - however toe-out yields much more dramatic effect



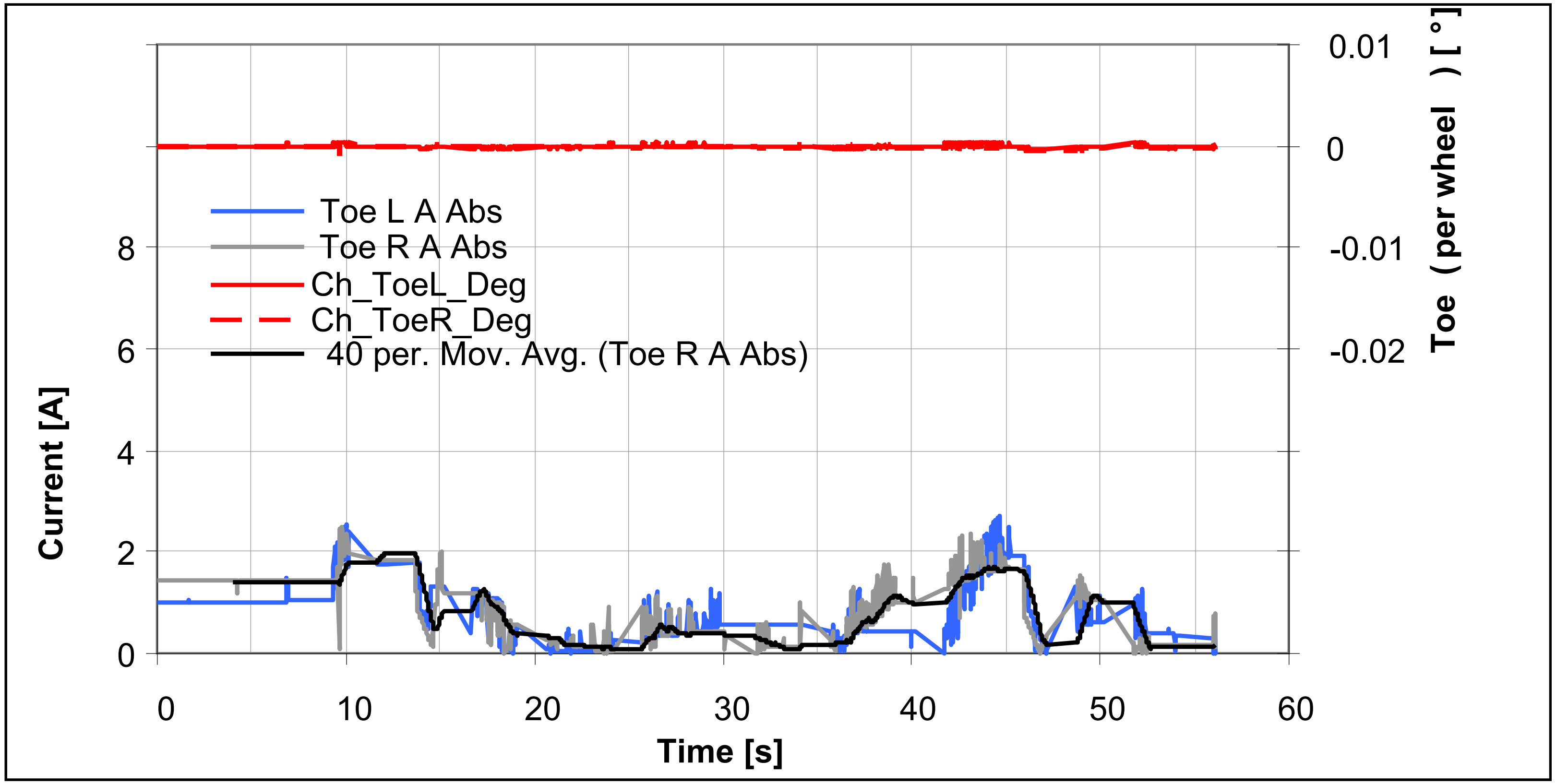
power demands for rear toe control

- An initial concern over toe ‘stiffness’ was assessed at length
- Actuator performance over rumble strips
  - ABS rumble strips used to confirm high frequency performance of toe control
  - toe change is minimal at all points



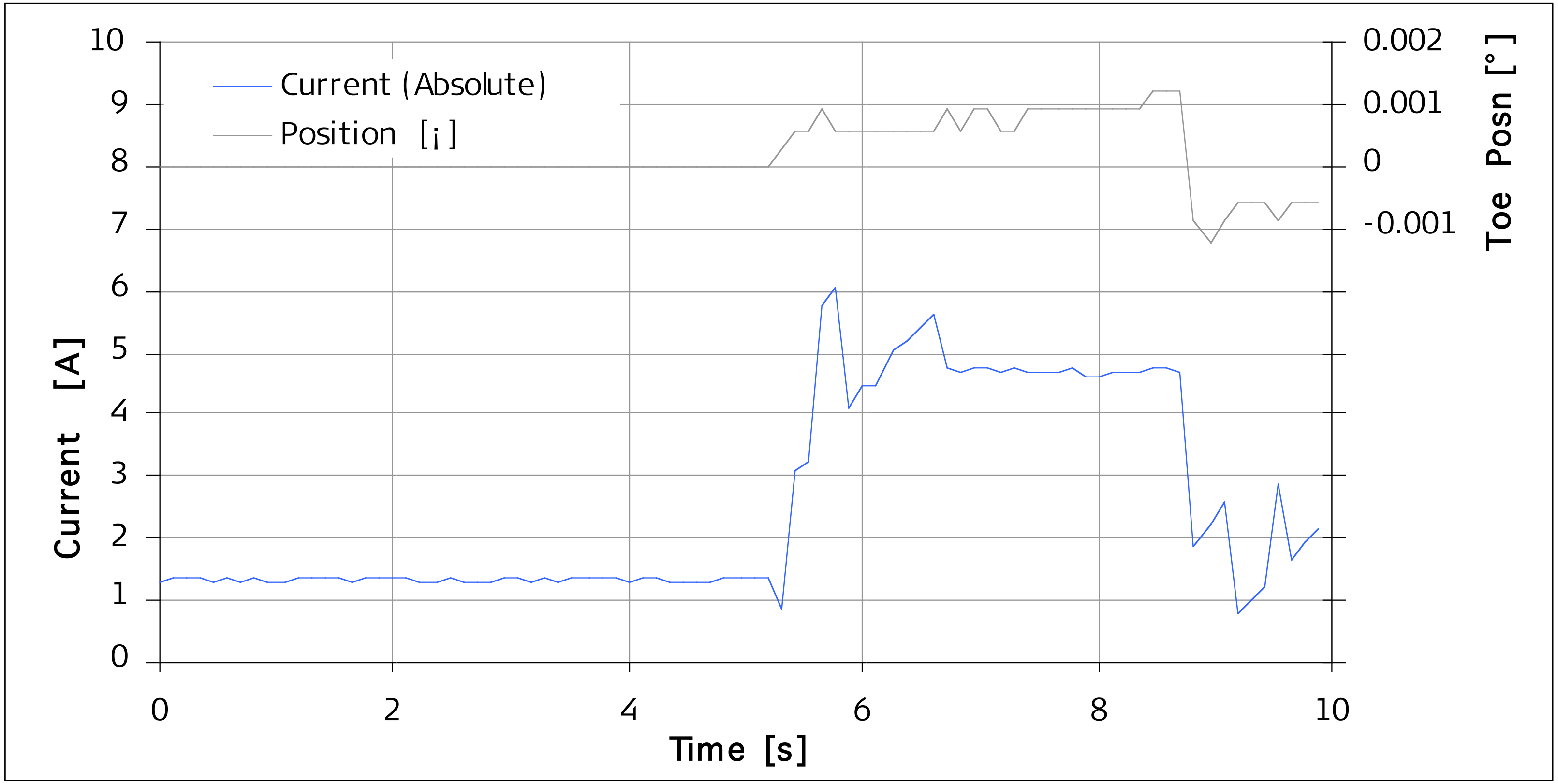
power demands for rear toe control

- Pursuit of efficiency benefits must not be compromised by actuator power
- Actuator performance on ride and handling circuit
  - Prodrive ride and handling circuit used to simulate on road driving
  - power consumption of system typically less than 60W peak



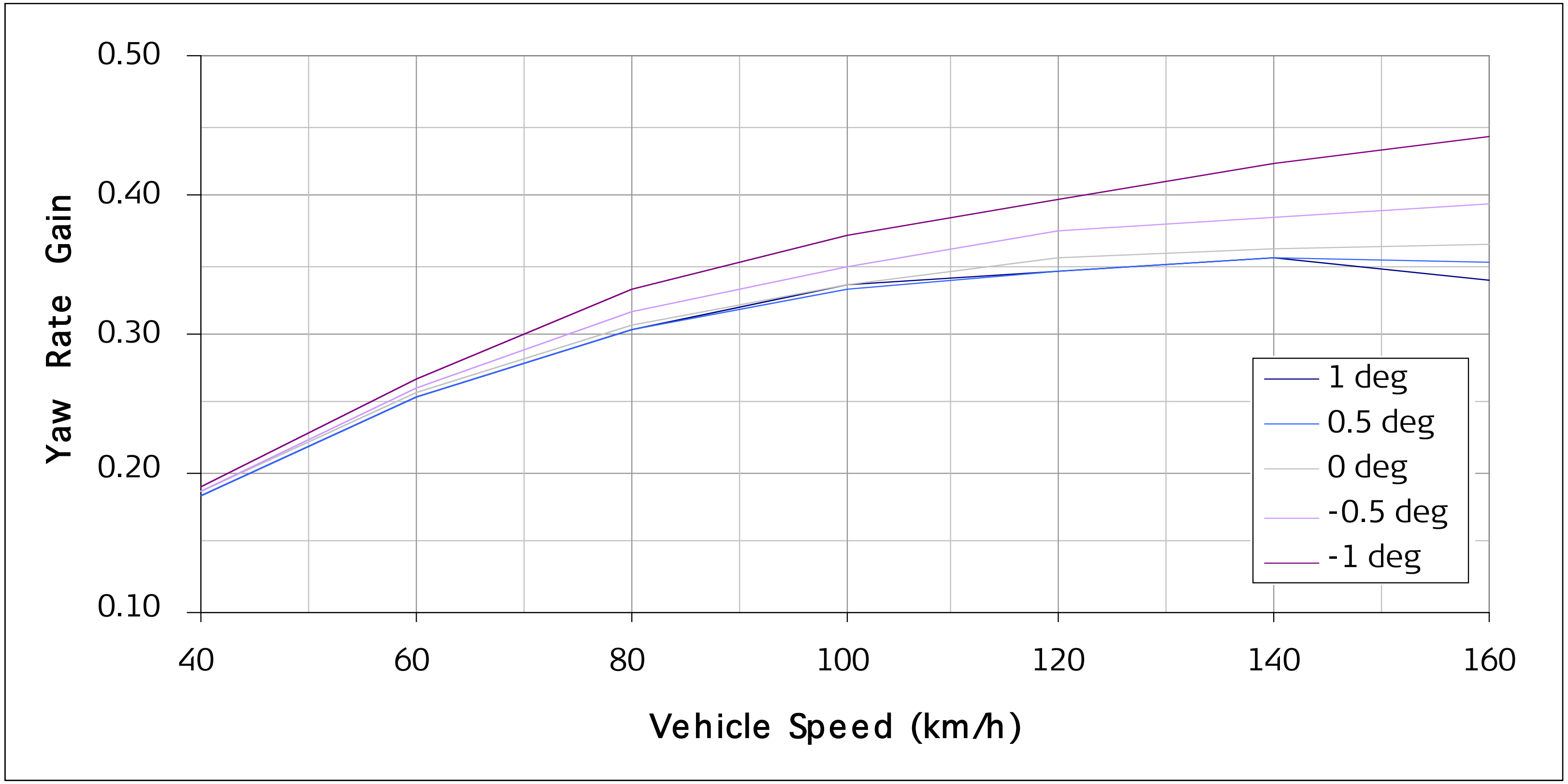
power demands for rear toe control

- Actuator performance on full throttle first gear launch
  - geometry of car makes this the greatest service load
  - actuator is still able to generate required force with acceptable power requirement



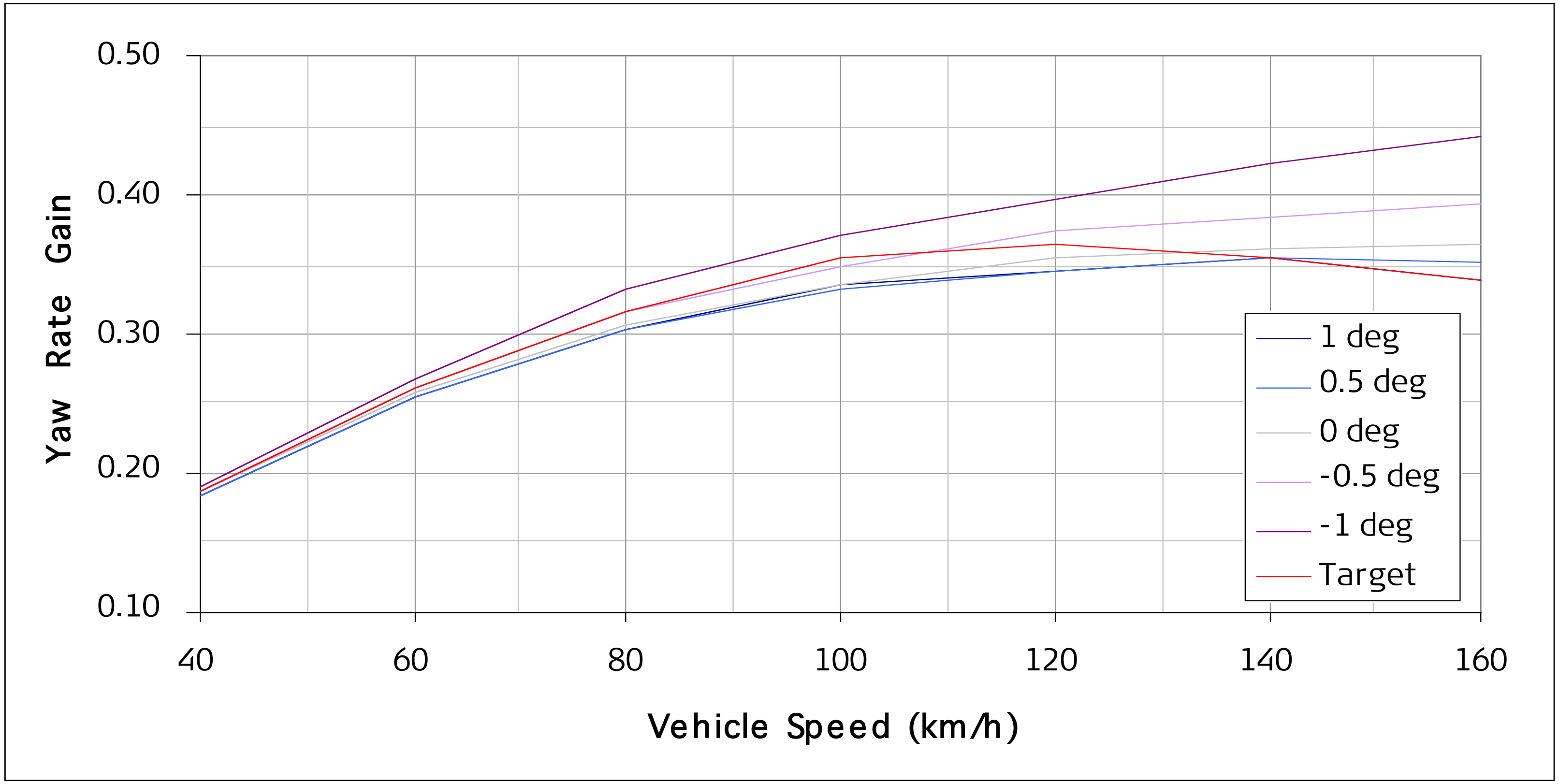
active control of yaw rate gain

- Based on the variability of yaw rate gain for large adjustments of rear toe angle
  - opportunity to generate 'sensible' operating range
  - range is viable for tyre wear control



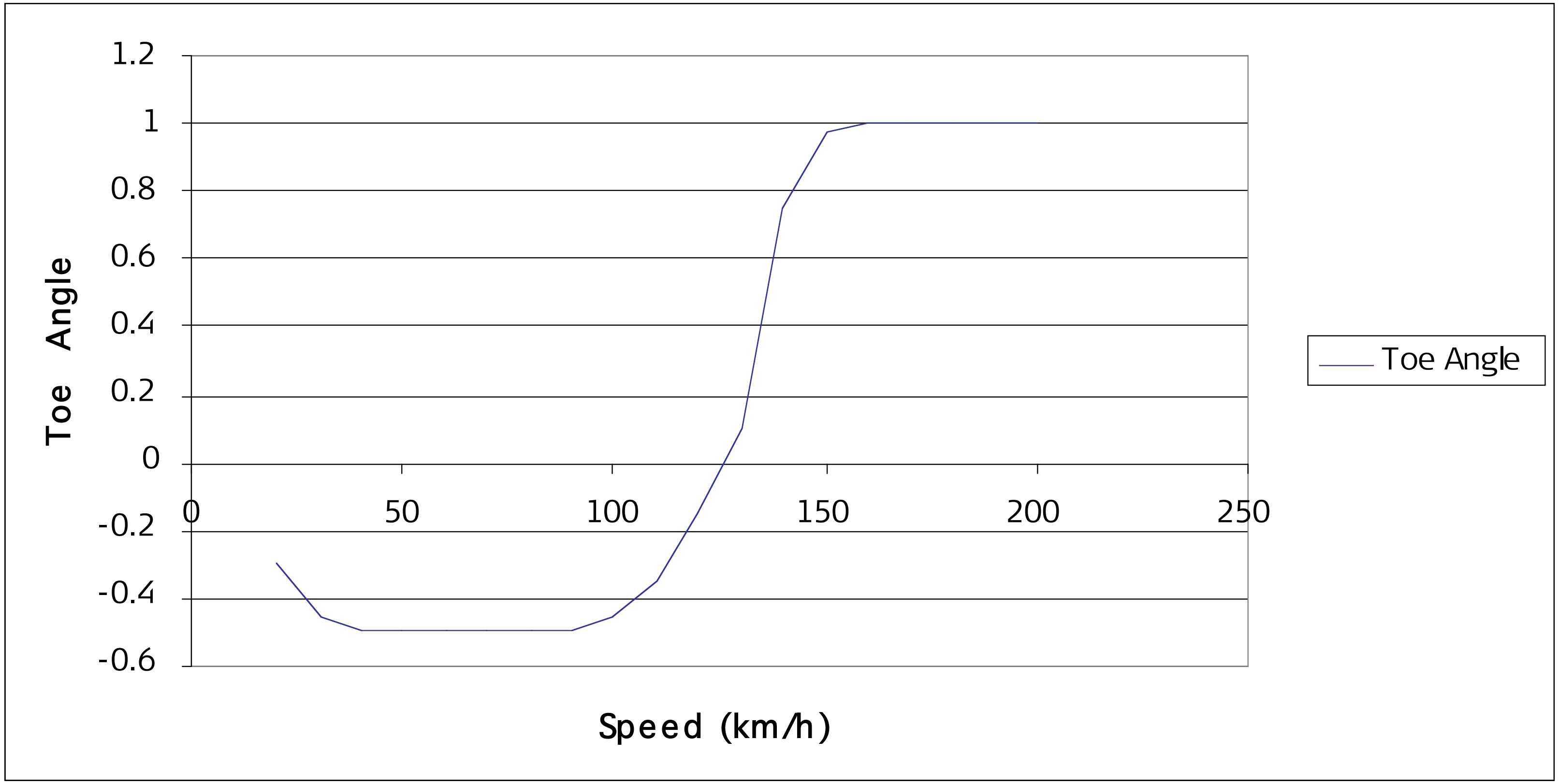
active control of yaw rate gain

- Simple strategy allows specification of yaw rate gain based on vehicle speed
  - target line arbitrarily generated during vehicle assessment
  - opportunity is obvious to vary gain curve based on other factors



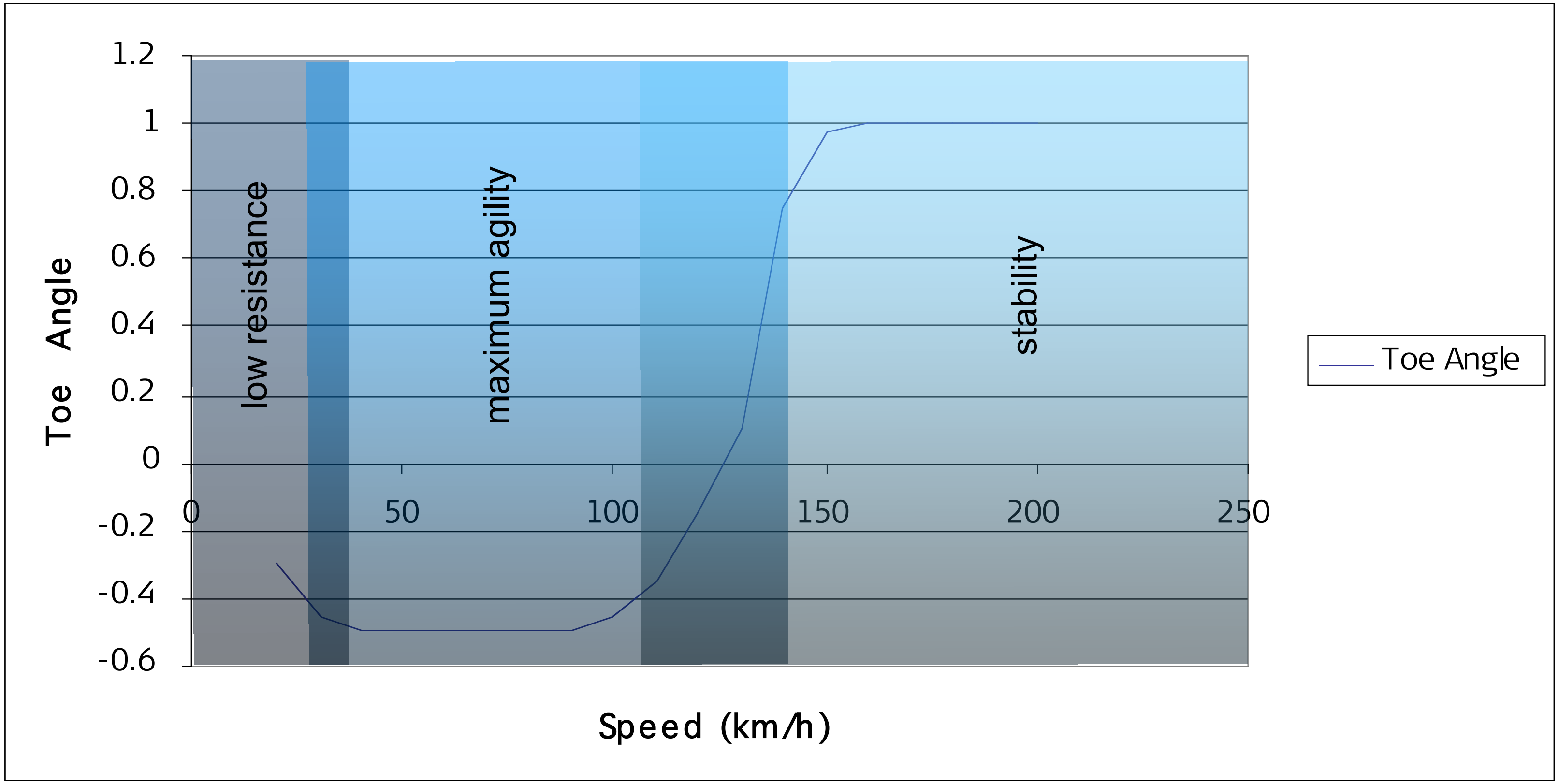
specification of very simple controller

- Consideration of boundary crossing points of target yaw rate gain curve through possible range yields a very simple speed / angle lookup table



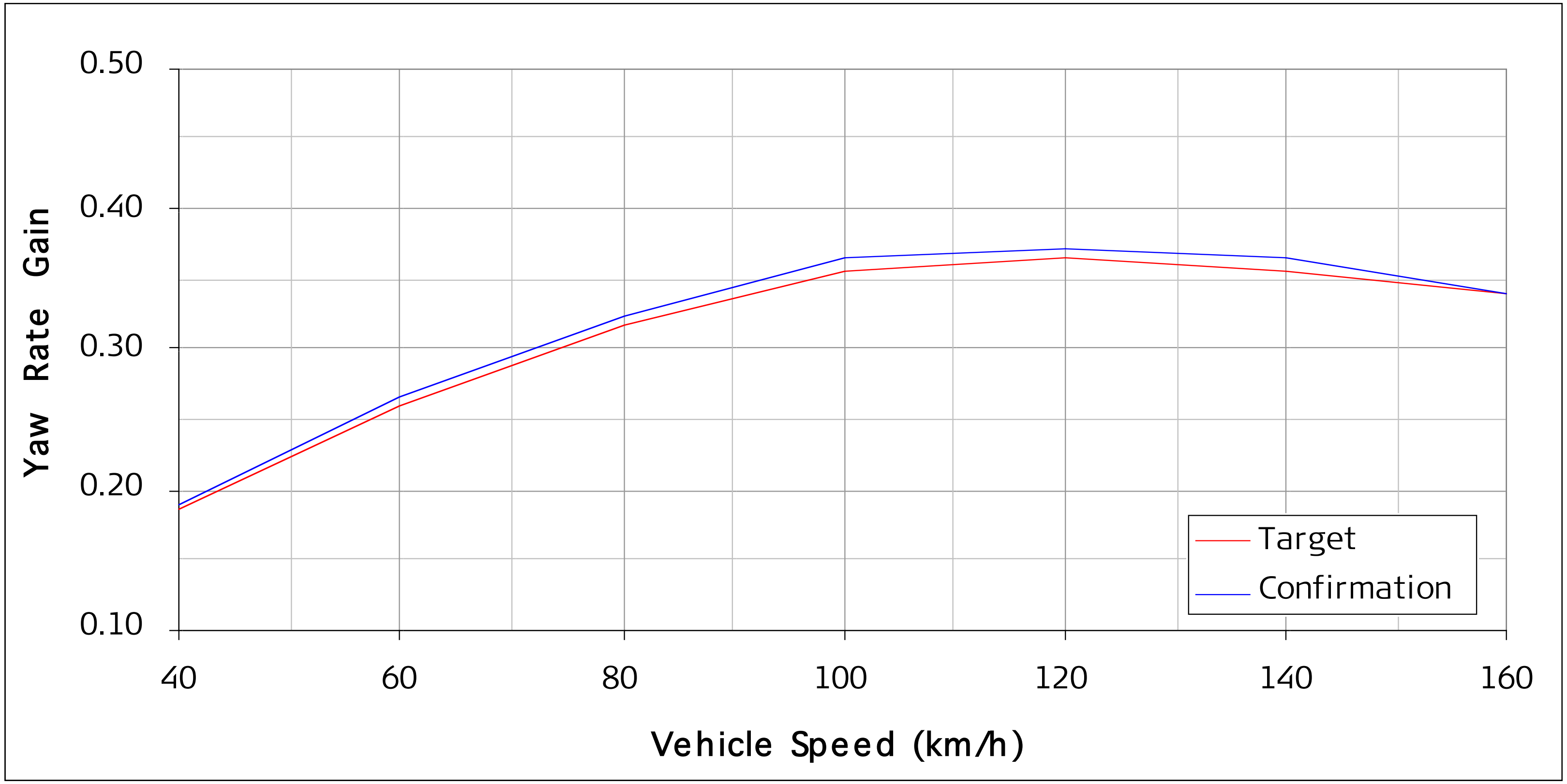
specification of very simple controller

- Consideration of boundary crossing points of target yaw rate gain curve through possible range yields a very simple speed / angle lookup table
  - low speed target is dominated by low rolling resistance
  - mid-speed focuses on response, high speed on stability



target achievement

- Low frequency swept sine test performed to confirm the vehicle's yaw rate gain curve
  - without iteration lookup table yielded results very close to target
  - system robustness follows simplicity of activation



subjective assessment

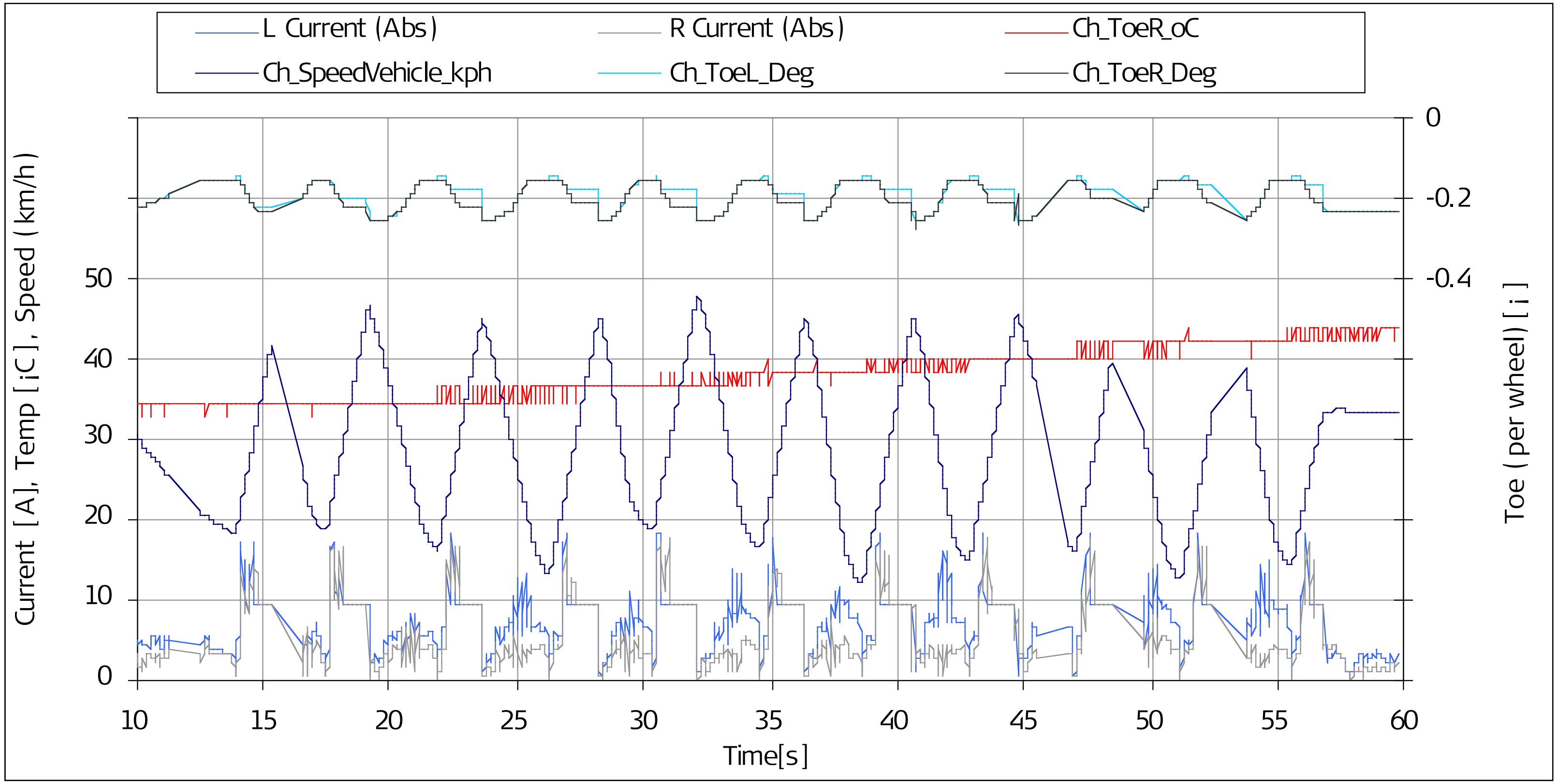
- Subjective appraisal shows very encouraging results
- Assessors comprised a variety of drivers
  - vehicle dynamics experts
  - supplier managers
  - novice drivers
- Assessment carried out at Prodrive's Ride and Handling circuit

subjective assessment

- Significant characteristic changes in vehicle
- All assessors agreed
  - high speed ‘feel’ improved by toe-in
  - mid-corner safety improved by toe-in
  - vehicle response on-centre felt much more agile toe-out
- Active control mode allowed tuning of vehicle character throughout course

thermal behaviour concerns

- Power consumption and dissipation strongly influenced by operating mode
  - as confirmed, power to maintain angle is very low
  - power required to continuously change angle is more significant
  - suspension compliances should target minimum actuator preload



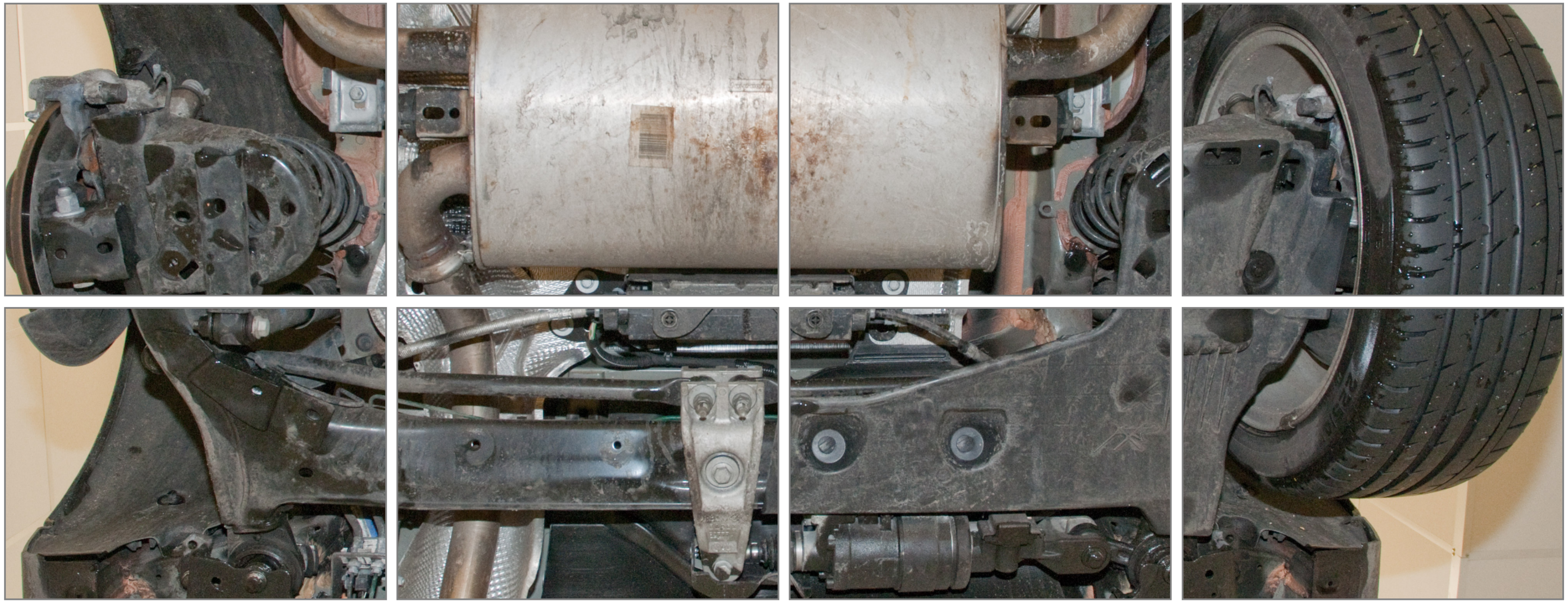
proven benefits

- Increased toe beyond existing static settings to improve high speed braking and yaw stability.
- Ability to reduce static camber values and compensate with optimisation of the toe value
  - reduction in rolling resistance through camber thrust axis forces
  - reduction in CO_2 output
- Reduce demands on mounting system of twist beam suspension – less requirement to provide lateral force toe-out compensation
- Reduce the effect of payload on vehicle dynamics and rolling resistance
- Ability to modify the yaw response and balance of the vehicle through parameter tuning
  - brand identification
  - consumer controlled modification (switch)
- Potentially reduce the tyre size while maintaining grip levels across the duty cycle of the vehicle providing opportunities to save mass, cost, and reduce CO2.

next steps

- Work already underway on customer demonstrator vehicle
- Renault Laguna used as donor vehicle
  - hardware lends itself to modification
  - proven high bandwidth system replaced

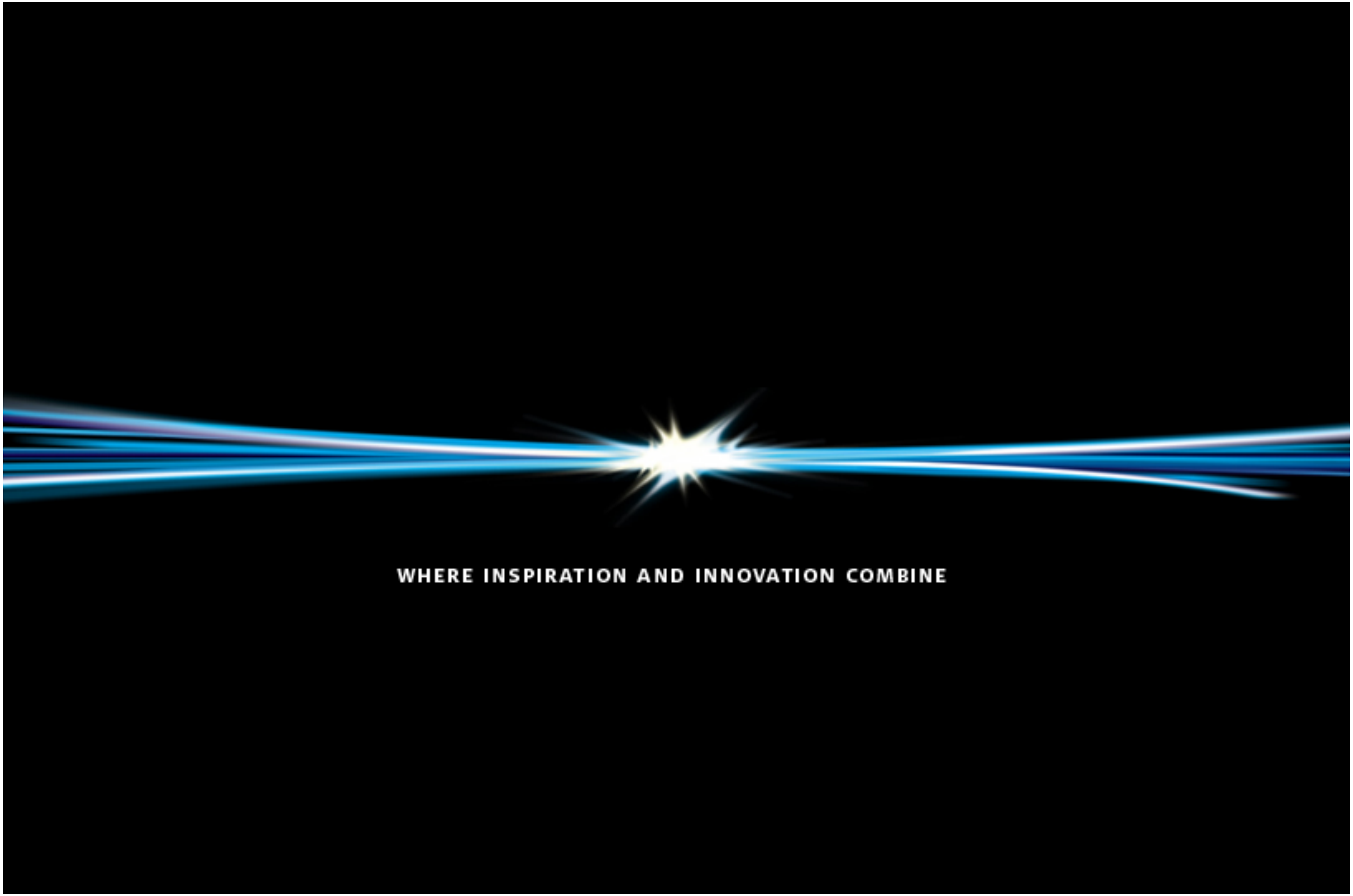
- Low bandwidth demonstrator scheduled to be complete mid-2011



summary

- Active toe provides saleable benefits to
  - vehicle character
  - NEDC performance

- Cost target remains low – target cost reduction compared to elabourate rear suspension



prodrive