Torque Vectoring with Overdrive

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The Automotive Market Place

- Recently, demands on car manufacturers have changed significantly
  - government legislation is creating a marked imperative to reduce CO_2 emissions
  - importantly, the legislation applies to carefully controlled testing environments
  - other demands – even those wanted by the customer – must take a second place or be made to complement the demands of legislation

- Careful marketing has modified customer expectations to some extent
  - CO_2 emissions figures are the new ‘performance figures’ in many social groups

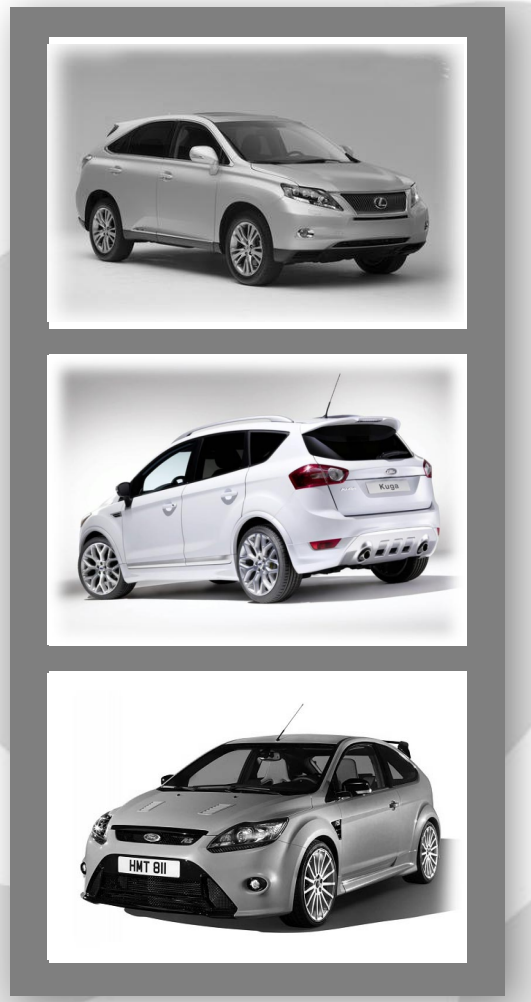
- Certain consumer desires remain un-swayed, however
  - vehicles continue to grow in size and mass - weight reduction measures still leave vehicles significantly heavier than they were thirty years ago with arguably only small changes in attribute delivery
  - despite usage profile, ‘off-road’ styling and all-wheel drive aspirations remain strong

Consumer Demands

- Customers are strongly led by the media and social trends

- Social trends are frequently in conflict
  - motorsport and ‘aspirational marketing’ promote style and speed
  - government and ‘the general good’ promote ‘green’
  - ‘soccer mom’ promotes 4 x 4 and SUV

- Manufacturers promote everything they can
  - multiple sales to same customer base
  - attribute separation from same platform
  - maximum diversity with minimum cost is very beneficial



Attribute Budget Concept

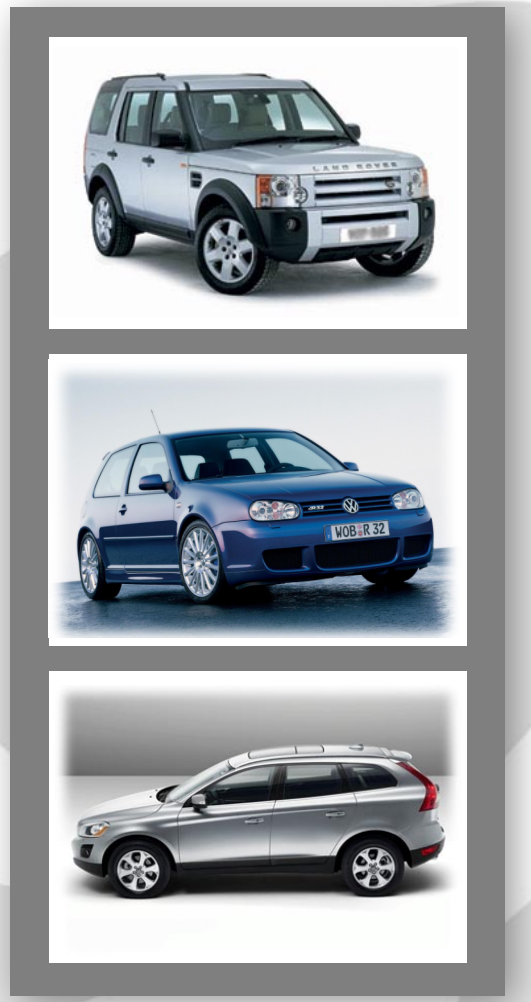
- Opportunity for OEM to produce cost effective concept exists in two ways
  - spend less money
  - achieve greater opportunity for sale from same spend
- ‘Attribute budget’ concept is created
- Adaptive damping is good example
  - dampers offer ride improvement potential
  - fitment allows ‘driver adjustable’ control
  - opportunity for ‘badge’ and additional final cost to customer

All Wheel Drive

- All wheel drive remains a strong seller despite
  - emissions compromise
  - fuel efficiency compromise
  - typical usage profile
  - why?

- All wheel drive represents a significant on cost
  - cost must be transferred to the customer

- Cost reduction measures are increasingly common
  - part time systems
  - partially geared systems
  - fully disconnecting drivelines



All Wheel Drive and Torque Vectoring

- Torque vectoring has proven itself over the last decade
  - pronounced effect on vehicle dynamics
  - enhanced safety
  - improved driver enjoyment

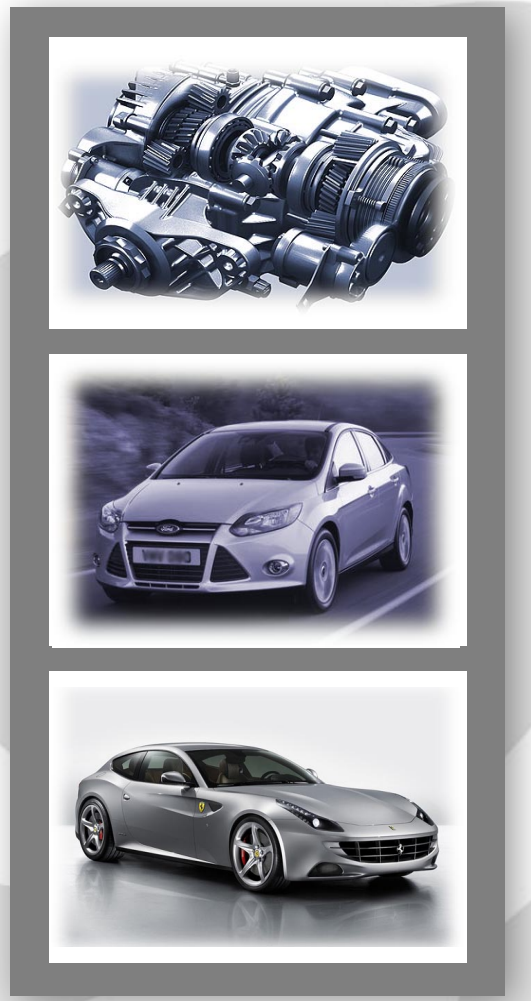
- Many manufacturers and Tier 1s increasingly use torque vectoring as value add over standard hardware

- Conventional part time all wheel drive systems can be used to influence vehicle dynamics and vehicle safety
  - standard hardware
  - alternative control strategy
  - most effectively implemented using front rear distribution torque strategy

- Theoretical maximum influence of track : wheelbase on vectoring concept

Front : Rear Torque Vectoring

- Application of front rear torque vectoring has been proven
  - non-matched torque split on centre differential
  - forced overspeed of rear axle (e.g. Prodrive ATD)
- Preferred approach from attribute performance is forced overspeed of rear or front axle
  - Ferrari FF pioneering example
  - torque splits fail when traction is limited and differential needs to be ‘locked’
- Over speed system can provide traction and dynamics benefits on ‘part time’ system
- Strong use of ‘Attribute Budget’



NEDC and Emissions Control

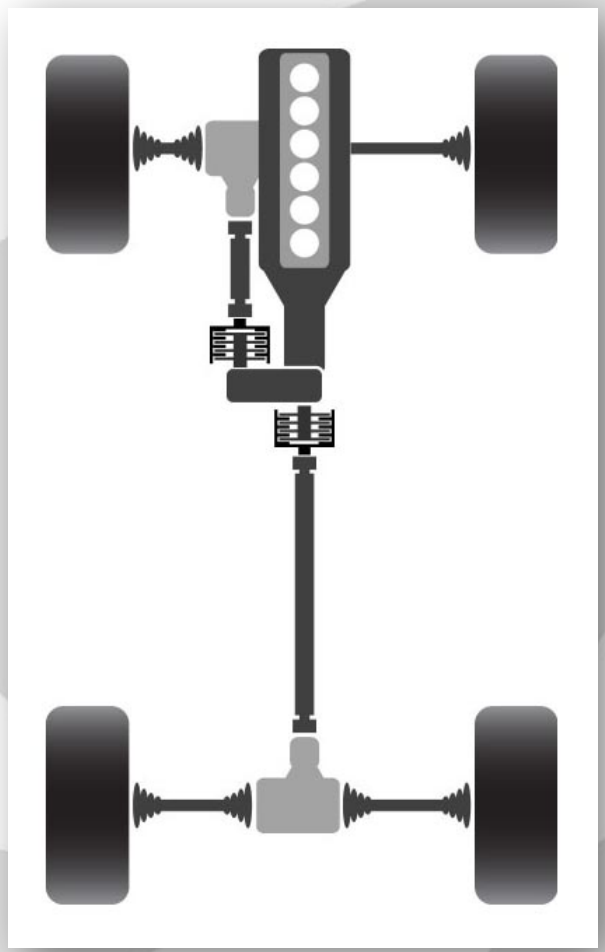
- Drive cycle performance is arguably the primary concern of manufacturers
  - stringent legislation and effective fines are in place
  - typically now one of the vehicle's 'vital statistics'
  - important for taxation

- Vehicle fuel economy 'real world' is increasingly important purchasing decision
  - anecdotally the most lied about commodity by German men
  - clearly driven by ever increasing fuel prices

- Many engineering goals are common to both, many are not:
  - gear shift indicators
  - 7+ speed automatic transmissions, automated manual transmissions
  - overdrive...

In Combination

- All three can be achieved
  - by inclusion of second clutch to front axle of a conventional part time AWD system
  - by mis-matched ratio on front and rear driveline
- Part time all wheel drive
  - achieved with both clutches partially engaged at lower speeds
- Front : Rear torque vectoring
  - achieved by appropriate engagement of secondary clutch at higher speeds
- Overdrive
  - by alternate engagement of front and rear clutches

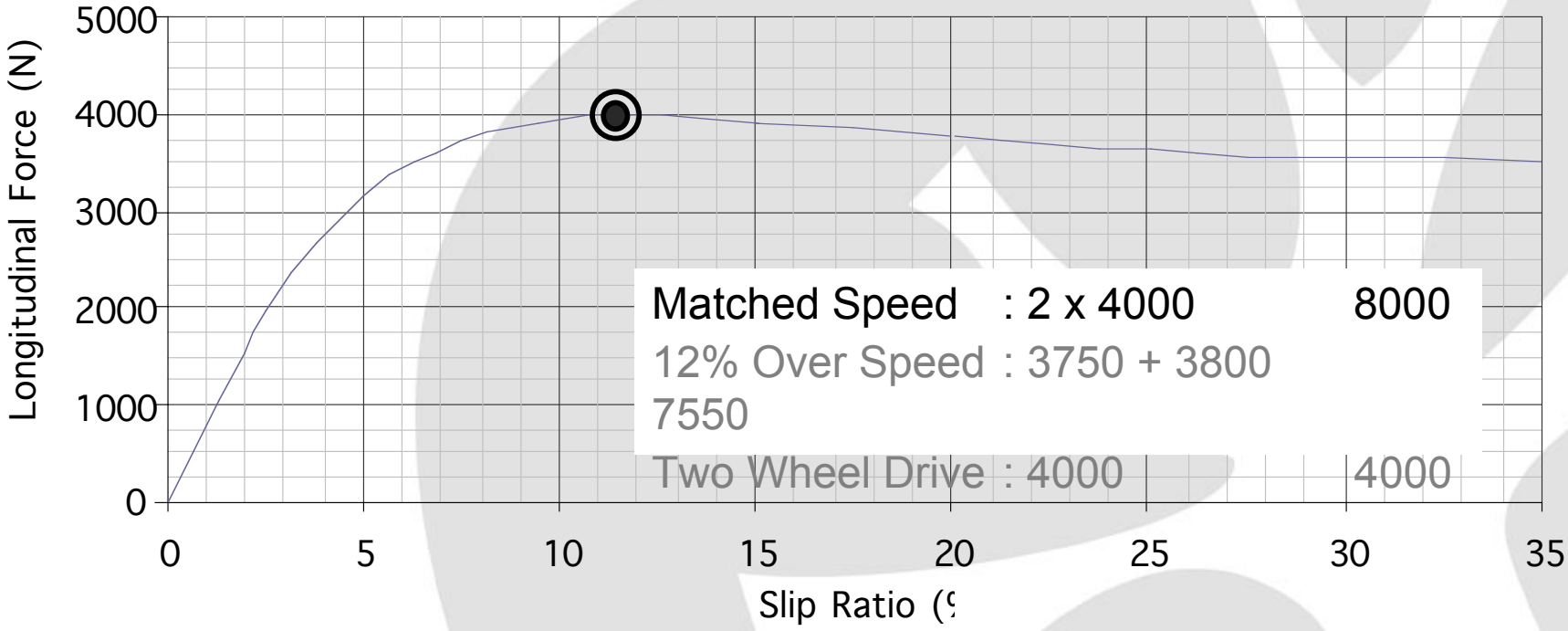


Part Time All Wheel Drive

- Majority requirement for all wheel drive is low speed
  - pull away traction on snow
  - wet road launch
  - split mu capability
- Axle mis-match ratio can be modulated by appropriate control strategy
  - fully locked clutch provides torque transfer for split mu
  - fully locked provides initial launch torque on low-mu
  - partial engagement ‘bleeds’ driveline wind up for extended periods
- Traction enhancement not typically required on dry asphalt
  - operating profile for part time system is typically low impact

Part Time All Wheel Drive

- 10 - 12% over speed allows significant improvement on launch capability
  - mis-matched axle speed effects small compromise
  - combined tractive effort lower than speed matched system



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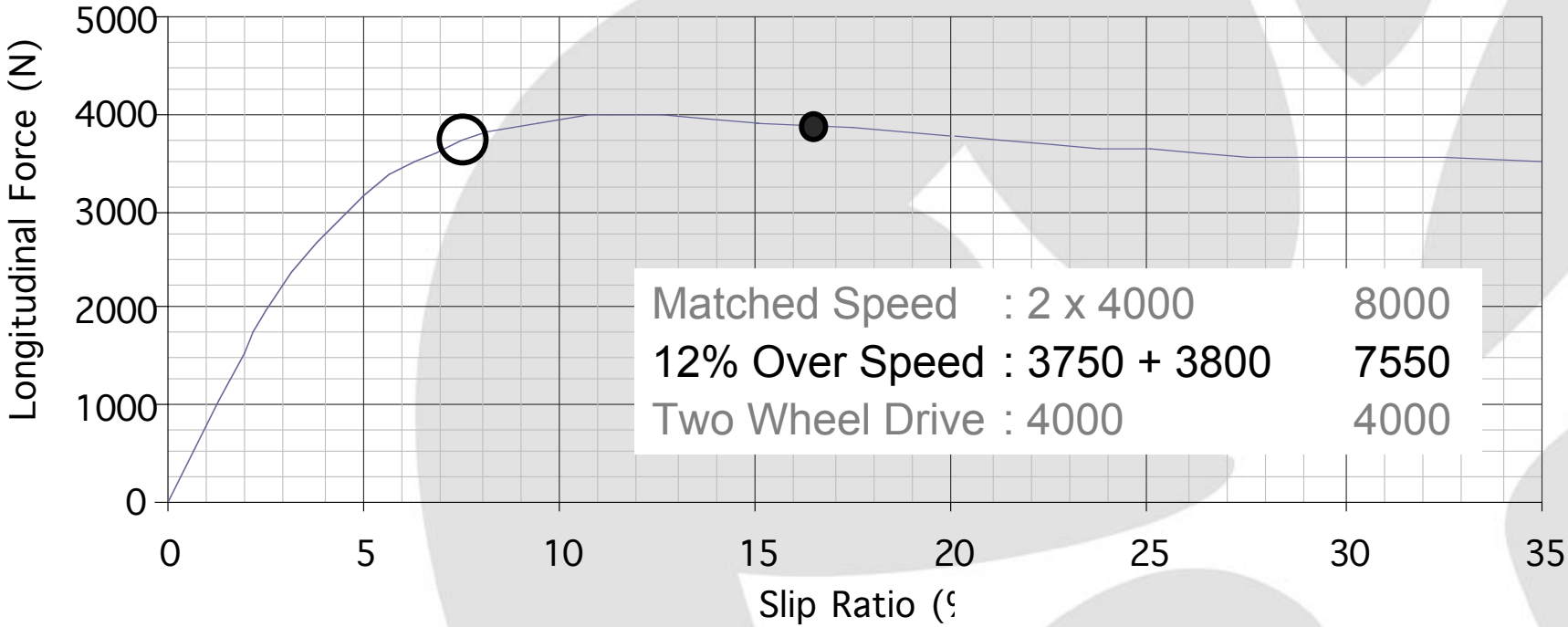
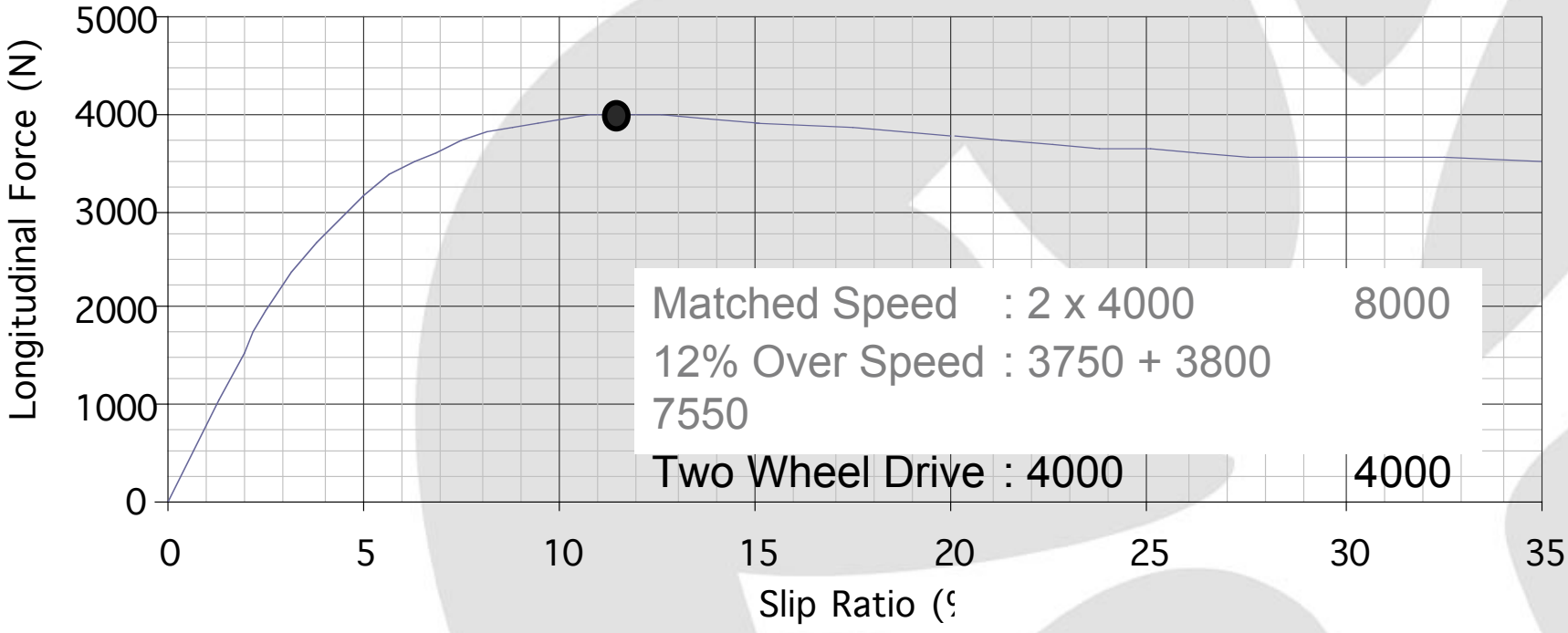


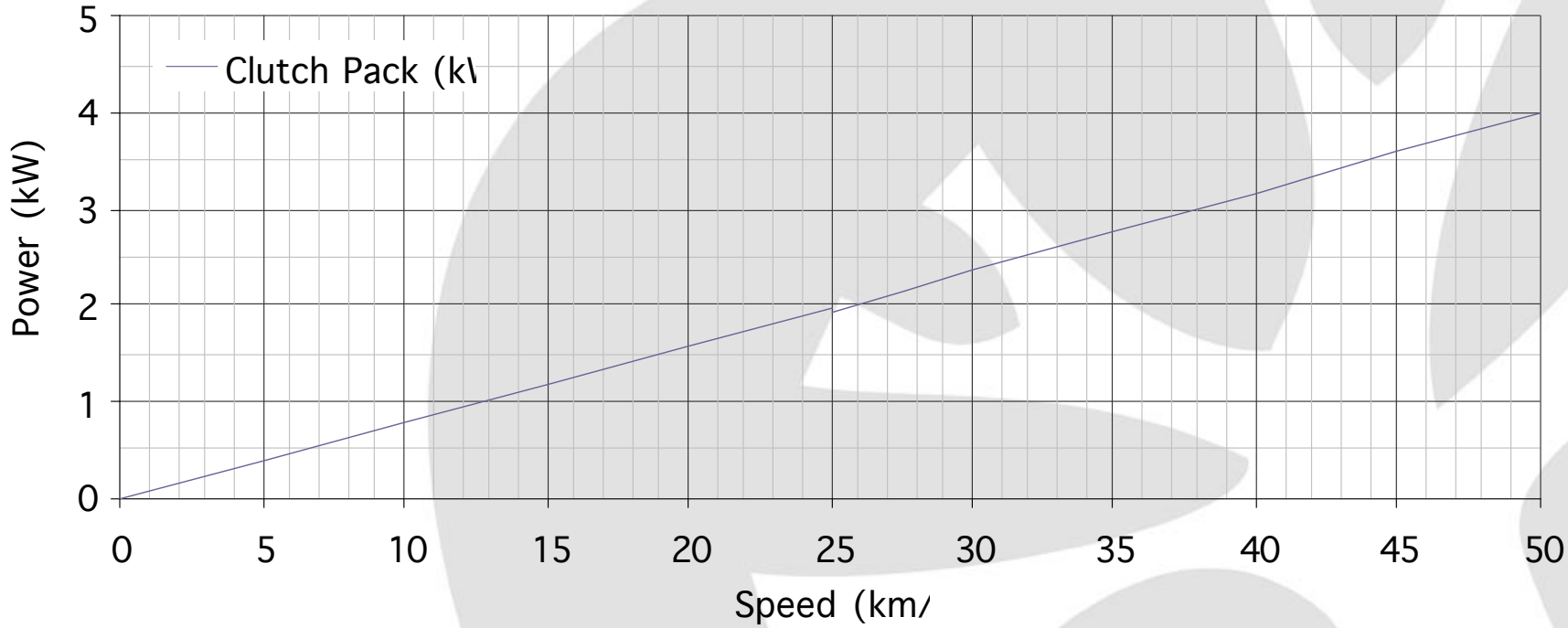
Part Time All Wheel Drive

- 10 - 12% over speed allows significant improvement on launch capability
  - mis-matched axle speed effects small compromise
  - combined tractive effort lower than speed matched system
  - significantly greater than two wheel drive traction



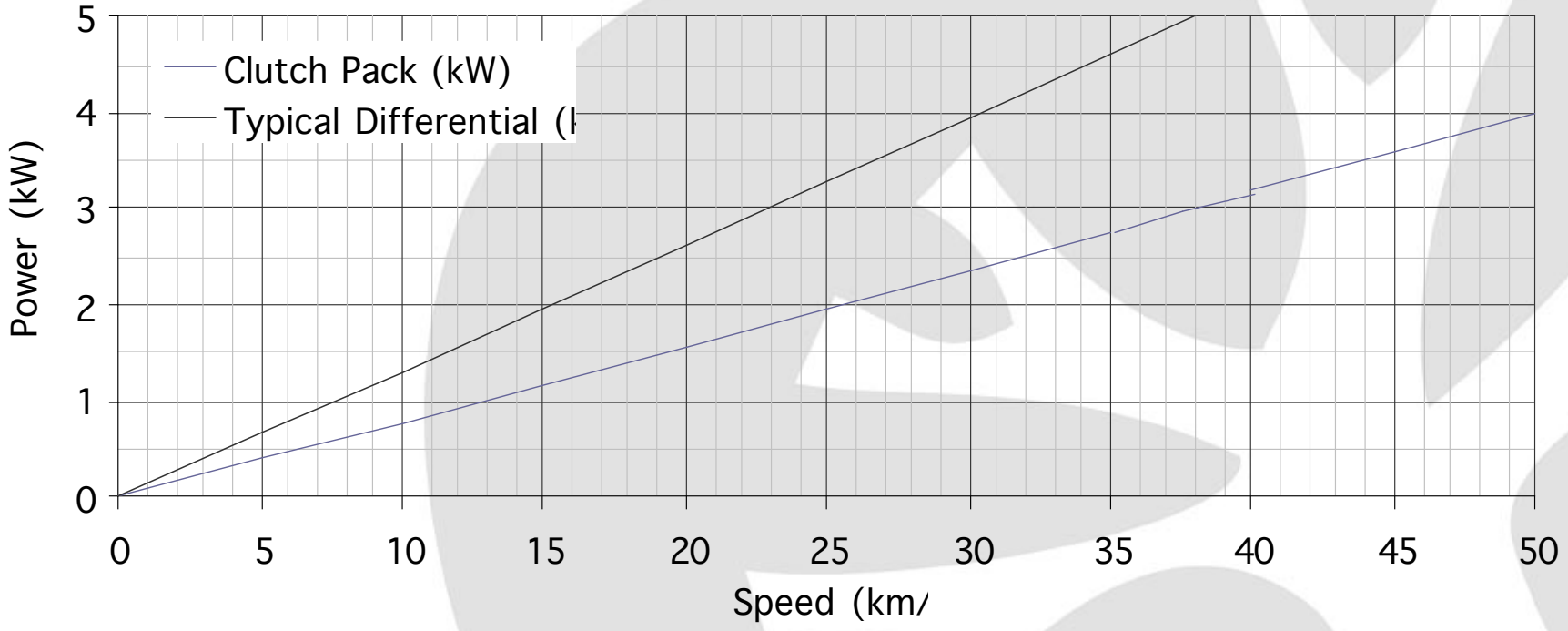
Part Time All Wheel Drive

- Prolonged engagement necessitates slip
  - power dissipated by clutch while slipping
  - 0.3G acceleration at 50:50 torque distribution, 1500kg vehicle



Part Time All Wheel Drive

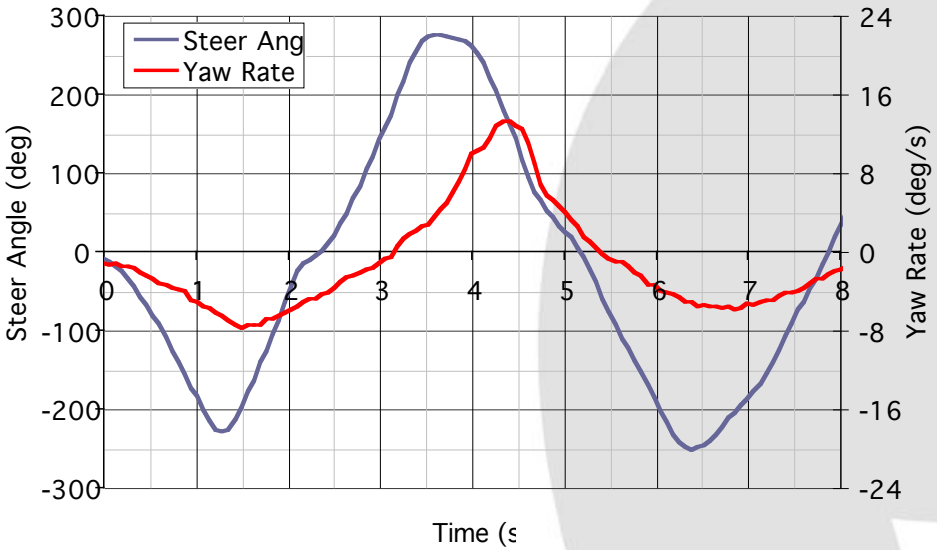
- Prolonged engagement necessitates slip
  - power dissipated by clutch while slipping
  - 0.3G acceleration at 50:50 torque distribution, 1500kg vehicle
  - compares well to ‘typical’ 10% loss in two wheel drive hypoid bevel pair

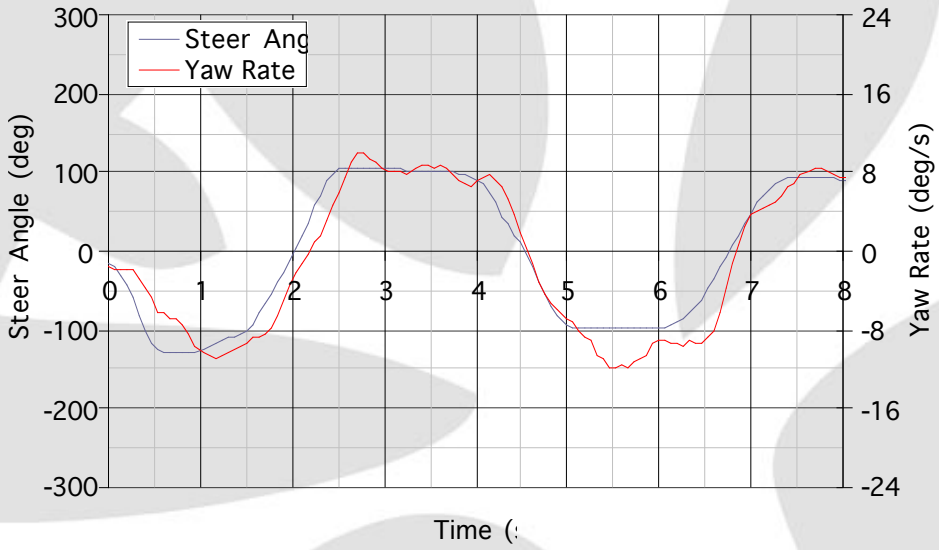


Torque Biasing Front : Rear

- Front rear torque biasing well proven over fifteen years
  - lateral force reduction modulates yaw damping
  - very low cost hardware implementation
  - concept focuses on limit improvement – authority and stability

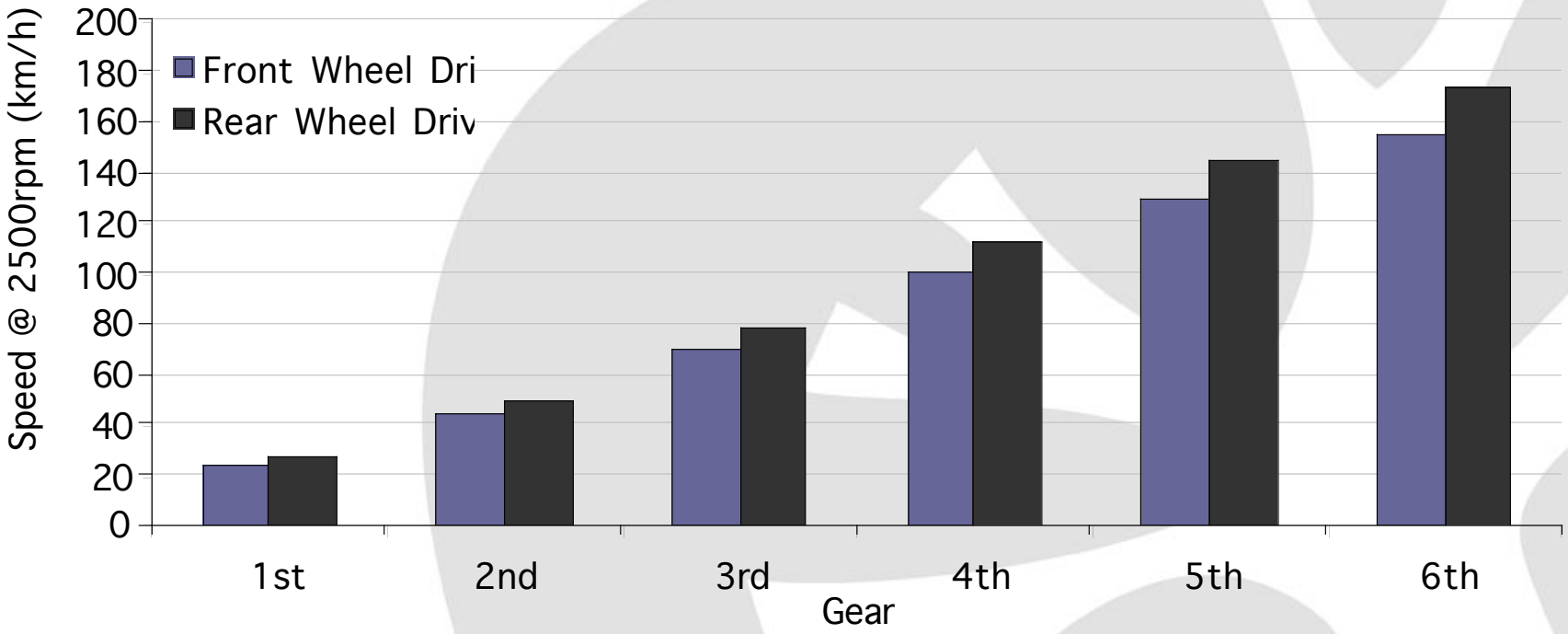
- A good deal of misunderstand is still prevalent in the industry





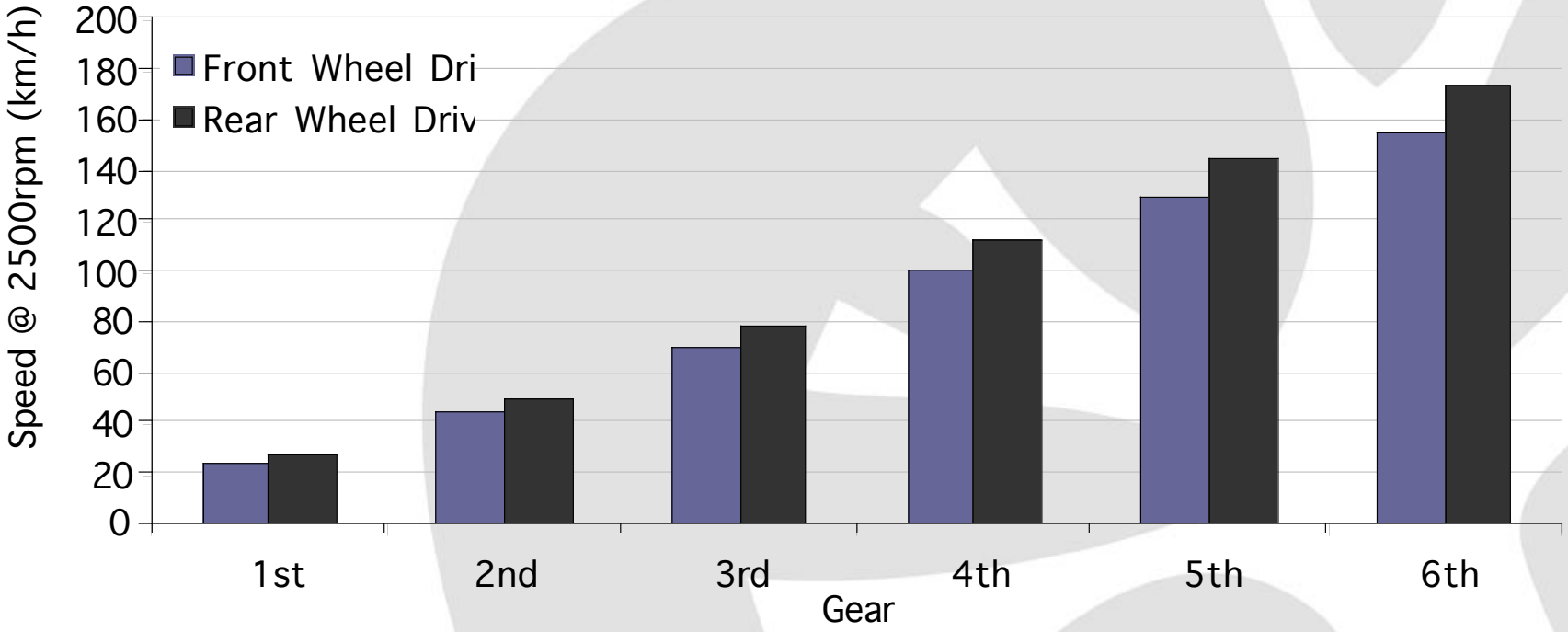
Overdrive System

- Overdrive can be effected by alternate selection of ‘axles’
  - front axle differential ‘datum’ ratio
  - rear axle differential at ~10% overspeed
  - rear wheel drive is over-driven compared to front wheel drive



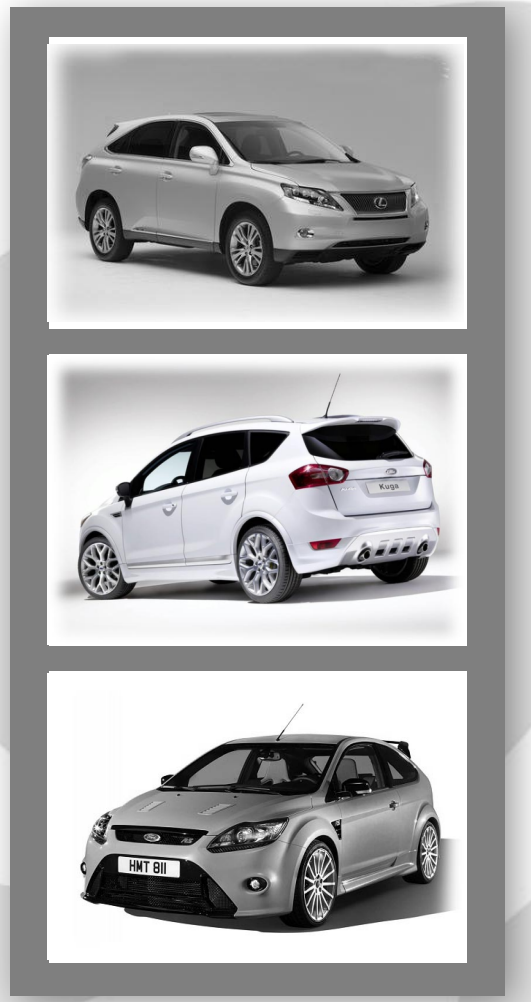
Overdrive System

- Overdrive is seeing renewed interest in a number of OEMs
  - compromise of base ratios is still damaging to performance figures
  - overdrive enables ‘stretching’ of gears on the drive cycle
  - without appropriate ‘attribute budget’ cost can be prohibitive



Summary

- Cars are now in an interesting position
  - great deal of claim that cars are increasingly a domestic item
  - budgets does not support such a claim
  - social position is very complicated
- Buying decisions are complex
  - social expectations (climate awareness)
  - perceived cost of driving (fuel economy)
  - performance (continues to climb)
  - styling, features and fashion
- OEMs must address as many as possible
  - features which address multiple requirements are key



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