Performance Equivalence with Alternative Fuels

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Introduction

- This presentation gives an overview of a project carried out by Ricardo for the Energy Efficient MotorSport (EEMS) group
  - Started June 2004

- EEMS is an initiative that falls under Motorsport Development UK and the Department of Trade & Industry

- At the request of EEMS Ricardo has investigated the possibility of implementing fuel flow regulations in motorsport and in collaboration with TOCA has undertaken a technical study based around the British TouringCar Championship series

Background: A very simplified overview of current drivers for engine development

Race engine development

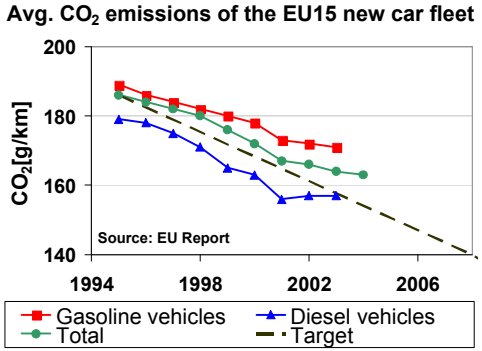
- "Unrestricted series" (F1):
  - Increase performance; main limiting factor is available development funds

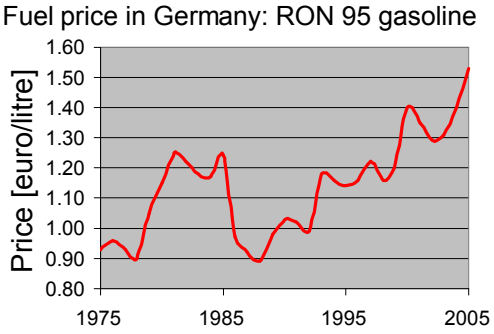
- Air-restricted race series:
  - "Suck as much air through a straw as possible"

- Endurance races (Le Mans):
  - Some element of fuel efficiency

Road car engine development

- Increase fuel efficiency:
  - Voluntary agreement with EU to reduce CO_2 emissions
  - Increasing oil/fuel price



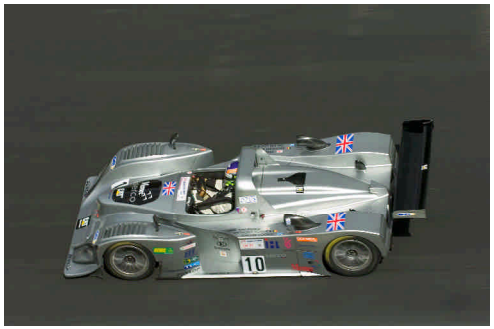


- Meet emissions legislation
- Increase performance
- Cost reduction

Spectators are fully aware that the technology on the race track is very different from road cars -> limited opportunities for the OEM to showcase their general technology on the track -> obstacle for OEM participation

Racing alternative fuels (fuels other than gasoline)

- The use of fuels other than gasoline in racing has rapidly gained interest over the last few years
- Regulations have been opened up to allow Diesel engines, for example
  - Diesel 2000 for Touring Cars
  - Specifications for Diesels under Le Mans Prototype LM P1
- Special rules for alternative fuels tend to be based on air restrictor sizing, defining boost pressures, compression ratios and artificial rpm limits
  - Setting numbers for these is not straightforward
  - The rules are not transparent for the spectator



The concept of Energy Efficient MotorSport

- Replace the air restrictor by a fuel flow limitation
  - Create an incentive for competitors to extract as much performance from a given fuel flow as possible
  - Fuel flow limitation depends on the used fuel
    - In first instance based on the energy content of the fuel
    - Limits can be refined to create a level playing field
  - The driver can still go flat out on the track – this is not a mileage marathon

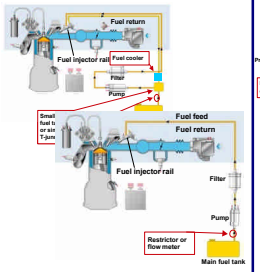
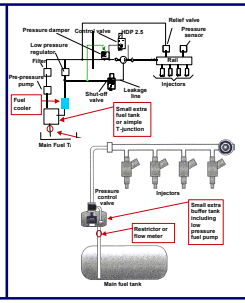
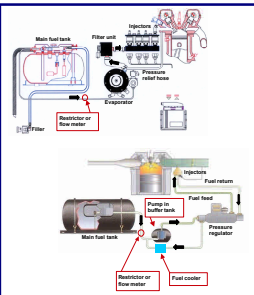
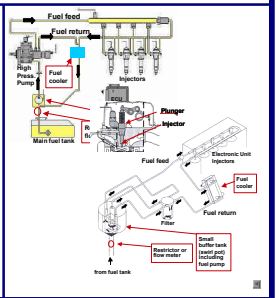
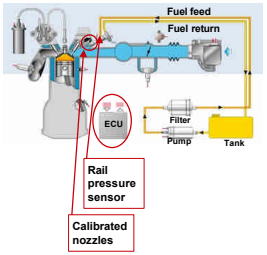
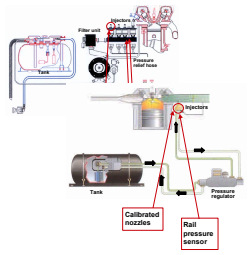
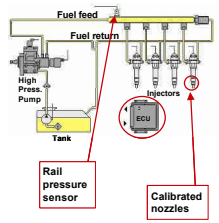
Simple rules that are transparent for the spectator

The fastest car is the one which creates most power from a limited fuel flow: This is great marketing value for the manufacturer

25,000 engineers are active in the motorsport industry in the UK alone: A significant resource pool that can contribute to develop fuel efficient and sustainable technologies

The first step: feasibility study

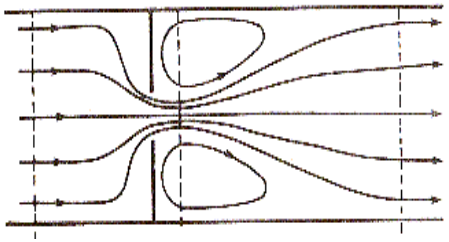
- Can this be done / how can we do it?
- Many possible solutions to limit fuel flow were considered and reviewed for
  - Ease of implementation and policing
  - Compatibility with current and potential fuels and fuel systems in motorsport
  - Cost and complexity

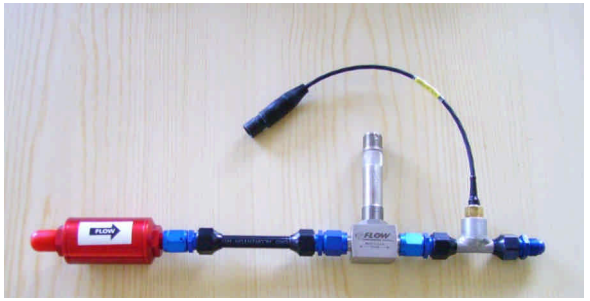
	Port injected Gasoline / Ethanol / Methanol fuel systems with return line and returnless	DI Gasoline / Ethanol / Methanol fuel systems with return line and returnless	LPG/CNG systems, gaseous and liquid injection	Diesel / biodiesel Common Rail and EUI
(1) Constant calorific tank: Applicable for endurance races only				
(2) Fuel mass flow rate restrictor (3)Fuel line mass flow measurement - Without RPM sensor, define fuel flow per sec - With RPM sensor), define fuel flow per cycle				
(4) Injector Nozzle calibration + Rail pressure limit - Without logging Injection Duration Limit and RPM sensor, define fuel flow per cycle - With logging Injection Duration Limit and RPM sensor, define fuel flow per cycle and sec				
(5) Lambda +(MAF&RPM sensor) or(5a) Air Restrictor; (6) CO_2 + RPM sensor: Similar solution for all fuel systems				

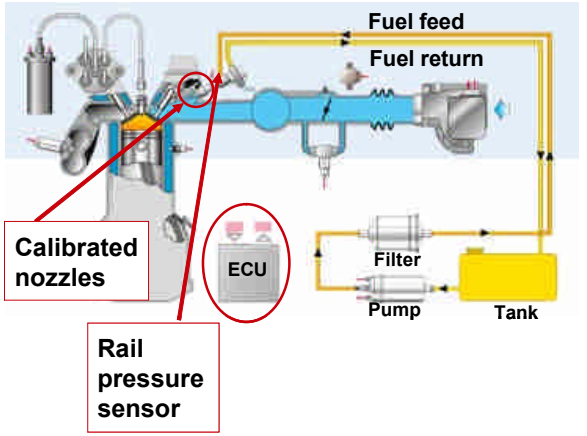
The most promising solutions were studied in more detail – Technical considerations

Ricardo conclusion:

- Fuel flow rate restrictor (orifice)
  - The only way to restrict fuel flow using an orifice is by sizing the orifices such that choking cavitation occurs at the desired maximum fuel flow: not ideal
- Fuel flow measurement
  - Initially thought not possible but eventually found supplier that has suitable measuring devices
- Use calibrated injection nozzles and monitor rail pressure, injection duration and RPM
  - Make use of a restriction that already exists in the fuel system: the injector
  - Still need to monitor pressure, injection duration and RPM
  - Potentially expensive solution



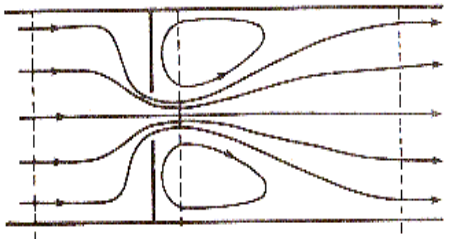




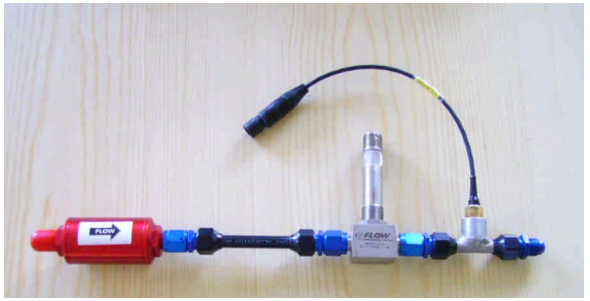
The most promising solutions were studied in more detail – Opinion of racing series

General opinion regulator and engine builders:

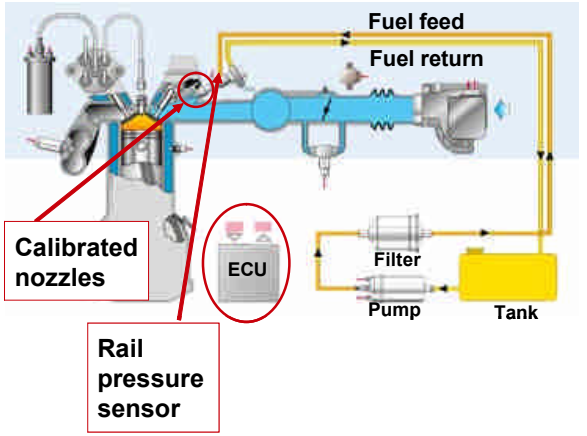
- Fuel flow rate restrictor (orifice)
  - The teams do not favour restricting devices; bad experience with RPM limiters in the past



- Fuel flow measurement
  - Possible; existing logger could be used to log the signal

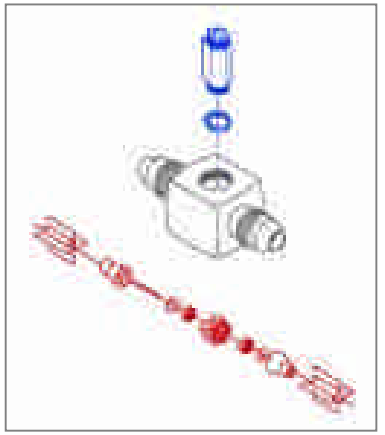


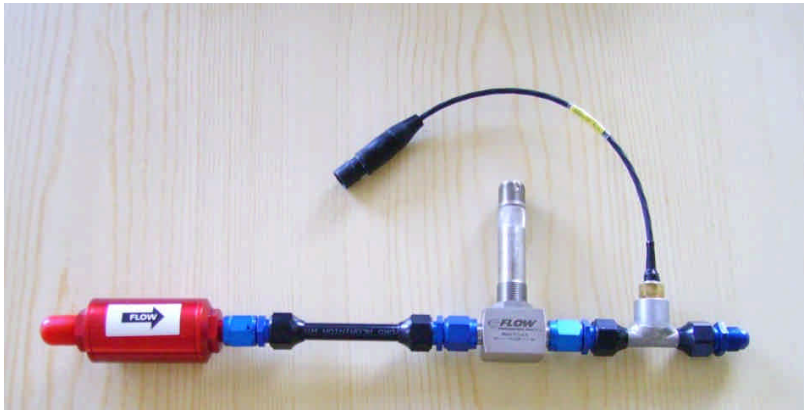
- Use calibrated injection nozzles and monitor rail pressure, injection duration and RPM
  - Could be complicated



The concept of fuel flow monitoring

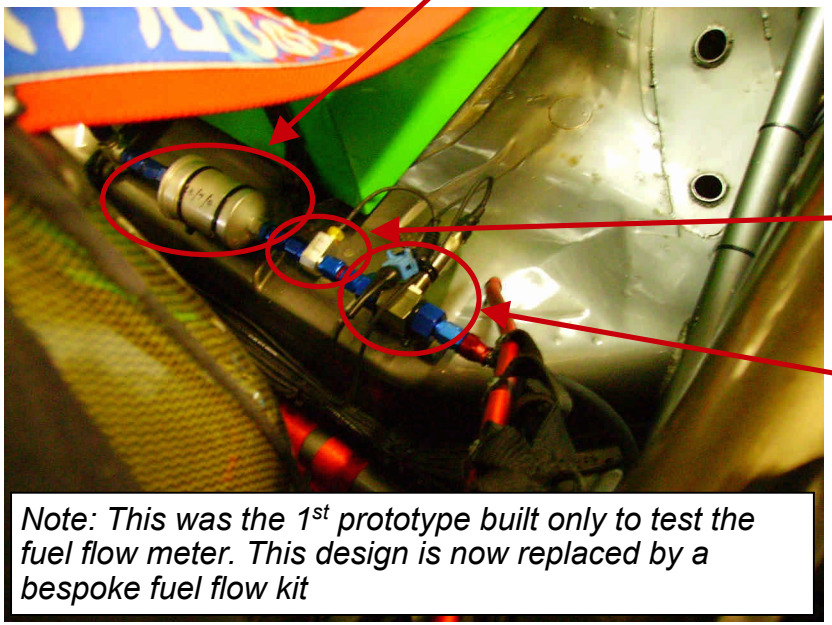
- A flow meter accurately monitors fuel flow to the engine
- The race series regulator provides all teams with a fuel flow limit that they must not exceed
  - The teams can keep below the limit by properly calibrating their engines
  - Compliance is enforced using the abovementioned fuel flow meter in combination with a data logger or telemetry system
  - The vehicle's Engine Control Unit can use the feedback from the fuel flow meter to fine tune the calibration and run as close to the set limit as possible ("self-learning" ECU)
  - The set fuel flow limit is dependent on the used fuel





The concept of fuel flow metering was tested on a BTCC vehicle running bioethanol

- The fuel flow meter was tested on a Vauxhall Astra that competes in the British Touring Car Championship (BTCC)
- The fuel flow was logged using the vehicle's standard scrutineering logger

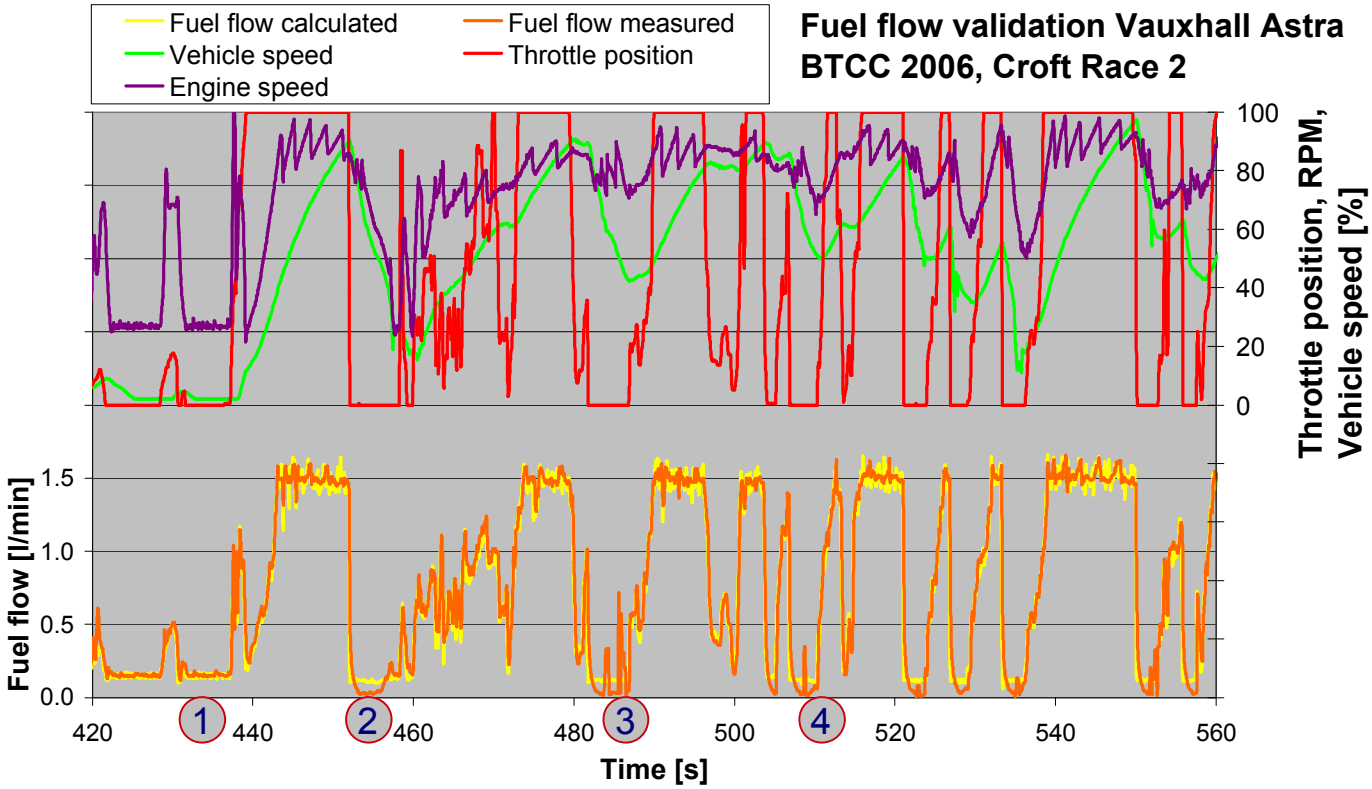


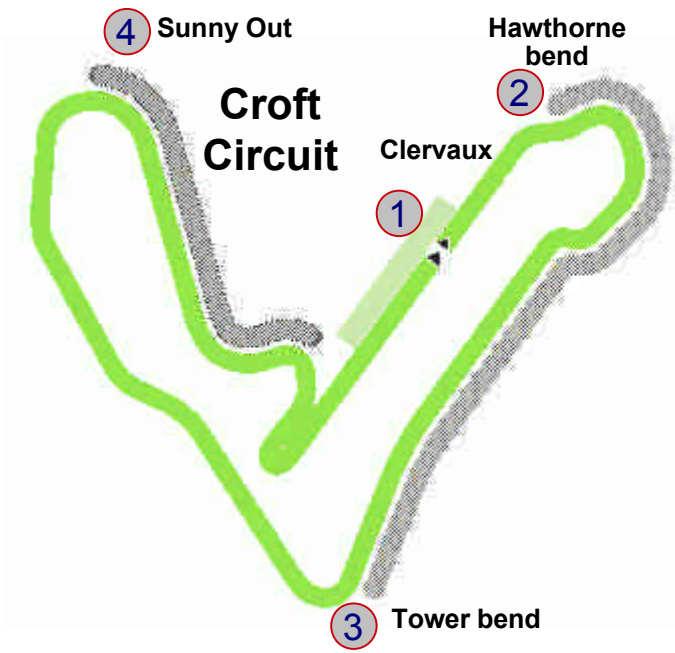
Note: This was the 1st prototype built only to test the fuel flow meter. This design is now replaced by a bespoke fuel flow kit

- In parallel fuelling parameters such as fuel pressure, injector opening time and engine speed were logged in the ECU
  - This allowed validation of the fuel flow sensor against independent data

Validation of the fuel flow meter on the race track

- The plot below shows measured fuel flow data (orange line) versus fuel flow data calculated from ECU parameters (yellow line) during a BTCC race on Croft Circuit

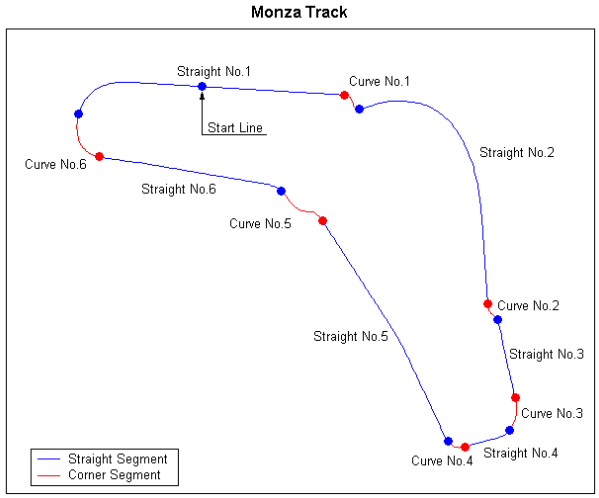




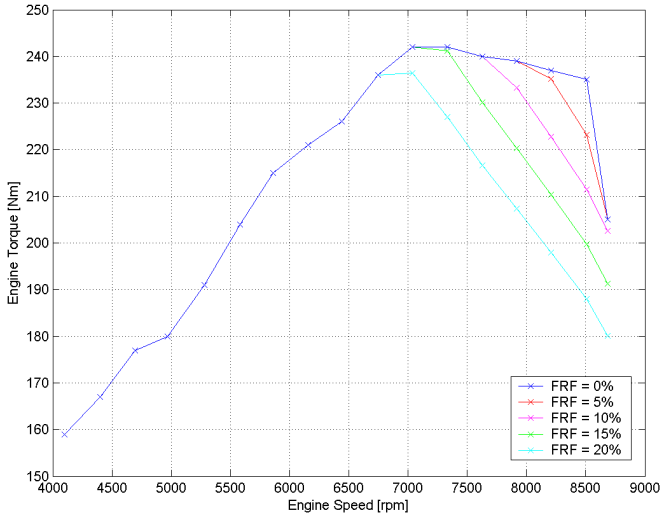
- *Note: This was the 7th race weekend since installation of the fuel flow sensor*

Limits for various fuels are defined using lap time simulation software

- The initial approach for setting fuel flow limits is based on the energy content of the fuel
  - All engines would be given the same maximum energy flow
  - This is proven to be too advantageous for Diesel vehicles
  - State of the art Diesel engines have approximately 30% better thermodynamic efficiency than their gasoline counter parts – this means they will be able to generate approximately 30% more power from the same energy flow
- A more elegant approach is the use of simulation software to define fuel flow limits that will help to generate a level playing field for the various fuels
- Ricardo has developed a simple vehicle and track model that allows the effect of fuel flow limits on gasoline, E85 and diesel vehicles to be compared



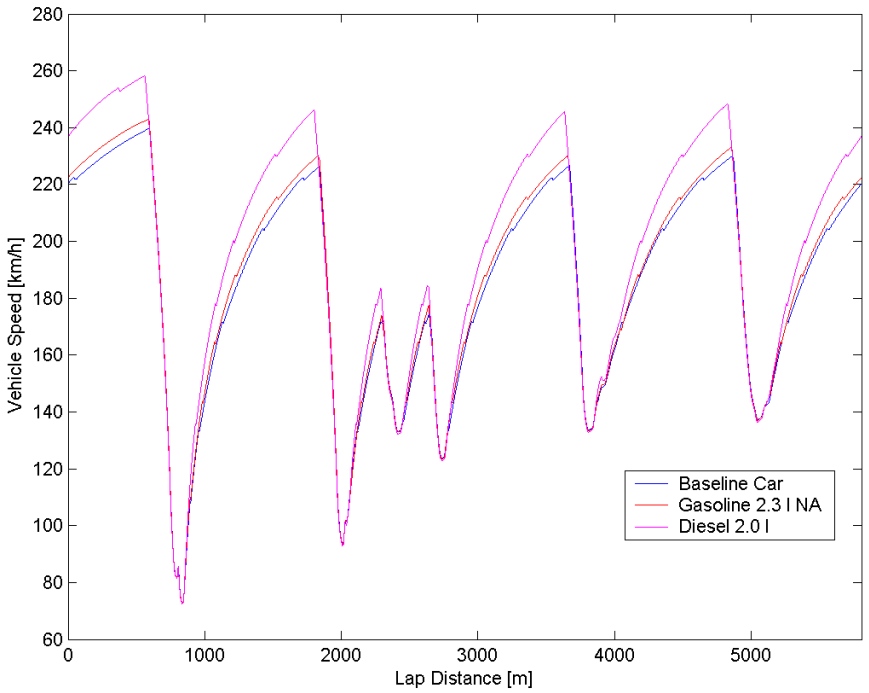
Lap time simulation Monza

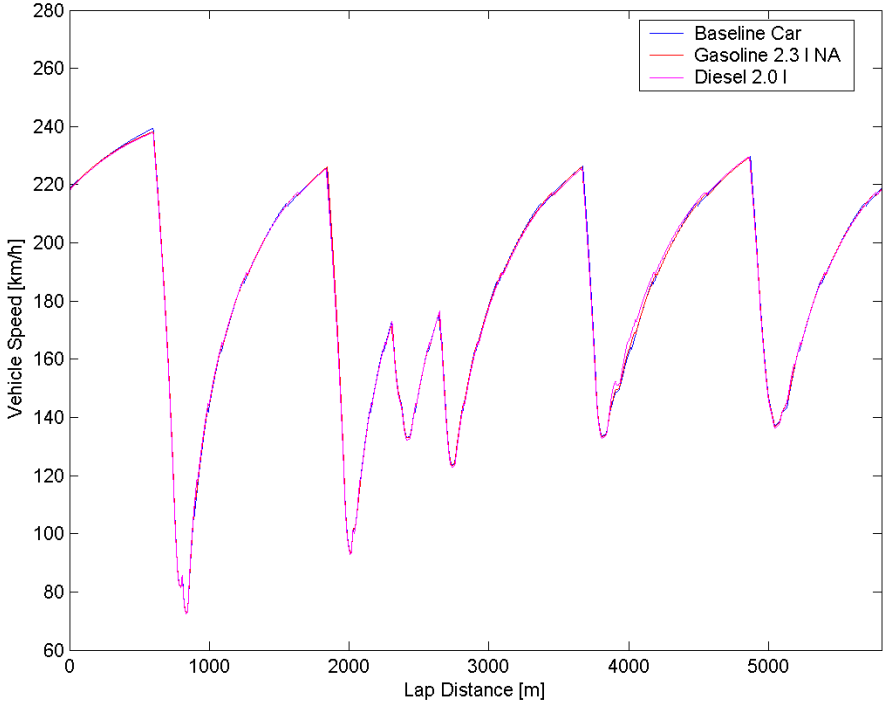


Engine torque for various Fuel Reduction Factors on a 2.0ℓ engine

Creating a level playing field

- The plots below show the effect of fuel flow limitation on a hypothetical Touring Car racing on Monza with either a gasoline, Diesel or E85 engine
- The plot on the left shows vehicle speed for the various engine configurations when limited on an energy equivalent basis
- The plot on the right shows vehicle speed for the same configurations after we have applied the correct fuel flow limits to create a level playing field





Thank you

- The authors would like to thank
  - The EEMS Project Team, in particular Dr. Steve Bunkhall
  - MDUK, Riches Technical Services, Tech-Speed Motorsport, Triple Eight Race Engineering Ltd., Ole Buhl Racing Ltd., Petrochem Carless and Pi Research

- We are grateful to Alan Gow, Chief Executive of TOCA who promote the British Touring Car Championship, for his advice and practical support of this work and the opportunity to canvas opinion from the championships technical staff and competitors. Peter Riches, Technical Director of TOCA, has also contributed valuable practical input and advice.

- We must stress that TOCA has greatly assisted in developing the method but there is NO policy to go the fuel flow limit route at this stage