Advanced Research Test Facilities: Methods to improve the Value of Emission Tests.

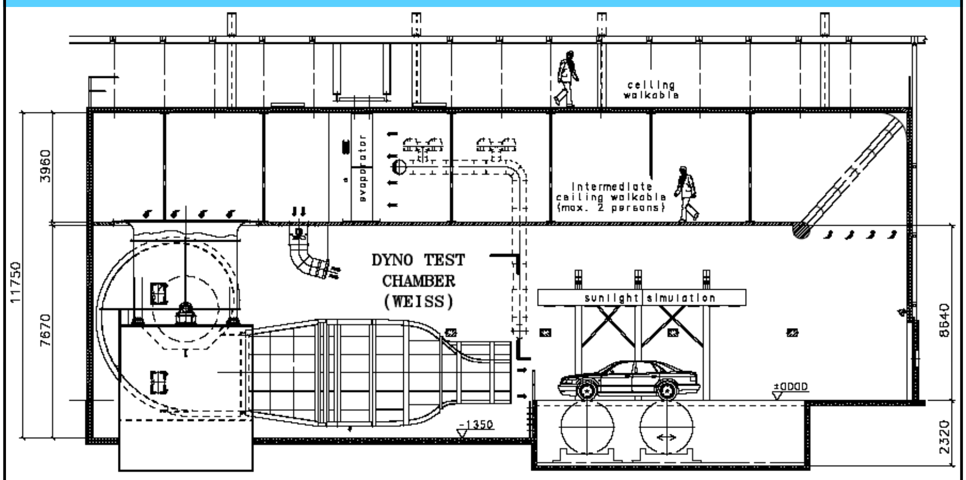
Agenda

- What is ACART ?
- Working with ACART
- ACART Facilities
  - Emission Lab
  - Wind Tunnel
- Sources for Variability
- Further Experience

What is ACART ?

- ACART is a collaborative venture between Ford Australia and the University of Melbourne (UoM) with the support of the Victorian State Government.
- ACART will provide the local automotive and transport industries with infrastructure and personnel for advanced automotive research and testing.
- ACART is located at two nodes:
  1. Ford (Lara):
     - Emissions Lab
     - Wind Tunnel
  2. UoM (Melbourne)
     - Engine dynamometer and emissions facility
     - Research staff
- ACART will focus on: low emission technologies, HVAC, alternative fuels, trucks

ACART Wind Tunnel



ACART Wind Tunnel

Wind Speed

- 250 km/h @ 2.7 m^2 nozzle
- 197 km/h @ 4.0 m^2 nozzle

Diurnal Sun Load Simulation

- Operating range: 600 - 1200W/m^2
- Irradiation area: 6 m by 2.5 m
- Irradiation uniformity: ±5%
- Full spectrum with UV-B filters

Dyno

- Front axel power (fixed): 150kW
- Front axle tractive force: 6000 N
- Rear axle (moveable): 300kW
- Rear axle tractive force: 10000 N
- Wheelbase: 2300mm - 4750mm
- Inertia range (2WD): 453 to 5443 kg
- Inertia range (4WD): 907 to 10886 kg
- Multiple point data recording

Air Conditioning

- Temperature: -40°C to +55°C
- Temperature stability: <0.5°C at constant load
- Cool down rate: +40°C to -20°C in 2.5 hours
- Heat up rate: -20°C to +36°C in 2.5 hours
- Humidity range: 10 to 95%rh
- Humidity range accuracy: ±2%rh
- Humidity range stability: ±5%rh
- 2 independent soak chambers

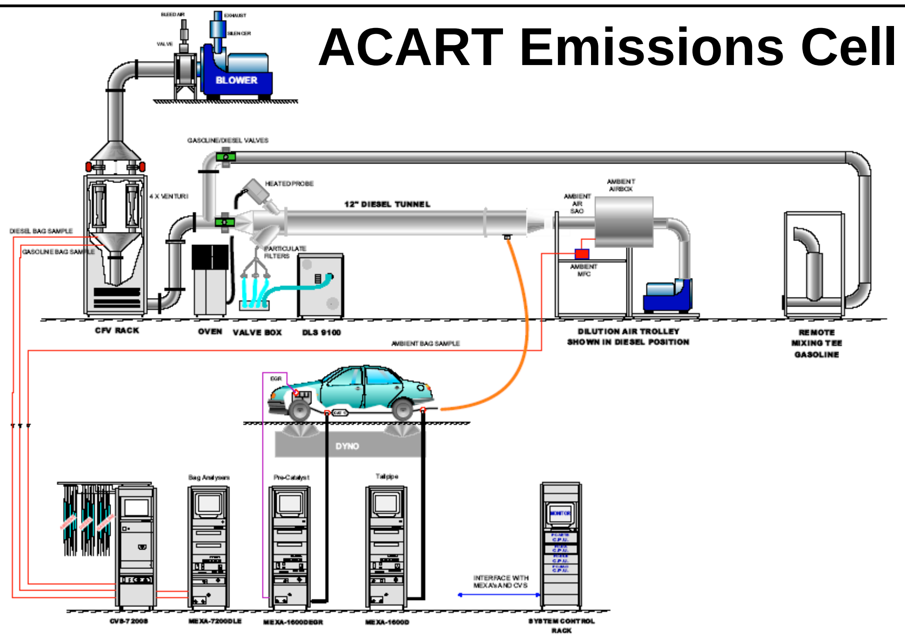
Future upgrades protected

- Snow simulation
- Rain simulation
- Secondary suction system to reduce boundary layer to 5mm

Ford Emission Lab Overview

Cell 1	Cell 2 (ACART- Diesel)	Cell 3 (Cold CO)
Emissions • Euro 4 • ULEV • 2 raw gas lines • Horiba 200 • HAD VETS 5.9	**Emissions** • Euro 5 Diesel • Euro 5 Petrol • SULEV • 2 raw gas lines • Horiba 7200 CVS • PC VETS • Particulate Tunnel • On-line Soot Measurement • FTIR: On-line non regulated emissions	**Emissions** • Euro 4 • ULEV • 2 raw gas lines • Horiba 200 • HAD VETS 5.9 • Cold CO (-7°C)
Dyno • Single Roll 48" • Real Time • MMI control system	**Dyno** • AWD 48" 300kW • AVL • MMI control system	**Dyno** • AWD 48" 300kW • AVL • MMI control system

ACART Emissions Cell



ACART Emissions Cell

FEV FEVER FTIR

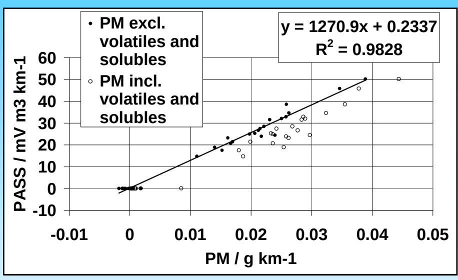
- Fourier Transformation Infrared Spectroscopy
- Fast Response: 1 sec
- Up to 30 emission components simultaneously
- Components can be selected from a table of up to 180 components
- Reprocessing: calculation of different components is possible later
- THC analyser included – can be used as 3rd modal sample line
- Measures in up to 40% H_2O
- Good correlation with CLD (Chemi-Luminescence Detector – NO, NO_x)

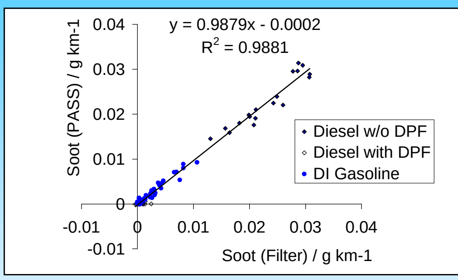
Gas	Detection Limits (real exhaust with Water and CO2 in %) LN2 cooled MCT @ 1Hz / 6Hz				
	MultiGas 2030		MultiGas HS		
CO	1.2	ppm	2.7	ppm	
CO2	0.08	%	0.2	%	
NO	1.25	ppm	2.8	ppm	
NO2	0.4	ppm	0.9	ppm	
H2O	0.03	%	0.1	%	
SO2	1.5	ppm	3.4	ppm	
COS	0.08	ppm	0.2	ppm	
H2S	150	ppm	335	ppm	
Methane	0.8	ppm	1.8	ppm	
Ethane	1.5	ppm	3.4	ppm	
Ethylene	0.5	ppm	1.1	ppm	
Ethanol	1.1	ppm	2.5	ppm	
Propane	3.6	ppm	8.0	ppm	
Propylene	1.8	ppm	4.0	ppm	
Acetaldehyde	2.5	ppm	5.6	ppm	
Acetylene	1.7	ppm	3.8	ppm	
Ammonia	0.28	ppm	0.6	ppm	
Formaldehyde	1.2	ppm	2.7	ppm	
Pentane	1.5	ppm	3.4	ppm	
Toluene	2.5	ppm	5.6	ppm	
Formic Acid	0.45	ppm	1.0	ppm	
N2O	0.3	ppm	0.7	ppm	
Isocyancaeure	3.6	ppm	7.2	ppm	
Diesel HC	5.4	ppm	12	ppm	Approximation Based on C1 hydrocarbon We normally run either dodecane or Diesel not both since they are similar
N Dodekan	0.5	ppm	1.2	ppm	
Benzol	7.2	ppm	15	ppm	
Methanol	1	ppm	2.2	ppm	
Ozon	1.2	ppm	2.5	ppm	
Xylol	We normally measure the Individual Xylenes but O-xylene overlaps CO2 heavily				
p-xylene	4.2	ppm	9	ppm	
m-xylene	6.6	ppm	15	ppm	

Particulate Measurements

- Micro balance: 0.1µg resolution
- Weighing Room - Euro 6 / US 2007
  - Class 6 Clean Room
  - Temperature 22 ± 0.8°C
  - Dewpoint temperature 9.5 ± 0.5°C
  - Air lock (2 doors)
  - Over-pressure
  - Static neutraliser < ±2VDC
- Cross reference checks with on-line instrument

Photo Acoustic Soot Sensor: Correlation with filter samples





- Detects soot only
- Dynamic on-line measurement (10Hz)
- Feedgas and Tail-pipe
- High Sensitivity (detection limit < 10 µg/m³)
- Compares well with filter soot measurements
- Independent on engine technology

Source: Ford Research Aachen

Importance of Fuel Economy Measurements

+ 0,1l/100km per Vehicle

≙

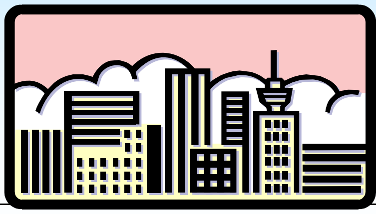
+ 15 Million Liter Fuel consumed

(production of 100.000 vehicles and an average lifetime mileage of 150.000km)

≙

Annual Energy Requirements of a Country Town

(**360.000 Tons CO_2**)



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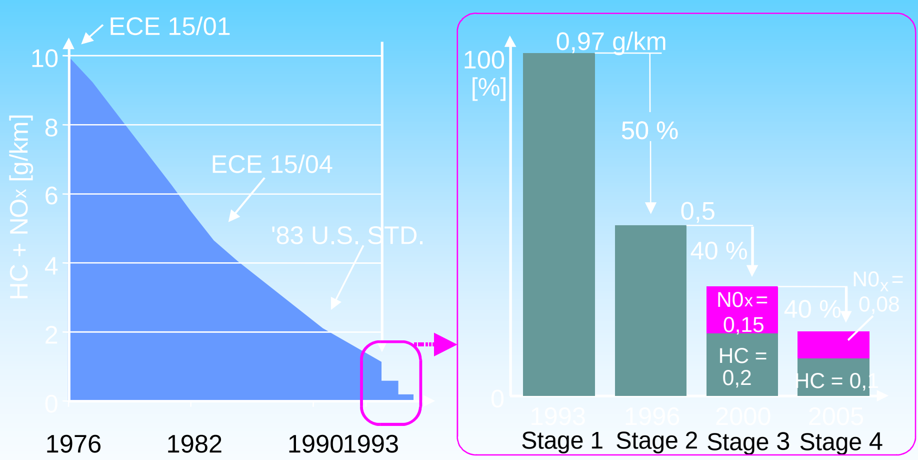
HC and NO_x - Emission Limits



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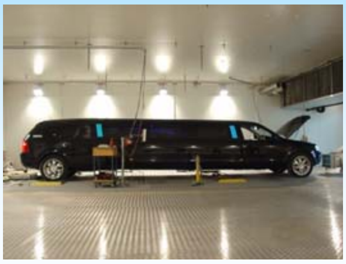
Sources for Variability

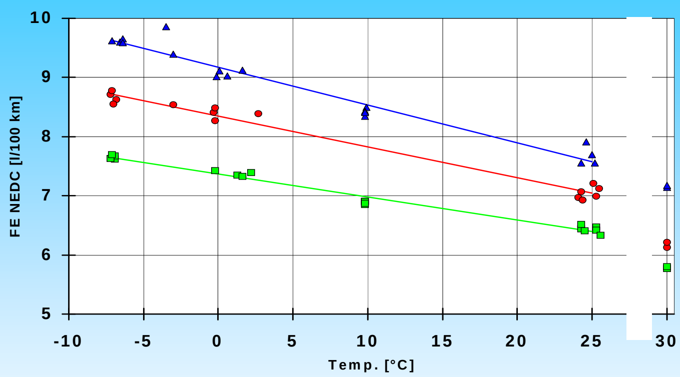
1. **Vehicle**
   – Road Load
     • Cookbook or coast down
     • Axle load
   – Tyre pressure
   – Battery charge (soak duration)
   – ECU adaptation
   – Run in effects
     • Wear
     • Oil dilution/contamination
   – Wheel alignment
   – Brake wear
   – Fluid levels
   – Carbon canister loading / purge



Sources for Variability

2. **Environmental effects**:
   – **Temperatures** (oils, coolant, air)
   – Humidity
   – Vehicle cooling fan
     • Position (distance, height, angle)
     • Nozzle size
     • Flow distribution/Linearity

Cell Air Conditioning



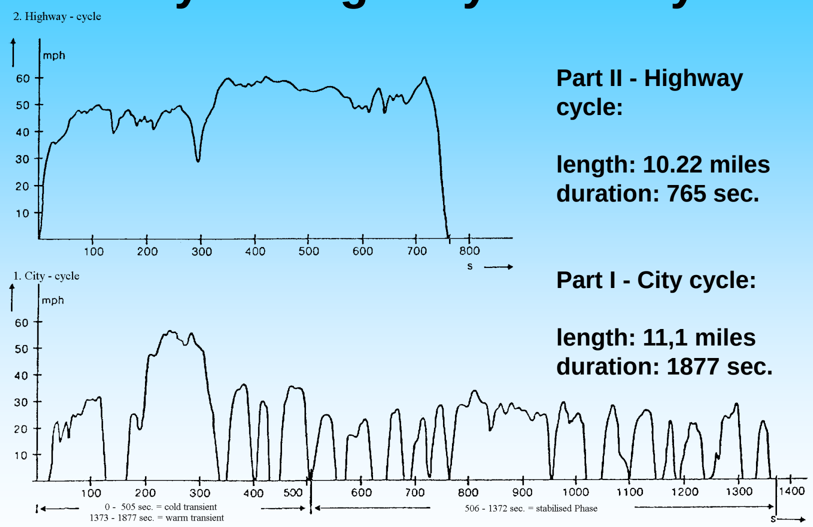
- Temperature control ± 0.5°C
- Humidity control ± 5% Rh
- Space for 7 cars

Sources for Variability

3. <u>Drive Style</u>

- Concentration (early/late shifts, workload)
- Difference between drivers
  - Experience
  - Motivation

US - City & - Highway Drive Cycle



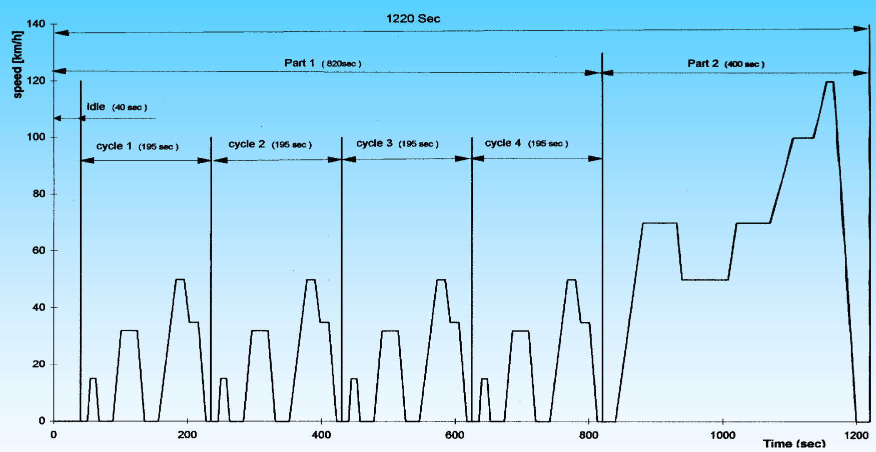
Part II - Highway cycle:

length: 10.22 miles
duration: 765 sec.

Part I - City cycle:

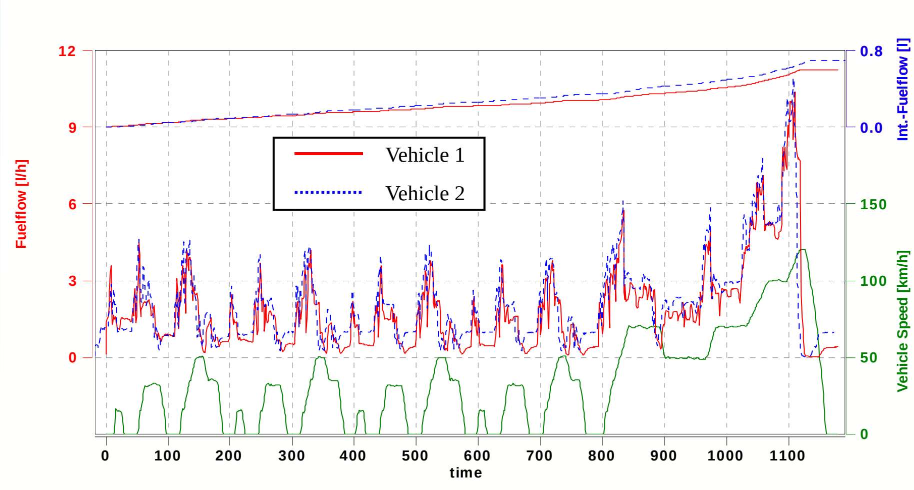
length: 11,1 miles
duration: 1877 sec.

NEW European Drive Cycle

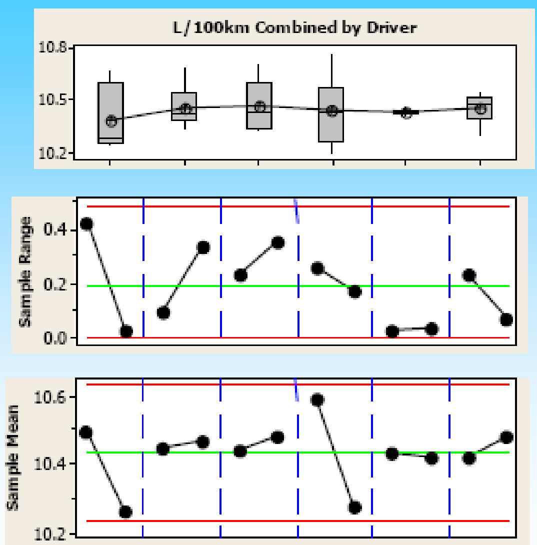


Length: 11.007 km Duration: 1180 sec. (EURO 3 ff.)

Fuel Consumption Development



Driver



For small changes:

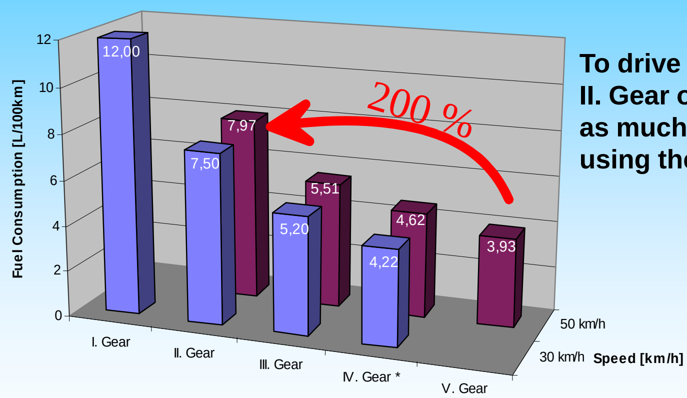
- Select most robust drivers
- Use same driver

Eco Driving (1)

- Check Tyre Pressure regularly
- Remove unnecessary weights from luggage compartment (additional 100 kg result in a additional fuel consumption of 0,5 l/100km)
- To carry goods on the roof use aerodynamic improved boxes (if possible)
- Drive longsighted,
  i.e. let vehicle coast down at red traffic lights
- Always use the highest possible Gear to drive at low engine speeds (see next slide!)

Eco Driving (2)

Use the highest possible Gear – also in the town !



To drive at 50 km/h in II. Gear one needs twice as much fuel as if using the V. Gear!

Fuel Consumption at constant Speeds using different Gears (Ford Focus 1,8 ltr.)

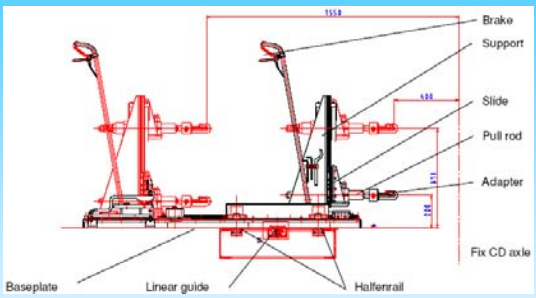
Sources for Variability

4. Dynamometer

- Force control
- Friction compensation
- Calibration
- Restrain system

ACART Dyno

- Four Wheel Drive
- Dog Sleigh Restraint System
  - No vertical forces
  - Quick set up
- High Accuracy Control System:
  - Dynamic power measurements
  - Constant force
  - Constant velocity
  - Gradient simulation
  - Automatic road load matching
  - Analysis of Powertrain friction
- Roll diameter: 48"
- Max. speed: 200 km/h
- Max. power: 516 kW
- Inertia range: 453 kg – 5443 kg
- Wheelbase: 2032 mm - 4699 mm
- Wheel track: 914 mm - 2743 mm
- Motorcycles included
- Speedo- and Odo-calibrations



Sources for Variability

5. Sampling/Gas-analysis

– Constant Volume Sampling
- Modal correction
- Dilution air / background
- Contamination (hang ups)
- Leaks
- Tailpipe pressure
- Water condensation
- Bag material permeation/out-gasing

– Analyser calibrations, - drifts

– Electric charges

Sources for Variability (4)

6. Consumables
- Gases (Span-, Zero-, Fuels-: tolerances, contamination)
- Fuel properties, EU - Regulations don't correct for
  - H/C ratio
  - Heat value

7. Regulations
- Ambient correction (US does not allow negative emissions)
- Lambda =1 dictated in calculation

Regulations

Issues with CVS (Constant Volume Sampling)

- Must correct for ambient pollutants
- Present correction for ambient not exact
- Ambient concentrations can be higher than vehicle emissions
- Needs large amount of ambient air, so removing pollutants difficult and expensive
- Dilution factor determination required but difficult, esp. for non-stoichiometric operation

Regulations (2)

$$m = \rho \cdot \left[\bar{c}_s - (1 - \frac{1}{DF}) \cdot \bar{c}_a \right] \cdot V_{CVS}$$

m = total mass of emitted pollutant
V_{CVS} = total volume of flow through CVS
ρ = density of pollutant as vapor
c_s = concentration of pollutant in sample bag
c_a = concentration of pollutant in ambient bag
DF = dilution factor of exhaust in sample

$$DF = \frac{13.4}{C_{CO2} + (C_{HC} + C_{CO}) \cdot 10^{-4}}$$

Regulations (3)

Problems with Equation

- Constant flow ambient sampling doesn't weight ambient bag the same way as ambient is weighted in sample bag
- Ambient concentrations can change with time, especially if charcoal gets contaminated
- DF calculation contains several errors
  - CO_2 in ambient bag not accounted for
  - Assumes stoichiometric combustion (CO_2 Vol% = 13.4)

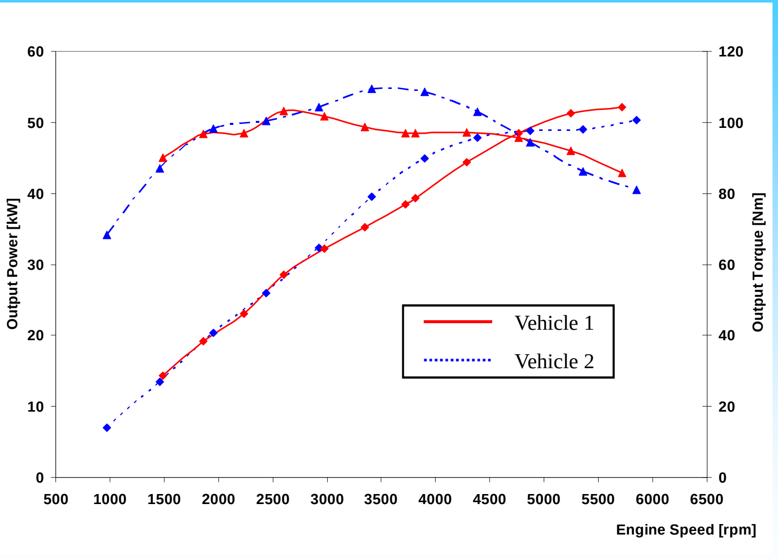
Additional QC Checks

- BOSS Test (Bag Only Safe Simulator)
  - 4 gas mixture
  - Eliminates vehicle, driver and dyno influences
  - Enables quick trouble shooting
- Blank tests
  - Monitors contamination
  - Reduce hang ups after high emitters
- Cross reference check for new gases & fuels
- Additional instruments

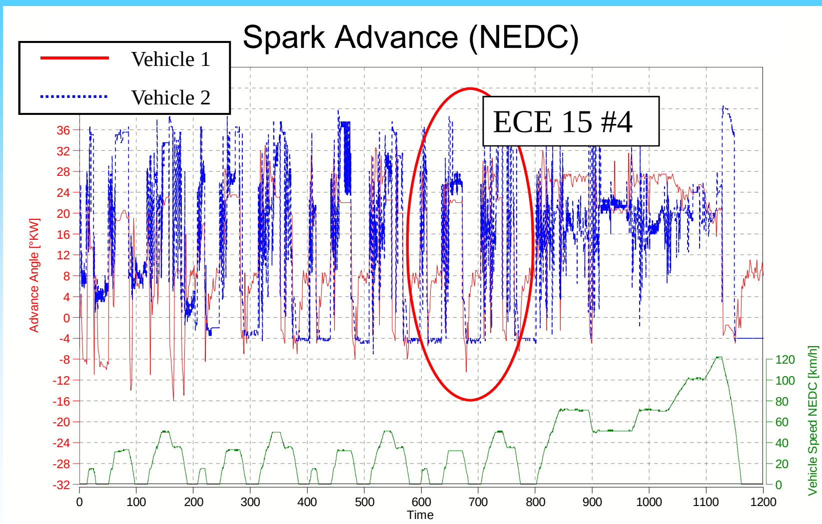
Further Experience

- Cold/Hot ratio to assess warm up
- Fuel Economy including vehicle AC
- Comparison of Low Friction Oils:
  - Weighting of oil mass
  - Purge with reference oil
  - Always use fresh oil
  - A-B-A sanity check
- EOBD Scan tools for:
  - Spark Advance
  - Coolant Temperature
  - Vehicle Speed
  - Engine Speed
  - Lambda

Performance



Engine Data



Q & A

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Back Up Material

Literature

– SAE 1999-01-0154 - PAS
– SAE 2002-01-0048 - Enhanced CVS
– SAE 2001-01-0209 - Error Analysis
– SAE 2003-01-1162 - De-Sulfation of NO_x traps
– SAE 2001-01-3530 - Hydrogen Sulphide
– SAE 2004-01-0968 - Soot Sensor

Regulations (4)

Non Combustion Difference

– Stoichiometric operation
  - If a typical DF is 20, corresponding to 13.4% CO_2 ,
  - then (1-1/DF) = 0.95, and 95% of ambient concentration is subtracted from that of sample

– Lean operation
  - If vehicle actually ran lean with the same exhaust flow (and same physical DF) and had, say, 9% CO_2,
  - then the denominator would be 9% / 20 = 0.45% and DF would be calculated as DF = 13.4% / 0.45% = 29.8
  - (1-1/DF) = 0.97, and 97% of ambient would be subtracted, giving a 2% difference for non-combustion air

Proportional Ambient Sampling (PAS)

(Source: Dick Chase)

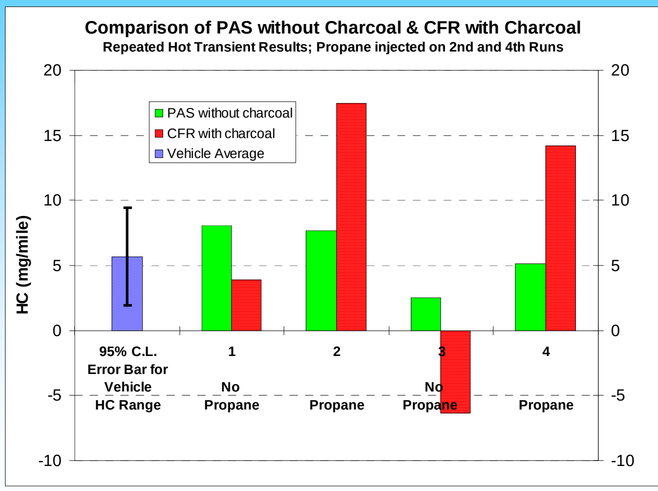
Corrects for contaminants in dilution air:

- Flow rate for ambient bag proportional to dilution air flow rate
  – Mass flow controller for ambient bag fill
- Measure V_{air} (in place of DF)
  – Inlet SAO gives V_{air} dilution air, also useful for
    - Modal measurements
    - CVS calibration

$$m = \rho \cdot \bar{c}_s \cdot \left[V_{CVS} + V_{sbag}\right] - \rho \cdot \bar{c}_a \cdot \left[V_{air} - V_{abag}\right]$$

Bag Results: PAS vs. CVS

Propane Injected in Ambient during Vehicle Test



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