Engines, Energy and Environment Group

POLITECNICO DI TORINO

Dipartimento Energia

Fuel Consumption, CO_2 and NO_x Emissions of a Passenger Car over the NEDC and WLTC driving cycles

Engine Emission Control – Automotive Engineering

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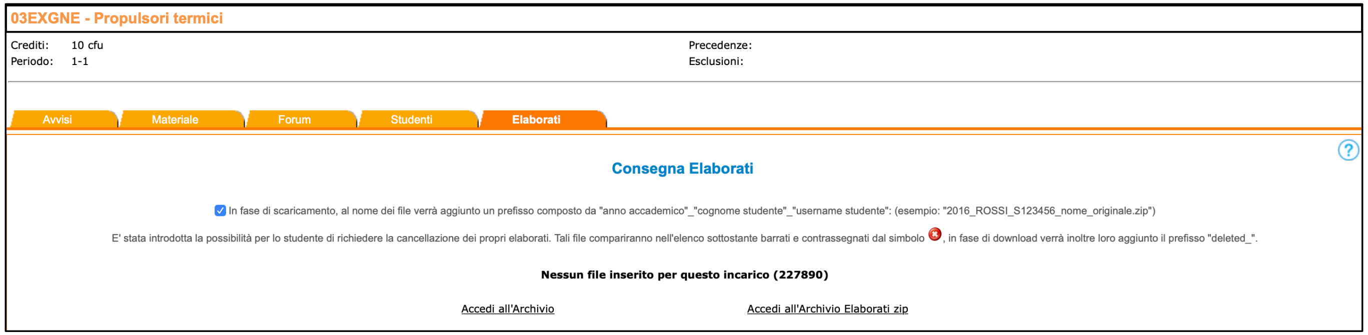
07-10-2019

Rules for the Report

- You should not re-discover the wheel:
  - The report should include the main **equations, hypothesis, numeric results and images**
  - The introduction of this presentation **must not** be included in the report with different words.
- Pay attention
  - to the shape of the pictures:
    - Axis/Fonts dimensions
    - Dimension of the lines
  - Table of numeric results ➔ significant digits
- The reports should be uploaded **at least 5 working days before the exam**



03EXGNE - Propulsori termici

Crediti: 10 cfu
Periodo: 1-1

Precedenze:
Esclusioni:

Avvisi | Materiale | Forum | Studenti | Elaborati

Consegna Elaborati

In fase di scaricamento, al nome dei file verrà aggiunto un prefisso composto da "anno accademico"_"cognome studente"_"username studente": (esempio: "2016_ROSSI_S123456_nome_originale.zip")

E' stata introdotta la possibilità per lo studente di richiedere la cancellazione dei propri elaborati. Tali file compariranno nell'elenco sottostante barrati e contrassegnati dal simbolo , in fase di download verrà inoltre loro aggiunto il prefisso "deleted_".

Nessun file inserito per questo incarico (227890)

Accedi all'Archivio   Accedi all'Archivio Elaborati zip

Agenda

- Introduction
- Goal of the Exercise
- Vehicle Model Building
- Model Limits
- CO_2 Legislation Targets
- Post-Processing

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Real vs Declared Emissions/Fuel Consumption

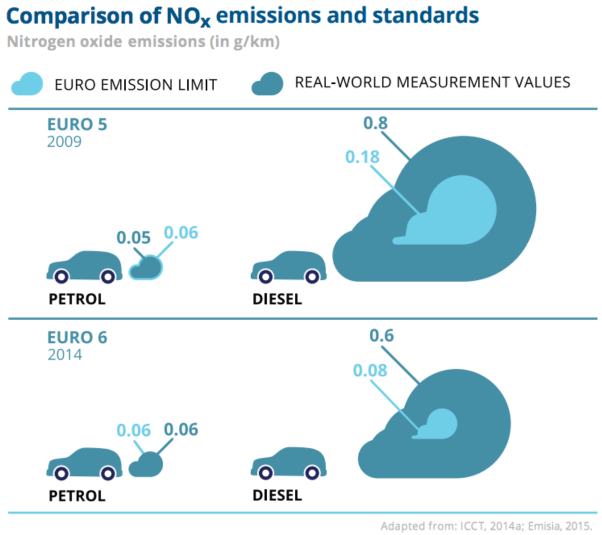
L'anidride carbonica allo scarico di 160 modelli

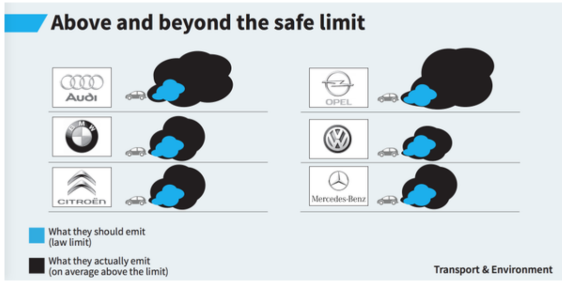
Quant'è lontana la realtà

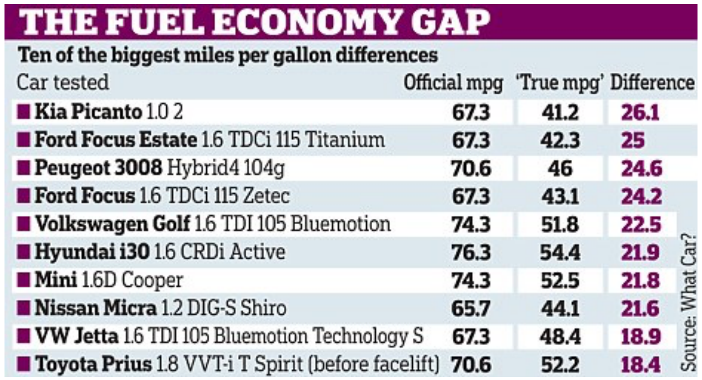
Nessuno fa eccezione: dalle prove di Quattroruote emerge chiaramente come i valori effettivi siano sempre molto superiori a quelli dichiarati. Ecco tutte le rilevazioni degli ultimi due anni

L'anomalia dei consumi reali più alti rispetto a quelli dichiarati non riguarda ovviamente solo il gruppo Volkswagen, ma interessa in modo generalizzato tutti i costruttori, sia pure con significative differenze tra un modello e l'altro. In nessun caso, le nostre rilevazioni sono risultate più favorevoli dei dati promessi dalle Case. E nessun costruttore può vantare maggior "sincerità" o, me-

Marca, modello e versione	Pubblicata	Carburante	Normativa	Cilindrata cm³	Consumo rilevato l/100 km	Consumo omologato l/100 km	Emiss. CO_2 rilevata g/km	Emiss. CO_2 dichiarata g/km	Differenza CO_2 %
Alfa Romeo Giulietta 1750 Turbo Tct Quadrifoglio Verde	sett. 2014	Benzina	Euro 6	1.742	9,4	7,0	225	162	+39
Alfa Romeo Giulietta 2.0 Jtdm-2 (150 CV)	gen. 2014	Gasolio	Euro 5	1.956	5,8	4,2	153	110	+39
Alfa Romeo Giulietta Sprint 2.0 JTDm-2 (175) TCT	feb. 2015	Gasolio	Euro 5	1.956	6,1	4,4	163	116	+40
Alfa Romeo MiTo 1.4 T 170 CV Quadrifoglio Verde	nov. 2014	Benzina	Euro 6	1.368	7,6	5,4	182	124	+47
Audi A1 Sportback 1.4 TDI	mag. 2015	Gasolio	Euro 6	1.422	5,6	3,4	150	89	+68
Audi A3 Sportback 1.6 TDI S tronic	mar. 2014	Gasolio	Euro 5	1.598	5,9	3,9	156	99	+57
Audi Q7 3.0 TDI quattro	set. 2015	Gasolio	Euro 6	2.967	9,4	5,7	250	149	[illegible]
Audi RS3 Sportback	ott. 2015	Benzina	Euro 6	2.480	9,9	8,1	236	194	[illegible]
Audi S1 2.0 TFSI quattro	ago. 2014	Benzina	Euro 6	1.984	8,1	7,0	193	162	[illegible]
Audi S3 Sportback 2.0 TFSI S tronic quattro	feb. 2014	Benzina	Euro 6	1.984	9,3	6,9	222	162	[illegible]
Audi TT 2.0 TDI	nov. 2014	Gasolio	Euro 6	1.968	5,9	4,2	156	110	[illegible]
BMW 116d Efficient Dynamics	giu. 2015	Gasolio	Euro 6	1.496	5,6	3,4	147	89	[illegible]
Bmw 218d Gran Tourer	ago. 2015	Gasolio	Euro 6	1.995	6,8	4,5	179	119	[illegible]
BMW 218d Active Tourer	ott. 2014	Gasolio	Euro 6	1.995	6,8	4,3	179	109	[illegible]
BMW 218i Active Tourer	apr. 2015	Benzina	Euro 6	1.499	7,3	4,9	174	115	[illegible]
BMW 220d Coupé Msport	ago. 2014	Gasolio	Euro 6	1.995	6,1	4,5	162	119	[illegible]
BMW 320d Touring Msport	ott. 2015	Gasolio	Euro 6	1.995	6,1	5,0	162	133	[illegible]
BMW X4 xDrive30d Msport	lug. 2014	Gasolio	Euro 6	2.993	8,7	6,1	230	156	[illegible]
[illegible]	[illegible]	[illegible]	Euro 6	2.993	9,9	6,2	262	162	[illegible]







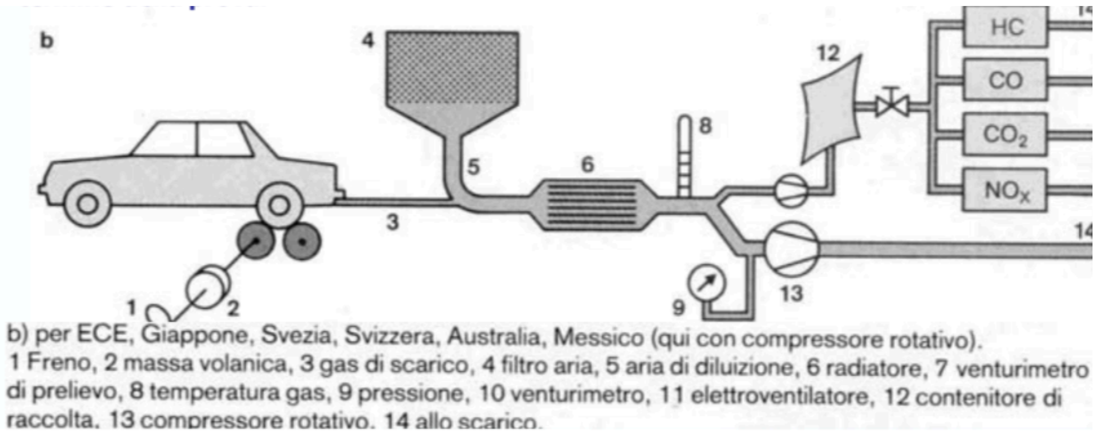
THE FUEL ECONOMY GAP

Ten of the biggest miles per gallon differences

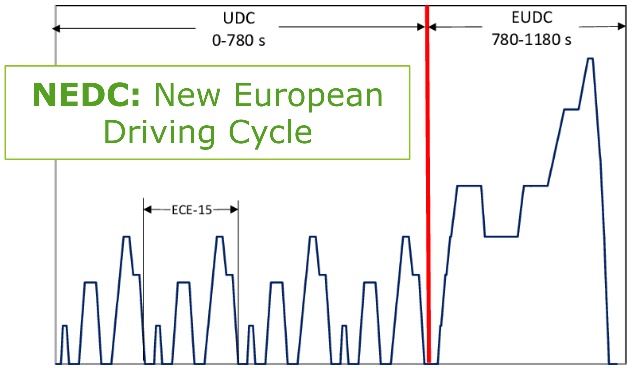
Car tested	Official mpg	'True mpg'	Difference
Kia Picanto 1.0 2	67.3	41.2	26.1
Ford Focus Estate 1.6 TDCi 115 Titanium	67.3	42.3	25
Peugeot 3008 Hybrid4 104g	70.6	46	24.6
Ford Focus 1.6 TDCi 115 Zetec	67.3	43.1	24.2
Volkswagen Golf 1.6 TDI 105 Bluemotion	74.3	51.8	22.5
Hyundai i30 1.6 CRDi Active	76.3	54.4	21.9
Mini 1.6D Cooper	74.3	52.5	21.8
Nissan Micra 1.2 DIG-S Shiro	65.7	44.1	21.6
VW Jetta 1.6 TDI 105 Bluemotion Technology S	67.3	48.4	18.9
Toyota Prius 1.8 VVT-i T Spirit (before facelift)	70.6	52.2	18.4

Source: What Car?

Test Bench Measurements

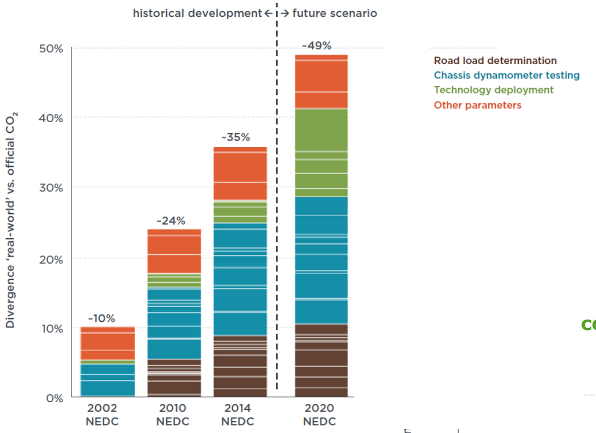


Constant Speed Pattern ➔ it is expected to represent real world driving conditions



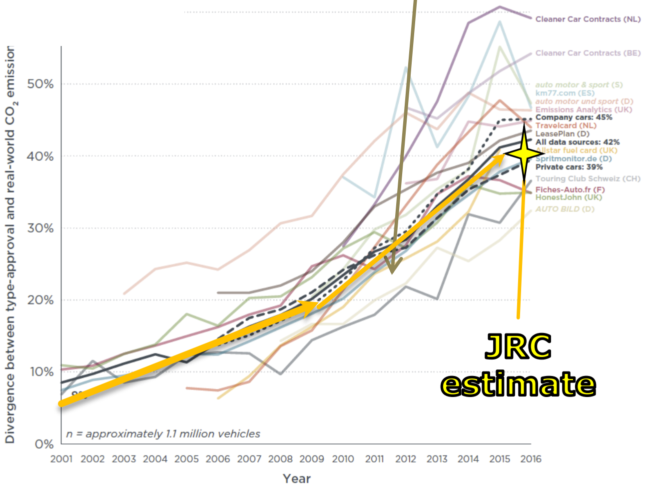
NEDC vs Real World - Discrepancy

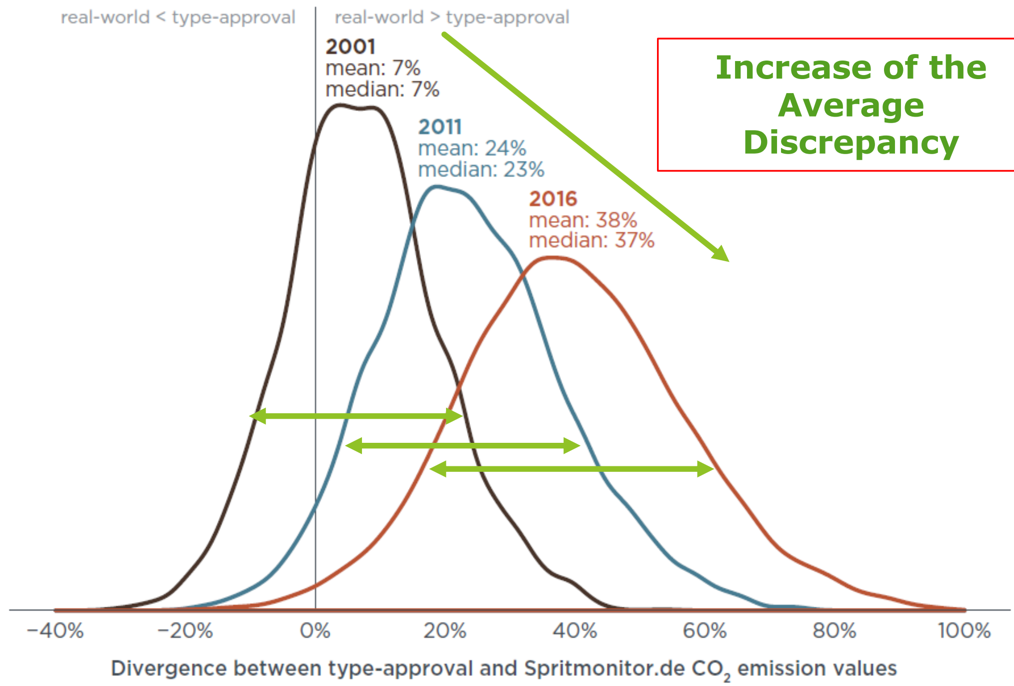
Increasing *Gap* between Type Approval and average real-world CO_2



Source: ICCT 2015

Introduction of binding targets: non-compliance penalties of up to 95€ per vehicle sold for each g of CO_2 in excess



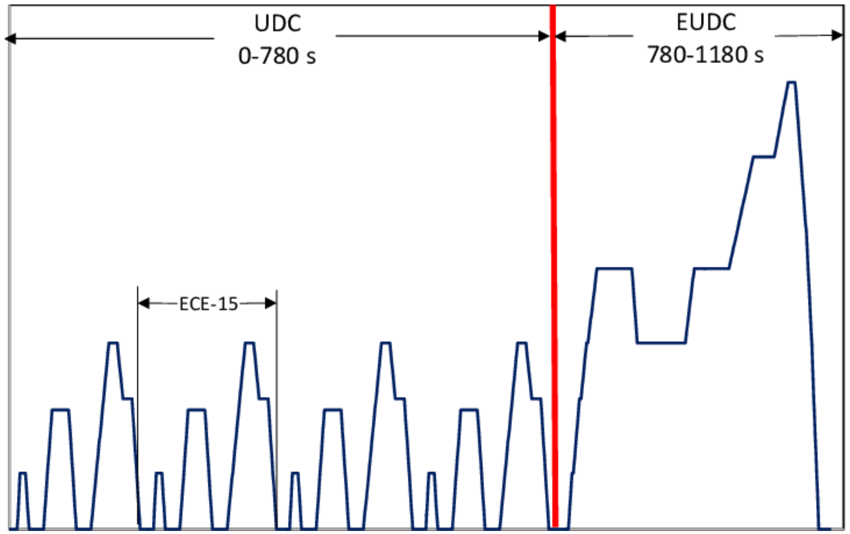


Increase of the Average Discrepancy

real-world individual variability increasing with time

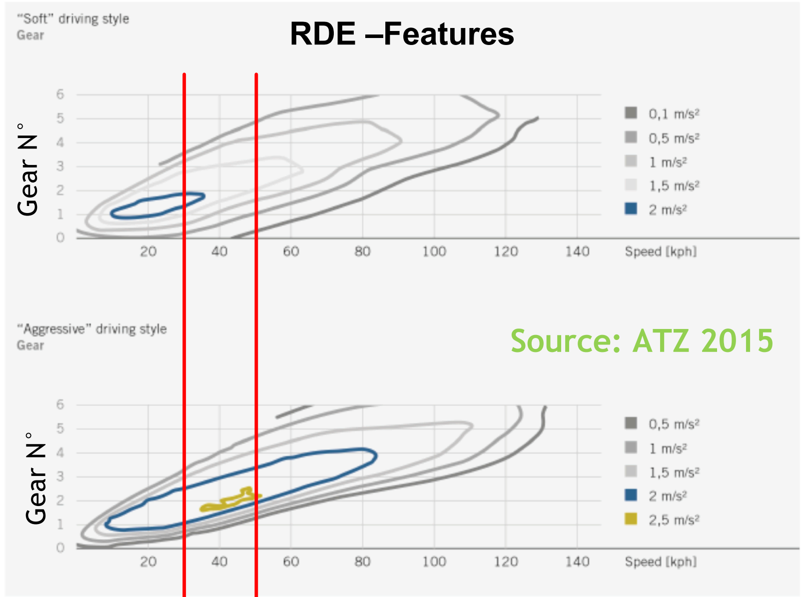
Source: ICCT 2016

NEDC vs Real World - Discrepancy



Characteristics	Unit	ECE 15	EUDC	NEDC†
Distance	km	0.9941	6.9549	10.9314
Total time	s	195	400	1180
Idle (standing) time	s	57	39	267
Average speed (incl. stops)	km/h	18.35	62.59	33.35
Average driving speed (excl. stops)	km/h	25.93	69.36	43.10
Maximum speed	km/h	50	120	120
Average acceleration[1]	m/s^2	0.599	0.354	0.506
Maximum acceleration[1]	m/s^2	1.042	0.833	1.042

† Four repetitions of ECE 15 followed by one EUDC
[1] Calculated using central difference method



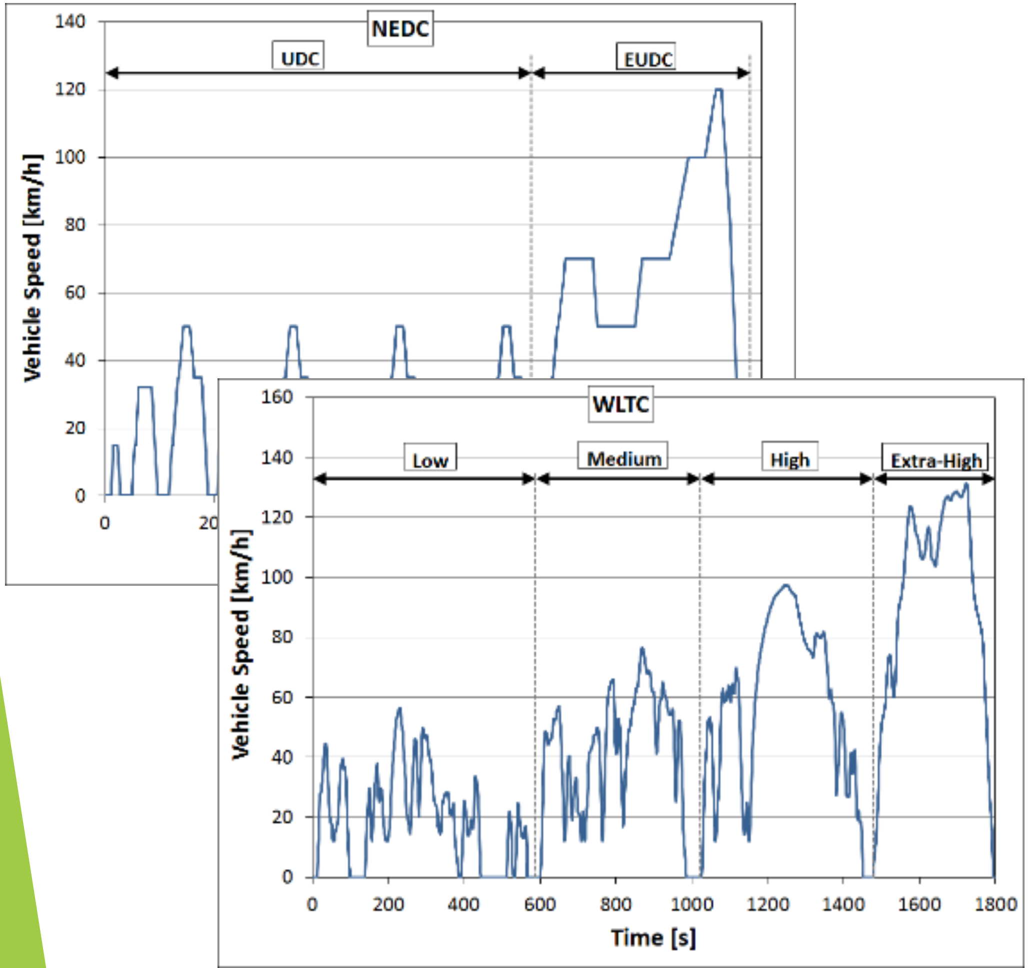
NEDC Avg. Spd

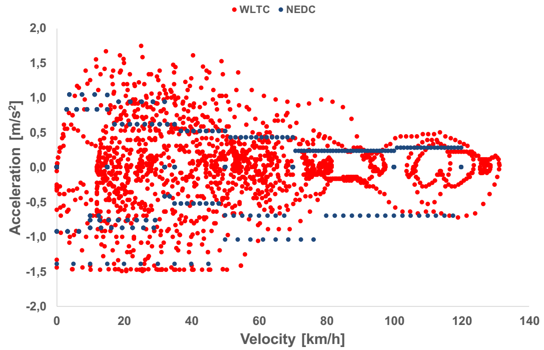
NEDC vs Real World - Discrepancy

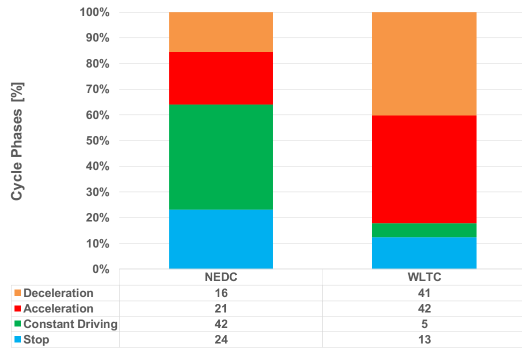
The lack of correlation wit

1. Real world driving, whi e accelerations/decelerations
   due to more aggressive
2. *Real world* vehicle mas
3. **Road incline;**
4. **Environmental conditi**

NEDC → WLTP







Parameter	NEDC	WLTC	Delta
Total time (s)	1180	1800	620
Distance (km)	11,0	23,3	12
Max speed (km/hr)	120	131	11
Average Speed (km/hr)	34	47	13
Max acceleration (m/s^2)	1,1	1,7	0,6
Max deceleration (m/s^2)	-1,4	-1,5	-0,1
Constant driving time (s)	475 (40%)	66 (3.5%)	-37%
Acceleration time (s)	247 (21%)	789 (44%)	23%
Deceleration time (s)	178 (15%)	719 (40%)	25%
Stop time (s)	280 (24%)	226 (12.5%)	-12%

NEDC → WLTP

Category	Item	in NEDC	in WLTP	Impact on CO_2
Road Load Determination	Vehicle test mass	Present	Modified	↑
	Tire selection	Present	Modified	↑
	Tire pressure	Present	Modified	↑
	Tire tread depth	Present	Modified	↑
	Calculation of resistance forces	Present	Corrected	↑
	Inertia of rotating parts	Absent	Introduced	↑
Laboratory test	Driving cycle	Present	Modified	±
	Test temperature	Present	Modified	↑
	Vehicle inertia	Present	Modified	↑
	Preconditioning	Present	Modified	↑
	Gear Shift strategy	Present	Modified	↓
Post-processing test results	SOC correction	Absent	Introduced	↑
	Correction of speed and distance	Absent	Under discussion	±
Declared value	Declaration of CO_2 emissions	Present	Modified	↑

$TM_{EU} = UM + 100$

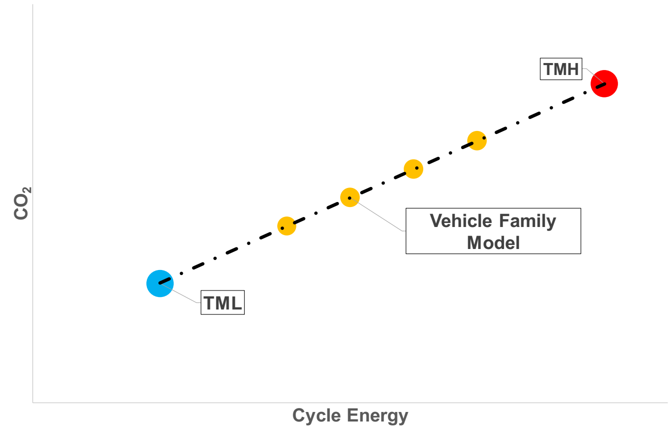
$TM_H = UM+OM+100+0,15*(LM-UM-OM-100)$

Where:

- UM is the curb mass of the vehicle
- OM is the mass of optional equipment
- LM is the technically permissible laden mass

WLTC features

- **Higher vehicle test mass (optional equipment)**
- **Higher & realistic road loads**



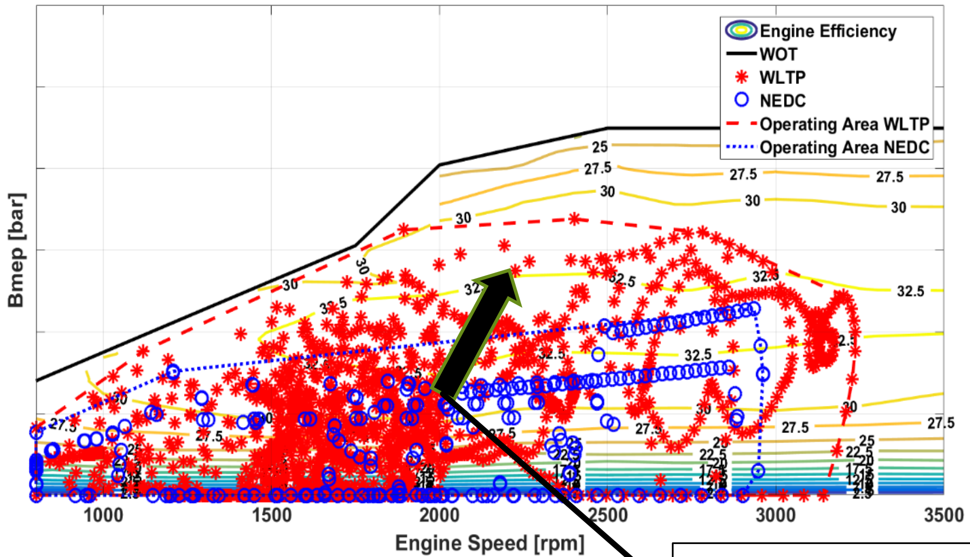
In particular 2 tests are considered:

- The ***Test Mass Low*** (TML) requires the lowest amount of energy to drive the test cycle, which has no optional equipment, lowest rolling resistance and least aerodynamic drag
- The ***Test Mass High*** (TMH) is equipped with all the optional equipment and it has the highest rolling resistance and the aerodynamic drag.

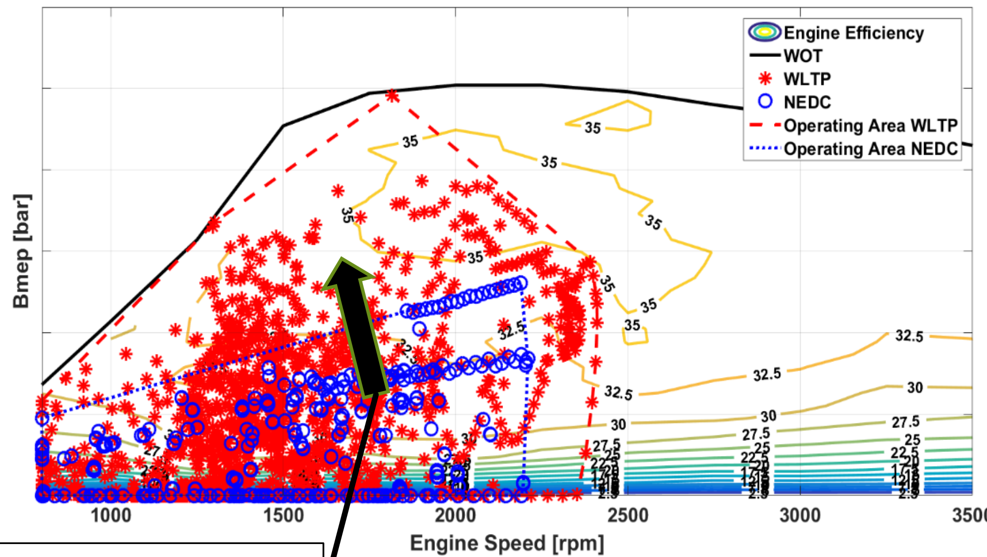
NEDC → WLTP

	Vehicle 1 (SI)	Vehicle 2 (CI)
NEDC	149 g/km	120 g/km
WLTP	164 g/km	149 g/km
Δ	+10%	+24%

Vehicle 1 – SI



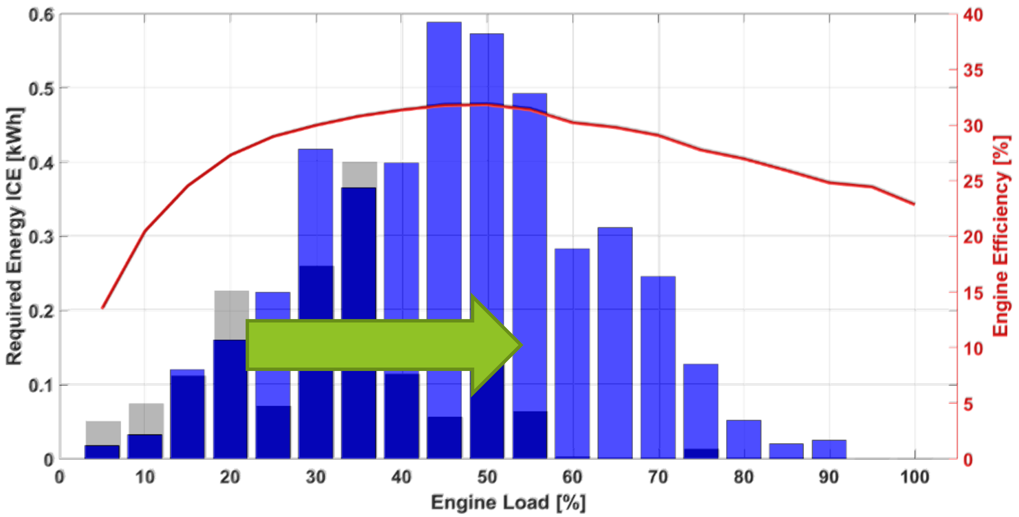
Vehicle 2 – CI



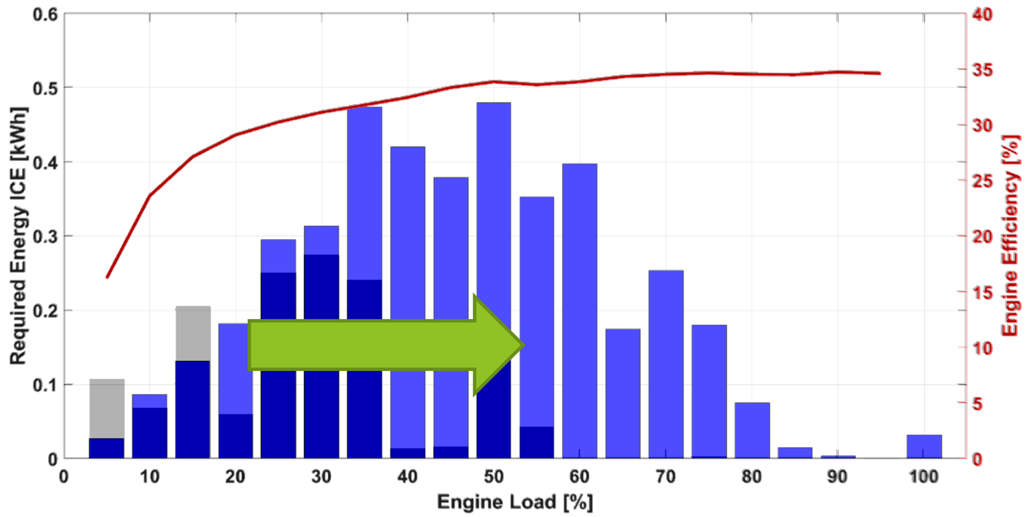
Shift of the engine operating points towards higher efficiency regions

NEDC vs WLTP – Energy Bins

Vehicle 1 – SI

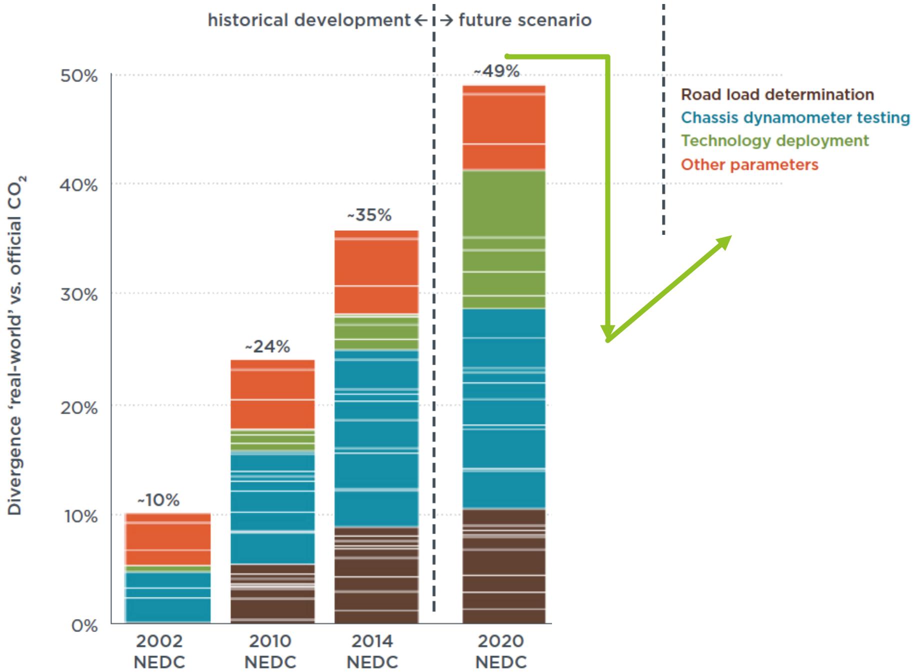


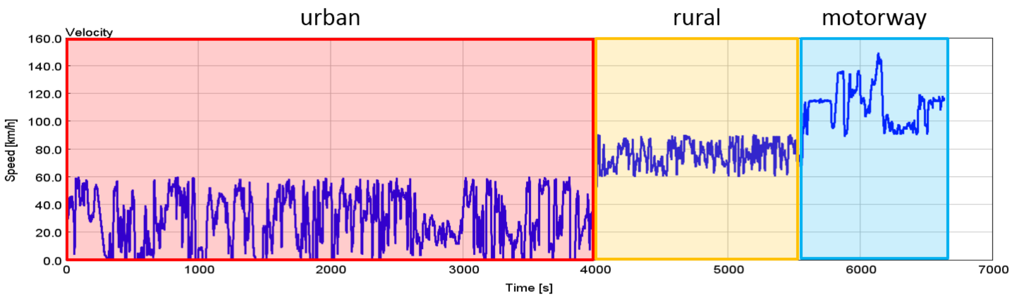
Vehicle 2 – CI



- Along the ***NEDC*** cycle a significant fraction of energy is provided by the two powertrains under poor efficiency conditions
- On ***WLTP*** the centre of gravity of the energy distribution is moved toward to the maximum efficiency area

NEDC → Real Driving Emissions





RDE imply need of:

- Statistical constraints on the speed pattern.
- Correction coefficients for ambient conditions

Agenda

- Introduction
- **Goal of the Exercise**
- Vehicle Model Building
- Model Limits
- CO2 Legislation Targets
- Post-Processing

Goal of the Exercise

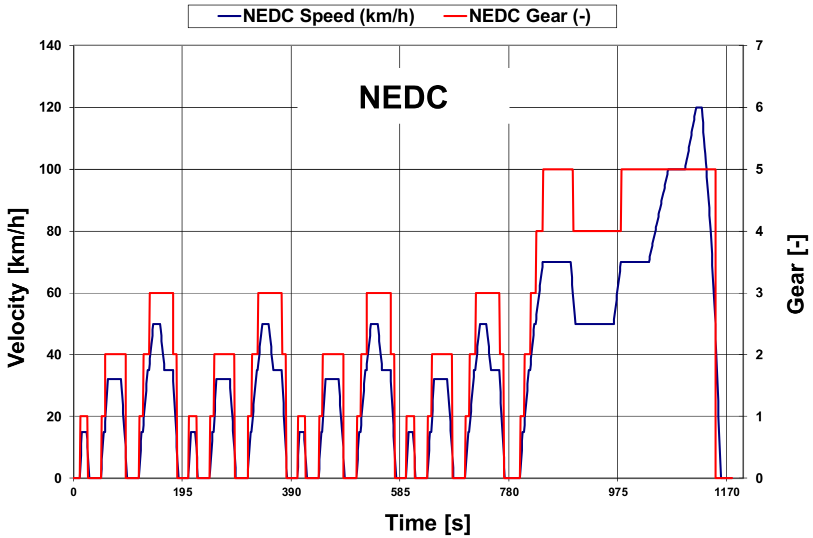
- The goal of this practice exercise is the evaluation, **through numerical simulations** of fuel consumption, CO_2 and NO_X emissions over two type approval driving cycles:
  - The ***New European Driving Cycle*** (NEDC);
  - The ***Worldwide Harmonized Light-duty Test Cycle*** (WLTC);
- Two Euro 4 B-Segment vehicles, equipped with a ***5 gears Manual Transmission*** (MT) and a ***1.3 liter Diesel engine*** and characterized by different masses and Road Loads (RLs), are the test cases used to assess the impact of ***NEDC*** and ***WLTC*** cycles on fuel consumption and pollutants emissions;

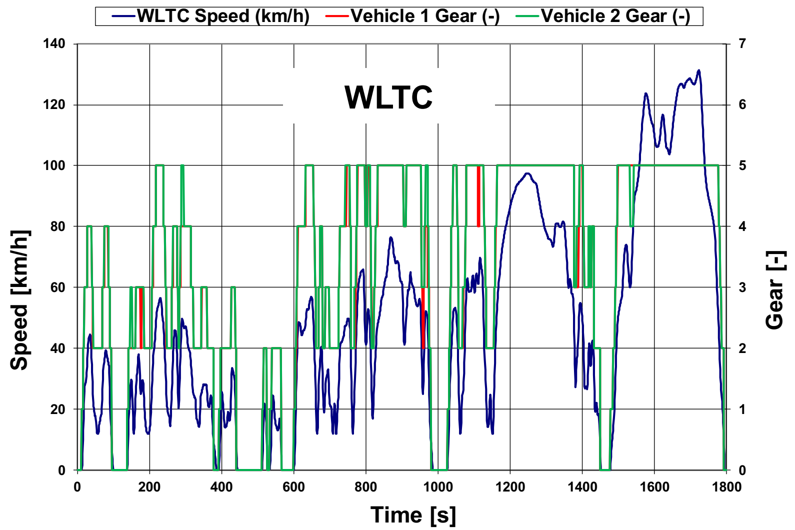
Fiat Idea

Fiat Punto

Test Conditions

- The ***NEDC*** and the ***WLTC*** cycles impose different test conditions:
  - The ***WLTC*** is characterized by higher speeds, steeper accelerations, less idling time compared to the ***NEDC***;
  - The ***WLTC*** cycle should be tested considering higher ***test mass***, ***RLs*** compared to the ***NEDC***;
  - In case of ***MT*** the ***WLTC*** cycle request a specific gearshift profile, designed as function of the vehicle characteristics (engine, gear ratios, etc..) and test conditions (***mass*** and ***RLs***), while the ***NEDC*** uses a unique gearshift pattern.
- Therefore, for the two vehicles the test conditions and the gearshift patterns for the two driving cycles are provided.





	NEDC	
Test Conditions	Idea	Punto
Mass [kg]	*1168*	*1063*
F0 [N]	*124,7*	*114,2*
F1 [N/(km/h)]	*0*	*0*
F2 [N/(km/h)²]	*0,0364*	*0,0344*

	WLTC	
Test Conditions	Idea	Punto
Mass [kg]	*1360*	*1210*
F0 [N]	*186*	*166*
F1 [N/(km/h)]	*0*	*0*
F2 [N/(km/h)²]	*0,0419*	*0,039*

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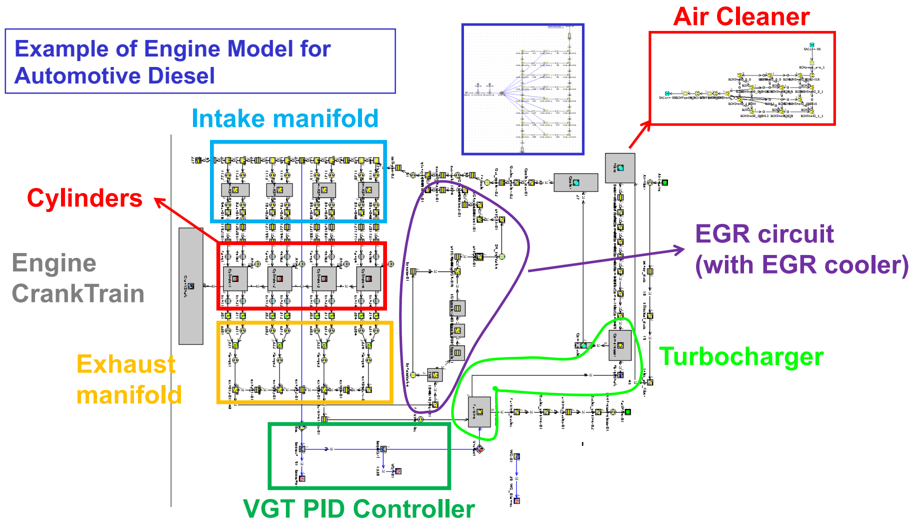
Modeling Approaches 1/2

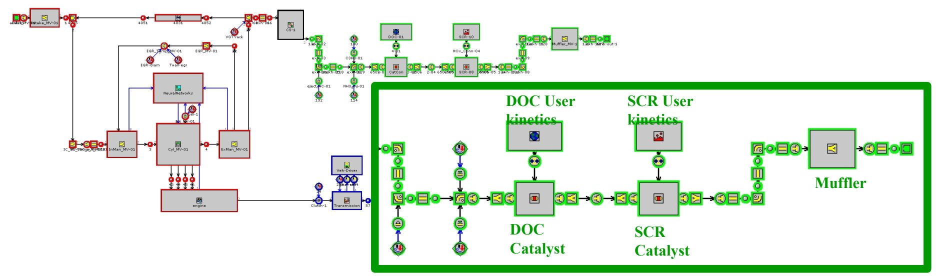
Dynamic Approach:

Not only the longitudinal vehicle dynamics equation is solved to determine the engine speed and the torque demand, but also the internal combustion engine behaviour during transients is modelled by means of detailed OD or 1D fluid-dynamic models. For instance, for an internal combustion engine, the intake and exhaust systems can be represented as a network of ducts connected by junctions that represent either physical joints between the ducts, such as area changes or volumes, or subsystems such as the engine cylinder.

- The solution of the equations governing the conservation of mass, momentum and energy of the flow for each element of the network can then obtained using a finite difference technique.
- In this way, even highly dynamic events, such as abrupt vehicle accelerations during tip-in manoeuvres can be properly and reliably simulated with a reasonable accuracy

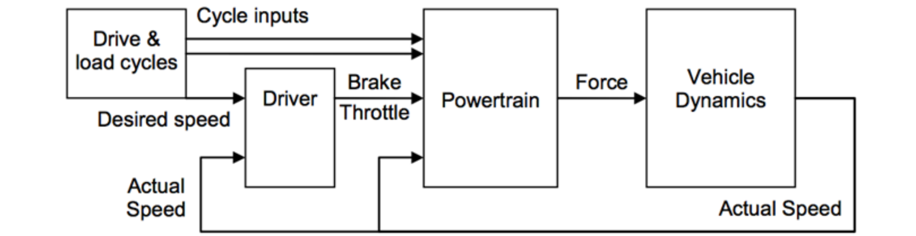


Example: Aftertreatment Models

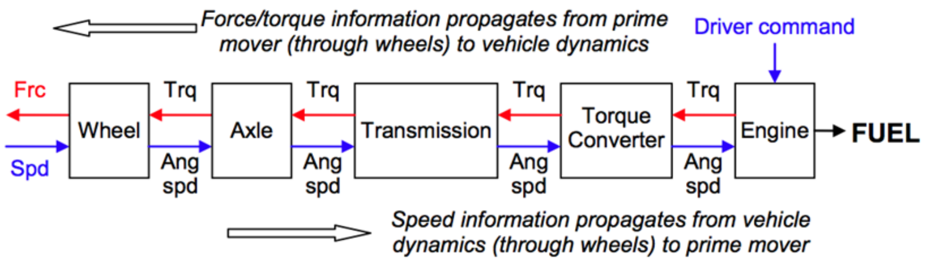


Modeling Approaches 2/2

Quasi Static Approach:
a driver model (typically a PID) compares the target vehicle speed with the actual speed and generates a power demand profile in order to follow the target vehicle speed profile, by solving the longitudinal vehicle dynamics equation as shown.

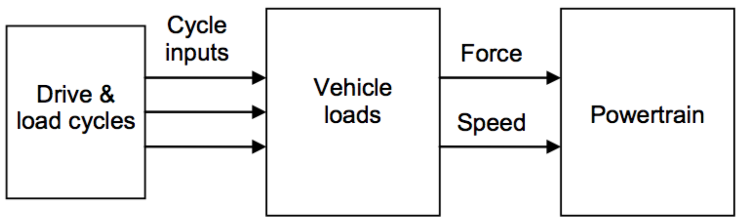


(a) Vehicle level

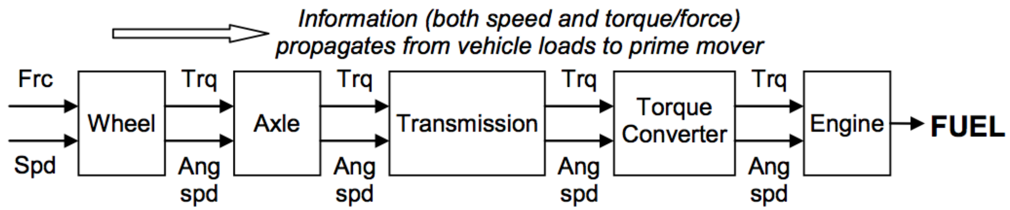


(b) Powertrain level

The kinematic approach:
it is based on a backward methodology where the input variables are the speed of the vehicle and the grade angle of the road. The engine speed can therefore be easily determined from simple kinematic relationships.

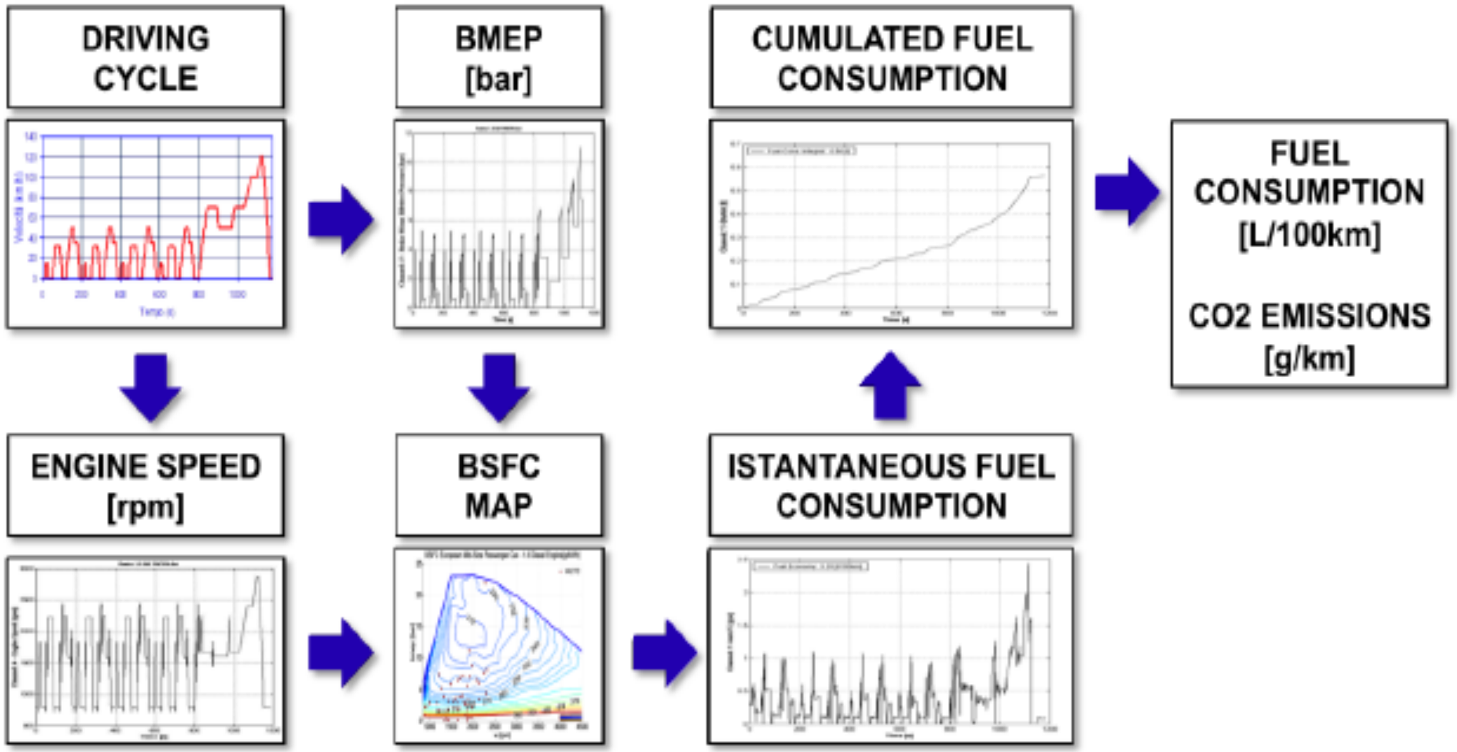


(a) Vehicle level

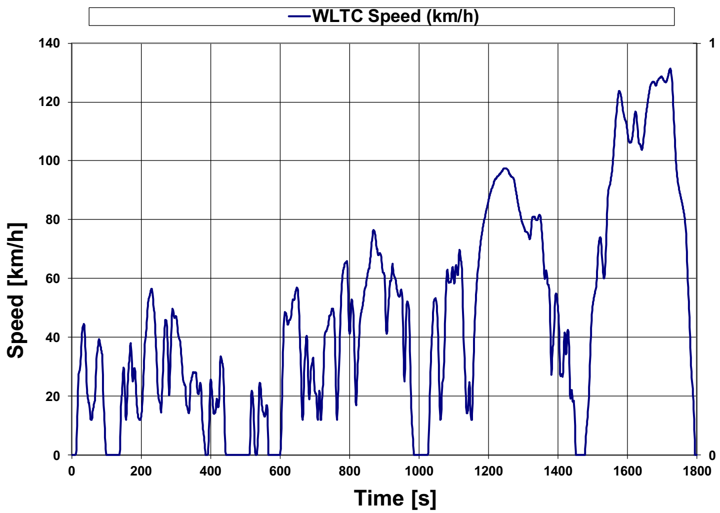


(b) Powertrain level

Vehicle Model



Calculation of the engine speed and BMEP



$$F_{res} = F_0 + F_1 * v + F_2 * v^2$$

$$P_m \eta_T [kW] = F_{res} * v + m_{tras} * \frac{dv}{dt} * v$$

$$bmep[bar] = 1200 \frac{P_m[kW]}{rpm * V[dm^3]}$$

$$rpm[rpm] = \frac{v\left[\frac{Km}{h}\right] * 60}{2 * \pi * R_0[m] * 3{,}6} * \tau_p * \tau_{marcia}$$

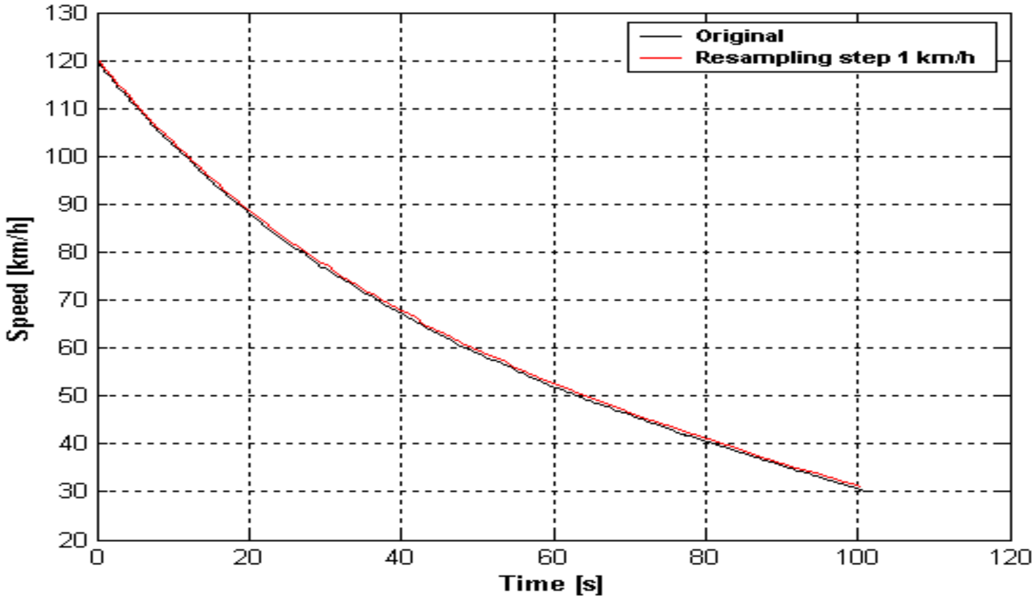
The engine speed should be limited to the idle speed equal to 800 rpm

The BMEP should be equal to 0 when the power is negative

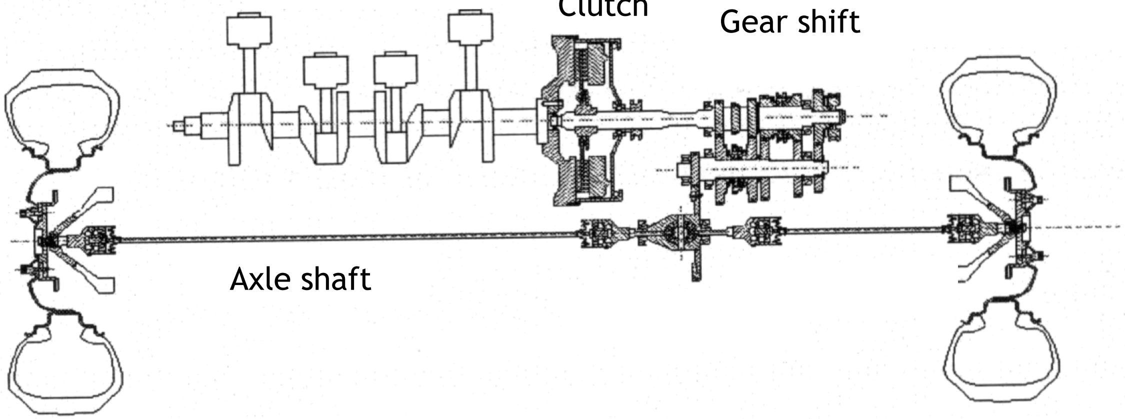
- F_{res} is the resistive force;
- **F0**, **F1** and **F2** are the Coast Down coefficients;
- M_{tras} the apparent mass of the vehicle;
- **v** is the vehicle speed;
- η_t is the efficiency of the transmission;
- P_m is the engine power;
- τ_p is the final drive ratio;
- τ_{marcia} is the gear ratio;
- **V** is the engine displacement

Coast Down Coefficient

$$-m_{tras}\frac{dv}{dt}=F_0+F_1v+F_2v^2$$

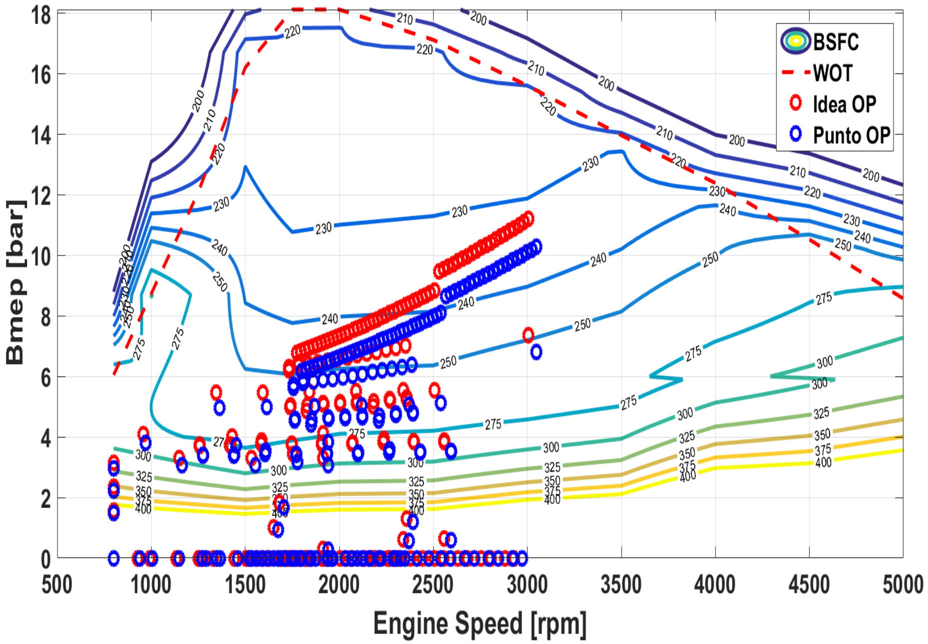


Apparent Mass



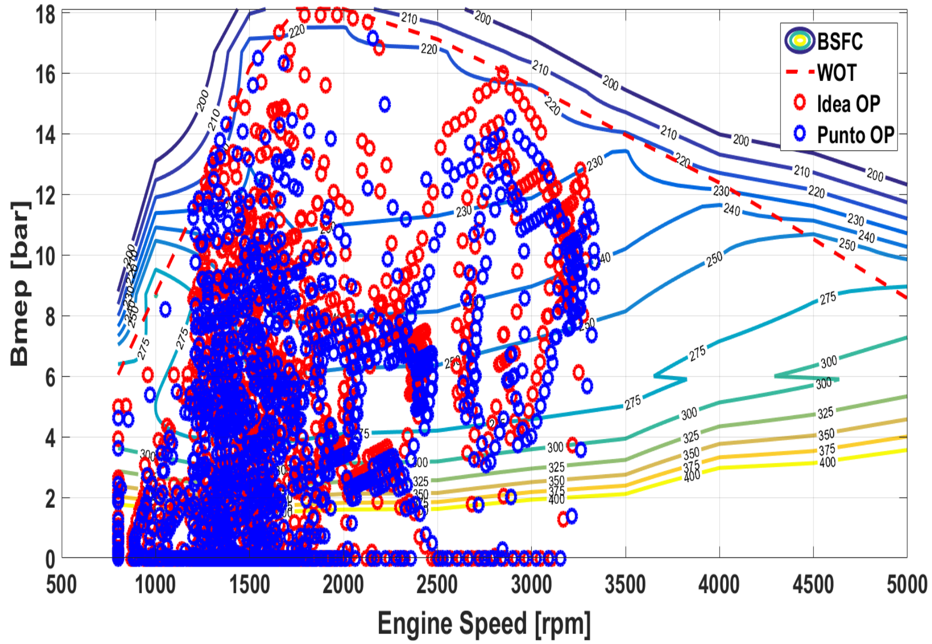
$$m_{apparent} \cong m_{vehicle} + J_{wheel}\frac{1}{r^2} + J_{eng}\frac{\tau_{gear}^2 \tau_{final}^2}{r^2}$$

Calculation of the engine speed and BMEP



NEDC

WLTC



Calculation of the engine speed and BMEP

The calculation of operating points (Engine speed, BMEP) requests the data import in Matlab of the vehicle speed and gear profiles

1. Create an M-File: edit cycle_simulation.m
2. Get data and text from Excel spreadsheet, using the command xlsread:

nedc = xlsread(NEDC_WLTP_data.xlsx,'NEDC')

Time [s]

Speed [km/h]

Gear [-]

```
nedc =

   1.0e+003 *

         0         0         0
    0.0010         0         0
    0.0020         0         0
    0.0030         0         0
    0.0040         0         0
    0.0050         0         0
    0.0060         0         0
    0.0070         0         0
    0.0080         0         0
    0.0090         0         0
    0.0100         0         0
    0.0110         0         0
    0.0120    0.0037    0.0010
    0.0130    0.0075    0.0010
    0.0140    0.0112    0.0010
    0.0150    0.0150    0.0010
```

Calculation of the engine speed and BMEP

3. Get columns time, speed, gear

```
time = nedc(:,1); speed = nedc(:,2); gear = nedc(:,3)
```

4. Define the variables necessary for the calculations:

```
mass = 1168;
ratio_I = 3.563;
eta_I = 0.94;
F0 = 124.7;
…
```

5. Choice of the gear ratio:

```
for i=1:length(speed)
    if gear(i)==0
            ratio=0
            eta=0;
    elseif gear(i)==1
            ratio=ratio_I;
            eta=eta_I;
    elseif ...
            ...
    end
```

6. Calculation of the Engine Speed

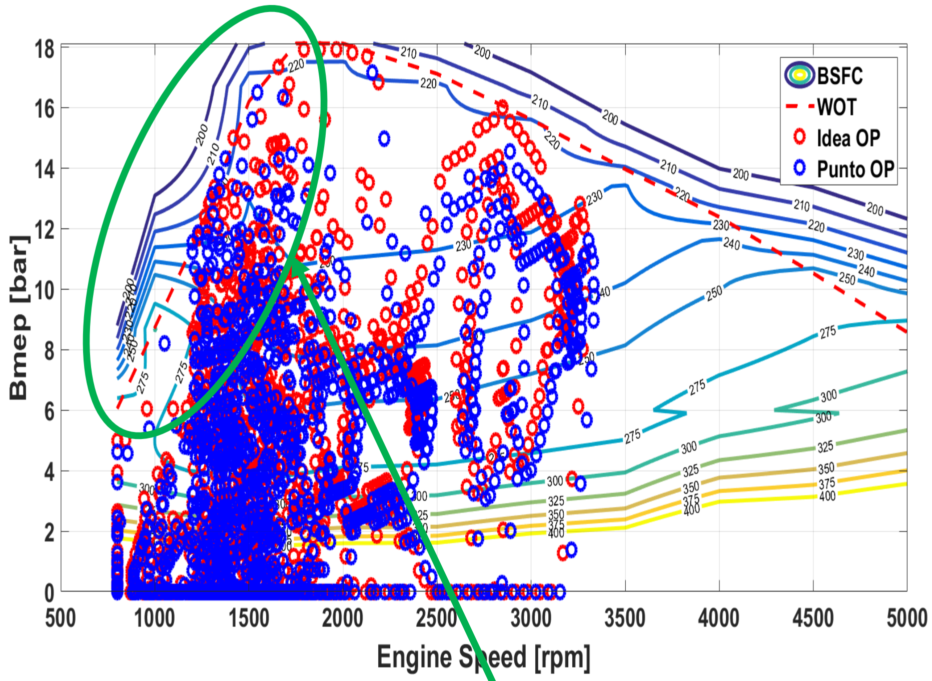
```
rpm(i) = speed(i)*60/2/pi/r_wheel/3.6*ratio_fin*ratio;
if rpm(i)<rpm_idle
 rpm(i)=rpm_idle;
end
```

To avoid down speeding below idling speed

7. Calculation of the BMEP:

```
fres(i) = F0+F1*speed(i)+F2*speed(i)^2; % Resistive Force [N]
m_trasl(i) = mass+J_wheel/r_wheel^2+J_eng/r_wheel^2*ratio^2*ratio_fin^2; % Apparent Mass [kg]
acc(i) = (speed(i)-speed(i-1))/(time(i)-time(i-1)); % Vehicle Acceleration [m/s²]
pwr(i) = (fres(i)+m_trasl(i)*acc(i))*speed(i); % Vehicle Motive Power
bmep(i) = 1200*pwr(i)/(rpm(i)*Vtot*eta_I); % Engine BMEP [bar]
If bmep(i) < 0
        bmep(i) = 0; % BMEP correction when vehicle motive power is negative
else
end
```

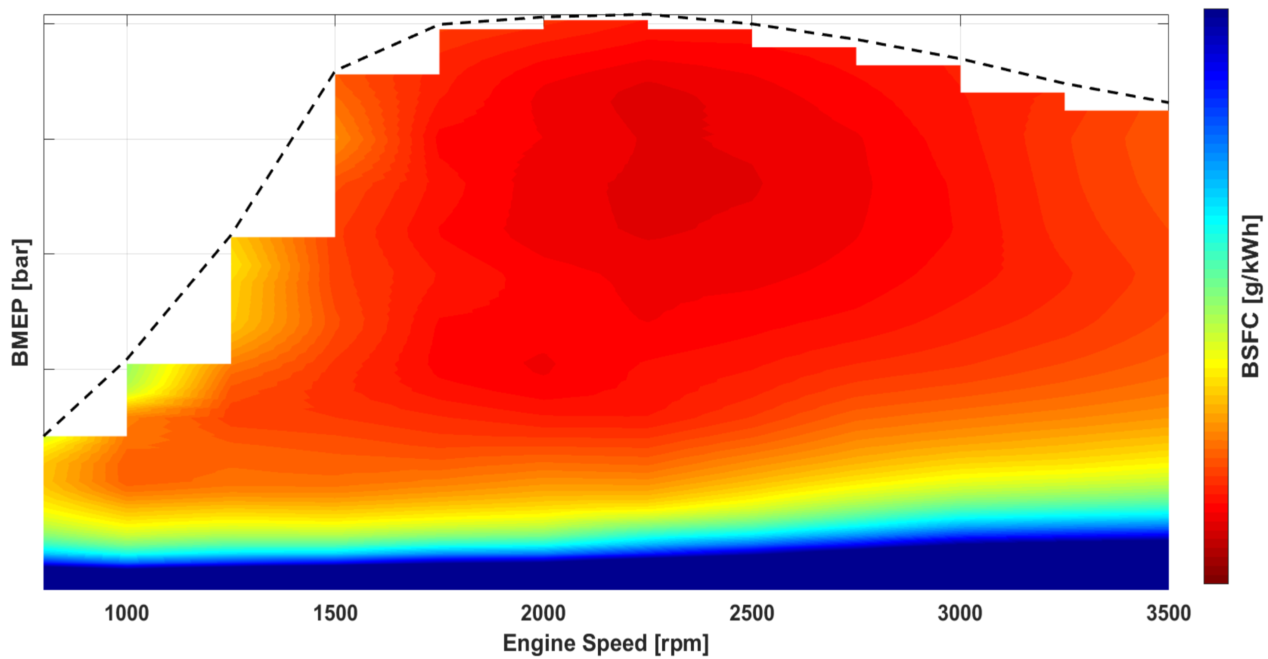
Calculation of the engine speed and BMEP



Along the ***WLTC*** cycle the internal combustion engine could operate along the Full Load Curve → **It is necessary to limit the engine power using the Full Load Curve**

Calculation of the fuel consumption/NOx emissions

The engine fuel consumption and the NO_x emissions are evaluated using performance maps, experimentally measured under steady state conditions



Example of engine fuel consumption map

Calculation of the fuel consumption/NOx emissions

1. Get fuel consumption map

```
pq=dlmread('fuel_cons_kg_h_vesr_matlab.pqm','\t');
rpm_pq=pq(1,2:end);
bmep_pq=pq(2:end,1);
fc_pq=pq(2:end,2:end); % [kg/h]
```

2. Interpolation to calculate the engine fuel rate

```
fc(i) = interp2(rpm_pq,bmep_pq,fc_pq,rpm(i),bmep(i));
```

CAUTION: The performance map is not defined for speed <850 rpm e BMEP<0.5 bar ! In these conditions the idle fuel consumption or other hypothesis should be applied

3. NO_x rate

```
nox_map = dlmread('nox_g_h.txt','\t');
rpm_nox = nox_map(1,2:end);
nox_pq = nox_map(2:end,1);
nox_pq = nox_map(2:end,2:end); % [g/h]
nox(i) = interp2(rpm_nox,bmep_nox,nox_pq,rpm(i),bmep(i));
```

CAUTION: The performance map is not defined for speed <1000 rpm e BMEP<1 bar! Hypothesis should be applied

4. Cumulative fuel consumption

fc_tot = fc_tot + fc(i)*(time(i)-time(i-1))/3.6; [g]

Alternative function: fc_tot = cumtrapz(time [s], fc [kg/h])/3.6 [g]

5. Cumulative NOx emissions

nox_tot = nox_tot+nox(i)*(time(i)-time(i-1))/3600; [g]

Alternative function: nox_tot = cumtrapz(time [s], nox [g/h])/3600 [g]

6. Distance travelled

km_tot = km_tot + speed(i)*(time(i)-time(i-1))/3600;

Alternative function: km_tot = cumtrapz(time [s], speed [km/h])/3600 [km]

7. Fuel Economy

l_100km = fc_tot/fuel_dens/km_tot*100;

8. NO_x Emissions

nox_spec = nox_tot/km_tot;

9. CO_2 Emissions

$$m_{CO_2}[g/km] = \frac{\rho_f[kg/l]}{0.0315} \cdot V[l/100km]$$

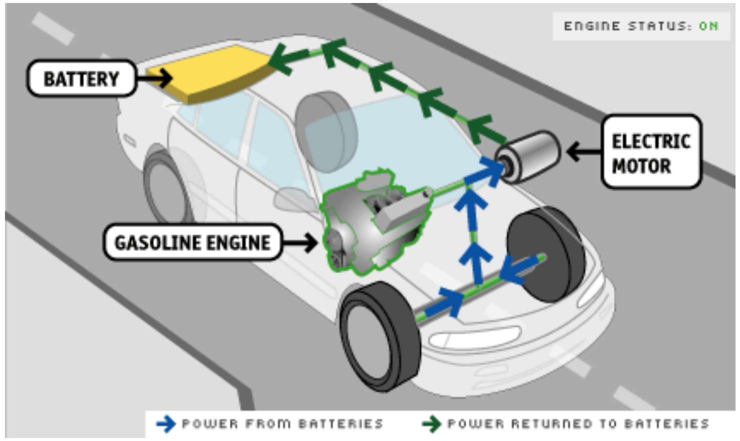
Calculation of the CO_2 Emissions

$$n_f = n_{CO_2} + n_{CO} + n_{HC} \quad \Rightarrow \quad m_f = n_f \mu_f = \left(\frac{m_{CO_2}}{\mu_{CO_2}} + \underbrace{\cancel{\frac{m_{CO}}{\mu_{CO}} + \frac{m_{HC}}{\mu_{HC}}}}_{\approx 0} \right) \mu_f$$

$$\Rightarrow \quad m_{CO_2} \approx m_f \frac{\mu_{CO_2}}{\mu_f} \quad \Rightarrow \quad m_{CO_2}[g/km] = \frac{\rho_f [kg/dm3]}{0.0315} \cdot V[l/100km]$$

Evaluation of the mechanical energy demand and of the maximum energy recovered through regenerative braking

- The cycle energy demand is an important parameter for a meaningful comparison between different driving cycles and test conditions;
- **The mechanical energy demand is computed by integrating the positive motive power as function of time** (resistive force + inertias);
- The **regenerative braking is an energy recovery mechanism which converts the kinetic energy during the braking phases into electrical energy through a electric generator**, which is stored inside battery, instead of dissipating it through mechanical brakes;
- The energy stored inside the battery can be used for electric drive (mild/strong hybrid vehicles) or to supply auxiliary components (cockpit, infotainment, etc..) for micro hybrid applications (48V);
- The application of regenerative braking is becoming popular between manufacturers to improve vehicle fuel economy;
- The goal of this practice exercise is the evaluation of the maximum energy that can be recovered along the driving cycle;
- The energy recovered along the cycle can be computed by integrating the negative motive power as function of time.



Regenerative braking[1]

[1]Source: https://www.quora.com/What-is-the-difference-between-conventional-braking-and-regenerative-braking-in-automobiles (Accessed on 10/05/2017)

Evaluation of the mechanical energy demand and of the maximum energy recovered through regenerative braking

1. Mechanical energy demand

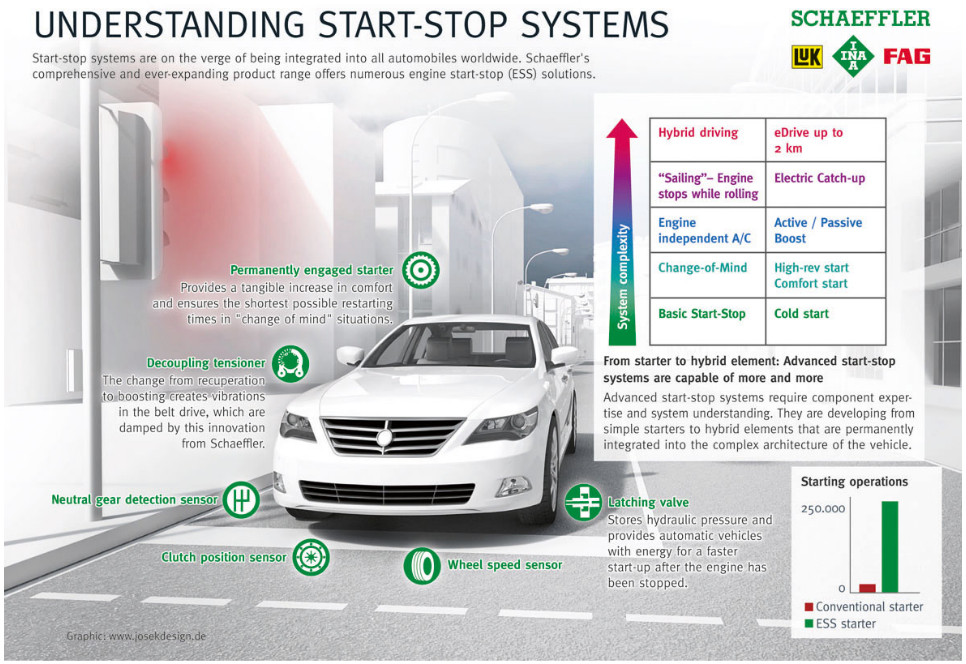
```
if pwr(i)>0
        pwr_pos(i) = pwr(i);
else
        pwr_pos(i) = 0;
end
mechanical_energy(i) = mechanical_energy(i-1) + pwr_pos(i)*(time(i)-time(i-1)) % [J]
                              …
specific_mechanical_energy = mechanical_energy/(1000*km_tot) % [kJ/km]
```

2. Maximum energy recovered through regenerative braking

```
If pwr(i)<0
        pwr_neg(i) = pwr(i);
else
        pwr_neg(i) = 0;
end
brake_energy(i) = brake_energy(i-1) + pwr_neg(i)*(time(i)-time(i-1)) % [J]
                              …
specific_brake_energy = brake_energy/(1000*km_tot) % [kJ/km]
```

Additional features: Cut-Off and Stop-Start

- **<u>The fuel cut-off is a particular control strategy available with electronic injection systems, which disables the fuel injection when the accelerator pedal is released</u>**;
- The cut-off is enabled when the engine speed is above a specific threshold (1000 ≤ speed threshold ≥ 1400 rpm) to guarantee a smooth deceleration of the vehicle;
- **<u>The Stop-Start system is used automatically shuts down the internal combustion engine to reduce the amount of time the engine spends idling, reducing fuel consumption and pollutants emissions</u>**;
- On MT vehicles, the Stop-Start is activated by pressing the clutch and moving the gear to neutral position when the vehicle is stopped (brake pedal pressed);
- The engine Stop-Start is disabled when the driver releases the clutch pedal;
- The possibility to enable the Stop-Start is also influenced by the coolant temperature (if the engine coolant temperature is below 40/50 °C the stop-start is disabled to accelerate the engine and after-treatment warm-up).



Stop-start technology[2]

[2]**Source:** http://www.car-engineer.com/stop-and-start-system-for-automatic-transmissions **(Accessed on 10/05/2017)**

Additional features: Cut-Off and Stop-Start

1. Fuel Cut-Off

```
if pwr(i) < 0 & rpm > 1000
        fc(i) = 0;
elseif
  ...
end
```

CAUTION: The same procedure should be applied to NOx emissions!

2. Stop-Start

```
 if speed(i) <= 0 & ratio <= 0
        fc(i) = 0;
    elseif
  ...
    end
```

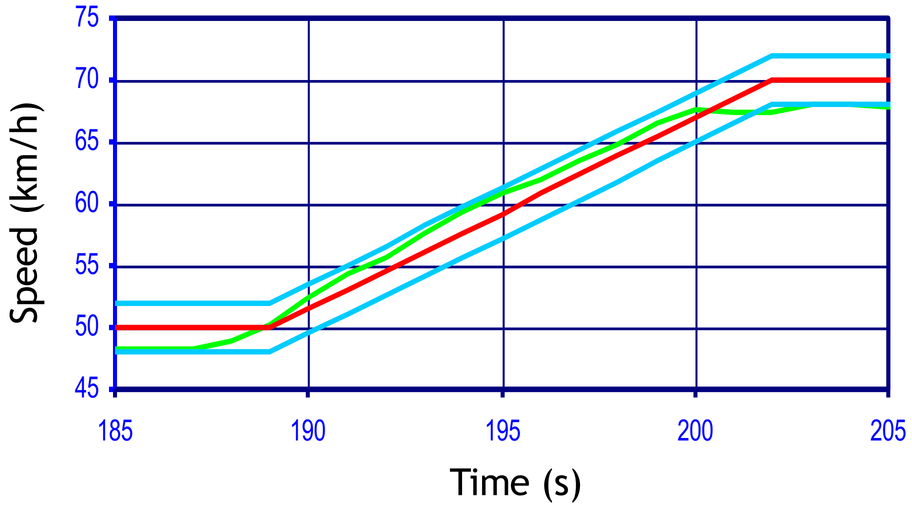
CAUTION: The same procedure should be applied to NOx emissions!

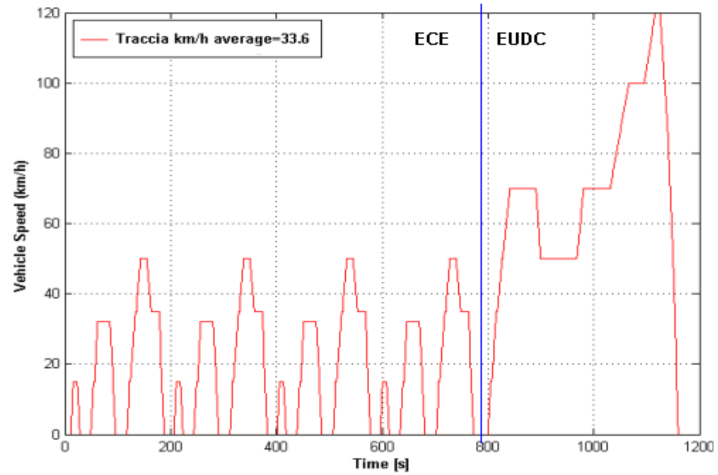
Agenda

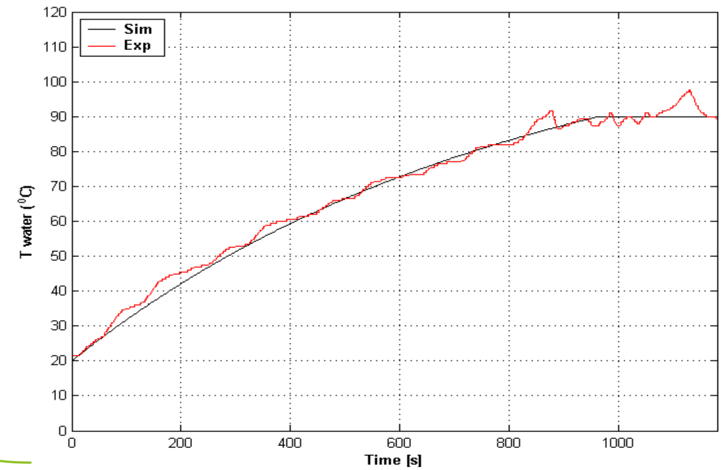
- Introduction
- Goal of the Exercise
- Vehicle Model Building
- **Model Limits**
- CO2 Legislation Targets
- Post-Processing

Model Limits

1. Thermal transient during warm-up not taken into account.
2. Real vehicle speed profile not simulated.

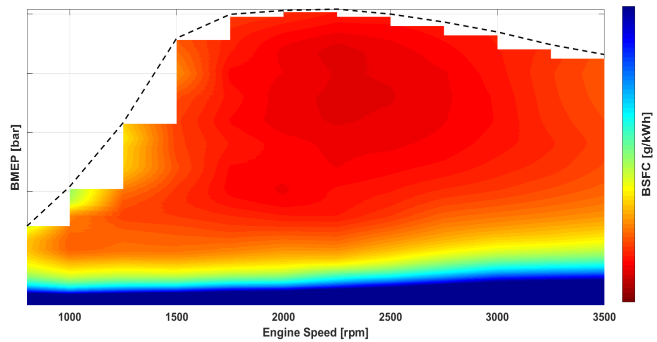


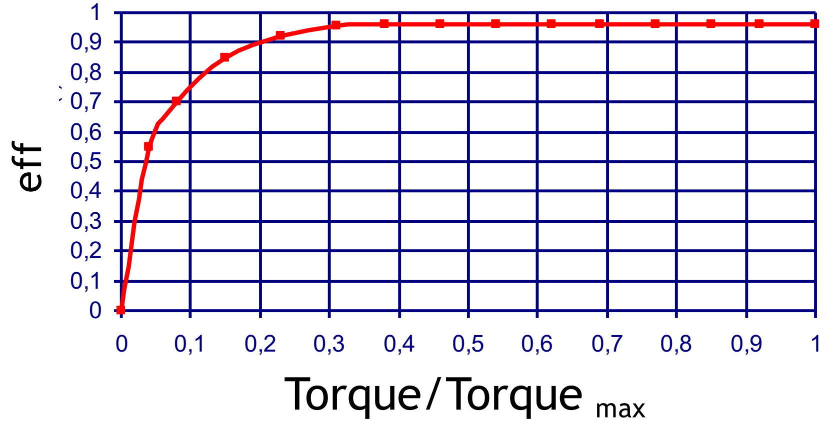




Model Limits

3. Transmission efficiency variations with load not taken into account
4. Transient conditions not taken into account: driving cycle simulated as a sequence of steady state conditions.





Although with some limitations, the analysis allows a number of issues to be evaluated, such as for instance:

- effects on fuel consumption of variations of gear ratios, coast down, vehicle mass
- effects of fuel cut-off, start&stop

Agenda

- Introduction
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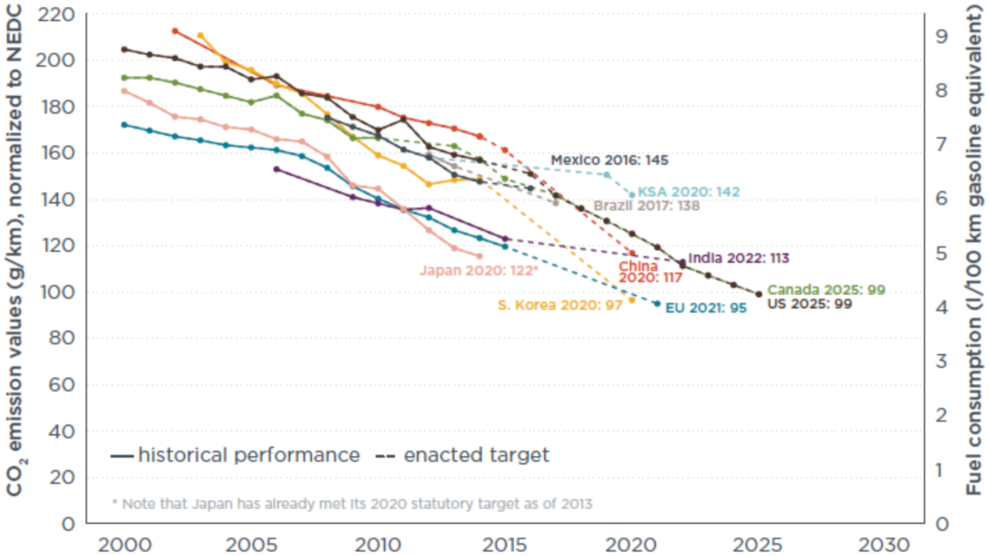
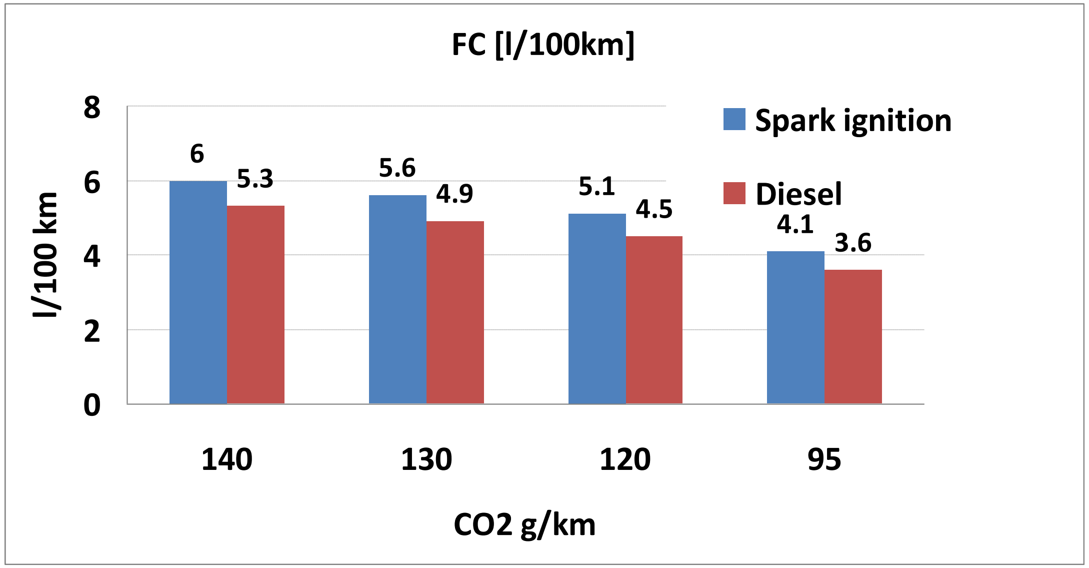
CO_2 Legislation Targets



For typical gasoline and diesel fuels, the following conversion factors from carbon balance apply to convert from CO2 g/km to liters/100 km :

$$V_f[l/100km] \cong \frac{0.0315 \cdot m_{CO2}[g/km]}{fuel\_density[kg/l]}$$

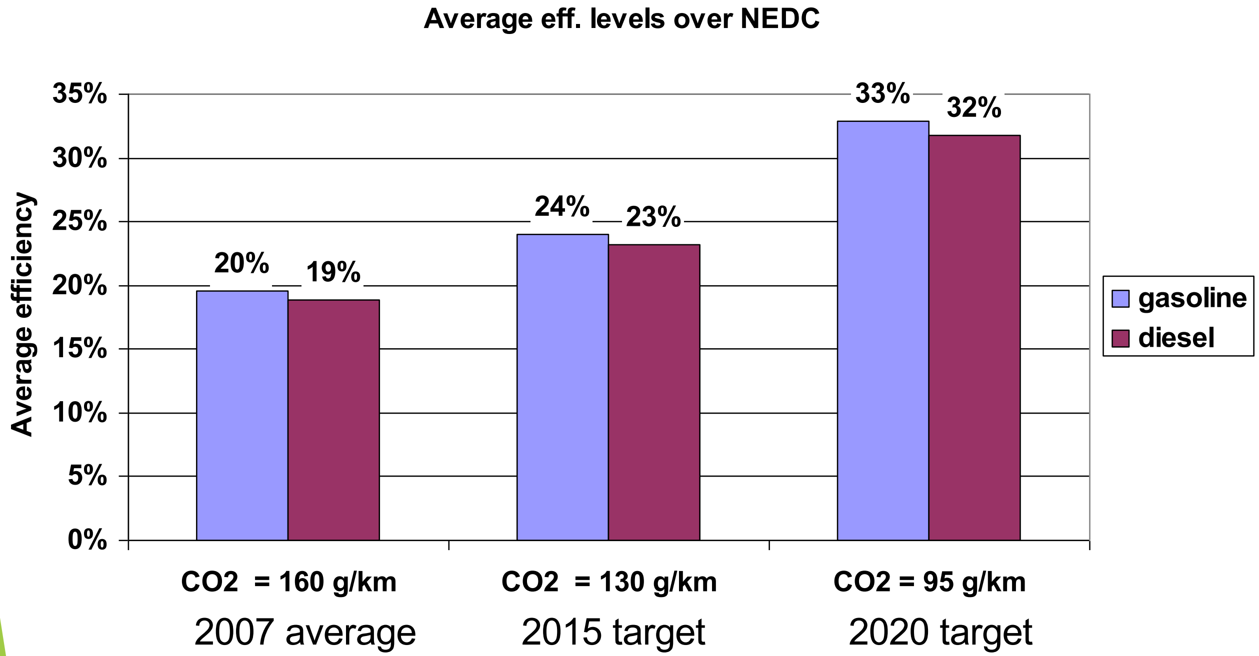
But… what does 130 grams of CO2 per km mean ?

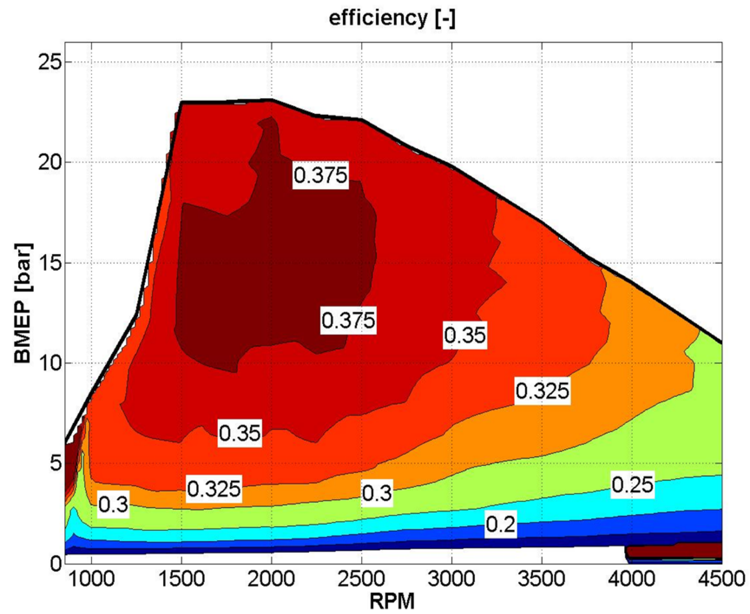


So the question is: can these targets be reached with current technologies?

CO_2 Legislation Targets

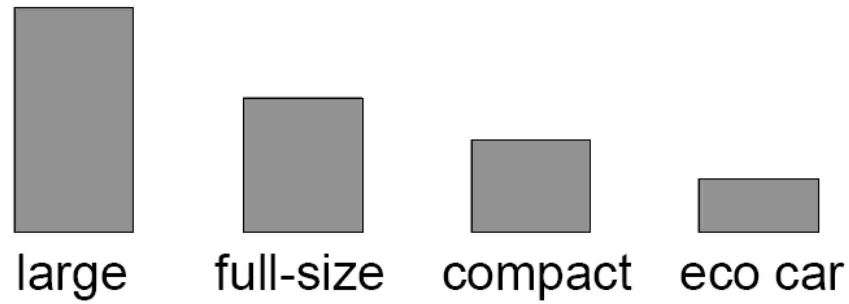
If future CO_2 target are to be met with powertrain improvements only (i.e. no possible tires or drag reduction should be taken in to account) for the "average" European passenger car the following average efficiencies values will be required, that, at least for gasoline engines, appear far beyond current system capabilities.

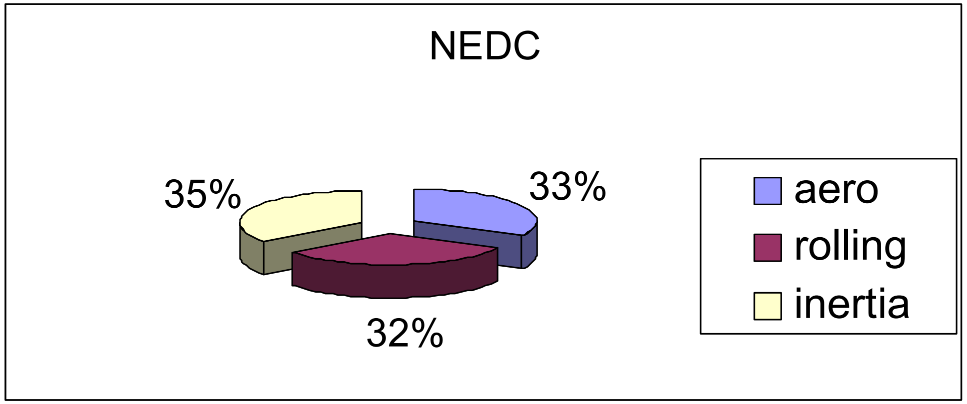




CO_2 Legislation Targets

Mechanical Energy Demand





For the “average” European passenger car

(1280 kg mass, c_{roll} 0.012, Cx*A = 0,7 m^2)

Energy requested for NEDC is about **40 MJ/100km**

(or about 110 Wh/km)

10% reduction in:

Aero → 3.3% red. En. Req.

Rolling → 3.2% red. En. Req.

Mass → 6.7% red. En. Req.

[1] Guzzella L.: *“Control of IC Engine Systems”,* 8th International Conference on Engines for Automobile, *SAE – ICE 2007*

Agenda

- Introduction
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- Vehicle Model Building
- Model Limits
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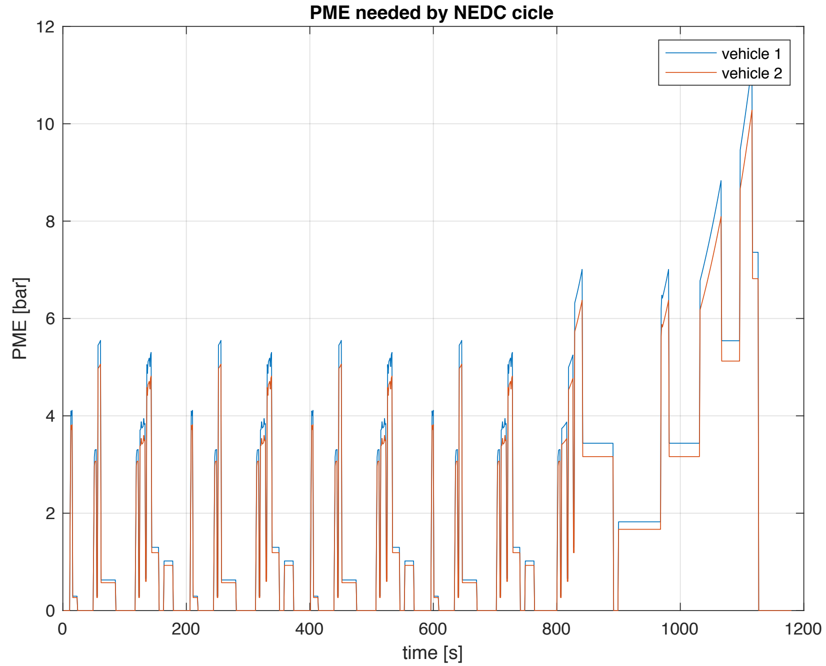
Post processing

1. Example: engine speed VS time plot

```
plot(time,rpm)
grid on % Insert a grid on the plot
xlabel('Time [s]') % Insert the label on the X-Axle
ylabel('Engine Speed [rpm]') % Insert the label on the Y-Axle
```

NOTE: The same script can be applied to engine BMEP, instantaneous fuel consumption, NOx instantaneous emissions, etc..



Post processing – Operating Map Creation

1. **Calculation of the BSFC map ➔** it should be performed starting **from the experimental fuel consumption map**
   1. **Calculation of the power corresponding to fuel consumption data:** P=bmep_pq*rpm_pq*V/1200; % [kW] **CAUTION: the matrix product should be performed in order to obtain a matrix with the same dimension of fc_pq ➔** Where: bmep_pq and rpm_pq are obtained from the first column of the experimental map of fuel consumption respectively; **ATTENTION: bmep_pq.*rpm_pq will return an error.**
   2. Bsfc = fc_pq **./** P*1000; % [g/kWh] ➔ **point to point ratio of the fuel consumption and of the power**
2. **Definition of the WOT performance**
   1. rpm_max = [800;1000;…;5000]; ➔ values of speed corresponding to WOT BMEP ➔ could be either manually defined or loaded from excel
   2. bmep_max = [6.05;8.73;…;8.57]; ➔ values WOT BMEP ➔ could be either manually defined or loaded from excel
3. **Limiting of the BSFC values to the WOT curve**
   1. bmep_wot = interp1(rpm_max, bmep_max, rpm_pq,'linear','extrap'); ➔ calculation of the maximum BMEP corresponding to the speed set points of the fuel consumption map
   2. bmep_mtx = repmat(bmep_wot,length(bmep_pq),1); ➔ ➔ matrix of max bmep index
   3. bmep_pq_mtx = repmat(bmep_pq,1,length(rpm_pq)); ➔ matrix of bmep index to be compared with the bmep_mtx matricx
   4. bsfc(bmep_pq_mtx > bmep_mtx) = NaN; ➔ all the bsfc point featuring a BMEP higher than the WOT values will be set to NaN

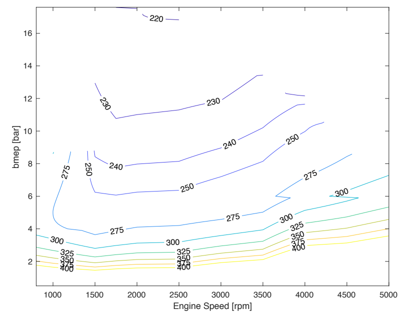
Post processing – Operating Map Creation

1. **Creation of BSFC Contour**

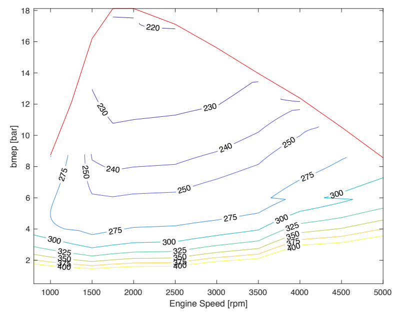
   V = [200 210 220 230 240 250 275 300 325 350 375 400]; ➔ **array with the BSFC values represented on the map ➔ decided by the user**

   figure, [c,h] = contour(rpm_pq,bmep_pq,bsfc,V) ➔ **Matlab command for creating the iso-level plot ➔** it requires x-index: rpm_pq – y-index: bmep_pq – z-values: bsfc – vector of iso-level curves to be represented

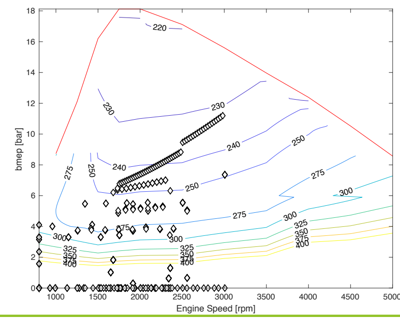
   clabel(c,h) ➔ **Add the labels to the iso-BSFC curves**



4. **Add Full Load curve on the BSFC map plot**
   1. hold all ➔ Enable to add new curves on the same figure
   2. plot(rpm_max,bmep_max,'—r') ➔ plot of the WOT profile in red



5. **Add engine operating point on the map**
   1. plot(rpm,bmep,'d','MarkerFaceColor','w', 'MarkerEdgeColor','k')



Appendix 1

- How to define a matrix:

```
Command Window
>> a= [1 2 3; 4 5 6]

a =

     1     2     3
     4     5     6
```

- Simple Operation between Vector or Matrix
  - Sum: **+**
  - Difference: **-**
  - Array multiply (it should be performed only between matrixes with the same dimension): .*

a=[3 4]   b=[5 6]

```
>> a.*b

ans =

    15    24
```

Appendix 2

- Matrix multiply:

a=[3 4]   b=[5; 6]

```
>> a*b

ans =

    39
```

```
>> b*a

ans =

    15    20
    18    24
```

- Array Operations
  - Array divide: **./**
  - Matrix divide: **/**
  - Array Power: **.^**
  - Matrix Power: **^**
  - Transpose: **‘**
- Write **;** at the end of each line to suppress the output in the command window
- Iterations: **for cycle**

```
for i=1:15
    ...
    ...
end
```

Appendix 3

- Conditionally executed statements: **if**

```
if a==b
    ...
    ...
else
    ...
    ...
end
```

- Interpolation (table lookup): **interp2**

Z = interp2(x_map,y_map,z_map,X,Y)