Vehicle Performance

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Lesson 6:
Fuel consumption and emissions

Outline

- FUEL CONSUMPTION AND EMISSIONS
  - Specific consumption of power plant
  - Vehicle fuel consumption measures
  - Constant speed consumption
  - Variable speed consumption and driving cycles
  - Chassis dynamometer

Fuel consumption and emissions

Introduction

- The fuel consumption and the emissions of vehicles has become a very important topics with climate and environmental issues
- Fuel consumption and emissions depend on :
    - The engine characteristics
    - The transmission characteristics (gear ratio, conversion efficiency)
    - The curb weight
    - The aerodynamics drag
    - The rolling resistance
    - The driving cycle and the travel characteristics
    - The behavior of the driver (aggressivity of the driving)

Fuel consumption of thermal engines

- The brake specific fuel consumption of the engine is the mass of fuel that is used to develop a given work *W* at the brake:

$$\mathrm{bsfc} = \frac{m_f}{W_{mot}}$$

- Under variable operating conditions

$$dW_{mot} = \dot{W}_{mot}\, dt$$

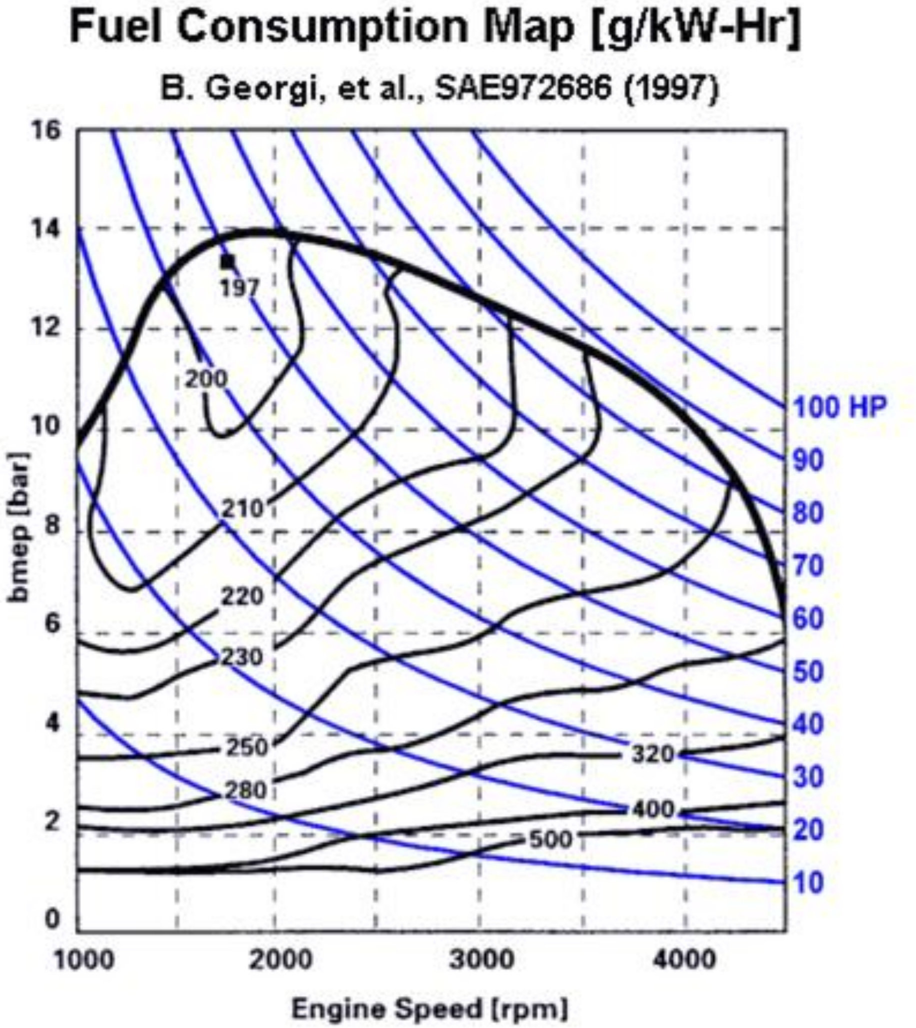
$$dm_f = \dot{m}_f\, dt$$

$$\mathrm{bsfc} = \frac{\dot{m}_f}{\dot{W}_{mot}}$$

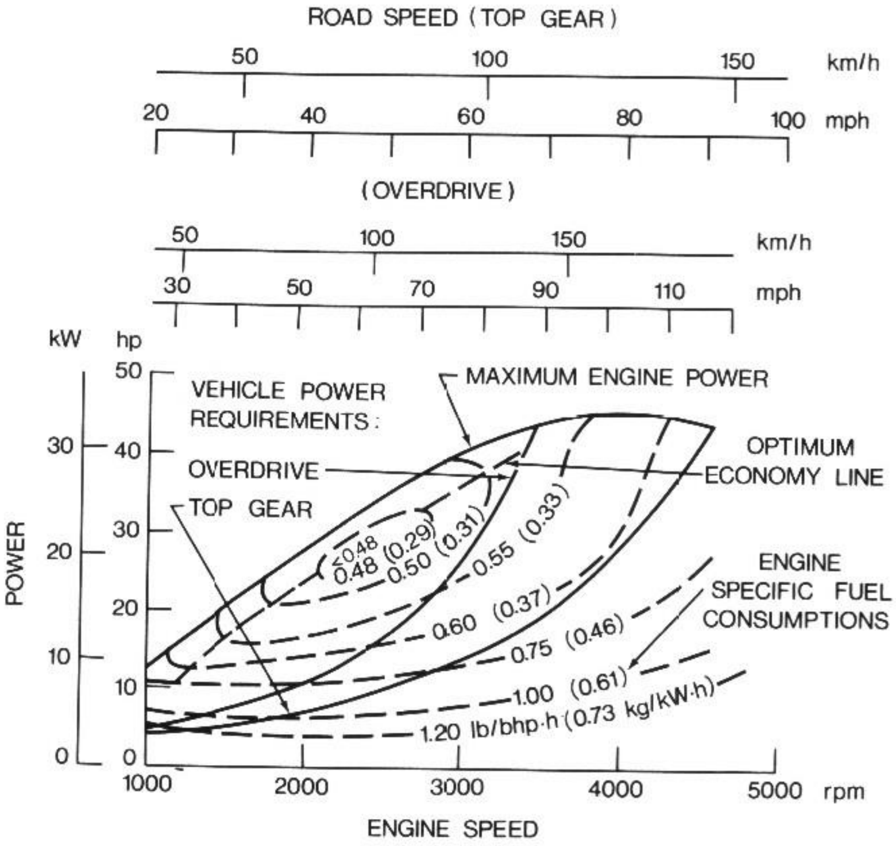
- The fuel consumption depends on the operation point (power/torque/rotation speed)
- The fuel consumption is mapped on the power / torque / bmep curve diagram wrt rotation speed

Fuel consumption of thermal engines

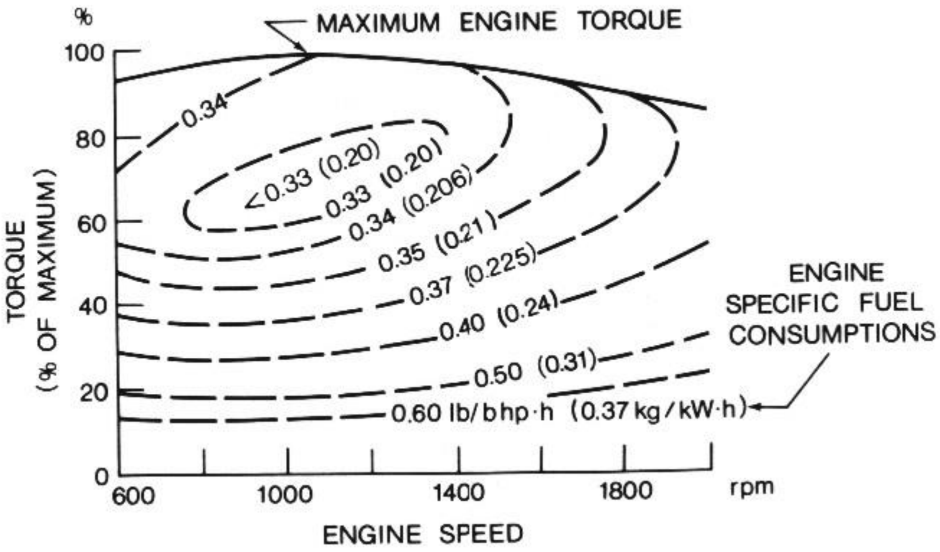
$$T = \frac{\text{bmep}\, V_d}{2\,\pi\, n_R}$$



Fuel consumption of thermal engines



Gazoline engine



Diesel engine

Wong. Fig. 3.41 et 3.42

Engine Universal Performance Map

- Golverk (SAE 941928) showed that a response surface modelled with quadratic terms can represent with a sufficient accuracy the bsfc engine map

$$\mathrm{bsfc} = a_1 + a_2\, n + a_3\, T + a_4\, n^2 + a_5\, n\, T + a_6\, T^2$$

  - bsfc [gr/kWh] the brake specific fuel consumption
  - T [Nm], the brake torque
  - N [rpm], the engine rotation speed
  - a_i: Empirical coefficients to be identified

Engine Universal Performance Map

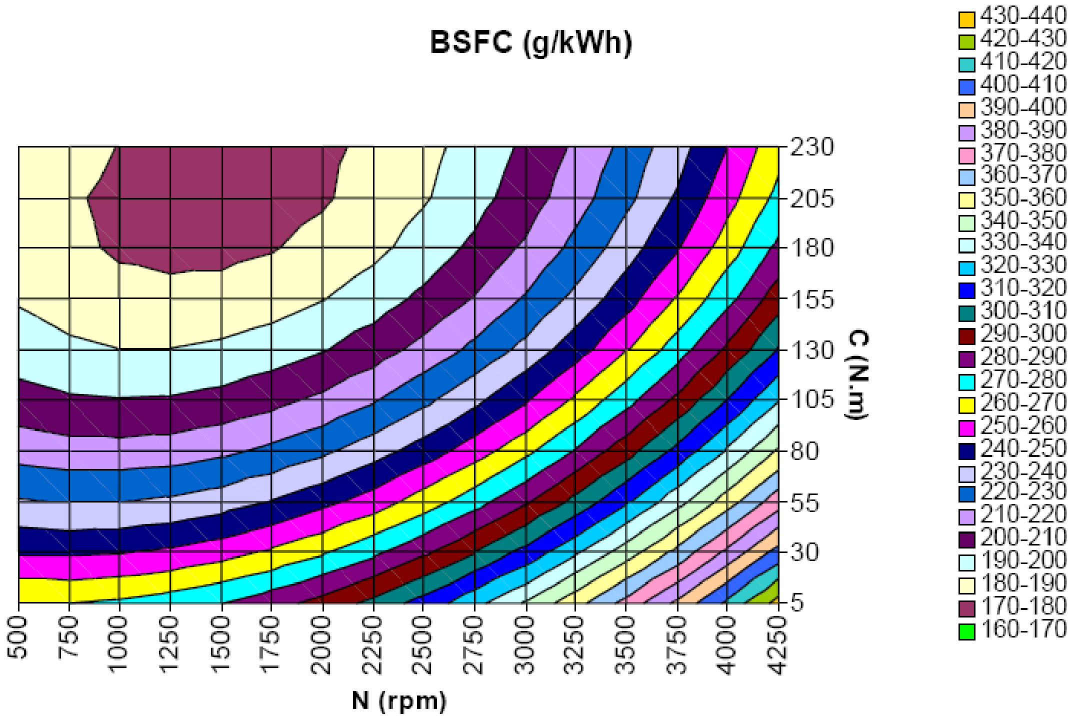
$BSFC = A1 + A2 . N + A3 . C + A4 . N^{2} + A5 . N . C + A6 . C^{2}$

N Speed (RPM)

C (N.m)

BSFC (g / kWh)

A1	278.65
A2	-0.01459011
A3	-0.87506231
A4	0.00001242
A5	-0.00010411
A6	0.00242572



Engine map of Diesel 1.6 TDCI

Fuel consumption of thermal engines

- It is also usual to use the energy efficiency of the plant, which is defined as the ratio between the mechanical output work and the input chemical energy associated to the mass of fuel with a given Lower Heat Value of the fuel $\mathrm{LHV}_{\mathrm{fuel}}$

$$\boxed{\eta_e = \frac{W_{mot}}{m_f \, \mathrm{LHV}_{fuel}}}$$

- That is

$$\boxed{\eta_e = \frac{\dot{W}_{mot}}{\dot{m}_f \, \mathrm{LHV}_{fuel}}}$$

Fuel consumption of thermal engines

- The efficiency and the fuel consumption are related to each other:

$$\eta_e = \frac{1}{\text{bsfc LHV}_{fuel}}$$

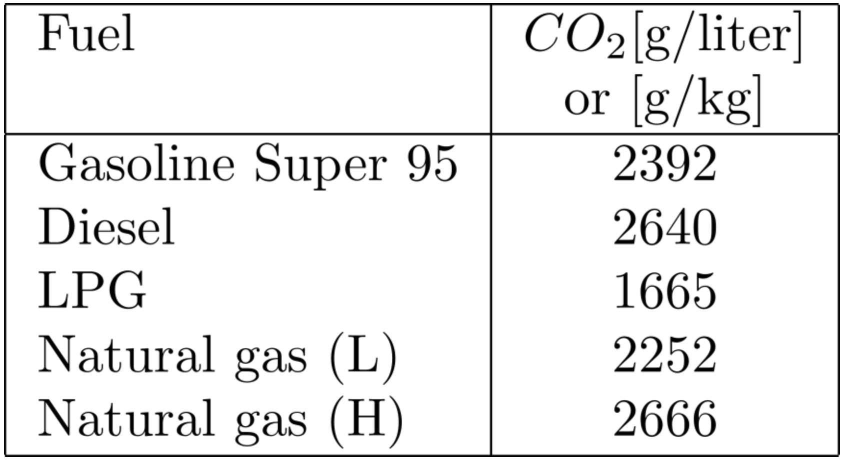
- Usual LHV

Fuel	LHV [kJ/kg]
Gasoline Super 95	42900
Diesel	42600
Ethanol	26900
Esther methylique of colza	37700
Dimethyl Ether	28430
Gepel Butagaz	46000
Natural gas	50000
Hydrogen	119930

Fuel consumption of thermal engines

- Nowadays, with the climate challenge, it is more usual to express the fuel consumption in terms of CO_2 emissions.

- Given the average chemical content of the fuel, it is possible to provide an equivalent conversion factor between one liter of fuel and the mass of CO_2 that is emitted when burning



Fuel	CO_2[g/liter] or [g/kg]
Gasoline Super 95	2392
Diesel	2640
LPG	1665
Natural gas (L)	2252
Natural gas (H)	2666

Fuel consumption of thermal engines

- Exercise:
  - A normalised fuel consumption of 5 litres per 100km of gasoline is equivalent to a CO_2 emission of

    5*2392 /100 = 119,6 gr CO_2/km

  - Target of 95 g of CO_2 per km is equivalent to
    - 95 *100/2392 = 3,97 l/100 km of gasoline
    - 95 *100/2640 = 3,59 l/100 km of Diesel

Energy efficiency of electric motors

- For electric motors, there is no fuel, but conversion of electrical power into mechanical power. This conversion is realized with a certain efficiency

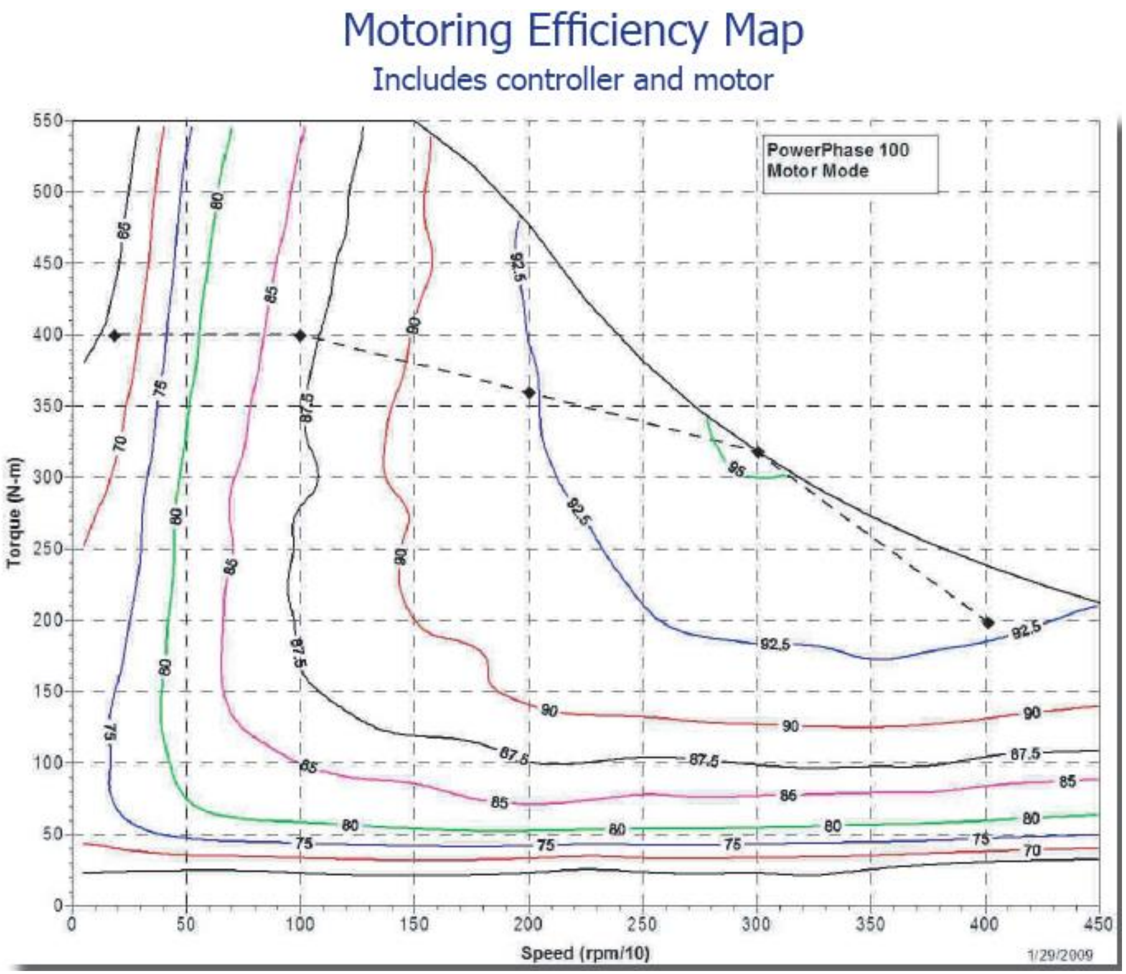
$$\boxed{\eta_e = \frac{\mathcal{P}_{meca}}{\mathcal{P}_{elec}}}$$

- One has also to consider the global efficiency of the electric traction chain: electric motor, power electronics, batteries…

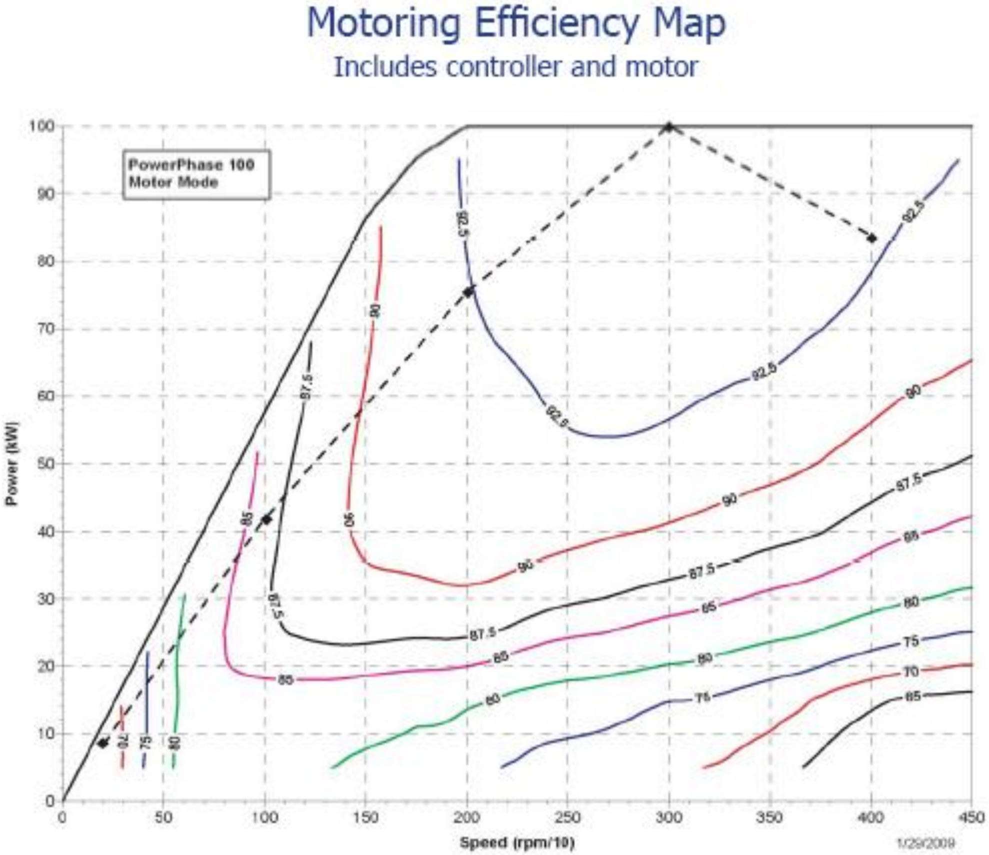
$$\eta_e = \eta_{\text{e-motor}}\, \eta_{\text{pow-elen}}\, \eta_{\text{battery}}$$

- Electric motor ~ 90 % - Power electronics ~ 95% - Batteries: from 70 to 85%

Energy efficiency of electric motors



Energy efficiency of electric motors

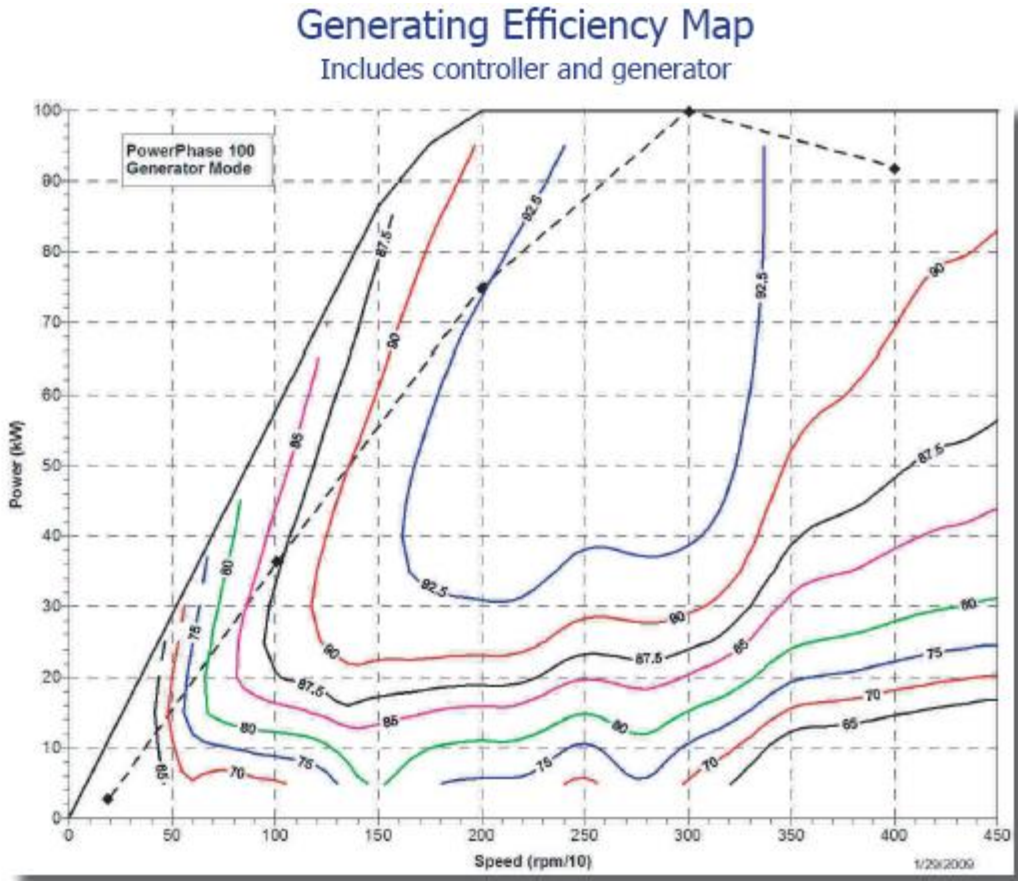


Motoring Efficiency Map

Includes controller and motor

1/29/2009

Energy efficiency of electric motors



Generating Efficiency Map

Includes controller and generator

Fuel consumption of vehicles

- For vehicles, one expresses the fuel consumption with respect to the travel distance.
    - In Europe: fuel consumption is given per km or 100 km: [liters / 100km], [MJ/100km], [kWh/km]
    - In the USA: distance per gallon of fuel (*fuel economy*) [miles per gallon]
- Both measures are related

$$[\mathrm{mpg}] = \frac{253,2}{[\mathrm{L}/100\ \mathrm{km}]}$$

Fuel consumption of vehicles

- The **fuel consumption** B [L/100 km] is calculated by integrating the volume flow [L/s] of fuel along the travel with a total duration T:

$$B = \frac{\int_0^T \dot{b}\, dt}{\int_0^T v\, dt}$$

Time integration of fuel/energy consumption

Travel distance

- The instantaneous volume flow of fuel is a function of the specific fuel consumption of the engine *bsfc*, of the tractive power that is required and of the density of the fuel:

$$\dot{b} = \frac{\mathrm{bsfc}\, \mathcal{P}_{mot}}{\rho_{\mathrm{fuel}}}$$

$$\dot{b}\,[l/s] = \frac{\mathrm{bsfc}\,[gr/kWh]\, \mathcal{P}_{mot}\,[kW]\, \frac{1}{3{,}6\, 10^6}}{\rho_{\mathrm{fuel}}\,[kg/l]}$$

Fuel consumption at variable speed

- For variable speed driving cycle, one computes the fuel at each time step as a function of the required engine power and of its rotation speed (that is prescribed by the gear ratio and the vehicle velocity)

$$B = \frac{\int_0^T \dot{b}\, dt}{\int_0^T v\, dt} = \frac{\int_0^T \frac{\mathrm{bsfc}\, [\mathcal{P}_{mot}]_+}{\rho_{\mathrm{fuel}}}\, dt}{\int_0^T v\, dt}$$

- IC engine consumption is cancelled during coasting phases

$$[\mathcal{P}_{mot}]_+ \;=\; \begin{cases} \mathcal{P}_{mot} & \text{if} \quad \mathcal{P}_{mot} \geq 0 \\ 0 & \text{if} \quad \mathcal{P}_{mot} < 0 \end{cases}$$

Fuel consumption at variable speed

- For a variable speed driving cycle, one can express the engine power in terms of the vehicle resistance power and the vehicle speed

$$B = \frac{\int \frac{\mathrm{bsfc}}{\eta} \left[mfg\cos\theta + 1/2\rho S C_x v^2 + mg\sin\theta + mdv/dt \right]_+ v\,dt}{\int \; v\,dt}$$

- This formula puts forward the key role of
  - The mass of the vehicle (inertia forces, grading forces, and rolling resistance)
  - The C_x and the aerodynamics
  - The tires and the rolling resistance

Fuel consumption at variable speed

- Influence of the vehicle parameters on the fuel consumption
  - Mass of the vehicle
  - Aerodynamics
  - Rolling resistance

- Practically, for internal combustion engines, one can mention the following order of magnitude for the energy saving when improving these parameters (m, C_x and f) by 10% :

	Δ	ΔB
Δm	10 %	6 %
ΔC_x	10 %	3 %
Δf	10 %	2 %

Fuel consumption of vehicles

- Conclusion: as the fuel consumption depends strongly on the travel conditions (grading, acceleration, etc.) it is necessary to define standard driving scenarios in order to carry out any objective comparison of different propulsion systems

- Concept of normalized driving cycles
  - Constant speed driving cycles
  - Variable speed driving cycles

Constant speed fuel consumption

- At constant speed, the fuel consumption is obtained by multiplying the required power to propel the car by the specific fuel consumption (bsfc) and the driving time.
- Engine power required to overcome the road resistance

$$\mathcal{P}_{res} = (A + Bv^2)\, v \qquad \mathcal{P}_{mot} = \frac{\mathcal{P}_{res}}{\eta_t} = \frac{A\,v + B\,v^3}{\eta_t}$$

- Work to spend along distance D

$$\Delta t = \frac{D}{v} \qquad W_{mot} = \mathcal{P}_{mot}\,\Delta t = \frac{\mathcal{P}_{mot}\,D}{v}$$

- Total fuel consumption

$$m_f = \mathrm{bsfc}\, W_{mot} = \mathrm{bsfc}\,\frac{\mathcal{P}_{mot}\,D}{v} = \mathrm{bsfc}\,\frac{A + B\,v^2}{\eta_t}\,D$$

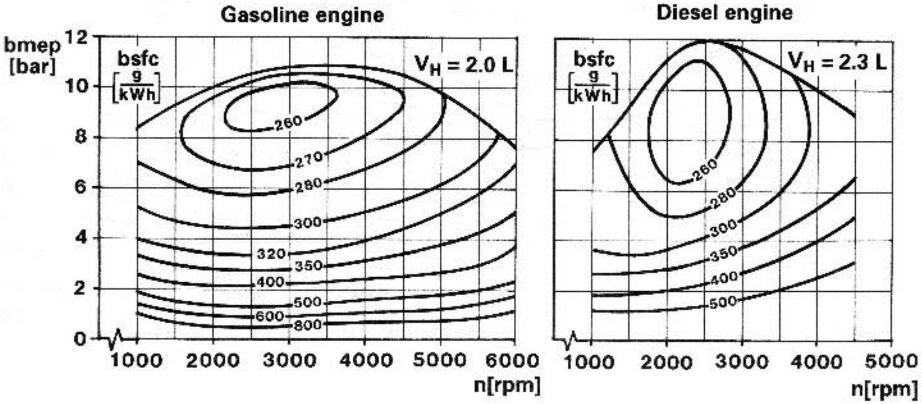
Constant speed fuel consumption

- The constant speed vehicle consumption expression

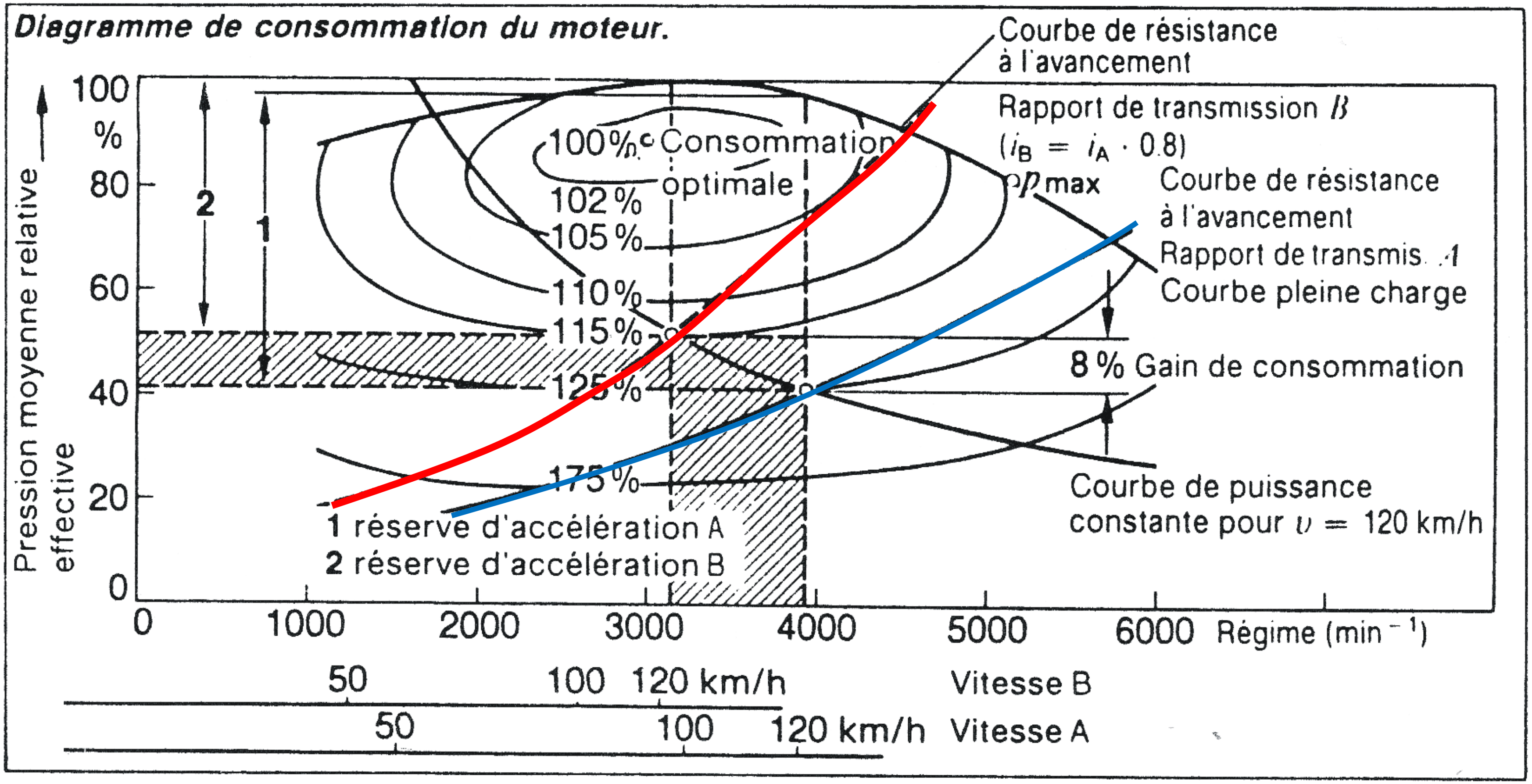
$$m_f = \mathrm{bsfc}\, W_{mot} = \mathrm{bsfc}\, \frac{\mathcal{P}_{mot}\, D}{v} = \mathrm{bsfc}\, \frac{A + B\, v^2}{\eta_t}\, D$$

shows that the fuel consumption is ruled by the square of the vehicle speed. However the fuel consumption depends also on the engine rotation speed and of the delivered power.

$$\mathrm{bsfc} = \mathrm{bsfc}(\omega_{mot}, \mathcal{P}_{mot}) = \mathrm{bsfc}(\frac{v.i}{R_e}, \mathcal{P}_{mot})$$



Constant speed fuel consumption



Constant speed fuel consumption

- To study the fuel consumption, it is usual to work in the engine map (torque or bmep vs rotation speed).
- The power dissipated by the resistance forces

$$\mathcal{P}_{mot} = \frac{\mathcal{P}_{res}}{\eta_t} = \frac{A\,v + B\,v^3}{\eta_t}$$

- Using

$$v = \frac{R_e}{i}\,\omega_{mot} = \frac{R_e}{i}\frac{2\pi}{60}N_{mot}$$

Has to be converted into the engine rotation speed

$$\begin{aligned}\mathcal{P}_{res} &= \frac{A}{\eta_t}\,\frac{R_e}{i}\,\omega_{mot} + \frac{B}{\eta_t}\left(\frac{R_e}{i}\right)^3 \omega_{mot}^3 \\ &= \frac{A}{\eta_t}\,\frac{R_e}{i}\,\frac{2\pi}{60}\,N_{mot} + \frac{B}{\eta_t}\left(\frac{R_e}{i}\,\frac{2\pi}{60}\right)^3 N_{mot}^3 \\ &= A'(i/R_e)\,N \;+\; B'(i/R_e)\,N_{mot}^3\end{aligned}$$

Constant speed fuel consumption

- The resistance curves expressed in the torque-speed map is

$$
\begin{aligned}
\mathcal{C}_{res} &= \frac{A}{\eta} + \frac{B}{\eta}\left(\frac{R_e}{i}\right)^2 \omega_{mot}^2 \\
&= A''(i/R_e) + \ B''(i/R_e)\, N_{mot}^2
\end{aligned}
$$

- The road resistance curve is quadratic in terms of the rotation speed
- The coefficients A” and B” depend on the characteristics of the vehicle (C_x, m, f, slope), but also of the gear ratio and of the transmission length.

Constant speed fuel consumption

- The constant power curves delivered by the engine in the engine map (torque C speed N curve) are hyperbole. It is the same if we work with the brake mean effective pressure (bmep):
- For a 4-stroke engine (N in rpm/s)

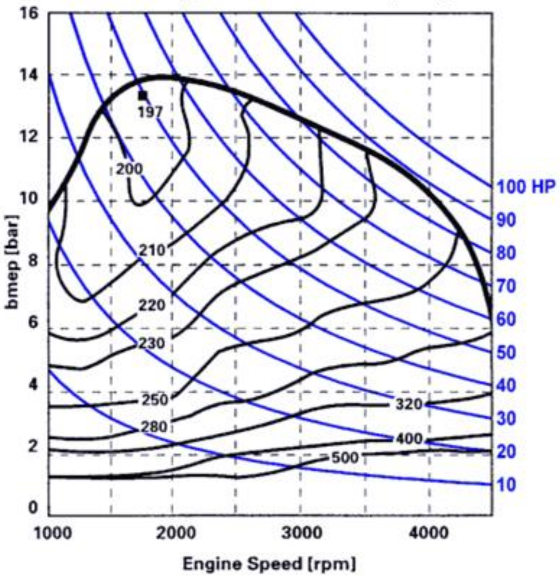
$$\text{bmep} = \frac{2\,\mathcal{P}}{V_H\, N}$$

- Thus

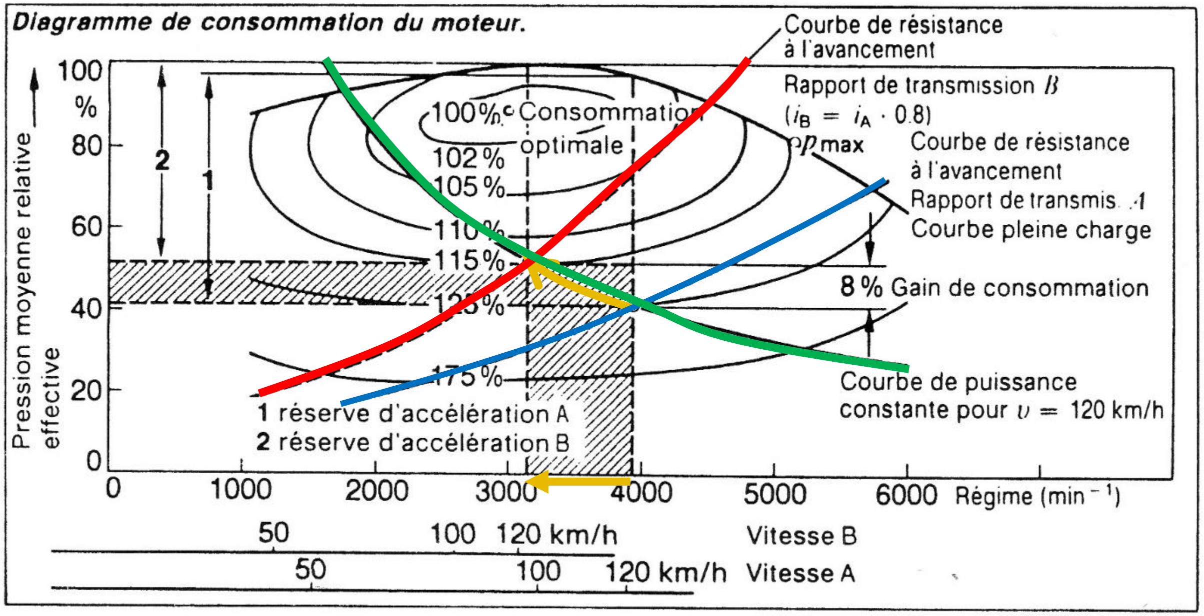
$$\text{bmep} * N = \frac{2\,\mathcal{P}_{res}}{V_H} = \text{Cste}$$

Fuel Consumption Map [g/kW-Hr]

B. Georgi, et al., SAE972686 (1997)



Constant speed fuel consumption



- Influence of the gear ratio i on the fuel consumption $i_B = 0{,}8\ i_A$.
  - The operating point moves along the constant power curve. It is located at the intersection of the road resistance curve that is modified with the gear ratio.
  - Reducing the gear ratio (B) can save 8% for the fuel consumption.

Fuel consumption of vehicles

- Constant speed driving cycles

- Standard driving cycles
  - US Cycles:
    - New York city cycle,
    - EPA cycles: city driving - highway cycle
    - SC03 et US06
  - EU Cycles
    - NEDC
  - WLTP

- Experimental set-up to determine the fuel consumption:
  - The chassis dynamometer

Constant speed fuel consumption

- Test can be conducted on chassis dynamometer or on the road
- Recommended velocities : 90 & 120 kph
- Travel
  - Longer than 2 km
  - Slope must be less than 2%
- Payload = 1/2 max payload and greater than 180 kg
- Fuel consumption must be corrected with the temperature because the fuel thermal expansion coefficient~0,001 /°C

$$B(20^\circ C) = \left[1 - \alpha_f (20 - t_c)\right] B(t_c)$$

- Old DIN70300 procedure : 110% of the measured fuel consumption at the given speed v= min(3/4 of max speed of the car, 110 kph)

Normalized driving cycle

- The driving cycles are standard driving travels in which one prescribes the speed, the acceleration, and the gear ratio if the car is equipped with a manual gear box.

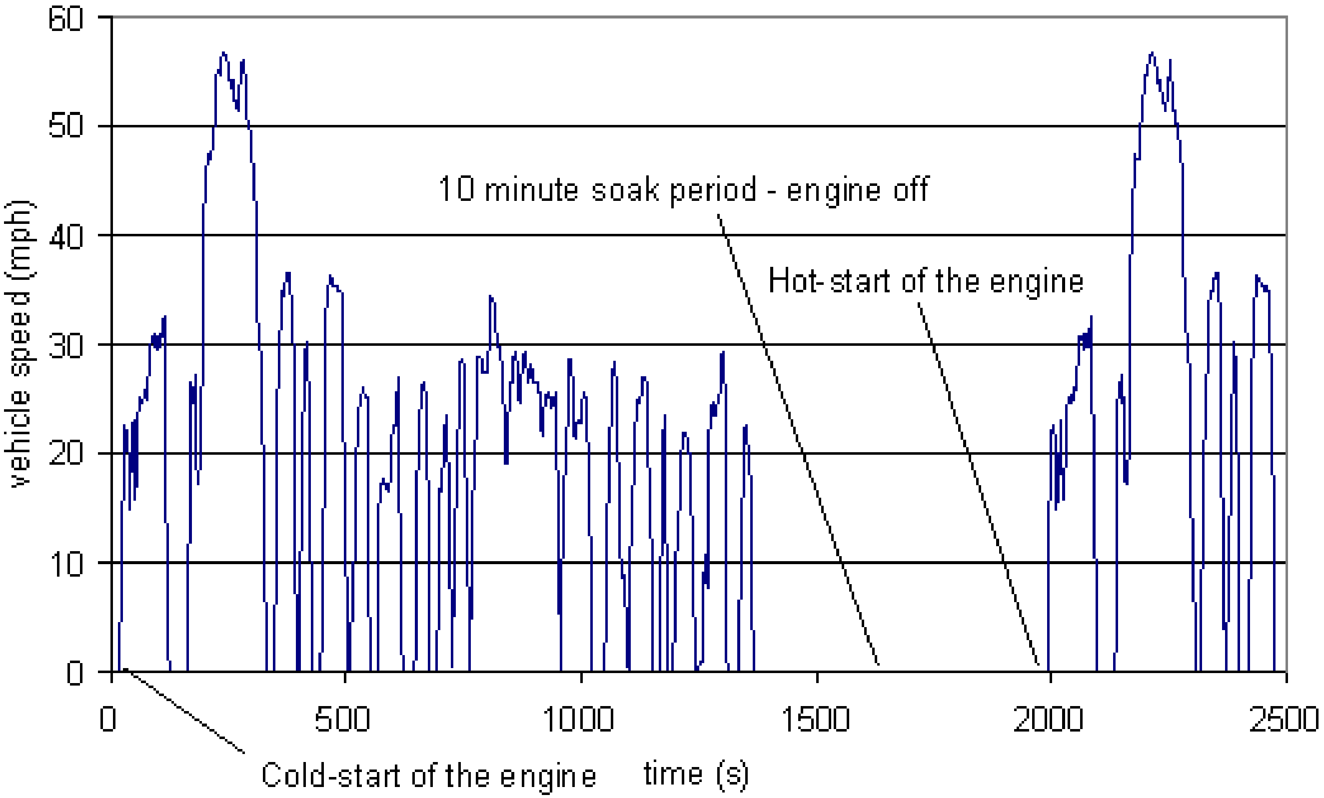
- Two kinds of driving cycles
  - The realistic cycles : are deduced directly from the experimental observation of traffic.
  - The synthetic cycles are tailored from the speed and acceleration records from observation of the traffic, which are sorted and weighted in terms of the frequency and their duration.

US driving cycles

- The US driving cycles are defined by the EPA (Environment Protection Agency).
- They are realistic driving cycles
- For passenger cars, four major driving cycles
    - FTP75 cycle (Federal Test Protocol) is an urban cycle
    - HWFET is a highway driving cycle
    - US06 is an aggressive driving cycle
    - SC03 is a cycle with a heavy load in terms of Air Conditioning
- The composite index is used to to determine the fuel consumption

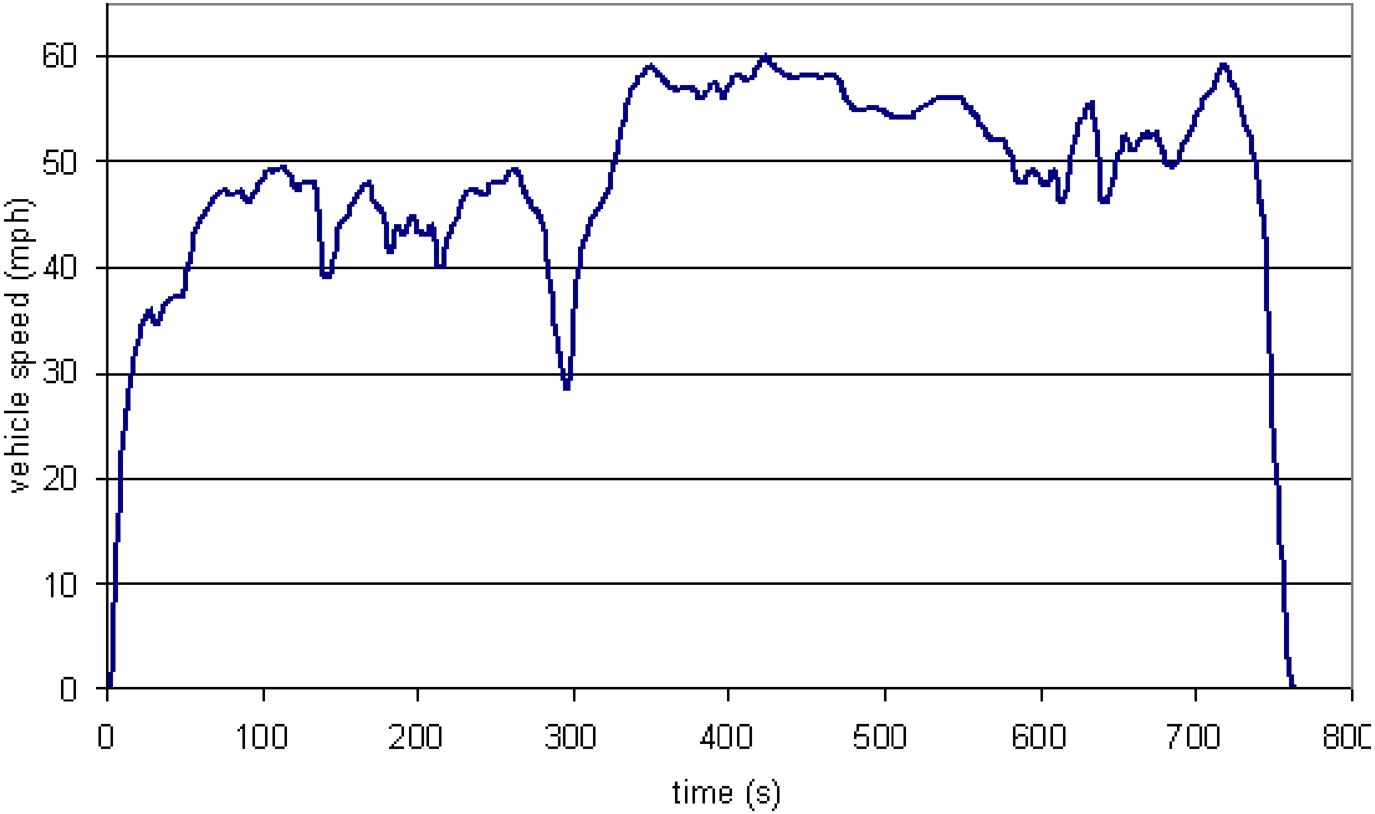
$$\frac{1}{\mathrm{mpg}_{\mathrm{combined}}} = \frac{0,55}{\mathrm{mpg}_{FTP75}} + \frac{0,45}{\mathrm{mpg}_{HWFET}}$$

US Urban Emissions and Fuel Economy test (FTP75)



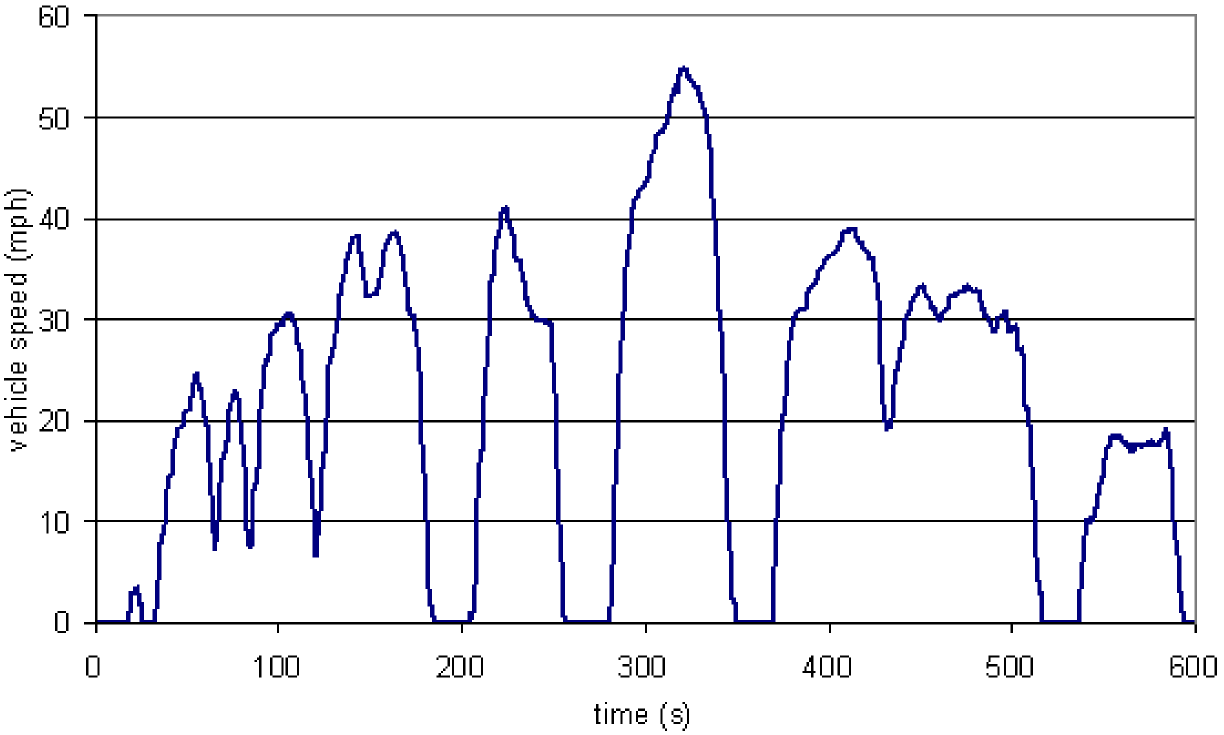
Federal Test Procedure for Urban Emissions and Fuel Economy (FTP-75)

US Highway Fuel Economy Test (HWFET)



Highway Fuel Economy Test (HWFET)

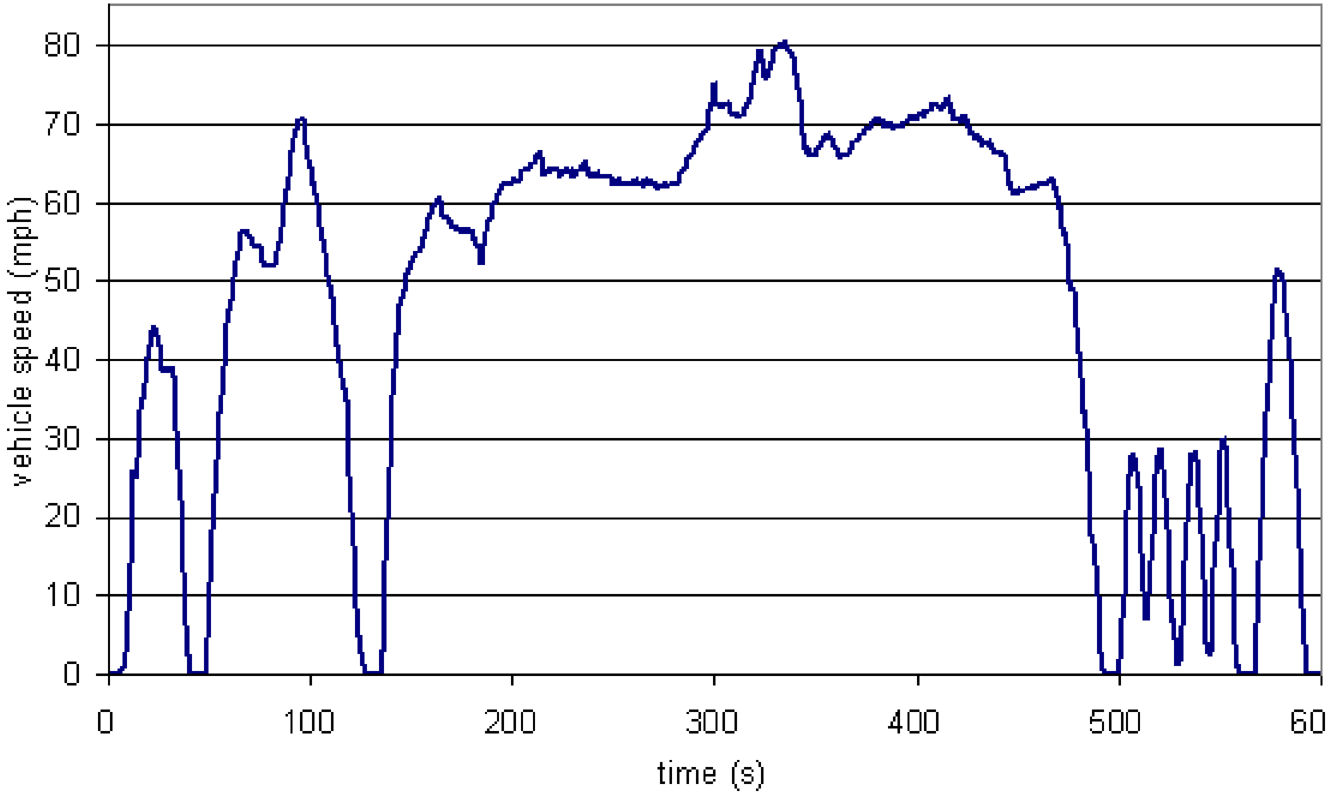
Cycle SC03



SC03 Driving Cycle

SC03: Driving cycle with a heavy load in terms of Air Conditioning

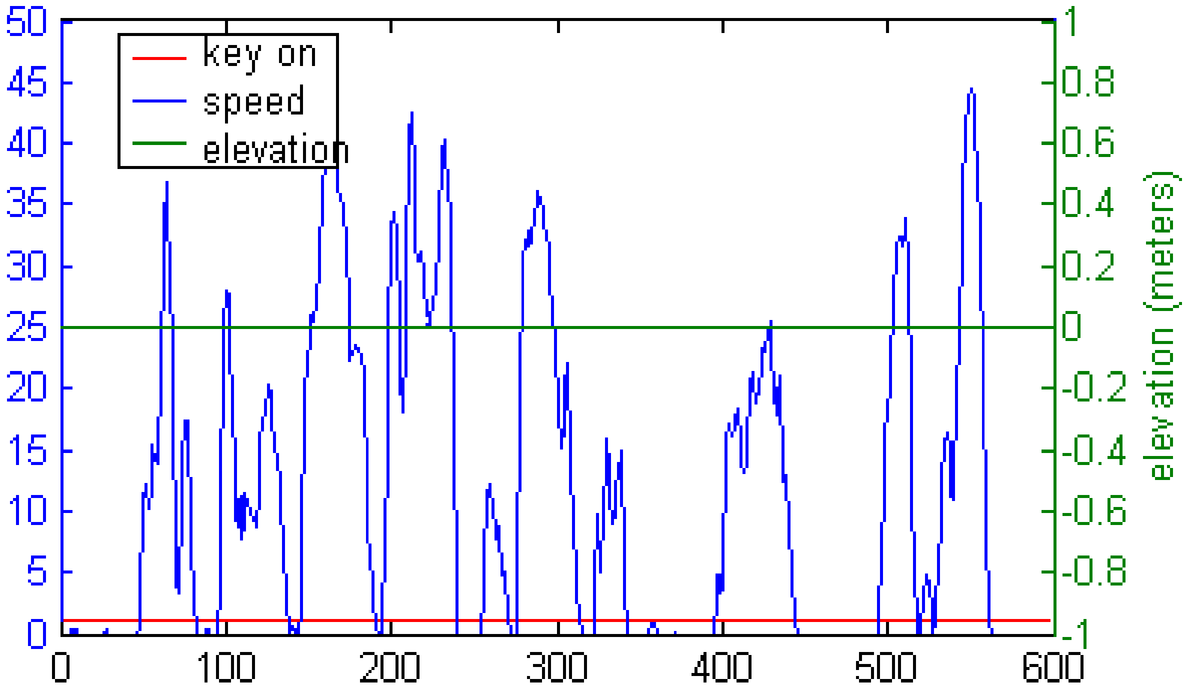
Cycle US06



US06 Aggressive Driving Cycle

US06: An aggressive driving cycle

US Cycles for heavy vehicles



time:	598 s
distance:	1.9 km
max speed:	44.58 km/h
avg speed:	11.41 km/h
max accel:	2.68 m/s^2
max decel:	-2.64 m/s^2
avg accel:	0.62 m/s^2
avg decel:	-0.61 m/s^2
idle time:	210 s
no. of stops:	18
max up grade:	0 %
avg up grade:	0 %
max dn grade:	0 %
avg dn grade:	0 %

New York city cycle for urban buses

US driving cycles

- US driving cycles suffers from several drawbacks
  - Heavy procedure to carry out from an experimental and technical point of view (complex cycle)
  - The vehicles are sorted by categories of weight so that the prescribed mass by the procedure is the not the real one on the road.
  - The sensitivity of the mass is not possible because of the class of mass
  - Discrepancies between the simulation studies (exact mass) and the official results of the test (prescribed mass by categories)

European Driving Cycle

Before 1978,

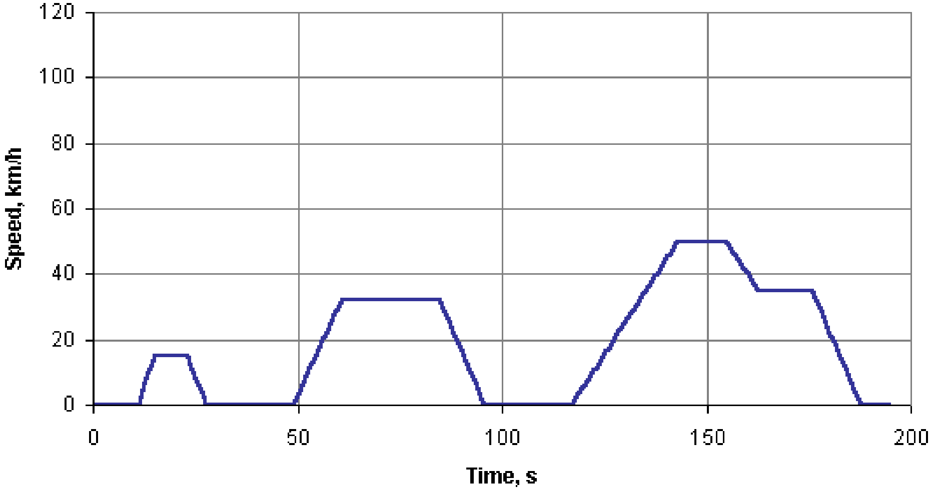
- Each country had its own regulations
- Early driving cycles
  - In the early 1970ies: E-75 and E-80.
  - Fuel consumption often realized with the US driving cycles

From 1978:

- EC regulation 80/1266/EEC and indicator EUROMIX
  - Definition of the EU urban driving cycle ECE15
  - Fuel consumption at constant speed (90 and 120 kph)
  - Composite fuel consumption index EUROMIX:

$$B_{\text{Euromix}} = \frac{1}{3}\left(B_{\text{City}} + B_{90} + B_{120}\right)$$

European Driving Cycle

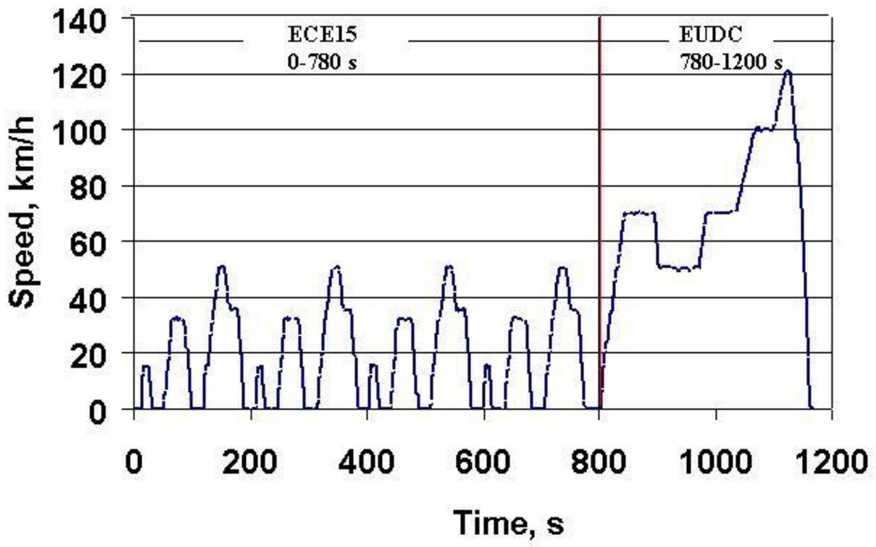


- ECE 15 urban driving cycle
  - Duration: 4 x 195 sec. = 780 sec.
  - Distance: 4*1,017 km = 4,052 km
  - Plateaus at 15, 32, 35 and 50 kph
  - Average speed: 18,77 km/h
  - Acceleration: 0-50 km/h in 26 sec.

European Driving Cycle

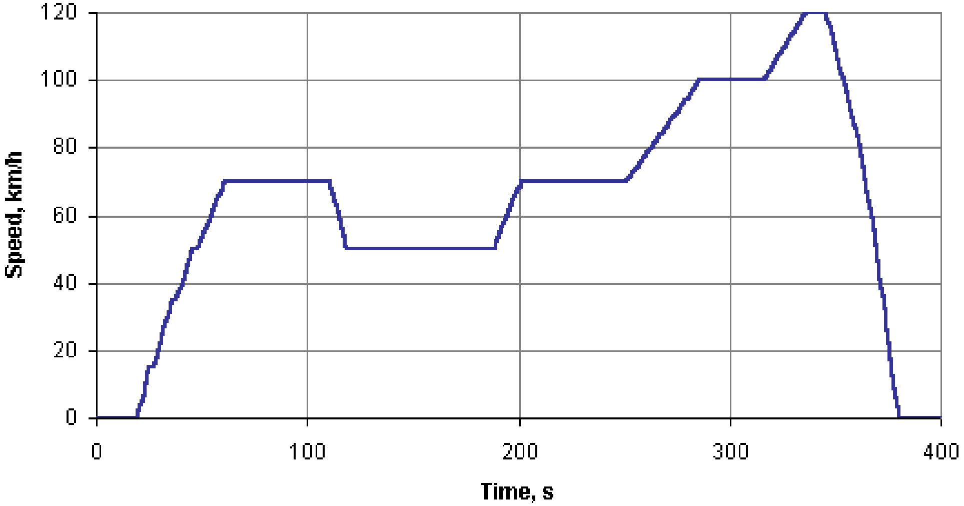
- Synthetic driving cycle
- Three idling periods
- Three constant speed periods, which is important i.e. not fully representative of city driving situations
- Urban part makes use of only 3 gear ratios
- The average speed (including two constant speed parts at 90 km/h and 120 km/h) in more important than FTP75 one, so it is more sensitive to the aerodynamic properties
- Simulation on a chassis dynamometer

New European Driving Cycle



- From 1996: New European Driving Cycle (NEDC) is adopted to measure both fuel consumption and emissions (EURO emissions)
  - 4 times the urban driving cycles ECE
  - 1 time a new high speed (peri-urban) driving cycle

New European Driving Cycle



- EUDC extra urban driving cycle
    - Length : 6,955 km
    - Duration 400 sec.
    - Plateaus at 50, 70, 90 and 120 km/h
    - Max speed 120 km/h during 10 sec.
    - Average speed 62,60 km/h

‘New European’ Driving Cycle

- The NEDC
    - Is used for both the fuel consumption and emissions of passenger cars and light duty vehicles
    - The constant parts at 90 and 120 km/h are replaced by a slower peri-urban cycles
    - The fuel consumption measure is less sensitive than the EUROMIX to aerodynamics and is similar to EPA
    - Acceleration parts are giving more importance to the mass
    - Should represent a good image of European driving habits?
- The NEDC receives some criticisms since
    - It does not represent correctly the real-life situation
    - It makes use of only 5 gear ratios
    - Should be associated to other driving cycles (ex. ADAC)

Comparison of driving cycles

Comparison of U.S., European, and Japanese Driving Cycles

	Time (seconds)	Percent of time stopped or decelerating	Distance (miles)	Average speed (mph)	Maximum speed (mph)	Maximum acceleration (mph/s)
Japanese 10/15 mode test cycle	631	52,3	2,6	14,8	43,5	1,8
New European Driving Cycle (NEDC)	1.181	24,9	6,84	20,9	74,6	2,4
U.S. EPA city cycle (LA4)[a]	1.372	43,2	7,5	19,5	56,7	3,3
U.S. EPA highway cycle	765	9,3	17,8	48,2	59,9	3,3
U.S. Corporate Average Fuel Economy cycle	2.137	27,9	10,3	29,9	59,9	3,3

Santini, D., A. Vyas, J. Anderson, and F. An, Estimating Trade-Offs along the Path to the PNGV 3X Goal, presented at the Transportation Research Board 80th Annual Meeting, Washington, DC, January 2001.

Consumption of HEV

- Energy Consumption of EV/HEV/PHEV is ruled by the regulation 101 of the United Nation Economic Commission for Europe
  - Based on NEDC driving cycle
  - Level road, no heating, no air conditioning

- Two modes:
  - Electric mode with battery fully charged
  - Hybrid / thermal mode with battery at minimal charge level

- Electric range
  - OVC range: the total distance covered during complete combined cycles run until the energy imparted by external charging of the battery (or other electric energy storage device) is depleted, as measured according to the procedure described in Annex 9

Consumption of HEV

- Fuel consumption:

$$C = \frac{D_{ovc}\,C_1 + D_{av}\,C_2}{D_{ovc} + D_{av}}$$

  - C = fuel consumption in liter/100km
  - C_1 = fuel consumption in l/100 km with a fully charged electrical energy/power storage device
  - C_2= fuel consumption in l/100 km with an electrical energy/power storage device in minimum state of charge (maximum discharge of capacity)
  - D_{ovc}= vehicle’s electric range on external battery charging
  - D_{av}= average distance between two battery recharges = 25 km

Consumption of HEV

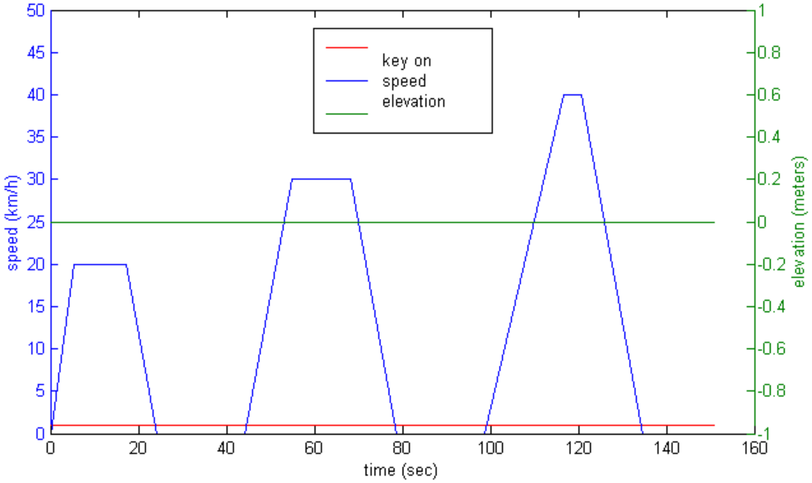
- Electric consumption:

$$E = \frac{D_e\, E_1 + D_{av}\, E_4}{D_e + D_{av}}$$

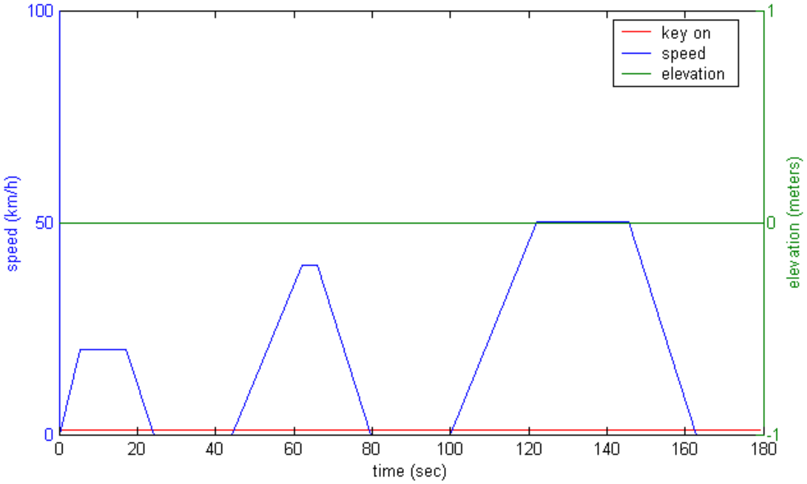
  - E = electric consumption in kWh/km
  - E_1= electric consumption [kWh/km] with battery fully charged
  - E_4= electric consumption [kWh/km] with an electrical energy/power storage device in minimum state of charge (maximum discharge of capacity)
  - D_e= vehicle's electric range
  - D_{av}= average distance between two battery recharges = 25 km

SORT cycles for buses

- Proposed by the UITP: cycles SORT (standardized on-road test) for the busses

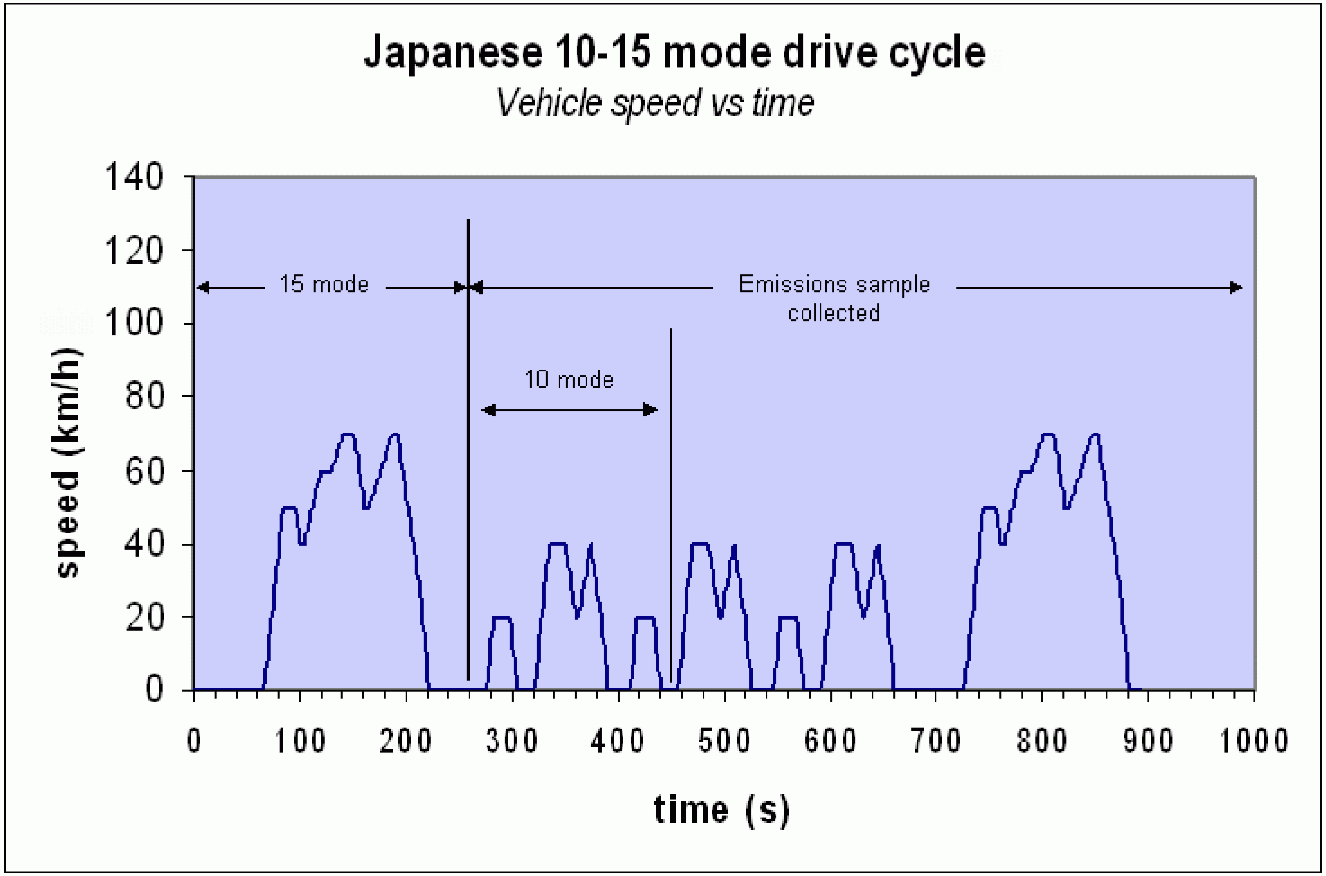


SORT 1 : Heavy urban SORT drive cycle



SORT 2: Easy urban SORT drive cycle

Japanese driving cycle



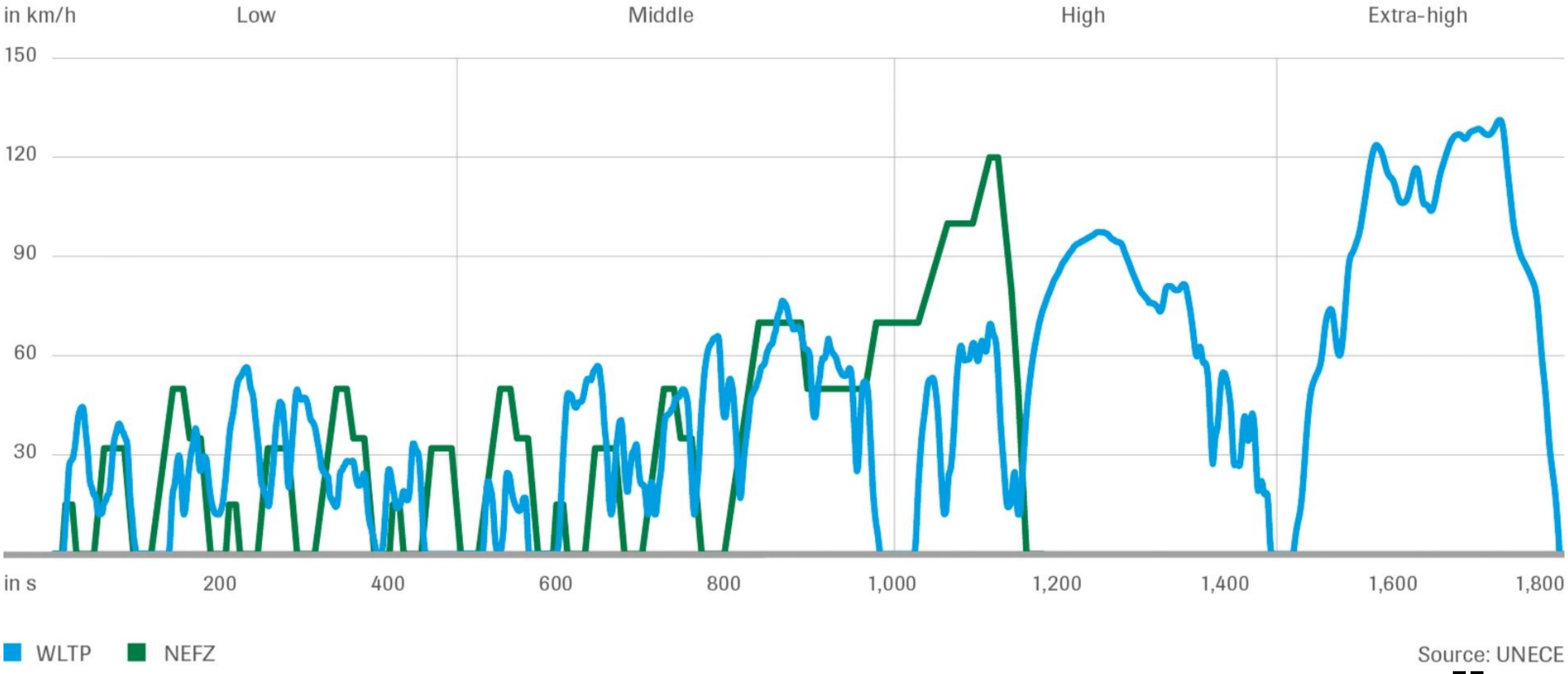
Drive cycle contained in the Japanese Automotive Type Approval Handbook, published by the Japan Automobile Standards Internationalization Centre (JASIC)

WLTP

	NEDC	WLTP
Test cycle	Unique driving cycle	Dynamic driving cycle closer to real-life driving conditions
Duration of the cycle	20 minutes	30 minutes
Distance of the cycle	11 kilometers	23,25 kilometres
Driving phases	2 phases, 66 % of urban driving and 34 % of rural driving	4 phases with more dynamics, 52% of urban driving and 48% of rural driving
Average speed	34 km/h	46,5 km/h
Maximum speed	120 km/h	131 km/h
Influence of individual options	NEDC does not account for the impact of options on CO_2 emissions and energy efficiency	Optional features (available on variants) are accounted for
Gear changes	Gear changes at fixed given speed	Gear change times are optimized for each vehicle
Test temperature	Mesures performed between 20 and 30 °C	Tests are realized at 23 °C, CO_2 corrected at 14 °C

WLTP

Speed profile in the future WLTP "world cycle"



Source: UNECE

WLTP

	WLTP	NEDC
Test temperatures	23°C	23°C
Cycle time	30 min	20 min
Stop-Driving phase	13%	25%
Cycle distance	23,25 km	11 km
Speed	Average speed : 46,5 km/h Max. speed : 131 km/h	Average speed : 34 km/h Max. speed : 120 km/h
Requested power	Average : 7,5 kW / 10,2 hp Max. : 47 kW / 63,9 hp	Average : 4 kW / 5,4 hp Max. : 34 kW / 46,2 hp

Chassis dynamometer

- Carrying out the different tests for fuel consumption and emissions requires an experimental set-up in which the external parameters (temperature, pressure, wind) can be controlled.
- The chassis dynamometer is a facility that allows reproducing in the laboratory environment the operating conditions of the vehicle 'as it was on the road'.
- The chassis dynamometer consists in one or two rollers driven by the tractive wheels and connected to a braking device that is able to absorb the power developed at wheels and that is able to regulate operating conditions as torque or rotation speed.
- A data acquisition system allows a feedback control of the rotation or the tractive force to mimic the road loads and to save the measured data

Chassis dynamometer

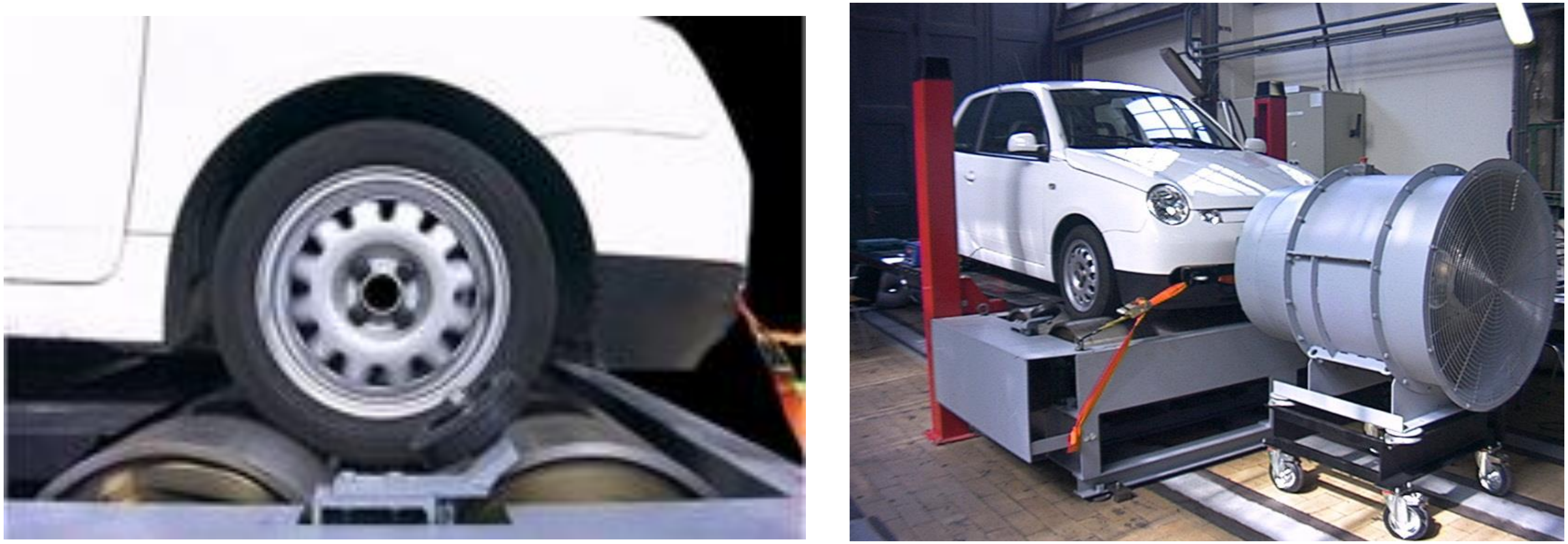
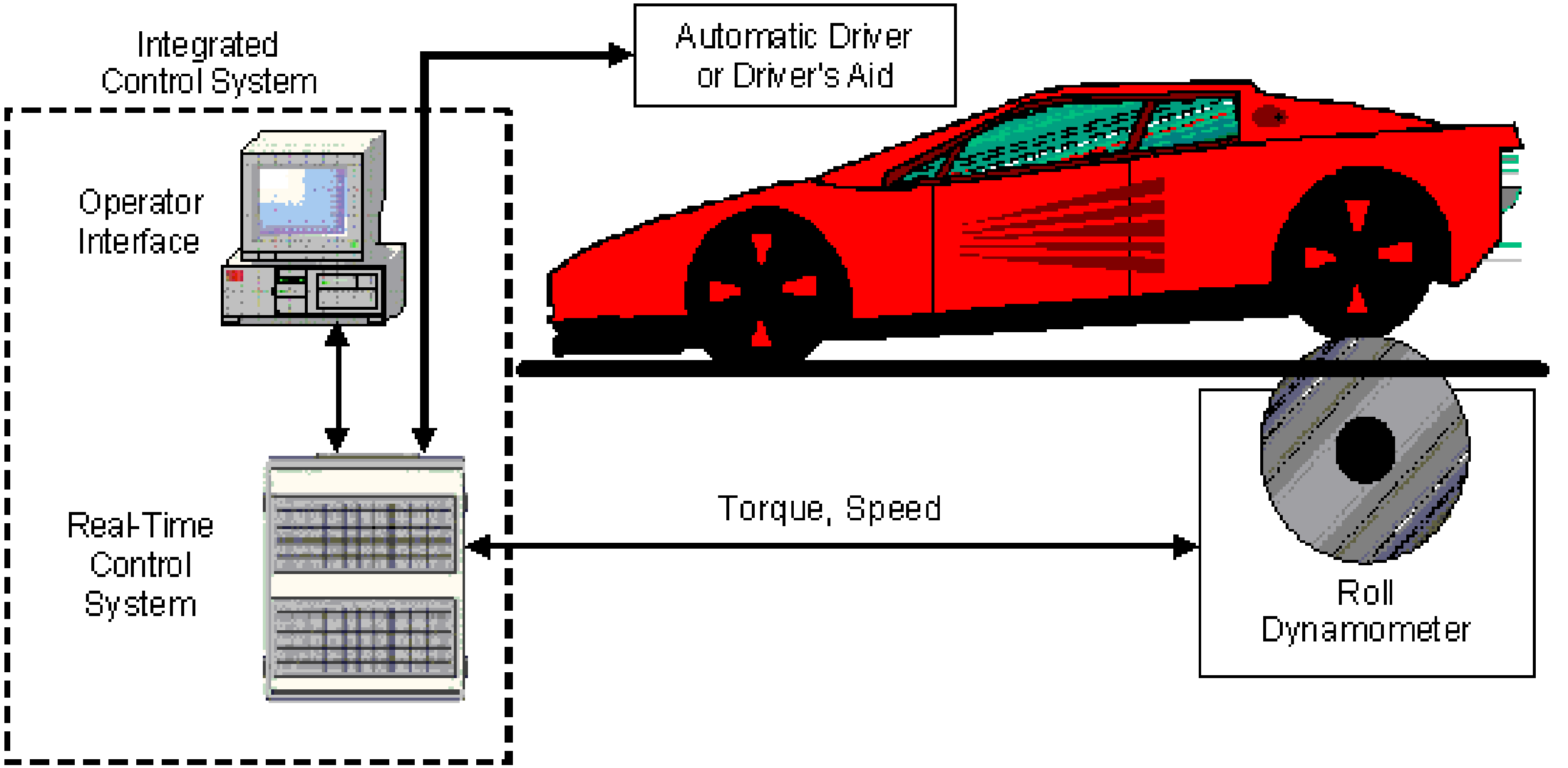


Fig. Set up on the Uliege chassis dynamometer

Chassis dynamometer



Chassis dynamometer

- Advantages of chassis dynamometer:
    - Testing the performance of the vehicle and its equipment without dismantling the car
    - Not necessary to remove the engine and to install it on the test bed
    - Simple test procedure
    - Accounts for the mounting in the engine in its vehicle environment
- Drawbacks
    - Precision and repeatability of the measure lower than on engine test bed (transmission losses, tire slip…)
    - Introduction of sensors limited

Chassis dynamometer

- Applications of chassis dynamometer
  - Checking up the tractive power / force at wheels of the car
  - Testing the powertrain when installed in the vehicle
  - Estimation and measurement of the driveline losses
  - Testing the real power developed by the vehicle when necessary
  - Carrying out some testing that requires the propulsion system to be implemented in the vehicle to characterize the fuel consumption, the emissions, the noise emissions…

Chassis dynamometer

Fig. Set up on the Uliege chassis dynamometer