Vehicle Propulsion Systems
Lecture 10
Summary of the Course

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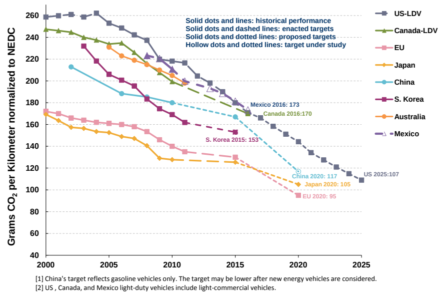
Outline

Customers and Legislation as Technology Drivers

	Customers	Legislation
New technologies	X	
Emissions		X
CO_2 – Fuel consumption –Commercial vehicles –Passenger cars	 X	 X

CO_2 performance and legislations

Fleet average from manufacturer.



130 g/km $\sim$ 0.55 l/10 km, 95 g/km $\sim$ 0.4 l/10 km

Possible Technical Solutions - Engine or Powertrain Efficiency

How can we reach the 95 g CO_2/km goals?

–My personal reflection

- Improving vehicle/powertrain efficiencies?
  – No, already well optimized, can shave off a few percent.
- New vehicles?
  – Yes, but will customers accept new vehicles.
- Bio fuels?
  – Yes, but not yet ready
- Electrification of vehicles?
  – Yes, the most probable short term solution

EU Legislation - ECE R101 rev 3 (12 April 2013)

3.4.2.1. In the case of testing according to paragraph 3.2.3.2.1.:

$$M = (De \cdot M1 + Dav \cdot M2)/(De + Dav)$$

Where:

- M = mass emission of CO2 in grams per kilometer.
- M1 = mass emission of CO2 in grams per kilometer with a fully charged electrical energy/power storage device.
- M2 = mass emission of CO2 in grams per kilometer with an electrical energy/power storage device in minimum state of charge (maximum discharge of capacity).
- De = vehicle's electric range, according to the procedure described in Annex 9 to this Regulation, where the manufacturer must provide the means for performing the measurement with the vehicle running in pure electric operating state.
- Dav = 25 km (assumed average distance between two battery recharges).

CO_2 Calculations – PHEV

According to the legislation proposal

PHEV – Electricity for charging no CO_2 emissions

- M = (De·M1 + Dav·M2)/(De + Dav) Where:
- M1 = 0
- Dav = 25 km

Reduction factor

- F = (De + 25)/25 reduction factor
- M = M2 / F
- De = plug-in distance in kilometer
- M2 = mass emission of CO2 in grams per kilometer with an electrical energy/power storage device in minimum state of charge. (Normal hybrid mode)

Technical Solution – Toyota Prius - PHEV

Hybrid

- I4, 1.8l, 60 kW (99 hp)
- Electric range < 1.6 km
- Weight > 1440 kg
- 3.9 l, 89 g/km
- 26800 EUR (DE)

Plug-in

- I4, 1.8l, 60 kW (99 hp)
- Electric range 25 km
- Weight > 1500 kg
- 2.1 l, 49 g/km (-45%)
- 36550 EUR (DE) (+36%)

Technical Solutions – Merceces S500 - PHEV

Normal

- V8, 320 kW
- Electric range 0 km
- 210 g/km

Plug-in

- V6, 254 kW + 80 kW el
- Electric range 30 km
- 69 g/km (-67%)

ECE reduction factor

F=(25+30)/25=2.2 (=55% reduction)

Side note: S300 BlueTec Hybrid 150 kW (204 hp), 4 cyl, Diesel, 20kW el, 115 g/km

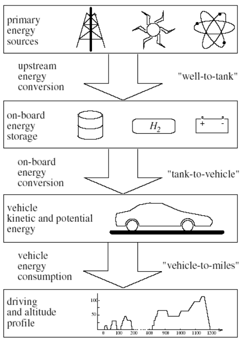
Outline

Guest lecturer: Martin Sivertsson

The PHEV benchmark.

Outline

Energy System Overview



Primary sources

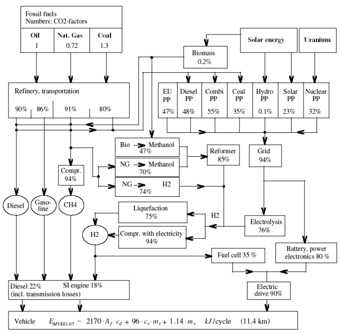
Different options for on-board energy storage

Powertrain energy conversion during driving

Cut at the wheel!

Driving mission has a minimum energy requirement.

Example of Some Energy Paths

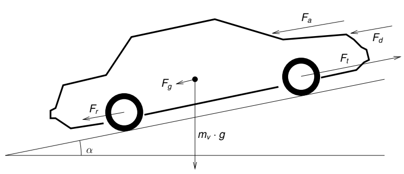


Outline

The Vehicle Motion Equation

Newtons second law for a vehicle

$$m_v \frac{d}{dt} v(t) = F_t(t) - (F_a(t) + F_r(t) + F_g(t) + F_d(t))$$



- F_t – tractive force
- F_a – aerodynamic drag force
- F_r – rolling resistance force
- F_g – gravitational force
- F_d – disturbance force

Vehicle Operating Modes

The Vehicle Motion Equation:

$$m_v \frac{d}{dt} v(t) = F_t(t) - (F_a(t) + F_r(t) + F_g(t) + F_d(t))$$

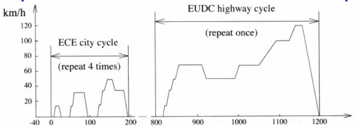
- $F_t > 0$ traction
- $F_t < 0$ braking
- $F_t = 0$ coasting

$$\frac{d}{dt} v(t) = -\frac{1}{2\, m_v} \rho_a\, A_f\, c_d\, v^2(t) - g\, c_r = \alpha^2\, v^2(t) - \beta^2$$

Coasting solution for $v > 0$

$$v(t) = \frac{\beta}{\alpha} \tan\left(\arctan\left(\frac{\alpha}{\beta}\, v(0)\right) - \alpha\, \beta\, t\right)$$

Fuel Consumption Demand – Values for cycles



Numerical values for MVEG-95, ECE, EUDC

$$\tilde{F}_{trac,a} = \frac{1}{x_{tot}} \sum_{i \in trac} \bar{v}_i^3\, h = \qquad \{319, 82.9, 455\}$$

$$\tilde{F}_{trac,r} = \frac{1}{x_{tot}} \sum_{i \in trac} \bar{v}_i\, h = \qquad \{.856, 0.81, 0.88\}$$

$$\tilde{F}_{trac,m} = \frac{1}{x_{tot}} \sum_{i \in trac} \bar{a}_i\, \bar{v}_i\, h = \qquad \{0.101, 0.126, 0.086\}$$

$$\bar{E}_{\text{MVEG-95}} \approx A_f\, c_d\, 1.9 \cdot 10^4 + m_v\, c_r\, 8.4 \cdot 10^2 + m_v\, 10 \qquad kJ/100km$$

Tasks in Hand-in assignment

Approximate car data

$$\bar{E}_{\text{MVEG-95}} \approx A_f\, c_d\, 1.9 \cdot 10^4 + m_v\, c_r\, 8.4 \cdot 10^2 + m_v\, 10 \qquad kJ/100km$$

	SUV	full-size	compact	light-weight	PAC-Car II
$A_f \cdot c_d$	1.2 m^2	0.7 m^2	0.6 m^2	0.4 m^2	.25 · .07 m^2
c_r	0.017	0.017	0.017	0.017	0.0008
m_v	2000 kg	1500 kg	1000 kg	750 kg	39 kg
$\bar{P}_{\text{MVEG-95}}$	11.3 kW	7.1 kW	5.0 kW	3.2 kW	
$\bar{P}_{\max}$	155 kW	115 kW	77 kW	57 kW	

Average and maximum power requirement for the cycle.

Outline

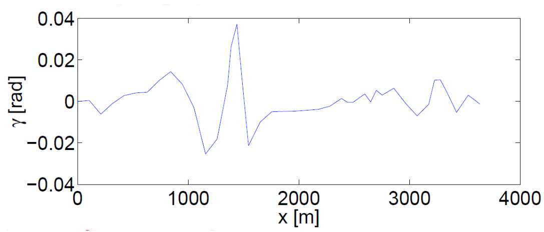
Problem Setup

- Run a fuel cell vehicle optimally on a racetrack

  - Start up lap
  - Repeated runs on the track
- Path to the solution
  - Measurements – Model
  - Simplified model
  - Optimal control solutions

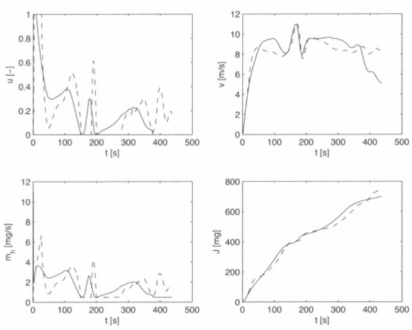
Problem Setup – Road Slope Given

Road slope $\gamma = \alpha(x)$



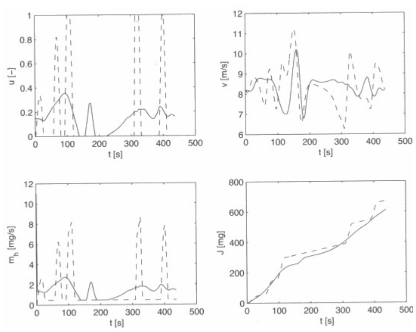
Fuel Optimal Trajectory – Start

Fuel optimal trajectory has 7% lower fuel consumption



Fuel Optimal Trajectory – Continuous Driving

Fuel optimal trajectory has 9% lower fuel consumption



Outline

Vehicle Propulsion Systems

A diversity of powertrain configurations is appearing

- Conventional Internal Combustion Engine (ICE) powertrain.
  Diesel, Gasoline, New concepts
- Hybrid powertrains – Parallel/Series/Complex configurations
- Fuel cell electric vehicles
- Electric vehicles

Course goal:

- Introduction to powertrain configuration and optimization problems
- Mathematical models and . . .
- . . . methods for
  - Analyzing powertrain performance
  - Optimizing the powertrain energy consumption
- Lectures:
  Broadened perspective about your engineering tasks.
  Vehicle/Infrastructure/Society/...