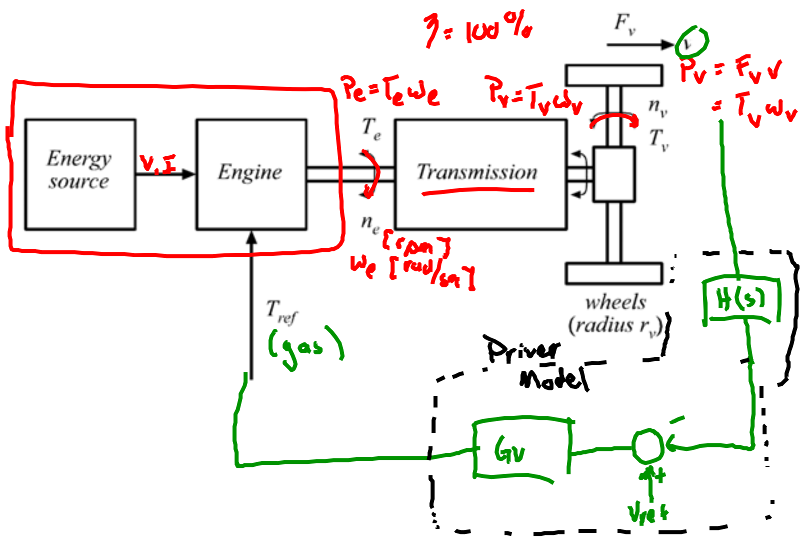
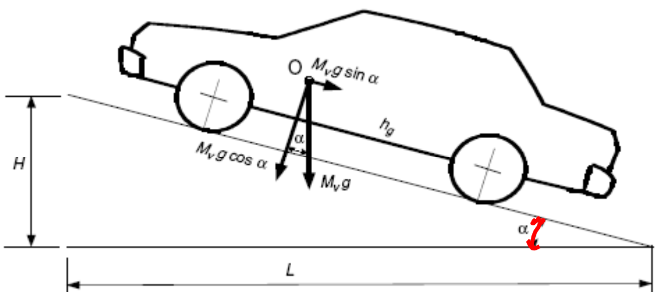
Introduction to Vehicle Dynamics

ECE 482 Lecture 3
January 13, 2014

Vehicle as a Feedback System



Basic Vehicle Dynamics



Angle of inclination

$$\alpha = \tan^{-1}\left(\frac{H}{L}\right)$$

Slope or "grade"

$$Z = \left(\frac{H}{L}\right)$$

$$g = 9.81\ \text{m/s}^2$$

Air density

$$\rho = 1.204\ \text{kg/m}^3$$

Rolling resistance coefficient C_r

Aerodynamic drag coefficient C_d

$F = ma$

drive, gravity, rolling res., aero. drag

$$M_v \frac{dv}{dt} = F_v - M_v g \sin\alpha - M_v g \cos\alpha\, C_r - \frac{1}{2}\rho C_d A_v v^2$$

for α small

$\sin\alpha \approx \tan\alpha = \frac{H}{L} = Z$

$\cos\alpha \approx 1$

$$M_v \frac{dv}{dt} \simeq F_v - \frac{1}{2}\rho C_d A_v v^2 - M_v g Z - M_v g C_r$$

Neglects:

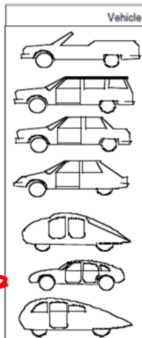
- C_d, C_r are functions of speed
- M_v is a function of speed
  - aerodynamic lift
  - Rotational inertia ($M_v^* > M_v$)
- Unequal dist. of weight

Rolling resistance coefficient C_r

Rolling Resistance Coefficients

Conditions	Rolling resistance coefficient
Car tires on concrete or asphalt	0.013
Car tires on rolled gravel	0.02
Tar macadam	0.025
Unpaved road	0.05
Field	0.1–0.35
Truck tires on concrete or asphalt	0.006–0.01
Wheels on rail	0.001–0.002

Aerodynamic drag coefficient C_d



Vehicle Type	Coefficient of Aerodymanic Resistance
Open convertible	0.5–0.7
Van body	0.5–0.7
Ponton body	0.4–0.55
Wedge-shaped body; headlamps and bumpers are integrated into the body, covered underbody, optimized cooling air flow	0.3–0.4
Headlamp and all wheels in body, covered underbody	0.2–0.25
K-shaped (small breakway section)	0.23
Optimum streamlined design	0.15–0.20
Trucks, road trains	0.8–1.5
Buses	0.6–0.7
Streamlined buses	0.3–0.4
Motorcycles	0.6–0.7

Reference: Mehrdad Ehsani, Yimin Gao, Sebastien E .Gay, and Ali Emadi, Modern Electric, Hybrid Electric, and Fuel Cell Vehicles, CRC Press 2004.
Chapter 2

Typical Performance Specifications

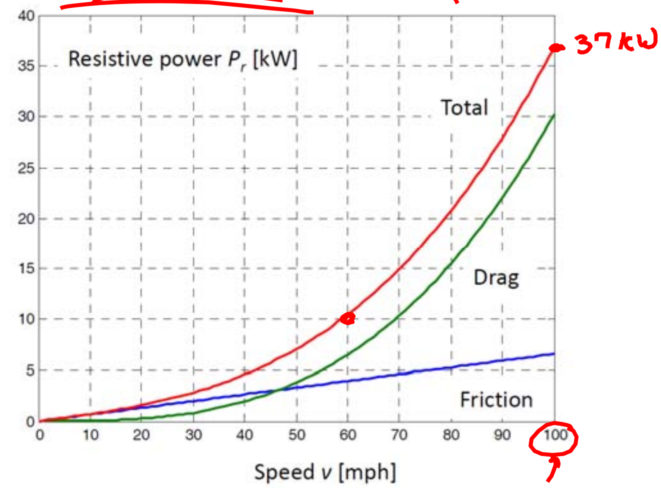
- Cruising (v = const) specs
  - Top cruising speed on a flat road: v_{max}
  - Gradeability: ability to ascend a road of grade Z (in %) at a cruising speed v_{zmax}
- Acceleration specs
  - Time t_a it takes to accelerate from v_s to v_f Typical: v_s = 0 mph to v_f = 60 mph (100 km/h) in t_a seconds

v_f: 20mph

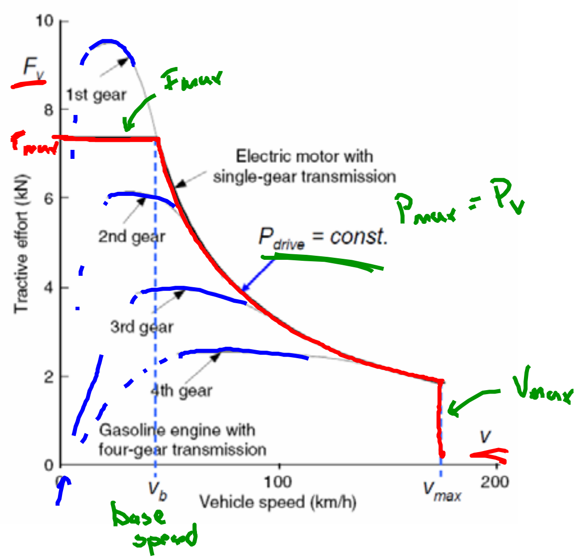
Cruising on a flat road

$$P_v = F_v v \approx \frac{1}{2}\rho C_d A_v v^3 + C_r M_v g v + M_v \frac{dv}{dt}$$

Example
M_v = 1500 kg
r_w = 0.3 m
C_d = 0.26
C_r = 0.01
A_v = 2.16 m²



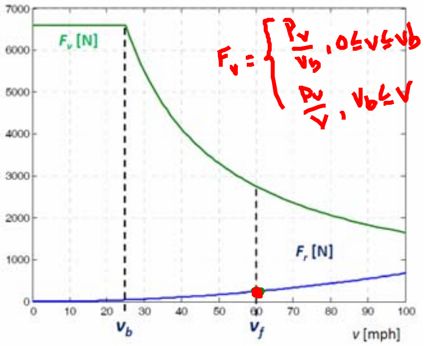
Engine Traction Characteristics



t_a seconds to go 0 to v_f

Acceleration Spec

$$M_v \frac{dv}{dt} \approx F_v - \frac{1}{2}\rho C_d A_v v^2 - C_r M_v g = F_v - F_r(v)$$



$$F_v = \begin{cases} \frac{P_v}{v_b}, & 0 \le v \le v_b \\ \frac{P_v}{v}, & v_b \le v \end{cases}$$

$$\int_0^{t_a} dt = \int_0^{v_f} \frac{M_v \, dv}{P_v - F_r(v)}$$

$$t_a = \int_0^{v_b} \frac{M_v \, dv}{\frac{P_v}{v_b} - F_r(v)} + \int_{v_b}^{v_f} \frac{M_v \, dv}{\frac{P_v}{v} - F_r(v)}$$

assume $F_r(v) \simeq \phi$ $\quad \frac{M_v}{P_v}\left(\frac{v^2}{2}\right)\Big|_{v_b}^{v_f}$

$$t_a = \frac{M_v}{P_v} v_b^2 + \frac{M_v}{P_v}\frac{1}{2}\left(v_f^2 - v_b^2\right)$$

$$t_a = \frac{M_v}{P_v}\frac{1}{2}\left(v_f^2 + v_b^2\right)$$ Neglecting $F_r(v)$

$$P_v \ge \frac{M_v}{t_a}\frac{1}{2}\left(v_f^2 + v_b\right) + F_r(v_f)v_f$$

Engine Power Rating

$$P_v \approx \frac{1}{2}\frac{M_v}{t_a}\left(v_b^{\;2}+v_f^{\;2}\right)+\frac{1}{2}\rho C_d A_v v_f^{\;3}+C_r M_v g v_f$$

$F_r(v_f)\,v_f$

Prius-sized EV

Example
M_v = 1500 kg
C_d = 0.26
C_r = 0.01
A_v = 2.16 m^2
x = 4 $= \frac{v_f}{v_b}$

Acc. performace spec: 0-60 mph in $t_a = 10\text{ s}$

$$\left(P_v\right)_{required} \approx 74\text{ kW }(99\text{ hp})$$

1 hp = 750 W