Electric Vehicle (EE60082)

Lecture 2: Vehicle Dynamics

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Evolution of EV and Gasoline Vehicles (recap)

- 1881: The first EV was built by Gustave Trouvé.
  - Tri-cycle driven by DC motor and lead-acid battery
  - not mature enough to compete with horse carriages
- 1894: Electrobat, first commercial EV was Morris and Salom
  - operated as a taxi in New York City
  - Higher initial cost, but more profitable
- 1897: invention of regenerative braking by M. A. Darracq
- 1899: “La Jamais Contente” by Camille Jenatzy, first vehicle to achieve speed over 100 km/h.

- 1885: Benz Patent-Motorwagen.
  - first practical gasoline-powered automobile
  - It was powered by a single-cylinder four-stroke engine
- 1891: Panhard et Levassor
  - Introduced the "system Panhard" layout: front-engine, rear-wheel drive, and a gearbox
- 1896: Duryea Motor Wagon Company
  - first gasoline car manufacturer in the United States
- 1899: “Daimler-Mercedes” sets record speed of 63 km/h for gasoline automobile.

Causes of EV disappearance (recap)

- Rapid development of gasoline vehicle technology
  - 1901: first mass-produced gasoline-powered car
  - 1908: first affordable car for the masses
  - 1911: Introduction of the Electric Starter
  - 1913: Ford Assembly Line – moving assembly line

- Cost: Reduction in vehicle cost from $850 in 1909 to $260 in 1925. EVs were more expensive.

- Reduction in gasoline cost: discovery of new oil fields such as Spindletop (Texas, 1901)

Causes of EV disappearance (recap)

- higher cost
- Infrastructure: Rural areas had very limited access to electricity to charge batteries
- Slow improvement of battery technology
  - Heavy battery
  - Long charging time
  - limited driving range and performance
- Difficulty in motor control
  - controlled by mechanical switches and resistors
  - Limited operating range
  - Very inefficient

Reappearance of EV – Technology (recap)

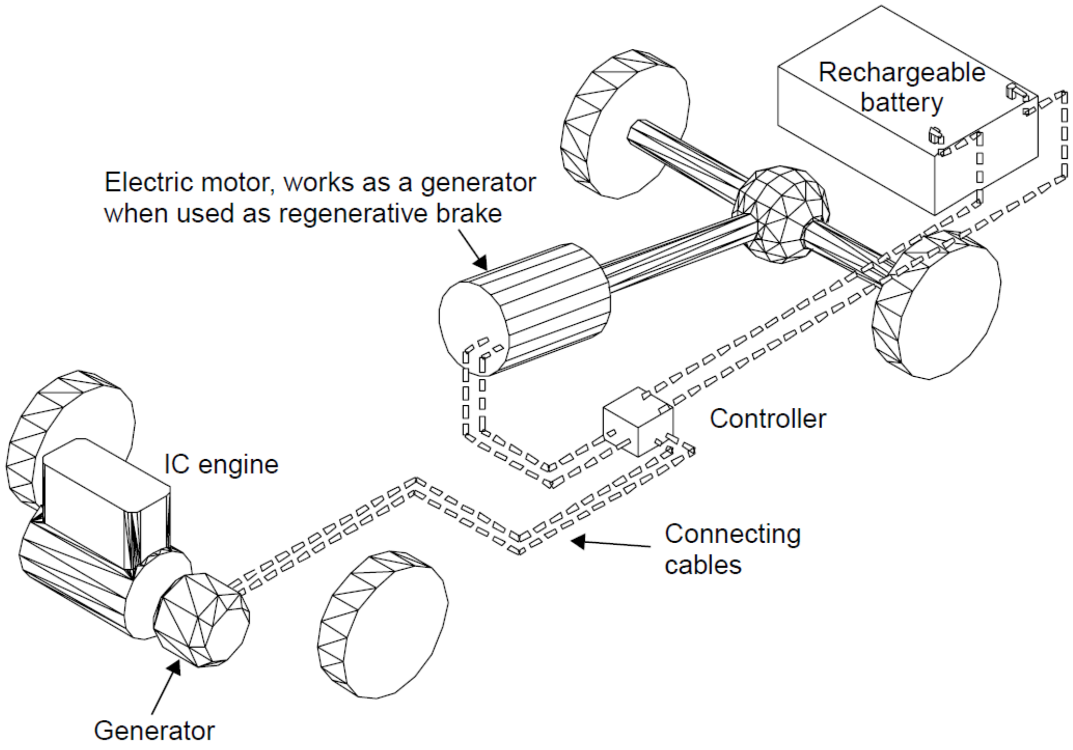
Battery technology

- 1970s: Research on Li-ion cells begins
- 1980: Lithium Cobalt Oxide (LCO) Cathode by John Goodenough
- 1991: First Commercial Lithium-Ion Battery by Sony
- 2004: Lithium Iron Phosphate (LFP) Cathode

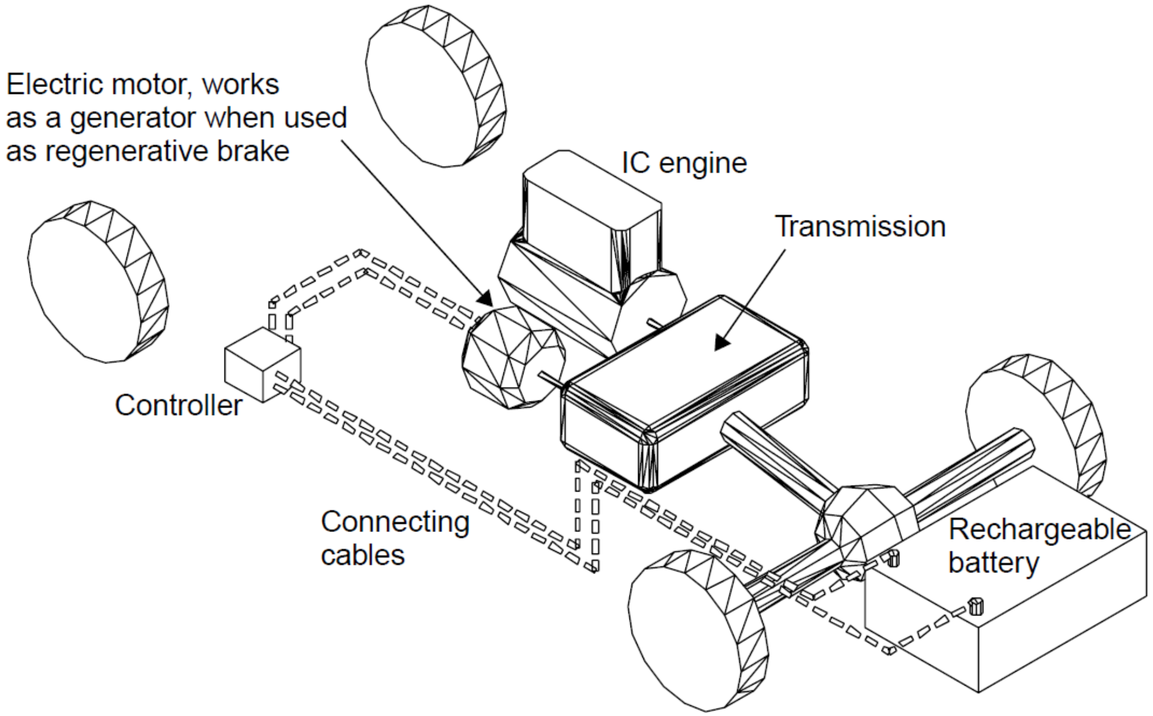
Power electronics

- 1947: Invention of the Transistor
- 1956: Invention of Thyristors
- 1975: Invention of IGBT
- 1980s: PWM techniques development
- 1990s: MOSFETs and advanced power converters

Hybrid EV (recap)



Series configuration

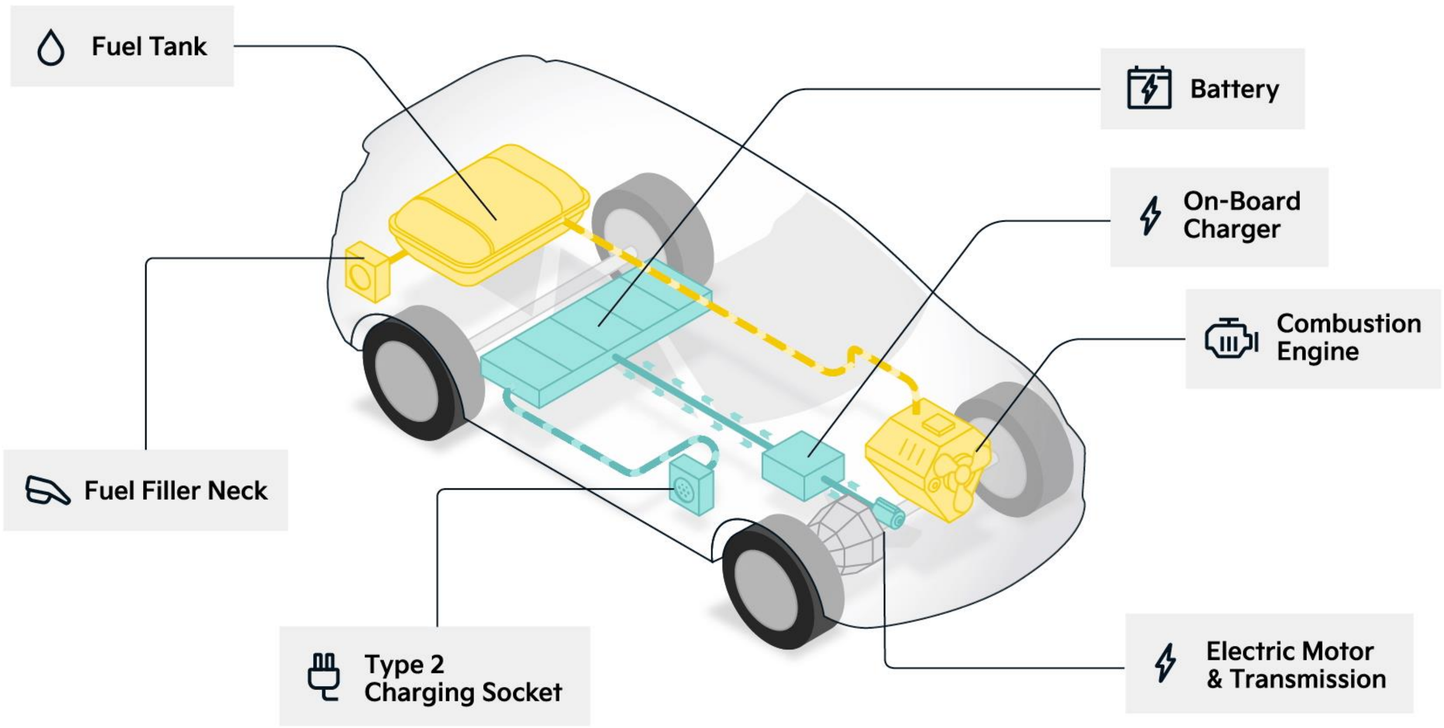


Parallel configuration

Plugged-in HEV (PHEV) (recap)

Plugged-in Hybrid EV – traditional gasoline vehicle with bigger battery

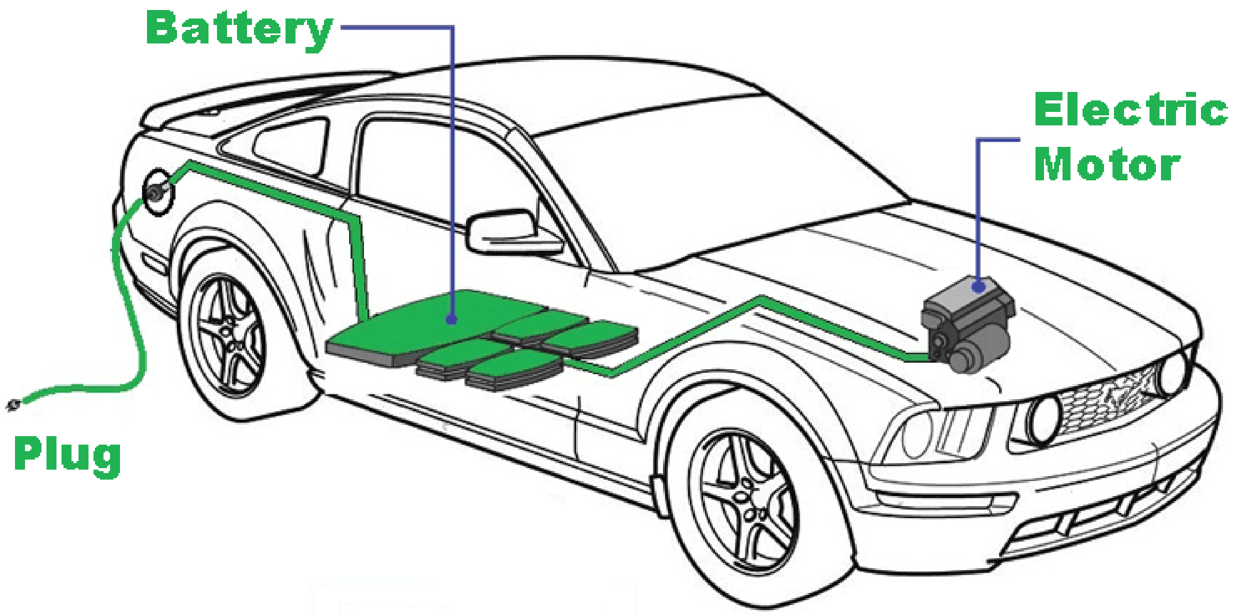
- Partially support the propulsion power
- Reduce IC engine size
- Reduce gasoline consumption
- Avoid range anxiety using IC engine



Battery Electric Vehicle (BEV) (recap)

Battery EV – gasoline engine replaced

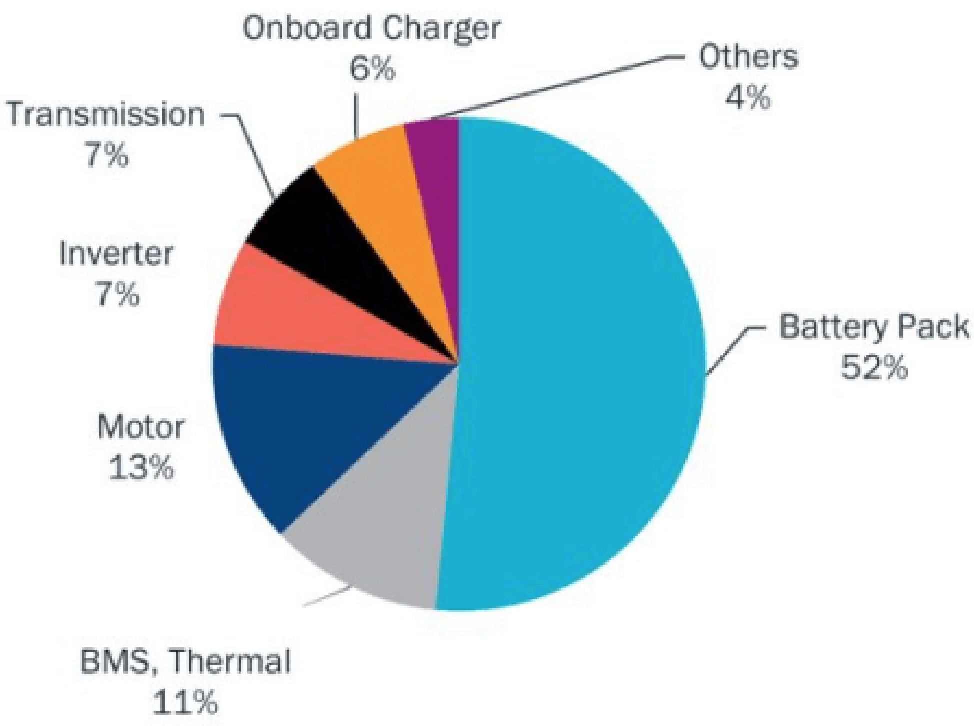
- Large battery pack
- No emission
- Low noise
- Low maintenance



Cost breakdown for EV power train

EV power train cost:

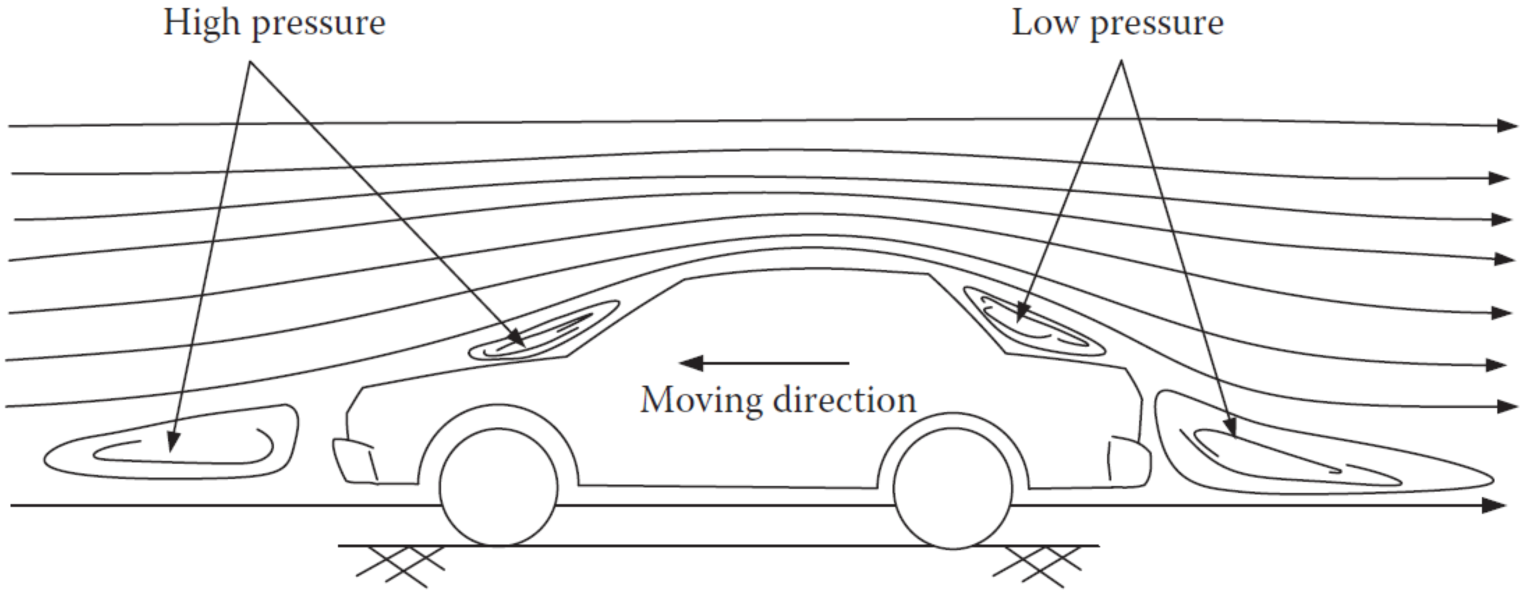
- about half the cost is due to the battery pack
- Power electronics cost is relatively low
  - Due to advanced power converter design
- Motor and thermal management have significant contribution



https://www.powertraininternationalweb.com/components/interact-analysis-which-ev-component-increased-price-the-most-in-2022/

Drag resistance

- Aerodynamic drag force
  - Skin Drag:
    - Car surface moves air with it
    - additional force is needed to overcome the friction between moving air and still air
    - depends on surface area
  - Shape Drag:
    - When car moves, there will be high pressure air region at front and low pressure air region on the back
    - This pressure difference creates backward force
    - Depends on car shape



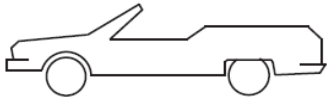
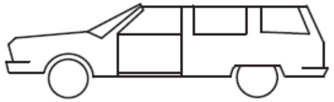
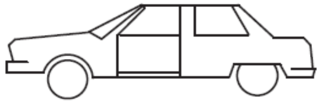
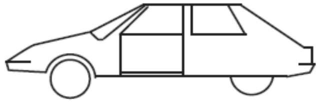
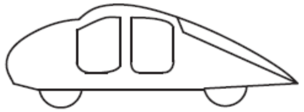
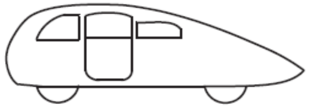
- Aerodynamic drag force is given by, $$F_W = \frac{1}{2}\rho A_f C_D (V - V_w)^2$$
- ρ is air density, A_f is front area, C_D is drag co-efficient, V_w is wind velocity

Typical drag co-efficient

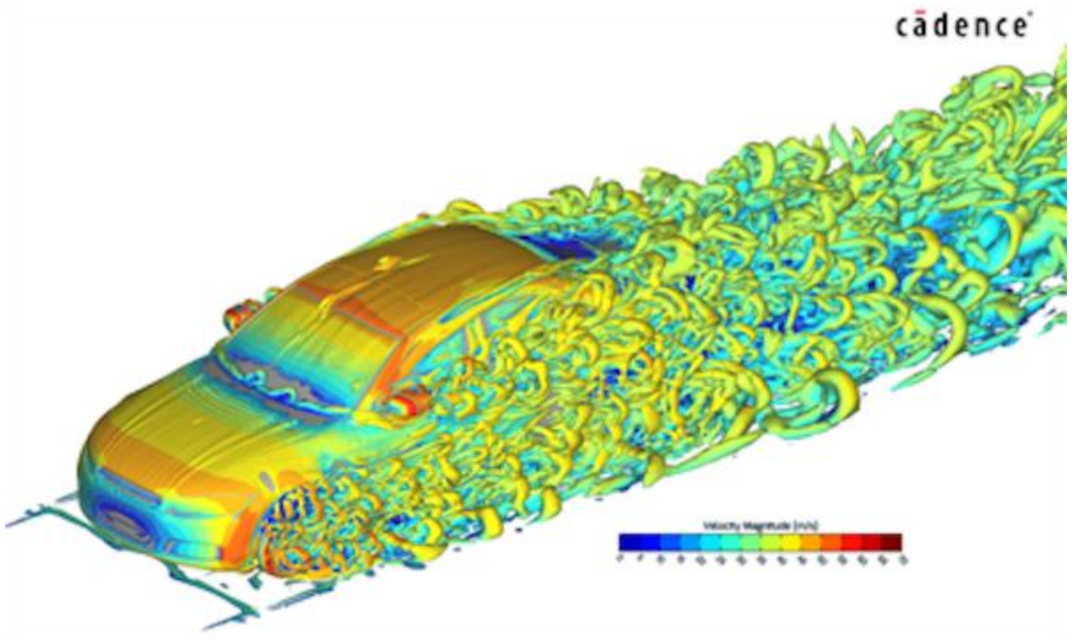
- Aerodynamic drag depends on,
  - vehicle body design, not directly on weight
  - wind velocity and direction

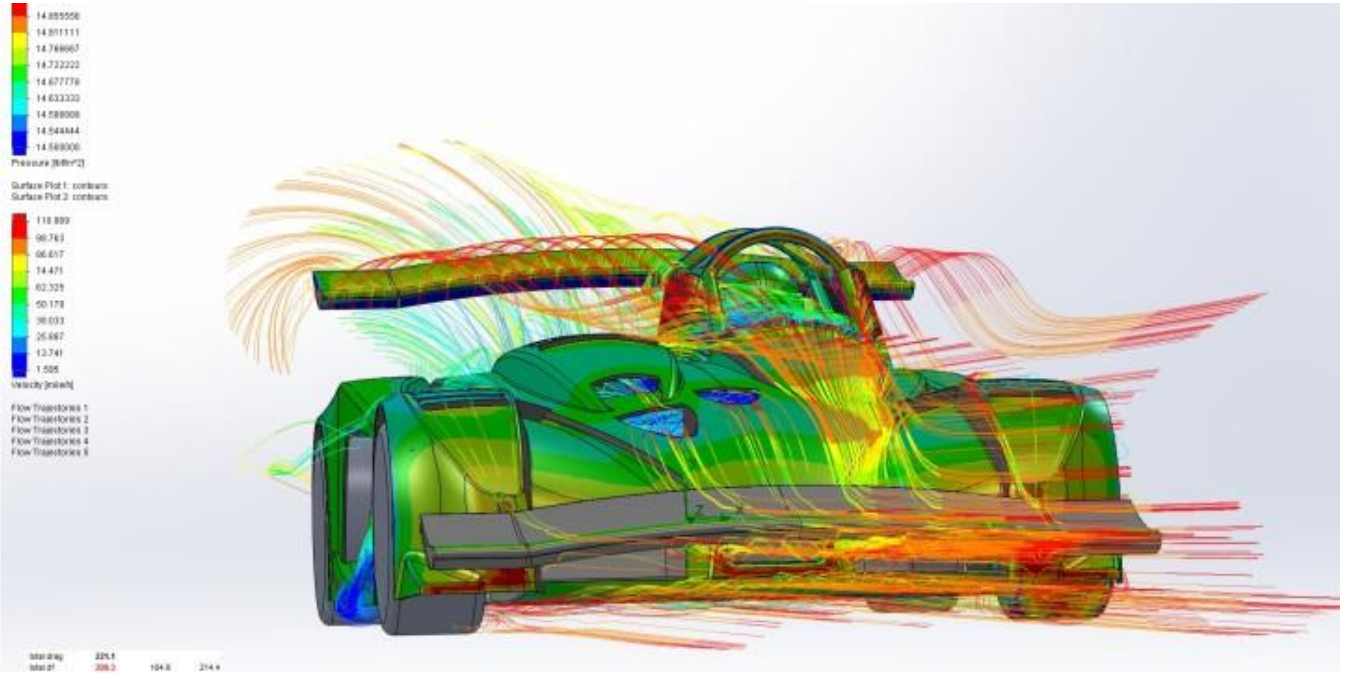
- Drag is significantly higher at higher speed

- Aerodynamics is extremely complex, drag resistance is based on empirical formulas

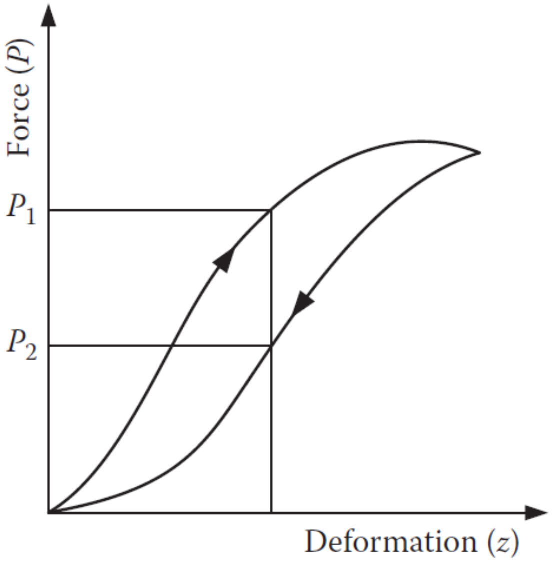
Vehicle type	Coefficient of aerodynamic resistance
 Open convertible	0.5…0.7
 Van body	0.5…0.7
 Ponton body	0.4…0.55
 Wedged-shaped body; headlamps and bumpers are integrated into the body, covered underbody, optimized cooling air flow	0.3…0.4
 Headlamp and all wheels in body, covered underbody	0.2…0.25
 *K*-shaped (small breakaway 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

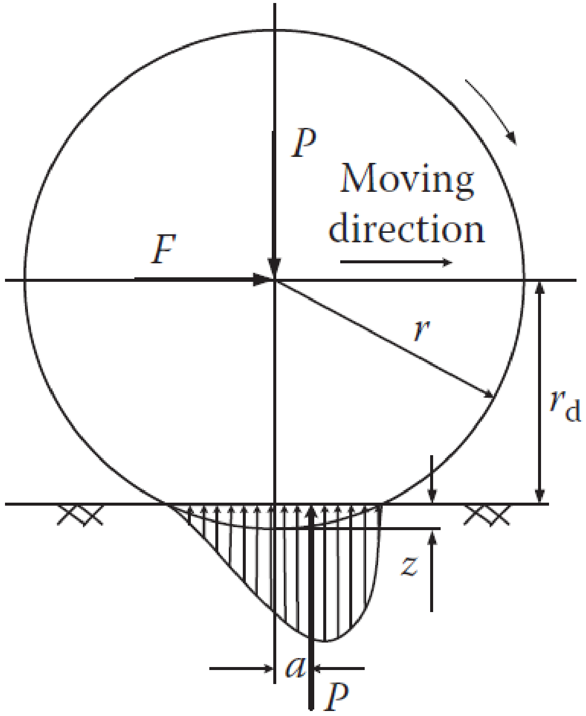
FEM simulation



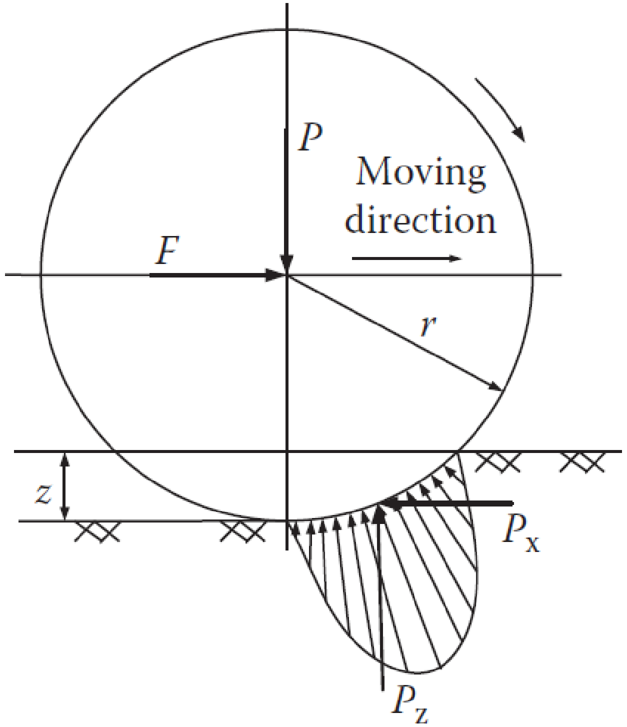


Rolling resistance





On hard road surface



On soft road surface

$$T_r = Pa$$

$$F = \frac{T_r}{r_d} = \frac{Pa}{r_d} = Pf_r.$$

- On hard road,
  - Car tire deforms
- On soft road,
  - road deforms
- Rolling resistance torque is created on wheels

Rolling resistance

Rolling resistance co-efficient,

$$f_r = f_0 + f_s\left(\frac{V}{100}\right)^{2.5}$$

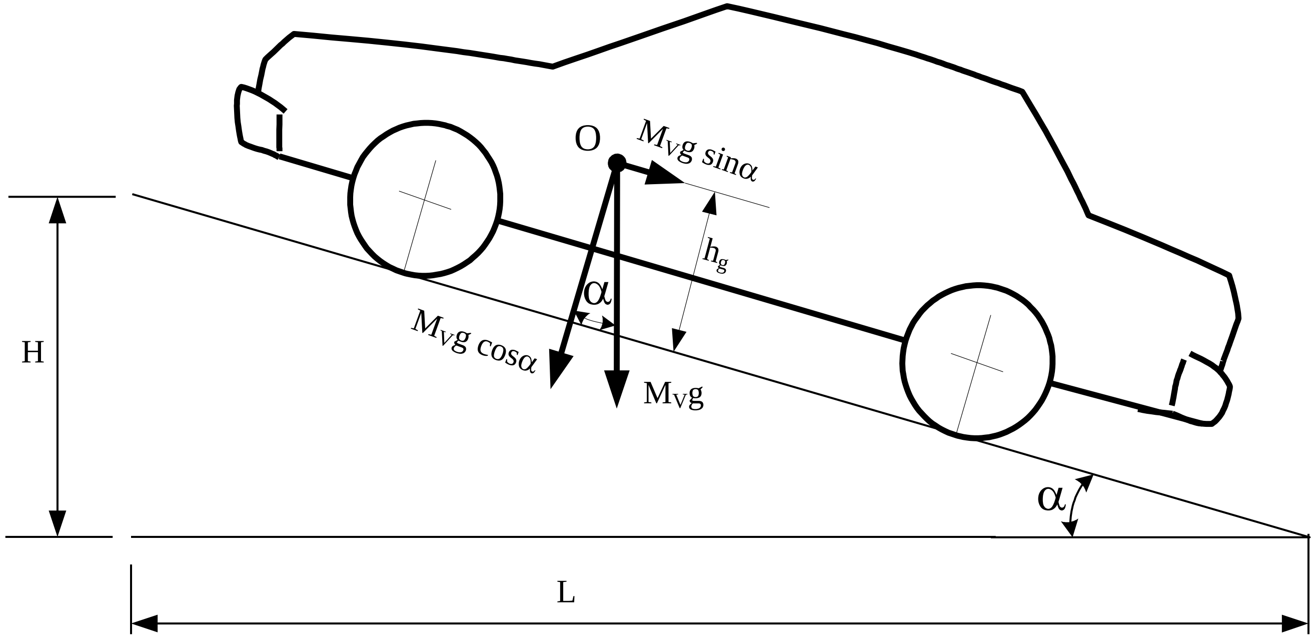
Rolling resistance co-efficient at low speed

Conditions	Rolling Resistance Coefficient
Car tires on concrete or asphalt road	0.013
Car tires on rolled gravel road	0.02
Tar macadam road	0.025
Unpaved road	0.05
Field	0.1–0.35
Truck tire on concrete or asphalt road	0.006–0.01
Wheel on iron rail	0.001–0.002

Grading resistance

The gravitational force, F_g depends on the slope of the roadway; it is positive when climbing a grade and is negative when descending a downgrade roadway. Where α is the grade angle with respect to the horizon, m is the total mass of the vehicle, g is the gravitational acceleration constant.

$$F_g = mg \sin \alpha$$



Thank you!