THE VEHICLE SYSTEM AND ITS MAJOR COMPONENTS

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References

- Julian Happian-Smith. « An introduction to Modern Vehicle Design ». Butterworth Heinemann 2002.
- T. Gillespie. « Fundamentals of vehicle Dynamics », 1992, Society of Automotive Engineers (SAE)
- W. Milliken & D. Milliken. « Race Car Vehicle Dynamics », 1995, Society of Automotive Engineers (SAE)
- J. Chagette. « Technique Automobile ». Tome 1, Le moteur. Tome 2 Le chassis. Dunod, Paris. 1965.
- R. Bosch. « Automotive Handbook ». 5th edition. 2002. Society of Automotive Engineers (SAE)
- J. Reimpell, H. Stoll, J. Betzler. « The automotive chassis: engineering principles ». 2nd edition. 2001, SAE.
- H. Heisler. « Vehicle and Engine Technology ». 2nd edition. SAE, 1999.
- H. Memeteau. « Technologie fonctionnelle de l'automobile » 2 tomes. Dunod. 2002.

Outline

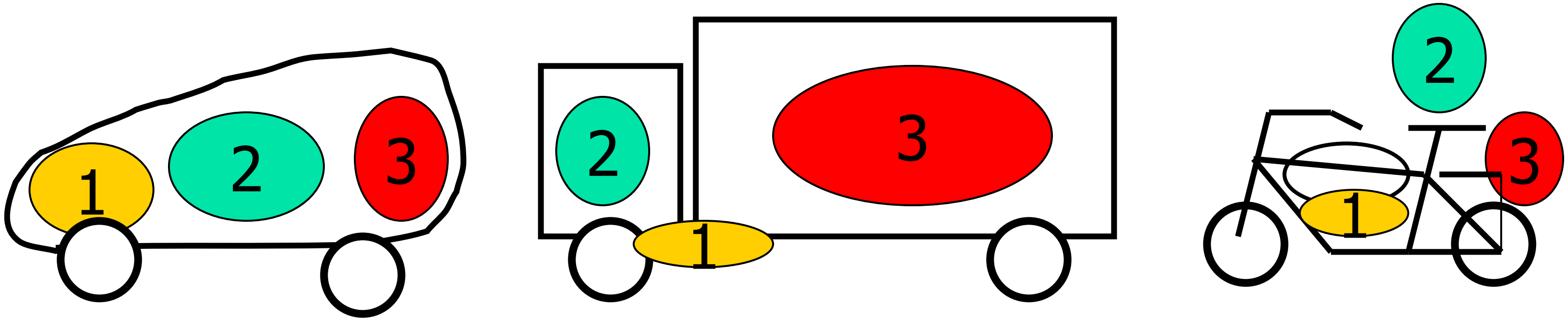
- Functionnal description of the automobile
- The vehicle layout
- The main subsystems
  - The body
  - The powertrain
  - Transmission line
  - Braking system
  - Electrical system
  - Active and passive safety systems

1. Functional description of the car

- What is an automobile?
  - The term automobile refers to any vehicle that is **capable of moving under its own power** and that **carries the energy** necessary for its operation and its motion

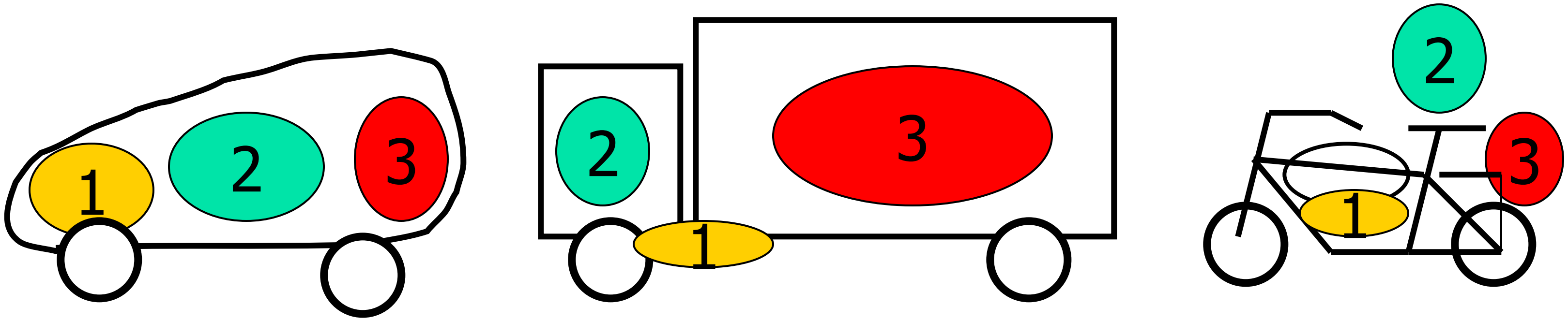
1. Functional description of the car

- What are the main parts of a car?
- In the system denoted as the body, there are three main parts:
  - 1/ A compartment containing the **propulsion system**, mechanically linked to the driving wheels;
  - 2/ A cell hosting the driver and passengers, called the **passenger compartment** or **cabin**
  - 3/ A **luggage** compartment.



1. Functional description of the car

- What are the main types of road vehicles?
  - 1/ **Passenger vehicles**: cars designed to carry passengers, which are the only ones to have retained the name of automobile
  - 2/ **Commercial vehicles**:
    - Public transport (buses, coaches),
    - Duty vehicles (vans, trucks, tractors and semi-trailers),
    - Special vehicles: construction equipment, fire engines, etc.
  - 3/ **Light vehicles** with two, three or four wheels: bicycles, motorbikes, three-wheelers, quads, etc.



1. Functional description of the car

The EU general classification of vehicle categories

➔ Motor vehicles with at least four wheels:

- Category M: used for the carriage of passengers
  - Category M1: **no** more than eight seats in addition to the driver's seat
  - More than eight seats in addition to the driver's seat:
    - Category M2: haves a maximum mass **not** exceeding 5 tons
    - Category M3: haves a maximum mass exceeding 5 tons
- Category N: used for the carriage of goods
  - Category N1: having a maximum mass **not** exceeding 3.5 tons
  - Category N2: having a maximum mass exceeding 3.5 tons but not exceeding 12 tons
  - Category N3: having a maximum mass exceeding 12 tons

1. Functional description of the car

The EU general classification of vehicle categories

- Category O: trailers (including semi-trailers)
  - Category O1: maximum mass **not** exceeding 0.75 tons
  - Category O2: exceeding 0.75 tons but **not** exceeding 3.5 tons
  - Category O3: exceeding 3.5 tons but **not** exceeding 10 tons
  - Category O4: exceeding 10 tons
- Symbol G: off-road vehicles
- Special purpose vehicles

1. Functional description of the car

- What are the functions of the automobile?
  - To **transport** passengers and goods in sufficient comfort to limit fatigue or damage
  - To **protect** the occupants as much as possible in the event of an impact
  - To achieve sufficient **speeds** and **accelerations**
  - To **stop** the vehicle, when necessary, in the shortest possible distance
  - To **follow and maintain the driver's desired trajectory** regardless of weather, road and traffic conditions.
  - To remain **reliable over time**
  - To **consume** the smallest amount of energy
  - To reduce the **pollution** to a minimum
  - To have a **design** that takes into account contemporary **aesthetics** and the current criteria of mass consumption and power

1. Functional description of the car

- What is the use function of the car?
  - For the user, the function of the car is **to transport the driver and his passengers or goods from point A to point B** in the best conditions of comfort and safety.

- What is the global function of the car?
  - From a technical point of view, the function of the automobile is to propel itself by **transforming the energy of the fuel** (chemical) **into kinetic energy**, which is transformed into **kinetic energy** by the driving wheels.

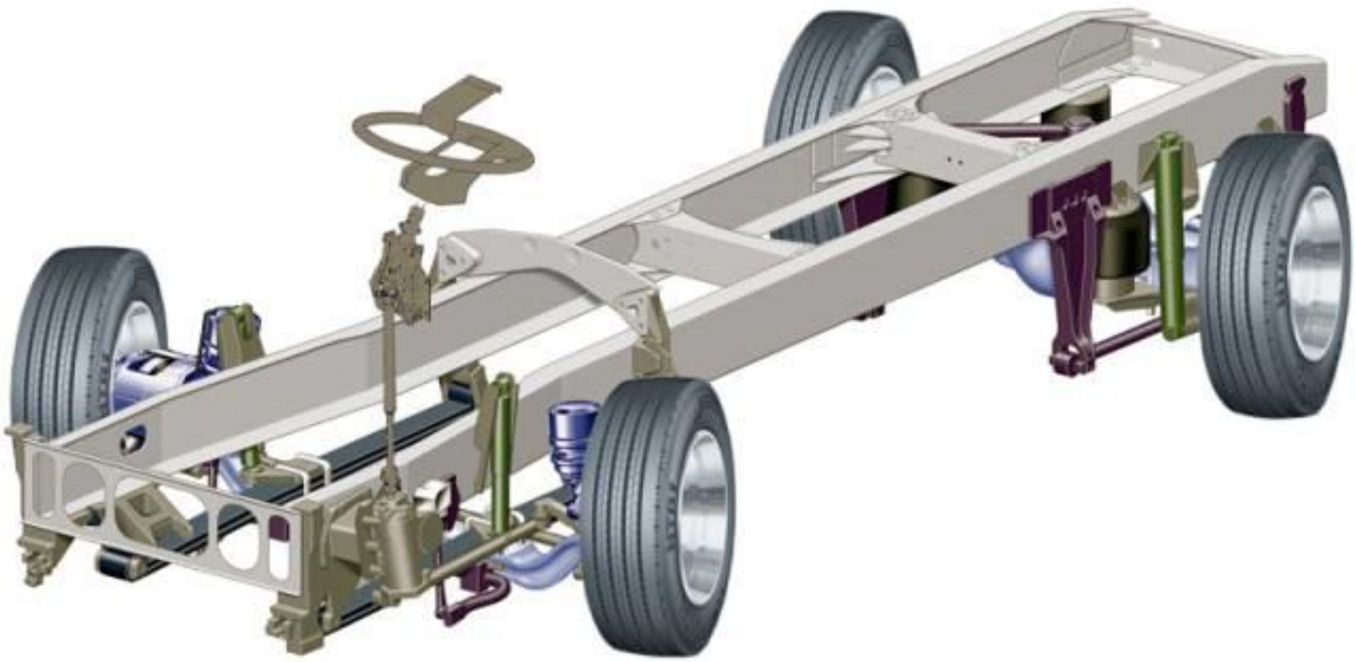
1. Functional description of the car

- How does the car interact with its environment?
  - The vehicle is **supported on the ground** by its four wheels under the **action of gravity**. The contact force under the wheels varies according to the dynamic conditions
  - The driving wheels transmit the propelling forces thanks to the **adhesion of the tyres**
  - To operate, the engine needs **fuel** (chemical potential energy) stored on board**, oxygen** available in the air and the environment and it **emits combustion (burnt) gases**
  - The driver communicates his/her **intentions via a set of control systems**: steering wheel, brake and accelerator pedals, switches, etc.

1. Functional description of the car

- What loads that the car has to sustain?
  - The **static weight of the vehicle**, W=mg, exerts a force that pushes the car onto the ground and is distributed over the four wheels.
    - This distribution can vary due to the modification of the position of the passengers or mechanical elements (static effect) and due to longitudinal, lateral or vertical accelerations experienced by the vehicle (dynamic effect)
  - The **dynamic forces** due to the movement:
    - Aerodynamic forces: $\frac{1}{2} \rho S C_x V^2$
    - Accelerations: acceleration forces F=ma but also centrifugal loads $F_c = M \omega^2 R$ during cornering
  - The **adhesion forces** at the wheel/ground contact patch which allow
    - To develop the propulsion / braking forces
    - To create lateral (cornering) forces

2. The automobile main subsystems



2. The automobile main subsystems

- The sub-systems and components of the car are
  - The **chassis** and the **body**
  - The **engine** or the motor
  - The **transmission**
  - The **braking** system
  - The **suspension** and the axles
  - The **tyres**
  - The **steering** system
  - The **electrical** equipment
  - The **hydraulic** and pneumatic equipment
  - The on-board **instruments**
  - The **safety** equipment
  - The **air conditioning** and hotel control
  - ...

2. The automobile main subsystems

- The power generation
  - The engine or electric/hydraulic/air compressed motor
  - Propulsion system
  - Accessories: water, oil pumps, etc.
  - Auxiliary systems
- The chassis and structural function
  - Structure, shell, and beams
- The transmission
  - Clutch, gearbox, differential, axles
- The rolling gears
  - Suspension
  - Spring, dampers
  - Steering systems
- The braking system
- The wheels and tyres

2. The automobile main subsystems

- The pneumatic and hydraulic systems
- The electrical system:
  - Electrical power supply: battery, alternator
  - The headlights and lighting system
- Conveniency: cigarette lighter, GPS, etc.
- On-board driving instruments
  - Tachometer, rotation speed sensor of the engine
- Driver assistance:
  - ABS, ASR, ESP, cruise control
- Safety systems:
  - Passive safety: airbags, seatbelt pre-tensioner
  - Active safety: ABS, ESP

3.1 The car body

- MAIN FUNCTIONS
  - Transport: to carry a certain load (passenger and goods) over a certain distance and at a certain speed in good and safe conditions.
  - For passengers:
    - Protection against wind, cold, noise
    - Safety and comfort
    - Space to be maximized
    - Reduce fatigue and morbidity factors
  - For freight:
    - Maximum space
    - Quick and easy loading and unloading

3.1 The car body

- MAIN FUNCTIONS
  - <u>Structural function</u>:
    - The backbone of the vehicle around which the other components are attached (engine, running gear, drive train, seats, etc.)
  - <u>Mechanical functions</u>:
    - Sustaining the reactions forces and preventing motions of the engine and wheel axles, transmission
    - Sustaining the reactions forces coming from the wheels during acceleration and braking
    - Sustaining the aerodynamic forces
    - Sustaining to the weight of the suspended mass and the road shocks transmitted via the suspension
    - Protection of the passengers in the event of an accident:
      - Non-deformable cell
      - Deformable energy absorption zones

3.1 The car body

- MAIN FUNCTIONS
  - Aerodynamic function:
    - Minimum aerodynamic resistance (C_x)
    - Mainly related to the shape of the body
    - Importance of details
  - Aesthetic function:
    - Ugly sells less well...
  - Insulation and protection function for the occupants from the environment:
    - Dusts
    - Sound
    - Cold…

3.1 The car body and the chassis

- **Chassis** = a structural frame usually consisting of beams and bars connected either by welding or by connection elements (bolts, rivets, etc.)
- **Body** = the shell of the car, characterized by the number of doors, seats arrangement, roof structure, etc.
- Current development for cars: tending to an <u>integrated construction</u> of body and chassis: semi-monocoque or monocoque type structures, resulting in more rigid structural systems
- For commercial vehicles and heavy vehicles: continuation of layout made of a <u>separate chassis</u> to which the body, the <u>cabin</u> are attached. This solution allows <u>greater modularity</u>.

3.1 The car body

Bodywork: cab, roof, tipper, etc.

Frame itself: beam structure

Integrated chassis and bodywork in modern passenger cars

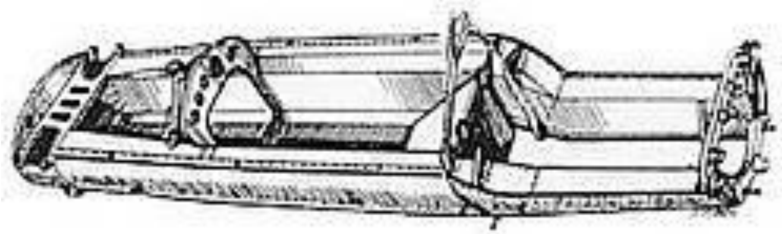
3.1 The car body

Ladder frame:
made up of beams

Semi-monocoque frame:
made of shells or
stiffened membranes

3.1 The car body

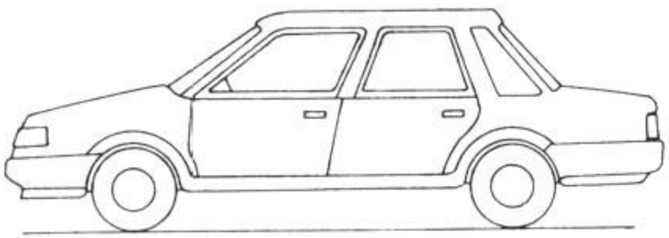
Tubular frame:
bar truss



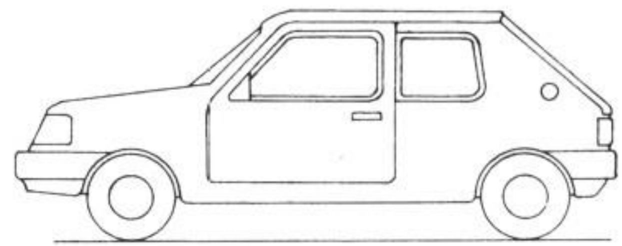
1962 Lotus 25 monocoque chassis
(C. Chapman)

Composite monocoque chassis
Ferrari Enzo

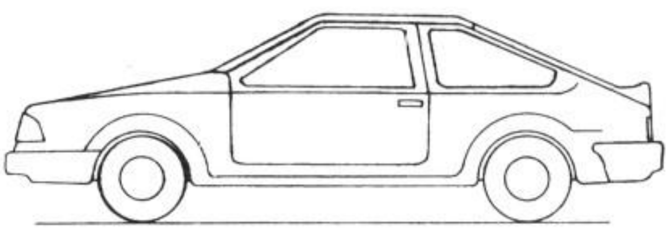
3.1 Different body types



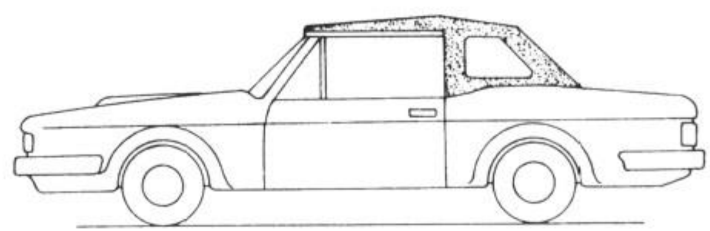
Sedan or saloon



Hatchback

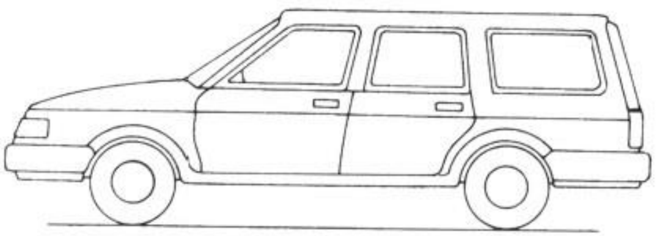


Coupé

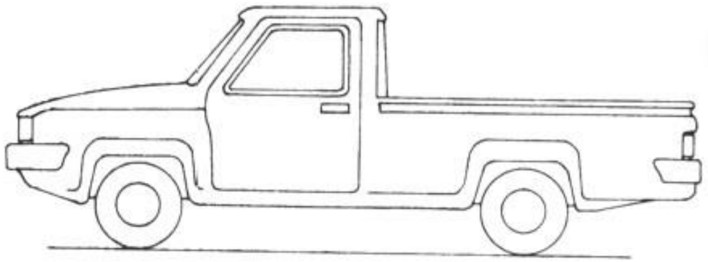


Convertible

3.1 Different body types



Estate or Station Wagon



Pick up

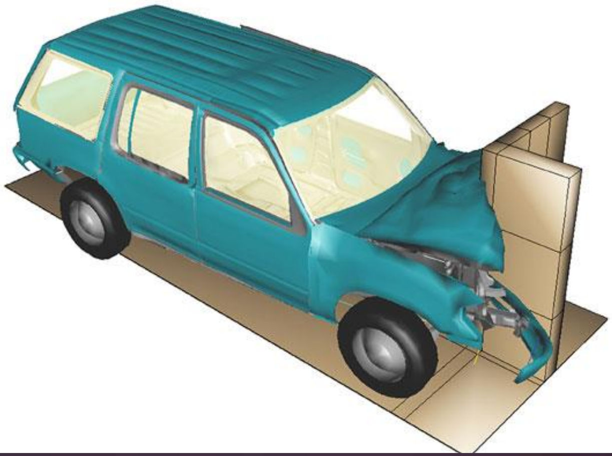
3.1 The car body

- DESIGN CONSTRAINTS ON THE DESIGN OF THE CHASSIS
  - Structural and mechanical constraints :
    - Maximum rigidity v.s. minimum mass
    - Stress constraints: fatigue and durability
    - Crashworthiness: dissipation of energy while undeformable survival cell around the passengers
    - Noise and vibration reduction
  - Manufacturing constraints :
    - Easy to manufacture, assembly, to dismantle, to recycle, to maintenance and to repair (Design for X)
    - Minimum manufacturing cost
  - Aerodynamic constraints :
    - Minimum Cx
    - Low side wind sensitivity
  - Aesthetic constraints

3.1 The car body

- DESIGN RESTRICTION ON THE CHASSIS DESIGN
  - Contributions to vehicle stability and handling
    - Stiffness: bending and torsional stiffness
    - Position of the centre of gravity, inertia tensor
  - Contributions to performance
    - Mass and aerodynamics
  - Contribution to safety
    - Deformable vs. non-deformable areas
  - Habitability
    - Interior volume
    - Easiness for loading / unloading
  - Operating costs
    - Maintenance
    - Energy consumption

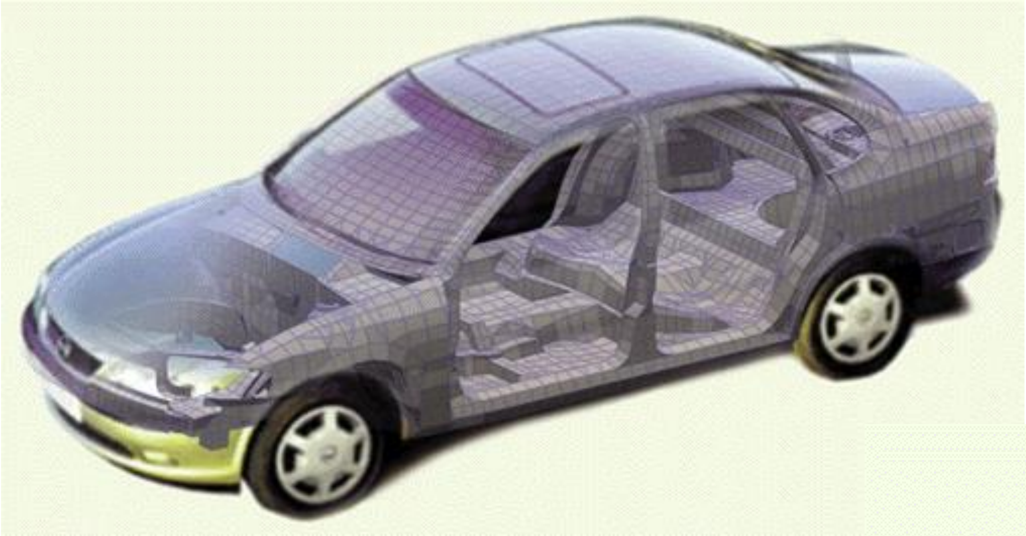
3.1 The car body



3.1 The car body

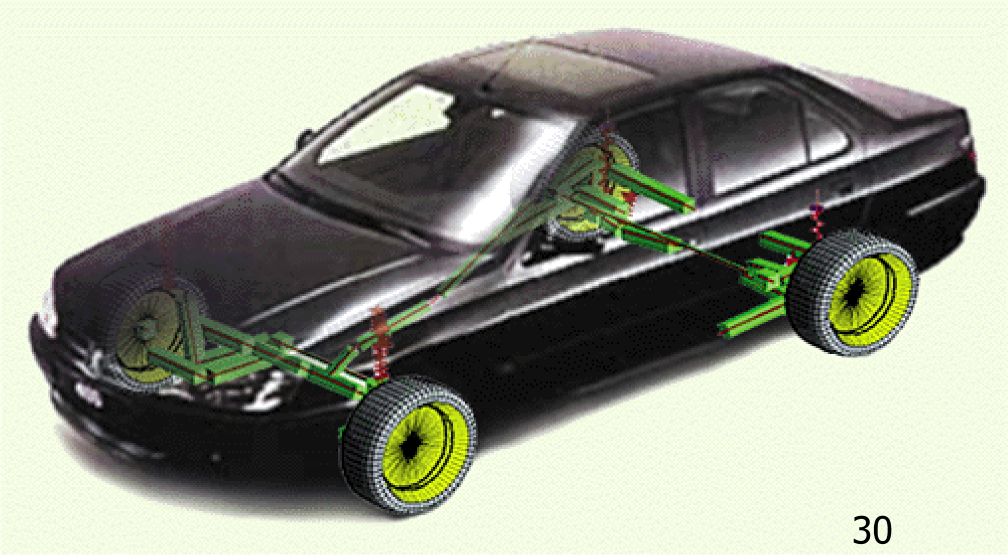
- DESIGN OF THE CHASSIS
  - Design based on virtual modelling and prototyping
    - CAD
    - Numerical simulation (Finite Elements)
    - Digital twin (Industry 4.0)
  - Optimization methods are becoming more and more widespread to support the design process
    - Systematic and rationale design methodology
    - Multi-disciplinary optimization enables to find the best compromises between conflicting constraints
    - Relieves the designer by taking over the management of iterations to improve the solution.
  - Concurrent engineering approaches
  - Cooperative engineering approach

3.1 Chassis and body design

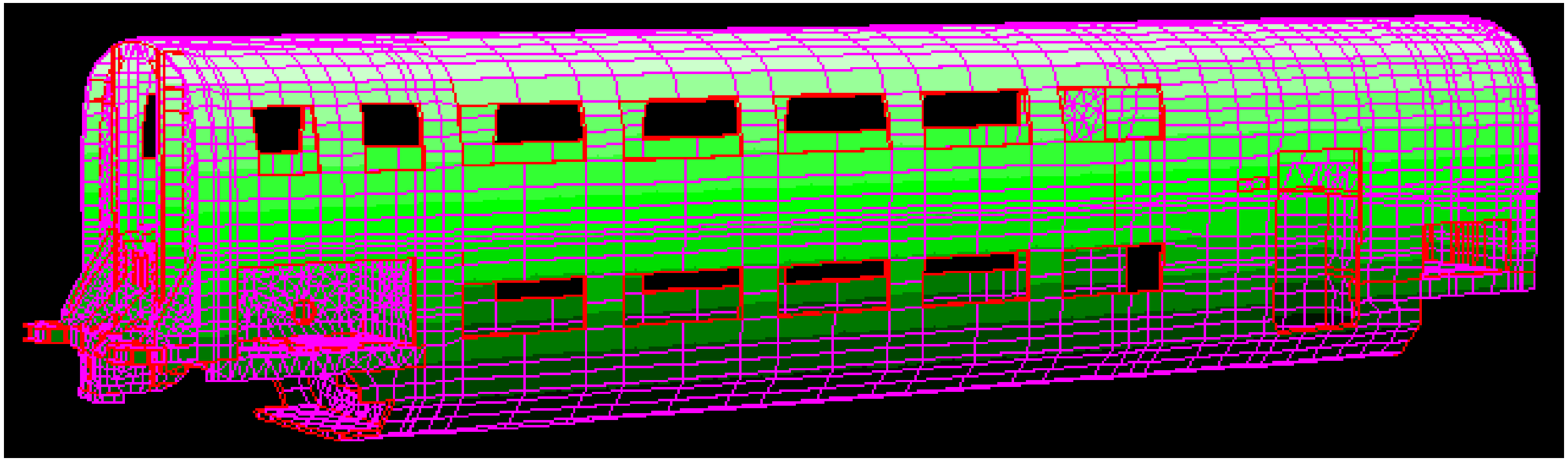


FE model of the car body
(Samcef - Mecano)

FE model of the suspension
(Samcef - Mecano)

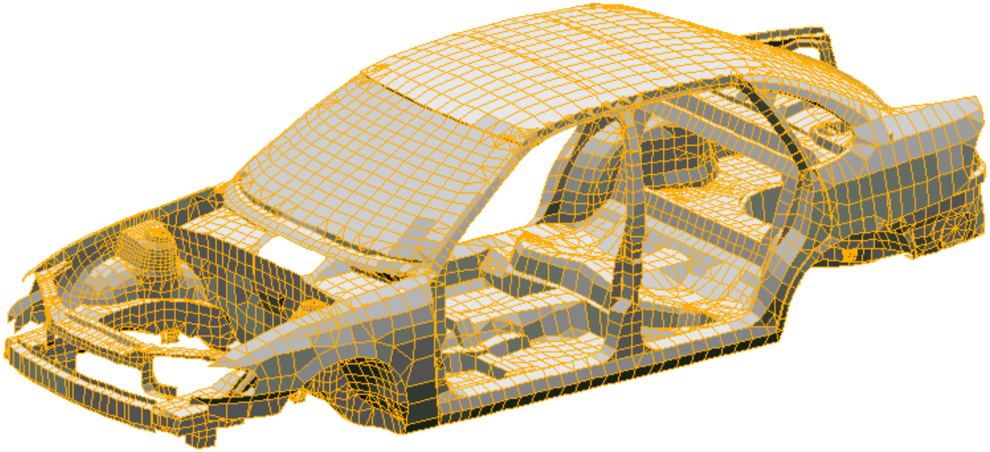


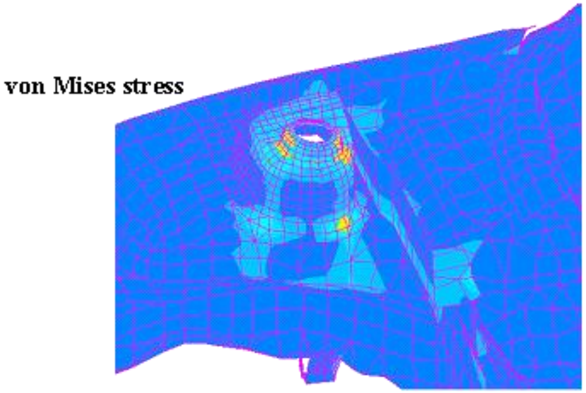
3.1 Chassis and body design



EF model of a railway wagon
(Samcef - Mecano)

3.1 Chassis and body design

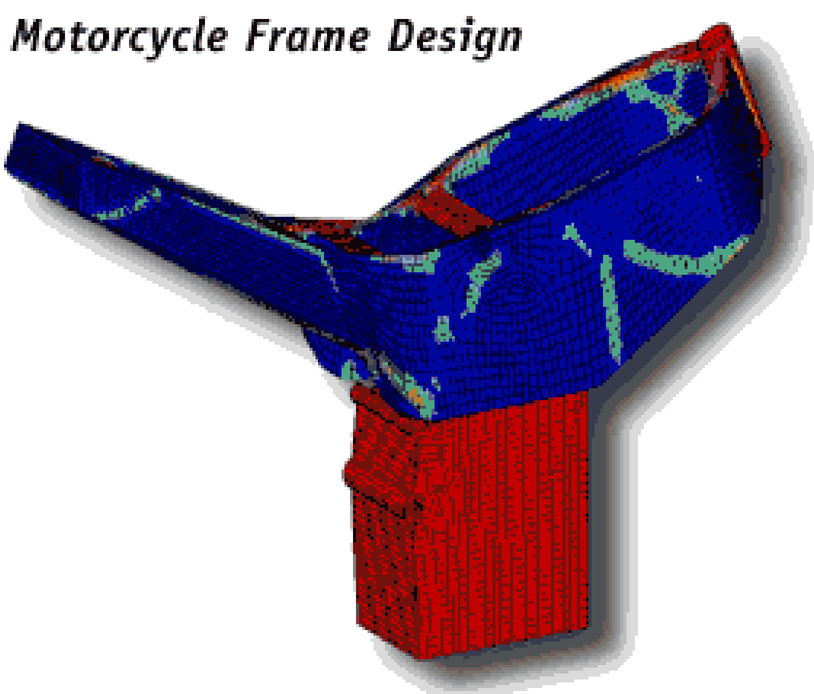


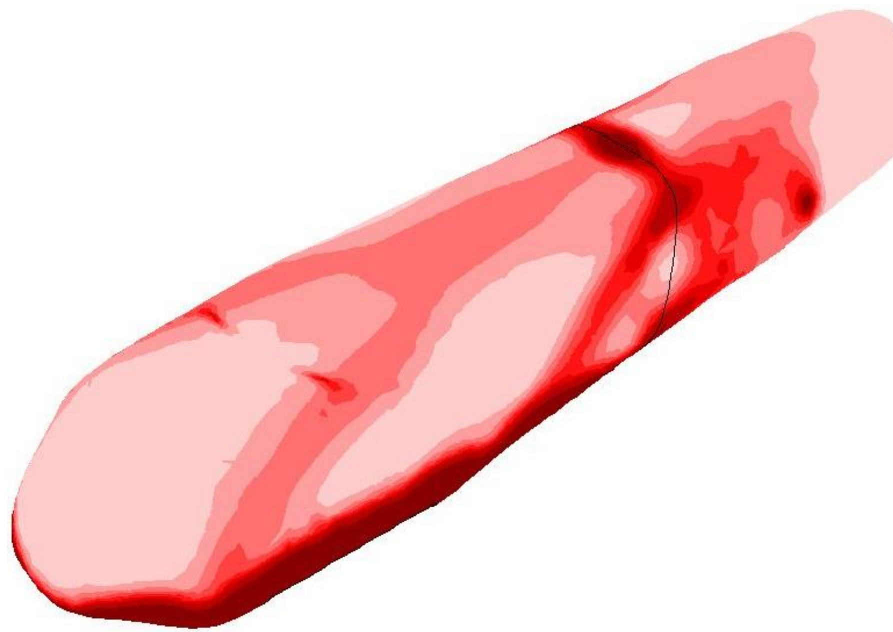


By courtesy of Samtech and PSA

Stress analysis of the body in white of a car using Finite Element method.

3.1 Chassis and body design





Topological optimisation of a motorbike structure

Topological optimisation of the structure of an eco-marathon

3.1 Materials for chassis and body

- **Materials**:
  - **Steel** often with alloy elements to improve its formability
    - High availability
    - Low cost (8 €/kg)
    - Easy to work (e.g. deep drawing, casting, stamping…)
  - **Aluminum**
    - Higher stiffness to weight ratio
  - **Composite** materials
    - Glass and carbon fibers for their orthotropic properties and high specific stiffness
    - Polyamide, polyester, polystyrene, polypropylene, which can be manufactured at low cost by plastics processing (injection molding)
  - **Painting and coating**
    - Corrosion
    - Often applied by electroplating for uniformity

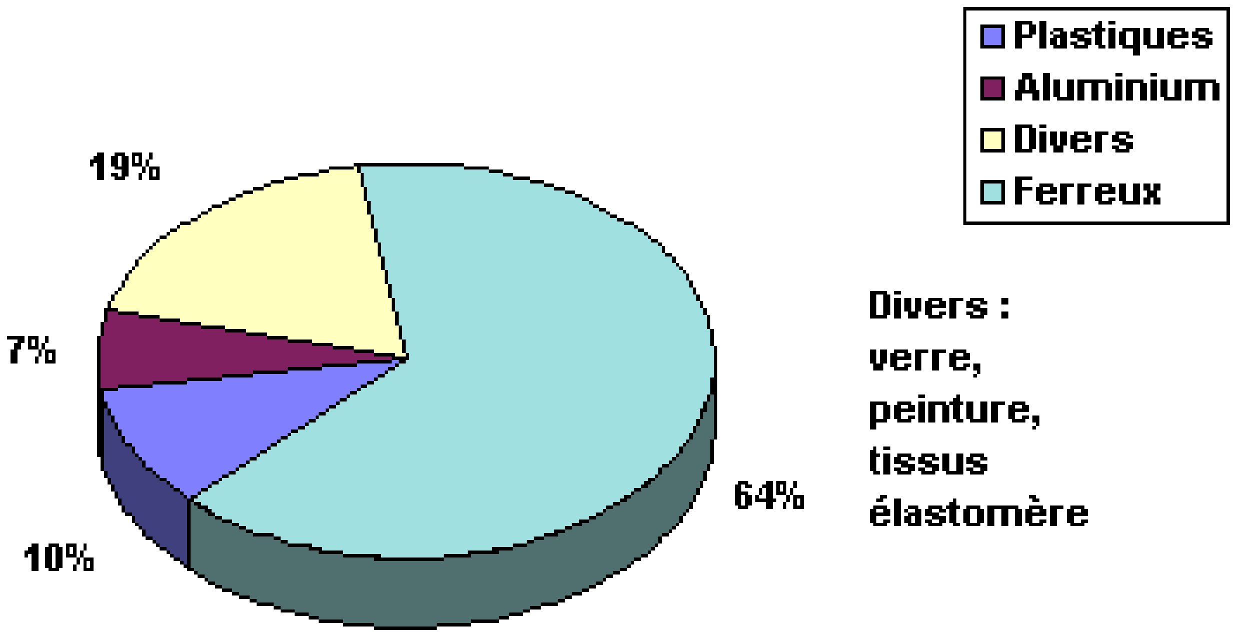
3.1 Materials for chassis and body

Classic steel design

Advanced design in composite materials

3.1 Materials for chassis and body

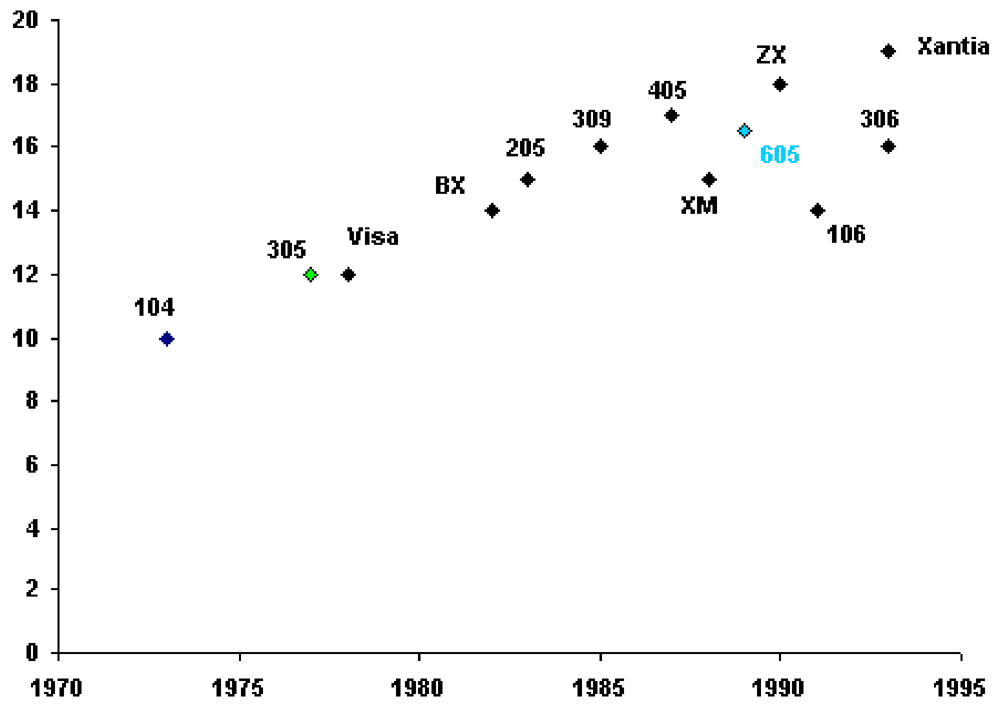
Average material break down in the vehicle
(% of the total vehicle mass)



Divers :
verre,
peinture,
tissus
élastomère

Source : Usine nouvelle

3.1 Materials for chassis and body



Evolution of the fraction of plastic materials over the years at PSA

3.1 Materials for chassis and body

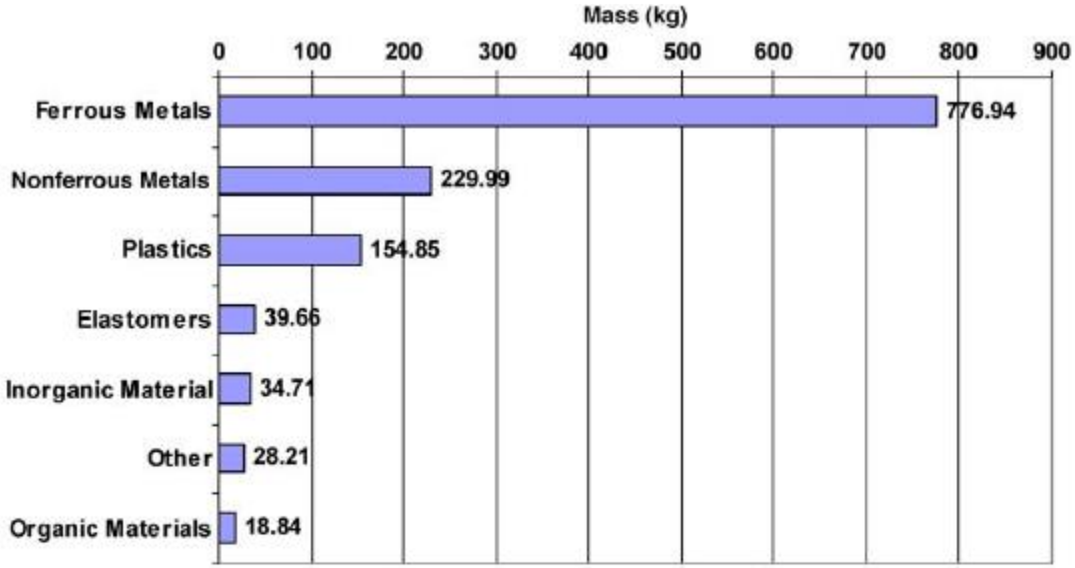


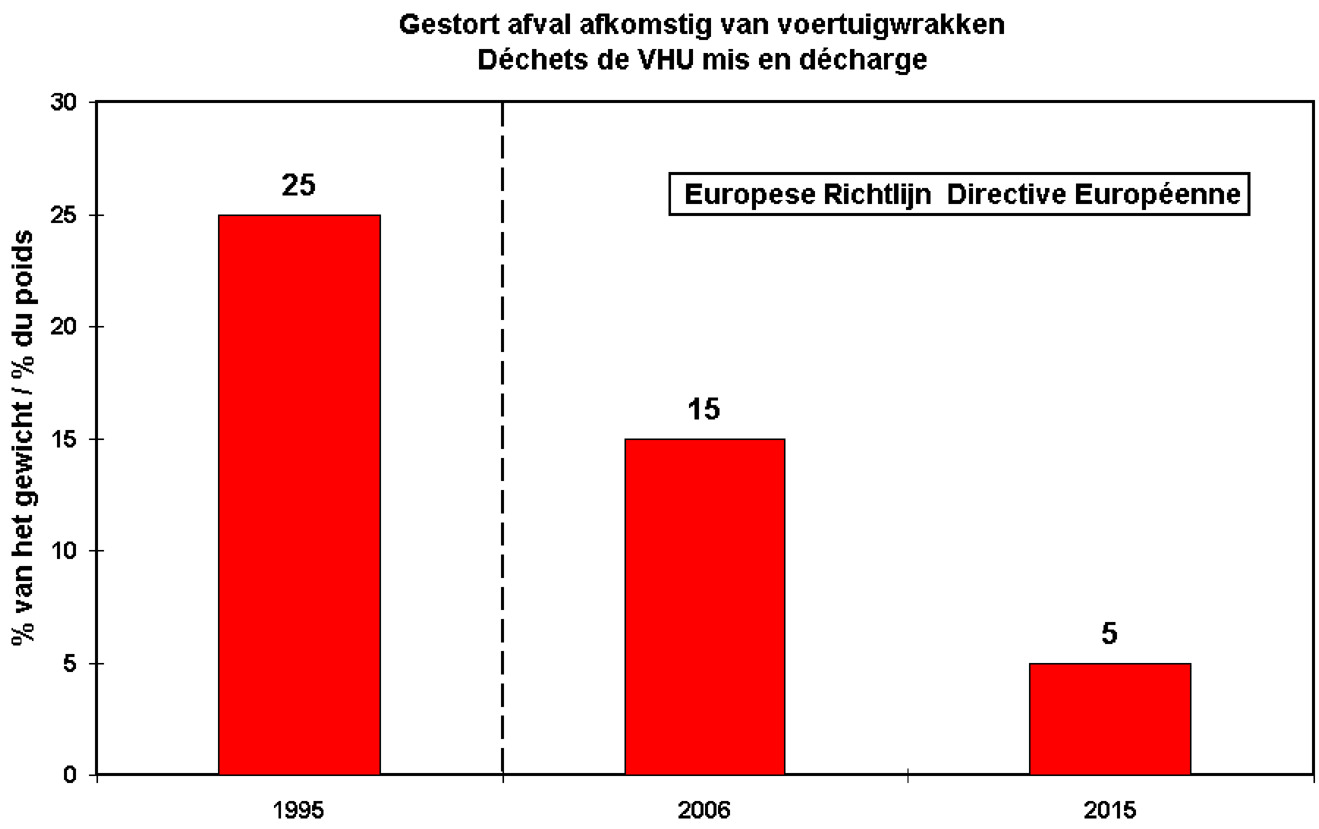
Figure 3. 2004 Toyota Prius materials breakdown.

Table 3. 2004 Toyota Prius materials breakdown

Materials	Mass (kg)	Percent
Ferrous metals	776.94	60.55
Nonferrous metals	229.99	17.92
Plastics	154.85	12.07
Elastomers	39.66	3.09
Inorganic material	34.71	2.71
Other	28.21	2.20
Organic materials	18.84	1.47
Vehicle mass (less fluids)	1283.1	100.00

Example of recyclability: the Toyota Prius

3.1 Materials for chassis and body



Evolution of recycling and wasted material (source FEBIAC)

3.2 The propulsion system

- **Role of the engine**: to overcome the resistance forces:
  - Provide acceleration capability
  - Overcome road resistance
    - Rolling resistance, aerodynamic resistance, grading resistance due to gravity
  - To drive the accessories as well:
    - Water pumps, oil pumps, fans, etc.
  - Provide power to auxiliary systems
    - The alternator to provide electrical power
    - Air conditioning

3.2 Types of engines

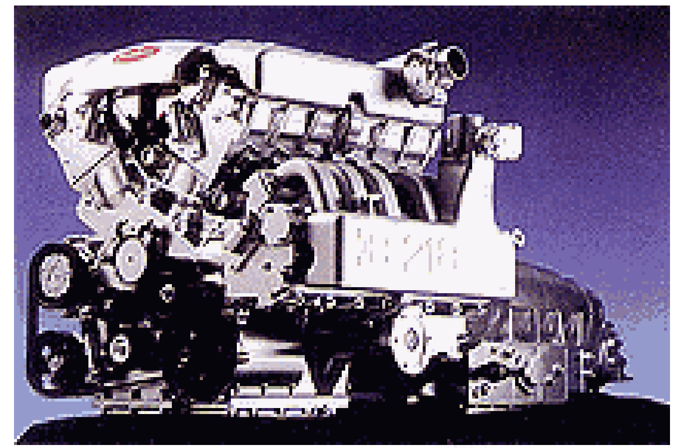
- Reciprocating piston engines
  - Gazoline
  - Diesel…
- Rotary piston engine : Wankel
- Gas turbines
- Stirling engine
- Steam engine (Rankine)
- Electric motors
  - Batteries
  - Fuel cells
- Hybrid systems

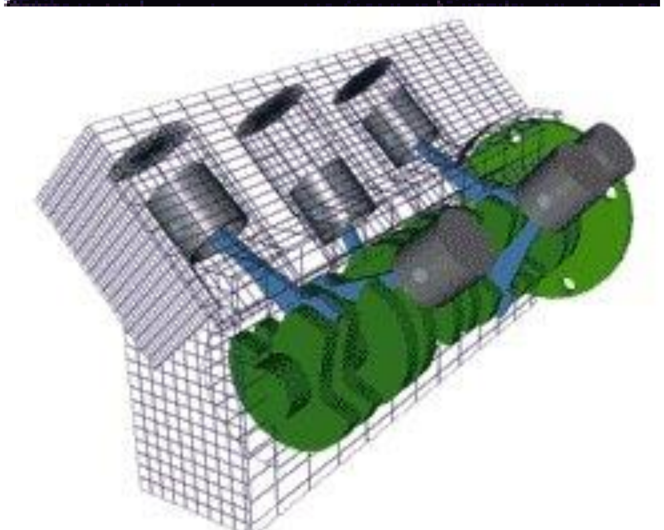
Open cycle

Closed cycles

3.2 Piston engines

- For more than a century the piston engine has been the dominant engine in motor vehicles:
  - Compact
  - Attractive specific power
  - Reasonable fuel/ energy consumption
  - Easy to use, maintain, produce in mass production
  - Otto cycle (spark ignition) or Diesel cycle (compression ignition)
  - Depollution system have been developed





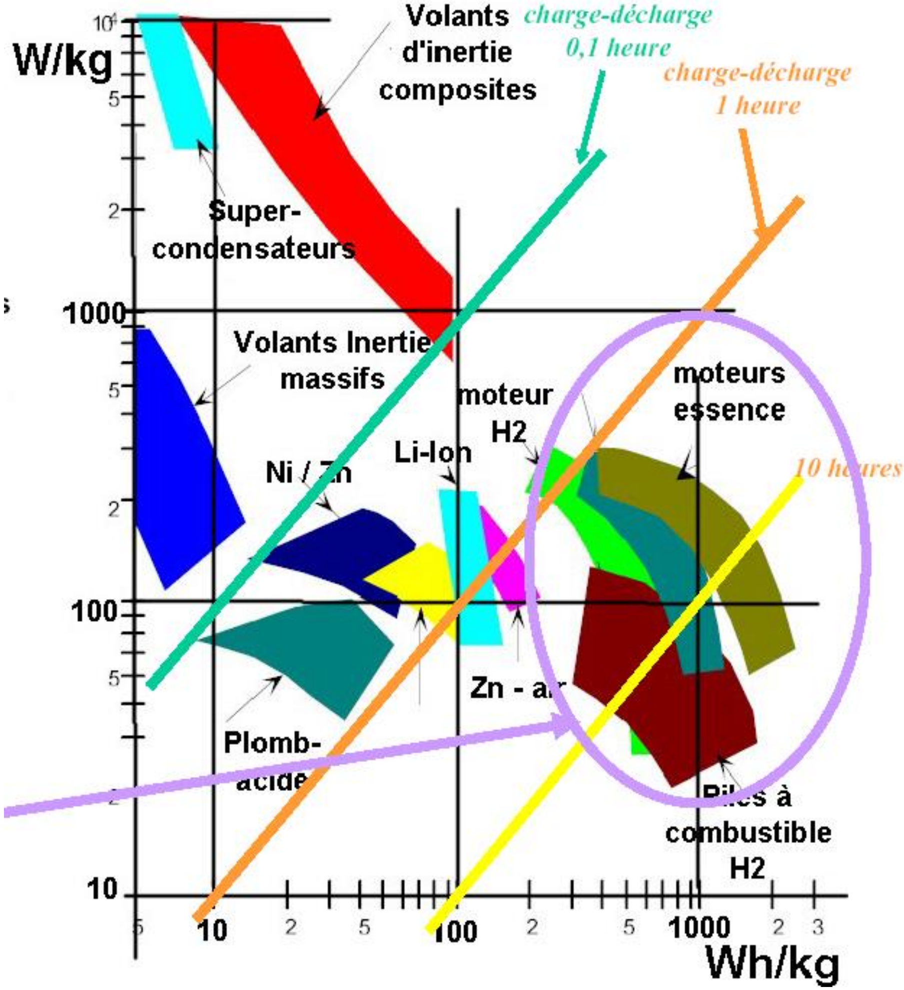
3.2 Engines and motors

- Criteria for choosing a technology for the propulsion system
  - Power and torque curves as a function of speed
    - Flexibility (torque)
    - Maximum power
  - Consumption curves
    - Engine efficiency
  - Pollution and CO_2 emissions etc.
  - Engine mass
    - Specific power
  - Dimensions
    - Volume

3.2 Engines and motors

- Criteria for choosing a technology for the propulsion system
  - Acquisition cost
  - Maintenance cost and time
  - Vibration and noise emissions

3.2 Engines and motors

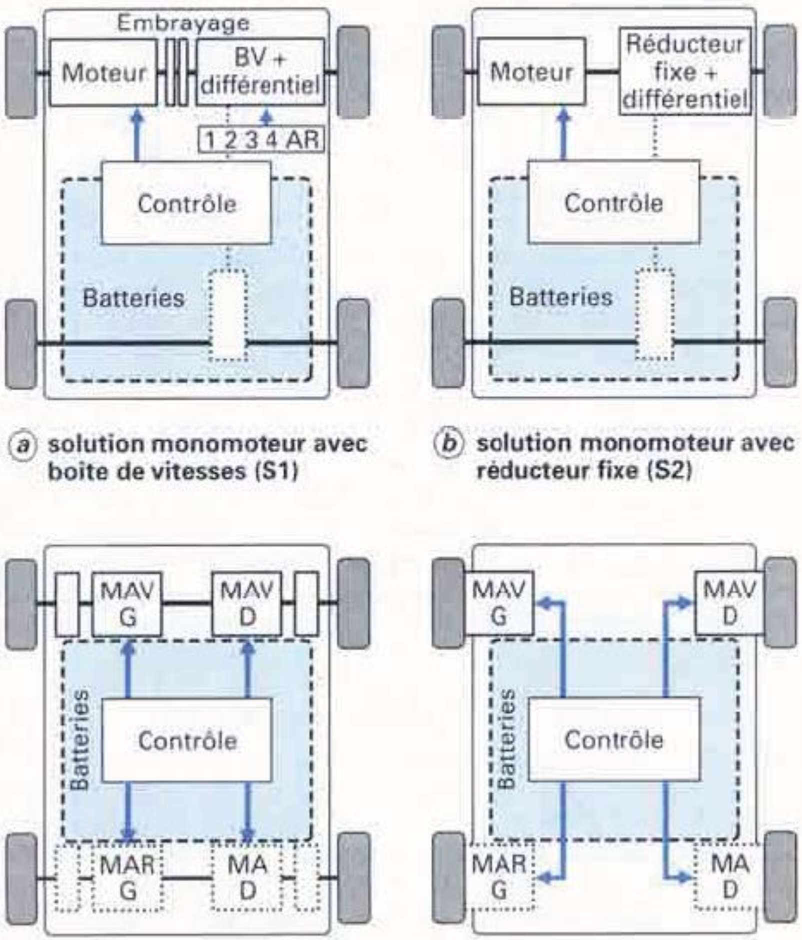


$$\tau = \frac{E}{P}$$

3.2 Engines and motors

- Engine location
  - Front engine
    - Often the case now for passenger cars that are front wheel drive
  - Rear engine
    - Porsche Carrera with rear-wheel drive...
  - Central engine
    - For example, trucks
  - Transverse vs longitudinal engine
  - Decentralized motorization
    - E-axle
    - In-Wheel motor (electric motor)

3.2 Propulsion system layout



(a) solution monomoteur avec boite de vitesses (S1)

(b) solution monomoteur avec réducteur fixe (S2)

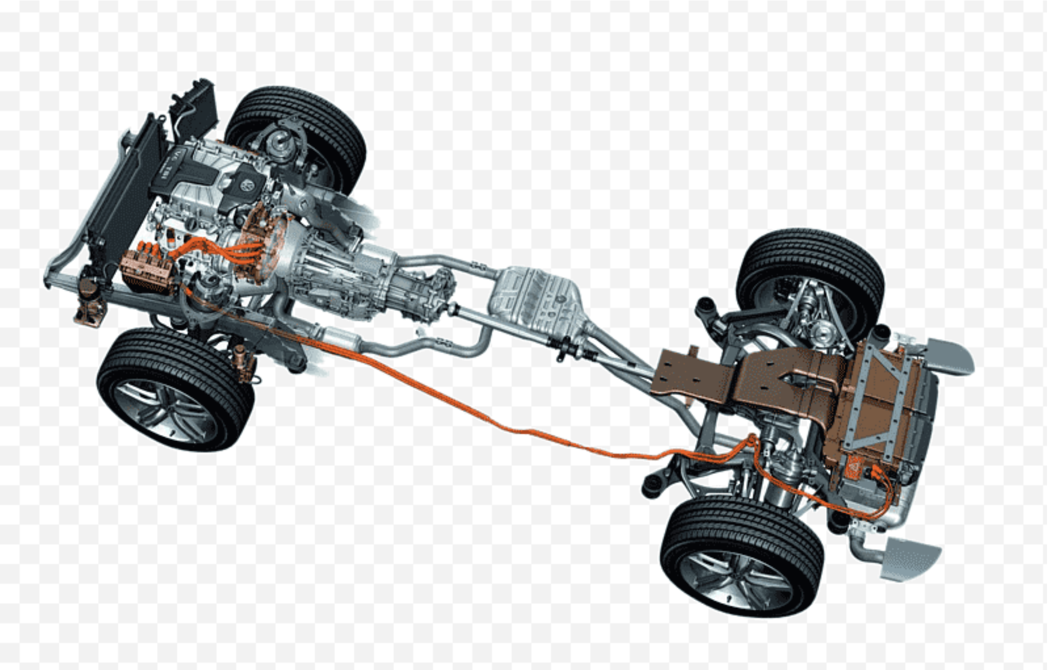
(c) motoréducteur répartis (S3)

(d) entraînement direct par moteurs intégrés dans les roues (S4)

Multon (2001)

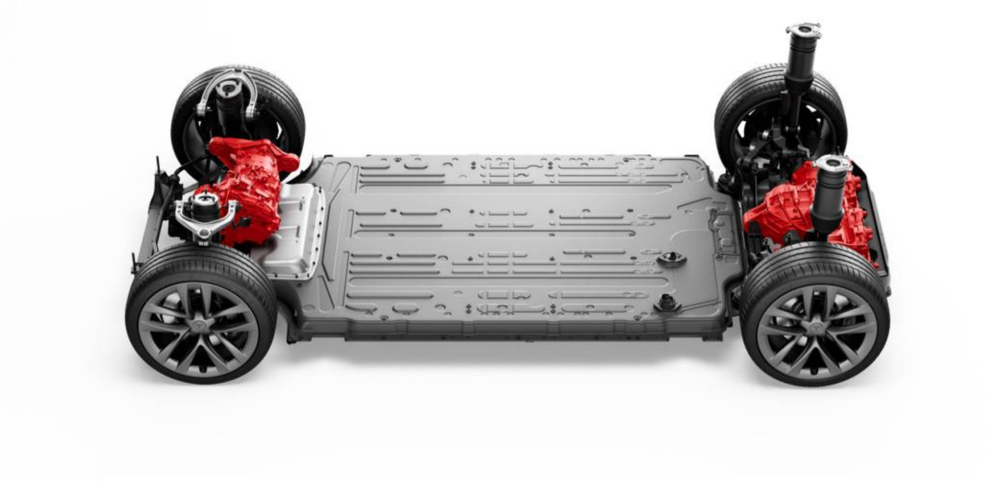
3.2 Propulsion system layout

Electric vehicle Car Volkswagen Touareg Powertrain



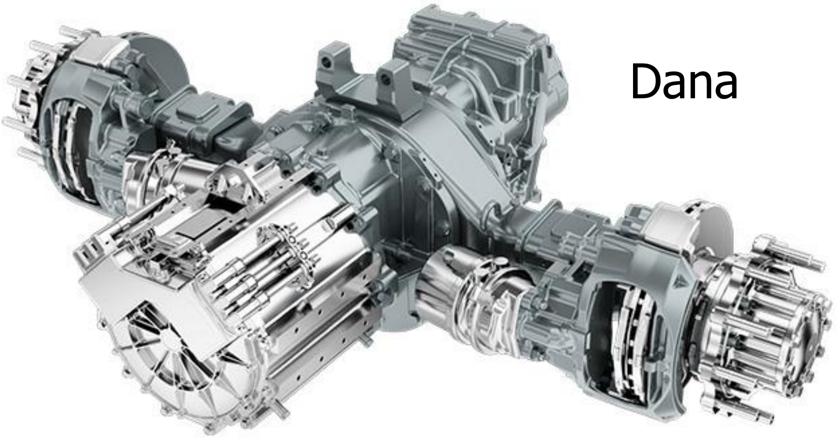
- Centralized motorization:
  - Similar concept to ICE engine
  - May be not adapted to modern electric motorization

3.2 Propulsion system layout

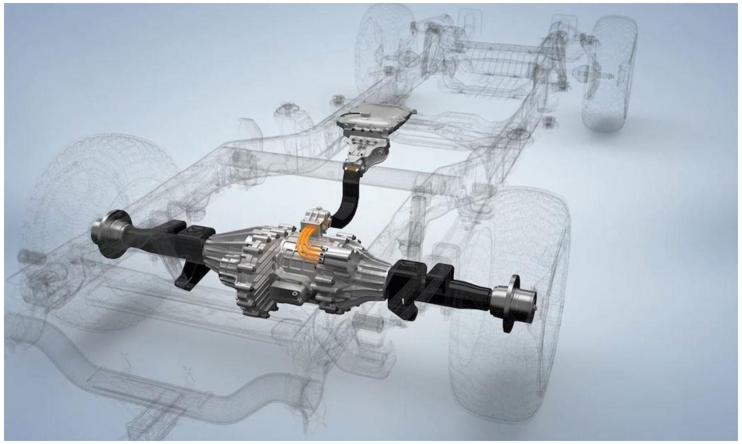


- Decentralized motorization:
  - Based on moving electric motors closer to the wheels
  - Dual motor of Tesla 3
  - All wheel drive solutions
  - Based on e-axle concept

3.2 Propulsion system layout



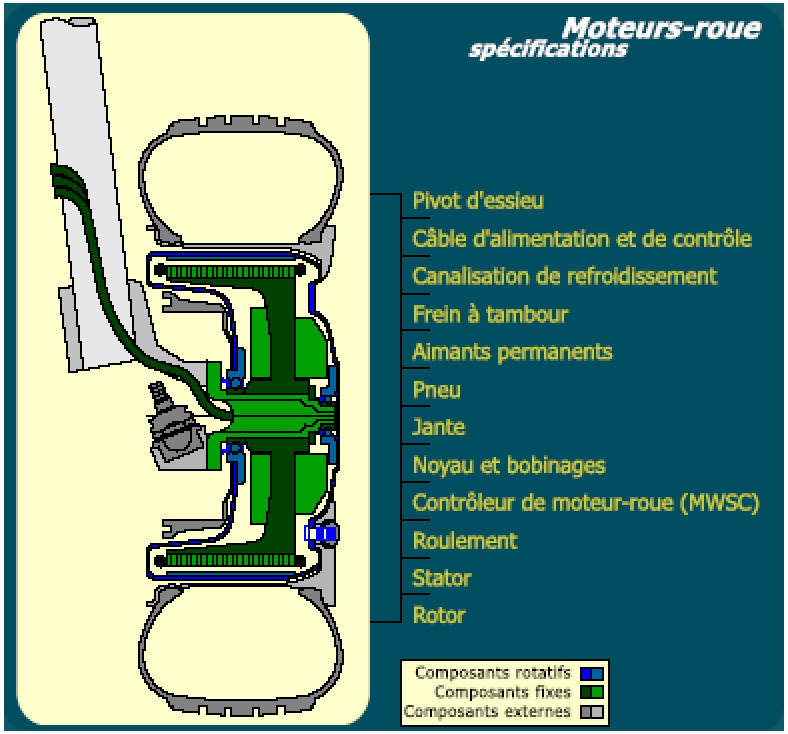
Dana

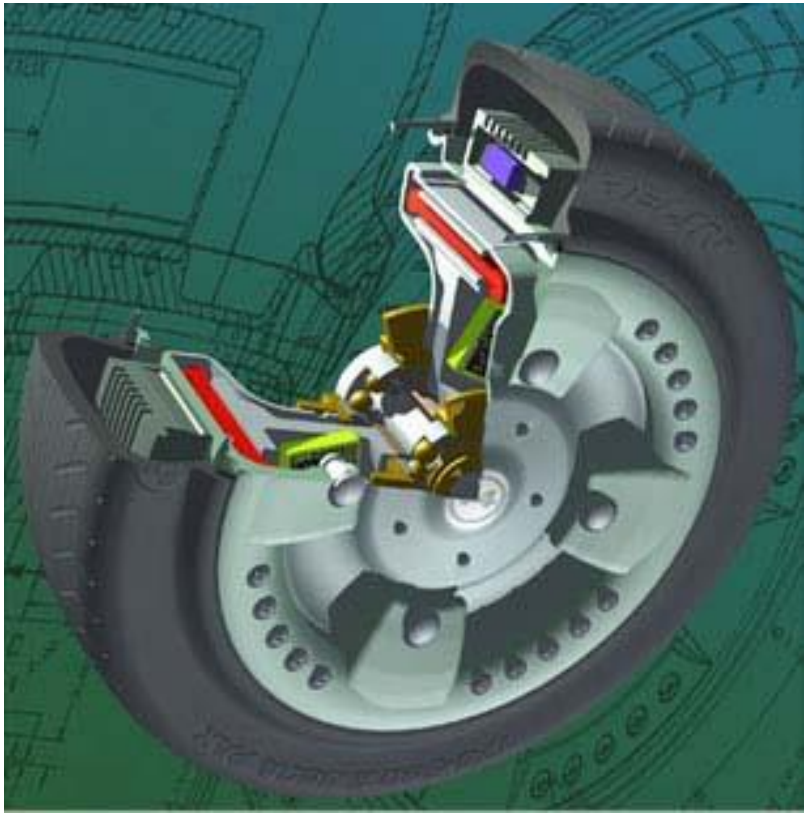


Magna

- Concept of e-axle.
- One electric drivetrain per axle: e-motor + gear box
- Directly operated on the axle

3.2 Propulsion system layout

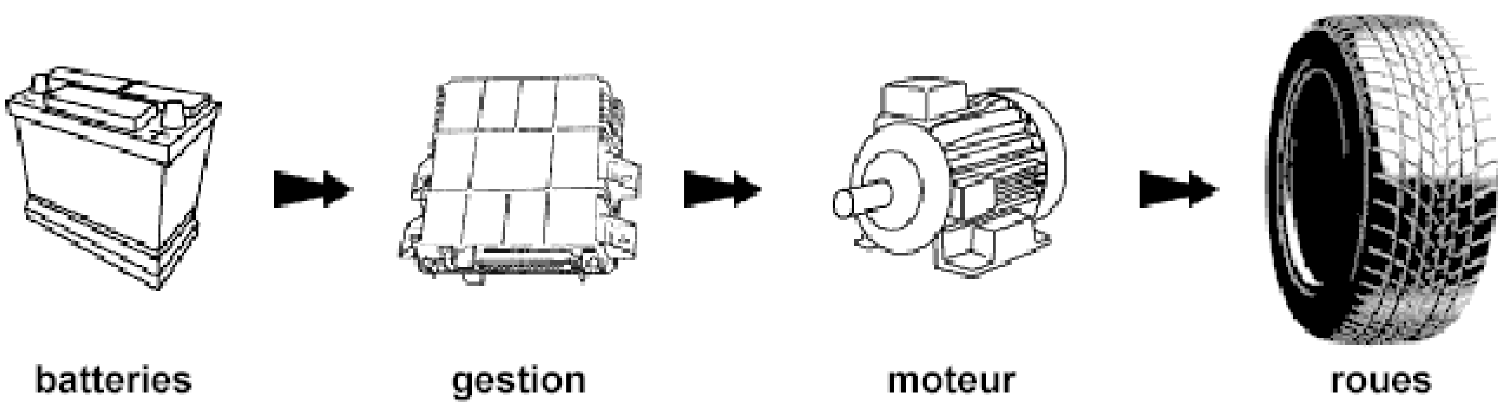




In-wheel motor by TM4 source www.tm4.com/

3.2 Electric propulsion system

- The electric drive train consists of:
  - A source of electric current and power: grid or battery
  - An energy management and modulation unit: power electronics system
  - An electric energy converter (e-motor/generator)
  - A simplified transmission system (speed reduction and power split)

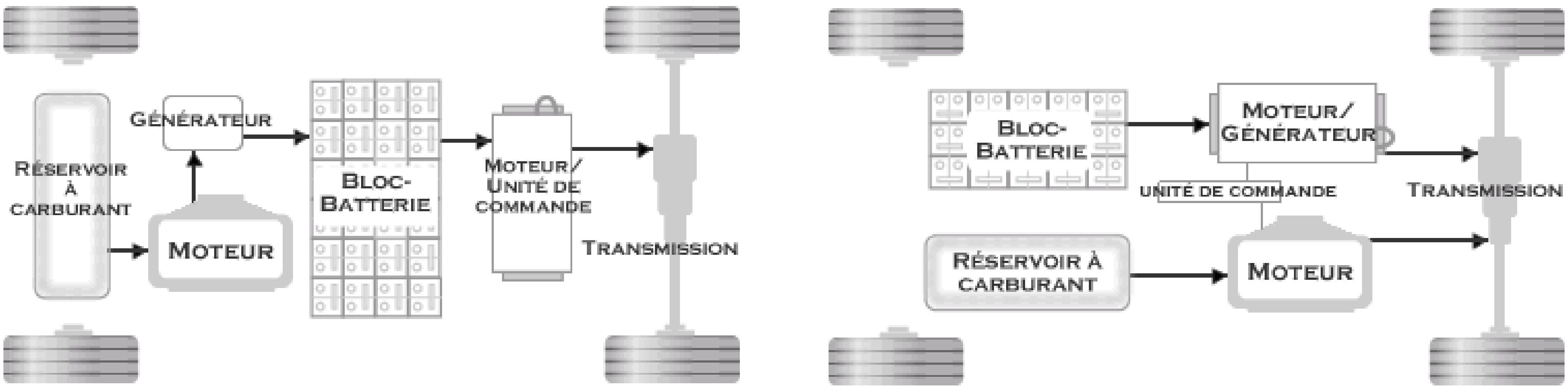


3.2 Hybrid propulsion system

- Hybrid powertrains combine two or more sources of energy storage and energy converters for vehicle propulsion
- Hybrid electric vehicles are the most common implementations of hybridization concepts
- There are several hybrid powertrain architectures
  - Series, parallel
  - Complex

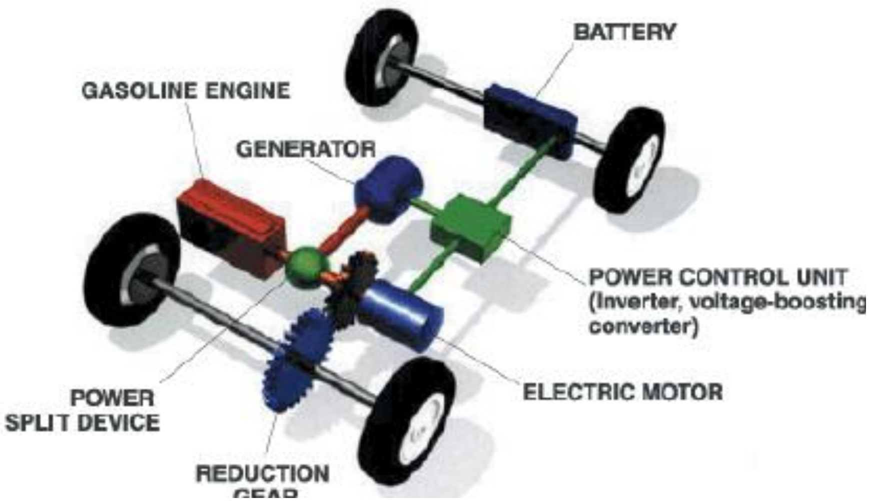
Hybrid electric powertrain Integrated Motor Assist (IMA) by Honda

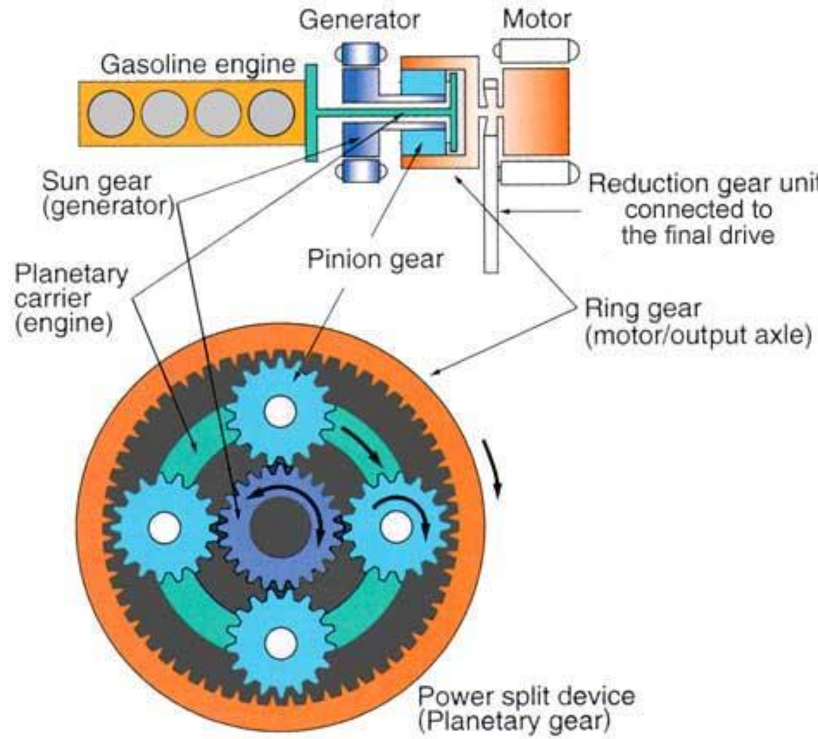
3.2 Hybrid propulsion system



Hybrid electric vehicles: series vs parallel architectures

3.2 Hybrid propulsion system

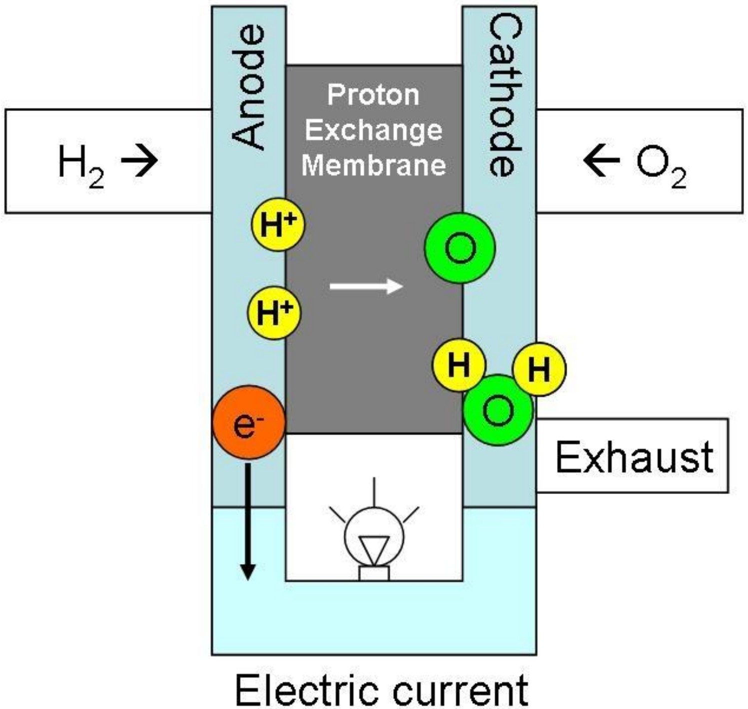




Courtesy: Toyota Motor Corporation

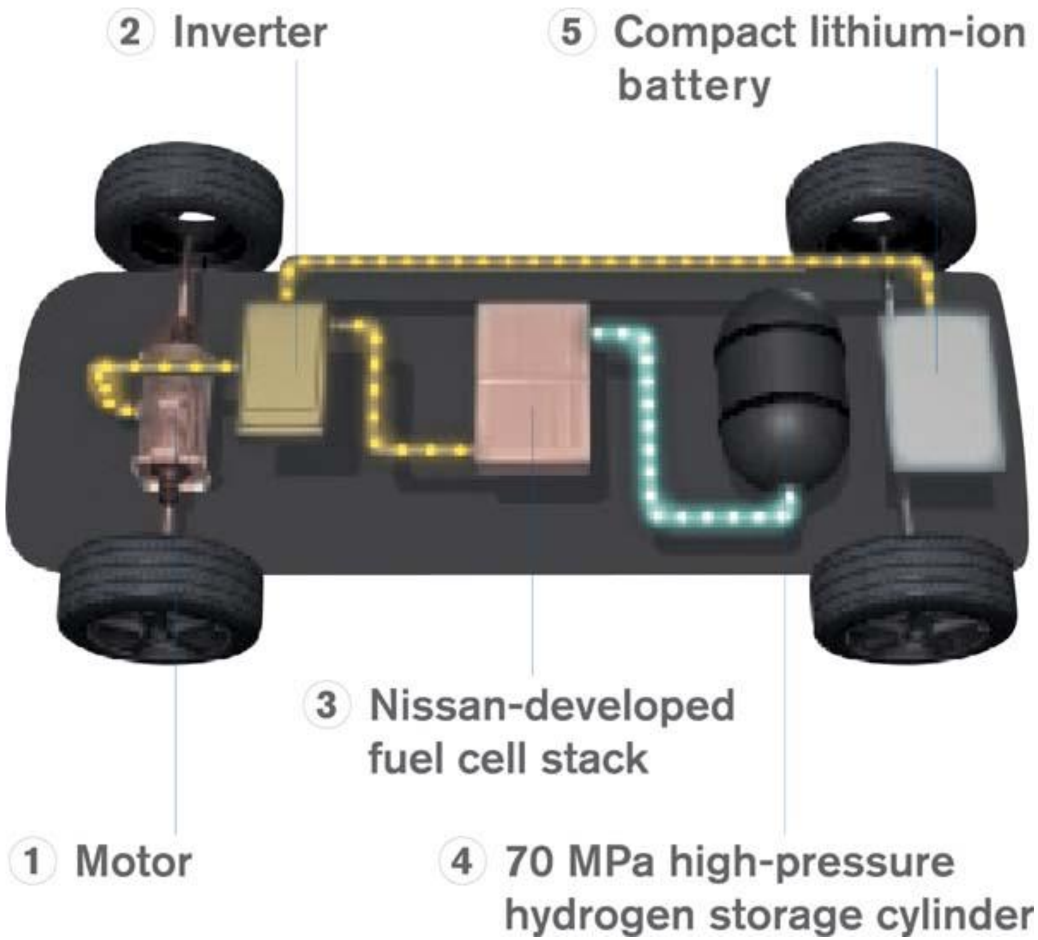
Example of complex hybrid powertrain architecture: Toyota Hybrid System THS, for instance Prius II

3.2 The fuel cell powertrain



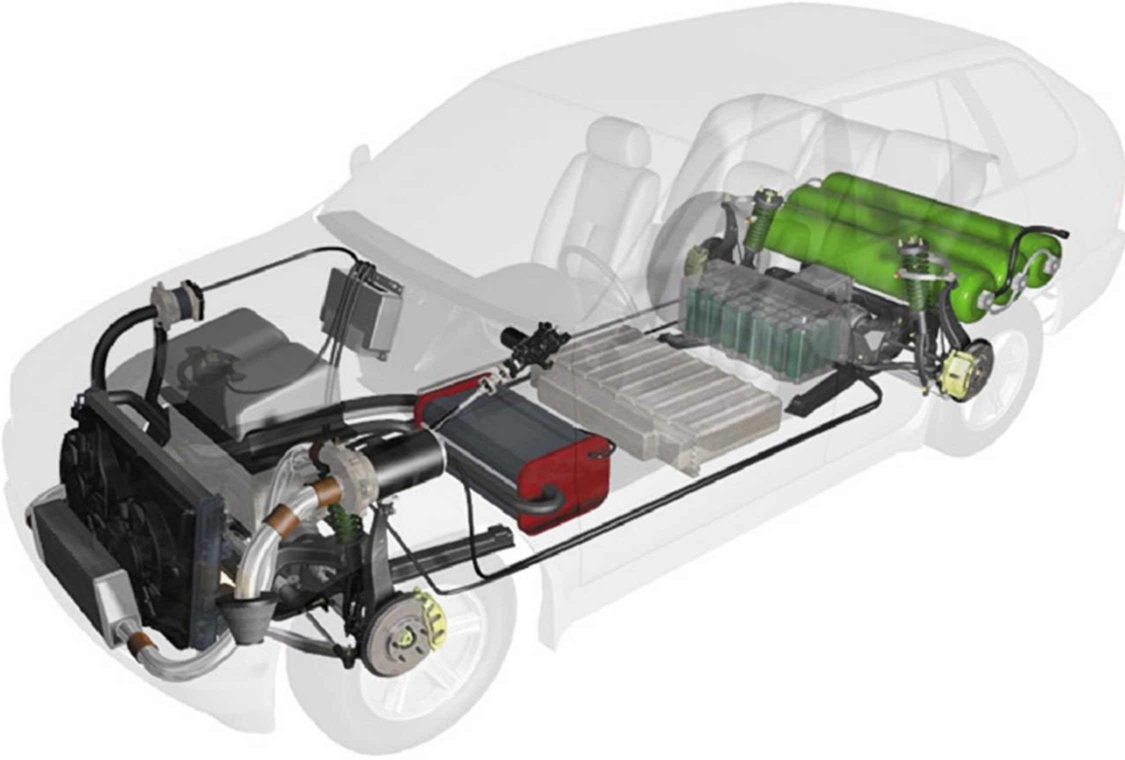
- The fuel cell is a system for the direct conversion of chemical energy into electrical energy
- It is naturally associated with an electric or hybrid electric drive train
- It is characterized by its high energy efficiency
  - Theoretical efficiency of PEM fuel cell: 92% @25°C
  - Practical efficiency of PEM fuel cell: 55% @25°C
  -

3.2 The fuel cell powertrain



Hybrid electric Fuel Cell powered car

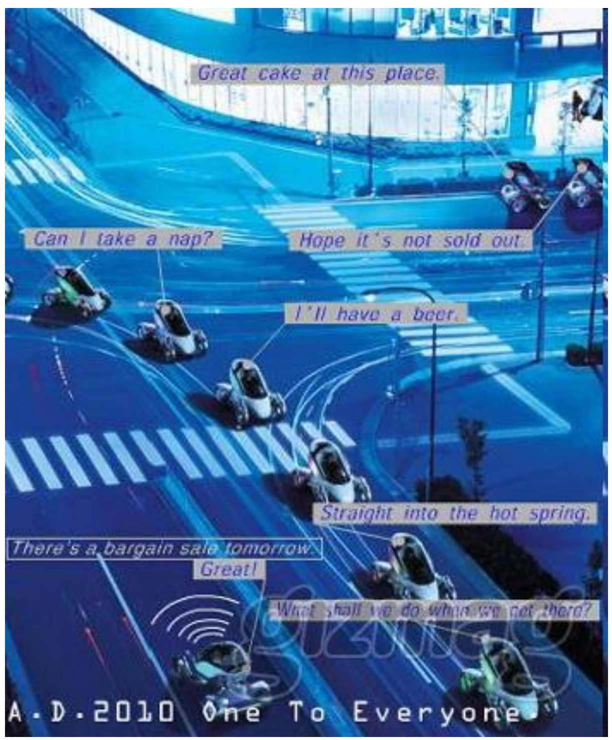
3.2 The fuel cell powertrain



Fuel cell powered car

3.2 Personal mobility concept

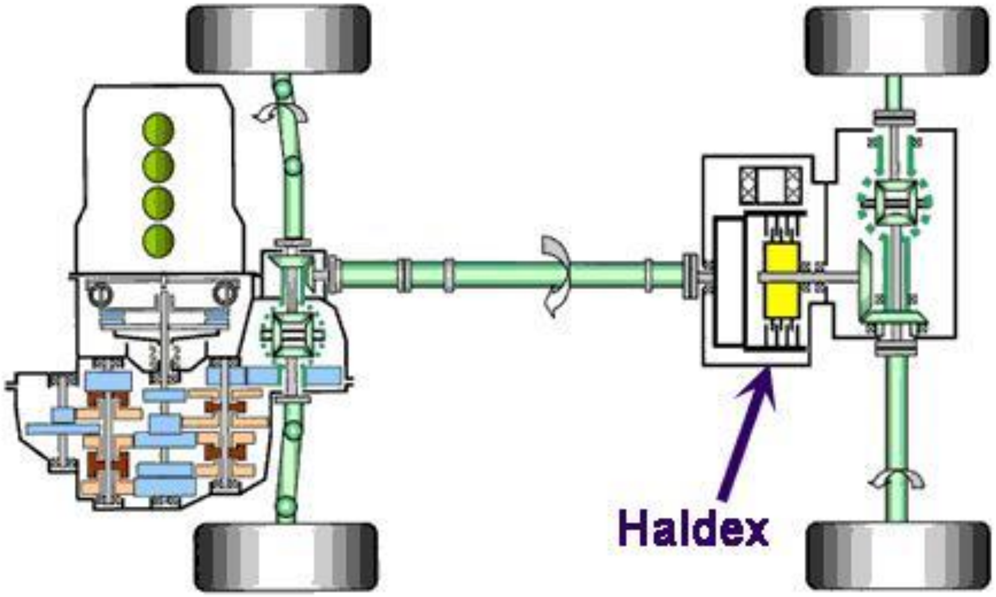
- Electric motorization is revolutionizing the architecture of transport systems



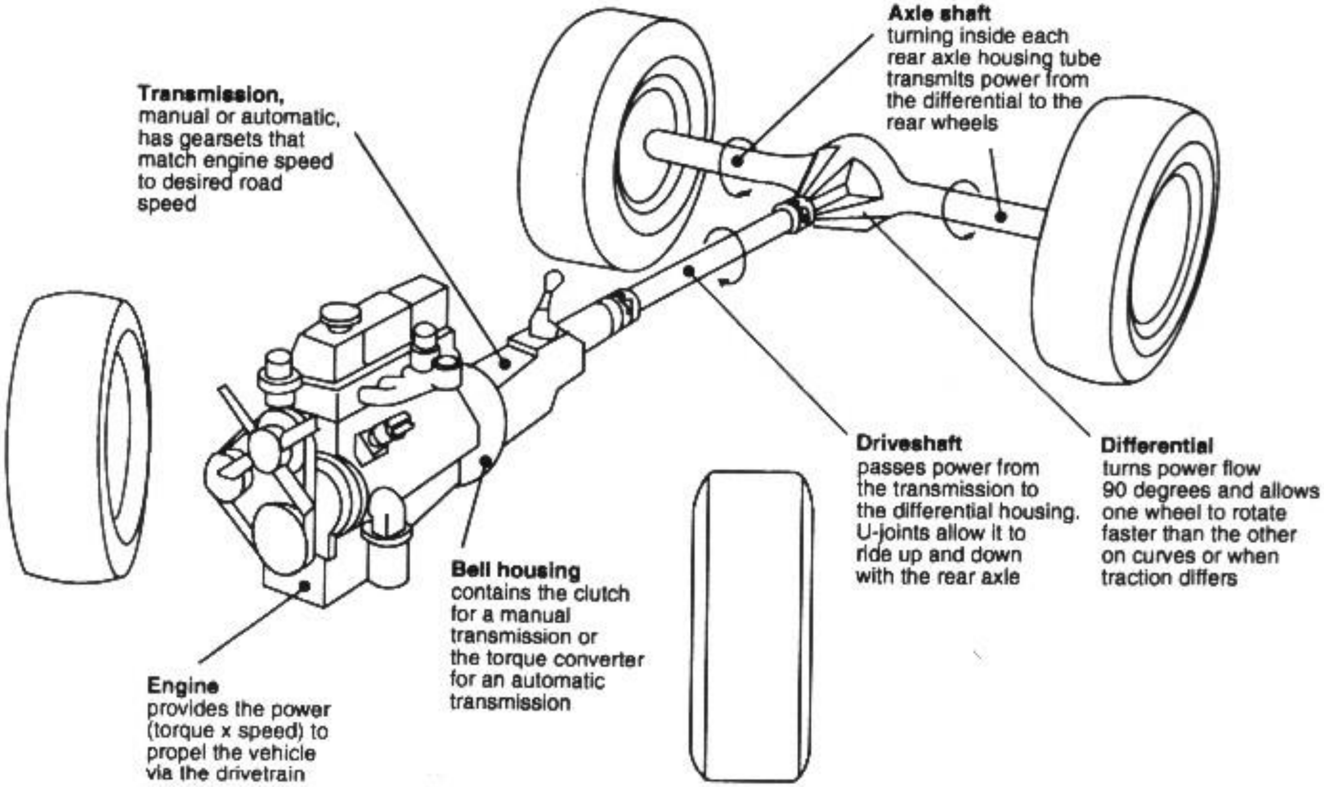
Toyota Personnal Mobility Concept

3.3 Transmission and driveline

- Clutch and coupling systems
- Gear box and variable reduction systems
- Transmission shafts
- Differential
- Axles



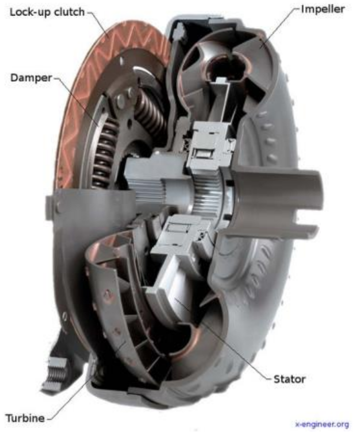
3.3 Transmission and driveline



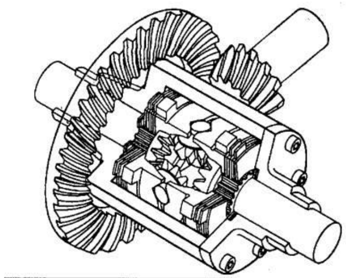
Gillespie, Fig. 2.3

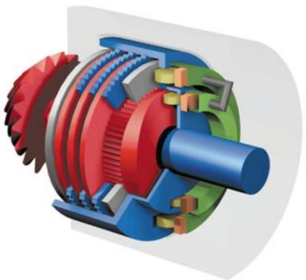
3.3 Transmission and driveline

Clutch

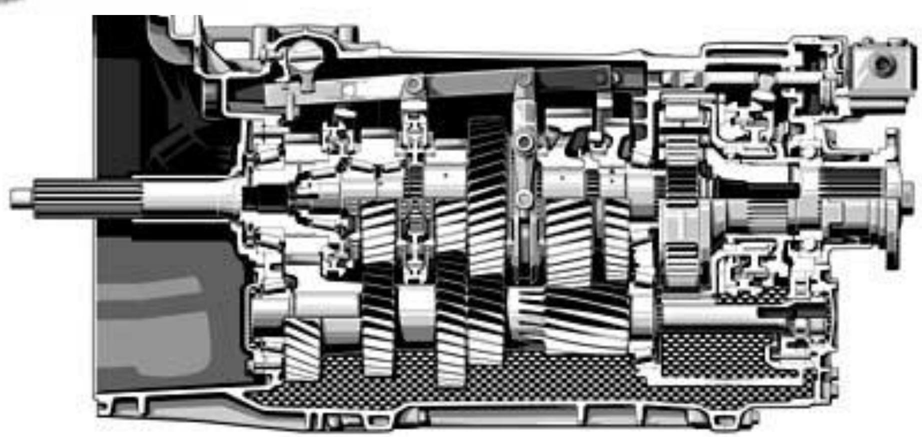


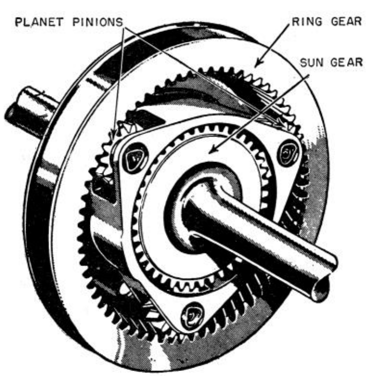
Differential





Gear box





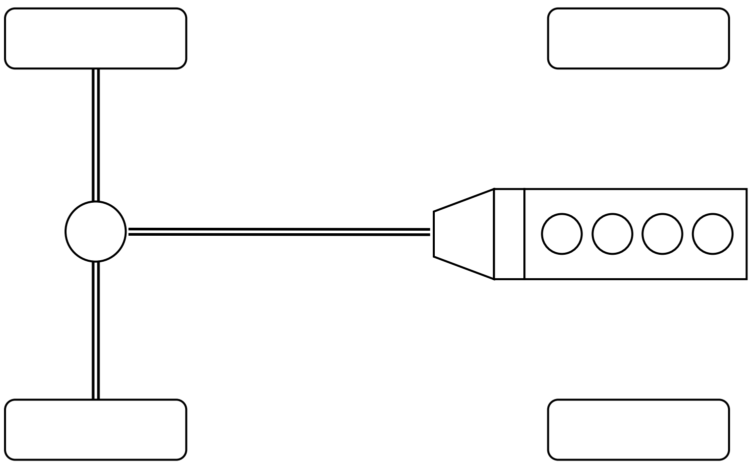
3.3 Transmission and driveline

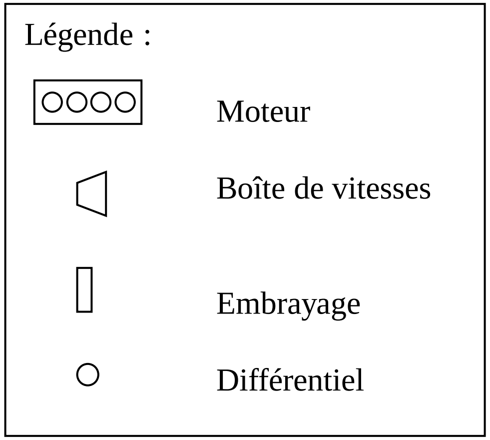
- The transmission system receives **mechanical energy** from the engine through the **flywheel**.
- It transmits it to the **driven wheels.**
- The driver can use the **clutch pedal** to **engage** or **disengage** the transmission
- The driver also acts on the **gearshift lever** which controls the **changes in gear ratios**.
- The **differential modifies the rotation angle** between the transmission shaft leaving the gearbox and the axles. It introduces also a **fixed speed reduction**. It **distributes the engine torque** to both drive wheels.

3.3 Transmission and driveline

- What is the overall function of the transmission system?
- The transmission system can :
  - Convey energy from the engine/motor to the drive wheels (torque, power);
  - Adapt this energy (speed reduction, torque increase) to the driving conditions, the resistant forces encountered by the vehicle (starting, acceleration, hills, descents, etc.).
  - Interrupt the coupling of the wheels to the engine at low speeds or when changing gear ratios

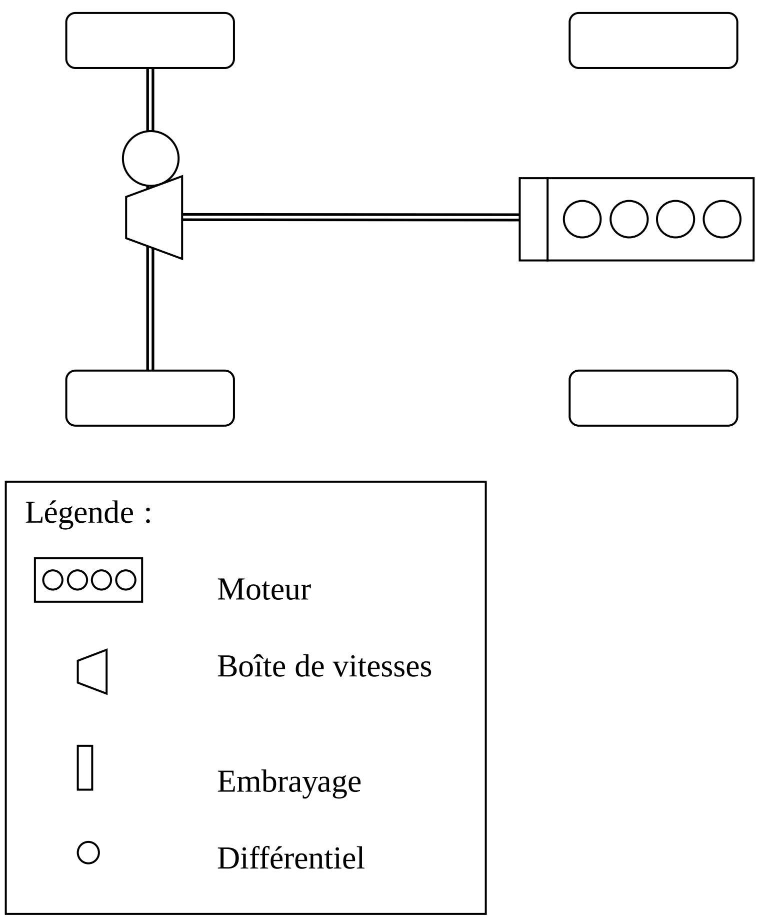
3.3 Transmission: layout





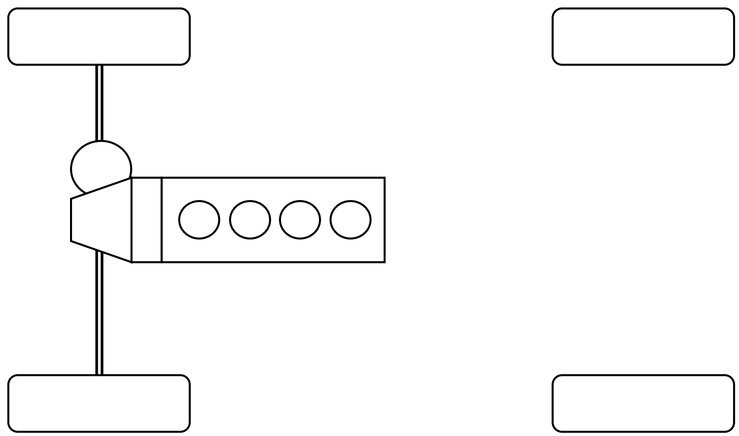
Longitudinal engine in front position,
rear-wheel drive
gearbox at the front
Example: BMW 3 series

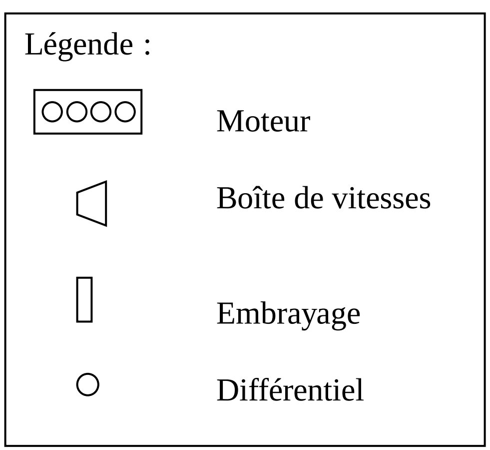
3.3 Transmission: layout



Longitudinal engine at the front & rear-wheel drive,
gearbox at the rear,
Example: Alfa 75

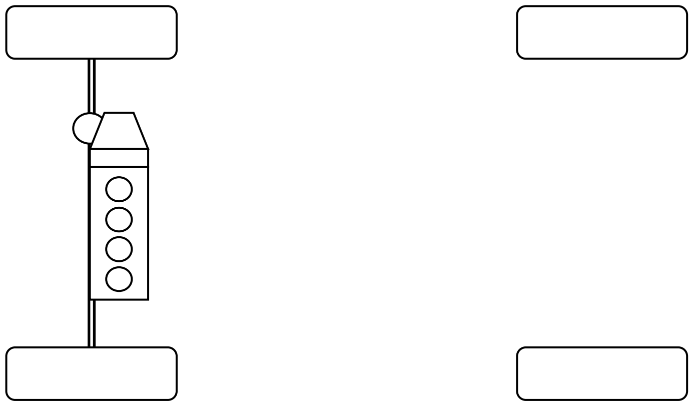
3.3 Transmission: layout





Longitudinal engine at the rear,
Rear wheel drive, rear gearbox,
Example: Ferrari 360

3.3 Transmission: layout

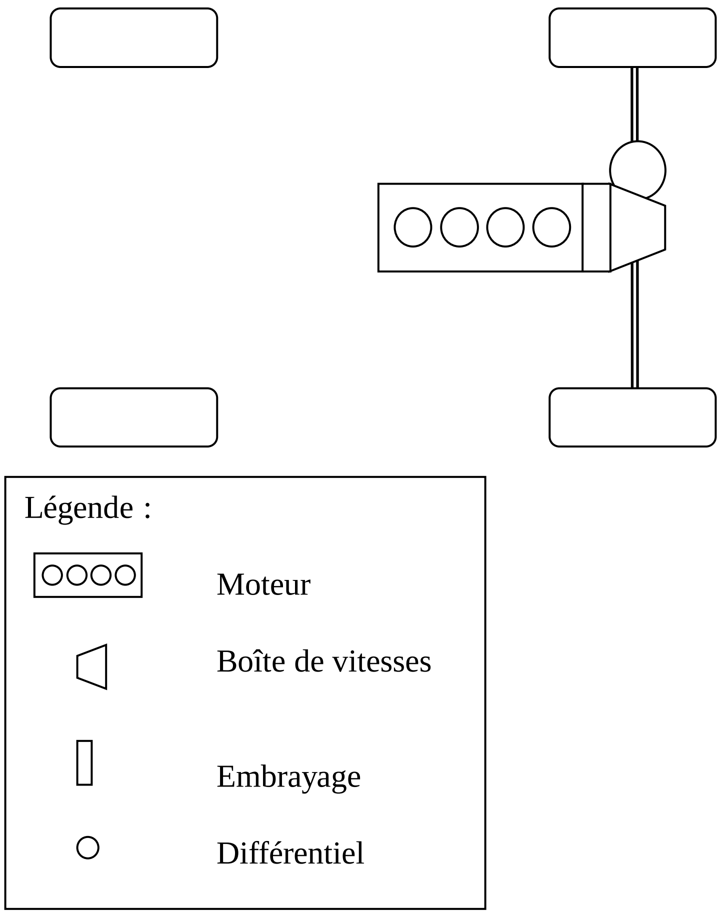


Légende :

- Moteur
- Boîte de vitesses
- Embrayage
- Différentiel

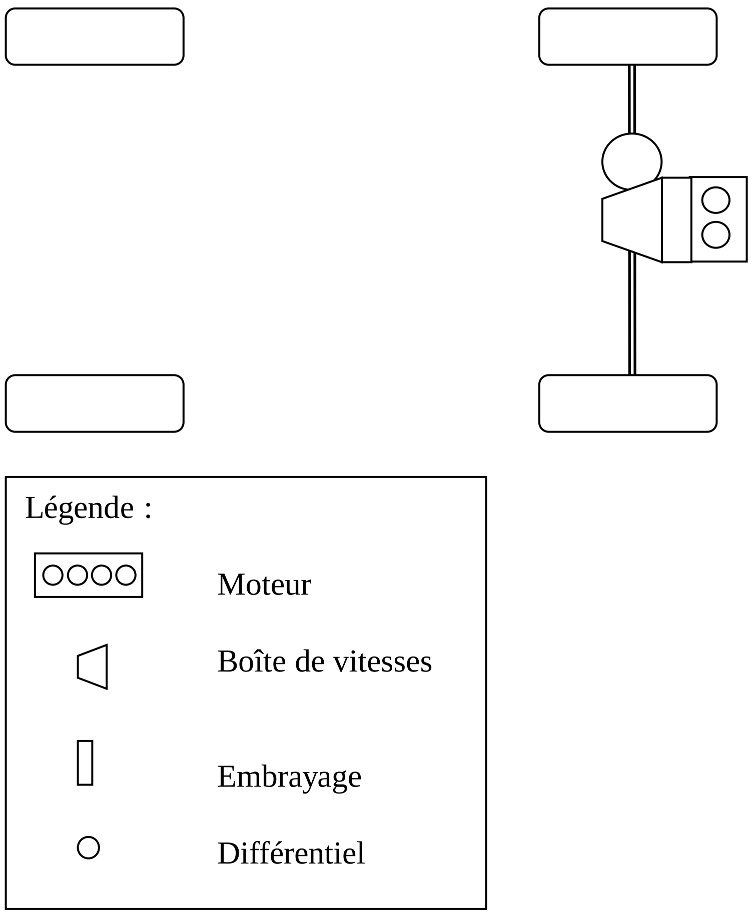
Transverse engine at the rear,
rear-wheel drive,
Example: Lamborghini

3.3 Transmission: layout



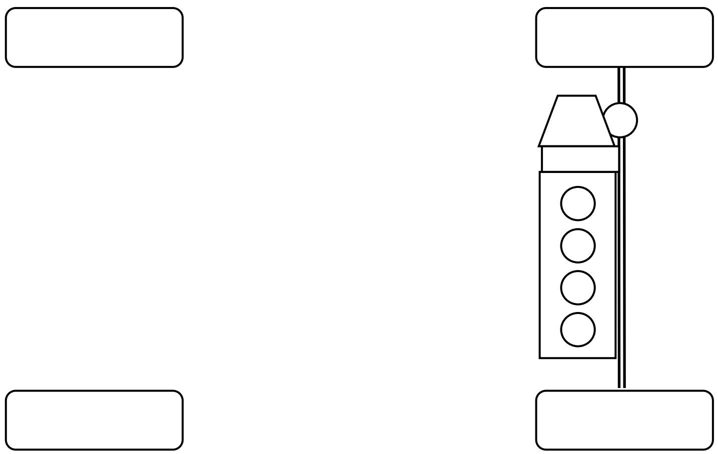
Longitudinal engine at the front,
Gearbox in front and front-wheel drive
Example: Citroën DS

3.3 Transmission: layout



Engine at the front, suspended front-wheel drive
Example: Citroën 2CV

3.3 Transmission: layout

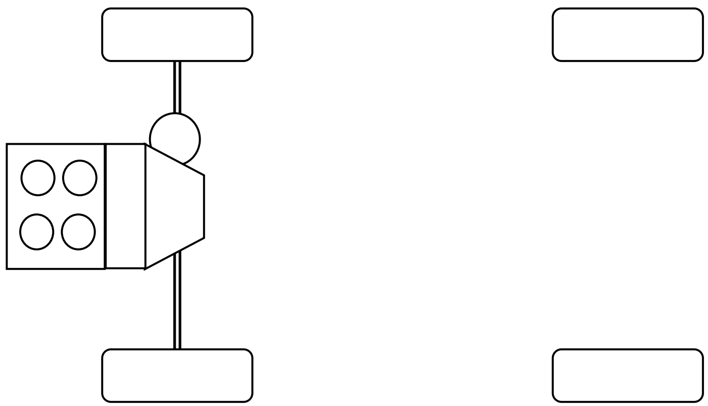


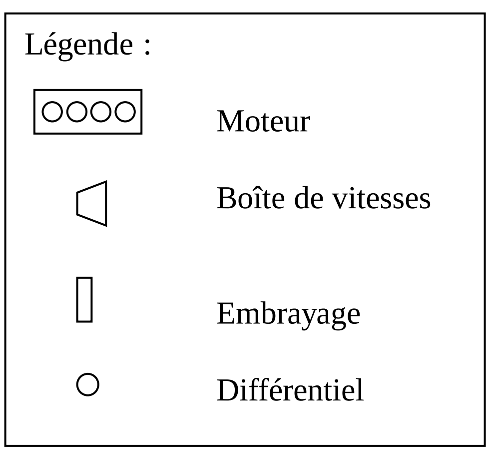
Légende :

- Moteur
- Boîte de vitesses
- Embrayage
- Différentiel

Transverse engine at the front,
Front-wheel drive
Example: Renault Megane

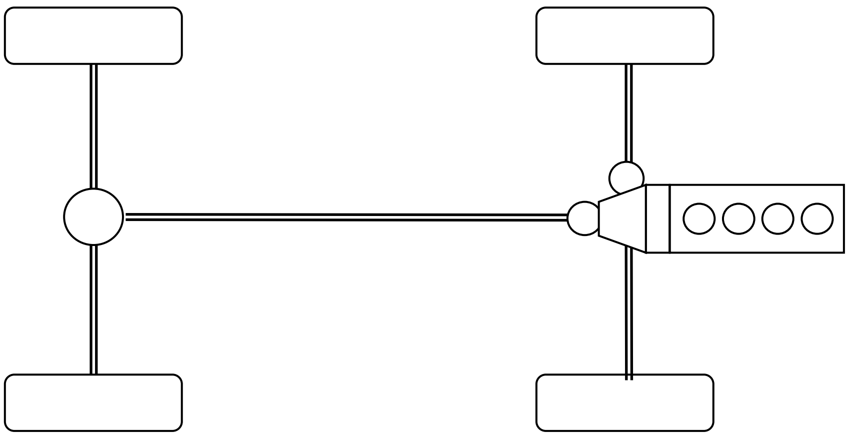
3.3 Transmission: layout

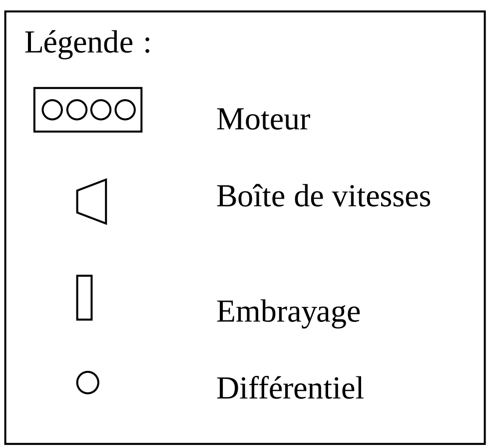




Rear transverse engine,
Suspended, rear wheel drive
Example: VW Beetle

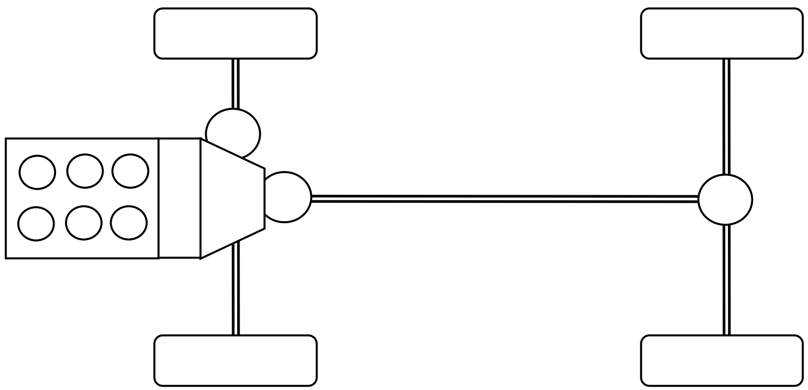
3.3 Transmission: layout

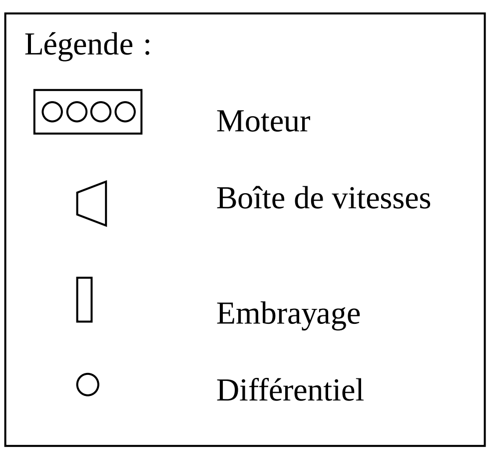




Front longitudinal engine,
All-wheel drive
Example: Audi quattro

3.3 Transmission: layout



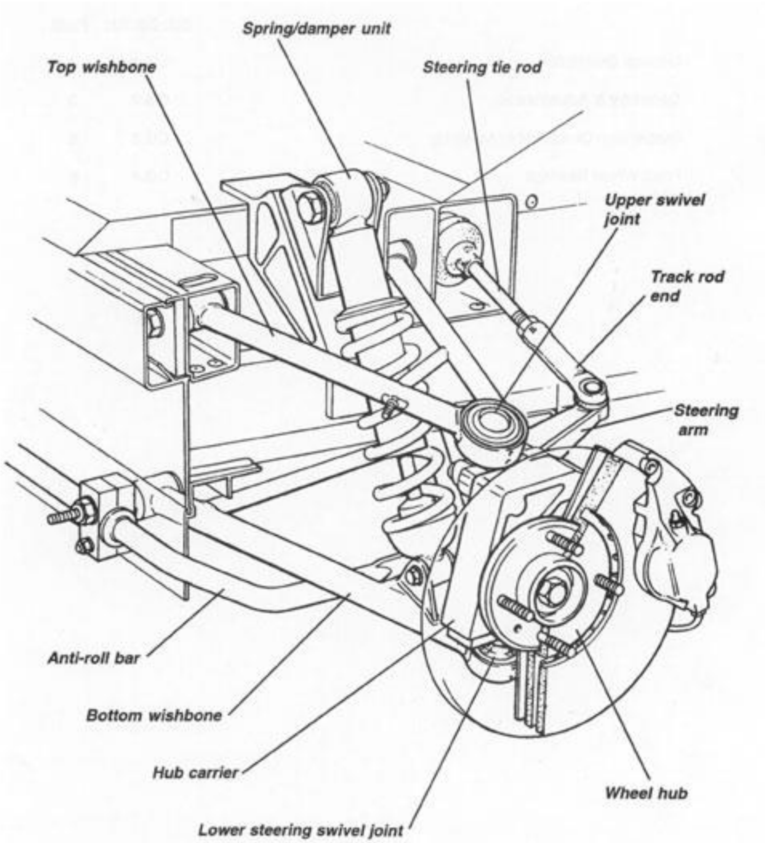


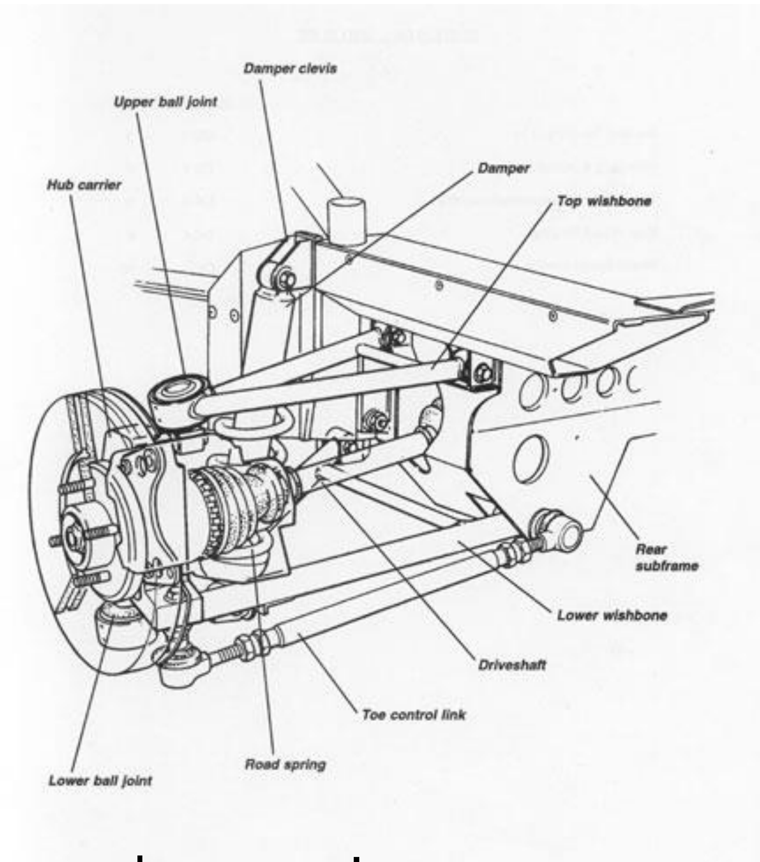
Rear longitudinal engine,
All-wheel drive
Example: Porsche Carrera 4

3.4 Rolling gear

- Suspension mechanism
- Shock absorbers
- Elastic elements
- Brakes
- Steering
- Wheels
- Tyres

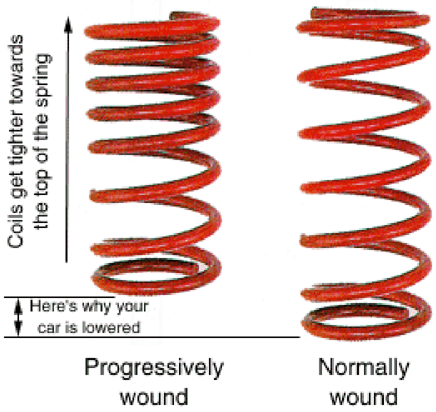
3.4 Rolling gear

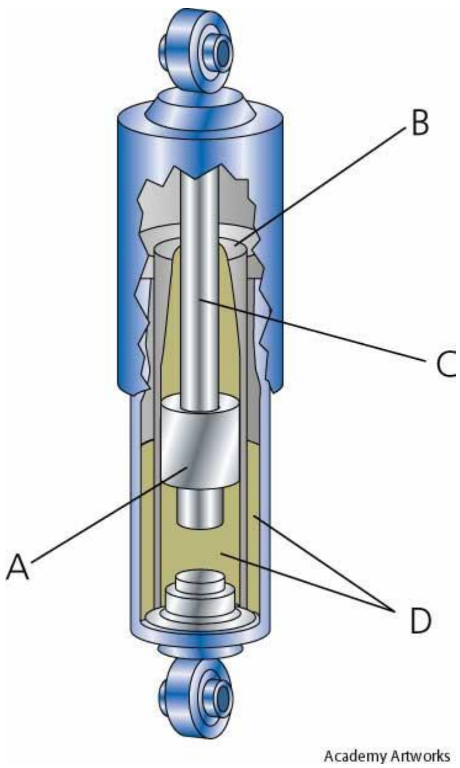




Lotus Elise rolling gear and suspension

3.4 Rolling gear





3.4 Suspension

- Function of the suspension:
  - The suspension aims at ensuring the **comfort of the passengers** by filtering the vibrations coming from the road and by absorbing part of the kinetic energy transferred to the wheel during shocks and vibrations from road roughness
  - The suspension has also to keep a good **road holding** capability while keeping a high level of tyre-road contact pressure despite wheel travel caused by the uneven road surface and the shocks

3.4 Suspension

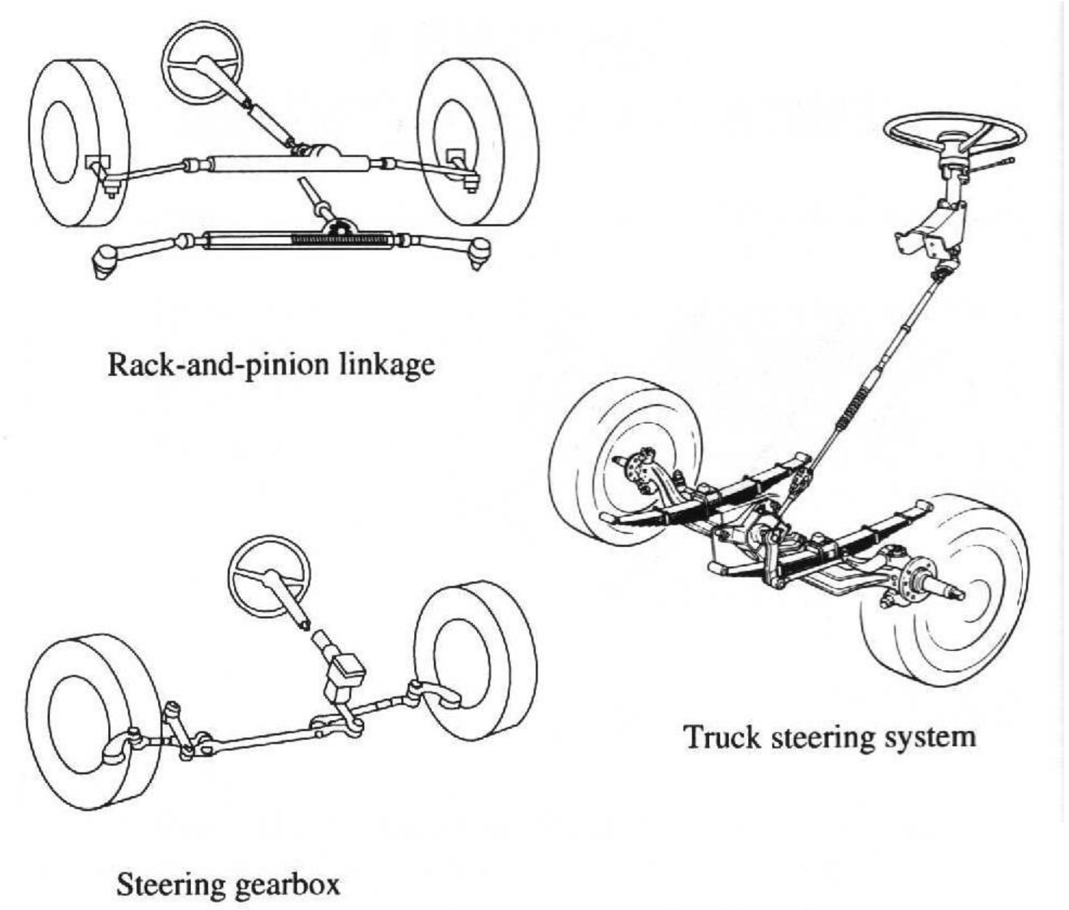
- Working principle:
  - The **vehicle weight** gives a down force that applies on the suspension. The **springs** are inserted between the suspended mass and suspension arms.
  - The pneumatic tyres make the contact with the ground.
  - A non smooth contact surface of the road creates oscillatory motions.
  - Shocks transfer kinetic energy into the suspension system.
  - The kinetic energy transfer to the suspended mass is mitigated by the **torsion and flexion of the springs** and while the shock absorbers **convert it into heat**.
  - The type adherence is ensured by keeping a right pressure contact force, which is preserved by the spring forces.

3.4 Steering system

- Function of the steering system :
  - The steering system has to maintain and modify the trajectory by modifying the steering angle of the wheel with respect to the travel direction. The steering action should be made with precision, without important efforts by the driver, and by keeping a satisfactory road holding.

- Working principle:
  - The driver acts on the steering wheel.
  - The front wheels rotates together about a virtual axis denoted steering axis. They remain more or less parallel thanks to a coupling mechanism including coupling links or rack and pinion device.

3.4 Steering system



Gillespie, Fig 1.8

3.5 The braking system

- Function of the braking system:
  - The brakes have to slow down the vehicle speed, to stop it or to keep it at standstill by dissipating the energy by friction or any other mechanism the kinetic energy of the vehicle.

- Operation scheme:
  - Initially, the vehicle has a certain speed, and it has a certain kinetic energy $\frac{1}{2} M V^2$
  - The driver acts on the **braking pedal**
  - The command system receives energy under various forms to provide assistance, using hydraulic, pneumatic, mechanical, electrical input to magnify the effort of the driver.
  - Each **brake** element converts the **kinetic energy** into **heat** using **friction.**

3.5 The brakes

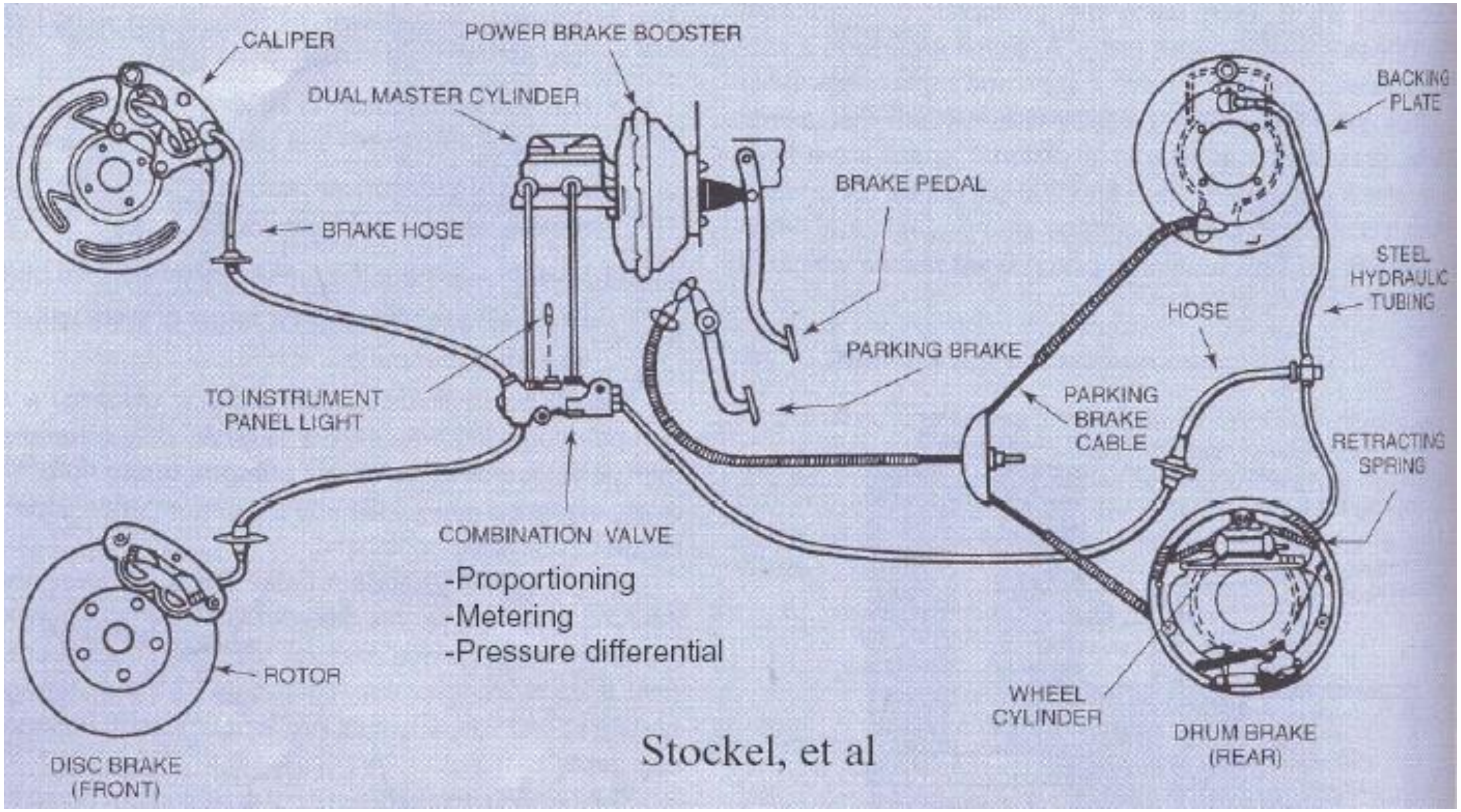
Brake disk

Continuous brake (TELMA)

3.5 The brakes

- The vehicle motion has certain amount of kinetic energy proportional to its mass and to the square of its speed.
- The **braking** aims at reducing or to dissipate totally the speed by **absorbing this kinetic energy**.
- Practically the kinetic energy is transformed into heat by friction between a fixed element, connected to the body and one connected to the spinning wheels (mobile element)
- Other disspiation mechanisms are possible (even if they are quite seldom) :
  - Aerodynamic dissipation by increasing the wet surface or downgrading the aerodynamics properties (increasing the C_x) (aerodynamic brakes)
  - Increasing the internal frictions:
    - Braking energy recovery in electric vehicles
    - Eddy current brakes
    - Engine brake

3.5 The brakes



The basic braking system

3.6 The electrical system

- Initialement: seule fonction = système d'ignition (allumage)
- Rapidement: apparition du système d'éclairage
  - 1er standard = 6V
- Après la seconde guerre mondiale: plus gros moteurs et apparition de systèmes électriques (radio, lève-vitre, etc.)
  - standard = 12 V
  - toujours en vigueur
- Futur: accroissement de la demande de puissance électrique
  - futur standard = 48 V ?

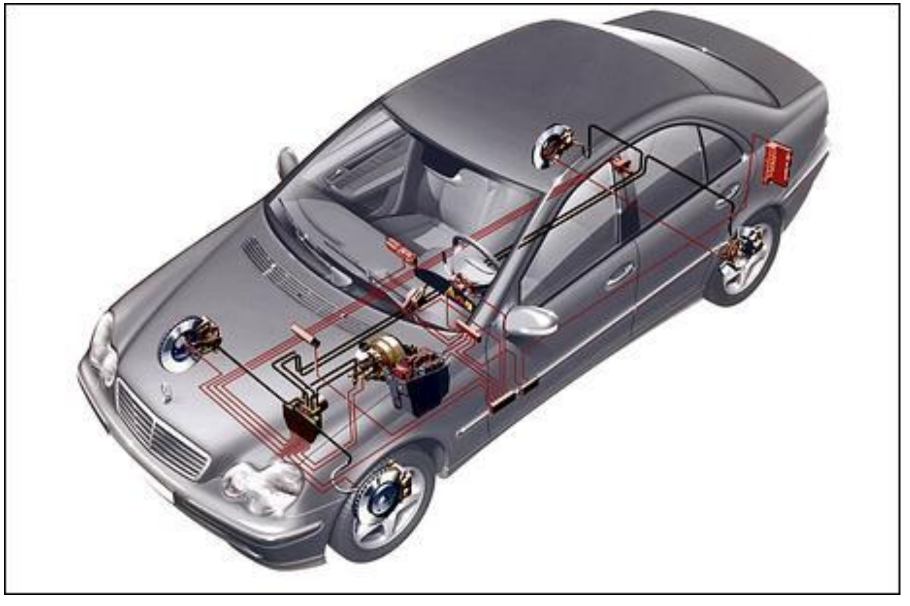
3.6 The electrical system

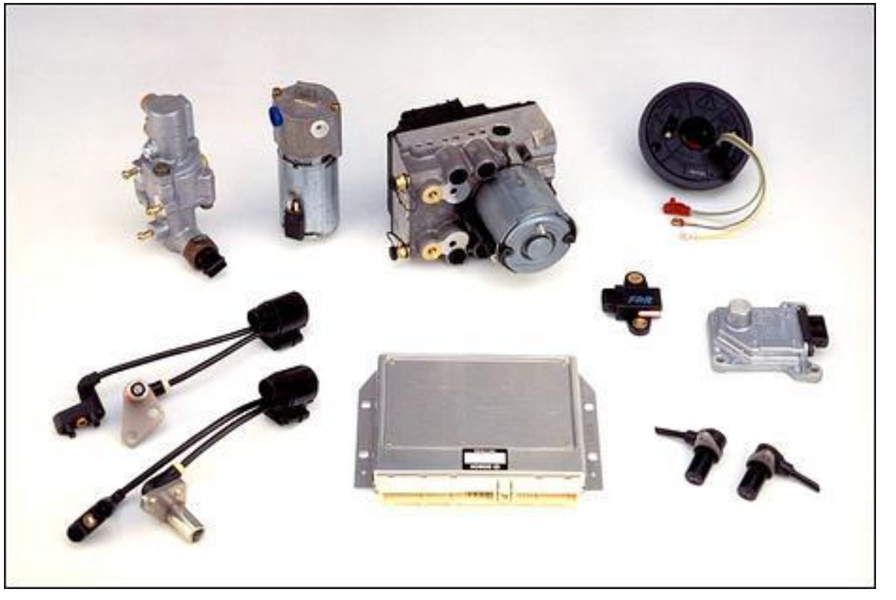
- Source de base de l'énergie électrique: génératrice
  - accouplée au vilebrequin par une courroie
  - génération de courant alternatif rectifié et régulé afin d'être compatible avec la charge électrique et permettre la charge de la batterie
- La batterie acide plomb
  - permet l'accumulation d'énergie électrique et la disponibilité d'énergie pour démarrer le moteur ou quand le moteur ne tourne pas assez vite (ralenti)
- Le démarreur
  - un petit moteur qui s'engage lorsque le moteur du démarreur commence à tourner et se retire automatiquement lorsque le moteur à combustion interne a démarré.
  - un petit moteur qui admet un fort courant pendant un court moment afin de pouvoir fournir une grande puissance pour un faible poids.

3.6 The electrical system

- Many accessories are electrically operated or electrified:
  - Lighting
  - windscreen wipers
  - Defrosting
  - Air conditioning
  - Navigation system
  - Entertainment
  - …

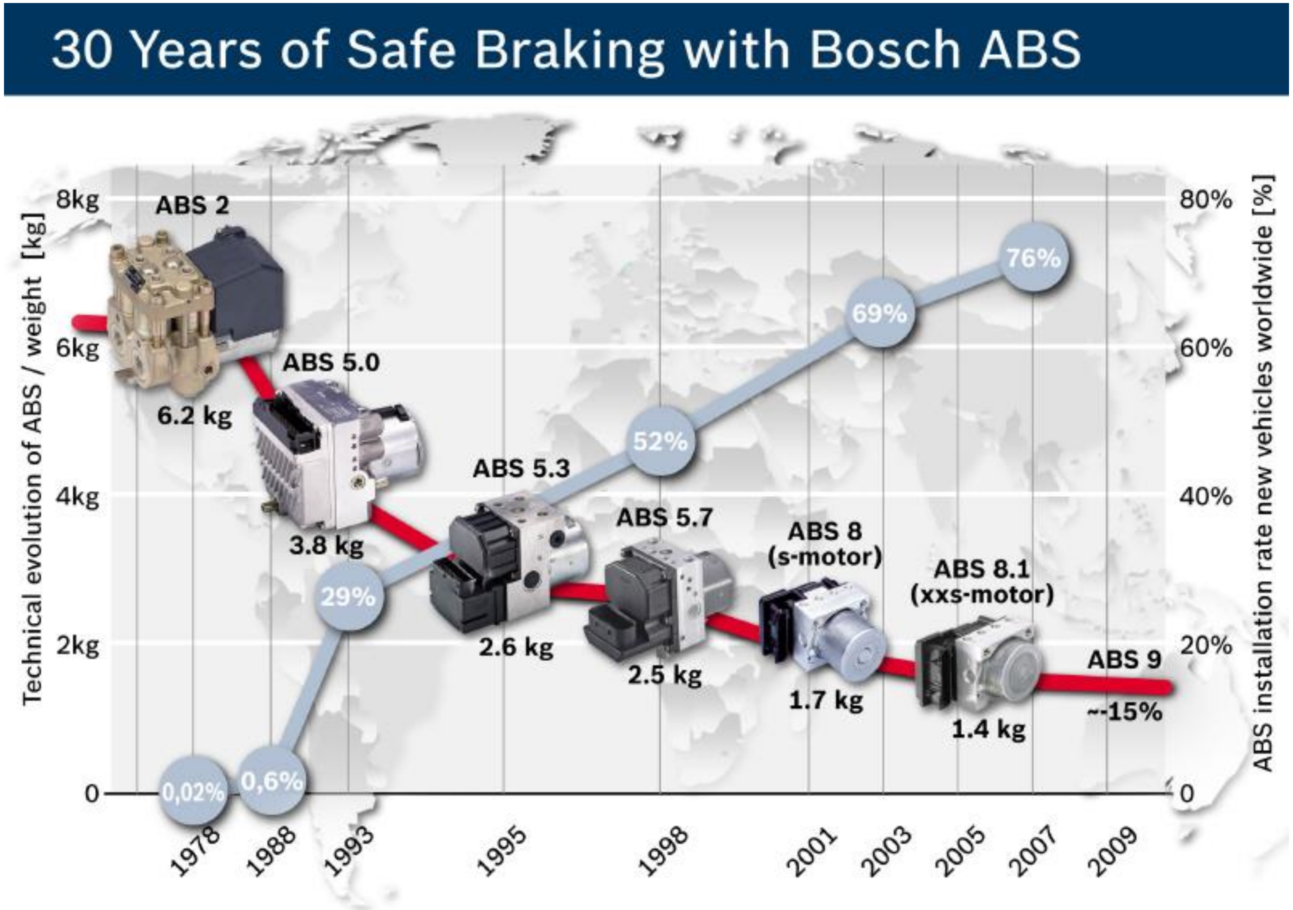
3.7 Safety systems



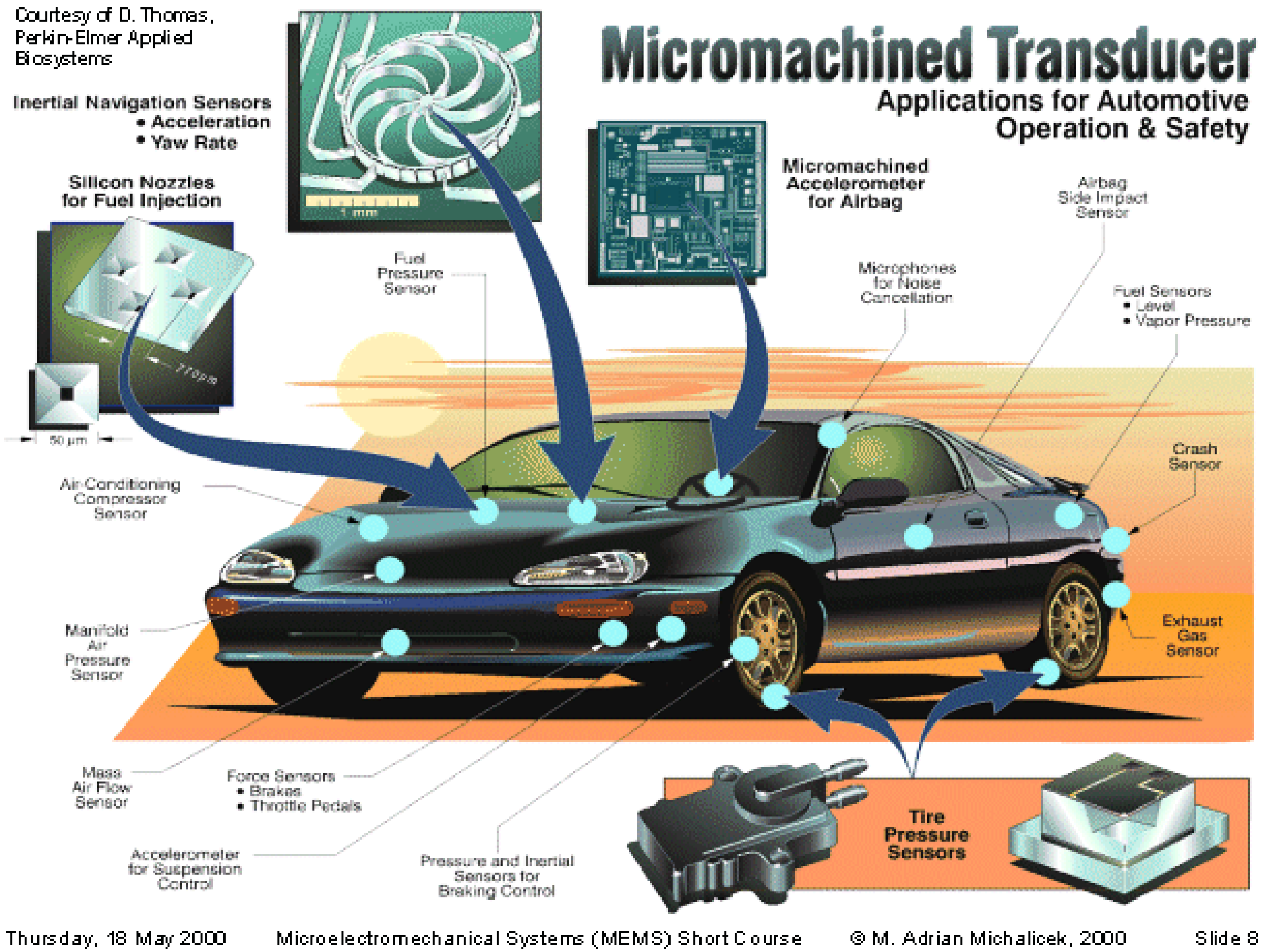


Modern ABS system on a Mercedes

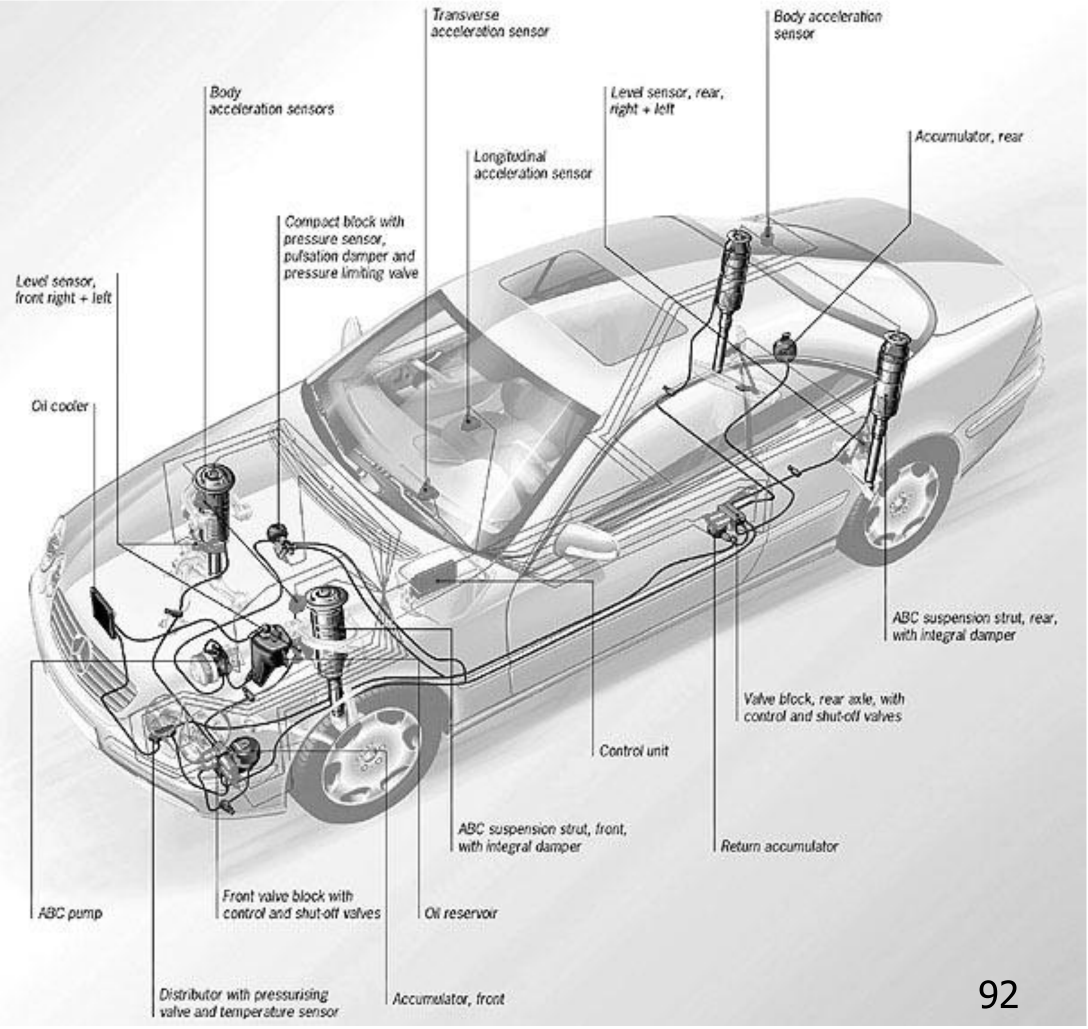
3.7 Safety systems



3.7 Safety systems

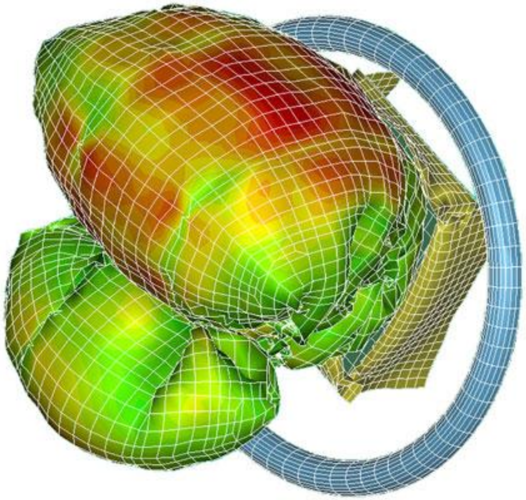


3.7 Safety systems



A multitude of sensors on a recent Mercedes

3.7 Safety systems



Airbag protection system