Department of Automotive Technologies –
Vehicle Mechanics Fundamentals

Gábor Sipos

BME
DEPARTMENT OF AUTOMOTIVE TECHNOLOGIES

Lecture 7

Basic information

Week nr.	Official nr.	Date	Lecture (Monday)			Lab (date+1;Tuesday)		
1	**1**	12th Feb	1	General information, Tyre, Driving force		1	Lab	
2	**2**	19th Feb	2	Longitudinal and lateral behaviour				
3	**3**	26th Feb	3	Concepts and over/understeer		2	Lab	
4	**4**	4th Mar	4	Weight transfer				
5	**5**	11th Mar	5	Bicycle model		3	Lab	
6	**6**	18th Mar	T1	Midterm exam I. ONLINE				
7	**7**	25th Mar	6	Braking and brakes ONLINE		4	Lab ONLINE	
8		1st Apr	-	Break				
9	**8**	8th Apr	7	Systems of the vehicle				
10	**9**	15th Apr	8	Quarter vehicle model ONLINE		T1 R	Exam 1 - subsequent ONLINE	
11	**10**	22th Apr		Break				
12	**11**	29th Apr	T2	Midterm exam II. ONLINE			Break	
13	**12**	6th May	9	Tyre management				
14	**13**	13th May	10	Racecar engineering		T2 R	Exam 2 - subsequent	
	14	20th May	11	Semester championship presentation				

Note

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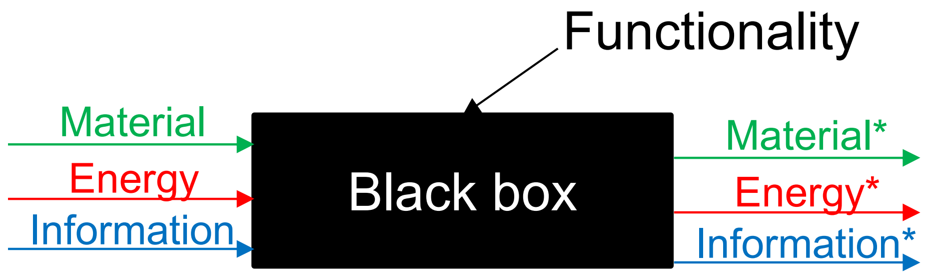
- Next Tuesday Midterm retake starts at 8:20

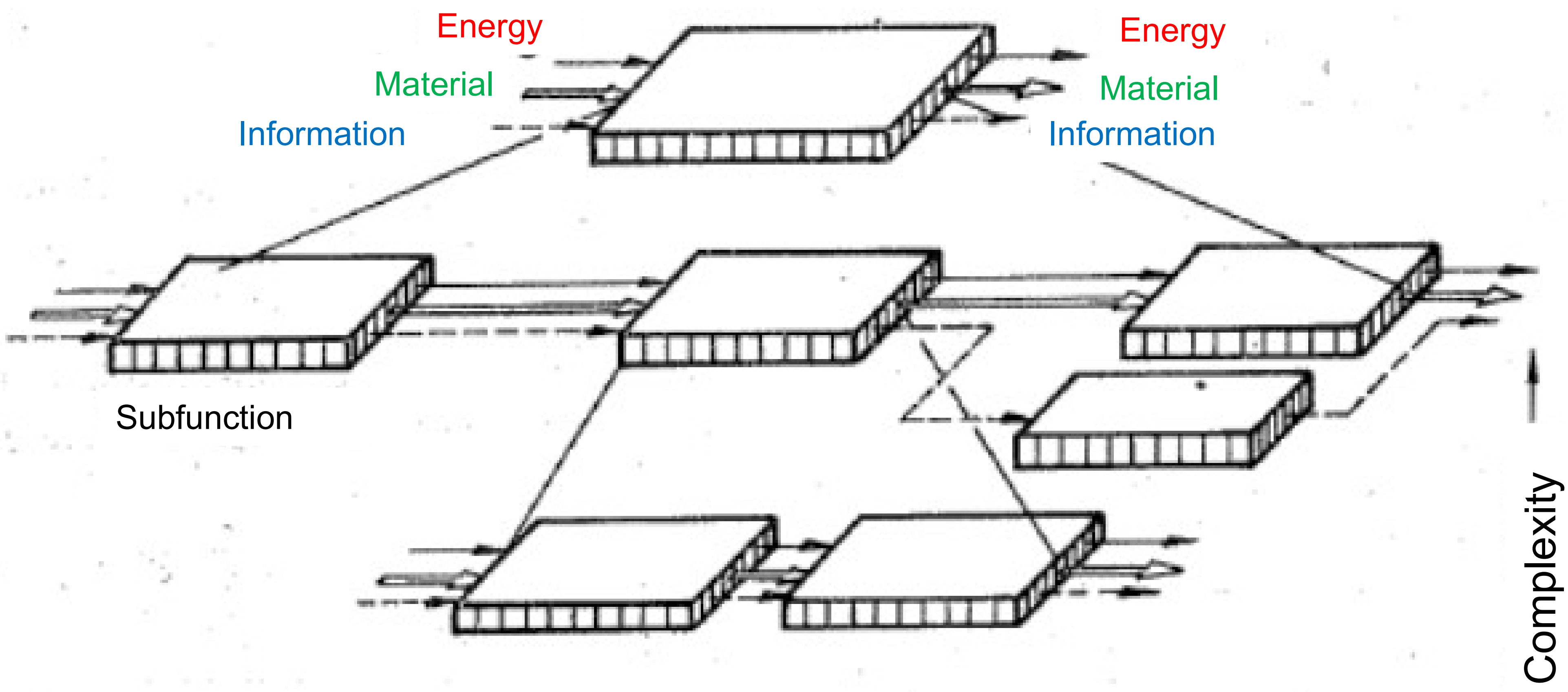
General engineering approach



- functional structure
- main function, subfunction, elementary function
- CAN
- HV cables
- mounting brace

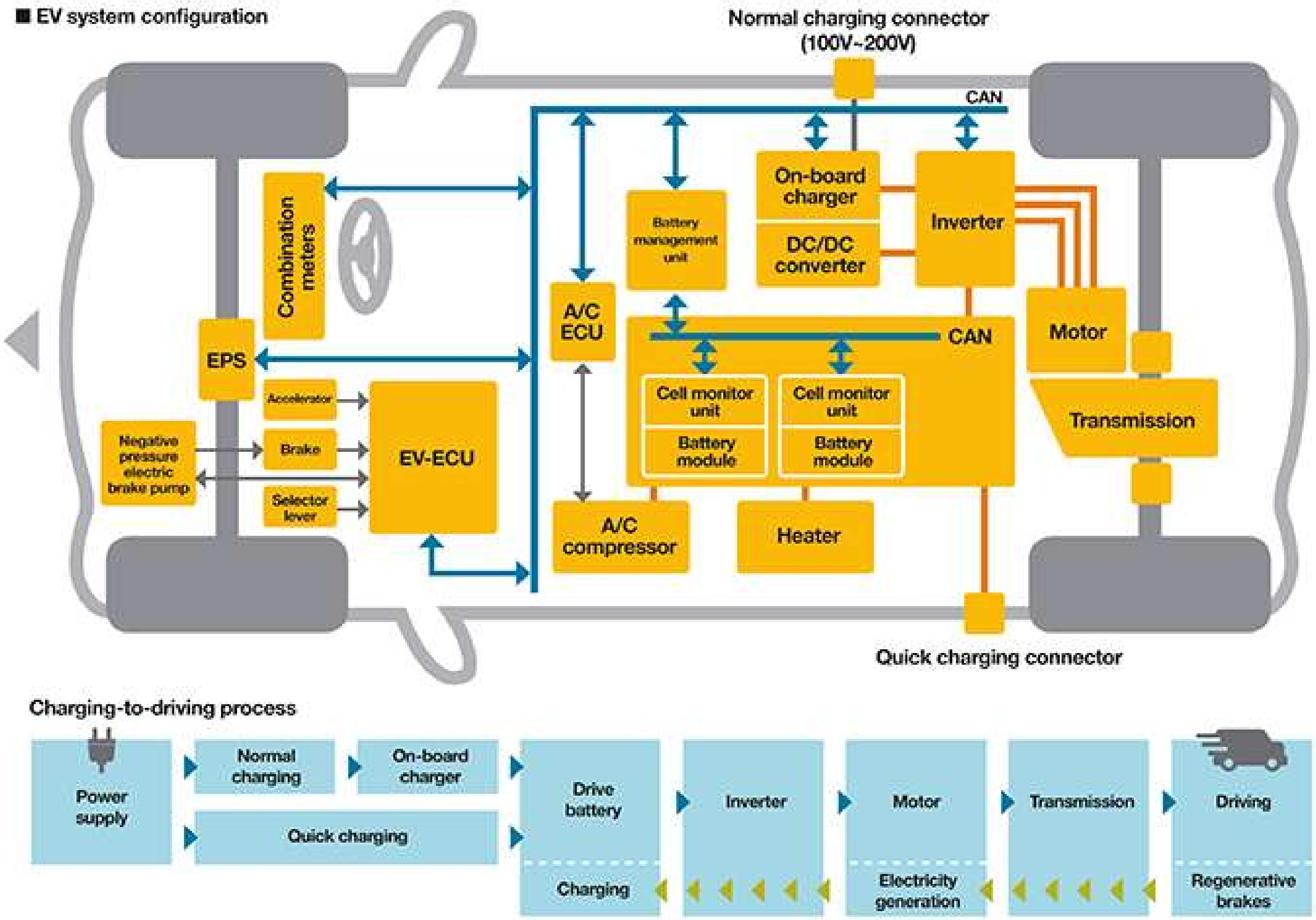
General engineering approach

Function structure



General engineering approach

Function structure



Powertrain

Function

- ensure power
- store energy?
- energy transformation (fuel/electric to kinetic)
- keep itself in proper condition
  - cooling system
  - aero

Resistance

- roll+slope+drag

- The sum of the resistance forces acting on a flat-moving vehicle:

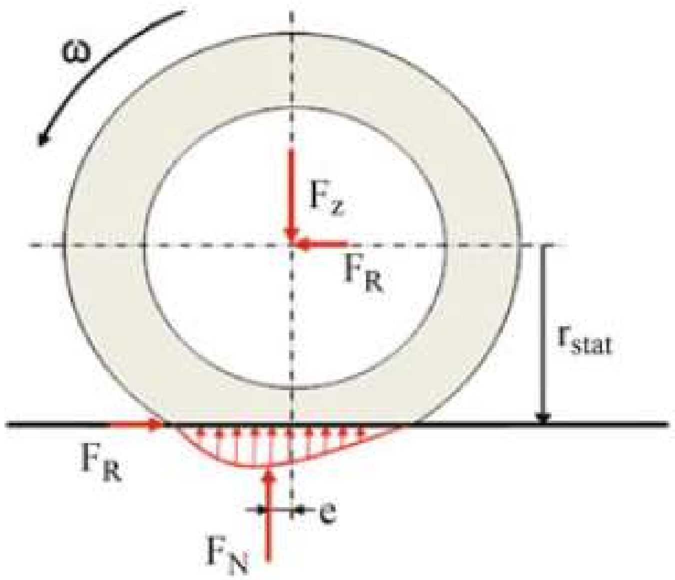
$$F_{res} = F_{roll} + F_{air} = fmg + \frac{1}{2}\rho_{air} \cdot c_d \cdot A \cdot v^2$$

Resistance

- Rolling

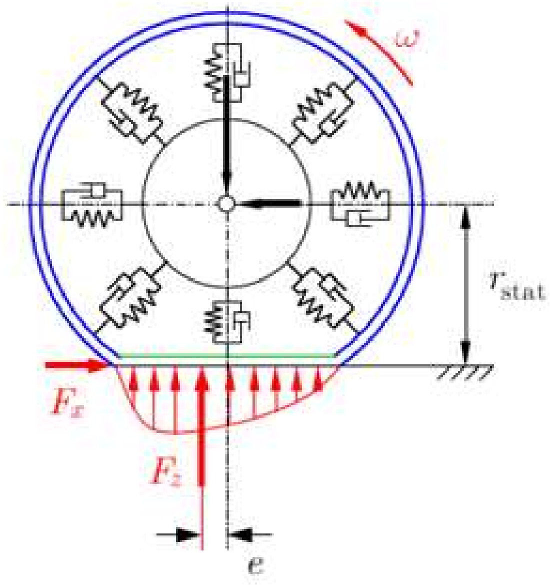
- Resistance forces acting on flat-moving vehicles:

Rolling resistance: $F_{roll} = F_{roll1} + F_{roll2} = fF_{Z,F} + fF_{Z,R} = f\left(F_{Z,F} + F_{Z,R}\right) = fmg$



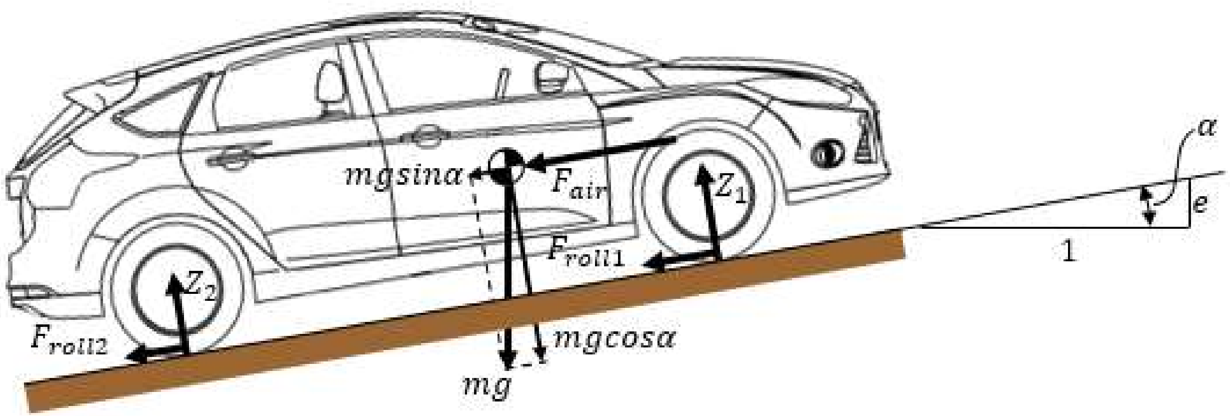
$$F_R \cdot r_{stat} = e \cdot F_z$$

$$F_R = \frac{e}{r_{stat}} \cdot F_N = f_R \cdot F_z.$$



Resistance

- Slope



- Interpretation of the slope percentage:

$$tg\alpha = e \Rightarrow \alpha = arctg(e), where\ 0 \leq e \leq 1\ and\ 0° \leq \alpha \leq 90°$$

- Resistance forces acting on a vehicle moving on a slope:

Rolling resistance: $F_{roll} = F_{roll1} + F_{roll2} = fZ_1 + fZ_2 = f(Z_1 + Z_2) = fmgcos\alpha$

Slope resistance: $F_{slope} = mgsin\alpha$

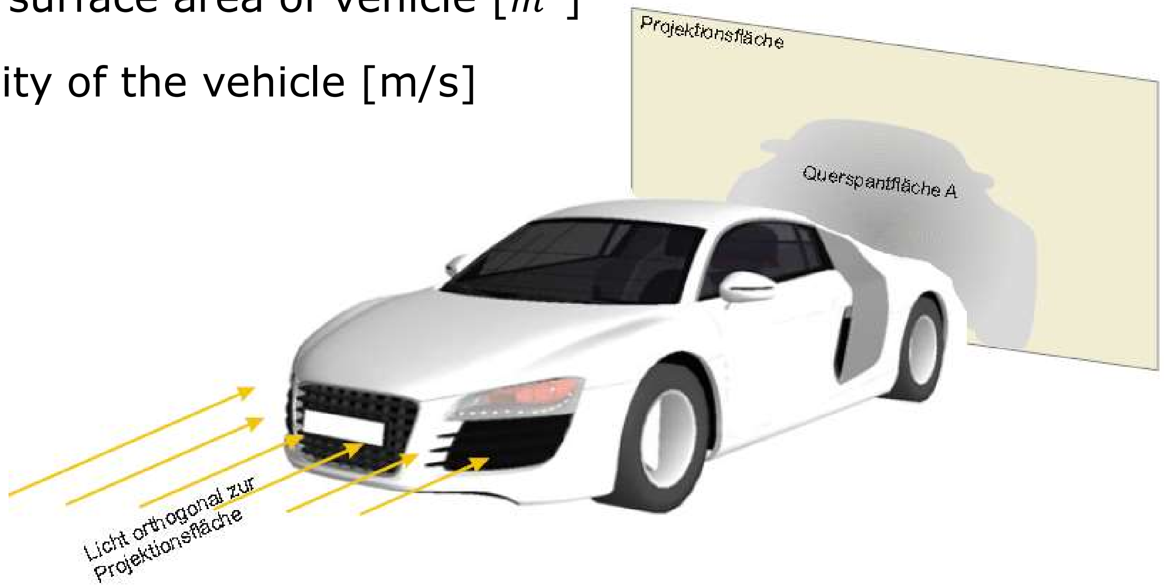
Resistance

- Drag

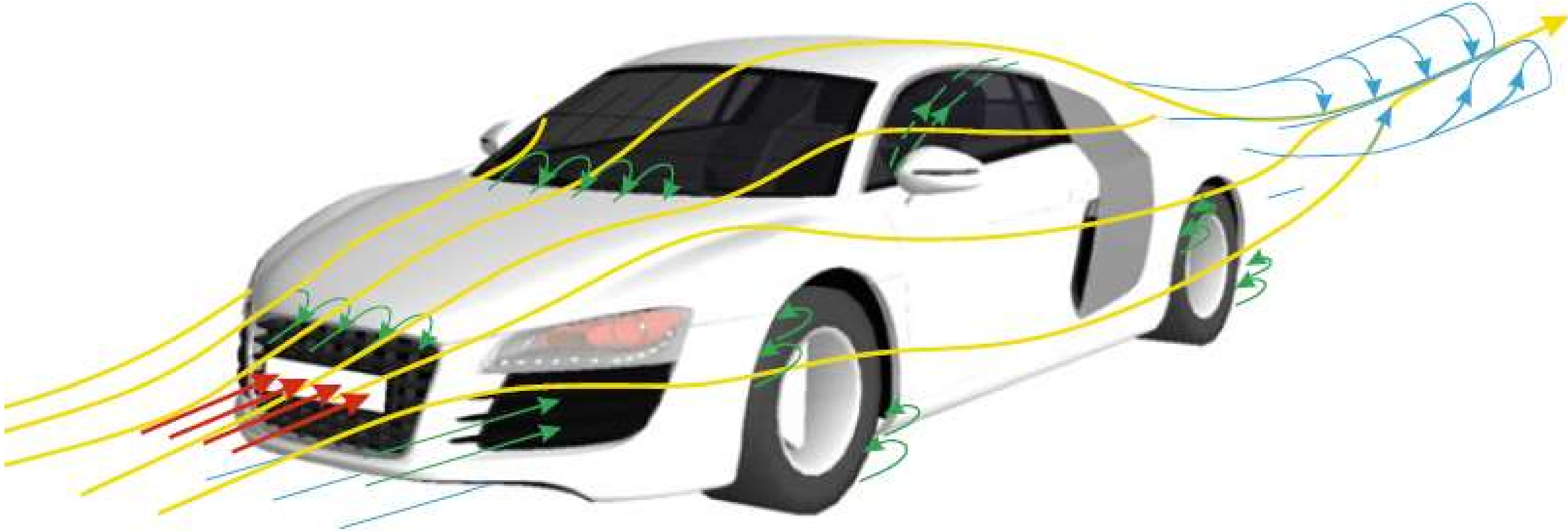
Air resistance: $F_{air} = \frac{1}{2}\rho_{air} \cdot c_d \cdot A \cdot v^2$

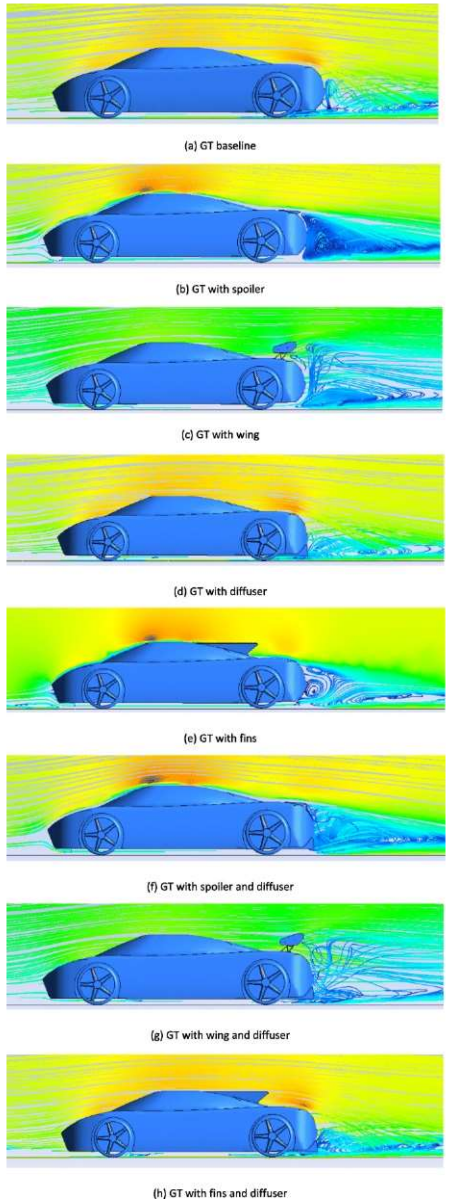
where:

ρ_{air}	air density [kg/m^3]
c_d	vehicle resistance factor [-]
A	front surface area of vehicle [m^2]
v	velocity of the vehicle [m/s]



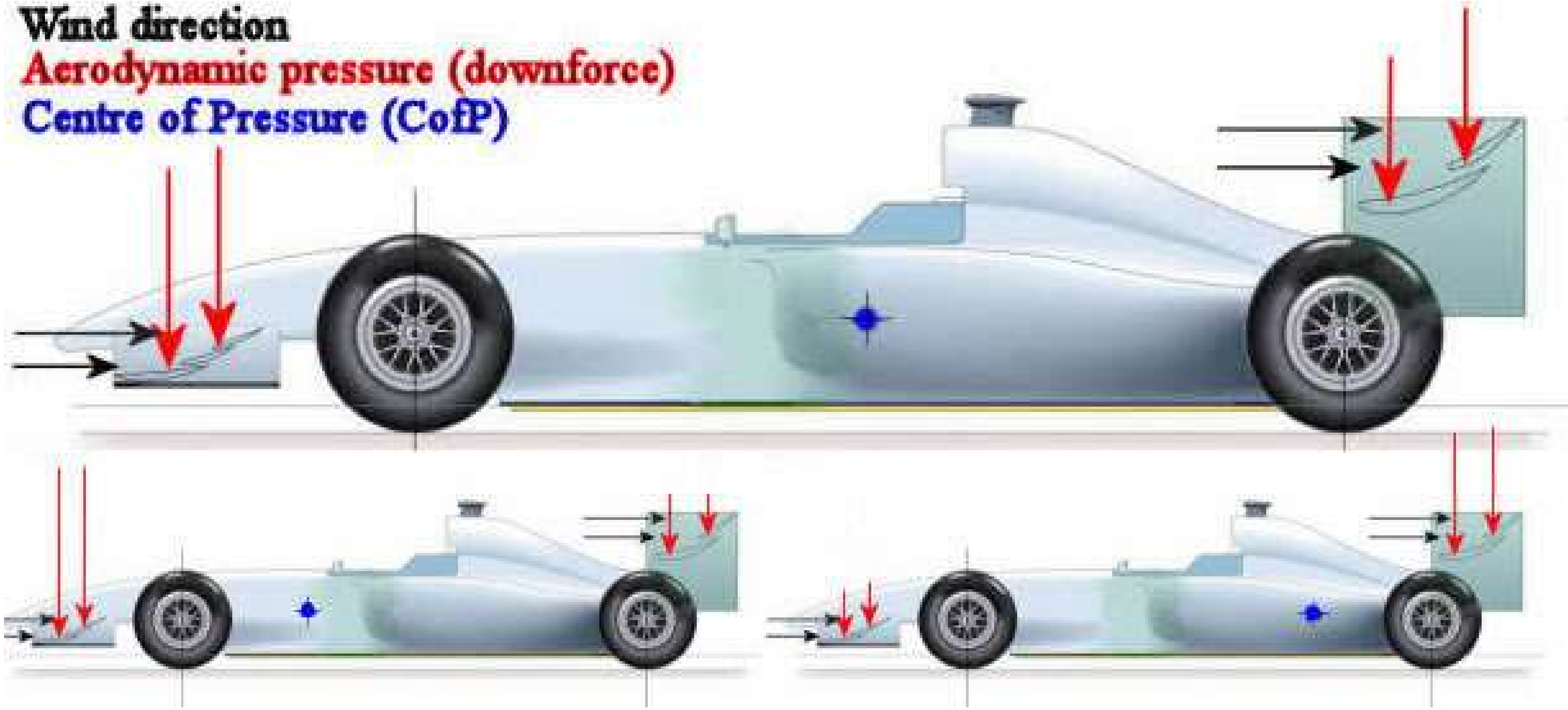
Resistance





Sematic view of air resistance (drag) *red* = *thrust (shape)*, *yellow* = friction, *green* = internal resistance, turbulence, *blue* = induced resistance)

Aero - CoP


Wind direction
Aerodynamic pressure (downforce)
Centre of Pressure (CofP)

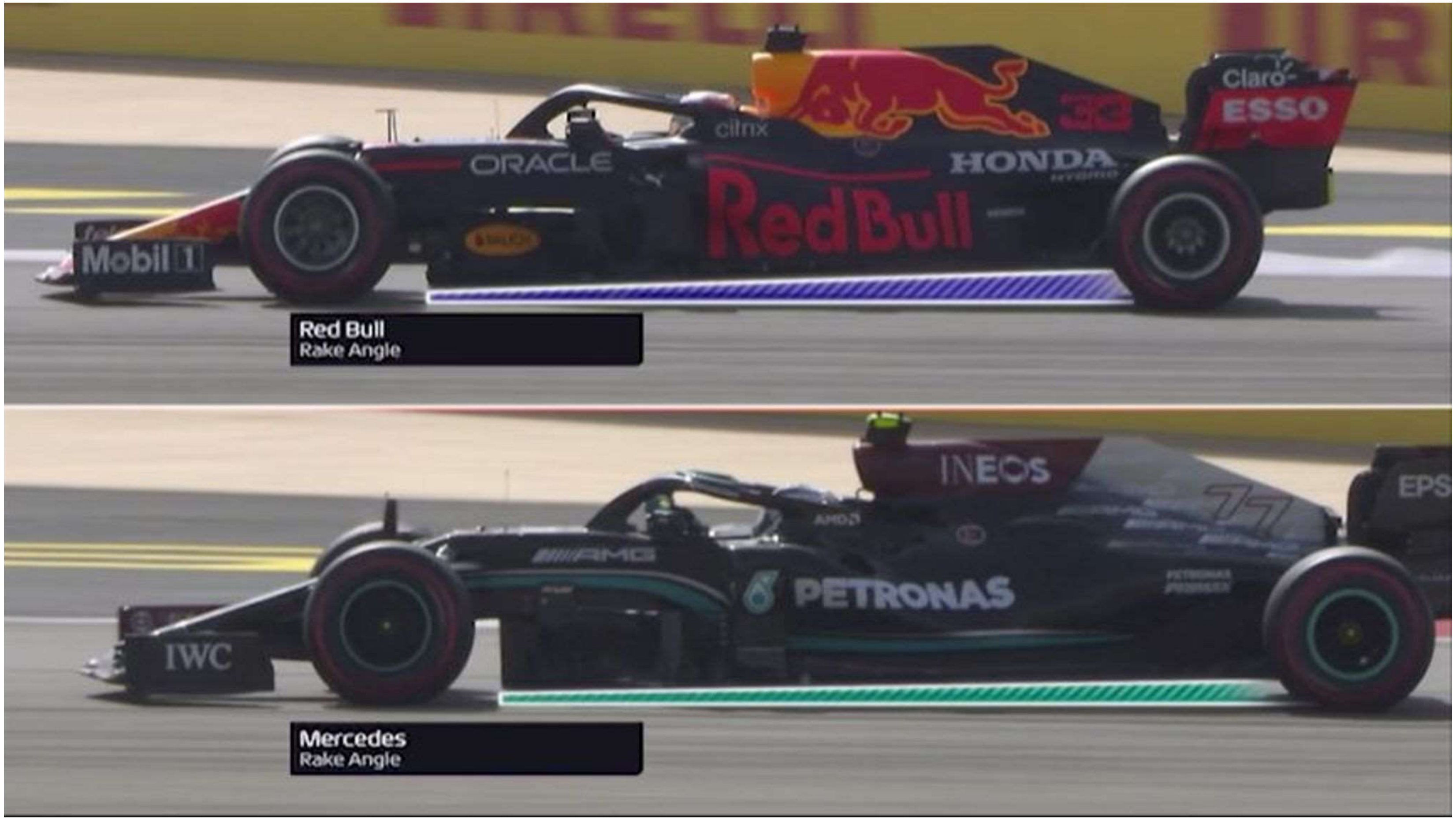
Powertrain

Aero

$$F_{drag} = c_D \cdot A_D \cdot \frac{\rho}{2} \cdot v^2$$

$$F_{down} = c_L \cdot A_L \cdot \frac{\rho}{2} \cdot v^2$$

Aero - rake



$$F_{drag} = c_D \cdot A_D \cdot \frac{\rho}{2} \cdot v^2$$

$$F_{down} = c_L \cdot A_L \cdot \frac{\rho}{2} \cdot v^2$$

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Aero - rake

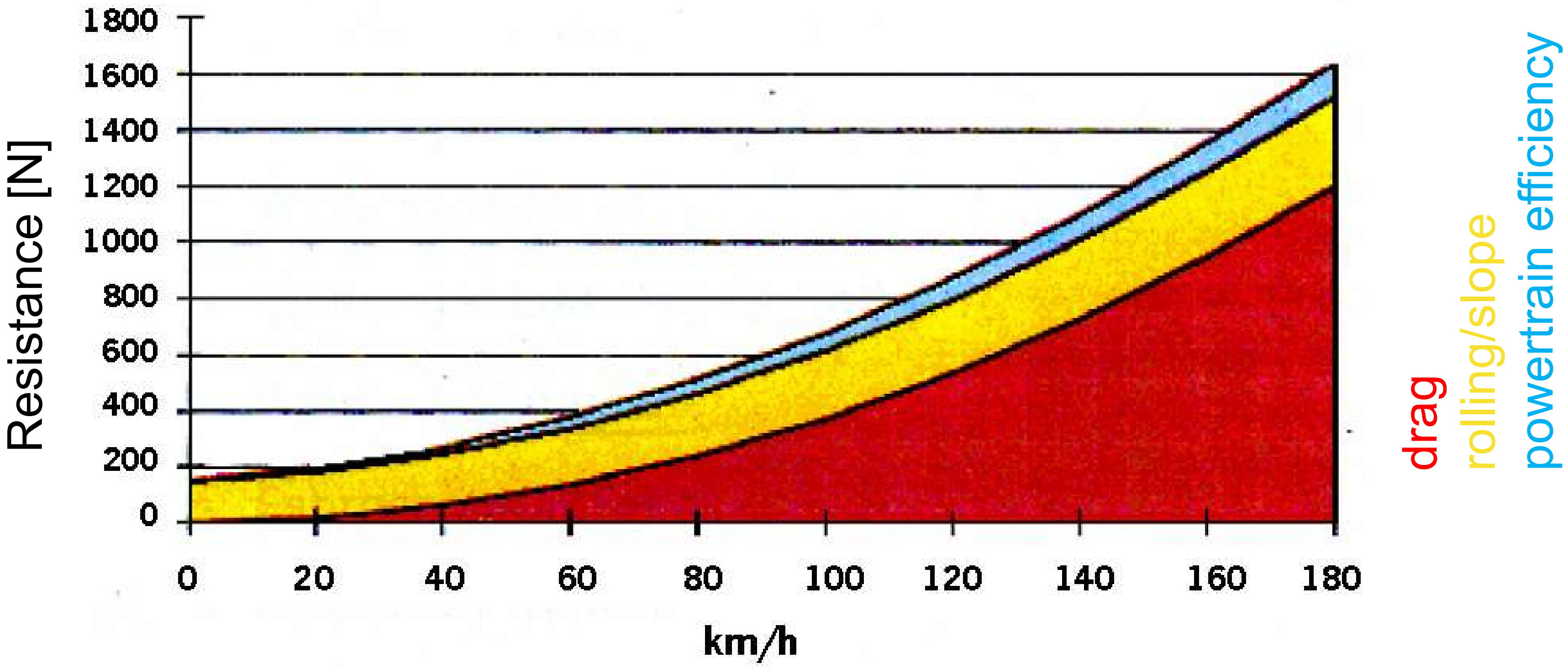
What will happen with the frontal area by definition?

$$F_{drag} = c_D \cdot A_D \cdot \frac{\rho}{2} \cdot v^2$$

$$F_{down} = c_L \cdot A_L \cdot \frac{\rho}{2} \cdot v^2$$

Powertrain

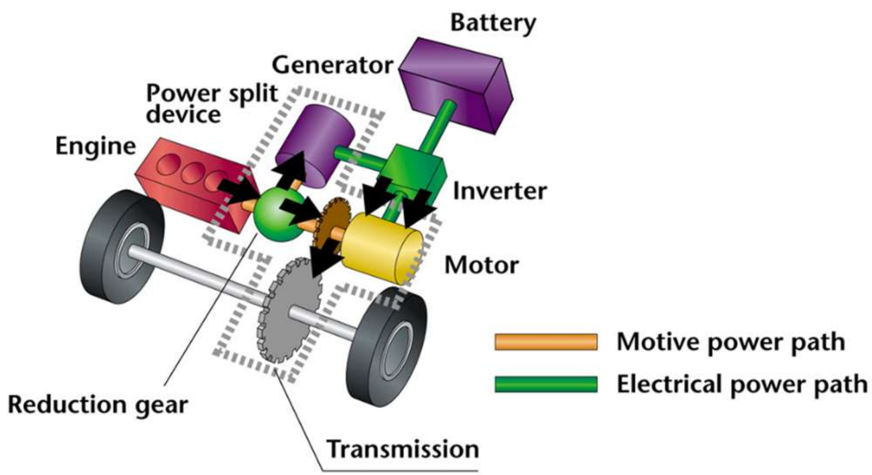
Resistance

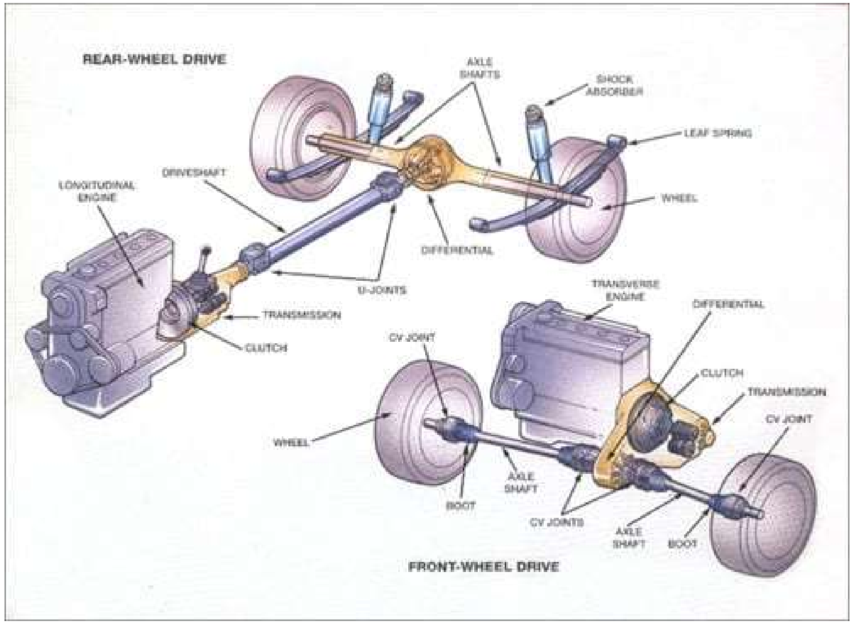


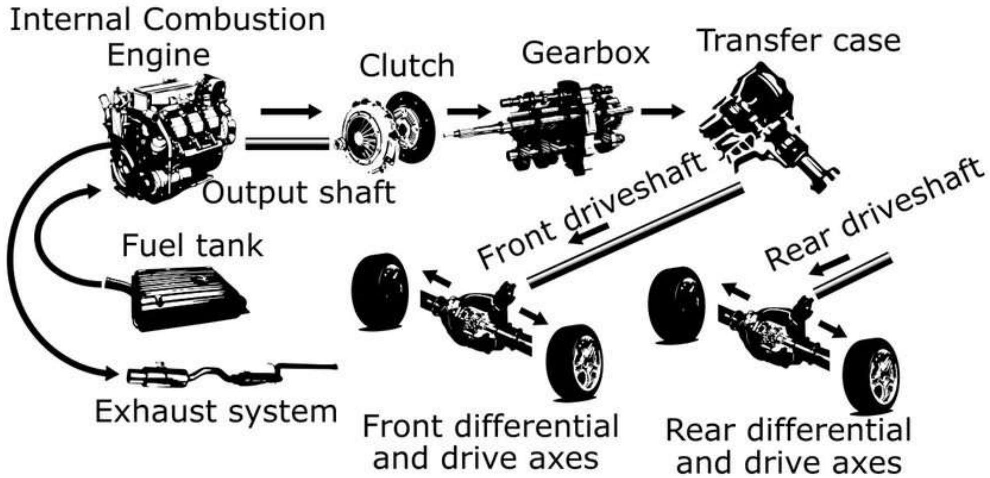
over 80 km/h the dominant effect is the drag

Powertrain

THS – Toyota Hybrid System

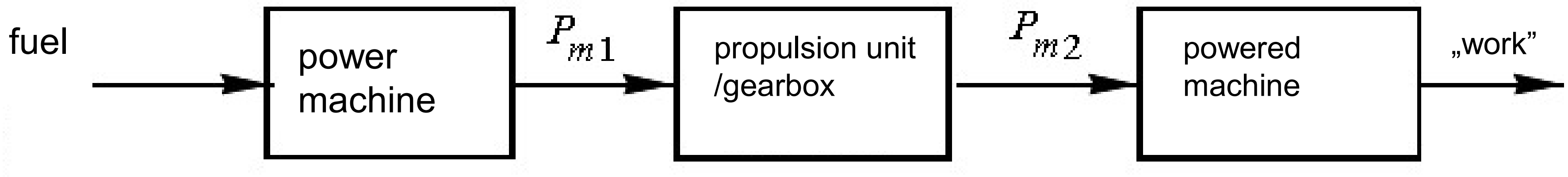






Powertrain

Powertrain general layout



coal
oil
natural gas
solar
wind

producing mechanical power
steam engine
steam turbine
water turbine
gas turbine
ICE
electric motor

mech. power transformation
steam engine
steam turbine
water turbine
gas turbine
ICE
electric motor

mech. power usage
work machine
transportation
manufacturing
vehicles

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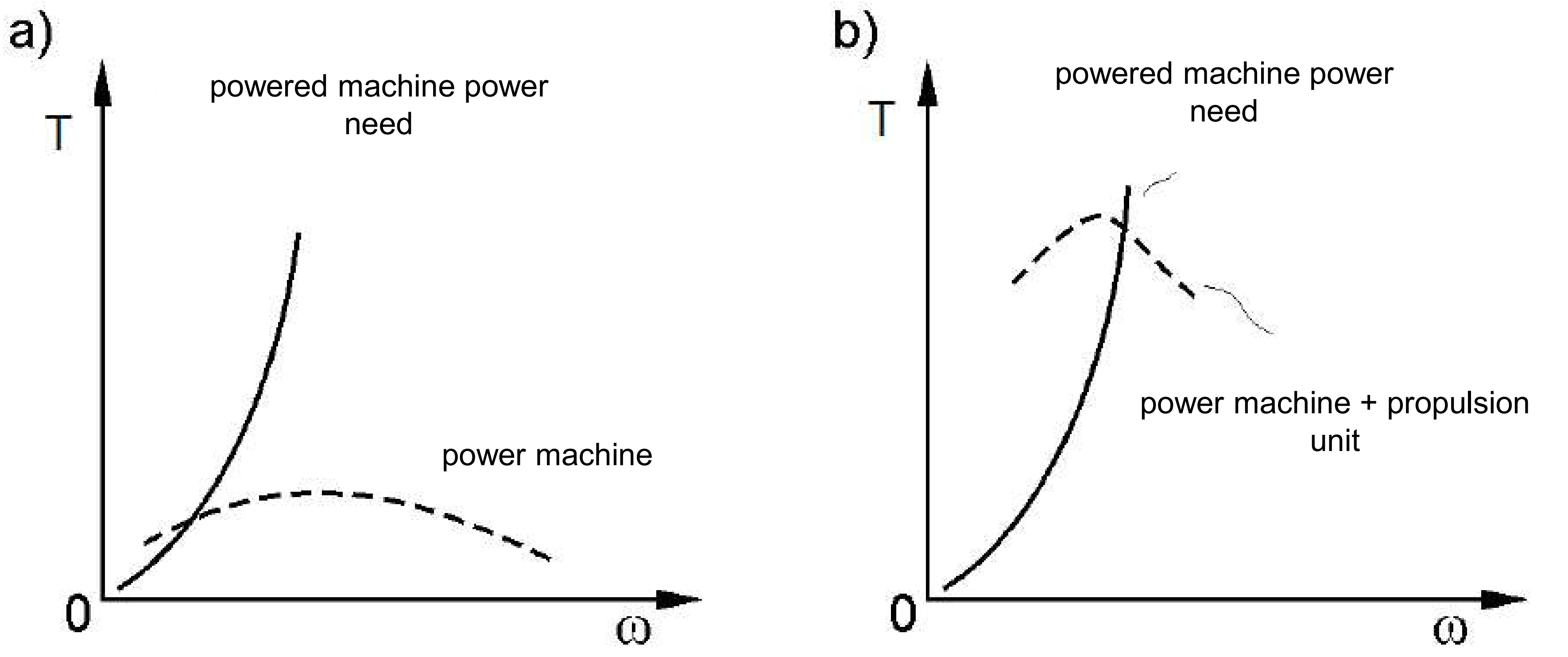
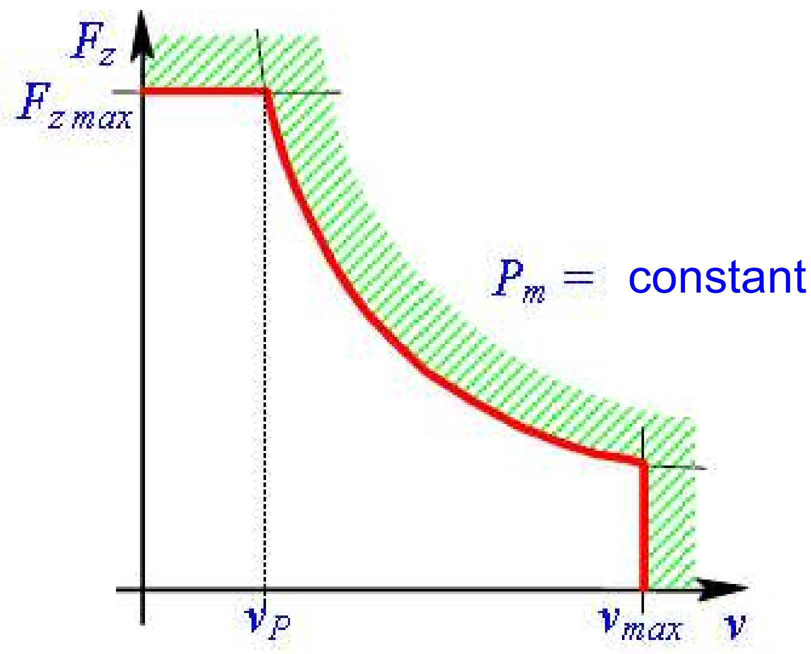
- Propulsion unit /Gearbox: the characteristics of (angular speed - torque) power and powered machine has to be synchronized

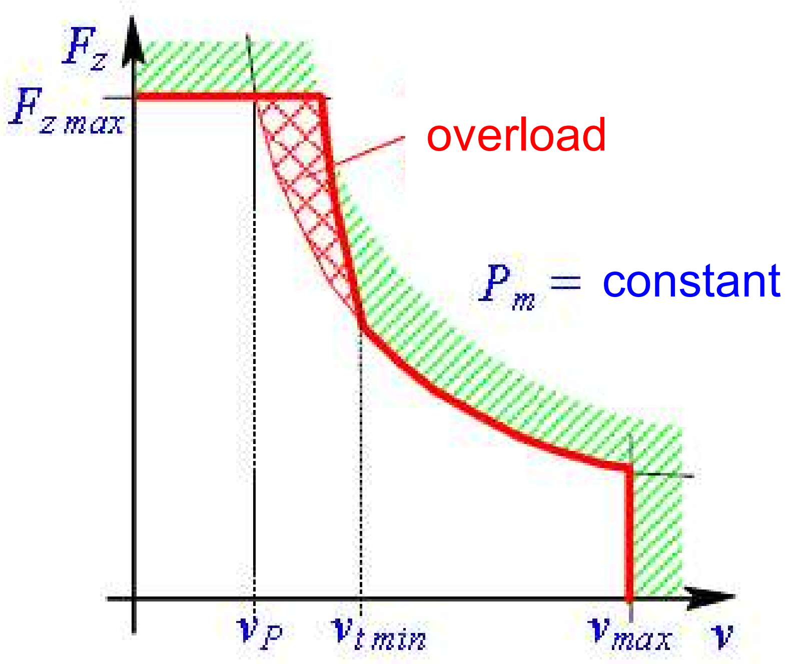
a.) actual status b.) required status



Traction force diagram

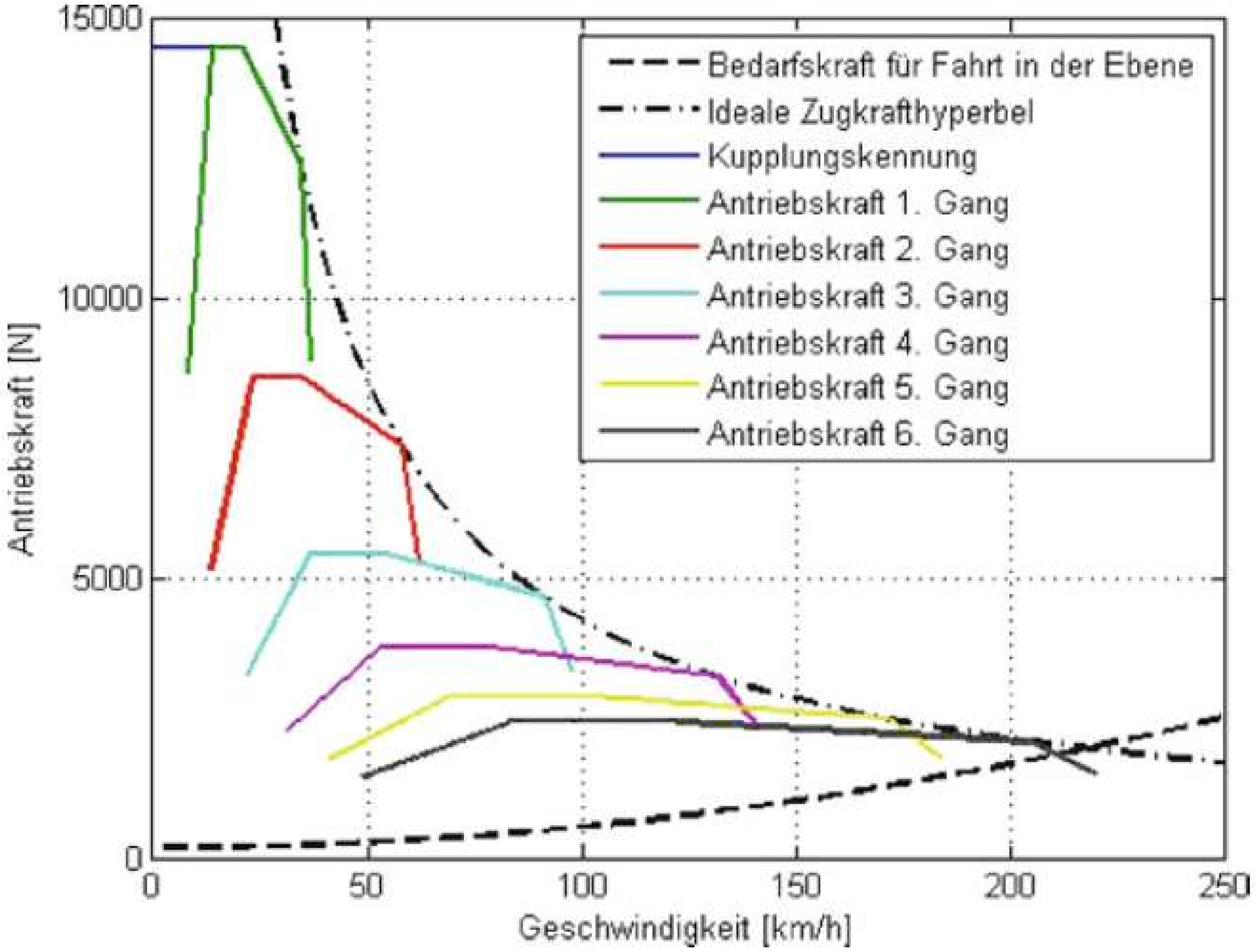


a.) powertrain overload not possible



b.) powertrain overload

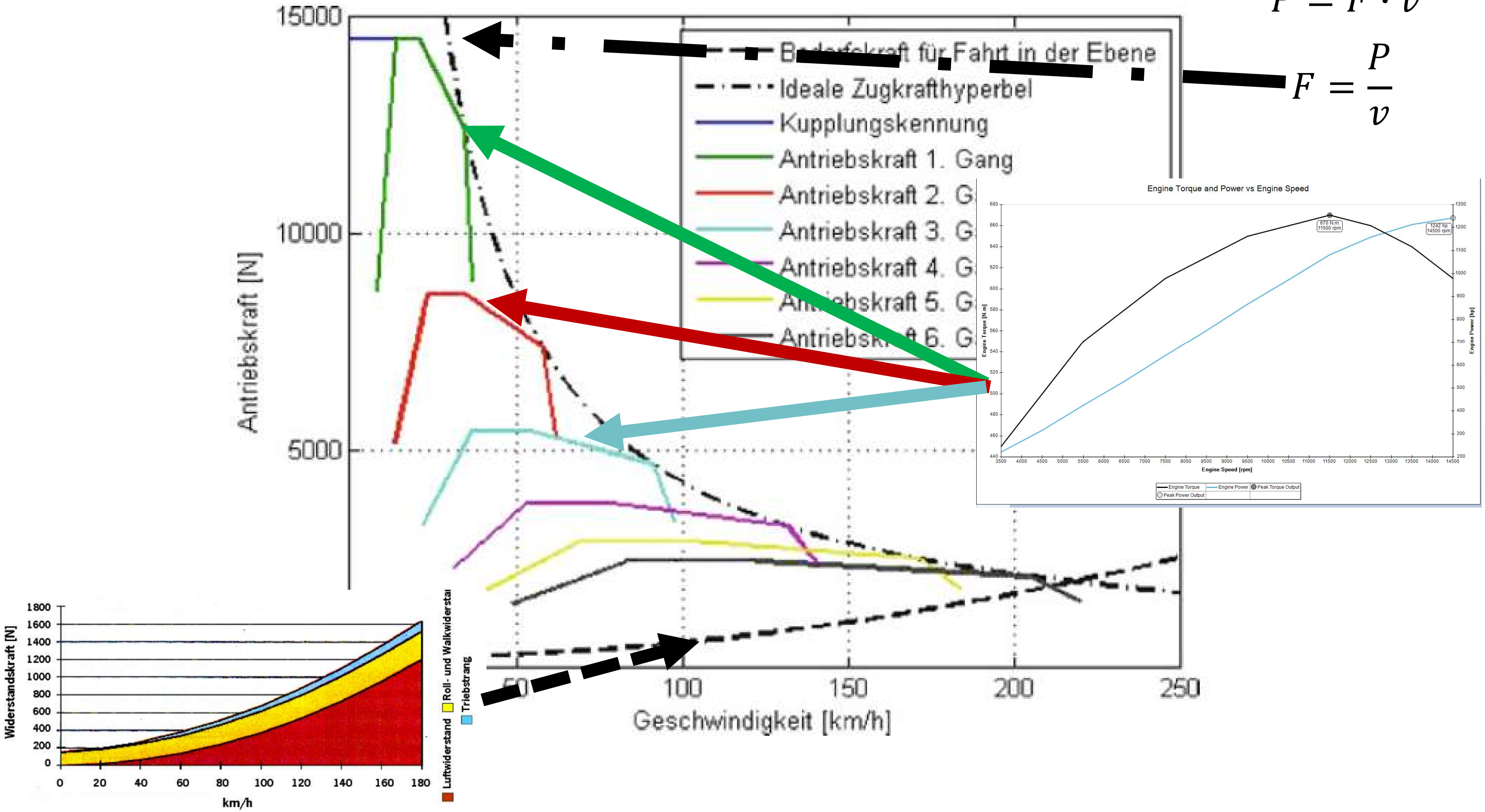
Traction force diagram



Traction force diagram

$$P = F \cdot v$$

$$F = \frac{P}{v}$$



Powertrain

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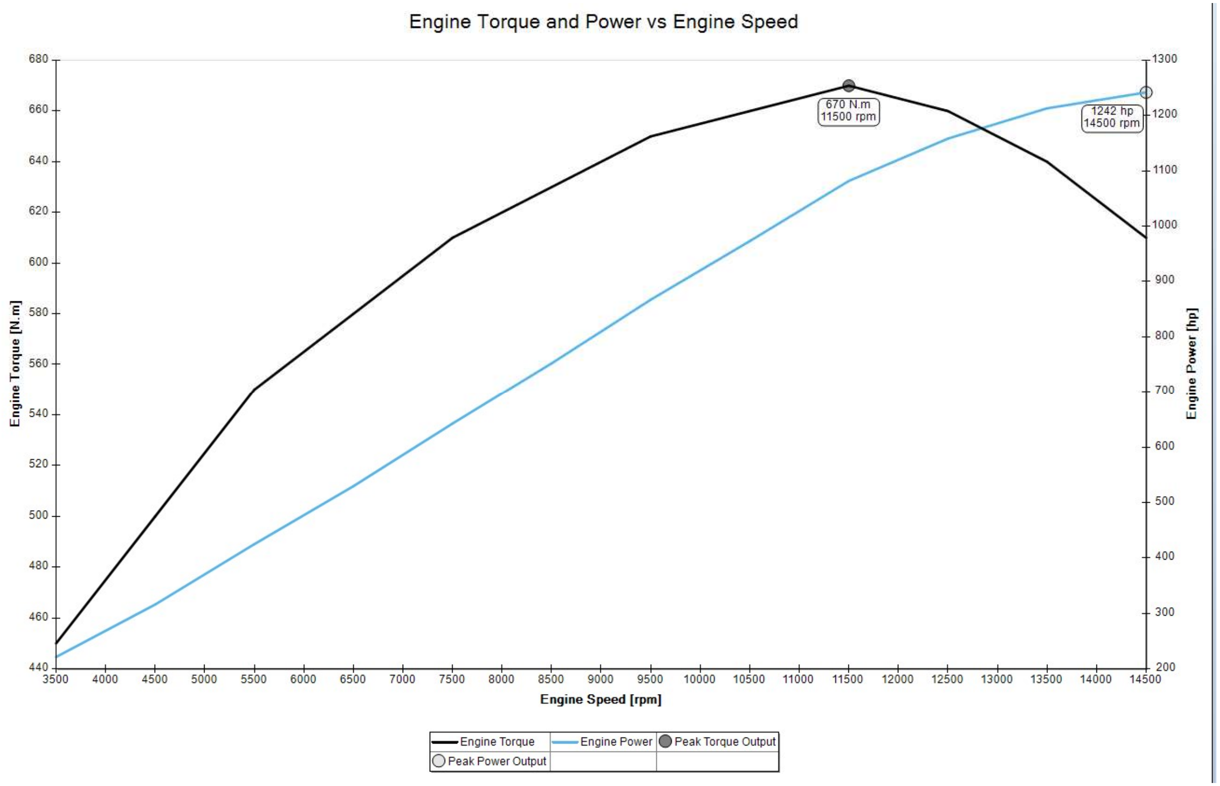
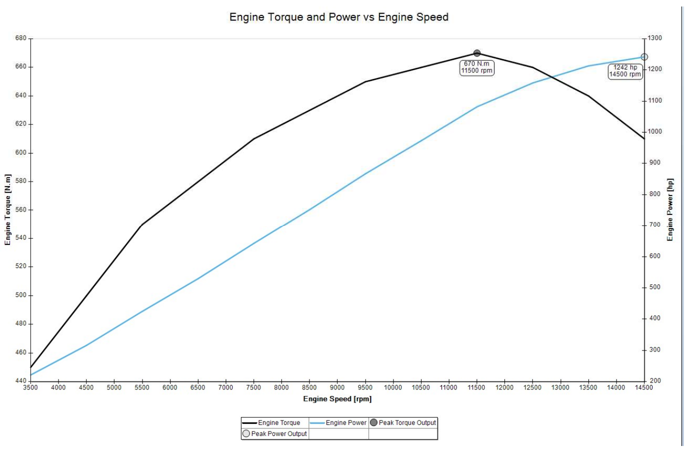
Traction force diagram

Engine Speed (rpm)	Engine Torque (N.m)
3500	450.00
4500	500.00
5500	550.00
6500	580.00
7500	610.00
8500	630.00
9500	650.00
10500	660.00
11500	670.00
12500	660.00
13500	640.00
14500	610.00

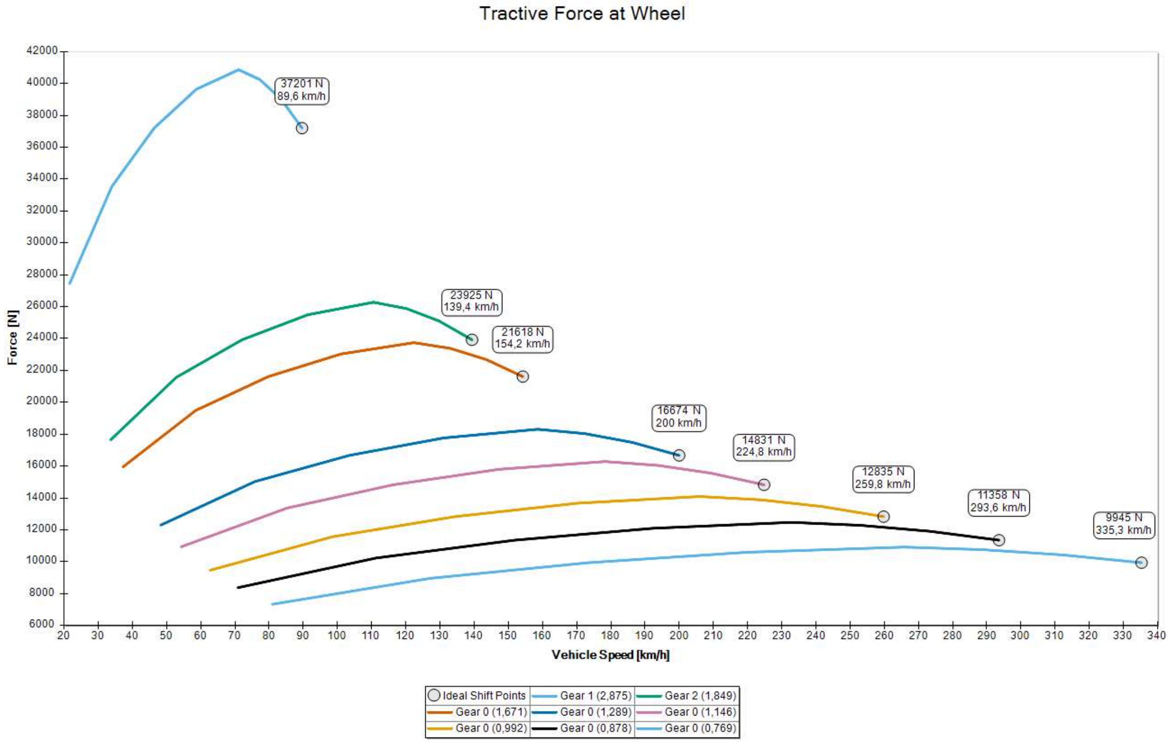


Powertrain

Driveline Model

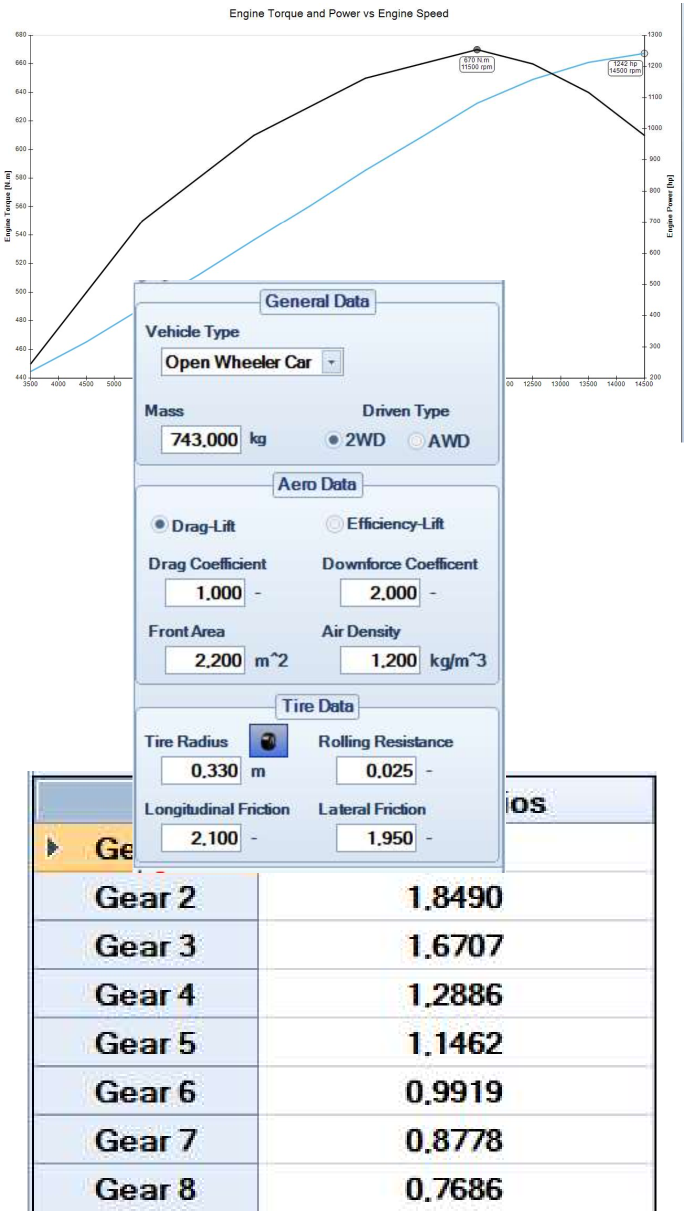


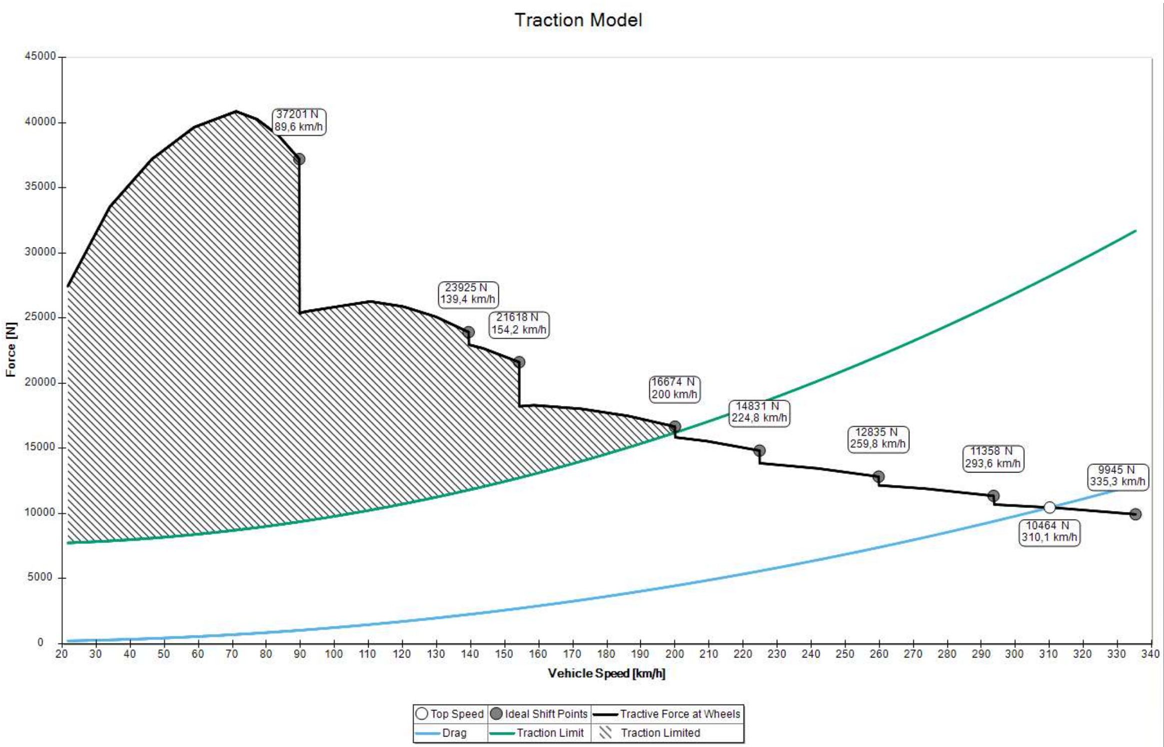
	Gear Ratios
Gear 1	2,8750
Gear 2	1,8490
Gear 3	1,6707
Gear 4	1,2886
Gear 5	1,1462
Gear 6	0,9919
Gear 7	0,8778
Gear 8	0,7686



What else is missing?

Traction Model



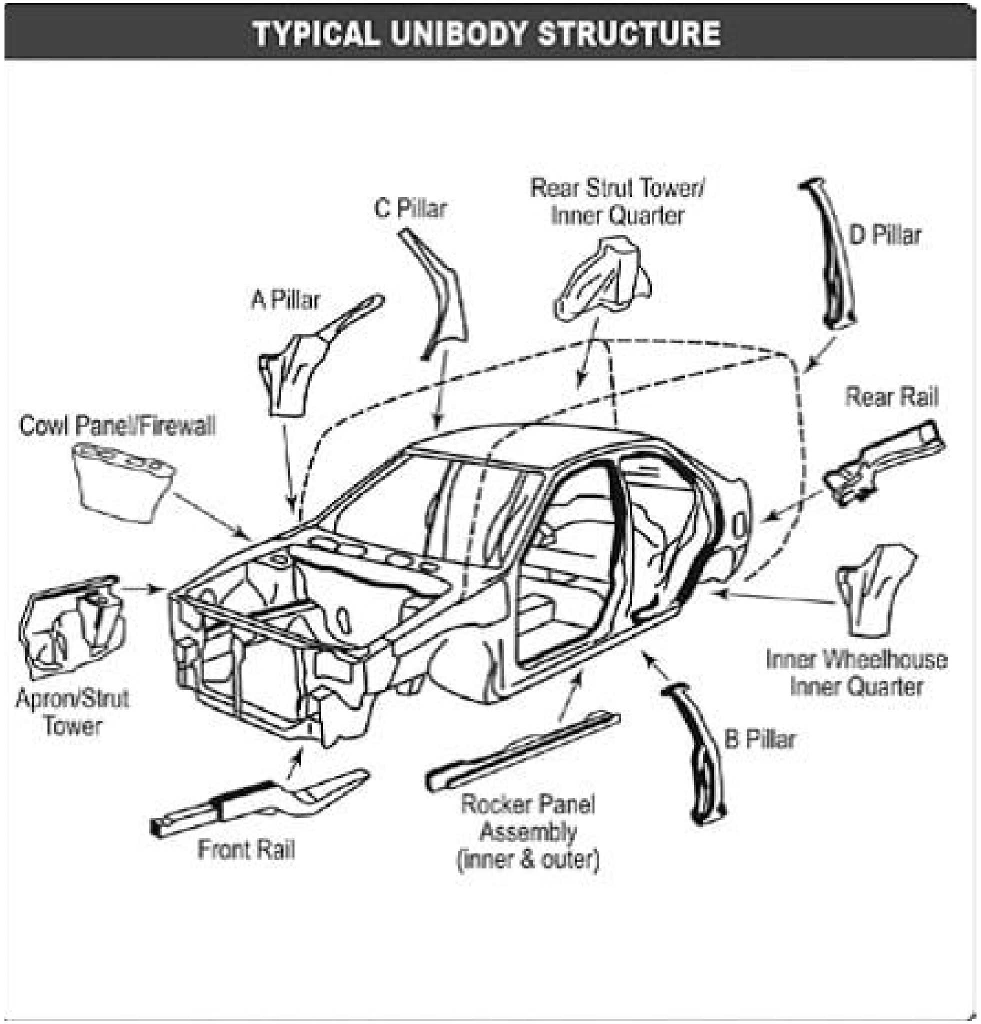


Traction Model

$$efficiency = \frac{c_l}{c_d}$$

Optimum lap check!

Chassis



TYPICAL UNIBODY STRUCTURE
C Pillar
Rear Strut Tower/
Inner Quarter
D Pillar
A Pillar
Rear Rail
Cowl Panel/Firewall
Apron/Strut
Tower
Inner Wheelhouse
Inner Quarter
B Pillar
Rocker Panel
Assembly
(inner & outer)
Front Rail

Mirrors
Hoods
Tailgates
Trunk Lids
Header &
Nose Panels
Tail
Lights
Radiator
Supports
Step
Bumpers
Grilles
A/C
Condensers
Bumpers
Headlights
Fenders
Radiators
Doors

Chassis

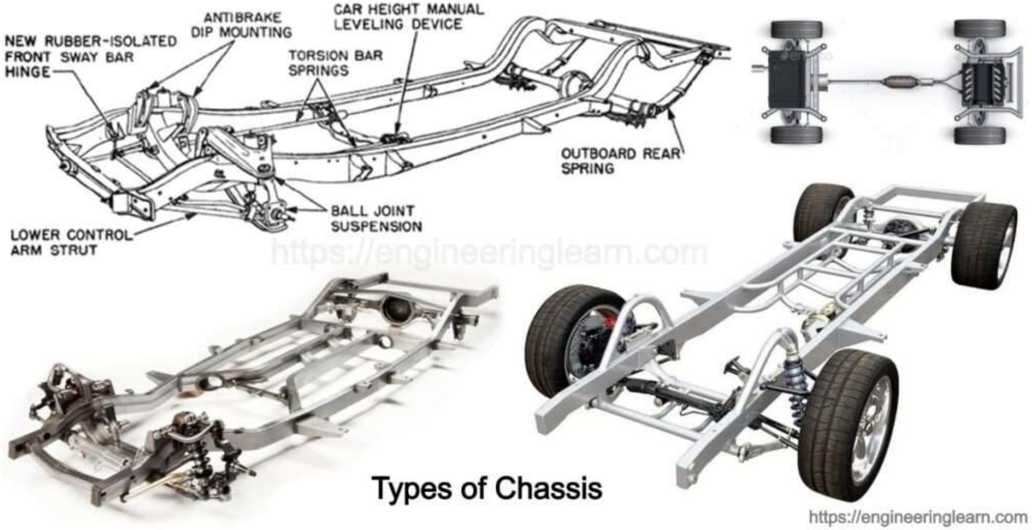
Function

- base for mounting
  - powertrain
  - suspension
  - steering …
- passenger zone
- let passengers in/out, ergonomics
- safety
- ensure proper torsional stiffness

Chassis

Types - Conventional

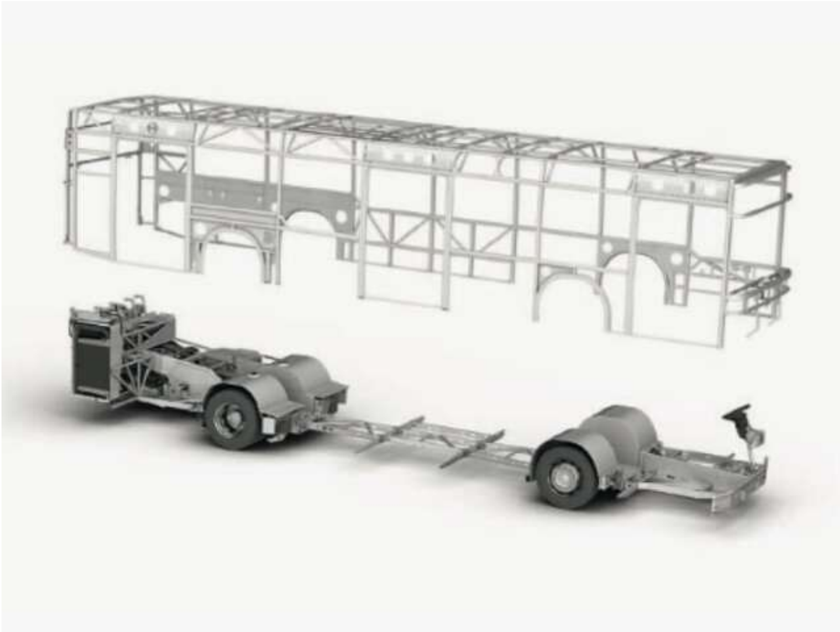
- Conventional
- open/ non-load carrying type
- separate frame to carry the load from suspension
- bodywork can be manufactured stiff or either flexible material, it is separated by deflection rubber mountings
- obsolete because of concentrated load at mounting points



Chassis

Types - Semi integral

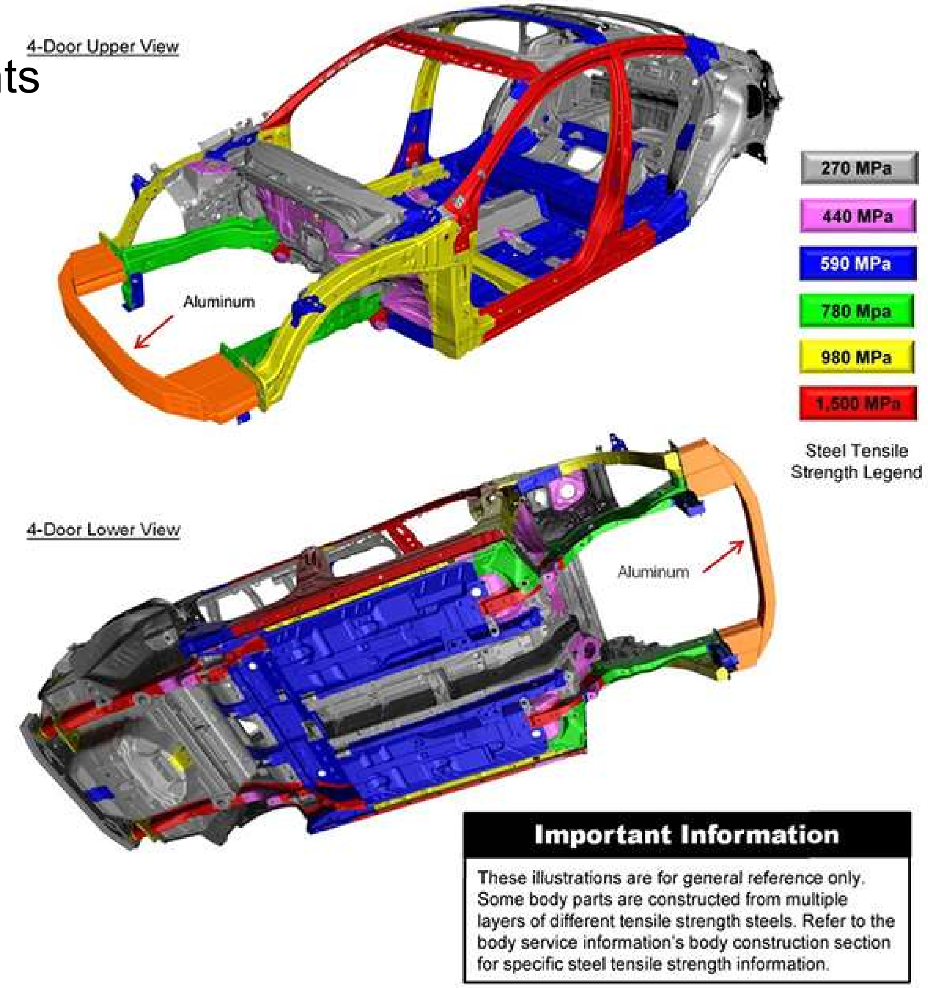
- Semi integral
- bodywork mounting points are stiff
- some of the load transferred to bodywork
- road noise can be eliminated



Chassis

Types - Integral

- Integral
- bodyshell is designed to carry all the load as a framework
- eliminates heavy load-carrier elements
- front and rear extensions, reinforcements
- lighter than any other solution
- widely used in road cars

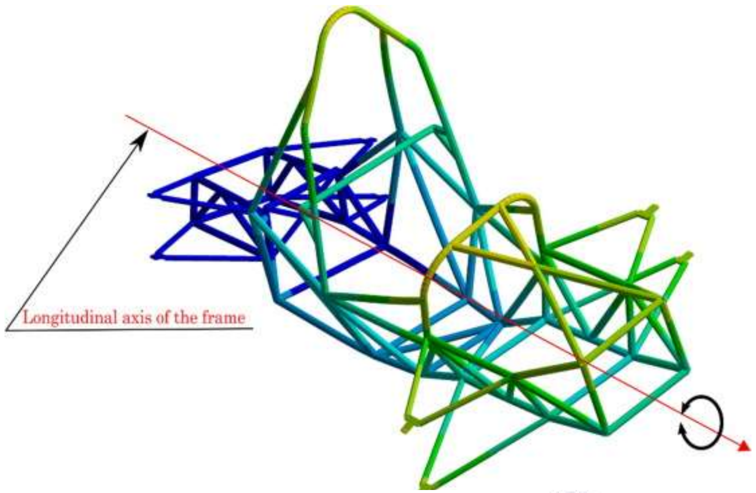


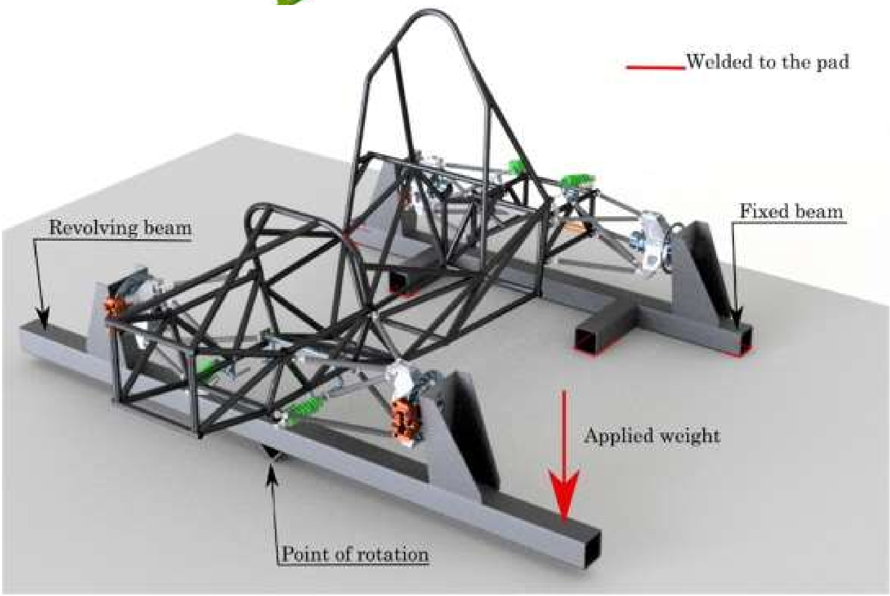
Chassis

Torsional stiffness

Chassis

Torsional stiffness





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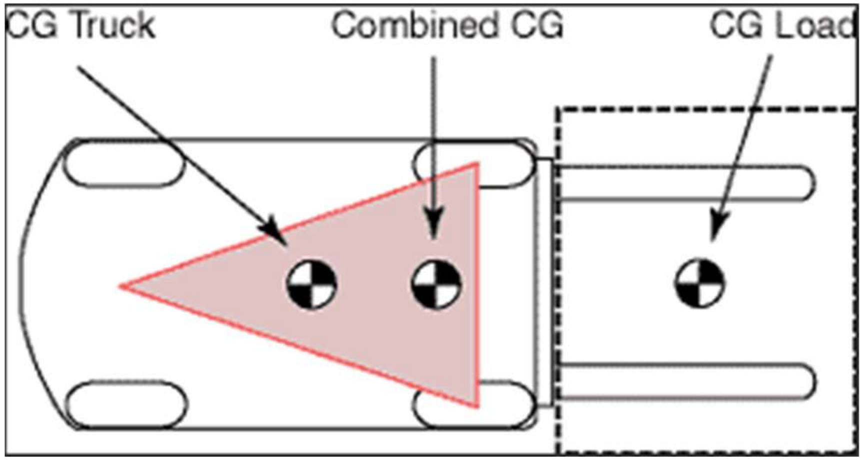
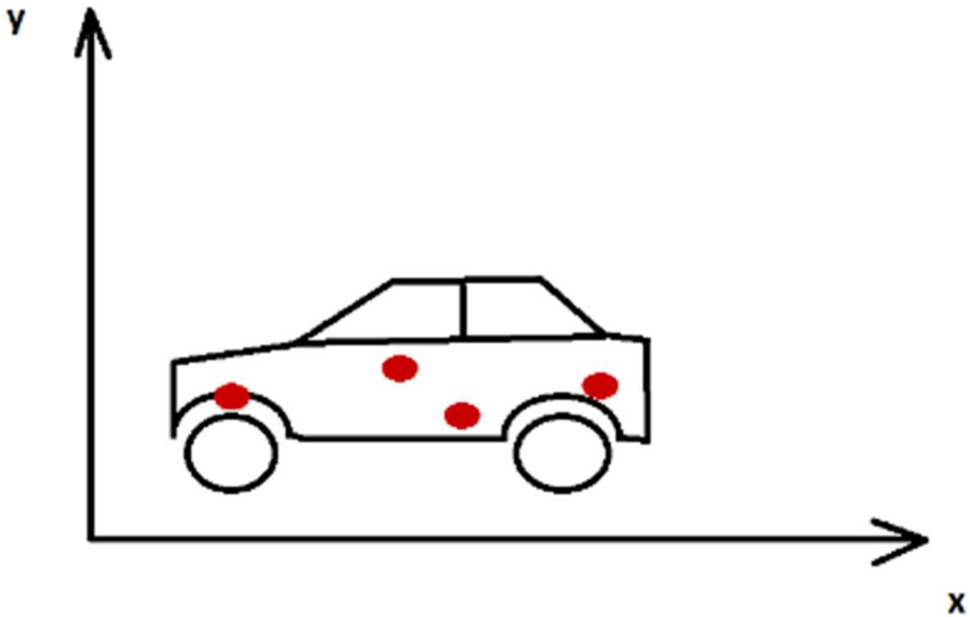
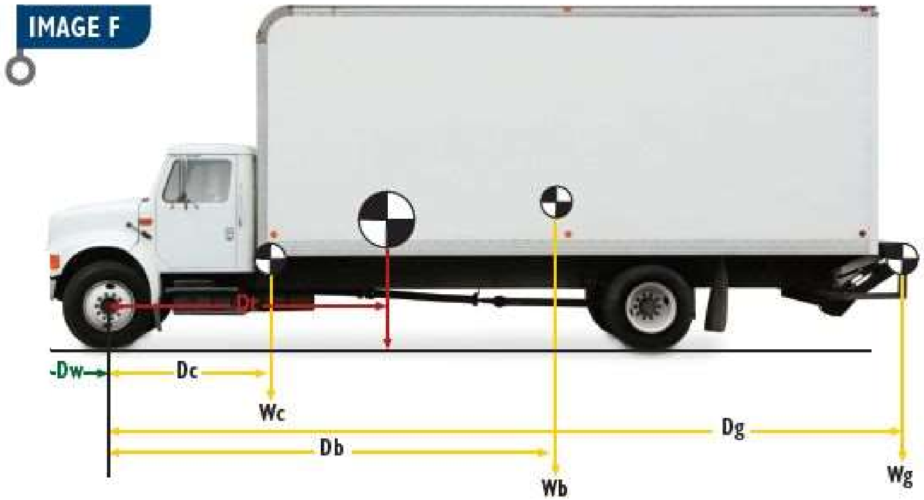
CoG height – Method 1







CoG height – Method 2

Sensors:

- steering angle
- throttle, brake pedal
- rpm
- accelerations (x,y)
- brake pressure
- speed – GPS
- wheel speed
- wheel travel
- temps
- gear
- …

CoG height – Method 2

Sensors:

- steering angle
- throttle, brake pedal
- rpm
- accelerations (x,y)
- brake pressure
- speed – GPS
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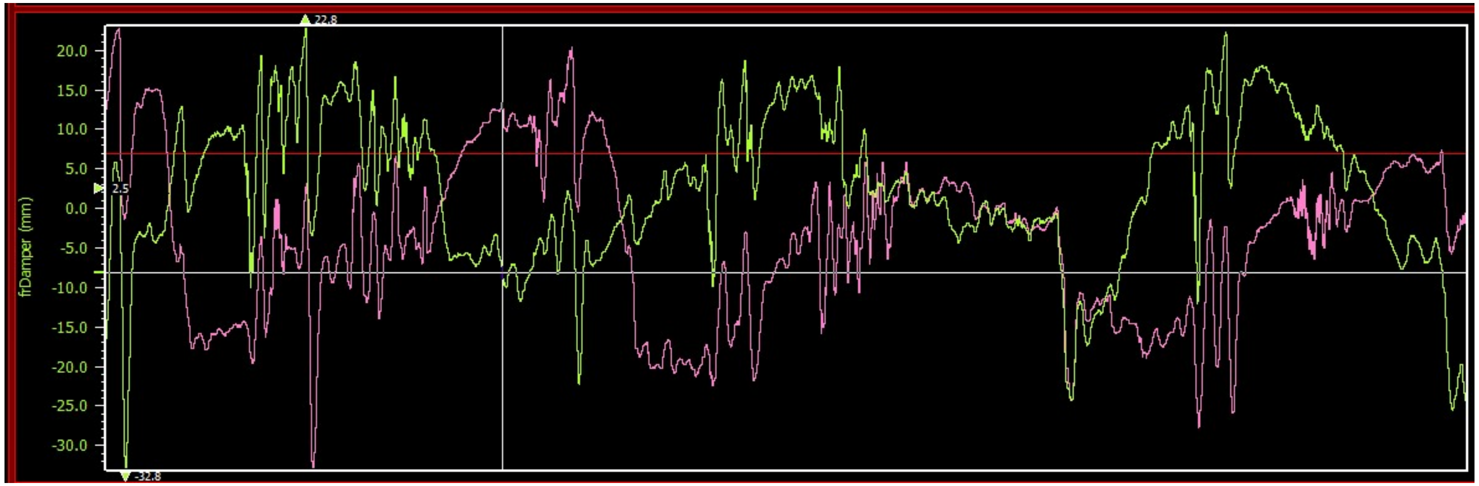
- wheel travel
- temps
- gear
- …

1.Normal force from spring stiffness

$F_{z,d} = k \cdot z_d$



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CoG height – Method 2

Sensors:

- steering angle
- throttle, brake pedal
- rpm
- accelerations (x,y)
- brake pressure
- <u>speed – GPS</u>
- wheel speed
- <u>wheel travel</u>
- temps
- gear
- …

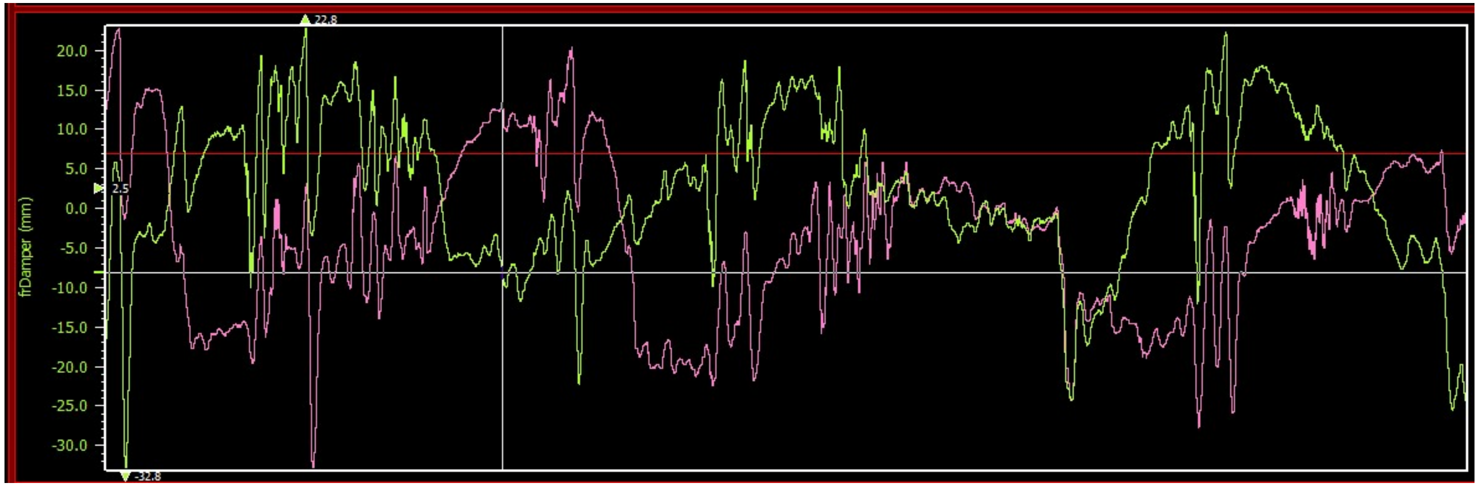
1.Normal force from spring stiffness

$F_{z,d} = k \cdot z_d$

VS

2. Normal force from the equation of weight transfer, assumed CoG height ‚h'

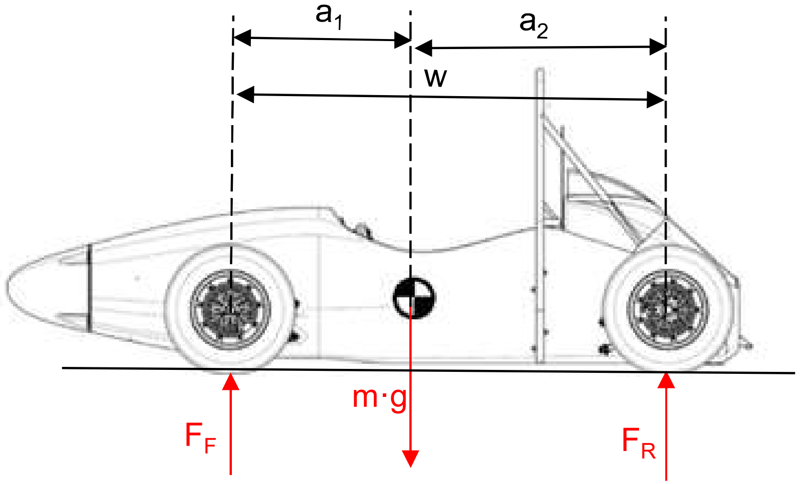
$$F_{z,WT} = \frac{1}{2} \cdot \mathrm{m} \cdot g \cdot \frac{a_2}{w} + m \cdot \dot{v} \cdot \frac{\boldsymbol{h}}{w}$$

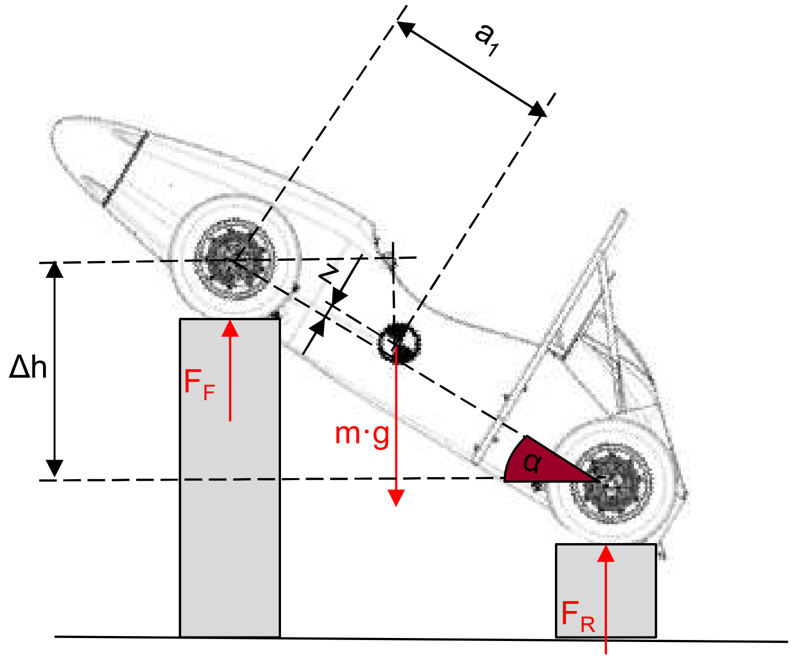


Chassis

CoG height – Method 3

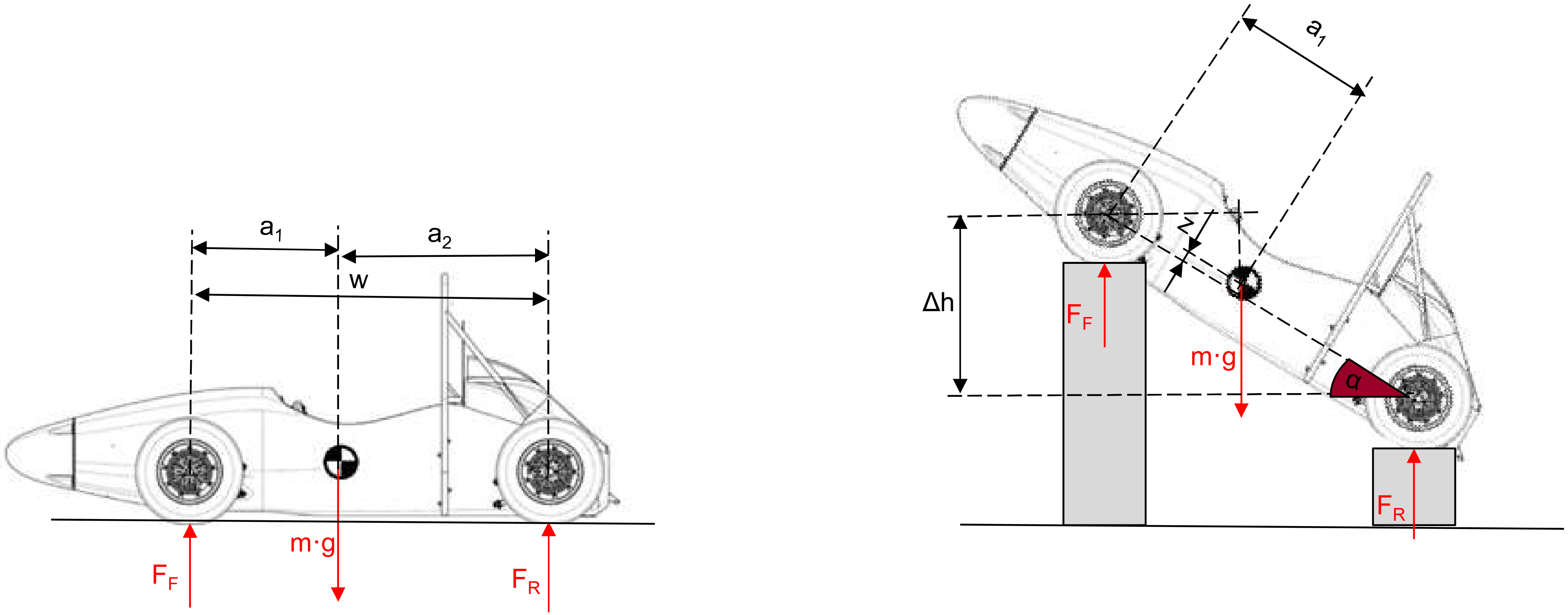
CoG height – Method 3





$$\alpha = arcsin\frac{\Delta h}{w}$$

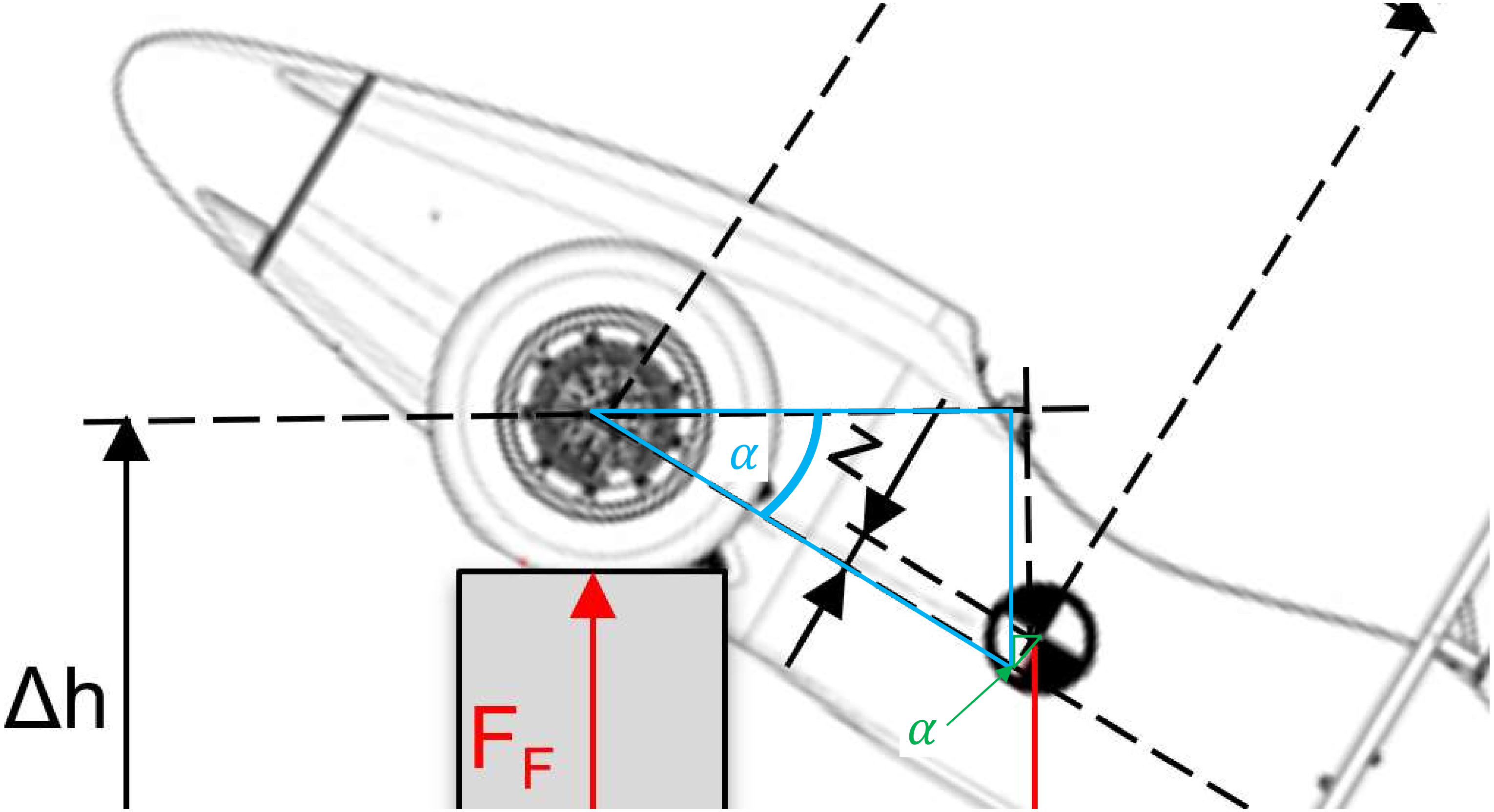
CoG height – Method 3



$$m \cdot g(a_1 \cdot cos\alpha + z \cdot sin\alpha) = F_R \cdot w \cdot cos\alpha$$

$$z = \frac{\frac{F_R \cdot w \cdot cos\alpha}{m \cdot g} - a_1 \cdot cos\alpha}{sin\alpha}$$

CoG height – Method 3



$$m \cdot g(a_1 \cdot cos\alpha + z \cdot sin\alpha) = F_R \cdot w \cdot cos\alpha$$

$$z = \frac{\frac{F_R \cdot w \cdot cos\alpha}{m \cdot g} - a_1 \cdot cos\alpha}{sin\alpha}$$

Midterm tests and exams

1

- know concepts and definitions – you are able to give definitions of :
  - different type of tyre radius
  - contact patch
  - tyre structures
  - slip ratio
  - slip angle
  - aware of the different characteristics of tyre behaviour and able to distinguish one from other
  - friction coefficient
  - brush tyre model and explanation of tyre force
  - able to orientate in the coordinate system of a vehicle
  - cornering stiffnes of a tyre
  - self aligning torque
  - pneumatic trail
  - friction ‚circle'
  - steady state basics equations
  - transient basics equation
  - characteristics of transient basics diagrams

Midterm tests and exams

2

- assymetric tyre behaviour to acceleration and braking
- static vertical tyre loads
- longitudinal weight transfer with the help of longitudinal model
- lateral weight transfer in steady state cornering
- understanding the effect of tyre degressivity and weight transfer
- braking system components
- optimal brake force distribution
- specific braking force
- EBD basic working principle
- Motorsport relevant braking aspects
- Function structure
- Powertrain: Types of resistance
- CoP
- Gearbox/Propulsion unit: power and powered machine tuning
- Traction force diagram
- 3 main type of chassis structure
- CoG determination methods

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Bibliography

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Thank you for your attention!