Department of Automotive Technologies –
Vehicle Mechanics Fundamentals

Gábor Sipos

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Lecture 7

Schedule

Week nr.	Date	Lecture (Wednesday)		Lab (Wednesday)	
1	12th Feb	1	General information, Tyre, Driving force	1	Lab
2	19th Feb	2	Longitudinal and lateral behaviour		
3	26th Feb	3	Concepts and over/understeer	2	Lab
4	5th Mar	4	Weight transfer		
5	12th Mar	5	Bicycle model	3	Lab
6	19th Mar	T1	Midterm exam I.		
7	26th Mar	6	Braking and brakes	T1 R	Exam 1 - replacement
8	2nd Apr	7	Systems of the vehicle		
9	9th Apr	-	Break		Break
10	16th Apr	8	Quarter vehicle model		
-	23th Apr		Break		Break
11	30th Apr	T2	Systems of vehicle II. ONLINE	4	Lab
12	7th May	9	Tyre management		
13	14th May	10	Midterm exam II.	11	Racecar engineering
14	21st May	T2 R	Exam 2 - replacement		

General engineering approach

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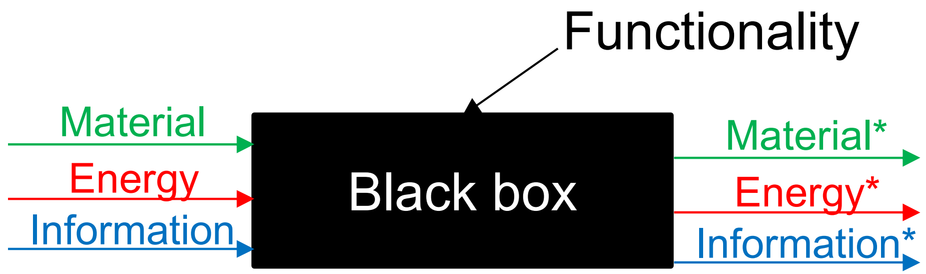
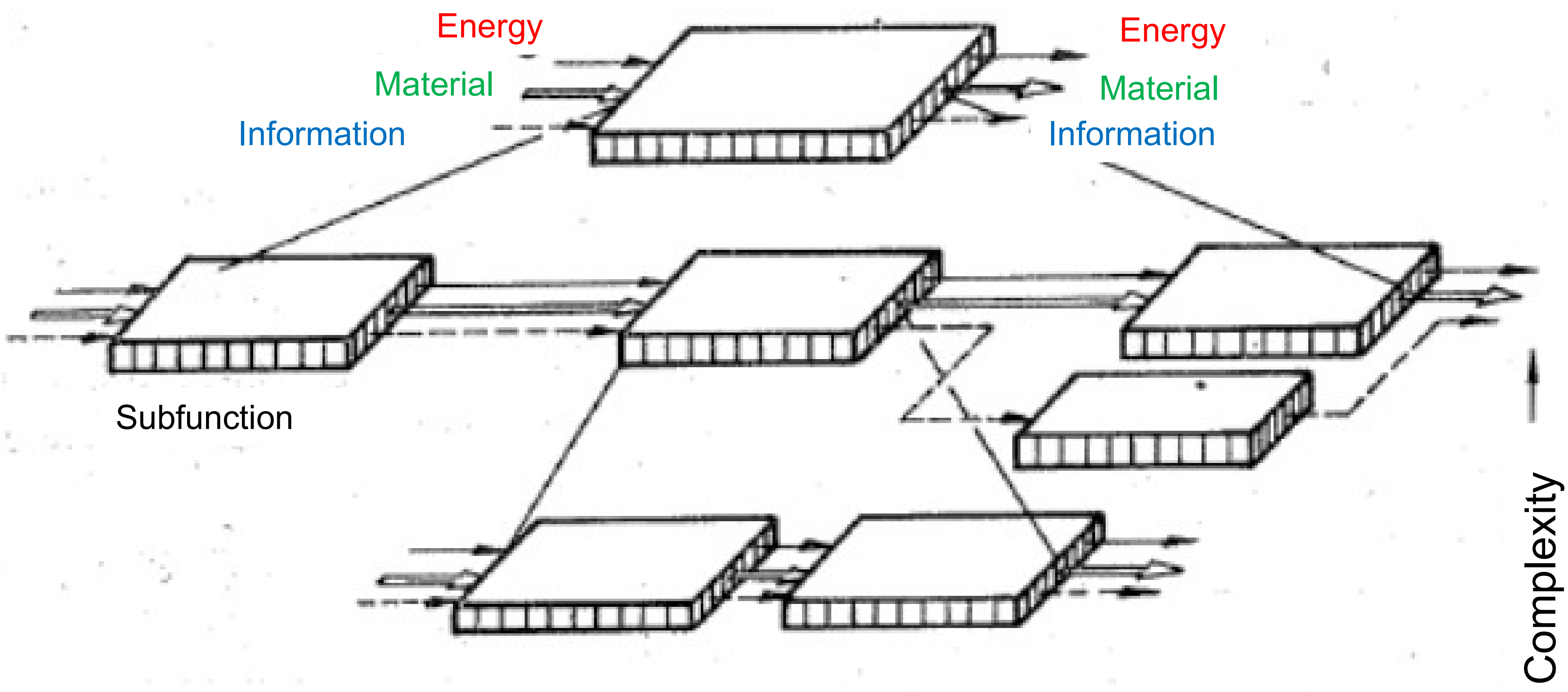


- functional structure
- main function, subfunction, elementary function
- CAN
- HV cables
- mounting brace

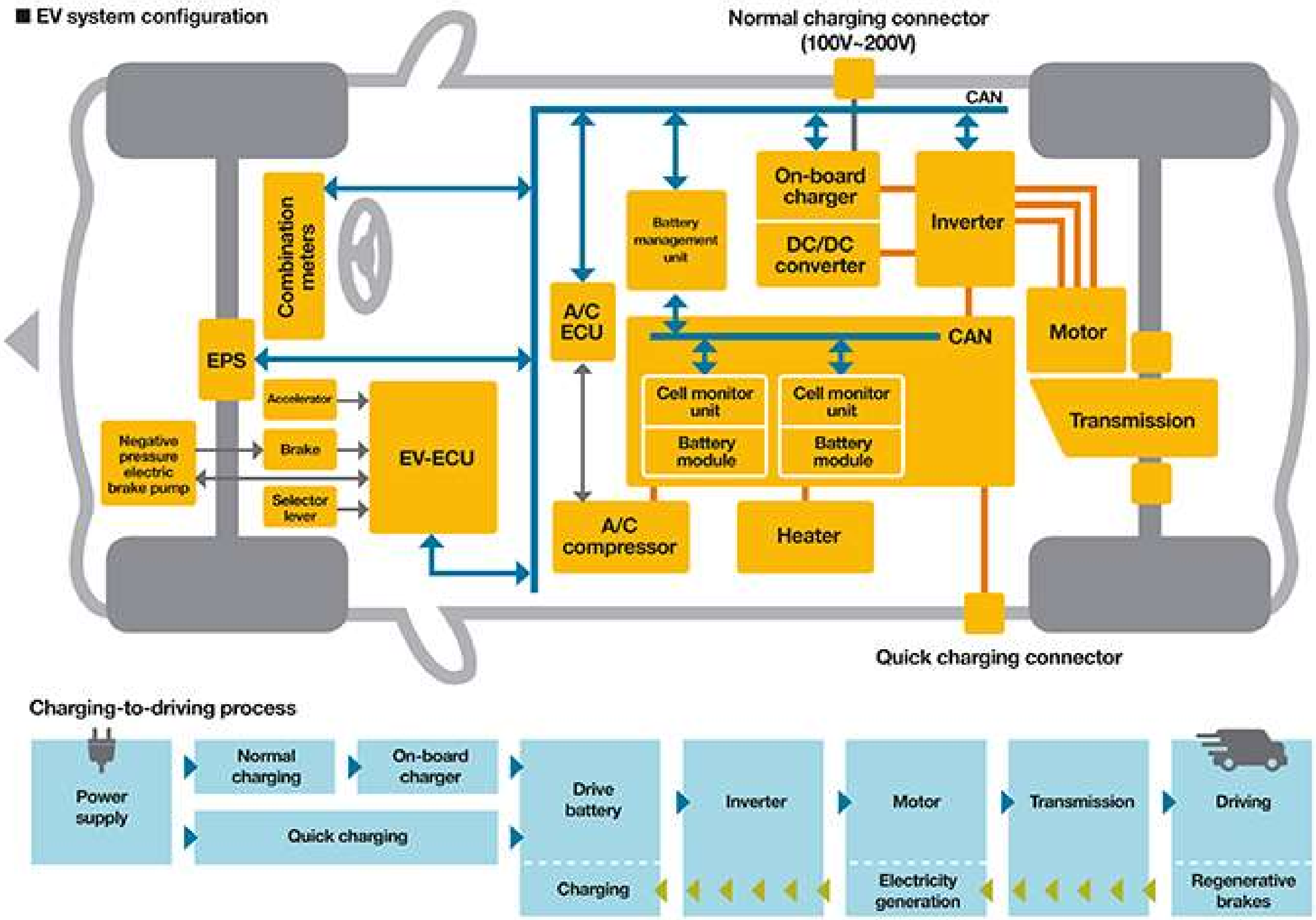
General engineering approach

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:

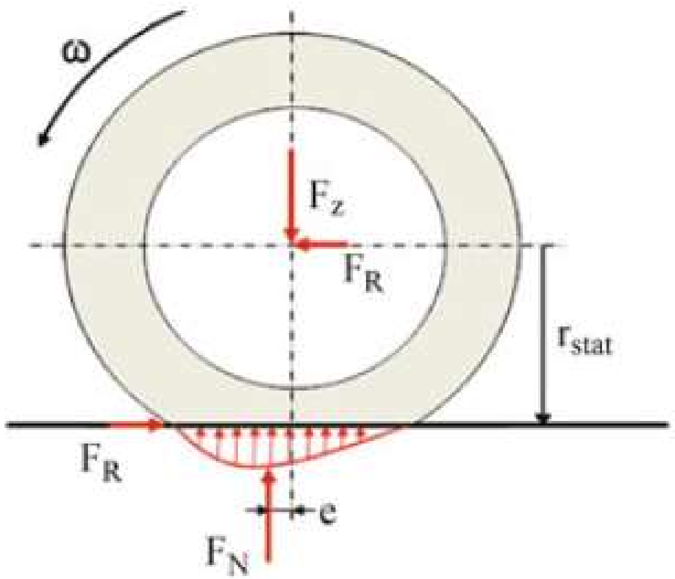
$$F_{res} = F_{roll} + F_{air} = fmg + \frac{1}{2}\rho_{air} \cdot c_d \cdot A \cdot v^2$$

Resistance

- Rolling

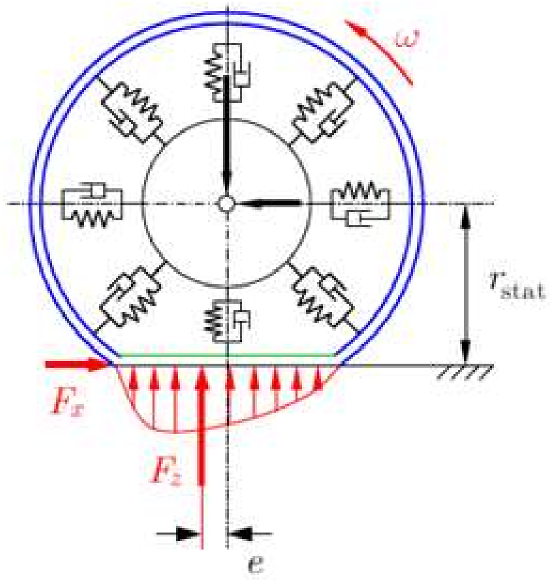
- Resistance forces acting on flat-moving vehicles:

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



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

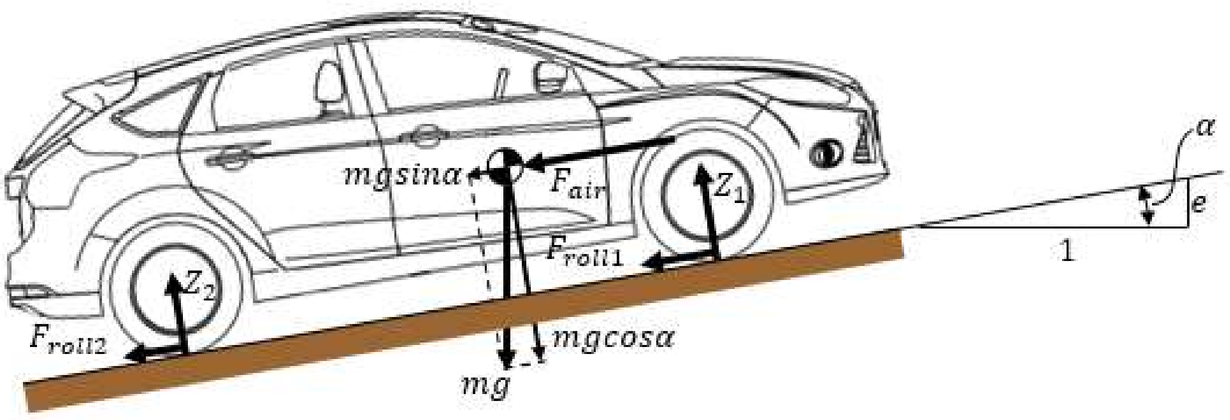
$$F_R = \frac{e}{r_{stat}} \cdot F_N = f_R \cdot F_Z$$



Powertrain

Resistance

- Slope



- Interpretation of the slope percentage:

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

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

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

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

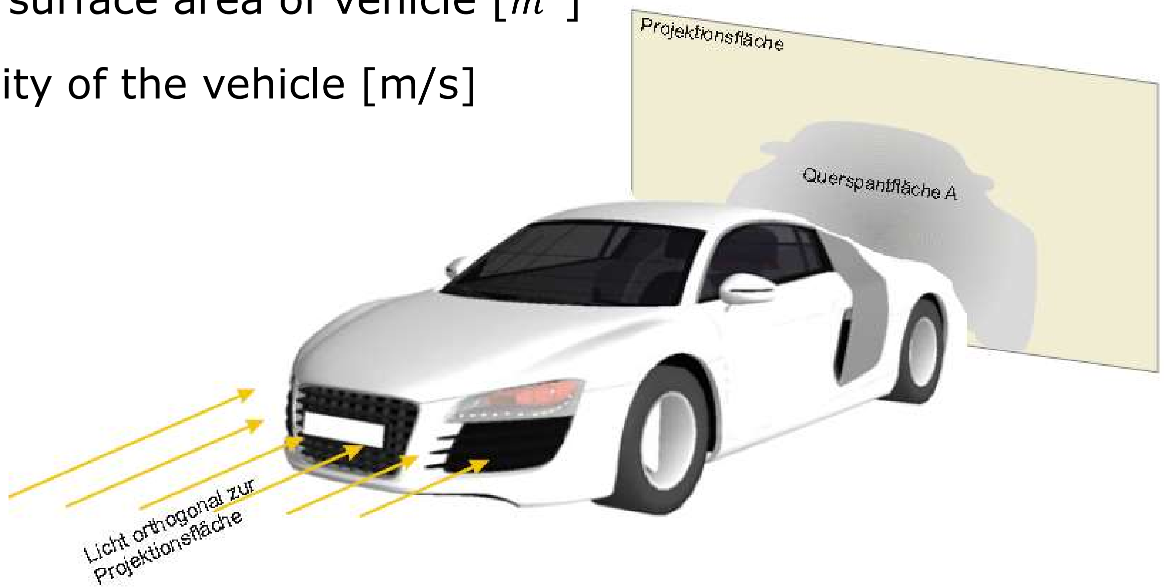
Resistance

- Drag

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

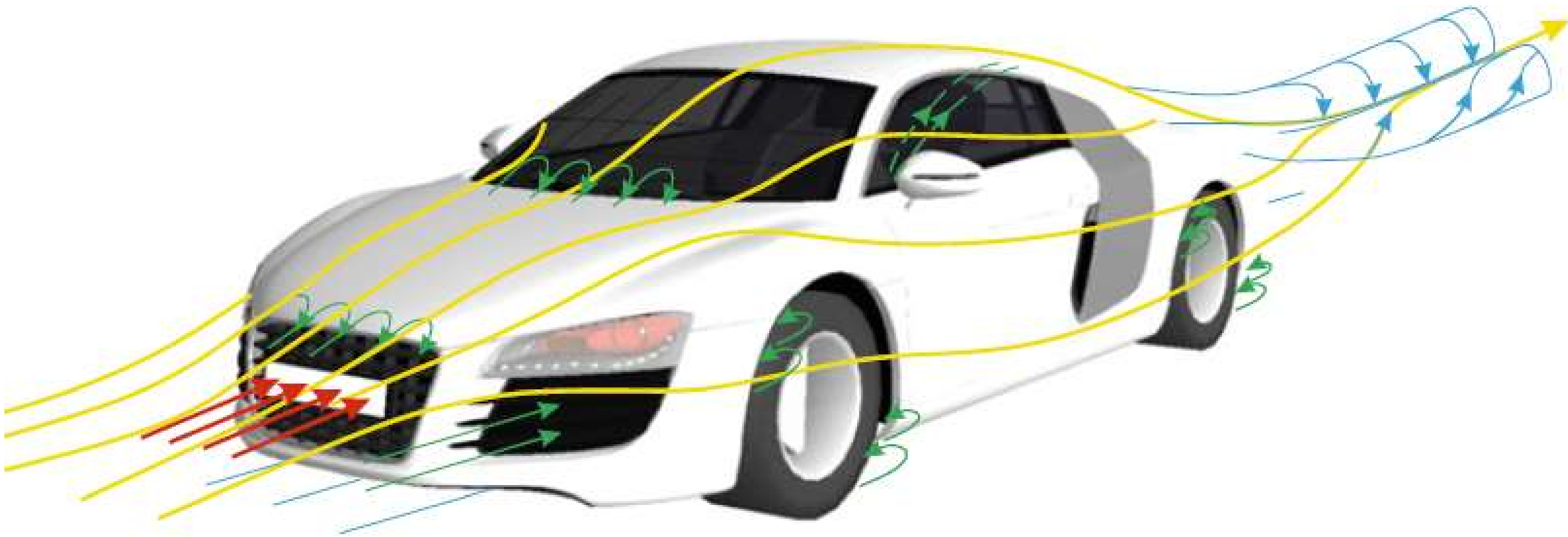
where:

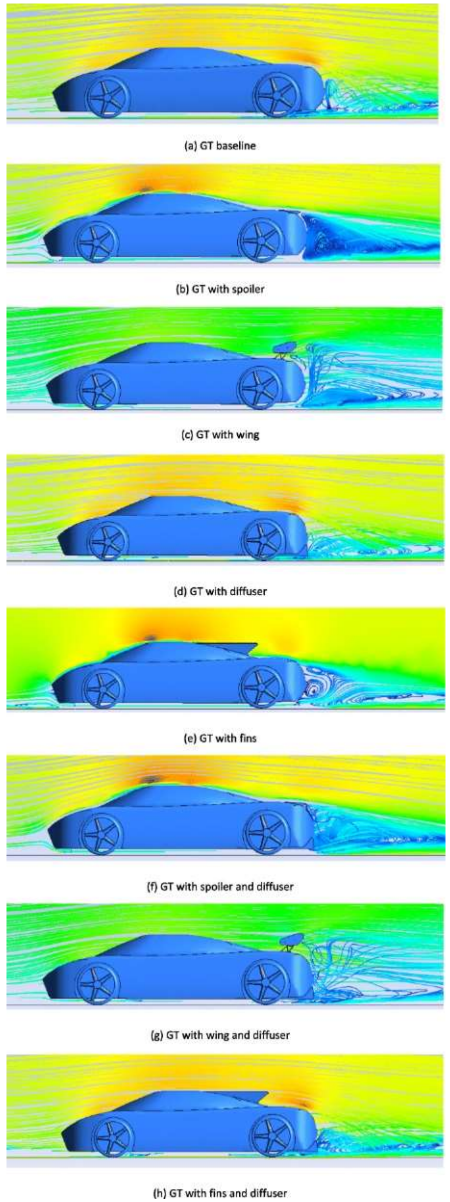
ρ_{air}	air density [kg/m^3]
c_d	vehicle resistance factor [-]
A	front surface area of vehicle [m^2]
v	velocity of the vehicle [m/s]



Powertrain

Resistance





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

Powertrain

Aero - CoP

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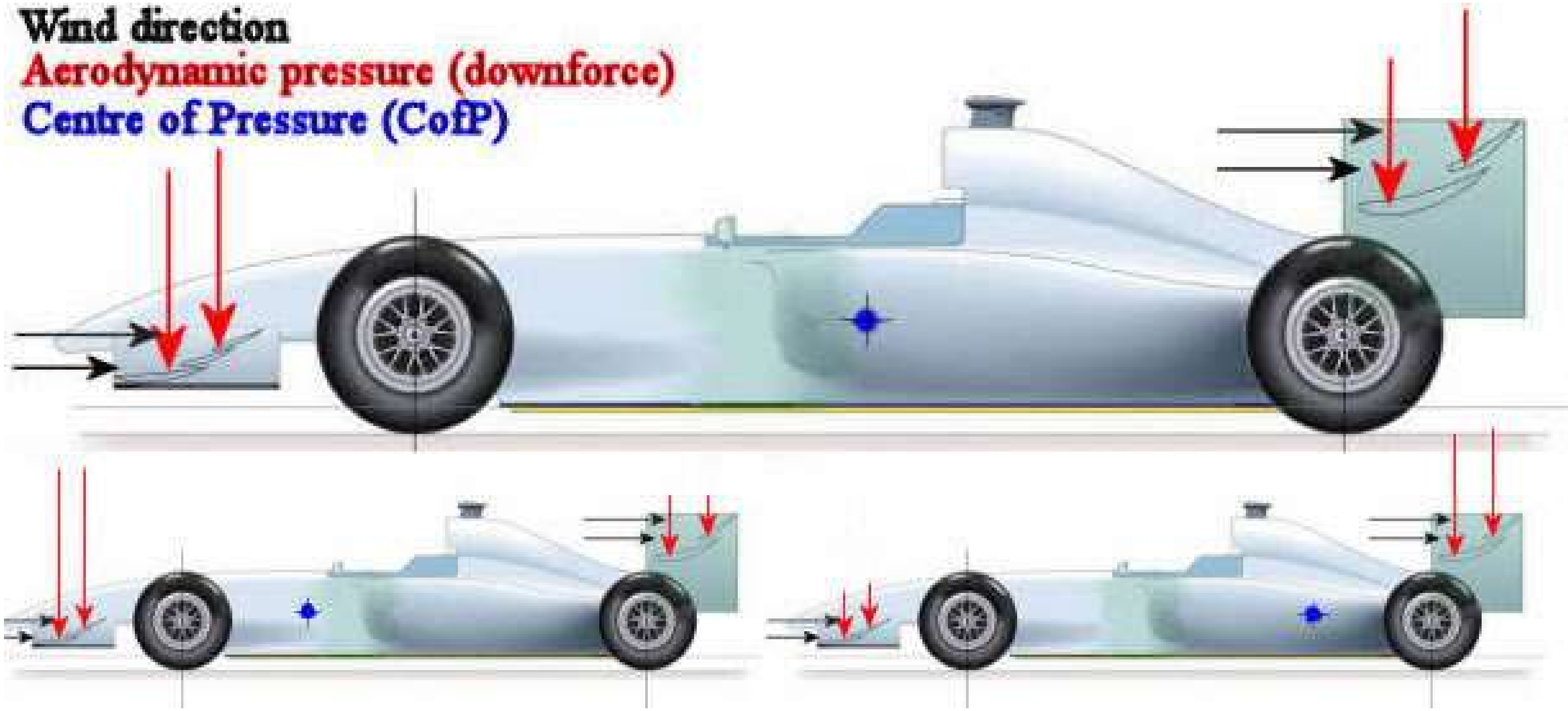

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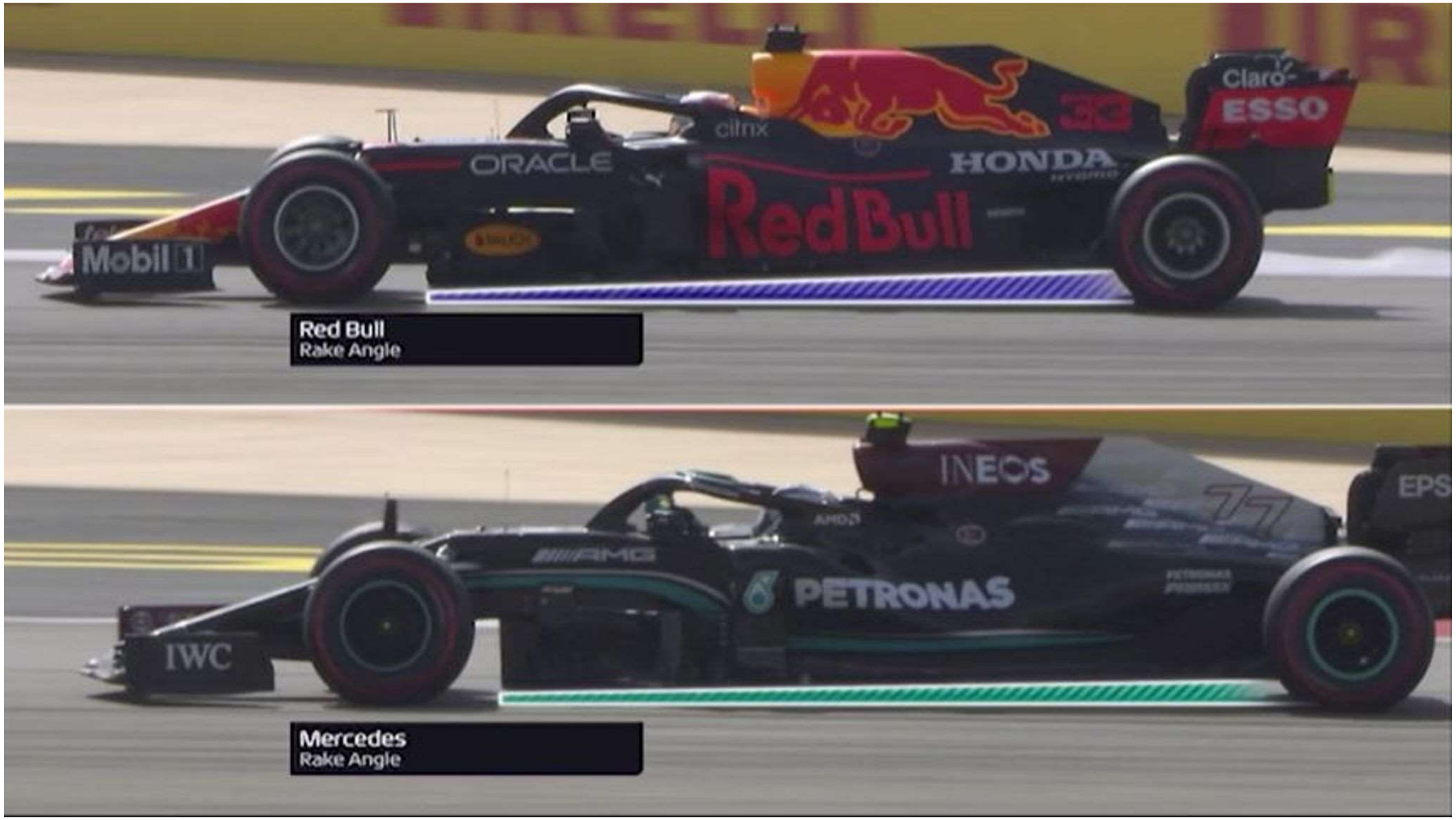
Aero

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

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

Aero - rake



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

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

Powertrain

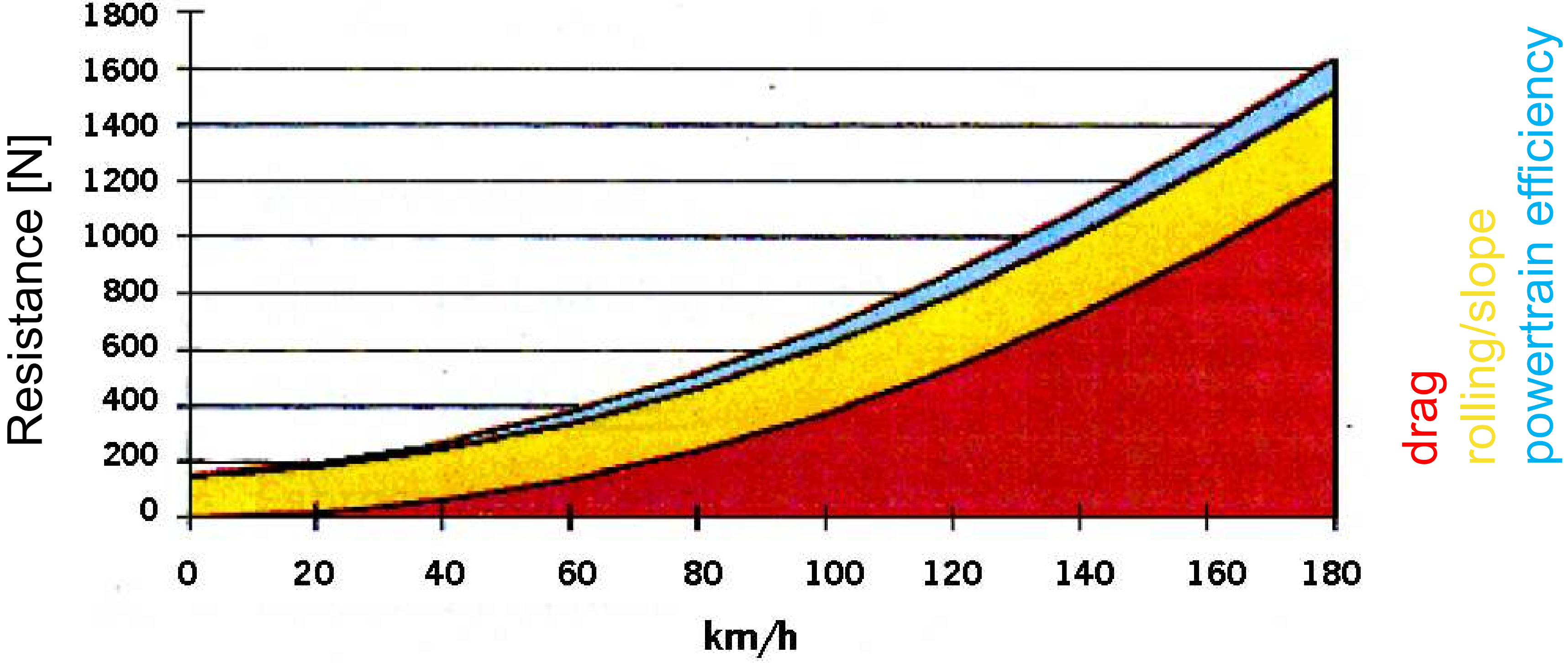
Aero - rake

What will happen with the frontal area by definition?

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

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

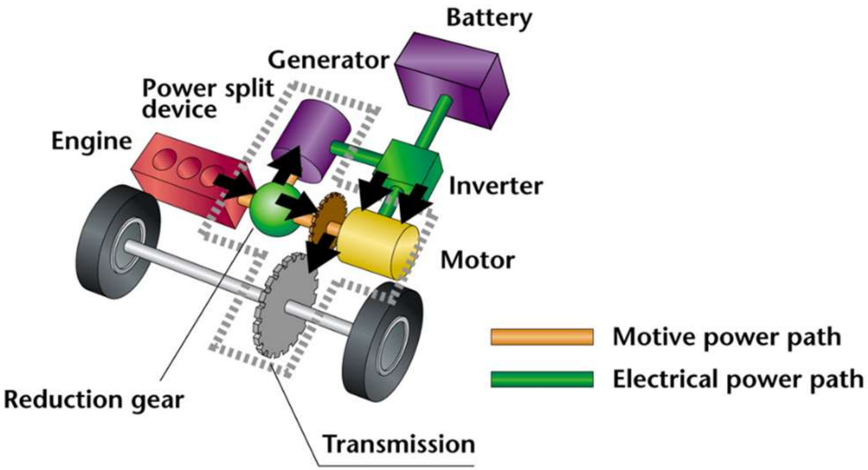
Resistance

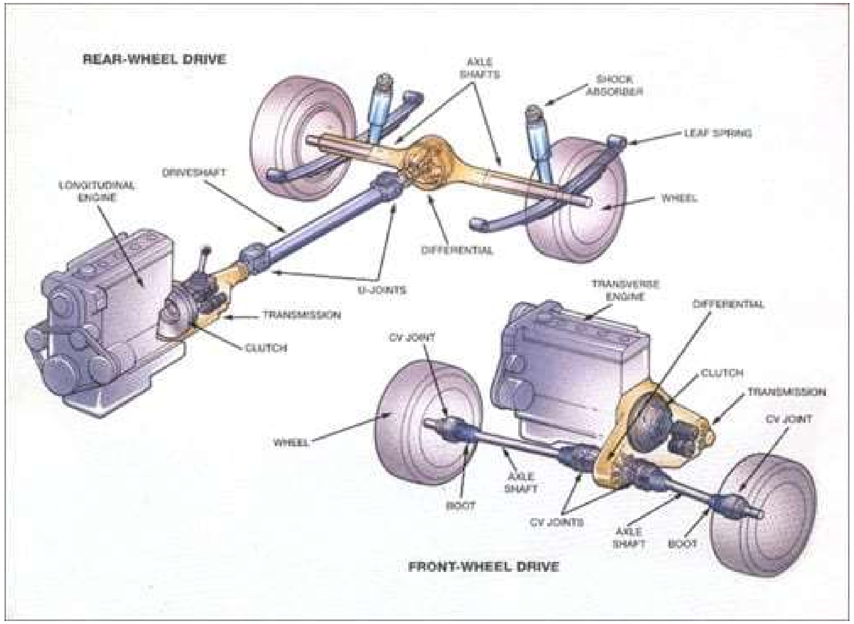


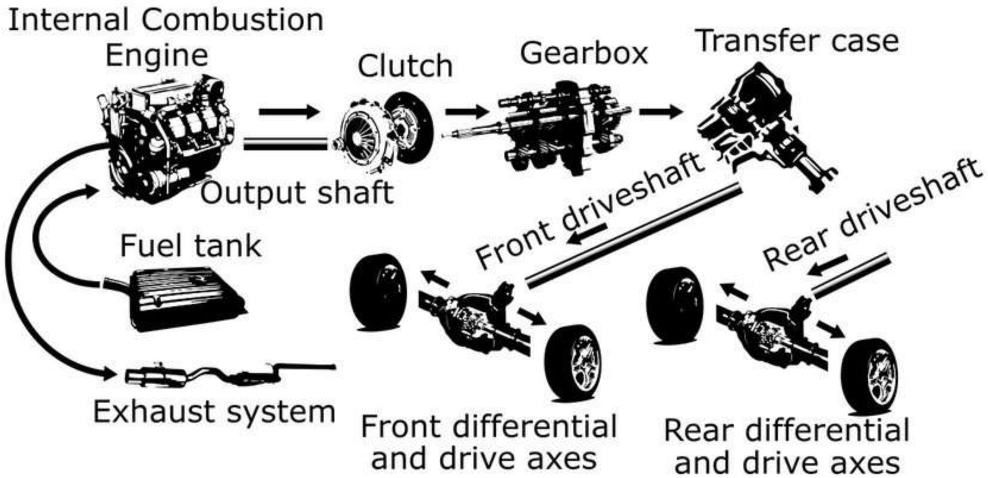
over 80 km/h the dominant effect is the drag

Powertrain

THS – Toyota Hybrid System







Powertrain

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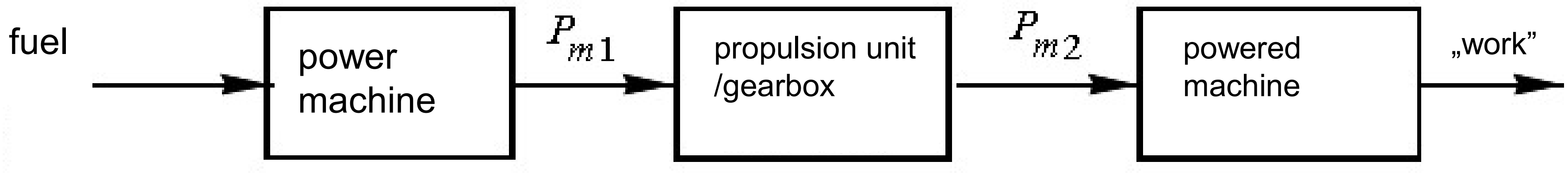
Powertrain general layout



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

Powertrain

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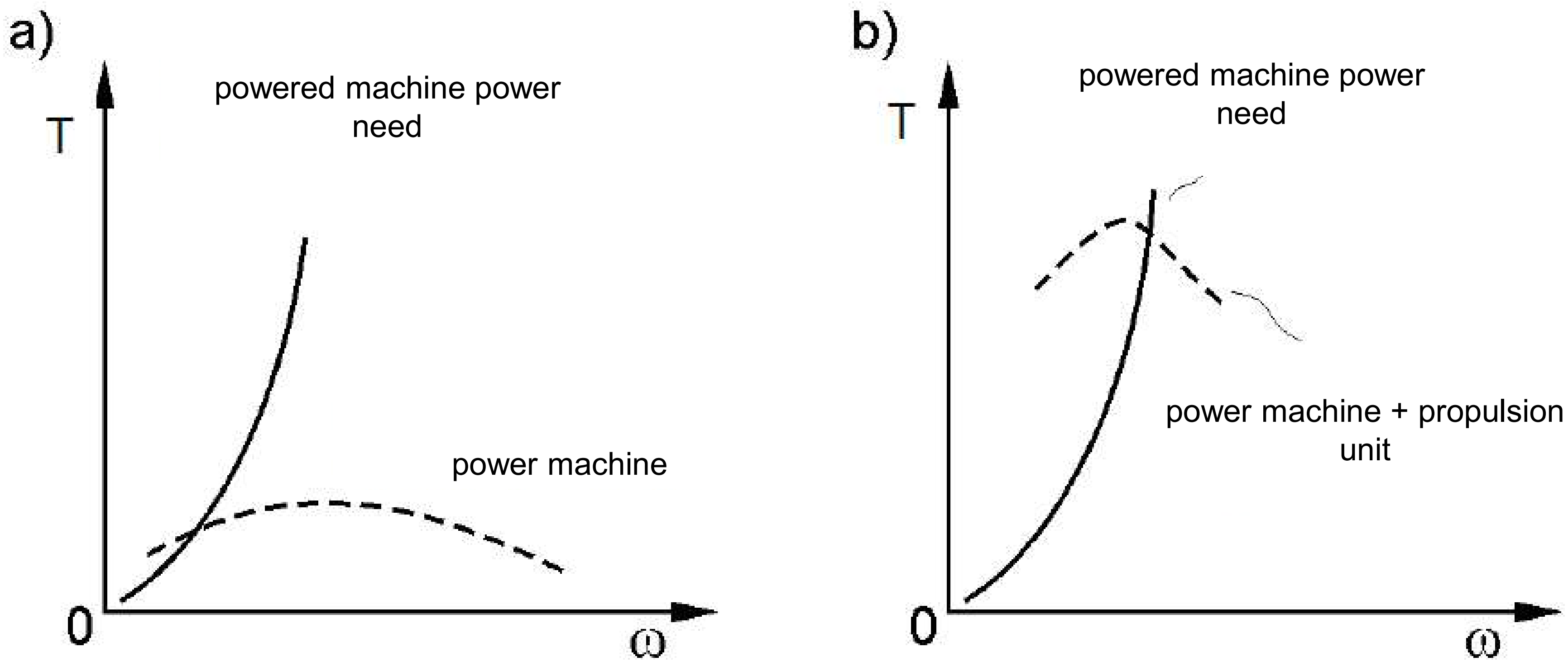
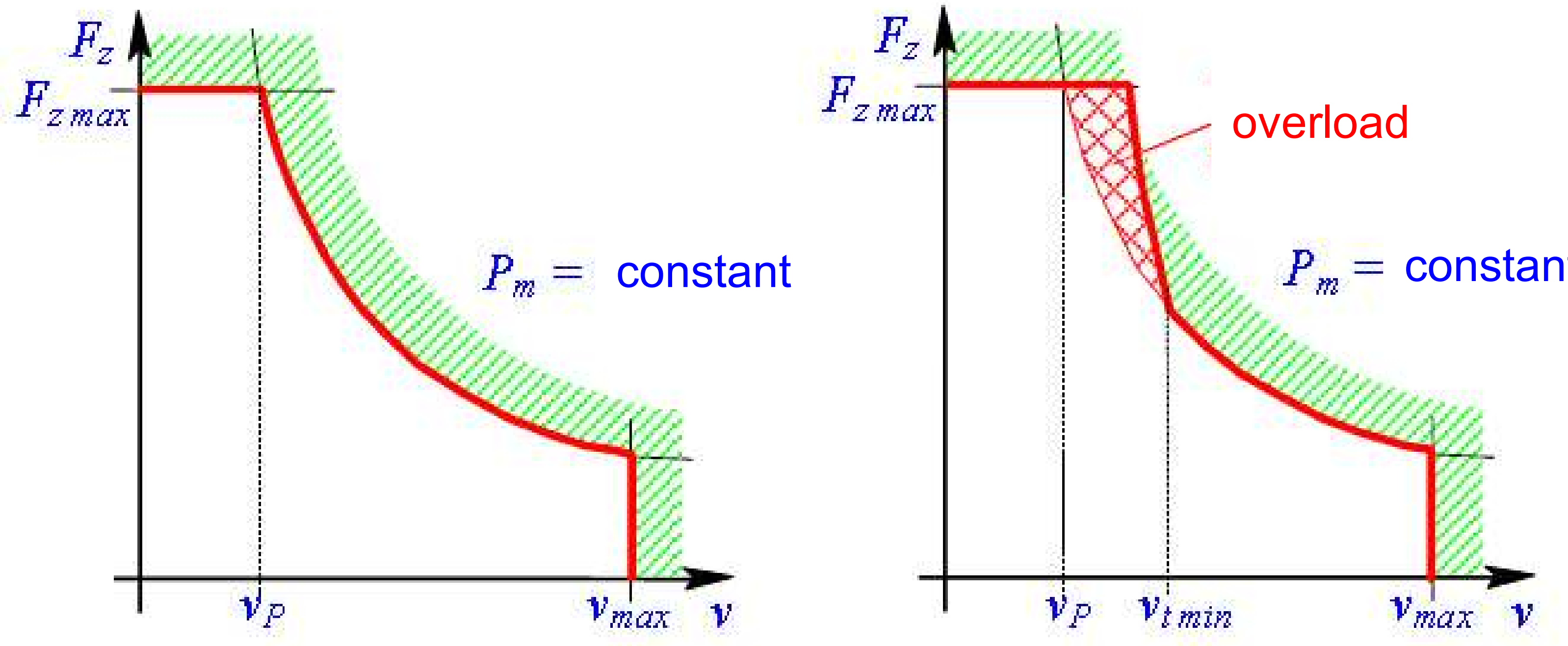
- Propulsion unit /Gearbox: the characteristics of (angular speed - torque) power and powered machine has to be synchronized

a.) actual status b.) required status

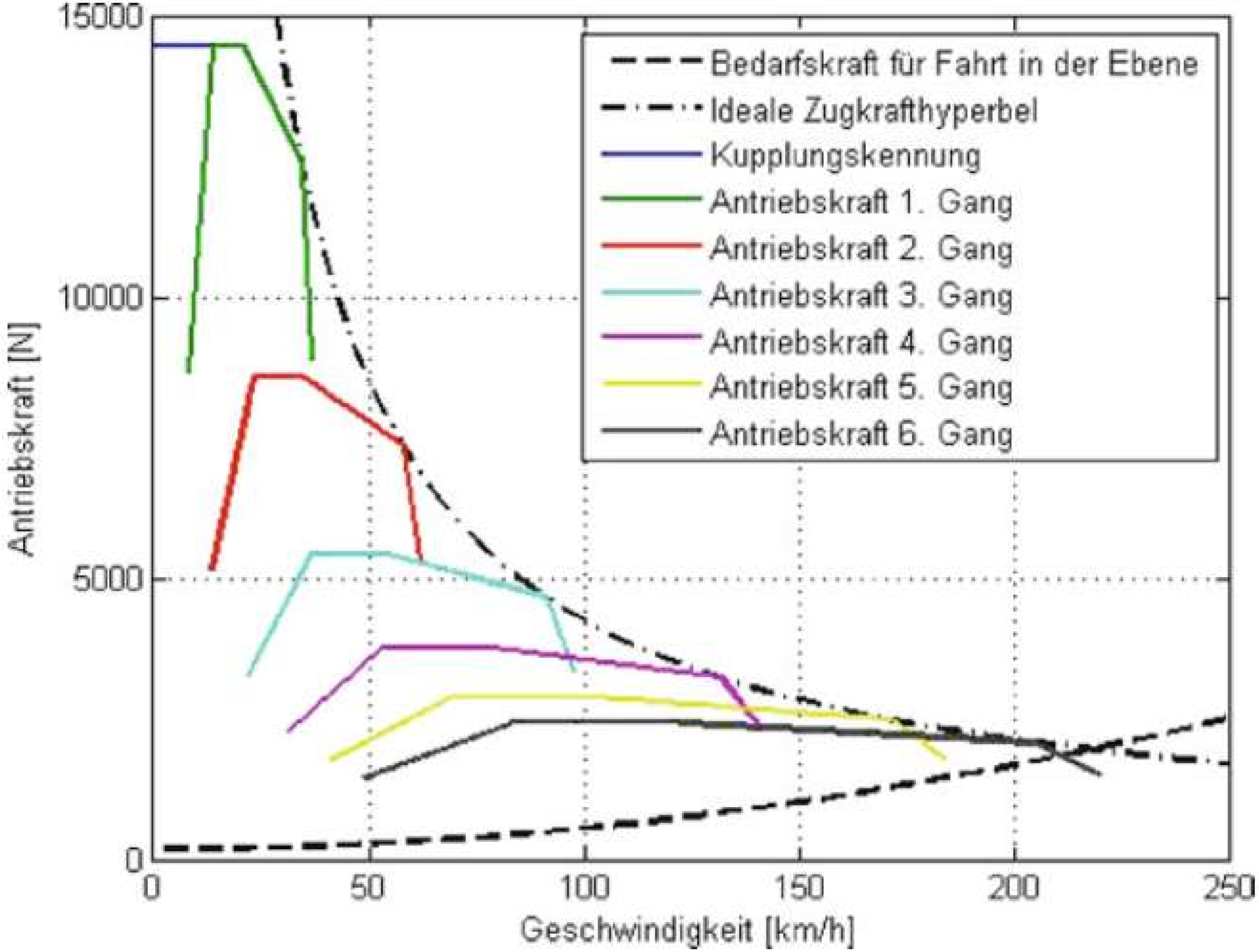


Traction force diagram



a.) powertrain overload not possible b.) powertrain overload

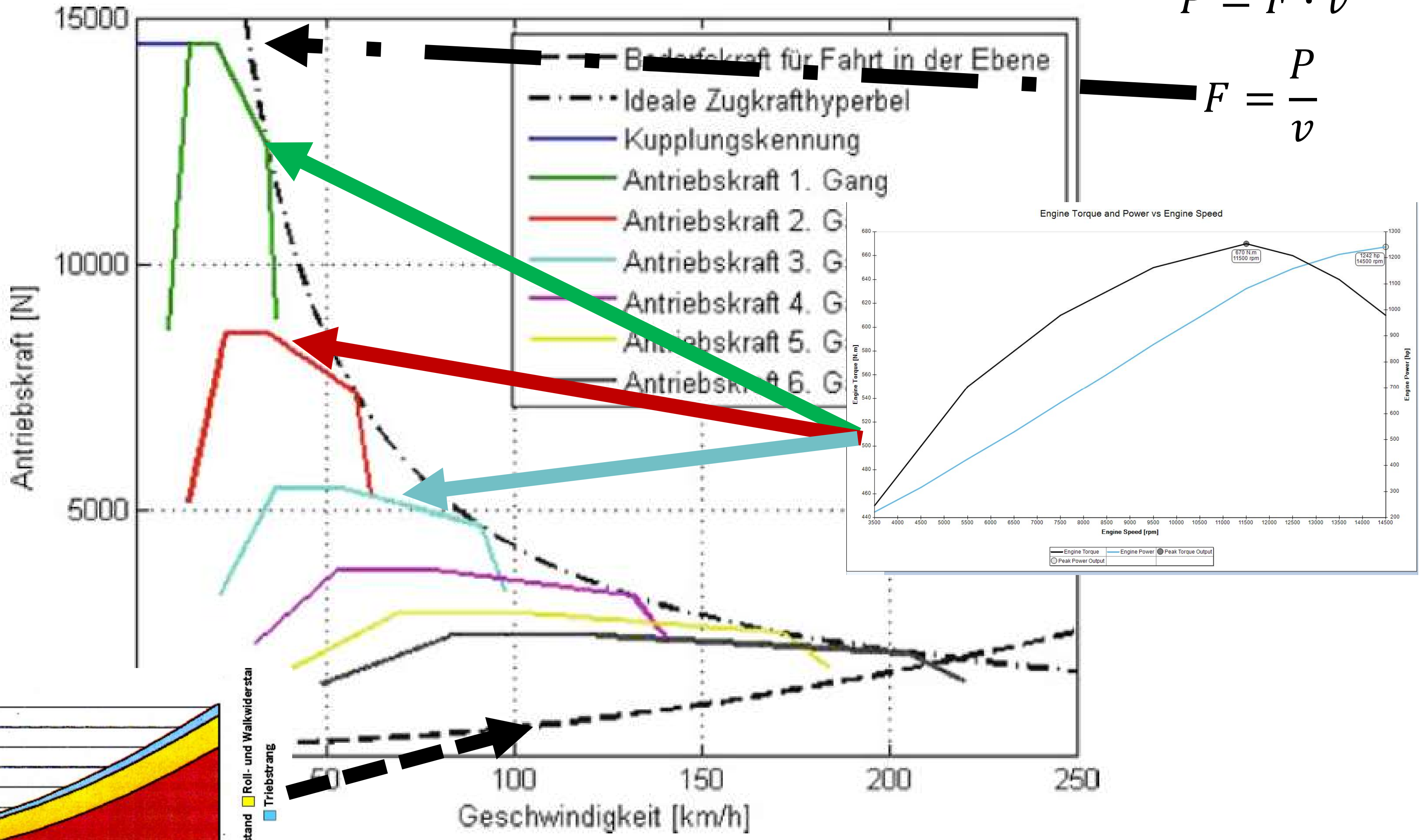
Traction force diagram

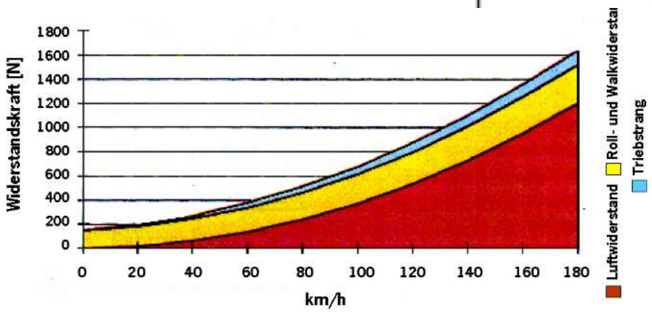


Traction force diagram

$$P = F \cdot v$$

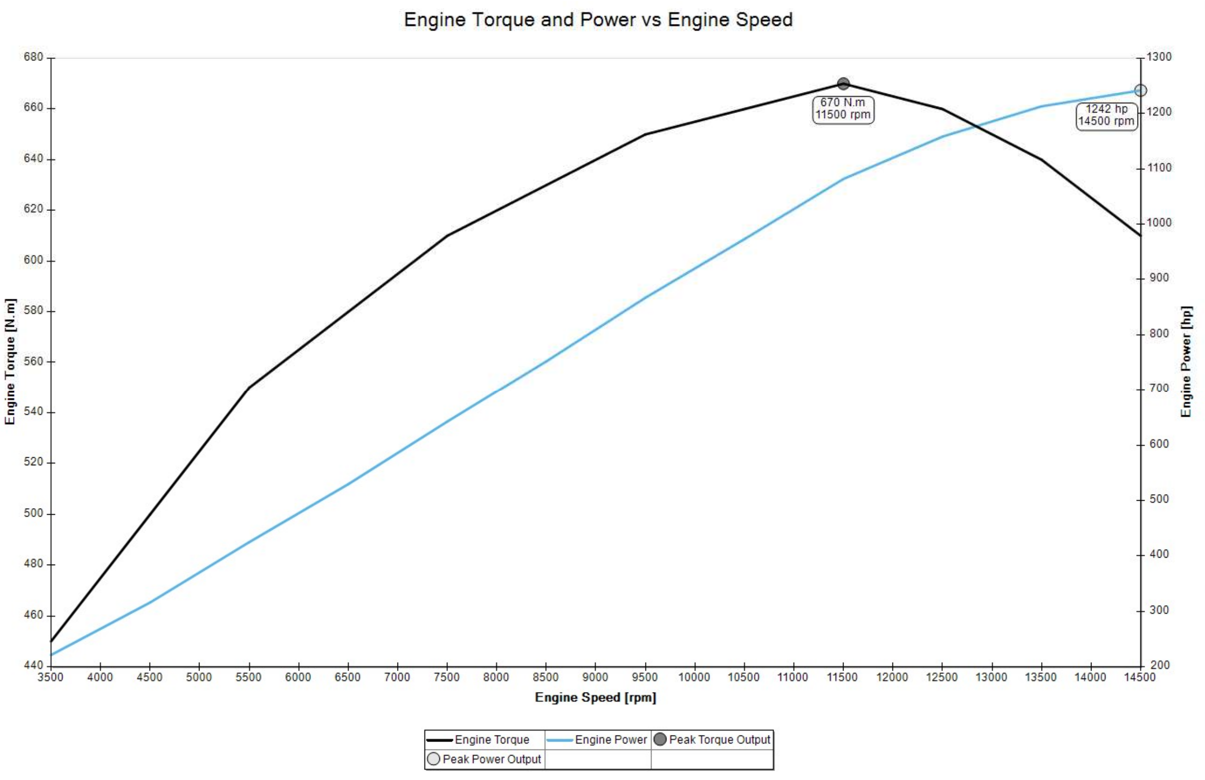
$$F = \frac{P}{v}$$





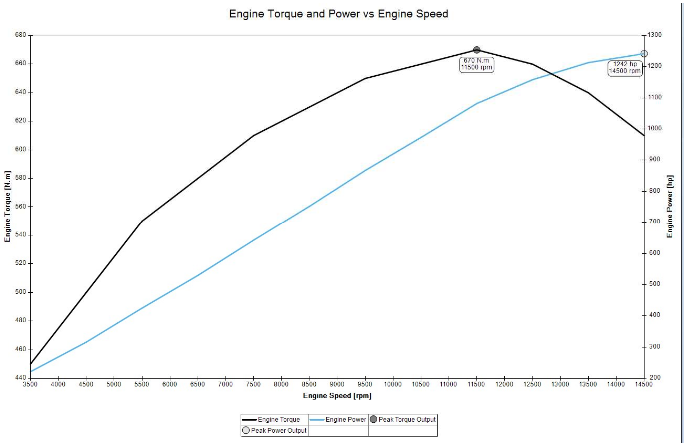
Traction force diagram

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

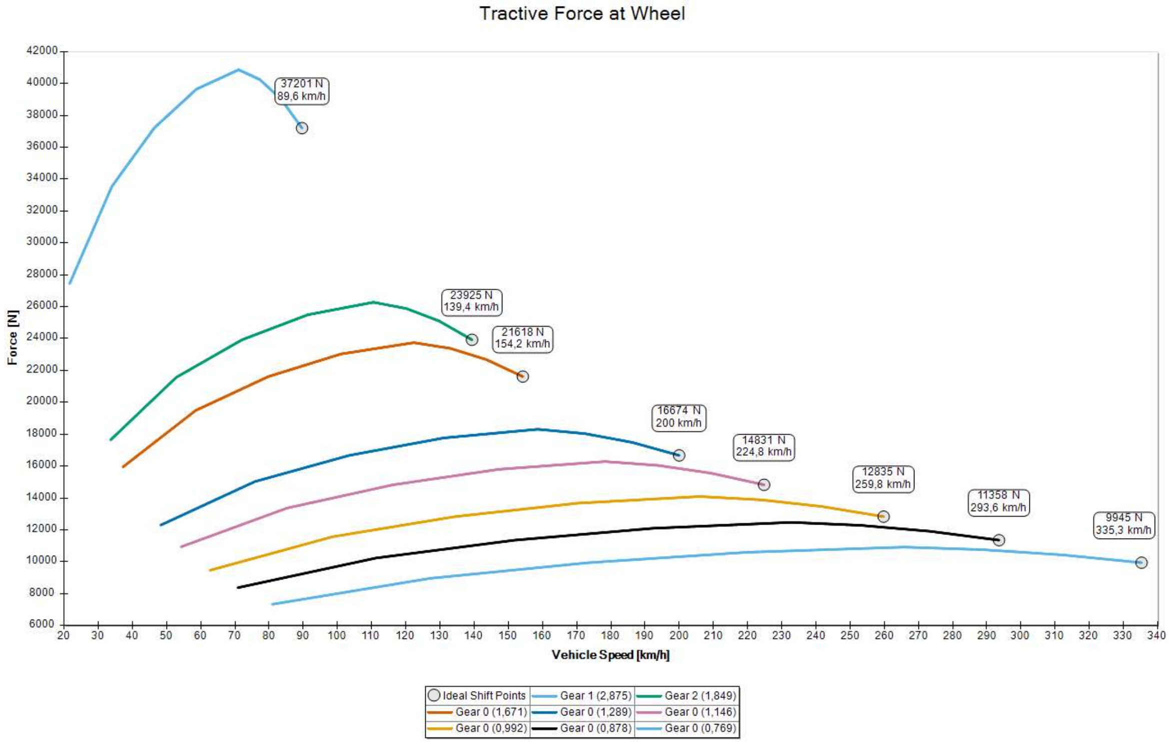


Powertrain

Driveline Model



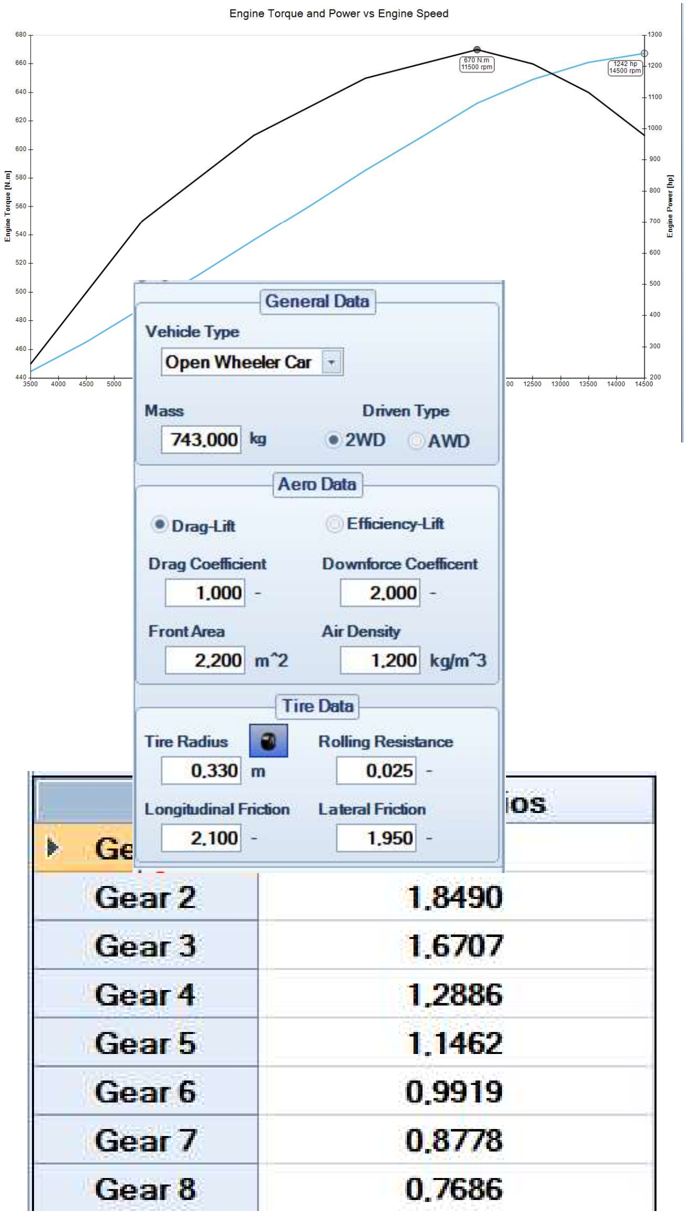
	Gear Ratios
Gear 1	2,8750
Gear 2	1,8490
Gear 3	1,6707
Gear 4	1,2886
Gear 5	1,1462
Gear 6	0,9919
Gear 7	0,8778
Gear 8	0,7686

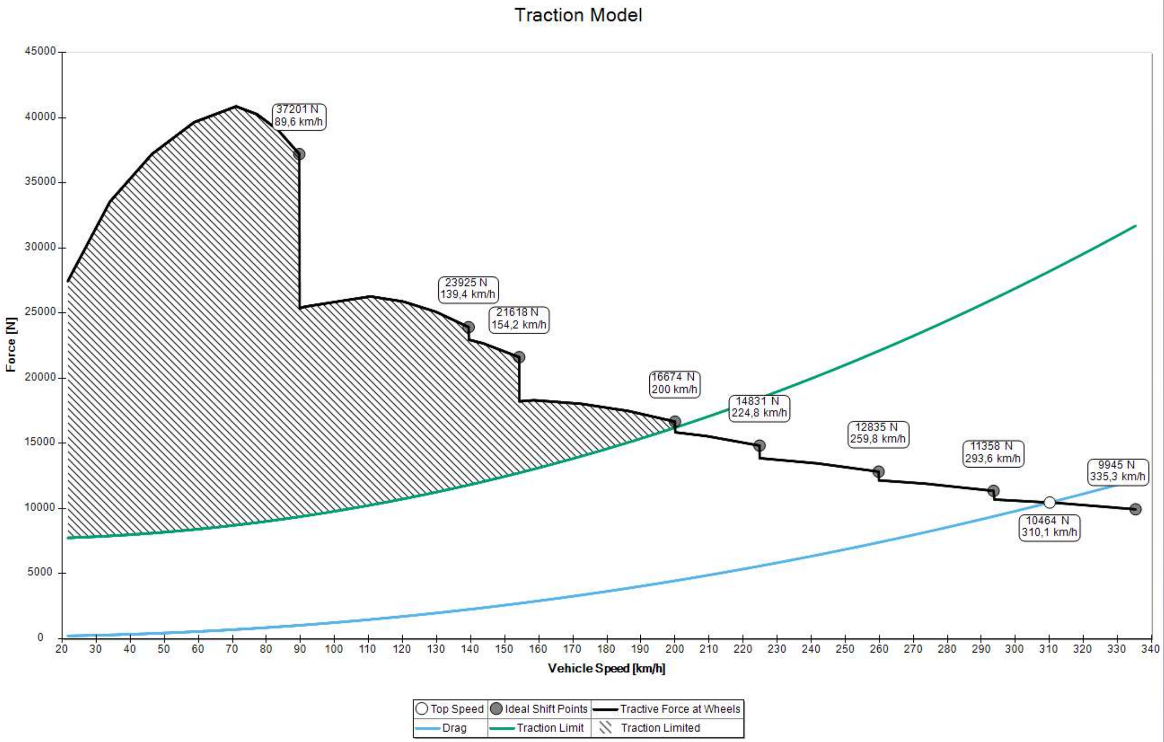


What else is missing?

Powertrain

Traction Model





Traction Model

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

Optimum lap check!

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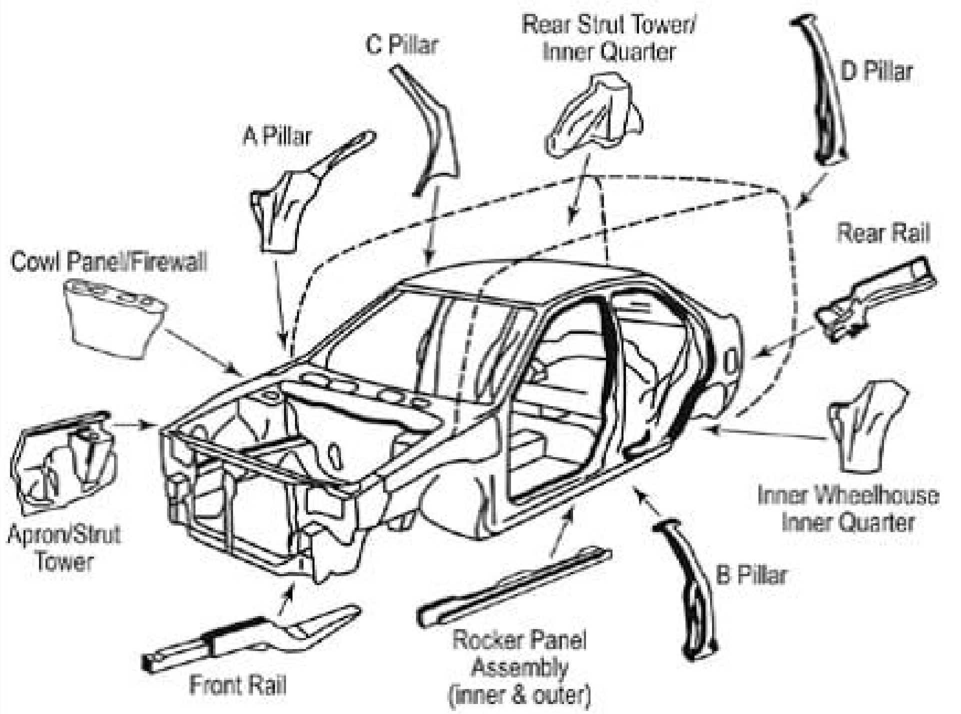
Chassis

TYPICAL UNIBODY STRUCTURE



Chassis

Function

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

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Types - Conventional

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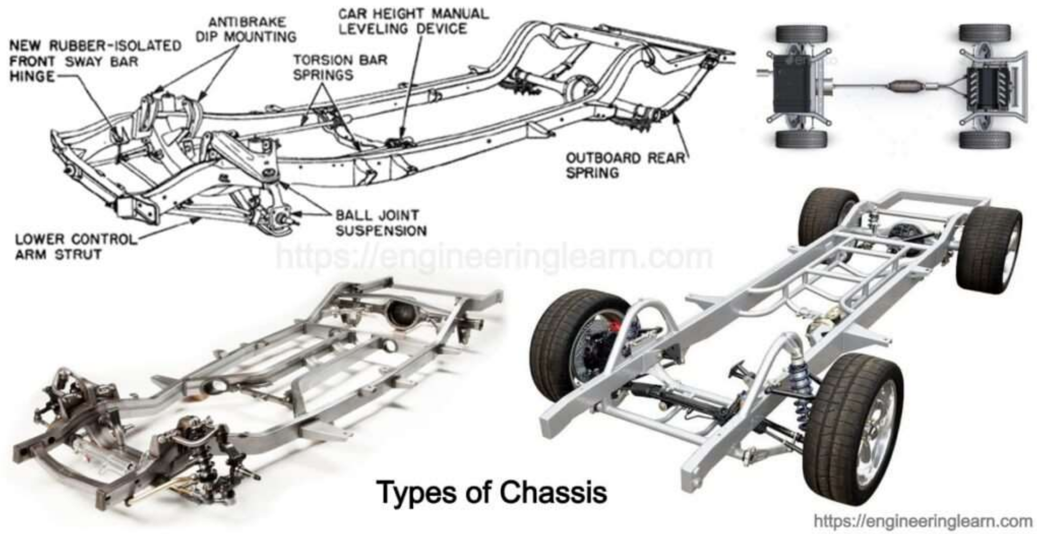
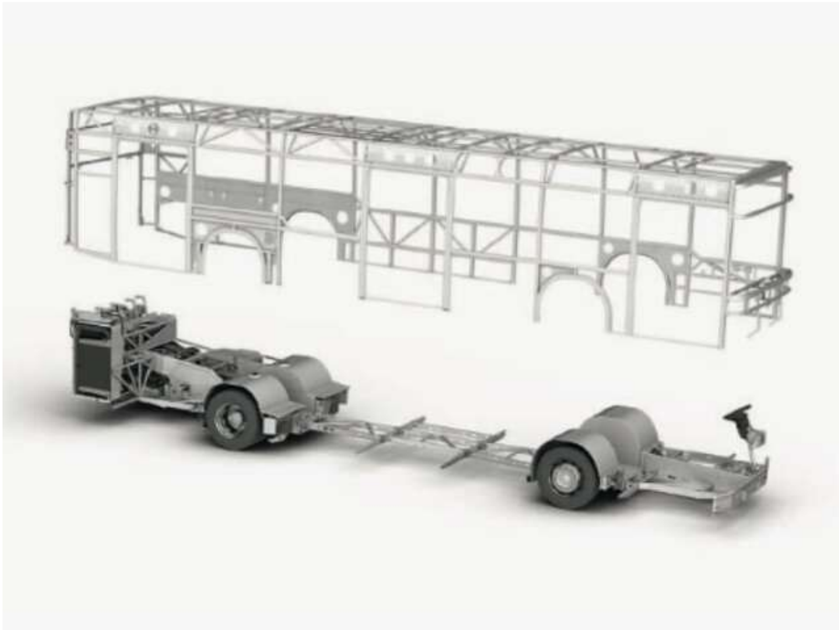
- Conventional
- open/ non-load carrying type
- separate frame to carry the load from suspension
- bodywork can be manufactured stiff or either flexible material, it is separated by deflection rubber mountings
- obsolete because of concentrated load at mounting points



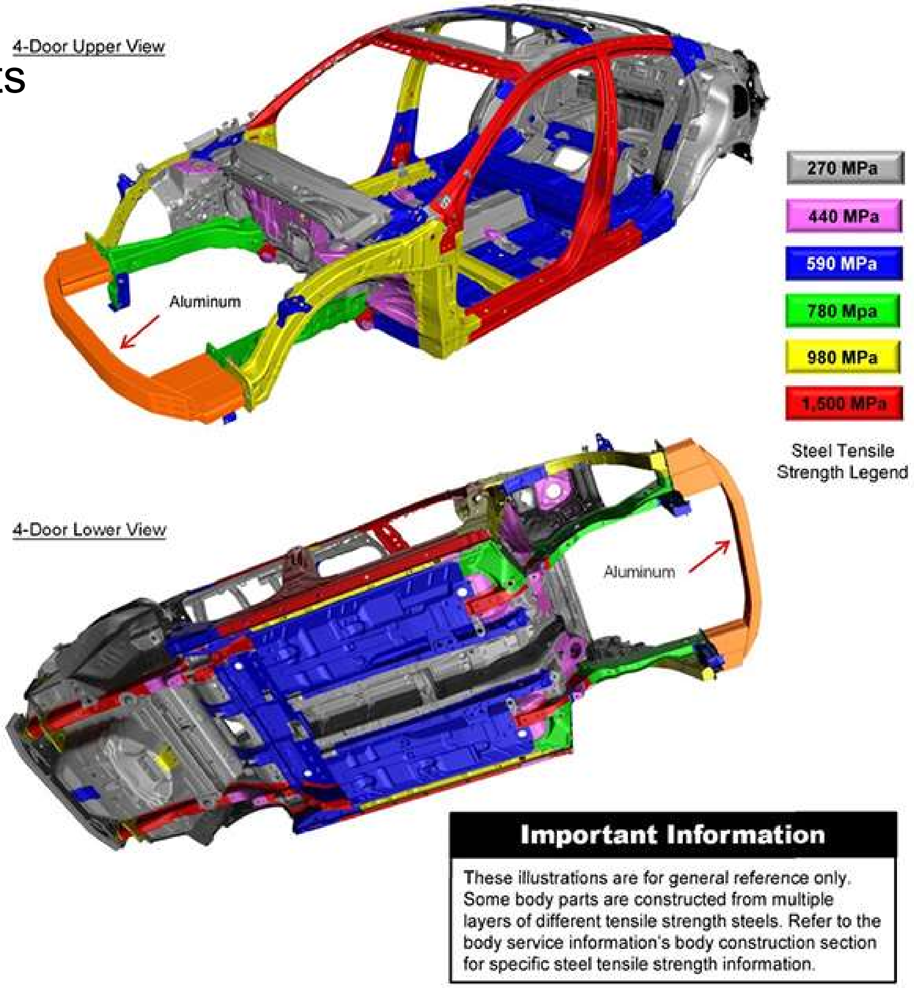
Types - Semi integral

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



Types - Integral

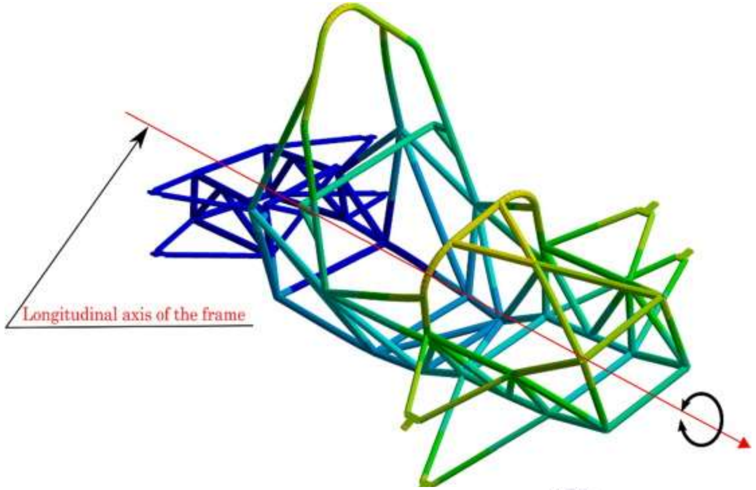
- Integral
- bodyshell is designed to carry all the load as a framework
- eliminates heavy load-carrier elements
- front and rear extensions, reinforcements
- lighter than any other solution
- widely used in road cars

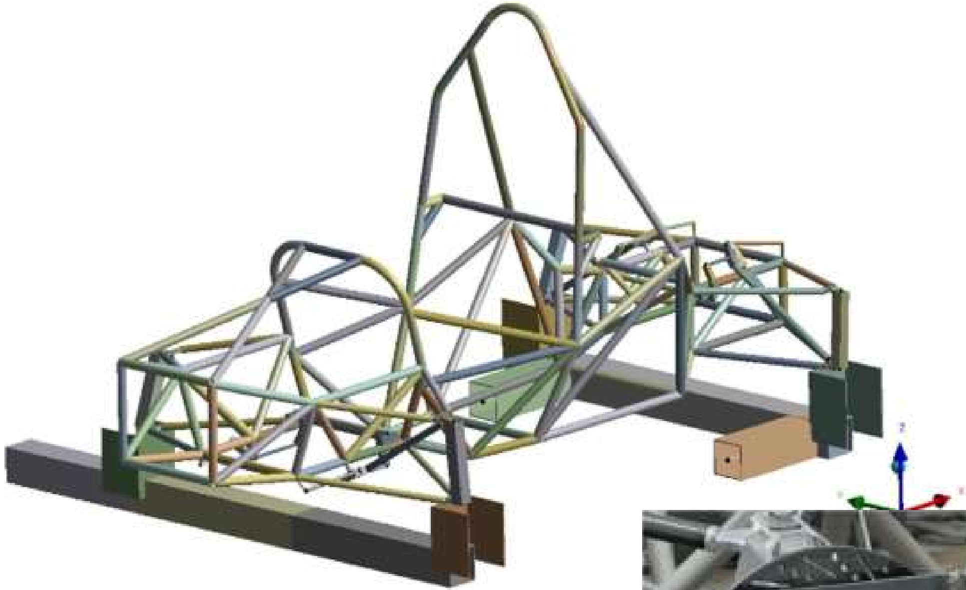


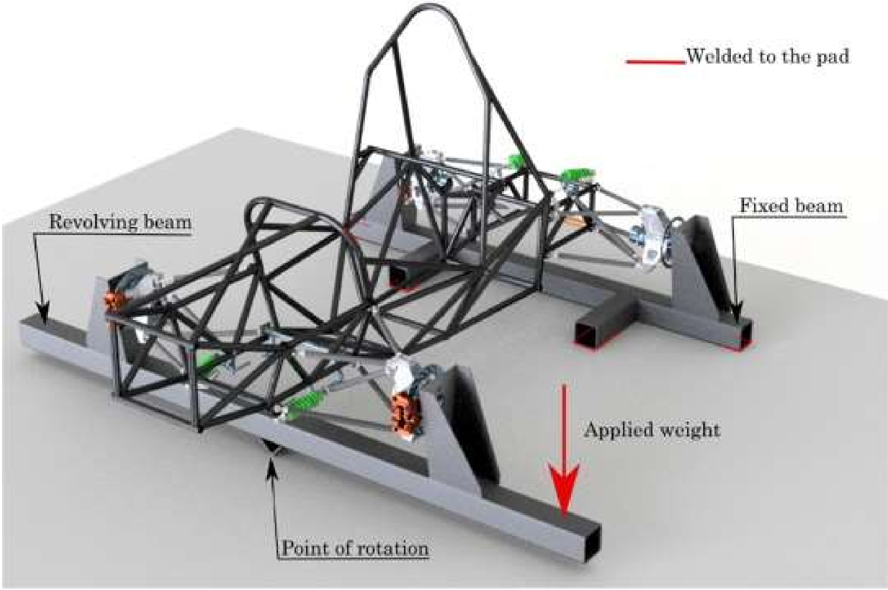
Torsional stiffness

Chassis

Torsional stiffness

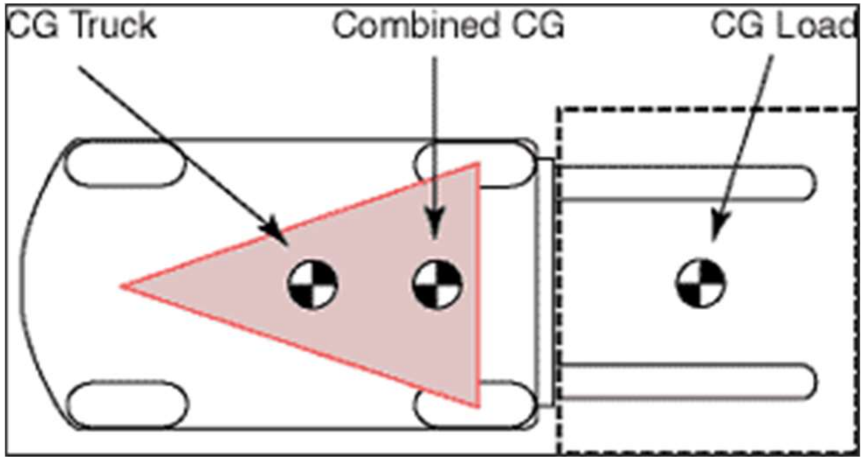


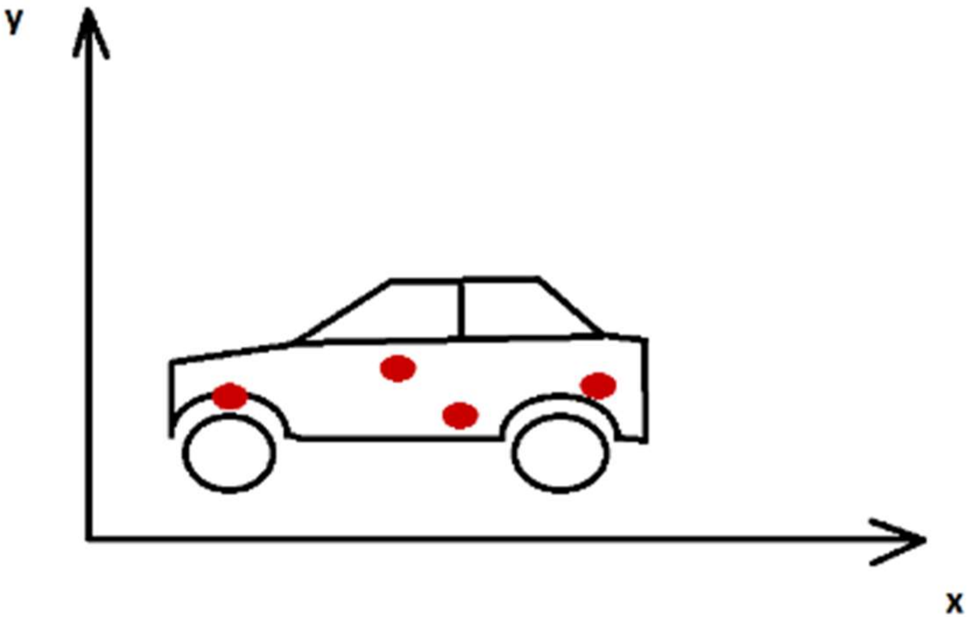


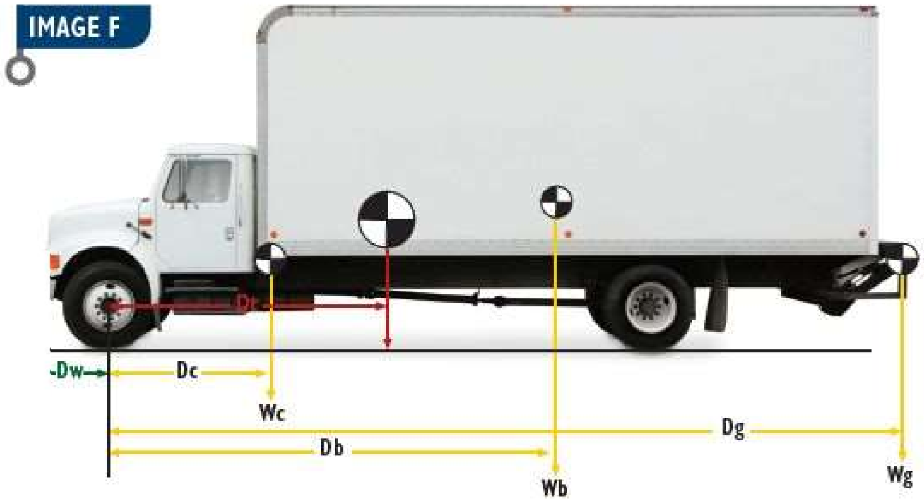


Chassis

CoG height – Method 1







Chassis

CoG height – Method 2

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Sensors:

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

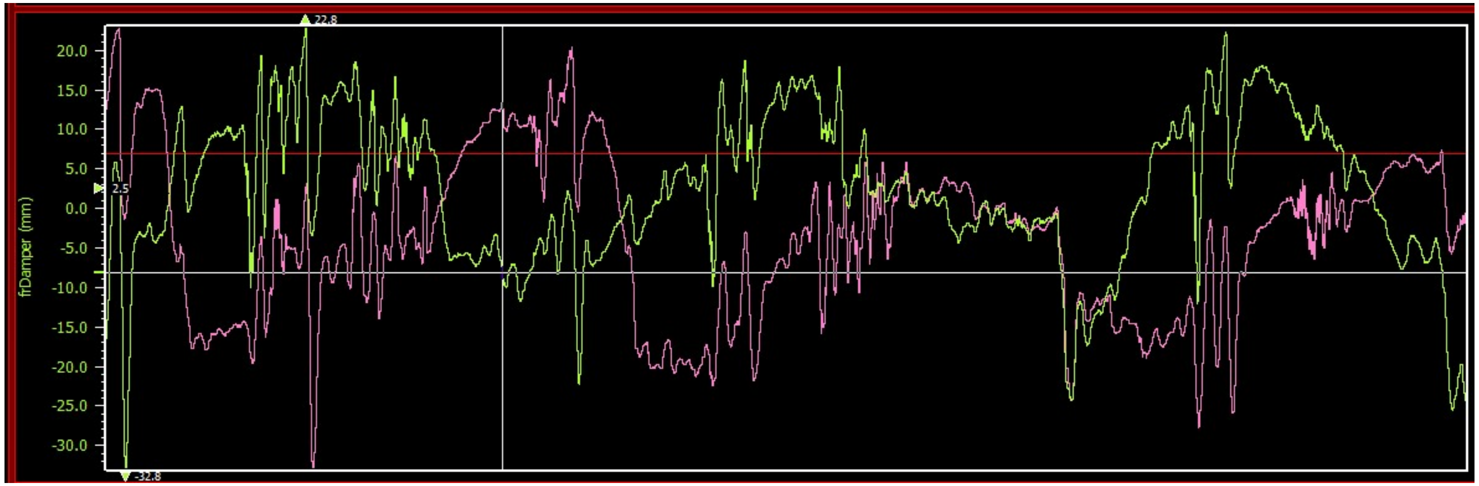
CoG height – Method 2

Sensors:

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

1.Normal force from spring stiffness

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



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
- …

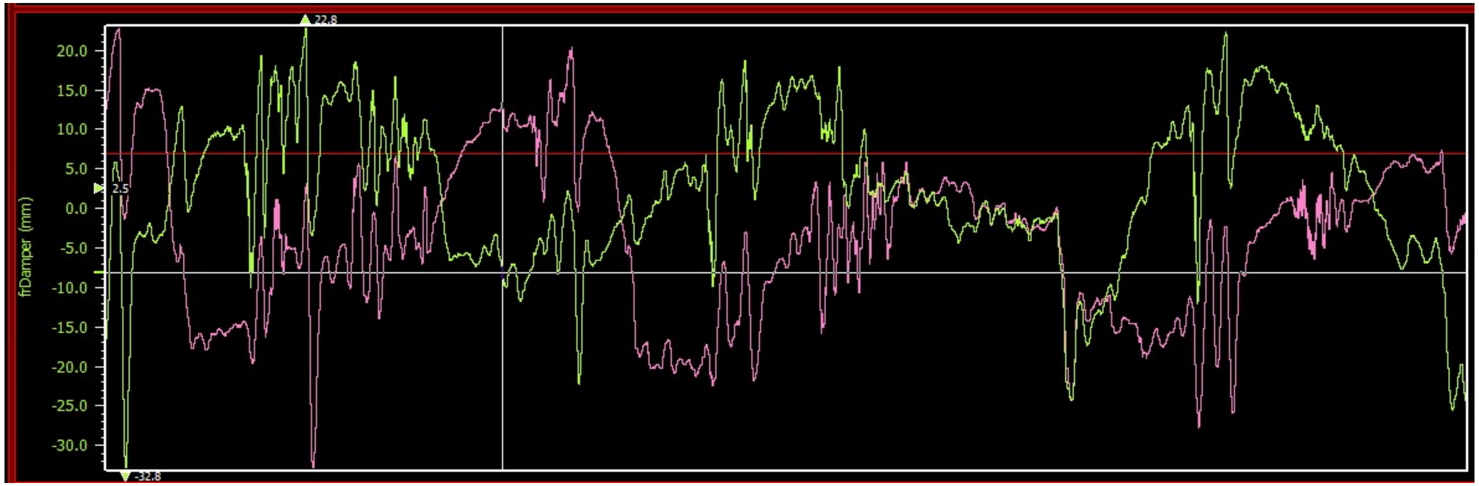
1.Normal force from spring stiffness

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

vs

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

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

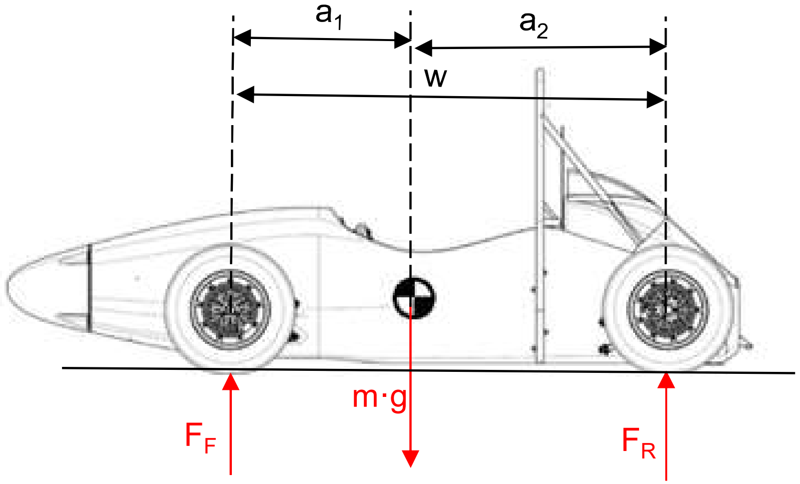


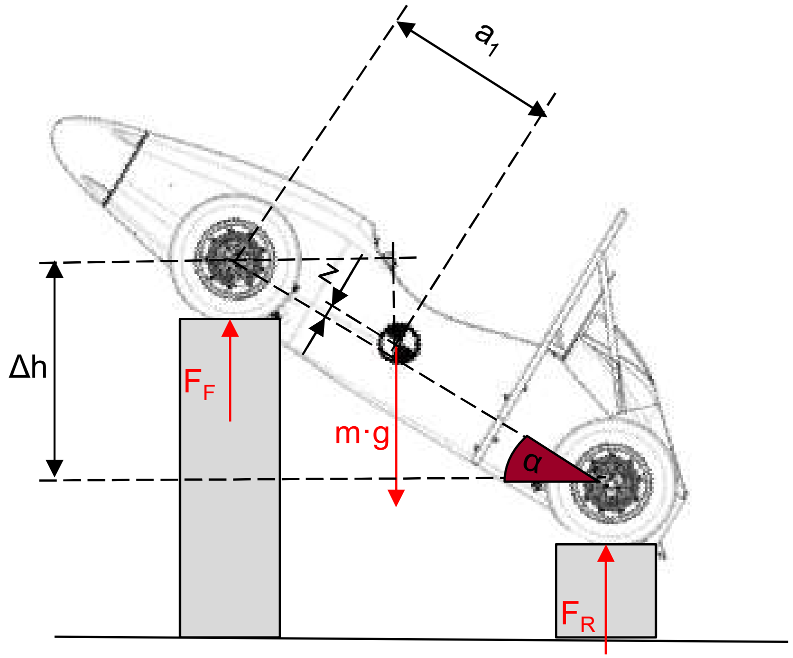
Chassis

CoG height – Method 3

Chassis

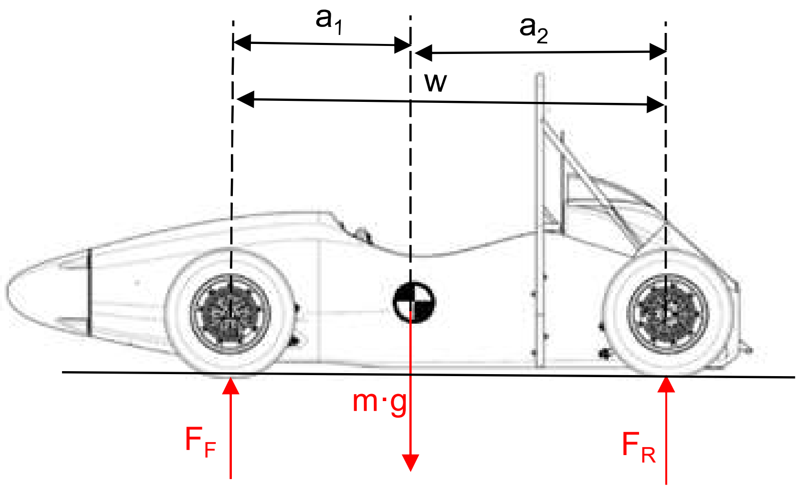
CoG height – Method 3

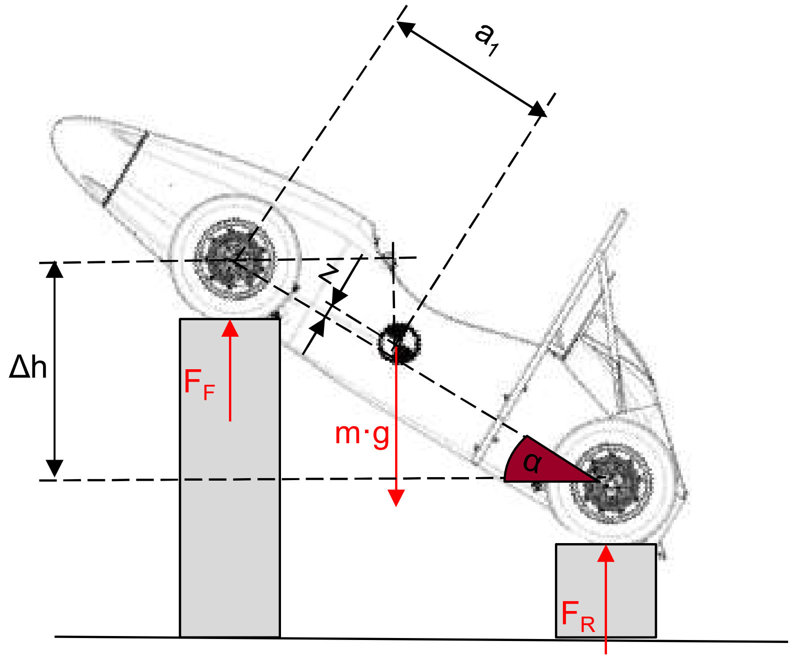




$$\alpha = arcsin\frac{\Delta h}{w}$$

CoG height – Method 3

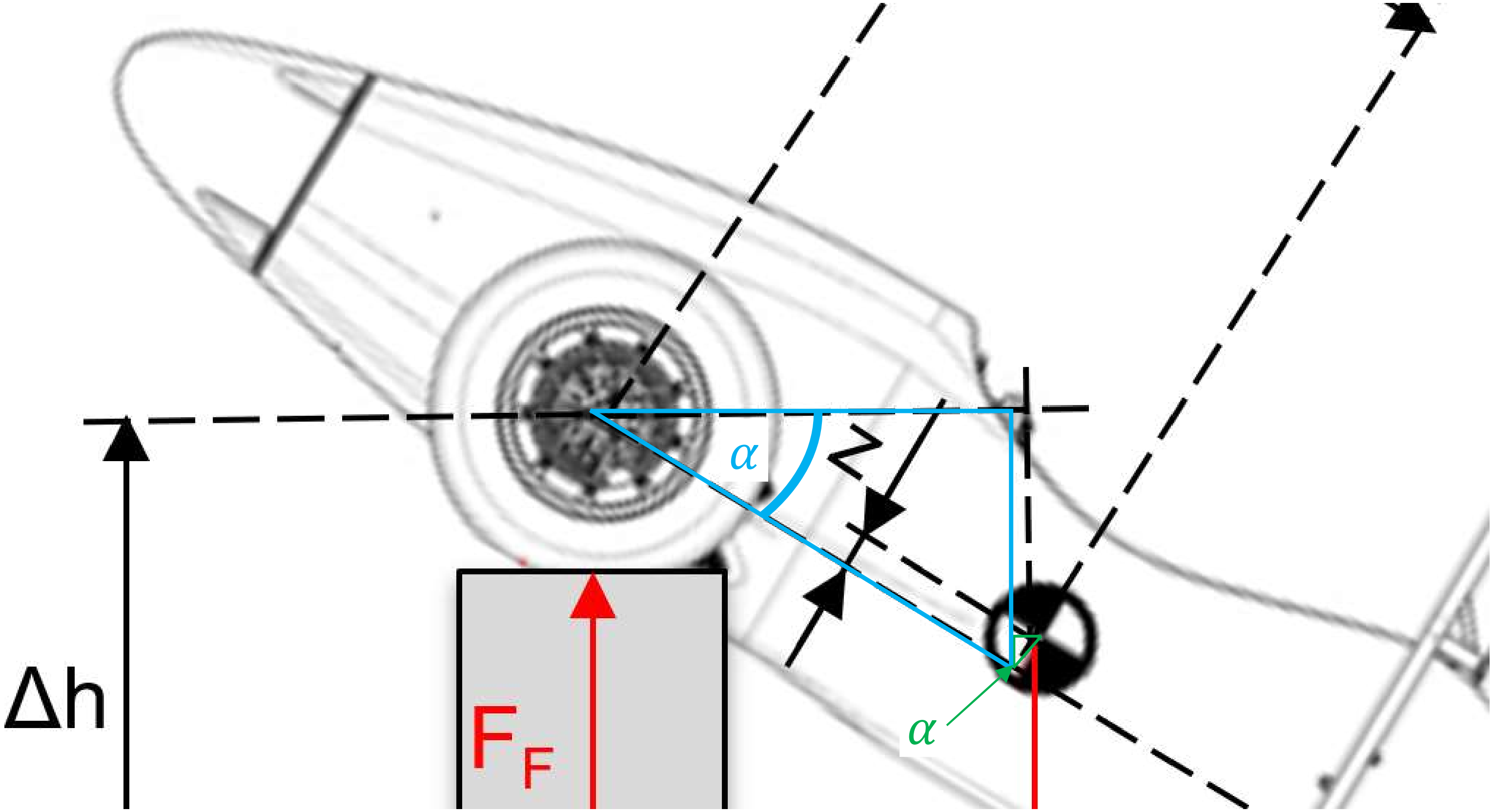




$$m \cdot g(a_1 \cdot cos\alpha + z \cdot sin\alpha) = F_R \cdot w \cdot cos\alpha$$

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

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

Q & A

- Main objective?
- Starting point - ending point?
- Complex parts?
- Less relevant part(s), could be omitted part(s)?
- Most useful part(s)?
- How could today's material have contributed to your professional goals?

Bibliography

- https://www.youtube.com/watch?v=S0TlRkNWheQ
- https://www.youtube.com/watch?v=0ykCdaRzn5g
- http://moodle.autolab.uni-pannon.hu/Mecha_tananyag/kozuti_jarmurendszerek_szerkezettana/ch13.html
- https://engineeringlearn.com/types-of-chassis-components-function-design-construction/
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- https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.skysports.com%2Ff1%2Fnews%2F12475%2F12269260%2Ff1-2021-how-red-bull-have-gained-on-mercedes-to-ignite-lewis-hamilton-max-verstappen-battle&psig=AOvVaw1G_9qnCYxnBcejkSRCCnDr&ust=1682407821454000&source=images&cd=vfe&ved=0CBEQjRxqFwoTCIDErtb_wf4CFQAAAAAdAAAAABA7

Thank you for your attention!

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