Battery training

Sizing 2: Traction Requirements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 875041

Trainings Scheme

Sizing 1

Setting the vehicle targets

18th May

Sizing 2

Vehicle targets cascading for battery sizing: traction requirements

19th May

Sizing 3

Vehicle targets cascading for battery sizing: energy requirements

20th May

Follow-up :

Q/A and results presentation

25 May

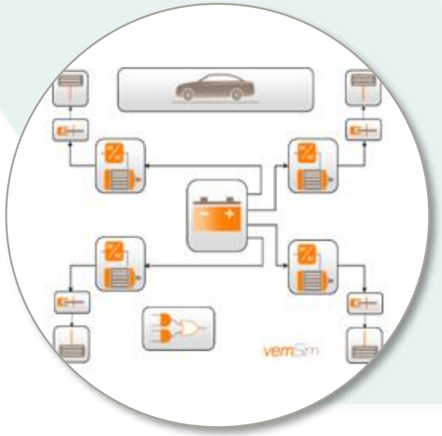
IDIADA Powertrain Department

Services Overview

Expert professionals to accompany you across your the product development cycle:

Benchmarking

Virtual Development



Functional Development

Testing and Validation

Laboratory Testing

IDIADA Powertrain Virtual Development

Our team

We will assist you in the product development to achieve your objectives

MULTIDISCIPLINARY
CAE PROFESSIONALS

DATA FROM
FIRST CLASS
TESTING
FACILITIES

OUR
ASSETS

ADAPTABILITY
WORLDWIDE

CONSTANT
INNOVATION
IN NEW SERVICES
AND TECHNOLOGIES

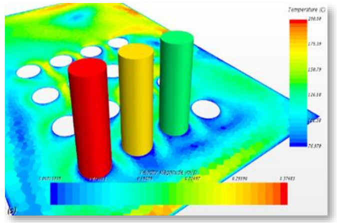
IDIADA Powertrain Virtual Development

Engineering

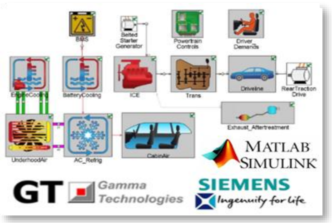
IDIADA offers continuous engineering & simulation support during all the phases of e-powertrain & vehicle development

VIRTUAL DEVELOPMENT PROCESS

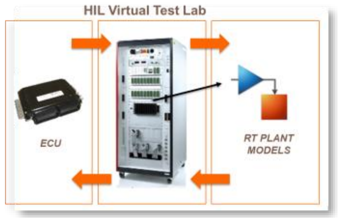
Concept Simulation



Detailed Design



System Integration



Virtual Validation

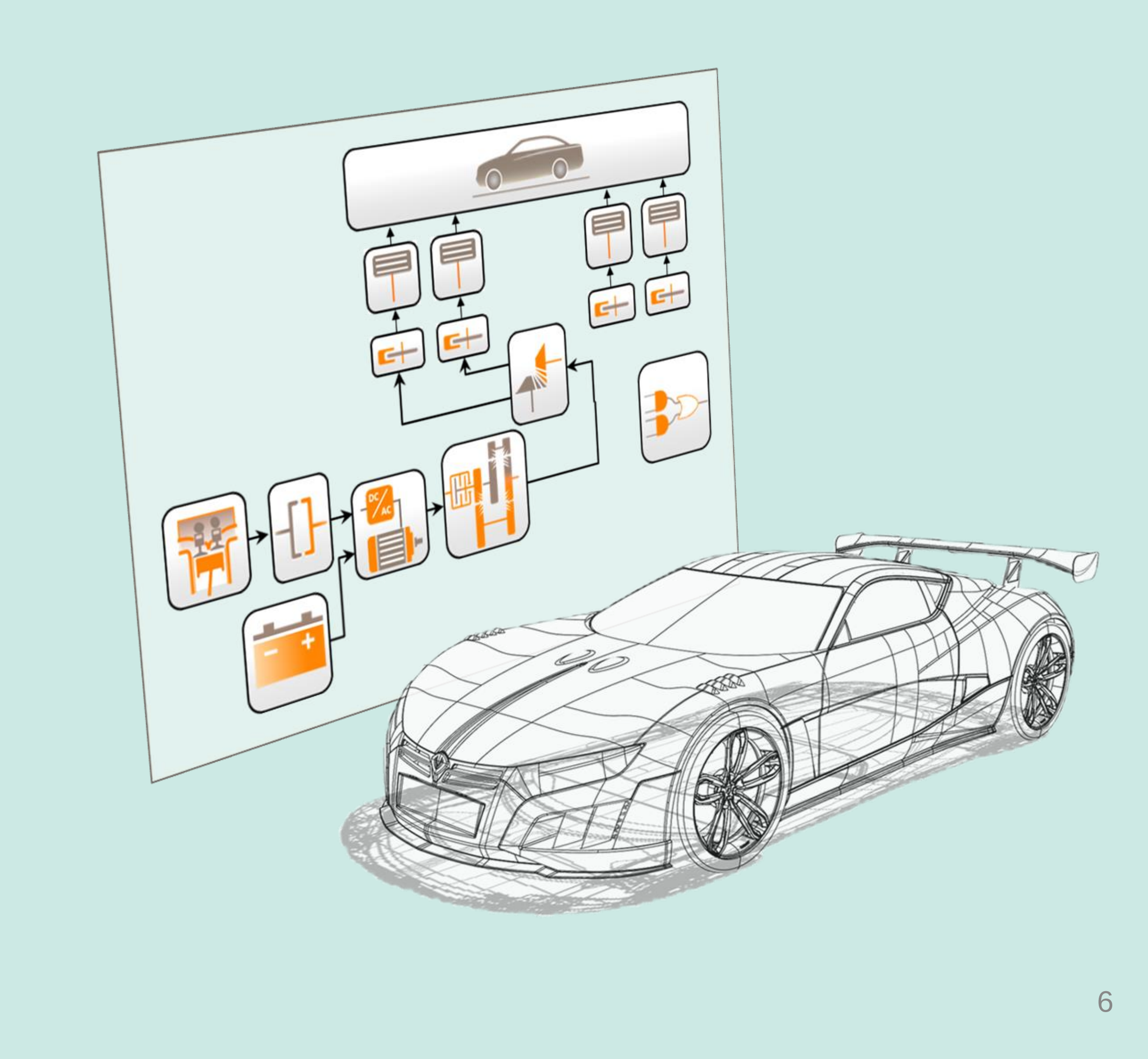
Concept Simulation

Scope

Concept models represent the <u>interaction</u> of vehicle subsystems …

… to calculate their <u>impact</u> on energy efficiency & performance

- <u>Sufficient fidelity</u> for the application. No more, no less
- Models can be calibrated with specification data or test data

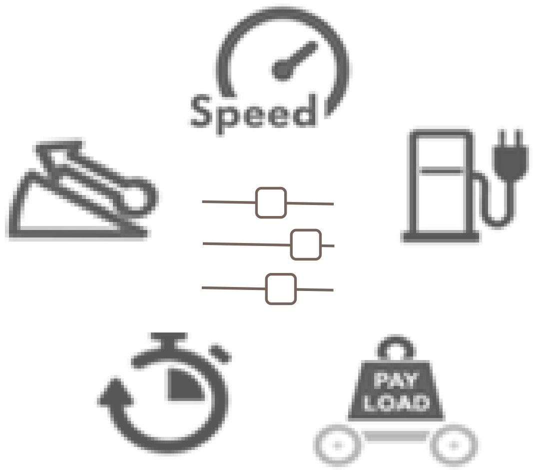


Concept Simulation

Workflow

We support to make objective powertrain system-level decisions

Vehicle Performance



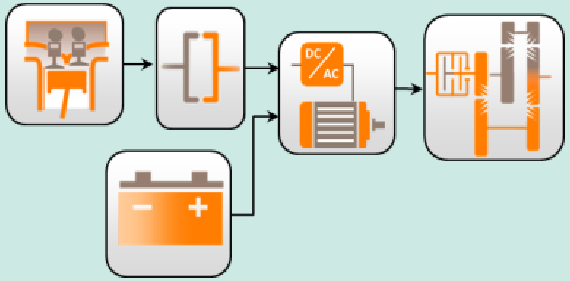
Efficiency · Acceleration
Climbing · Reliability · Cost

Simulation

Powertrain Subsystems

Control Strategies

Vehicle



System Specs

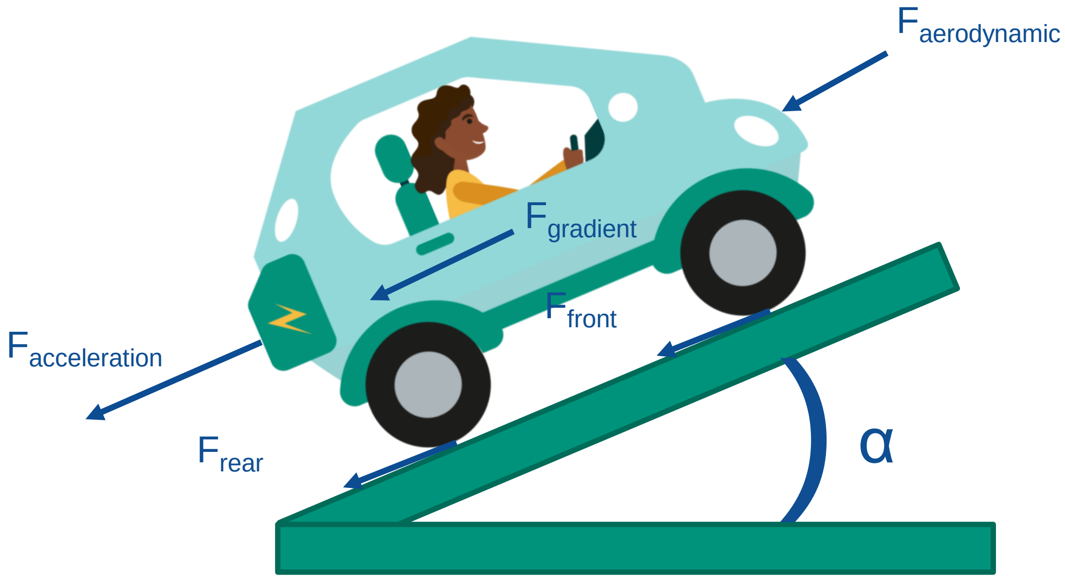
- Architecture
- Running resistance
- Body
- eMotors
- Batteries
- Energy Management

Agenda

Vehicle Running Resistance Estimation

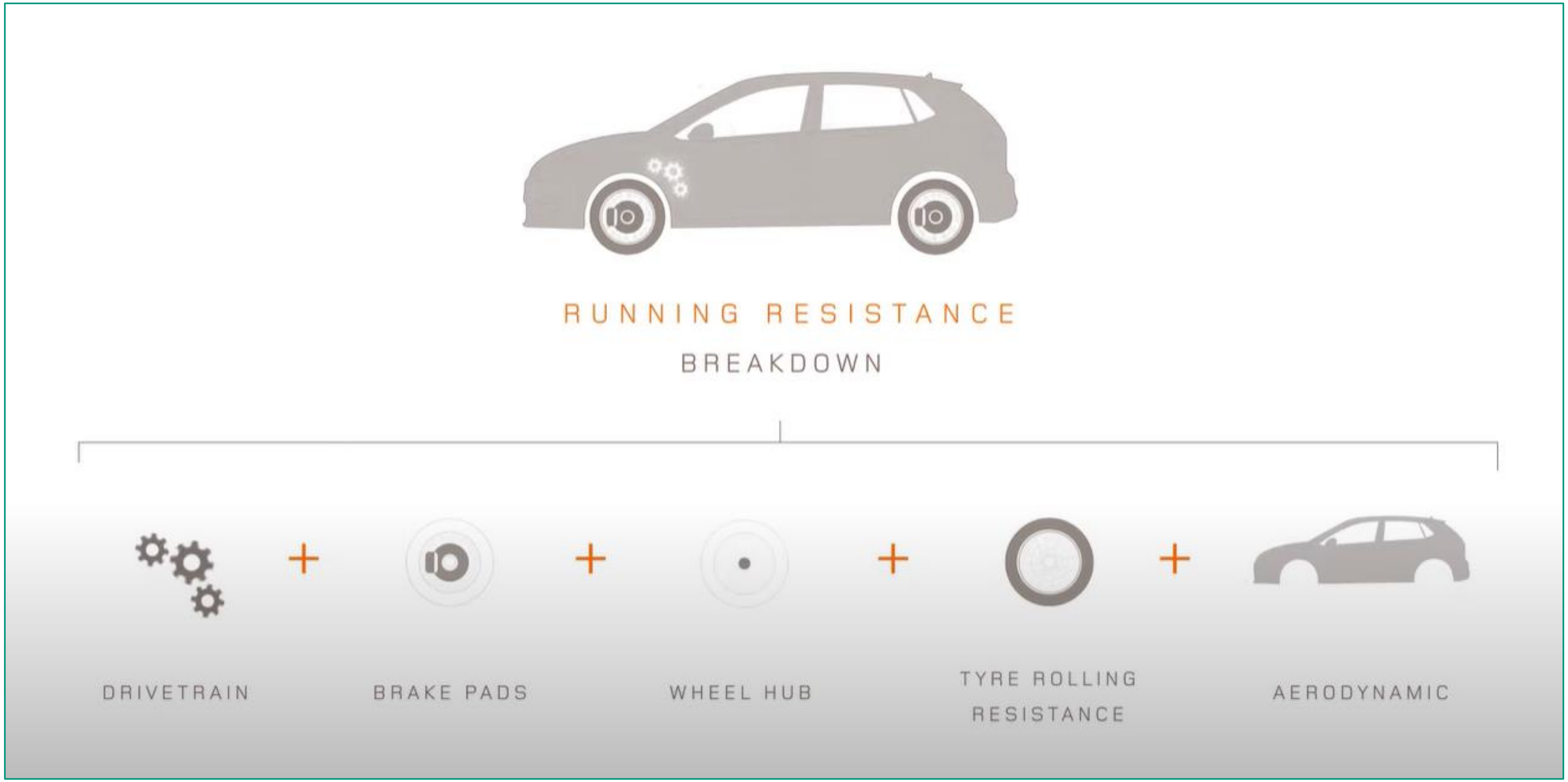
What is the running resistance?

- Is the sum of rolling and aerodynamic resistance



Vehicle Running Resistance Estimation

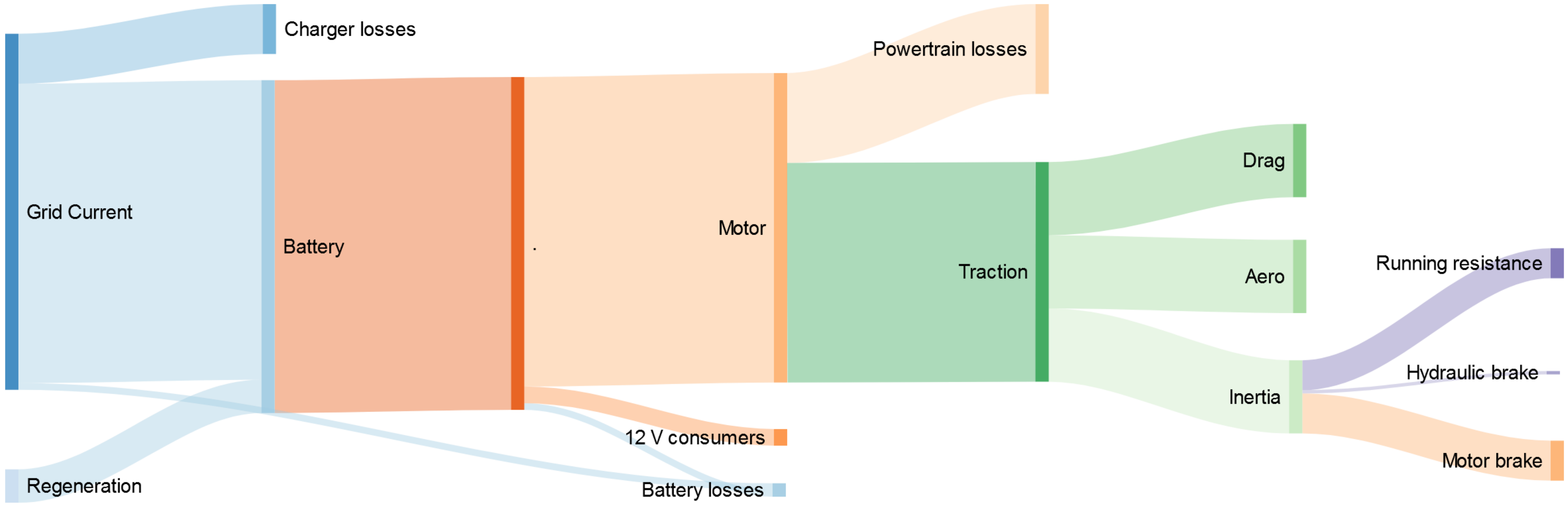
Running Resistance coming from… *https://www.youtube.com/watch?v=x23bQoTDtM8*



Vehicle Running Resistance Estimation

Electric Vehicle Energy Breakdown

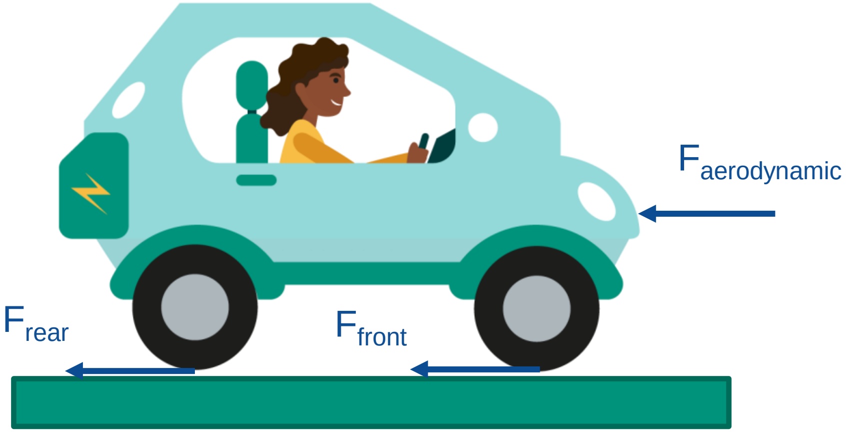
- For Electric Vehicles most of the energy is used to overcome the vehicle running resistance.

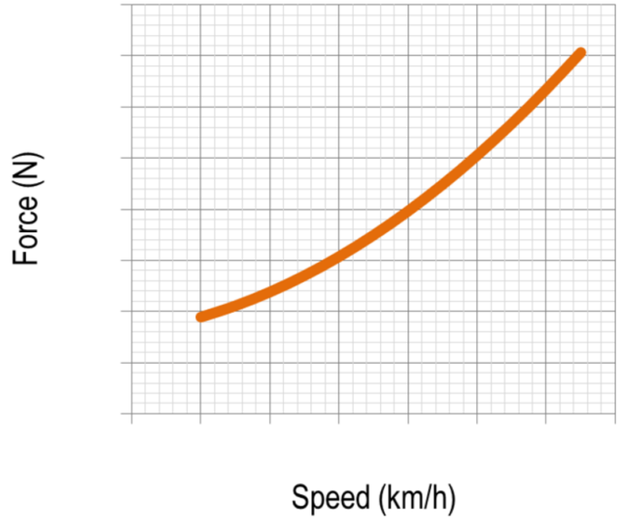


Vehicle Running Resistance Estimation

Coast Down Testing

- United Nations Global Technical Regulation Nº15 (UN GTR15).
- Vehicle Weight & Deceleration times Measurement on test track.
- Weather requirements for wind speed and ambient temperature.





$$F_{res} = f_0 + f_1 \cdot v + f_2 \cdot v^2$$

Vehicle Running Resistance Estimation

Alternatives to estimate running resistance:

- Matematical formula based on vehicle parameters as described on UN GTR15 Normative:

$$F_{res} = f_0 + f_1 \cdot v + f_2 \cdot v^2$$

Rolling resistance (f_0) — Aerodynamic drag ($f_2 \cdot v^2$)

- $F_c = Calculated\ defalut\ road\ load\ force\ as\ a\ function\ of\ vehicle\ speed$
- $f_0 = 0{,}140 \cdot TM$
- $f_1 = 0$
- $f_2 = (2{,}8 \cdot 10^{-6} \cdot TM) + (0{,}0170 \cdot width \cdot height)$

** $TM = Test\ Mass\ [kg]$

Vehicle Running Resistance Estimation

Alternatives to estimate running resistance:

- Matematical formula based on vehicle parameters:

$$F_{res} = f_0 + f_1 \cdot v + f_2 \cdot v^2 \approx \underbrace{mgf_r + drag}_{f_0} + \underbrace{\frac{1}{2}\rho C_x A}_{f_2} \cdot v^2$$

Rolling resistance

Aerodynamic drag

Vehicle Running Resistance Estimation

Alternatives to estimate running resistance:

- Matematical formula based on vehicle parameters:

$$f_0 \approx mgf_r + drag$$

Rolling resistance

$m = Vehicle\ mass$

$g = Gravity$

$f_r = Rolling\ resistance\ coefficient \sim 0.005 - 0.007$

$drag = Additional\ rotating\ parts\ drag$

Vehicle Running Resistance Estimation

Alternatives to estimate running resistance:

- Matematical formula based on vehicle parameters:

$$f_2 = \frac{1}{2}\rho C_x A$$

Aerodynamic drag

$\rho = Air\ density\ (1.188\frac{kg}{m^3}\ at\ 20ºC)$

$*C_x = Aerodynamic\ coefficient$

$*A = Frontal\ area\ (m^2)$

$*For\ "C_x"\ \&\ "A"\ related\ to\ bikes, quadricyles, or\ other\ kind\ of\ vehicles\ this\ information\ can\ be\ found\ on\ internet.$

Vehicle Running Resistance Estimation

Rotational parts inertia:

- Not only the vehicle accelerates, all the rotating parts also increase their rotational speed when accelerating.

- Rotational inertia increases the required energy to accelerate.

$$F = ma + m_{eq}a = m_k a$$

$$m_{eq} \approx 0.05 \cdot m_{empty}$$

Agenda

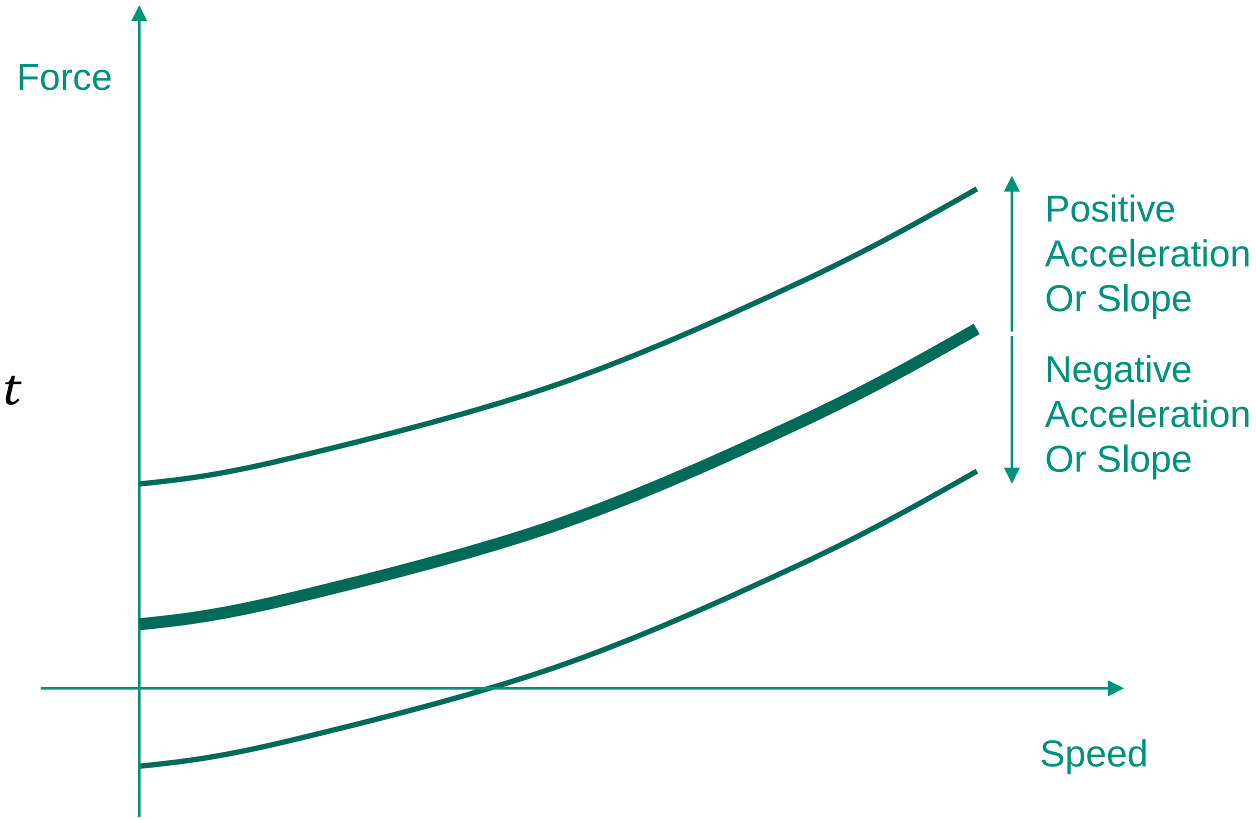
Vehicle Traction Requirements Calculation

Tractive force formula:

$$F_{Wheel} = F_{res}(v) + m_k a + mgsin\alpha$$

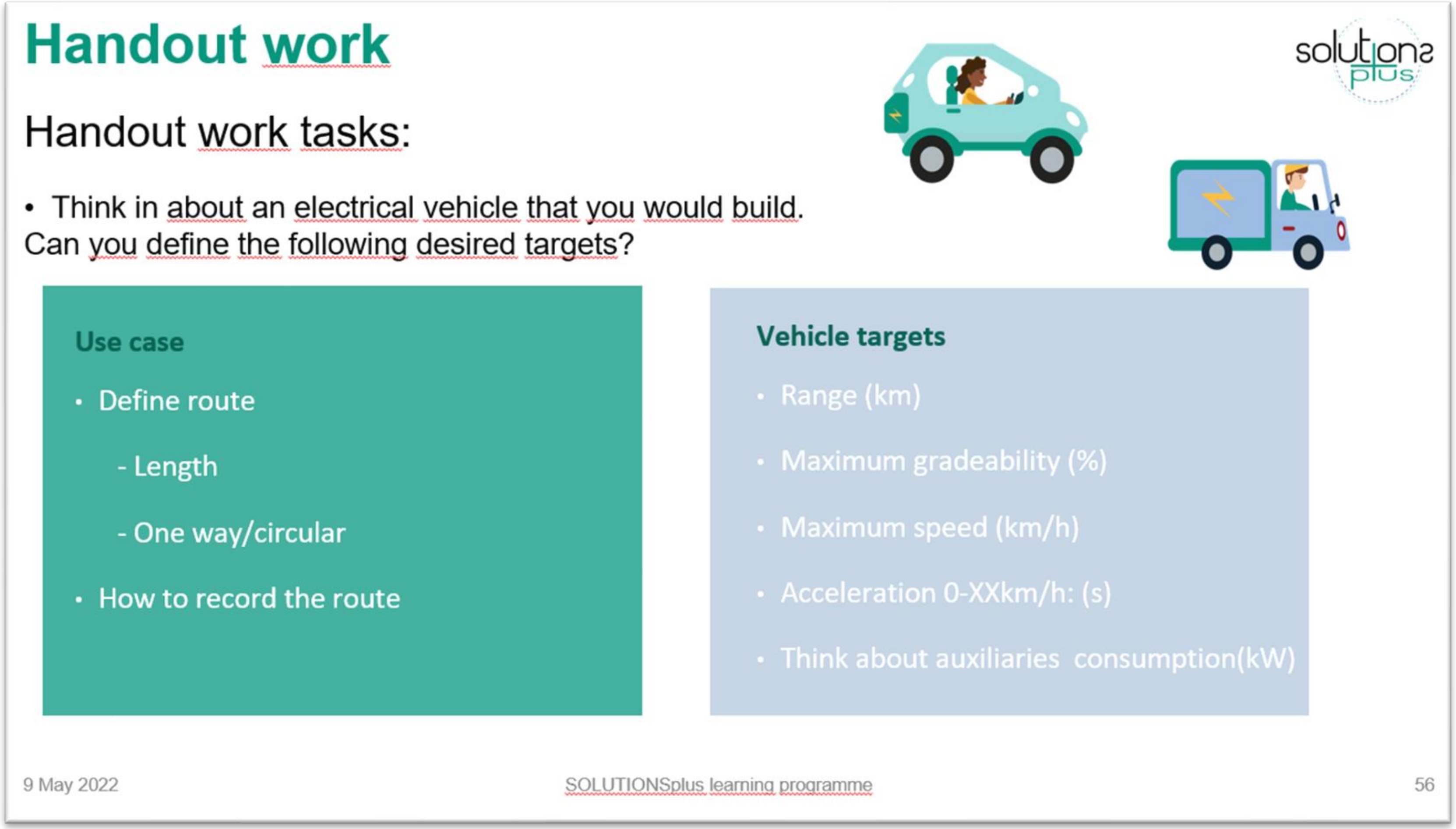
$$m_k = m_{empty} + m_{driver} + m_{load} + m_{eq,rot}$$

$$m = m_{empty} + m_{driver} + m_{load}$$



Vehicle Traction Requirements Calculation

Sesion 1 Handout work:



Vehicle Traction Requirements Calculation

Vehicle targets review:

Max Speed

Acceleration

Sustained gradeability

Max gradeability

Startability

Load

Range

Vehicle Traction Requirements Calculation

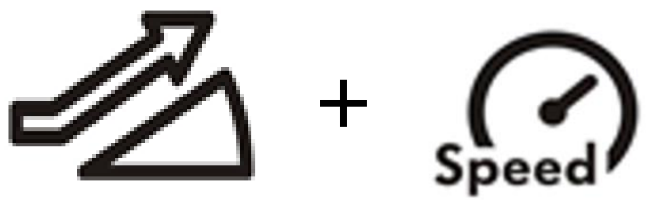
Combined targets:

It is important that vehicle complies with combined targets

“max speed can be achieved also at 2% grade“

but usually combined targets are recuded

“the vehicle can climb 20% slope, but we also want it to climb 8% slope at 80 km/h“



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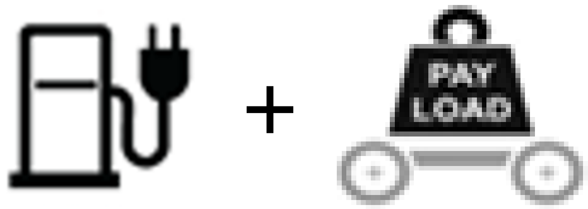
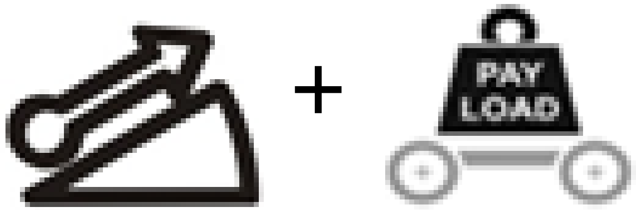




…

Vehicle Traction Requirements Calculation

Vehicle targets handover from Sizing 1 session:

List of targets, including combined targets. In this table format we need to put targets related to:

Max Speed

Sustained gradeability

Startability

Max gradeability

Load

Target	Slope (%)	Load mass (kg)	Speed (km/h)	Acceleration (m/s^2)
Max speed	x	x	x	x
Max slope (short)	x	x	x	x
Max slope (long)	x	x	x	x
Max slope loaded	x	x	x	x
…	…	…	…	…

Vehicle Traction Requirements Calculation

Vehicle targets and force requirement calculation:

Calculate force requirements for each of the targets with the formula:

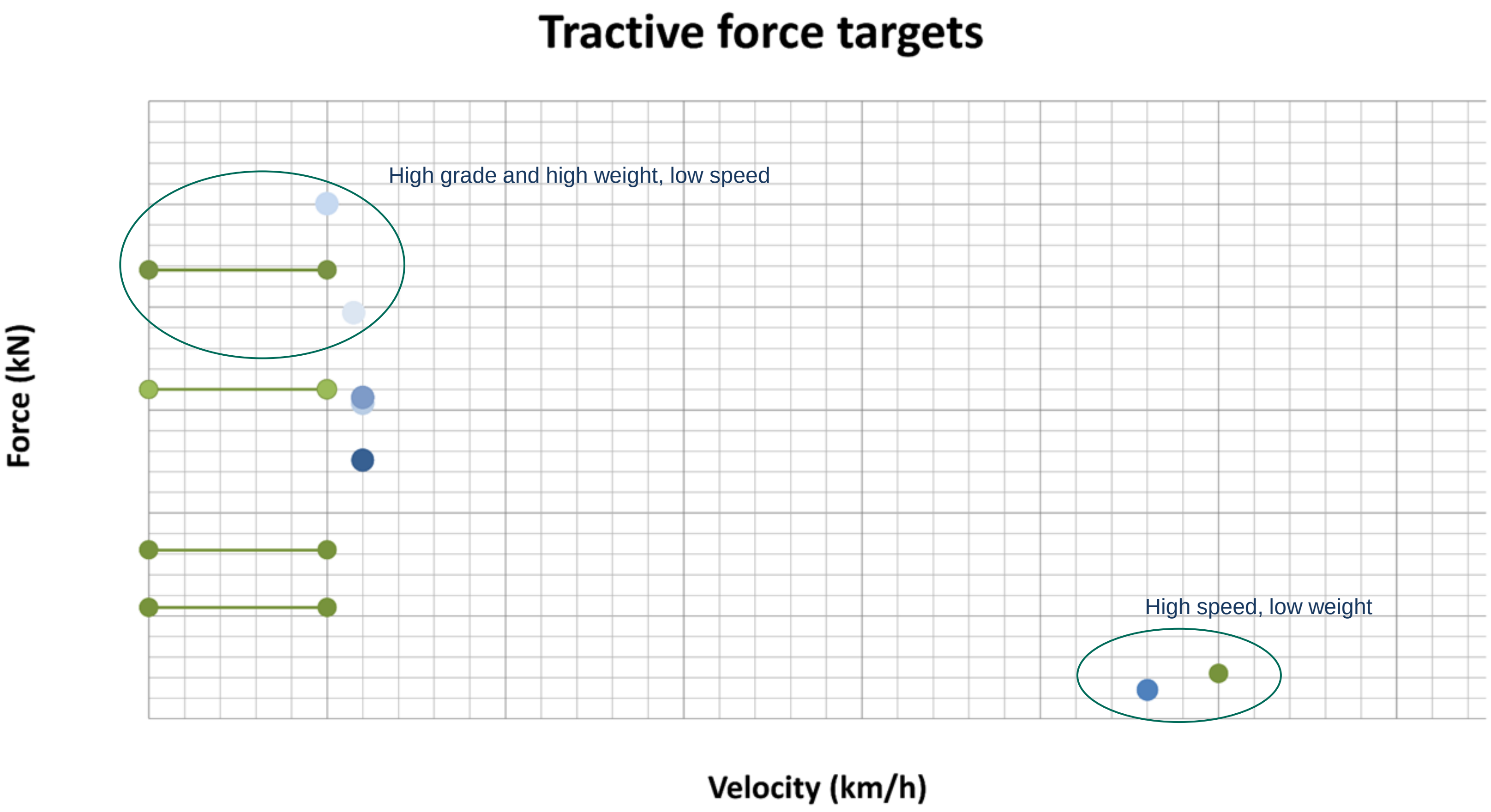
$$F_{Wheel} = F_{res}(v) + m_k a + mgsin\alpha$$

Target	Slope (%)	Load mass (kg)	Speed (km/h)	Acceleration (m/s²)	Force (N)
Max speed	x	x	x	x	To be Calculated
Max slope (short)	x	x	x	x	To be Calculated
Max slope (long)	x	x	x	x	To be Calculated
Max slope loaded	x	x	x	x	To be Calculated
…	…	…	…	…	To be Calculated

Vehicle Traction Requirements Calculation

Tractive force targets graphics:

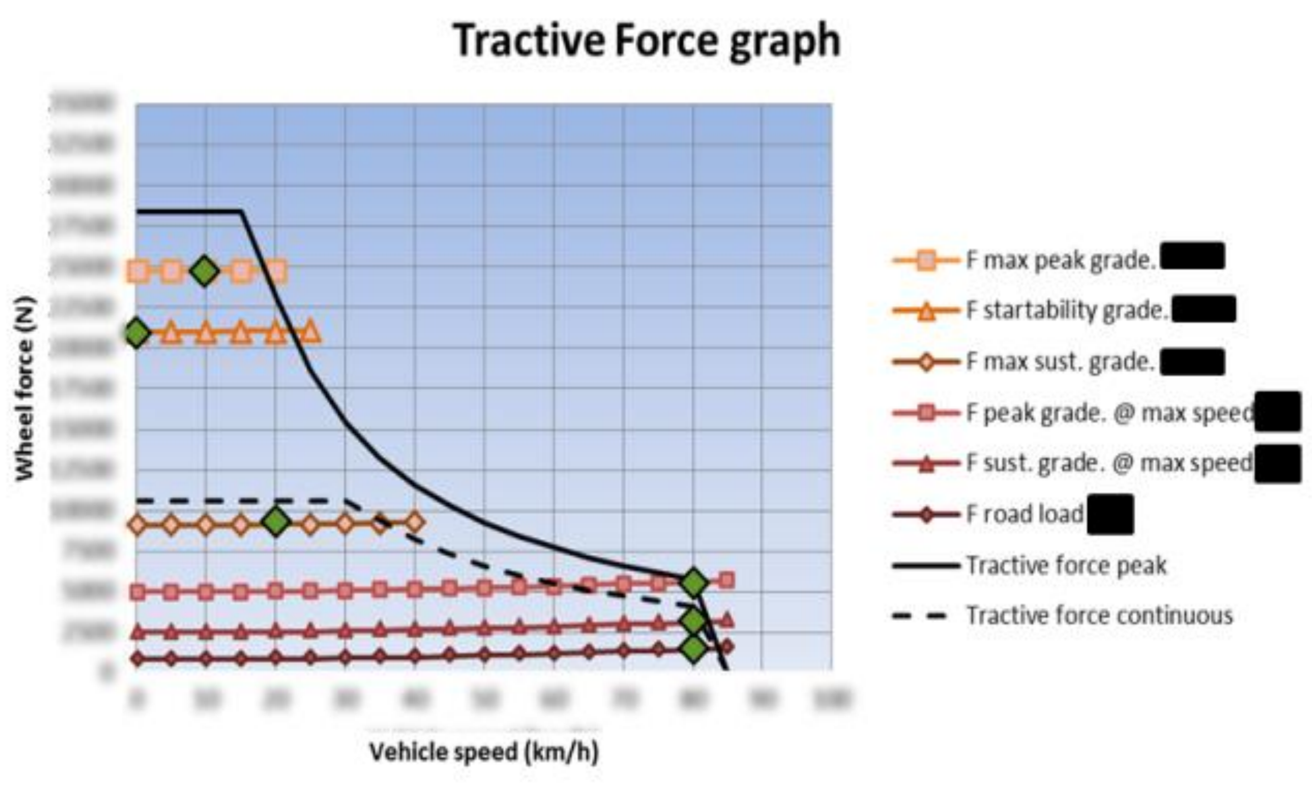
- Once the targets are defined, this kind of graphic can be plotted. Each point representing one target:



Vehicle Traction Requirements Calculation

Tractive force targets graphics:

- The area covering the different targets points on the graphic will define the optimus electric motor fitting the vehicle traction requirements.



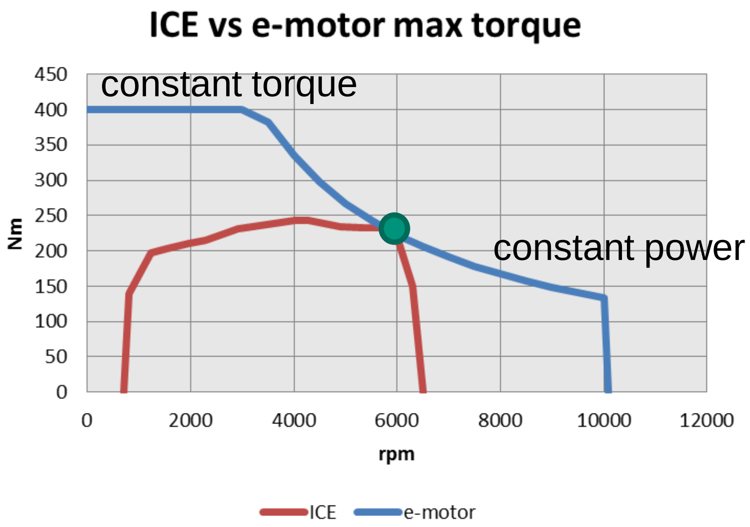
Agenda

1. Vehicle Running Resistance Estimation
2. Vehicle Traction Requirements Calculation
3. Definition of Tractive Force & Power at Wheel
4. Definition of Battery Target Power
5. References
6. Handout work

Definition of Tractive Force & Power at Wheel

Tractive force area:

- Differences between Electric Motors & Internal Combusition Engines



- Eletric Motors developed for automotive applications usually have that shape in order to cover ICE operative area with no need of gear change. This characteristic is usually defined by the characteristic

$$\chi = \frac{rpm_{max}}{rpm_{Tmax}}$$

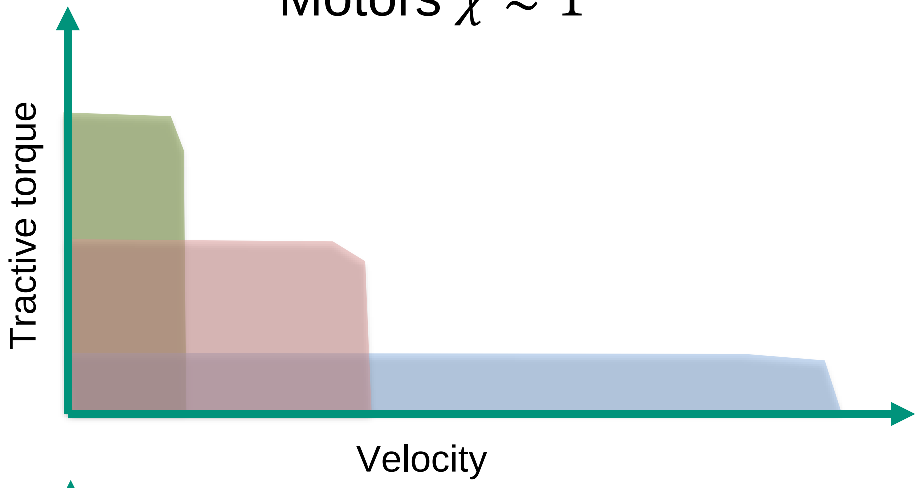
Example: $\chi = \frac{10000}{3000} = 3{,}33$

Definition of Tractive Force & Power at Wheel

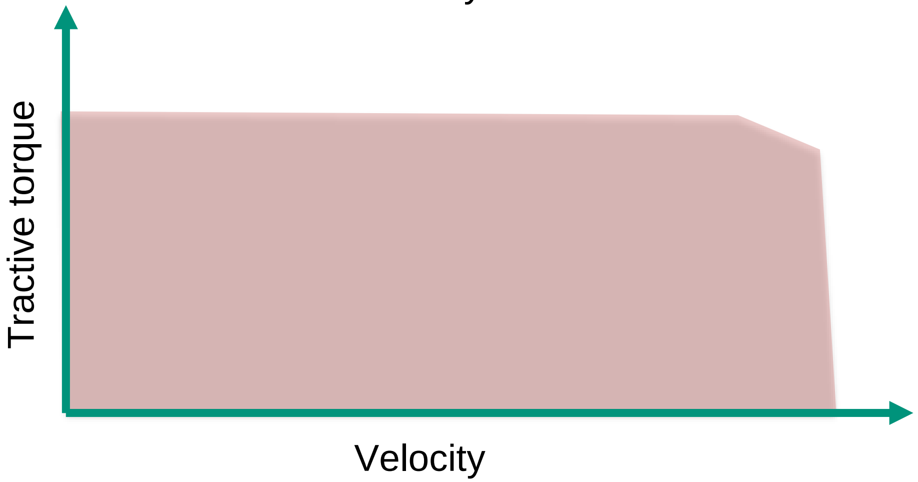
Tractive force area:

- Options to cover the same tractive force area of an ICE with an Electric Motor.

Motors $\chi \approx 1$

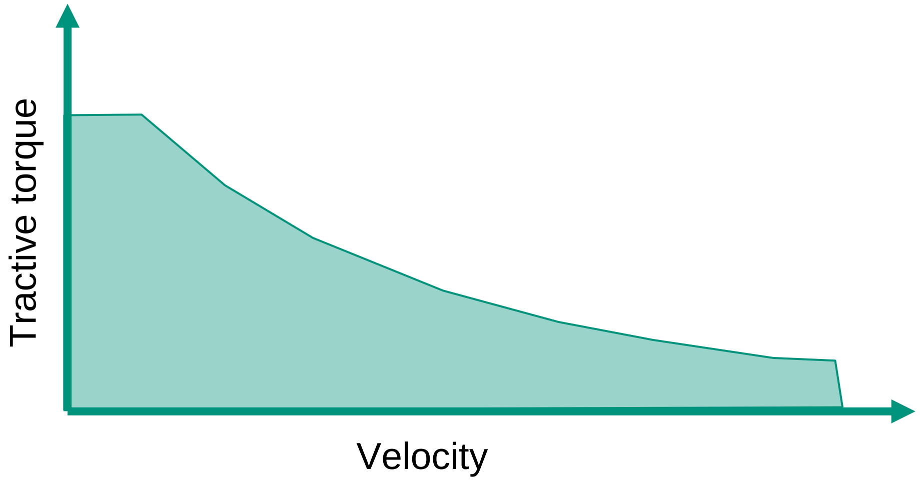


Gears
are required



Over-powered
motor is required

Motors $\chi > 2$

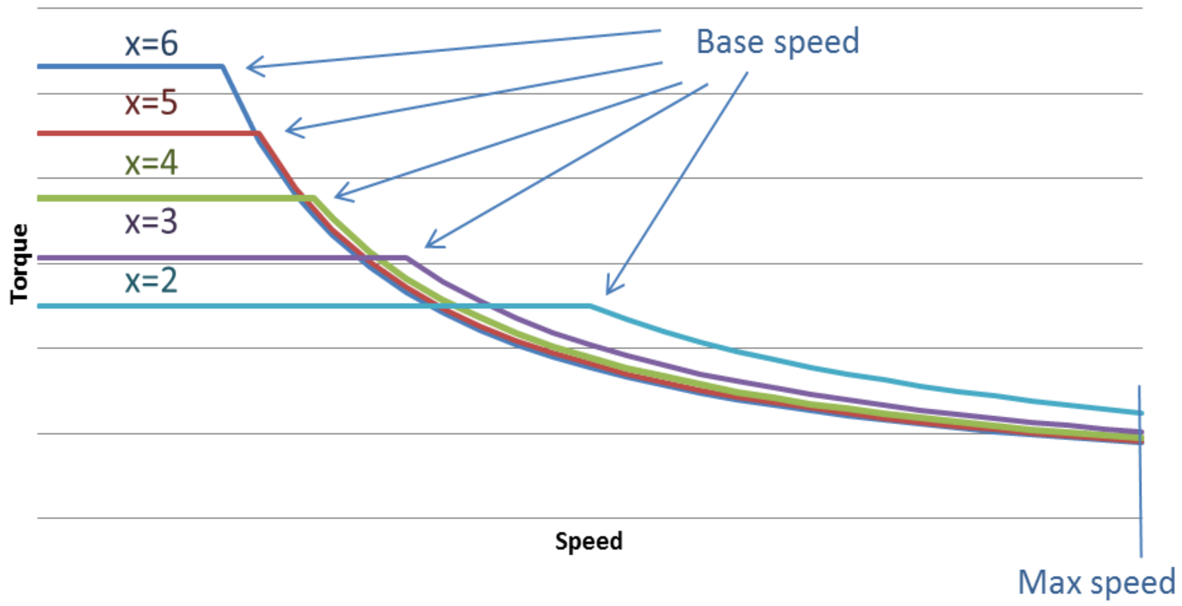


Electric Motor for Automotive applications

Definition of Tractive Force & Power at Wheel

Acceleration & Power:

- Different Electric motors can fit the acceleration target.
- Same acceleration time can requiere different power depending on the electric motor specifications.

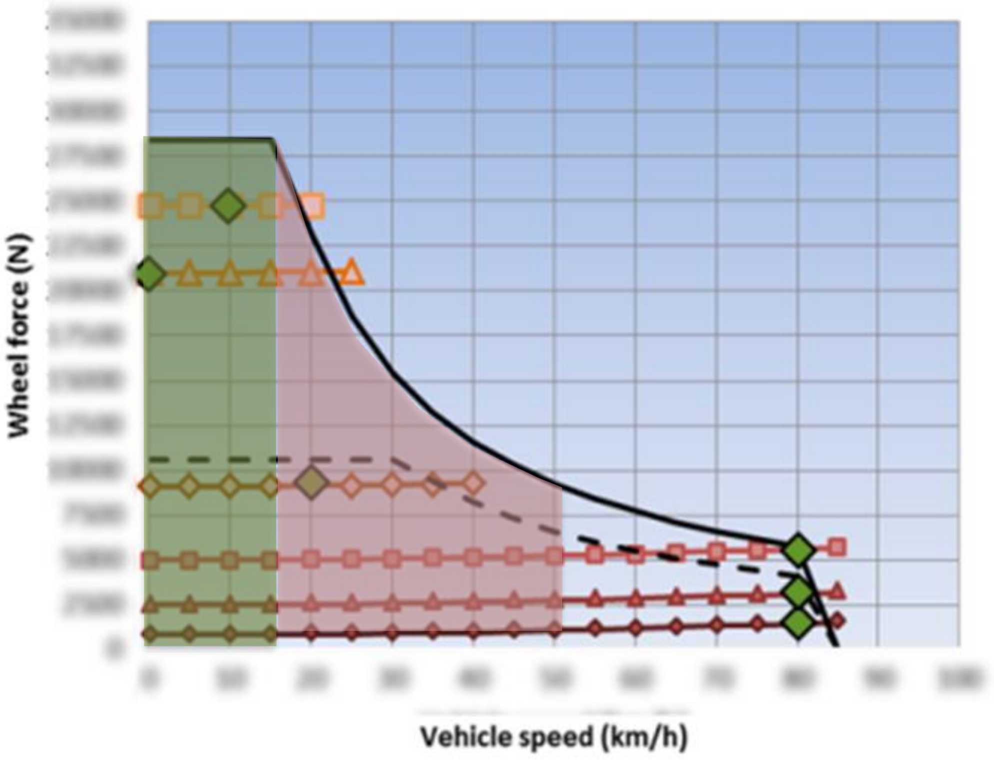


Roche, M., Sabrià, D., Mammetti, M., "An Accesible Predesign Calculation Tool to Support the definition of EV Component", International Journal of Automotive Technology, Vol. 17, No. 3, pp. 509−521 (2016). DOI 10.1007/s12239−016−0052−7.

Definition of Tractive Force & Power at Wheel

Acceleration & Power:

- The power required for acceleration can be estimated with an analytical formula:



The plotted area should be calculated

$$P_t \approx \frac{m_k}{2t_a}(v_f^2 + v_b^2)$$

m_k is the mass to accelerate, considering rotational inertia

t_a is the target acceleration time

v_f is speed to which we want to accelerate

v_b is speed at which we expect to change from constant torque to constant power:

$$v_b = \frac{v_{max}}{\chi}$$

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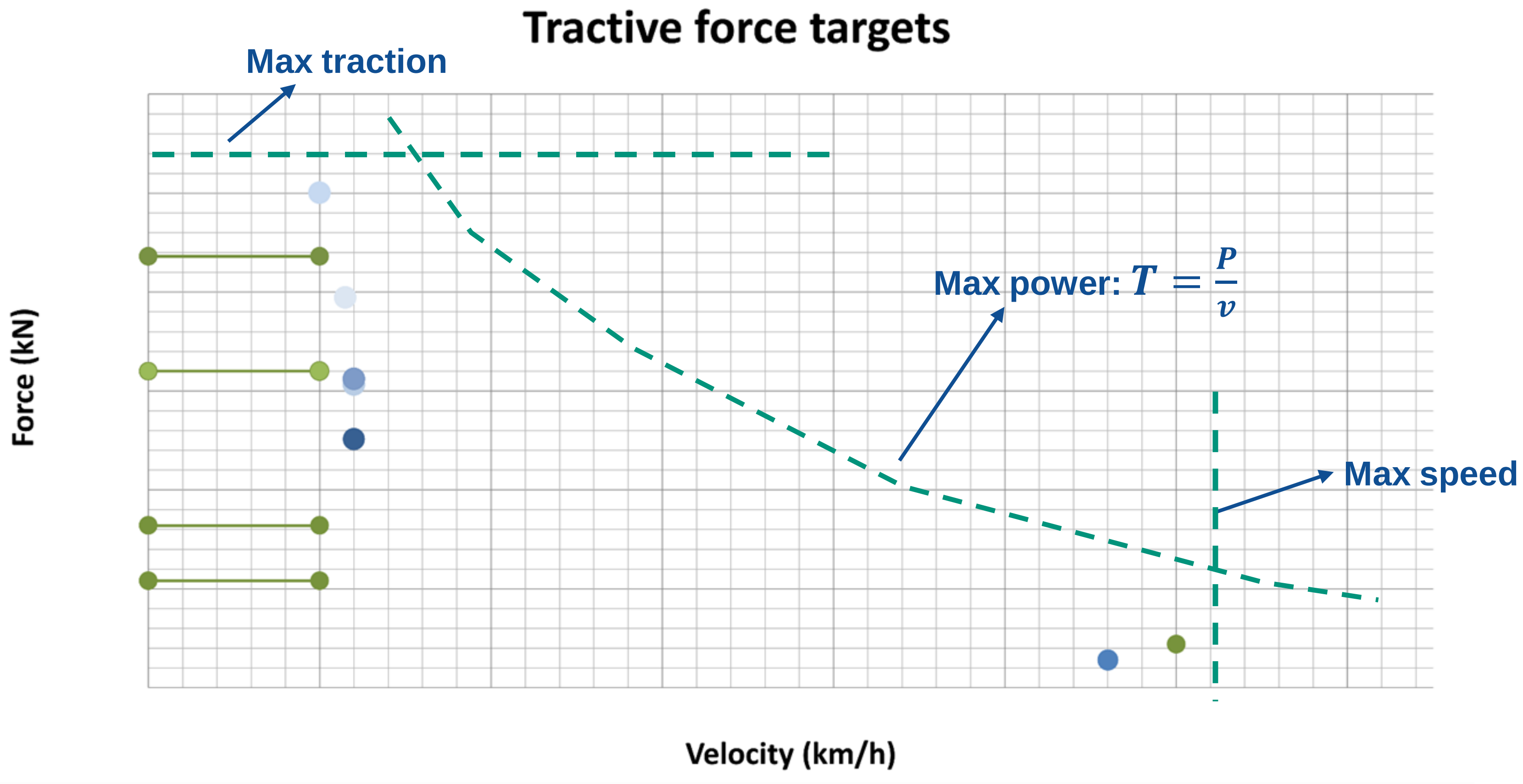
Definition of Battery target power

Identify traction and power requirements

- Once we know the required power, we can create an envelope with our requirements:



Definition of Battery target power

Continuous and peak performance

- Continuous power can be mantained during long time periods.

- Peak power is available only for a short periods of time in order to assure the electric motor reliability. (These periods are normally between 10s and 60s).

Definition of Battery target power

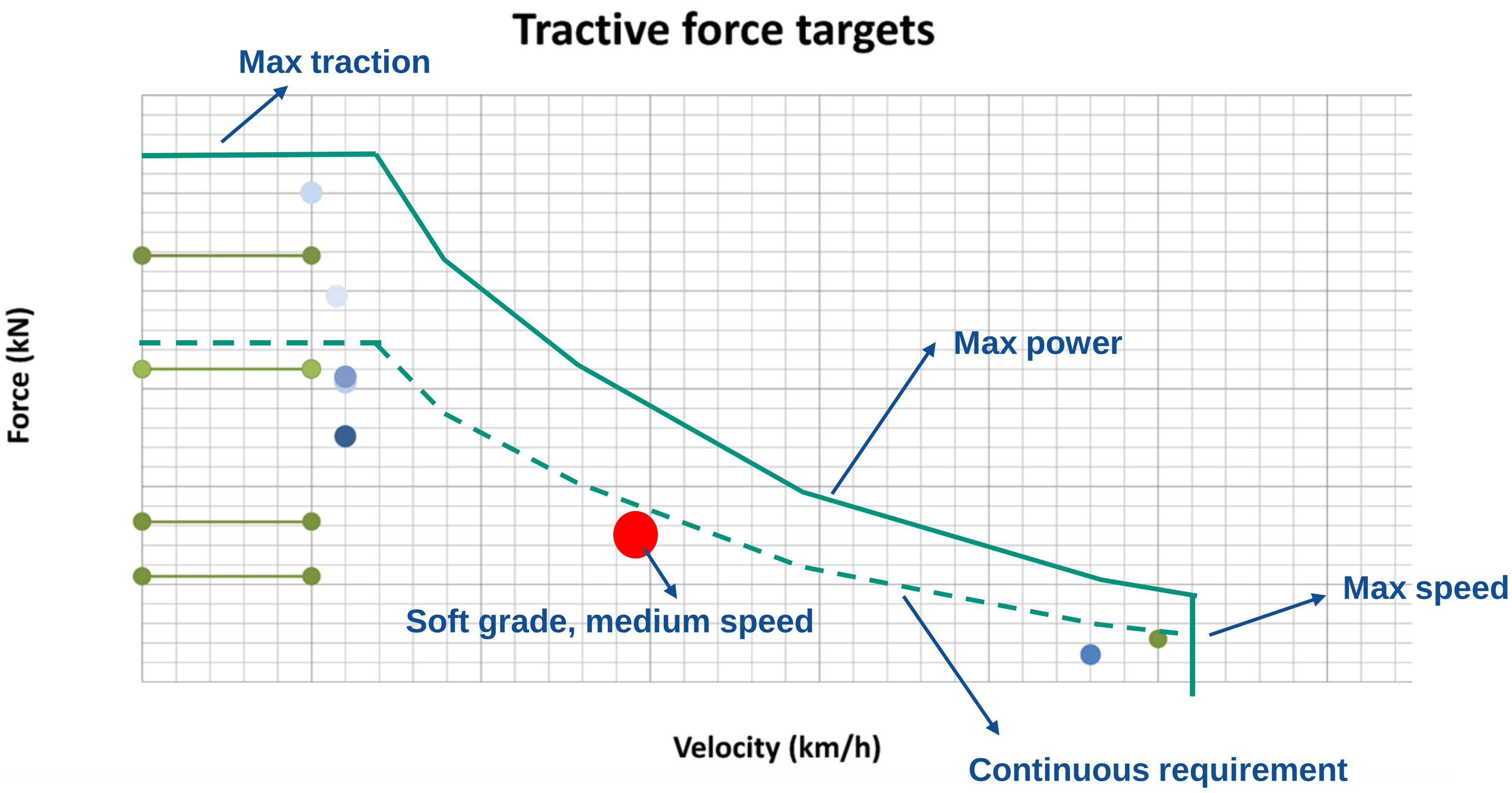
Identify continuous requirements

Define conditions to cover with peak power in which short time is acceptable. Eg:

- Maximum acceleration
- Short grades

Define conditions to cover with continuous power in which long time is required. Eg:

- Long grades
- Soft grades at medium speed
- Max speed at 2% grade



Definition of Battery target power

Identify Battery power

$$P_{motor} = \frac{P_{wheel}}{\eta_{transmission}}$$

$\eta_{transmission} = Transmission\ efficiency \sim 90\% - 95\%$

$$P_{bat} = \frac{P_{motor}}{\eta_{mot,inv}} + P_{cons}$$

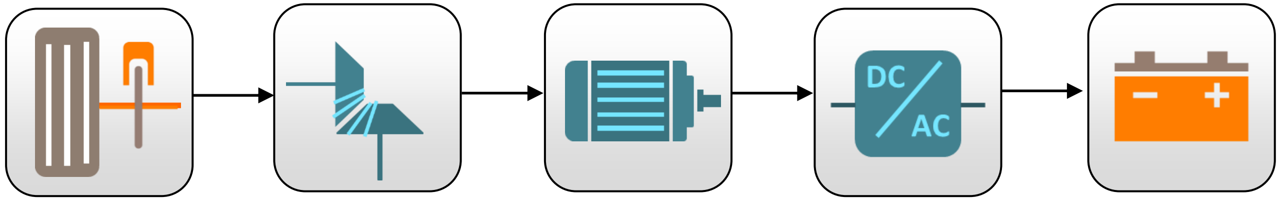
$\eta_{mot,inv} = Motor\ \&\ Inverted\ combined\ efficiency \sim 80\% - 85\%$

P_{cons} *is the power due to additional consumers* $(VCUs, HMIs, comfort, cargo\ cooling\ \ldots)$

$$P_{bat} = \frac{P_{motor}}{\eta_{mot,inv}} = \frac{P_{wheel}}{\eta_{mot,inv} \cdot \eta_{transmission}} + P_{cons}$$

These calculation should be made for peak & continuous power

- $P_{bat,peak}$
- $P_{bat,continuous}$



Definition of Battery target power

Identify Battery power

- In case of electric bikes don‘t forget to substract the power executed by the rider:

Recreational riders:	100-200 W
Recreational fit riders:	250-300 W
Profesional riders:	400W

$$P_{bat} = \frac{P_{wheel} - P_{rider}}{\eta_{mot,inv} \cdot \eta_{transmission}} + P_{cons}$$

Definition of Battery target power

Calculate Battery Peak and Continuous power

- The batteries also have peak and continuous power limits. Also consider that the battery pack limits are usually more restricitive than the cell limits.
- Power limits are usually defined by the C-rate: The C-rate is inverse proportional to the time it takes to fully charge or discharge. 1 C means it fully charges/discharges in 1h. 2 C means it fully charges in 0,5h
- If we only know the C-rate, we can estimate the power limit by:

$$P_{peak} \approx Capacity \cdot Crate_{peak}$$

$$P_{cont} \approx Capacity \cdot Crate_{cont}$$

Definition of Battery target power

Battery Technology investigation

- C-rate strongly depends on battery technology and is usually more restrictive for recharge.

- You can check power for different cells at: https://www.batemo.de/products/batemo-cell-library/

Definition of Battery target power

Benchmarking Analysis:

- It is always useful to validate your analysis and calculations with the competitors in order to validate the sizing of the electric motor and battery.
- To validate the power calculation, compare the power you obtained for the emotor with the power declared by the competitor
- Differences can be due to different use case targets. But are useful to validate our calculation and target setting

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References

- *EU Coast Down regulation: United Nationals Global Technical Regulation Nº15 (UN GTR15)*
- *Running Resistance Video: https://www.youtube.com/watch?v=x23bQoTDtM8*
- *Vehicle tyre labeling:* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0740&from=EN
- *Rolling resistance of bikes: https://www.researchgate.net/publication/279323381_Comparison_of_tyre_rolling_resistance_for_different_mountain_bike_tyre_diameters_and_surface_conditions*
- *Aerodynamic Resistance for bicycles: https://ridefar.info/bike/cycling-speed/air-resistance-cyclist/*
- *Paper about impact of slope in running resistance measurement: Roche, M., Mammetti, M., "Accurate measurements in proving ground for fuel consumption reduction study in heavy duty vehicles", SAE SIAT 2015 Technical Paper 2015-26-0036, doi:10.4271/2015-26-0036.*
- *Paper on calculation tool: Roche, M., Sabrià, D., Mammetti, M., "An Accesible Predesign Calculation Tool to Support the definition of EV Component", International Journal of Automotive Technology, Vol. 17, No. 3, pp. 509−521 (2016). DOI 10.1007/s12239−016−0052−7.*
- *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles Fundamentals, Theory, and Design (M. Ehsani, Y. Gao, S. E. Gay, A. Emadi)*
- *Continuous and peak performance: https://chargedevs.com/features/how-to-ensure-ev-traction-motor-magnets-arent-pushed-beyond-their-operating-limits/*
- *Battery C-Rating: https://www.power-sonic.com/blog/what-is-a-battery-c-rating/*
- *Battery Cells Power: https://www.batemo.de/products/batemo-cell-library/*

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6 Handout work

Handout work

Handout work tasks:

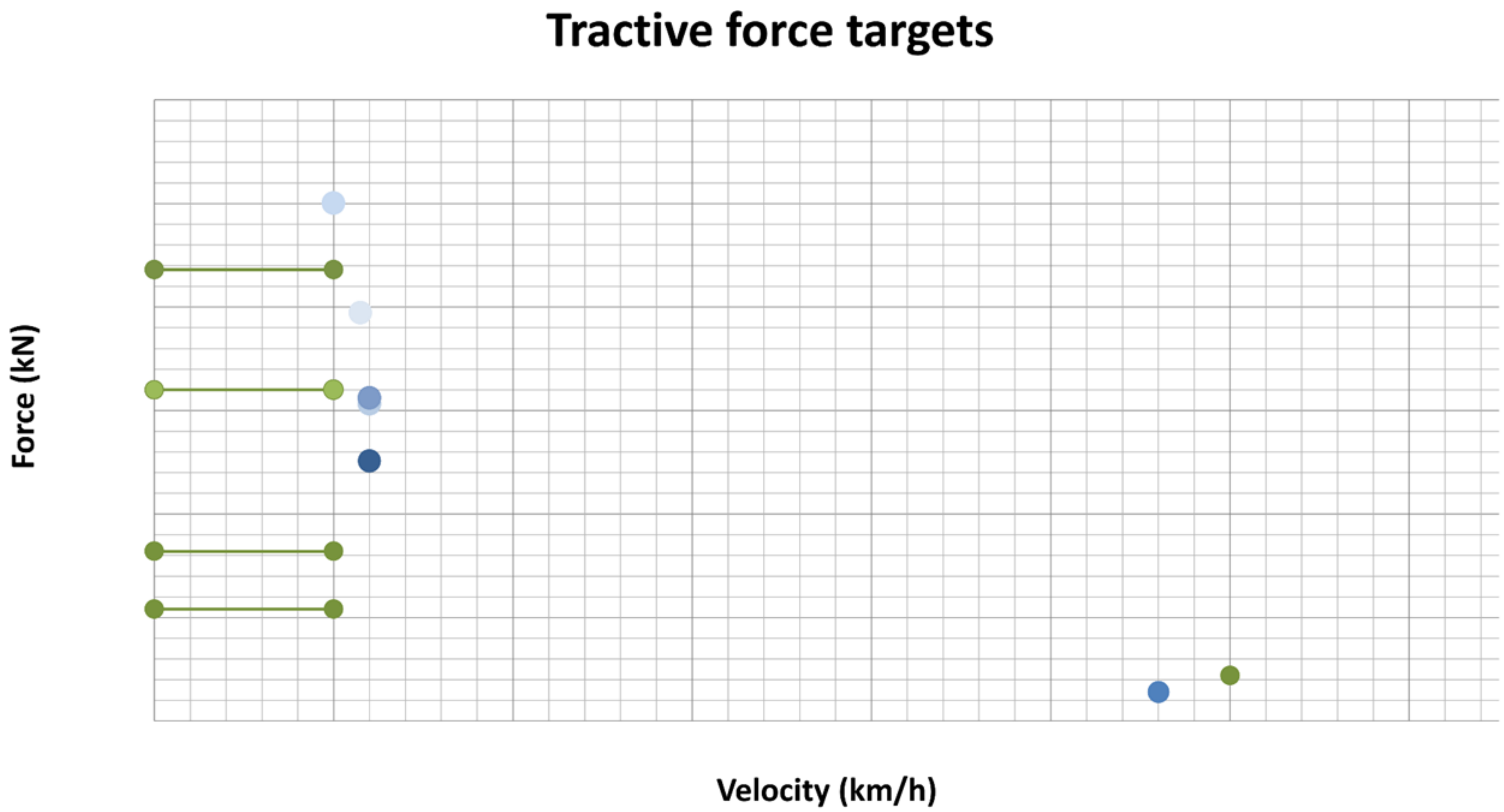
- Calculate running resistance coefficients
- Calculate force requirements for each of the targets
- Calculate acceleration power for your vehicle
- Calculate battery requirements
- Competitors Benchmarking

Target	Slope (%)	Load mass (kg)	Speed (km/h)	Acceleration (m/s^2)	Force (N)
Max speed	x	x	x	x	To be Calculated
Max slope (short)	x	x	x	x	To be Calculated
Max slope (long)	x	x	x	x	To be Calculated
Max slope loaded	x	x	x	x	To be Calculated
…	…	…	…	…	To be Calculated

Handout work

Tractive force targets graphics:

- Once the targets are defined, this kind of graphic can be plotted:



Thanks for your kind attention