Simulation of an electrically assisted bicycle using the Energetic Macroscopic Representation

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Goal of the exercise

- From theory to implementation
  - Modelling
    - From the cyclist to the bicycle
  - Representation using EMR
    - Deduction of an Inverse Based Control
  - SIMULATION
    - To see if it works as expected

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Outline

- Introduction
- Modelling and representation of the system
- Identification of the Inverse Based Control
- Implementation using Matlab/Simulink

Introduction

- System to model

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Introduction

- Objectives
  - Identify the potential of electrically assisted bicycle in helping people to choose efficient transportation means (and good for health)
  - Identify the constraints applied on the electrical part of the system
  - Analysis of the working principle for such systems
- Assumptions
  - Damping systems are not considered
  - Cyclist is supposed to be a rigid mass (!), always sited.
  - No modification of mass repartition during acceleration or braking.
  - Inertias of all rotating masses are neglected
  - No friction losses in the pedalboard, wheel axes or in the transmission
  - Contact wheel/ground without loss (no slip phenomena)
  - No pedal binding

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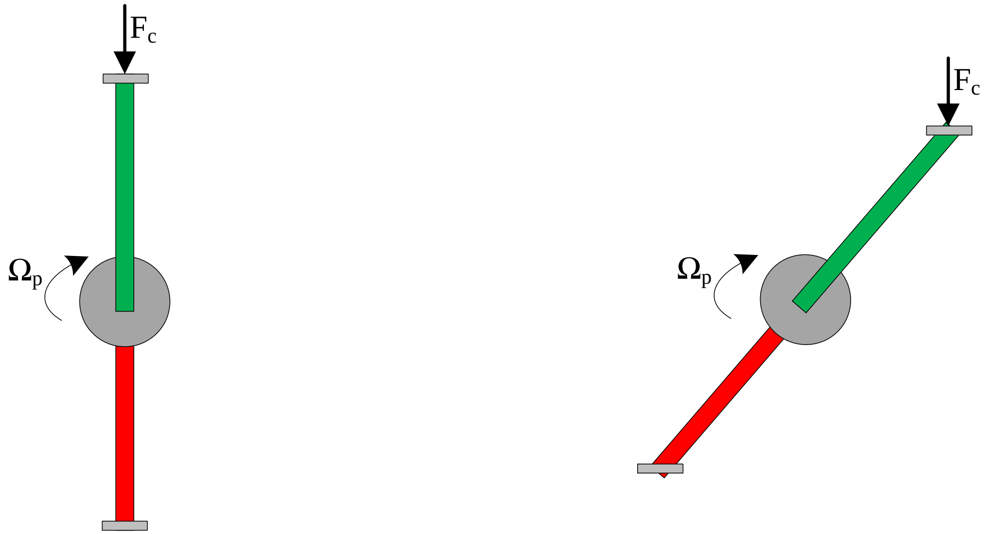
Modelling and representation

- Divide and conquer: sub-systems to consider
  - Cyclist
  - Batteries (1)
  - Electrical assistance (2)
  - Pedals (3)
  - Pedal axis (4)
  - Transmission/Reduction (Pedal axis, gear wheels and chain) (5)
  - Free wheeling system on rear wheel (6)
  - Disc brakes on the rear and front wheels (7)
  - Frame of bike, saddle and handlebars
  - Environment

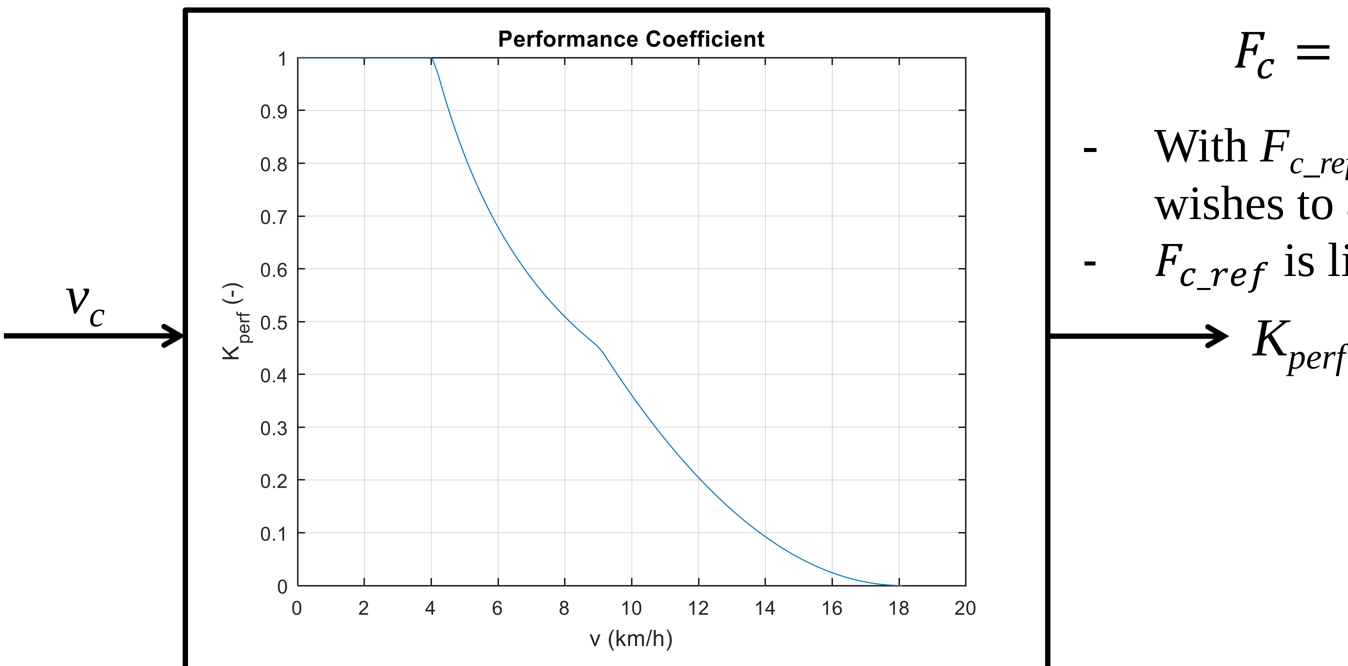
Modelling and representation

- Model of a cyclist
  - From a pure static point of view, a human being can support at least its weight, up to twice its weight or more…. (!?)
  - For a cyclist, who does not want to force to much, assumption will be made that the maximum weight applied on the descending pedal will be defined between 50% and 75% of its own weight (up to you to decide). There is no pedal binding: no force applied on the ascending pedal.
  - The force on the pedals is always vertically applied



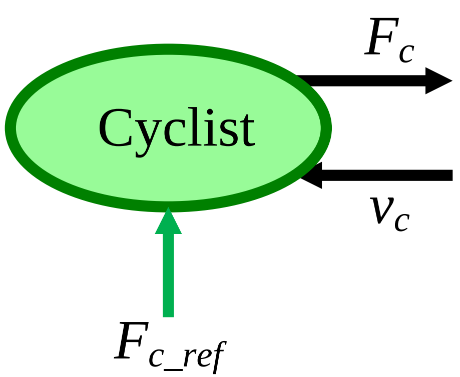
Modelling and representation

- Model and representation of a cyclist
  - Movement of the foot are such as it is circular
    - Defined by its peripheral velocity v_c
  - Introducing K_{pref}, coefficient of perfomance:
    - $K_{perf} = 1$: the cyclist can apply the force he wants (!)
    - $K_{perf} < 1$: limitation of performances at high peripheral velocity.



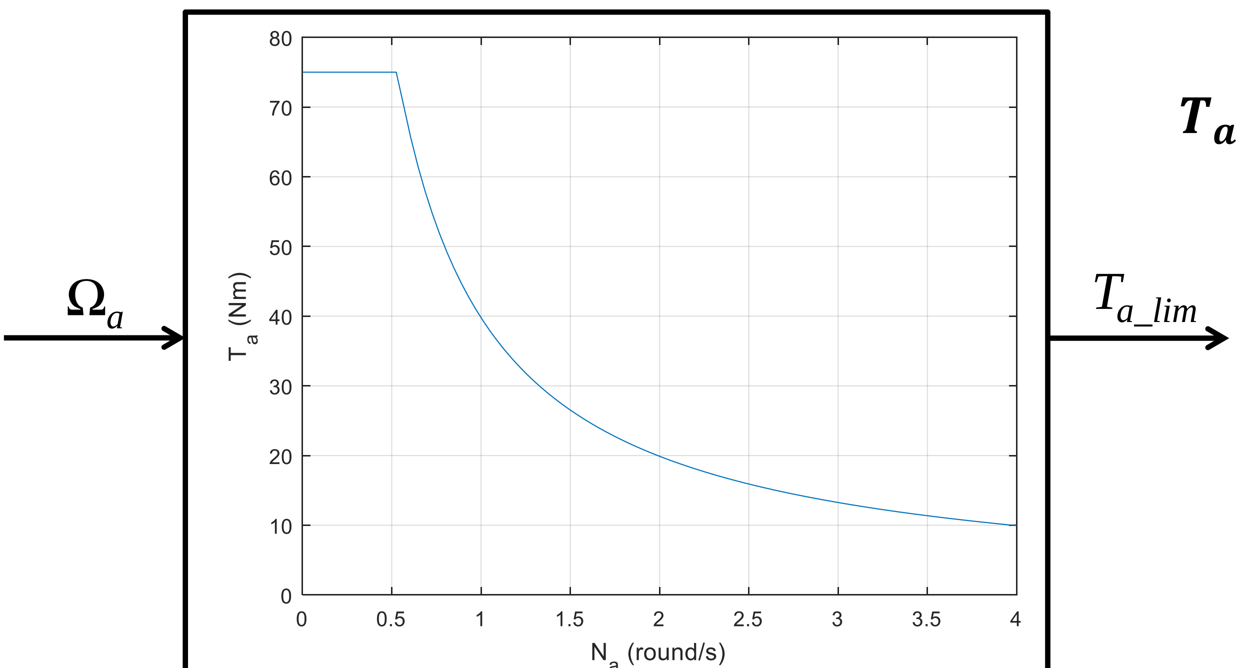
$$F_c = K_{perf} . F_{c\_ref}$$

- With F_{c_ref} the force the cyclist wishes to apply
- F_{c_ref} is limited to 0.75.M.g

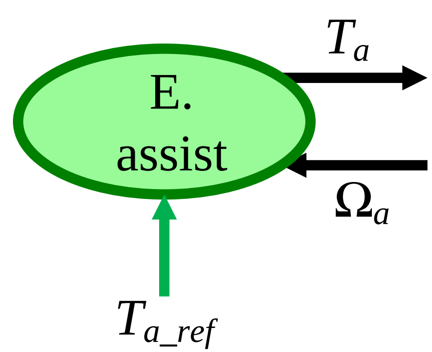


Modelling and representation

- Model and representation of the electrical assistance
  - In a first approach, considered as a source.
  - Maximum torque applied at the pedal axis: $T_{a\_max}=75Nm$
  - Maximum Power: $P_{a\_max}=250W$
  - Applies the torque T_a on the pedal axis, upon request,



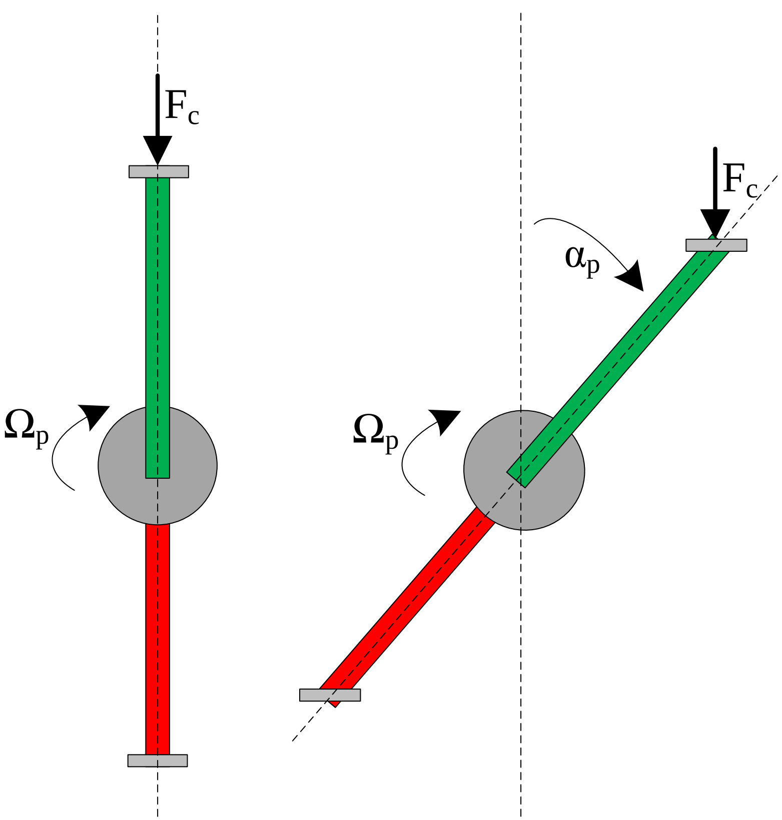
$$T_a = min(T_{a\_lim}, T_{a\_ref})$$

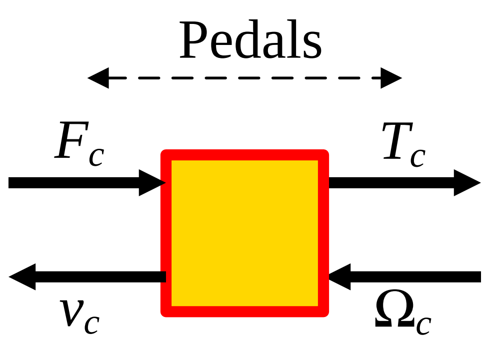


Modelling and representation

- Model and representation of the pedals
  - Radius R_p, convert the force F_c from the cyclist to the torque T_c applied to the pedal axis.

$$\begin{cases} T_c = R_p . F_c . |sin(\alpha_c)| \;\; with \;\; \alpha_c = \int \Omega_c . dt \\ \Omega_c = \dfrac{1}{\mathrm{R_p}} . \mathrm{v_c} \end{cases}$$





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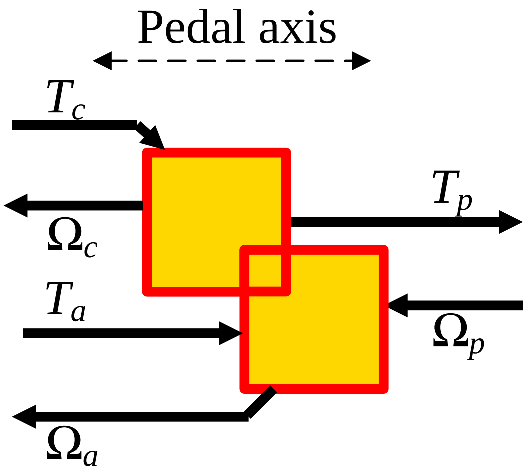
Modelling and representation

- Model and representation of the pedal axis
  - Coupling of the torques from the pedals and the electrical assistance

$$\begin{cases} T_p = T_c + T_a \\ \Omega_p = \Omega_c = \Omega_a \end{cases}$$



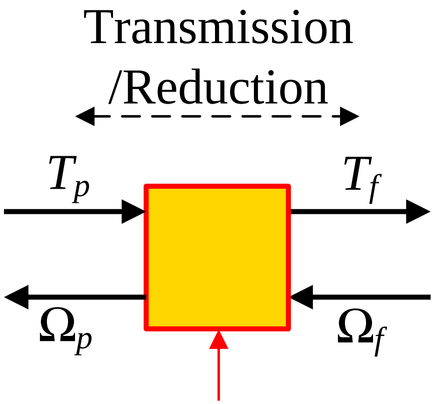
Modelling and representation

- Model and representation of Transmission/Reduction (Pedal axis, gear wheels and chain)
  - The cyclist can use 10 speeds, defined by the conversion ratio K_{vit}:

K_{vit}	36/18	34/18	30/18	28/18	25/18	22/18	20/18	17/18	14/18	11/18

  - The torque applied on the rear wheel free-wheeling system, and the angular velocity are defined by:

$$\begin{cases} T_f = K_{vit}.T_p \\ \Omega_p = \mathrm{K_{vit}}.\Omega_f \end{cases}$$



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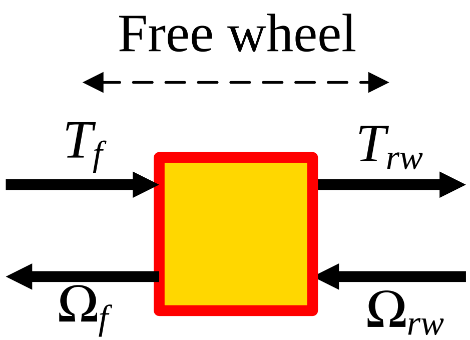
Modelling and representation

- Model and representation of the free wheeling system on rear wheel
  - This mechanism forbids the cyclist to apply negative torque on the rear wheel
  - This mechanism allows the cyclist to stop pushing the pedals even if the cycle velocity is positive
    - The torque applied on the rear wheel free-wheeling system will be transmitted to the rear wheel on the only condition it is positive.

$$\begin{cases} T_{rw} = T_f \\ \Omega_{rw} = \Omega_f \end{cases} \quad if \quad T_f > 0 \qquad\qquad \begin{cases} T_{rw} = 0 \\ \Omega_f = 0 \end{cases} \quad if \quad T_f \leq 0$$



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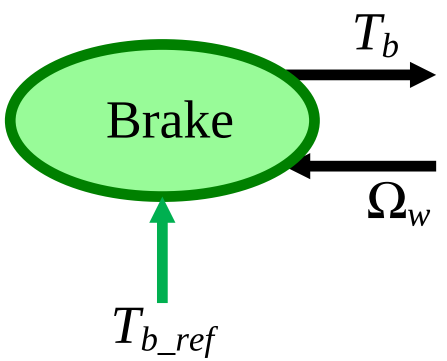
Modelling and representation

- Model and representation of the disc brakes on the rear and front wheels:
  - In a first approach, considered as sources
  - As a simplification, one will consider that the brakes generate a torque directly one each wheel axis.
  - The braking torque is directly imposed by the cyclist from the brake pedals.
  - By convention, this torque will be in any case null or negative.

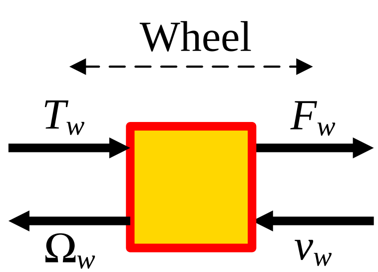
$$T_b = T_{b\_ref} \; with \; T_{b\_ref} \leq 0$$



Modelling and representation

- Model and representation of the wheels:
  - Of course, there are two wheels:
    - Rear wheel: its axis adda torques from the free-wheeling system and from the rear brake
    - Front wheel: only the front brake will apply a torque
  - Convert torque into force and linear velocity into angular velocity
    - Radius R_w

$$\begin{cases} F_w = \dfrac{1}{R_w} T_w \\ v_w = R_w . v_w \end{cases}$$



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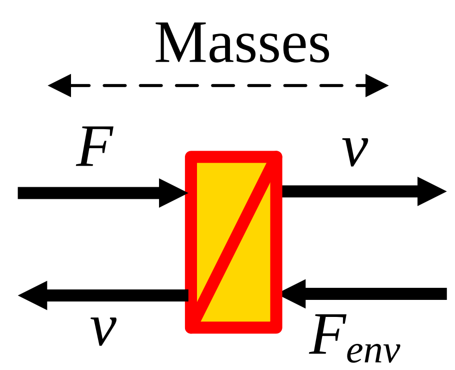
Modelling and representation

- Model and representation of the Frame of bike, saddle and handlebars:
  - The two wheels are ideally linked by the ground:
    - They have the same linear velocity, and add the force *F* they apply.
    - Assuming that *M* is the mass od the cyclist, M_b is the mass of the cycle
    - For a velocity *v*:

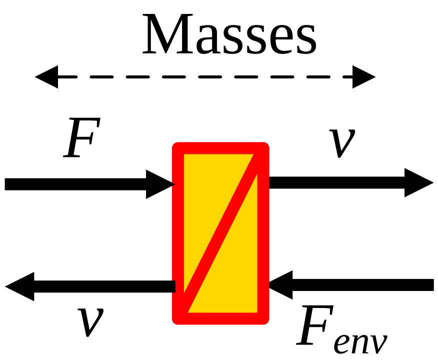
$$(M + M_b).\frac{dv}{dt} = F - F_{env}$$



Modelling and representation

- Model and representation of the environnement:
  - The two wheels are ideally linked by the ground:
    - They have the same linear velocity, and add the force *F* they apply.
    - Assuming that *M* is the mass od the cyclist, M_b is the mass of the cycle
    - For a velocity *v*:

$$(M + M_b).\frac{dv}{dt} = F - F_{env}$$

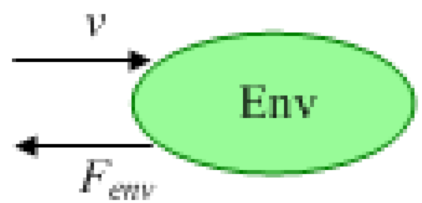


Modelling and Representation

- Model of the environment

  – Model

  - F_{aero} : aerodynamic resistance
  - F_{roll} : rolling resistance
  - F_{grade} : grade resistance

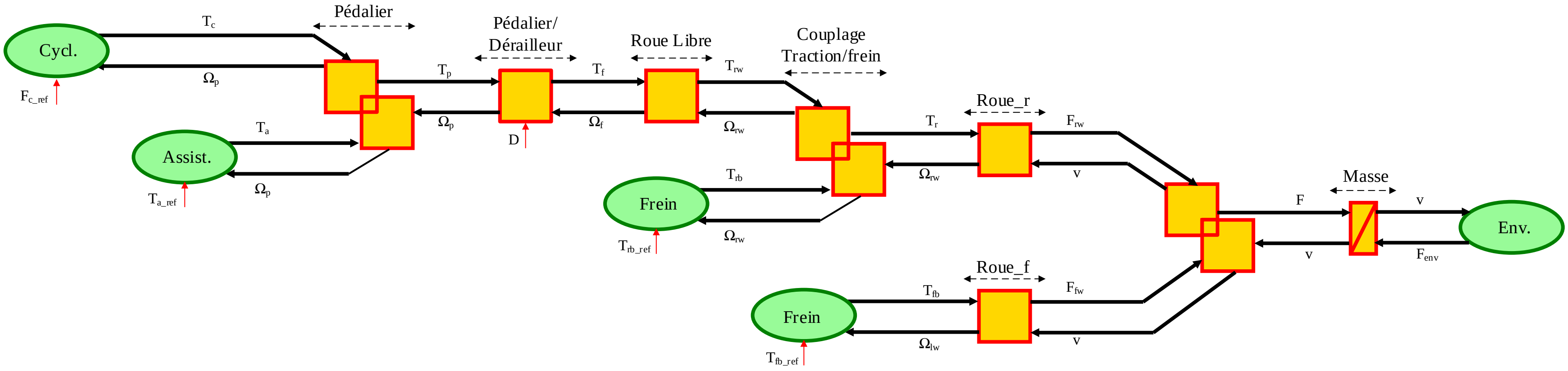


$$\begin{cases} F_{aero} = \dfrac{1}{2}\rho_{air} S_{CX}.v^2 \\ F_{roll} = C_{rr}(M+M_b).g.cos\alpha \\ F_{grade} = (M+M_b).g.sin\alpha \end{cases}$$

If *α* small (h/L<20%)

$$\begin{cases} F_{aero} = \dfrac{1}{2}\rho_{air} S_{CX}.v^2 \\ F_{roll} = C_{rr}(M+M_b).g \\ F_{grade} = (M+M_b).g.\dfrac{h}{L} \end{cases}$$

EMR of the bike



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Activity 1

- Define the Inversed Based Control of the system
  - On the paper
  - Implementation on Matlab/Simulink
    - Tests on a dedicated track (try to respect a 15km/h speed)
    - With/without electrical assistance