« EMR and Delivery E-bike »

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- Kargo Bike (kargo.bike) is a small regional company:
  - Ensures the daily collection of mail and parcels,
  - Promotes sustainable mobility solutions: fleet of cycles – adapted cycles – trailers

- Up to now
  - Some Cycles are electrically assisted
  - All trailers are "home made" and "passives"

- This company wishes to transport heavier loads (up to 300kg payload). Pre-study has been launched to:
  - ➢ Identify a mechanical design for an electrically powered trailer,
  - ➢ Identify constraints for sizing the power train, and size the batteries
  - ➢ Identify means to control this trailer

- Main specifications :
  - ➢ The only link between the trailer and the cycle is a mechanical link, having the only function to guide the trailer
  - ➢ The trailer is fully autonomous for its traction (and brake operation)
  - ➢ No control signal is exchanged between the cycle and the trailer
  - ➢ Effortless and unobstructive for cyclists.

1. EMR of a Cycle
2. EMR of an Electric Assisted Trailer
3. Simulation Results

« EMR of a cycle »

- Assumptions -

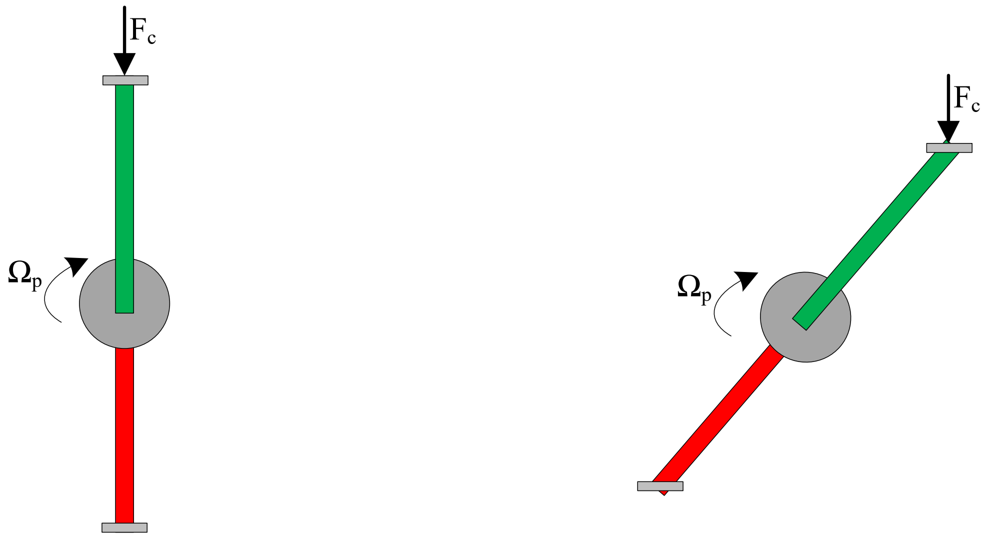
- Damping systems are not considered
- Cyclist is supposed to be a rigid mass (!), always sited.
- No modification of mass repartition during acceleration or braking.
- Inertias of all rotating masses are neglected (but it is a cycle)
- No friction losses in the pedalboard, wheel axes or in the transmission
- Contact wheel/ground without loss (no slip phenomena)
- No pedal binding

- Cyclist

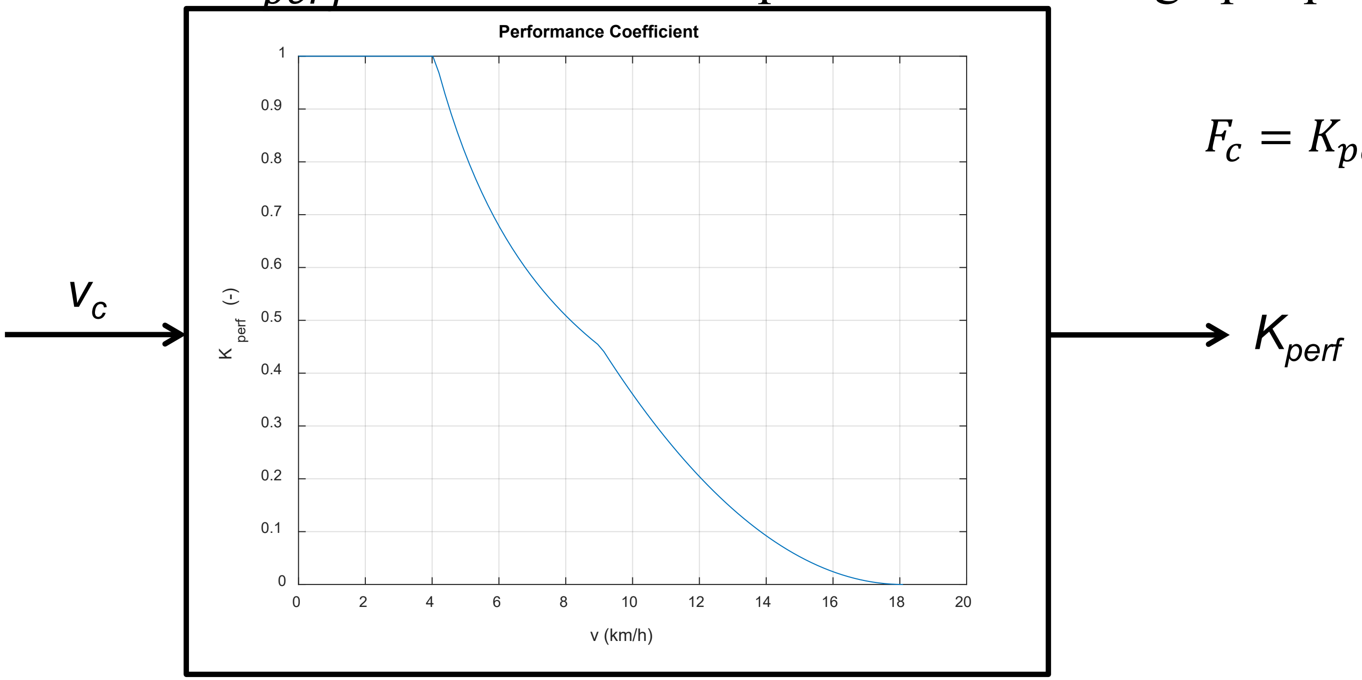
- Pedals (1)
- Pedal axis (2)
- Transmission/Reduction (Pedal axis, gear wheels and chain) (3)
- Free wheeling system on rear wheel (4)
- Brakes on the rear and front wheels (5)

- Frame of bike, saddle and handlebars

- 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.
- There is no pedal binding: no force applied on the ascending pedal.
- The force on the pedals is always vertically applied

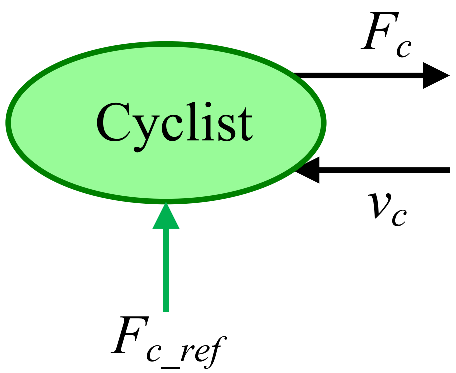


- Model and representation of a cyclist
  - Movement of the foot are such as it is circular
  - Defined by its peripheral velocity v_c
  - Introducing K_{perf}, coefficient of perfomance:
    - $K_{perf} = 1$: the cyclist can apply the force he wants (!)
    - $K_{perf} < 1$: limitation of performances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

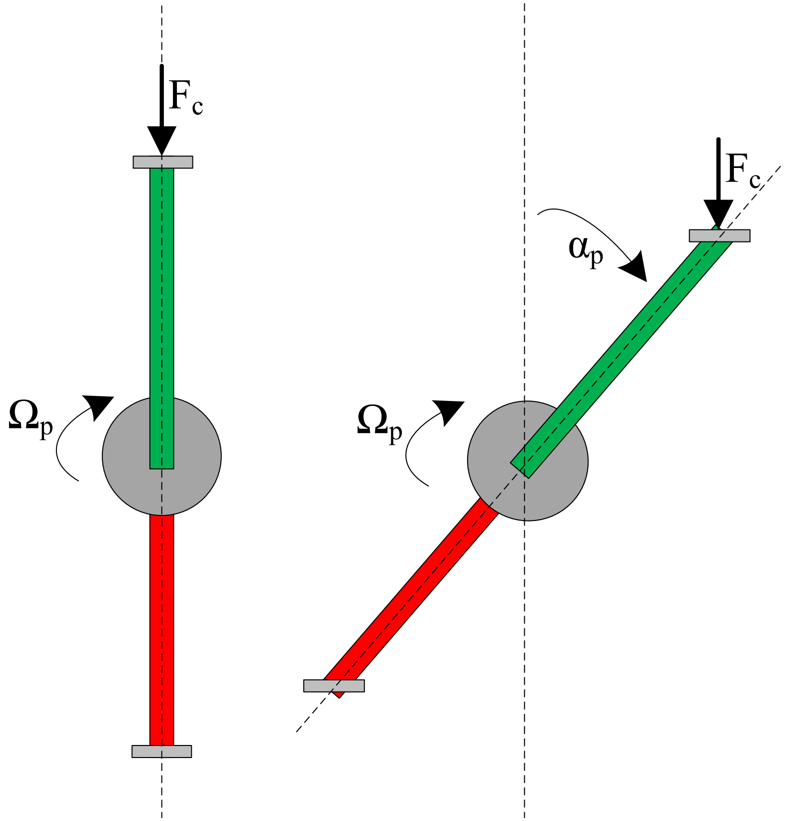


$$F_c = K_{perf} . F_{c\_ref}$$

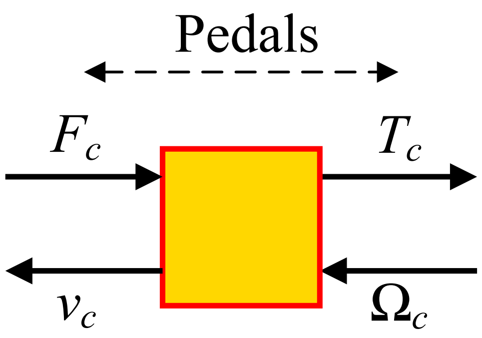
- With F_{c_ref} the force the cyclist wishes to apply
- F_{c_ref} is limited to 0.75.M.g



- 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.



$$\begin{cases} T_c = R_p . F_c . \left|sin(\alpha_p)\right| \ with \ \alpha_c = \int \Omega_c . dt \\ \Omega_c = \frac{1}{R_p} . v_c \end{cases}$$

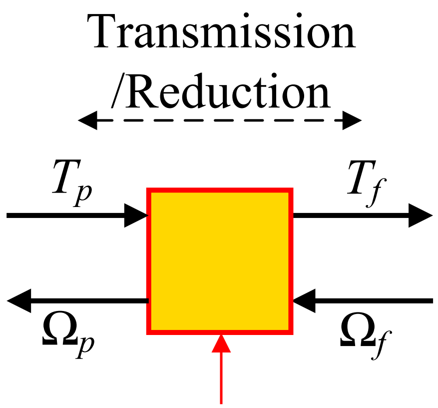


- The cyclist can use 10 speeds, defined by the conversion ratio K_{vit}:

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

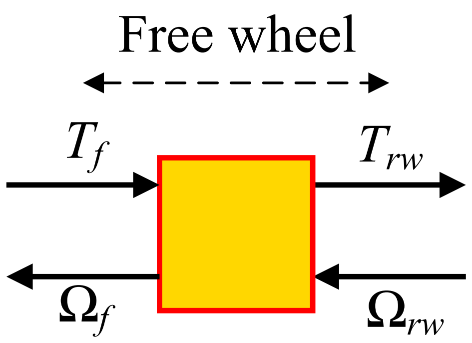
- The torque applied on the rear wheel free-wheeling system, and the angular velocity are defined by:

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



- 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.

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



- Cycle EMR -

- Pedals (1)
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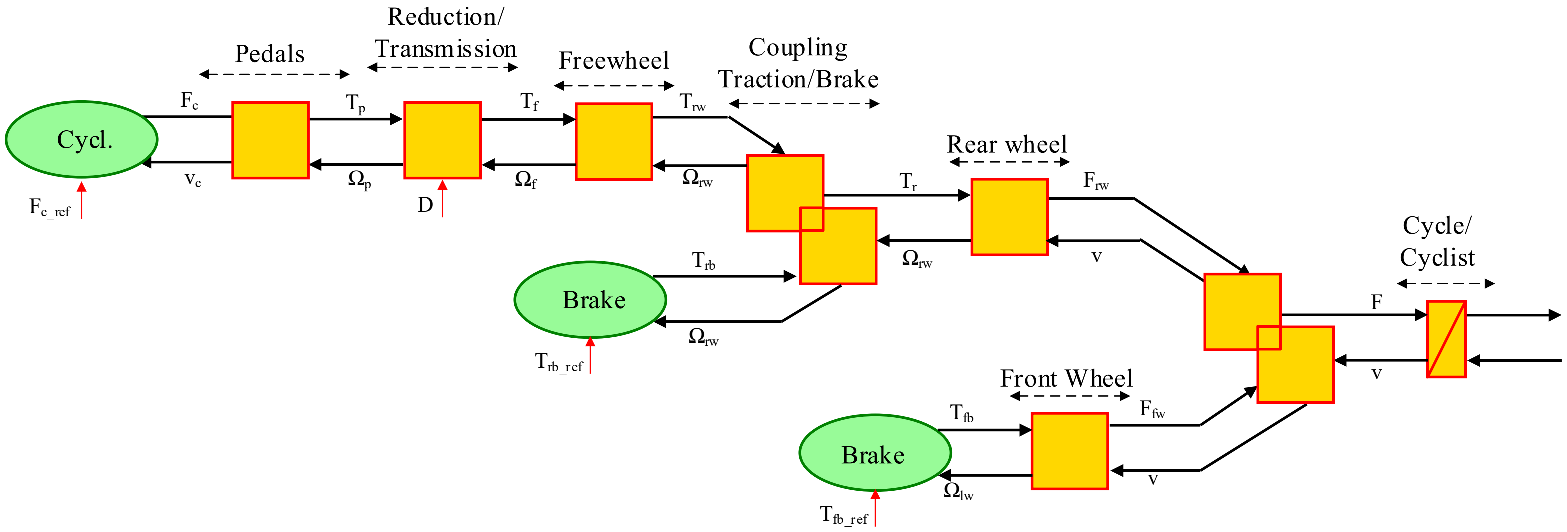
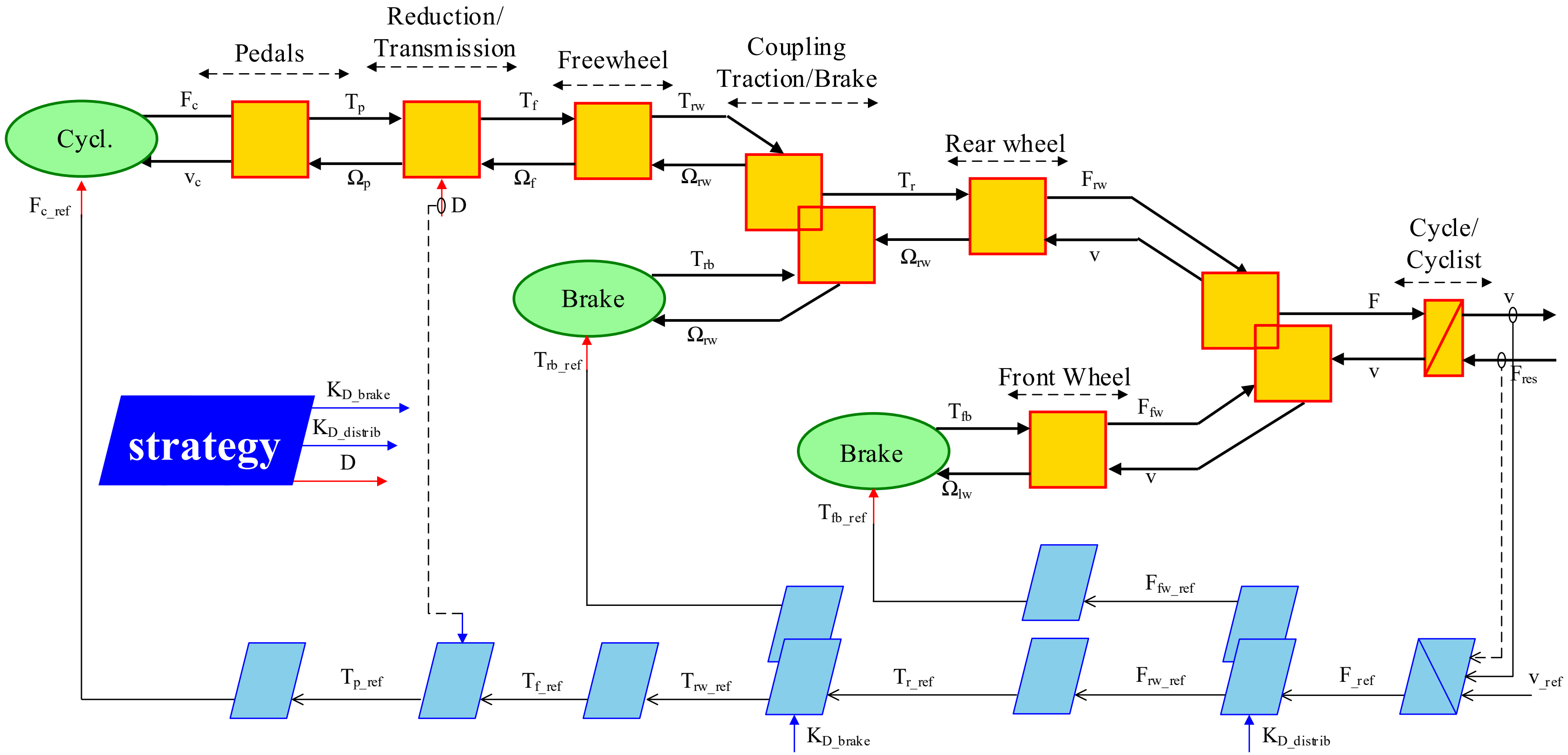




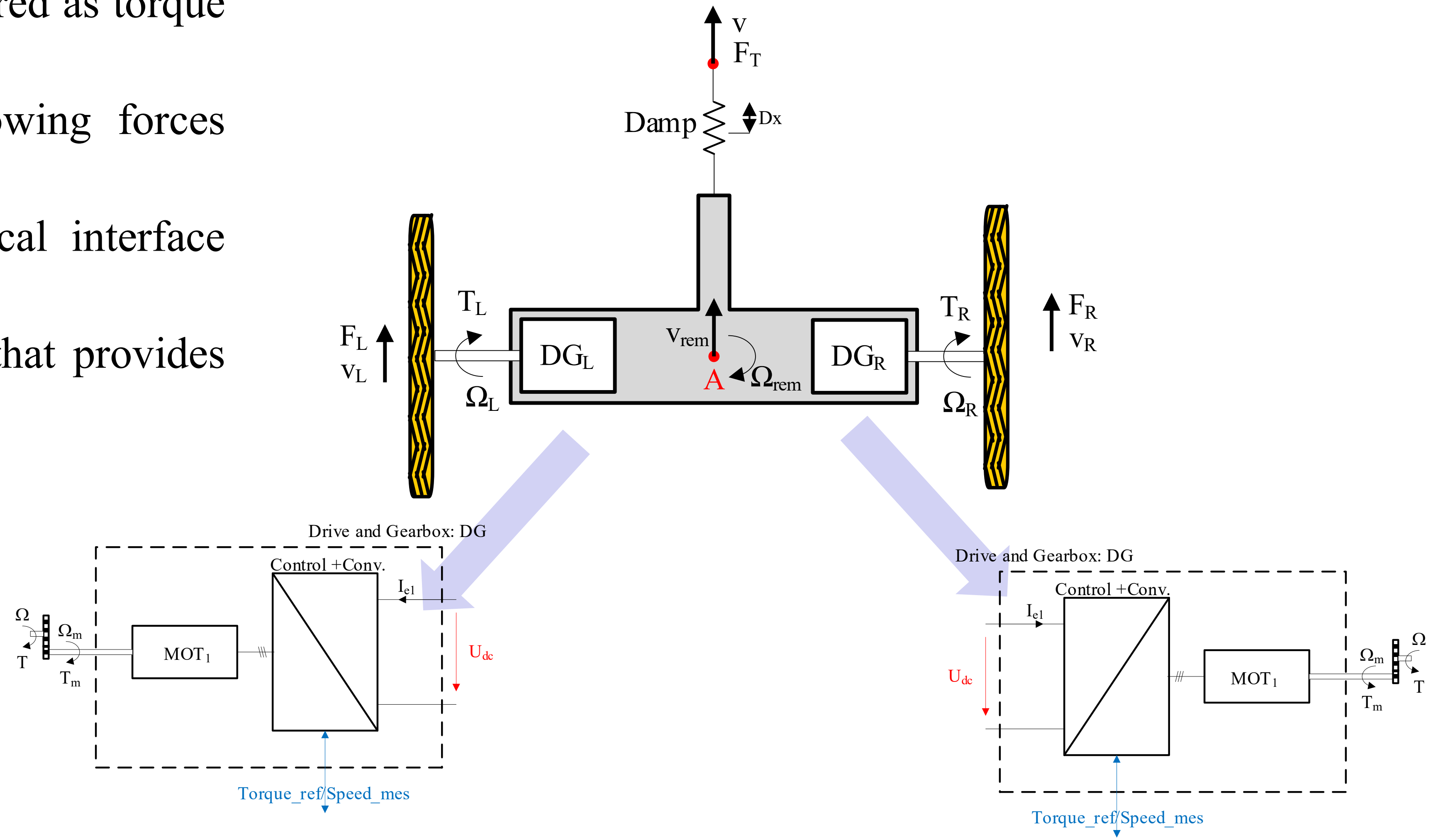
Inverse based control:

- identified following strictly rules
- Emulates quite close the behaviour of a normal cyclist

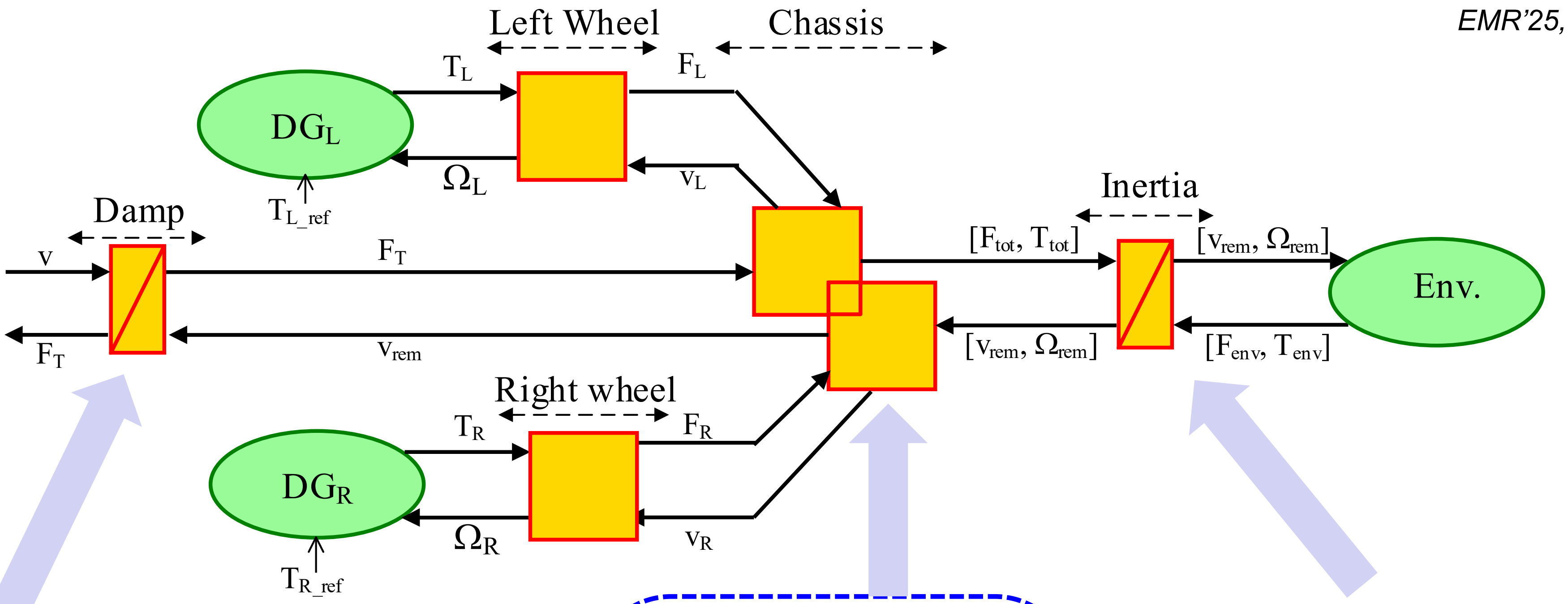
«EMR of an Electric Assisted Trailer »

- Structural representation for modelling -

- Trailer powered by two independent wheels
- Drives are not sized yet, considered as torque sources
- Geometry defined just for allowing forces balance
- A Damper is used as mechanical interface between the cycle and the trailer
- The Damper includes a sensor that provides information on its elongation Dx



- EMR of Trailer -



$$F_T = d.\frac{dDx}{dt} + K.Dx$$

$$\text{with } \frac{dDx}{dt} = v - v_{rem}$$

$$\begin{cases} F_{tot} = F_T + F_L + F_R \\ T_{tot} = \frac{L}{2}(F_R - F_L) \end{cases}$$

$$\begin{cases} v_L = v_{rem} - \Omega_{rem}.\frac{L}{2} \\ v_R = v_{rem} + \Omega_{rem}.\frac{L}{2} \end{cases}$$

$$\begin{cases} v_{rem} = \frac{1}{M_{rem}}\int (F_{tot} - F_{env}).dt \\ \Omega_{rem} = \frac{1}{J_{rem}}\int (T_{tot} - T_{env}).dt \end{cases}$$

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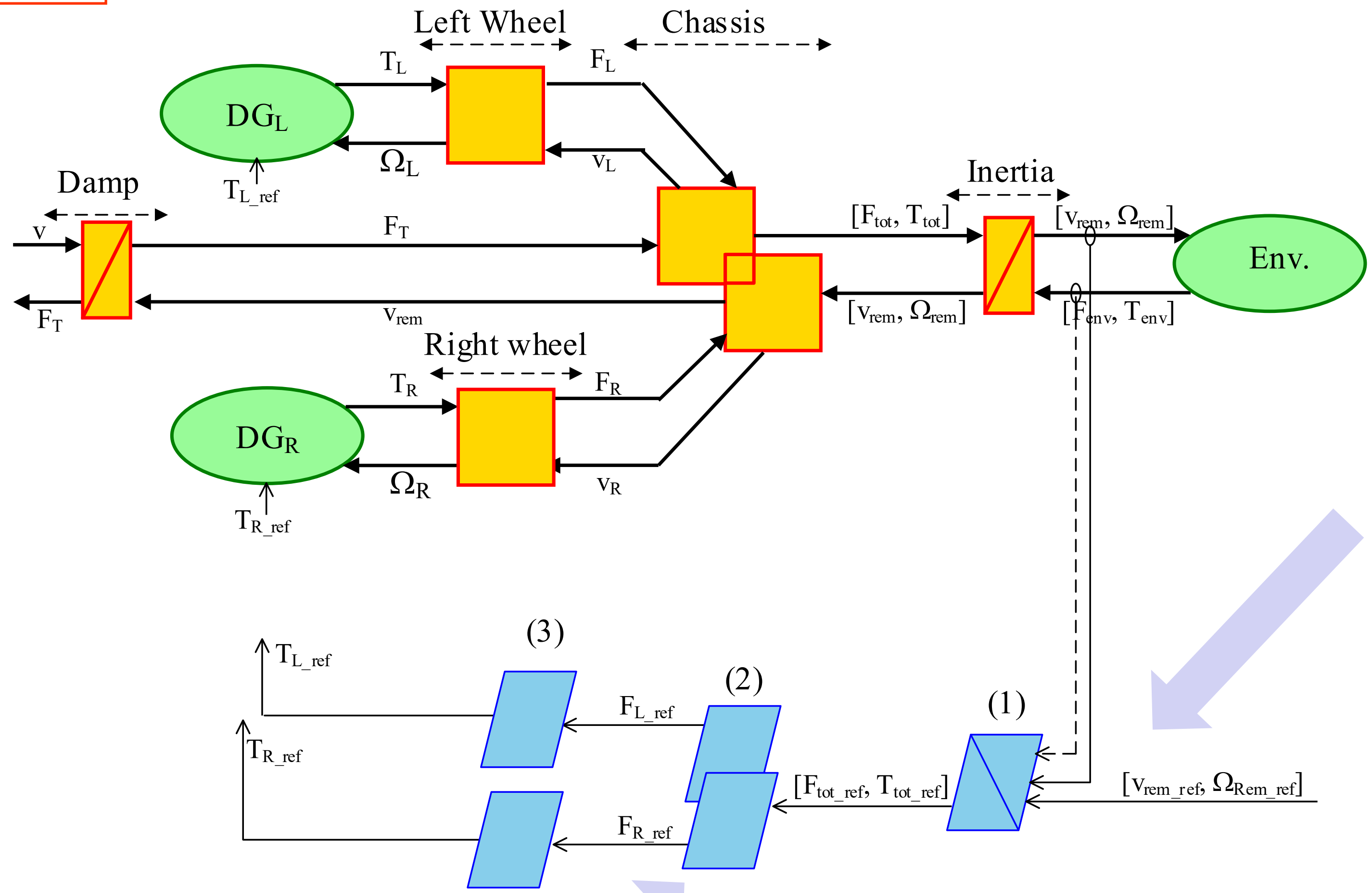
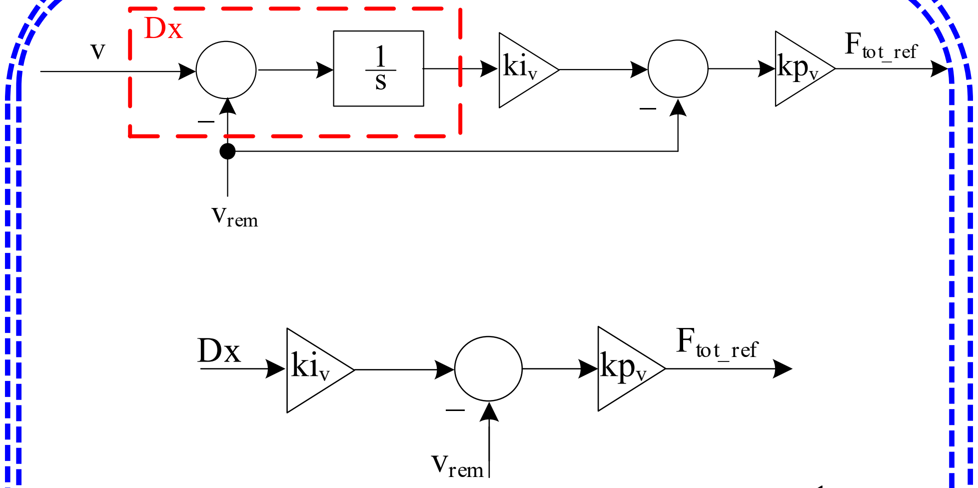
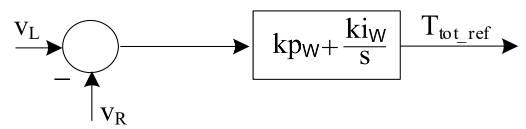
- From EMR to IBC -

EMR'25, Lille, July 2025





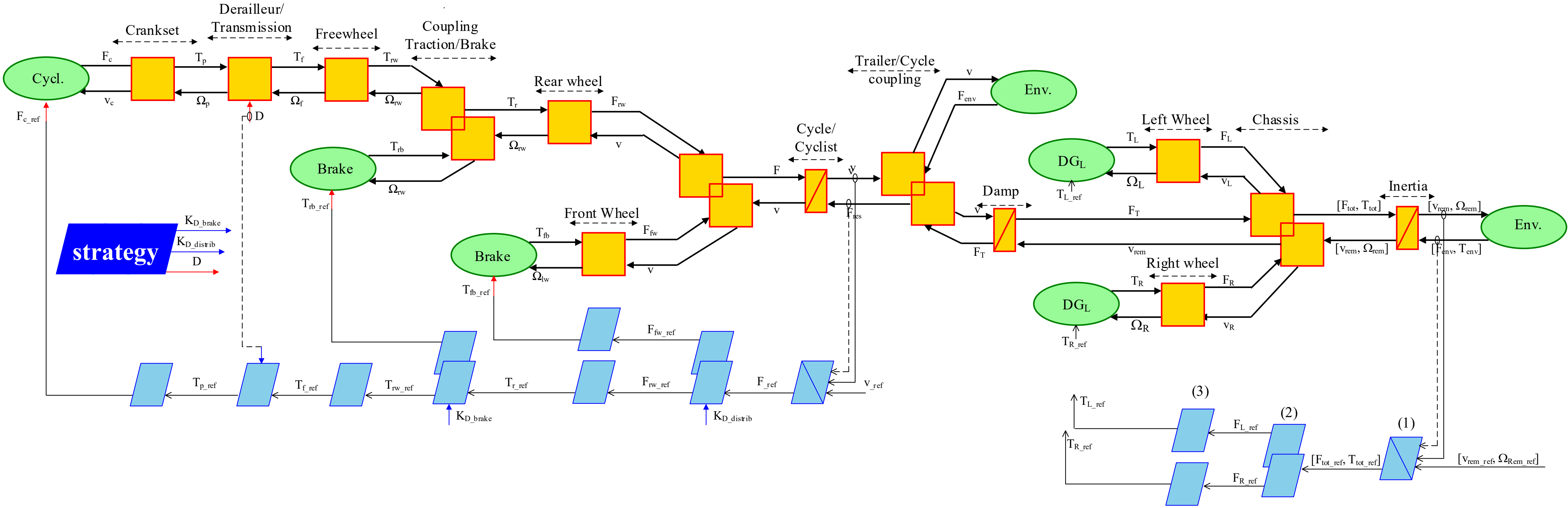
$$F_T = d.\frac{dDx}{dt} + K.Dx \Longrightarrow \quad Dx(s) = F_T(s).\frac{\frac{1}{K}}{\frac{d}{K}.s + 1}$$



$$\begin{cases} F_{R\_ref} = \frac{1}{2}.F_{tot\_ref} - \frac{L}{2}.T_{tot\_ref} \\ F_{L\_ref} = \frac{1}{2}.F_{tot\_ref} + \frac{L}{2}.T_{tot\_ref} \end{cases}$$

« Simulation Results »

- EMR and IBC of a bike with an electrically assisted Trailer-



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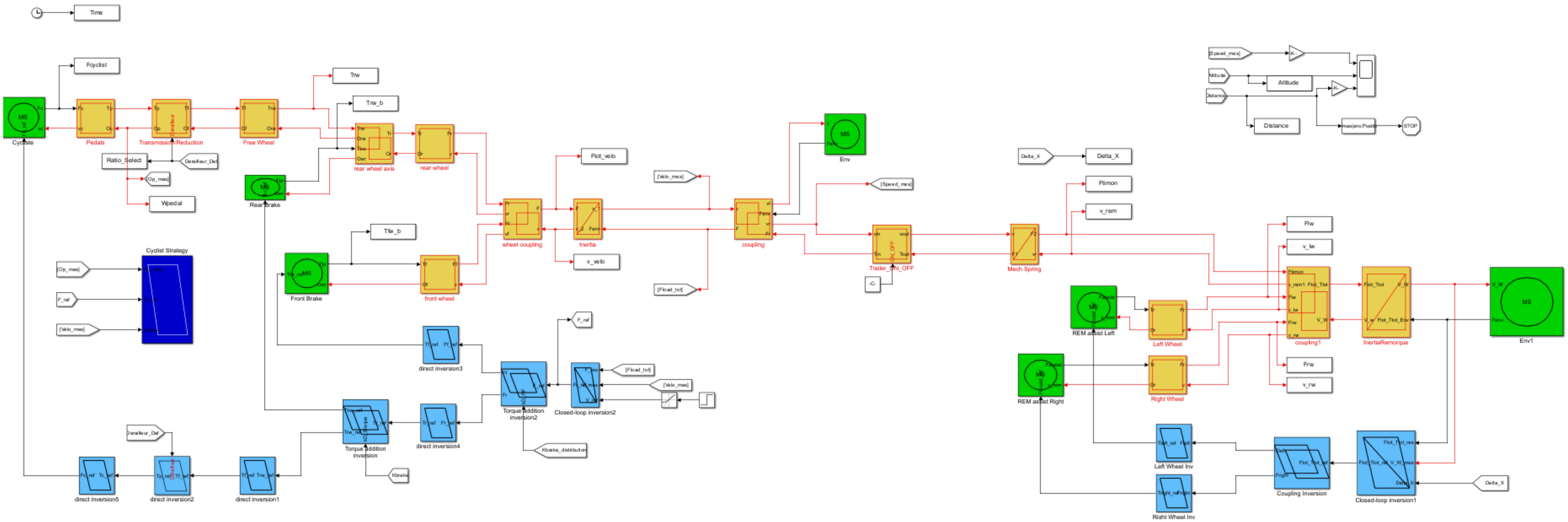
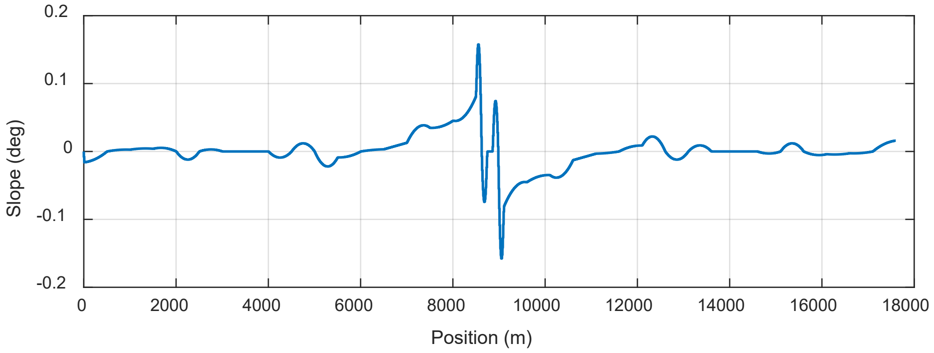
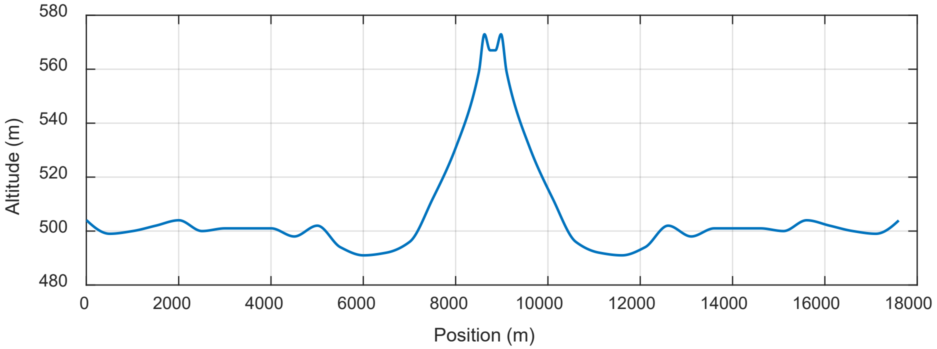
- Implementation for simulation -

EMR'25, Lille, July 2025

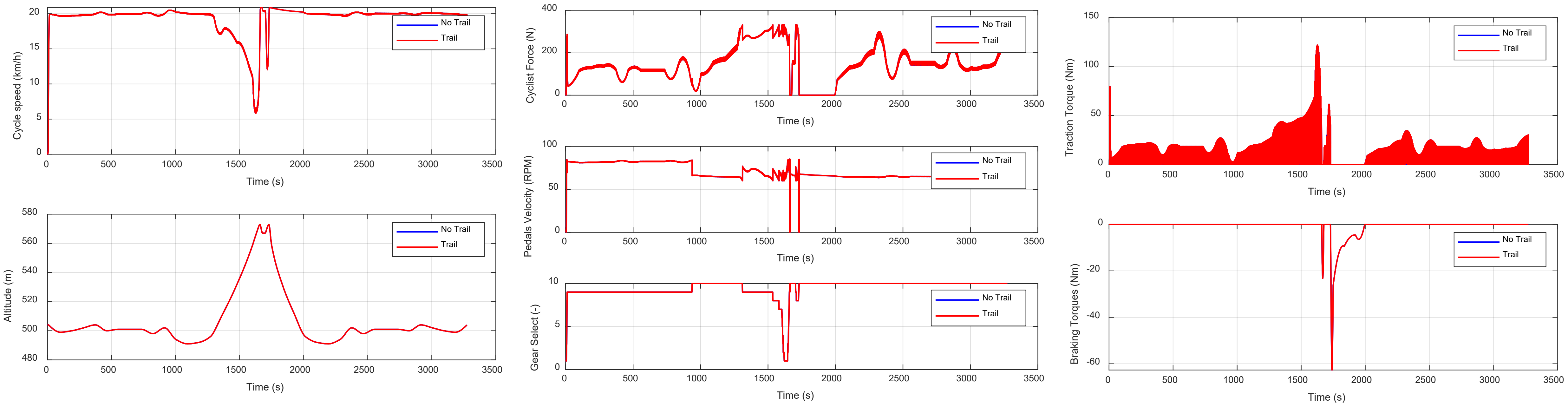






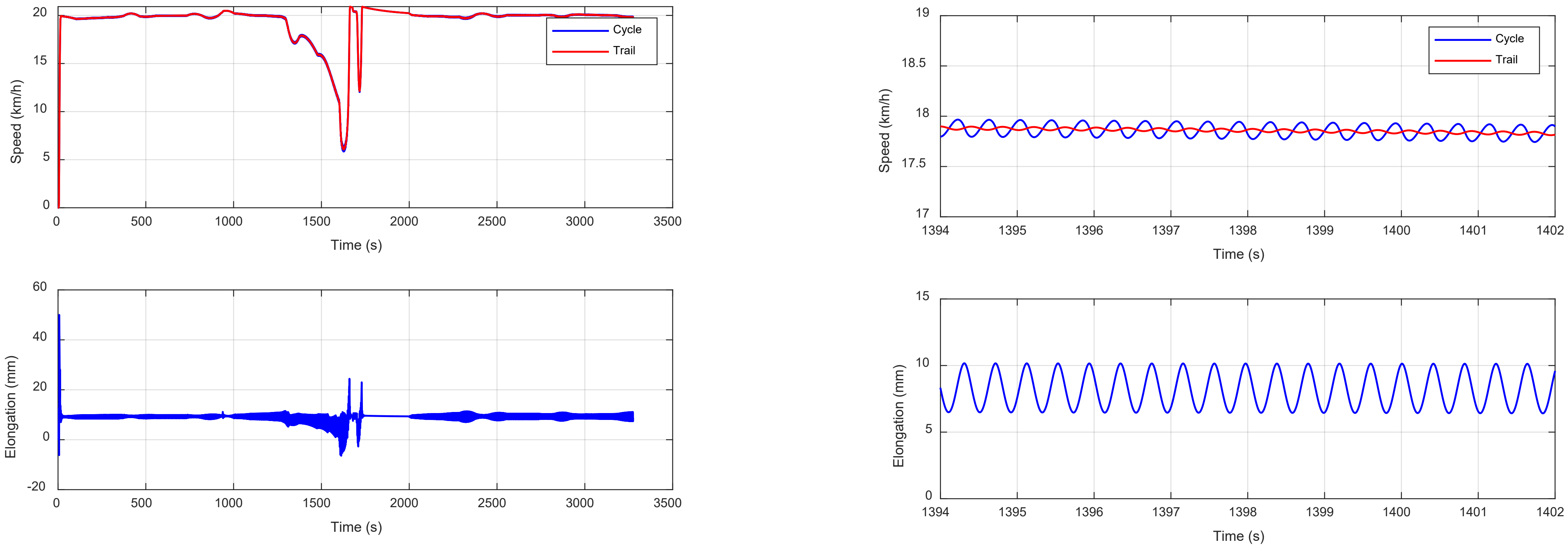
Main conditions:

- whished speed for the cyclist (*65kg*): *20km/h*
- Trailer mass (with load): *400kg*



With or without trailer:

- No changes for the effort on the cyclist
- No significant additional constraints on the cycle



- Elongation of the damper stays below the limits
- Damper plays its role of low pass filter

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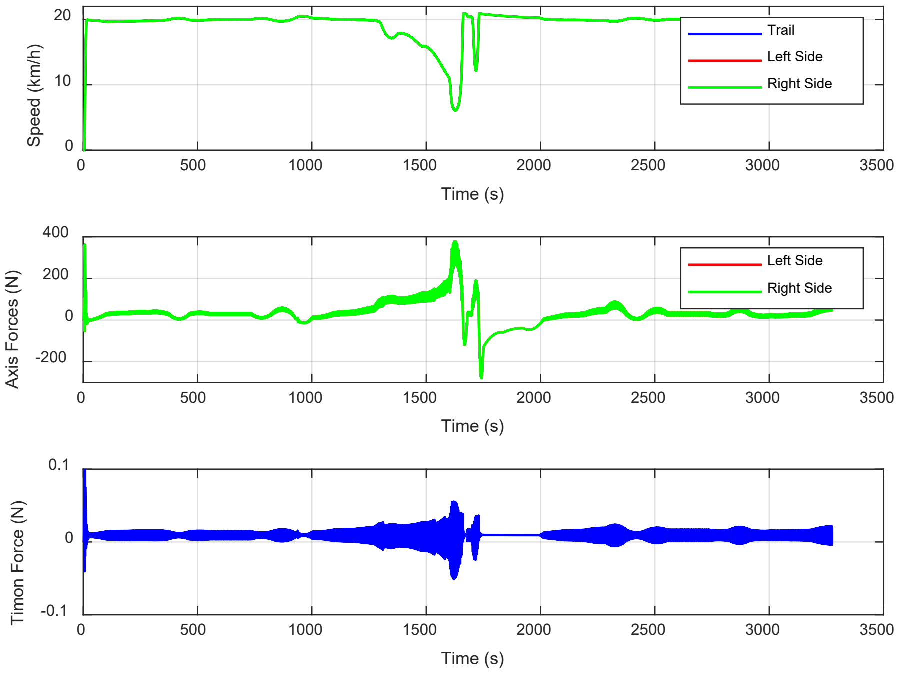
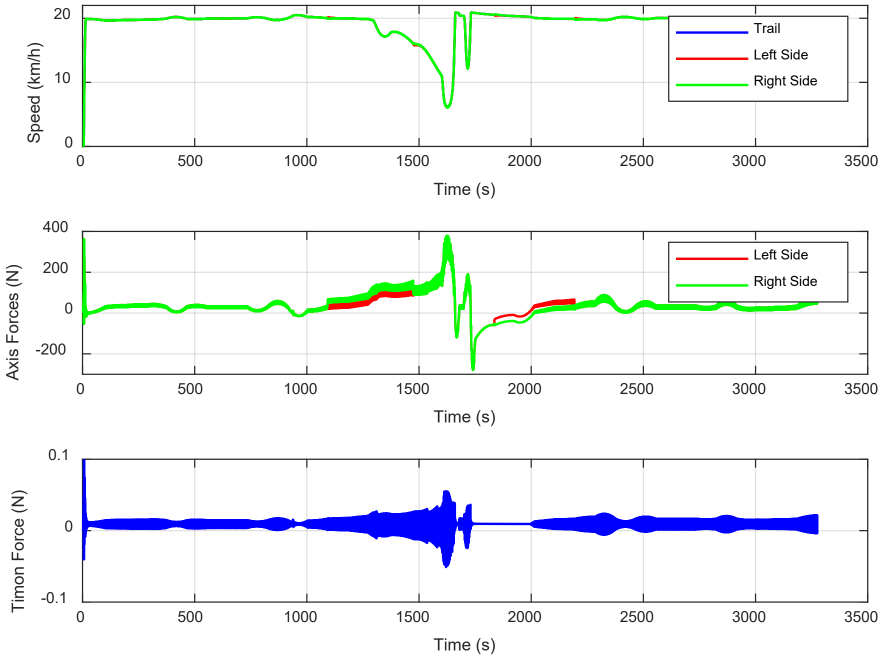
- Balance on forces -





- All forces to move the trailer are coming from the traction system
- Force for the drawbar in negligible
- Differential speed controller plays its role: trailer goes forward even if some resistive forces are non symmetrical on the wheels.

« Conclusion »

- Summary-

- EMR and IBC for a bike and an electrically powered trailer have been proposed
- Control of the trailer does not require any other information than some small solicitations of its drawbar
- Control allows also to determine sizing criteria for the Damper required for coupling the trailer with a cycle
- EMR methodology is not only efficient for defining the control of a system: it is also an efficient tool for system design.