



SCIENCES 2024

Sports et Sciences, une alliance en Or

La physique de la natation

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La Natation

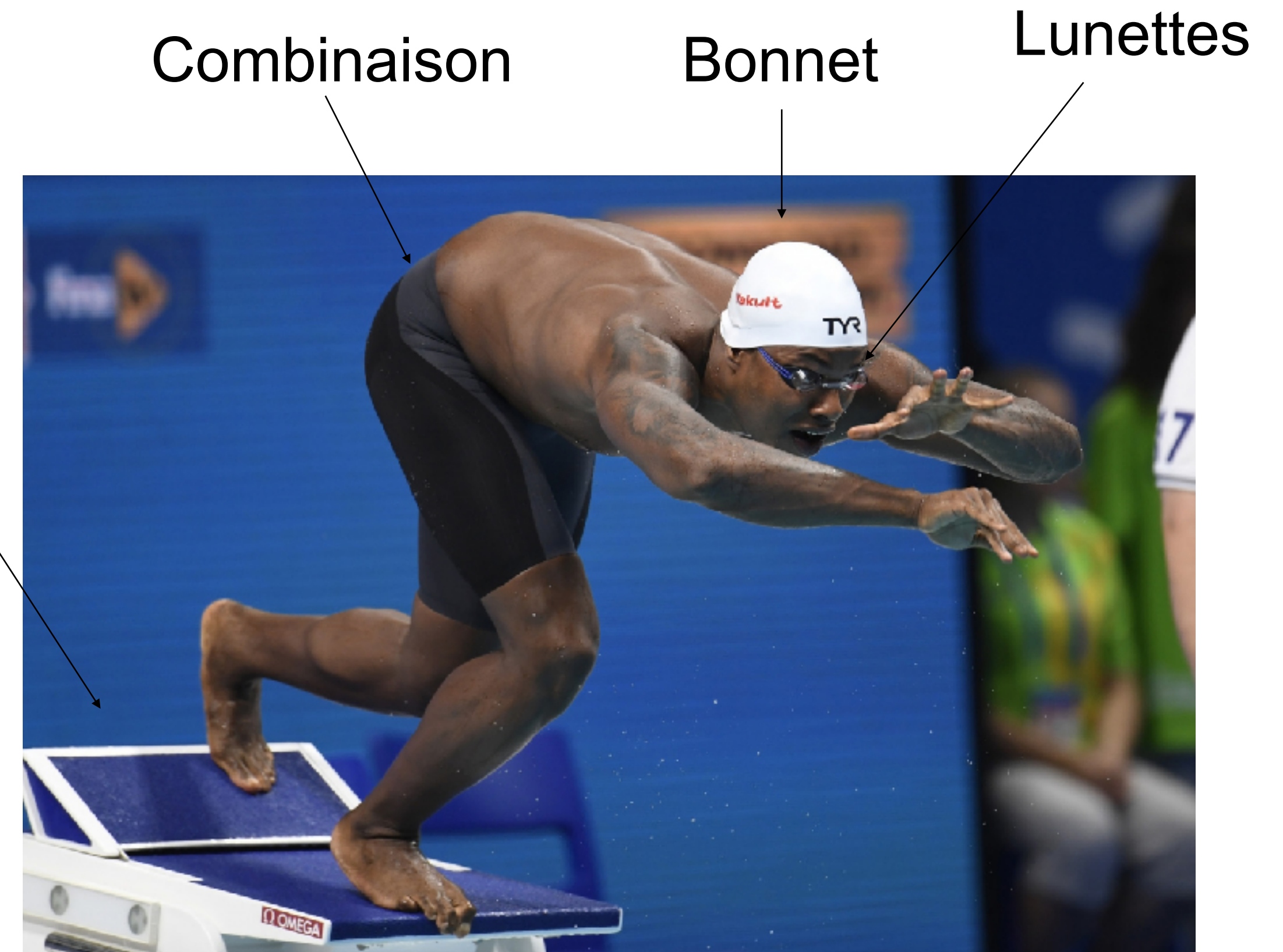
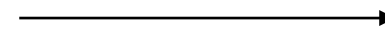
« Sciences2024 pour l'aviron, le tir,... ok mais la natation y a pas de matériel donc y a rien à faire! »

Oui a priori pas de place pour la technologie!



Scandale du polyuréthane

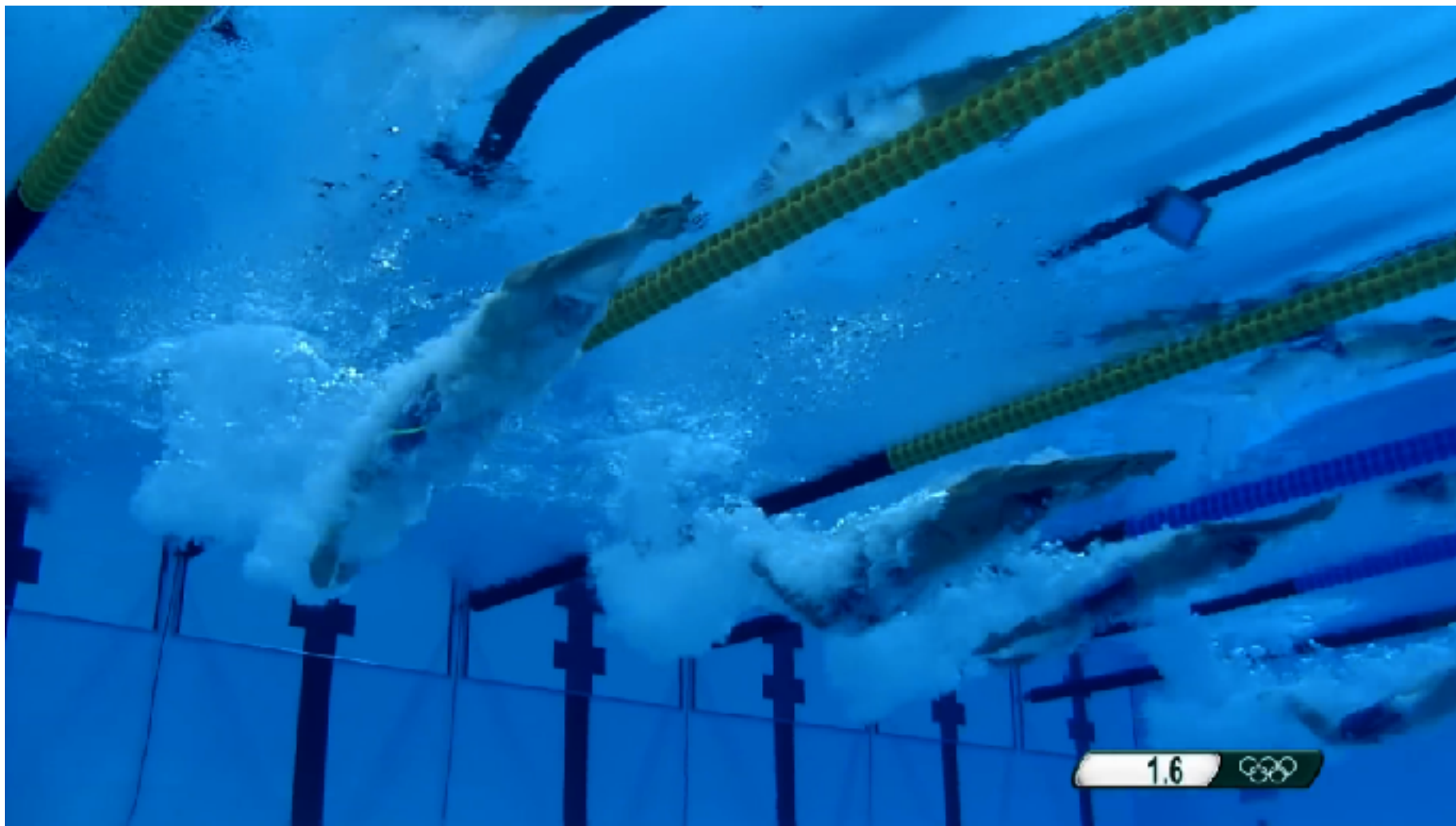
Plot de départ



Les lignes d'eau, la « préparation du bassin »,...

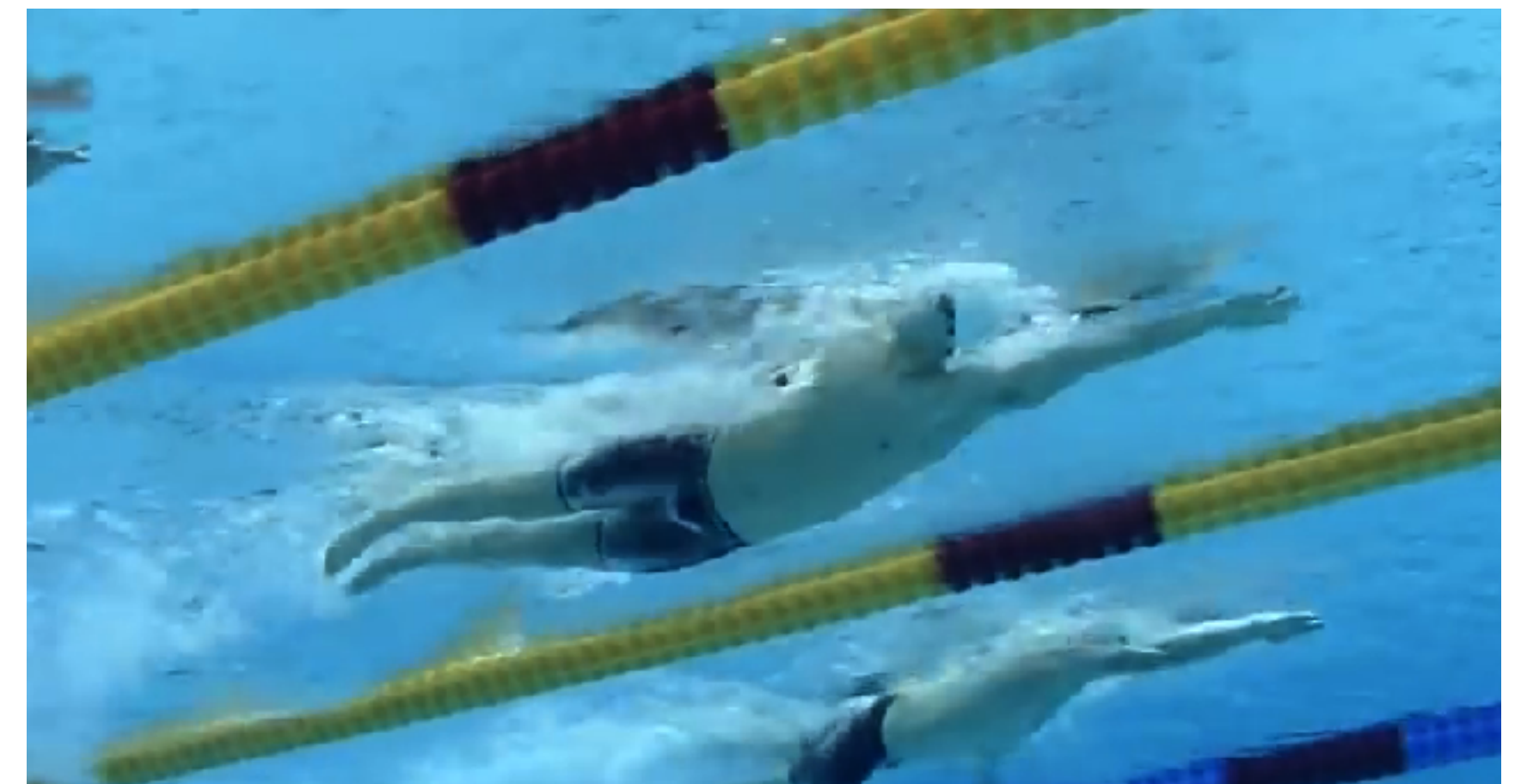
La Natation

La technique!



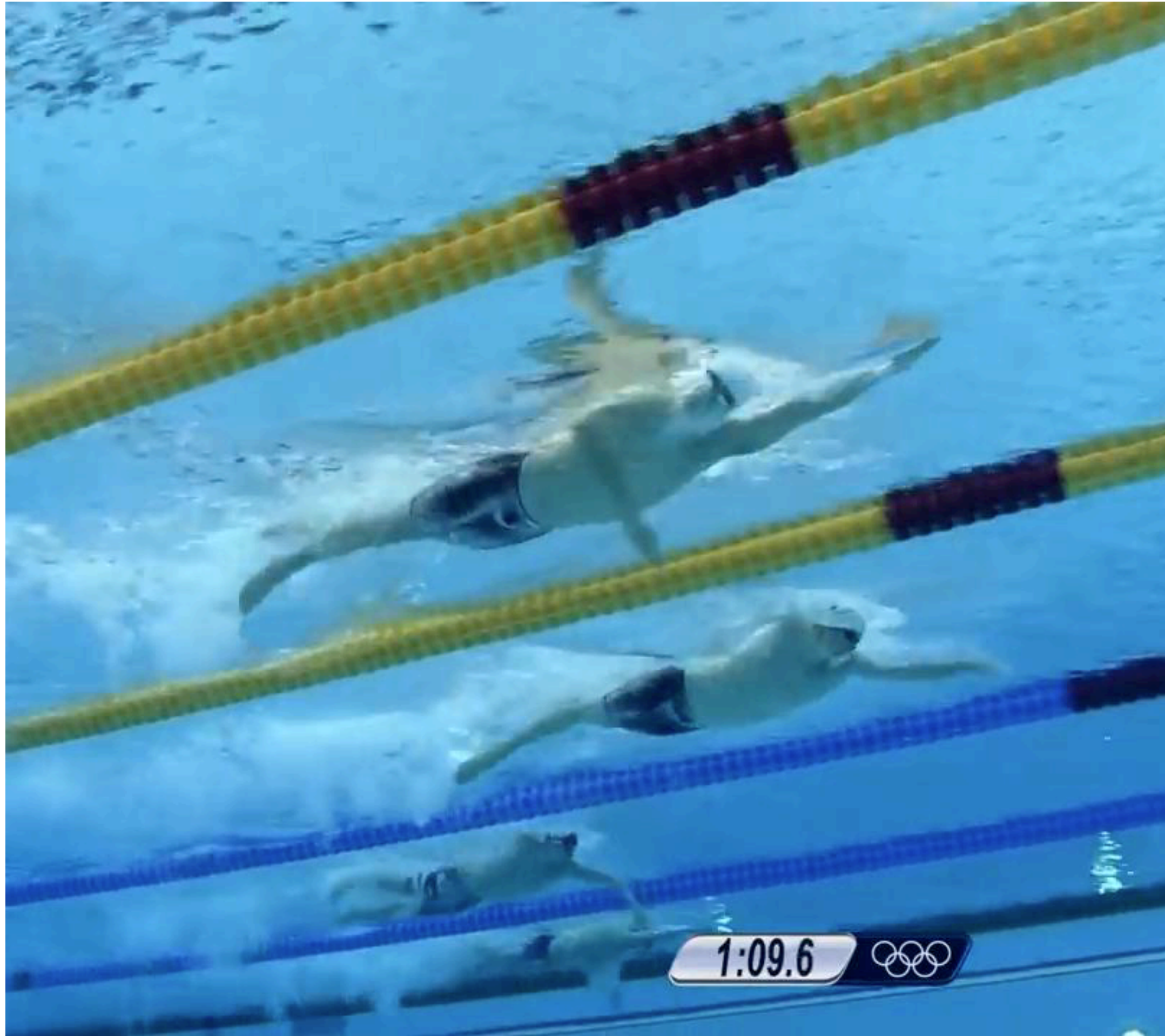
La technique de plongeon

Profondeur optimal?
Angle d'entrée dans l'eau? trajectoire?
Cadence de bras en sortie?

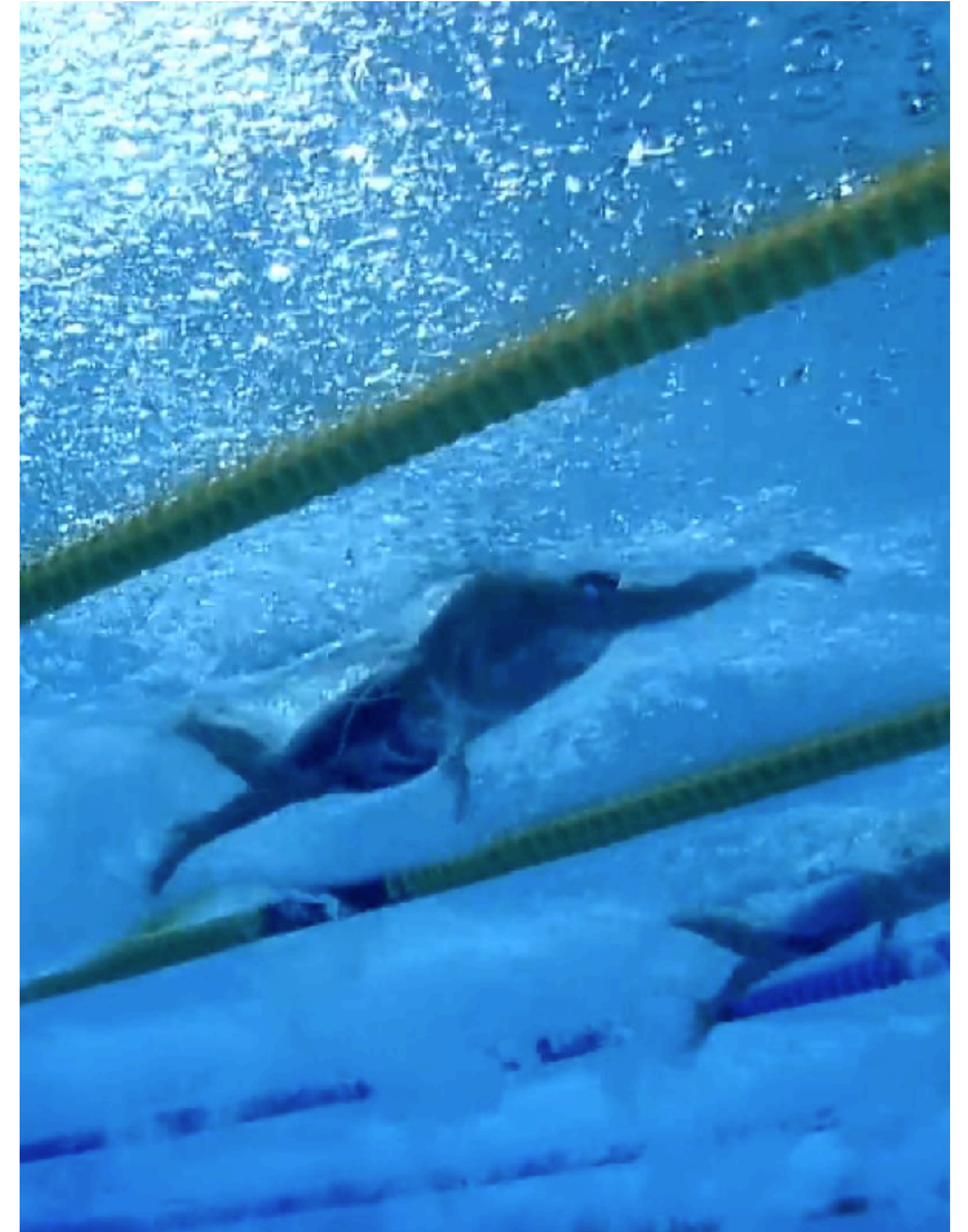


La technique de nage

Long Distance → Sprint



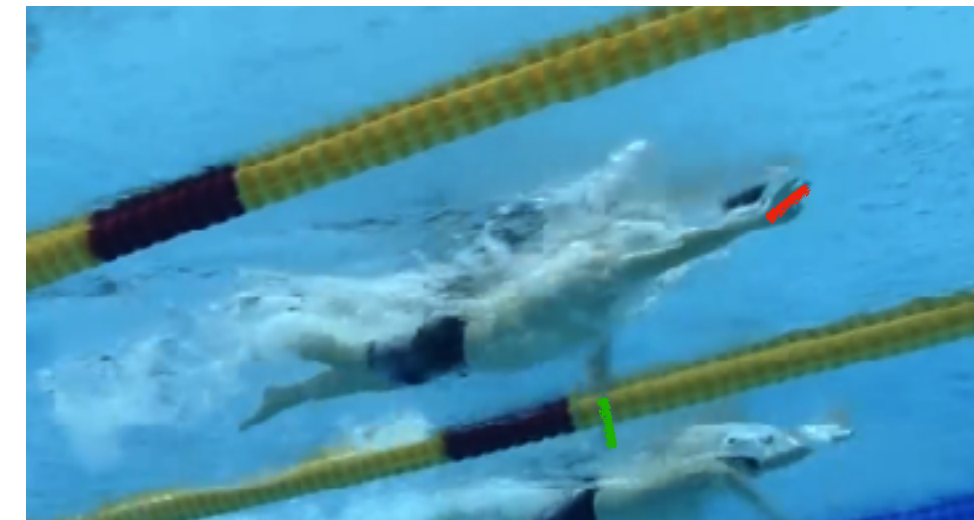
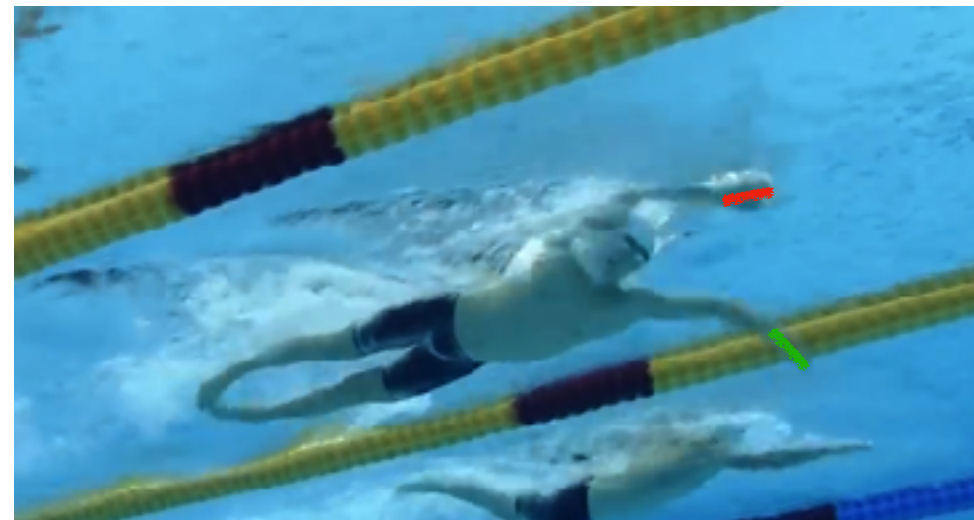
Sun Yang 1500 m à Londres 2012



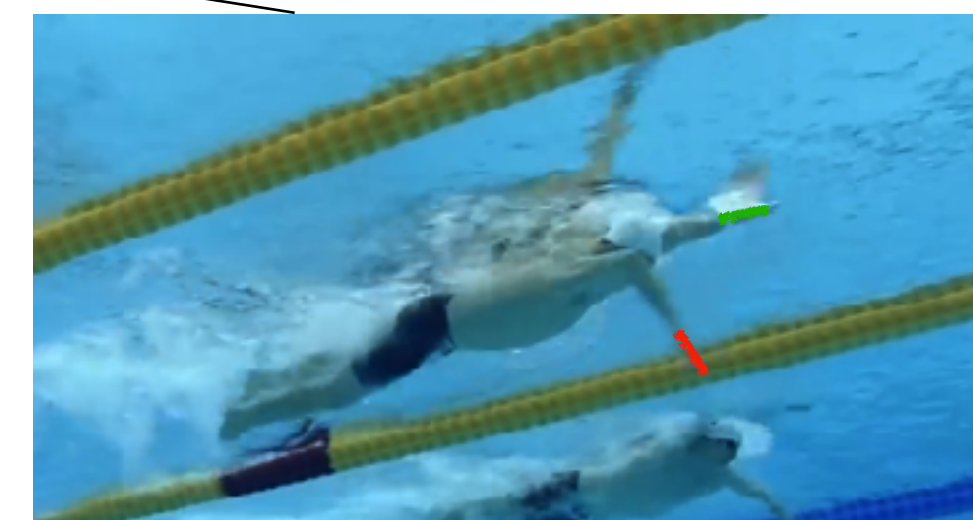
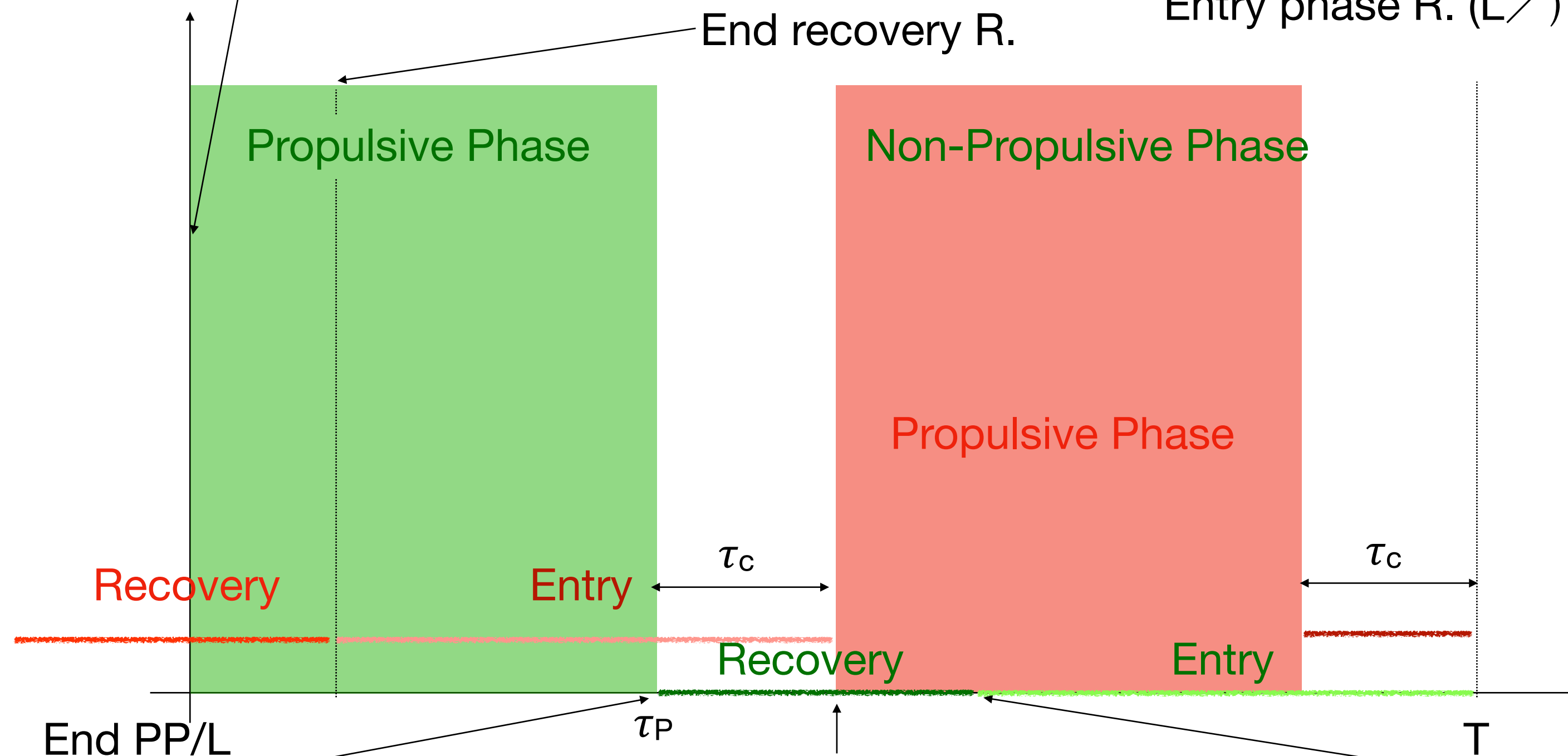
Manaudou 50 m à Rio 2016

Long distance

Start of PP/L



Entry phase R. (L↗)



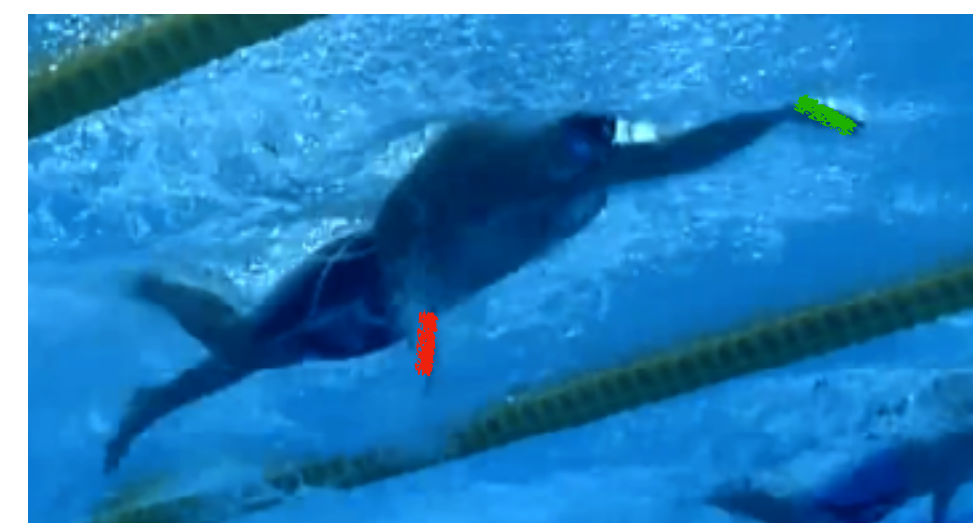
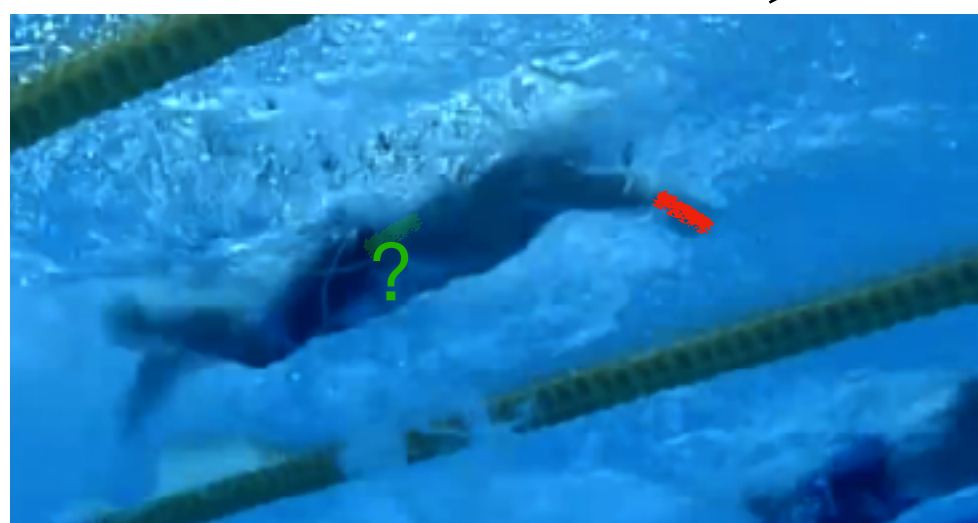
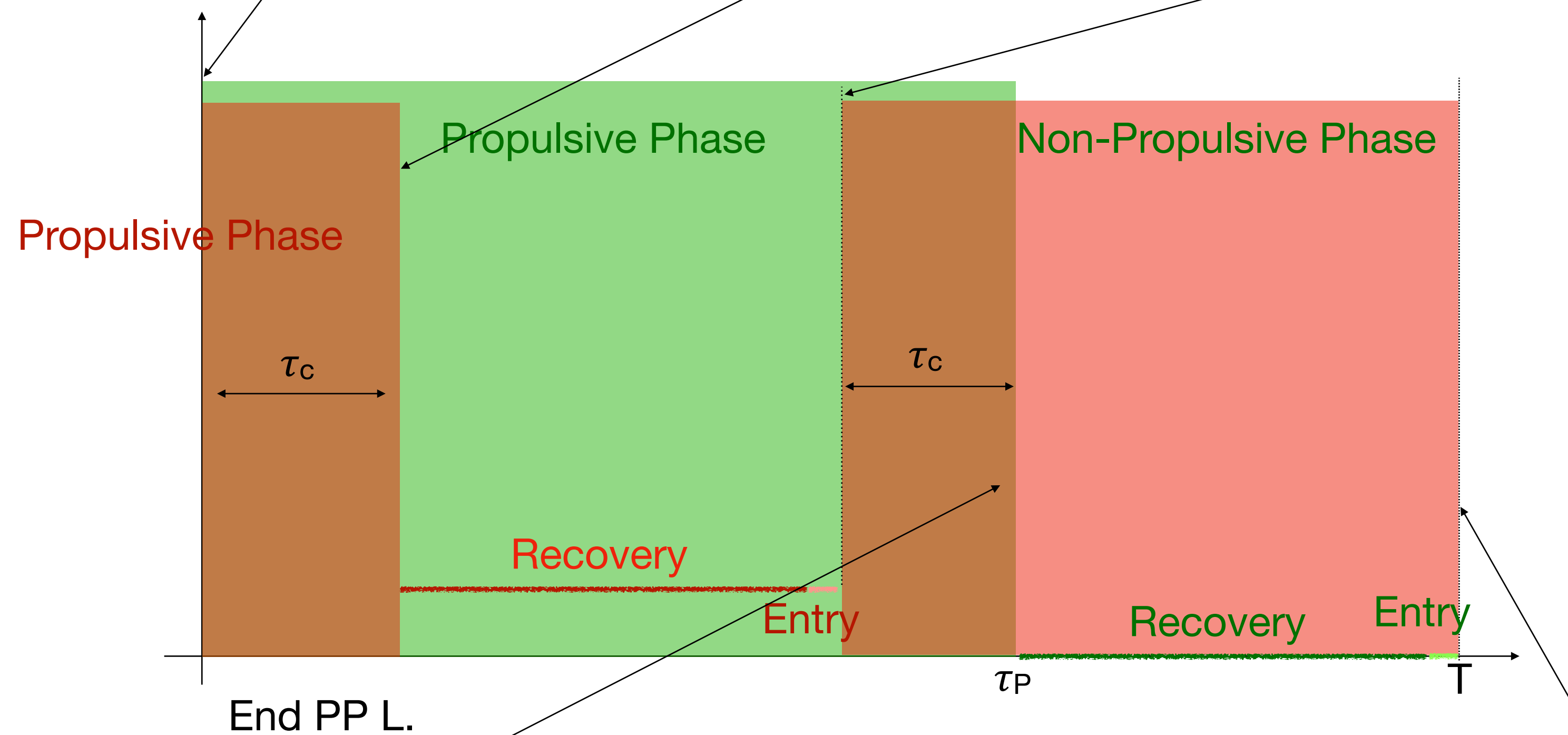
Sprint

Start of PP. L

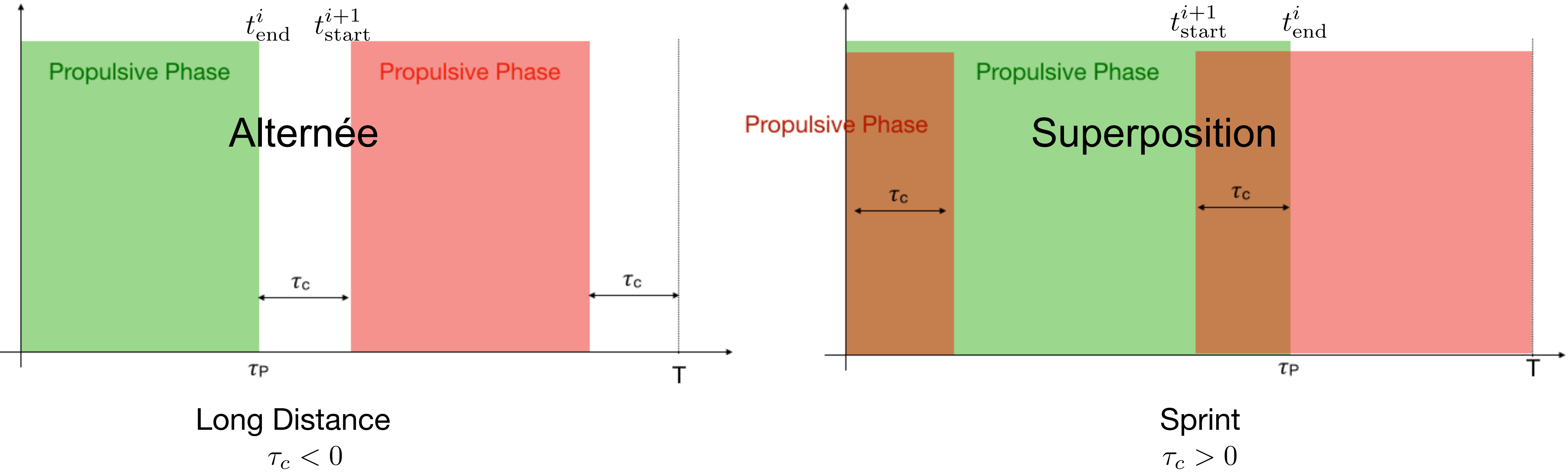


End PP R.

End NPP R.



Coordination motrice

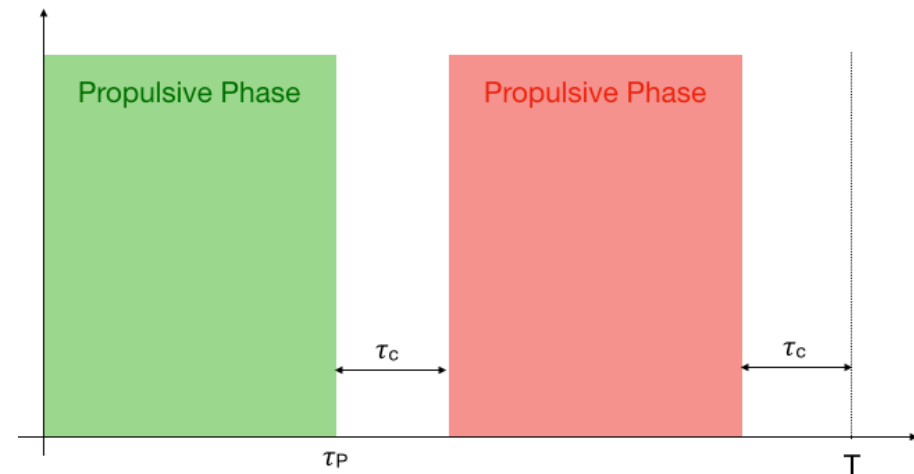
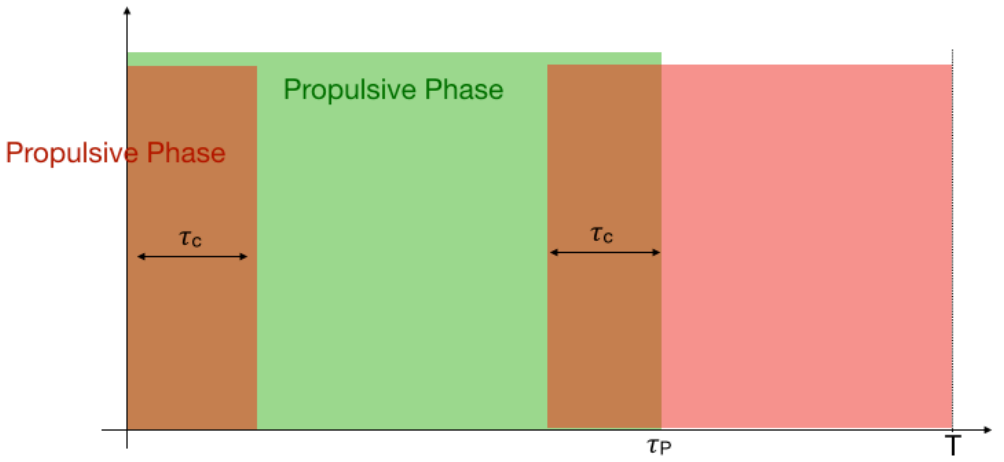


τ_c : Décalage entre deux phases motrices

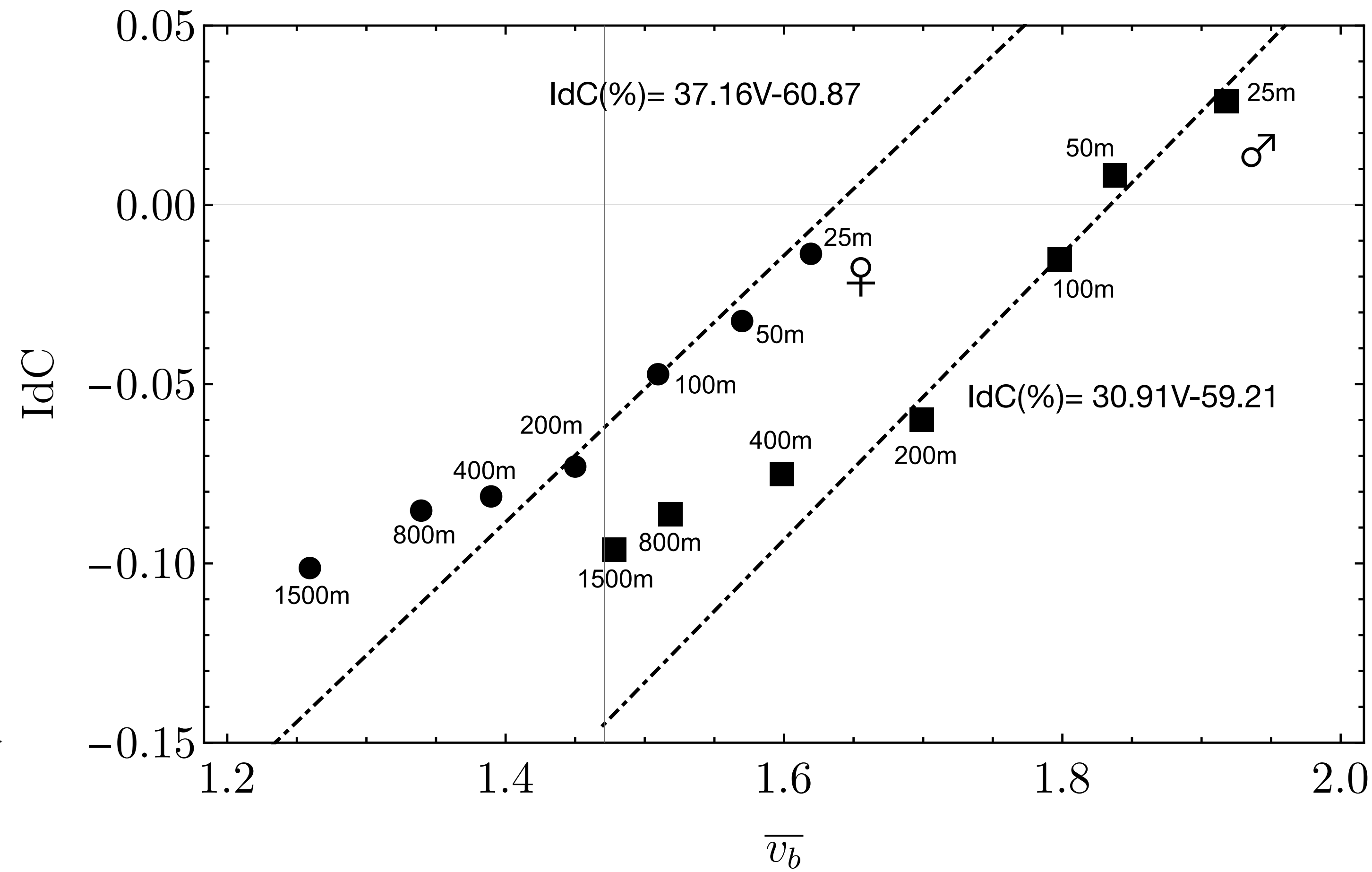
$\tau_c = t_{\text{end}}^i - t_{\text{start}}^{i+1}$ i : une phase de propulsion

Indice de coordination: $\text{IdC} = \frac{\tau_c}{T}$

Coordination motrice



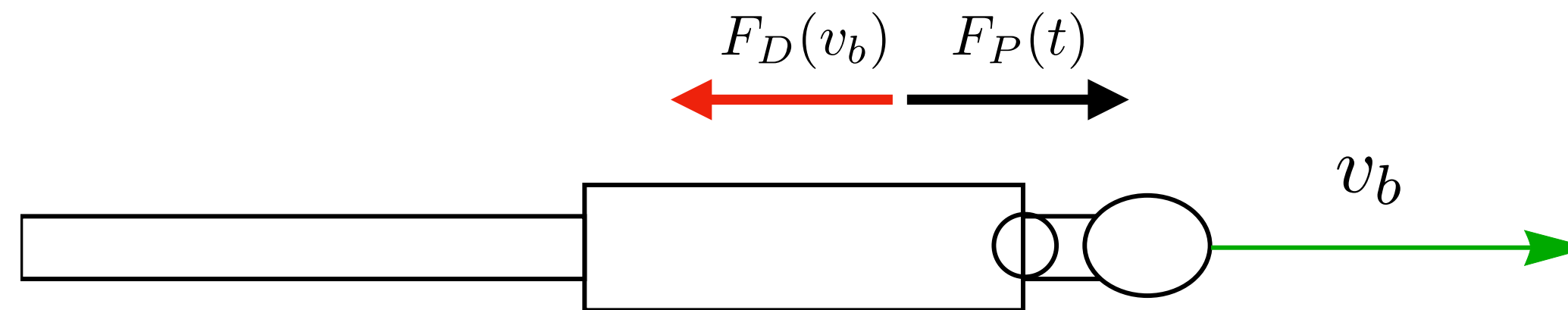
Test de simulation de courses



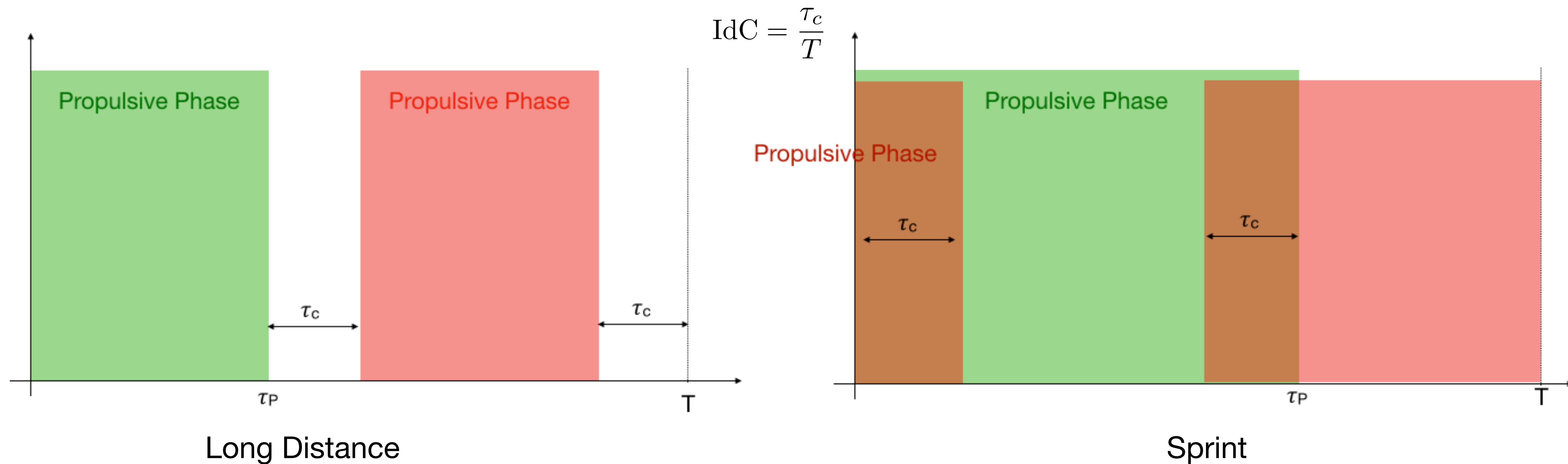
1500 m à 25 m

Transition à 200 m

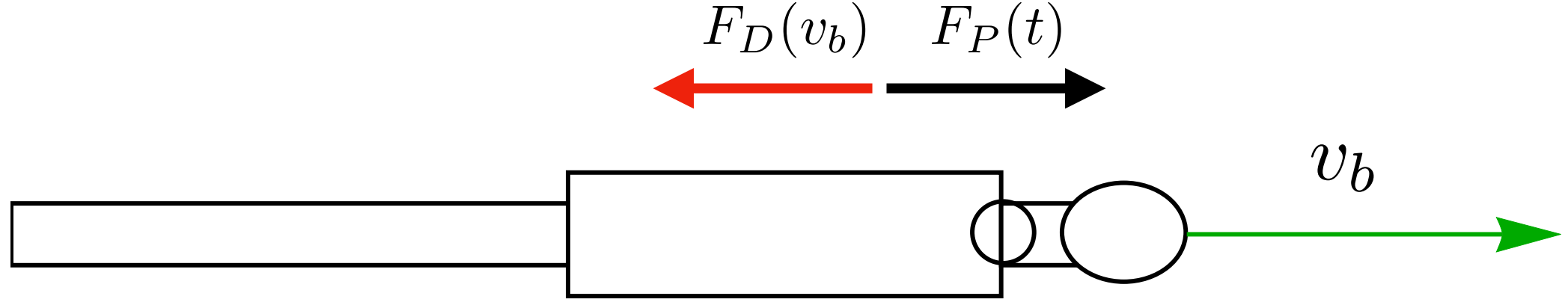
Modélisation la plus simple



$$m_b \frac{dv_b}{dt} = F_P(t) - F_D(v_b) \quad \longrightarrow \quad \bar{v}_b \approx v^* \sqrt{1 + 2\text{IdC}} \quad v^* = \sqrt{\frac{\overline{F_a}}{k_b}} \quad \overline{F_a} \in [0, F_{a,max}]$$



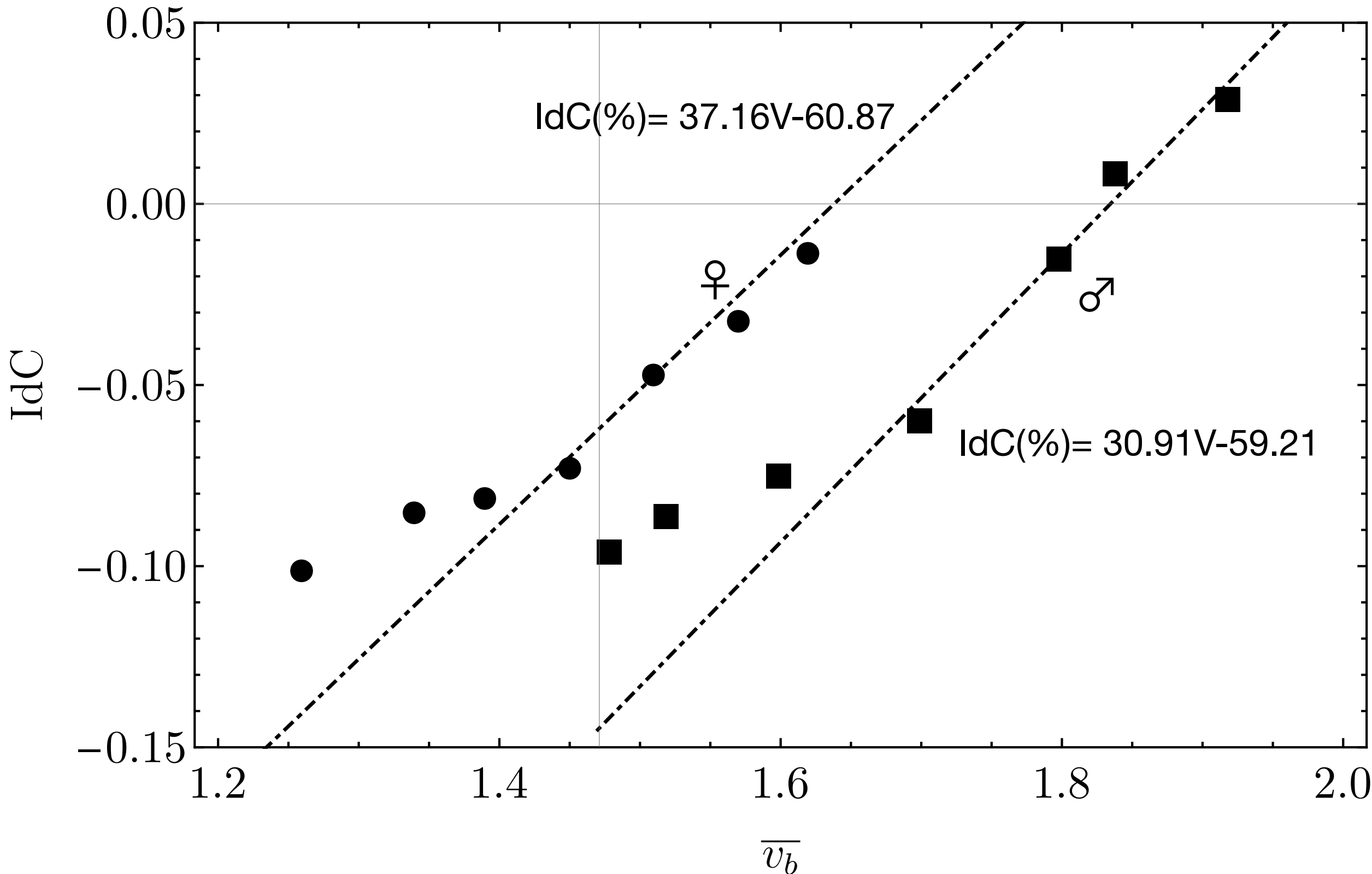
Vitesse et IdC



$$\overline{v_b} \approx v^* \sqrt{1 + 2\text{IdC}}$$

$$v^* = \sqrt{\frac{\overline{F_a}}{k_b}} \quad \overline{F_a} \in [0, F_{a,max}]$$

Test de simulation de courses

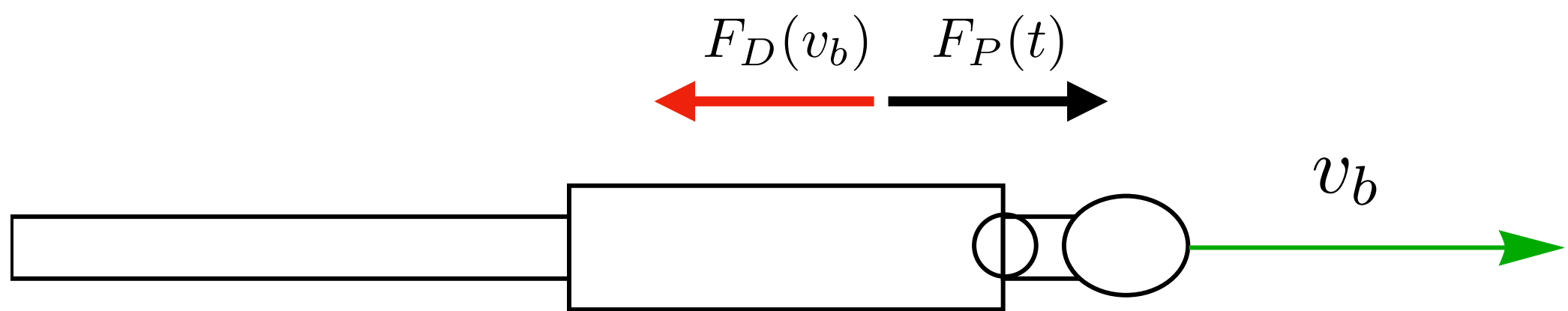


Seifert et al. 2007

1500 m à 25 m

Transition à 200 m

Vitesse et IdC



$$\overline{v_b} \approx v^* \sqrt{1 + 2\text{IdC}}$$

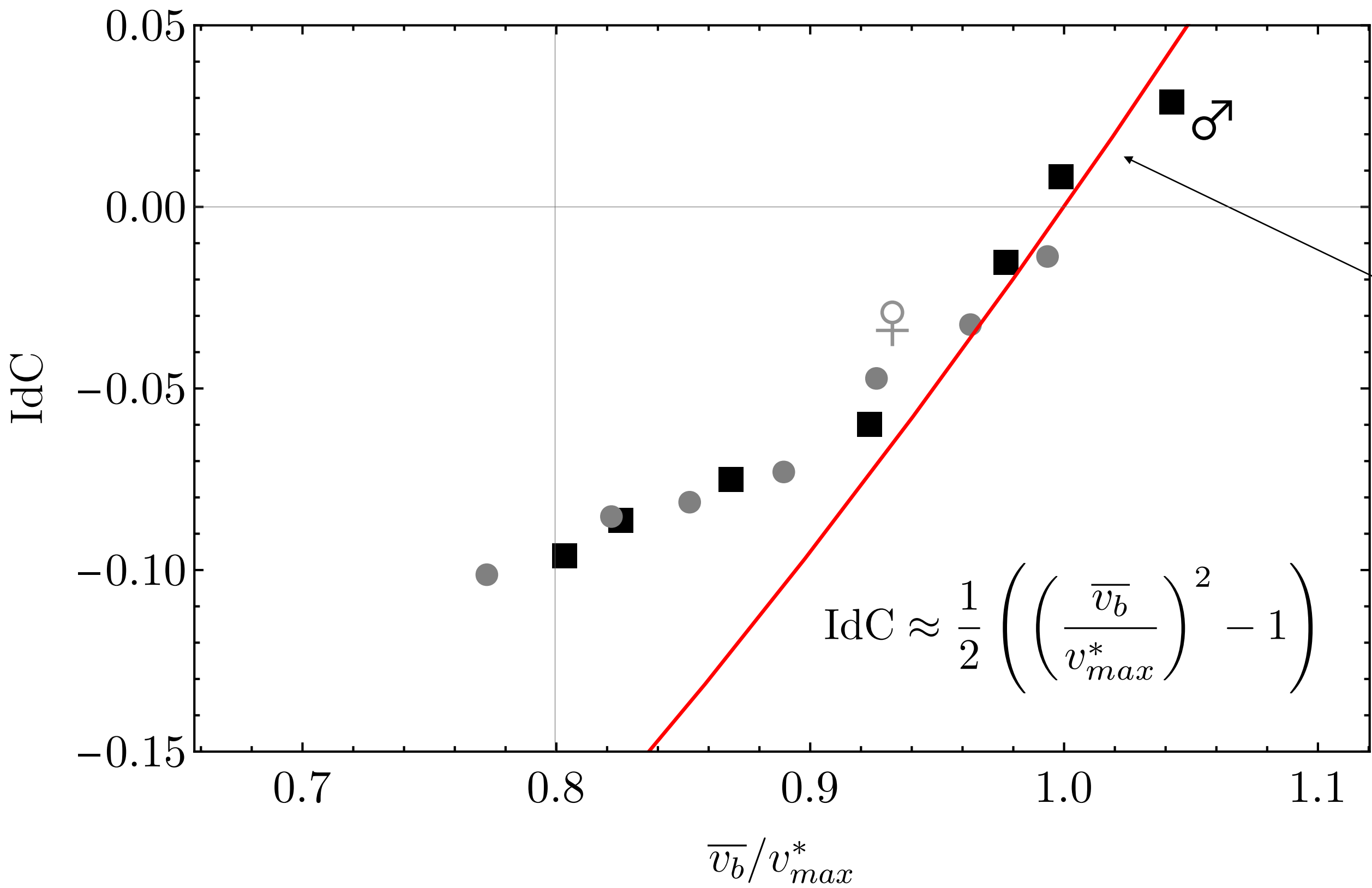
$$v^* = \sqrt{\frac{\overline{F_a}}{k_b}} \quad \overline{F_a} \in [0, F_{a,max}]$$

♂ $v^*_{max} \approx 1.8 \text{ m/s}$

$F_{a,max} \approx 100\text{N}$

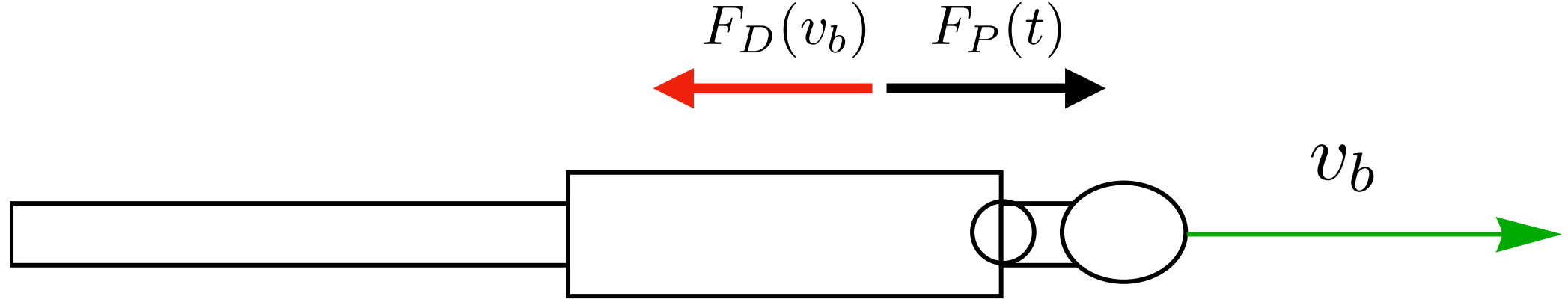
♀ $v^*_{max} \approx 1.6 \text{ m/s}$

$F_{a,max} \approx 59\text{N}$



Force max constante

Vitesse et Energie



$$v^* = \sqrt{\frac{\overline{F}_a}{k_b}} \quad \overline{F}_a \in [0, F_{a,max}]$$

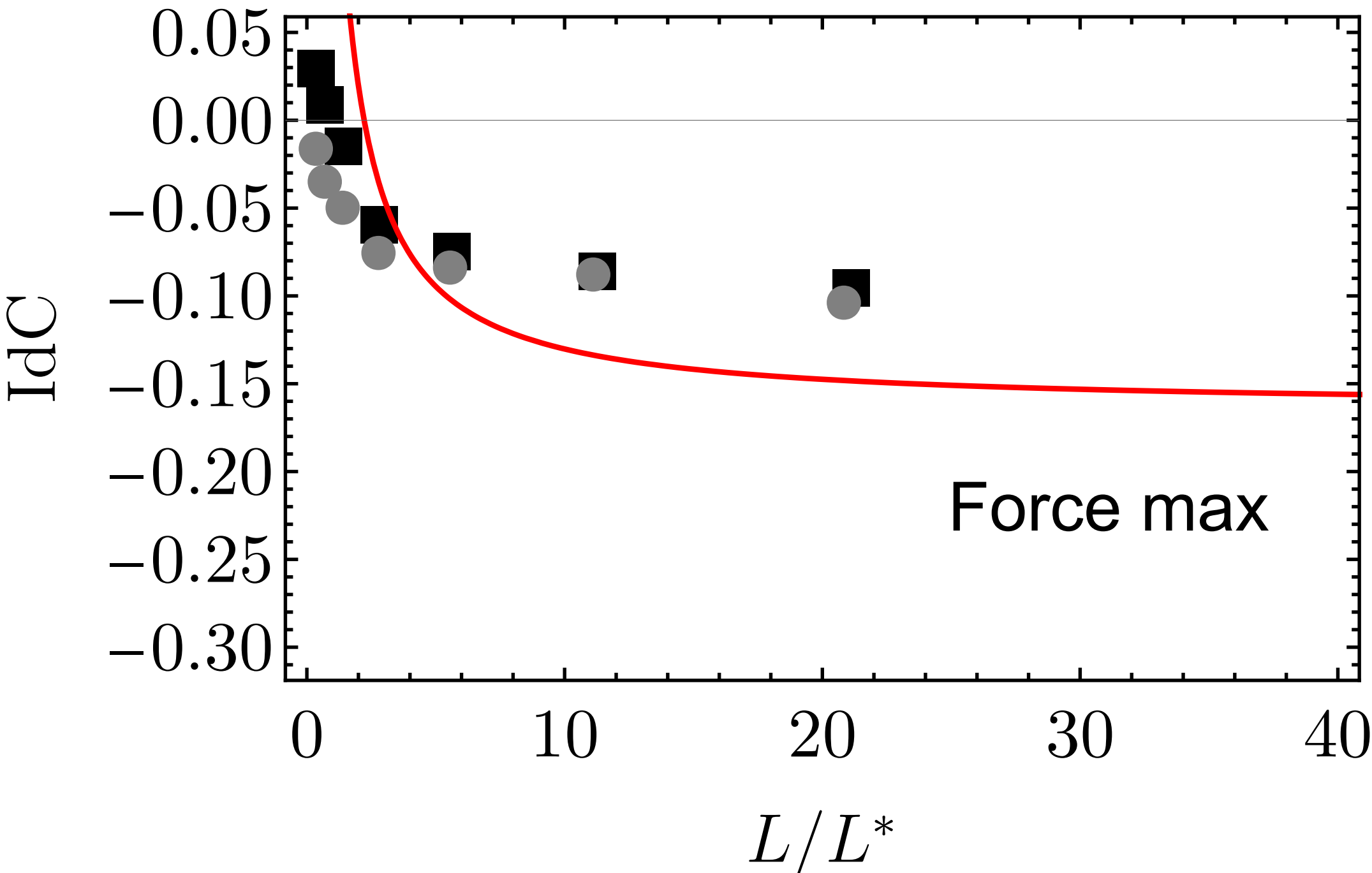
Dynamique

$$m_b \frac{dv_b}{dt} = F_P(t) - F_D(v_b) \quad \longrightarrow \quad \overline{v_b} \approx v^* \sqrt{1 + 2\text{IdC}} \quad (\text{sur un cycle})$$

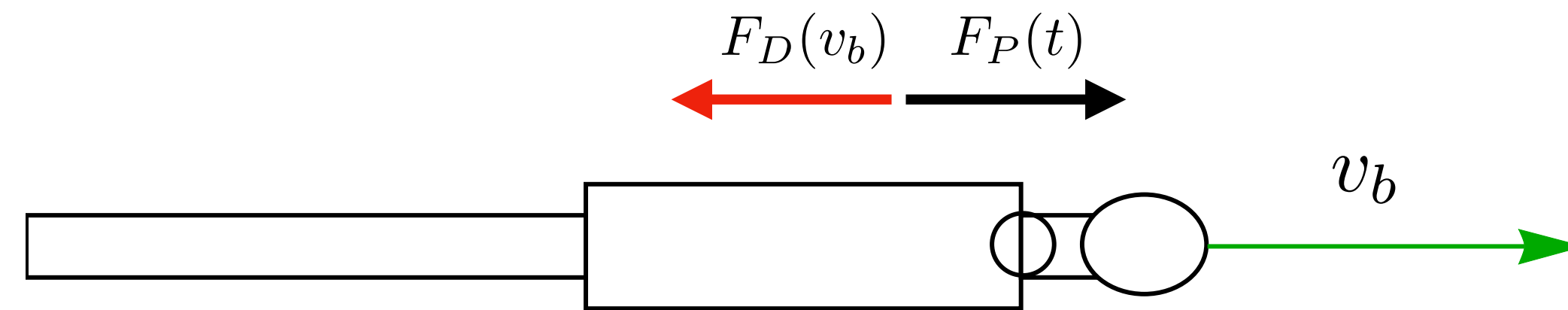
Physio

$$\frac{dE}{dt} = \sigma - f(t)v_b(t) \quad \longrightarrow \quad \frac{L^*}{L} = (1 + 2\text{IdC}) - \frac{v_R/v^*}{\sqrt{1 + 2\text{IdC}}} \quad (\text{sur la course})$$

$$L^* = \frac{E_0}{\overline{F}_a} \quad v_R = \frac{\sigma}{\overline{F}_a}$$



Vitesse et Energie



$$v^* = \sqrt{\frac{\overline{F}_a}{k_b}} \quad \overline{F}_a \in [0, F_{a,max}]$$

Dynamique

$$m_b \frac{dv_b}{dt} = F_P(t) - F_D(v_b) \quad \longrightarrow \quad \overline{v}_b \approx v^* \sqrt{1 + 2\text{IdC}} \quad (\text{sur un cycle})$$

Physio

$$\frac{dE}{dt} = \sigma - f(t)v_b(t) \quad \longrightarrow \quad \frac{L^*}{L} = (1 + 2\text{IdC}) - \frac{v_R/v^*}{\sqrt{1 + 2\text{IdC}}} \quad (\text{sur la course})$$

$$L^* = \frac{E_0}{\overline{F}_a}$$

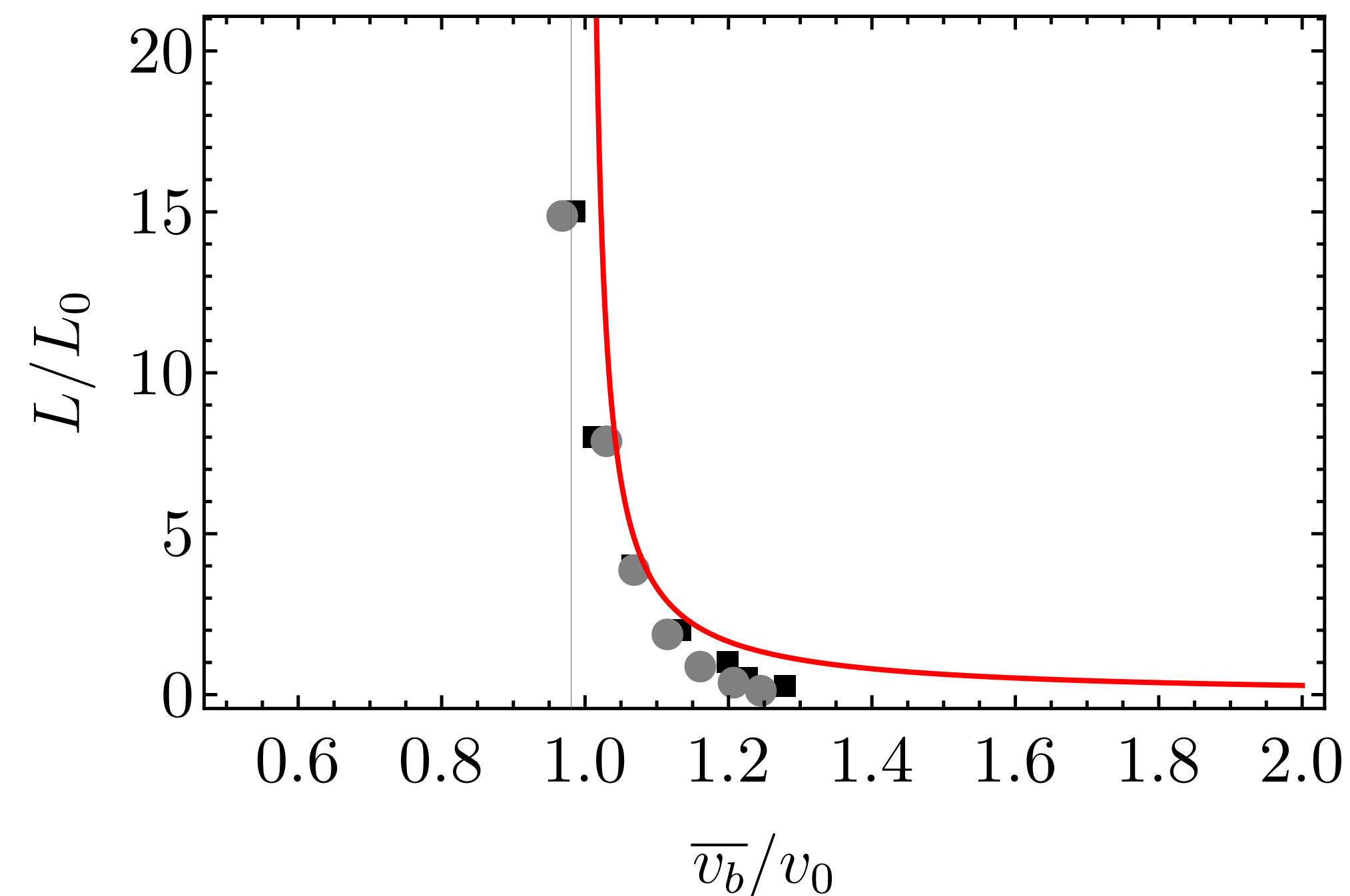
$$v_R = \frac{\sigma}{\overline{F}_a}$$



$$\frac{L_0}{L} = \left(\frac{\overline{v}_b}{v_0} \right)^2 - \frac{v_0}{\overline{v}_b}$$

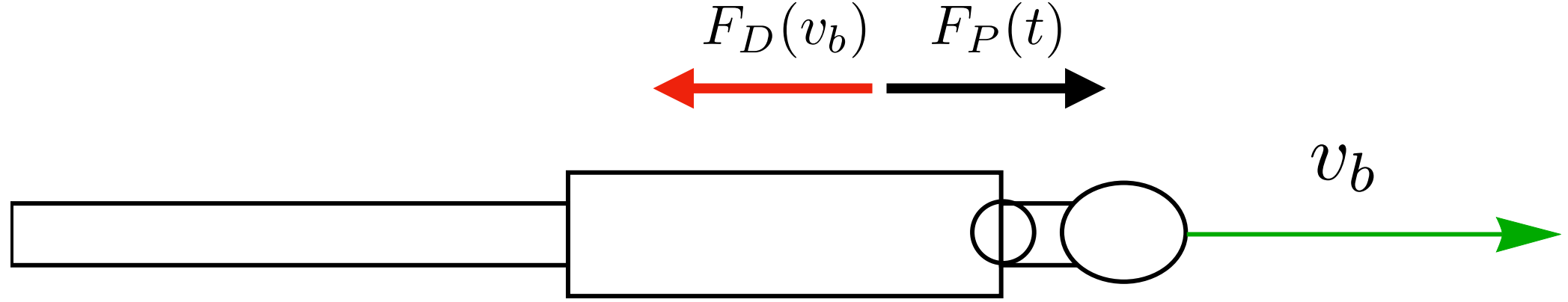
$$L_0 = \frac{E_0}{\sigma^{2/3} k_b^{1/3}}$$

$$v_0 = \left(\frac{\sigma}{k_b} \right)^{1/3}$$



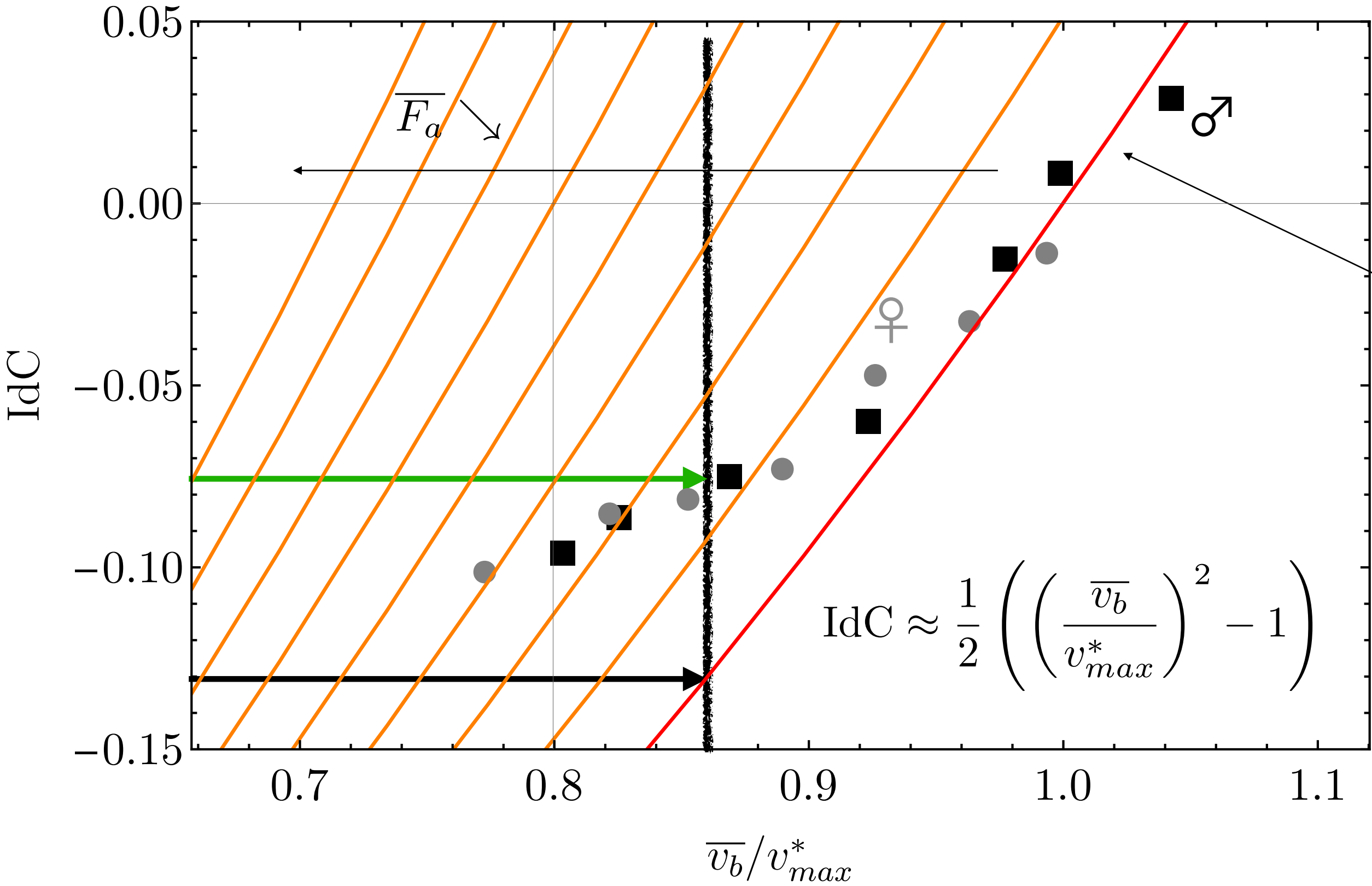
Toujours pas d'information sur le choix de coordination...

Vitesse et IdC



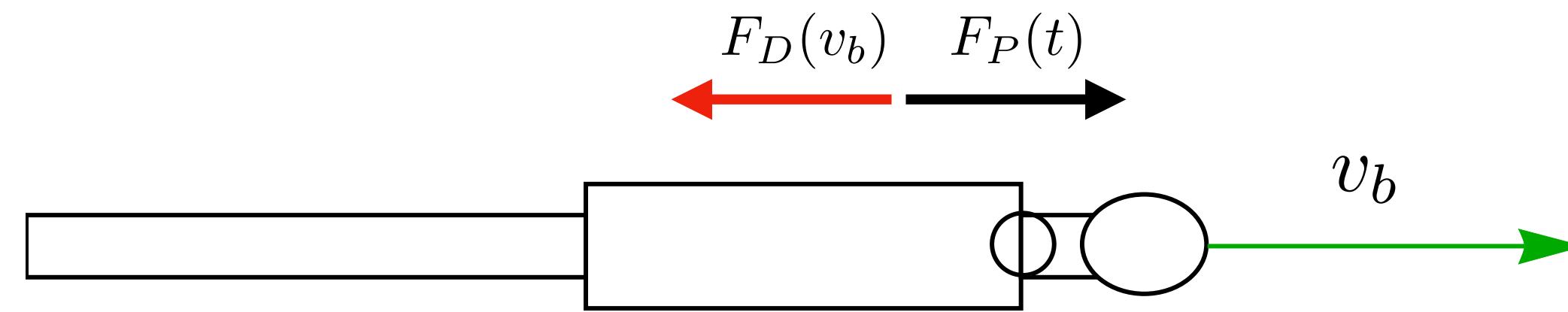
$$\overline{v_b} \approx v^* \sqrt{1 + 2\text{IdC}}$$

$$v^* = \sqrt{\frac{\overline{F_a}}{k_b}} \quad \overline{F_a} \in [0, F_{a,max}]$$



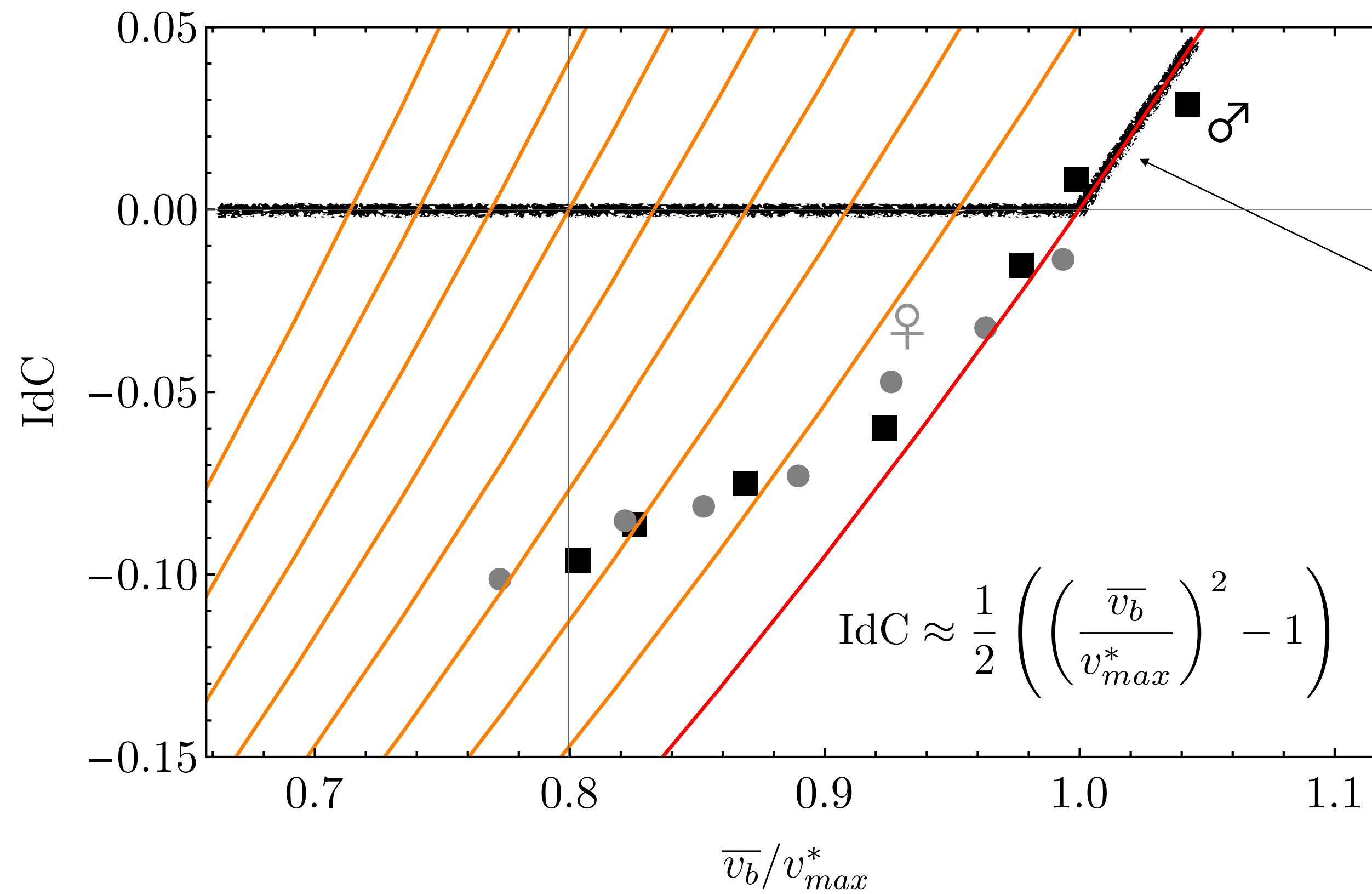
Force max constante

Vitesse et IdC



$$\overline{v_b} \approx v^* \sqrt{1 + 2\text{IdC}}$$

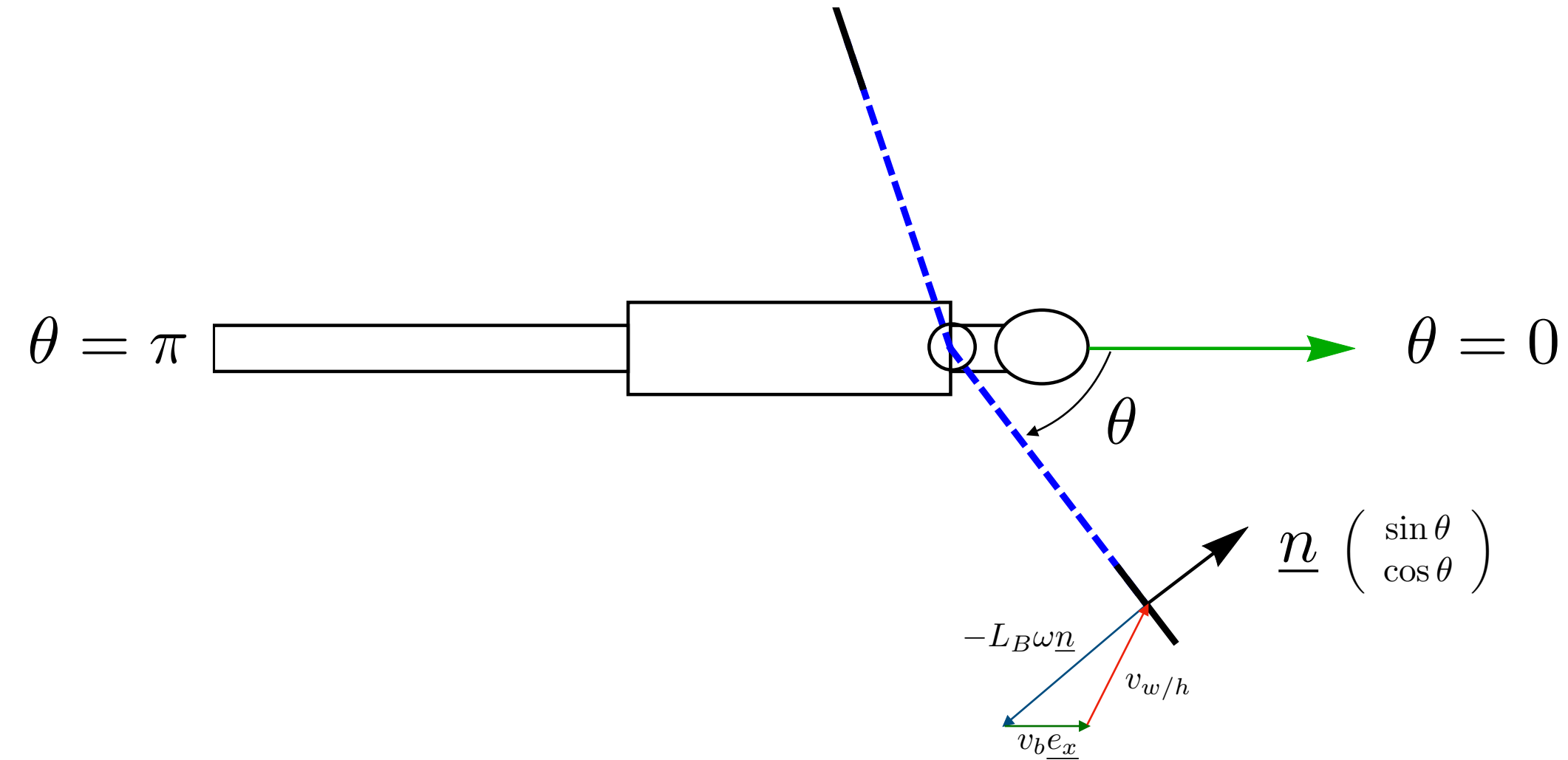
$$v^* = \sqrt{\frac{\overline{F_a}}{k_b}} \quad \overline{F_a} \in [0, F_{a,max}]$$



$$\text{IdC} \approx \frac{1}{2} \left(\left(\frac{\overline{v_b}}{v_{max}^*} \right)^2 - 1 \right)$$

Seifert et al. 2007

Modèle avec rames



Résistance due à la pression

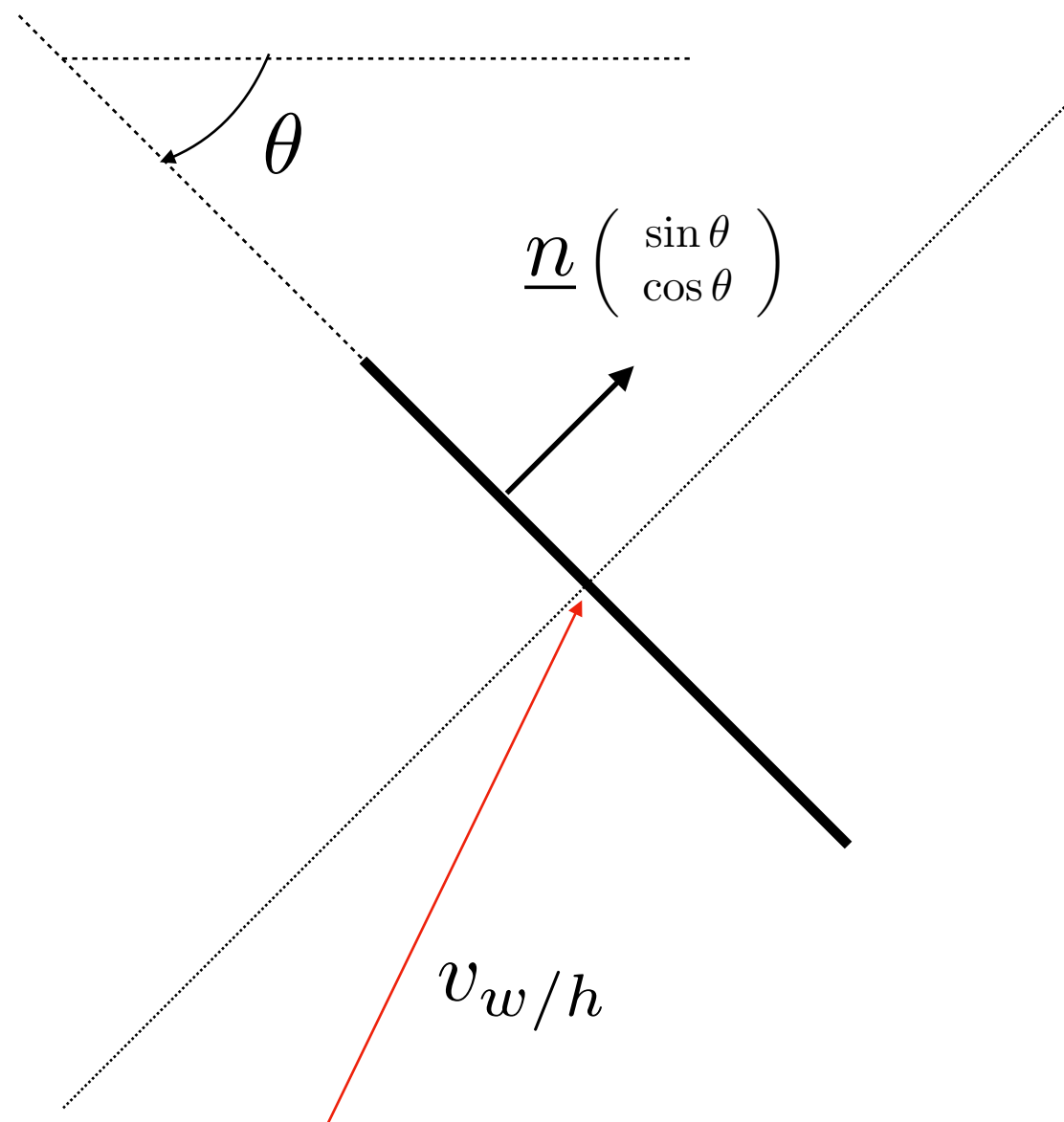
$$\underline{F}_{w/h}^P = -\frac{1}{2} \rho S_h C_{D,h} |v_{h/w}| \left(\underline{v}_{h/w} \cdot \underline{n} \right) \underline{n}$$

$$\underline{v}_{h/w} = -L_B \omega \underline{n} + v_b \underline{e}_x$$

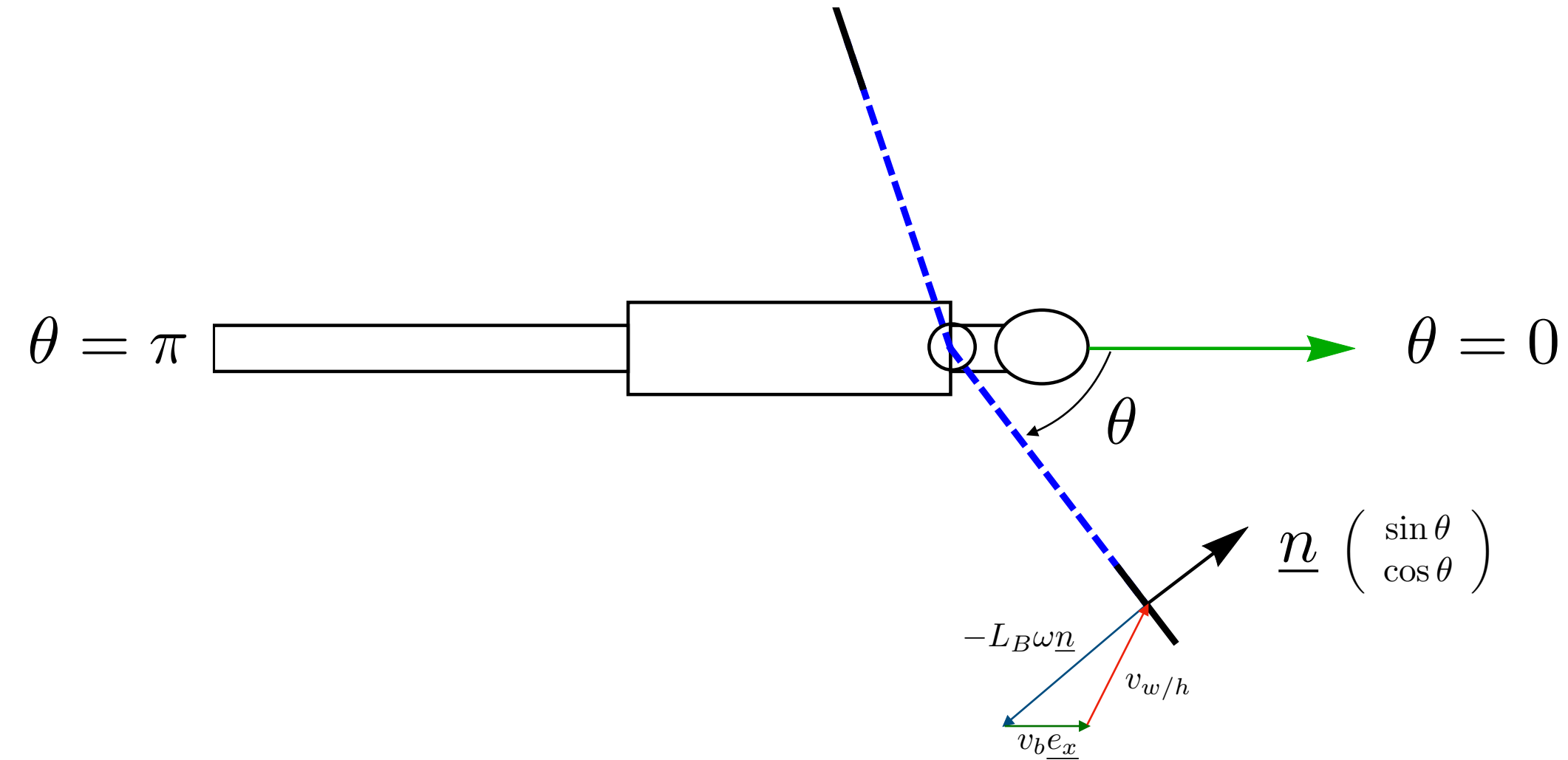
Résistance due aux effets de masse ajoutée

$$\underline{F}_{w/h}^A = -\frac{\pi}{4} \rho (S_h \times l_h) C_{A,h} \left(\frac{d}{dt} \underline{v}_{h/w} \cdot \underline{n} \right) \underline{n}$$

$$\frac{d}{dt} \underline{v}_{h/w} \cdot \underline{n} = -L_B \frac{d\omega}{dt} + \frac{dv_b}{dt} \sin \theta$$



Modèle avec rames



Supposons que le nageur impose un couple constant à ses épaules :

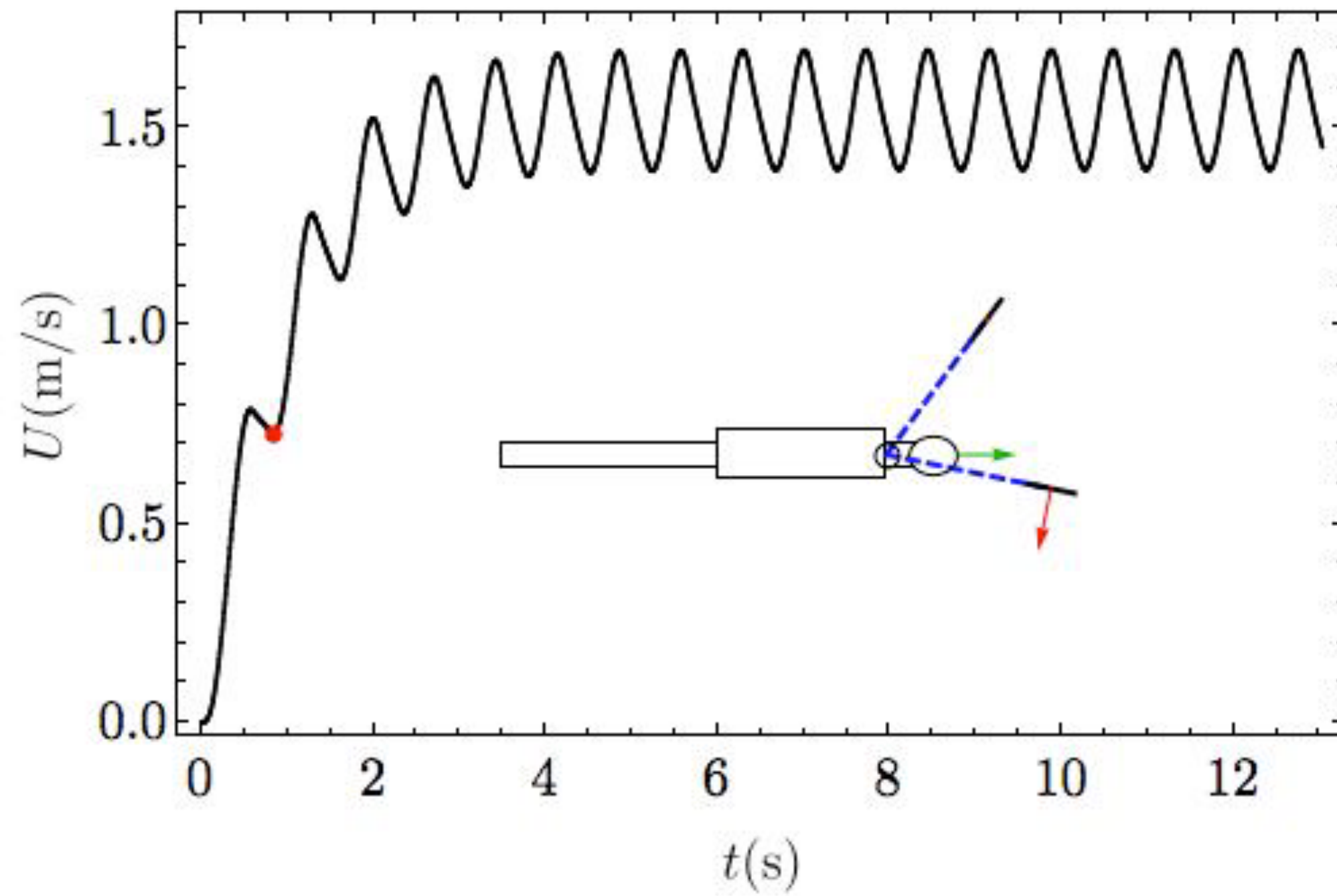
Eq. de la main $I_h \frac{d\omega}{dt} = \Gamma - L_B \underline{F}_{w/h} \cdot \underline{n}$ où : $I_h = L_B^2 m_h$

Note : il y a toujours une phase d'entrée

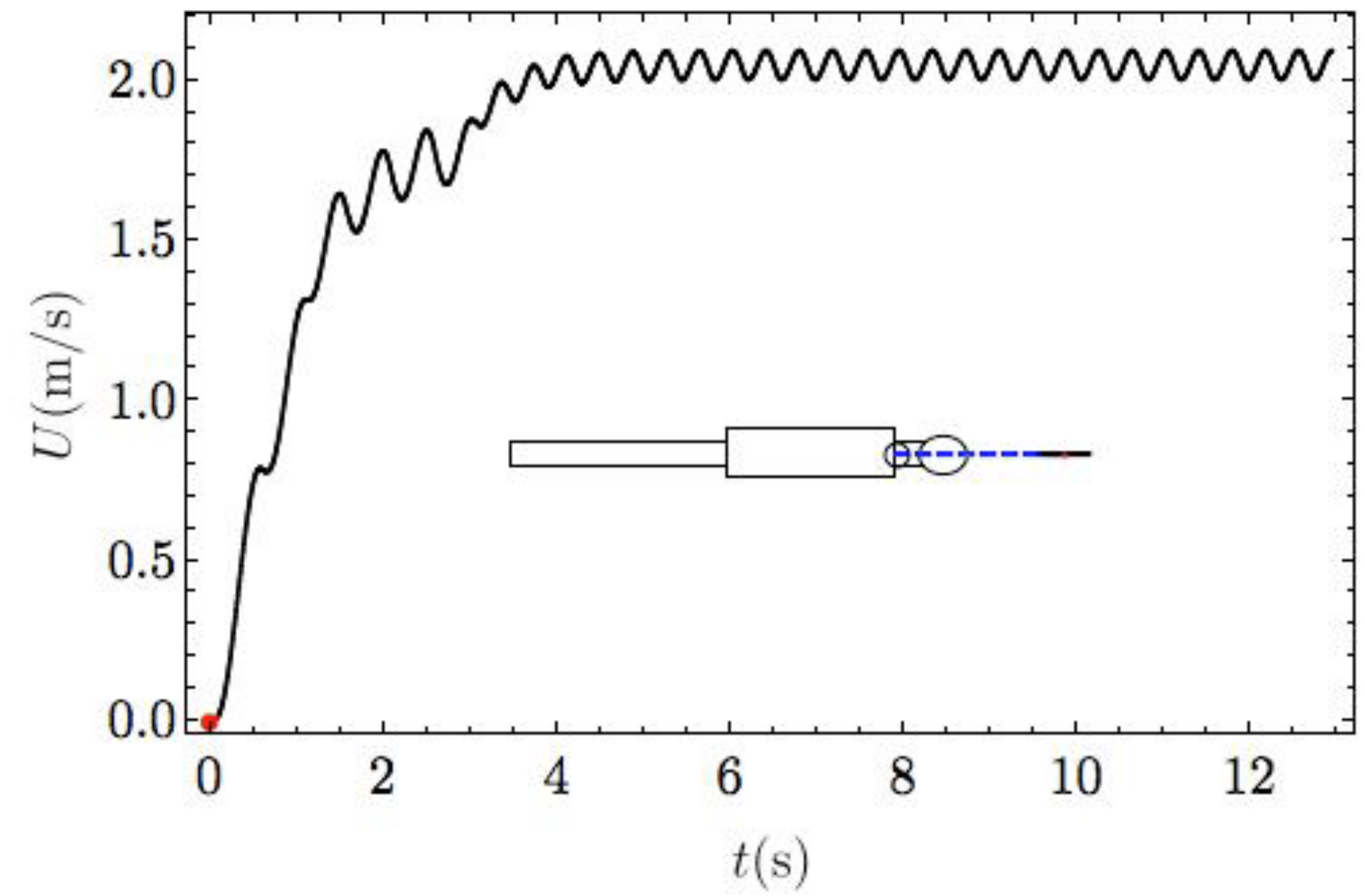
Eq. pour le corps $m_b \frac{dv_b}{dt} = \underline{F}_{w/h} \cdot \underline{e}_x - k_b v_b^2$

Simulations

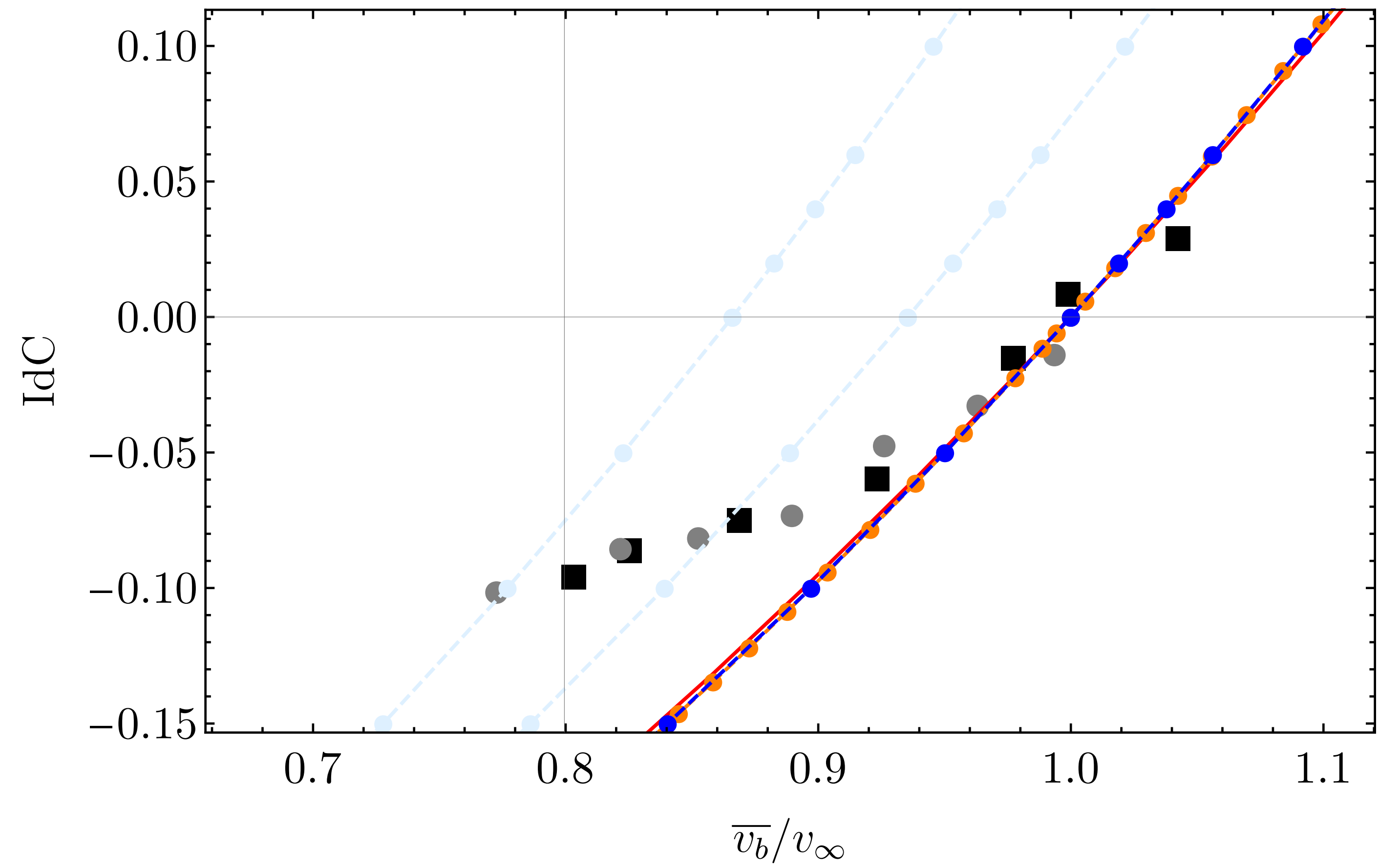
Alternée



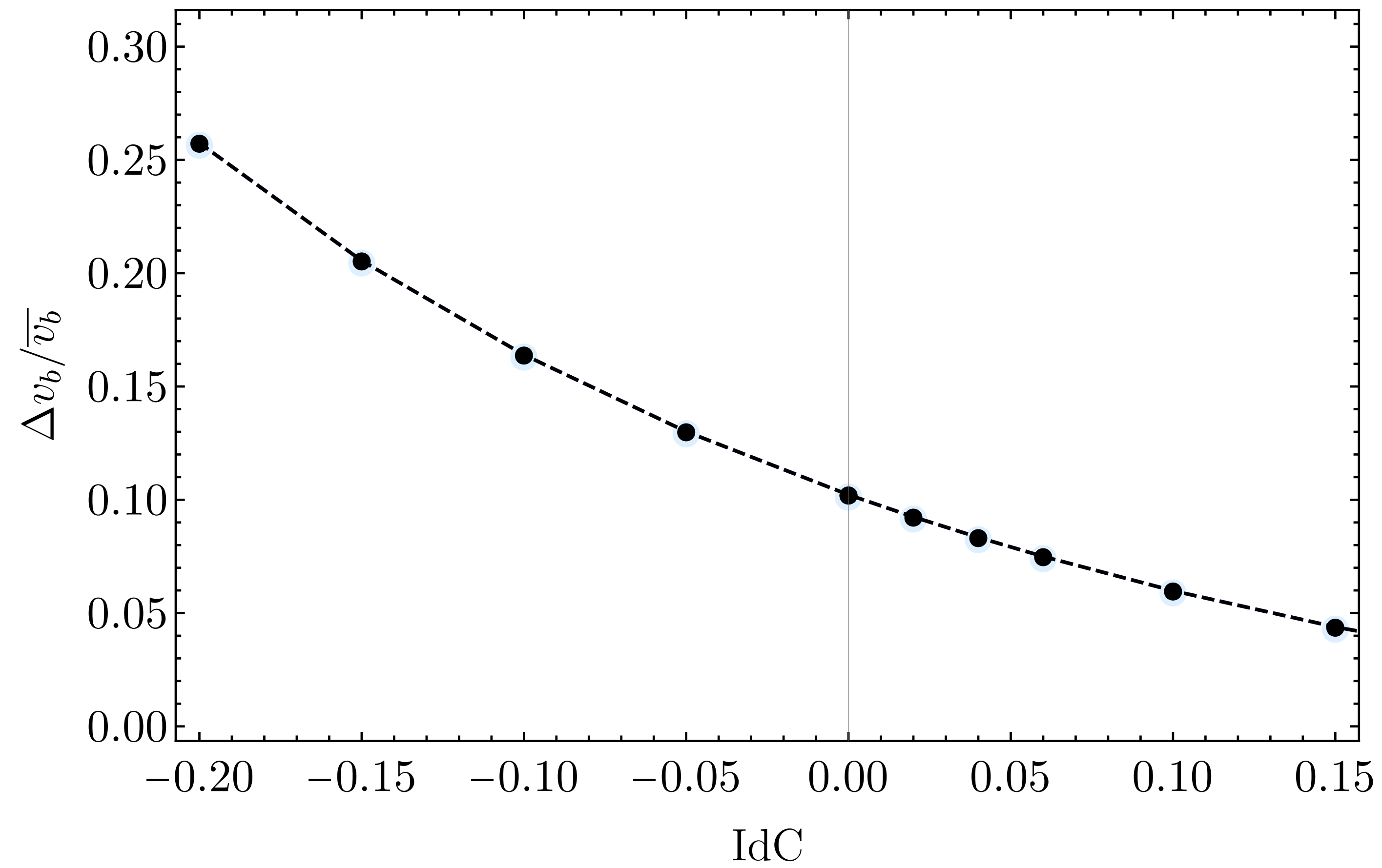
Superposition



Coordination/Vitesse



Coordination/Fluctuations



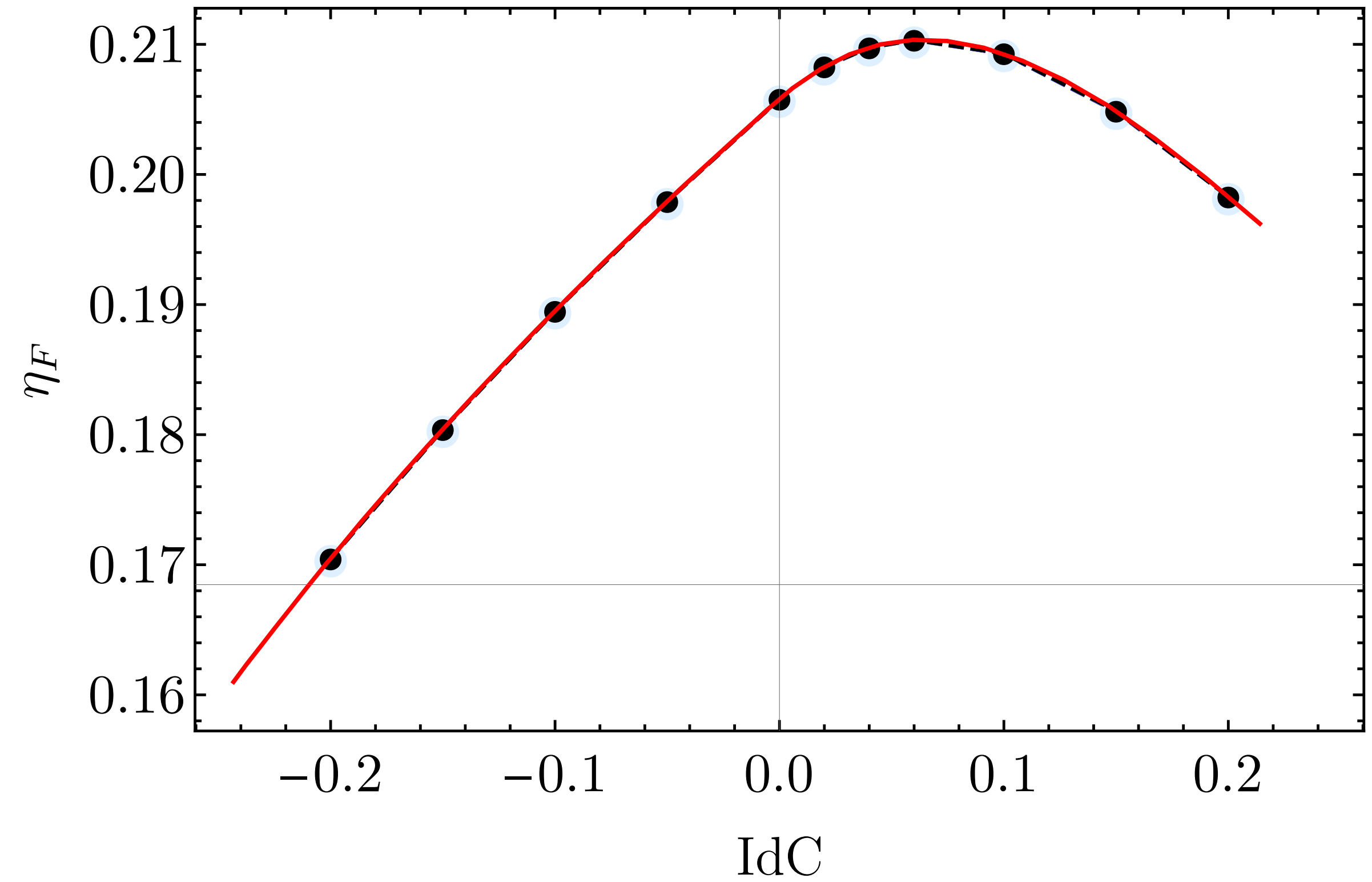
Efficacité?

$$\eta_F(t) = \frac{P_{\text{useful}}(t)}{P_{\text{provided}}(t)}$$

$$P_{\text{provided}}(t) = \Gamma\omega$$

$$P_{\text{useful}}(t) = \underline{F}_{w/h} \cdot \underline{e}_x v_b$$

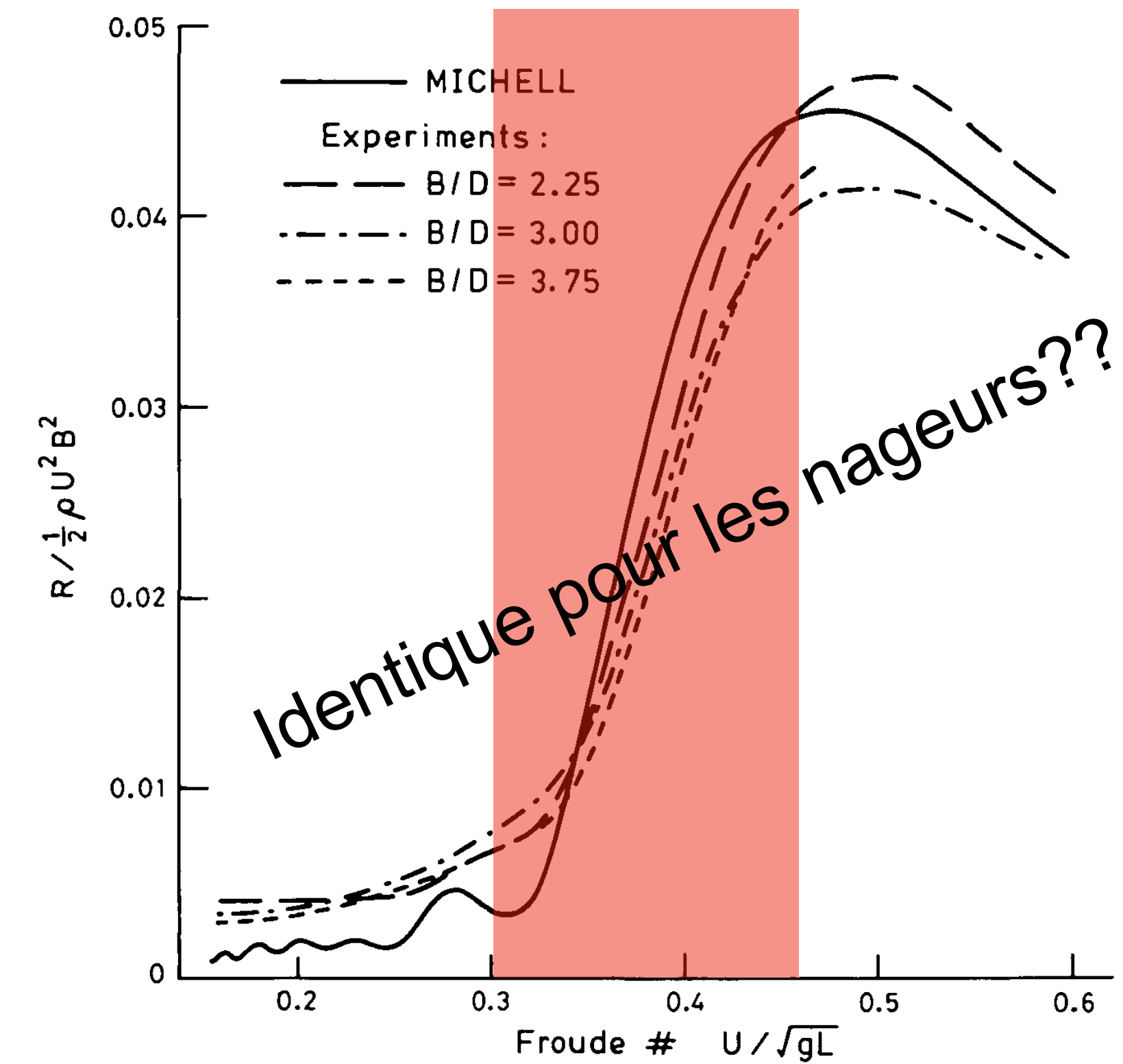
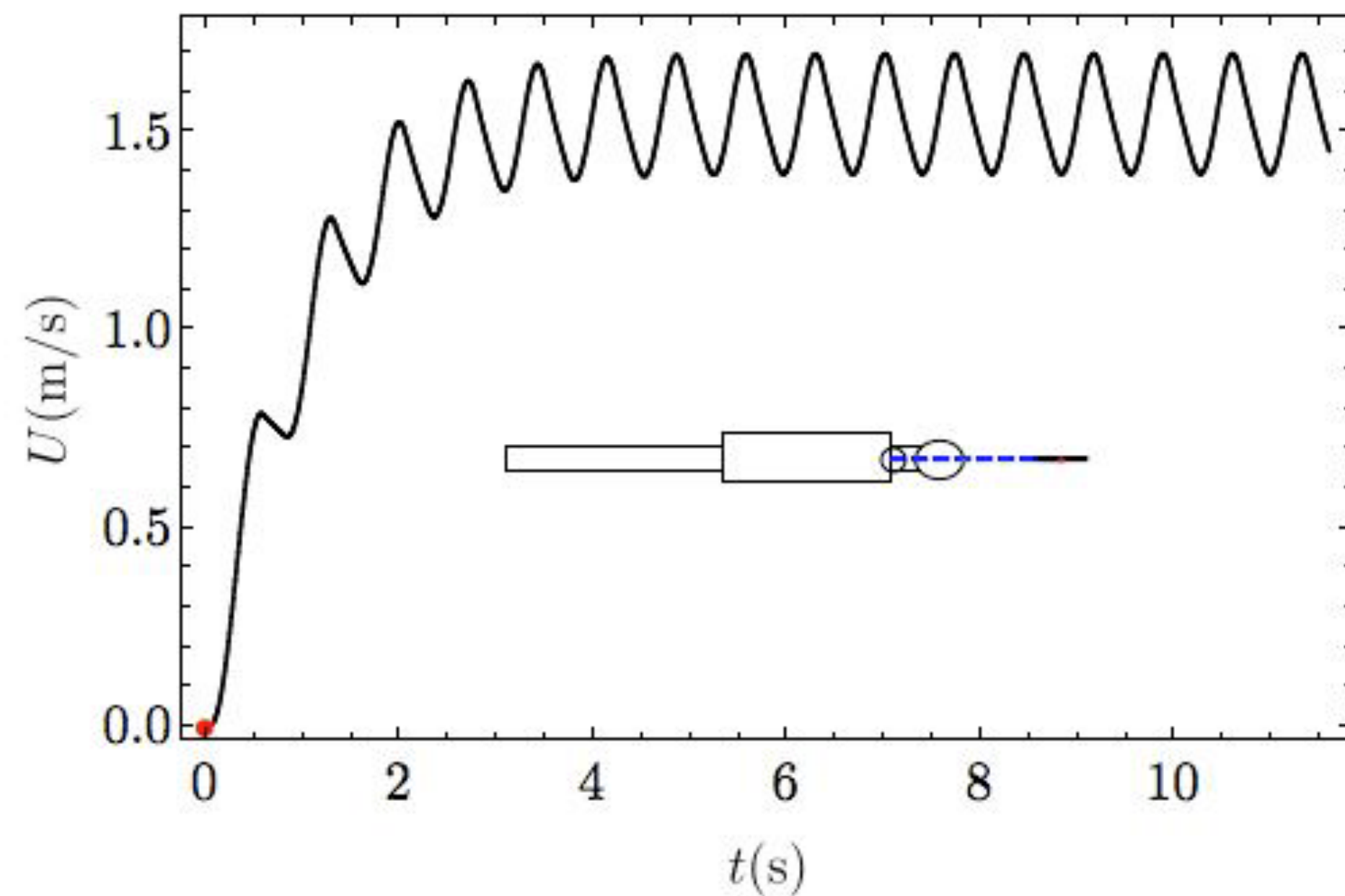
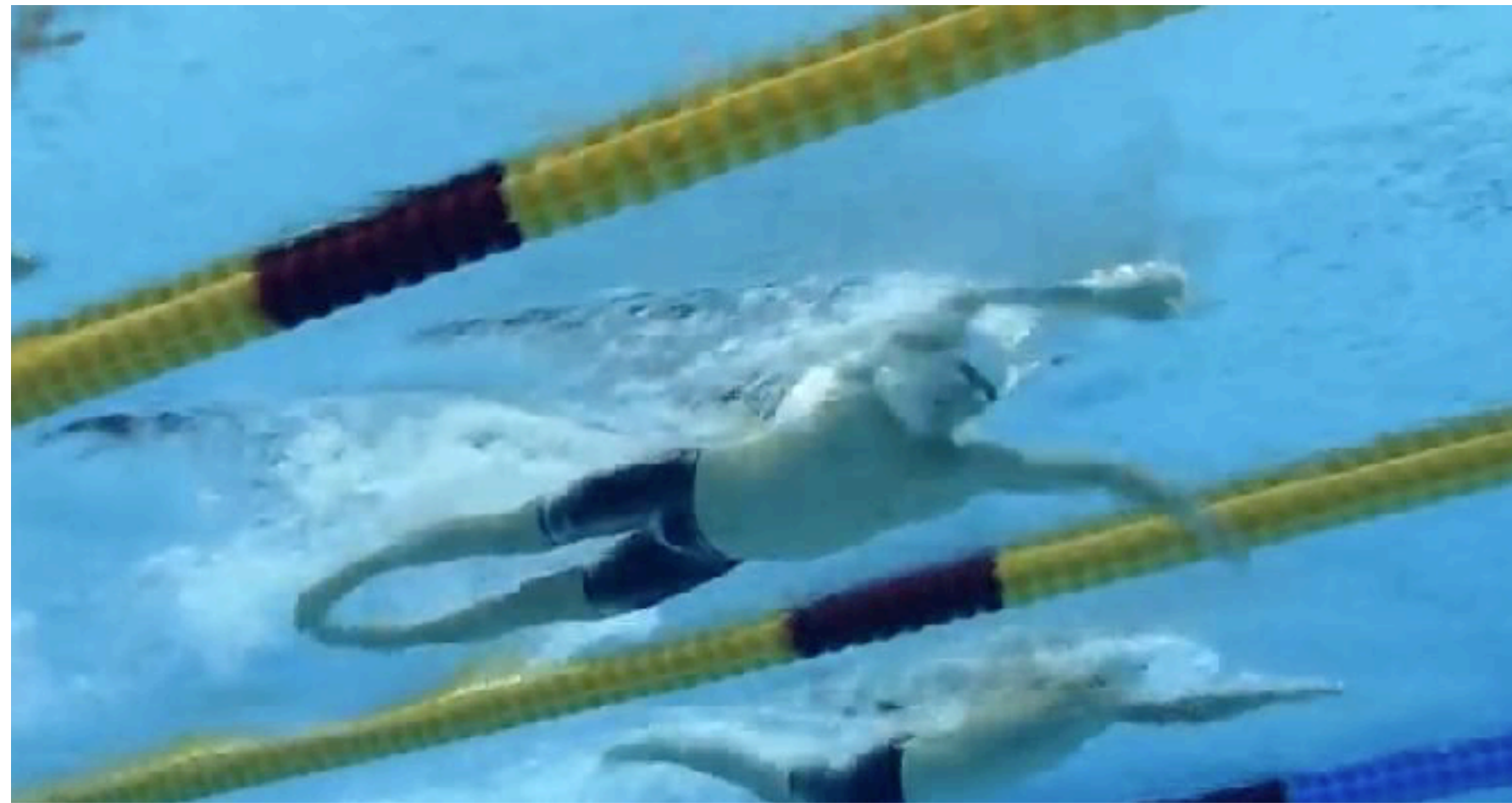
$$\eta_F = \frac{1}{2\tau_p} \int_0^T \eta_F(t) dt$$



Avantage de la nage alternée?

Longue phase bras tendu devant

$$Fr = \frac{\overline{v_b}}{\sqrt{gL}}$$



Expériences avec des « nageurs »



$L \approx 20 \text{ cm}$



Coordination dans les autres sports de glisse?



J.P. Boucher, R. Labbé

Stratégie équipe de France?



Figure 6 : Championnats de France d'eau libre de Gravelines 2017



Merci pour votre attention!



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