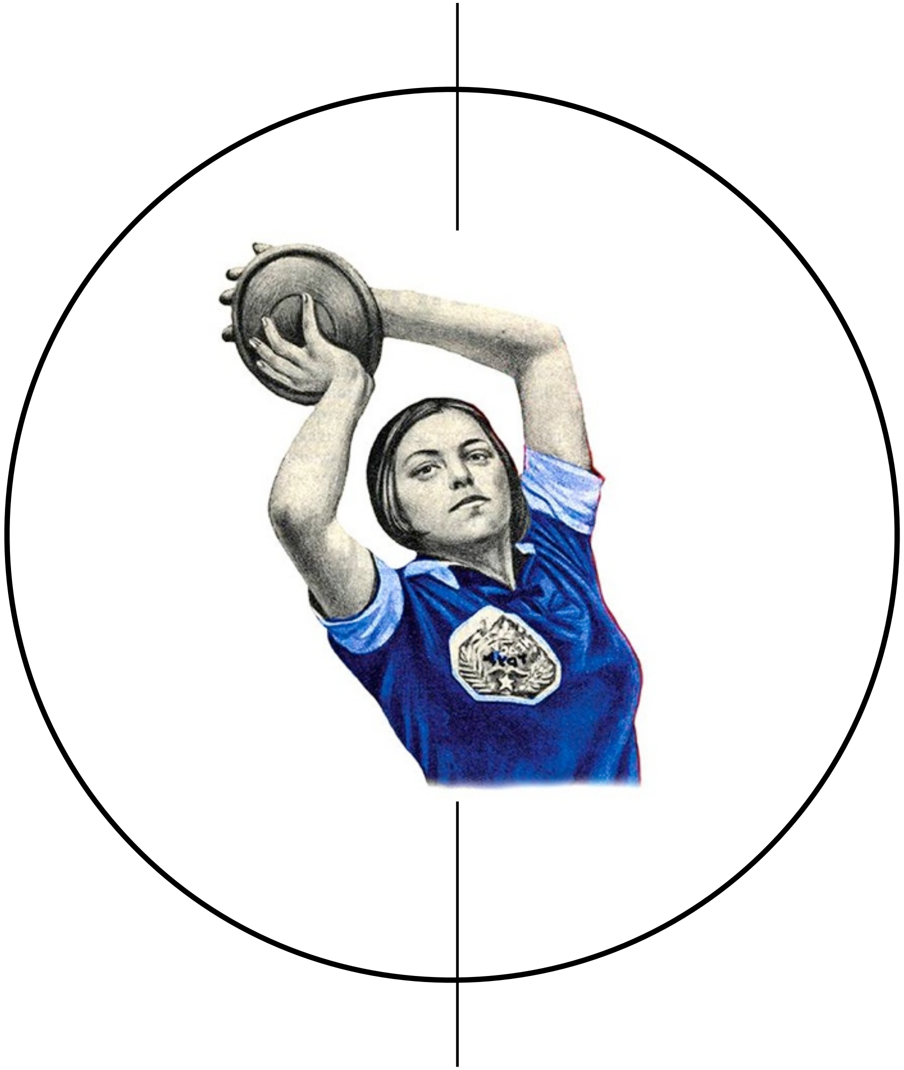
# Sports Physics



# Sports Physics

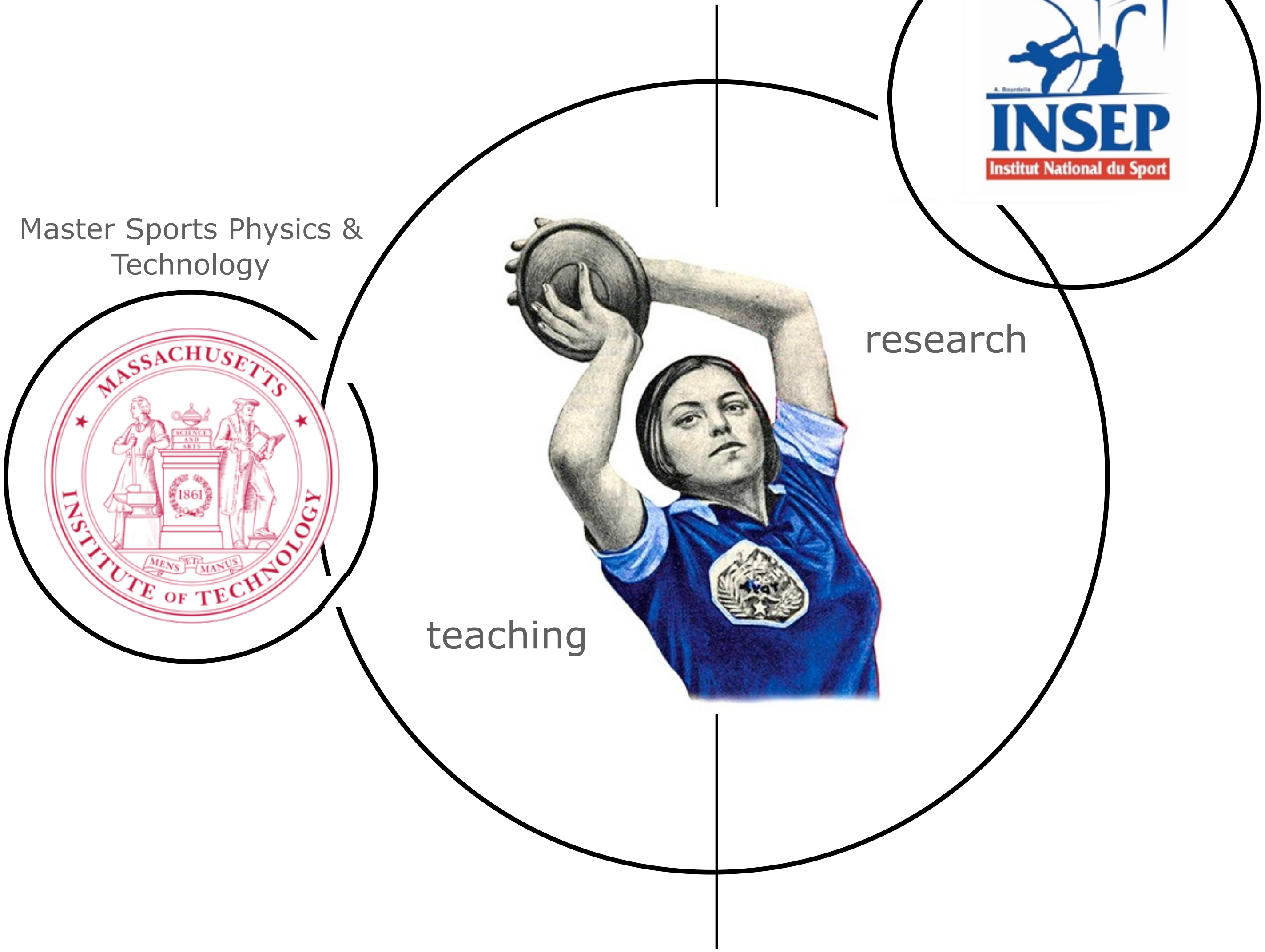
Master Sports Physics & Technology

teaching

# Sports Physics

optimisation of
human performances

Master Sports Physics &
Technology



# Sports Physics

optimisation of
human performances

Master Sports Physics &
Technology

research

teaching

restoring human
performance

# Sports Physics

optimisation of
human performances

innovation

Master Sports Physics &
Technology

research

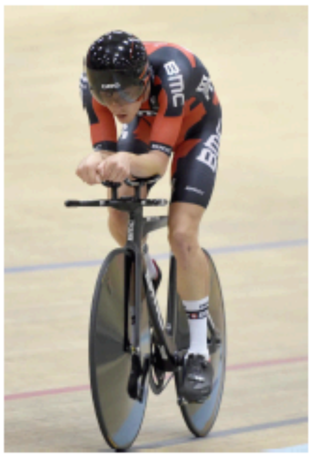
teaching

restoring human
performance

# research

Sport - Mouvement
et nouveaux outils de diagnostic

Sport et matériaux pour
la performance



Sports de glisse et
Transport à faible coût

Sport et matériaux
pour la performance

collaboration avec **Martin Fourcade**


collaboration avec Lydéric Bocquet - ENS ULM

Sport de glisse et transport à faible cout


Emmanuel du Pontavice

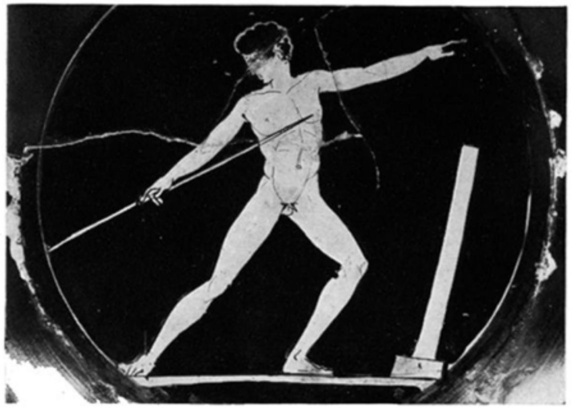
races

weightlifting

Caroline Cohen,
Guillaume Laffaye
Loïc Auvray

jumps

throwns



# OPTIMAL VELOCITY IN A RACE

• The American Mathematical Monthly >
Vol. 81, No. 5, May, 1974

JOSEPH B. KELLER

**1. Formulation.** We wish to determine how a runner should vary his speed $v(t)$ during a race of distance $D$ in order to run it in the shortest time. Previously we formulated this problem in the following way [1]:

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The force $f(t)$ is controlled by the runner, but it cannot exceed the maximum value $F$,

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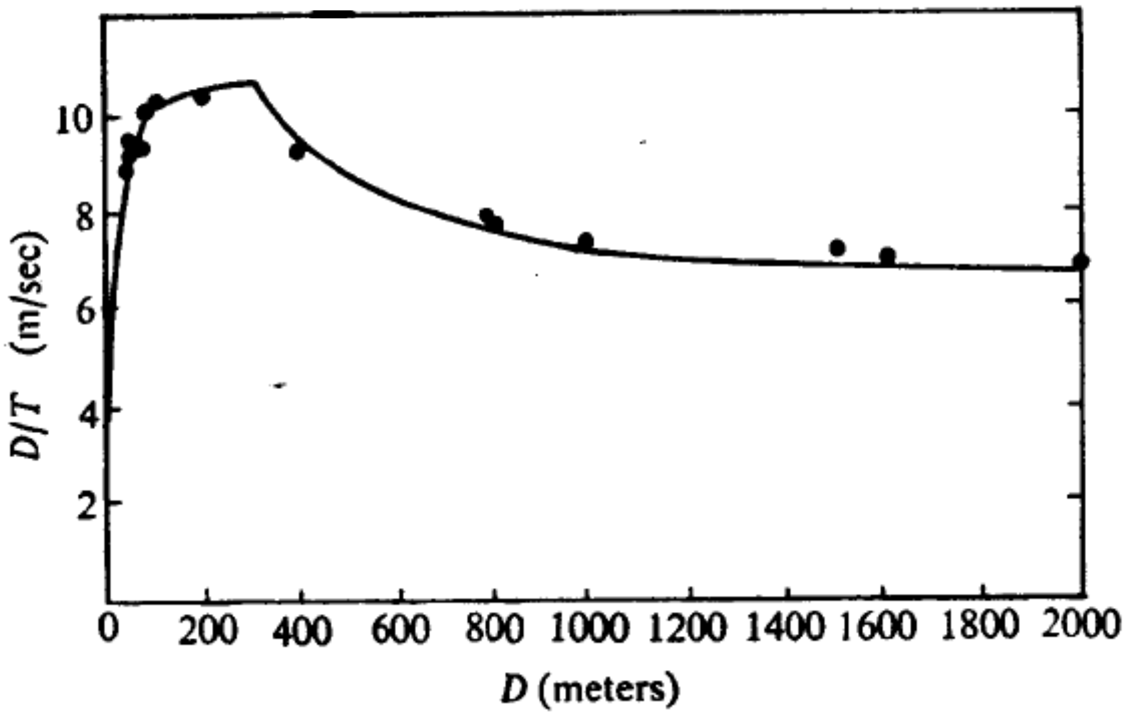
$$\frac{dE}{dt} = \sigma - fv. \tag{1.5}$$

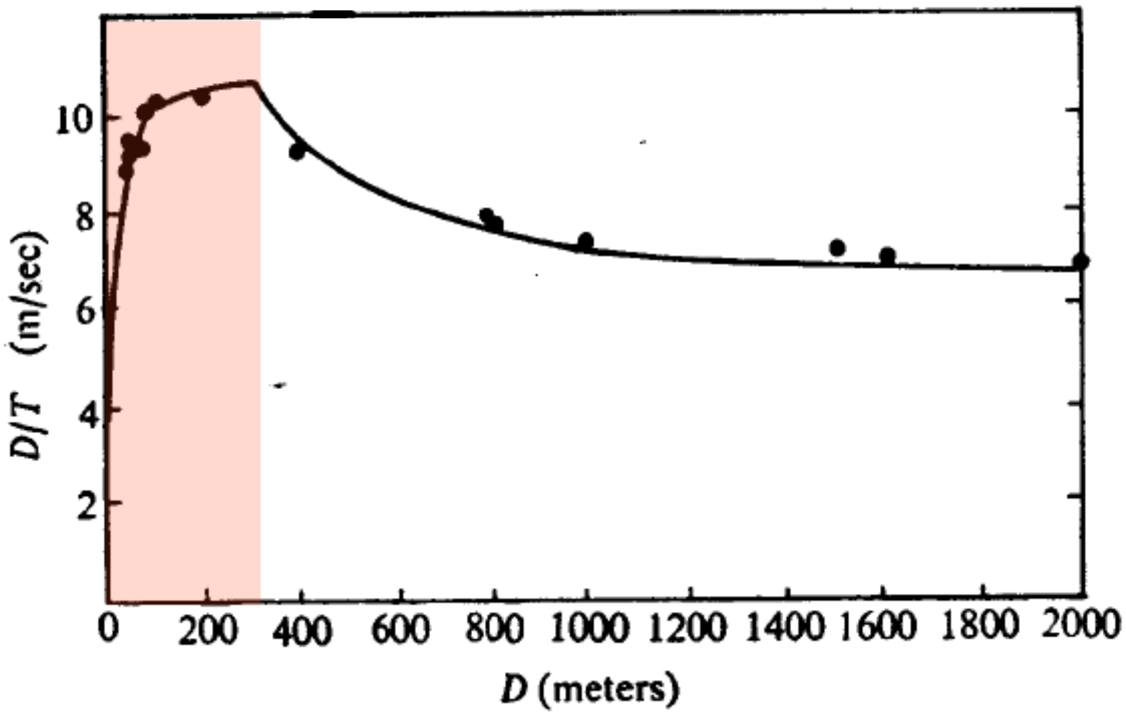
In (1.5) and elsewhere we measure oxygen in units of the amount of energy it would yield in a reaction. Initially

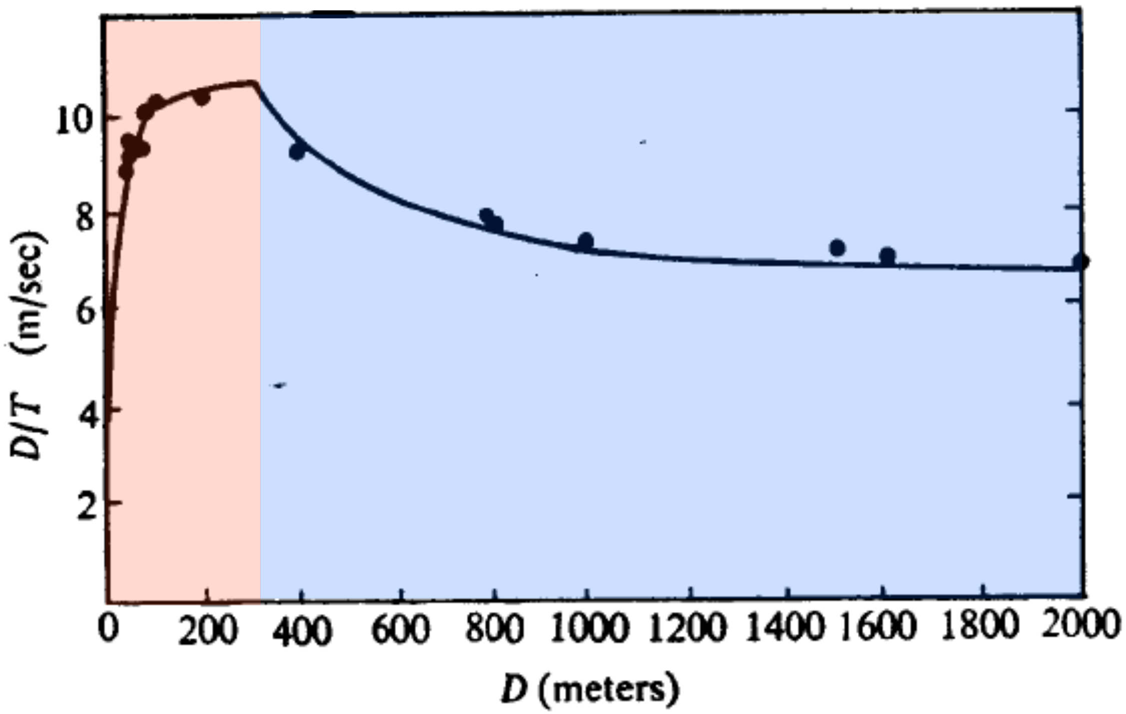
$$E(0) = E_0. \tag{1.6}$$

Since $E(t)$ can never be negative, we have

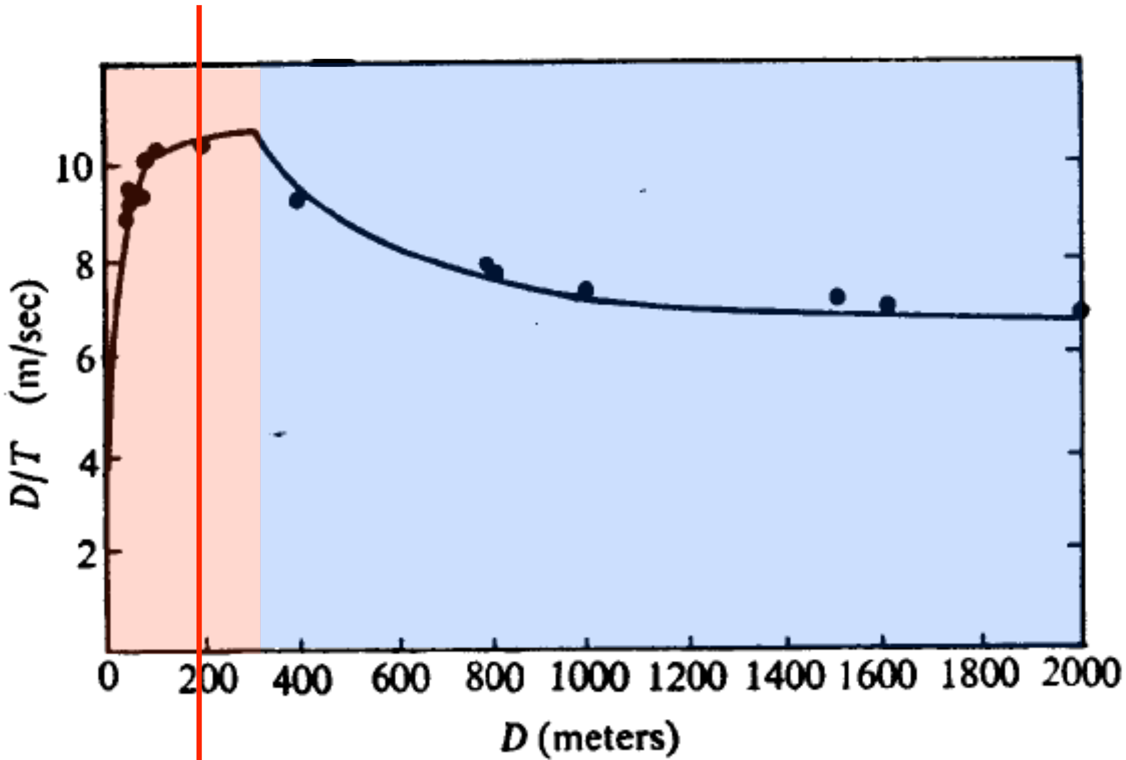
$$E(t) \geqq 0. \tag{1.7}$$


D/T (m/sec)
10
8
6
4
2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
D (meters)


10
8
6
4
2
D/T (m/sec)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
D (meters)



10
8
6
4
2
D/T (m/sec)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
D (meters)




Stade d’Olympie -800 BC

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The force also affects the quantity $E(t)$ of available oxygen in the muscles per unit mass, since oxygen is consumed in reactions which release the energy used in running. Energy is used at the rate $fv$, and we assume that oxygen is supplied by breathing and circulation at the rate $\sigma$ in excess of that supplied in the non-running state. Then the oxygen balance equation is

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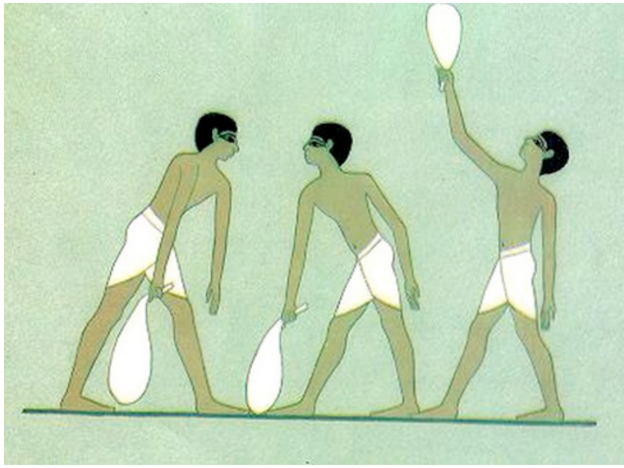
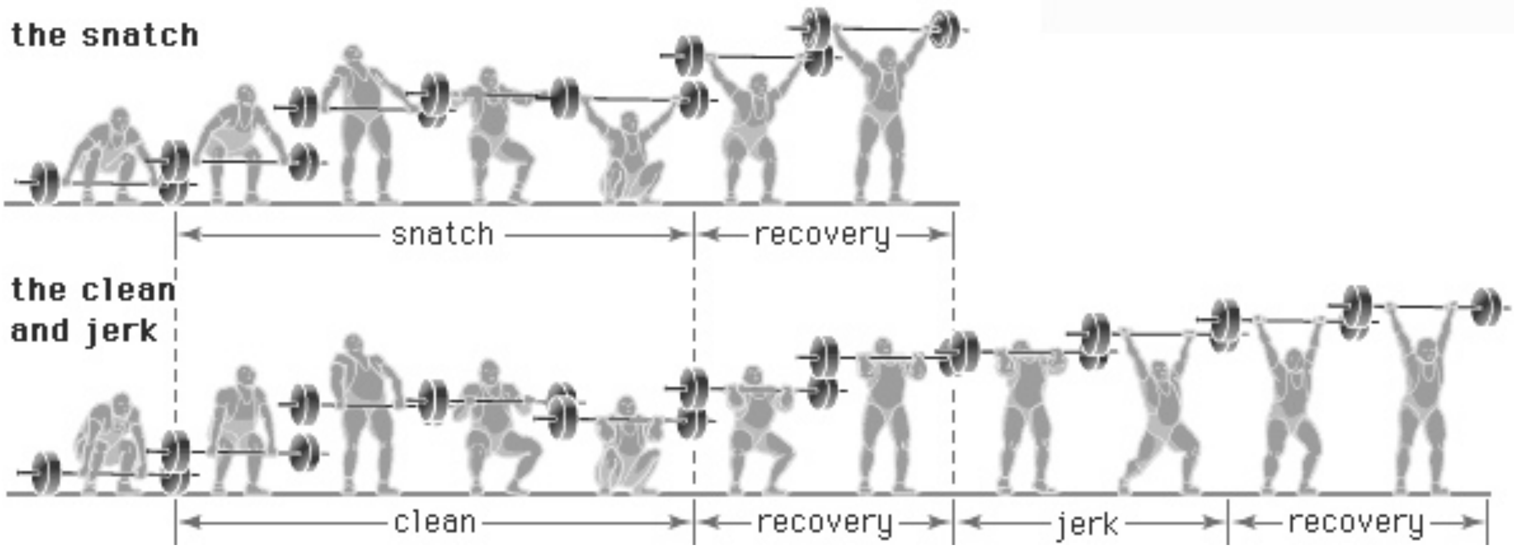
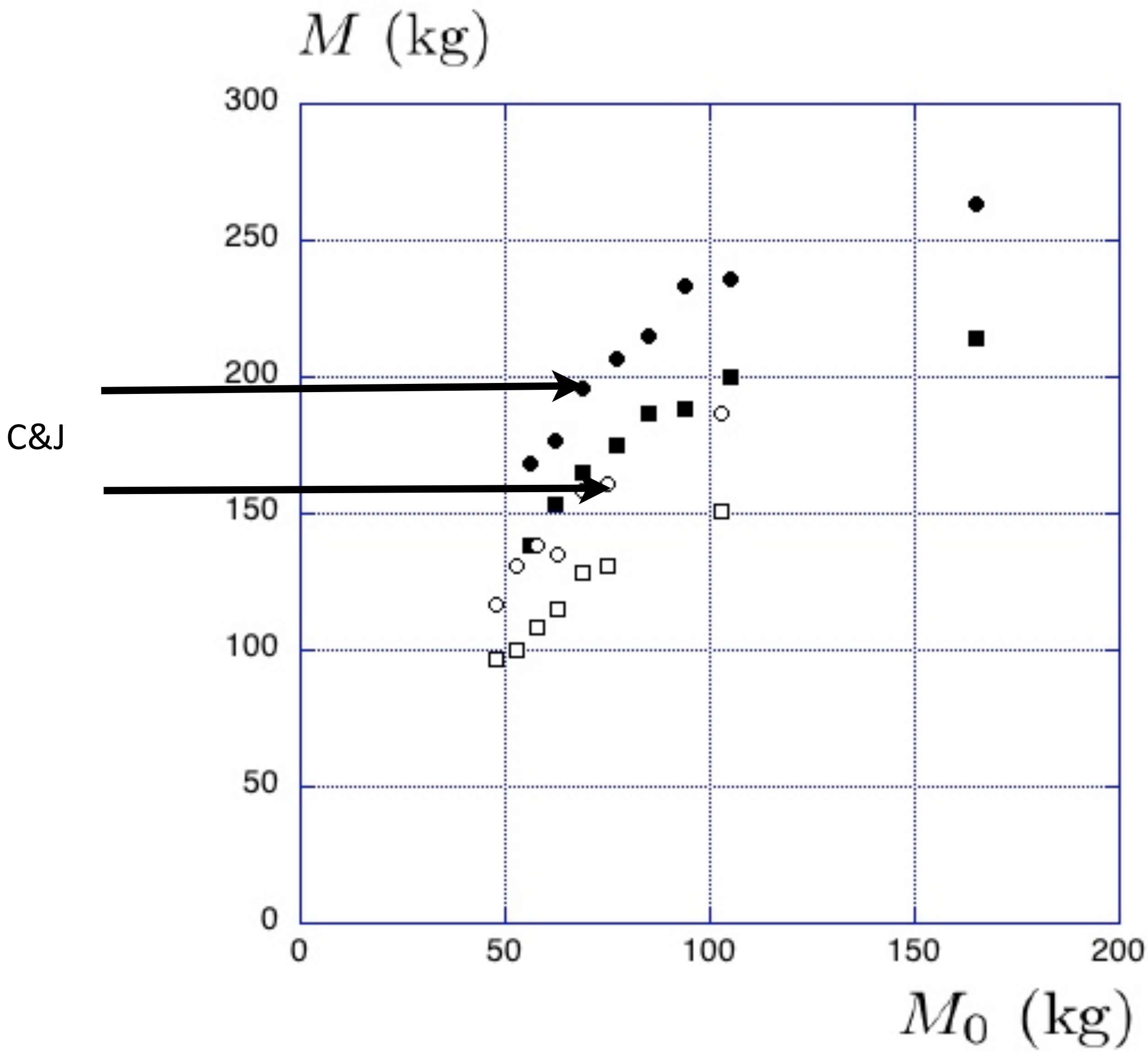
vendredi 17 juin 2016

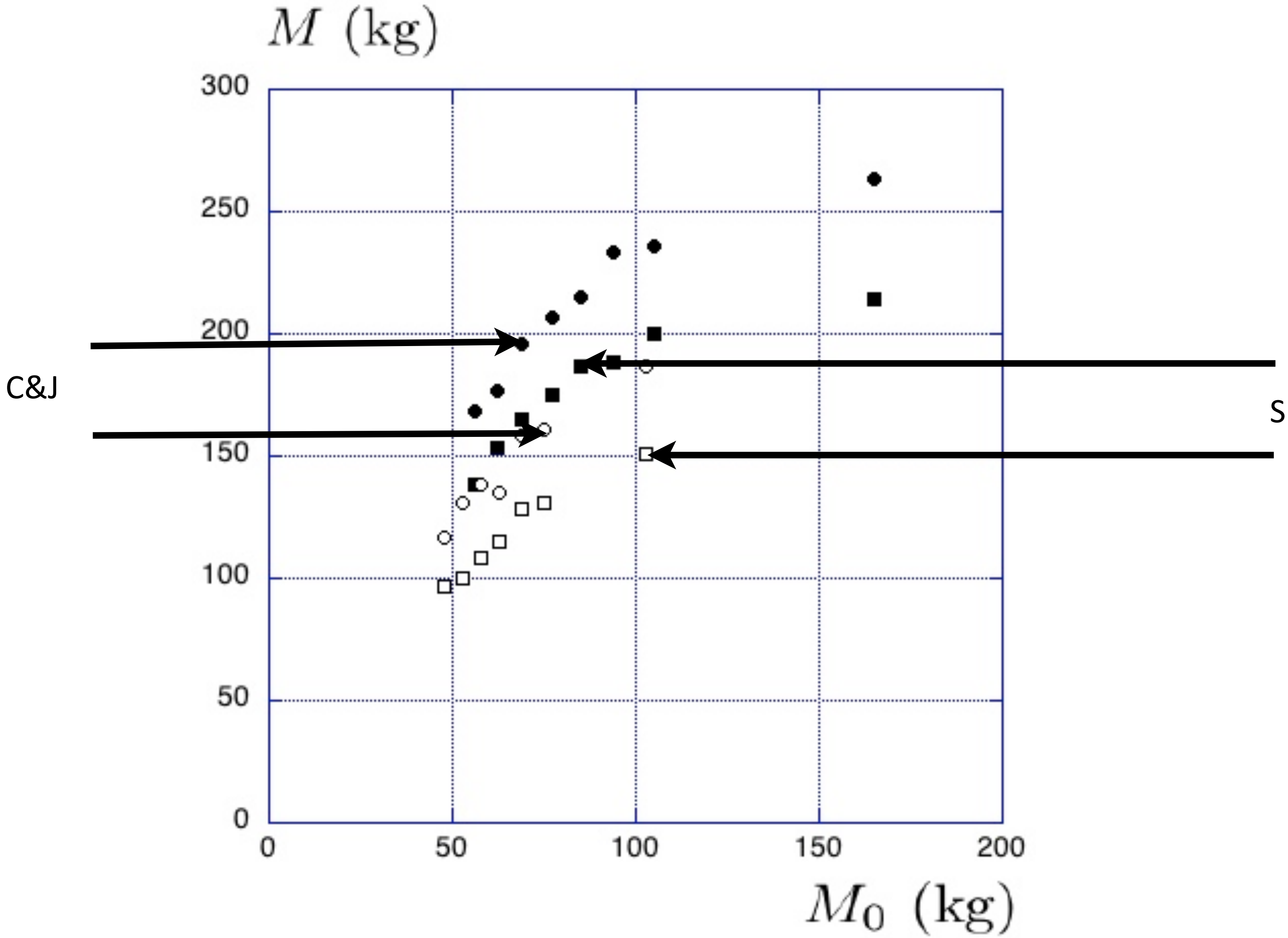
# - 5000 BC

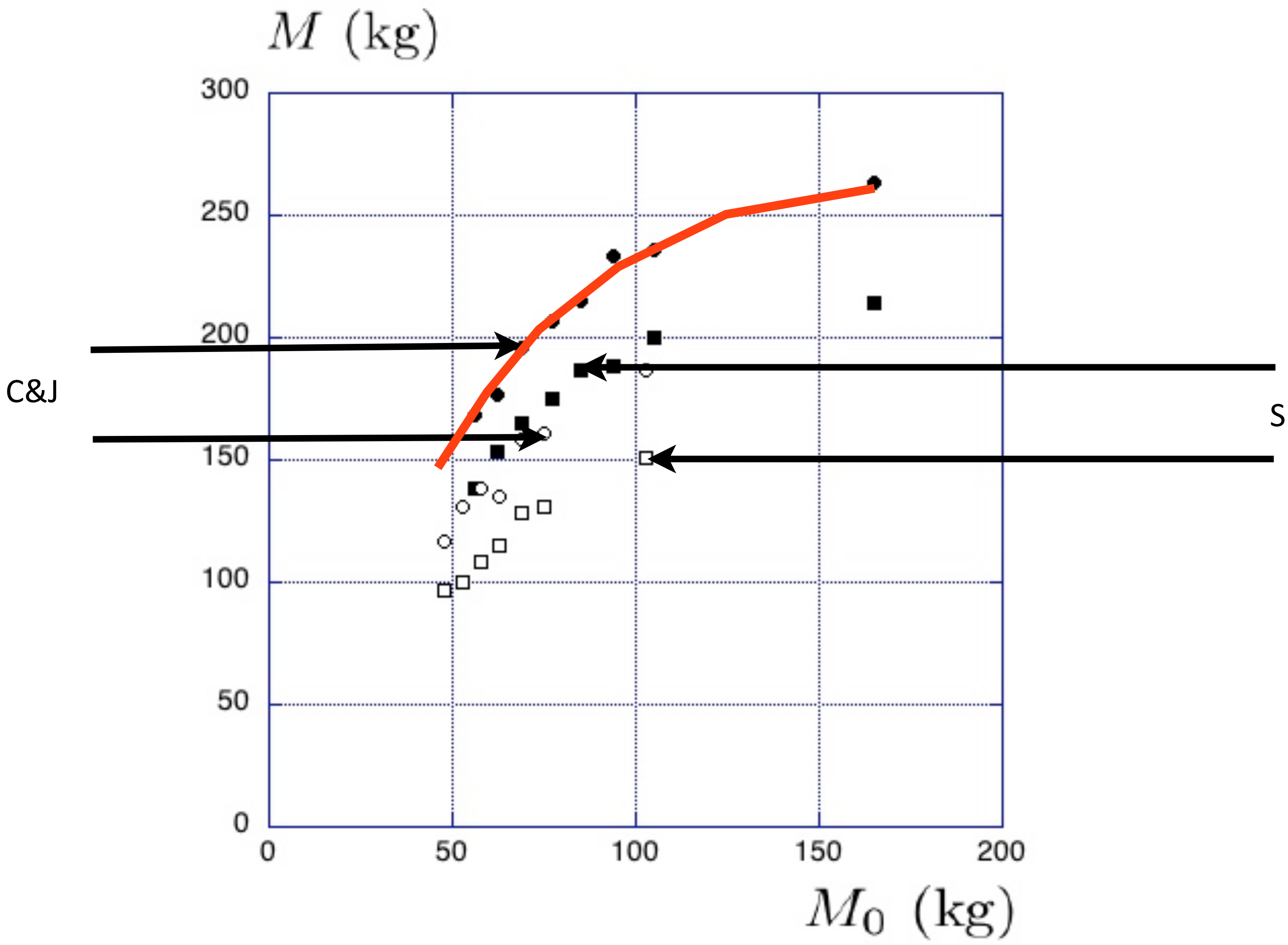



the snatch
snatch
recovery
the clean and jerk
clean
recovery
jerk
recovery

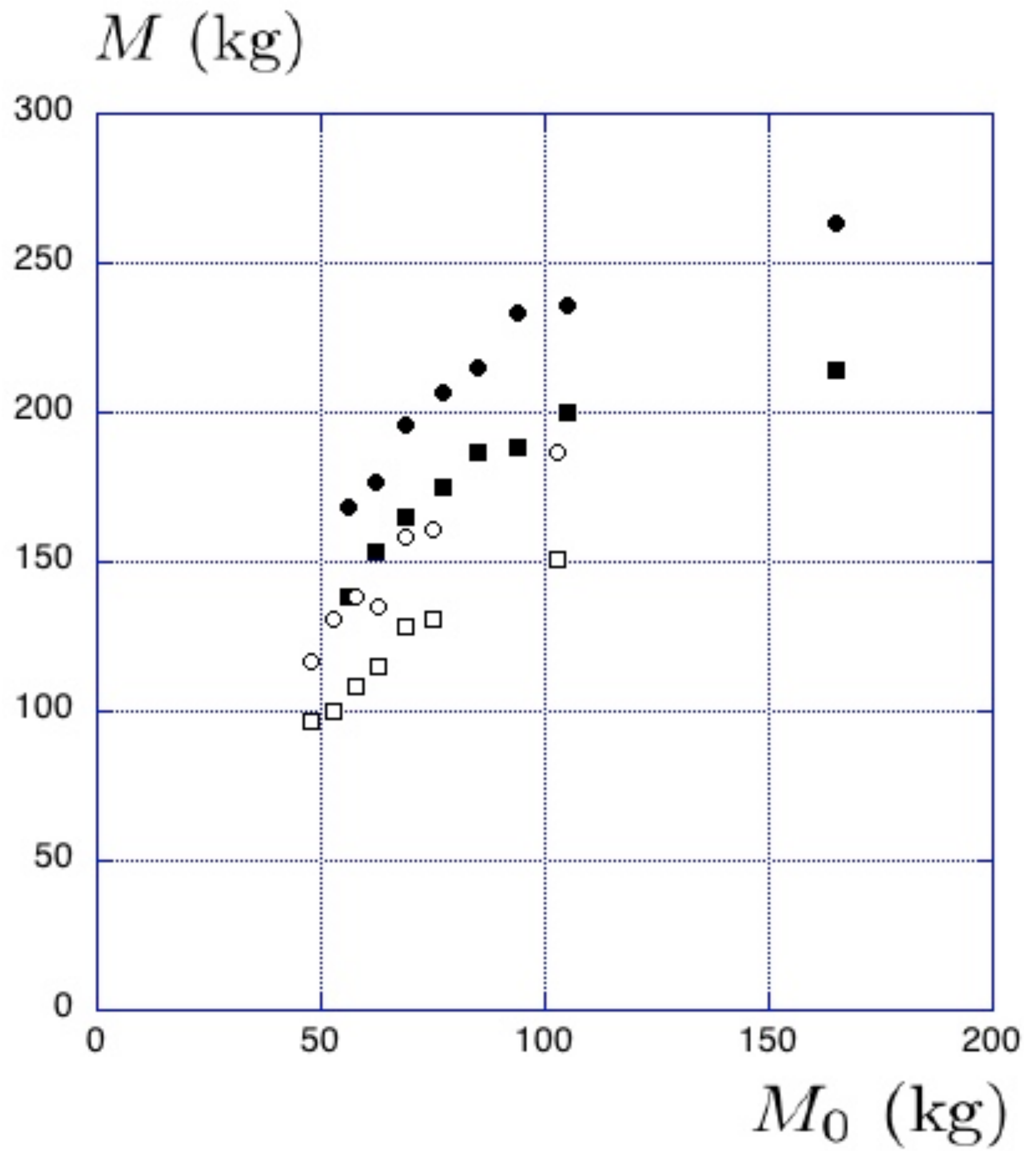


$M$ (kg)
300
250
200
150
100
50
0
0
50
100
150
200
$M_0$ (kg)
C&J

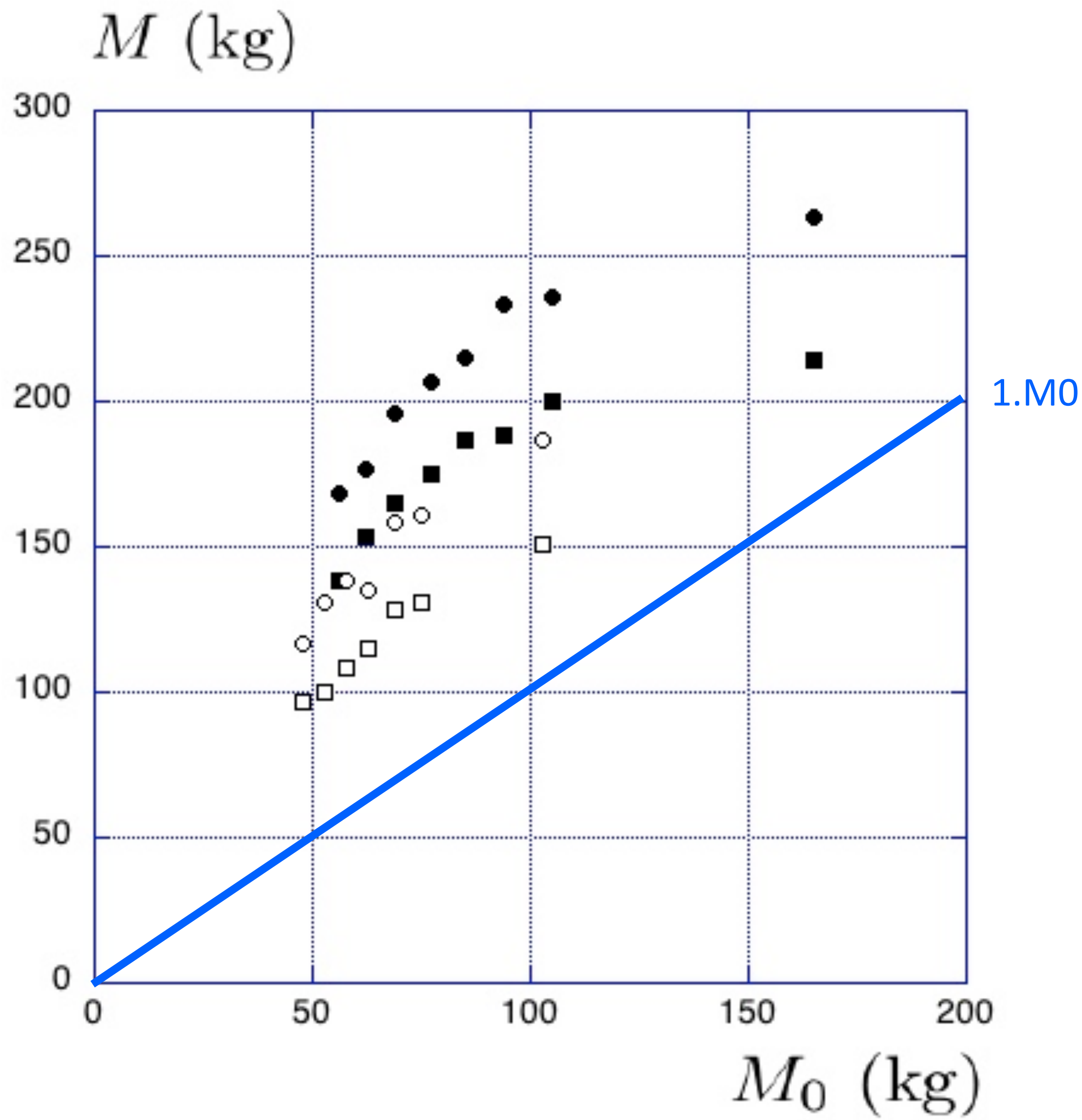

M (kg)
300
250
200
150
100
50
0
0
50
100
150
200
M0 (kg)
C&J
S

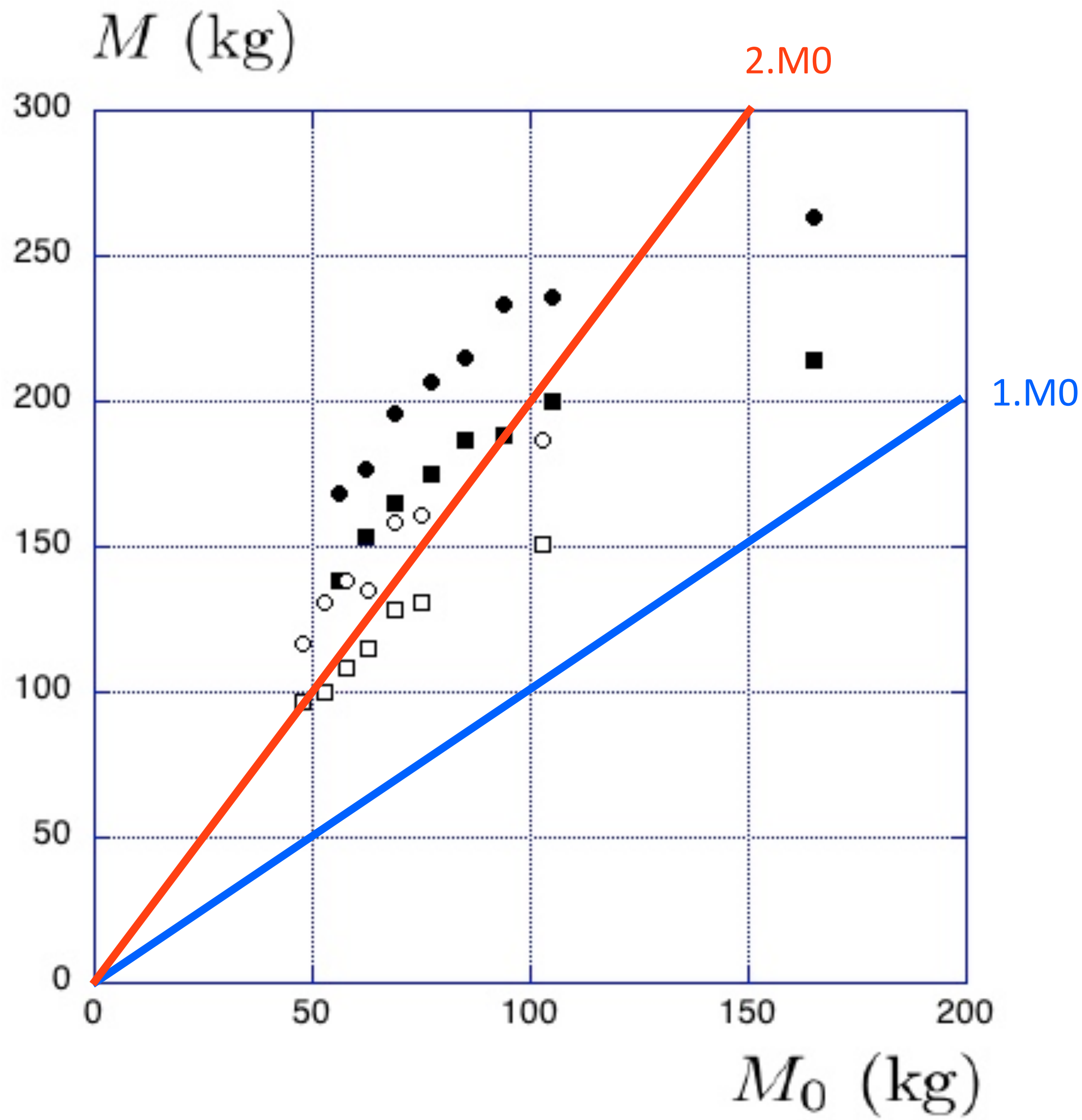


M (kg)
300
250
200
150
100
50
0
0
50
100
150
200
$M_0$ (kg)
C&J
S

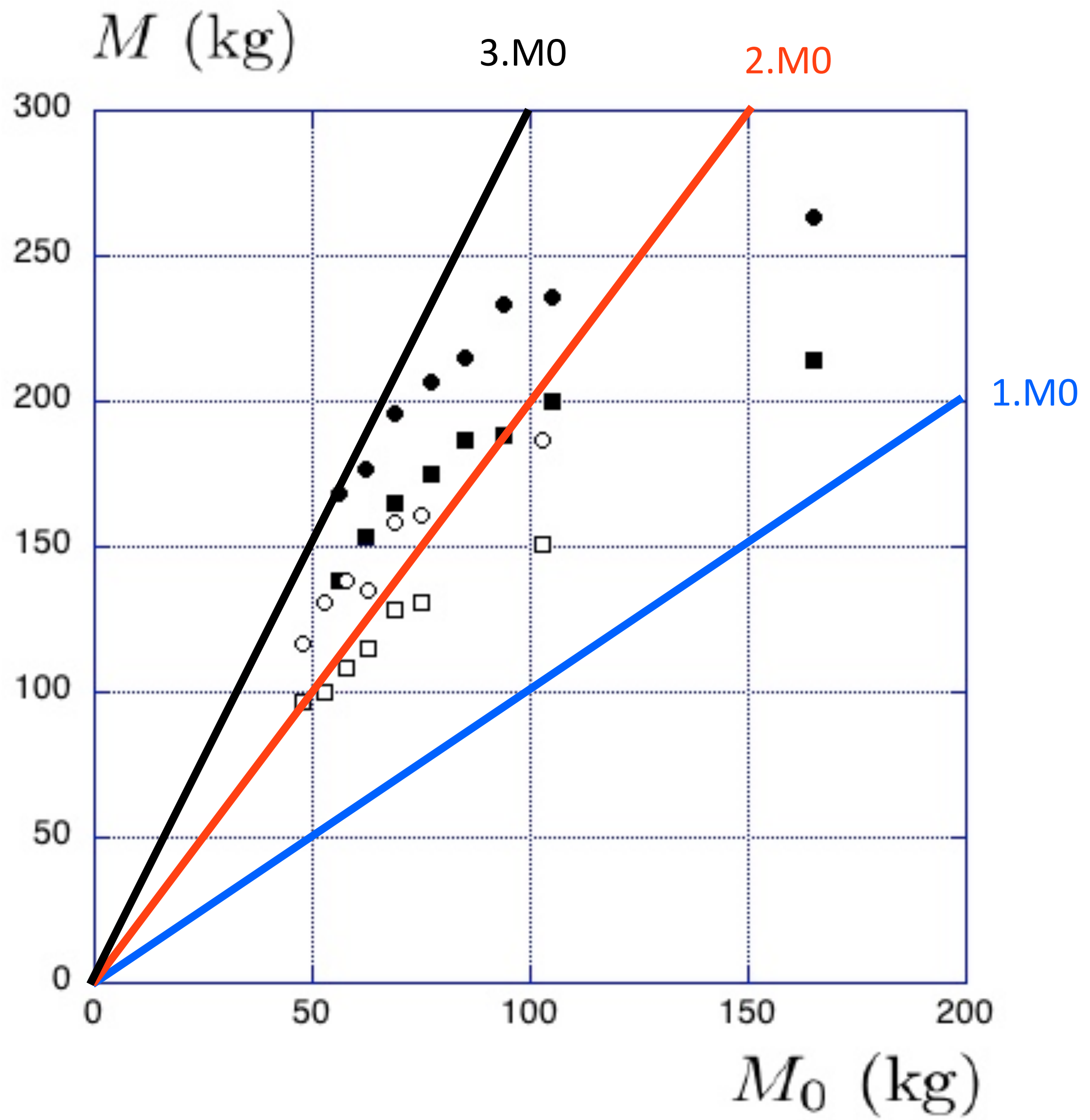


$M$ (kg)
300
250
200
150
100
50
0
0
50
100
150
200
$M_0$ (kg)

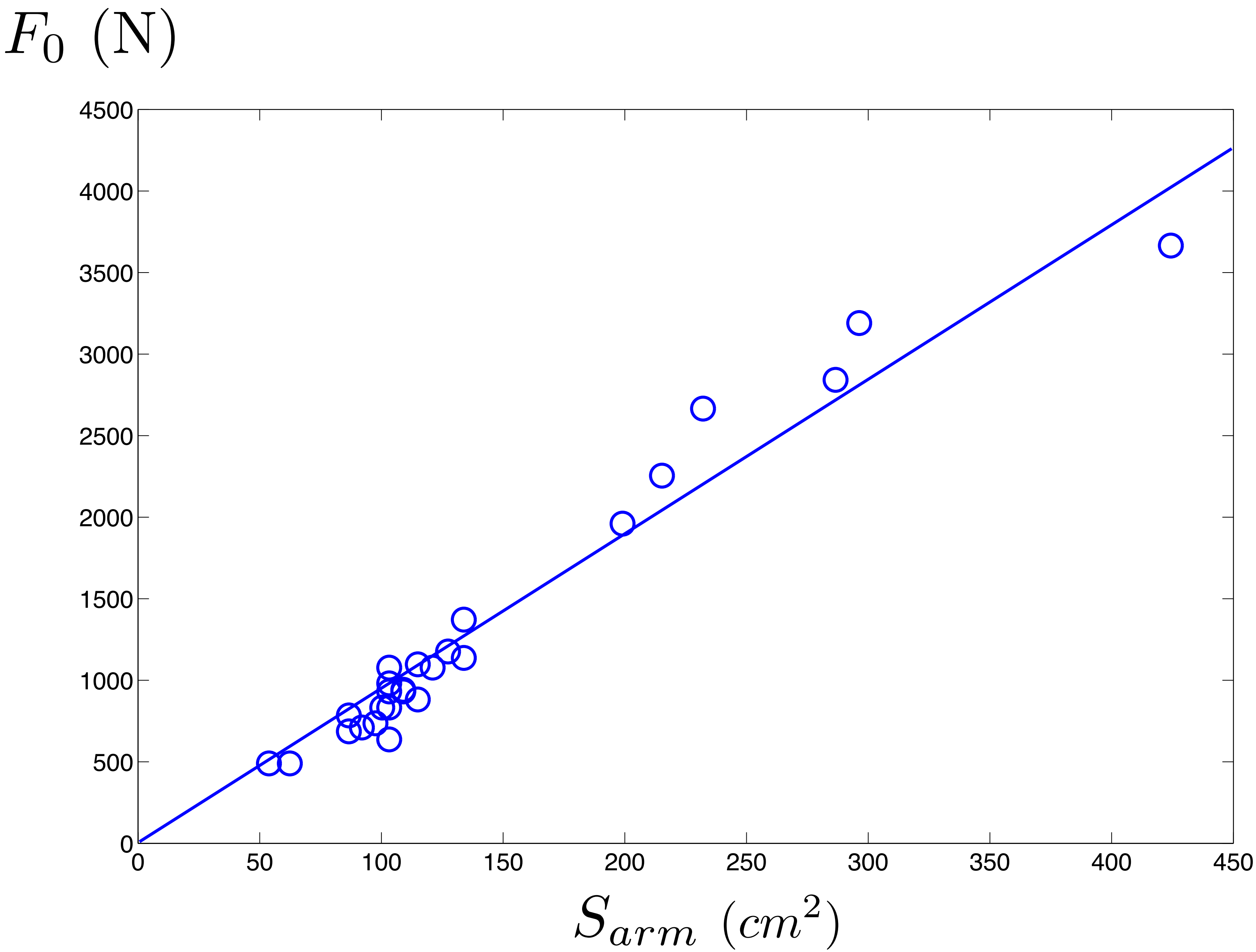

$M$ (kg)
300
250
200
150
100
50
0
0
50
100
150
200
$M_0$ (kg)
1.M0



M (kg)
300
250
200
150
100
50
0
0
50
100
150
200
$M_0$ (kg)
2.M0
1.M0



M (kg)
3.M0
2.M0
1.M0
300
250
200
150
100
50
0
0
50
100
150
200
M0 (kg)


$F_0$ (N)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
50
100
150
200
250
300
350
400
450
$S_{arm}$ $(cm^2)$

$$F_{max} \sim S \sim K M_0^{2/3}$$

$$F_{max} \sim S \qquad \sim K M_0^{2/3}$$

$$F_{max} \sim (M + M_0)\, g$$

$$F_{max} \sim S \sim K M_0^{2/3}$$

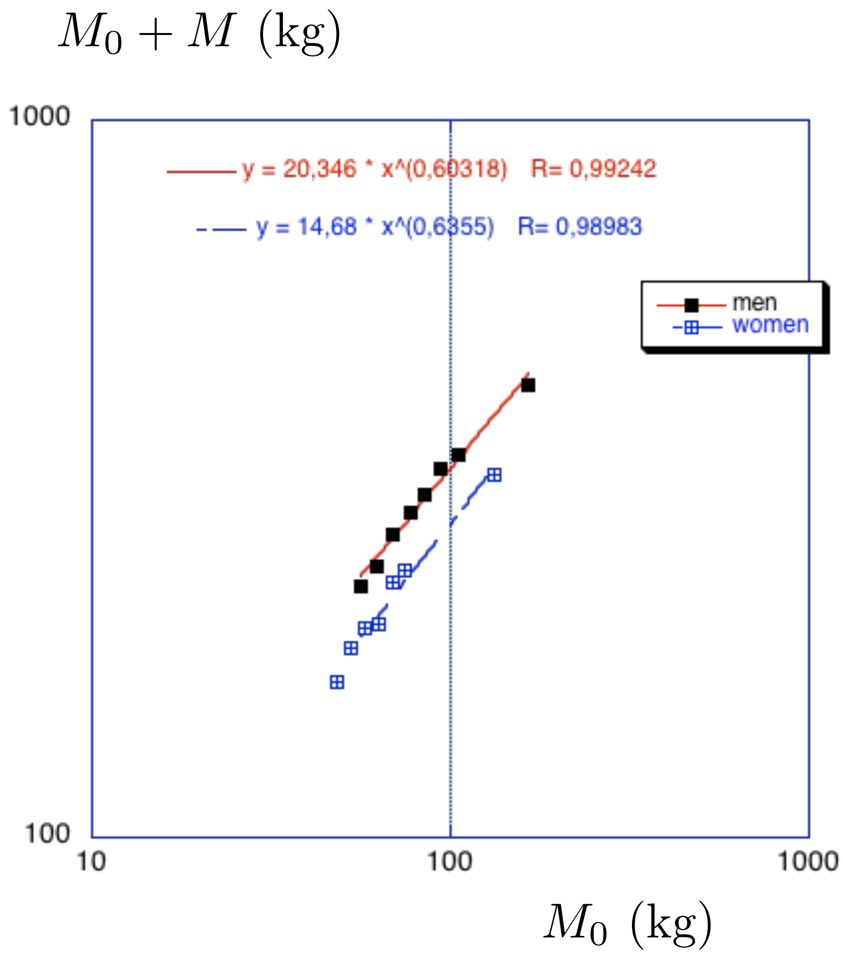
$$F_{max} \sim (M + M_0) g$$

$$\boxed{M + M_0 \sim \frac{K}{g} M_0^{2/3}}$$

$$F_{max} \sim S \sim K M_0^{2/3}$$

$$F_{max} \sim (M + M_0)\, g$$

$$\boxed{M + M_0 \sim \frac{K}{g} M_0^{2/3}}$$



$$M + m_0 \sim \frac{k}{g} m_0^{2/3}$$

$$M + M_0 \sim \frac{K}{g} M_0^{2/3}$$

$$M = \frac{K}{g} M_0^{2/3} \left(1 - \frac{g}{K} M_0^{1/3}\right)$$

$$M + M_0 \sim \frac{K}{g} M_0^{2/3}$$

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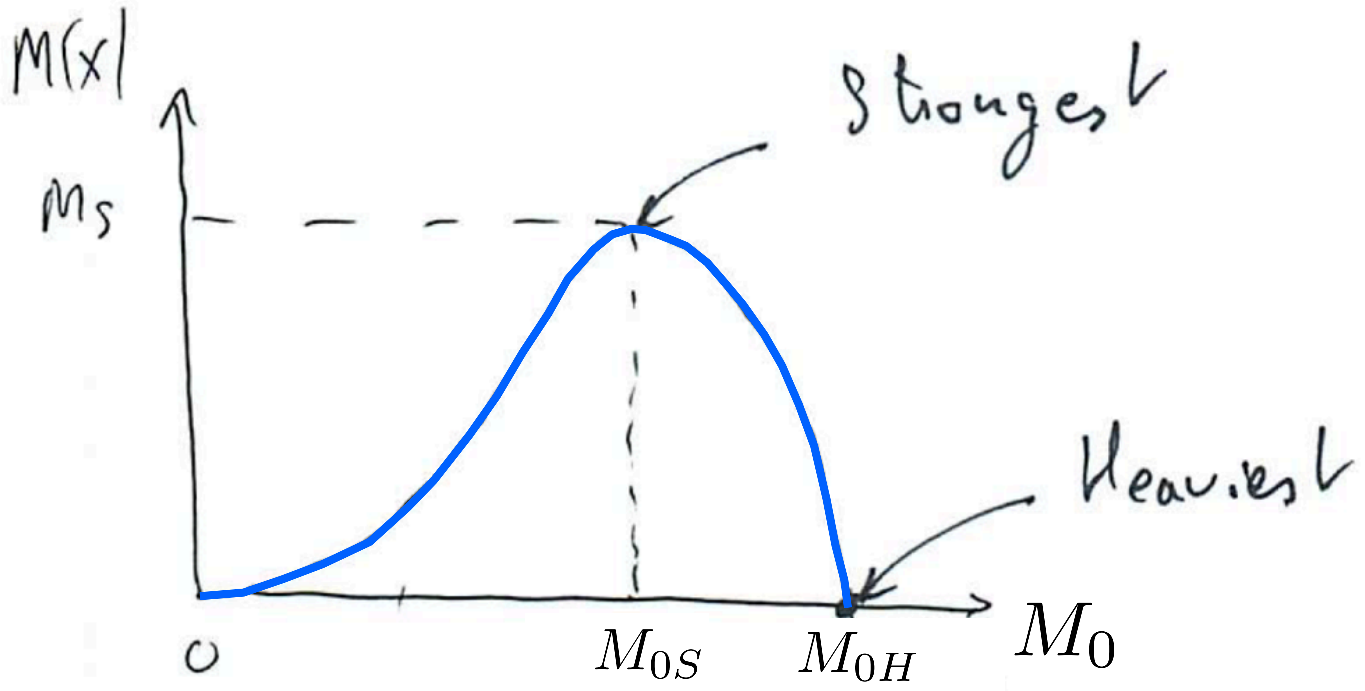

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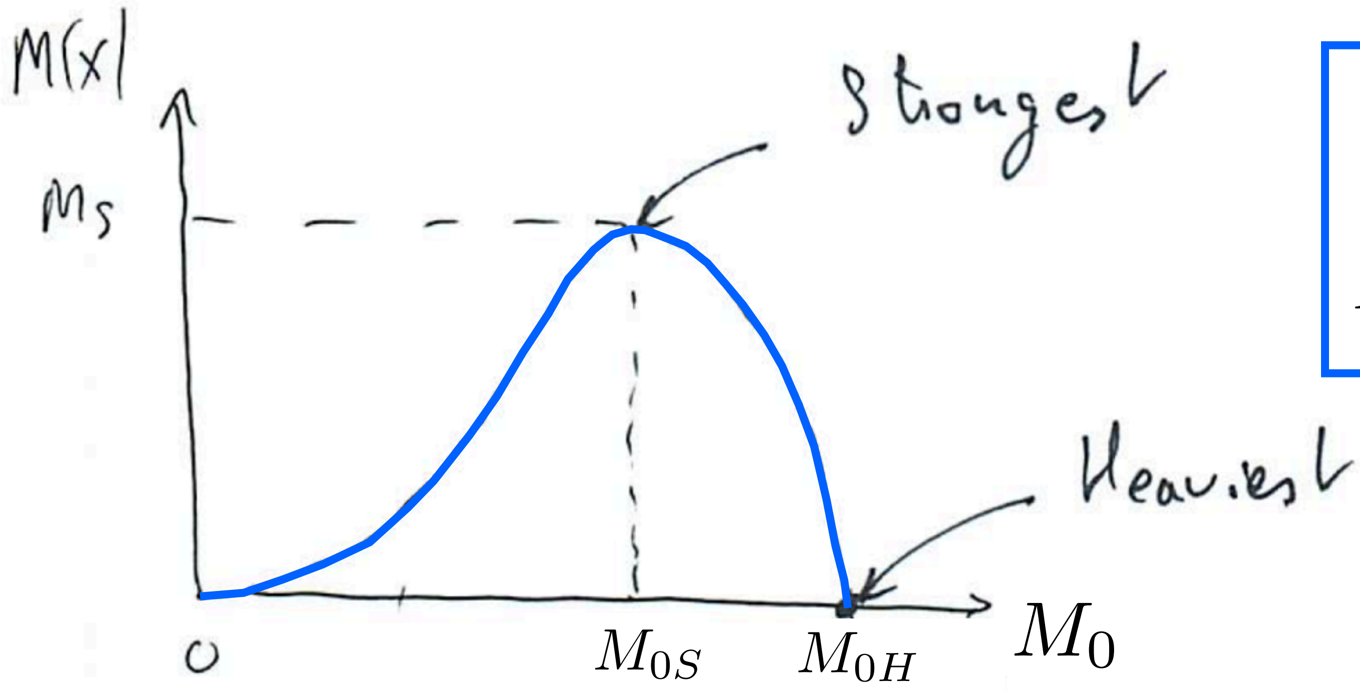


$$M_{0S} = \frac{8}{27} M_{0H}$$

$$M_{0S} \approx 0.296\ M_{0H}$$


**Hossein Reza Zadeh** (Iran)

$$M = 263kg$$
$$M_0 = 190kg$$


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# List of the heaviest people

From Wikipedia, the free encyclopedia

This is a **list of the heaviest people** recorded. The table includes each person's name, peak weig individuals who weighed over 440 kg (970 lbs).

| Name | Country | Sex | B. | D. | Height | Peak weight | Peak BMI (kg/m²) |
|---|---|---|---|---|---|---|---|
| Jon Brower Minnoch | United States | M | 1941 | 1983 | 1.85 m (6 ft 1 in) | 635 kg (1,400 lbs) | 185.5 |
| Khalid Bin Mohsen Shaari[2] | Saudi Arabia | M | 1991 | living | 1.73 m (5 ft 8 in) | 610 kg (1,345 lbs) | 204 |
| Manuel Uribe[4] | Mexico | M | 1965 | 2014 | 1.96 m (6 ft 5 in) | 597 kg (1,316 lbs) | 174.5 |
| Carol Yager[6] | United States | F | 1960 | 1994 | 1.70 m (5 ft 7 in) | 544 kg (1,200 lbs) | 188 |
| Walter Hudson | United States | M | 1944 | 1991 | 1.78 m (5 ft 10 in) | 543 kg (1,197 lbs) | 171 |
| Francis John Lang (Michael Walker)[7][8] | United States | M | 1934 | Unknown | 1.88 m (6 ft 2 in) | 538 kg (1,187 lbs) | 152 |
| Michael Hebranko | United States | M | 1953 | 2013 | 1.83 m (6 ft 0 in) | 499 kg (1,100 lbs) | 149 |
| Patrick Deuel | United States | M | 1962 | living | 1.77 m (5 ft 10 in) | 486 kg (1,072 lbs) | 155 |
| Robert Earl Hughes | United States | M | 1926 | 1958 | 1.84 m (6 ft 0 in) | 485 kg (1,069 lbs) | 143 |
| Rosalie Bradford | United States | F | 1943 | 2006 | 1.68 m (5 ft 6 in) | 477 kg (1,053 lbs) | 169 |
| Mayra Rosales | United States | F | 1980 | living | 1.60 m (5 ft 3 in) | 470 kg (1,036 lbs) | 183.5 |
| Kenneth Brumley | United States | M | 1968 | living | | 468 kg (1,033 lbs) | |
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**Hossein Reza Zadeh** (Iran)

$$M = 263kg$$
$$M_0 = 190kg$$

$$\frac{M_{0S}}{M_{0H}} = \frac{190}{635} \approx 0,299$$

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*Record du monde à l'épaulé-jeté (+105kg)*

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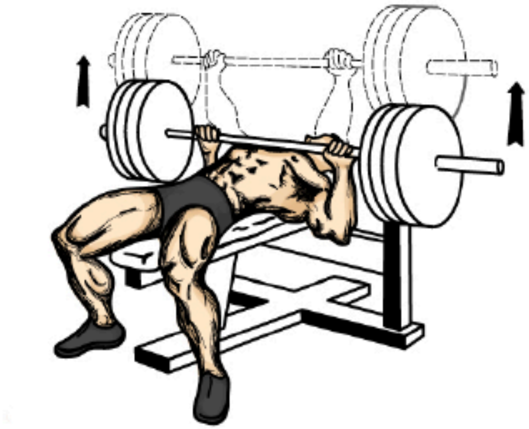
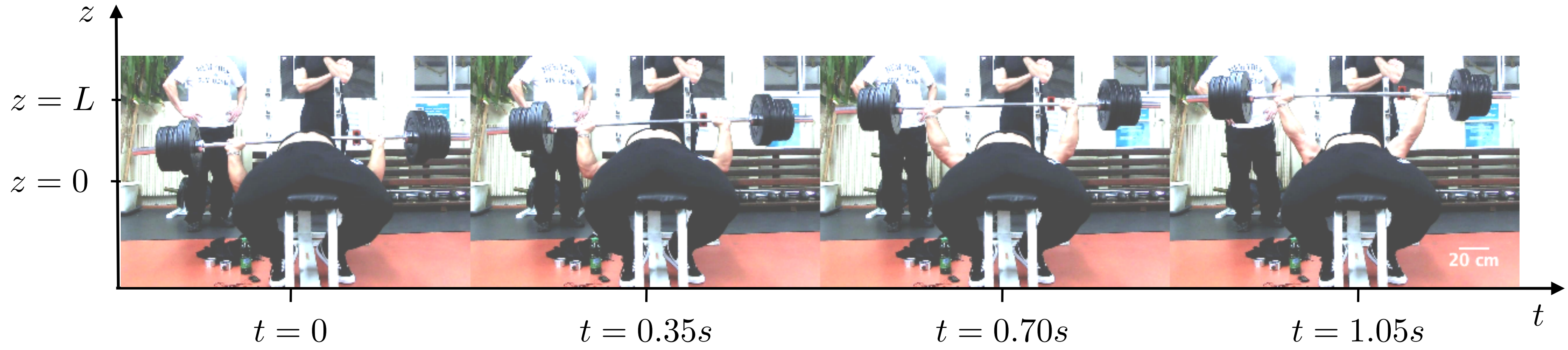
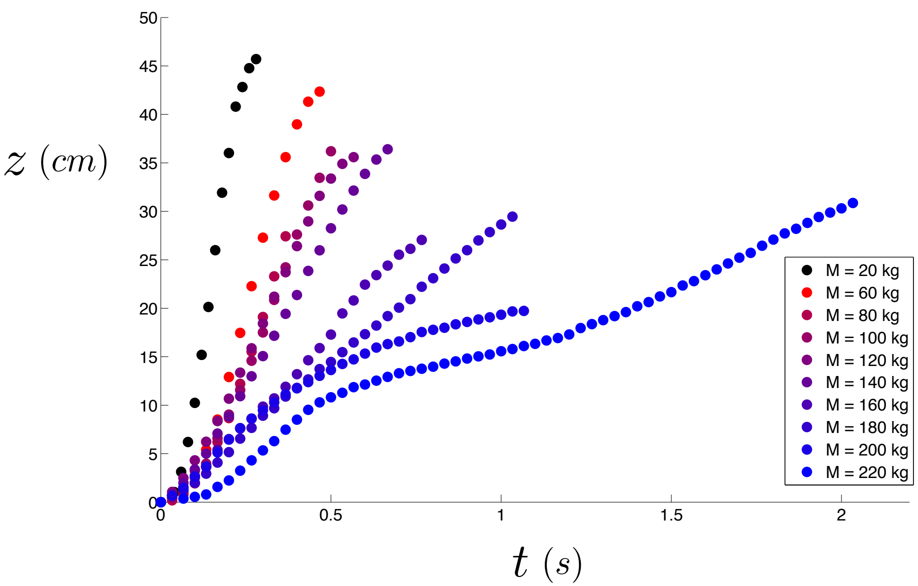
$$M_0 = 190kg$$

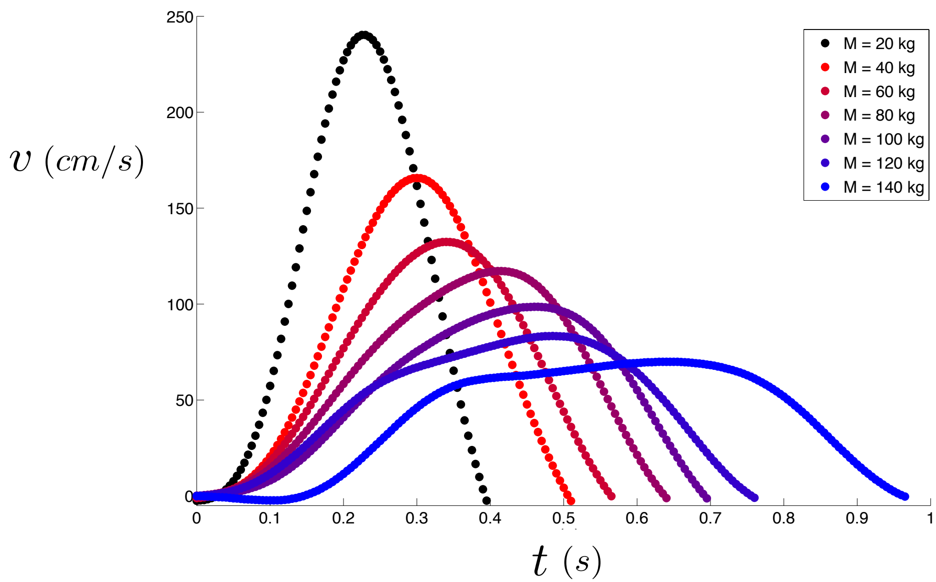


| Athlete | $H$ (m) | $M_0$ (kg) | $L_{arm}$ (cm) | $S_{arm}$ (cm$^2$) | $M_{min}$ (kg) | $M^*$ (kg) |
|---|---|---|---|---|---|---|
| Gregory | 1,80 | 114 | 35 | 241 | 20 | 230 |
| Guillaume | 1,85 | 84 | 40,5 | 127 | 2 | 115 |
| Michael | 1,80 | 71 | 37 | 109 | 2 | 95 |
| Georges | 1,89 | 77 | 34,5 | 100 | 2 | 85 |
| Maxime | 1,75 | 66 | 38 | 92 | 2 | 85 |
| Wilfried | 1,82 | 72 | 40 | 103 | 2 | 85 |
| Romain | 1,90 | 78 | 38 | 103 | 2 | 65 |

Greg $(M_0 = 114kg)$



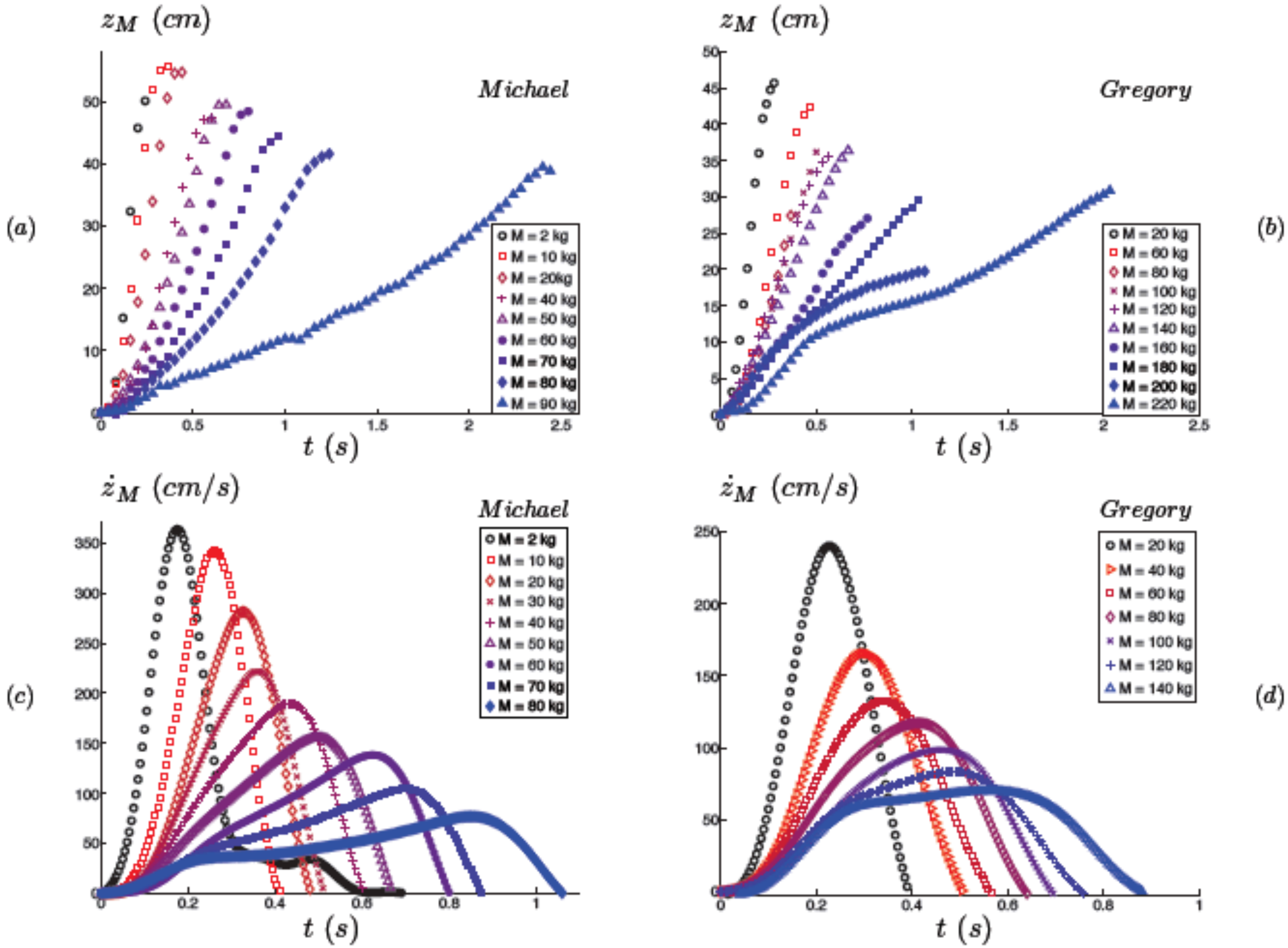
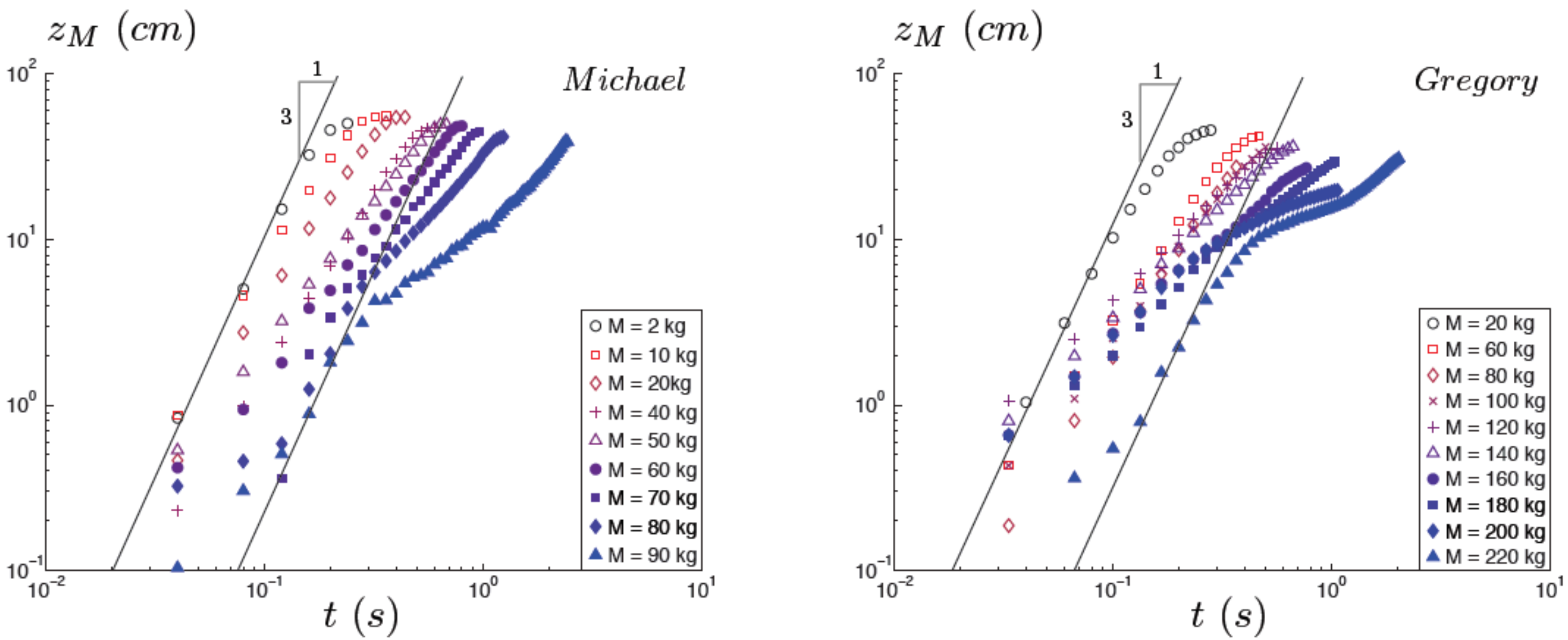
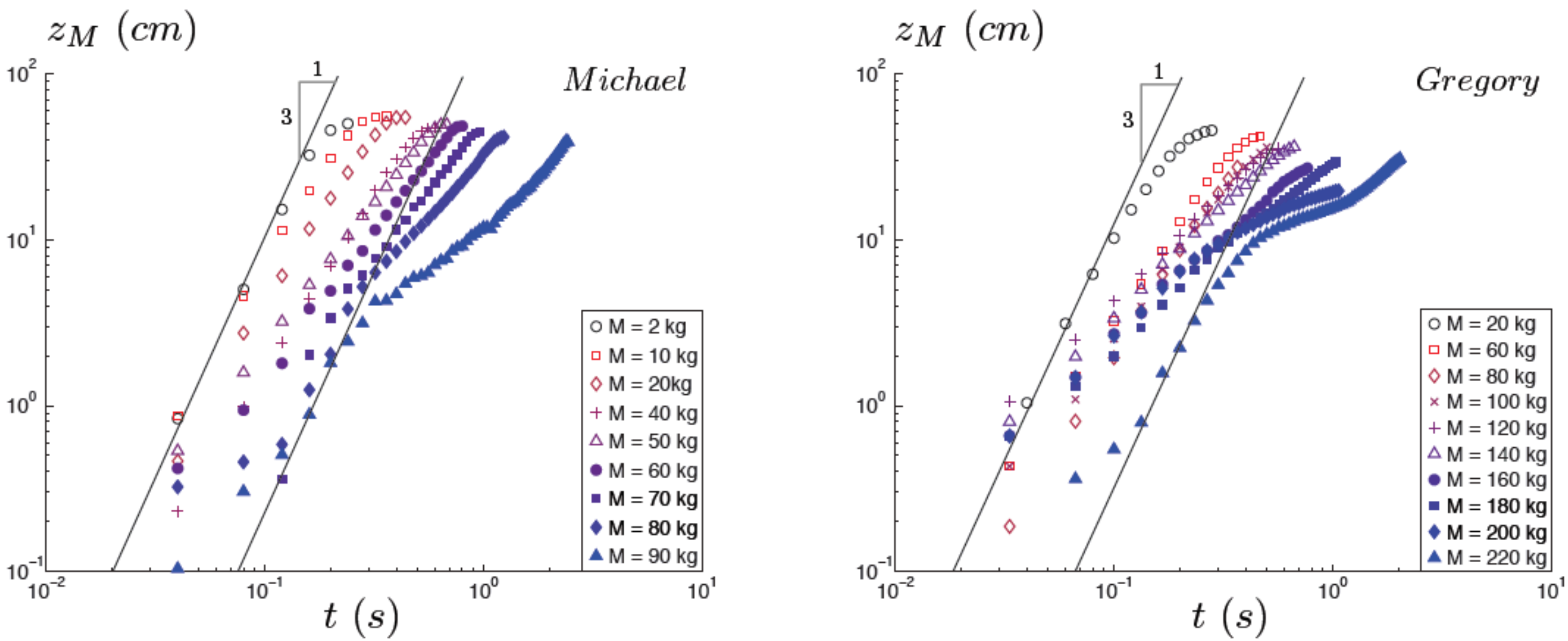



**Fig. 4.** Barbell dynamics: vertical position $z_M(t)$ and velocity $\dot{z}_M(t)$ for different masses of the barbell from $M_{min}$ and $M^*$ and for Michael ($M_0 = 71$ kg, $M^* = 105$ kg) on the left [(a) and (c)], and Gregory ($M_0 = 114$ kg, $M^* = 230$ kg) on the right [(b) and (d)].



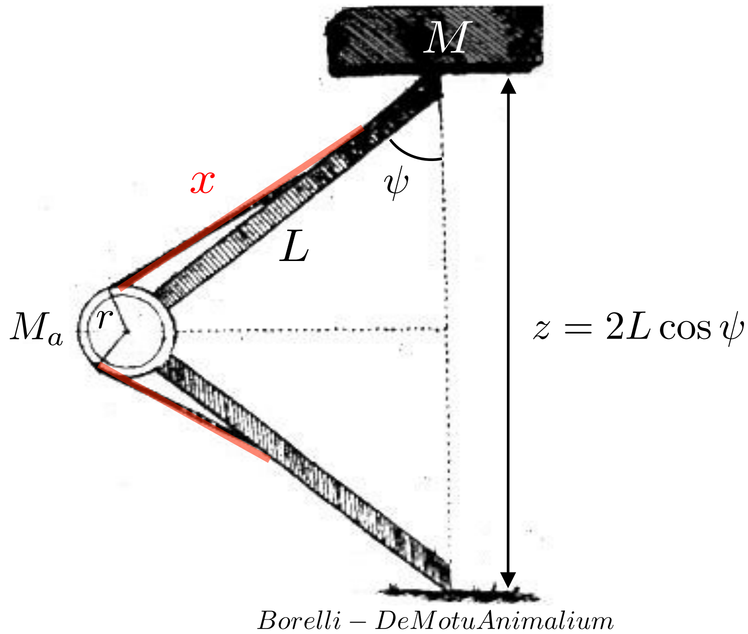
$z_M$ (cm)
Michael
1
3
M = 2 kg
M = 10 kg
M = 20kg
M = 40 kg
M = 50 kg
M = 60 kg
M = 70 kg
M = 80 kg
M = 90 kg
$t$ (s)
$z_M$ (cm)
Gregory
1
3
M = 20 kg
M = 60 kg
M = 80 kg
M = 100 kg
M = 120 kg
M = 140 kg
M = 160 kg
M = 180 kg
M = 200 kg
M = 220 kg
$t$ (s)

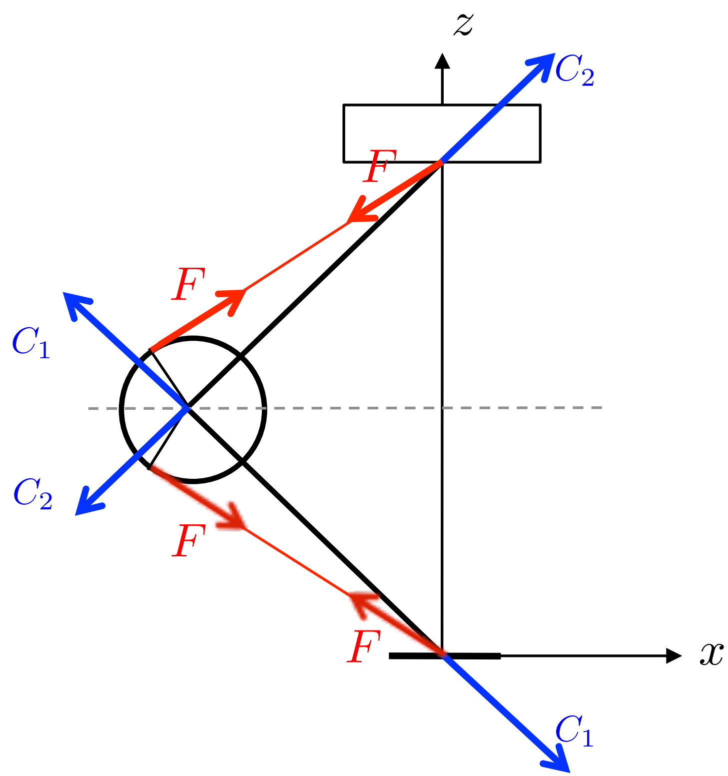


zM (cm)
Michael
1
3
M = 2 kg
M = 10 kg
M = 20kg
M = 40 kg
M = 50 kg
M = 60 kg
M = 70 kg
M = 80 kg
M = 90 kg
t (s)
zM (cm)
Gregory
1
3
M = 20 kg
M = 60 kg
M = 80 kg
M = 100 kg
M = 120 kg
M = 140 kg
M = 160 kg
M = 180 kg
M = 200 kg
M = 220 kg
t (s)


$$z_M \sim t^3$$

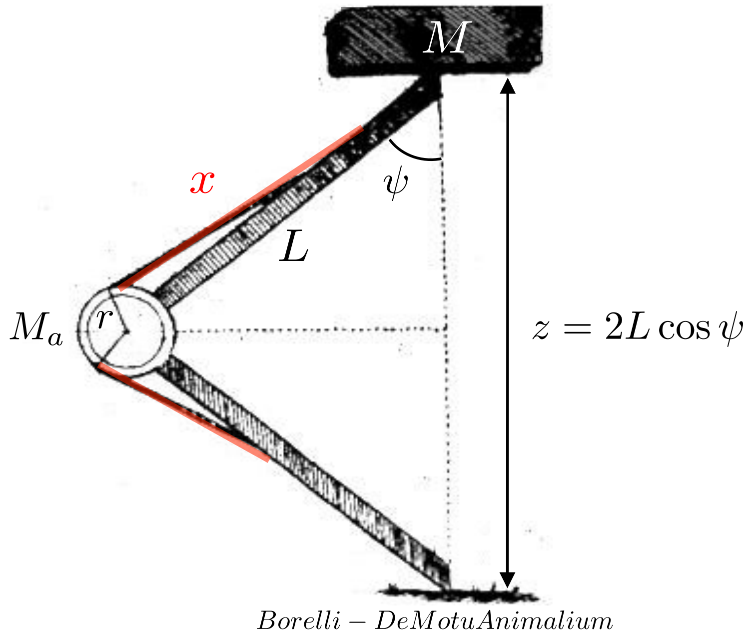
mouvement = muscle + articulation

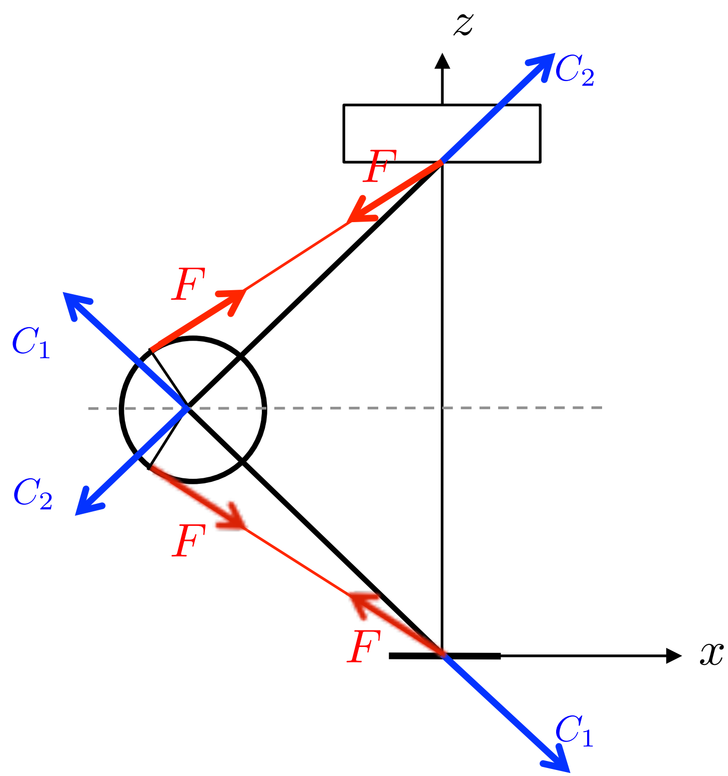



$$\left(M_a + 4M\sin^2\psi\right) L\ddot{\psi} + 4ML\sin\psi\cos\psi\dot{\psi}^2 = (M_a + 2M)\, g\sin\psi - 2F\frac{r}{L}$$

mouvement = muscle + articulation

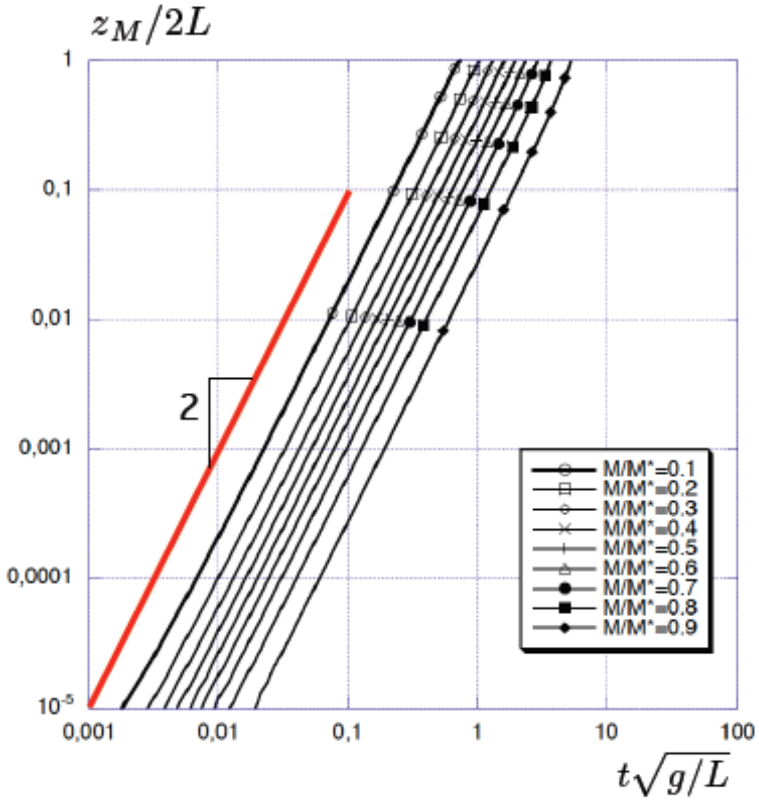


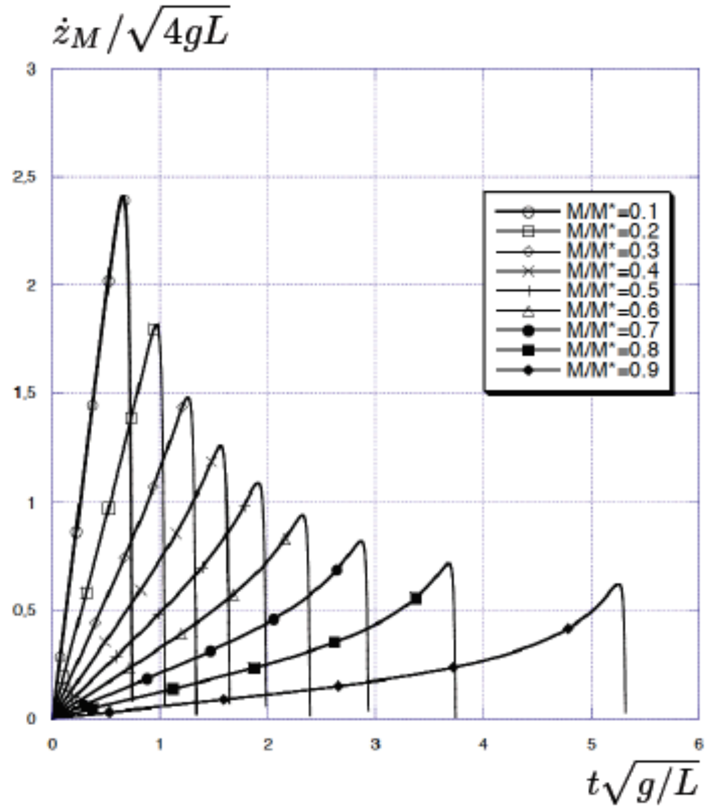

$$\left(M_a + 4M\sin^2\psi\right) L\ddot{\psi} + 4ML\sin\psi\cos\psi\dot{\psi}^2 = (M_a + 2M)\, g\sin\psi - 2F\frac{r}{L}$$

$$F = F^* = \left(M^* + \frac{M_a}{2}\right)\frac{gL}{r}$$

$$F = F^\star$$

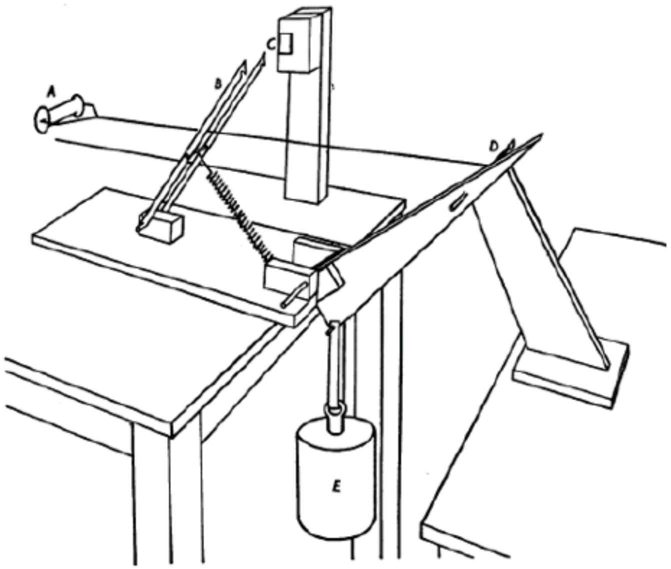


$z_M/2L$
1
0,1
0,01
0,001
0,0001
$10^{-5}$
0,001
0,01
0,1
1
10
100
2
M/M*=0.1
M/M*=0.2
M/M*=0.3
M/M*=0.4
M/M*=0.5
M/M*=0.6
M/M*=0.7
M/M*=0.8
M/M*=0.9
$t\sqrt{g/L}$

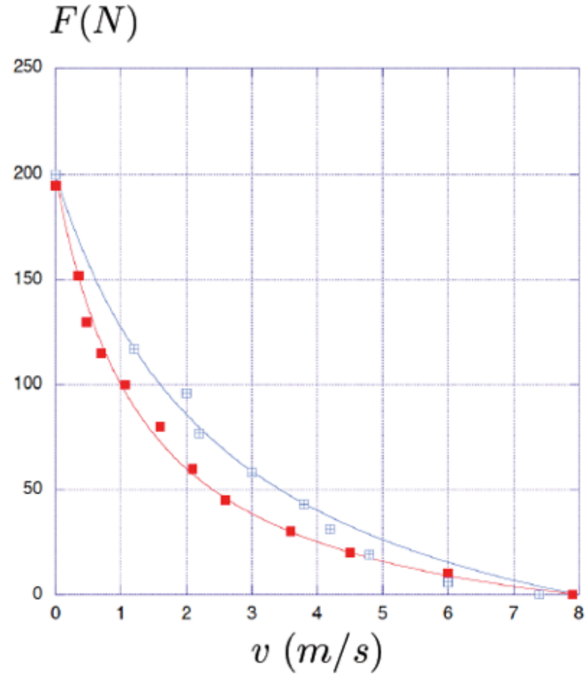



$\dot{z}_M/\sqrt{4gL}$
3
2,5
2
1,5
1
0,5
0
0
1
2
3
4
5
6
M/M*=0.1
M/M*=0.2
M/M*=0.3
M/M*=0.4
M/M*=0.5
M/M*=0.6
M/M*=0.7
M/M*=0.8
M/M*=0.9
$t\sqrt{g/L}$

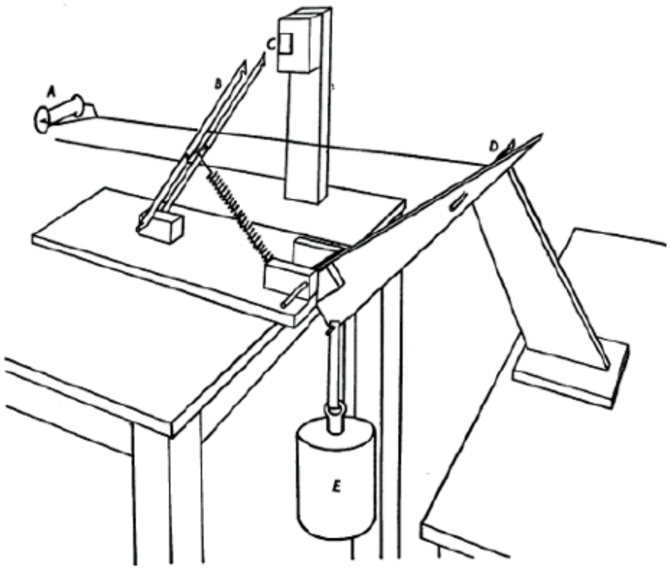
(a)



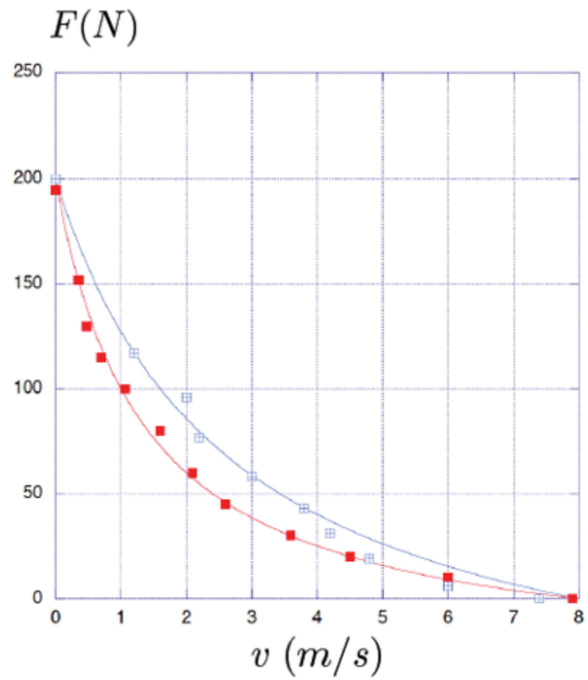

(b)



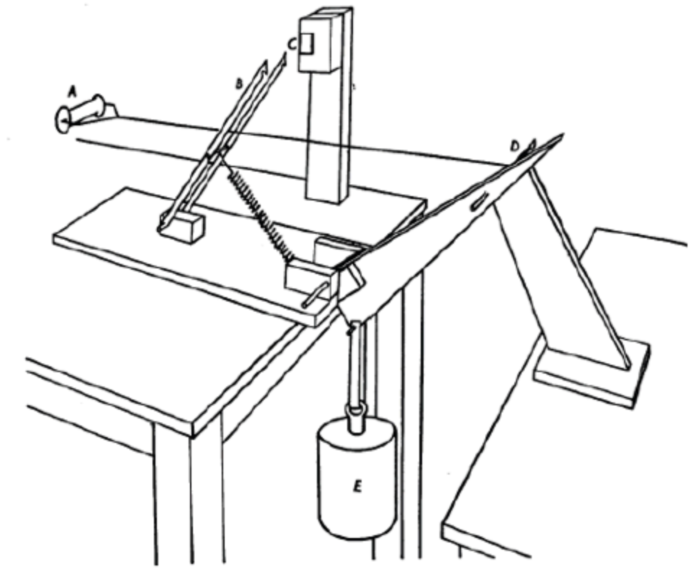
(a)



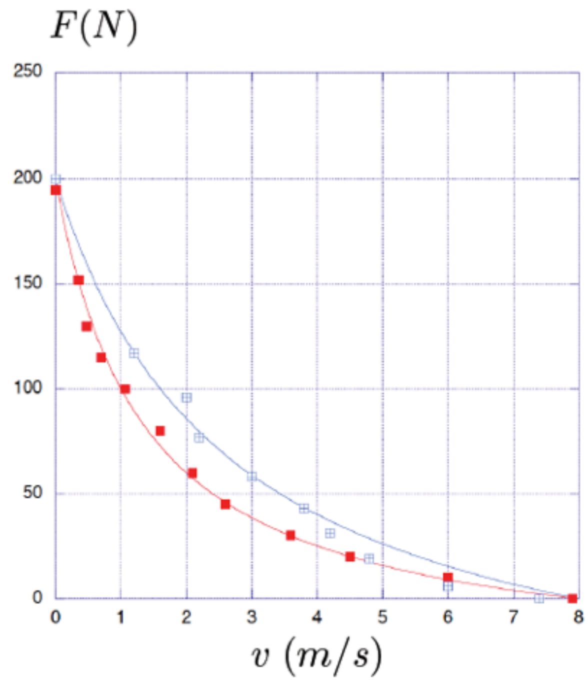

(b)

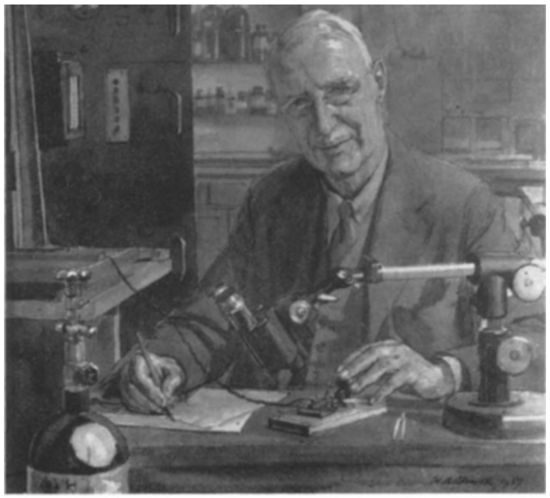


(a)




(b)



A. V. HILL, from a portrait by H. Andrew Freeth, A.R.A., 1957, in the possession of King's College, Cambridge.

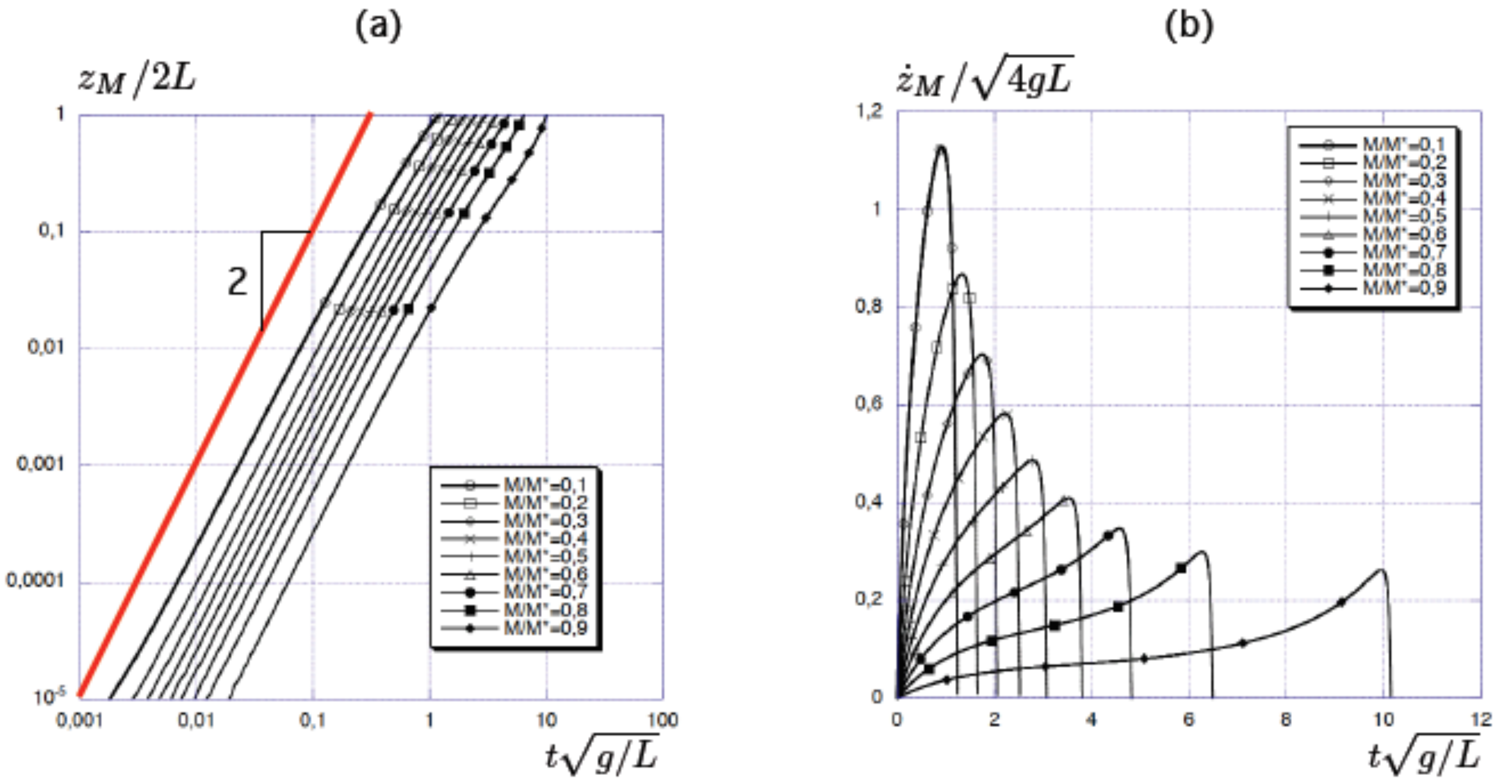
$$\frac{F}{F_0} = \frac{1 - v/v_{max}}{1 + (F_0/a)\,.v/v_{max}}$$

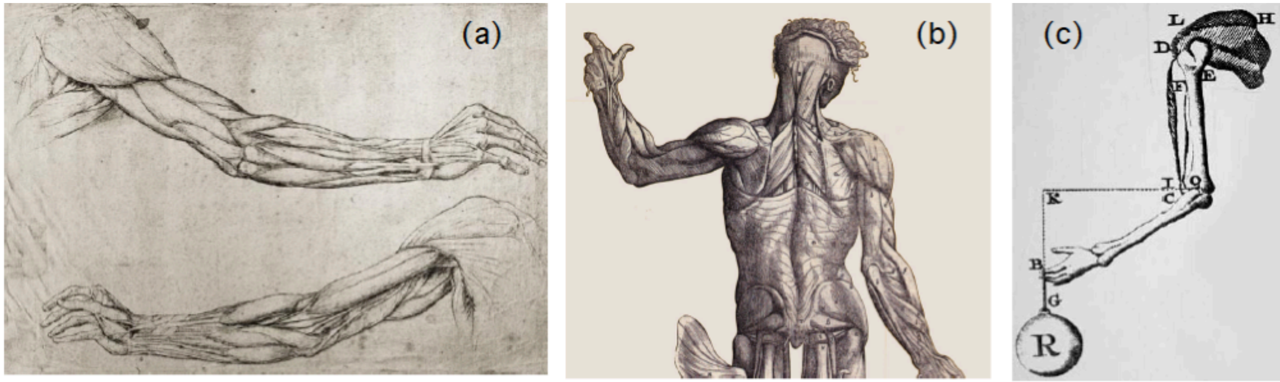
équation de A.V.Hill (1938)

# Hill's equation

$$\frac{Fr}{MgL} = \frac{M^\star}{M}\left(\frac{1+G\bar{\dot{\psi}}}{1-\frac{F_0}{a}G\bar{\dot{\psi}}}\right)$$

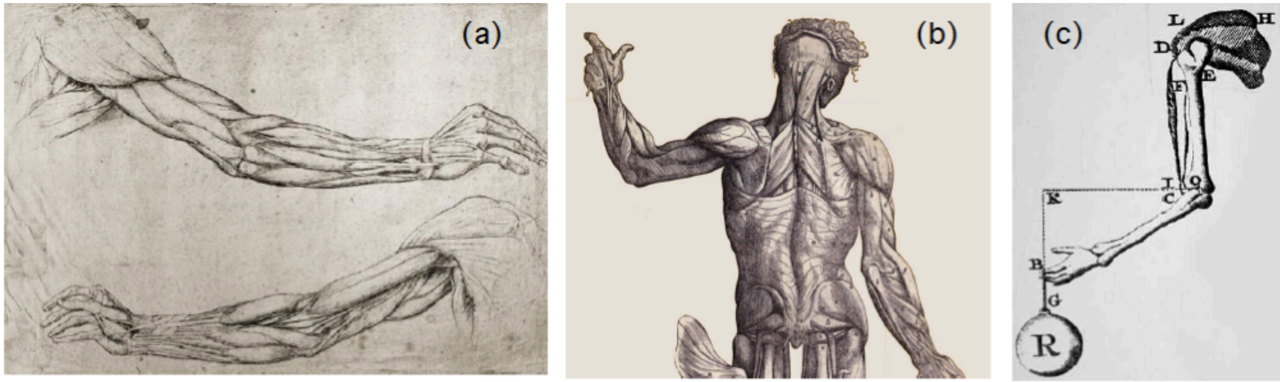
$$G = \frac{r}{v_{max}}\sqrt{\frac{g}{2L}}$$






$L_1 \sim 1$ m

FIGURE 1 – (a) "Study of arms". Pen and ink paper by Leonard de Vinci (around 1510). Paris, musée du Louvre (b) Illustration from Vesalius' human anatomy [6] (c) Plate of Borelli's *De motu animalium* [7].

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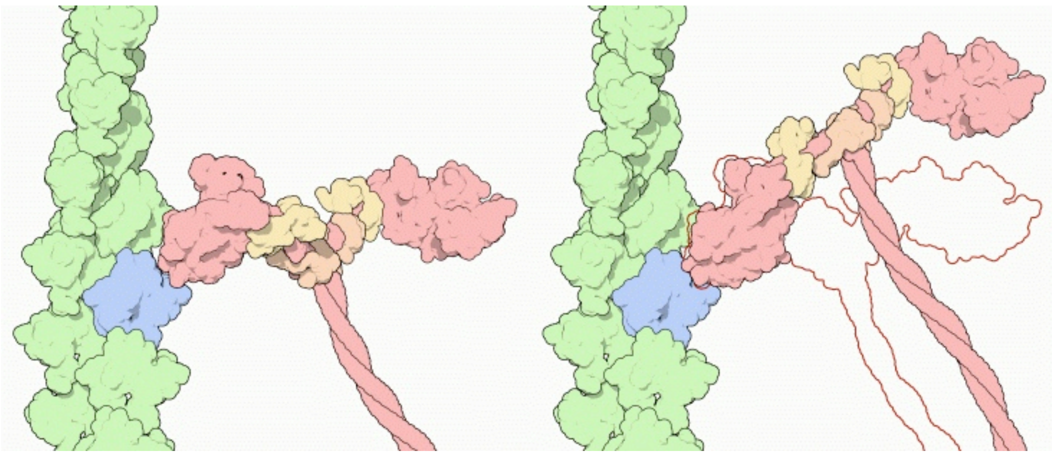
$L_1 \sim 1$ m



$L_2 \sim 10$ nm

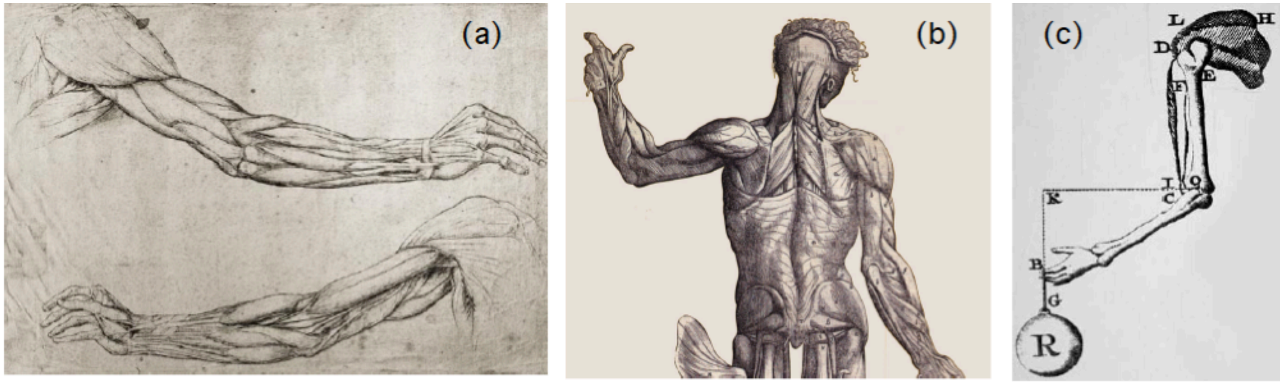
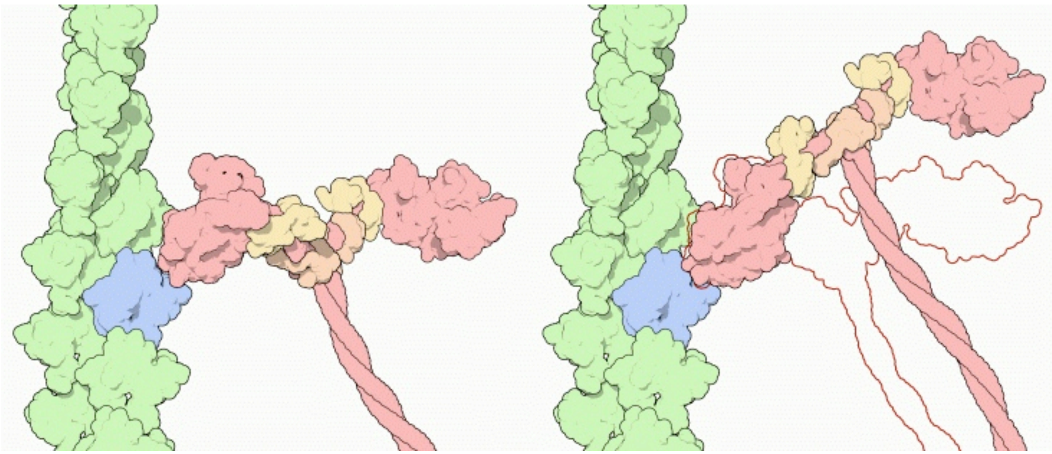



FIGURE 1 – (a) "Study of arms". Pen and ink paper by Leonard de Vinci (around 1510). Paris, musée du Louvre (b) Illustration from Vesalius' human anatomy [6] (c) Plate of Borelli's *De motu animalium* [7].

$L_1 \sim 1 \text{ m}$

$$\frac{L_1}{L_2} \sim 10^8$$



$L_2 \sim 10 \text{ nm}$

# X-Ray Analysis and the Problem of Muscle

H. E. Huxley

*Proc. R. Soc. Lond. B* 1953 **141**, doi: 10.1098/rspb.1953.0017, published
11 March 1953

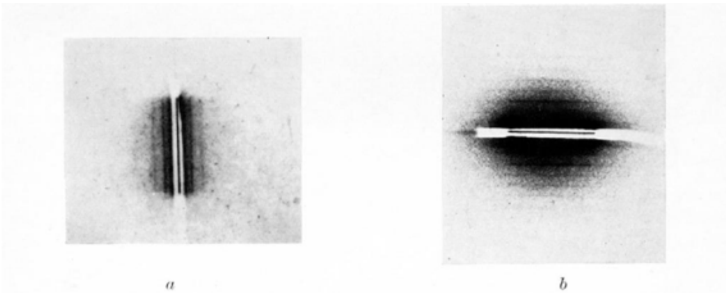



FIGURE 22. Living frog sartorius muscle. *a*, transverse (450 Å Hex.); *b*, axial (420 Å).

# X-Ray Analysis and the Problem of Muscle

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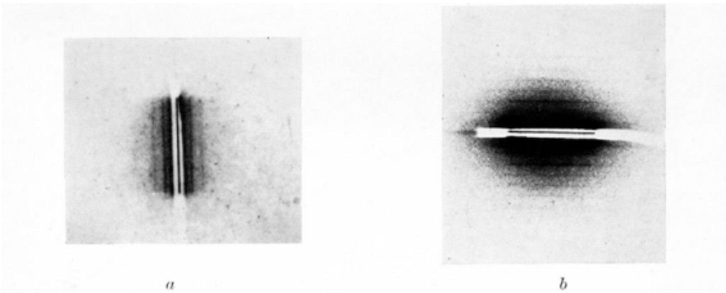
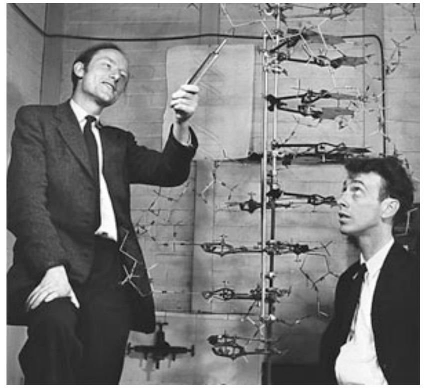



FIGURE 22. Living frog sartorius muscle. *a*, transverse (450 Å Hex.); *b*, axial (420 Å).



Le 25 avril 1953

# X-Ray Analysis and the Problem of Muscle

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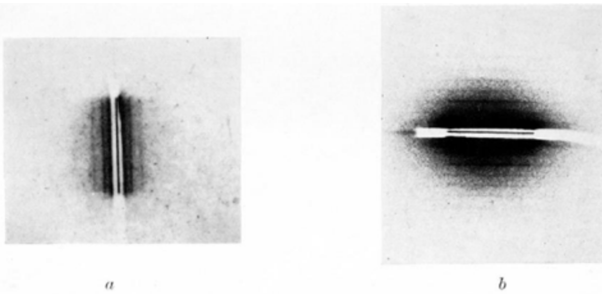
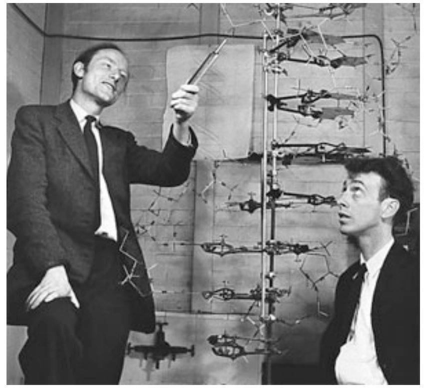
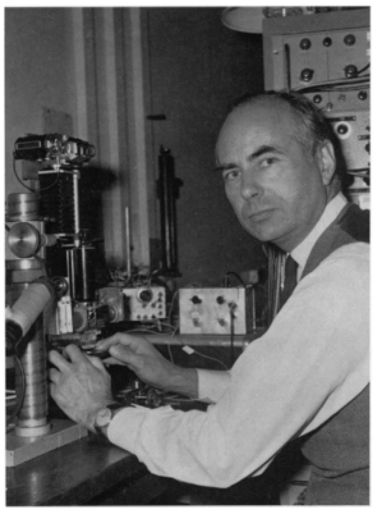


FIGURE 22. Living frog sartorius muscle. *a*, transverse (450 Å Hex.); *b*, axial (420 Å).

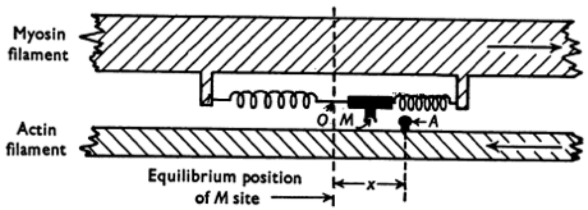


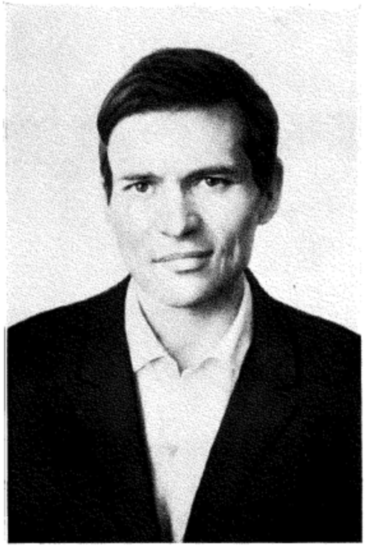
Le 25 avril 1953

HUXLEY, A. F. (1957). Muscle structure and theories of contraction. *Prog. Biophys. biophys. Chem.* **7**, 255–318.



A. F. HUXLEY





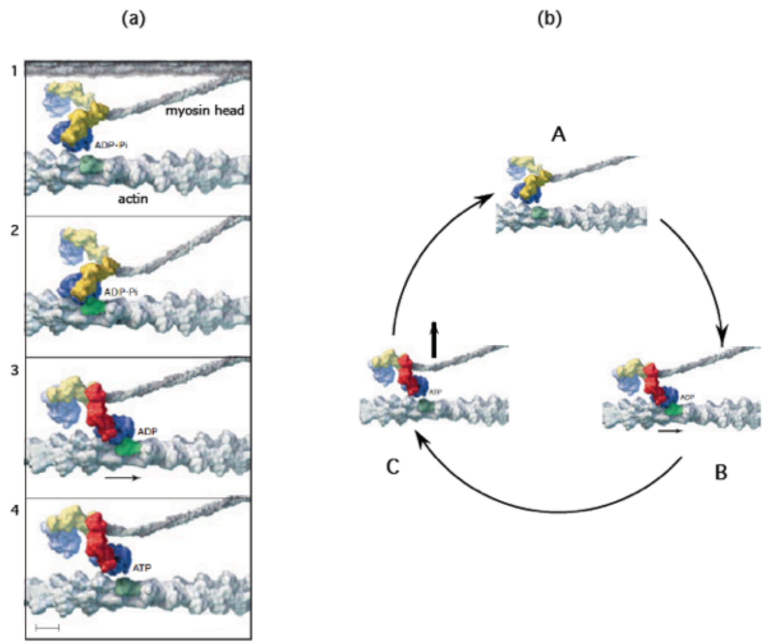
Deshcherevski V.I.
1939-1975

# TWO MODELS OF MUSCULAR CONTRACTION*

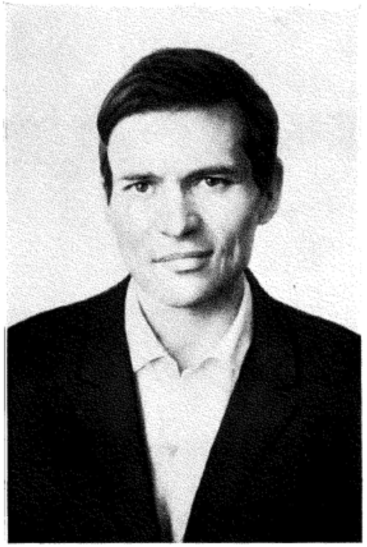
V. I. DESHCHEREVSKII

Institute of Biological Physics, U.S.S.R. Academy of Sciences, Pushchino (Moscow Region)

Biofizika 13: No. 5, 928–935, 1968.

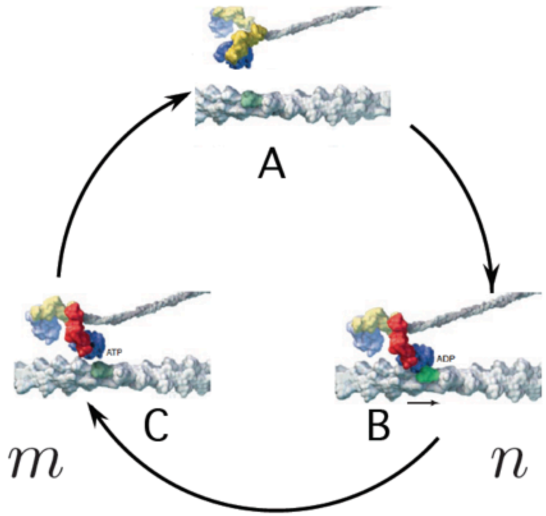


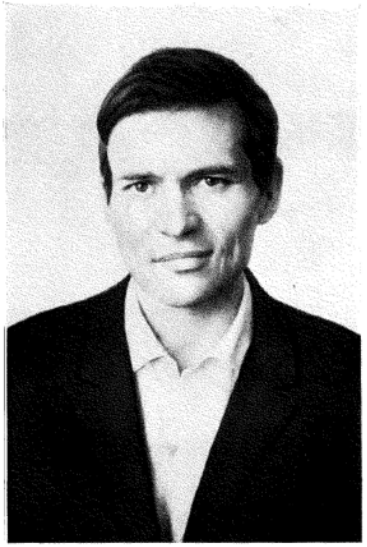

Apparently, the first and only attempt of such a kind was made by Huxley [6] who showed that a model based on the sliding hypothesis allows one quantitatively to explain the contractile and thermal properties of the muscle. However, the mathematical description of the model in this work is incorrect (see note, p. 1098).



Deshcherevski V.I.
1939-1975

$$\alpha_D - n - m$$





Deshcherevski V.I.
1939-1975

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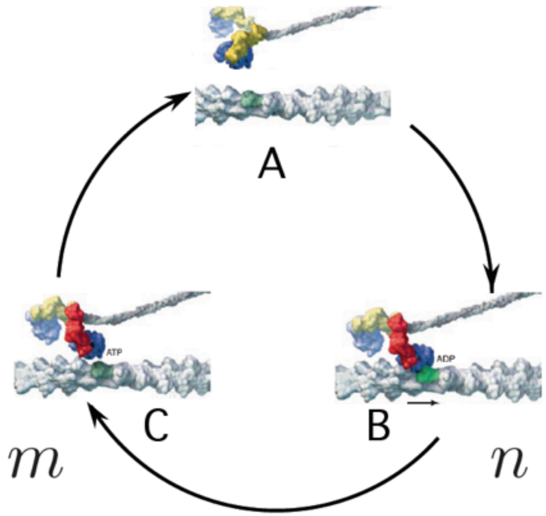
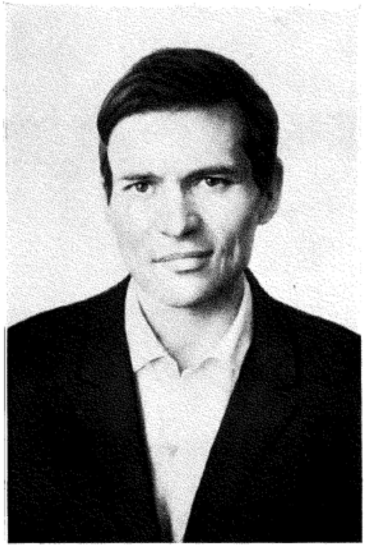
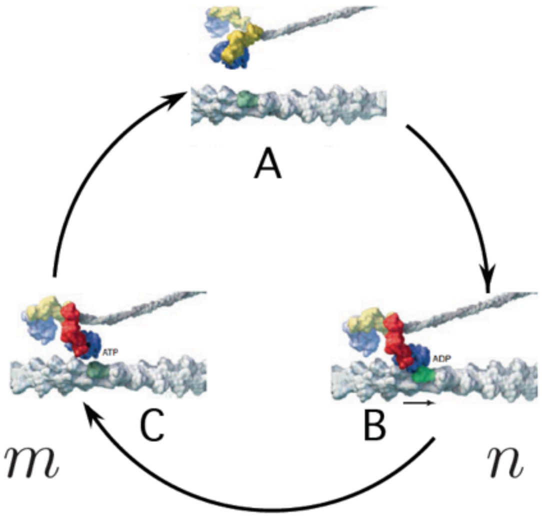



$$\frac{dn}{dt} = \frac{\alpha_D - (n+m)}{\tau_1} - \frac{v_s}{l} n$$



Deshcherevski V.I.
1939-1975

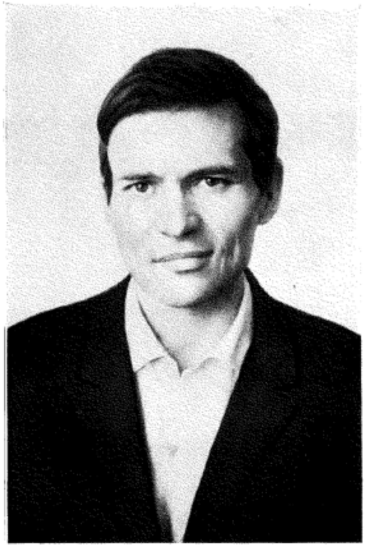



$$\alpha_D - n - m$$

$m$ $n$

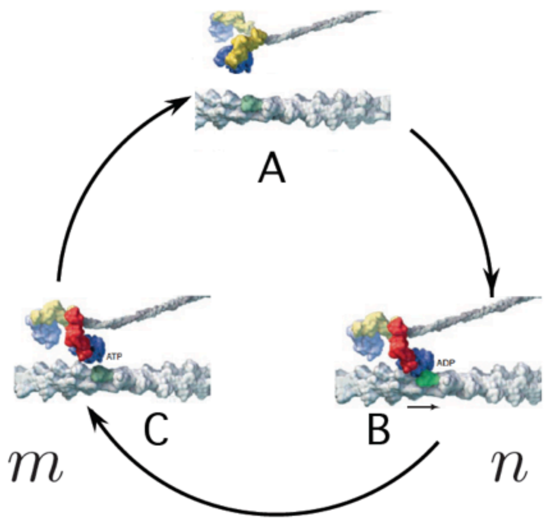
$$\frac{dn}{dt} = \frac{\alpha_D - (n+m)}{\tau_1} - \frac{v_s}{l} n$$

$$\frac{dm}{dt} = \frac{v_s}{l} n - \frac{m}{\tau_2}$$



Deshcherevski V.I.
1939-1975

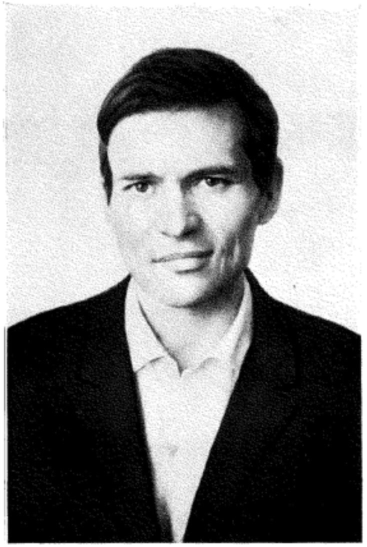
$$\alpha_D - n - m$$




$$\frac{dn}{dt} = \frac{\alpha_D - (n+m)}{\tau_1} - \frac{v_s}{l} n$$

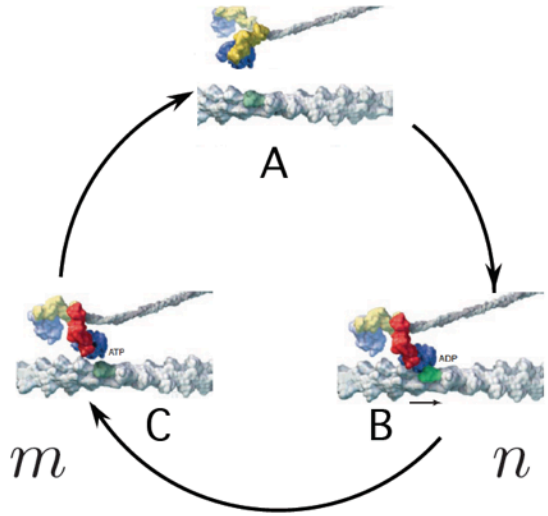
$$\frac{dm}{dt} = \frac{v_s}{l} n - \frac{m}{\tau_2}$$

$$F_s = f\,(n - m)$$



Deshcherevski V.I.
1939-1975

$$\alpha_D - n - m$$



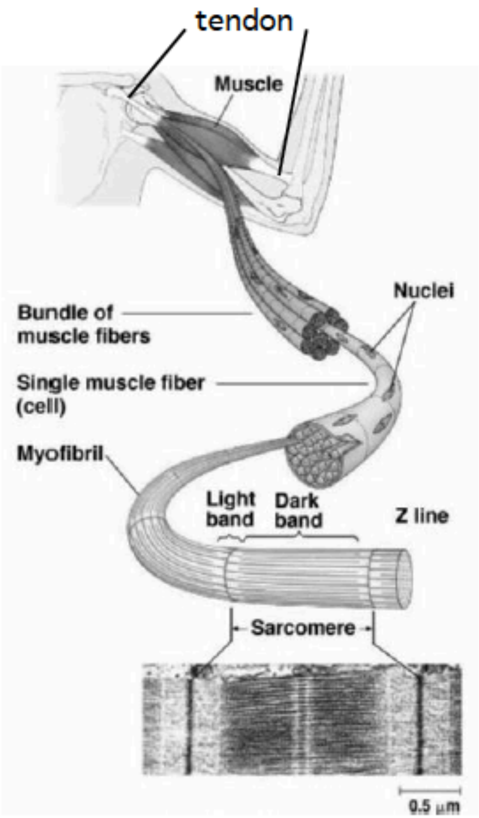

$$\frac{dn}{dt} = \frac{\alpha_D - (n+m)}{\tau_1} - \frac{v_s}{l} n$$

$$\frac{dm}{dt} = \frac{v_s}{l} n - \frac{m}{\tau_2}$$

$$F_s = f\,(n - m)$$

$$\bar{\tau}_1 \bar{\tau}_2 \ddot{n} + \left(\bar{\tau}_1 + \bar{\tau}_2 - \bar{\tau}_1 G \dot{\bar{\psi}}\right) \dot{n} + \left[1 - \left(1 + \bar{\tau}_1 / \bar{\tau}_2\right) G \dot{\bar{\psi}} - \bar{\tau}_1 G \ddot{\bar{\psi}}\right] = 1$$

# du sarcomere au muscle

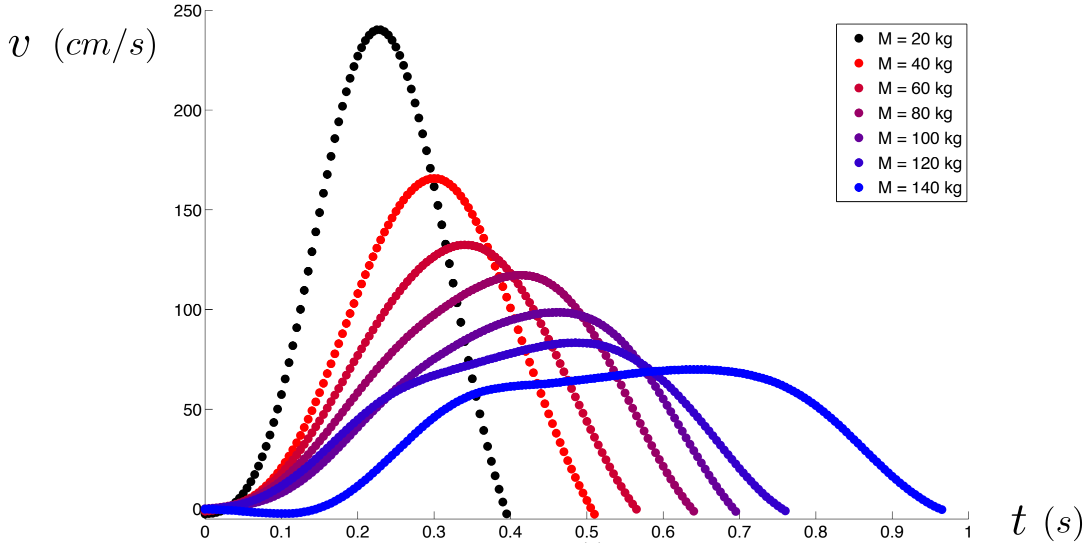


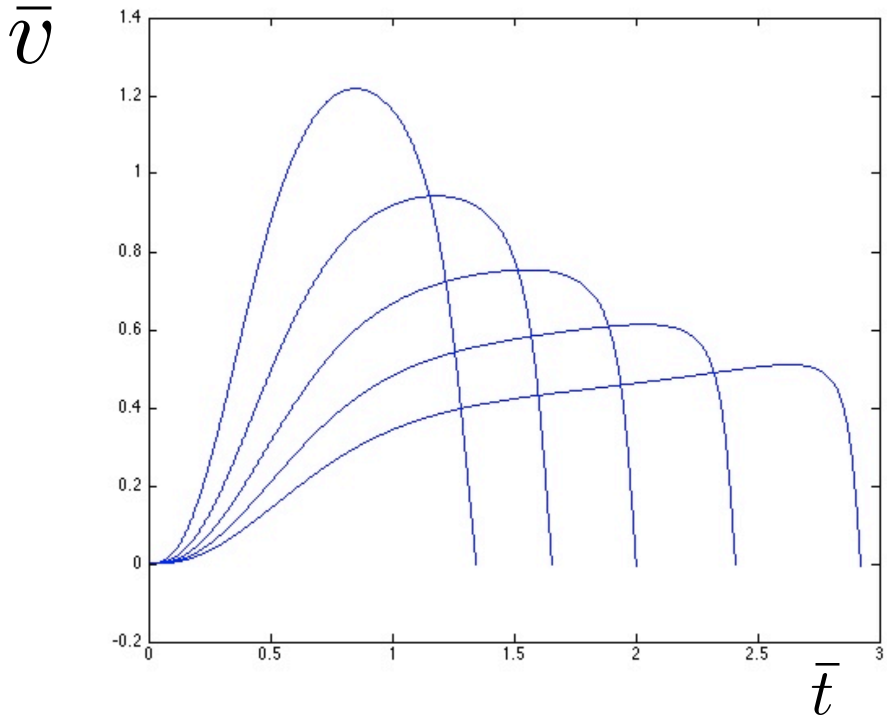

$$v = v_s . N_s$$

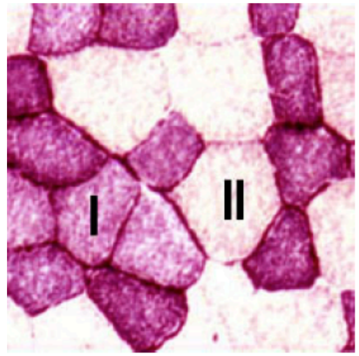
$$F = F_s . N_p$$

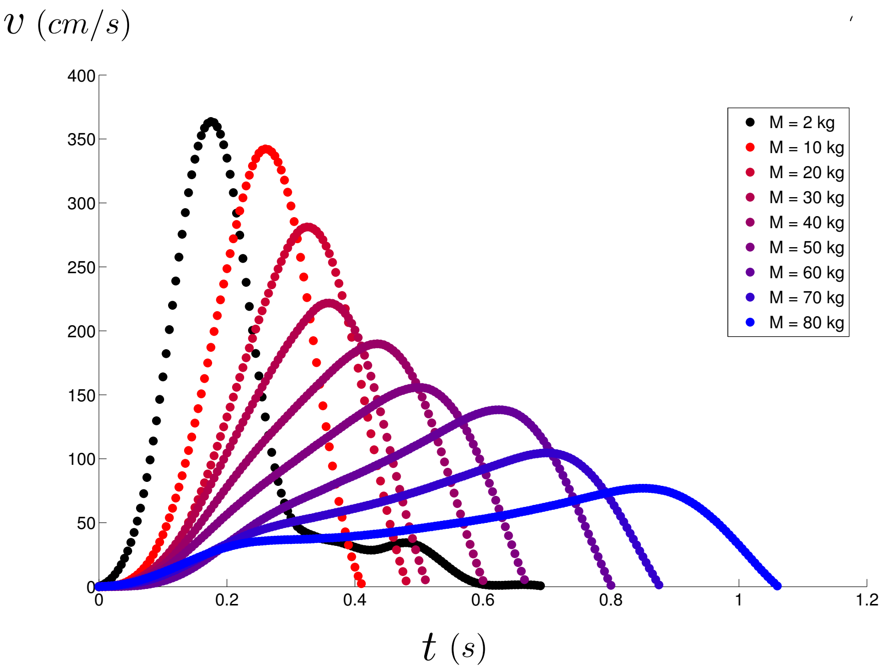
$Greg \quad M_0 = 114\, kg$

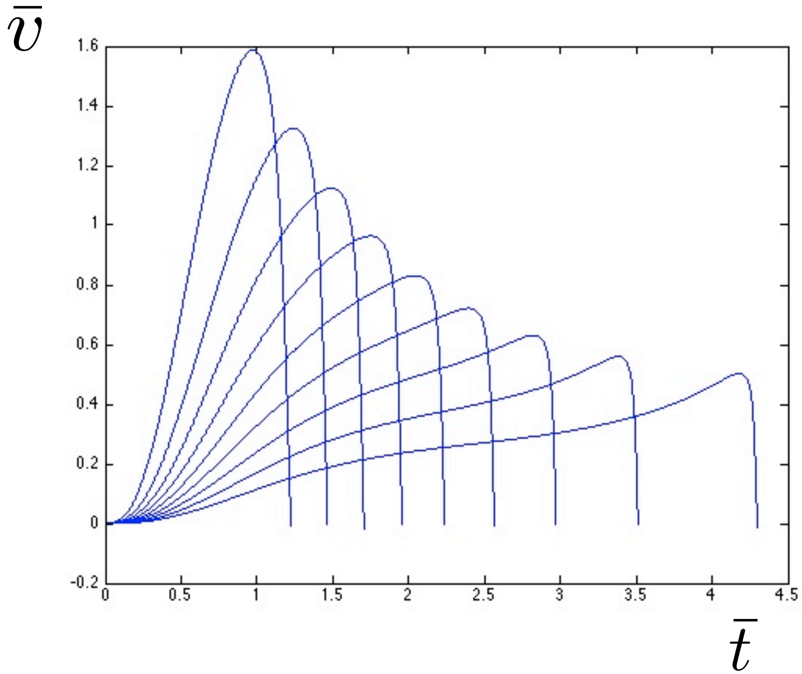
$M^* = 230\, kg$



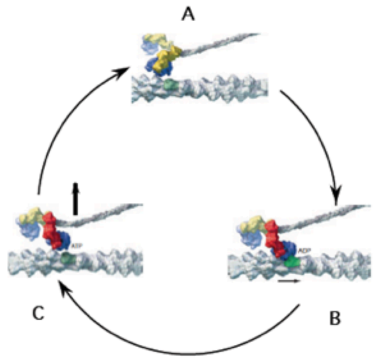




I
II

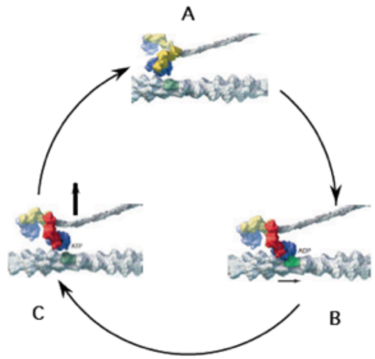

$v\ (cm/s)$
400
350
300
250
200
150
100
50
0
0
0.2
0.4
0.6
0.8
1
1.2
M = 2 kg
M = 10 kg
M = 20 kg
M = 30 kg
M = 40 kg
M = 50 kg
M = 60 kg
M = 70 kg
M = 80 kg
$t\ (s)$


$\bar{v}$
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
$\bar{t}$

# what's new ?



what's new ?

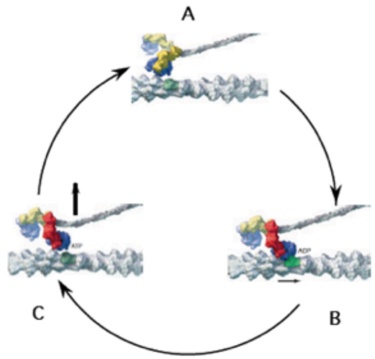



$$\frac{dn}{dt} = \frac{\alpha_D - (n+m)}{\tau_1} - \frac{v_s}{l} n$$

$$\frac{dm}{dt} = \frac{v_s}{l} n - \frac{m}{\tau_2}$$

$$F_s = f\,(n - m)$$

## what's new ?




$$\frac{dn}{dt} = \frac{\alpha_D - (n+m)}{\tau_1} - \frac{v_s}{l} n$$

$$\frac{dm}{dt} = \frac{v_s}{l} n - \frac{m}{\tau_2}$$

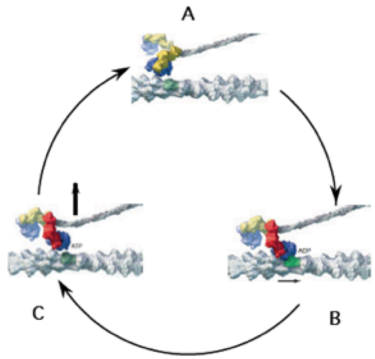
$$F_s = f\,(n - m)$$

Hill en stationnaire :

$$F = F_0 \frac{1 - v/v_{max}}{1 + \frac{1}{a} v/v_{max}}$$

$$F_0 = \alpha . f \quad v_{max} = l/\tau_2 \quad 1/a = 1 + \tau_1/\tau_2$$

# what's new ?




$$\frac{dn}{dt} = \frac{\alpha_D - (n+m)}{\tau_1} - \frac{v_s}{l} n$$

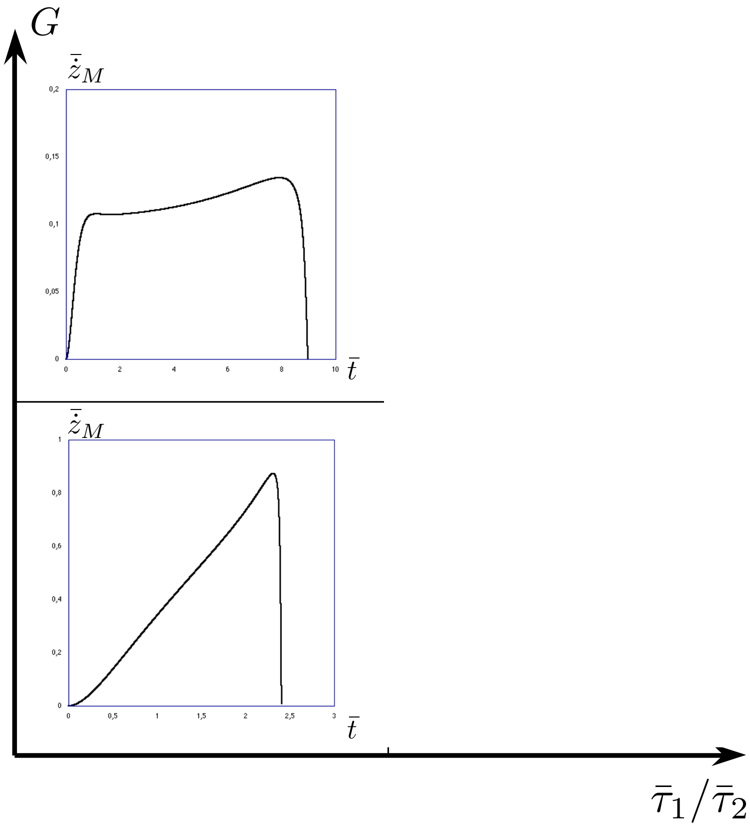
$$\frac{dm}{dt} = \frac{v_s}{l} n - \frac{m}{\tau_2}$$

$$F_s = f\,(n-m)$$

Hill en stationnaire :

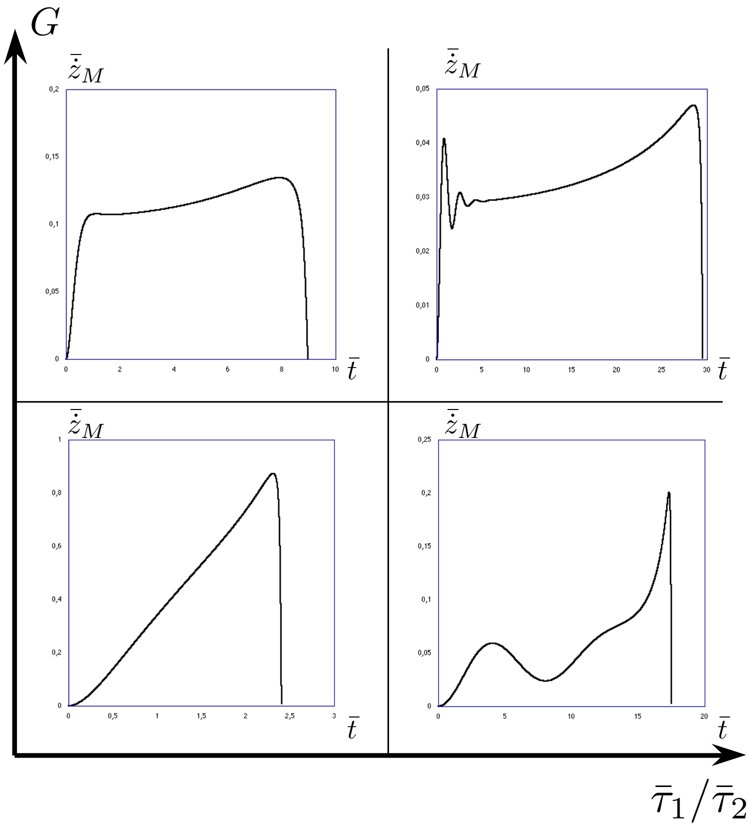
$$F = F_0 \frac{1 - v/v_{max}}{1 + \frac{1}{a} v/v_{max}}$$

$$F_0 = \alpha . f \quad v_{max} = l/\tau_2 \quad 1/a = 1 + \tau_1/\tau_2$$

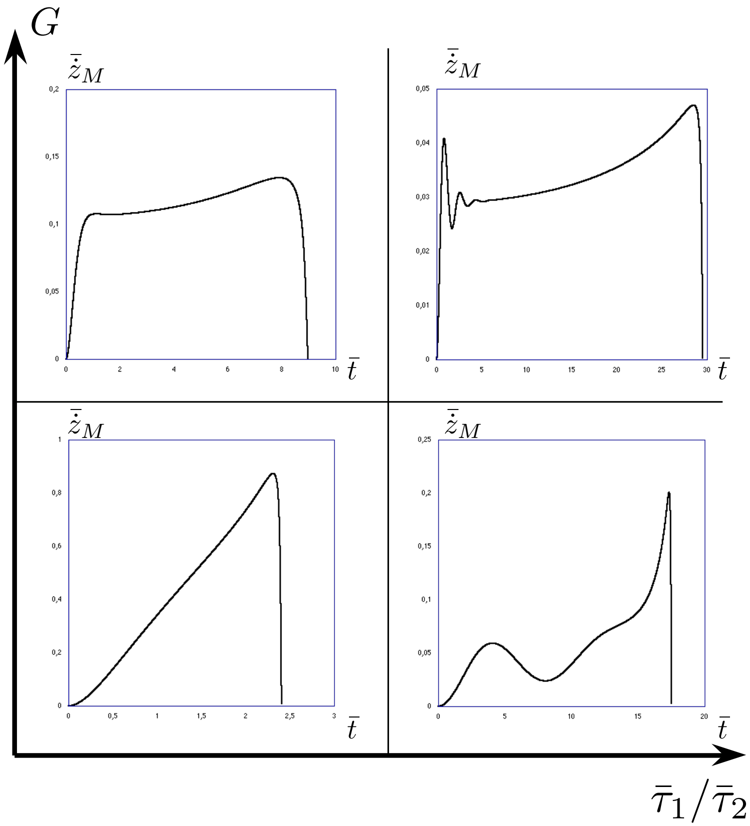





vendredi 17 juin 2016



$G$
$\bar{z}_M$
$\bar{\dot{z}}_M$
$\bar{\dot{z}}_M$
$\bar{\dot{z}}_M$
$\bar{t}$
$\bar{t}$
$\bar{t}$
$\bar{t}$
$\bar{\tau}_1/\bar{\tau}_2$




**maladies neuromusculaires**

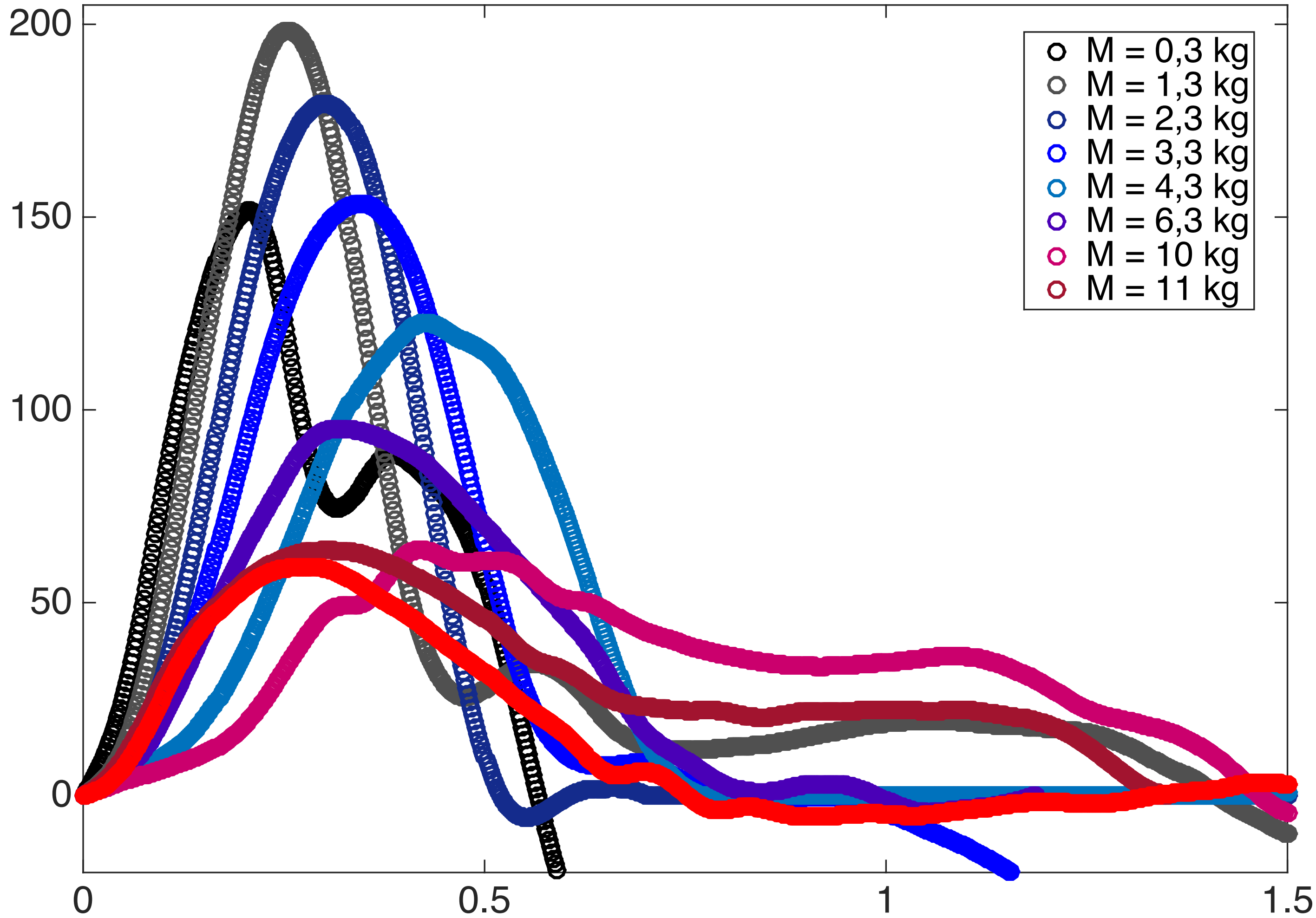
# Loïc AUVRAY

Amyotrophic Lateral Sclerosis (ALS)

# Loïc AUVRAY

Amyotrophic lateral sclerosis (ALS), sometimes called Lou Gehrig's disease, is a rapidly progressive, invariably fatal neurological disease that attacks the nerve cells *(neurons)* responsible for controlling voluntary muscles (muscle action we are able to control, such as those in the arms, legs, and face). The disease belongs to a group of disorders known as *motor neuron diseases,* which are characterized by the gradual degeneration and death of motor neurons.

Amyotrophic Lateral Sclerosis (ALS)


200
150
100
50
0
0
0.5
1
1.5
M = 0,3 kg
M = 1,3 kg
M = 2,3 kg
M = 3,3 kg
M = 4,3 kg
M = 6,3 kg
M = 10 kg
M = 11 kg

**L'ambition de cette partie est de mettre au point un rhéomètre musculaire reposant sur un modèle physique du muscle. Les innovations envisagées sont multiples, soit pour l'amélioration des performances et des techniques d'entrainement, soit pour l'identification précoce de pathologies.**

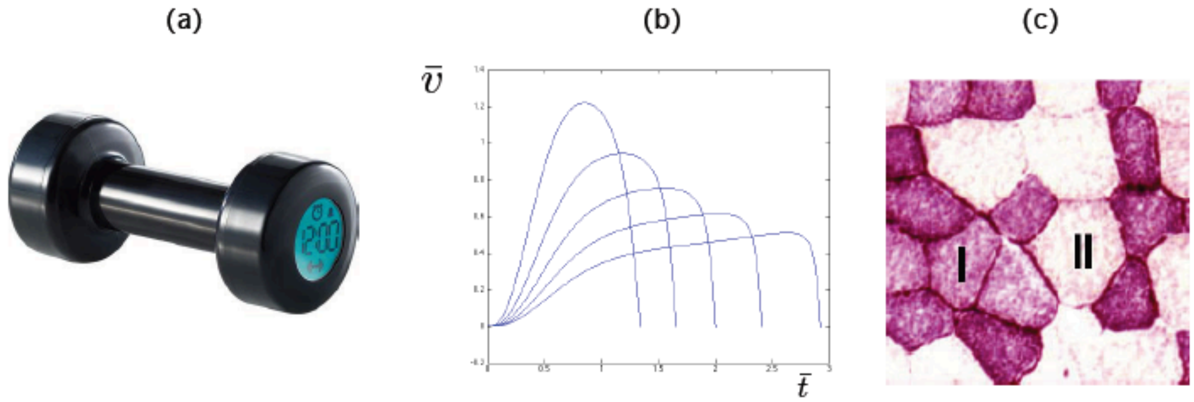
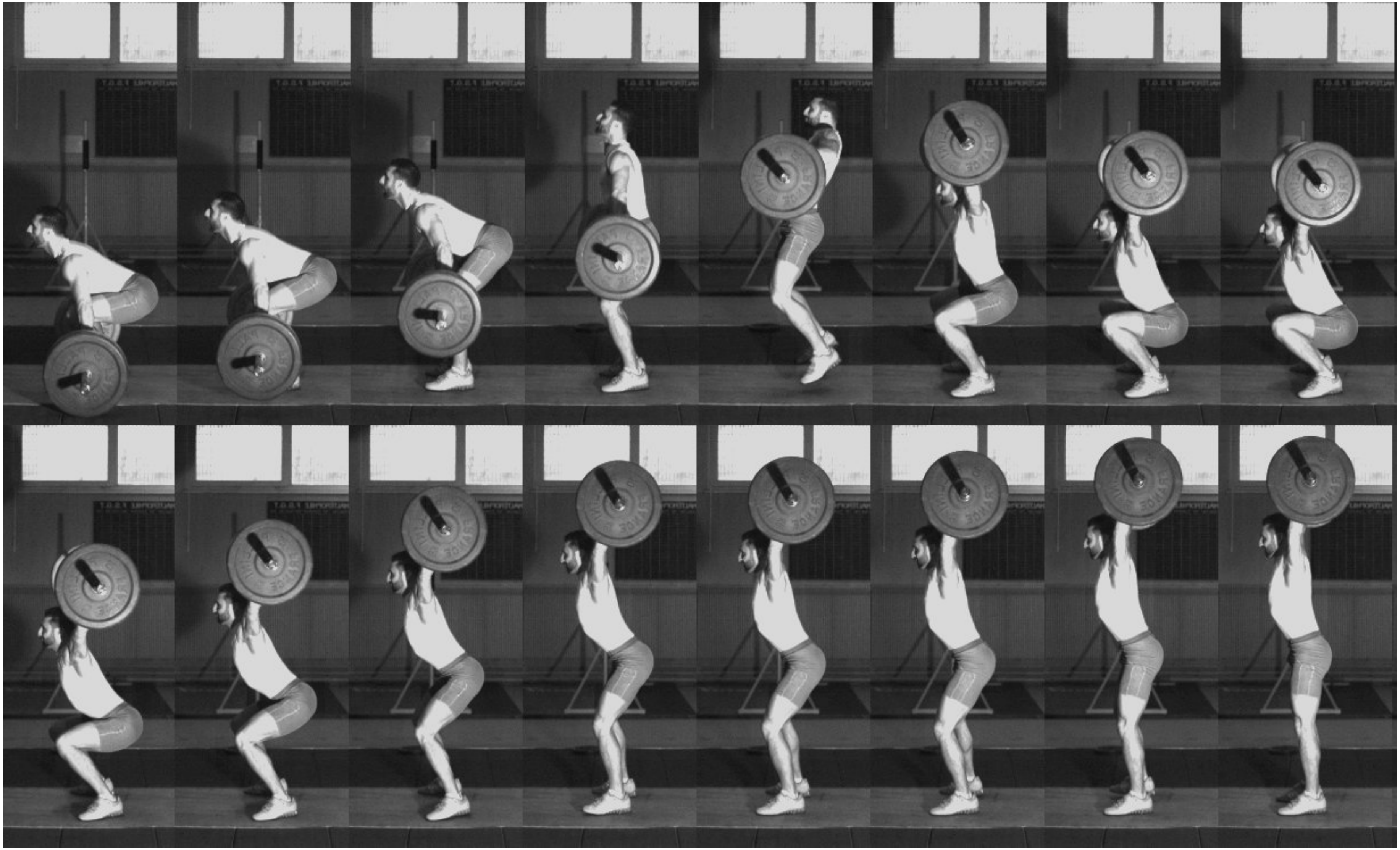
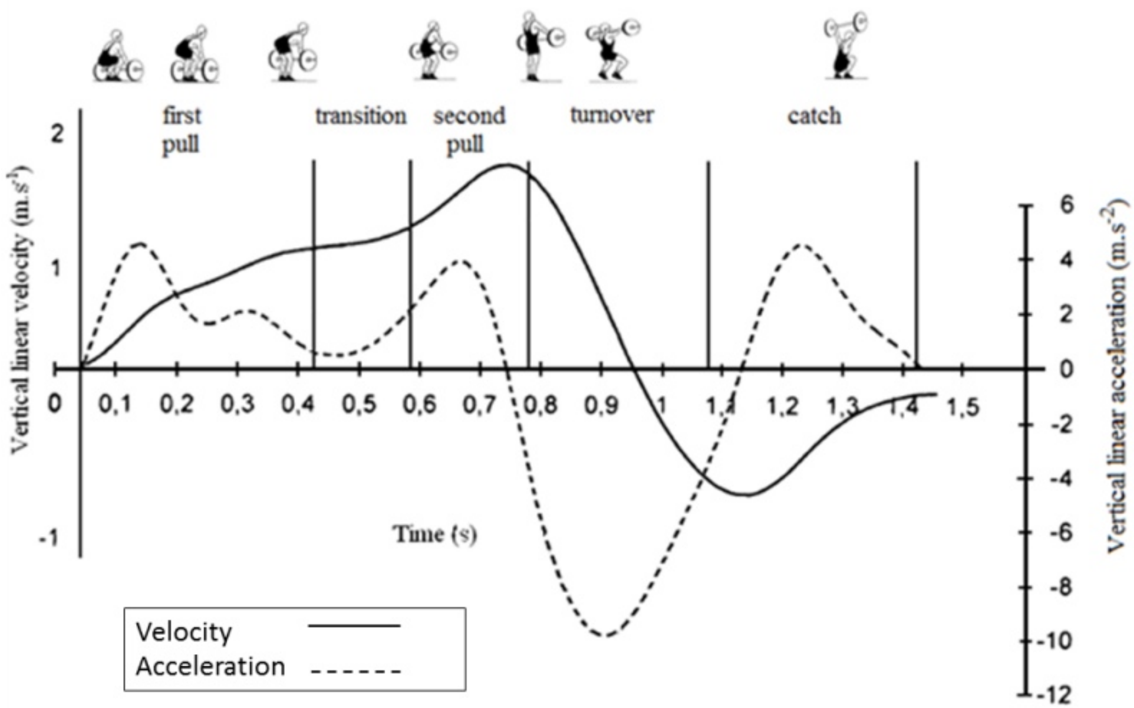



FIGURE 4.2 – (a) Haltère connectée (b) Analyse des lois de levée (c) diagnostic.



Snatch $M = 75\,kg \quad dt = 0.4\,s$



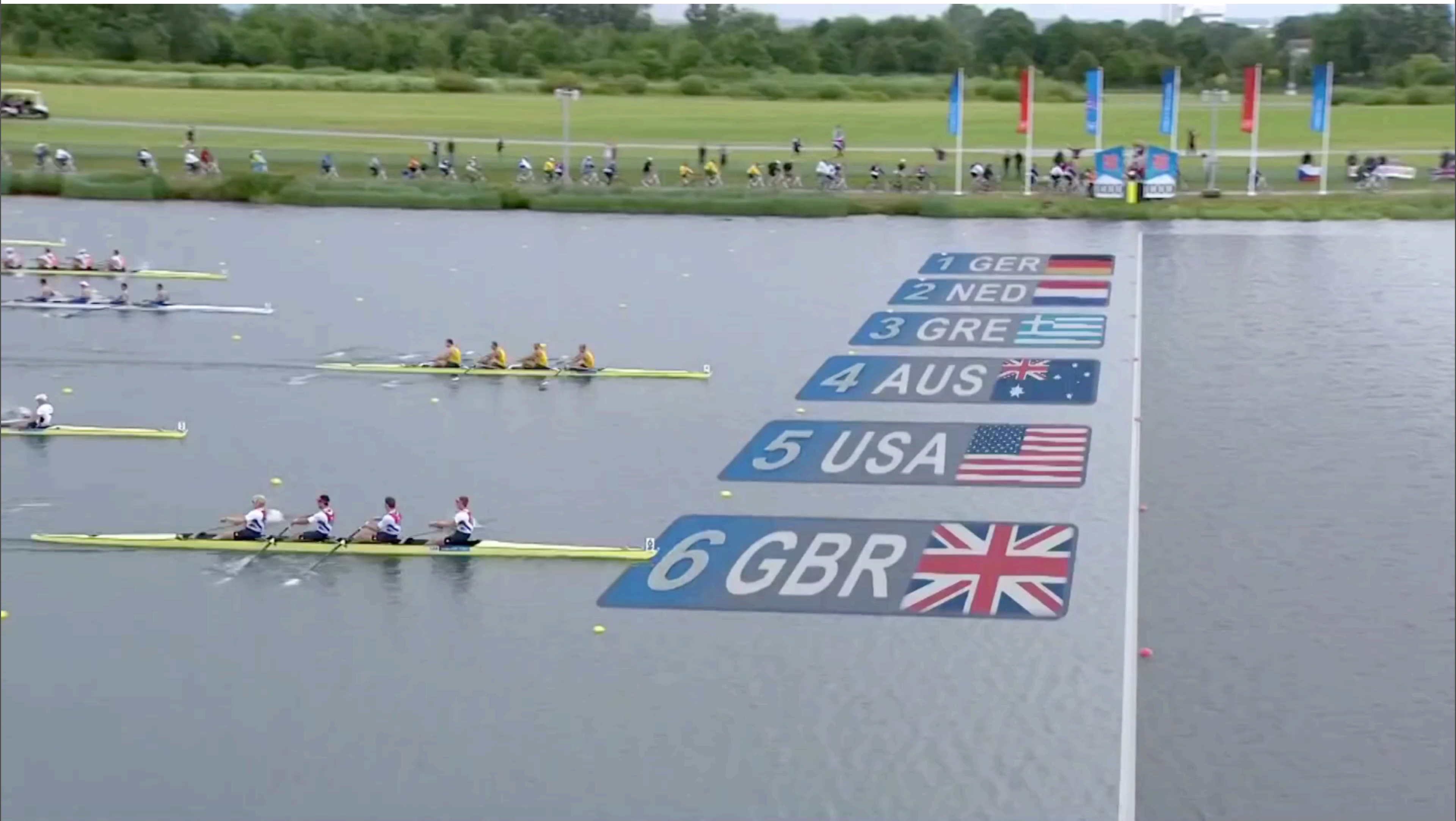

Campillo 2012

# The Physics of Rowing

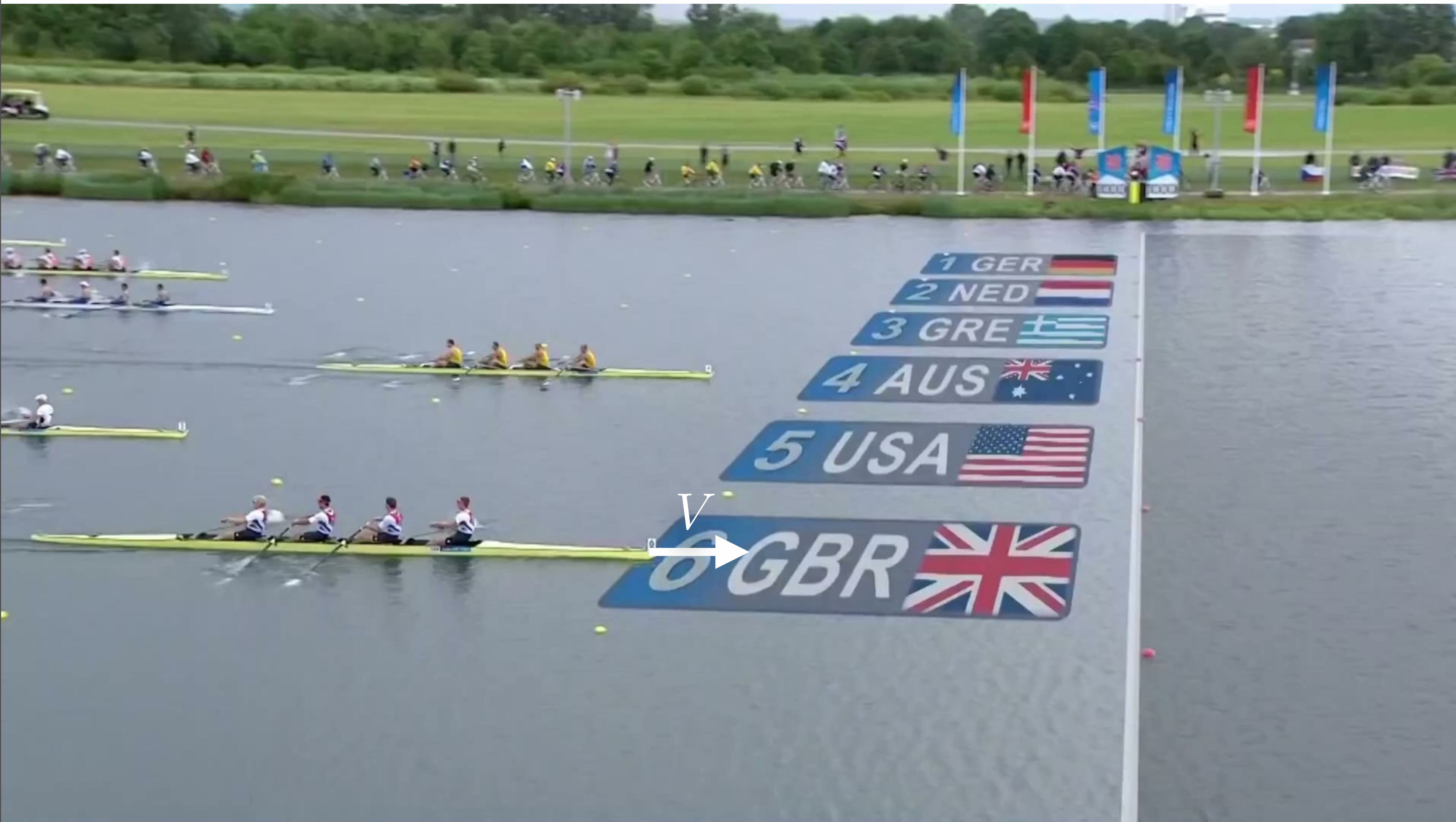
## A matter of synchronization ?

Jean-Philippe Boucher
Romain Labbé
Timothée Mouterde

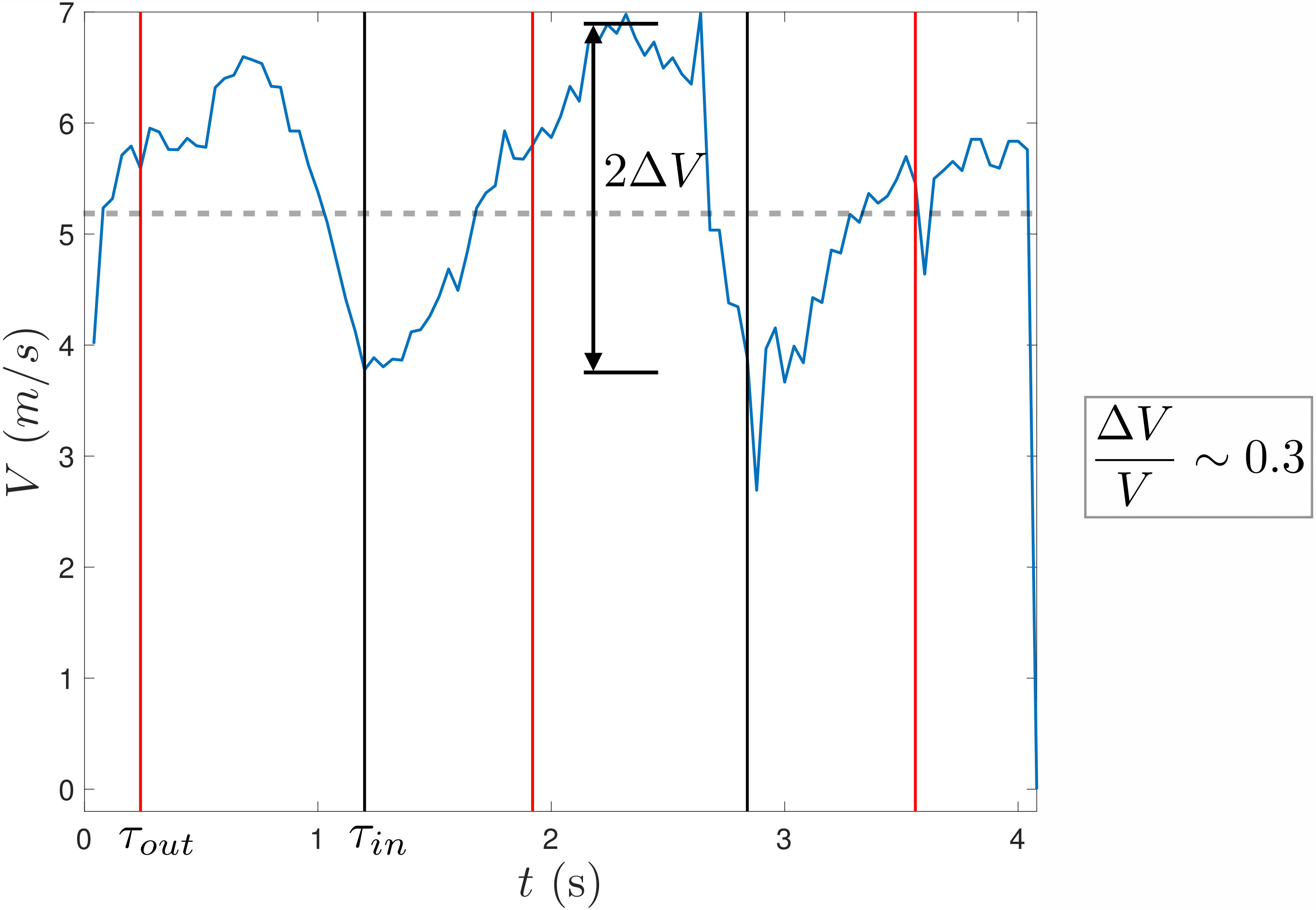
Men's Four Rowing Final - London 2012 Olympics




Men's Four Rowing Final - London 2012 Olympics




Men's Four Rowing Final - London 2012 Olympics




vendredi 17 juin 2016

# Why should rowers desynchronize ?

For $Re \sim 10^6$, $$F_{drag} \sim \frac{1}{2}\rho S V^2$$

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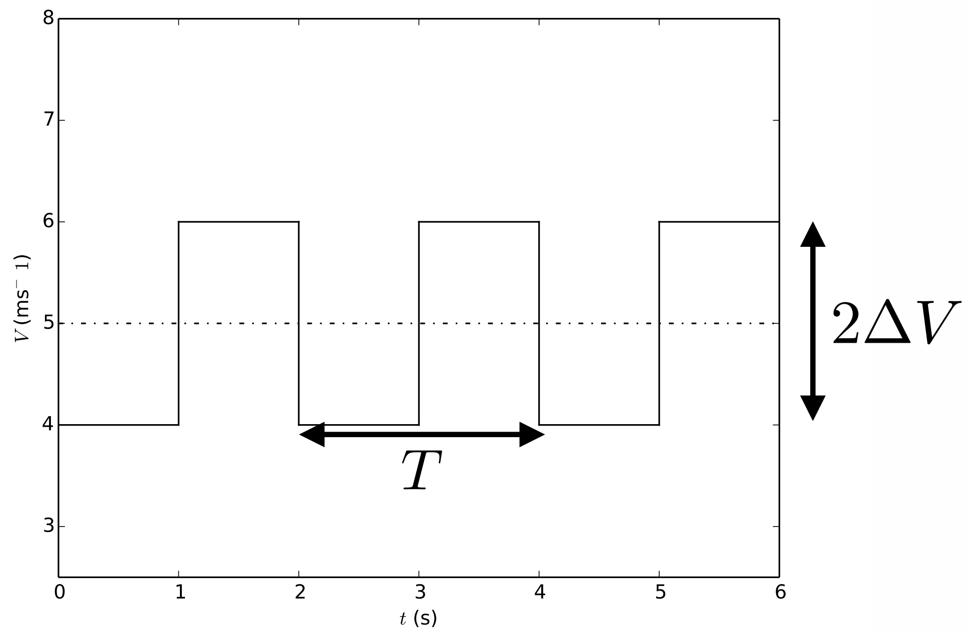
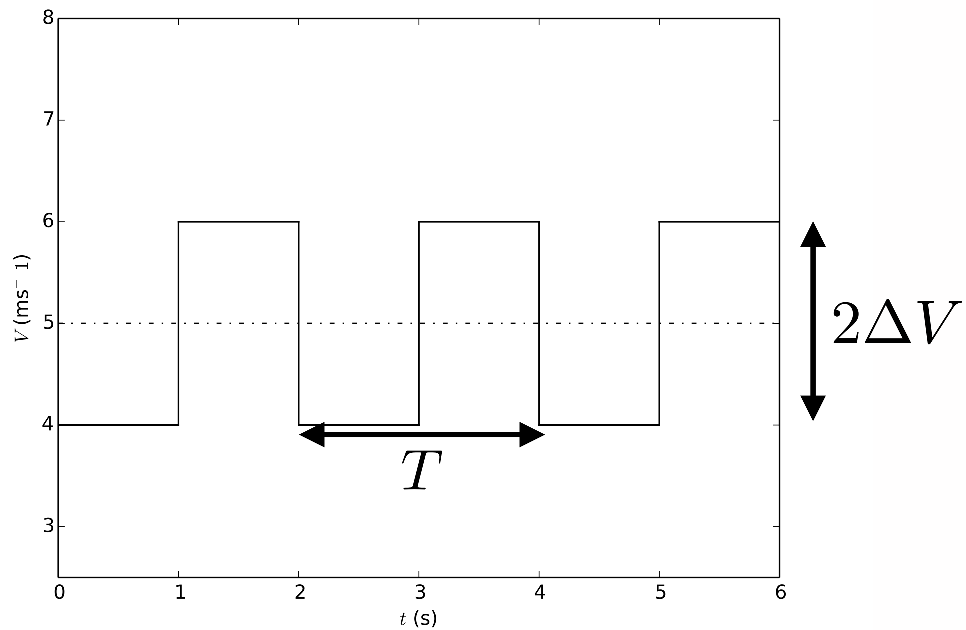


# Why should rowers desynchronize ?

For $Re \sim 10^6$, $\qquad F_{drag} \sim \frac{1}{2}\rho S V^2$




## Mean power dissipated during one cycle :

$$\overline{\mathcal{P}} \sim \overline{F_{drag} V} \sim \frac{1}{2}\rho S \overline{V}^3 \left(1 + 3\left(\frac{\Delta V}{\overline{V}}\right)^2\right)$$

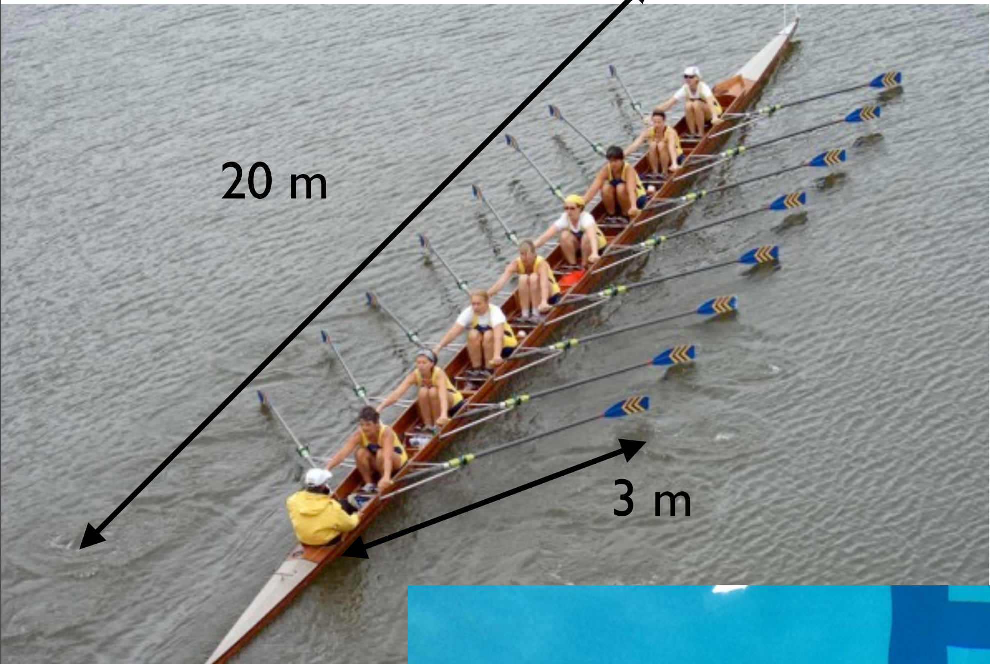
# How do shrimps swim ?

$$Re \sim 100$$

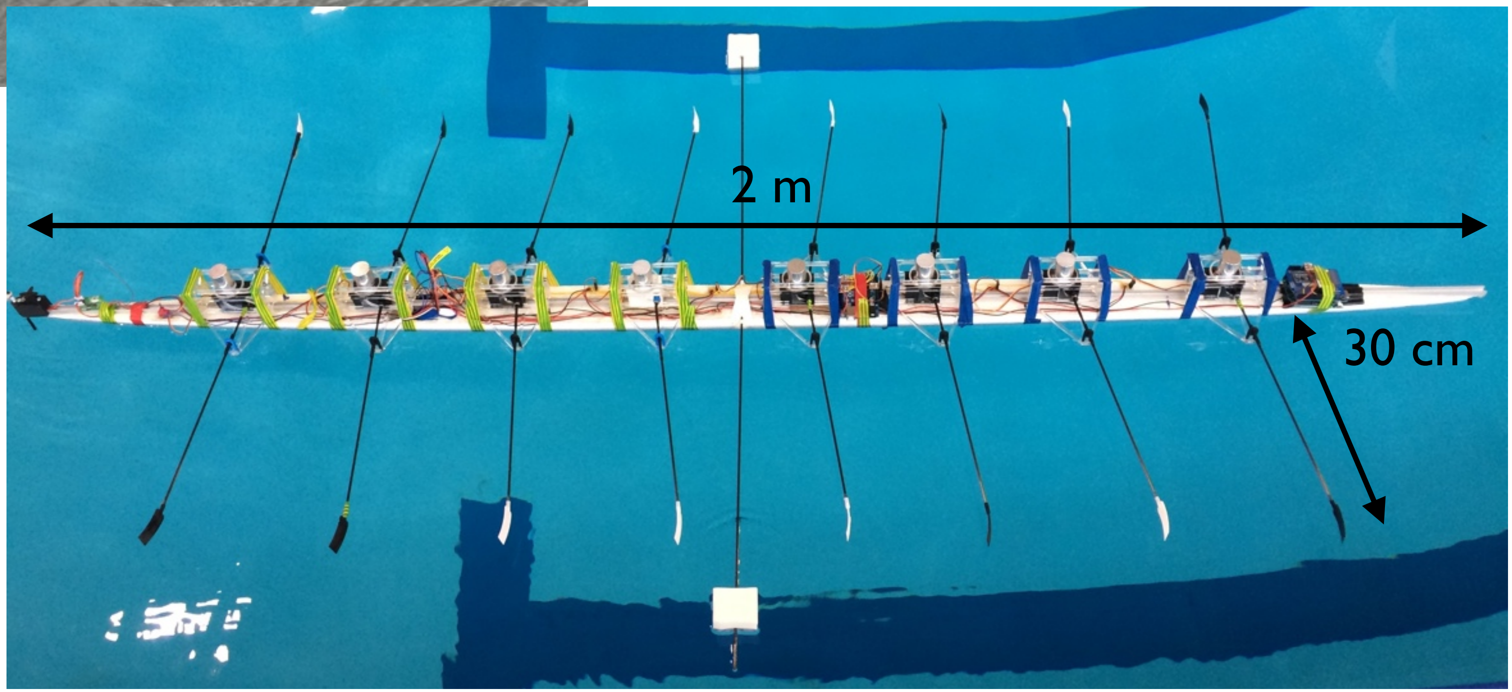
# How do shrimps swim ?

$$Re \sim 100$$

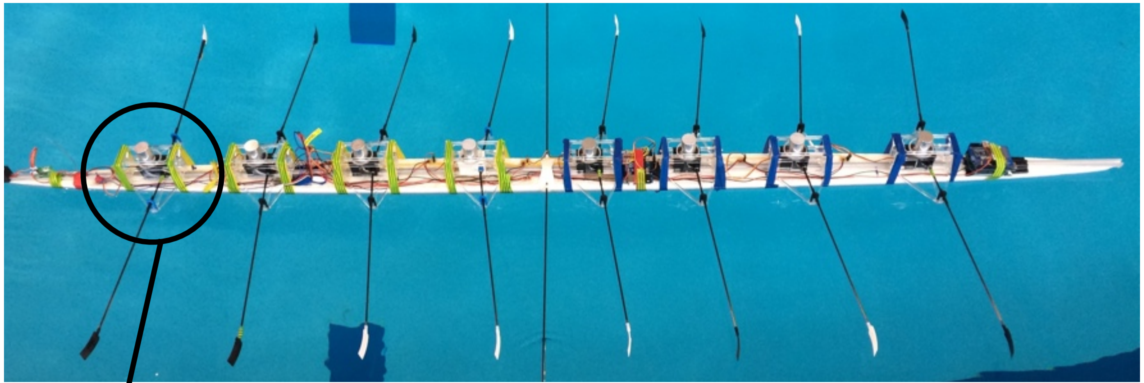
# Design of a remote rowing boat with 8 rowers

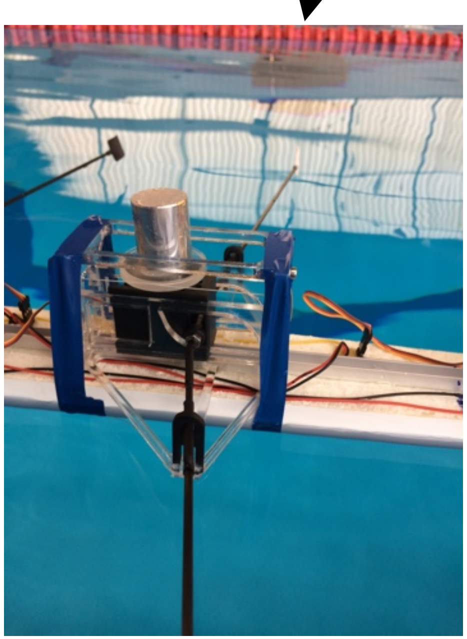



1/10 scale



# Same mass ratio between the boat and the rower





**Real Life**

$$M_{boat} = 150\text{kg}$$

$$\frac{M_{boat}}{M_{rower}} \sim 1.5$$

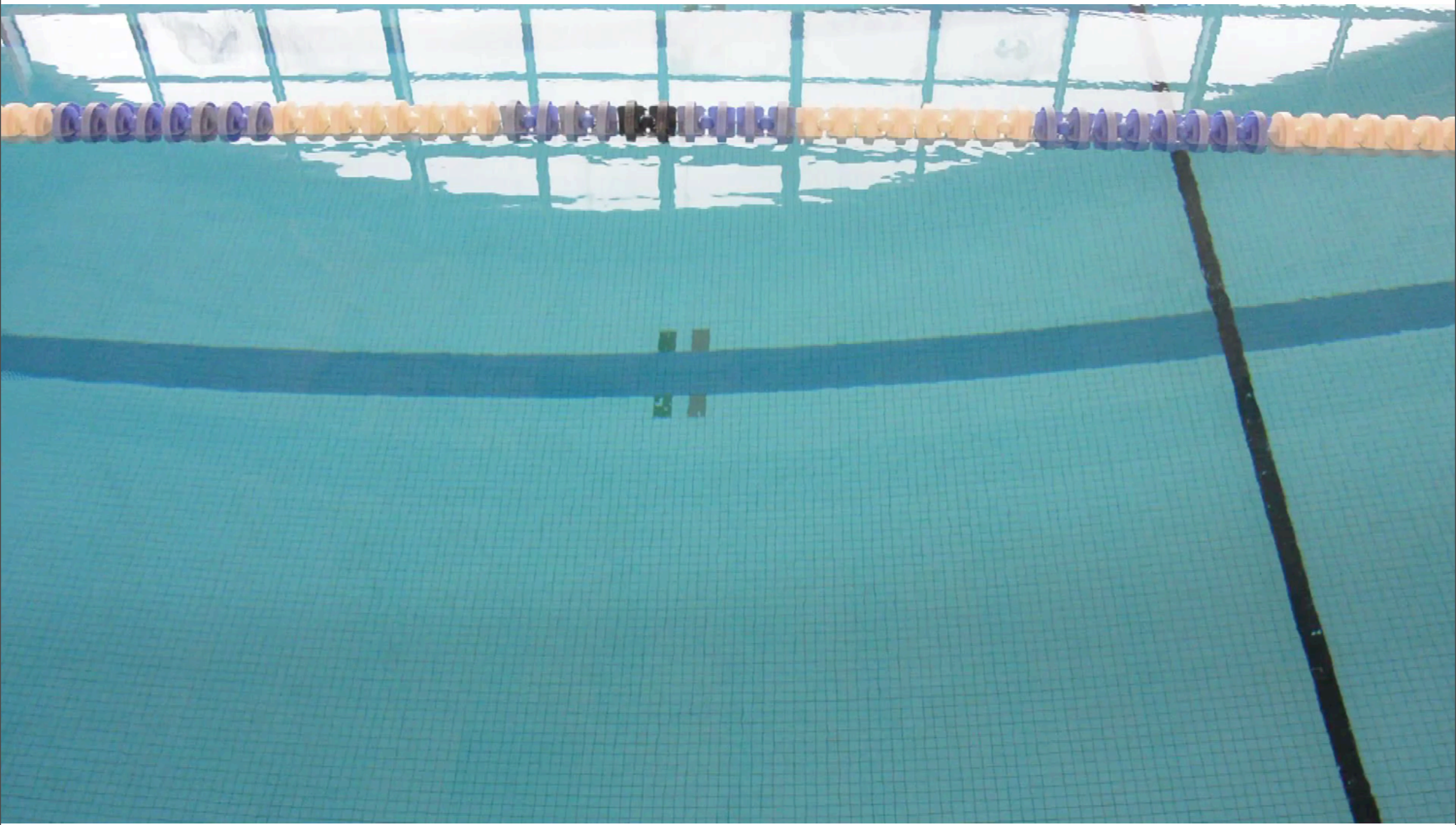
**Lab Life**

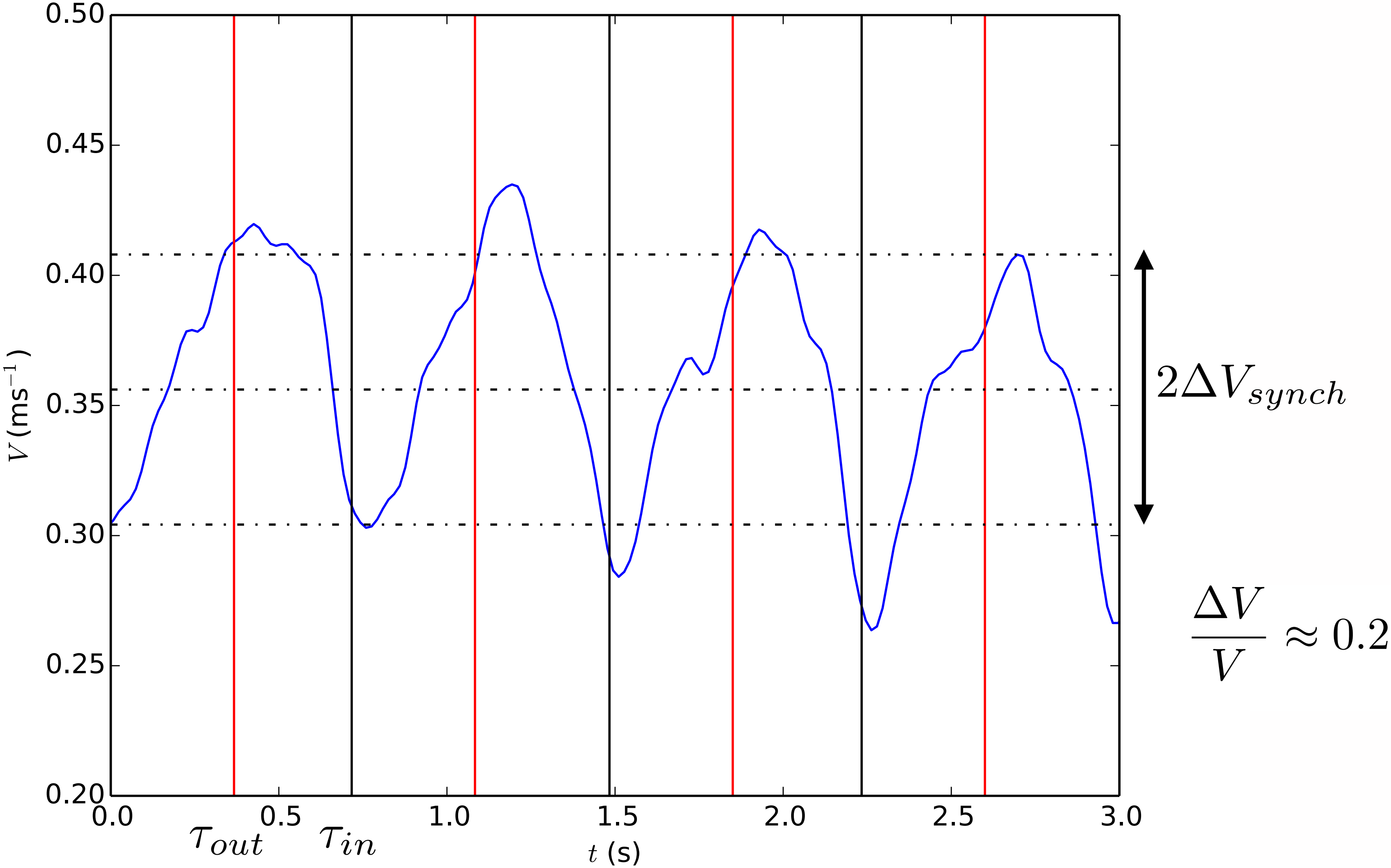
$$M_{boat} = 350 \text{ g}$$

$$\frac{M_{boat}}{M_{rower}} \sim 1.4$$

# Synchronous state : $\phi = 0$

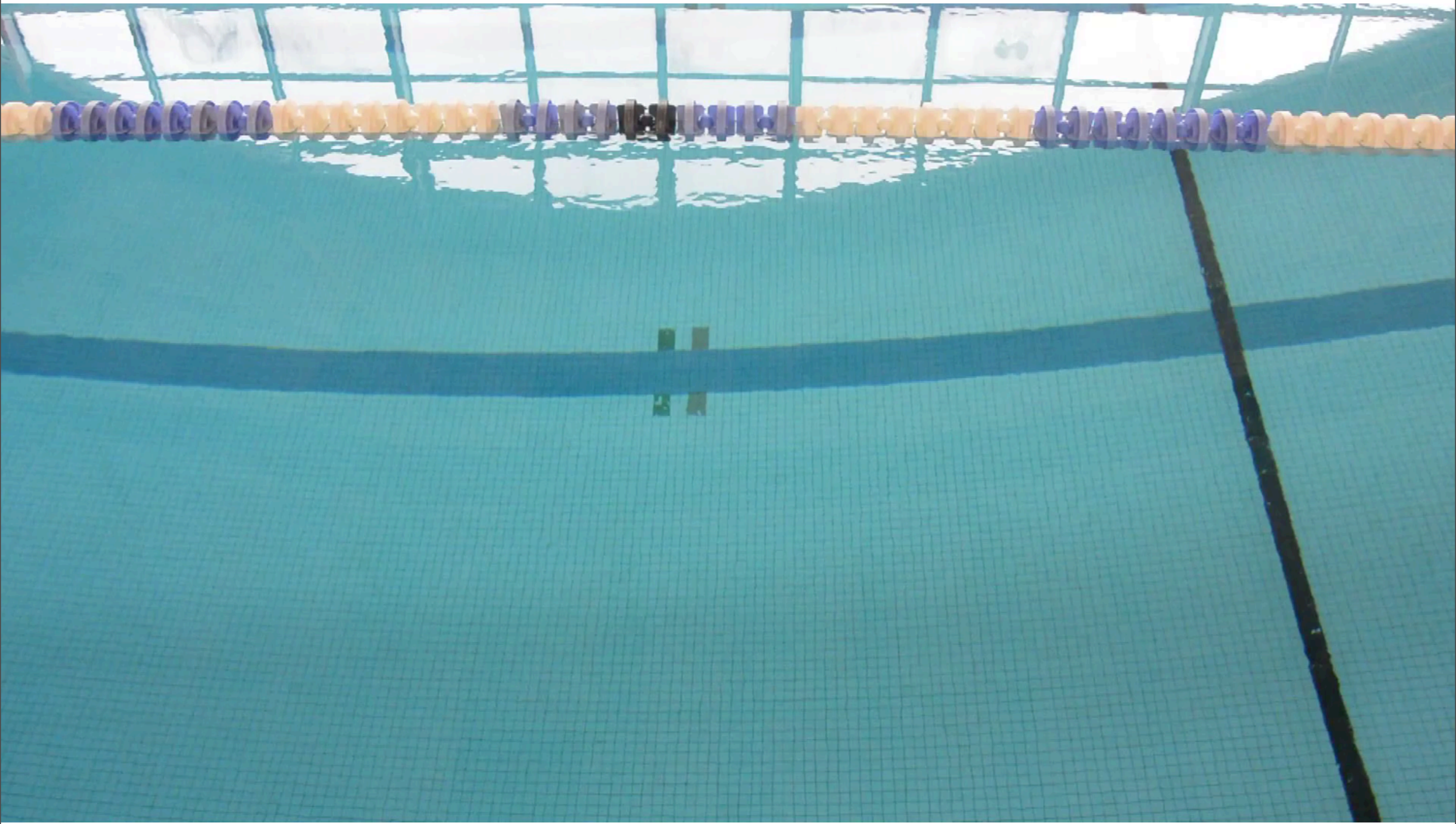
# Synchronous state :   $\phi = 0$

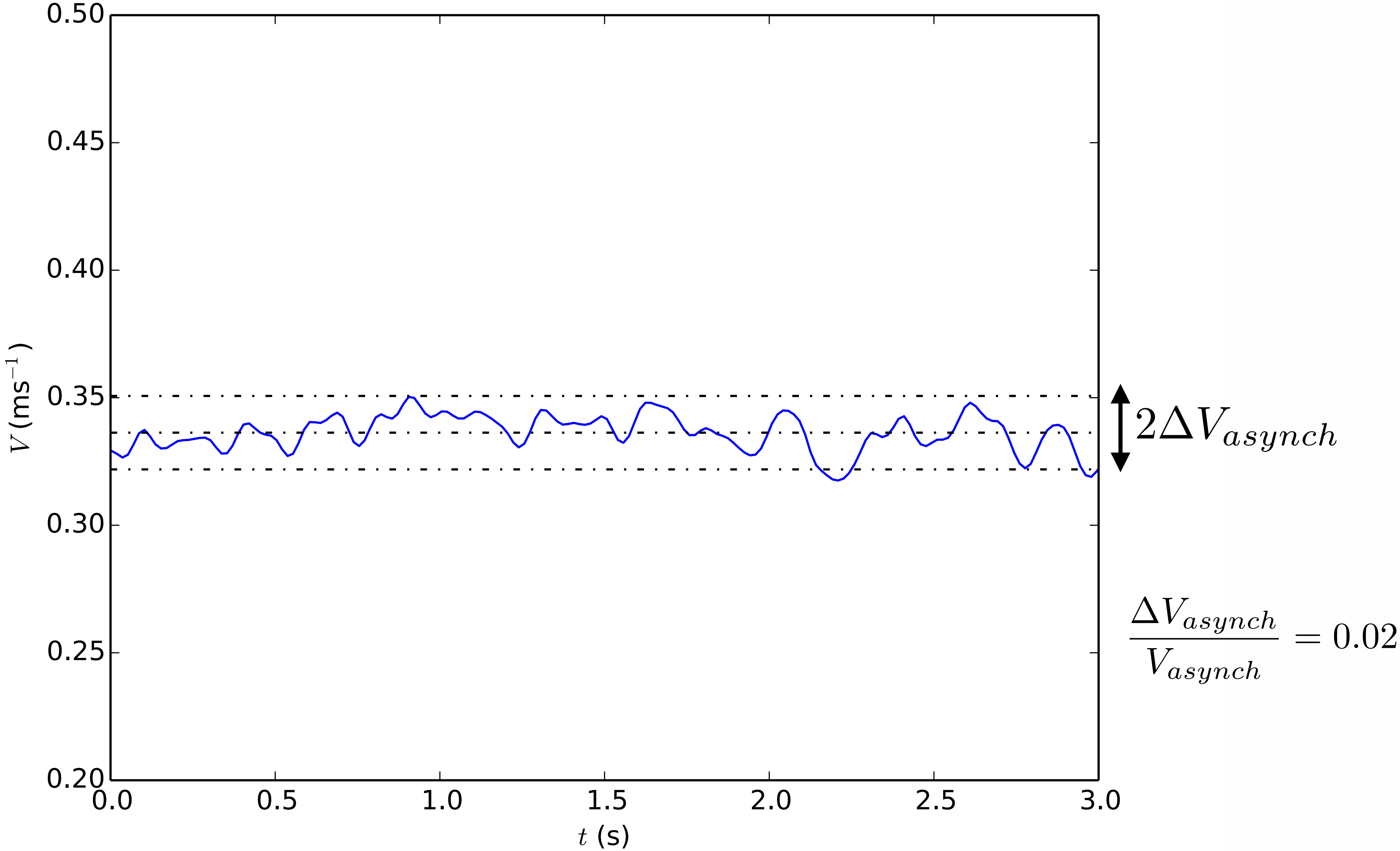


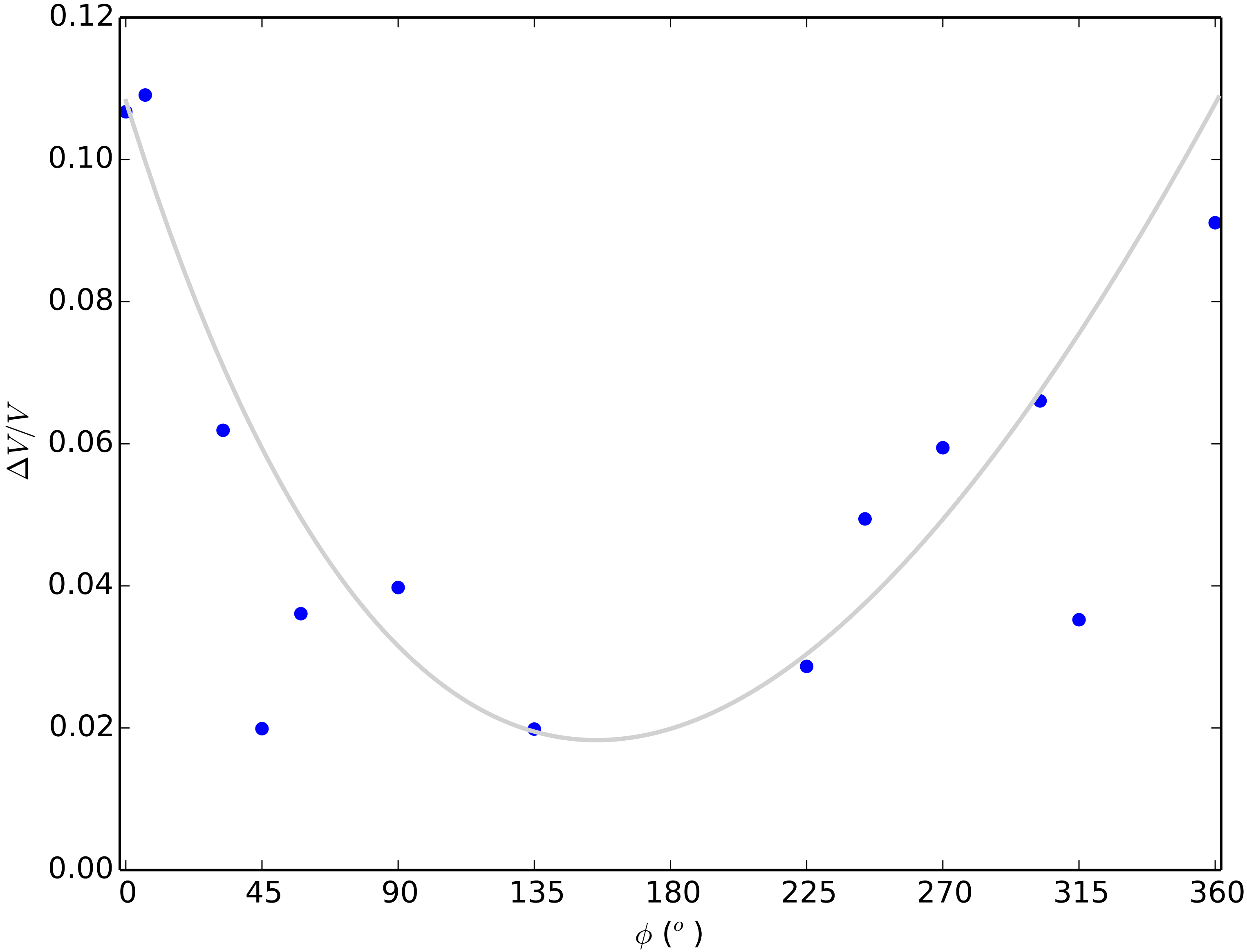

0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
$V$ (ms$^{-1}$)
$t$ (s)
$\tau_{out}$
$\tau_{in}$
$2\Delta V_{synch}$
$\frac{\Delta V}{V} \approx 0.2$

# Asynchronous state : $\phi = 45^\circ$

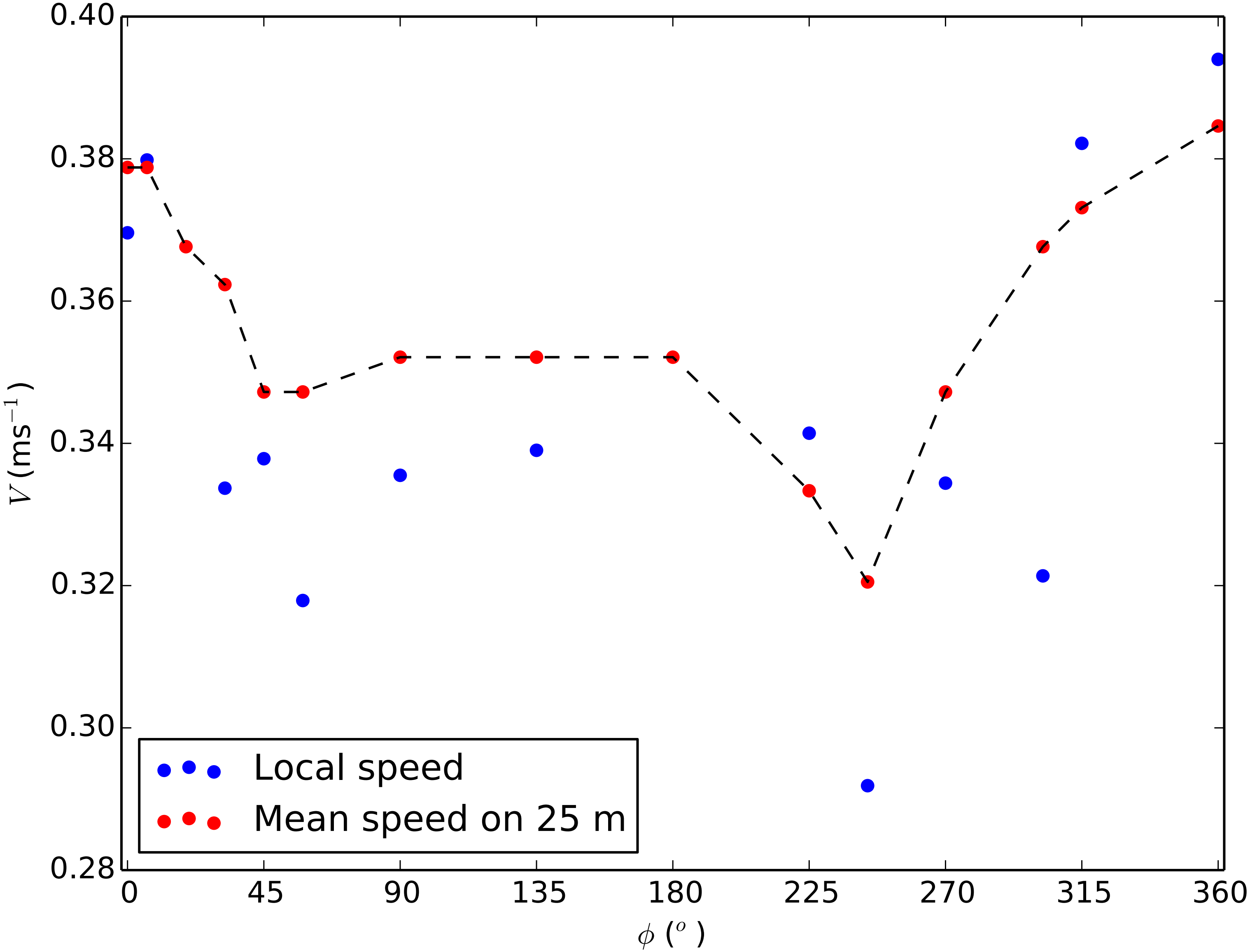
# Asynchronous state : $\phi = 45^\circ$




0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
$t$ (s)
$V$ (ms$^{-1}$)
$2\Delta V_{asynch}$
$\frac{\Delta V_{asynch}}{V_{asynch}} = 0.02$



0.12
0.10
0.08
0.06
0.04
0.02
0.00
$\Delta V/V$
0
45
90
135
180
225
270
315
360
$\phi$ ($^o$ )

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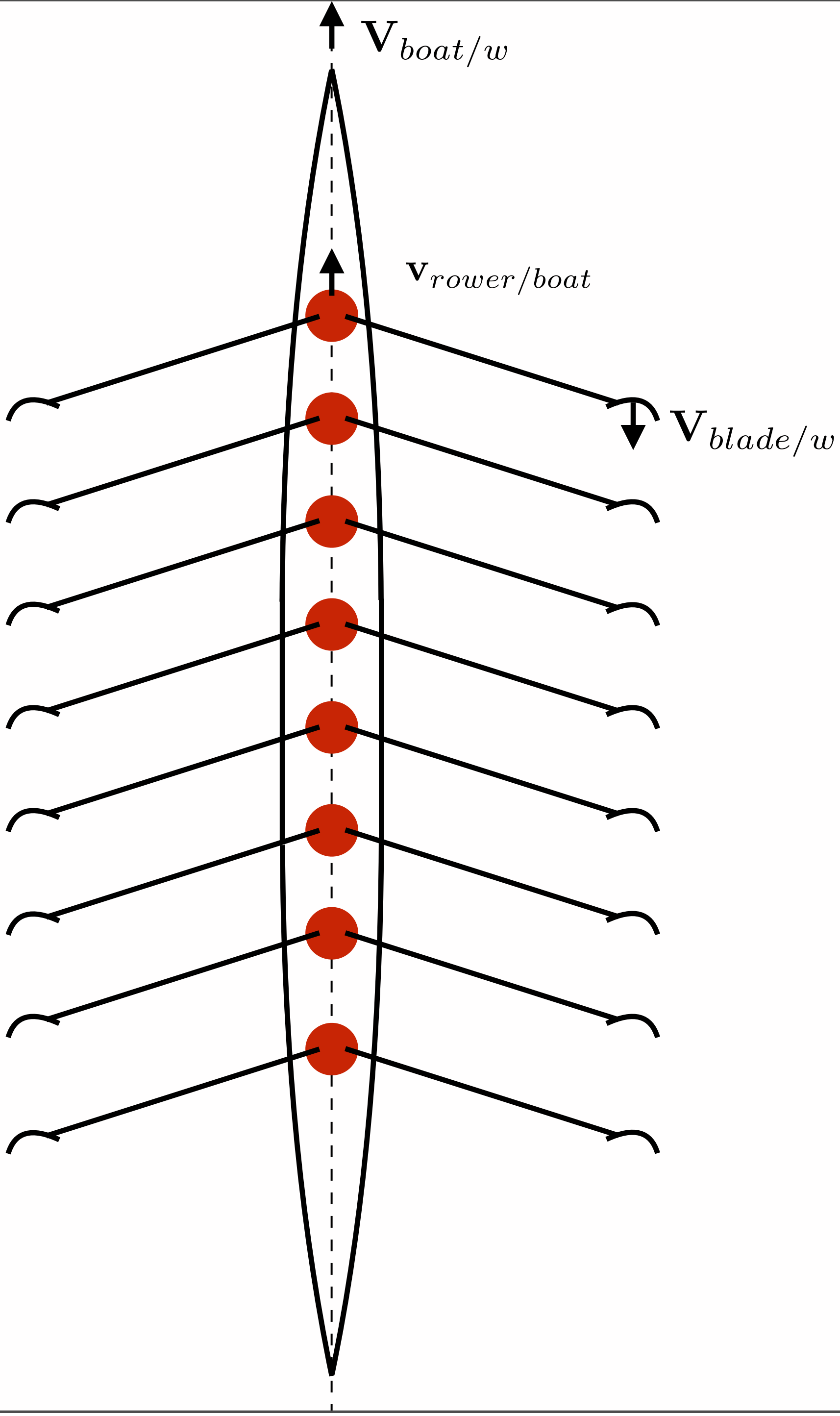
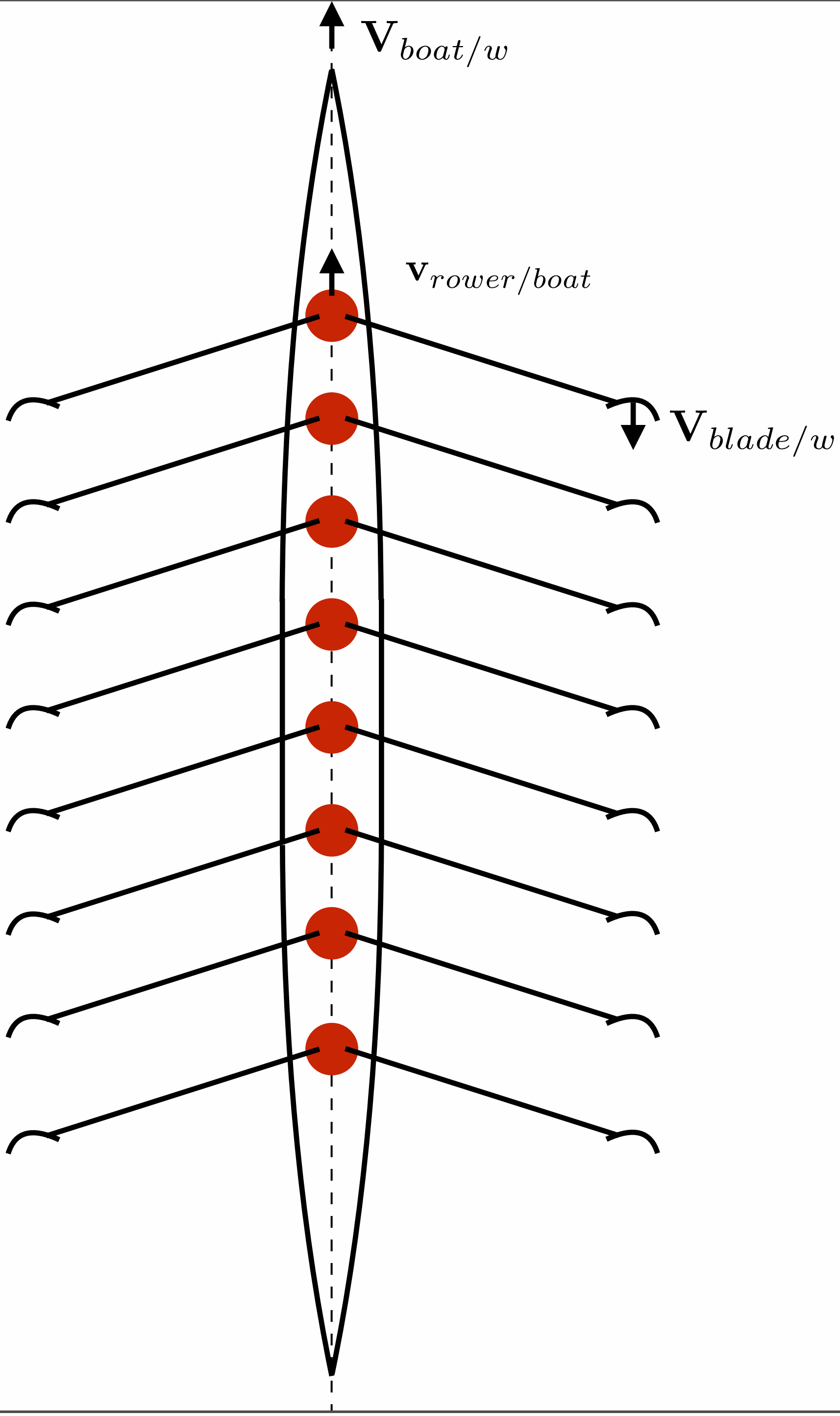



# Propulsive force

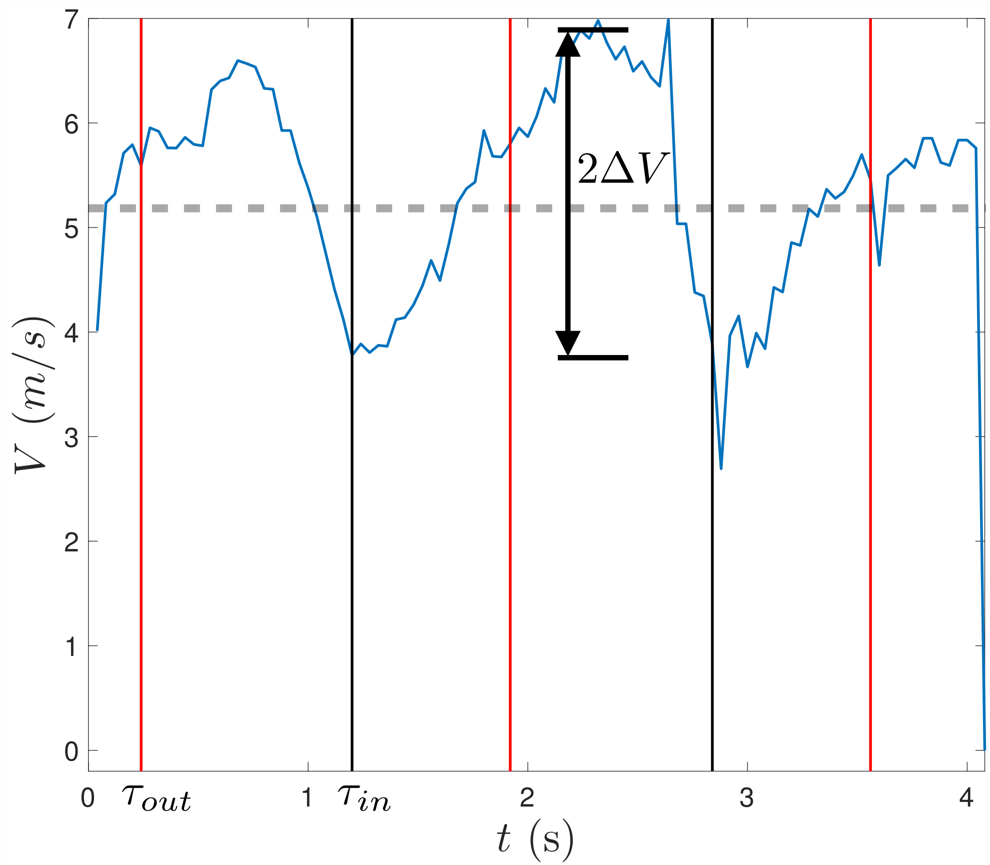
$$\overline{F_{prop}} \sim \rho S_{blade} \overline{V^2_{blade/w}}$$

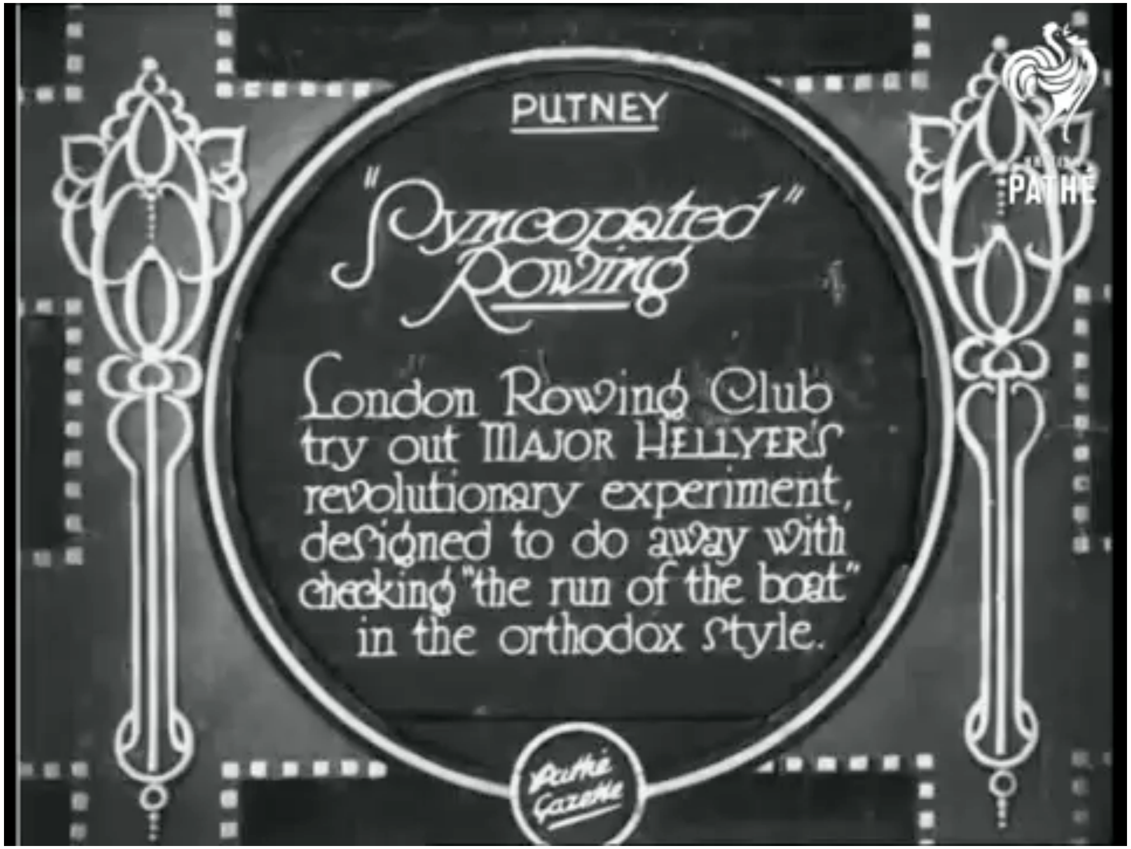



# Propulsive force

$$\overline{F_{prop}} \sim \rho S_{blade} \overline{V^2_{blade/w}}$$

$$V_{blade/w} = V_{boat/w} - \beta v_{rower/boat}$$




PUTNEY
"Syncopated" Rowing
London Rowing Club try out MAJOR HELLYER'S revolutionary experiment, designed to do away with checking "the run of the boat" in the orthodox style.

# Sports Physics