FISICA E FISIOLOGIA DEL CICLISMO

Mario Zeppegno Paolo Baldissera

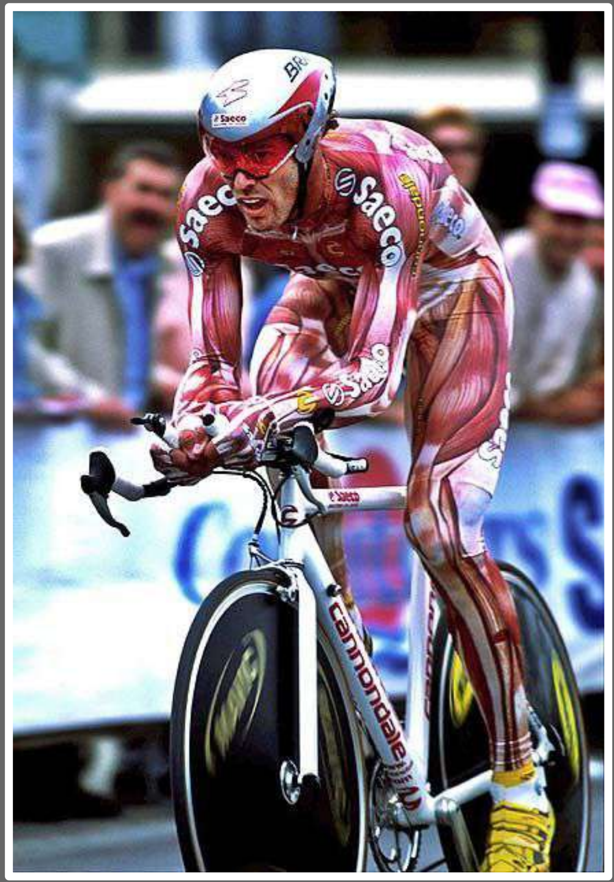
Versione online con video e animazioni:
https://goo.gl/956534

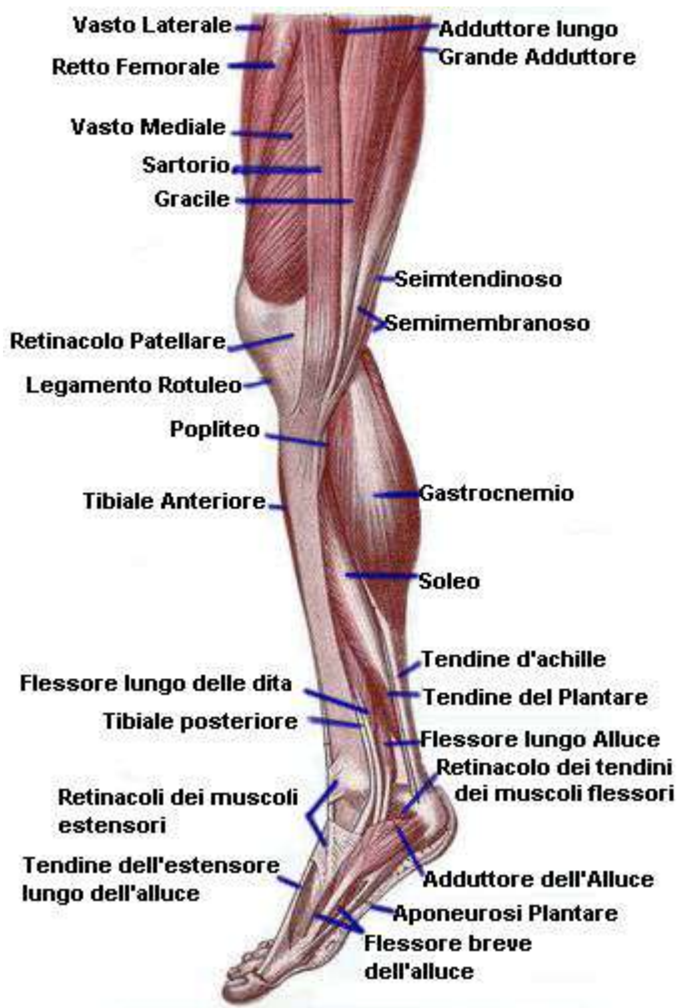
In principio Dio creò il Paradiso Terrestre che abbellì con il triciclo, indi gli animali che su di esso vi scorrazzarono in lungo e in largo.

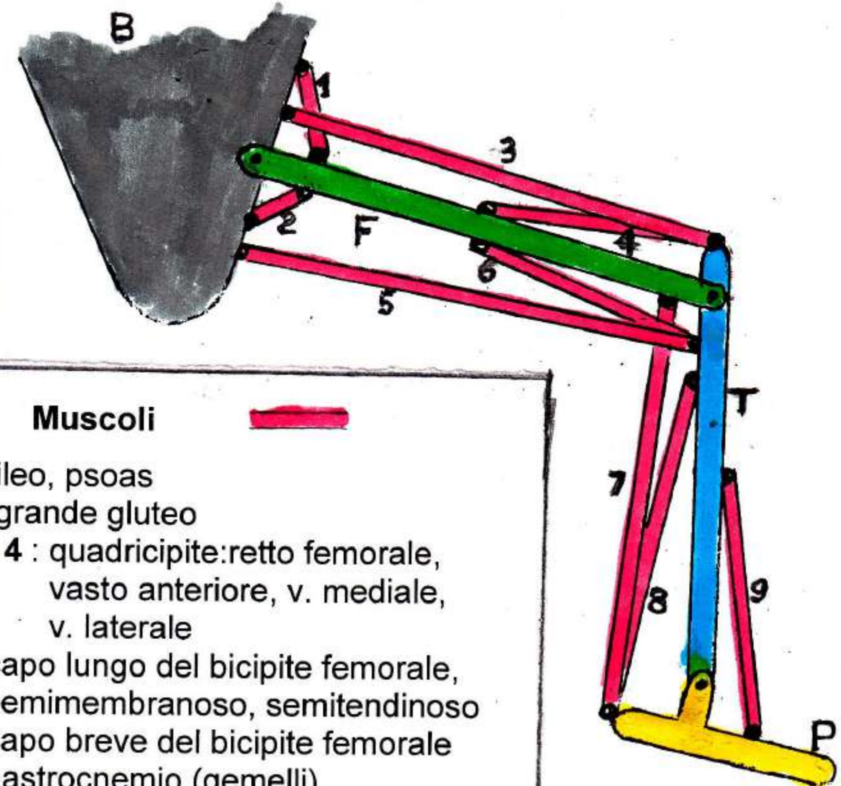
Poi commise un peccato di superbia:
creò la bicicletta, che però non stava in piedi.

Dio allora creò l'uomo che,
per miracolo,
riuscì a dominarla.

Forze







B : bacino
F : femore
T : tibia
P : piede

Muscoli

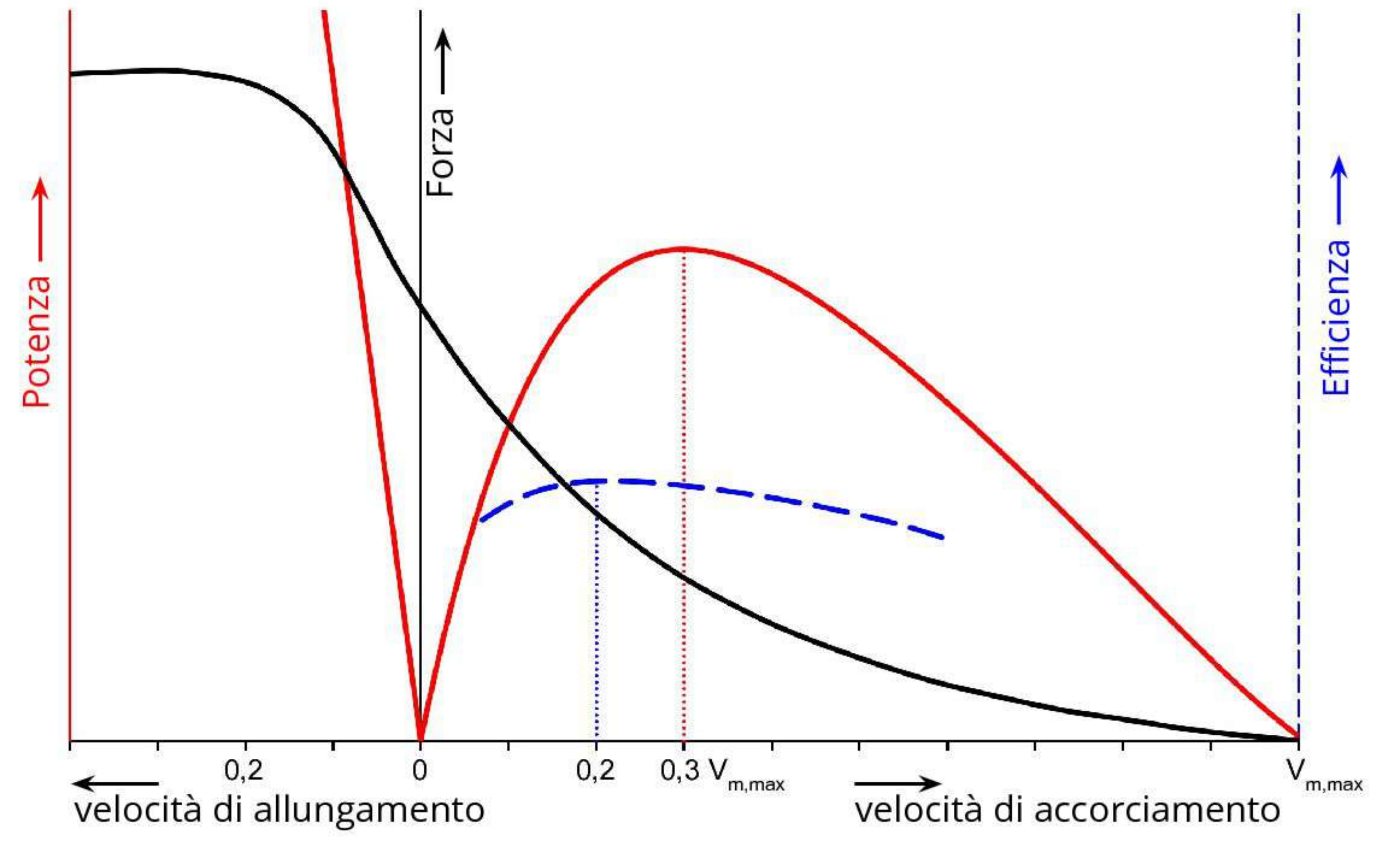
1 : ileo, psoas
2 : grande gluteo
3 e **4** : quadricipite:retto femorale, vasto anteriore, v. mediale, v. laterale
5 : capo lungo del bicipite femorale, semimembranoso, semitendinoso
6 : capo breve del bicipite femorale
7 : gastrocnemio (gemelli)
8 : soleo
9 : tibiale anteriore, estensore lungo dell'alluce, estens. lungo delle dita

Modalità di contrazione muscolare

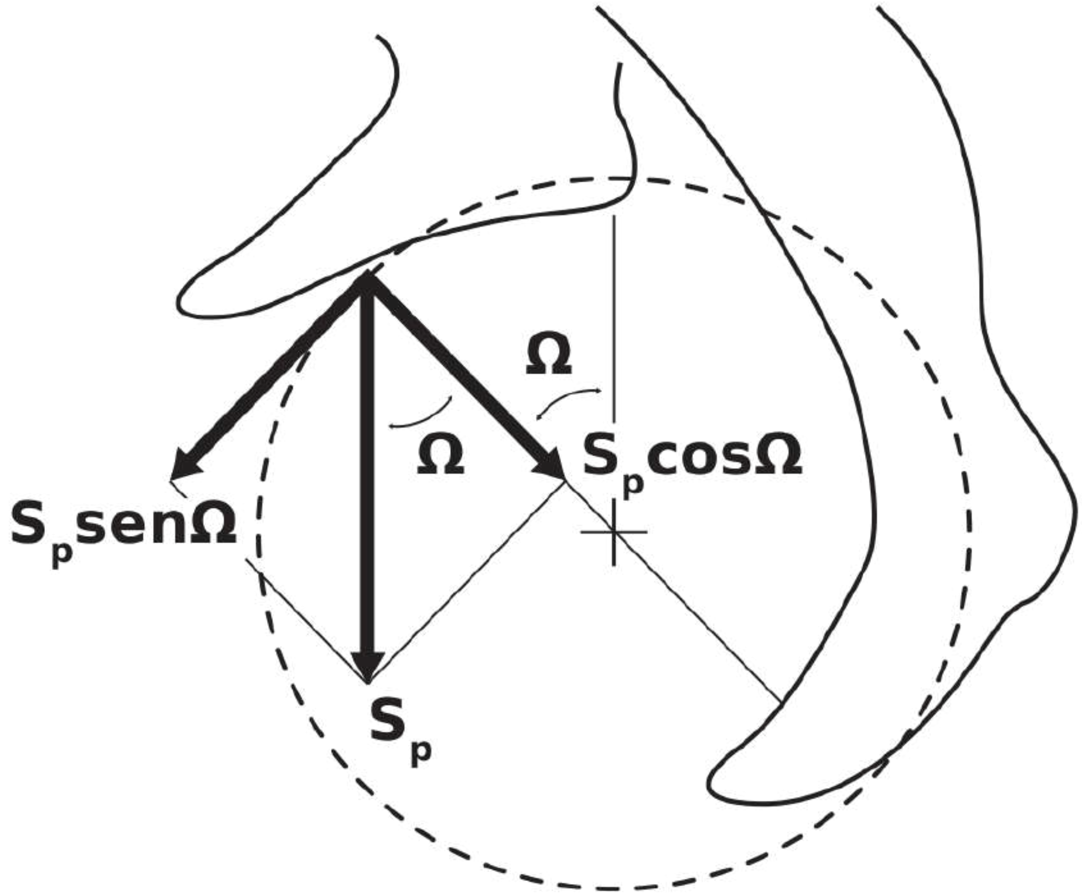
- **ISOMETRICA**
  azione statica
  es. soleo / tendine d'Achille

- **CONCENTRICA**
  azione dinamica con accorciamento
  es. quadricipite estensore della gamba

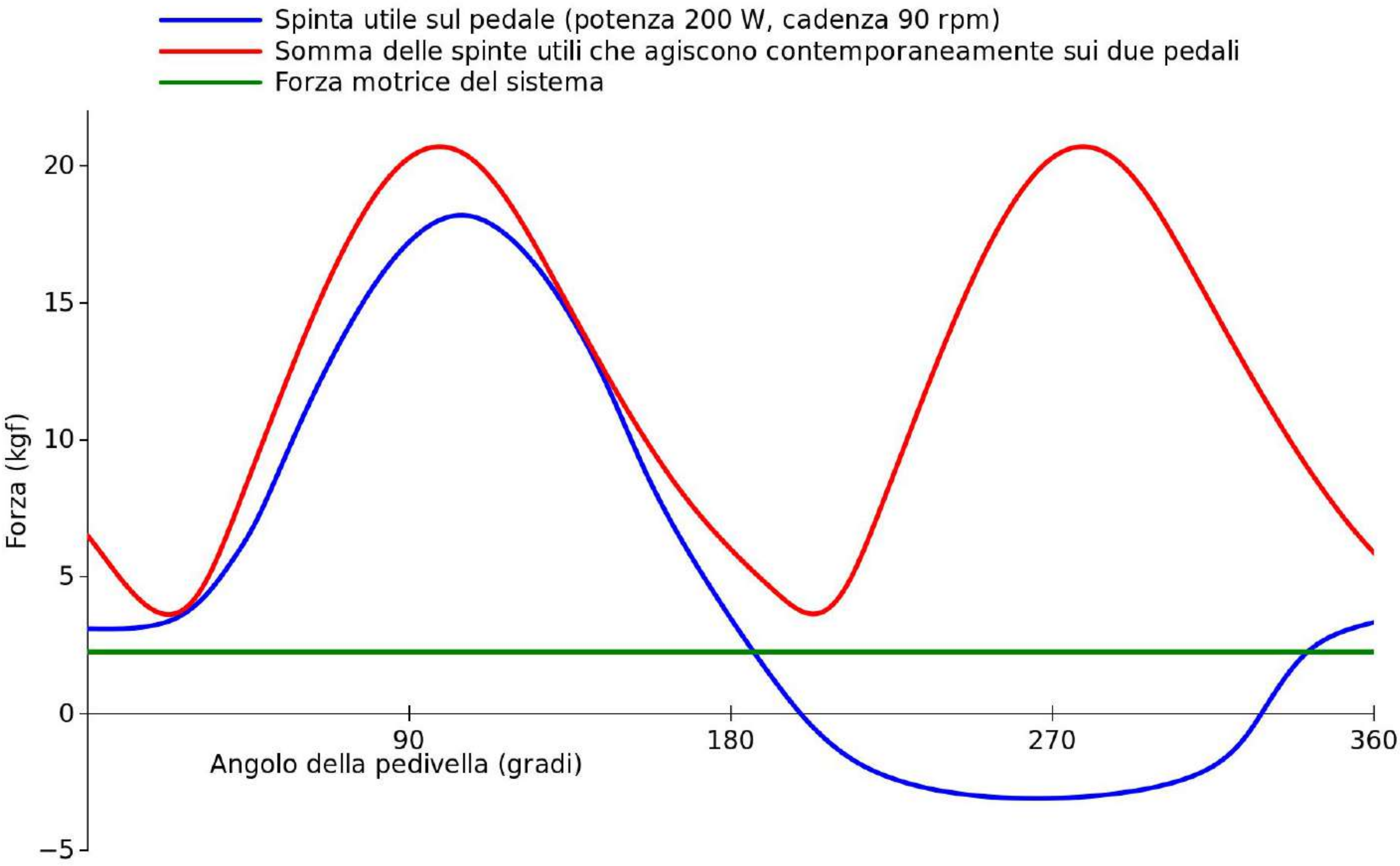
- **ECCENTRICA**
  azione dinamica con allungamento
  es. quadricipite flessore della gamba

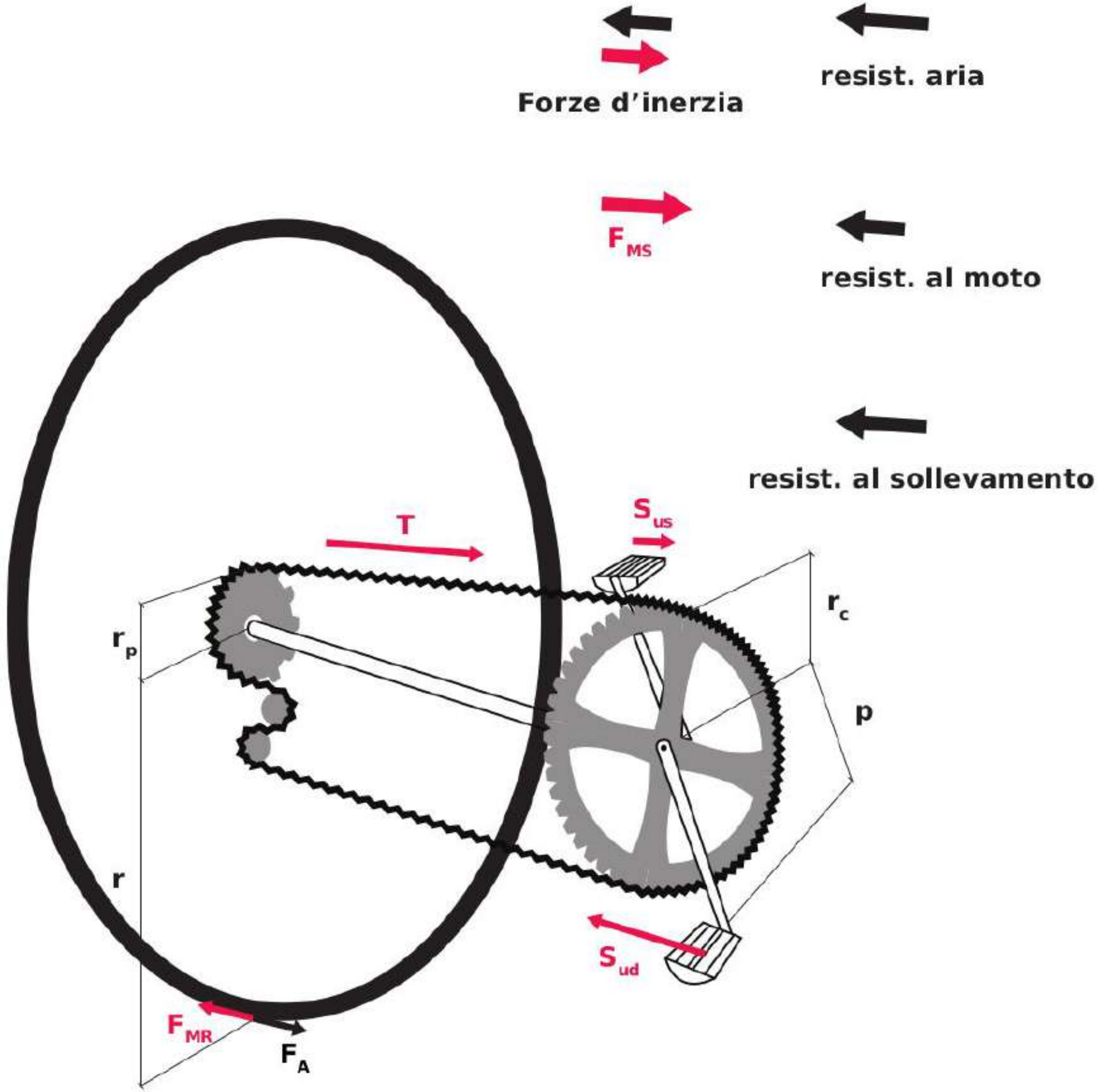


Potenza
Forza
Efficienza
0,2
0
0,2
0,3 $V_{m,max}$
$V_{m,max}$
velocità di allungamento
velocità di accorciamento

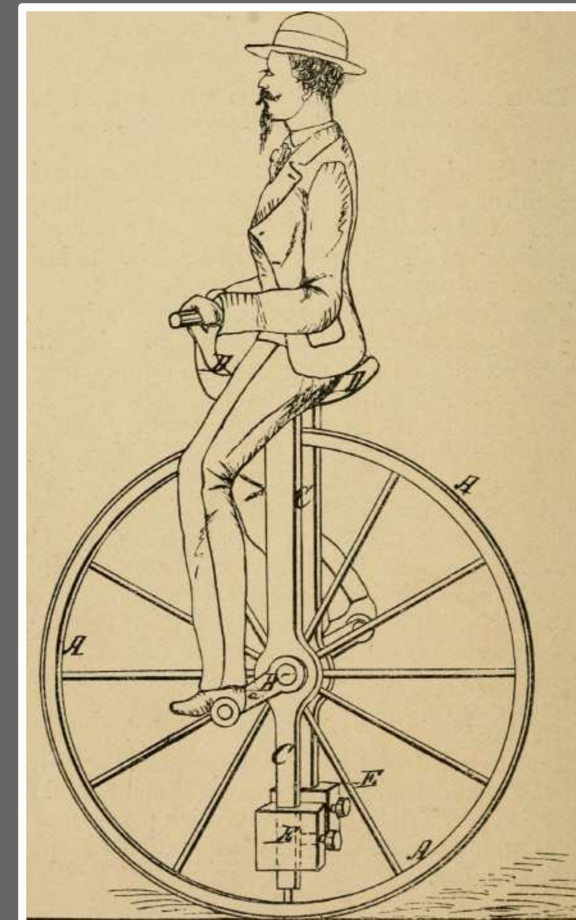


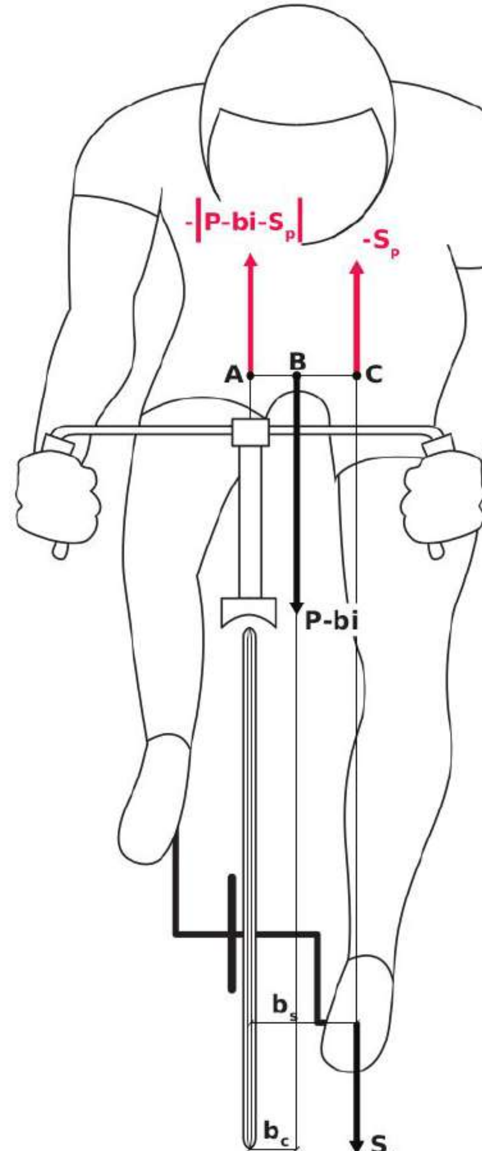
Ω
$S_p \cos\Omega$
Ω
$S_p \mathrm{sen}\Omega$
S_p


Spinta utile sul pedale (potenza 200 W, cadenza 90 rpm)
Somma delle spinte utili che agiscono contemporaneamente sui due pedali
Forza motrice del sistema
Forza (kgf)
20
15
10
5
0
−5
90
180
270
360
Angolo della pedivella (gradi)


Forze d'inerzia
resist. aria
F_{MS}
resist. al moto
resist. al sollevamento
T
S_{us}
r_c
r_p
p
r
S_{ud}
F_{MR}
F_A

Equilibrio





-|P-bi-Sp|
-Sp
A
B
C
P-bi
bs
bc
Sp

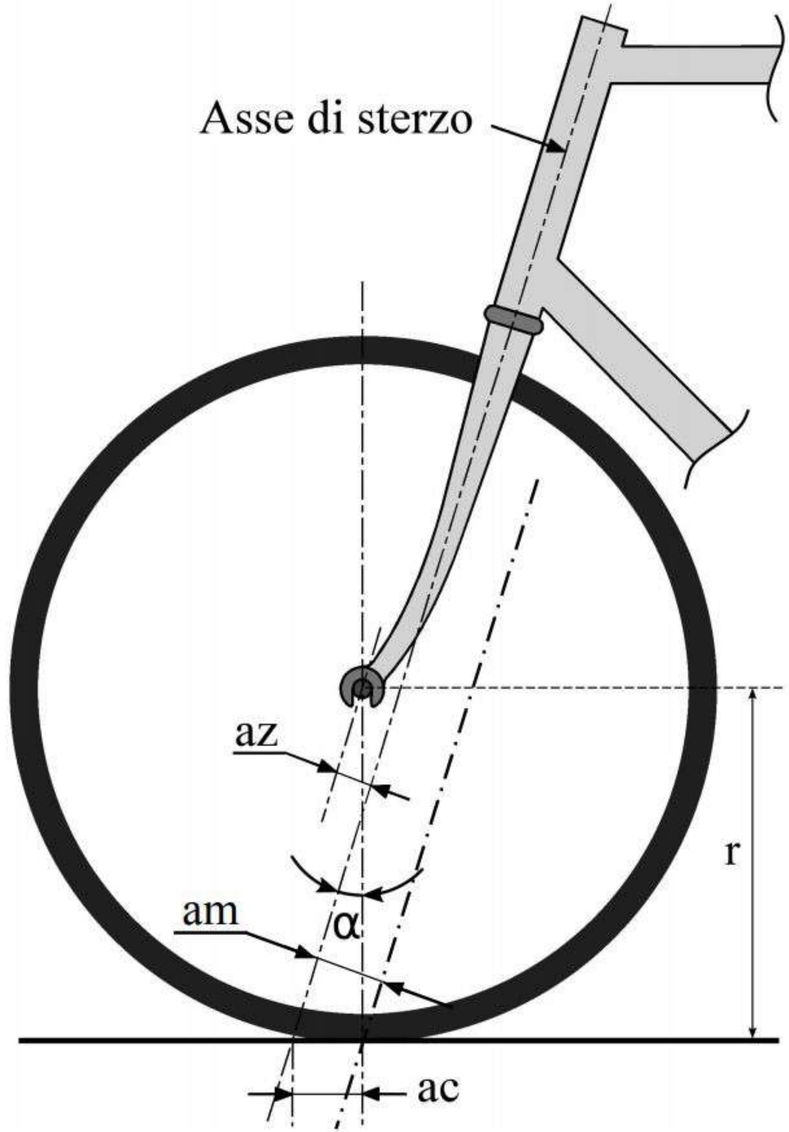
Deviazione dalla traiettoria rettilinea

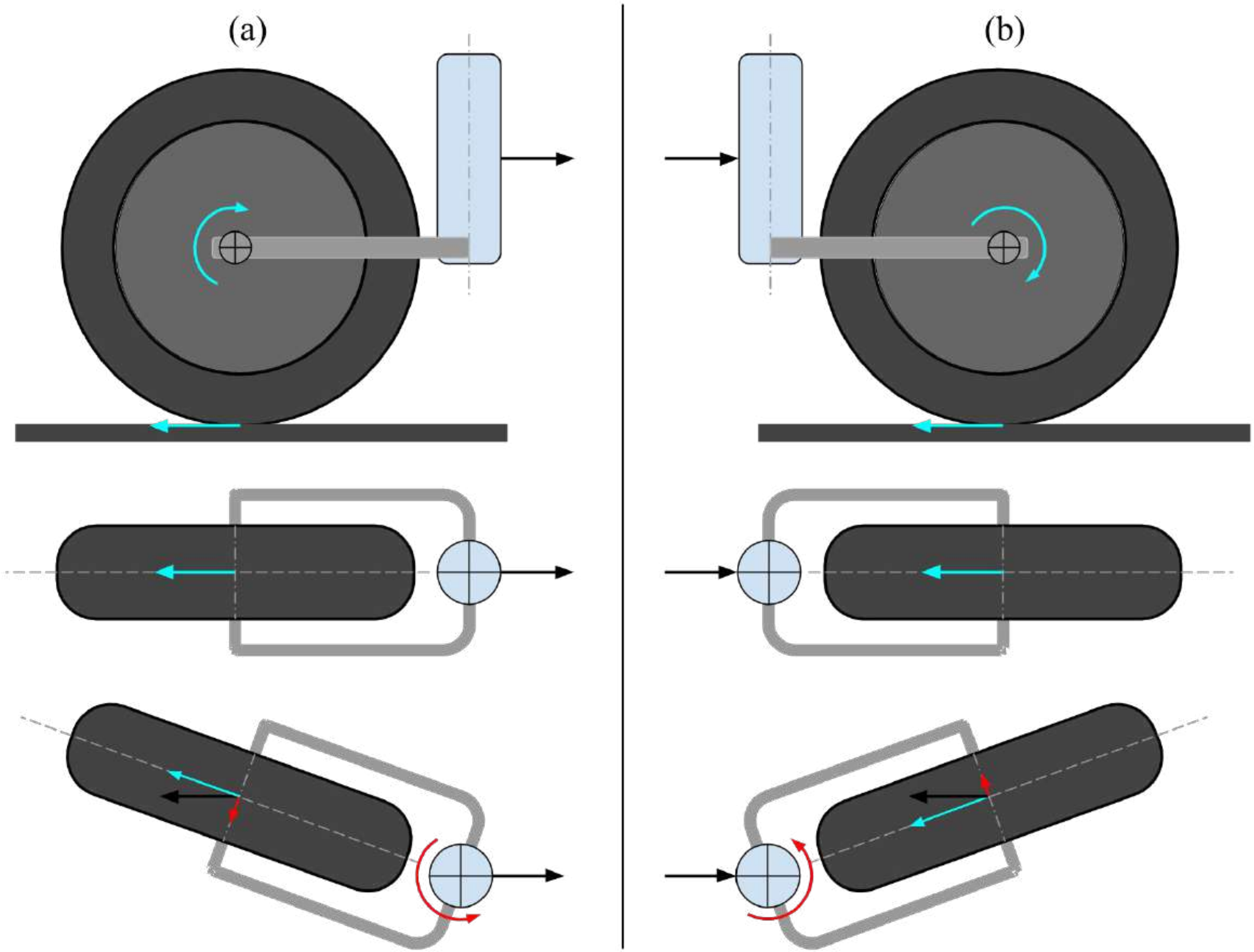
$$\dot{\psi} = \frac{P \times \tan\Theta \times g}{P \times v} \text{(rad/s)}$$


GIANT
JOKER
Alpecin


GIANT
JOKER

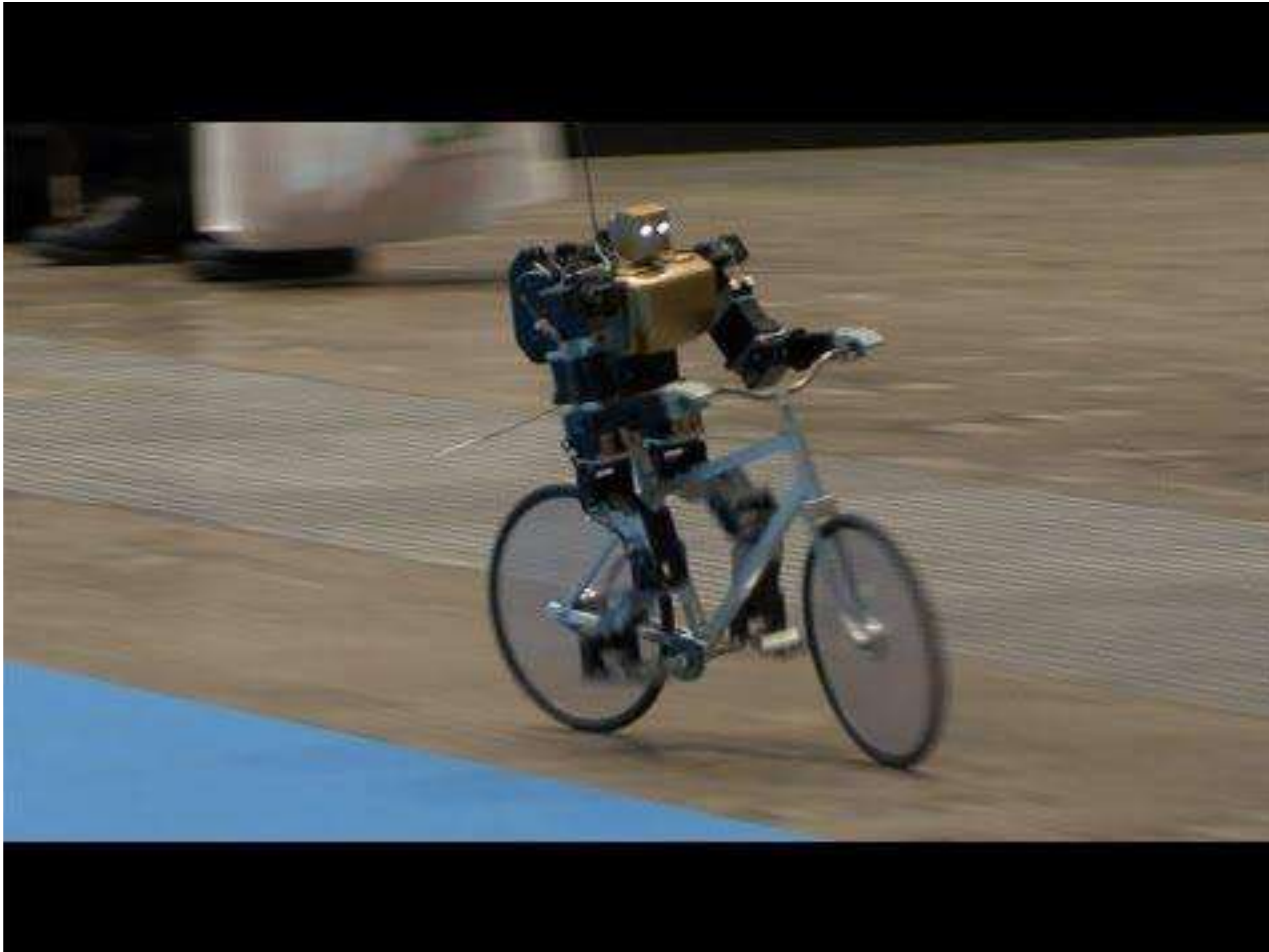

TREK


Asse di sterzo
az
α
am
r
ac


(a)
(b)

Deviazione dalla traiettoria rettilinea

$$\dot{\psi} = \frac{P \times \tan\Theta \times g}{P \times v} \ (rad/s)$$



$$\left.\begin{aligned} x_1 &= x + a\frac{dx}{ds}, \\ y_1 &= y + a\frac{dy}{ds}, \\ (x_1 - x)^2 + (y_1 - y)^2 &= a^2. \end{aligned}\right\} \qquad (l)$$

Differentiating the last of these equations and using the first two, we obtain,

$$dx(dx_1 - dx) + dy(dy_1 - dy) = 0,$$

from which

$$dx\,dx_1 + dy\,dy_1 = dx^2 + dy^2 = ds^2$$

or

$$\frac{dx}{ds}\frac{dx_1}{ds} + \frac{dy}{ds}\frac{dy_1}{ds} = 1. \qquad (m)$$

Considering now the trajectory s_1 of the point of contact B of the front wheel and denoting by ds_1 an element of this trajectory, the cosines of the angles that this element makes with the x- and y-axes are

$$\frac{dx_1}{ds_1} \quad \text{and} \quad \frac{dy_1}{ds_1},$$

and we find, for the cosine of the angle α, the following expression:

$$\cos\alpha = \frac{dx}{ds}\frac{dx_1}{ds_1} + \frac{dy}{ds}\frac{dy_1}{ds_1}. \qquad (n)$$

Comparing Eqs. (m) and (n), we conclude that

$$ds = ds_1 \cos\alpha. \qquad (o)$$

Differentiating now the first two of Eqs. (l), squaring them, and adding together, we find

$$\begin{aligned} a^2\left[\left(\frac{d^2x}{ds^2}\right)^2 + \left(\frac{d^2y}{ds^2}\right)^2\right] &= \left(\frac{dx_1}{ds} - \frac{dx}{ds}\right)^2 + \left(\frac{dy_1}{ds} - \frac{dy}{ds}\right)^2 \\ &= \left(\frac{dx_1}{ds_1}\frac{1}{\cos\alpha} - \frac{dx}{ds}\right)^2 + \left(\frac{dy_1}{ds_1}\frac{1}{\cos\alpha} - \frac{dy}{ds}\right)^2. \end{aligned} \qquad (p)$$

Assuming now that the x-axis coincides with the line AM, we obtain

$$\frac{dx_1}{ds_1} = \cos\alpha, \qquad \frac{dx}{ds} = 1, \qquad \frac{dy_1}{ds_1} = \sin\alpha, \qquad \frac{dy}{ds} = 0,$$

and Eq. (p) gives

$$a^2\left[\left(\frac{d^2x}{ds^2}\right)^2 + \left(\frac{d^2y}{ds^2}\right)^2\right] = \frac{a^2}{R^2} = \tan^2\alpha$$

or

$$a = R\tan\alpha. \qquad (q)$$

The same conclusion can be obtained also from the right triangle ABO in Fig. 196, which proves that the intersection point O of the perpendiculars AO and BO is the center of curvature of the trajectory s. If we keep the angle α constant, both the trajectories s and s_1 become concentric circles of radii R and $R/\cos\alpha$, respectively.

Using Eq. (q), we rewrite now our equation of motion (k) in the following form:

$$\frac{d^2\theta}{dt^2} + \frac{b}{h}\frac{d}{dt}\left(\frac{v\tan\alpha}{a}\right) = \frac{g\theta}{h} - \frac{v^2}{hR}. \qquad (r)$$

We obtain a very simple solution of this equation by assuming θ, α, and v constant. The bicycle is moving with constant velocity, with constant angle of inclination of the plane of the frame to the vertical, and with a constant angle α. Equation (r) is then satisfied if we put

$$\frac{g\theta}{h} - \frac{v^2}{hR} = 0. \qquad (s)$$

This same conclusion may be reached in a very simple manner by equating the moments, with respect to the axis AB, of the gravity force and of the centrifugal force applied at the center of gravity C.

We can discuss also some more complicated cases if we only assume that the angle α is small and that the velocity v is approximately constant. Substituting α for $\tan\alpha$ and the average velocity v_a for v in Eq. (r), we obtain

$$\frac{d^2\theta}{dt^2} + \frac{bv_a}{ha}\frac{d\alpha}{dt} = \frac{g}{h}\left(\theta - \frac{v_a^2\alpha}{ga}\right). \qquad (t)$$

It is seen that by a proper variation of the angle α, we can make the bicycle move with a constant angle of inclination θ of the frame. When θ is constant, Eq. (t) gives

$$\frac{d\alpha}{dt} = \frac{ag}{bv_a}\left(\theta - \frac{v_a^2\alpha}{ga}\right);$$

and by integration we obtain,

$$\alpha = \frac{ag\theta}{v_a^2} + Ce^{-\frac{v_a t}{b}}, \qquad (u)$$

where C is a constant of integration which can be determined if the initial value of α is known. We see that the term containing C diminishes with time and the angle α approaches the value satisfying the condition of equilibrium (s) between the gravity force and the centrifugal force.

Returning now to Eq. (t), we assume that the right-hand side of this equation does not vanish; *i.e.*, there is no equilibrium of the gravity force and centrifugal force. If at the same time α is constant, the term containing $d\alpha/dt$ vanishes and we can integrate the equation. In this way, we shall obtain for θ an exponential function which indicates that the condition is unstable. If the right-hand side of the equation is positive and $d\theta/dt$ is positive, the angle θ will be increasing and the bicycle will be falling down. To prevent this, we have to change the sign of $d\theta/dt$. This can be accomplished by utilizing, in Eq. (t), the term containing $d\alpha/dt$. By rapidly increasing the angle α, we can make $d^2\theta/dt^2$ negative, which will finally change the sign of $d\theta/dt$. By rapidly turning the front wheel in the direction in which the bicycle is falling, we can stop the increase of the angle θ. We see that the necessary stability of the moving bicycle can be established by proper turning of the front wheel.

We neglected in our discussion the rotation of the wheels with respect to their axes and considered only the motion of the center of gravity of the system. This is by far the most important factor, and the approximate equation (t) gives a satisfactory explanation of the stability of a bicycle.

$$\left.\begin{aligned} x_1 &= x + a\frac{dx}{ds}, \\ y_1 &= y + a\frac{dy}{ds}, \\ (x_1 - x)^2 + (y_1 - y)^2 &= a^2. \end{aligned}\right\} \tag{l}$$

Differentiating the last of these equations and using the first two, we obtain,

$$dx(dx_1 - dx) + dy(dy_1 - dy) = 0,$$

from which

$$dx\,dx_1 + dy\,dy_1 = dx^2 + dy^2 = ds^2$$

or

$$\cos\alpha = \frac{dx}{ds}\frac{dx_1}{ds_1} + \frac{dy}{ds}\frac{dy_1}{ds_1}. \tag{n}$$

and Eq. (p) gives

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Deviazione dalla traiettoria rettilinea

Senza rotazione delle ruote:

$$\dot{\psi} = \frac{P \times \tan\Theta \times g}{P \times v} \text{ (rad/s)}$$

Con rotazione delle ruote:

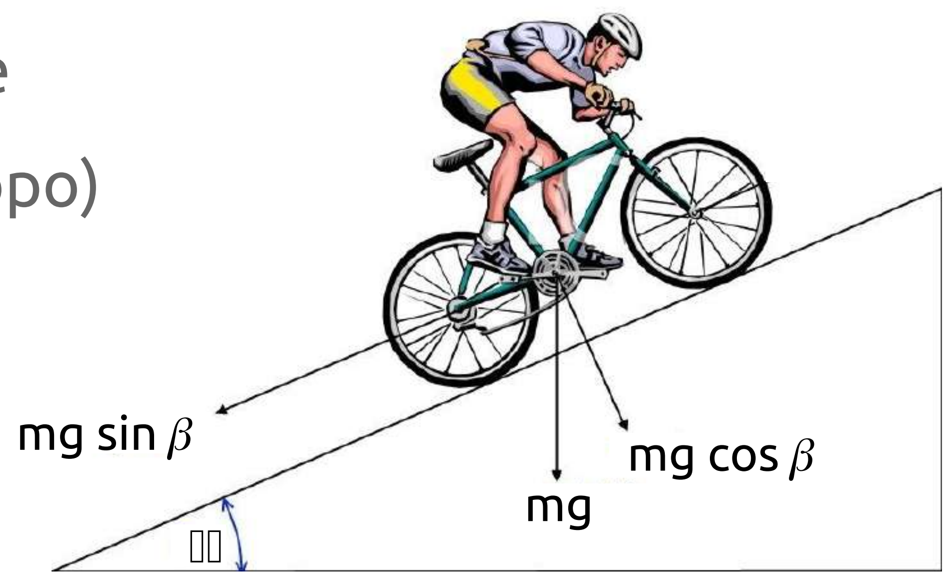
$$\dot{\psi} = \frac{P \times \tan\Theta \times g}{P \times v} : \left(1 + \boxed{\frac{2I}{Pdr}}\right) \text{ (rad/s)}$$

$$\frac{2I}{Pdr} = \mathbf{0{,}0087}$$

Resistenze

Gravità

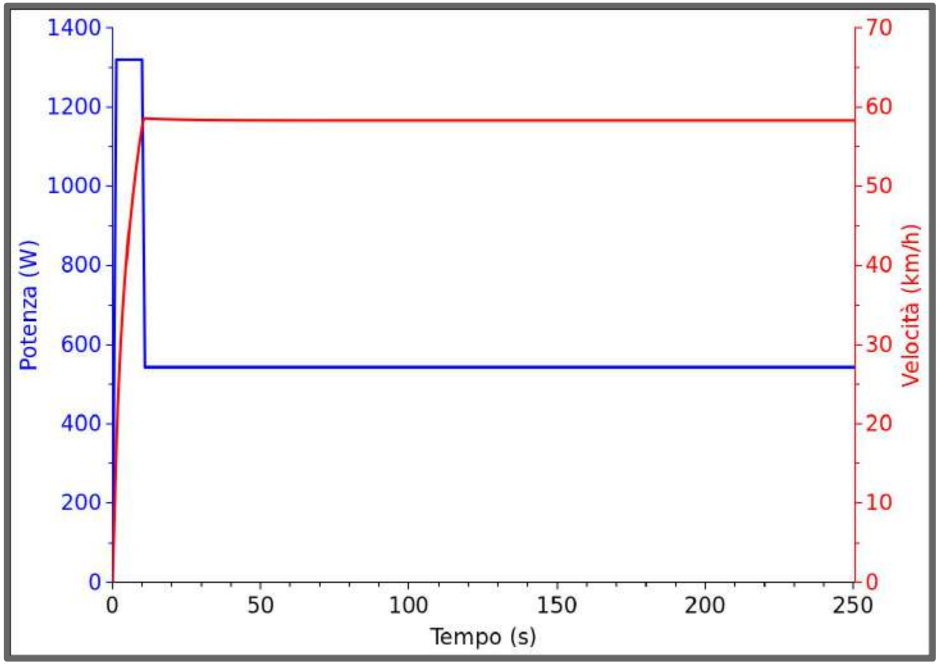
- La resistenza più “popolare”
  E’ uno dei principali “motori” del mercato ciclistico: salite famose, emulazione pro, maniaci del grammo, ecc.
- Restituzione energia potenziale in discesa solo parziale:
  - necessità di frenare
  - aerodinamica (v. dopo)



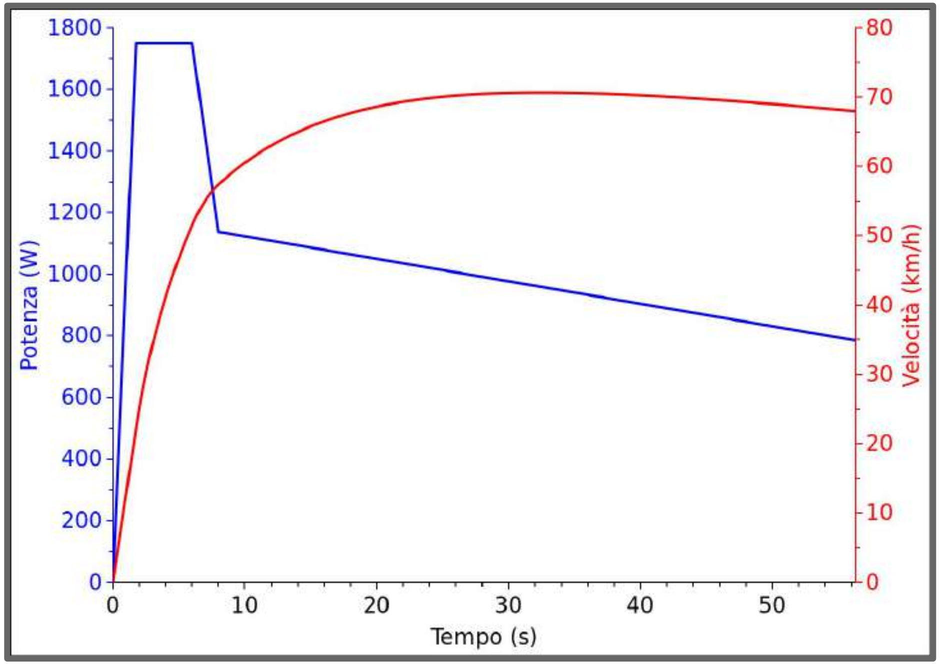
Inerzia

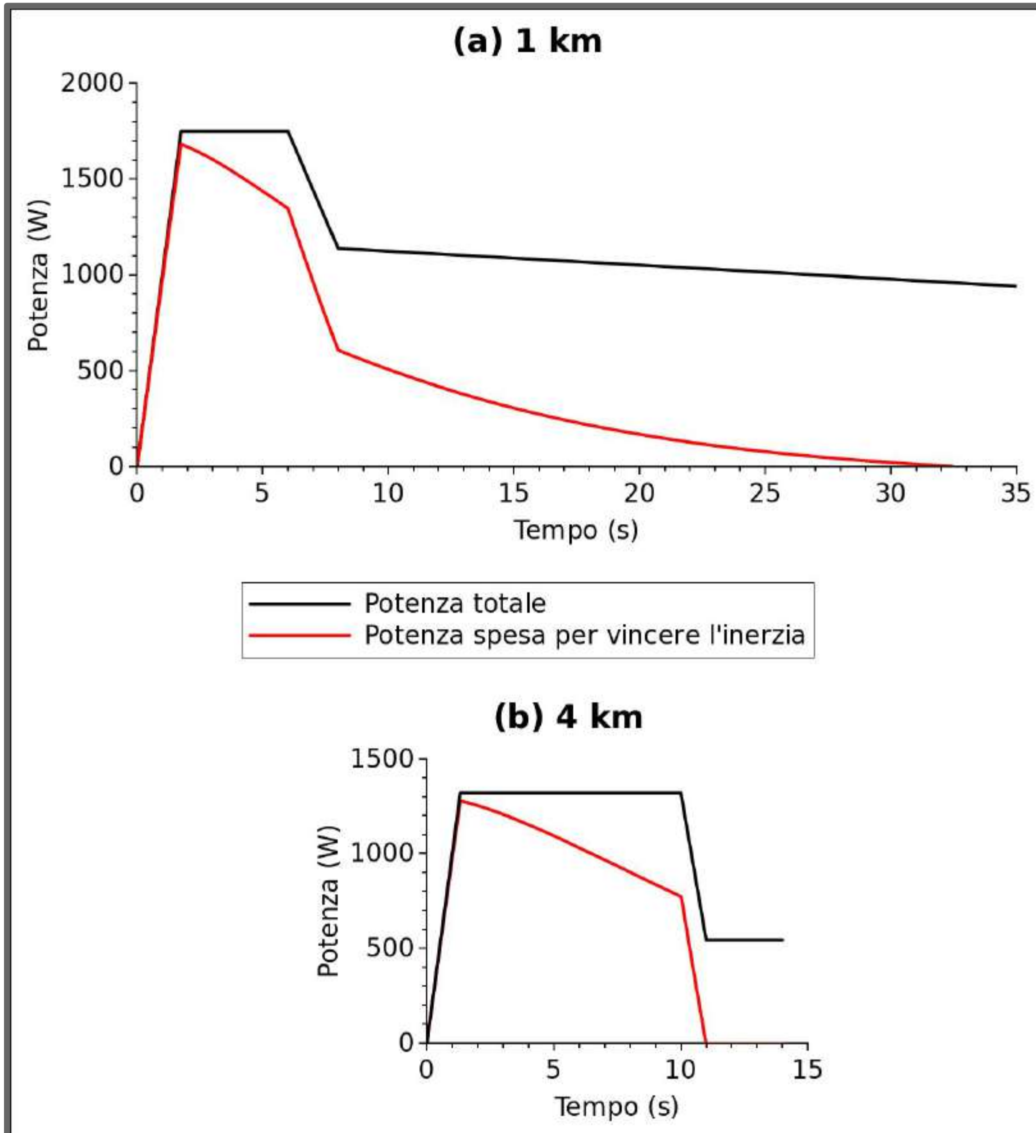
Arma a doppio taglio: gioca sempre contro le variazioni di velocità. Utile per “rifiatare”, costa per accelerare.

4 km inseguimento



1 km da fermo




(a) 1 km
2000
1500
1000
500
0
Potenza (W)
0
5
10
15
20
25
30
35
Tempo (s)
Potenza totale
Potenza spesa per vincere l'inerzia
(b) 4 km
1500
1000
500
0
Potenza (W)
0
5
10
15
Tempo (s)

Perdite nella trasmissione della potenza

1. **Deformazioni cicliche** sotto carico:
   a. pedali e pedivelle;
   b. telaio, forcella, manubrio, ruote;
   c. corone dentate e catena.

→ **RIGIDEZZA**

2. **Attriti**:
   a. nei cuscinetti;
   b. nelle maglie della catena;
   c. tra catena e corone/pignoni.

→ **PRECISIONE**
LUBRIFICAZIONE
ALLINEAMENTO

Dettaglio catena

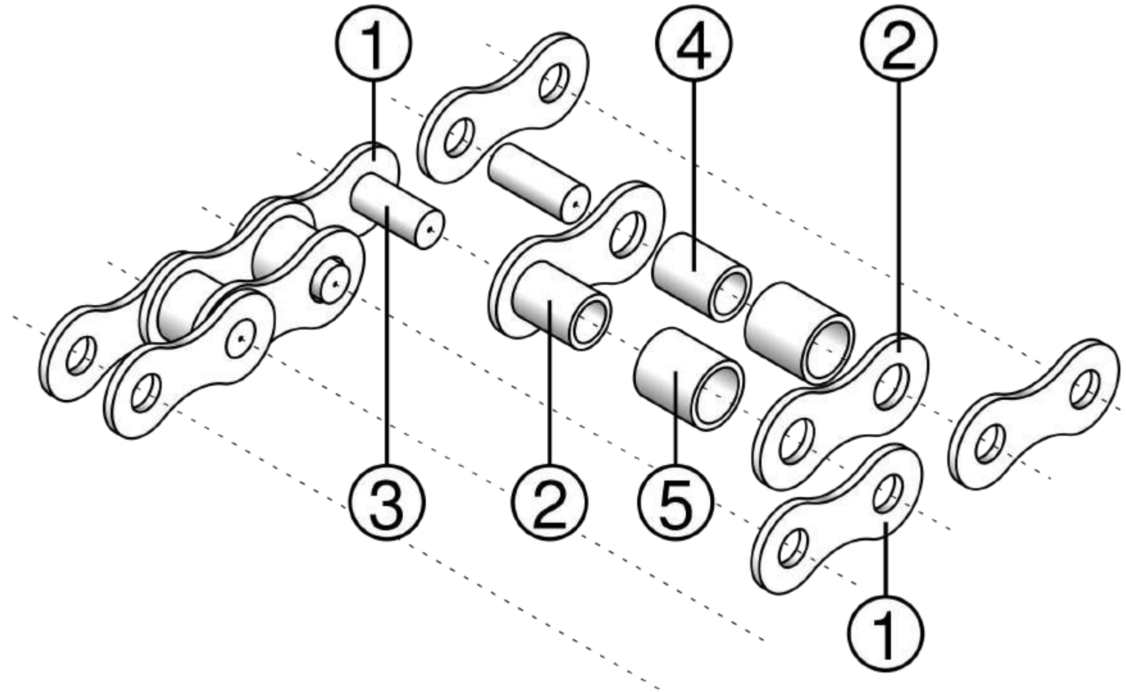
1) Maglia esterna

2) Maglia interna

3) Perno

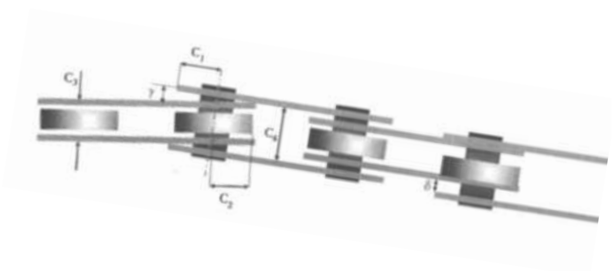
4) Bussole

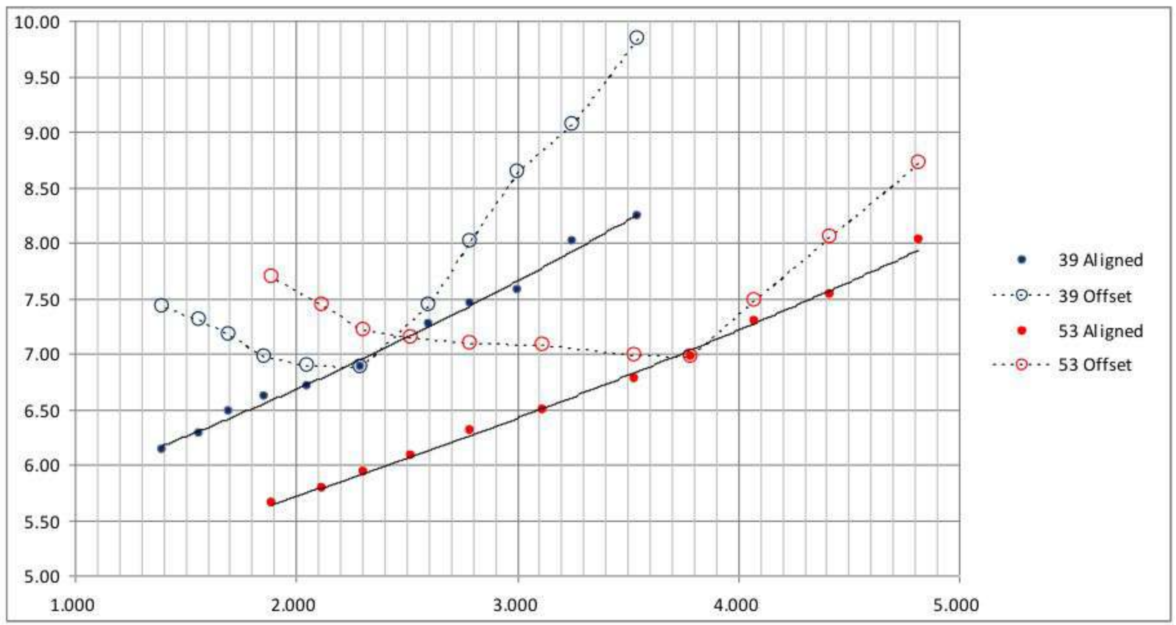
5) Rullo girevole



Il lubrificante funziona anche (soprattutto?) da “riempitivo” evitando che entri sporcizia nei giochi tra le parti.


11
10
9
8
7
6
5
4
3
2
1
Pignoni da 6 a 11 con la corona interna
Pignoni da 1 a 8 con la corona esterna




10.00
9.50
9.00
8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
1.000
2.000
3.000
4.000
5.000
39 Aligned
39 Offset
53 Aligned
53 Offset

Resistenza al rotolamento

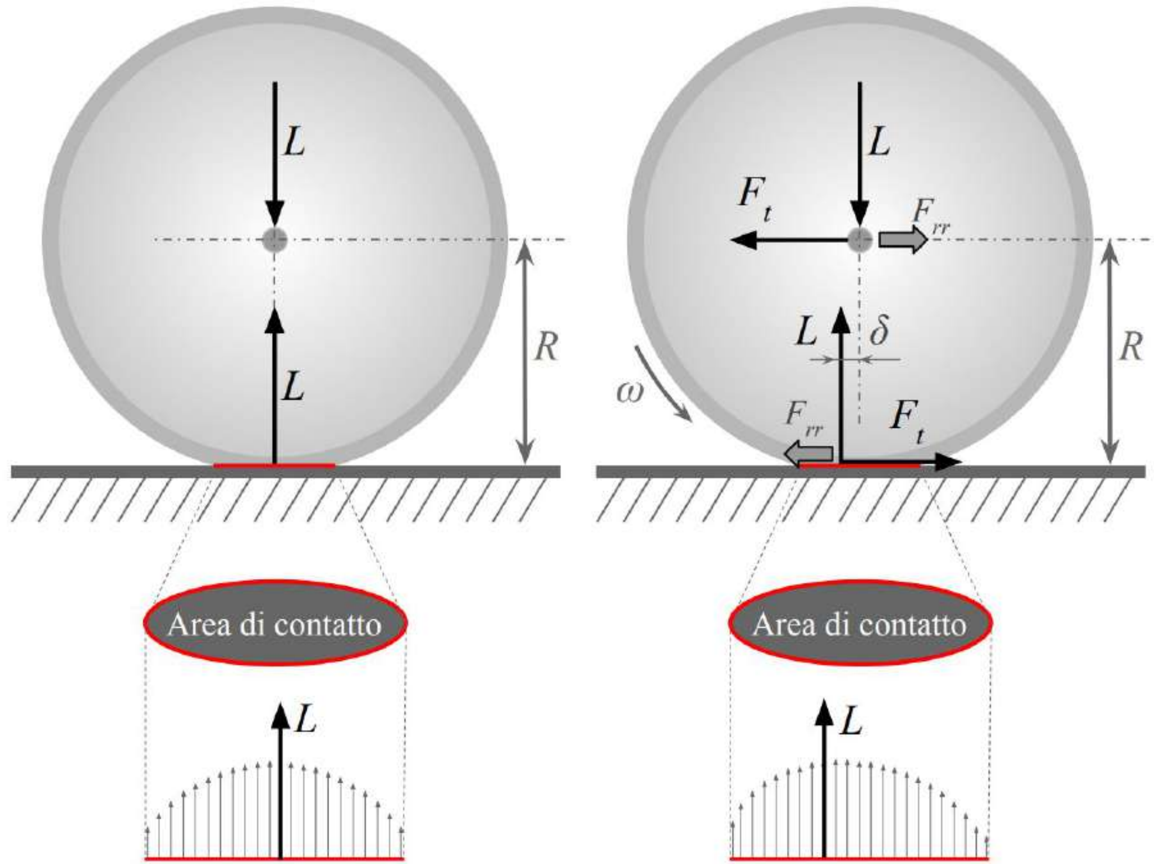
$$P_{rr} = m \cdot C_{rr} \cdot v \,[\mathrm{W}]$$

Valori tipici C_{rr} :

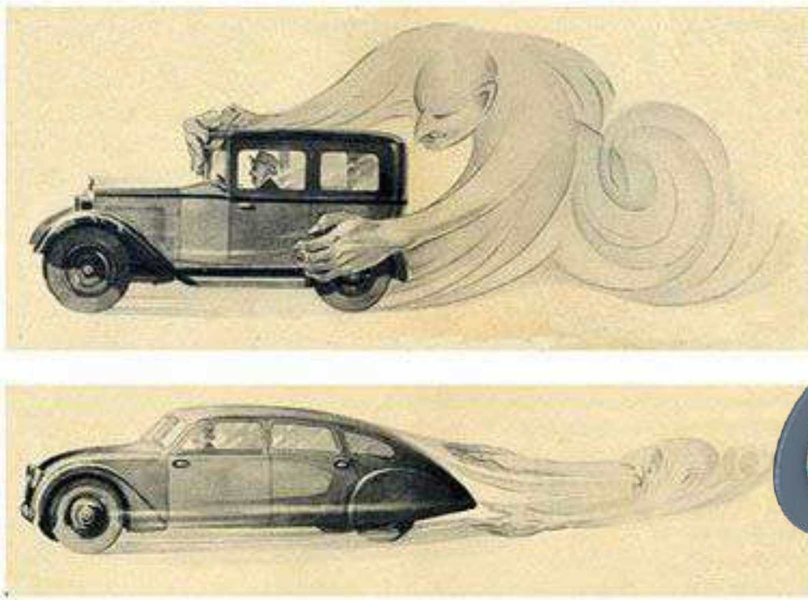
Asfalto 0.004-0.005

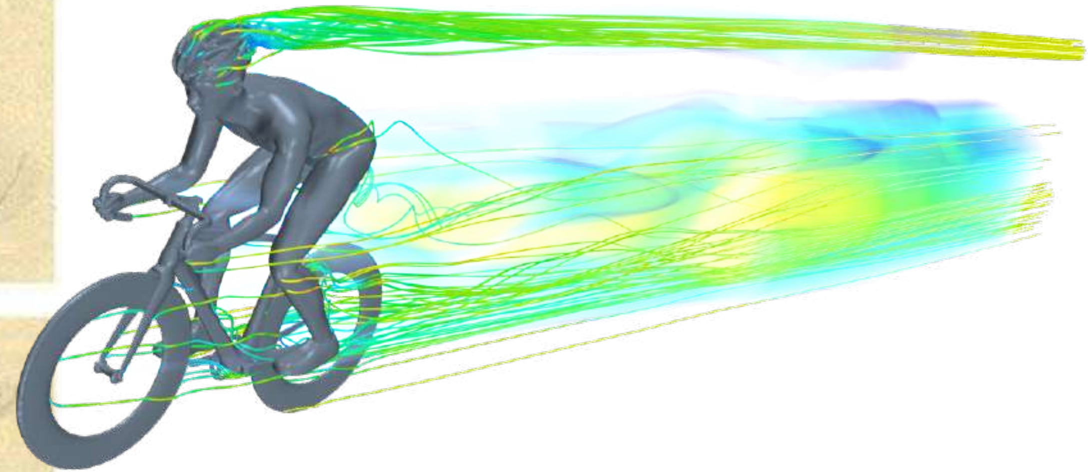
Cemento levigato 0.002

Legno 0.001



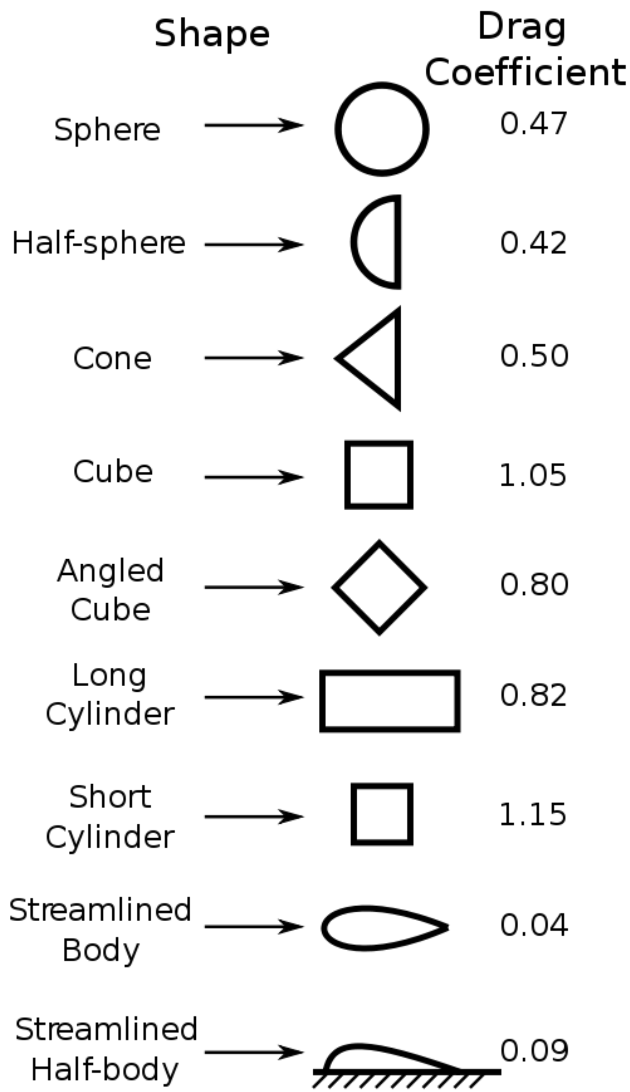
Aerodinamica





$$C_D = \frac{2D}{\rho A v^2} \quad \Rightarrow \quad D = \frac{1}{2}\rho \boxed{AC_D} v^2 \ [\mathrm{N}]$$

$$P = D \cdot v = \frac{1}{2}\rho \boxed{AC_D} v^3 \ [\mathrm{W}]$$

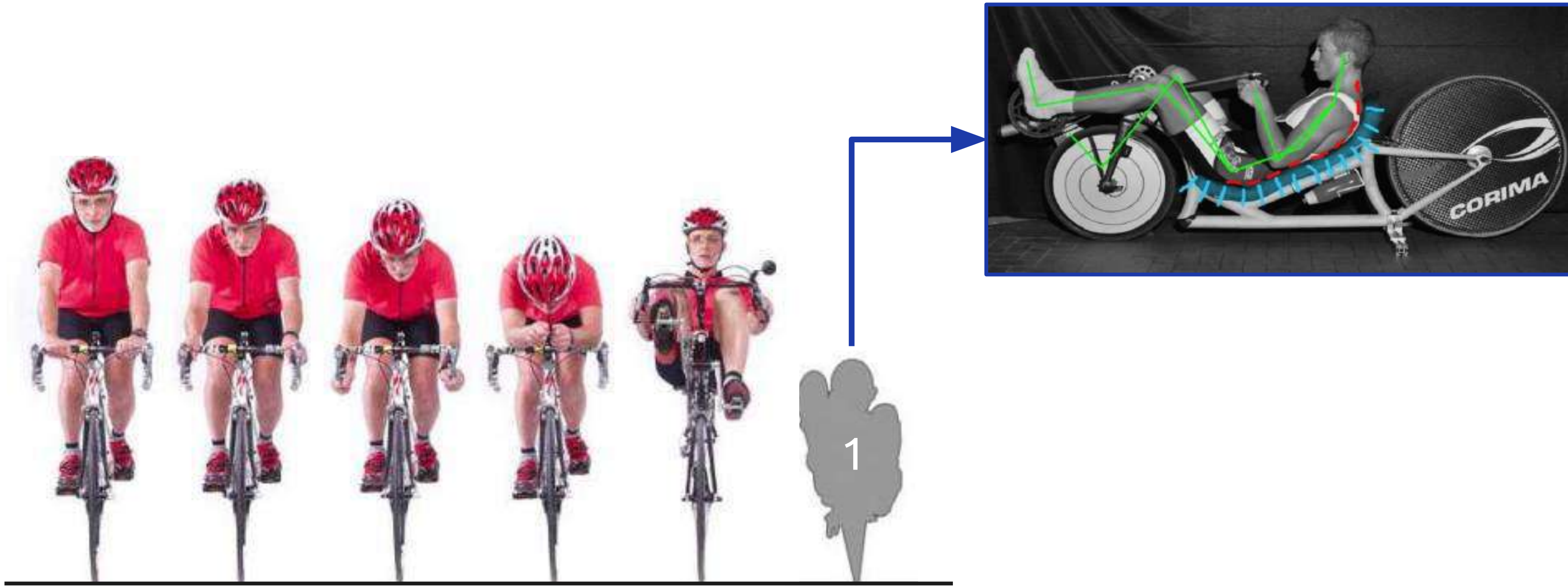

Shape
Drag Coefficient
Sphere 0.47
Half-sphere 0.42
Cone 0.50
Cube 1.05
Angled Cube 0.80
Long Cylinder 0.82
Short Cylinder 1.15
Streamlined Body 0.04
Streamlined Half-body 0.09


PAC-CAR
$C_D = 0.075$

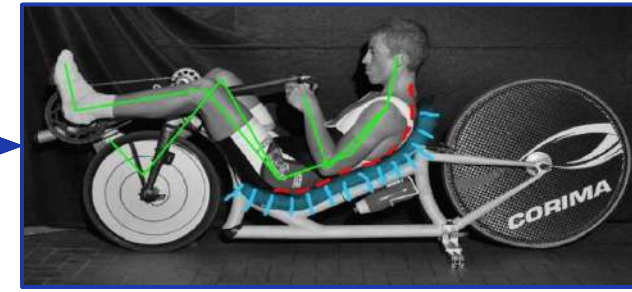

FIAT Turbina
$C_D = 0.14$


Tesla model 3
$C_D = 0.23$

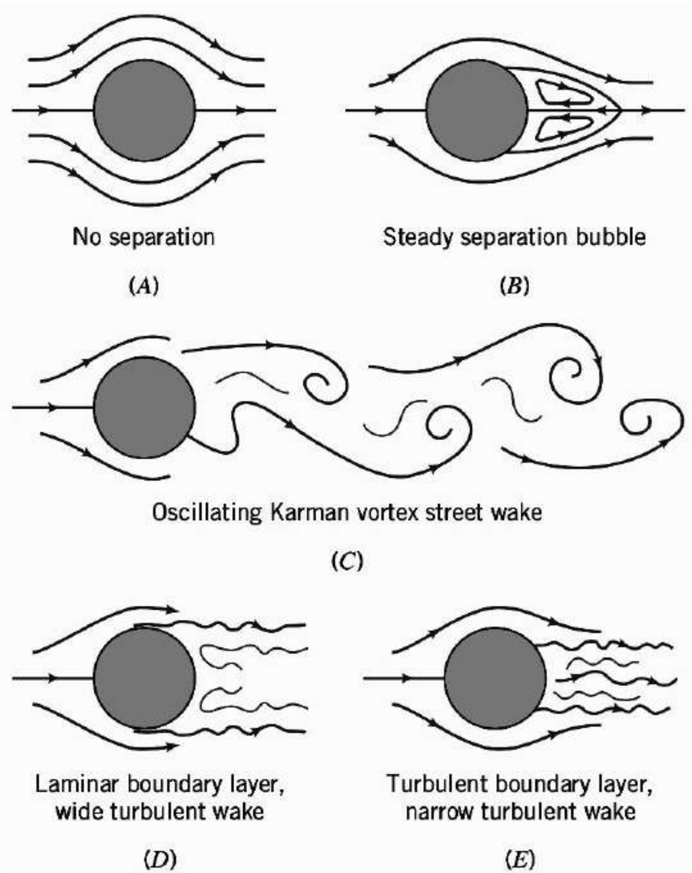
C_D	0.80	0.70	0.60	0.40
$C_D A$ [m^2]	0.50	0.40	0.30	0.20

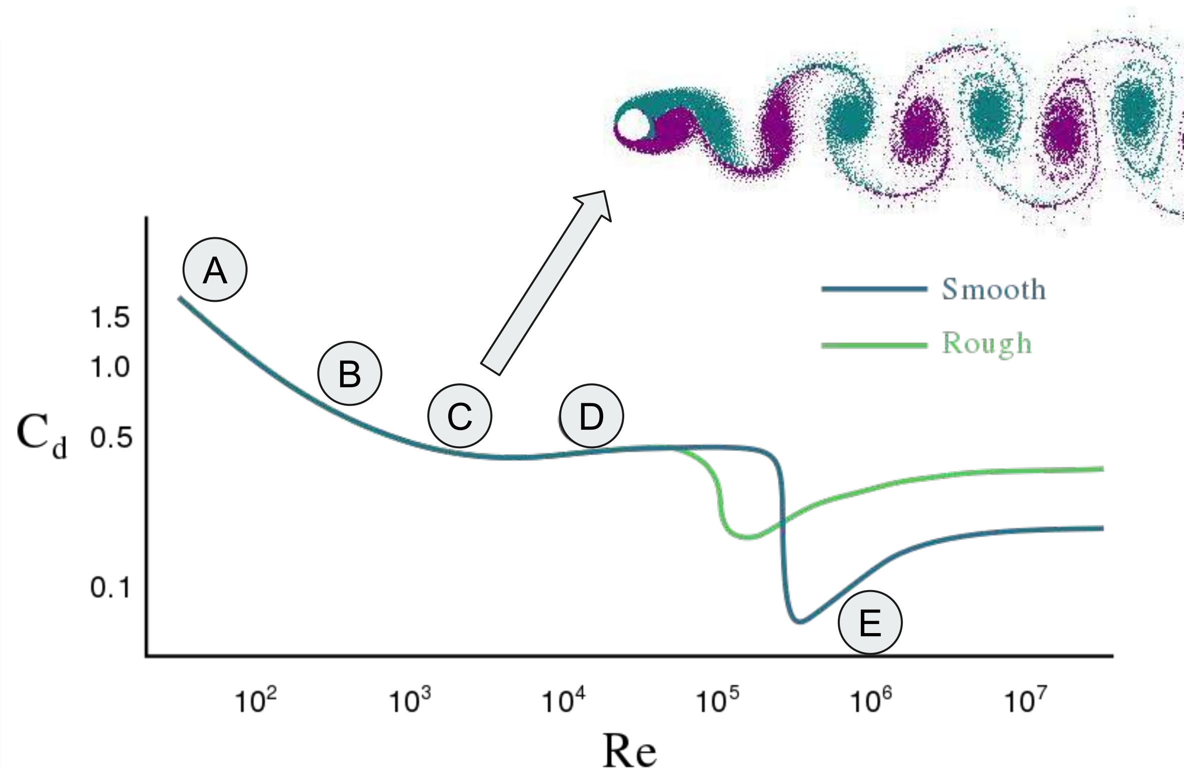


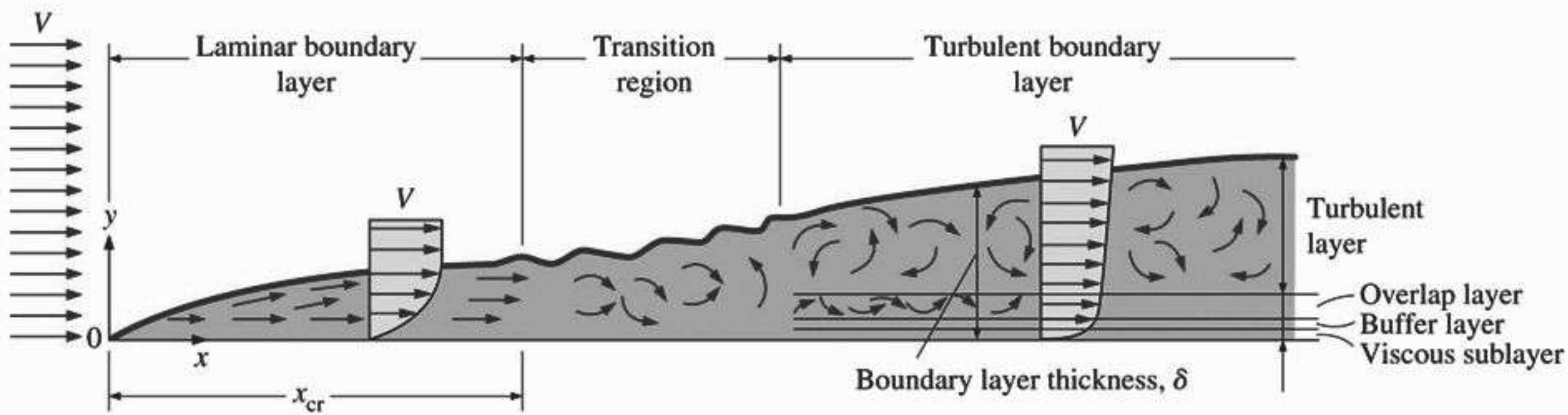
C_D	0.80	0.70	0.60	0.40	0.35	0.35
$C_D A$ [m^2]	0.50	0.40	0.30	0.20	0.12	0.10



C_D	0.80	0.70	0.60	0.40	0.35	0.35	**0.039**
$C_D A$ [m^2]	0.50	0.40	0.30	0.20	0.12	0.10	**0.011**

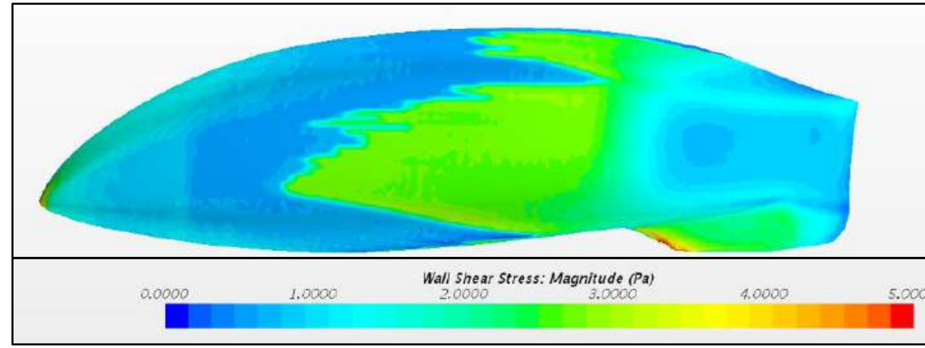

No separation
(A)
Steady separation bubble
(B)
Oscillating Karman vortex street wake
(C)
Laminar boundary layer,
wide turbulent wake
(D)
Turbulent boundary layer,
narrow turbulent wake
(E)


A
B
C
D
E
Smooth
Rough
C_d
1.5
1.0
0.5
0.1
10^2
10^3
10^4
10^5
10^6
10^7
Re


V
Laminar boundary layer
Transition region
Turbulent boundary layer
V
V
y
0
x
x_{cr}
Turbulent layer
Overlap layer
Buffer layer
Viscous sublayer
Boundary layer thickness, δ

Taurus 130 km/h:

Pressione	1.76 N	→	24%
Attrito superficiale	5.60 N	→	76%



$$D = \tfrac{1}{2}\,\rho\,(\overset{24\%}{C_{dp} A} + \overset{76\%}{C_{ds} S})\, v^2$$

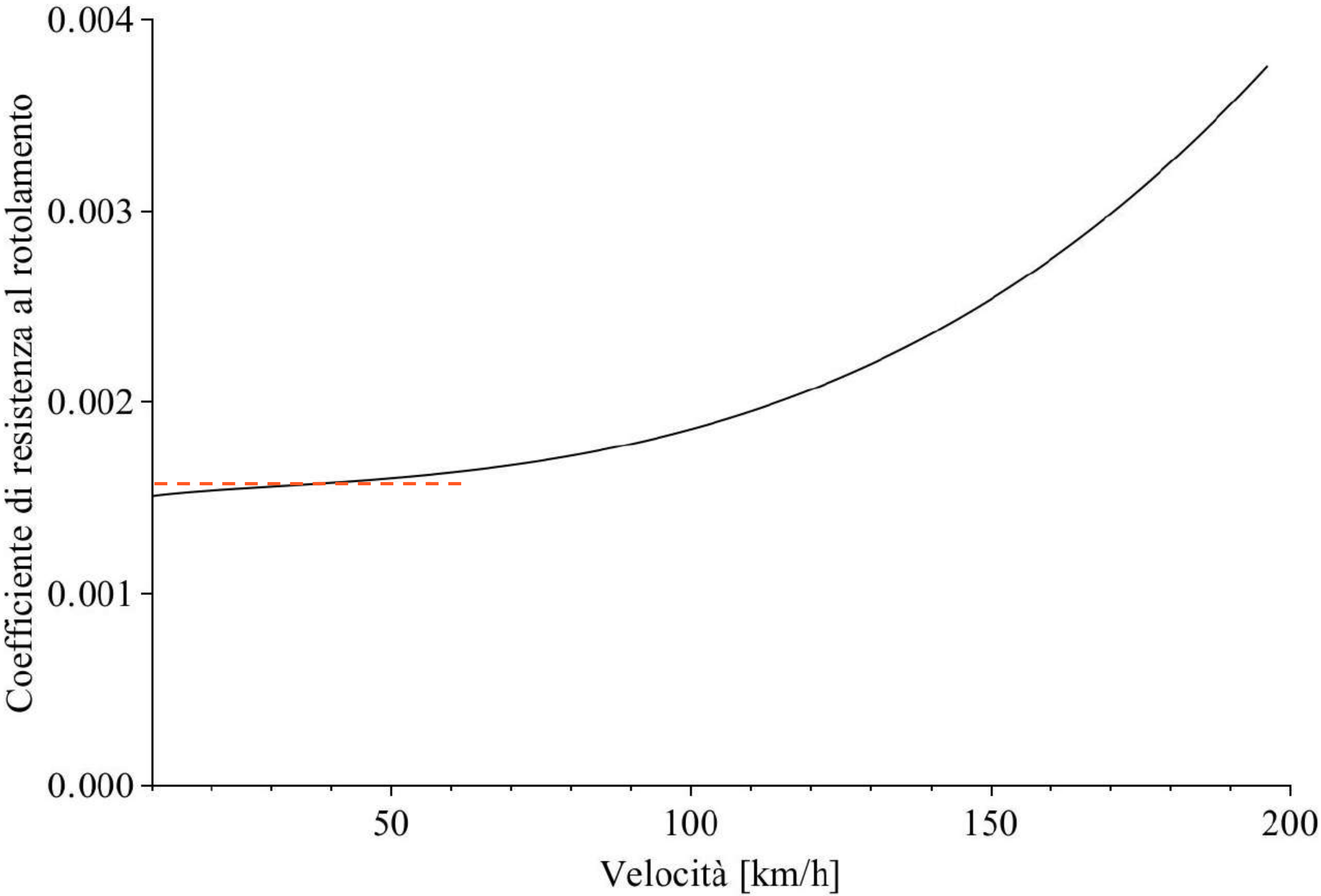
$C_{dp} = 0.0093$
$A = 0.285\ m^2$

$$C_{dp} A = 0.00265\ m^2$$

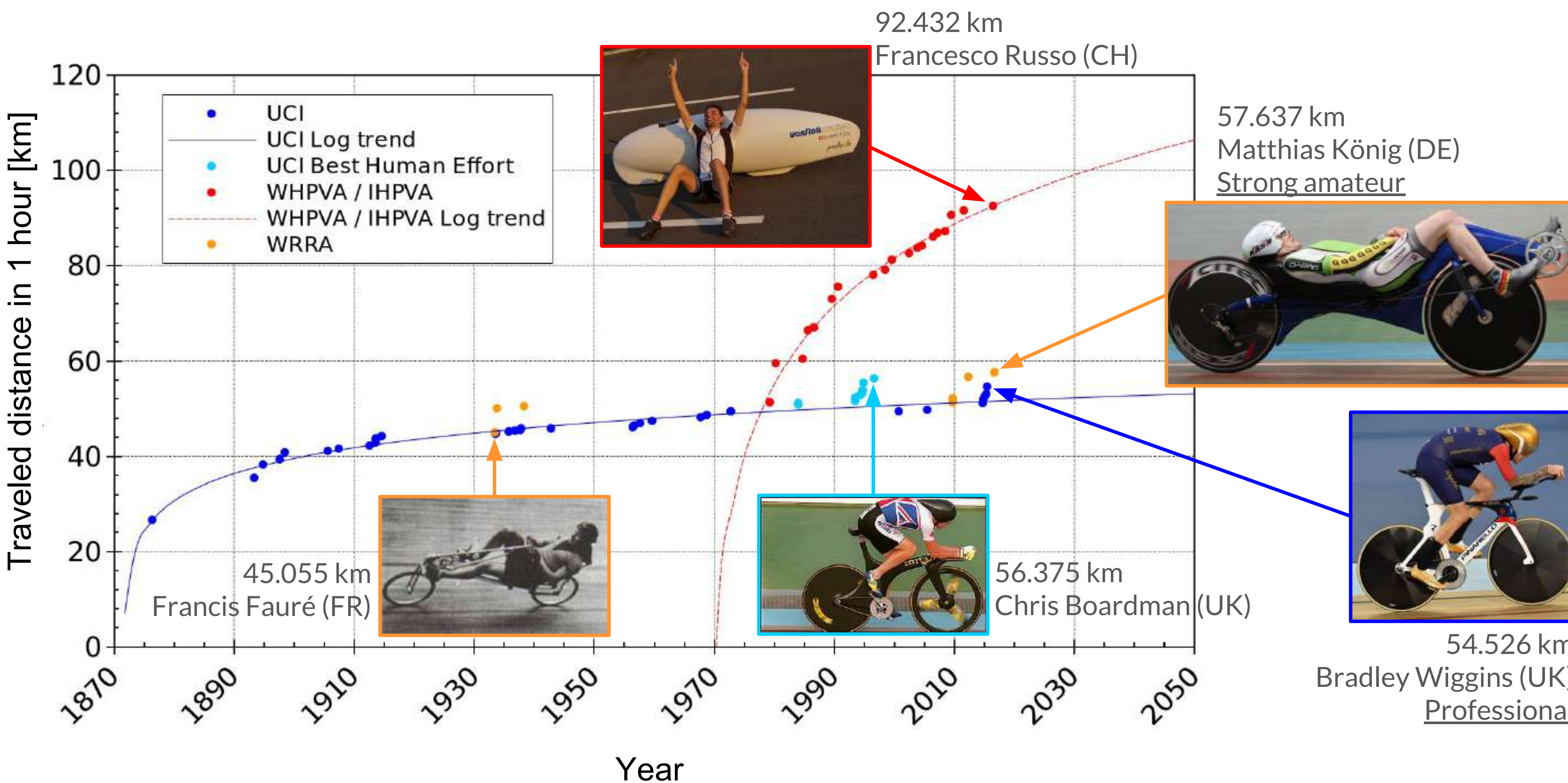
$C_{ds} = 0.00213$
$S = 3.95\ m^2$

$$C_{ds} S = 0.00841\ m^2$$

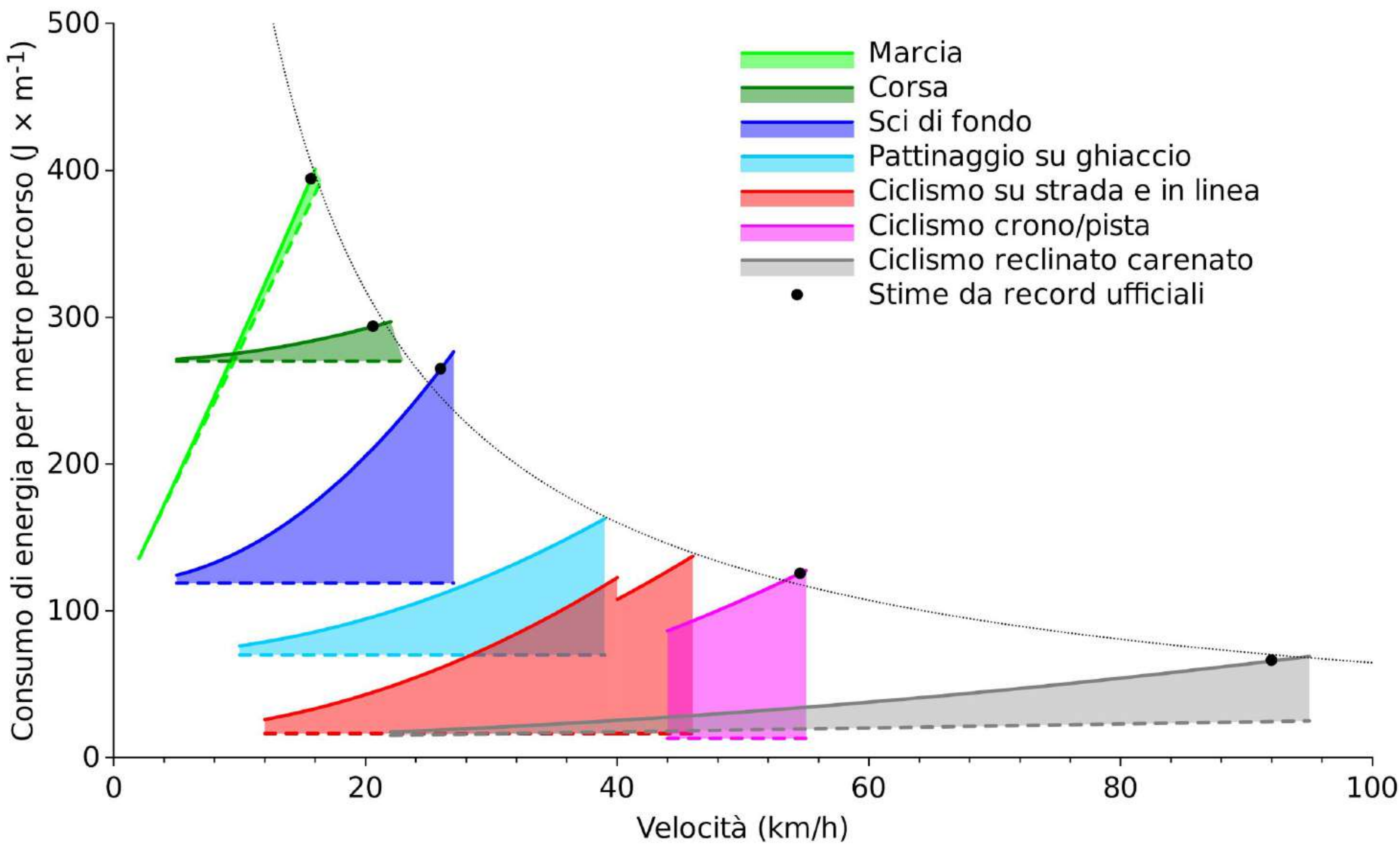
$$C_d A^* = 0.0111\ m^2$$


0.004
0.003
0.002
0.001
0.000
Coefficiente di resistenza al rotolamento
50
100
150
200
Velocità [km/h]


THE
SPEED CHALLENGE
RENNA
TEP
STAR-CCM+
EXPERIENCE

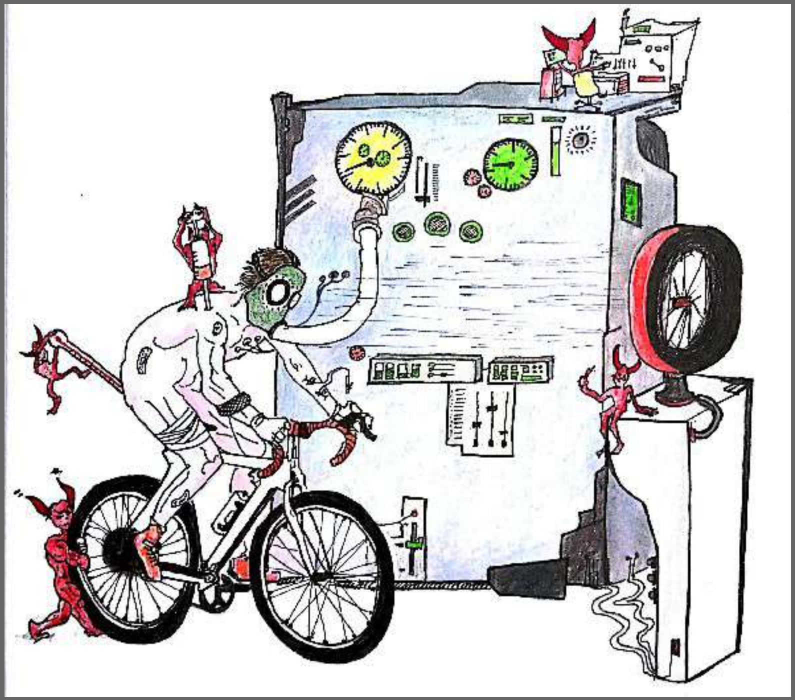


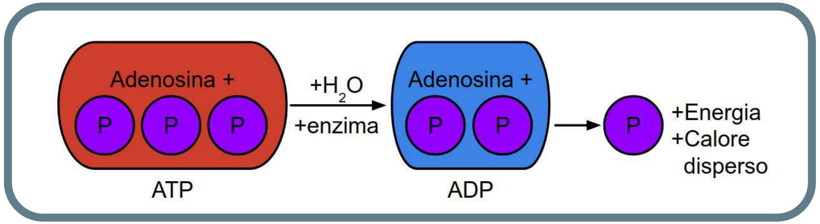
92.432 km
Francesco Russo (CH)
57.637 km
Matthias König (DE)
Strong amateur
56.375 km
Chris Boardman (UK)
45.055 km
Francis Fauré (FR)
54.526 km
Bradley Wiggins (UK)
Professional
UCI
UCI Log trend
UCI Best Human Effort
WHPVA / IHPVA
WHPVA / IHPVA Log trend
WRRA
Traveled distance in 1 hour [km]
Year
0
20
40
60
80
100
120
1870
1890
1910
1930
1950
1970
1990
2010
2030
2050

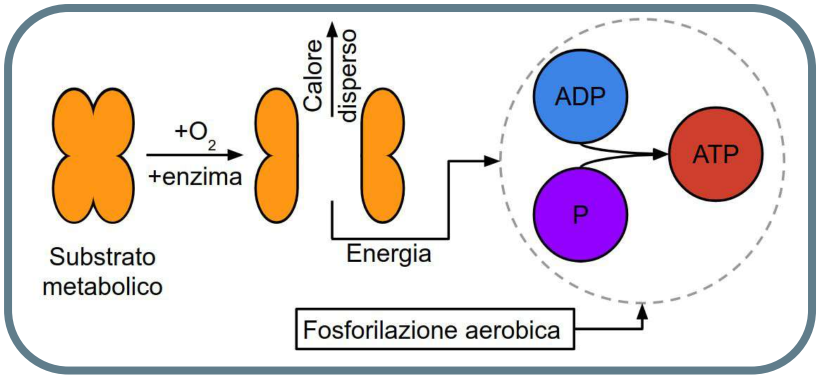


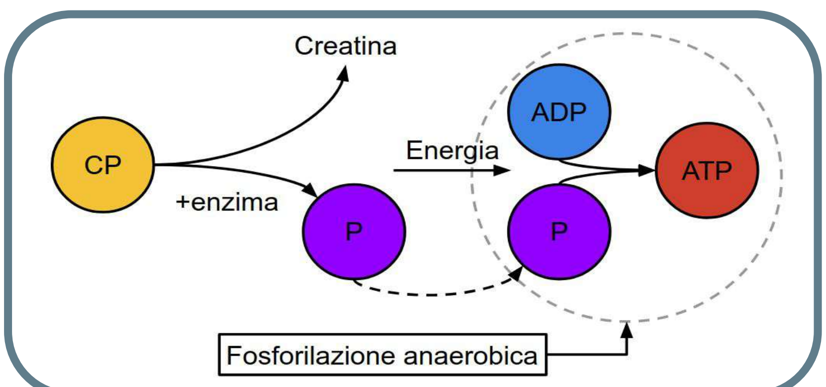
Marcia
Corsa
Sci di fondo
Pattinaggio su ghiaccio
Ciclismo su strada e in linea
Ciclismo crono/pista
Ciclismo reclinato carenato
Stime da record ufficiali
Consumo di energia per metro percorso (J × m-1)
Velocità (km/h)
0
100
200
300
400
500
0
20
40
60
80
100

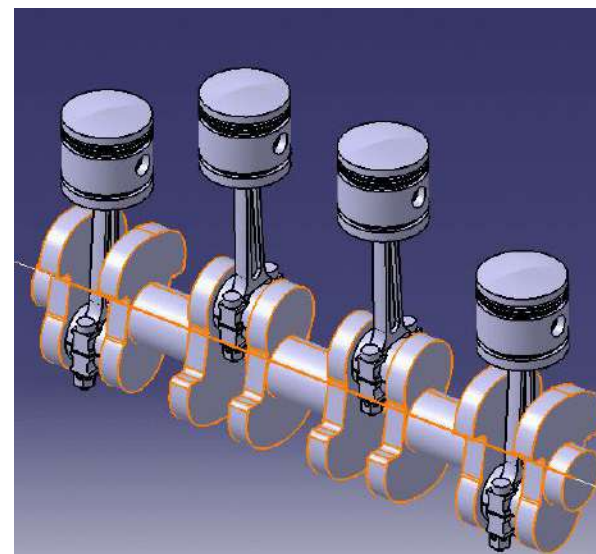
Il motore umano

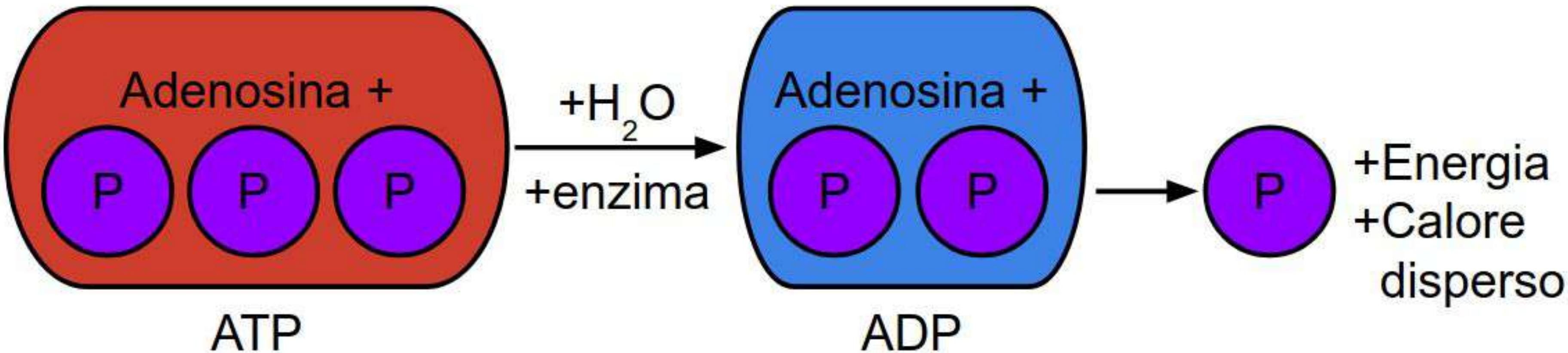



Adenosina +
P P P
ATP
$+H_2O$
+enzima
Adenosina +
P P
ADP
P
+Energia
+Calore
disperso

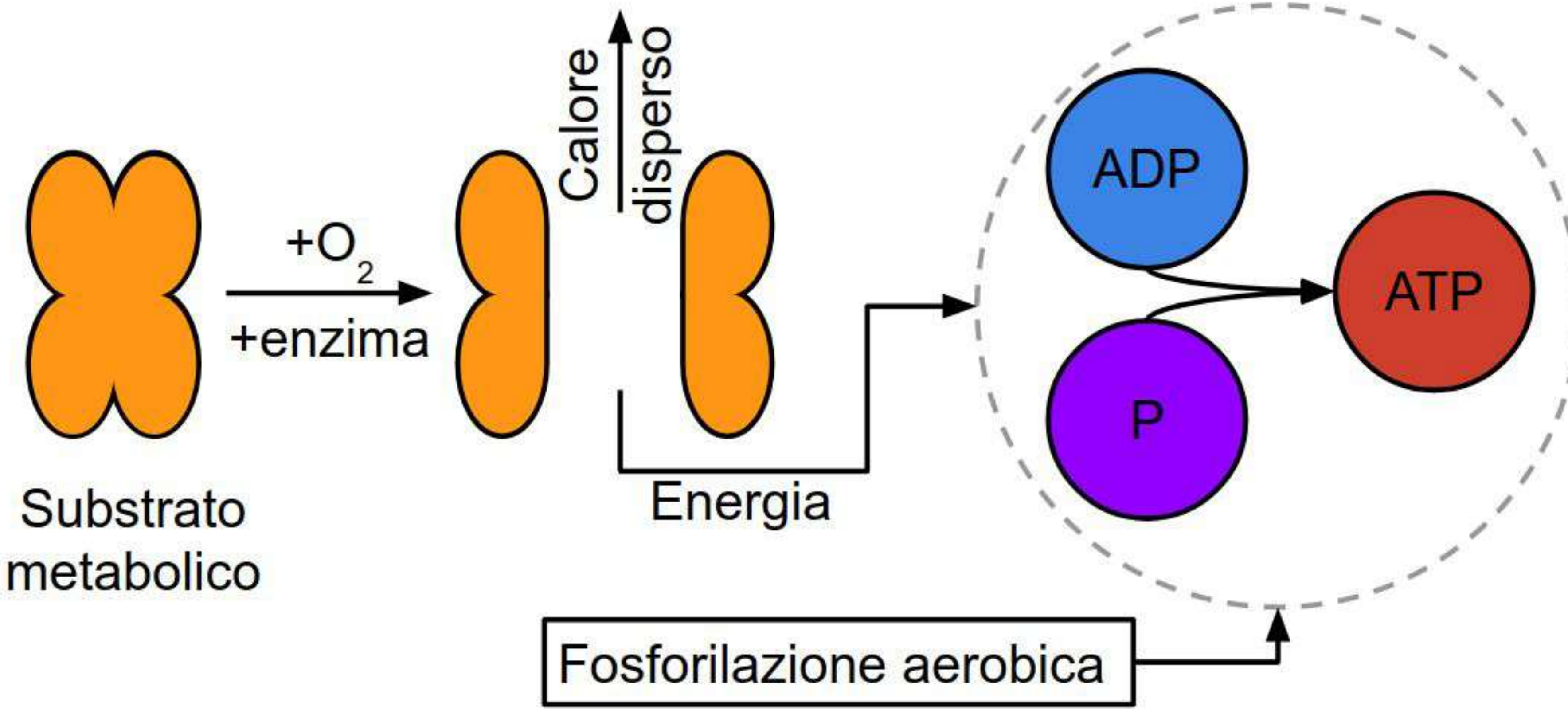

Substrato
metabolico
$+O_2$
+enzima
Calore
disperso
Energia
ADP
P
ATP
Fosforilazione aerobica


CP
Creatina
+enzima
P
Energia
ADP
P
ATP
Fosforilazione anaerobica

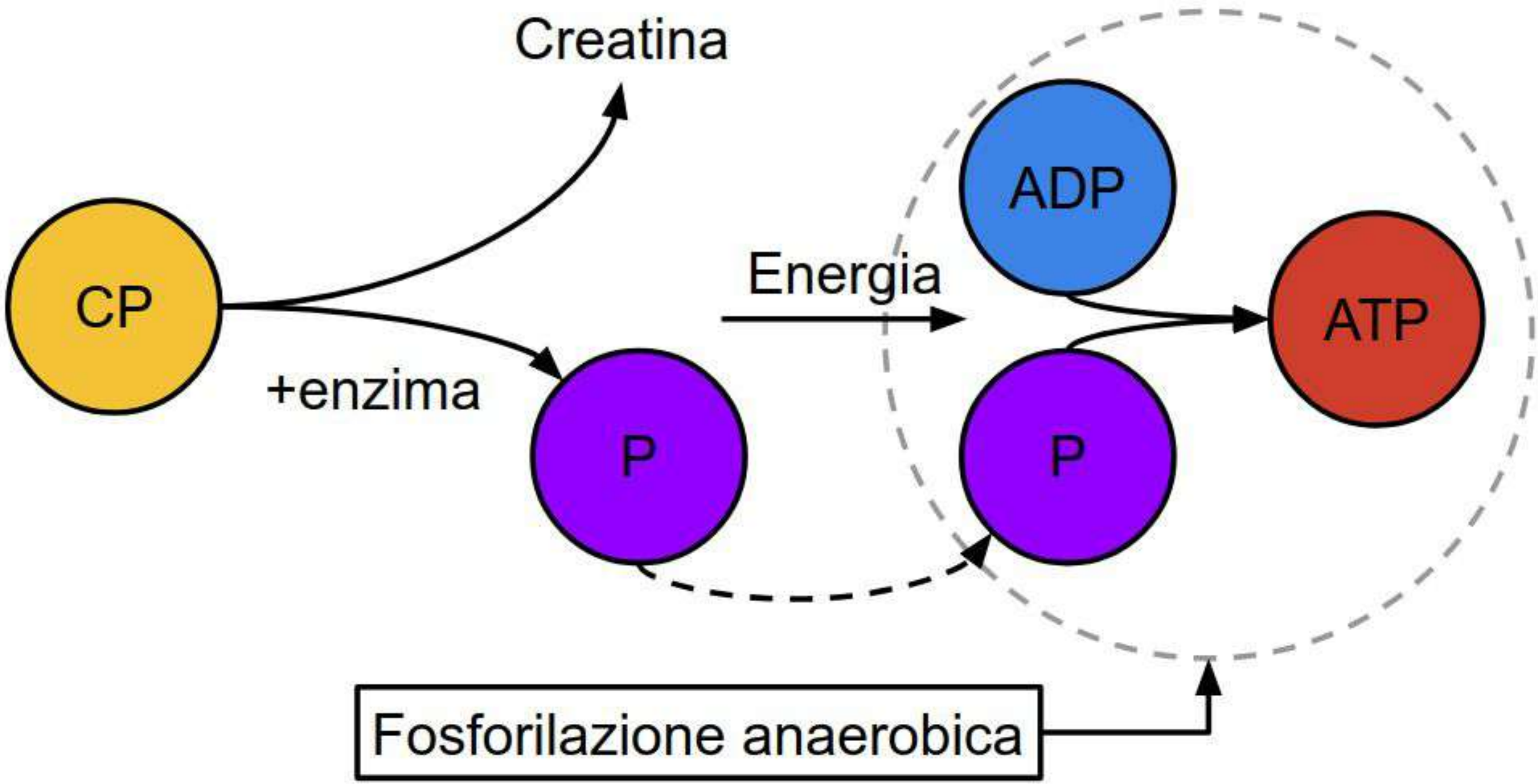




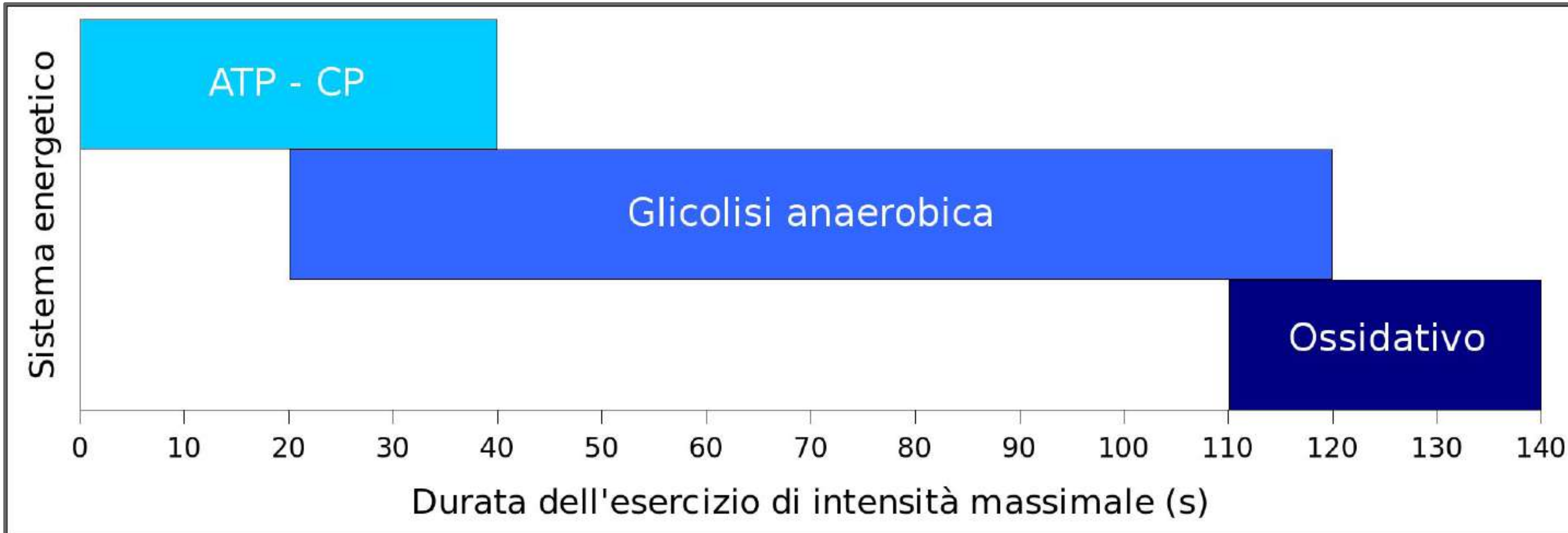
Come l’energia viene liberata dall’ATP



Sistema ossidativo (con risintesi aerobica dell'ATP)



Sistema ATP-CP (con risintesi anaerobica dell'ATP)



Sistema energetico
ATP - CP
Glicolisi anaerobica
Ossidativo
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Durata dell'esercizio di intensità massimale (s)

Reazioni dell'ossidazione

Metano $CH_4 + 2O_2 = CO_2 + 2H_2O + Q$

Eptano (benzina) $C_7H_{16} + 11O_2 = 7CO_2 + 8H_2O + Q$

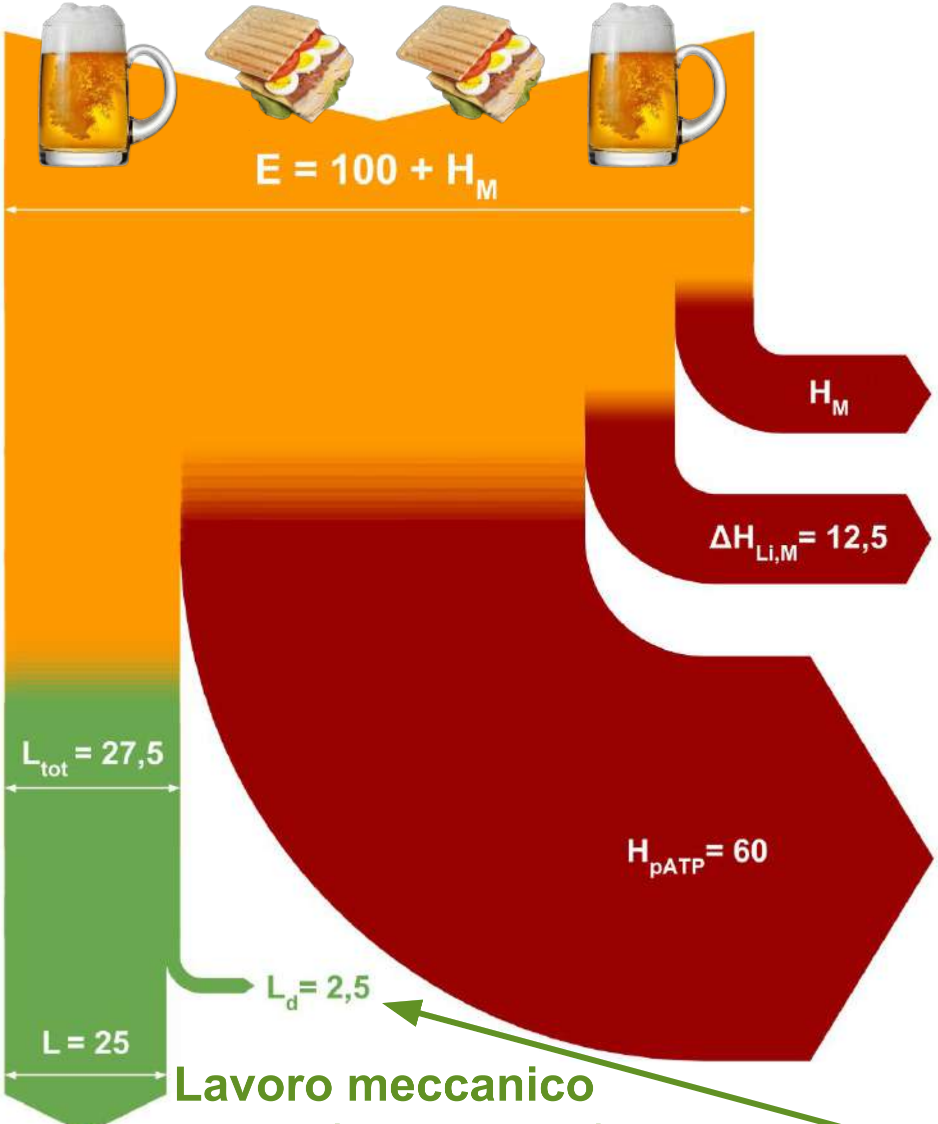
Glucosio $C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + Q =$

$= 6CO_2 + 6H_2O + 38ATP + Q'$

$Q' = 0{,}6 \times Q$ $Q = 4100$ kcal / kg

$RO = 1$ 1 ATP = 7,5 kcal

EFFICIENZA 27,5%



Metabolismo a riposo

Calore sviluppato da:

- lavoro interno per accresciute funzioni vitali
- trasformazione dell'ATP muscolare

Calore da reazioni di produzione dell'ATP

Lavoro meccanico UTILE (alla corona)

Lavoro meccanico disperso (→ Calore)

Il sistema di raffreddamento

Smaltimento del calore

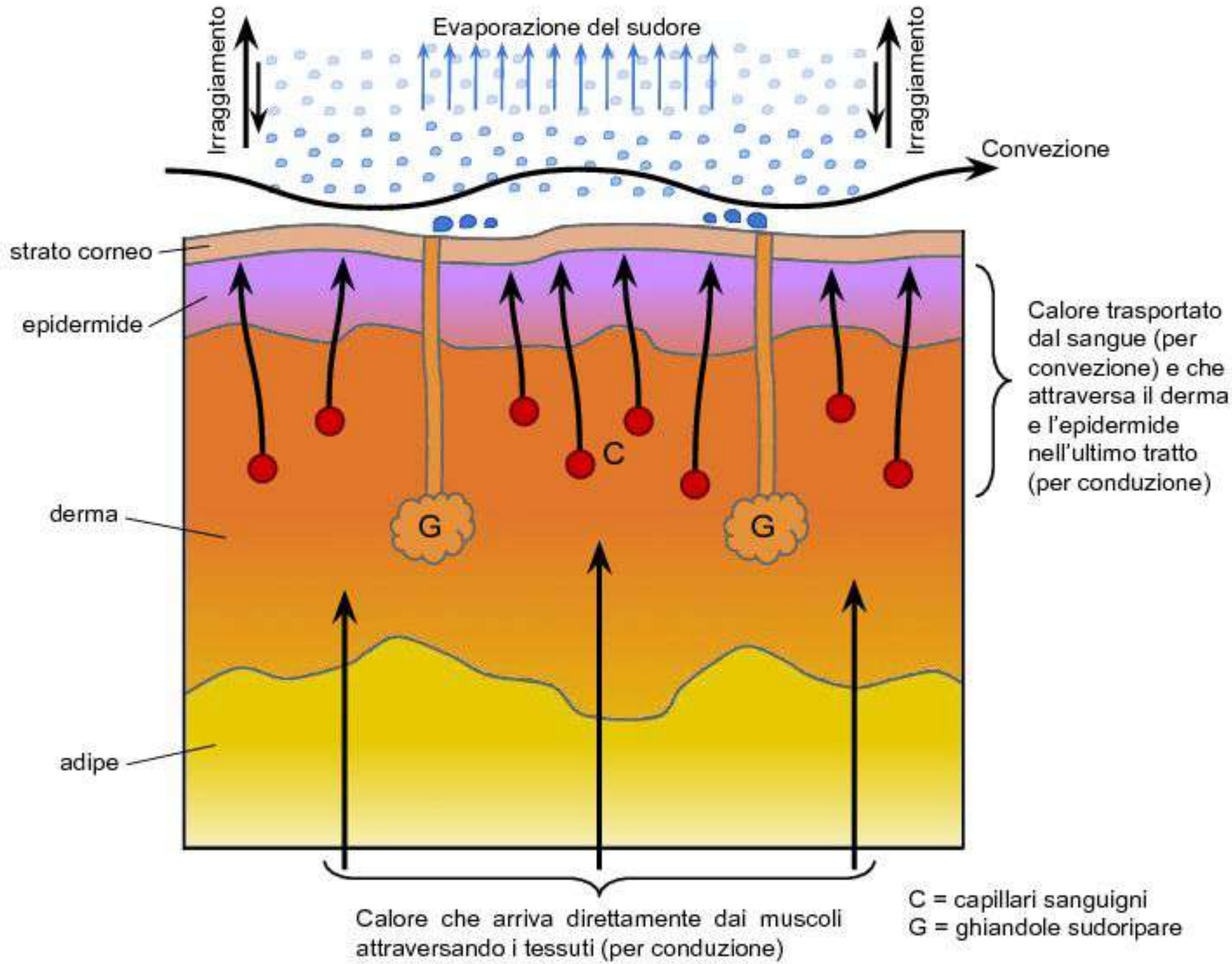
Termoregolazione → 37 °C

Attività aerobica → 11x calore a riposo → da smaltire!

Meccanismi:

- Conduzione
- Convezione
- Irraggiamento

+ Evaporazione acqua corporea

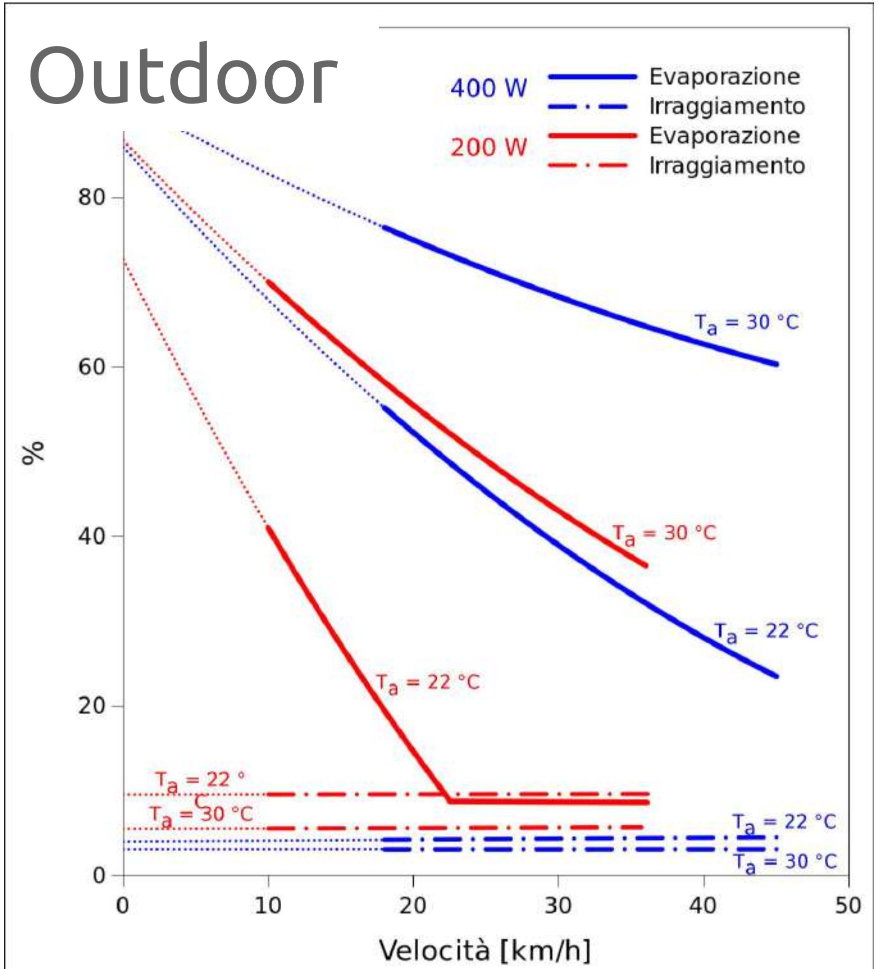

Evaporazione del sudore
Irraggiamento
Irraggiamento
Convezione
strato corneo
epidermide
derma
adipe
C
G
G
Calore trasportato dal sangue (per convezione) e che attraversa il derma e l'epidermide nell'ultimo tratto (per conduzione)
Calore che arriva direttamente dai muscoli attraversando i tessuti (per conduzione)
C = capillari sanguigni
G = ghiandole sudoripare


p.poljanski
Rhône-Alpes, France
Follow
13.7k likes
1,387 comments
After sixteen stages I think my legs look little tired 😩
#tourdefrance
15 HOURS AGO


hansgrohe
BORA
cooking systems
CRAFT
117
SPECIALIZED


FUJI
ENDURA

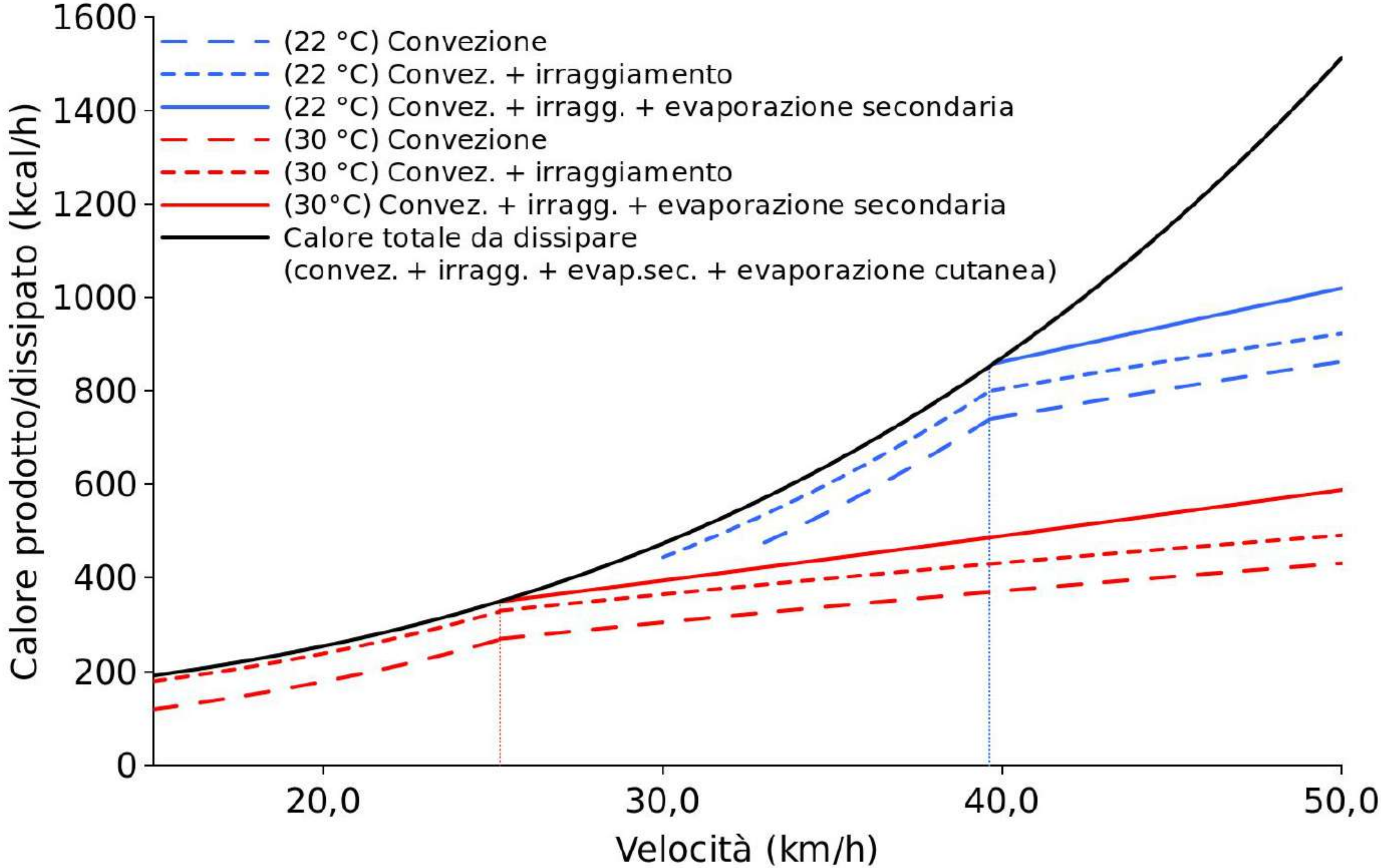
Quanto incide l'evaporazione



Indoor:

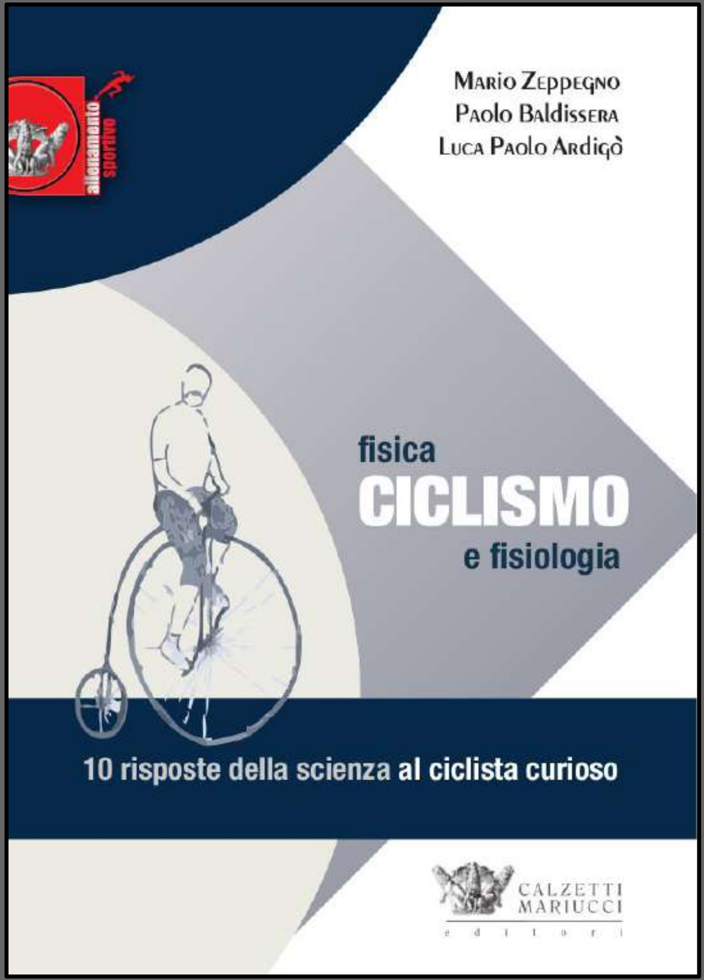
22 °C → 73%

30 °C → 94%



(22 °C) Convezione
(22 °C) Convez. + irraggiamento
(22 °C) Convez. + irragg. + evaporazione secondaria
(30 °C) Convezione
(30 °C) Convez. + irraggiamento
(30°C) Convez. + irragg. + evaporazione secondaria
Calore totale da dissipare
(convez. + irragg. + evap.sec. + evaporazione cutanea)
Calore prodotto/dissipato (kcal/h)
1600
1400
1200
1000
800
600
400
200
0
20,0
30,0
40,0
50,0
Velocità (km/h)

GRAZIE PER LA CORTESE ATTENZIONE



Fatica

FATICA = STANCHEZZA ASSOCIATA AD UN PEGGIORAMENTO DELLA PRESTAZIONE

CAUSE:

1. **ESAURIMENTO, IMPOVERIMENTO O CAMBIO DEL COMBUSTIBILE**

   1.a SFORZO ANAEROBICO

   Esaurimento della **fosfocreatina** (CP)
   e **accumulo di fosfati** (P)

(continua)

1.b SFORZO ANAEROBICO

Attivazione della **glicolisi** e rapido **impoverimento del glicogeno**; a seguire, **cambio del combustibile**, con passaggio ai **grassi**.

1.c SFORZO AEROBICO

Impoverimento del glicogeno, anche se il livello dei grassi si mantiene elevato.

Fatica percepita: inversamente proporzionale alla concentrazione di glicogeno nei muscoli.

Se **glicogeno < 50 mmol/kg di muscolo** (rispetto a 150 iniziali) → fatica **rapidamente insostenibile.**

2. **FORMAZIONE DI METABOLITI**
   → Acido lattico → H+ → Diminuzione del PH →
   → Inibizione degli enzimi della glicolisi →
   → Riduzione del tasso di produzione dell’ATP →
   → Difficoltà di contrazione dei muscoli →
   → Mialgia, fatica.

3. **NEUROMUSCOLARI**
   Difficoltà/incapacità del sistema nervoso
   di attivare le fibre muscolari.

E ANCORA GRAZIE…