



Physics of sports

C. Cohen, B. Darbois Texier, G. Dupeux

Soft Matter Group



smart surfaces

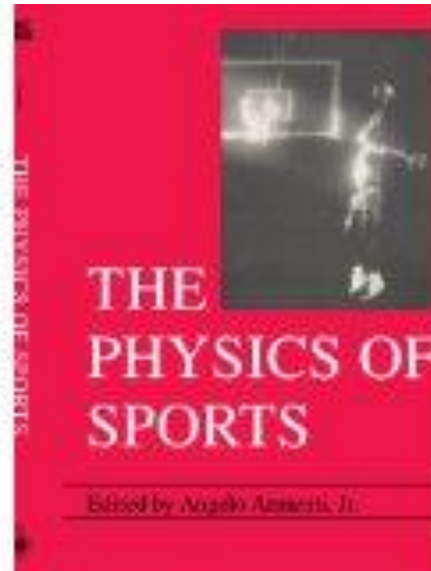


soft surfaces





« Don't cry, you will only bury my body. »



The Physics of Sports
Edited by Angelo Armenti in 1992

Aristote (384-322 B.C.) and the Physics of Sports in
his treatise on the Progression of Animals:

"Hence athletes jump farther if they have the weights in their hands
than if they have not, and runners run faster if they swing their arms"

without

with

alone



variational principle



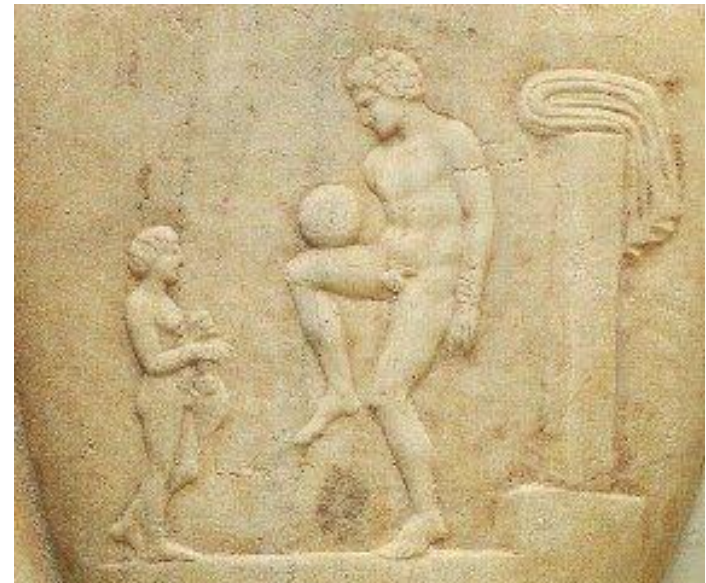
Tsu Chu (China, 5000 BC)



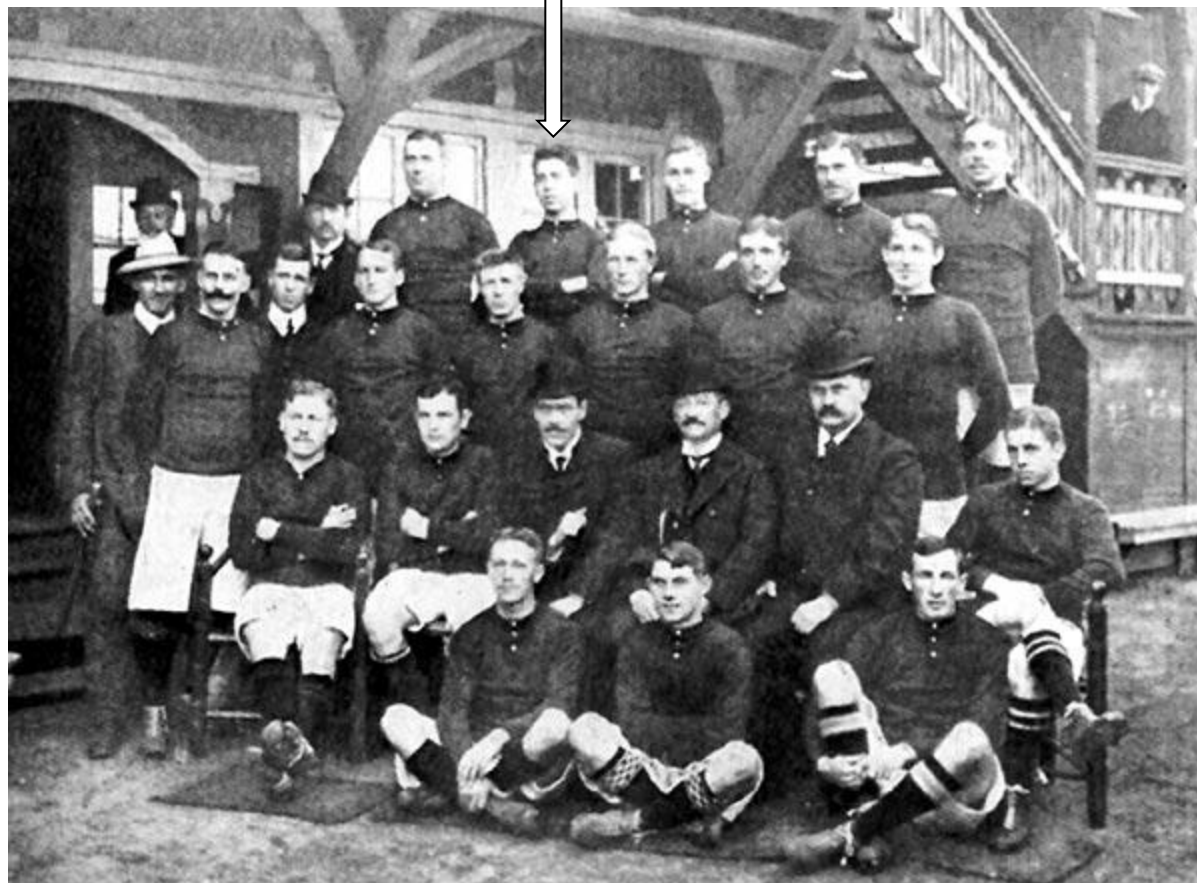
?? (Egypt, 3000 BC)



Pok a Tok (Maya-Mexique, 3000 BC)

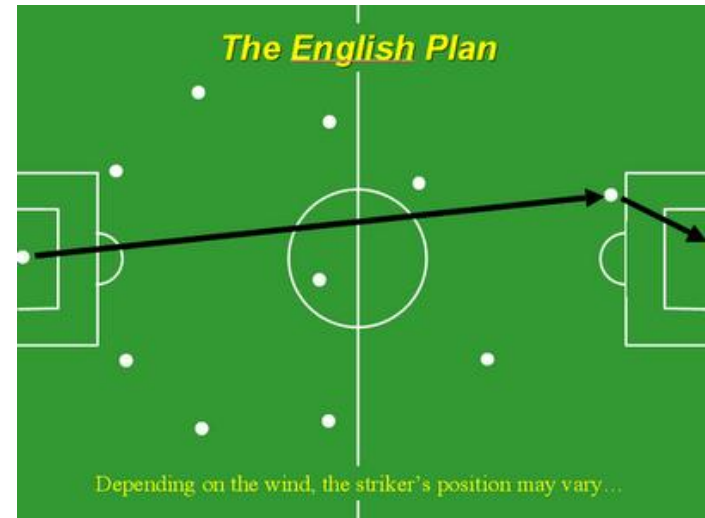


Episkyros (Grèce, 800 BC)



Danmark: Back, f. l. t. r. (above) two officials, Harald Hansen, Harald Bohr, "Sophus" Nielsen, Marius Andersen, Oskar Nielsen; Back, f. l. t. r. official, Johannes Gandii, Charles Williams (coach), Charles von Buchwald, Bjørn Rasmussen, "Kristian" Middelboe, Nils Middelboe, Ludwig Drescher; Middle, f. l. t. r. August Lindgren, Knud Hansen, H. P. Katberg (DBU/official), Ludvig Sylow (DBU/official), Dr. Jørgen Jensen (DBU/official), Vilhelm Wolfhagen; Front, f. l. t. r. Ødbert Bjarnholt, Magnus Beck, Einar Middelboe.





C. REEP AND B. BENJAMIN 1968 Skill and Chance in Association Football. In *Journal of the Royal Statistical Society. Series A (General)* 131 pp. 581-585.

C. REEP, R. POLLARD AND B. BENJAMIN 1971 Skill and Chance in Ball Games. In *Journal of the Royal Statistical Society. Series A (General)* 134 pp. 623-629.

NETHERLANDS



2 - 1

ARGENTINA



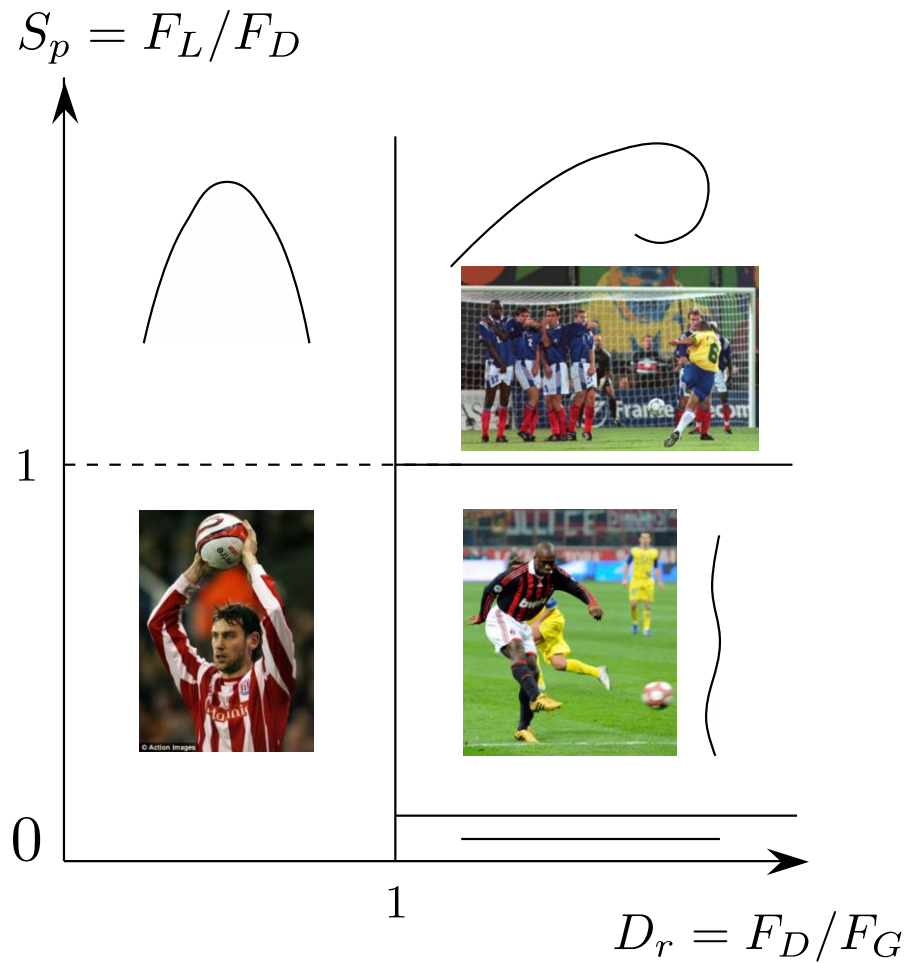
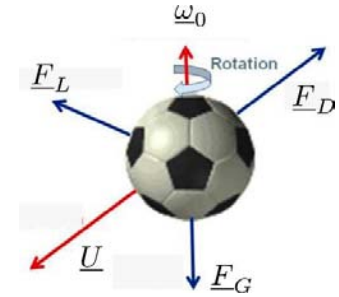
FIFA World Cup '98

90th Minute Quarterfinal

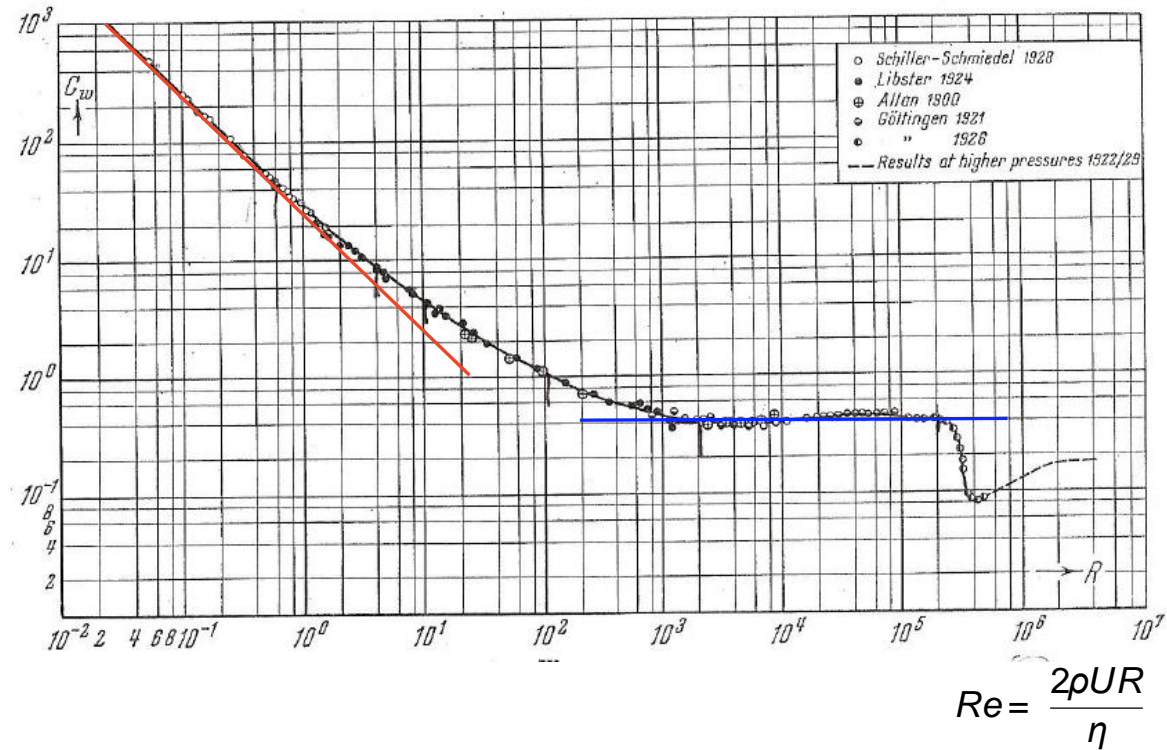
Assist: Frank de Boer

Goal: Dennis Bergkamp

$$M \frac{dU}{dt} = \underline{F}_G + \underline{F}_D + \underline{F}_L$$



$$C_D = \frac{F_D}{\frac{1}{2}\rho U^2 \pi R^2}$$

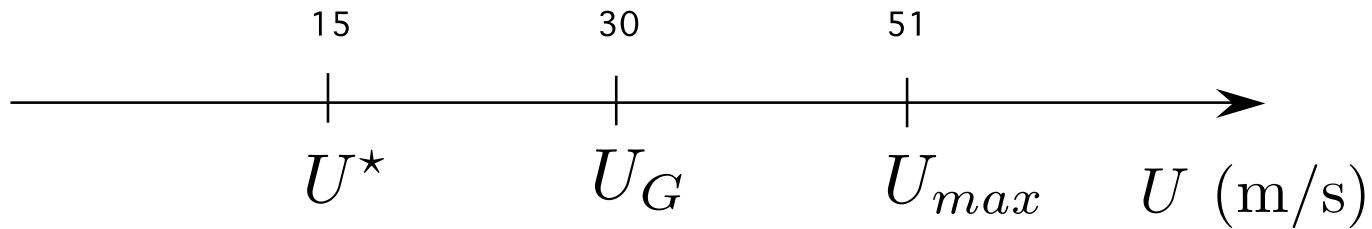


$$U^* \approx 15 \text{ m/s}$$

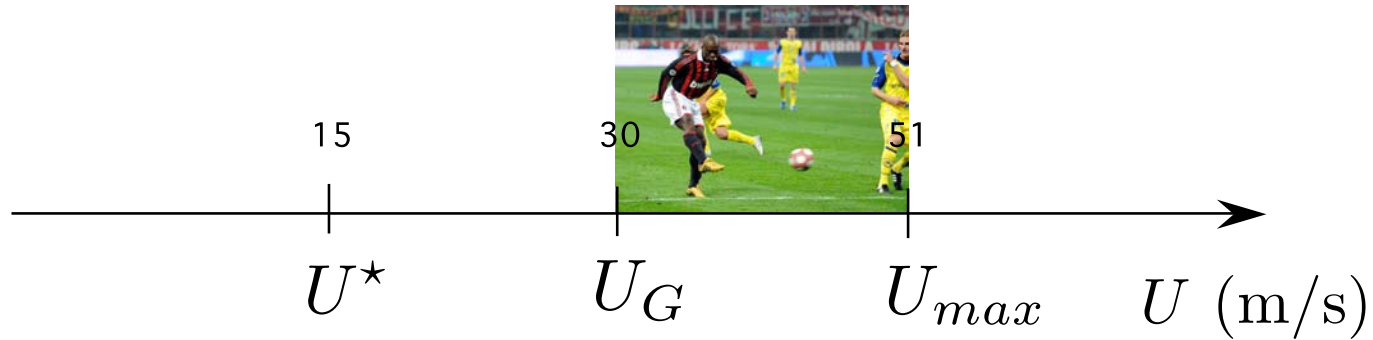


Joueur	U_0 (m/s)	Match
David Hirst	51	Sheffield / Arsenal (16/09/96)
David Beckham	44	Man Utd / Chelsea (22/02/97)
David Trezeguet	43	Monaco / Man Utd (19/03/98)
Richie Humphreys	42.8	Sheffield / Aston Villa (17/08/96)
Matt Le Tissier	39	Southampton / Newcastle (18/01/97)
Alan Shearer	38.3	Newcastle / Leicester (02/02/97)
Roberto Carlos	38.1	Brésil / France (03/06/97)

$$\left. \begin{aligned}
 F_G &= M \cdot g \approx 4.5 \text{ N} \\
 F_D &= \frac{1}{2} \rho U^2 \pi R^2 C_D
 \end{aligned} \right\} U_G = \sqrt{\frac{2Mg}{\rho \pi R^2 C_D}} \approx 30 \text{ m/s}$$



$$M \frac{d\underline{U}}{dt} = \underline{F}_D$$



$$M \frac{dU}{dt} = -\frac{1}{2} \rho \pi R^2 C_D |U| U \quad (\text{straight line})$$

$$\underline{.t} \quad MU \frac{dU}{ds} = -\frac{1}{2} \rho \pi R^2 C_D U^2$$

$$U(s) = U_0 e^{-s/\mathcal{L}}$$

$$\mathcal{L} = \frac{2M}{\rho \pi R^2 C_D} \approx 100 \text{ m}$$

Heavy kick from Steven Reid (déc 2005- Blackburn/Wigan)





ONAL - BOAVISTA, 2-0

A SÉRIE DE NOVE JOGOS SEM D

NETHERLANDS



2 - 1

ARGENTINA



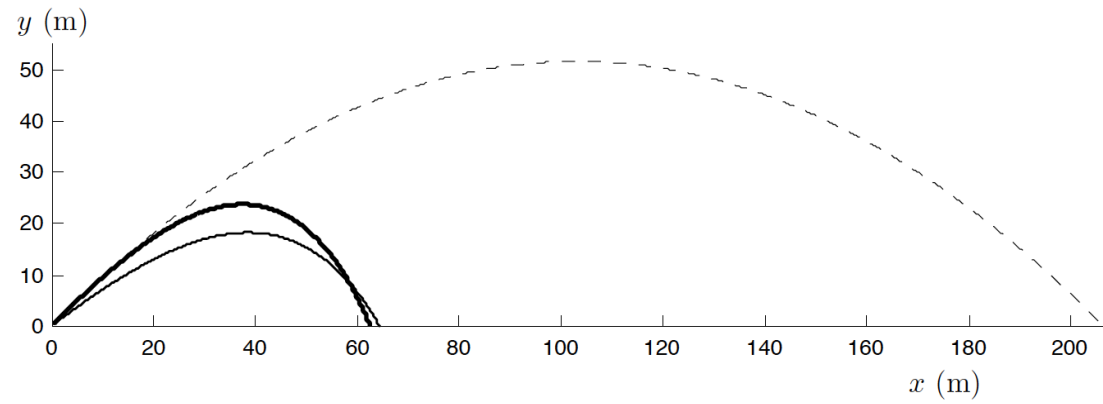
FIFA World Cup '98

90th Minute Quarterfinal

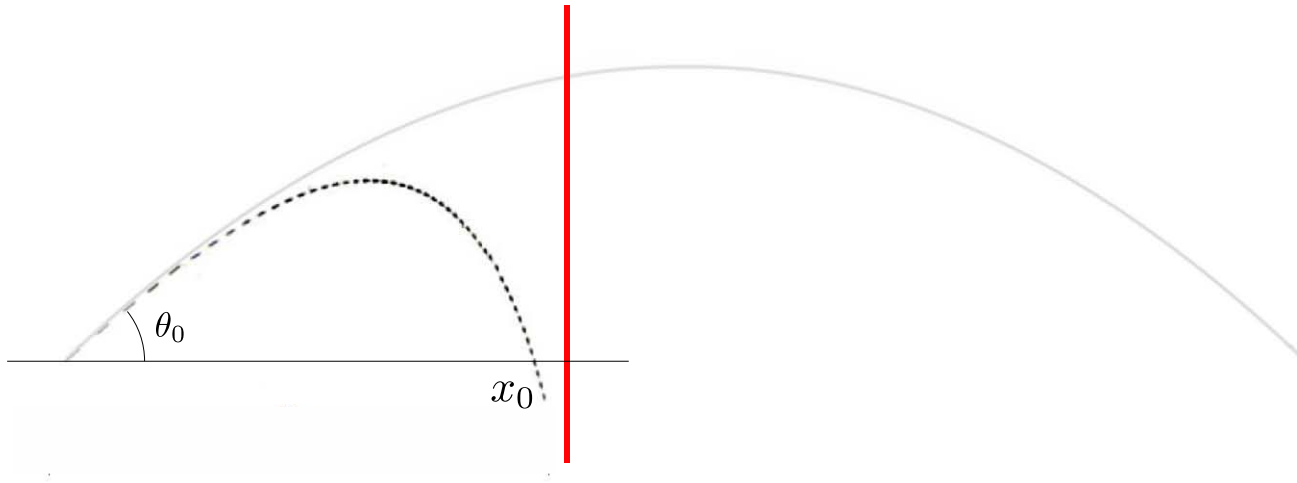
Assist: Frank de Boer

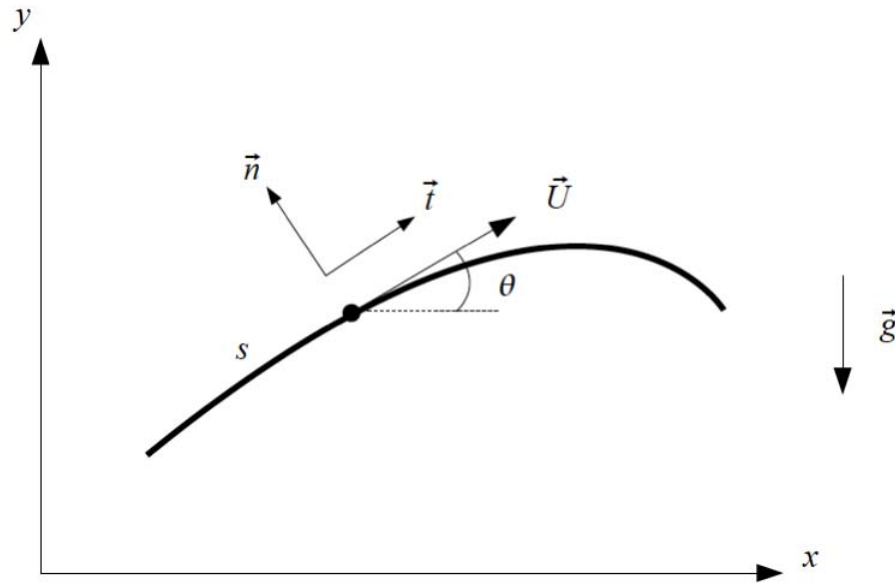
Goal: Dennis Bergkamp

$$M \frac{d\underline{U}}{dt} = \underline{F}_D + \underline{F}_G$$



$$M \frac{d\underline{U}}{dt} = M \underline{g} - \frac{1}{2} \rho_{air} S C_D |\underline{U}| \underline{U}$$





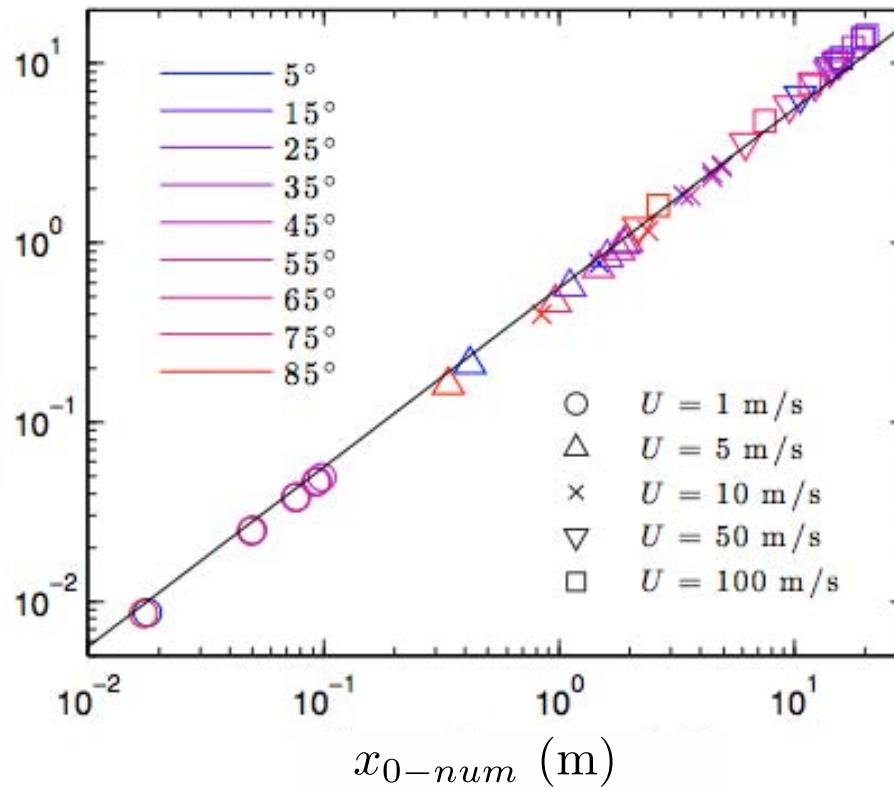
e_x $U_x(s) = U_0 \cdot \cos \theta_0 \cdot e^{-s/\mathcal{L}}$

n $U^2 \frac{d\theta}{ds} = -g \cos \theta$

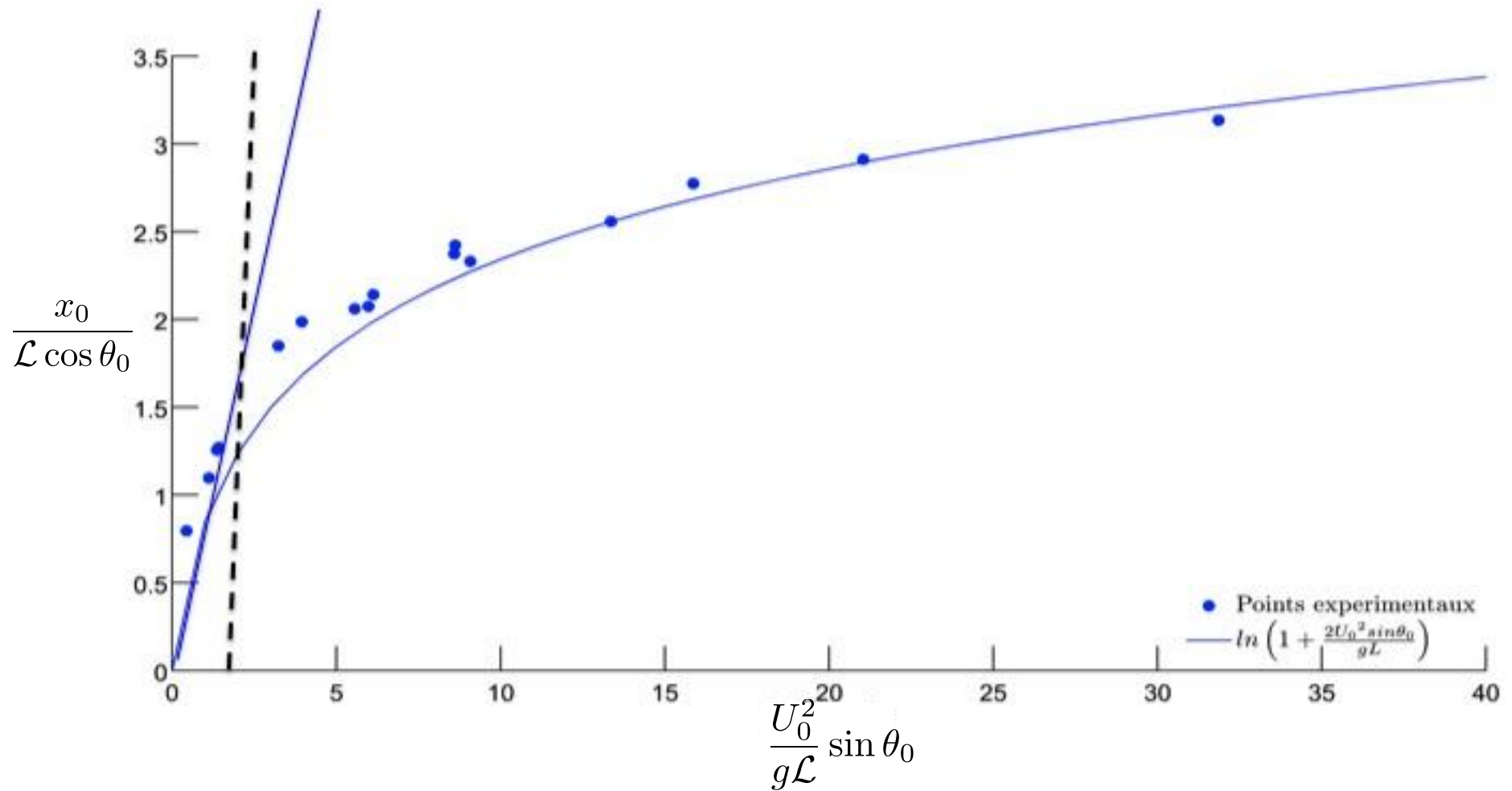
$$\left[\ln \left(\frac{1 + \cos \theta}{\sin \theta} + \frac{\sin \theta}{\cos^2 \theta} \right) \right]_{\theta_0}^{\theta} = \frac{g\mathcal{L}}{U_0 \cdot \cos \theta_0} \left(e^{2s/\mathcal{L}} - 1 \right)$$

$$x_0 \approx \frac{1}{2} \mathcal{L} \cos \theta_0 \ln \left(1 + \frac{2U_0^2}{g\mathcal{L}} \sin \theta_0 \right)$$

x_{0-th} (m)

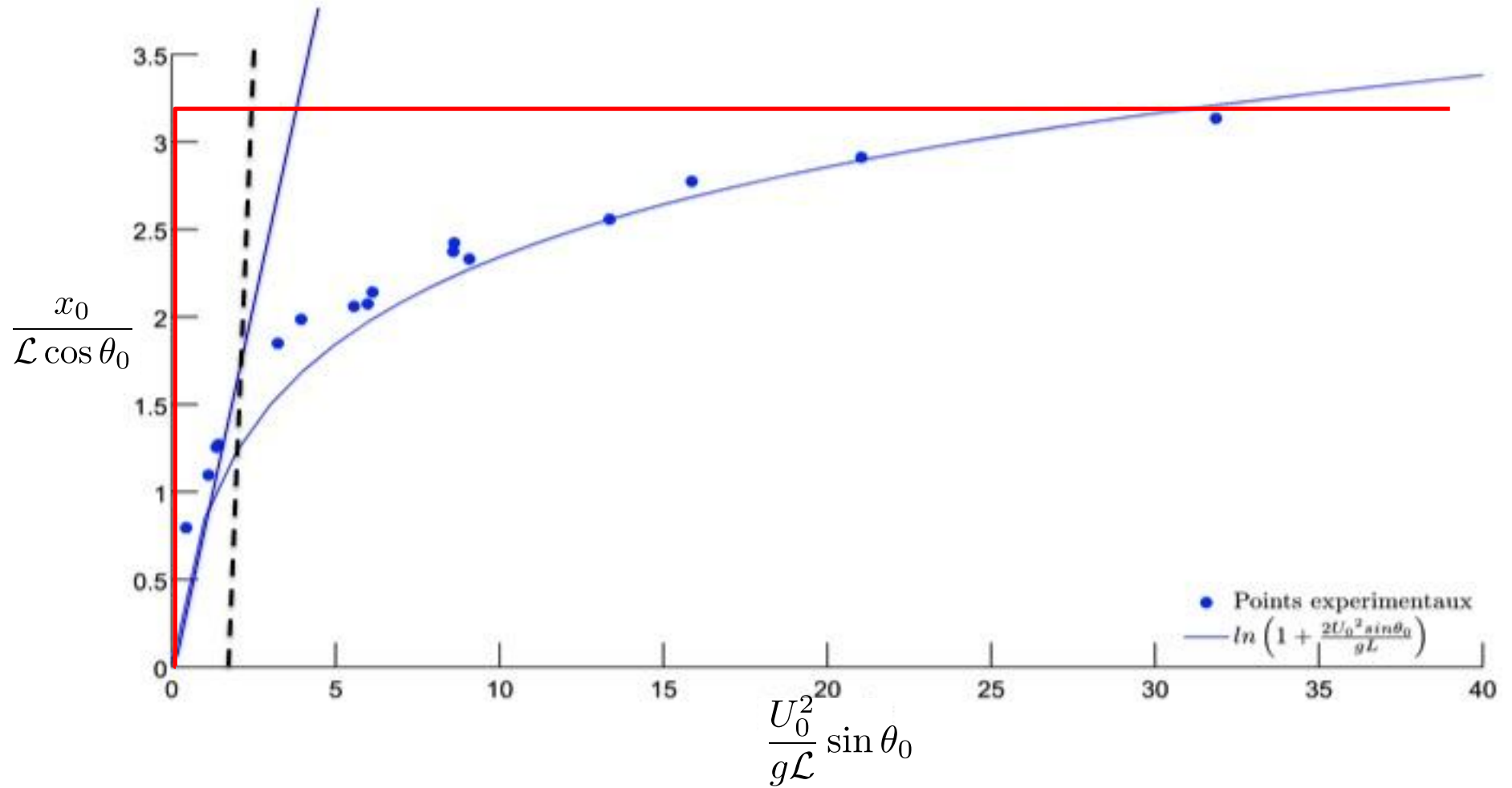


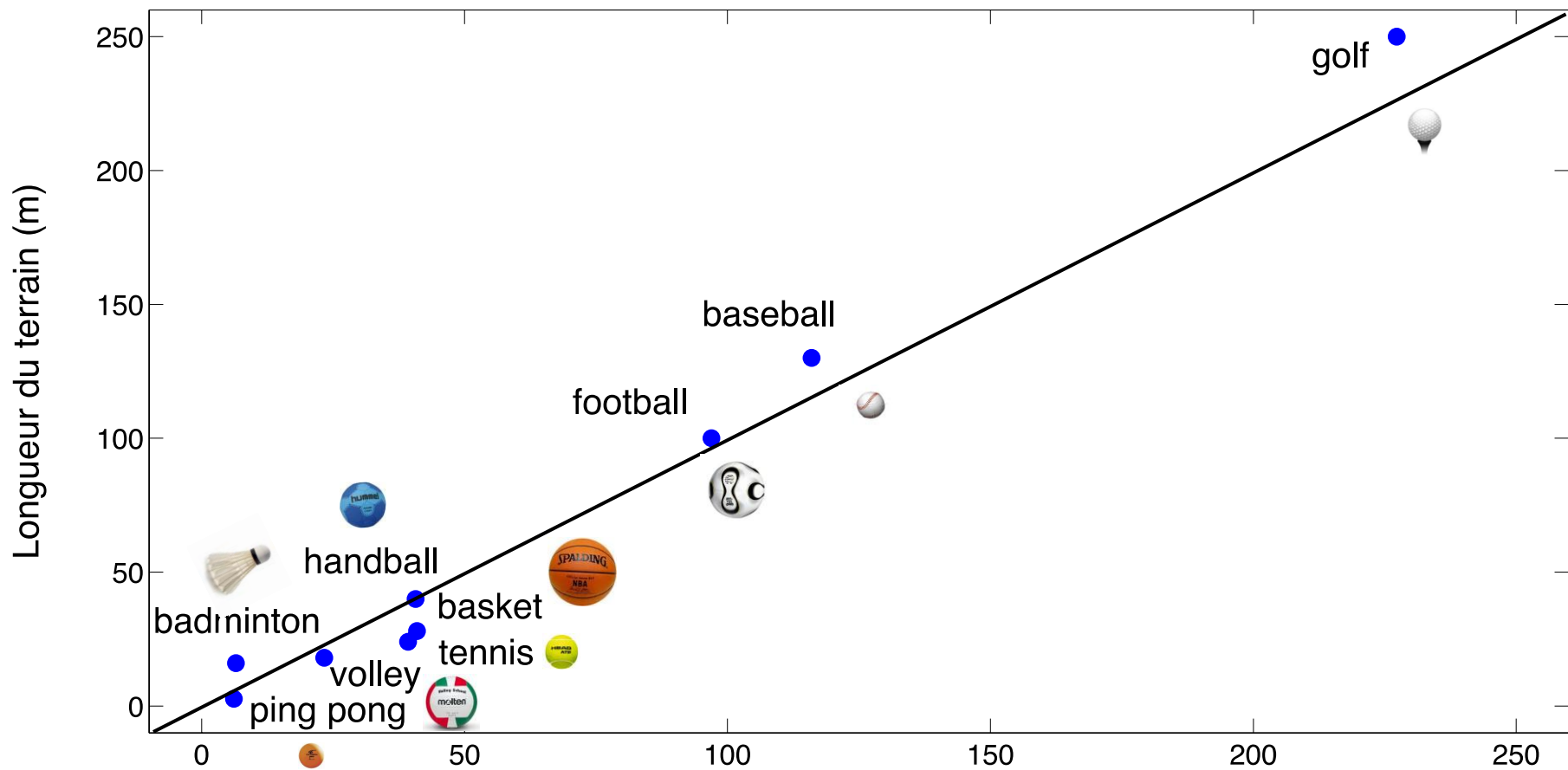
$$x_0 \approx \frac{1}{2} \mathcal{L} \cos \theta_0 \ln \left(1 + \frac{2U_0^2}{g\mathcal{L}} \sin \theta_0 \right)$$



	$M(g)$	$2R$ (cm)	U_0 (m/s)	Re	C_D	$U_0^2/g\mathcal{L}$
badminton	5	6.0	60	2.7e+05	0.60	96
table tennis	2	4.0	30	8.0e+04	0.50	14
tennis	55	6.0	60	2.6e+05	0.50	6.6
golf	45	4.0	80	2.2e+05	0.22	2.7
soccer	450	21	40	5.6e+05	0.22	1.7
baseball	145	7.0	40	1.9e+05	0.40	1.0
volley	210	21	20	2.8e+05	0.22	0.89
handball	450	19	20	2.5e+05	0.22	0.34
basket	650	24	10	1.6e+05	0.50	0.21
javelin	800	3.0	30	7.0e+04	0.50	0.033
hammer	7250	12	25	2.0e+05	0.40	0.024

On the size of pitches



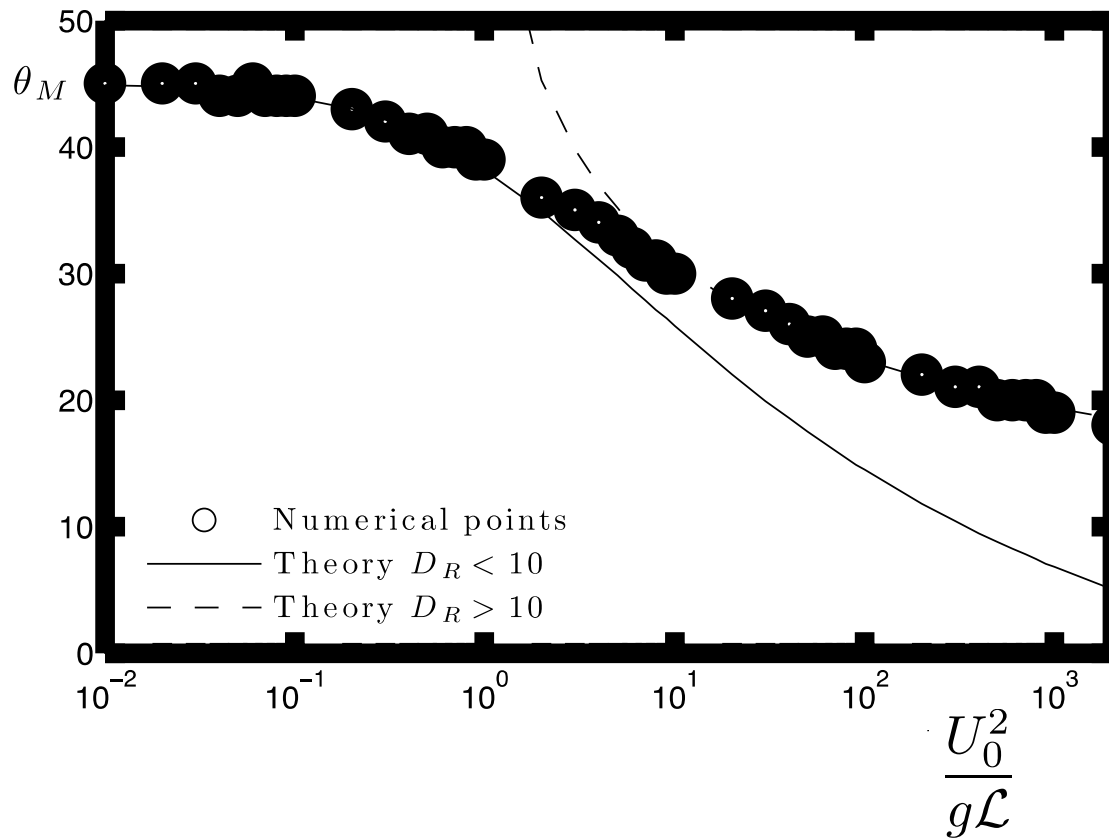


$$\mathcal{L} = \frac{2M}{\rho\pi R^2 C_D}$$

The optimal angle is not 45°

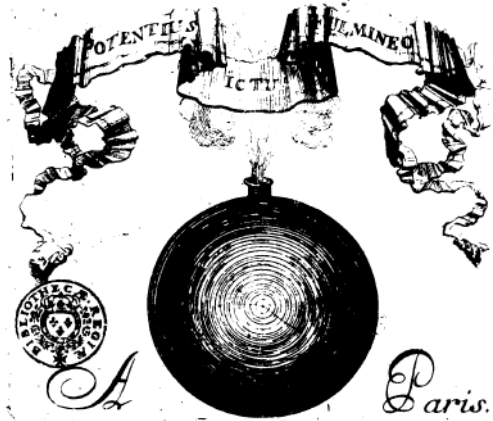


$$x_0 \approx \frac{1}{2} \mathcal{L} \cos \theta_0 \ln \left(1 + \frac{2U_0^2}{g\mathcal{L}} \sin \theta_0 \right)$$



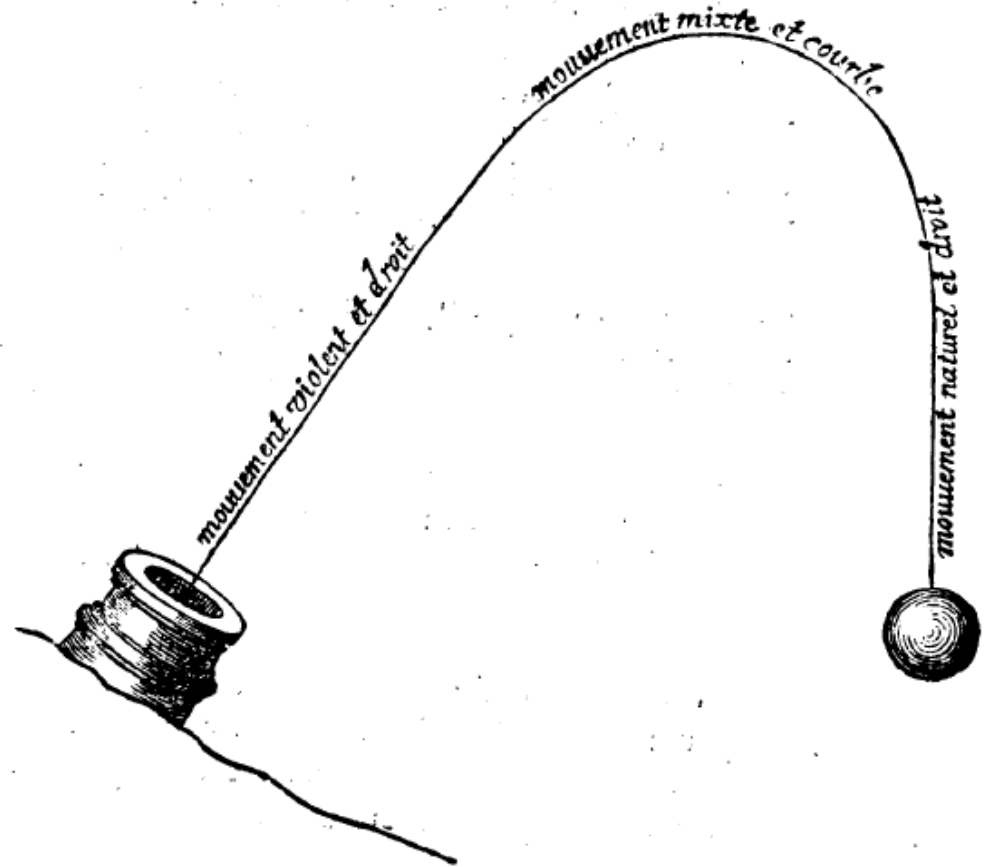
L'ART DE JETTER LES BOMBES.

PAR MONSIEUR BLONDEL MARECHAL
de Camp aux Armées du Roy, & cy-devant Maître
de Mathématique de Monseigneur le Dauphin.



Chez } L'AUTEUR au Faux-bourg S. Germain rue Jacob, au
coin de celle de S. Benoît.
Et NICOLAS LANGLOIS rue S. Jâques à la Victoire.

M. DC. LXXXIII.
AVEC PRIVILEGE DU ROY.



$$M \approx 6 \text{ kg}$$

$$D \approx 0.12 \text{ m}$$

$$U_0 \approx 300 \text{ m/s}$$

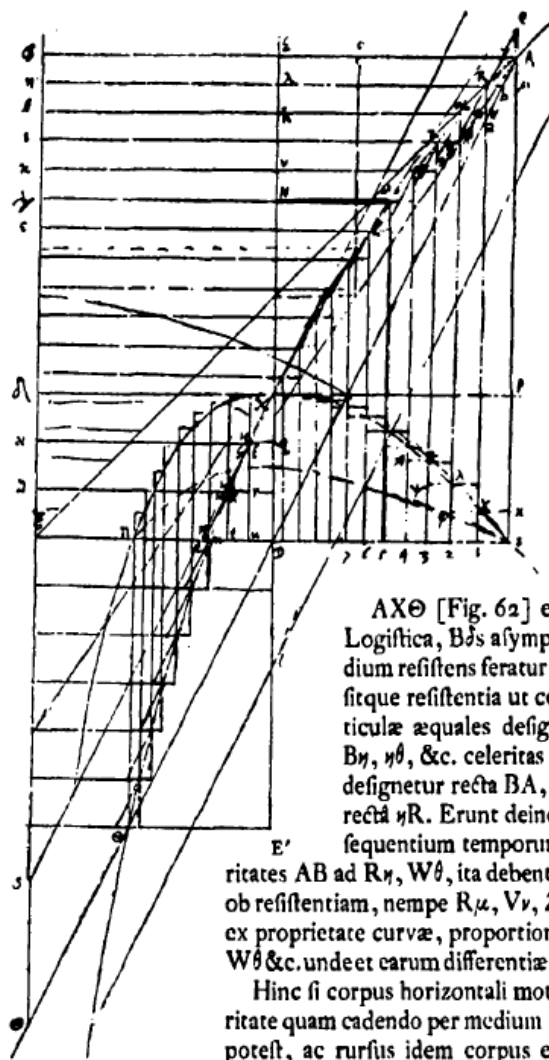
$$\mathcal{L} \approx 3 \text{ km}$$

$$\frac{U_0^2}{g\mathcal{L}} \approx 3$$

ŒUVRES COMPLÈTES
DE
CHRISTIAAN HUYGENS

PUBLIÉE PAR LA
SOCIÉTÉ HOLLANDAISE DES SCIENCES
TOME DIX-NEUVIÈME
MÉCANIQUE THÉORIQUE ET PHYSIQUE
DE 1666 à 1695.
HUYGENS À L'ACADÉMIE ROYALE DES SCIENCES.

[Fig. 62.]

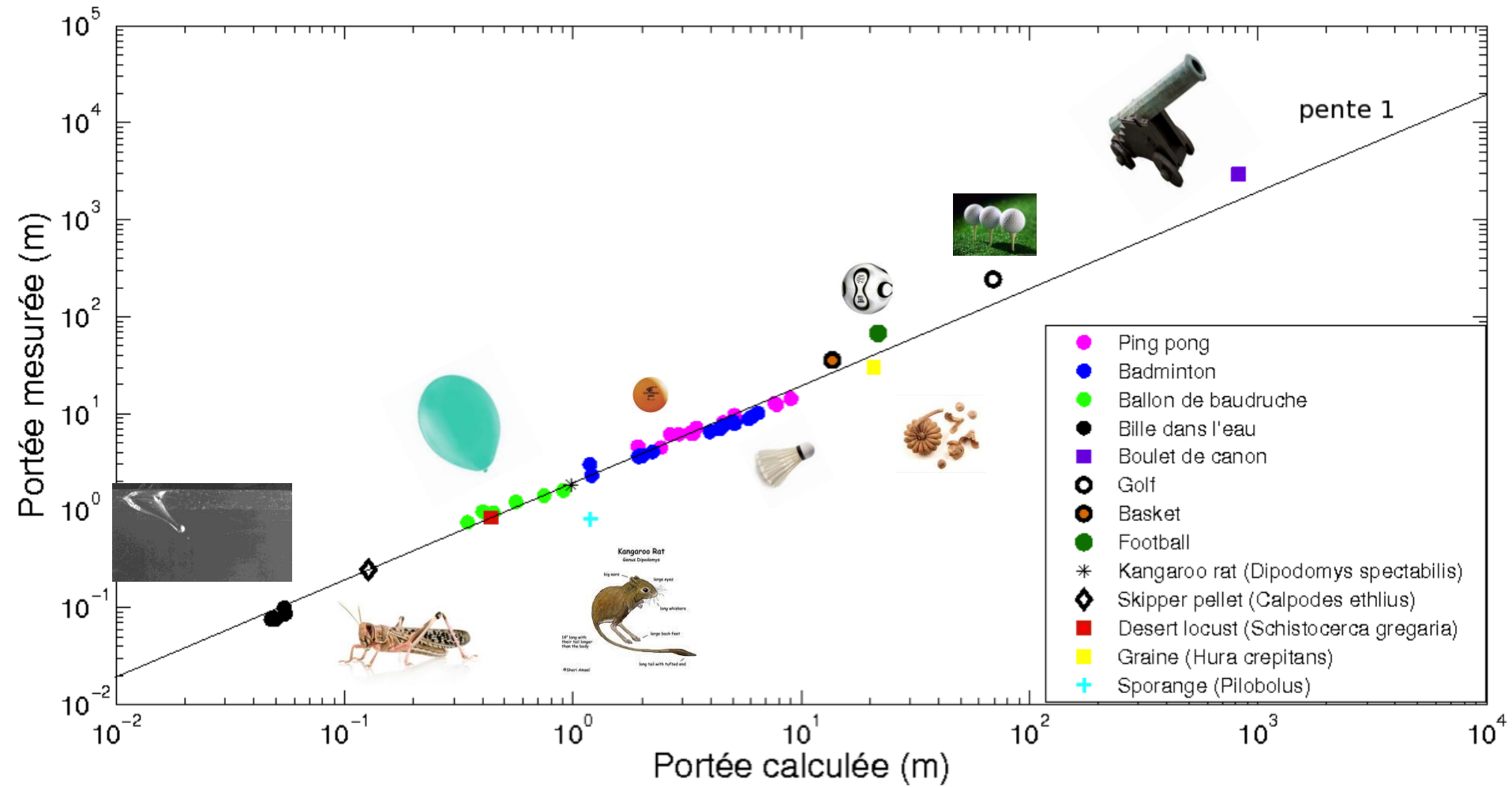


et in fine descensus deorsum quæ erant ut BF ad FA; nec non et longitudinum ascensus et descensus quæ erant item ut BF ad FA. Item curvam jactus ipsi BDA proportionalem manere. Quod si tamen manente eadem celeritate sursum, celeritas in longitudinem minor ponatur, fiet amplitudo jactus proportionaliter minor, ut si celeritas in longitudinem sit tantum $\frac{1}{2}$ GK, fiet et amplitudo jactus $\propto \frac{1}{2}$ BA.

§ 8. [Mouvement horizontal avec une vitesse initiale égale à la „vitesse terminale”.]

AXΘ [Fig. 62] est Curva Logarithmica sive Logistica, Bδs asymptotos ejus. Si corpus per medium resistens feratur super planomotu horizontali, sitque resistentiæ ut celeritas. temporis autem particulæ æquales designentur particulis æqualibus Bη, ηθ, &c. celeritas autem corporis initio motus designetur recta BA, initio vero secundi temporis recta ηR. Erunt deinceps θW, ζZ celeritates initio sequentium temporum θι, ικ, &c. Quia sicut celeritates AB ad Rη, Wθ, ita debent esse decremента celeritatum ob resistentiæ, nempe Rμ, Vν, Zπ. quod hic contingit. nam ex proprietate curvæ, proportionales continuè sunt AB, Rη, Wθ &c. unde et earum differentiæ in eadem ratione decremunt. Hinc si corpus horizontali motu impellatur, atque ea celeritate quam cadendo per medium resistens maximam acquirere potest, ac rursus idem corpus eadem hac celeritate sursum

sance de la vitesse du mobile: les résistances éprouvées par les deux mobiles auxiliaires peuvent alors être considérées comme des projections de la résistance éprouvée par le corps lui-même.



Position du mur aérodynamique pour différents projectiles



北京オリンピック2次予選



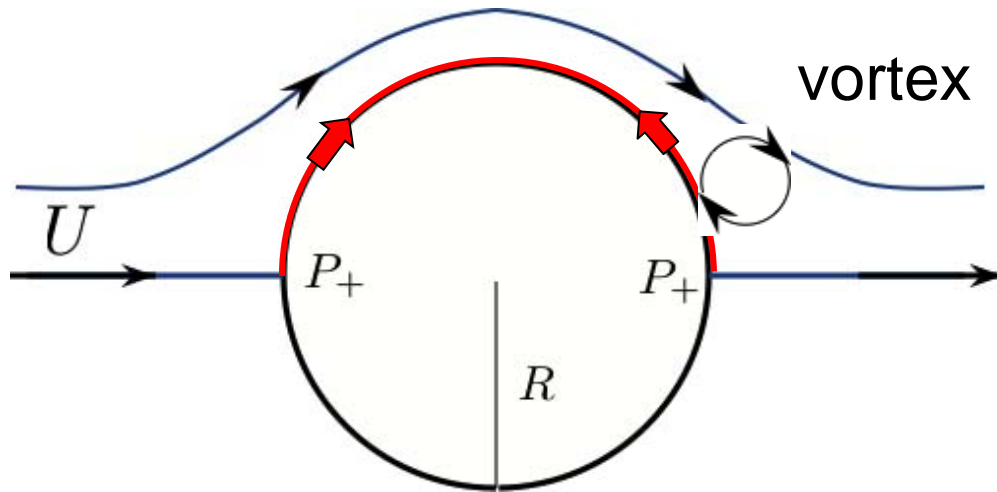


COLO COLO 0 0 << SANTOS 3:56

FOX SPORTS
VIVO

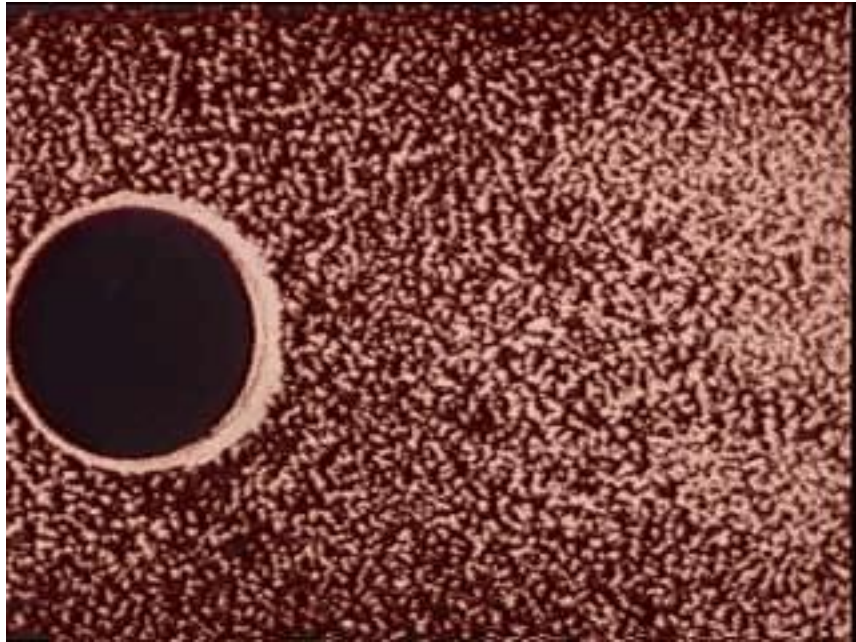
Santander

VISA



— $Re \equiv \frac{\rho U R}{\eta} \gg 1 : \rho \frac{d\underline{U}}{dt} \sim -\underline{\text{grad}} P$

— $Re \ll 1 : \underline{U} \sim -\kappa \underline{\text{grad}} P$

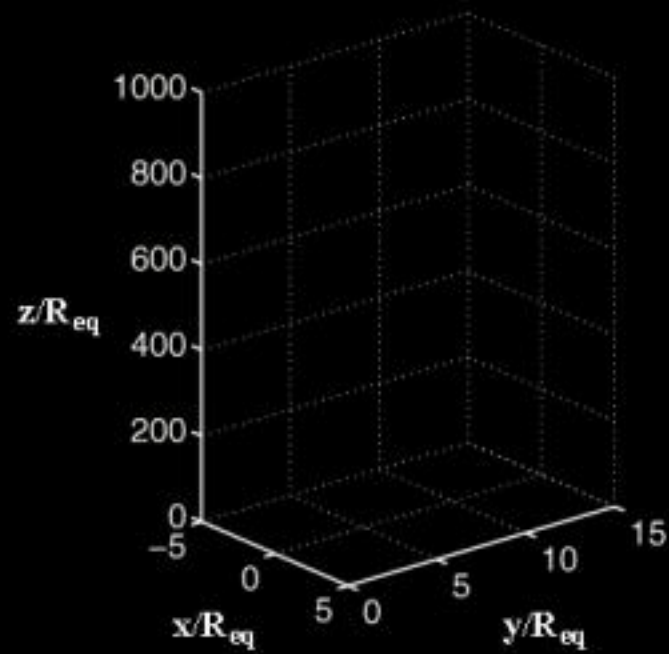


Phys. Rev. Lett. 88, 014502 (2001) Path Instability
of a Rising Bubble
Magnaudet J., Mougin G.

Trailing Vorticity



3D Trajectory





$$M \frac{\delta}{\tau^2} \sim \rho \Gamma U R$$

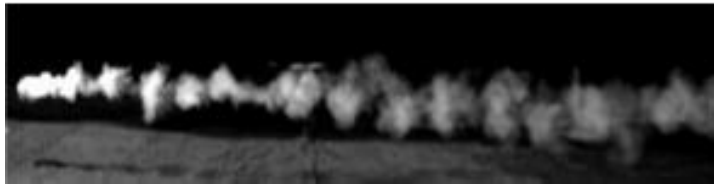
$$\frac{\delta}{R} \sim \frac{\rho U^2 R^2 \tau^2}{M R}$$

$$\frac{\delta}{R} \sim \frac{\rho}{\rho_s} \approx 2\%$$

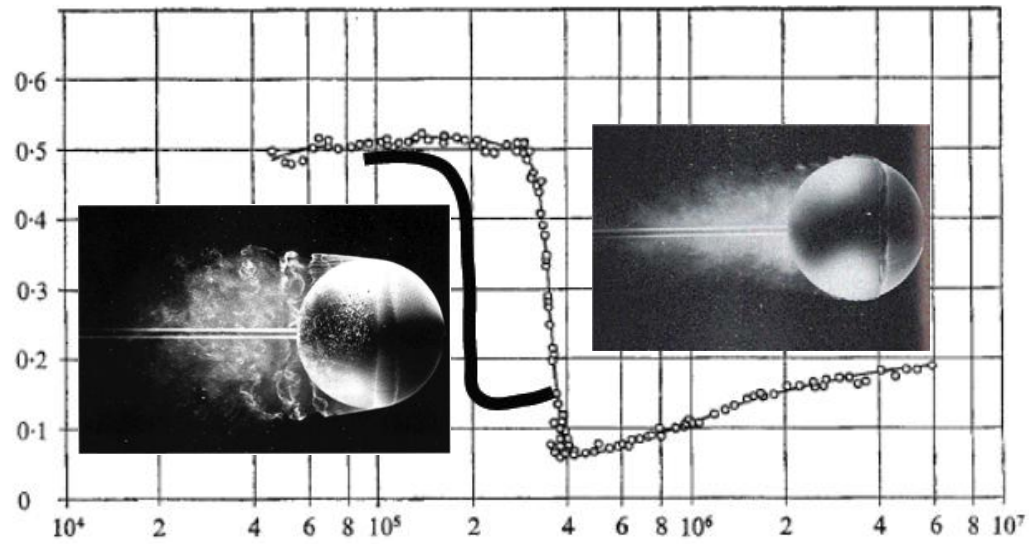
Fundamental aerodynamics of the soccer ball

T. Asai,* K. Seo,[†] O. Kobayashi[‡] and R. Sakashita[§]

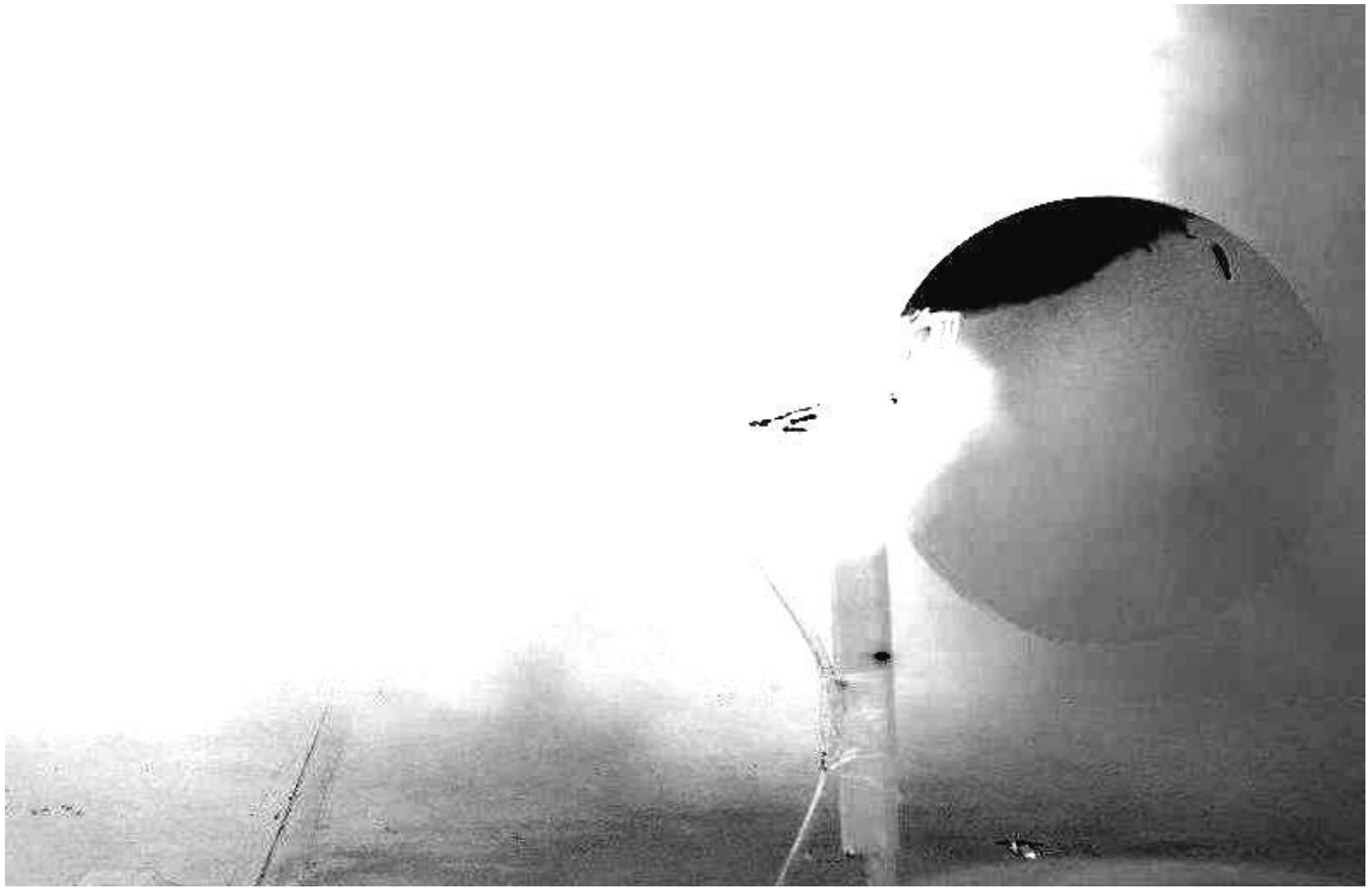
Sports Engineering (2007) 10, 101–110

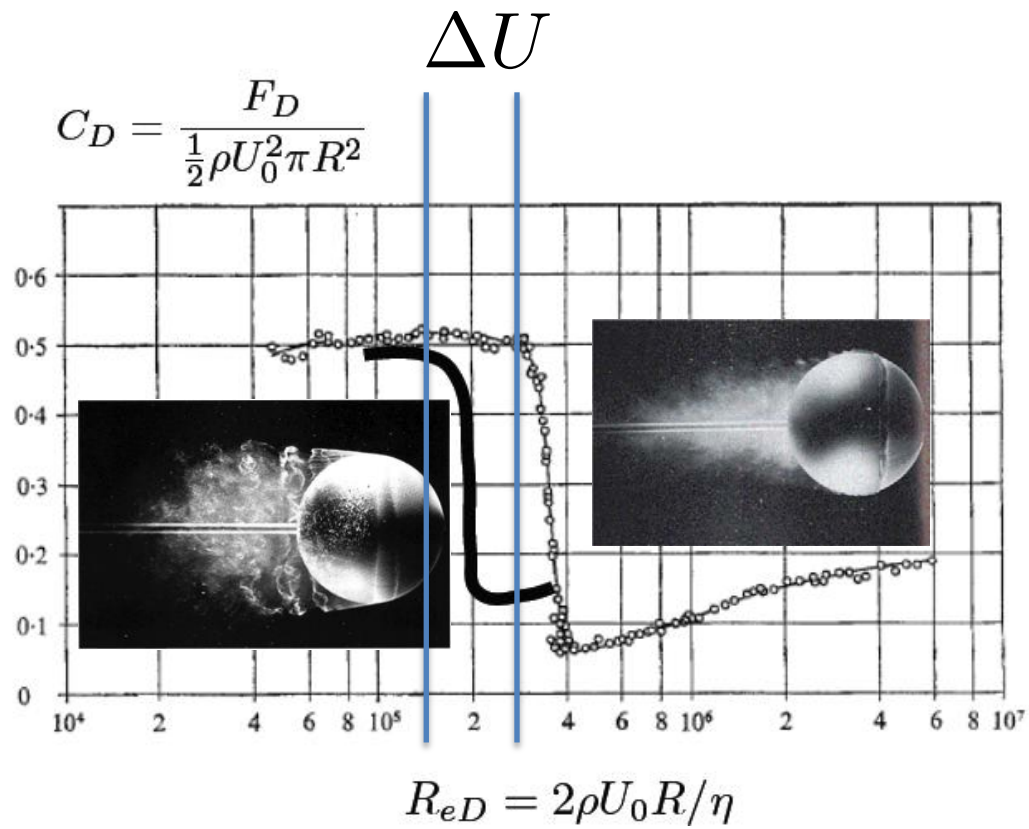


$$C_D = \frac{F_D}{\frac{1}{2}\rho U_0^2 \pi R^2}$$

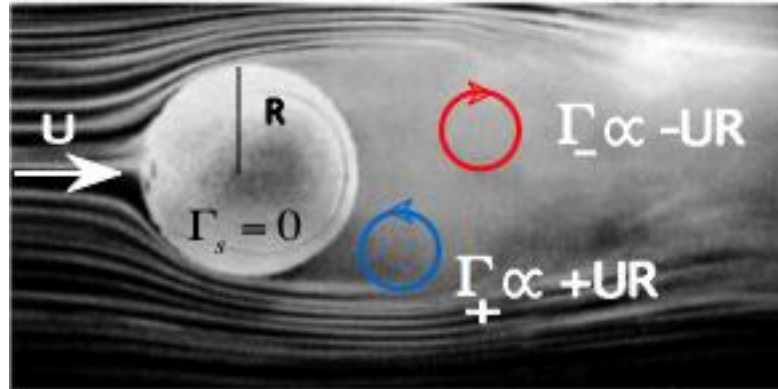


$$Re_D = 2\rho U_0 R / \eta$$

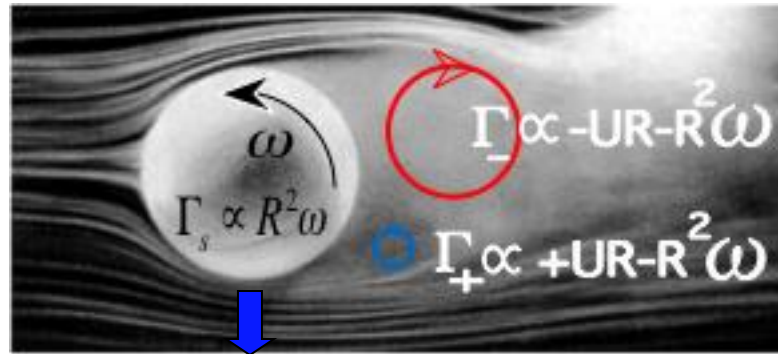




$$\left. \begin{aligned} \tau &\sim \frac{M \Delta U}{\rho U^2 R^2} \\ \frac{\delta}{R} &\sim \frac{\rho U^2 R^2 \tau^2}{M R} \end{aligned} \right\} \frac{\delta}{R} \sim \frac{\rho_s}{\rho} \left(\frac{\Delta U}{U} \right)^2$$



$$F_D \sim \rho U^2 R^2$$



$$F_L \sim -\rho \Gamma_s U R$$

The Roberto Carlos spiral

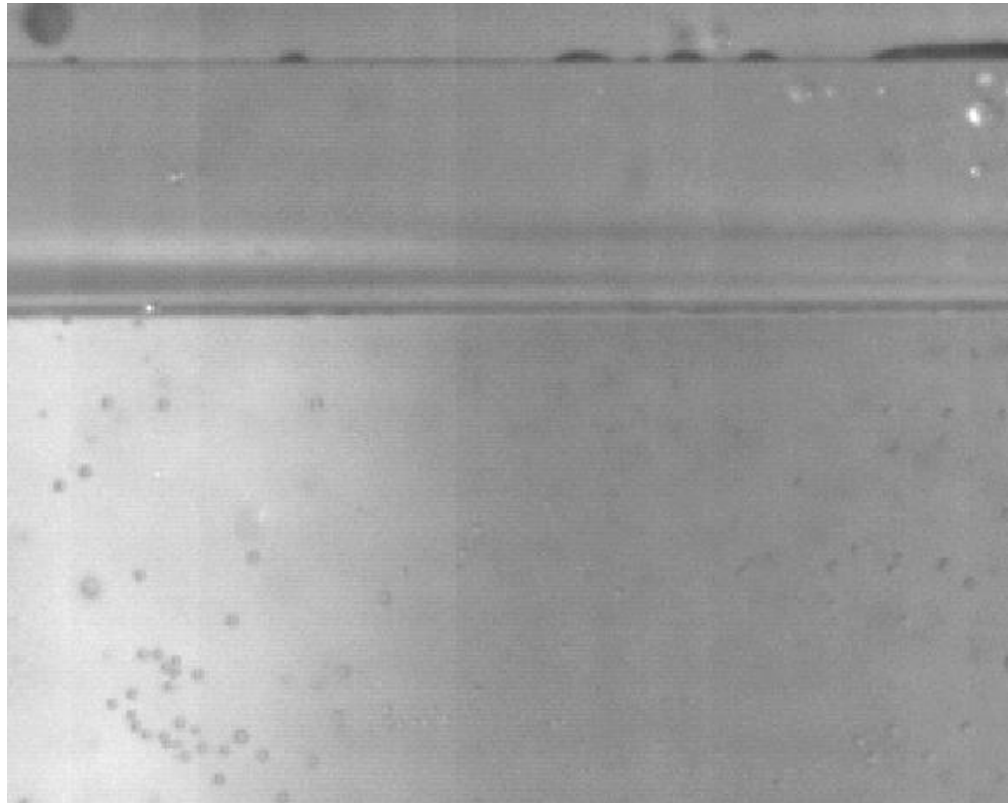


A. Le Goff, G. Dupeux, D. Quéré

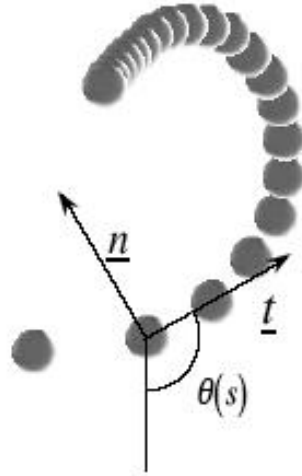
$$M \frac{d\underline{U}}{dt} = \underline{F}_D + \underline{F}_L$$

$$\mathcal{L} = \frac{2M}{\rho S C_D} \sim \frac{\rho_s}{\rho} R$$









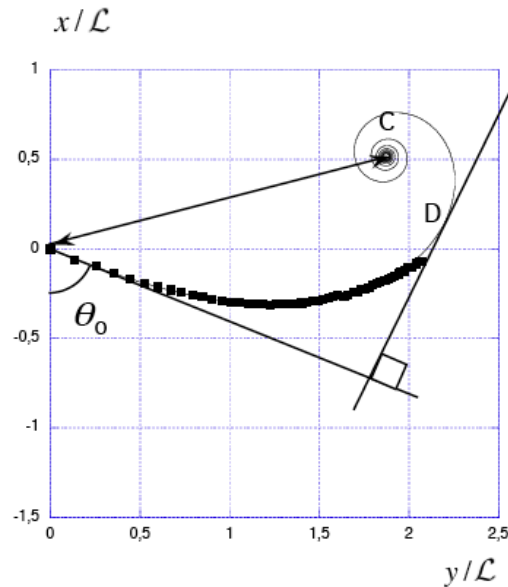
t

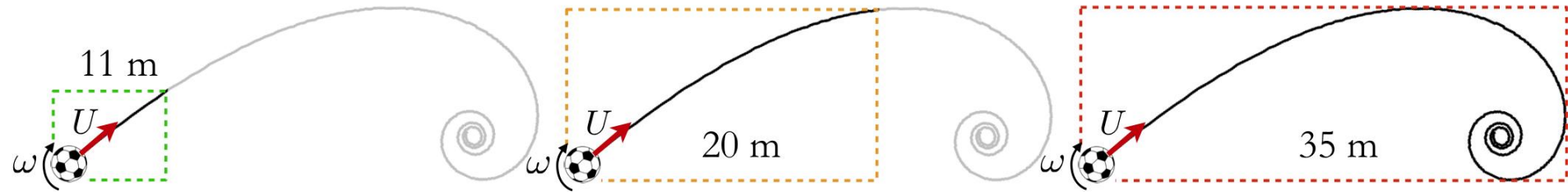
$$M(1 + C_M)U \frac{dU}{ds} = -\frac{1}{2}\rho U^2 \pi R^2 C_D$$

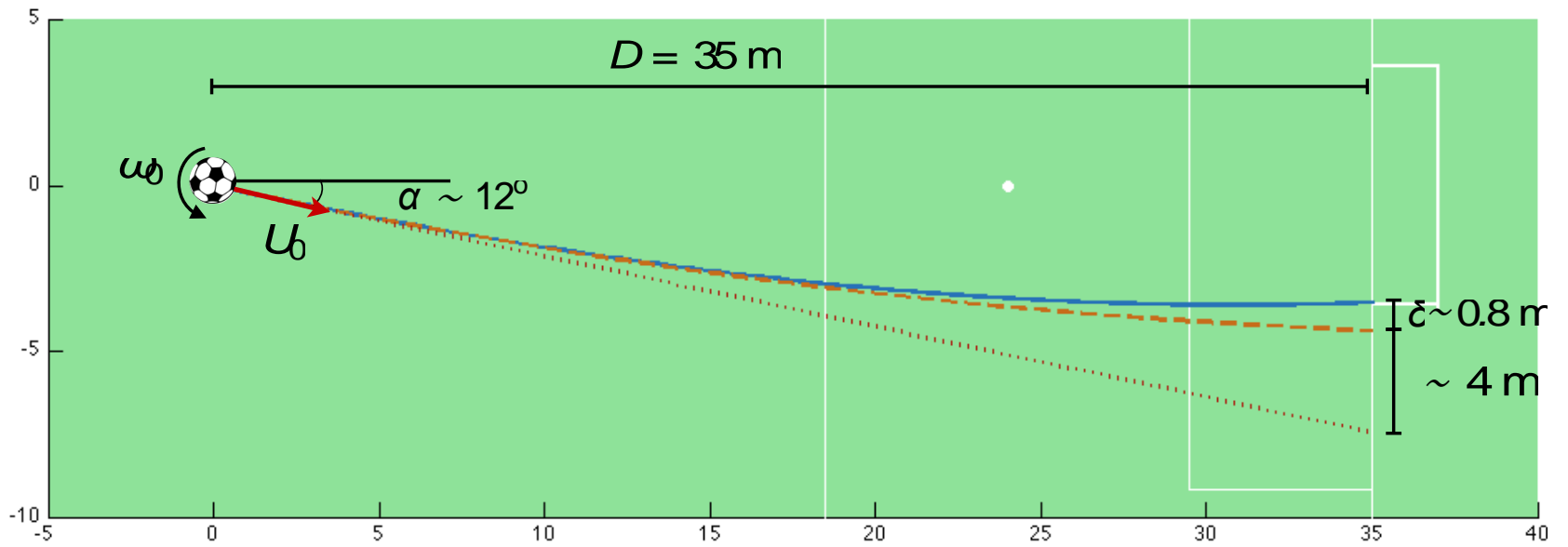
$$U(s) = U_0 e^{-s/\mathcal{L}} \quad \text{with} \quad \mathcal{L} = \frac{8}{3} \frac{1 + C_M}{C_D} \frac{\rho_s}{\rho} R$$

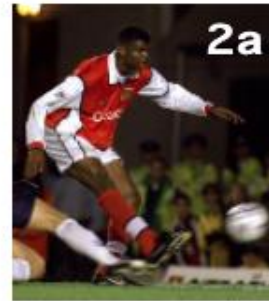
n

$$\left. \begin{aligned} M(1 + C_M)U^2 \frac{d\theta}{ds} &= F_L \\ F_L &\sim -\rho R^3 \omega U \end{aligned} \right\} \boxed{\frac{d\theta}{ds} \sim \frac{\rho}{\rho_s} \frac{\omega}{U} \sim \frac{\rho}{\rho_s} \frac{\omega_0}{U_0} e^{s/\mathcal{L}}}$$









47

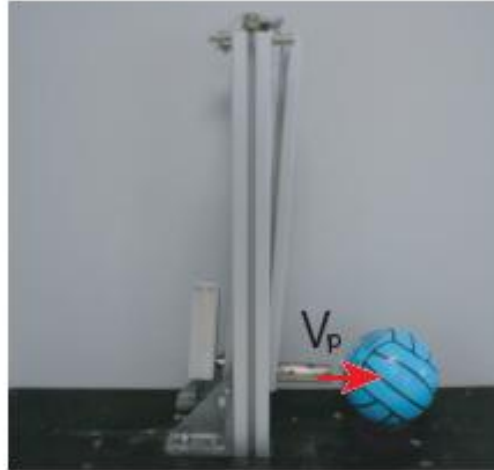
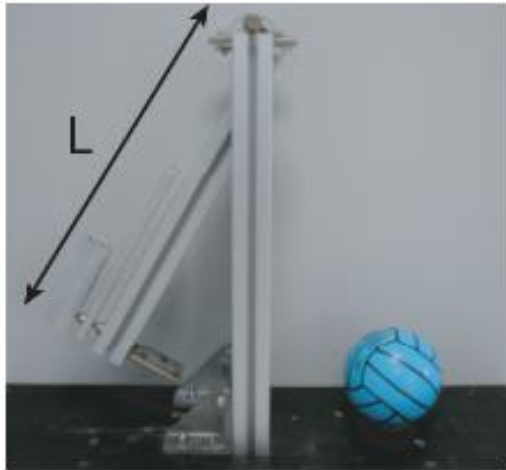
The number '47' is rendered in a large, bold, green font. The number '7' contains a small, white silhouette of a soccer player in a white jersey and blue shorts, positioned as if they are about to kick a ball. The number '4' also contains a small, white silhouette of a soccer player in a white jersey and blue shorts, positioned as if they are about to kick a ball.

Vienna, 27 Maggio 1987
Porto - Bayern Monaco 2-1
77' MADJER (1-1)



When and why?





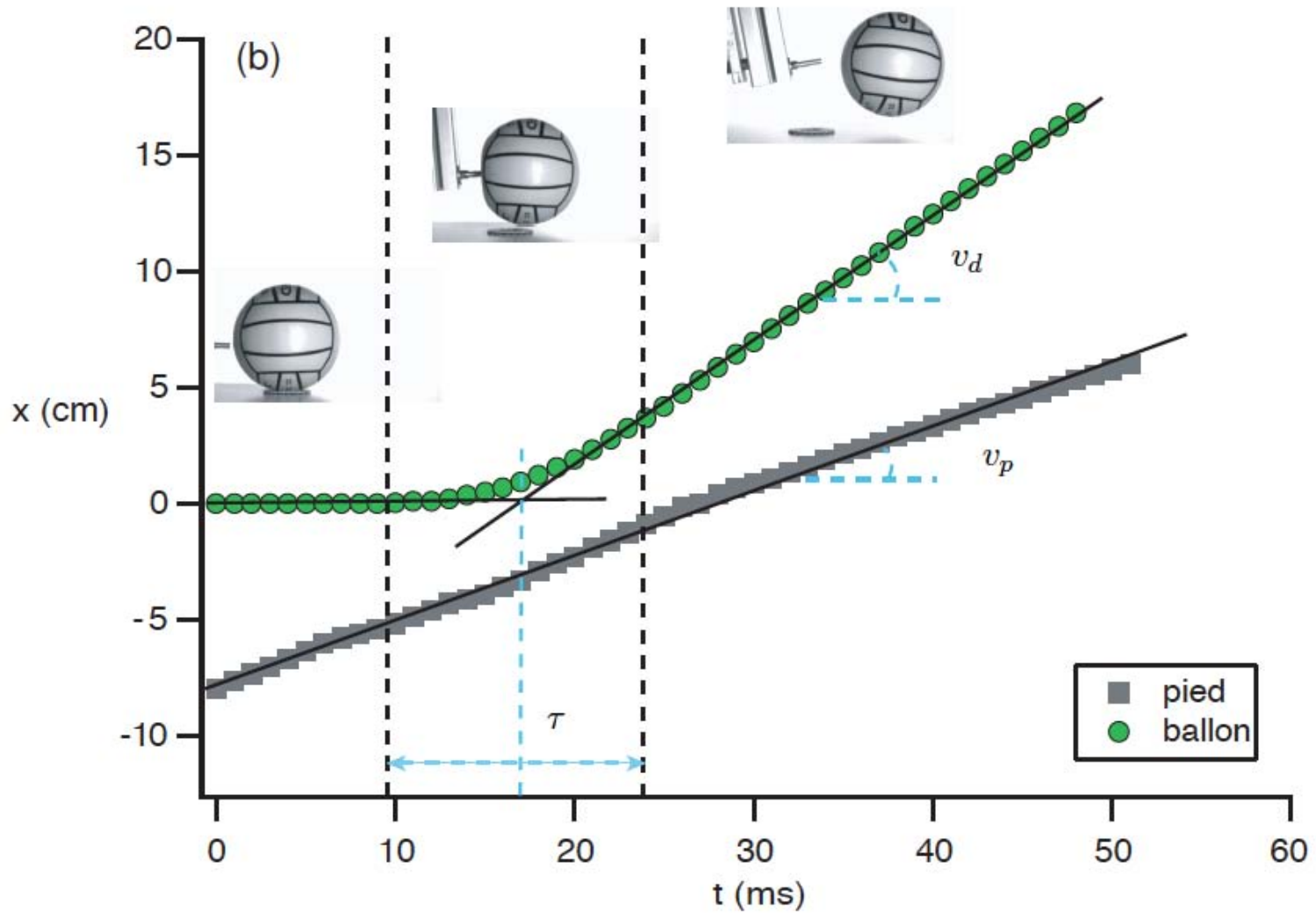
$R_0=5$
9mm

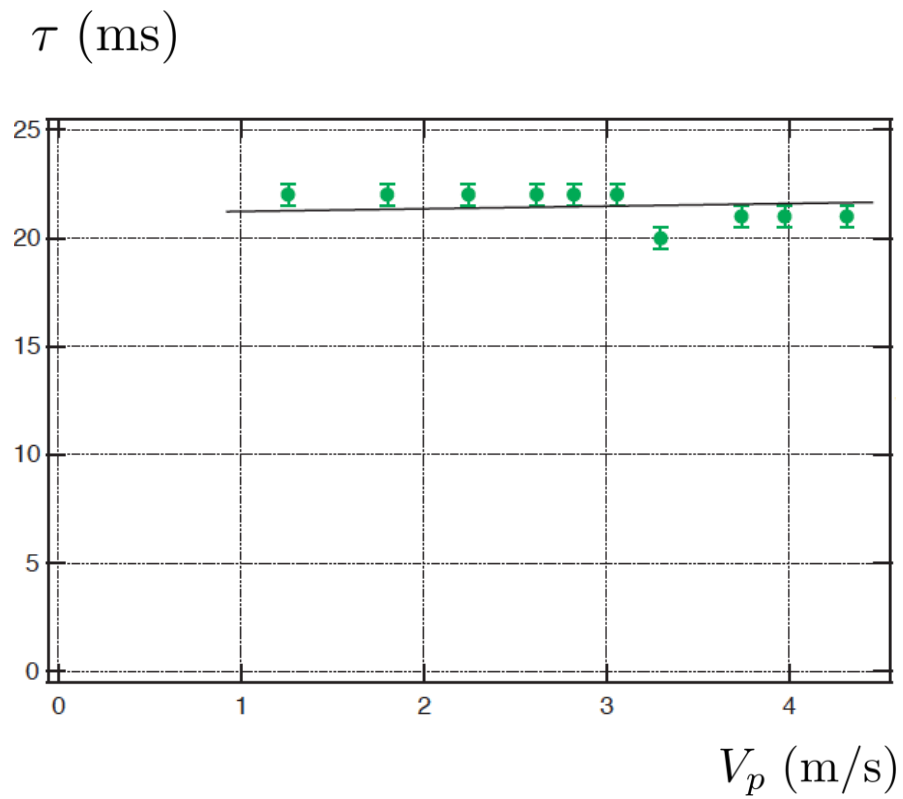
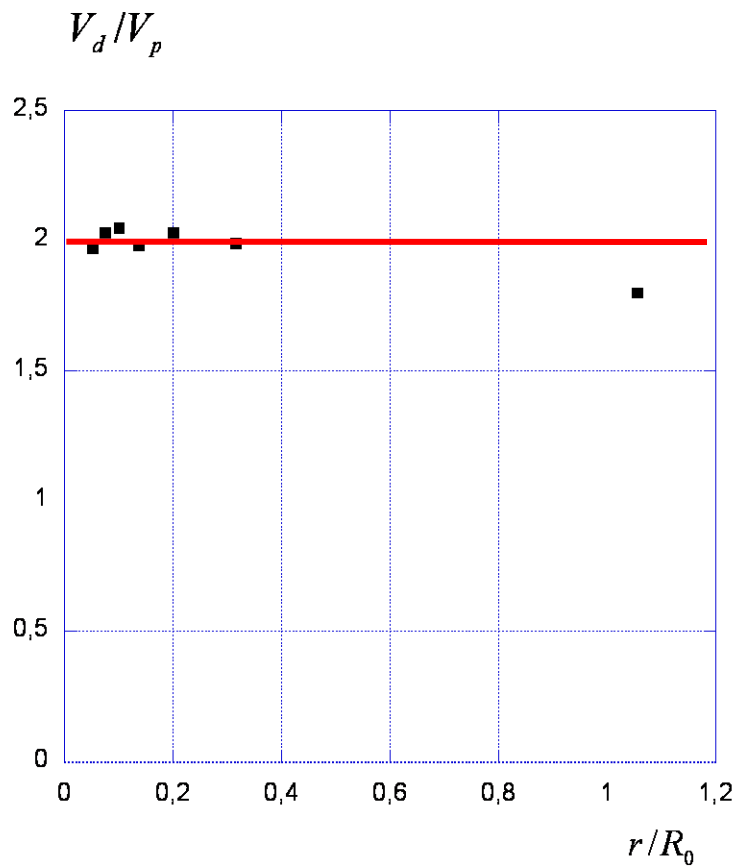
$m=7$
0g

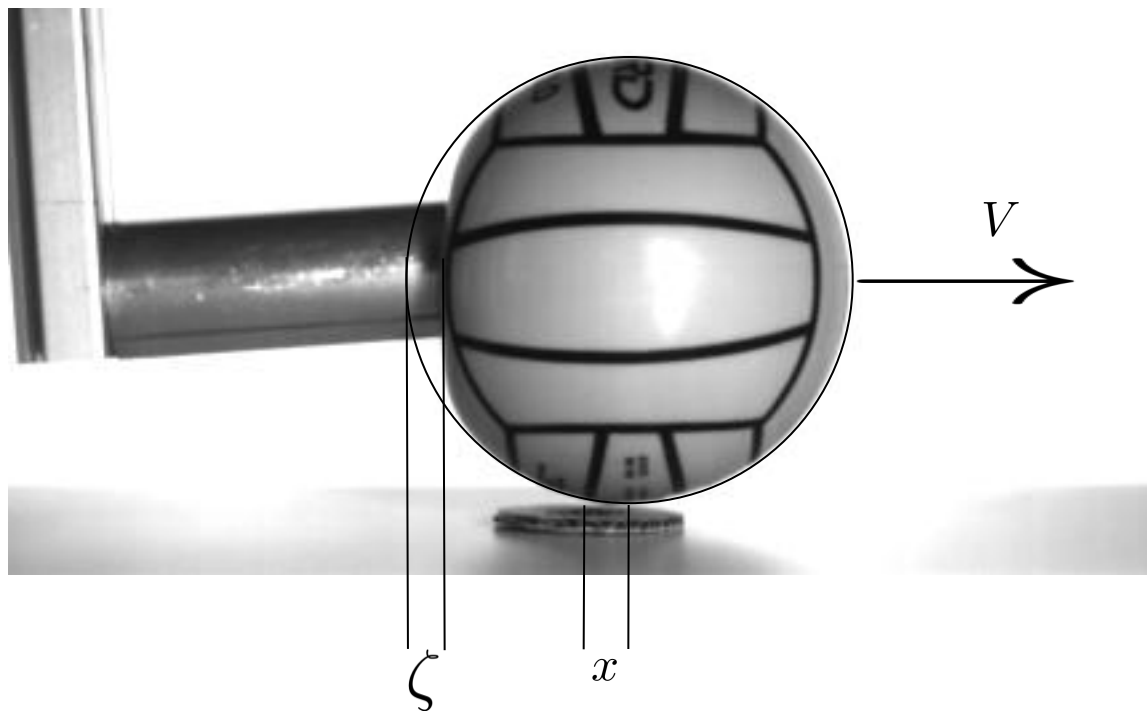


$r=3, 4.5, 6, 8.2, 12,$
19 mm









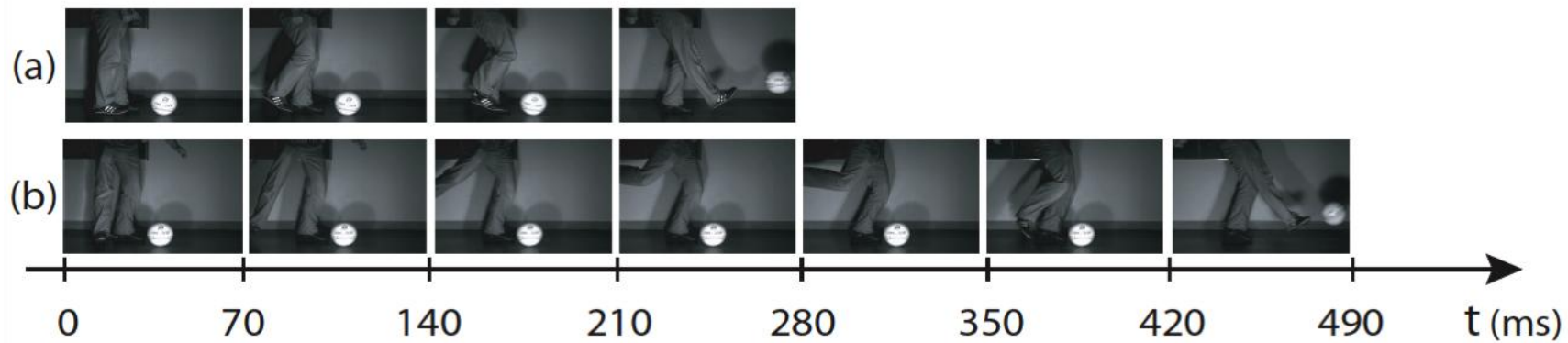
$$\left. \begin{aligned}
 M \frac{dV}{dt} &= F(\zeta) \\
 \zeta &= V_p t - x \\
 F(\zeta) &\sim k\zeta \\
 (k &\sim PR)
 \end{aligned} \right\}
 \begin{aligned}
 M \frac{d^2V}{dt^2} &= k(V_p - V) \\
 (\omega &= \sqrt{k/M})
 \end{aligned}
 \left\{ \begin{aligned}
 V &= V_p (1 - \cos \omega t) \\
 \zeta &= \frac{v_p}{\omega} \sin \omega t
 \end{aligned} \right.$$



440ms



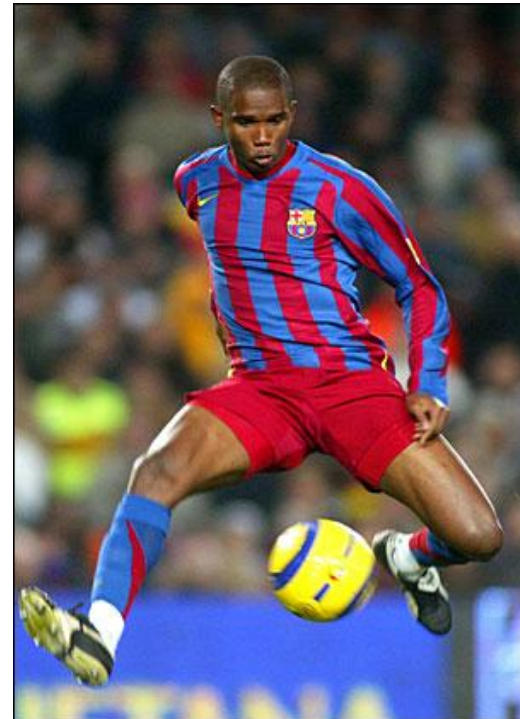
120ms



Toe poke as the emergency kick



dribbling

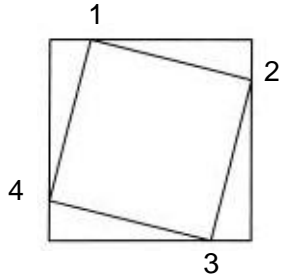
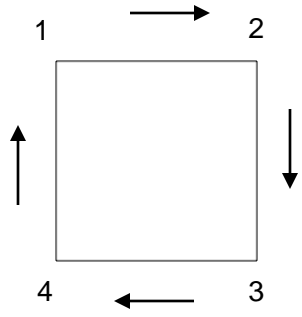




a poor and illiterate boy



Botafogo vs. Flamengo



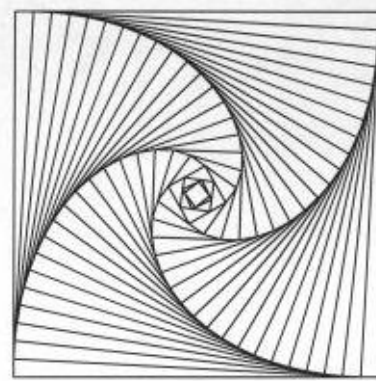
4

1

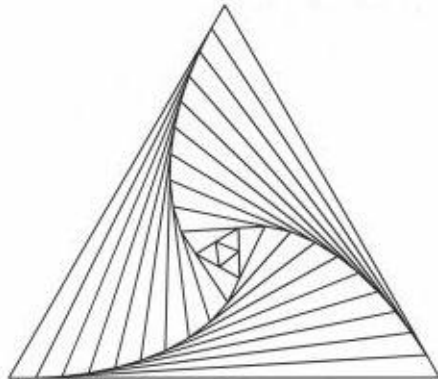
2

3

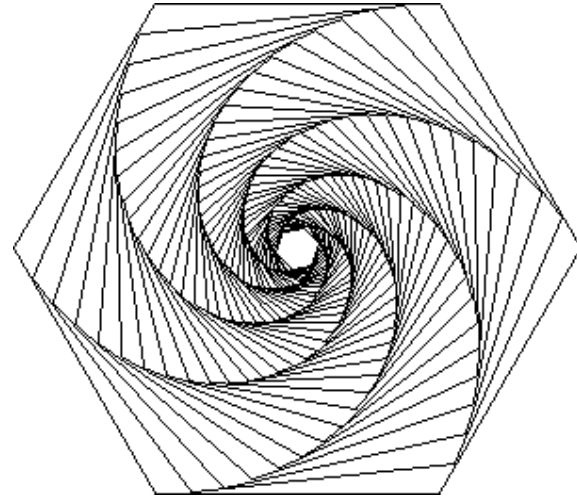
4



3



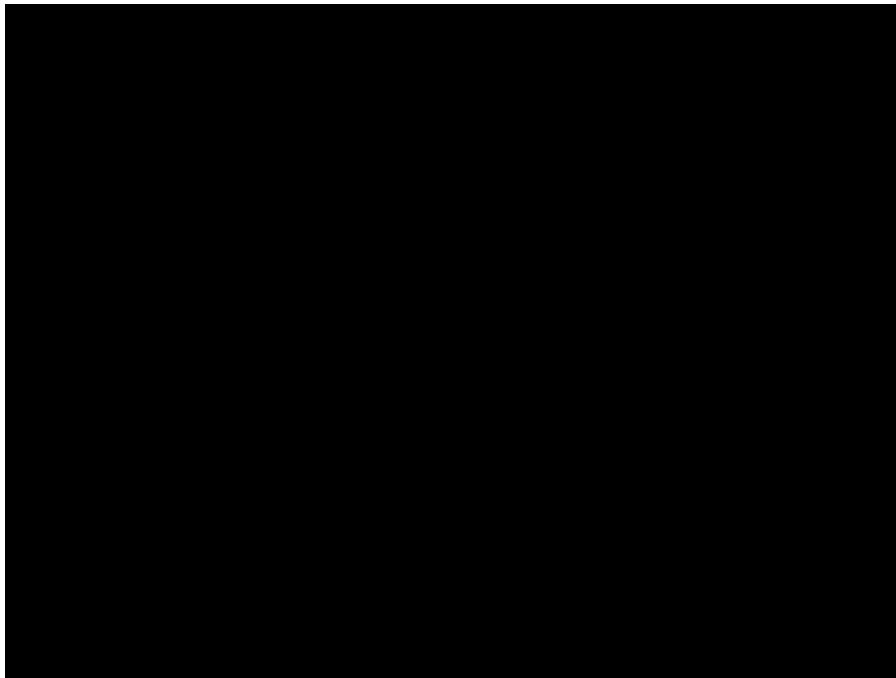
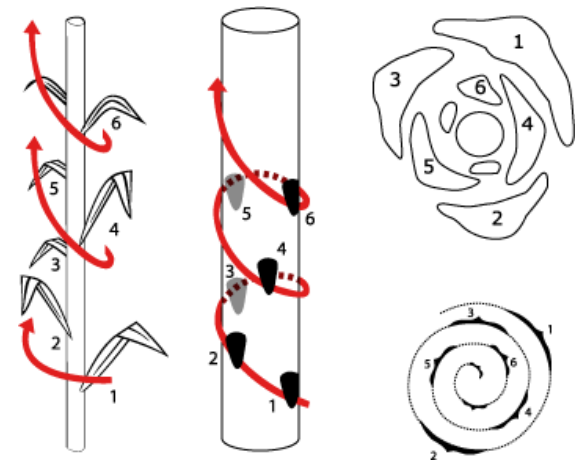
6



Phyllotaxis as a Physical Self-Organized Growth Process

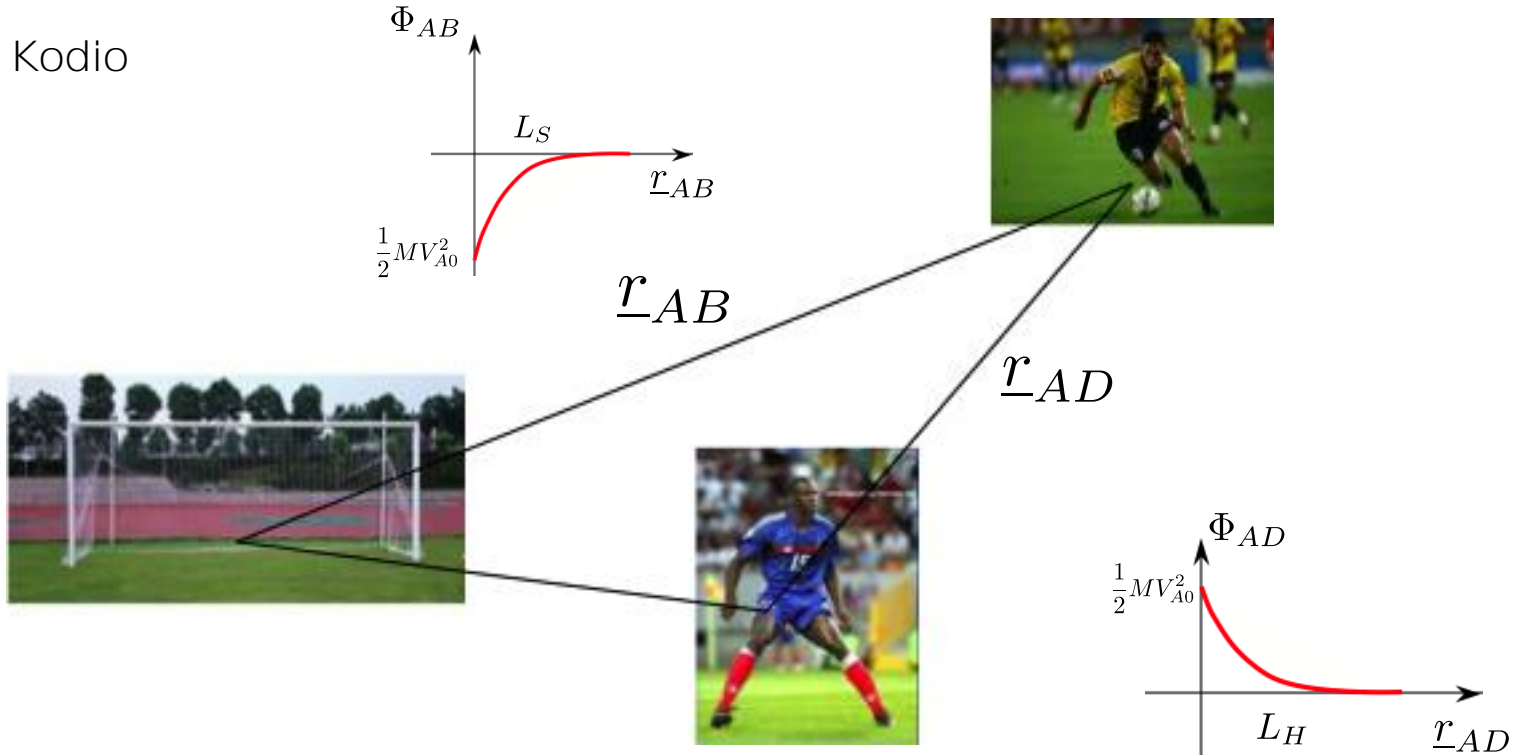
S. Douady^(a) and Y. Couder

*Laboratoire de Physique Statistique, 24 rue Lhomond, 75231 Paris CEDEX 05, France
(Received 12 November 1991)*



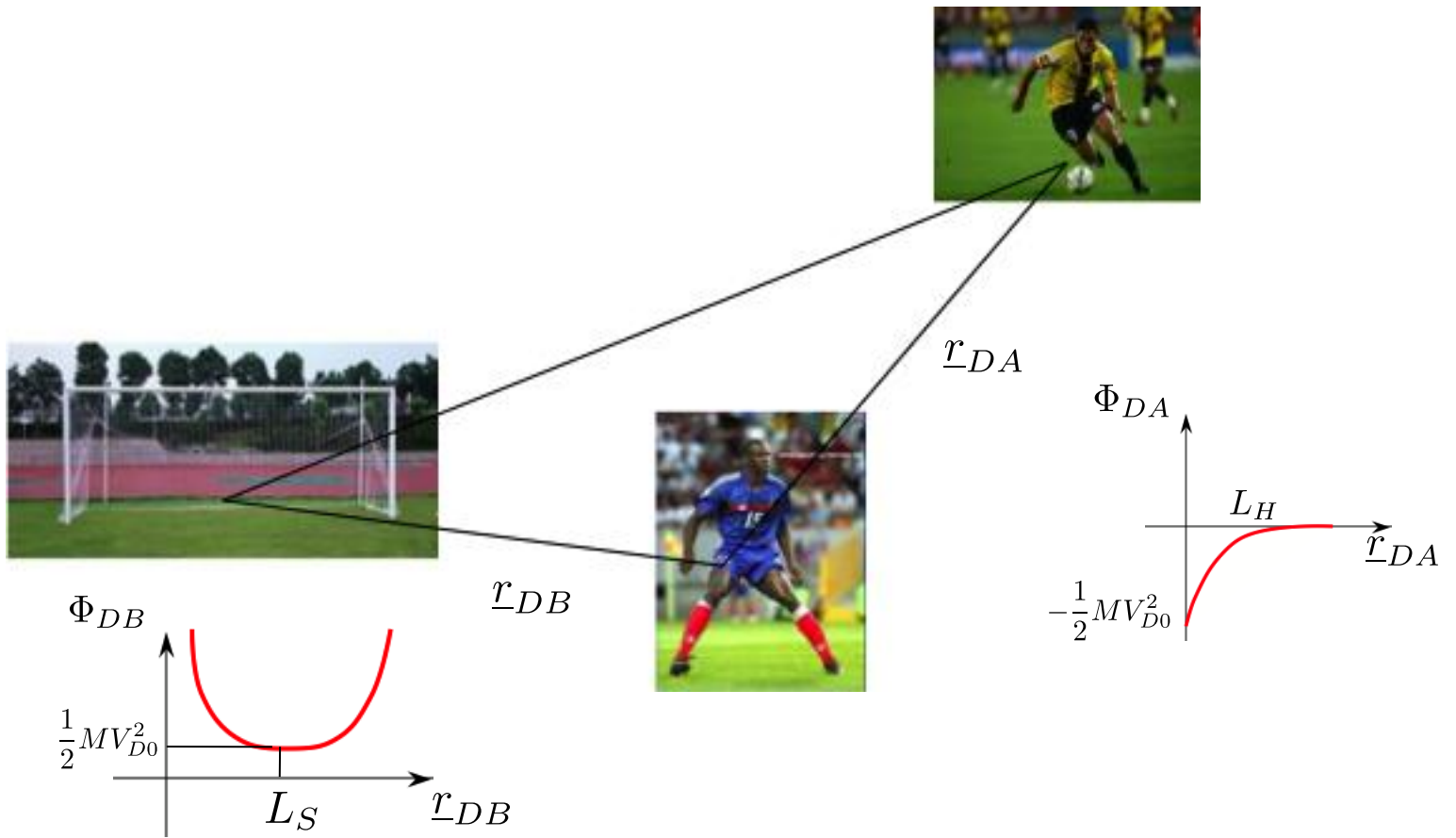
1,2,3,5,8,13,21,...

Ousame Kodio



$$\Phi_A = \Phi_{AB} + \Phi_{AD}$$

$$M \frac{d\underline{V}_A}{dt} = -\underline{\text{grad}} \Phi_A$$

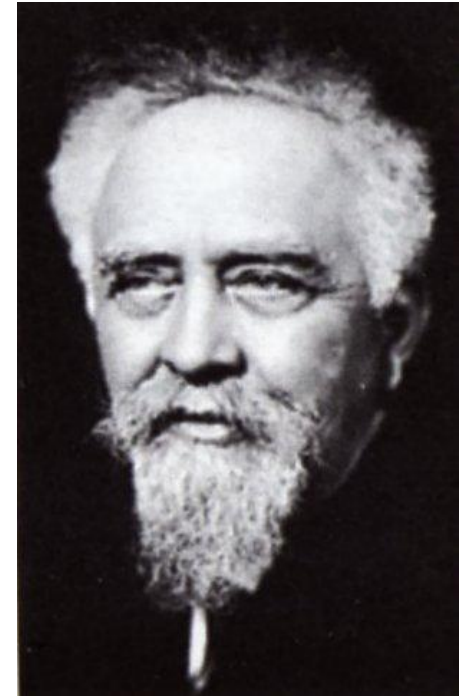
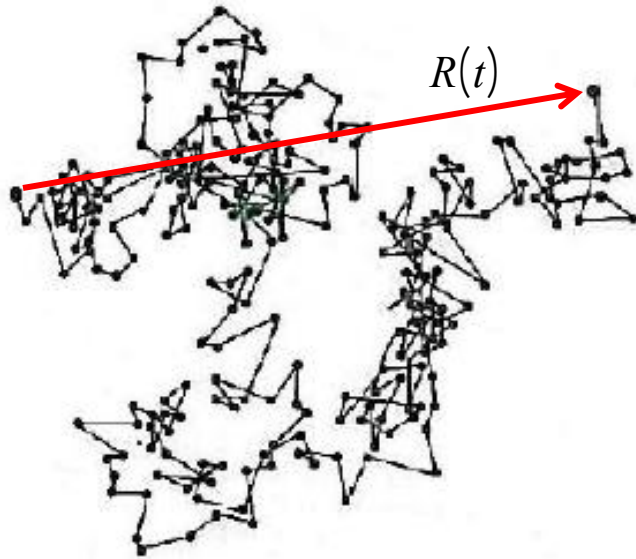


$$\Phi_D = \Phi_{DB} + \Phi_{DA}$$

$$M \frac{d\underline{V}_D}{dt} = -\underline{\text{grad}} \Phi_D$$



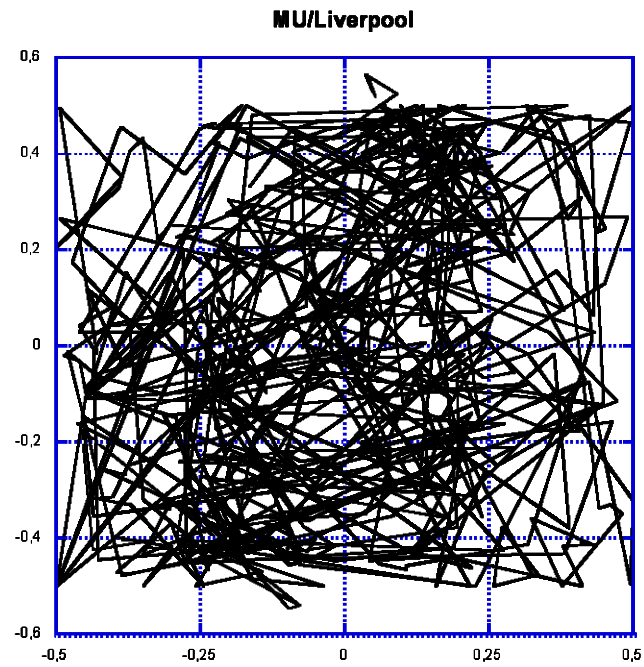
La Fillette au Volant – Jean Siméon Chardin 1741



Jean Perrin, 1870-1942

$$\langle R^2 \rangle \propto D.t$$

Foot et physique statistique



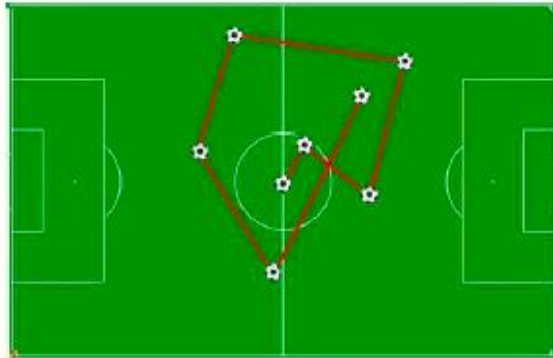


Fig 1 : 7 consecutive passes

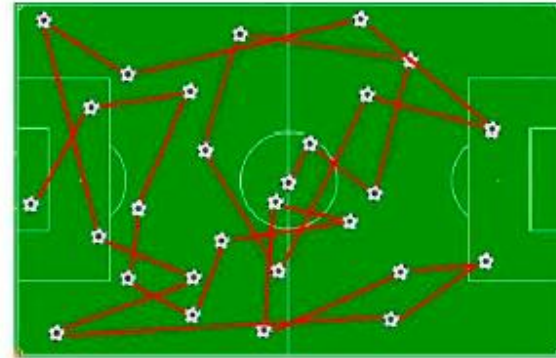
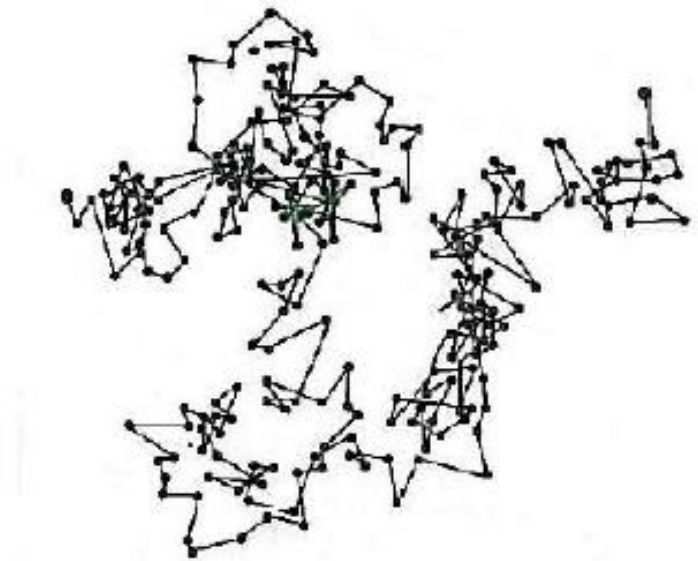
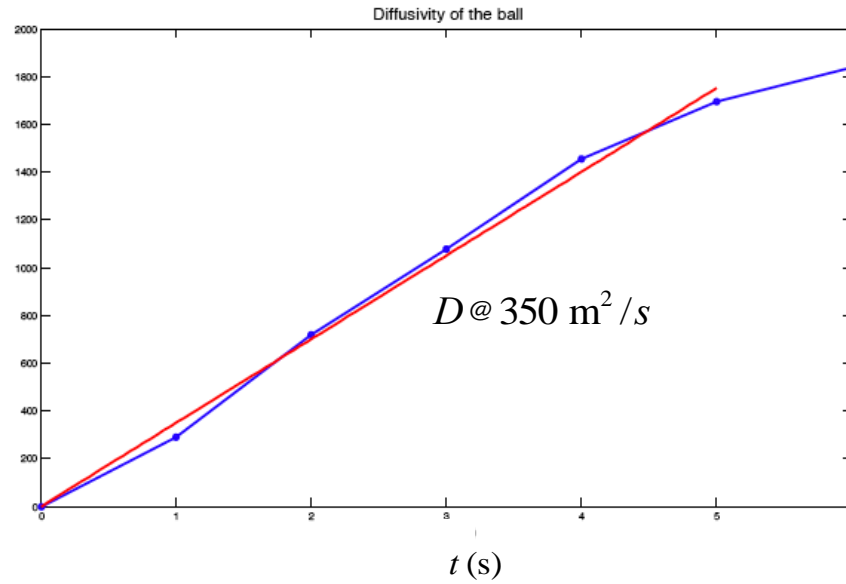


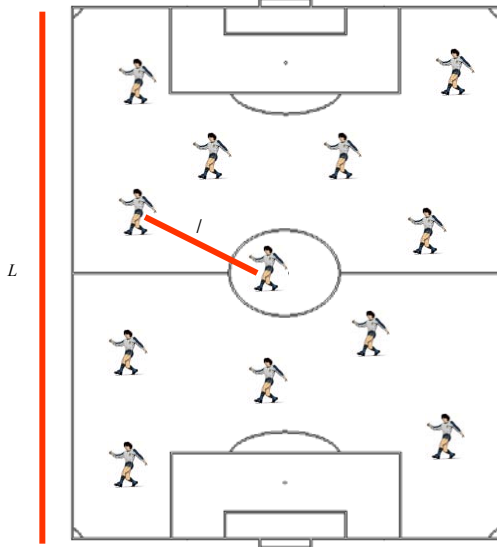
Fig 2 : A sequence of 45 seconds



$$\langle R(t)^2 \rangle (m^2)$$



libre parcours moyen

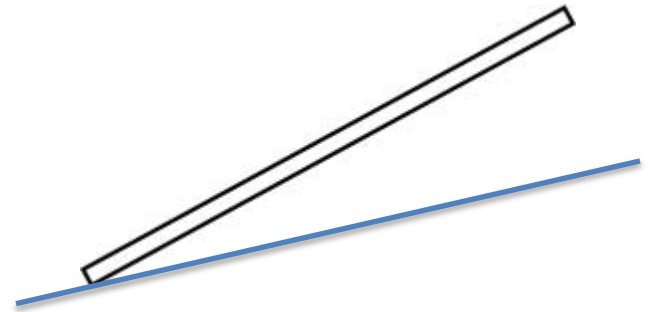
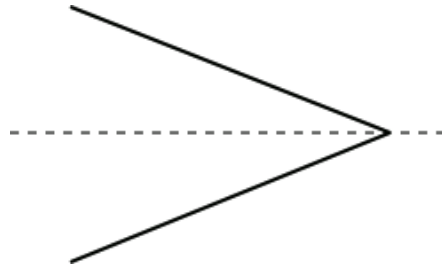
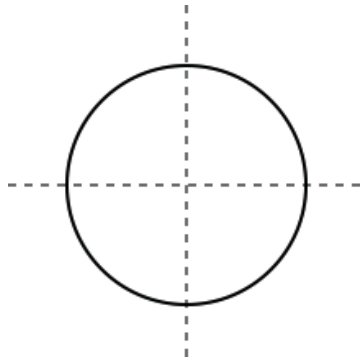


$$L^2 \propto N \cdot l^2$$

$$l \propto \frac{L}{\sqrt{N}} \propto 20 \text{ m}$$

coefficient de diffusion

$$D \propto l \cdot c \propto 300 \text{ m}^2/s$$







Baptiste Darbois-TeXier



Caroline Cohen



Guillaume Dupeux