Physics of Sports

Dr. Muhammad Ali Yousuf

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http://pages.jh.edu/~maliyou1/Physics_of_Sports/

Image https://amazingpict.com/hd-wallpapers-background-images/mickey-mouse-basketball/

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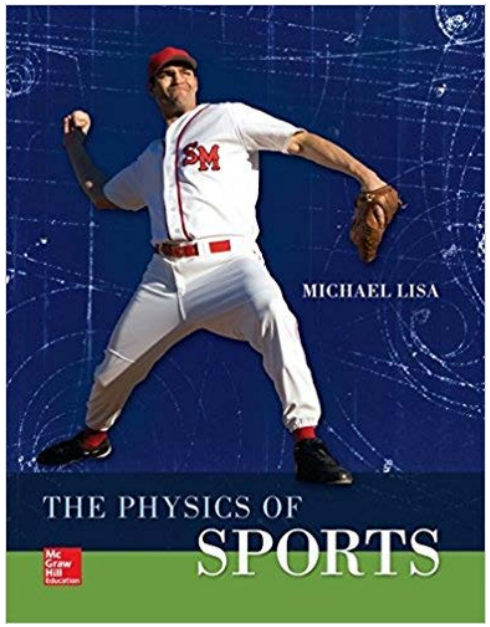
- If you feel a reference is missing, please let me know and I'll either remove the content or will provide the reference.

The physics of sports isn't rocket science.
It's much harder.
Bob Adair in *The Physics of Baseball*

Introduction



Course Number: AS.360.167.13
Dates: Monday 1/8/2018 - Friday 1/26/2018
Times: Monday - 6-8:30 | Friday - 6-8:30
Location: Homewood Campus, Hodson 213
Webpage: http://pages.jh.edu/~maliyou1/
Textbook: Michael Lisa, The Physics of Sports.
ISBN-13: 978-0073513973
Grading: Class participation 30%, two written assignments (15%+15%), project (40%).

Introduce yourself:

- Write, in one single line (since there are many participants, if you write on multiple lines, messages will get mixed up):

(1) your preferred name,

(2) your area of study and/or research, and

(3) something interesting about you which will help others remember you.

- I'll start with myself …
- (1) My name is Ali, (2) though I am a theoretical physicist by education, my field of research is Biomedical Engineering/Medical Devices. (3) I am a big fan of Star Wars movies and deeply inspired by Yoda, I am.

History of the Physics of Sports

- In early 1850s the subject of rotating artillery shells was explored by the German professor Heinrich Magnus. In this project he investigated sideways deflection of artillery shells which were rotating.
- In 1877 Lord Rayleigh wrote a paper on the irregular flight of a tennis-ball. It can be found here.
- It is also a good topic for projects.

Plan for Today

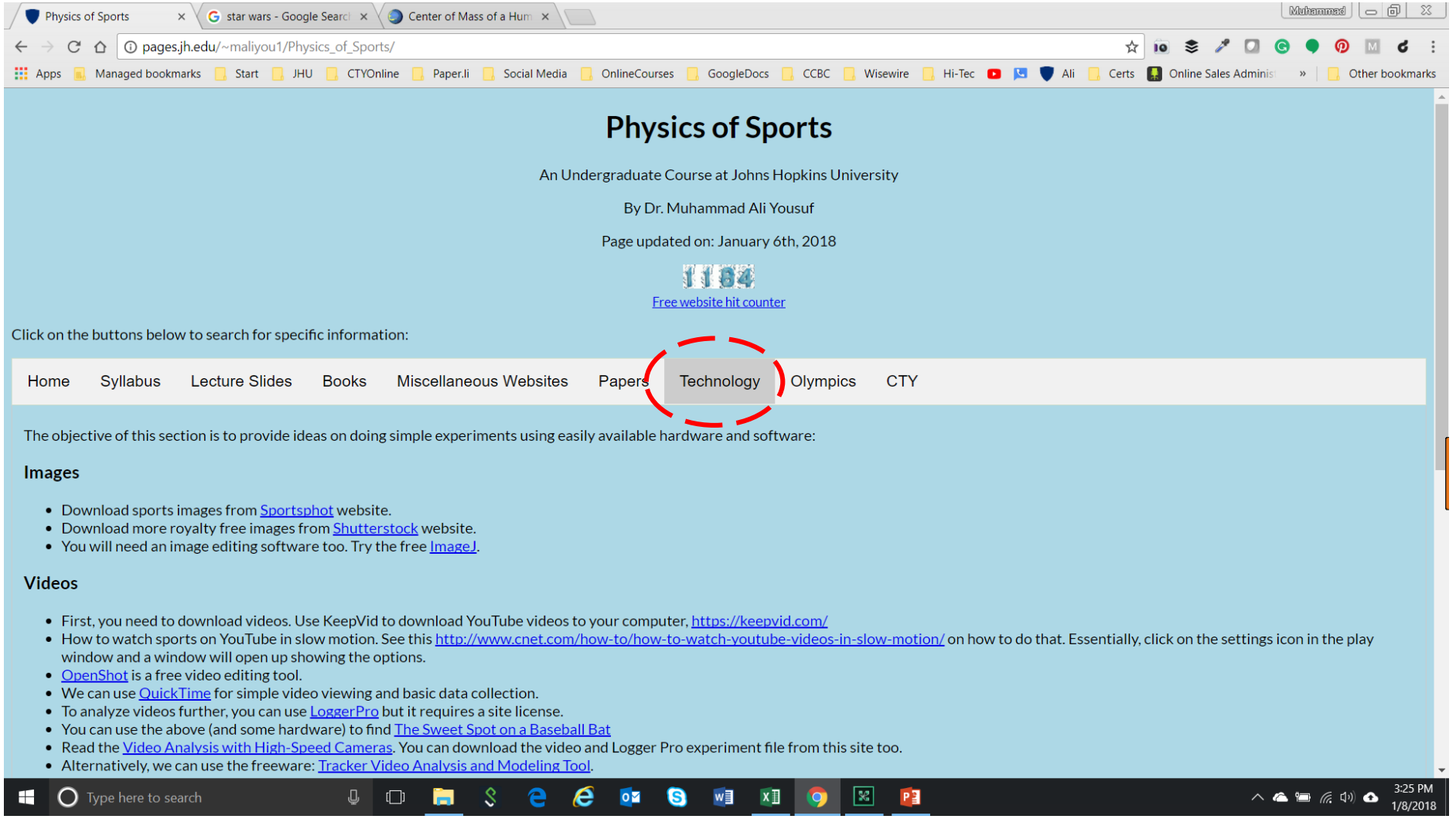
A. Introduction to Physics of Sports and a survey of kinematics
   1. Warm-up: Basic Concepts
      I. Quantifying the world of sports
      II. When we don't have exact numbers
      III. The center of mass
   2. Racing, Mathematically
      I. Phelps in Beijing (Swimming, https://www.youtube.com/watch?v=AVExBUxIcIs&list=PLm4DmlOa3zay-bL9vDVPTShhEzZhjgtDa)
      II. Bolt in Berlin (https://www.youtube.com/watch?v=3nbjhpcZ9_g)
      III. Rope-climbing and diving

B. Measurement tools available, photo and video analysis.

Measurement tools available, photo and video analysis

Resources on the Website

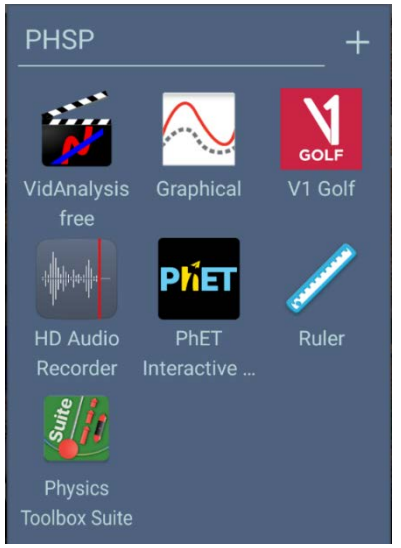
http://pages.jh.edu/~maliyou1/Physics_of_Sports/



Images

- Download sports images from Sportsphot website.
- Download more royalty free images from Shutterstock website.
- You will need an image editing software too. Try the free ImageJ.

Videos



- First, you need to download videos. Use KeepVid to download YouTube videos to your computer, https://keepvid.com/
- OpenShot is a free video editing tool.
- Freeware: Tracker Video Analysis and Modeling Tool.
- ~~Free Android App, Vernier Graphical Analysis. It provides interface to LoggerPro but you can also do experiments with onboard sensors.~~
- ~~Free iPhone App, Vernier Graphical Analysis . It provides interface to LoggerPro but you can also do experiments with onboard sensors.~~

Sound

- You will need the Audacity software to record and analyze the sound spectrum. Audacity is free, open source, cross-platform software for recording and editing sounds. It can be found here: http://audacity.sourceforge.net/
- To measure time between two events (like hitting a ball which then strikes a wall) you can use computer's internal sound card to record and analyze it.
- See: Using the Sound Card as a Timer by Aguiar and Pereira, at http://scitation.aip.org/content/aapt/journal/tpt/49/1/10.1119/1.3527753

Simulations

- The following PhET and other simulations each has some relevant physics concept explained:
  - Projectile Motion
  - Forces and Motion
  - Energy Skate Park
  - Sports Software Download

Projectile Motion

http://www.physicsclassroom.com/Physics-Interactives/Vectors-and-Projectiles/Projectile-Simulator/Projectile-Simulator-Interactive

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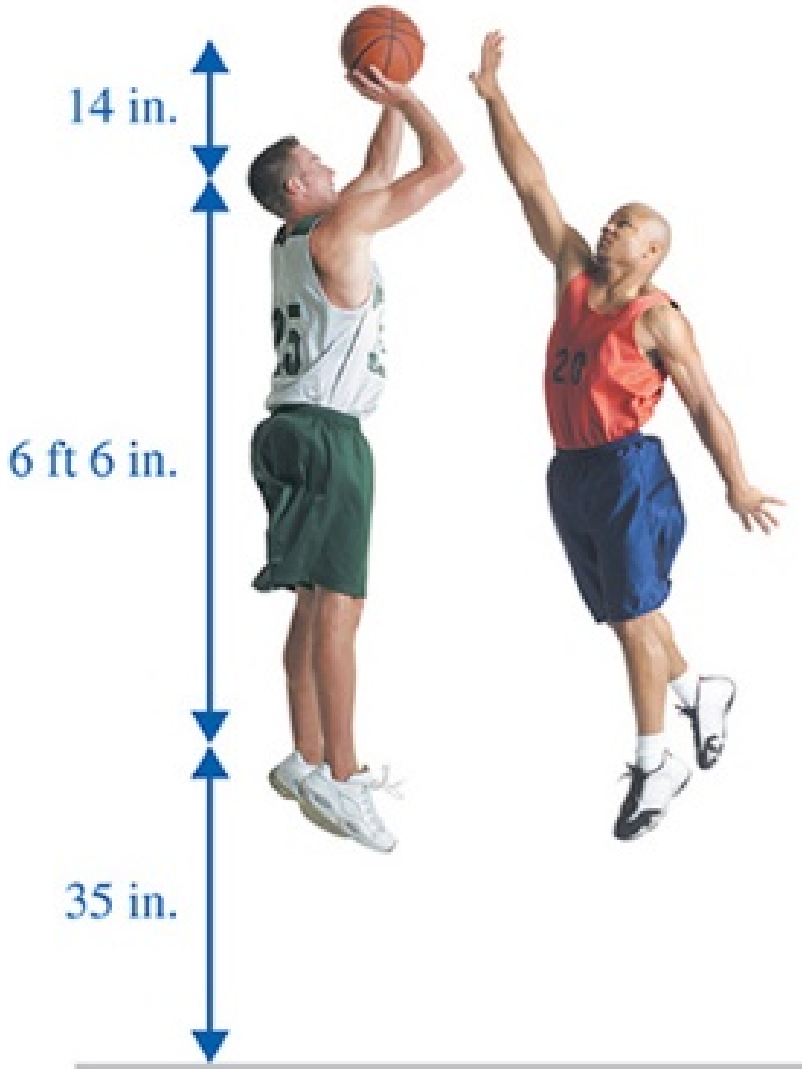
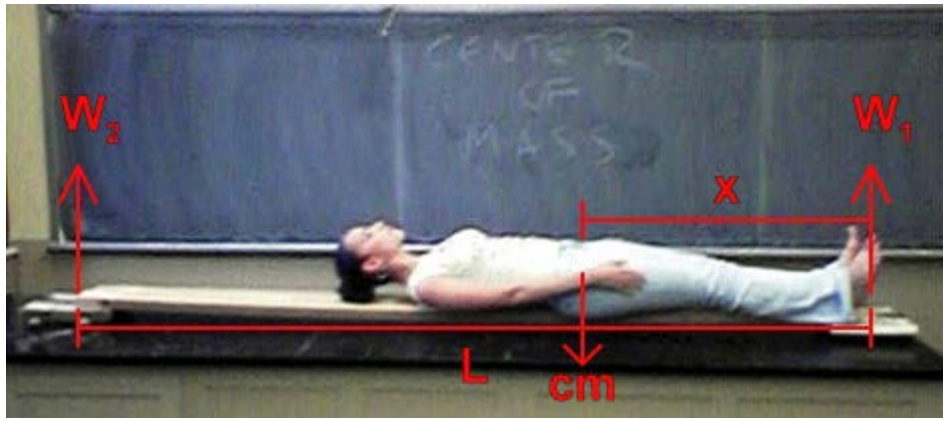
Heights



"Typical" sizes of a basketball player taking a jump shot.

Where is the center of mass of a human?

- A person's center of mass is slightly below his/her belly button, which is nearly the geometric center of a person.
- Males and females have different centers of mass- females' centers of mass are lower than those of males.
- The average ratio of center of mass to height in females is approximately 0.543 and the average ratio of center of mass to height in males is approximately 0.560.



https://hypertextbook.com/facts/2006/centerofmass.shtml

Differences between sports

- Does height matter in sports?
- https://www.youtube.com/watch?v=IcTNIk0yfj0

http://www.pxleyes.com/blog/2012/03/50-brilliant-examples-of-sequence-photography/

Questions (Estimates)

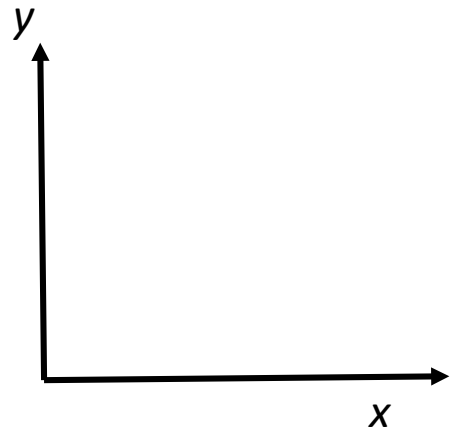
1. What is the height of the sportsman? (that fixes a scale for the photo)
2. Assuming the first image at the origin of the coordinates, what is the maximum height reached?
3. What is the range?
4. What is the launch angle?
5. What are the horizontal and vertical accelerations?
6. What is the initial launch velocity $\boldsymbol{v}$? (you need kinematic equations here).
7. What is the time of flight? (you need kinematic equations here).
8. What is the frame rate (fps) used by the camera?

$$x = v_{0x}t + \frac{1}{2}a_x t^2$$

$$x = \frac{v_{0x} + v_{fx}}{2}t$$

$$v_{fx} = v_{0x} + a_x t$$

$$2a_x x = v_{fx}^2 - v_{0x}^2$$



$$y = v_{0y}t + \frac{1}{2}a_y t^2$$

$$y = \frac{v_{0y} + v_{fy}}{2}t$$

$$v_{fy} = v_{0y} + a_y t$$

$$2a_y y = v_{fy}^2 - v_{0y}^2$$

$$\text{Range} = x_{\max} = \frac{v_0^2 \sin 2\theta}{g}$$

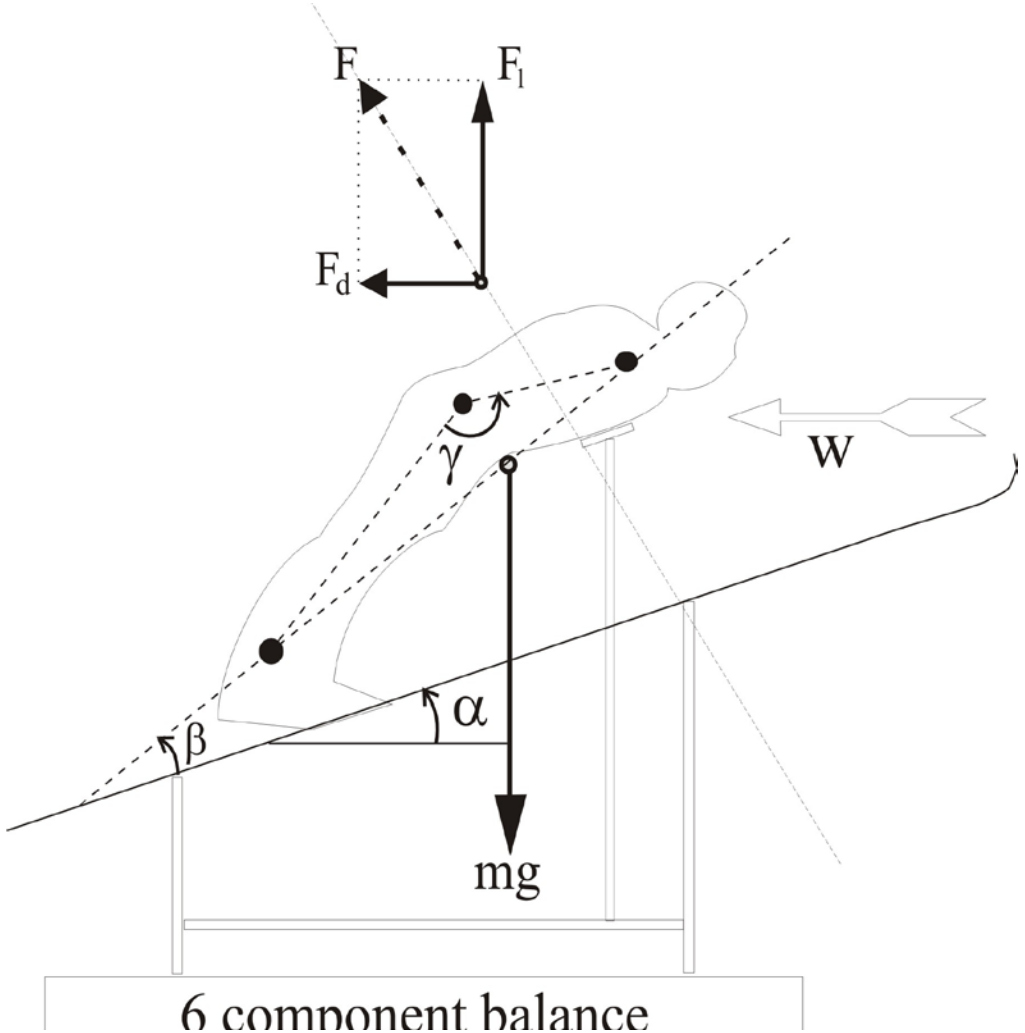
$$\text{Height} = y_{\max} = \frac{v_0^2 \sin^2 \theta}{2g}$$

$$\text{Time of flight} = T = \frac{2v \sin \theta}{g}$$

x	v0x	ax	t	vfx

y	v0y	ay	t	vfy

The physics of ski jumping,
https://pdfs.semanticscholar.org/e956/0e12923567efef9e37bead23b9e85bfe0ca3.pdf



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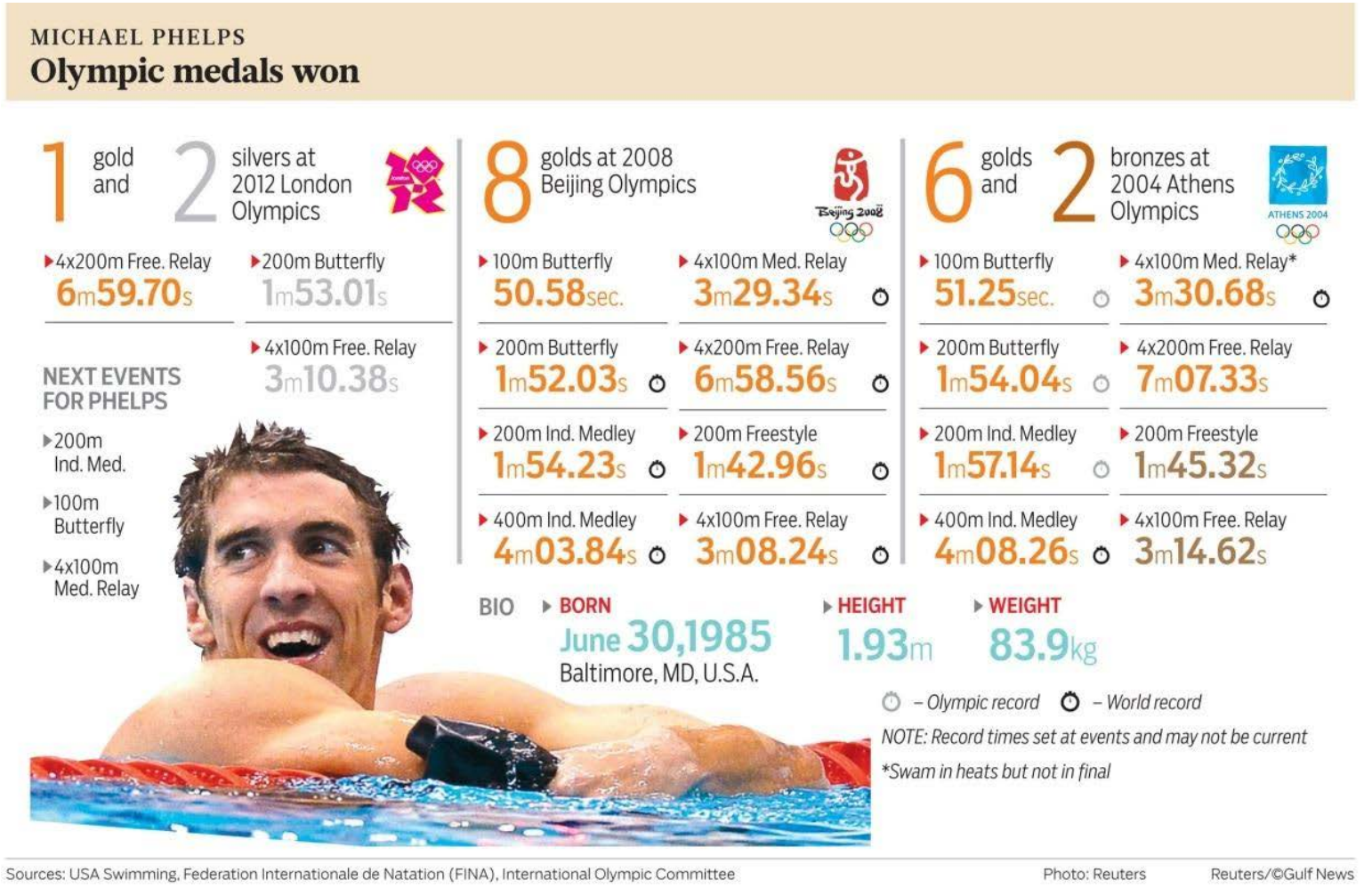
Swimming

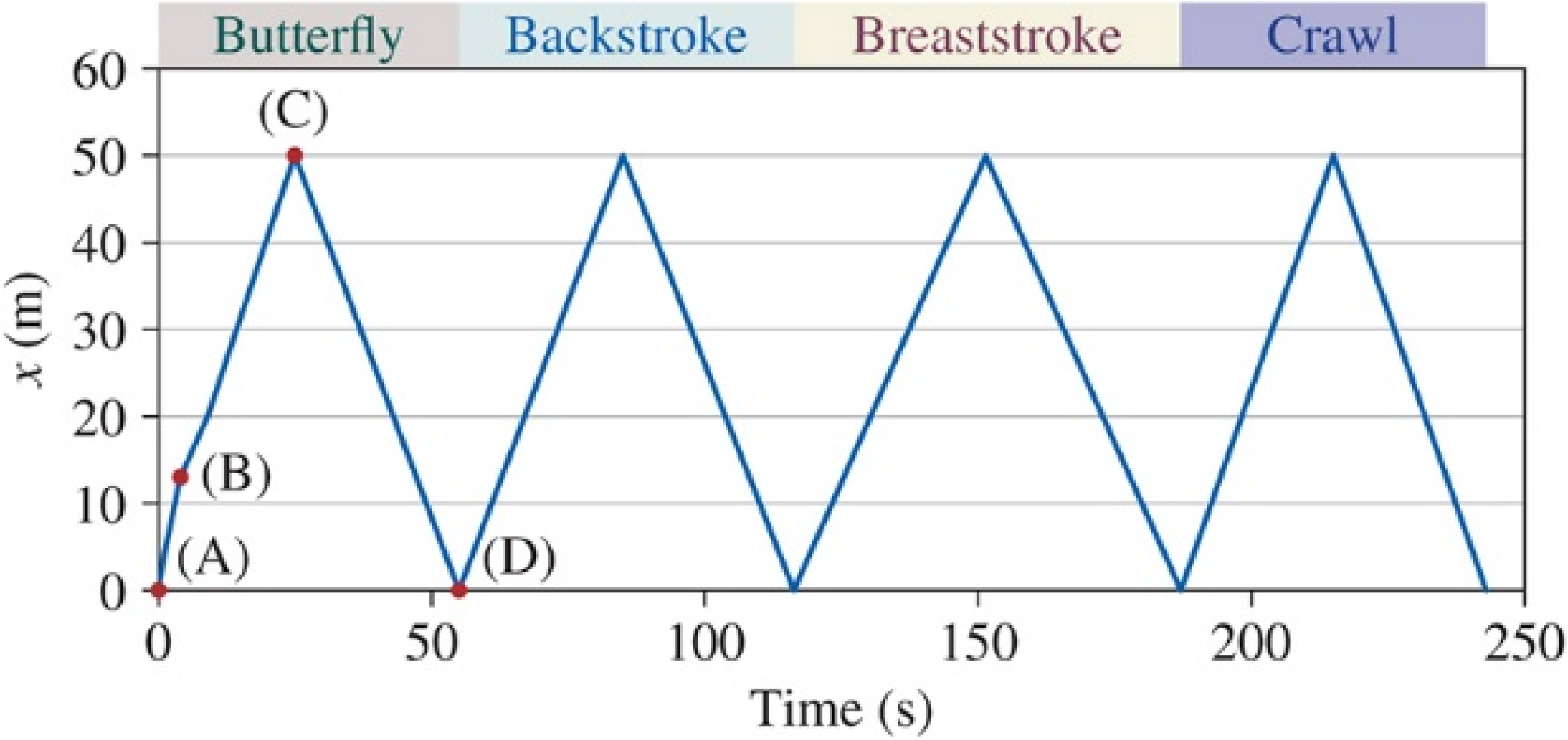
Phelps in Beijing (section 2.1)



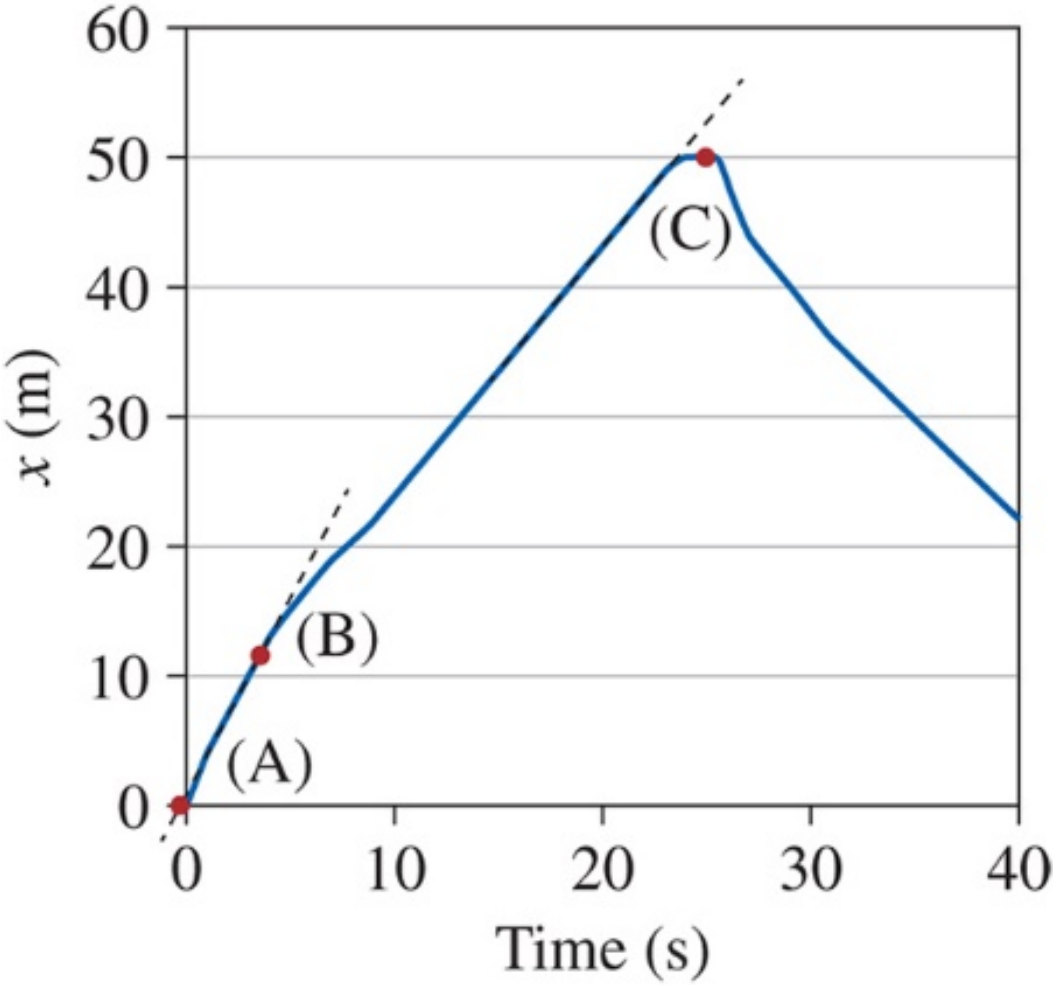
http://cdn23.us1.fansshare.com/photos/michaelphelps/diet-1021618498.jpg

Calculations

- Let’s find Phelps’s speed during the second length in m/s:



Michael Phelps's world-record-setting 400-m medley race in the 2008 Summer Olympics.
Phelps's displacement relative to the edge of the pool is plotted on the vertical axis, versus time on the horizontal.



Instantaneous velocity

A blown-up portion of the graph shown in figure 2.1. Two tangent lines are drawn. What do they represent?

Running

Bolt in Berlin

http://www.all-athletics.com/en-us/photos/usain-bolt-berlin-2009-19

How to run the 100m

The SPIKES guide to beating Bolt, brought to you by leading UK Athletics coach Dan Pfaff

The 100m is all about just running like the clappers, right? Well, ***SPIKES*** spoke to coach Dan Pfaff, the director at UK Athletics' High Performance Centre in north London and found it is actually very technical and somewhat tricky to master.

The 100m can be broken down into the five phases on the right, according to Pfaff – who should know a thing or two about it having been coach to 1996 Olympic 100m champion Donovan Bailey. Some sprinters are masters of particular phases, but no one has yet mastered them all. So if you plan to take Usain Bolt's 9.58 world record, this is the place to start.

Reaction time

Put simply, this is an athlete's ability to react to the starting gun. Some believe it is an innate skill which cannot be improved. However, Pfaff is not so sure. "In my experience, with better mechanics and block set-up you can improve. Whether the improvement is massive, I don't think so."

Block clearance

This is the initial explosion from the blocks to the first step. An athlete supplies force on both block pedals and in the process the body is launched in the air. The angle of launch is determined by block settings, hand and head position, and Pfaff believes this is critical. "The most efficient projectile angle is 45 degrees. If people project too low they climb along the ground. The opposite is someone who gets up very rapidly and get less drive from the blocks. The biomechanics can be taught and mastered. Hip strength is a huge asset."

The drive phase

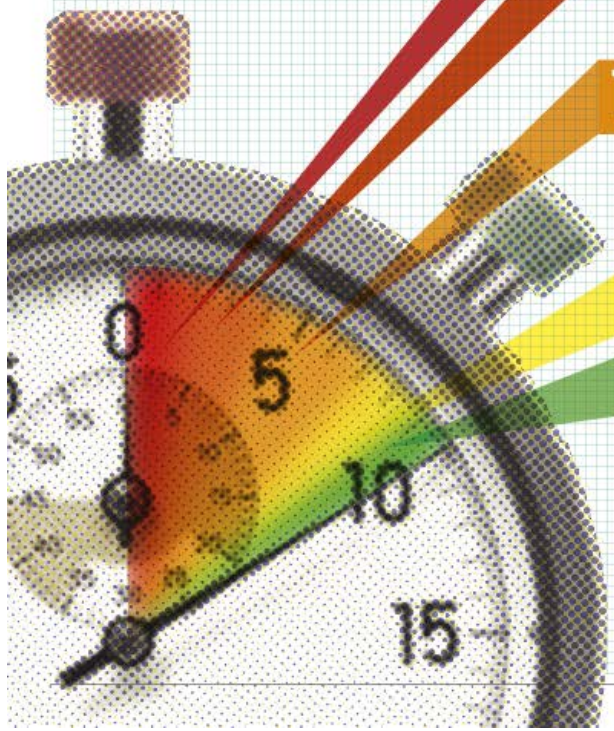
This is the period – often up to 50m – when an athlete builds up speed to the maximum. Each stride in this phase should be longer and quicker and the angle of the body to the ground will increase with each step. "The world's best sprinters and sprint coaches spend a lot of time on this area. It is very, very complex. All the elements in a sprint are difficult to master, but this phase can easily go wrong, particularly when you are in a state of arousal and excitement. The end of this phase is known as the transition, when the sprinter moves into an upright posture and reaches the run's fastest speed."

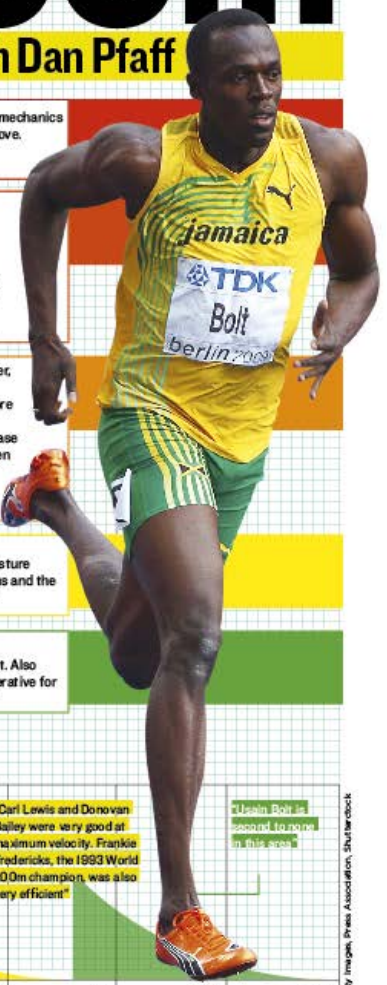
Max velocity

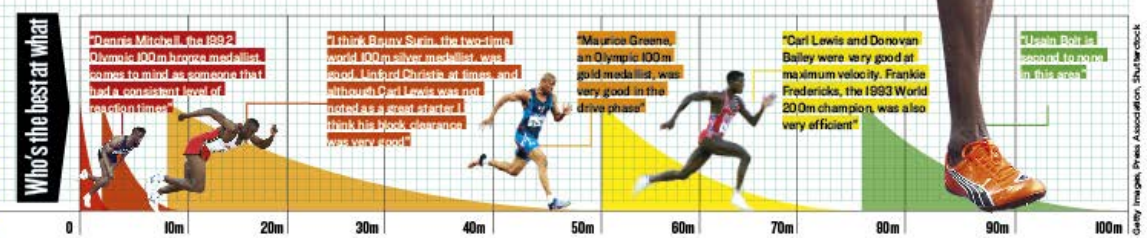
The point where an athlete is sprinting at top speed. Most biomechanical reports say this is from 50-60m for women and 60-70m for men, however Usain Bolt can extend this to beyond 80m. "You have to have excellent posture and excellent timing of the arms and the legs in this phase of the race."

Deceleration

The fifth and final phase of the race. Often it looks like an athlete may be running away from the group in the last 20m but in reality they are slowing down slightly less than their rivals. "Relaxation is a key component. Also training at high velocity is imperative for improving in this final phase."





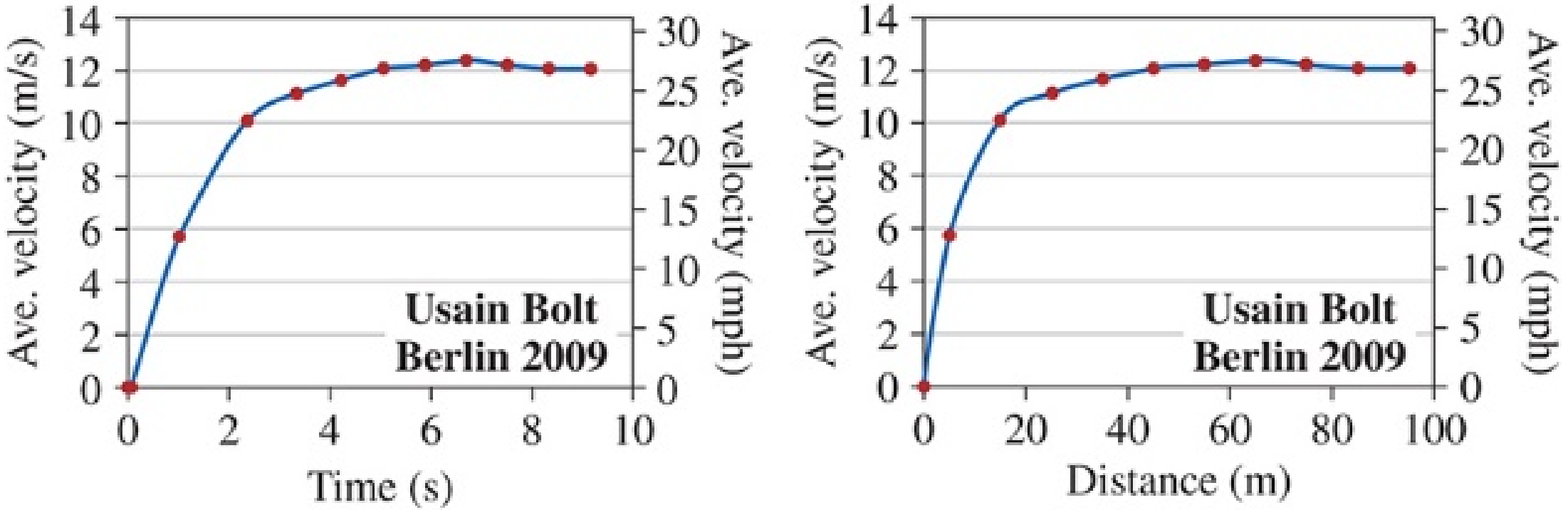


http://speedendurance.com/2017/07/22/will-usain-bolt-win-the-100m-world-championships/

Usain Bolt's Winning Time & Margin of Victory

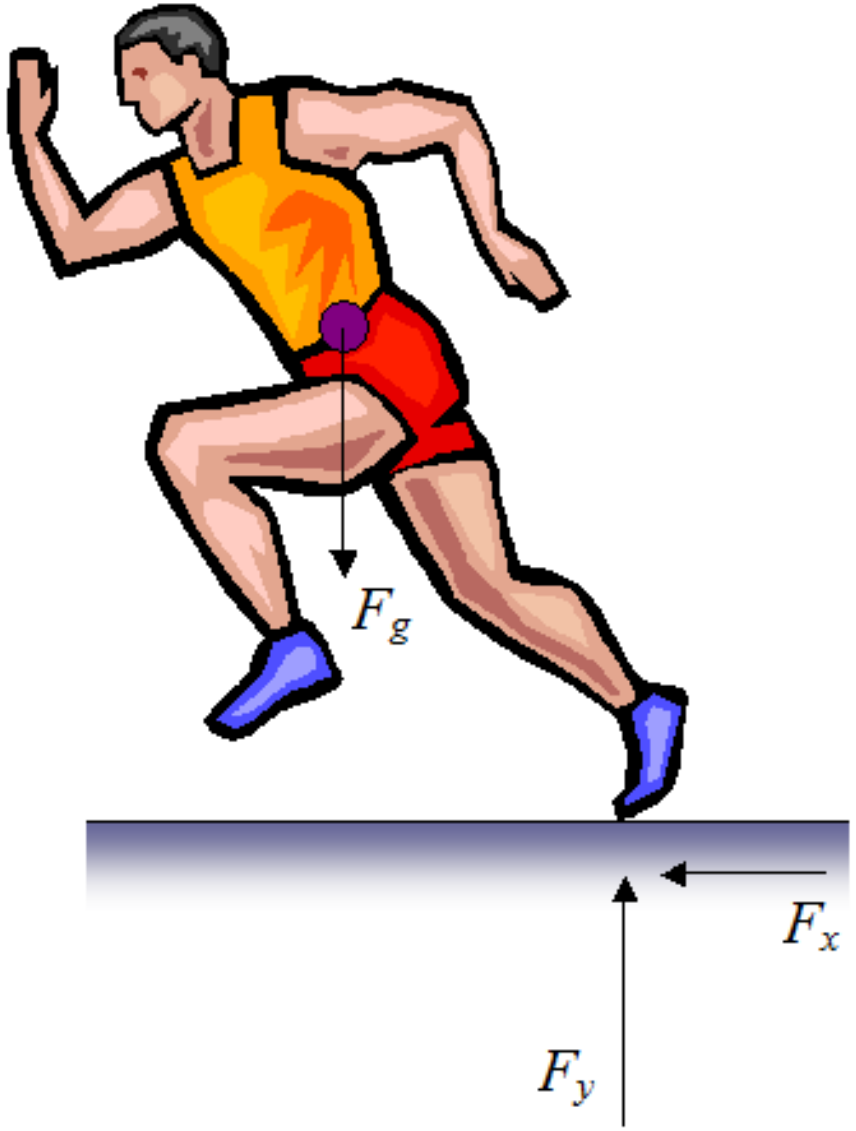
2008	1	Usain Bolt	9.69
	2	Richard Thompson	9.89
			0.20
2009	1	Usain Bolt	9.58
	2	Tyson Gay	9.71
			0.13
2011	1	Yohan Blake	9.92
	2	Walter Dix	10.08
		*Usain Bolt DQ	**0.16**
2012	1	Usain Bolt	9.63
	2	Yohan Blake	9.75
			0.12
2013	1	Usain Bolt	9.77
	2	Justin Gatlin	9.85
			0.08
2015	1	Usain Bolt	9.79
	2	Justin Gatlin	9.80
			0.01
2016	1	Usain Bolt	9.81
	2	Justin Gatlin	9.89
			0.08
2017	1		
	2		
	?		

Courtesy of SpeedEndurance.com

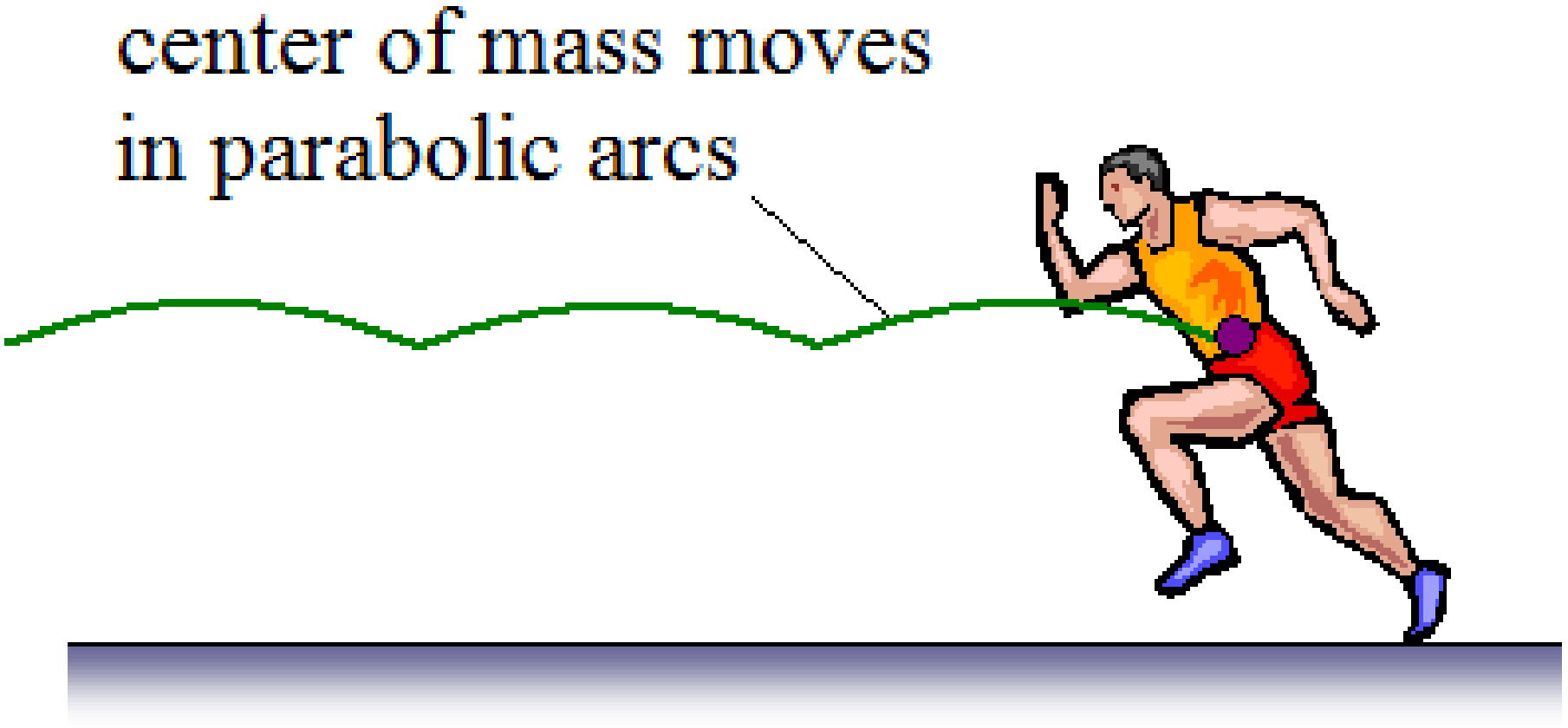


Velocity graphs for Usain Bolt's record-setting 100-m dash. On the left is the "physicist's style" of plotting velocity versus time; the acceleration is the slope of this curve at any point. On the right is a common graph found in sports newspapers and magazines, of velocity versus distance.

Bolt in Berlin



https://www.real-world-physics-problems.com/physics-of-running.html



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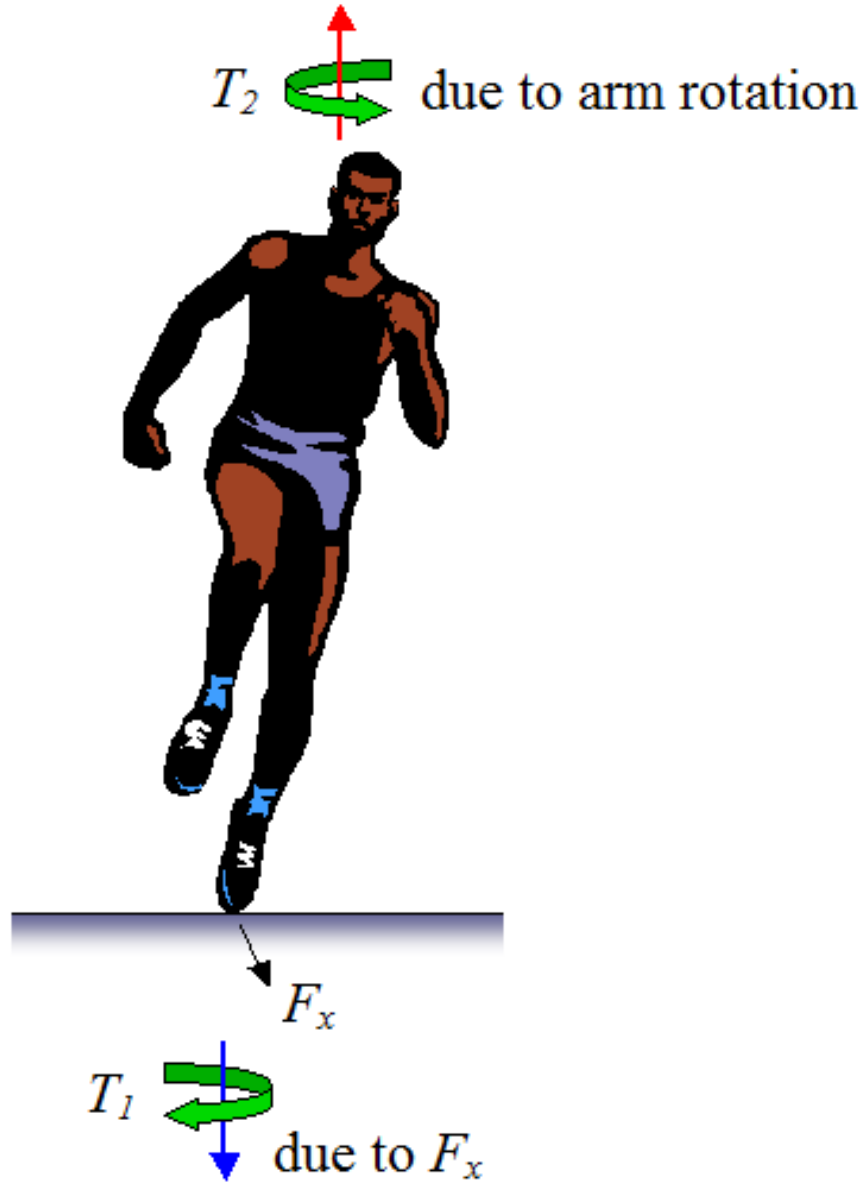

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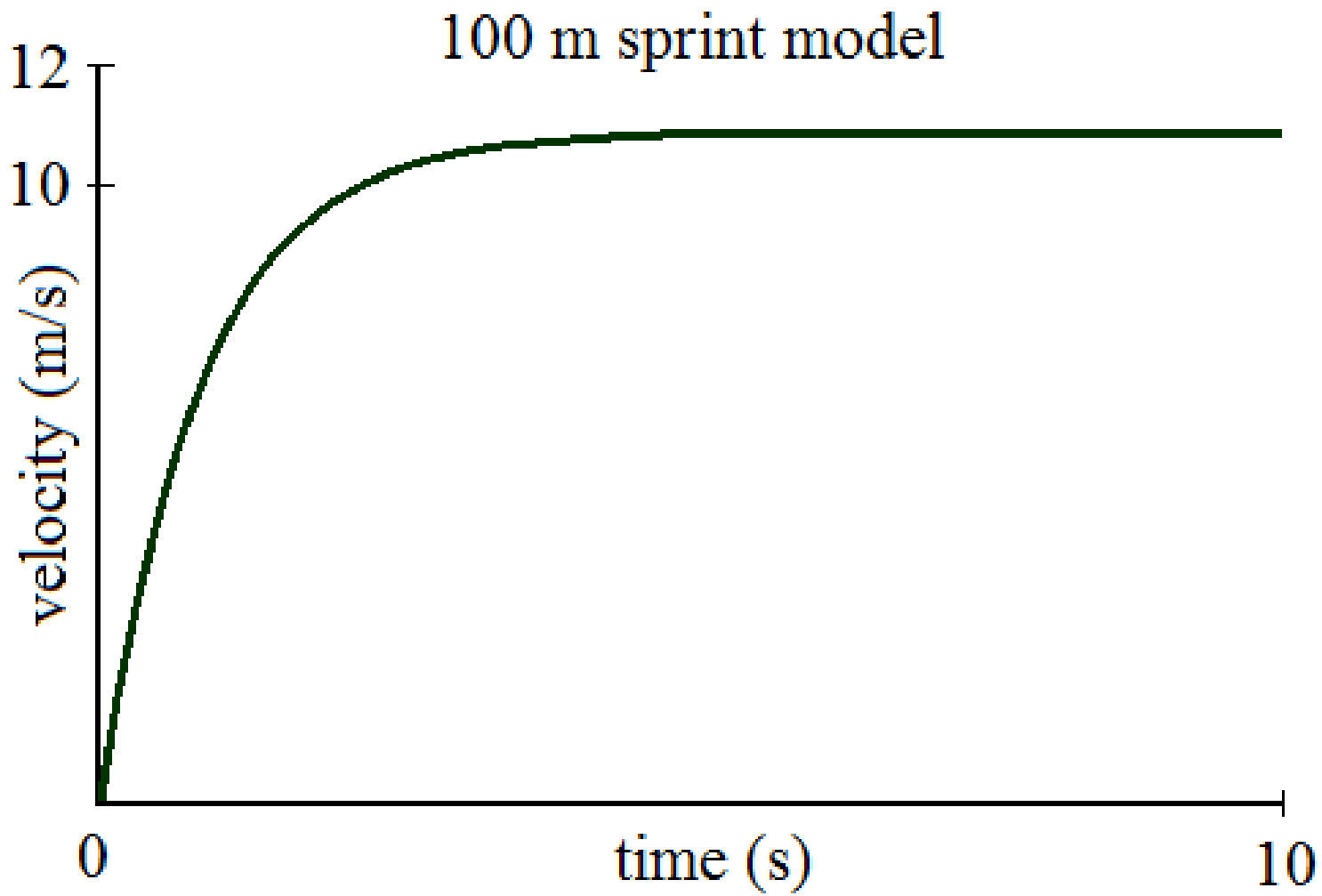

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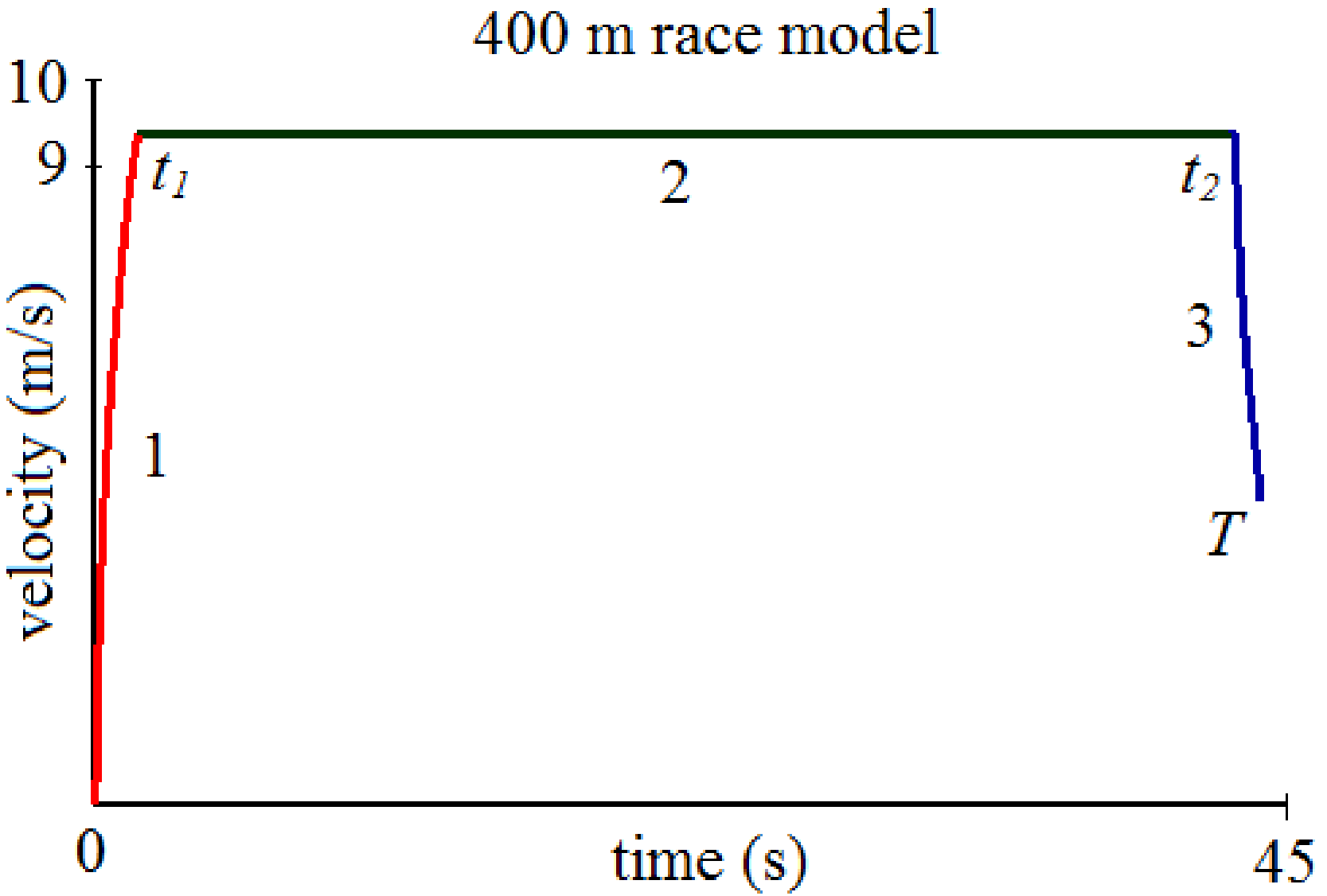
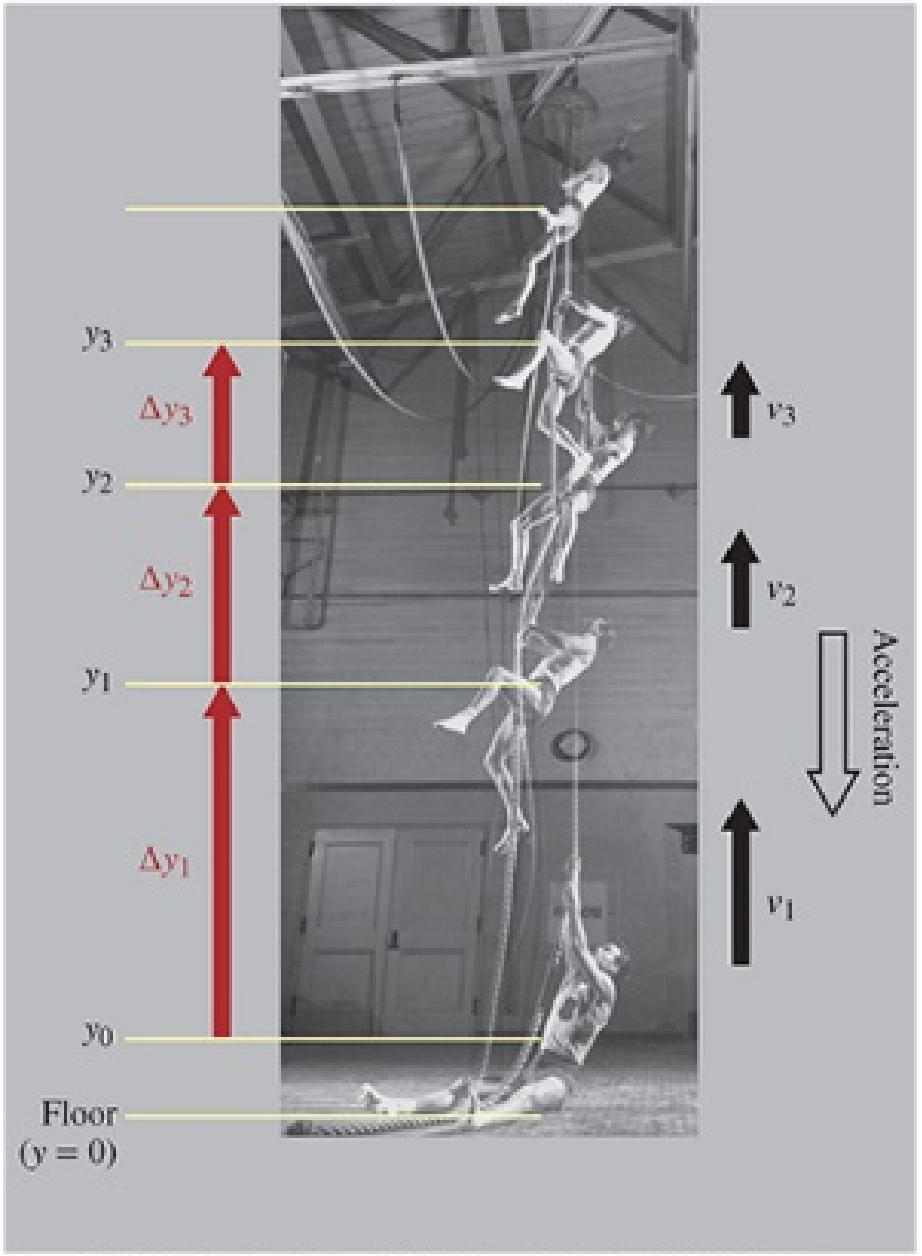
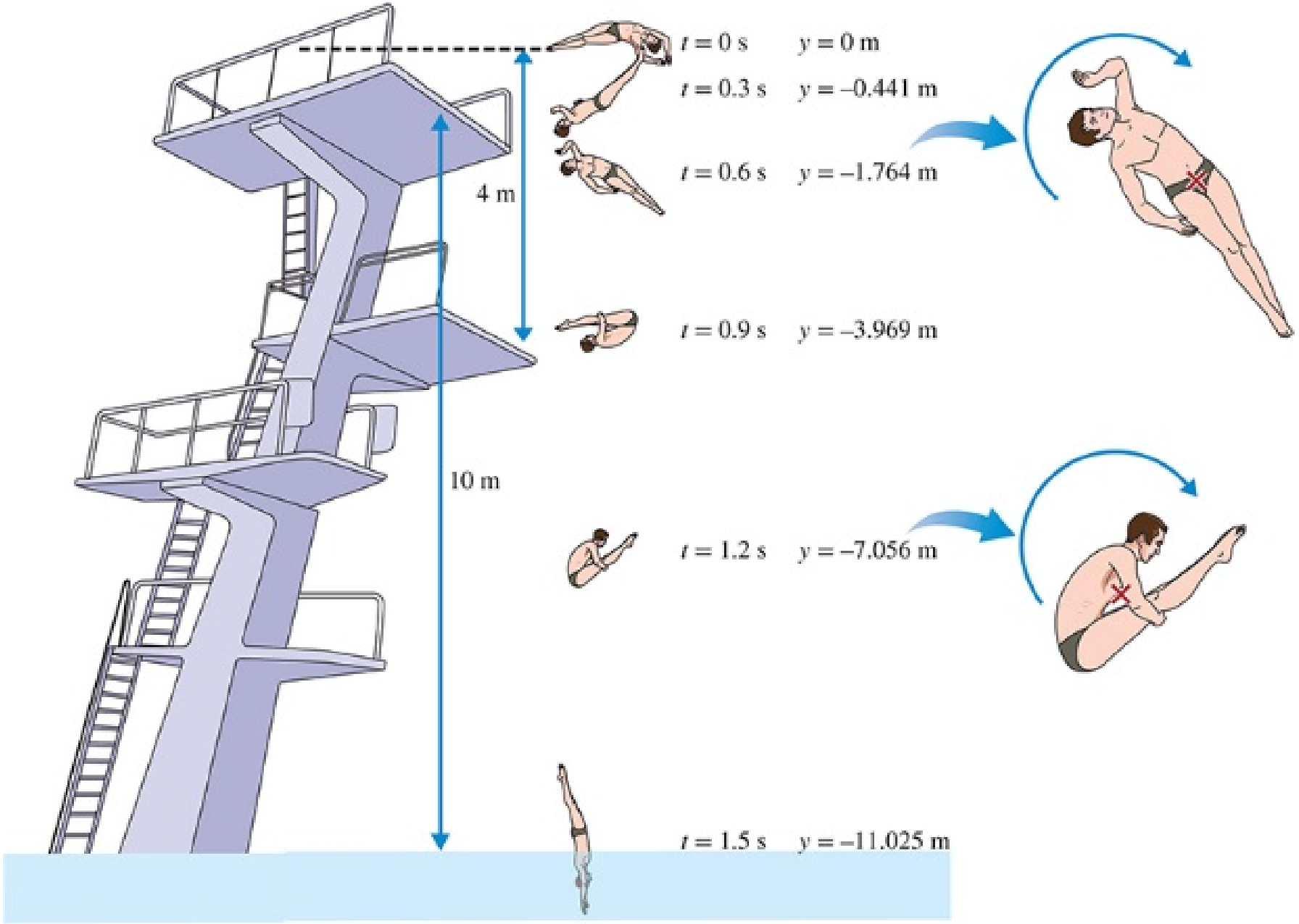


https://www.real-world-physics-problems.com/physics-of-running.html

Rope-climbing and diving

Calculate the free fall time from the top, assuming his feet are 13 ft above the ground at that time.





https://www.pinterest.com/beakymcgee/time-lapse-photos/

Food for thought

- What is Magnus effect?

References

1. Dan Whitt, *Mathematical Models of Running*, UMS talk, September 24, 2008. http://www.stanford.edu/~dwhitt/UMS-talk.pdf
2. Joseph B. Keller, *A Theory of Competitive Running*, Physics Today **26(9)**, 42-47 (1973).
3. Igor Alexandrov and Philip Lucht, *Physics of Sprinting*, American Journal of Physics **49**, 254-257 (1981).