# Kinematic Measurements from YouTube Videos

**Michael J. Ruiz,** University of North Carolina at Asheville, Asheville, NC

Video analysis of motion has been in use now for some time.[1-3] However, some teachers may not have video equipment or may be looking for innovative ways to engage students with interesting applications at no cost. The recent advent of YouTube offers opportunities for students to measure kinematic properties of real-life events using their computers. This paper provides examples such as measuring the average speed of a winning horse at the Kentucky Derby, plotting speed versus time from watching the speedometer of a high-performance bike, and determining acceleration for circular motion of amusement park rides.

YouTube is a website where you can view videos of all kinds—videos that other users simply put up for all to enjoy. YouTube started in 2005, and by July 2006 users were viewing 100 million videos each day, with more than 65,000 videos being added daily.[4] A few months later, in October 2006, Google bought YouTube for $1.65 billion.[5] Since virtually all our students have heard of YouTube and use it frequently, it is an ideal resource. Let's see how we can use selected YouTube videos for generating excitement in the learning of kinematics.

Before we begin, we note that the basic parameters in kinematics are time, distance, speed, and acceleration. In a YouTube video, the student can always measure the time to a resolution of one second by simply pausing the video and reading the seconds off the YouTube video player. But we need to also measure one of the other three parameters. For starters, we will consider videos where we know a distance; then we will consider a video from which we plot speed as a function of time.

Students can be imaginative and search for useful videos where a distance is known. A video of a race is perhaps one of the easiest to consider. If a student was intent on trying to measure the average speed of a squirrel running up a tree, however, all the student would have to do would be to estimate the height of the tree, judging it against a known length such as the length of the squirrel itself. A football fan might choose a video of a football player running across the yard lines of a football field. Part of the fun is the hunt for videos that appeal to the student.

Table I shows several examples of measuring average speeds from YouTube videos involving races. The best way to search for a video is to use keywords such as "200-meter dash," "horse race," or "Indy 500." With so many videos on YouTube, you are sure to find several useful ones. For the average speeds we only need to make two time measurements: one at the beginning and one at the end of the known distance.

If the word "acceleration" is typed into the YouTube search field, one of the many videos that comes up is called "bmw k1200s acceleration from 0-280." This video[11] shows the speedometer and the road from the driver's viewpoint of a BMW high-performance motorcycle (model K1200S). The driver accelerates from 10 km/h to 280 km/h in less than 40 seconds. In directing students to this video, it is wise to add the reminder that one should never drive over the legal speed limit.

The graph in Fig. 1 is a plot of speed against time


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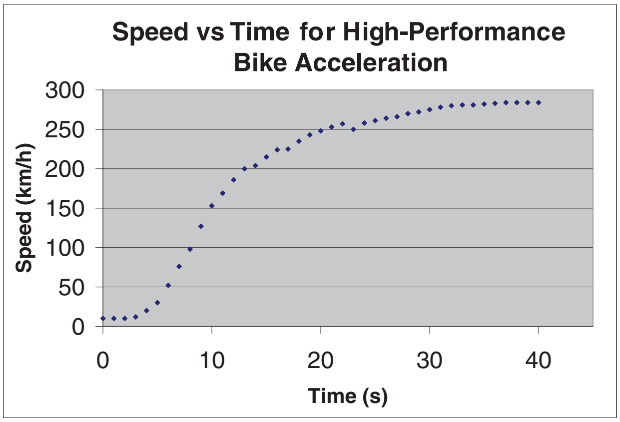


**Fig. 1. Speed against time for a BMW bike clip on YouTube.**

for the BMW bike clip, where the speed is recorded at each second. The plot was made from a spreadsheet in Excel. The speedometer shakes at times in the video, and viewing at full screen is useful in extracting the data each time the video is paused. Click on the lower right box of the YouTube video player to view at full screen. The clip can always be stopped with the pause control or set to an earlier time segment with the slider of the video player in order to check or redo a measurement. The slope of the graph gives the acceleration in km/h per second and a unit of area under the curve is equal to a traveled distance of

$$\frac{\text{km}}{\text{h}} \bullet \text{s} = \frac{1000\ \text{m}}{3600\ \text{s}} \bullet \text{s} = \frac{5}{18}\text{m}.$$

Note the little dips in speed as the driver either shifted gears or eased up momentarily on the acceleration.

An Excel spreadsheet can be used to calculate the area under the curve using the simple trapezoid rule. Using Excel to calculate the area of 40 trapezoids, one for each time interval of one second, we find the distance traveled over the 40 seconds to be 2235 m = 2.2 km. Alternatively, a student can simply draw three or four trapezoids by hand to obtain an estimate of the area under the curve. A quick estimate of the area using this latter approach is given in Table II, starting at $t$ = 5 s and using three gross trapezoids. This approach indicates that the bike traveled roughly 2 km during the 40 seconds.

Analysis of YouTube videos is not limited to races and linear acceleration. There are limitless possibilities and directions that students can pursue. For example, we can visit a museum in France to count oscillations of the majestic Foucault pendulum.[12] Observing five periods in 79 seconds gives a period $T$ = 15.8 s. From the period, the length of the pendulum can be estimated using

$$T = 2\pi\sqrt{\frac{l}{g}}$$

to arrive at $l$ = 62 m. Students can then search to find the actual length of the pendulum for comparison.

Then we can go off to the Ashton Court festival and take a seat behind a camera on a Ferris wheel, a ride that presents many interesting possibilities such as calculating the period, speed, and acceleration. In one video, we witness the exciting view as we complete 10 revolutions on the Ashton Court Ferris wheel during a time of 100 seconds.[13] This gives us a period $T$ = 10 s and associated frequency $f$ = 0.1 Hz.

We can also estimate our speed and acceleration if we know the radius. Since our example video does not clearly show the entire Ferris wheel at Ashton Court, a Google image search takes us to Flickr,[14] another popular website visited often by students. From there, we can estimate that the radius of the Ferris wheel is about eight meters. Our speed is

$$v = \frac{2\pi r}{T} = \frac{2\pi(8)}{10} = 5\frac{\text{m}}{\text{s}}$$

and acceleration

$$a = \frac{v^2}{r} = \frac{5^2}{8} = 3\frac{\text{m}}{\text{s}^2} = 0.3g.$$

Students may be impressed to discover that this means if we were sitting on a scale, it would read 1.3 times our weight at the bottom of the ride and 0.7 times our weight at the top.

For those who find the Ferris wheel too tame, other adventuresome amusement park rides offer more excitement and challenging calculations. Let's examine the Top Spin ride, another circular ride.[15] The easy measurement is the period of rotation, which is 1 Hz during the fast phase of the ride. The somewhat difficult determination is the acceleration because it is hard to judge the distance between the rider and the axis of rotation. But if you have students set up rows of chairs to replicate the seating arrangement seen in the video, an estimate of the radius is much easier. The two rows

**Table I. Average Speeds from YouTube Videos.**

| YouTube Title and Comments | Distance | Start (min: s) | End (min: s) | Speed (m/s) |
|---|---|---|---|---|
| Charis Runs Her Own Dash[6] (50-yd, from whistle sound to stepping on finish line) | 45.7 m | 0:29 | 0:41 ± 1 | 4 |
| Girls 4x200[7] (measuring the second lap of the relay from handing over of the baton) | 200 m | 0:55 | 1:26 | 6 |
| Jessica Beard Wins 200-meter Dash[8] (start gunshot sound to crossing finish) | 200 m | 0:01 | 0:26 | 8 |
| 2007 Kentucky Derby – Street Sense[9] (from start bell sound to crossing finish) | 2 km | 0:00 | 2:04 | 16 |
| Lap at Indianapolis – On Board Kenny Bräck[10] (when stand's edge passes upper left screen) | 4 km | 0:29 | 1:22 | 75 |

**Table II. Quick estimate of distance traveled by BMW bike.**

| Trapezoid | $t_1$ (s) | $t_2$ (s) | $v_1$ (km/h) | $v_2$ (km/h) | area $\frac{\text{km}}{\text{h}} \cdot \text{s}$ | $d$ (m) |
|---|---|---|---|---|---|---|
| 1 | 5 | 15 | 50 | 200 | 1250 | 347 |
| 2 | 15 | 20 | 200 | 250 | 1125 | 313 |
| 3 | 20 | 40 | 250 | 280 | 5300 | 1472 |
| Total estimate is 2000 m = 2 km. | | | | | | 2132 |

are about one meter apart with the axis of rotation in the middle. Therefore, $r = 0.5$ m, approximately.

Given the rotational period and distance from the axis of rotation, we can calculate the speed and acceleration. The corresponding speed is

$$v = \frac{2\pi r}{T} = \frac{2\pi(0.5)}{1} = 3\,\frac{\text{m}}{\text{s}}$$

and acceleration

$$a = \frac{v^2}{r} = \frac{3^2}{0.5} = 18\,\frac{\text{m}}{\text{s}^2} \approx 2\text{ g},$$

where 2 is called a *g*-factor,[16] neglecting the effect of gravity for the moment. The *g*-factor at the bottom of the ride would increase to 3 (adding 1 due to gravity), which means a scale would read three times the rider's weight. Since Top Spin is not uniform, the *g*-factor could momentarily be even greater. As a comparison, the maximum accelerometer reading[16] on Witch's Wheel is a *g*-factor of about 4 (includes acceleration and effects of gravity combined). Students may want to pursue the investigation of physiological effects of *g*-factors and human limits.

Finally, students should always be encouraged to discuss sources of experimental error. These include difficulties in making length estimates due to the lack of reference scales, errors in timing, and perception due to camera angles and movement. Teachers can choose pedagogical approaches to YouTube analysis that best suit their students. For example, teachers can ask students what to measure and to make estimates before proceeding. Students can then work in groups to analyze the videos and report their results afterwards. Often, their work will raise new questions and topics to investigate.

In conclusion, YouTube is free to access with many new videos added every day. Students of the ever-growing technology age can be empowered in finding unique videos of interest to investigate. Whenever there is a computer with an Internet connection, students can do YouTube physics.


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**Michael J. Ruiz**, *professor of physics at UNCA, specializes in teaching general education courses in light, sound, and astronomy. His innovative e-texts for these courses have been featured on CNN.*

**Department of Physics, University of North Carolina at Ashevelle, Asheville, NC 28804; ruiz@unca.edu**