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Speed, acceleration, and distance plots from a racecar speedometer (0 – 300 km h^{-1})

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Abstract

A spreadsheet plotting assignment of real-life data from a racecar is employed to help students master the relationships among speed, acceleration, and distance. The racecar application will capture the imagination and interest of the student. The data is obtained by reading speedometer values from a YouTube video for 40 seconds as a racecar accelerates from rest to 300 km h^{-1}. A spreadsheet is then used to plot the speed in m s^{-1} against time. Dimensional analysis guides the student to realize the acceleration as the slope of the velocity plot. Units further direct students to understand that the area under the velocity graph gives the distance traveled. Though this activity is in kinematics, which can be assigned at the secondary school level, students learn about the fundamental concepts of the derived slope function (differential calculus) and area under a graph (integral calculus).

Real-world physics

A generation ago Edward Redish pointed out an experience of many teachers of introductory physics involving basic graphs [1]. He indicated that reasonably successful students can produce graphs, but cannot say what the graphs mean [1]. This racecar paper addresses the difficulty students have in understanding what the three most important graphs in kinematics tell us. The activity described starts with speedometer readings, which students are familiar with. Then, through dimensional analysis, students are led to see how acceleration and distance graphs can be extracted from the velocity graph.

Another benefit of our exercise is that we use data from real life. Patricia Blanton, a column editor of *The Physics Teacher*, writes in an essay for the new teacher that the 'purpose of education in today's world must be to help students *learn how to learn* by applying facts to real-world situations' [2]. The advantages of integrating practical applications into a physics course have been pointed out by authors over the years. Elizabeth Whitelegg and Malcolm Parry, working with real-life physics projects in the United Kingdom and Australia, state that students must be 'sufficiently motivated to study the theory in order to make an effort to understand the application' [3]. They go on to say that rather than presenting formal theory first, then application, context-based learning right at the start has a better potential for motivating student interest [3]. When Donald Smith in the United States surveyed his introductory calculus-based physics students near the end of the course about a 'real-world event or process for which they now realized they had a better understanding,' he found that by 'far the most commonly cited examples had to do with the motion of vehicles' [4]. Applying kinematics to a fast racing car will provide for motivation to learn basic physics covered typically at the beginning of the introductory courses.

Data Source

The data used in this paper is readily available on YouTube. In particular, we use a YouTube video [5] of the speedometer as a 2018 Camaro ZL1 stock car accelerates from rest to 300 km h^{-1} in 40 s for a trial run during the summer of 2018. Two similar Camaros appear in figure 1, an exciting telephoto shot [6] of three cars in the NASCAR Pocono Green 250 (Pennsylvania, USA) taken 10 June 2017 by Zach Catanzareti. The cars were approximately 50 m away from the photographer and the photo is from early in the race when there were about 40 cars on the 4 km track [7]. For readers interested in learning more about NASCAR, they can consult a book written by my colleague Dan Pierce in the Department of History at my university [8].

Figure 1. Three cars racing, Courtesy Photographer Zach Catanzareti. Used by permission. See reference 6 for a link to a gallery of racing photos taken by Zach Catanzareti.

Getting speed data and time from the YouTube video

Back in 2004 Gary Williams [9] described in a Frontline paper how students can use a car-driving computer game to plot speed against time. He suggested that by ‘projecting the games onto a screen the whole class can see the action and the readings on the speedometer’ [9]. A similar projection can be used for the activity described below. The title of the Williams paper [9], ‘The need for speed: putting the thrill back into data collection,’ captures the excitement of gathering data in these student activities.

In the April 2009 issue of *The Physics Teacher* I described how students can use YouTube videos to make kinematic measurements [10]. A more recent paper published in this journal plots speed against time from a United Kingdom rail journey [11], another example of using real-world data. Teachers and students can readily find many videos on YouTube that show the speedometer in an accelerating vehicle. I choose one [5] which only shows the speedometer, making the reading of the data very easy and straightforward. Also, in the video I selected no one breaks the law. In contrast, some videos on YouTube depict cars speeding dangerously on public highways. Our chosen video for this paper is from a test run of a Camaro stock car accelerating from rest to 300 km h^{-1} [5] on a race track.

Figure 2. A typical speedometer seen in YouTube videos, showing both analog and digital measurements. Courtesy Jan2575, Pixabay, License: Free for commercial use, no attribution required

[12].

YouTube videos often have speedometer displays like the one shown in figure 2. There is an analog speedometer and the center console is usually selected by the driver to show a digital display of the same speed. The video players indicate the seconds. Students will know about speed and the concept of recording the speed every second. The video we are using has a clear digital display for 38 of the 40 data points recorded every second. In the two instances with no digital readout, we must resort to the analog speedometer. Since there can be a slight delay registered with the analog versus digital readouts on the dashboard, it is better to stick with one method for as many points as possible. I tell my students that technically speed is a scalar, which has only a magnitude such as 50 km h^{-1} and that velocity adds a direction to this magnitude. However, in everyday speaking, velocity is often used interchangeably with speed.

The data analysis

We will use a spreadsheet for the analysis. Spreadsheets have been effectively used in physics teaching from the early 1990s [13] to current times, e.g. the 2017 paper in this journal by Uddin, Ahsanuddin, and Khan on 'teaching physics using Microsoft Excel' [14]. The first step is to open a blank spreadsheet and in the first two columns enter the time in seconds (s) and the speed in kilometers per hour (km h^{-1}). For the time column, the method of adding 1 to the cell above it and copying to the lower cells in the column gets all the time values quickly.

The speeds are easily obtained from the video. I was able to drag the time slider of the video player to quickly find the speeds at each second. The next task is to use a third column where we convert the speeds to m s^{-1}. Our graphs will go from 0 to 40 s, but we need one data point beyond 40 s in order to calculate the acceleration for the 40^{th} point. Figure 3 illustrates how to extract the acceleration (slope) and distance (area) from the speed versus time data.

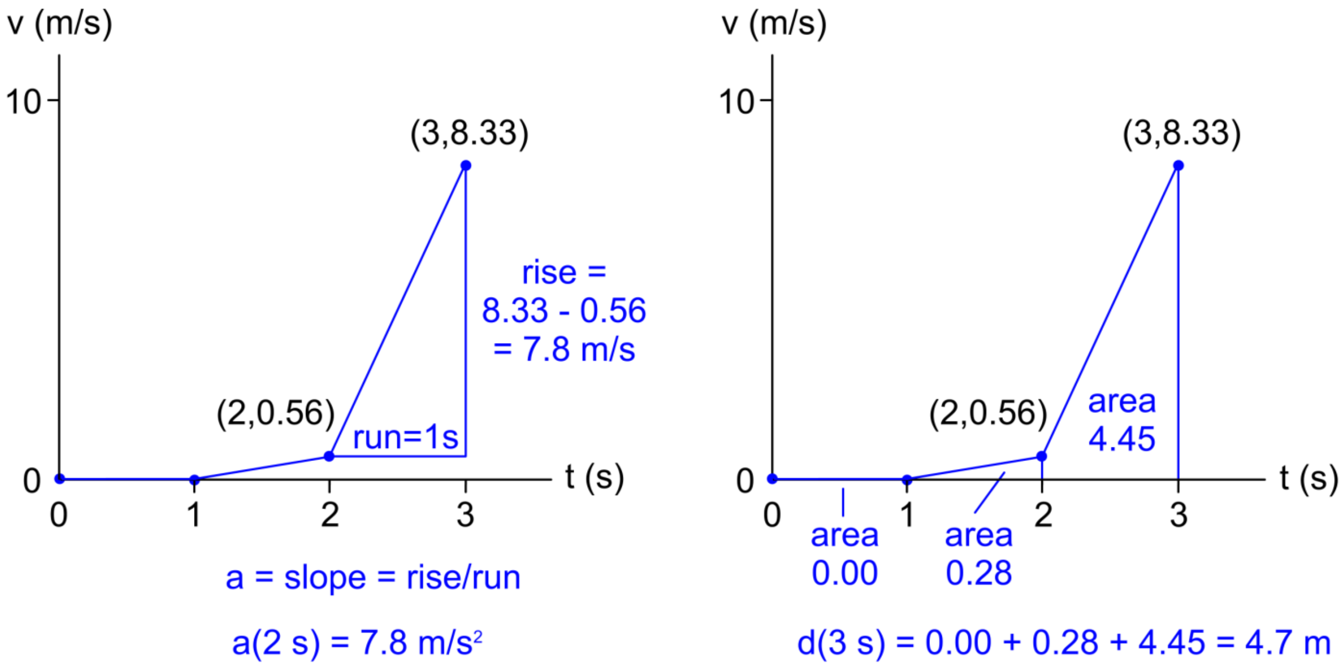

Figure 3. Calculating the slope and area from a plot of speed versus time. The units for the slope are acceleration (m s^{-2}) and the units for the area give distance (m). The distances traveled for the first 3 seconds are d(0) = 0 m, d(1) = 0 m, d(2) = 0.28 m, and d(3) = 0.28 + 4.45 = 4.7 m respectively.

Students may be confused that an area can represent distance. Here is where dimensional analysis and units are very important. Multiplying the units for the area will result in (m s^{-1}) s = m. The final step is then to plot the graphs within the spreadsheet. The results appear in figures 4, 5, and 6. It is interesting to note that the car traveled 2.5 kilometers during the 40 seconds.

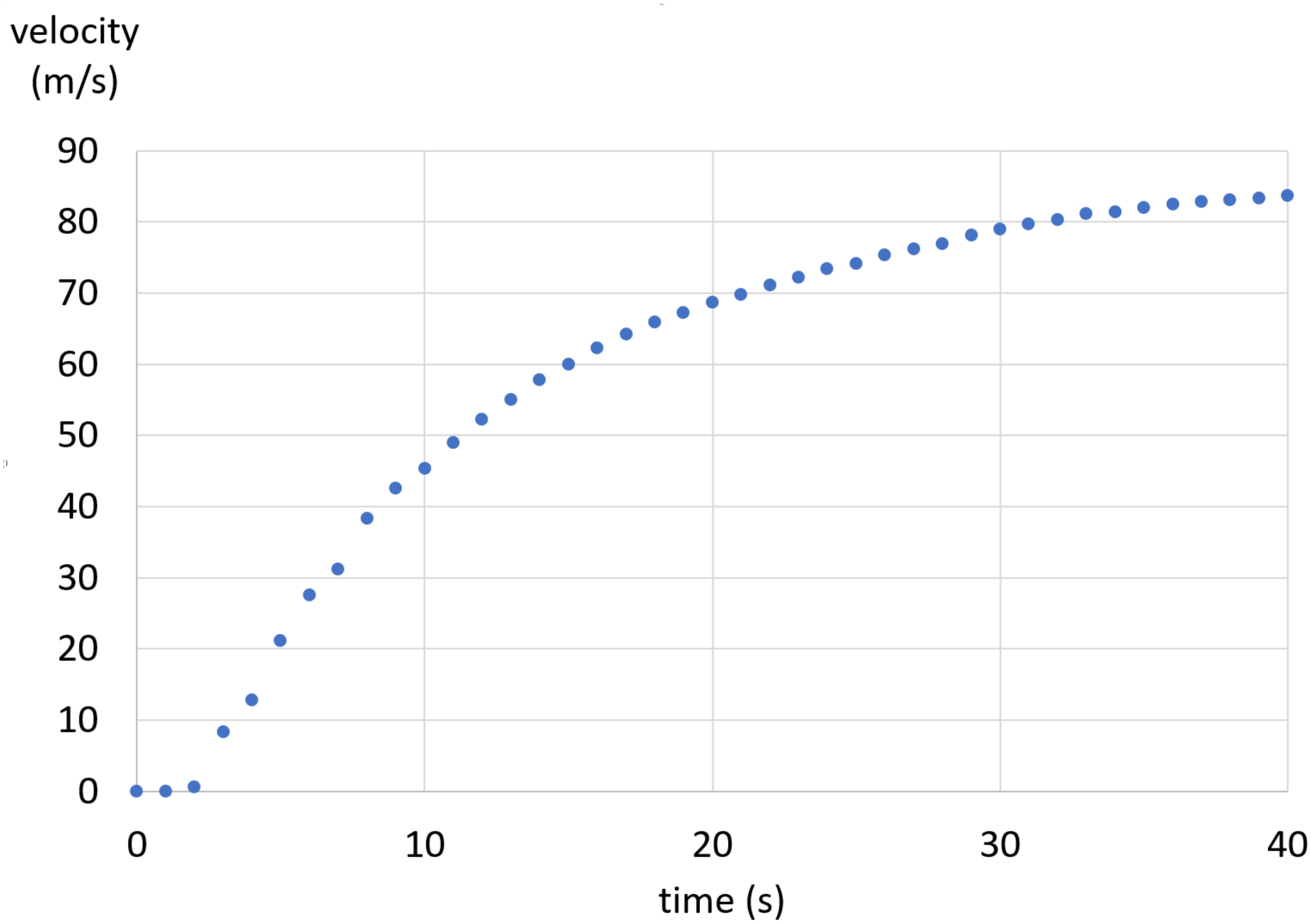

Figure 4. The velocity (speed) against time.

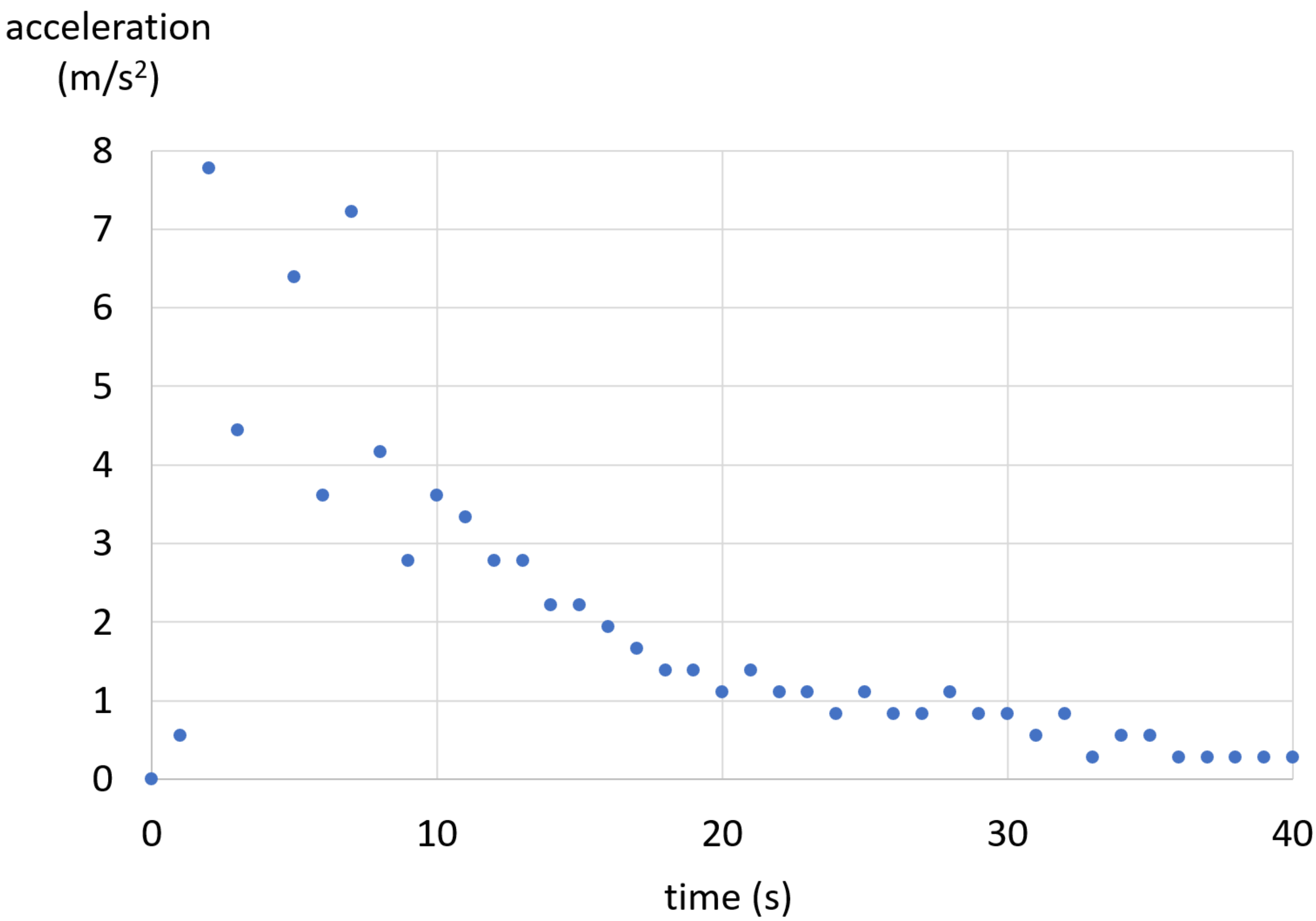

Figure 5. The acceleration against time.

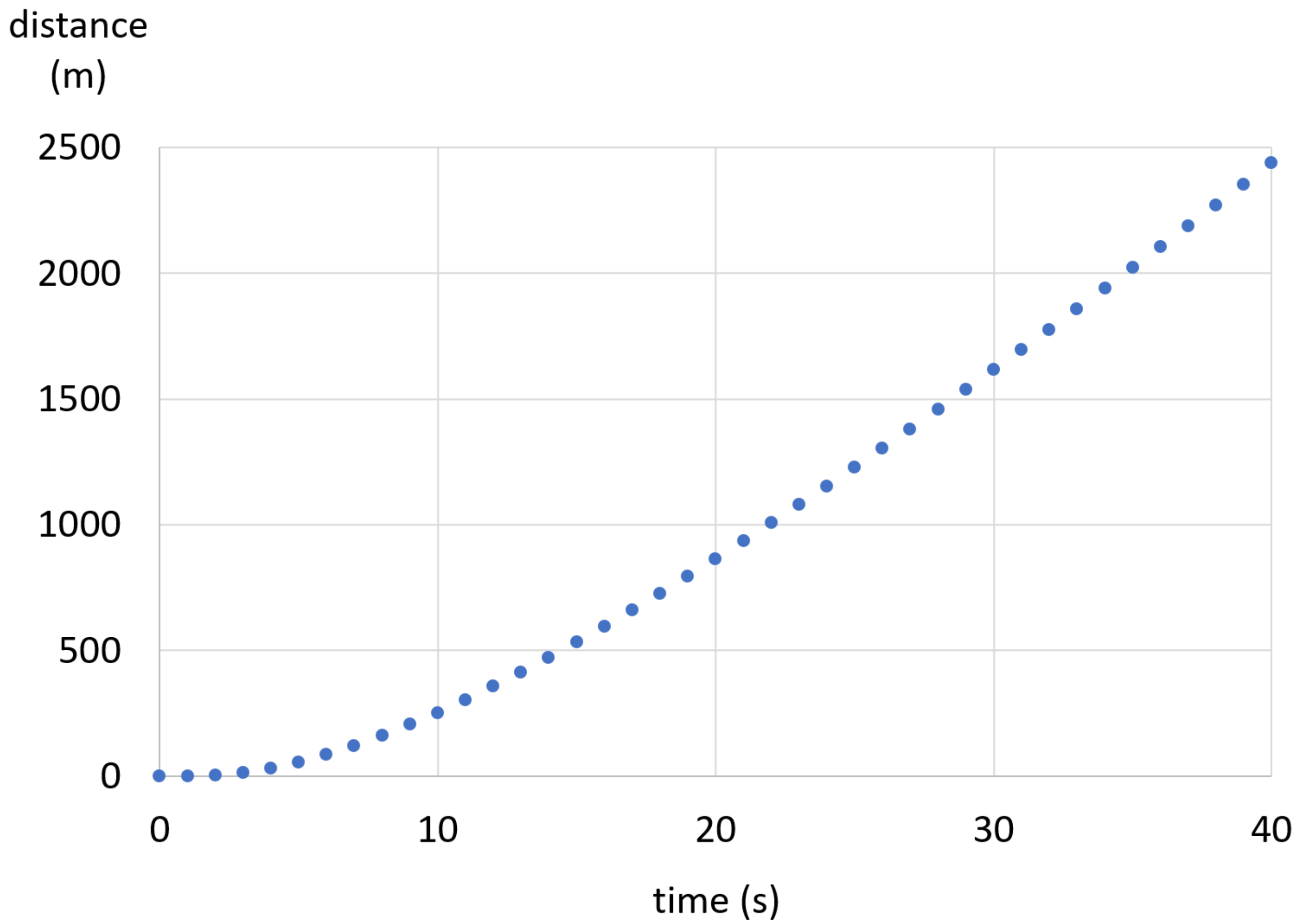

Figure 6. The distance against time.

Note that the acceleration is a little erratic at the beginning of the trip. Students can discuss their own experiences in cars that accelerate from rest. Then, things smooth out. As an optional task, the original speed data can be smoothed out to make the acceleration plot look more continuous. Sokolowski in a very recent paper in this journal points out the ‘need for adherence to principles of function continuity and differentiability’ [15]. The concept of smoothing is simple to understand. One averages the speed with its immediate neighbors. But the student need not complicate the spreadsheet by doing any programming of formulas. Instead, it is fun to drop the speed column of values into a textbox at a smoothing website and immediately get the results. I went to a webpage of King’s College

London called CHARM (Centre for the History and Analysis of Recorded Music) [16] and pasted the speed column from the spreadsheet into their data box. Their default smooth factor is 0.5. I experimented and found 0.4 gave excellent results. The speeds at each second are very close to the original data. Though the difference may be slight, the smoothed values significantly produce an acceleration graph easy to recognize as continuous throughout.

Conclusion

Our spreadsheet activity uses real-world data in kinematics. The excitement of racecars is captured in the assignment as students plot velocity against time for a car accelerating from 0 to 300 km h^{-1} in 40 seconds. Students then produce the acceleration versus time and the distance versus time plots from the speed graph. This analysis can be taught at the secondary school level. In doing so, the student is not only exposed to basic kinematics, but also to the fundamental ideas of differential and integral calculus.

See figure 7 for the relationship among distance, speed, and acceleration within the framework of calculus. Differential calculus involves plotting the slope of a function. Moving to the right in figure 7 shows the derivatives. Integral calculus gives the area under the graph, illustrated in figure 7 as moving to the left.

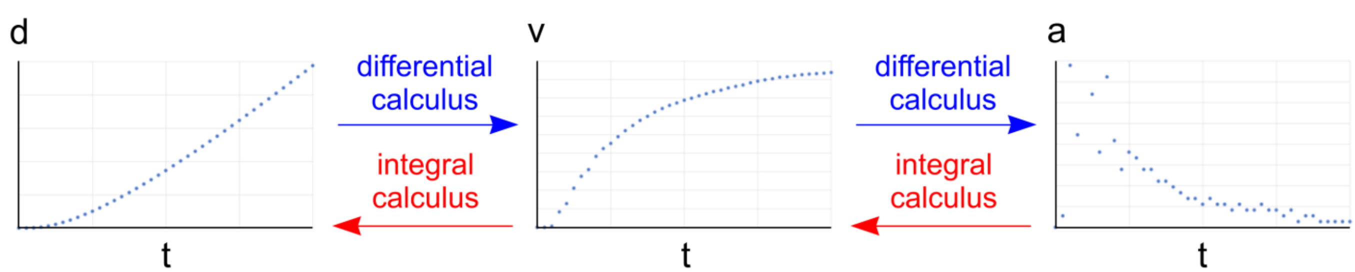

Figure 7. Distance, speed, and acceleration plots related to differential and integral calculus.

Students can check by the units that indeed slopes and areas give the appropriate dimensions for the plots in figure 7. In summary, the assignment combines racecars, kinematics of motion with real-world data, spreadsheet plotting, dimensional analysis, and the underlying principles of both differential and integral calculus.

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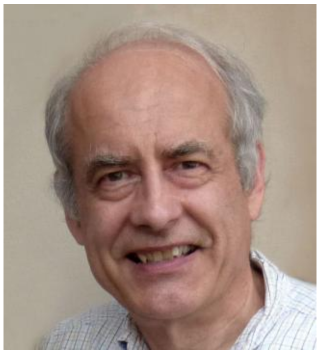

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