

# Teaching Physics Modeling Using Computer Interfaced Video: The Case of Paper Baskets

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## MODELING IN PHYSICS

In typical high school and BS Physics courses, students study the results of physics rather than the process of doing physics. Even most laboratory work are verification of known results of physics, rather than doing physics with yet unknown results. Students are rarely exposed to a core activity of physicists: modeling. The availability of computer-video interfacing and analysis software, such as Videopoint and Coach, has greatly expanded the possibilities of doing real modeling in physics education at the high school and college levels. In this paper, we present and work out a simple modeling problem on the free fall of paper baskets. Our purpose is to illustrate the possibilities of modeling in the classroom.

## THE PROBLEM

When leaves of trees or sheets of paper fall, they fall in a very irregular way. The paper zigzags slowly to the ground in an unpredictable way. However, if we fold the edges of the paper and make it into a little “basket”, the fall is much more regular. The paper basket moves slowly, but nearly straight to the ground. This is not free fall; air resistance plays a big role. How can we describe this motion mathematically? Is it possible to make a model so that we will be able to predict what influence different factors have, such as the mass of the paper, the area of the bottom of the basket, etc.?

When observing the basket falling, we notice that almost immediately a constant velocity is reached: the terminal velocity ( $v$ ). Different baskets have different terminal velocities. Factors which influence the terminal velocity might be the mass ( $m$ ) of the basket (greater  $m$ , greater  $v$ ) or the area ( $A$ ) of the basket (greater  $A$ , smaller  $v$ ). In high school level physics courses, we may use aerodynamics to get a proper model. In lower level courses, we can do some smart trial and error. Let us try this:

$$v = k \cdot \frac{m}{A} \quad (1)$$

This is a simple formula that mathematizes our idea that a greater mass should result in a greater terminal velocity and that a greater area should result in a smaller terminal velocity. The  $k$  is just a constant that we can try to find experimentally. Also, perhaps it should not be  $m$ , but  $m^2$  or  $m^{1/2}$ . Similarly, we might have to take a function of  $A$  rather than  $A$  straight, or if we know something about aerodynamics, we might already want to write  $v^2$  rather than  $v$ .

Our next task is to try to test the model in an experiment. Then we can use the results to improve our formula and get a better fit with data.

Please note that so far we have not used any physics beyond high school level. At this stage we could still introduce a force equation:

$$\sum F = mg - F_{drag}$$

Our task is now to design an experiment to test the model represented by Eq. (1).

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### THE COMPUTER-VIDEO INTERFACE

We can capture our own video of a falling paper basket or we can right away analyze a video which had been captured and edited earlier.

Videos are recorded by way of a video capturing device like the VIDCAP. The videos are processed using a video editing software such as Corel Draw. The essential series of frames are saved. The edited videos are then converted to a position-time graph by marking the center of mass of the paper basket at every frame. Fig. 1 shows an example of a graph recorded with the Coach software.

With the same software, a velocity-time graph is derived from the position-time graph as shown in Fig. 2. The slope at any point of each of these graphs can be determined, and therefore, the terminal velocity.

### THE VARIABLES

From the graphs, we determine the terminal velocity of the falling paper basket (varying bottom area and mass). Then, we can commence the investigation of the correctness of the model (Center for Microcomputer Applications, 1999).

With the mass of the paper basket held constant while varying the cross sectional area of the paper basket, we obtain a graph of  $v$  versus  $1/A$  as shown in Fig. 3. The curve formed by the data points seems parabolic.

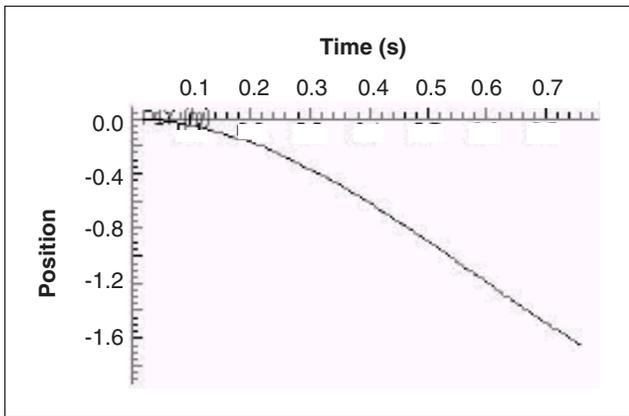


Fig. 1. Position-time graph recorded with the Coach software.

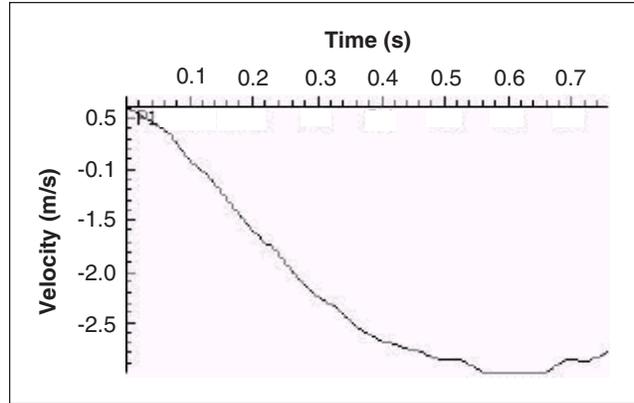


Fig. 2. Velocity-time graph derived by the Coach software from the position-time graph shown in Fig. 1.

Taking the square root of  $A$  (Fig. 4), the result looks linear. From this we can then revise Eq. (1) to:

$$v = k \frac{m}{\sqrt{A}} \quad (2)$$

To investigate the influence of mass on terminal velocity, we keep the cross sectional area constant and vary the mass by adding whole pieces of paper of the same kind into the basket. The result looks linear (Fig. 5).

Based on these experiments, our best model is represented by Eq. (2).

We could experiment further and try some other variations of the basic formula. We could be more sophisticated in deciding which graphs provide the best

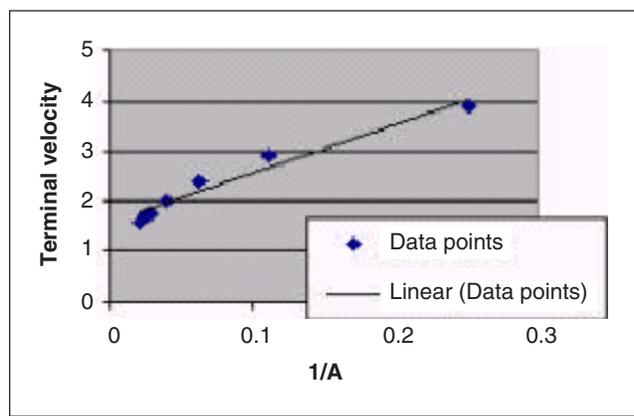


Fig. 3. Graph of  $v$  versus  $1/A$ .

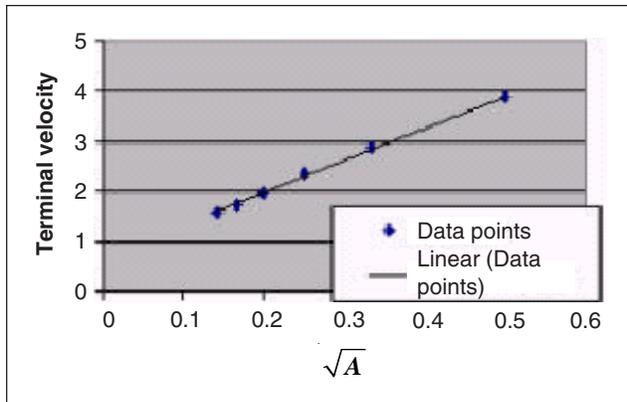


Fig. 4. Graph of  $v$  versus  $\sqrt{A}$ .

fit, for example, we could use least squares techniques. But remember that this modeling exercise is intended for students in introductory physics courses. We think this semi-quantitative way of working with data provides an attractive experience in modeling.

Sources of error in this modeling exercise are the following: (1) some inherent instability in the motion of the paper basket; even in basket shape, it still wobbles a bit; (2) the clicking on the marked point could be off by a few millimeters, and in addition, there could be a slight parallax error; (3) within the series, no frame should be dropped in order to have a reliable time base; and (4) differentiation of the position-time graph in order to obtain a velocity-time graph introduces some instability.

In spite of these inaccuracies, it is possible to obtain and verify a reasonable model for students in introductory physics courses.

## CONCLUSION

In physics, we try to describe phenomena. Once we have a good description, we can use that to predict or even control phenomena. We try to describe phenomena as precisely as possible using mathematics to create our models. With a creative use of theory we try to make a model and then we conduct experiments to test the model and to improve it. That is what we did in this experiment. The purpose of doing it was to illustrate the way we work in physics. This experiment shows that modeling in physics can also be done with the

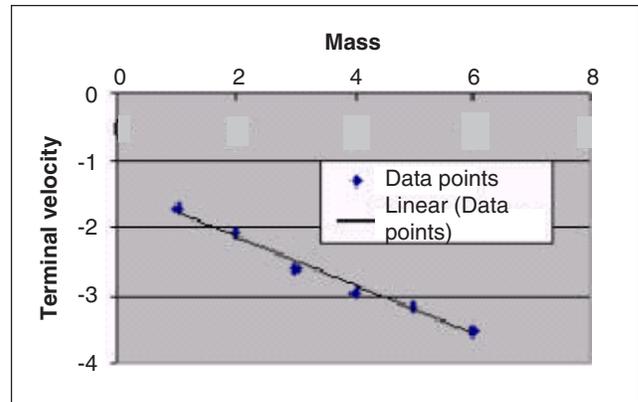


Fig. 5. Graph of  $v$  versus  $m$ .

simple physics available to high school and lower level college physics.

## REFERENCE

CMA Centre of Microcomputer Applications, 1999. Coach system workbook. AMSTEL Institute, Universiteit van Amsterdam.