High-Speed Video Analysis in a Conceptual Physics Class

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The use of probe ware and computers has become quite common in introductory physics classrooms.[1] Video analysis is also becoming more popular and is available to a wide range of students through commercially available and/or free software.[2,3] Video analysis allows for the study of motions that cannot be easily measured in the traditional lab setting and also allows real-world situations to be analyzed. Many motions are too fast to easily be captured at the standard video frame rate of 30 frames per second (fps) employed by most video cameras. This paper will discuss using a consumer camera that can record high-frame-rate video in a college-level conceptual physics class. In particular this will involve the use of model rockets to determine the acceleration during the boost period right at launch and compare it to a simple model of the expected acceleration.

The idea for this activity came from my wanting to get the conceptual physics students doing more interesting and exciting studies of forces and motion than have traditionally been done. My love of rockets led me to have the students build and launch rockets, but I needed a way for the exercise to be more than just building and launching a rocket. The introduction of Casio's EXILIM cameras several years ago with high-speed video allowed for that opportunity.[4] These cameras range from \$200-300. The students use an FX-H20 model (no longer made, but the replacement would be the EX-ZR100) to take the video.

The students must build their rockets from scratch using only items they have at their homes. The one seen in Fig. 1 was made from an empty water bottle and cardboard. The rocket can't be made of metal or have a mass greater than is appropriate for the rocket motors being used. In this case students used Estes C6-5 motors and maximum lift-off mass of 133.2 grams.

Students compare the results of their video analysis to a simple Newton's second law prediction of the acceleration. The simple model used ignores air resistance and, over the time they can take video, this is not a horrible assumption. They get the peak thrust for the motor from the National Association of Rocketry (NAR) motor certification page[5] and assume this is the thrust over the whole time they capture. This is also not a bad assumption since the video is shot over a short period of time; in this example it is about 0.15 seconds. Thus, students end up with a Newton's second law expression like the following:

$$F_{\text{net}} = ma = F_{\text{thrust}} - mg, \qquad (1)$$

where F_{thrust} is the force of the motor on the rocket. Students take the mass of their rocket and easily calculate the expected acceleration. Over this brief period of time, the mass of the rocket does not change appreciably even though the fuel is being burned.

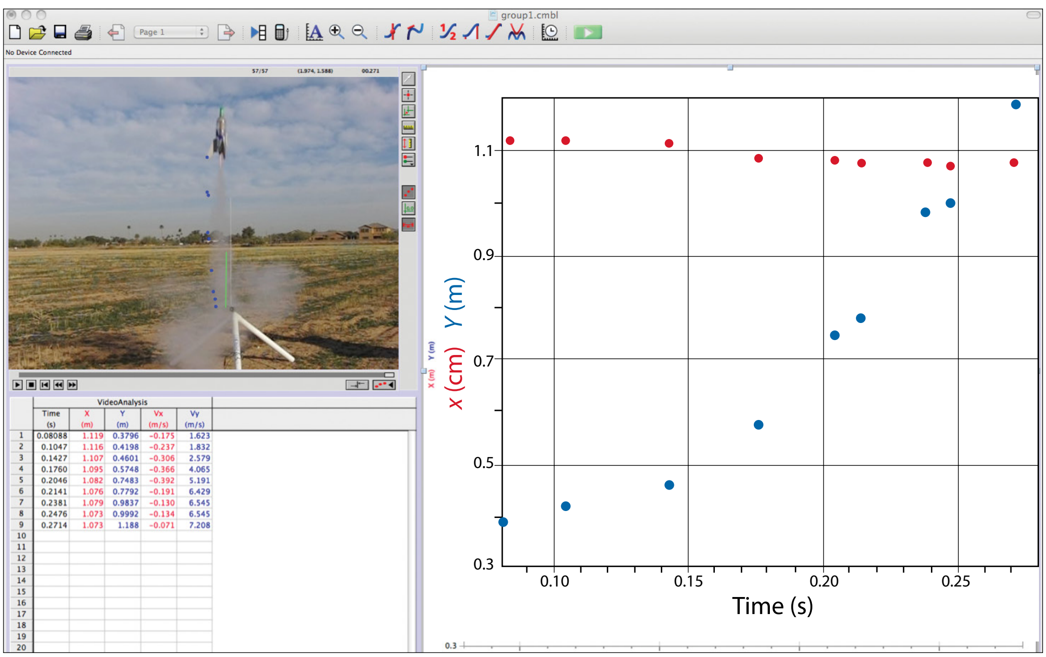

Fig. 1. Screen capture from Logger Pro. The accompanying *TPT Online* video clip shows the complete launch. (URL: http://dx.doi.org/....)

Nothing to this point is very interesting and it has been done in physics classrooms for years.[6] The interesting thing is now being able to find the acceleration of the actual launch. Using a frame rate of 210 fps, the groups take video of their launch and edit it down to just the actual launch (you get a lot of frames in a very short period of time). In video analysis you need an object to scale your movie, and the students use the length of their rocket to accomplish this. An actual student analysis using Logger Pro can be seen in Fig. 1.

Even though this video occurs over less than 0.3 s

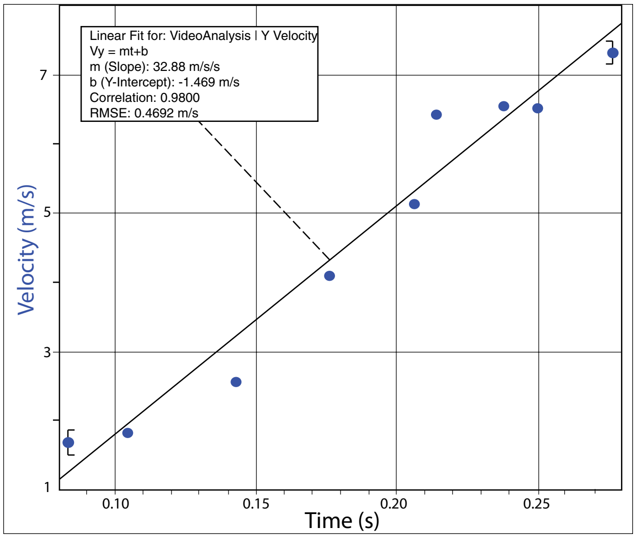

Fig. 2. Velocity-vs-Time graph.

(which would yield about 60 frames of video at 210 fps), there are plenty of frames to make a good analysis. In fact, in this case the students skipped frames as they found that at times the rocket had not moved enough to make a good determination of the position. In Fig. 2 you can see the vertical velocity graph for this launch along with a best-fit line. The slope of the line provides the acceleration of the rocket, which in this case is 32.9 m/s^2. This compares nicely to the group's calculated value of 31 m/s^2. These results are pretty typical both in value of acceleration of the rockets from the video and deviation from the Newton's second law predicted value.

While the results are impressive, the real power of this is having students be able to measure accelerations approaching 4 *g*'s and compare to a simple model. These students don't have strong mathematical skills (recall this is a conceptual physics class), but still can analyze a complex situation and come up with results that make sense and compare nicely to the actual video data. Students comment on how much they enjoy building the rocket and getting data from the video.

Currently all videos are taken from one camera, which is set up to give the best view of the launch pad. The videos are downloaded onto one computer and then the students bring a USB drive to grab their video so they can do their editing and analysis. Thus, the cost of equipment for this is minimal, as only one camera is needed.

In higher-level classes the complexity of the models and situations available open up even more quality opportunities. An example was an honors project a student did where he took video of a golf club hitting a ball to determine the speed of the ball after impact and angle of initial velocity. He then compared the actual displacement of the ball to what would be predicted by standard kinematics.

Finally a word about safety and using rockets in your classroom. I love doing rockets in my class, but please always follow appropriate safety codes and all local and federal ordinances on rockets. For safety information on size of field and safe launch practices, please visit the NAR safety code website.[7]

References

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7. www.nar.org/NARmrsc.html.

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