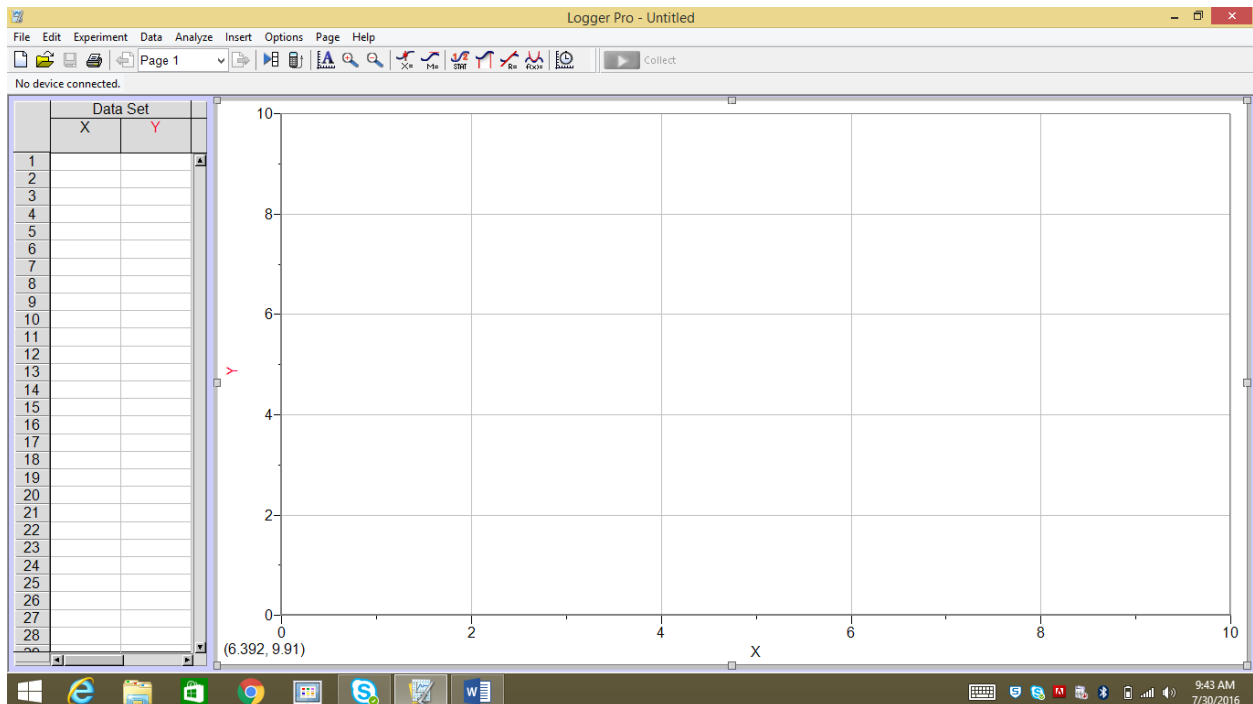
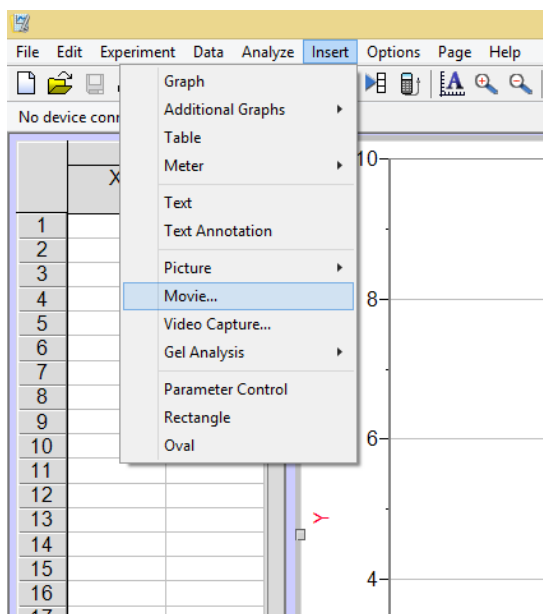


Detailed instructions for video analysis using Logger Pro.

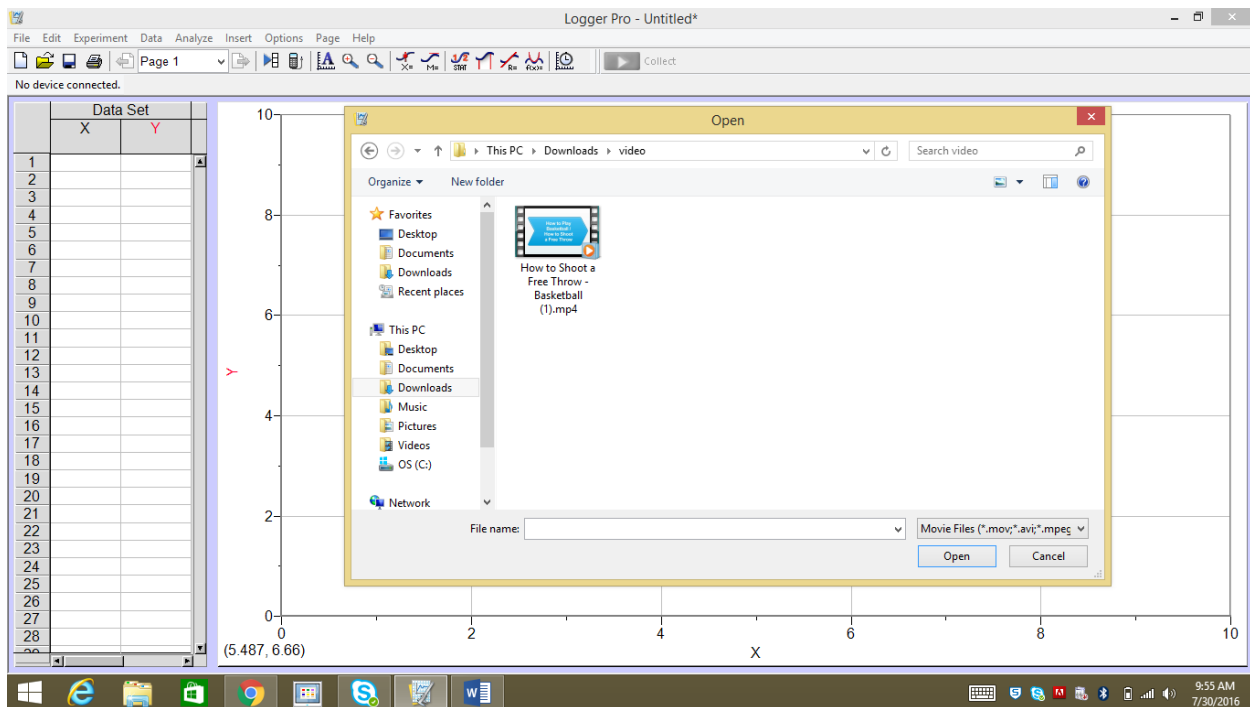
1. Begin by locating or creating a video of a projectile (or any moving object). Save it to your computer. Most video file types are accepted, including: *.mov and *.mp4.



2. Open Logger Pro. (The software is not free, although a free trial version can be used for 30 days. Find it at <http://www.vernier.com/downloads/logger-pro-demo/>. Many schools, however, own the software.)



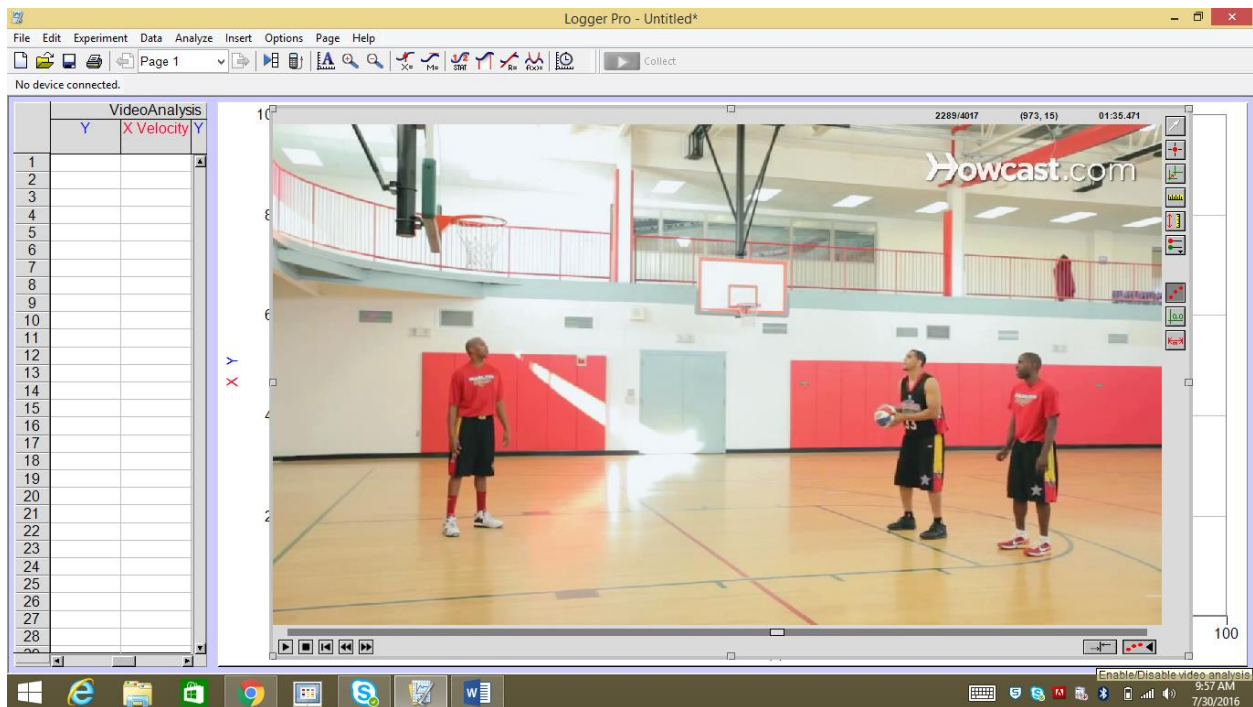
3. Navigate to Insert > Movie...




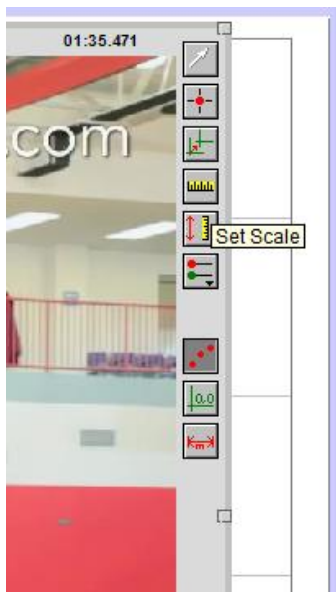
4. Navigate to the location where you saved your video, and Open it.



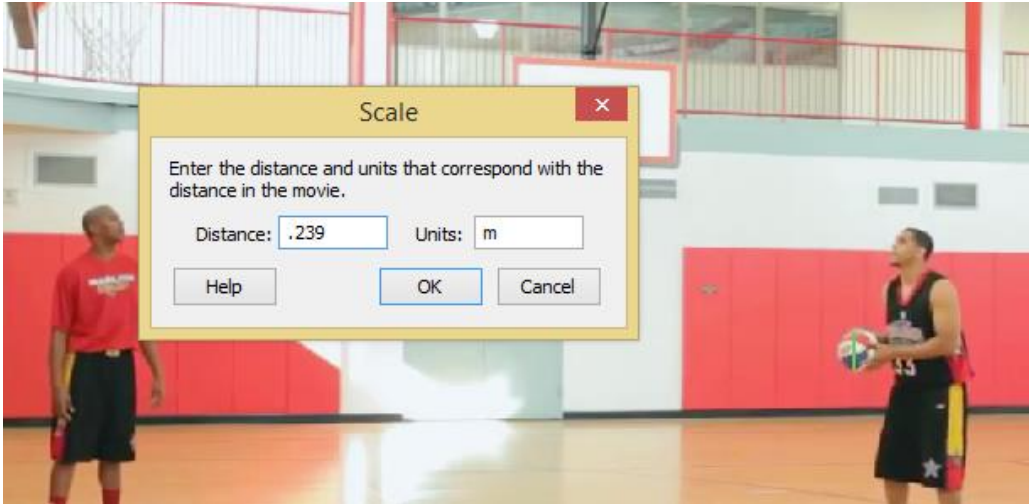
5. The video will display within its own window. Controls at the bottom left of the window allow you to play, stop, rewind and move through the video frame by frame.



6. Advance to a portion of the video that contains your projectile. Then click on the  button to reveal a collection of video analysis tools.



7. We must now set a scale in the video. (If our ball moves one inch across the video screen, does this correspond to one meter in “real life”, or one hundred meters, or just a centimeter? Logger Pro doesn’t know.) Click on the Set Scale button, then draw a line on the video screen such that you know its true length in “real life”. See the next step for additional help.



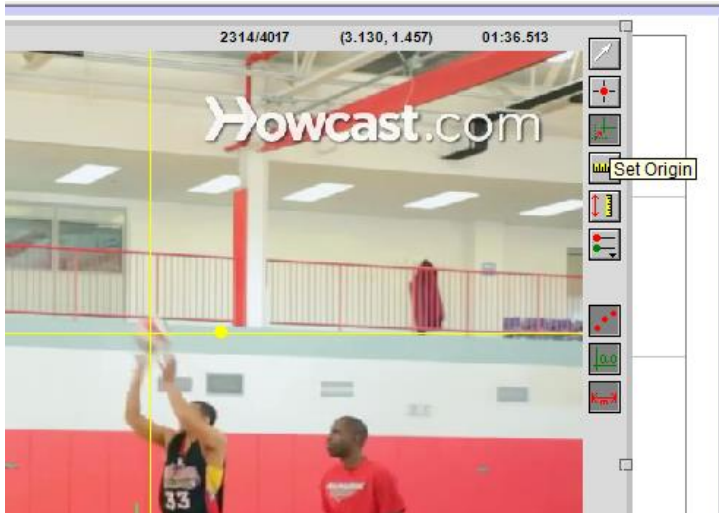
8. Here, as an example, I've drawn a green line across the basketball. I did this because I know the actual diameter of a regulation basketball. Drawing this line causes the Scale box to pop up. Here, you enter the length of that green line in "real life" (i.e. the length of the real object behind it) in the Distance box. It is recommended that you use the metric system and keep your units in meters, although you don't have to.

The diameter of a regulation men's basketball is approximately 0.239 meters.

I could have drawn a green line vertically across the person, if he was standing up straight and I knew his true height. But drawing a line across one of the red rectangles in the background would have been a mistake. The scale for objects that distance from the camera is different than the scale for objects at the distance of the ball. Don't forget this.



9. You now want to advance to the frame of the video where the projectile has begun its period of free fall. In this case, the ball has left the player's hands. If you start tracking the object before it begins its period of free fall, you'll have to be a lot more careful analyzing your data.

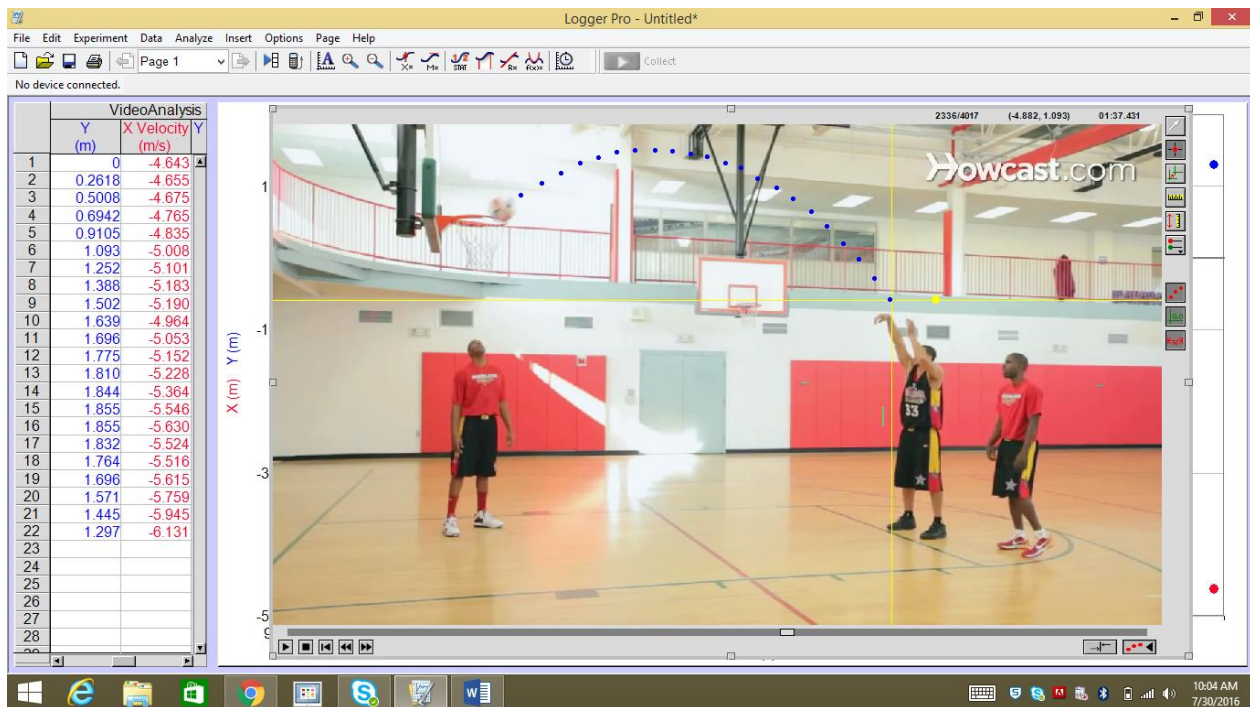


10. This step is not essential, although it does affect the kinematic models you generate. Here, I set the origin of my Cartesian coordinate system. I've chosen to do so in the center of the ball, in the frame where the ball has just begun its free fall motion. To set the origin, simply click on the Set Origin button on the side of the window, then click in the video where you wish to place your origin.

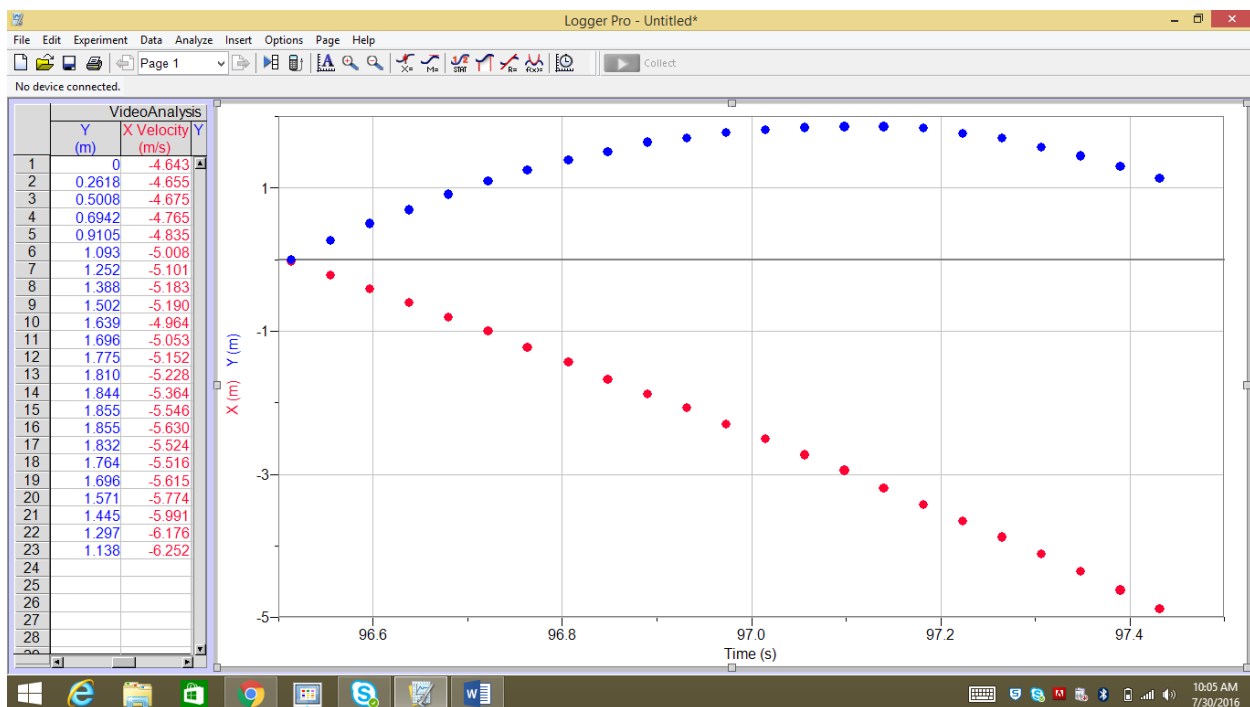


11. It is now time to collect data. Click on the Add Point button, then click on a particular spot on your projectile. The x,y and time coordinates of that point are recorded, and the video is automatically advanced one frame. Click again, on the very same spot on your projectile, and again the x,y and time data is recorded. Do this again and again.

Be careful to always click on the same spot on your projectile. (For a ball, I'd aim for the center.)

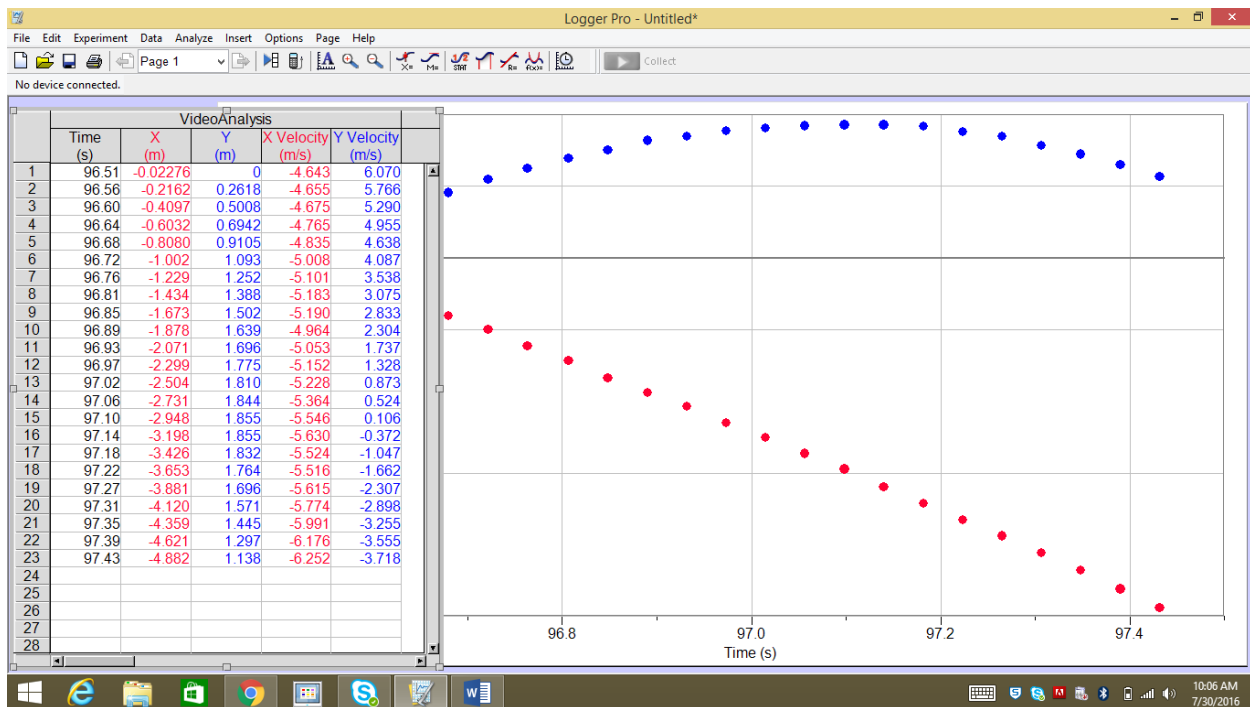


12. I've clicked on the ball 22 times and collected 22 rows of data. (I'll click one more time before I stop.)

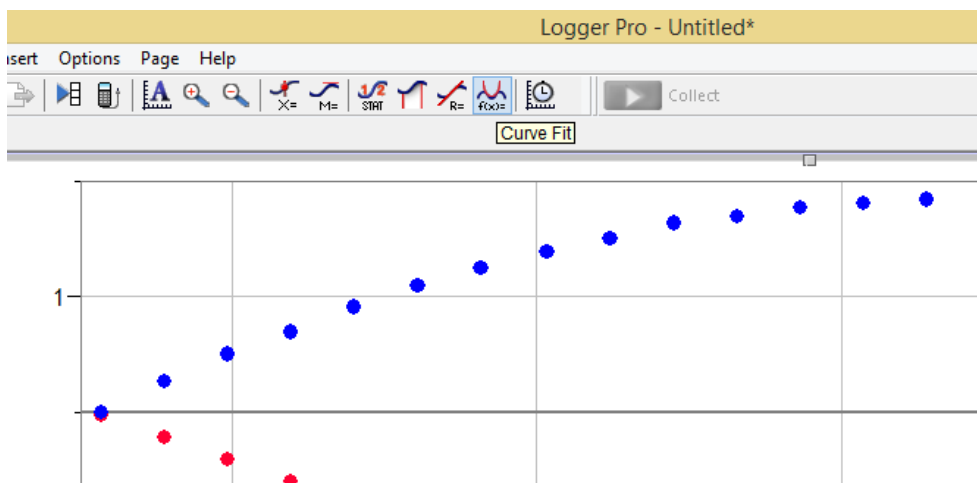


13. To see the graph, which has been hiding behind the video window all along, I clicked on the edge of it, peeking out from behind the video. (The video is now hiding behind the graph.)

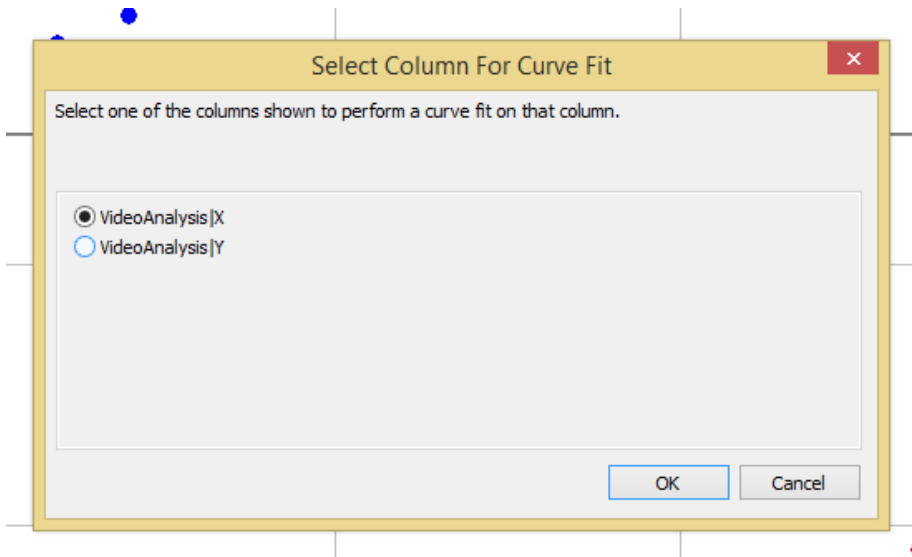
Here, we see two scatter plots displayed at the same time, on the same axes. As we've seen before, the Y vs t plot is parabolic (quadratic) and the X vs t plot is linear.



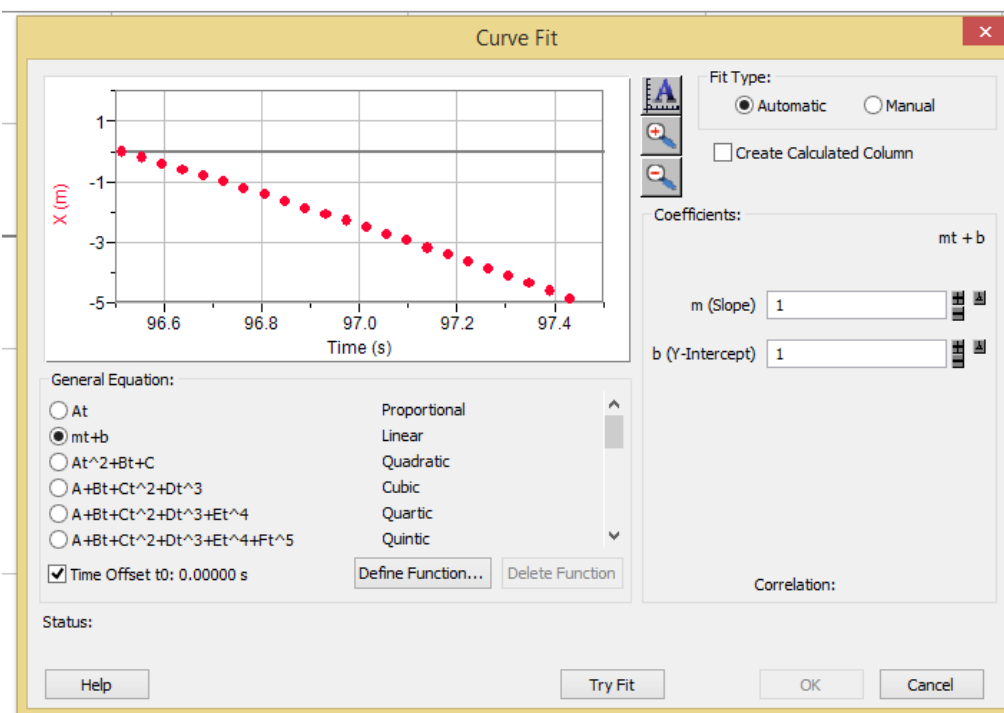
14. Here, I just want to show you all of the data that was collected. You can't see all of it unless you expand the data table window.



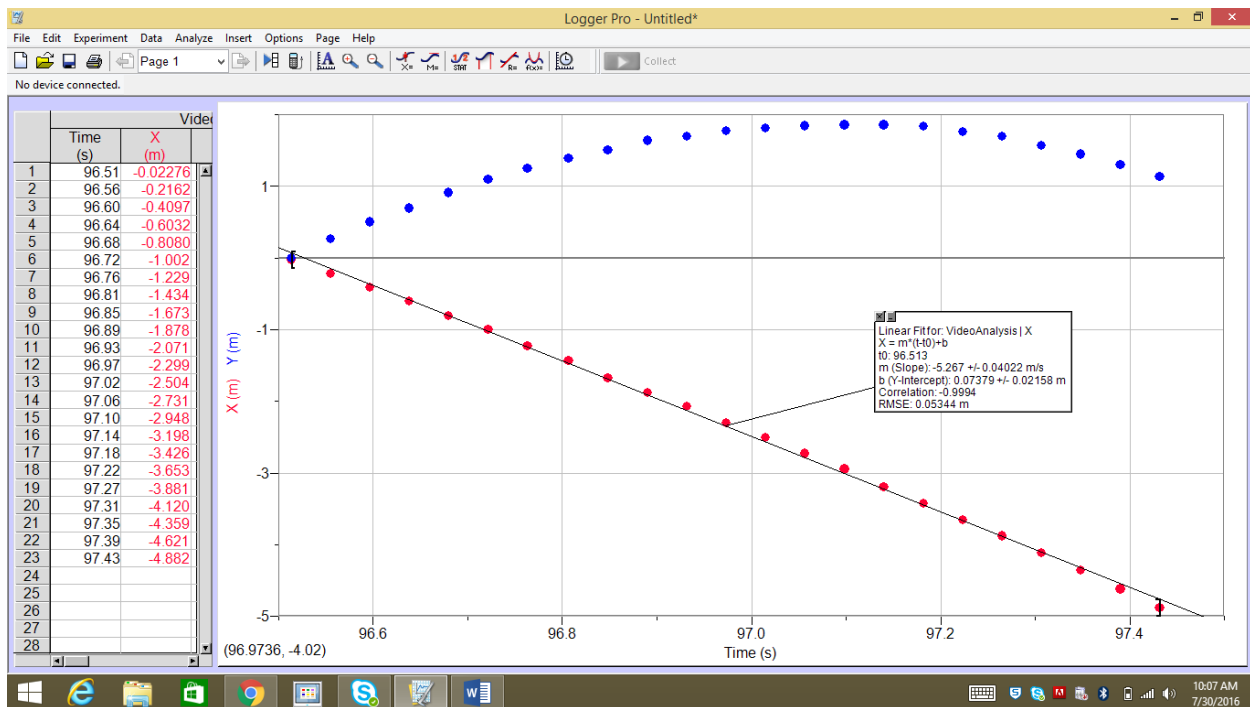
15. It's time to generate our models! That is, we want to add trend lines to our plots. To do this, click on the Curve Fit button, seen above.



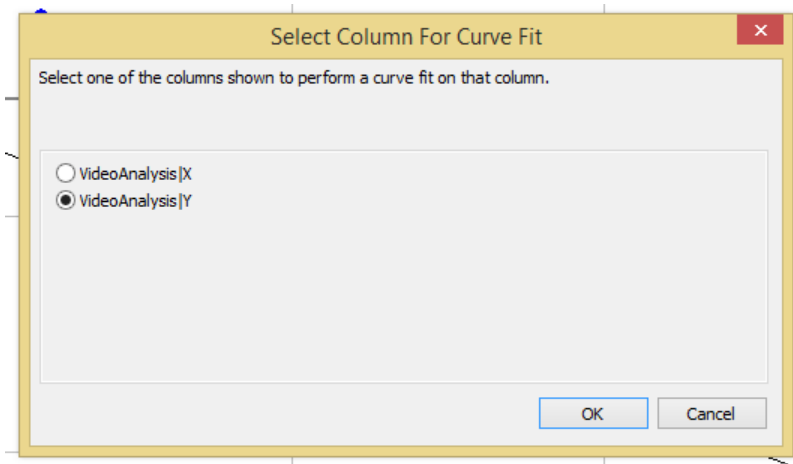
16. Because we have two sets of data plotted on the same axes, we must tell Logger Pro which set of data to use for the trend line. We'll end up doing both. Here, I start with the X data.



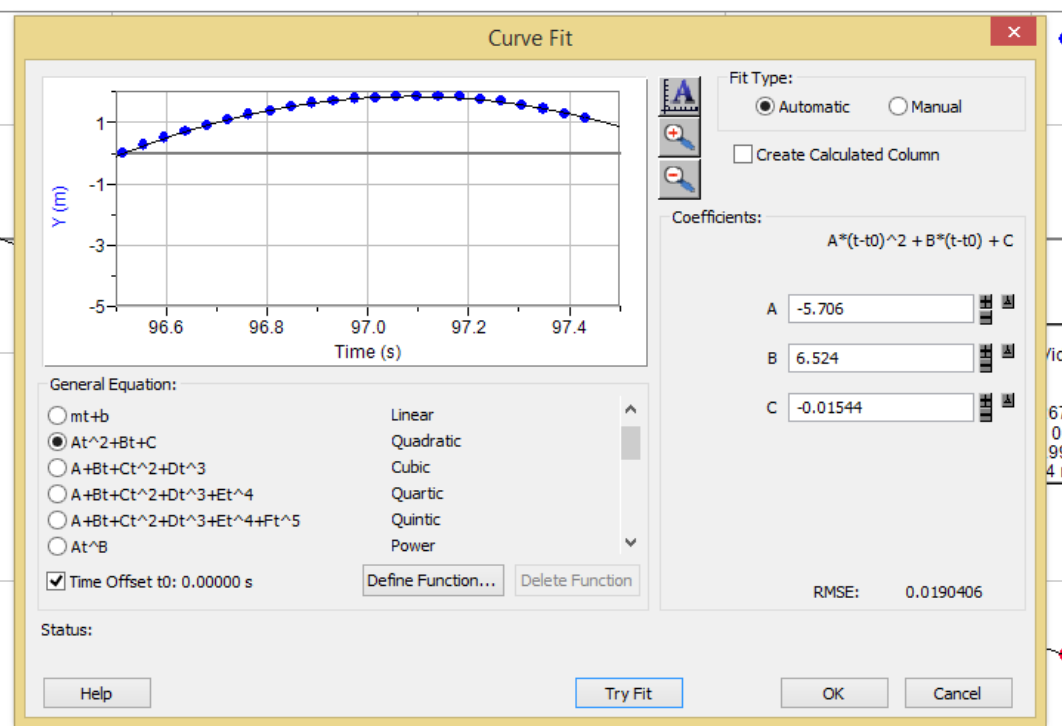
17. We must help Logger Pro to generate the trend line. First, we select “Linear” from the General Equation list. We do this because the data is obviously linear. Second, we check the “Time Offset” box. Doing this associates the first data point with a time of zero ($t = 0$), instead of the 96.5 that it would otherwise be (for this particular video). This generates a model that is easier to interpret. Third, we must click the “Try Fit” button. Fourth, click OK.



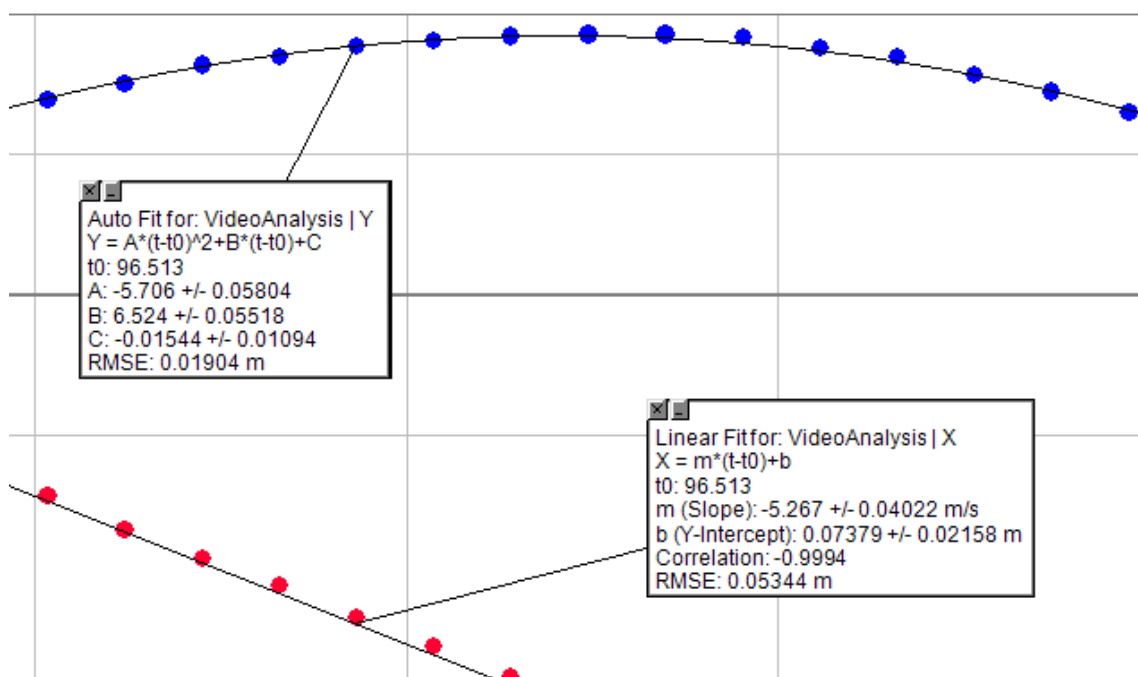
18. A text box is now displayed on the graph. It contains the information that defines our trend line. We'll take a closer look at it shortly.



19. Click once again on the Curve Fit button, then select "VideoAnalysis|Y". We'll now generate a trend line for the Y vs t data.

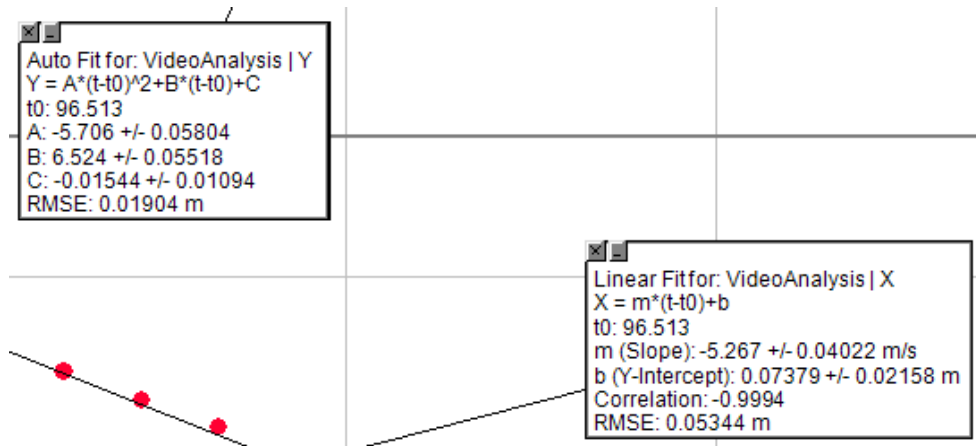


20. Here, we help Logger Pro to generate an appropriate trend line for our Y vs t data. The data appears to show a “Quadratic” relationship, so we select that option under General Equations. (For projectiles, Y vs t will always be quadratic.) Check the box for “Time Offset”, then click “Try Fit”. Finally, click OK.



21. We have (in an ugly format) two models that track, respectively, the vertical and horizontal motions of the projectile. On the next page, we’ll learn to read this information.

Interpreting our Trend lines



For Y vs t, we have $Y = A(t-t_0)^2 + B(t-t_0) + C$, where A is -5.706, B is 6.524 and C is about zero (as it *should* be, because I set my origin where the ball originated). The time is represented as $(t-t_0)$, which indicates the number of seconds not from the start of the video but from the launch of the projectile. This notation is a result of us checking the “Time Offset” box. Notice that $t_0 = 96.513$ seconds. This was the clock reading when the ball was just launched. When the clock reads 97.513 seconds, we know that one second has passed, since the launch, and $(t-t_0) = (97.513-96.513) = 1.0$ second. For our purposes, we’re going to write out our model using just “t” and pretend like the ball was launched at $t = 0$.

The \pm followed by a small number, attached to the values for A, B, and C, represents the error or uncertainty in the numbers. The value of A is somewhere within the range of $-5.706 - 0.05804 = -5.76404$ and $-5.706 + 0.05804 = -5.64796$; i.e. somewhere between -5.76404 and -5.64796. Likewise, the value of B is somewhere between the values of 6.46882 and 6.57918. For now, we are going to ignore this uncertainty. We’re also ignoring C, because it’s approximately zero.

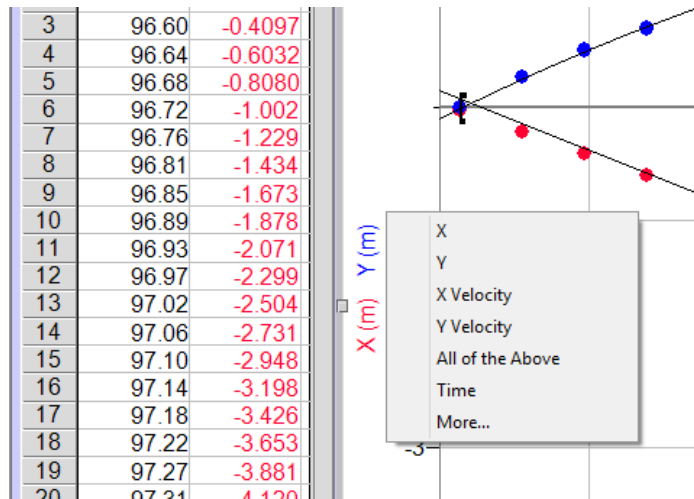
Our model representing vertical motion becomes: $\Delta y = -5.706t^2 + 6.524t$.

The initial vertical velocity is 6.524 m/s, and the vertical acceleration is -11.412 m/s^2 .

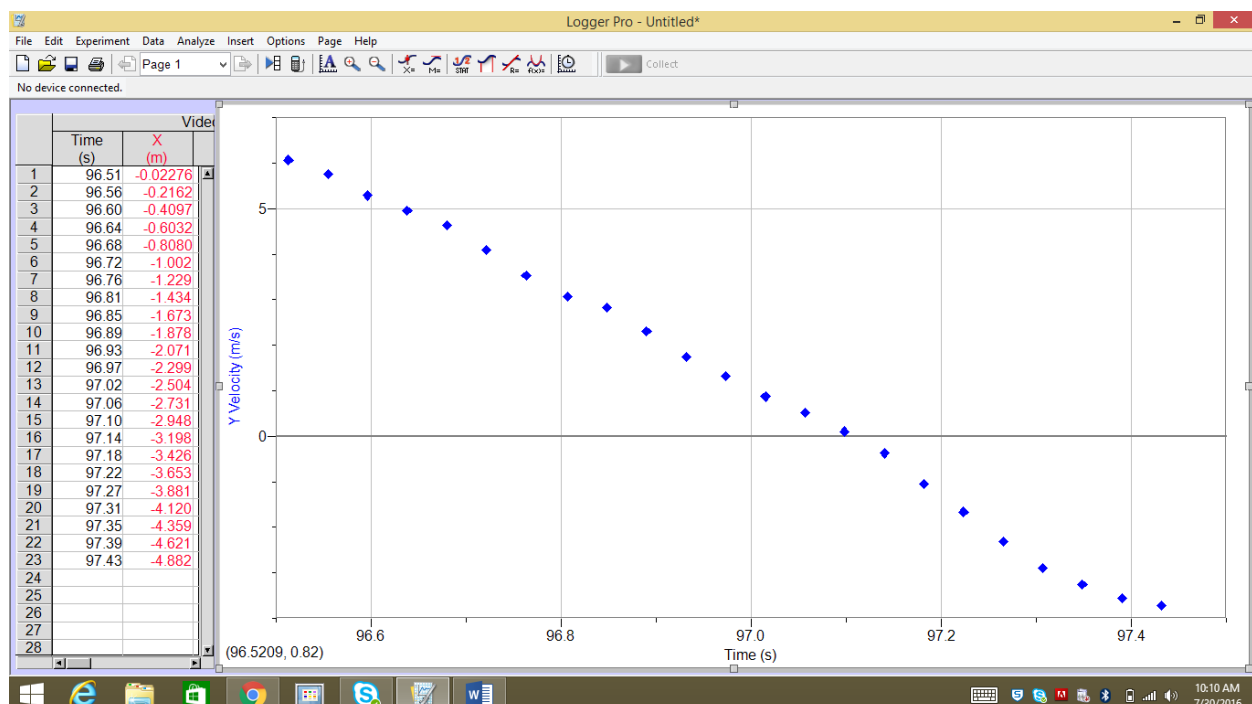
ALERT!! The acceleration is NOT -9.8 m/s^2 , as it should be on Earth. What does this mean? Only because many people have already tested the acceleration much more carefully than we have, we come to the conclusion that we probably made a mistake. (There are times, as a scientist, when you are the first person to measure something. In such cases, you can’t check your number against a previously published value. So you just double and triple check your work, then publish your number, and hope you didn’t make a big mistake.) What could be the source of our error? Don’t you dare say “human error”, which is a generic, meaningless phrase. Here’s what I think it could be. The basketball in the video is not a regulation men’s ball, and so its diameter isn’t the 0.239 m we input when we set the scale. (I found this video on the Internet. Had I recorded this video for myself, I would have measured the basketball’s exact diameter.) Here’s another possible source of error. The basketball did not maintain a fixed distance from the camera. Our perspective was a bit skewed.

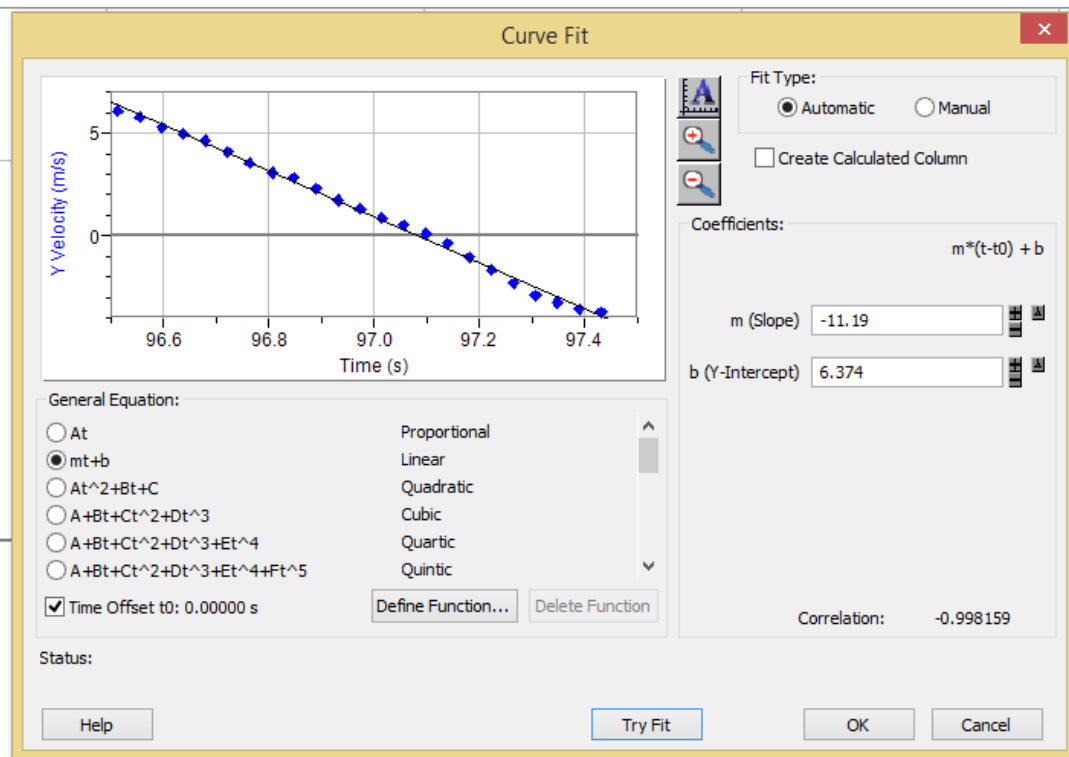
Errors are a part of life. When they occur, you should try to fix them and redo your analysis.

Okay, now for the X vs t model. We have $\Delta x = -5.267t$, where -5.267 m/s is our initial (and constant) horizontal velocity. Well, technically, we have $x_f = -5.267t + 0.07379$, which goes to show that I didn't put my origin exactly where I wanted it. I wanted the $x_i = 0.07379 \text{ m}$ to be zero. This bit of the model seems a bit arbitrary, and it is; we can arbitrarily put the origin anywhere we'd like. This bit of the model doesn't tell us anything that's really useful. So let's ignore it. An important piece of information is the horizontal velocity, and that is *not* dependent on where the origin is placed. That's what we take away from this model.



22. There are two additional plots to look at: "X Velocity vs time" and "Y Velocity vs time". As the X Velocity plot is boring, we'll just look at the Y Velocity plot. Display it by clicking on the vertical axis label, so that the grey box (see above) pops up. Then select "Y Velocity".





23. As before, click on the Curve Fit button, then a) select “Linear” under General Equations, b) check the “Time Offset” box, and c) click “Try Fit”. Then click OK.

Linear Fit for: VideoAnalysis | Y Velocity
 $V_y = m \cdot (t - t_0) + b$
 $t_0: 96.513$
 $m \text{ (Slope)}: -11.19 \pm 0.1484 \text{ m/s/s}$
 $b \text{ (Y-Intercept)}: 6.374 \pm 0.07963 \text{ m/s}$
 $\text{Correlation}: -0.9982$
 $\text{RMSE}: 0.1972 \text{ m/s}$

24. Here, we see that the model for the vertical velocity of the projectile must be:
 $v_f = -11.19t + 6.374$, where 6.374 m/s is our initial vertical velocity and -11.19 m/s² is our vertical acceleration.

It's unfortunate that these two values do not match the values from the Y vs t plot (6.524 m/s and -11.412 m/s²). Really, they *should* match. At least, the range of the initial velocity given for the Y vs t plot should overlap the range of the initial velocity given for the Y Velocity vs t plot. And likewise for the accelerations. Again, we see evidence of error. The same error that plagued our previous models.

Yet, despite the error in our models, we have made our way through all of the steps in video analysis of a projectile. Now you try!