

Course: Physics  
Tracker Lab - Constructing a Mathematical Model



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We have used Tracker to analyze the kinematics of an object and answer questions that start with 'how fast' or 'where is it'. The program has the ability to take the positions of the object from clicking through each frame and use them to calculate velocity and acceleration. Application of Newton's 2nd law then allows

One of the more powerful capabilities of Tracker is that it can instead let us use what we know about the forces acting on an object to describe how it moves. There is then no 'clicking' through each frame. Here is the idea:

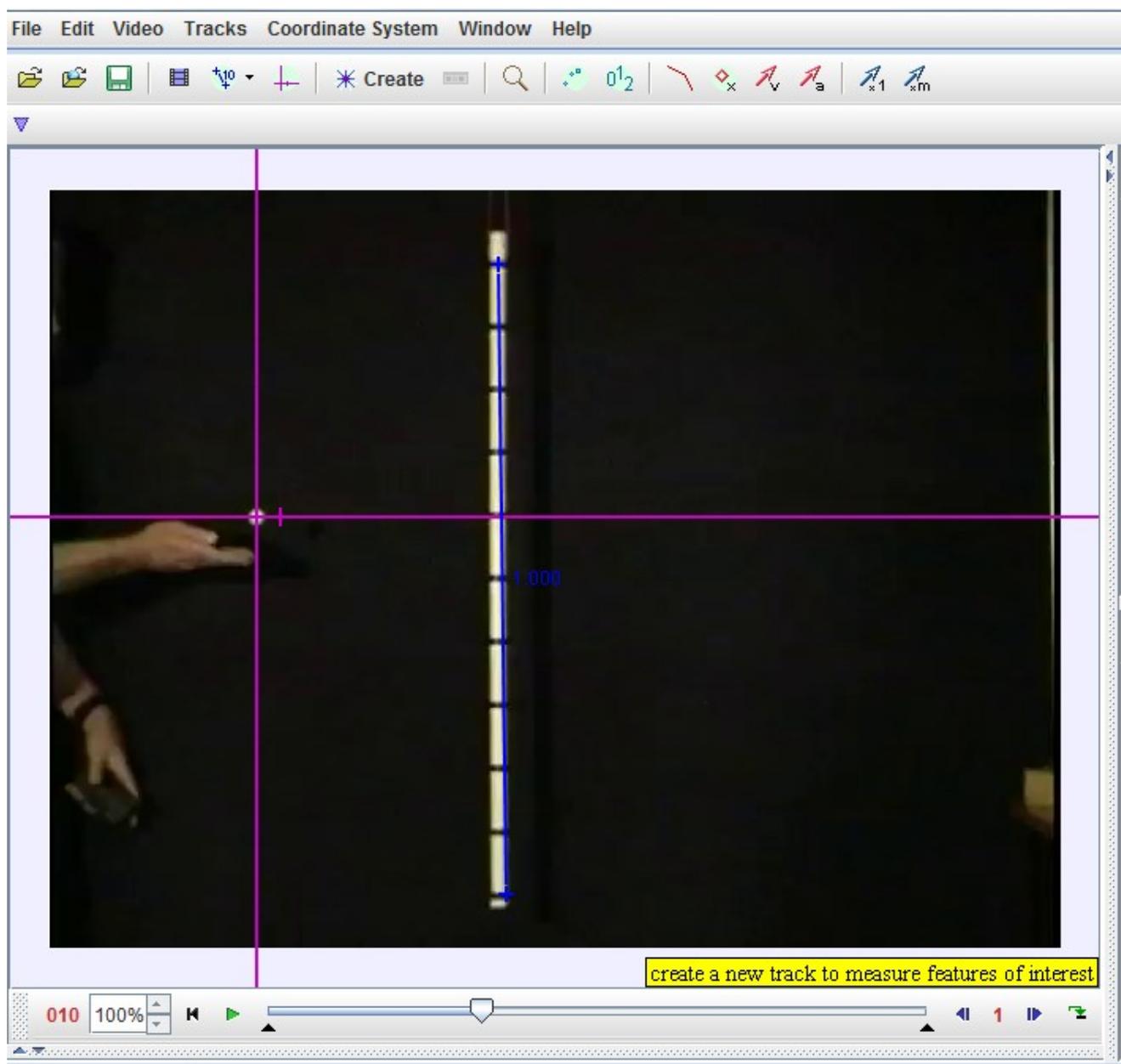
1. A video of a moving object is loaded into Tracker. The initial velocity and position of the object can be determined from the video.
2. A mathematical model comes from writing Newton's 2nd Law for an object from its free body diagram.
3. The program uses Newton's 2nd law to calculate the acceleration of the object.
4. Using Calculus, the program can then figure out how the velocity and position of the object will change between frames of the video.
5. The program puts a mark on the video where the model says the object should be in the next frame.
6. Based on its new position, the model is used to calculate a new acceleration of the object, and the cycle repeats.

Tracker lets you see both the object in the video AND the location where the model says it *should* be. The model can then be adjusted to match what is being seen in the video.

**Follow the written instructions below to set up the model:**

- Open 'BallTossOut.mov' from the 'videos' folder where you installed Tracker. Get to frame 10 of the video.
- Select the Axes button (looks like a set of axes) and move it so the origin is on the ball.
- Select the Calibration stick and stretch it so it matches the tick marks on the white line in the video. This length is 1.0 meters.

Your screen should now look something like the image on the next page:



- Draw a free body diagram of the ball. Make your axes the same as what they are in Tracker (up positive y, right positive x)
- What is the net force in the x-direction? y-direction?
- Select the **Create** button and choose 'Dynamic Particle Model' and then Cartesian. This will allow us to tell Tracker about position, velocity, and force in the x and y directions.
- In the bottom of the model builder window, enter '0' in the force function  $F_x$  (since this is the net force in x) and enter  $-m \cdot g$  in the force function  $F_y$  (since this is the net force in the y-direction)

The program should complain using red letters - look at the 'Parameters' box of the model

builder. Notice there is an **m**, but no **g**.

- Select 'Add' and enter **g** in place of 'param' in the name column. Enter **9.8** in the box for **g**.
- In the 'Start' box, enter frame 10 since we are starting our simulation at frame 10.

Move the video slider to frame 20. You should notice that Tracker is now adding a circle to each frame of the video. These circles represent the numerical model, but it clearly isn't correct yet since it isn't located on the ball. Now comes the fun part.

- Adjust the initial velocity **vx** of the model so that the model location is at the same x position as the ball in frame 20. You can do this by going to the 'Initial Values' section of the model builder, and double clicking on the 'Expression' column next to **vx**.
- Adjust the initial y-velocity so that the model is in the same location as the ball.

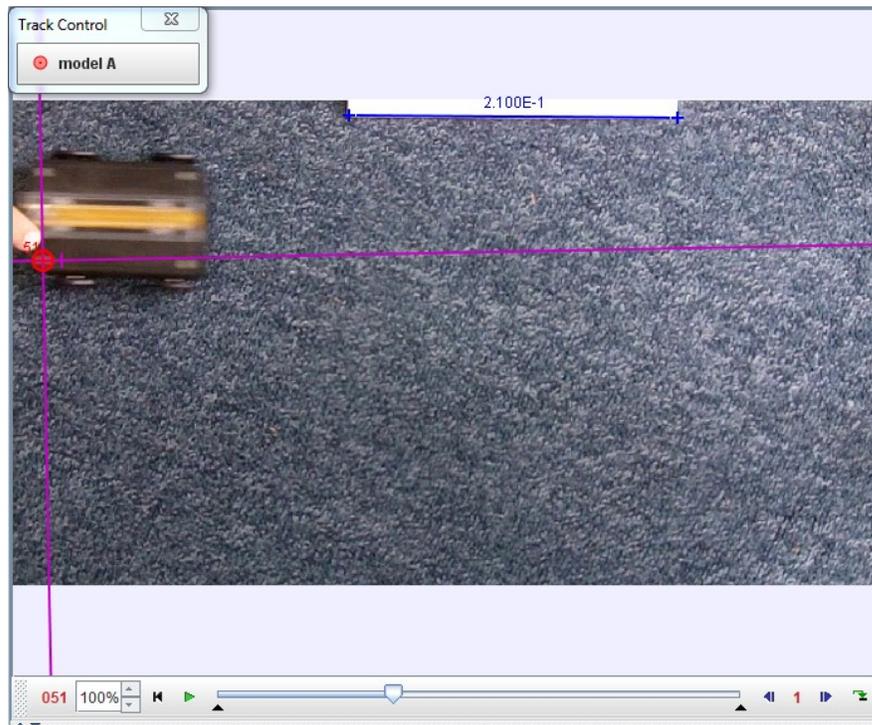
Move the video slider back to the beginning of the video and press play. How well does the model match the video?

- Continue adjusting the values until the model is accurate out to frame 30.

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Now you will create your own model!

Load 'car on the floor.trk' into Tracker. Watch the entire video. Afterward, move the video slider to frame 51.



In this file, the axes have been positioned to match the car's location in this frame. The mass of the car has been measured at 116 grams.

- Draw a free body diagram of the car from the point of view of the camera. What forces should you include in your model that affect the movement of the car in the video? (Draw a system schema if you are not sure what forces are acting during the car's movement.)
- What are the net forces in the x and y directions? These are what you will put in the model builder for  $F_x$  and  $F_y$ .
- Create a new 'Dynamic Particle model' and select 'Cartesian'. Make the 'Start' frame 51 and make the initial position of the car zero in both x and y. Enter your expressions for force in the 'Force Functions' section of the model builder.
- Adjust the initial velocity of the car ( $v_x$ ) until the model and the car are close between frames 51 and 52.
- Adjust the magnitude of the force in your model so that the location where the car stops is the same as where the model stops.
- At what time value does the model stop accurately describing the movement of the car? Why?
- Enter this frame as the 'End' frame at the top of the model builder window. This means the model will not be applied after the frame you selected.
- Play the video one more time to see if the model matches the video to your liking. If it does, select 'Close'.

Some questions to consider:

1. How do the position, velocity, and acceleration graphs compare to the ones you generated by clicking through each frame?
2. Is it appropriate to say that acceleration is constant during the movement of the car? How does the use of the model support your answer?

## The Falling Tissue Ball

We can now analyze a situation in which the force acting on the ball may not be constant. Here is some relevant data:

- The tissue ball in the video has a mass of 1.3 grams.
- The 'Danger' sign in the video has a height of 21 centimeters.

Construct a model using Tracker to simulate the movement of the ball. Draw a free body diagram to determine the forces acting on the object. Input this information into the model builder in the same way we did for the car.

Answer the following questions for next time:

- Is it appropriate to say that acceleration is constant for the ball? Why or why not?
- Suppose you add a force  $(-b \cdot v_y)$  to your force function to simulate air friction. What value of  $b$  results in the best model of the movement of the object?