LAB A4V: TRAJECTORIES ON THE AIR TABLE--PROJECTILE MOTION *9-5-03*

INTRODUCTION

Recall that you used a tilted air track and a sparker to study one-dimensional motion with constant acceleration. In this lab, you will use a tilted air table to study two-dimensional projectile motion. We will refer to the two dimensions involved as "horizontal" and "vertical" even though they aren't literally so. For convenience, in this lab we will also refer to the vertical and horizontal directions as the “y-direction” and the “x-direction,” respectively. Two experiments will be performed on the tilted air table:

1) a “drop,” in which a puck released with no initial speed on the tilted air table will accelerate in one dimension down the table

2) a “launch,” in which the same puck will be initially propelled (by a hand) as a projectile. In this case, the puck will be given both an initial upward vertical velocity ($v_{i,y}$) and an initial horizontal velocity ($v_{i,x}$) on the same tilted air table.

The method of recording data will be different than any we've used before. Digital video clips of the drop and the launch will be prepared in advance. During the lab period, you'll use Videopoint, a video analysis program, to extract data from the clips frame-by-frame. Then you'll export the data to Graphical Analysis for curve fitting.

GOALS

- to determine if the horizontal motion of the launched puck has any effect on its vertical acceleration
- to compare the measured values of the range, height, and time to reach maximum height of the launch with values predicted by the d-v-a-t formulas.

READING: Chapter 4(1-5), Walker. Go to courses.ncssm.edu/physics/video/airtable1.htm and select a "drop" or "launch" to view. Click on the first image frame to play the movie.

PRELAB

In the case of the two-dimensional launch, where acceleration acts in one of the dimensions (the vertical, y), but not in the other (the horizontal, x), the equations for the displacement in the x and y directions are:

$$x = v_{ix}\,t + x_i \qquad \text{and} \qquad y = v_{iy}\,t + \tfrac{1}{2} a_y t^2 + y_i$$

In lab, you will choose your origin at the first good point of the video.
At this point, you will set: x = 0, y= 0, t = 0. This makes x_i and y_i zero, simplifying the above two formulas.
1) In this part, you will derive expressions for each of three “unknowns” in terms of ONLY the given “known” quantities which are v_{ix}, v_{iy}, and a_y.
“Derive” means you are to completely set up this scenario like any other 2-dimensional dvat problem you would solve. Use the appropriate d-v-a-t formula to solve for the desired “unknown”. Use symbols only and show ALL steps of logic and any algebra.

a) Derive the expression $y_{max} = -v_{iy}^2/2a_y$ which represents the maximum value of y (i.e., y_{max}, the maximum vertical height that the puck reaches) during the launch trajectory.

b) Derive the expression for the time it takes the puck to reach maximum height (i.e., t_{top}). Hint: what velocity condition occurs at maximum height?

c) Derive the expression for the horizontal distance (i.e., x_{max}, also called the “range”) that the puck travels from the beginning of the launch until it again returns to $y = 0$.

2) Do the necessary algebra to eliminate the variable t from the original two d-v-a-t equations given above and solve for y as a function of x and the "known" constants ($v_{i,x}$, $v_{i,y}$, and a_y). You will thus be finding the shape of the launch trajectory. [note: this does NOT require using any results from number 1!]

3) What do mathematicians call the shape of the curve represented by the equation in #2?

PROCEDURE

The method used to obtain the actual video clips of the launch and the drop on the air table will be demonstrated. The air table will be tilted with respect to the horizontal by some small angle, so that a puck placed near the upper edge will drift toward the lower edge with a constant acceleration.

IMPORTANT CONSIDERATIONS USED IN FILMING

1) The camera should be positioned relative to the air table in such a way as to minimize perspective distortion.
   - Ideally, all points of the air table should be the same distance from the light-sensing element of the camera. Why is this necessary?
   - Why is the above impossible in practice?
   - How can the camera be positioned to get as close to ideal as possible?
2) Video is normally shot at a **rate of 30 frames per second**. Each frame is composed of two fields, and each of these is exposed to light for 1/60 second. When viewing individual frames of video, as you will be doing in this lab, fast-moving objects will appear blurred if exposed for 1/60 s. Therefore, the clips that you will be using were filmed using a much shorter exposure time, generally 1/1000 s. This, however, doesn't change the number of frames per second. The frames go by at the same rate but each is exposed to light for a shorter time. Note: some video is shot at **15 frames per second**.
3) Suppose that you were using a recording method similar to the one that you used in the air track lab. That is, sparks would be recorded on a sheet of paper showing successive positions of the puck at equal intervals of time. The way you would obtain data from the paper would be to measure distances with a meter stick. Your video clip, on the other hand, will be scaled down from actual size. You can't place a meter stick against the video screen and obtain meaningful measurements. You'll need to **obtain a <u>scaling factor</u>**, that is, the ratio of actual distances to the corresponding screen distances. How might you determine this scaling factor?
4) When you analyze the launch data, you'll need to **establish a <u>coordinate system</u>** in two dimensions. It's important that the y-axis actually correspond to the vertical. One purpose of the drop is to allow you to determine the y-axis and hence, the x-axis. It is essential, therefore, that the camera not be moved between the filming of the launch and the drop. (Note that any camera movement could change the scale factor in addition to the orientation of the vertical relative to a video frame.)

THE LAUNCH

For this run, the puck is started near a bottom corner and launched upwards and also toward the opposite side of the table. The goal is to have the puck launch path cover as much of the table as possible. The puck should hit the bottom or the side of the table near the bottom opposite corner.

THE DROP

For this run, the puck is initially held motionless near the top center of the table. The puck is released in such a way as to minimize any sideways motion.

OVERVIEW OF THE ANALYSIS

During the lab, you'll be given detailed, step-by-step instructions for how to perform the video analysis. For now, here's a summary of how you'll obtain data and then analyze it.

You will …

- … work in two's at a computer. One person will analyze the video clip of the drop, and the other person will analyze the launch.

- … use Videopoint to mark the position of the puck in successive frames of a clip. You'll establish a coordinate system and apply a scale factor to the data, resulting in an electronically-generated table that gives the coordinates of each point as a function of time.

- … paste the data table into Graphical Analysis for Windows and carry out quadratic fits on the x vs. t and y vs. t graphs (one partner will do this for the drop, the other partner for the launch). Pick an **appropriate** scale for the drop x-t graph. Print all four of these graphs.

- … create a graph of y vs. x for the launch and do the appropriate fit. Print this graph large enough so that it will just fill a page of your journal. Using this printed graph and the y vs t graph, make direct measurements of the following launch characteristics (each partner will do this and the following parts of the lab):

  a) maximum vertical height reached during the launch
  b) time required to reach maximum height
  c) the range (horizontal distance) covered by the launched puck

- … calculate values for these same three launch quantities using the d-v-a-t formulas (derived in the Prelab) and the initial and now known conditions ($v_{i,x}$, $v_{i,y}$, and a_y) for the launch.

- … compare the measured and calculated quantities a) –> c). Make a table to organize this. Hint: what does compare mean to do?

- … compare the values obtained for vertical acceleration for the drop and the launch.

- … discuss and summarize your results.

COLLECTING DATA WITH VIDEOPOINT

Take heed! The key to success in this lab is following these instructions!

In the instructions that follow, the questions to answer and the data to record are underlined. Write your responses in your lab book <u>and be sure to label them with the given number and letter of the question.</u> As you answer the questions, make it clear if you are answering for the drop or the launch or, in appropriate cases, both. Also label each section of your book using the same titles as in these instructions, e.g., "Collecting Data with Videopoint".

1. finding the movie data and assigning tasks……….

The movie data is at http://courses.ncssm.edu/physics/video/airtable1.htm
Open a browser window now and access the above page. **DO NOT try to OPEN the clips here!**
Your teacher will assign partners a set of 2 video clips to analyze. These might be labeled, for example, "atdrp3.avi" and "atlnch3.avi". "drp" stands for drop, "lnch" for launch, and 3 for the number of bricks used to prop up the table for the run. Note that both clips in a given set were taken under identical setup conditions. That is, nothing was changed about the airtable or the camera between the launch and the drop. Now do the following to get started with your recording.

a) <u>Record your lab partner's name.</u>
b) <u>Record the letter of your computer. (Look on the front of the monitor.)</u>
c) <u>Record the complete filenames of the 2 clips that you were assigned</u>.
d) <u>Why is it important that neither the table nor the camera moved for the drop and launch clips that you will be analyzing?</u>

Each of you (you and your partner) will analyze one of the video clips. Decide now who will do the drop clip and who will do the launch. If your responsibility is, for example, the drop, that means you have to actually be at the keyboard performing all the necessary procedures to collect data for the drop clip with Videopoint and then plot and fit the data with Graphical Analysis. Of course, the other person is expected to act in an advisory capacity. Once *both* video clips are analyzed, then you and your partner are expected to work together to complete the interpretations.

e) <u>Record which clip will be your responsibility.</u>

Whoever has the responsibility for the drop clip will start at the computer.

2. Getting the movie clip…………

To get a movie clip, ***right click*** on the link, and use **Save Link As**… to save the clip to **your** M: drive.
[You might create a separate directory (called airtable) in which you store all of your A4 related data.]

3. Opening the movie clip in Videopoint…………

Once your movie clip has been saved, open the Videopoint software (click on Start, then mouseover Programs, Videopoint 2.0, Videopoint 2.1). Close the About Videopoint dialog box that comes up. You'll see the introduction screen, which will ask you what you want to do. Click on the **Open Movie** button.

Find the movie clip's location on your M drive and select the movie file to open the movie.

There will be a question asking how many objects you wish to follow on the movie. Select 1 object and click **OK**. The movie will appear in the main program window together with a **Table** window and a **Coordinate System** window.

4. Viewing the movie clip…………….

View the movie by pushing the play button on the left of the bar at the bottom of the movie window (it looks like a play button on a tape recorder). You'll see the puck in a vertical drop on the table. (Remember that the term *vertical* is used even though we know it's not a true vertical line.) The puck should be free of the experimenter's hand in the first frame.

Why shouldn't you use a frame in which the hand was in contact with the puck?

5. Getting started on position data from the movie clip……….

Rewind the movie by dragging the slider at the bottom of the window all the way back to the left. Grab the lower right-hand corner of the movie window with the mouse pointer and drag the window open to about twice its original size. As you move the mouse around, you'll see a pointer on the screen labeled *Point S1*. Center this pointer over the initial position of the puck. The portion of the puck that you use is important. We recommend that you use the *base* of the puck handle rather than the top of the handle. In fact, there's a bright metallic circle at the base of the puck, and the size of this circle is almost the same as *Point S1*. Position *Point S1* within this circle as precisely as possible. Then single-click the left mouse button. When you click, try to hold the mouse as steady as possible. After you've clicked, the movie automatically advances to the next frame.

a) Why wouldn't you want to use the top of the puck handle as the point that you mark for analysis?
b) How does increasing the size of the movie window increase the precision of measurement?

6. Viewing the data table for the clip………..

The coordinates of your first data point should have appeared in the data table. In order to view the table, click on **View** in the main menu bar and then select **Data Table**. This will bring the table to the front. Note that the (x,y) coordinates of the first point are given in pixels relative to the coordinate axis shown on the movie window. Later, you'll learn how to scale these measurements to meters and reposition the coordinate origin. Note also the sequence of times. These are the actual times for sequential frames. If, for example, your clip was taken at 30.0 frames per second, the times would increase in $1/30^{th}$ second intervals.

What is the time interval between frames for your clip?

7. Completing the data table…………

Click once on the Videopoint title bar or on the movie window to bring the movie back into the foreground. You should be on frame 2 of the clip. (This is indicated in the upper right-hand corner together with the total number of frames.) *Point S1* should be visible again. Center it on the puck and click. This will advance you to frame 3. If at any time you need to change the coordinates for a point because you clicked on it wrong, do the following:

a) Use the frame-by-frame buttons below the movie until you are at the frame for which you want to change your data. *Point S1* should be visible on the movie.
b) On the main menu bar at the top of the screen, click **Edit, Clear Selection on Frame**. The coordinates for that frame will be deleted from the data table.
c) Reposition *Point S1* to the center of the puck and click. The new coordinates will be entered in the table.

Continue to click on the center of the puck for all the frames of the movie.

8. Checking your data points…………

When you're done collecting the data points, press Ctrl-T. This will show you a trail of the points that you clicked, each point being indicated by a crosshair. If you want to check any of them, use the frame-by-frame buttons to move to the frame of interest. Then you can see how well your marked points match up with center of the puck. If you need to change any points, use the procedure described in 7a)-c) above.

9. Checking and saving the data table……….

View your data table once again. All of the data should now be entered. IMPORTANT: Videopoint, like all software, sometimes crashes, so it's a very good idea to save your data regularly to your M: drive. Do this now - on the main menu bar, select **File, Save As**. Give the file a unique name and be sure that "VPT (.VPT) files" is showing in the **Save As Type** box. Then click **OK.**

Record the filename in your data book.

10. Scaling the position data…………

Now it's time to scale your data in meters. First, you'll need to find two fixed and identifiable points on the air table between which you can measure a distance in meters. Look at the first frame of the clip and see if you can find two such points. **Pick them as far apart as you can.** Then go to the actual air table provided in the classroom/labroom and measure, in units of meters, the separation of the two points you selected to 3 significant figures.

a) In your lab journal, sketch the air table, indicating the two points that you selected. Then write down the separation that you measured.
b) Why should the two points be as far apart as possible?

Now that you know the actual distance between the two points, you must enter that information into Videopoint so that the coordinates of your data points will be scaled in actual meters. Here's the procedure:

c) Select the movie window by clicking on its title bar. In the main menu bar, click on **Create.** In the Create menu, select **Point**. In the popup box, select **Fixed** instead of **Frame-by-Frame**. Click **OK**. This creates *Point S2* and will define one endpoint of your distance scale. Place the cursor on one of the two fixed points that you identified in step 10. Click to record the coordinates.
d) Repeat step c) for your second fixed point. This will create *Point S3*.
e) Once again, select **Create** but this time click on **Scale**. In the dialogue box, select **Point S2** and then click on **Add**. Repeat for **Point S3**. Then, in the **Length** box, type the actual distance (in meters) between the two points. Then click **OK**.

11. Setting the origin……….

There's one more thing to do before your data is ready for analysis. You must move the origin to a convenient location - in this case, to the location of your first data point. In the **Coordinate Systems** window, there is a row labeled **Origin 1**. Click on this to highlight the row. Now click on the origin (the point labeled origin) in the movie, and hold down the left mouse button. This allows you to move the origin around. Center it as nearly as possible on the crosshairs of your first data point.

Later, you will use your position vs. time data to determine the x- and y- initial velocities and accelerations of the puck. Will it matter if you don't position the origin exactly on this first data point? Explain.

12. Last data check before analysis…………….

Now your data table should have meaningful numbers. Look at the **Table** window to check this. Consider these questions:

a) What pattern do you expect the x-coordinates to follow ?
b) What sign do you expect the y-coordinates to have? Do the values of the coordinates make sense?
c) Does the total time of fall (or launch) make sense?

13. Save your final data………….

If you're satisfied with your results, it's time to save your data file once again. In the main menu, select **File, Save**. You won't have to give a filename this time, since you selected one before.

14. Delete the movie clip……………

At this point, you should no longer need the movie clip (a *.avi file) that you saved in your M: directory at the start. We suggest that you delete it now, since it takes up much disk space.

TRANSFERRING THE DATA TO GRAPHICAL ANALYSIS

Although Videopoint has analysis options, Graphical Analysis for Windows is much better for this. Here's the quickest way to transfer your data.

1. While still in Videopoint, go to the **Table** window. Click at the top of one of your three data columns (time, x-pos, y-pos) under the S1 heading, then press the CTRL key on your keyboard, then click at the top of the other two data columns while holding the CTRL key down. All three of the data columns should now be highlighted in black. Now release the mouse button and CTRL key and move the cursor to **Edit** on the main menu. Click on **Edit** followed by **Copy Data**. This copies your data to the Windows clipboard.

2. Minimize the Videopoint window by clicking on the minimize button in the upper right corner. Then open Graphical Analysis by going to the Start button on your computer's menu bar, then choosing Graphical Analysis .

3. After Graphical Analysis loads, change the names of the two columns in the Graphical Analysis data table to **Time** and **x** and give them correct units and significant figures. Then, on the main menu bar, select **Data, New Column, Manually-entered**. In the dialogue box that appears, type **y** for the name and enter the units and significant figures.

4. Click on the title of the table: **Data Set 1**. On the main menu, select **Edit, Paste Data**. All your data from Videopoint should appear. Before working with the data, you should save it as a .dat file in your M: directory. On the main menu bar, select **File, Save As**. In the **Filename:** box, type the same name that you used for your Videopoint file with this exception: leave off the .vpt extension. Click **OK**. Graphical Analysis will automatically add the extension .dat to your filename. You can check this by looking at the title bar at the top of the screen. It should read: **Graphical Analysis ["c:\data\filename.dat"]**. Of course, *filename* will be the name that you gave to the file.

   a) <u>Record the name of your .dat file.</u>
   b) <u>Save the file to your M drive.</u>

THE SWITCH

Now it's time for you to switch roles with your partner for the analysis of the launch clip. Bring Videopoint back up on the screen and close all the windows. On the main menu bar, select **File, New Startup**. Then open the launch clip. The procedure from here is almost identical to that described above. The only differences will be the names of your Videopoint and Graphical Analysis files. OK, there's one more: You don't have to answer for a second time those questions that obviously have the same answer as for the drop clip. If there are any other differences, we'd like to hear about them.

SAVING YOUR .DAT FILES

In the event that you don't complete all the analysis in class, you should save your .dat files to your M: drive. Do not save your data to the computer's hard drive – the drives are wiped clean regularly, and we can not guarantee that your files will remain on the computer for later use. If you are using a diskette, and your disk is infected with a virus, the computer will make a chirping sound and your screen may go blank. This means that the computer has detected a virus. If this happens, let your instructor know immediately.

FITTING THE DATA

You now have complete data for both video clips. It's time to do the curve-fitting with Graphical Analysis. Since you've already received instruction in using this program, the details of what menu items to select to carry out particular operations will be left out. If you have questions, refer to the Graphical Analysis handout that was distributed previously in class. One note of caution: Make sure all variables are labeled appropriately and units given. You should also change the name of the data table from **Data Set 1: Data** to something more appropriate for this lab. Just double click on the title and change it.

Do the following for the clip for which you have responsibility:

1. Perform quadratic fits on both the x vs. t data and the y vs. t data.

2. Type the following things in the text box on the screen. Type them in the given order.

   a) name of the person who did this analysis
   b) name of the other person
   c) name of the file (that way, it will be included on the final printout)

3. Save the final version of the file on to **both** partners' M: drives

4. Obtain printouts of the data tables, text boxes and all graphs with fits. Size them so that they'll fit neatly in your lab book with no folding. Make sure that the results of the fits show on the printed graphs. Print the y vs. t graph for the launch as large as you can, because you'll need to take direct measurements from it.

5. You'll need one more graph, a graph of y vs. x for the launch. This gives the launch trajectory of the puck. Print this graph as large as you can, because you'll need to take direct measurements from it.

DIRECT MEASUREMENTS OF LAUNCH CHARACTERISTICS

Each person should do the following independently on their own copies of the printed graphs. Afterwards, partners can compare their results.

1. Carefully measure and record the following two quantities directly from the launch trajectory (graph of y vs. x). Use a ruler (or two) to help in obtaining the most precise measurements that you can. Draw lines on the graph so that it's obvious what you measured. Record positions and distances to the nearest 0.001 m and time to the nearest 0.001 s. Record values both on the graph and in your lab book.

   a) maximum vertical height reached during the launch
   b) the range (horizontal distance) covered by the launched puck

2. On your graph of y vs. t for the launch, use the above procedure to measure the

   c)time required to reach maximum height

ACCELERATIONS AND PREDICTED LAUNCH CHARACTERISTICS

Just a reminder, you should be working with your partner in completing the lab. Discuss the physics with each other, but compose your own answers. The remainder of your work goes in your lab book.

1. Look at your y vs. t fit for the drop. As you did for the air track lab, construct a matching table for the graph on the page opposite where the graph is to be placed in your lab book. Refer to the instructions for this table [math equation of the fit, the physics equation that it represents, and the appropriate list of math variables, physics variables, and numerical values (with units) of the fit variables] are in the green sheets pasted into your lab book.

2. From your equation of fit (the physics version), determine the value of a_y, the acceleration of the drop.

3. Look at your fits for x vs. t for the drop, and for x vs. t and y vs. t for the launch. Again write out a matching table in your lab book on the page opposite the appropriate graph. Then use the fit variables to determine the values of $v_{i,x}$, $v_{i,y}$, a_x and a_y.

4. Use the coefficients obtained in step 3, together with the formulas derived in the Prelab, to calculate values for the maximum height reached, the time to reach maximum height and the range. Show all your work, express units throughout and give answers to the proper number of significant figures.

ANALYSIS

1. Compare the vertical accelerations for the drop and the launch. ["Compare" from now on in Physics Lab means "write the two values down side-by-side and find the % difference between them."] Should the two different values of a_y be identical? Why or why not?

2. Examine your x vs. t graphs for both the drop and the launch. Are there significant horizontal accelerations ? Should there be? For the launch, how does the magnitude of the horizontal acceleration compare to the vertical acceleration ?

3. In a table, list and compare the directly measured values of the maximum height reached, time to maximum height, and the horizontal range along with the values calculated from the d-v-a-t formulas (using the graphically determined values of $v_{i,x}$, $v_{i,y}$, and a_y).

SUMMARY

Bring together everything that you've learned in this lab. Using good English composition (namely, readable sentences, paragraphs, correct spelling and grammar), describe the following:

- how the data were obtained
- how you fit the data & why you fit the data the way you did
- what results you expected & what results you obtained