Ball Toss

When a juggler tosses a ball straight upward, the ball slows down until it reaches the top of its path. The ball then speeds up on its way back down. A graph of its velocity *vs.* time would show these changes. Is there a mathematical pattern to the changes in velocity? What is the accompanying pattern to the position *vs.* time graph? What would the acceleration *vs.* time graph look like?

In this experiment, you will use a Motion Detector to collect position, velocity, and acceleration data for a ball thrown straight upward. Analysis of the graphs of this motion will answer the questions asked above.

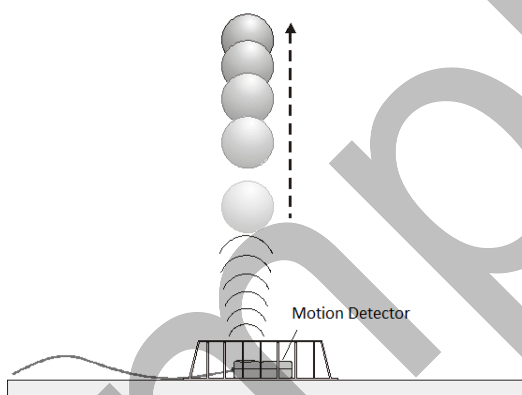


Figure 1

OBJECTIVES

- Collect position, velocity, and acceleration data as a ball travels straight up and down.
- Analyze position *vs.* time, velocity *vs.* time, and acceleration *vs.* time graphs.
- Determine the best-fit equations for the position *vs.* time and velocity *vs.* time graphs.
- Determine the mean acceleration from the acceleration *vs.* time graph.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Motion Detector
volleyball **or** basketball
wire basket

PRELIMINARY QUESTIONS

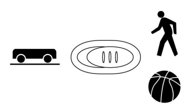
1. Consider the motion of a ball as it travels straight up and down in freefall. Sketch your prediction for the position *vs.* time graph. Describe in words what this graph means.

2. Sketch your prediction for the velocity *vs.* time graph. Describe in words what this graph means.

3. Sketch your prediction for the acceleration *vs.* time graph. Describe in words what this graph means.

PROCEDURE

1. Connect the Vernier Motion Detector to a digital (DIG) port of the interface. Set the Motion Detector sensitivity switch to Ball/Walk.



2. Place the Motion Detector on the floor and protect it by placing a wire basket over it.

3. Open the file "06 Ball Toss" from the *Physics with Vernier* folder.

4. Collect data. During data collection you will toss the ball straight upward above the Motion Detector and let it fall back toward the Motion Detector. It may require some practice to collect clean data. To achieve the best results, keep in mind the following tips:

   - Hold the ball approximately 0.5 m directly above the Motion Detector when you start data collection.
   - A toss so the ball moves from 0.5 m to 1.0 m above the detector works well.
   - After the toss, catch the ball at a height of 0.5 m above the detector and hold it still until data collection is complete.
   - Use two hands and pull your hands away from the ball after it starts moving so they are not picked up by the Motion Detector.

   When you are ready to collect data, click ▶ Collect to start data collection and then toss the ball as you have practiced.

5. Examine the position *vs.* time graph. Repeat Step 4 if your position *vs.* time graph does not show an area of smoothly changing position. Check with your instructor if you are not sure whether you need to repeat the data collection.

DATA TABLE

Curve fit parameters	A	B	C
Distance ($Ax^2 + Bx + C$)			
Velocity ($Ax + B$)			
Average acceleration			

ANALYSIS

1. Print or sketch the three motion graphs. The graphs you have recorded are fairly complex and it is important to identify different regions of each graph. Click Examine, , and move the mouse across any graph to answer the following questions. Record your answers directly on the printed or sketched graphs.
   a. Identify the region when the ball was being tossed but still in your hands:
      - Examine the velocity *vs.* time graph and identify this region. Label this on the graph.
      - Examine the acceleration *vs.* time graph and identify the same region. Label the graph.

   b. Identify the region where the ball is in free fall:
      - Label the region on each graph where the ball was in free fall and moving upward.
      - Label the region on each graph where the ball was in free fall and moving downward.

   c. Determine the position, velocity, and acceleration at specific points.
      - On the velocity *vs.* time graph, decide where the ball had its maximum velocity, just as the ball was released. Mark the spot and record the value on the graph.
      - On the position *vs.* time graph, locate the maximum height of the ball during free fall. Mark the spot and record the value on the graph.
      - What was the velocity of the ball at the top of its motion?
      - What was the acceleration of the ball at the top of its motion?

2. The motion of an object in free fall is modeled by $y = ½\, gt^2 + v_0t + y_0$ where y is the vertical position, g is the magnitude of the free-fall acceleration, t is time, and v_0 is the initial velocity. This is a quadratic equation whose graph is a parabola. Your graph of position *vs.* time should be parabolic. To fit a quadratic equation to your data, click and drag the mouse across the portion of the position *vs.* time graph that is parabolic, highlighting the free-fall portion.

   Click Curve Fit, , select Quadratic fit from the list of models and click Try Fit. Examine the fit of the curve to your data and click OK to return to the main graph.

3. How closely does the coefficient of the t^2 term in the curve fit compare to ½ g?

4. What does a linear segment of a velocity *vs.* time graph indicate? What is the significance of the slope of that linear segment?

5. The graph of velocity *vs.* time should be linear. To fit a line to this data, click and drag the mouse across the free-fall region of the motion. Click Linear Fit, .

6. How closely does the coefficient of the *t* term in the fit compare to the accepted value for *g*?

7. The graph of acceleration *vs.* time should appear to be more or less constant. Click and drag the mouse across the free-fall section of the motion and click Statistics, .

8. How closely does the mean acceleration compare to the values of *g* found in Steps 3 and 6?

9. List some reasons why your values for the ball's acceleration may be different from the accepted value for *g*.

EXTENSIONS

1. Determine the consistency of your acceleration values and compare your measurement of *g* to the accepted value of *g*. Do this by repeating the ball toss experiment five more times. Each time, fit a straight line to the free-fall portion of the velocity graph and record the slope of that line. Average your six slopes to find a final value for your measurement of *g*. Does the variation in your six measurements explain any discrepancy between your average value and the accepted value of *g*?

2. The ball used in this lab is large enough and light enough that a buoyant force and air resistance may affect the acceleration. Perform the same curve fitting and statistical analysis techniques, but this time analyze each half of the motion separately. How do the fitted curves for the upward motion compare to the downward motion? Explain any differences.

3. Perform the same lab using a beach ball or other very light, large ball. See the questions in Analysis Question 1.

4. Use a smaller, more dense ball where buoyant force and air resistance will not be a factor. Compare the results to your results with the larger, less dense ball.

5. Instead of throwing a ball upward, drop a ball and have it bounce on the ground. (Position the Motion Detector above the ball.) Predict what the three graphs will look like, then analyze the resulting graphs using the same techniques as this lab.

6. Repeat your quadratic and linear curve fits to the position graphs but use the time offset option in the general curve fit dialog. Interpret the constant and linear terms of the quadratic fit. What do they signify? What are the units of each term?

7. Repeat the linear fit to the velocity graph but use the general Curve Fit, . In that dialog, choose the linear fit and enable the time offset option. Interpret the y-intercept of the linear fit. What does it signify? What are its units?

Ball Toss

See *Appendix A* for information about the word-processing files of the student experiments, as well as any other electronic resources available for this book.

RELATED SKILLS

- Select and zoom in on data
- View different graphs
- Add curve fits to data
- Use the Statistics tool to calculate statistics

ESTIMATED TIME

We estimate that data collection and analysis for this experiment can be completed in one 45-minute class period.

EQUIPMENT TIPS

1. Collecting data for a ball toss requires practice. The following tips can help students obtain a uniform parabola:
   - A small toss where the ball only rises 0.5 m above the hands works well. If the ball is tossed too high, it may not be detected by the Motion Detector. It is also hard to make a toss that is both high and straight above the detector.
   - If the students use two hands, one on either side of the ball, they can toss it up gently and reliably, then clear their hands out with minimum interference to the actual data collection.
   - If data are not uniform and are interrupted by small values, it is likely that the student's hands got in the way. If the data are interrupted by large values, it is likely that the ball got tossed off-center and moved out of the Motion Detector's detection cone.

   If you would like additional tips, watch the Ball Toss video, available in the Sample Movies Folder in Logger *Pro*.

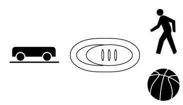
2. The wire basket included in the materials list is used to protect the Motion Detector during data collection and it does not affect the data that are collected. Wire baskets, such as an "in box" available at an office supply store, work well.

3. A volleyball or basketball works well in this experiment. Since these are rather large, a buoyant force and air resistance will affect the acceleration. The students will probably not get 9.8 m/s^2, but the shapes of the curves will be correct. Smaller objects that yield better g

values are difficult to use because they do not reflect the ultrasound well. Do not use a light ball such as a beach ball, since air resistance is too large compared to the gravitational force. The analysis of the motion of a beach ball is suggested as an extension.

4. Using a beach ball (Extension 3) will yield more air resistance and buoyant force effects, while using a baseball or dense rubber ball (Extension 4) will do the opposite. Careful analysis may show some small differences between the dense balls and the others. Over a short distance and with the velocities relatively low, air resistance does not become a major factor, except for the beach ball.

5. Tips for obtaining useful data with a Motion Detector.
   - Motion Detectors *with* a sensitivity switch (shown below) will detect objects as close as 0.15 m. Ideally, an experiment is set up so that the target is nearly this close at the point of closest approach, giving the best possible data. **Note**: Motion Detectors *without* a sensitivity switch do not properly detect objects closer than 0.45 m. As a result, such Motion Detectors must be farther away from the experiment than described in the student notes.

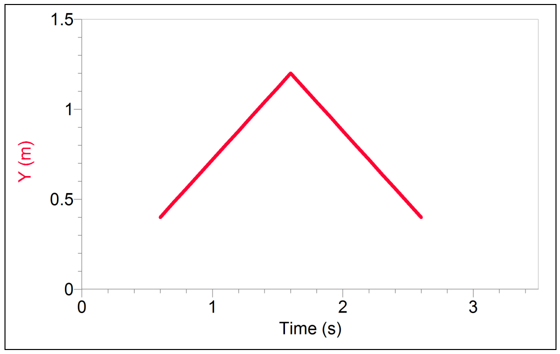


   - Ultrasound is emitted from the Motion Detector in a cone about 15° off the axis (30° wide); this includes downward. Anything within the ultrasound cone can cause a reflection and possibly an accidental measurement. A common problem is getting unintentional reflections from a desk, chair, or computer. Unintended reflections can be minimized by tilting the Motion Detector slightly. When collecting data on an incline or ramp, it is usually best to point the Motion Detector slightly upward.
   - The maximum range for all Motion Detectors is about 6 m. Stray objects in the detection cone can be problematic at this distance and therefore, typical maximum practical range is 2 m.
   - If the velocity and acceleration graphs are noisy, try to increase the strength of the ultrasonic reflection from the target by increasing the target's area and ensuring the target creates a strong reflection of the ultrasound. Try having your students hold a large book out in front of them as they walk in front of the Motion Detector.
   - If you begin with a velocity or acceleration graph and obtain a confusing display, switch back to the position graph for troubleshooting.

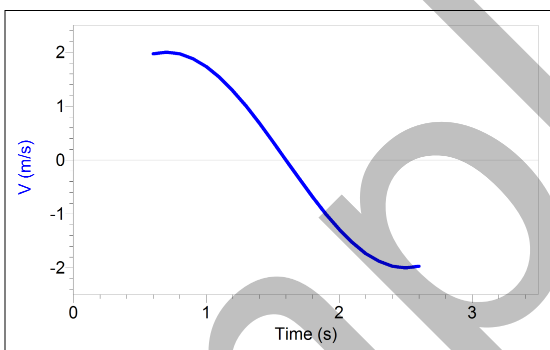
ANSWERS TO PRELIMINARY QUESTIONS

Answers to the Preliminary Questions will vary. There is no wrong answer if graphs are explained and justified. Sample student responses are provided below.

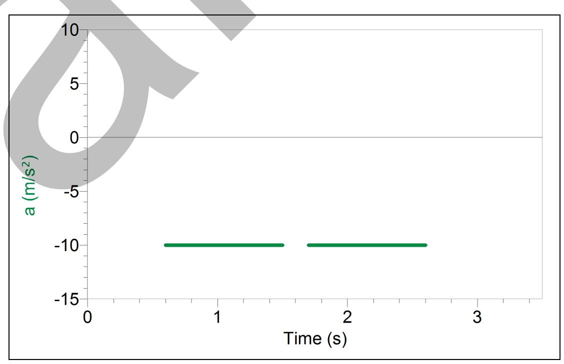
1. "The ball goes up and comes down, getting farther from the floor and then nearer. I assumed a coordinate system where up is positive."



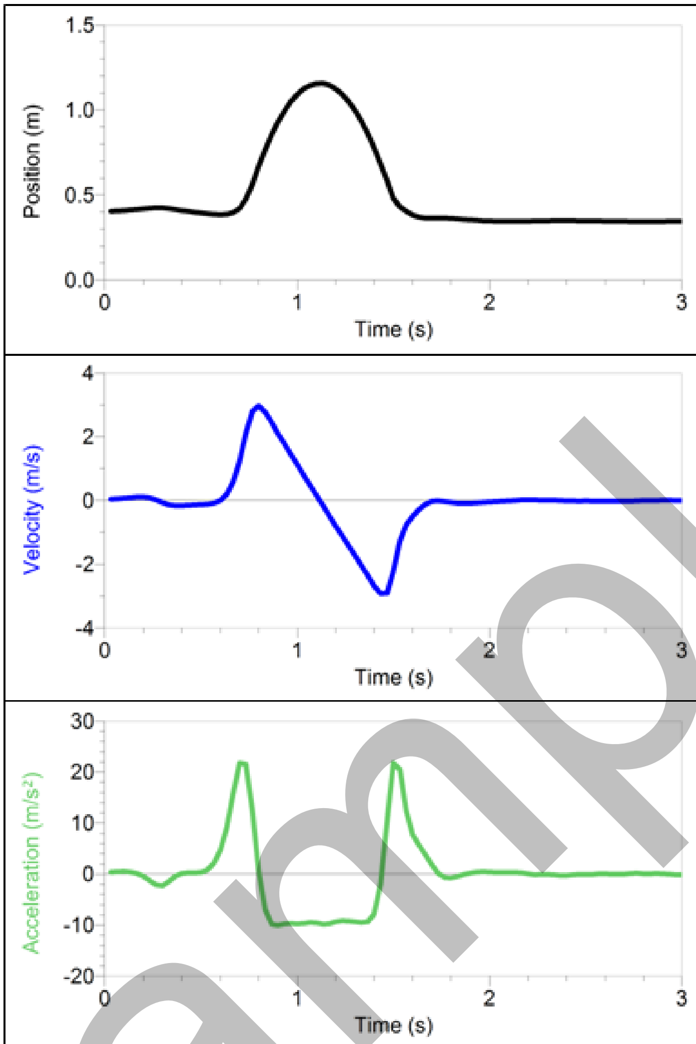
2. "The ball is first moving in the positive direction, then in the negative direction as it falls. The velocity will be initially positive, then negative."



3. "The ball is slowing down on the way up—that means the acceleration is against the motion, or in the negative direction. On the way down, the ball is speeding up with negative velocity, so the acceleration must still be negative. I'm not sure if the values are the same for up and down, let's experiment."



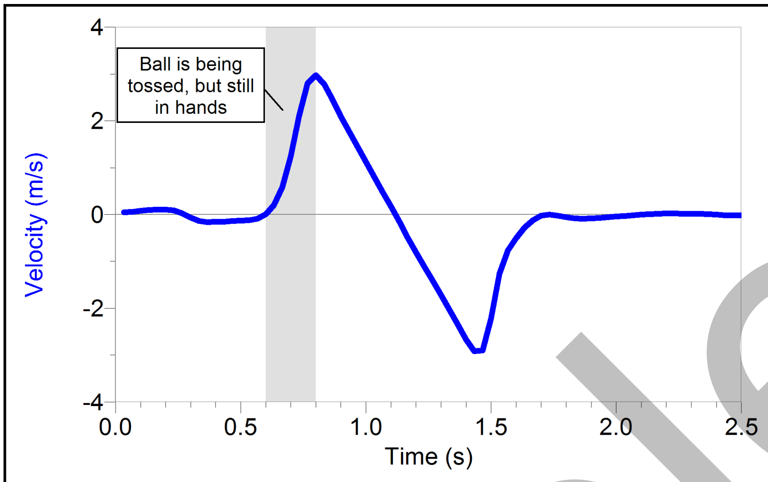
SAMPLE RESULTS



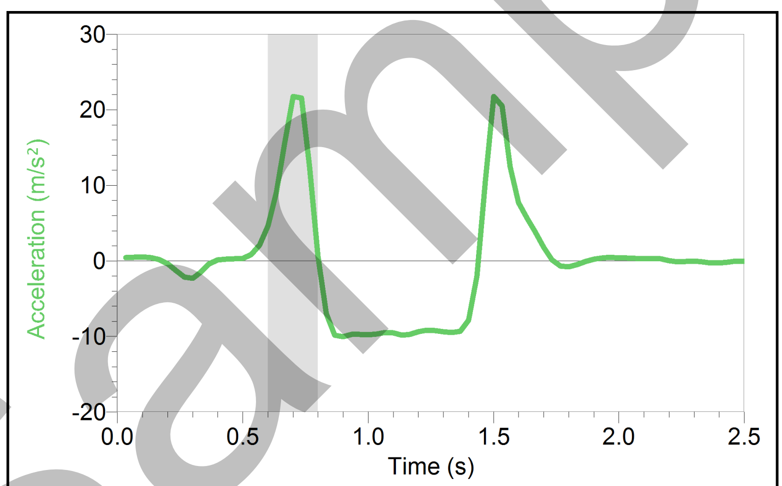
Position, velocity, and acceleration of tossed ball

ANSWERS TO ANALYSIS QUESTIONS

1. (a)

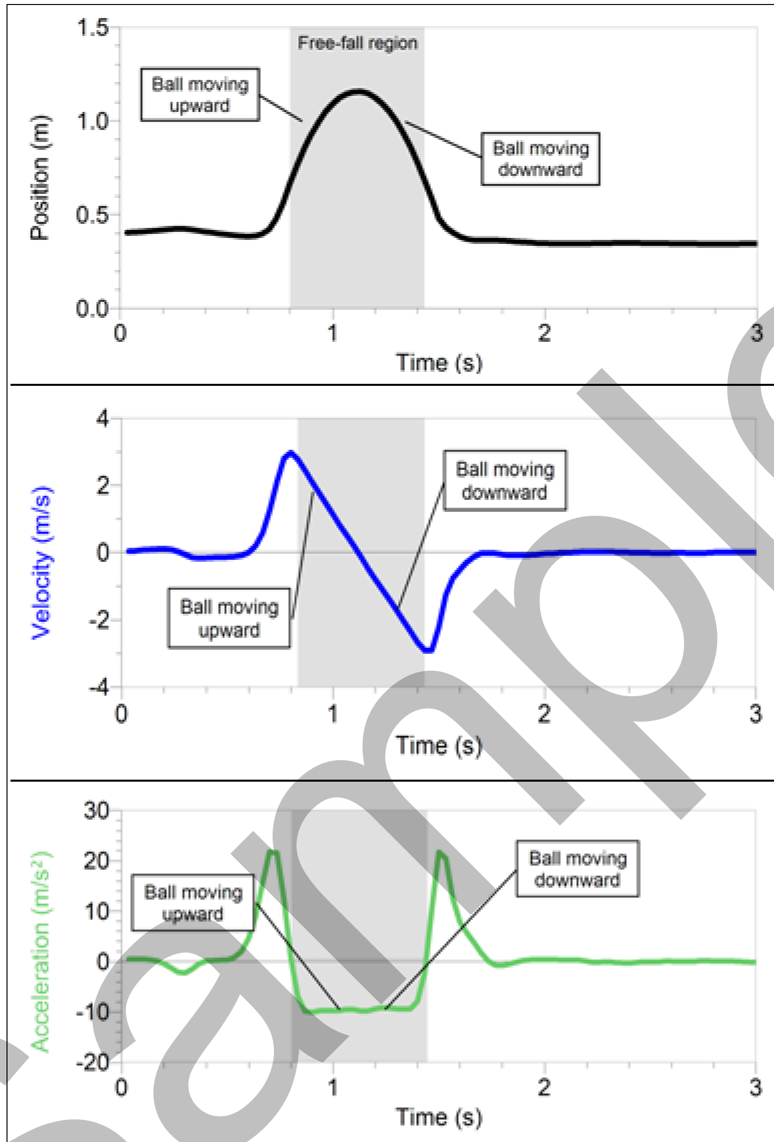


Graph of velocity vs. *time. Notice the positive velocity as the ball is being tossed upward.*



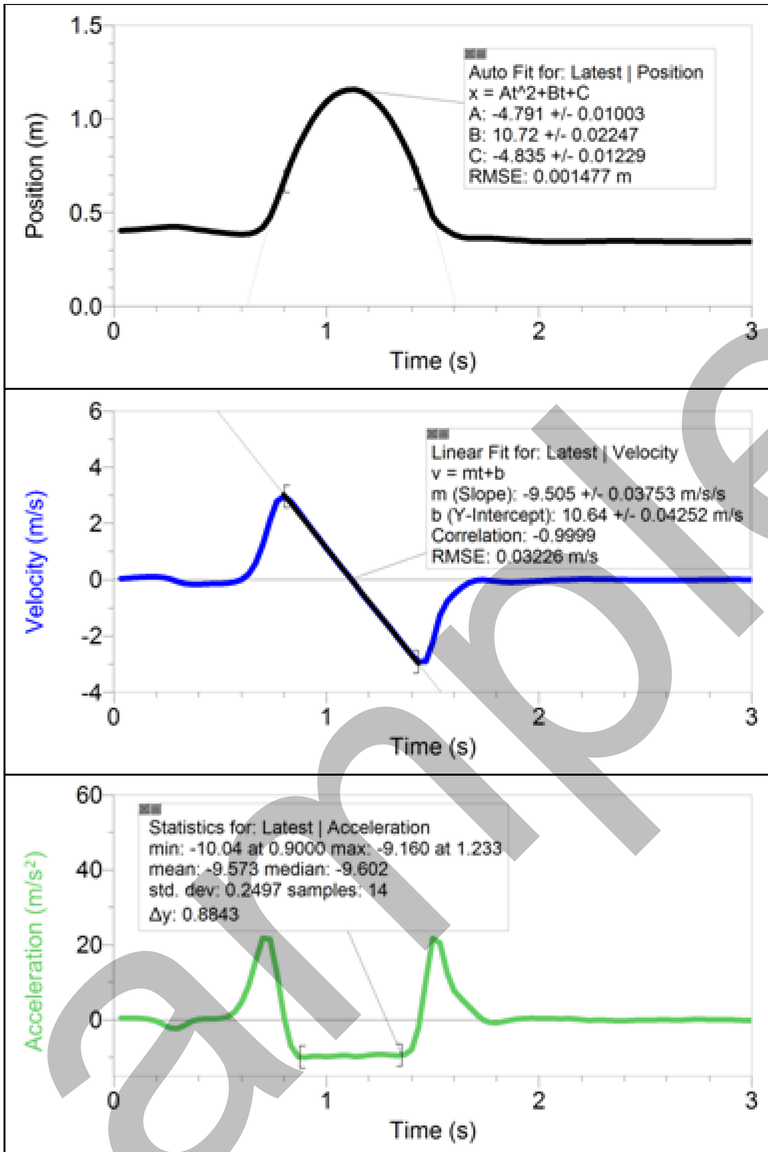
Graph of acceleration vs. *time. Notice that the region does not exactly match the velocity graph, because the derivative is being determined over a finite number of points.*

1. (b) Identifying the free-fall region on the position *vs.* time graph is difficult. It is easier to see the free fall on the velocity *vs.* time graph.



1. (c) In this example, the maximum velocity was 2.9 m/s.
   - The maximum height was 1.2 m.
   - The velocity at the top was 0 m/s.

- The acceleration at the top was –9.6 m/s^2.



Motion graphs with fitted curves and statistics

3. In this example, the coefficient of the t^2 (time) term is –4.79. For free fall without air resistance, ½ g should be –4.90.

4. The acceleration is constant during that segment. The slope is the value for the constant acceleration.

6. When a straight line is fit to the velocity graph, the slope of the line is –9.51 m/s^2, compared to the acceleration due to gravity of –9.80 m/s^2.

8. The mean acceleration from the acceleration graph is $-9.57\ m/s^2$, compared to the acceleration due to gravity of $-9.80\ m/s^2$.

9. The acceleration of the ball was consistently smaller than the accepted acceleration due to gravity. This is largely due to air resistance and the buoyancy of the surrounding air.