Bungee Jump Accelerations

In this experiment, you will investigate the accelerations that occur during a bungee jump. The graph below records the acceleration *vs*. time for an actual bungee jump, where the jumper jumped straight upward, then fell vertically downward. The positive direction on the graph is upward.

For about the first 2 seconds, the jumper stands on the platform in preparation for the jump. At this point the acceleration is 0 m/s^2. In the next short period of time, the jumper dips downward then pushes upward, both accelerations showing up on the graph. Between about 2.5 seconds and 4.5 seconds, the jumper is freely falling and the acceleration is near – 9.8 m/s^2.

When all of the slack is out of the bungee cord, the acceleration begins to change. As the bungee cord stretches, it exerts an upward force on the jumper. Eventually the acceleration is upward although the jumper is still falling. A maximum positive acceleration corresponds to the bungee cord being extended to its maximum. One should be sufficient since, unlike an actual bungee jump, you will be able to control the rotation of your jumper.

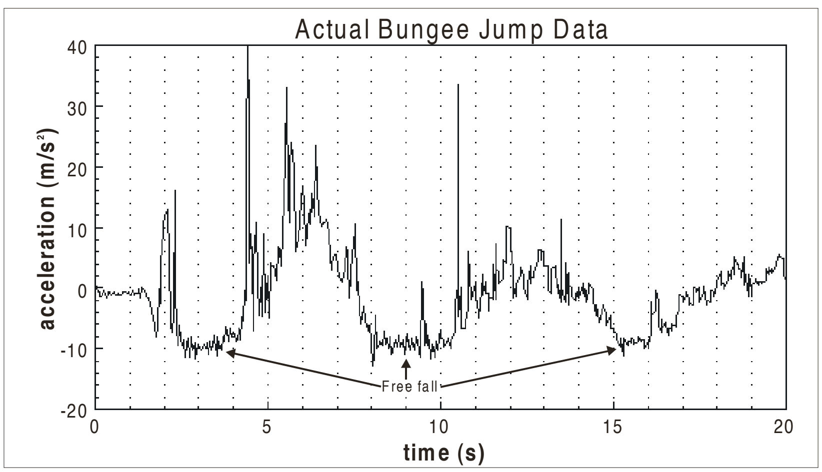


Figure 1

In your experiment, a block of wood or a toy doll will substitute for the jumper, and a rubber band will substitute for the bungee cord. An Accelerometer connected to the "jumper" will be used to monitor the accelerations.

OBJECTIVES

- Use an Accelerometer to analyze the motion of a bungee jumper from just prior to the jump through a few oscillations after the jump.
- Determine where in the motion the acceleration is at a maximum and at a minimum.
- Compare the laboratory jump with an actual bungee jump.

MATERIALS

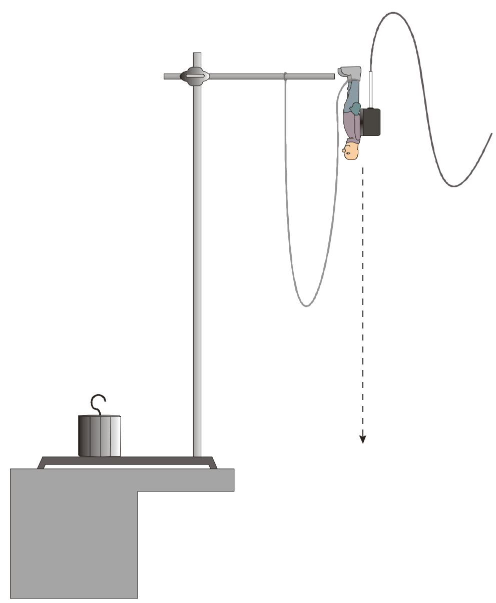
LabPro or CBL 2 interface
TI Graphing Calculator
DataMate program
Vernier Low-g Accelerometer
bungee jumper (wooden block or small doll)
bungee cord (long, flexible rubber band)
ring stand

PRELIMINARY QUESTIONS

1. Consider the forces acting on the bungee jumper at the lowest point of the jump. Draw a free-body diagram indicating the forces acting on the jumper. Longer arrows should represent the force vectors with greater magnitude. Label the force vectors.
2. Study the graph of the acceleration during an actual bungee jump (Figure 1). On the graph, label the time corresponding to the lowest position during the jump.
3. What was the acceleration at that point? Was the direction of the acceleration up or down?
4. Label the time where the jumper reached the highest position during the first bounce.
5. What was the magnitude of the acceleration at that time? Was the direction of the acceleration up or down?
6. How long was the bungee cord used in the real bungee jump? Hint: Consider the time the jumper fell before the cord started to apply a force.

PROCEDURE

Part I The Jump–Step by Step



1. Connect the Vernier Low-g Accelerometer to Channel 1 of the LabPro or CBL 2 unit. Use the link cable to connect the TI Graphing Calculator to the interface. Firmly press in the cable ends. Attach a block of wood or small doll (your jumper) to the Accelerometer. The arrow on the Accelerometer should be pointing upward (toward the hook if using a block, or toward the feet of the doll).
2. Tie the rubber band to the hook on the wooden block or to the feet of the doll. Tie the other end of the rubber band to a rigid support, such as a large ring stand. Adjust the length of the cord so that the block or doll does not hit the floor when dropped.
3. Turn on the calculator and start the DATAMATE program. Press CLEAR to reset the program.
4. If CH 1 displays the Accelerometer and its current reading, skip the remainder of this step. Set up DATAMATE for the sensors manually. To do this,
   a. Select SETUP from the main screen.
   b. Press ENTER to select CH1.
   c. Choose ACCELEROMETER from the SELECT SENSOR list.
   d. Choose LOW G ACCEL from the ACCELEROMETER list.
   e. Select OK to return to the main screen.

5. The Accelerometer must be zeroed so that it reads, only for the vertical direction, zero acceleration when at rest and – 9.8 m/s^2 when in free fall. You will verify this later in Step 8.
   a. Select SETUP from the main screen.
   b. Rest the bungee jumper stationary on the table, with the Accelerometer arrow pointing directly upward.
   c. Select ZERO from the MAIN MENU.
   d. Select CH 1 from the SELECT CHANNEL screen.
   e. When the accelerometer reading is stable, press ENTER.

6. Make sure your jumper is oriented properly (arrow pointed up). Select START to begin collecting data. Hold the jumper motionless for one second, and then release it. Catch the jumper while the cord is still slack.

7. When data collection has finished, your graph will be displayed. Trace across the graph with the cursor keys. For the first second or so, the acceleration should be near zero, since you zeroed the sensor in Step 5. This value represents the acceleration of the jumper prior to jumping.

8. Trace farther to the right on your graph and read the acceleration during the fall. It should be close to –9.8 m/s^2. Ignore any data collected after you caught the jumper.

9. Now collect some data corresponding to the bounces after the free fall portion of the jump.
   a. Let the jumper hang from the bungee cord.
   b. Press ENTER to return to the main screen.
   c. Pull the jumper down 5 cm and hold it stationary.
   d. Select START to begin data collection.
   e. Wait about one second, and then release the jumper, creating an up-and-down oscillation similar to a mass suspended from a spring.
   f. After data collection has finished, your graph is displayed. Determine the point in the motion where acceleration is both positive in direction and has a maximum magnitude. Does this occur when the jumper is at the bottom, middle, or top of the oscillation?

Part II A Complete Jump

10. Lift the bungee jumper to the height of the ring stand, as shown in Figure 2. The bungee cord should be hanging to the side and the Accelerometer cable should be clear of the jump path. Make sure that the Accelerometer arrow is pointing upward. The connection point between the bungee cord and the jumper should also be pointing upward, so that the jumper does not turn over during the jump.
    a. Press ENTER to return to the main screen.
    b. Select START to begin collecting data.
    c. Wait 1 second and release the bungee jumper so that it falls straight down with a minimum of rotation. Let the jumper bounce a few times. Be sure that the Accelerometer cable still has some slack when the jumper reaches the lowest point.

11. Repeat the measurement until you have a satisfactory set of data. A successful run should include a minimum of rotation, a section of free fall before the cord starts to pull on the jumper, and a few bounces, with at least the first bounce high enough to cause the cord to again go slack. The acceleration *vs.* time graph for the laboratory jump should show features similar to the graph of the real bungee jump. Print or sketch your final graph.

DATA TABLE

Time (s)	Acceleration (m/s^2)	Direction of motion (up, down, or rest)

ANALYSIS

1. Trace across your acceleration *vs*. time graph using the cursor keys. Determine the acceleration at eight different points on the graph, choosing points during the initial rest, free fall, when the cord is taut, and several bounces. Record the values in your Data Table. Indicate the direction of the motion using *up, down*, or *at rest*.
2. Perform the same analysis on your bungee jump as was done on the real bungee jump in the Preliminary Questions section.
3. How well does the laboratory jump compare with the real jump? Discuss the similarities and differences.
4. How could you improve the correlation between the lab jump and the real jump?

EXTENSIONS

1. Place a Motion Detector on the floor during a jump. Examine the Motion Detector data (distance *vs*. time and velocity *vs*. time graphs) of the jump. How do these data compare to the Accelerometer data? Which sensor do you think is a better tool for the analysis of the jump? Explain.
2. If a video camera is available, videotape the laboratory bungee jump or a real bungee jump. View the videotape and match the Accelerometer graph with the video of the jump.
3. 3. Repeat the experiment with a jumper of different mass. What are the similarities and differences between the two sets of data? Discuss some methods that might be used by operators of commercial bungee jumps to assure the safety of jumpers of different weights.
4. Connect the bungee cord to a Force Sensor to examine the cord tension during the jump.
5. Use reference books or the Internet to learn the accelerations experienced by the Shuttle astronauts during takeoff and re-entry. How do the accelerations experienced by the astronauts compare to the maximum acceleration experienced by a bungee jumper?

TEACHER INFORMATION

Bungee Jump Accelerations

1. The rubber bungee cord should be very flexible. When the bungee jumper reaches the bottom of the jump, the rubber band should still have some stretch left. You can create a long bungee cord by connecting a number of smaller rubber bands. The rubber band from a paddle-ball toy works very well. A paddle-ball rubber band, with an unstretched length of 1 m, was used for the sample data.

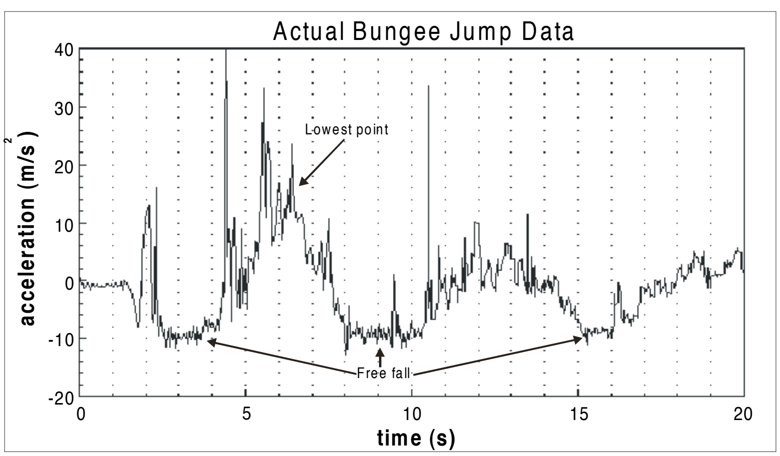
2. A mass of 100 g was used for the sample data. The bungee cord was a sample of name-tag elastic. It stretched to a maximum of about 1.5 m.

3. Some students may try to analyze the acceleration graph as if it were a record of position. This lab will be a challenge to a student with a limited concept of acceleration. Remember that acceleration is proportional to the net force on the jumper, and that the total force is largest and upward when the bungee cord is stretched to the maximum extent.

4. Use a sturdy ring stand that does not move or bend.

5. The bungee jump data displayed in this experiment was taken in July 1997 by Marvin Giesting (Connersville High School, Connersville, IN), a physics teacher attending Project PHYSLab in Portland, Oregon. Marvin had our Three-Axis Accelerometer (3D-DIN) in a CBL case. This is equivalent to three Low-g Accelerometers mounted at right angles, in one package. The CBL case was in a backpack worn during the jump. For this real jump, we calculated and graphed the magnitude of the vector sum of the three accelerations. In the laboratory jump, the orientation of the jumper can be controlled and the Three-Axis Accelerometer is not needed.

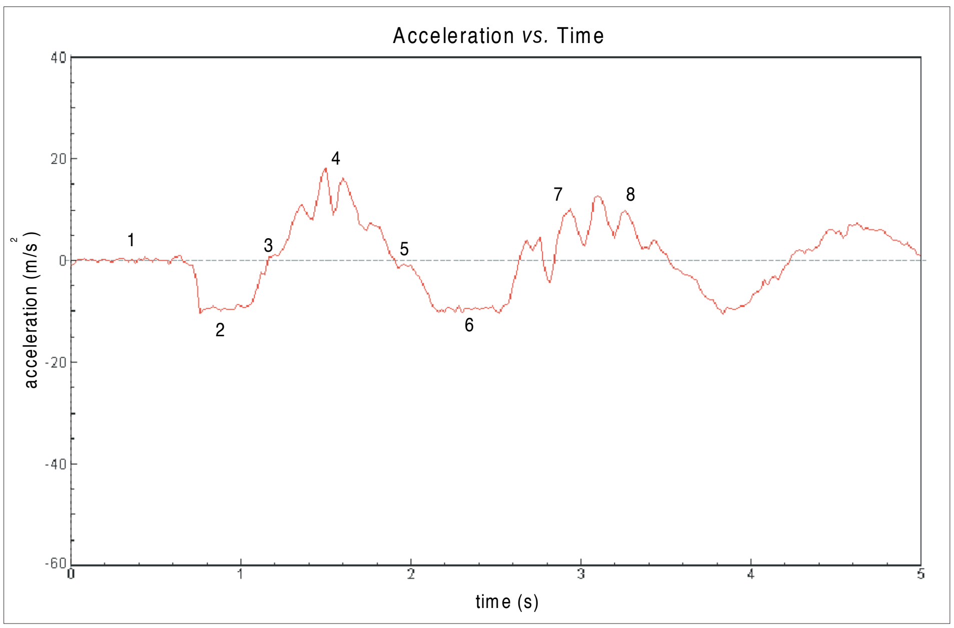
6. If a larger mass is desired to approximate an actual bungee jump, a 5-lb sack of rice, sugar, flour, or beans could be used. Tape the Accelerometer to the side of the "jumper." For a bungee cord, 1/4″ and 3/8″ bungee cord is available from most hardware stores. A very sturdy hook must be used in this case.



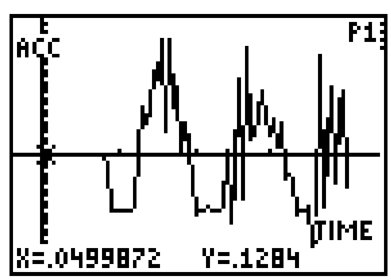
This jump was made by Marvin Giesting (July 1997, Portland, Oregon)

SAMPLE RESULTS

Time (s)	Acceleration (m/s²)	Direction of motion (up, down, rest)
0.50	0.0	rest
0.92	–9.6	down
1.16	0.6	down
1.50	18.0	rest
1.90	0.4	up
2.36	–9.6	rest
2.90	8.9	down
3.26	9.8	up



In this TI-83 screen the free-fall region can be seen as a constant-acceleration region. The graph above of another jump was produced with Graphical Analysis.



ANSWERS TO PRELIMINARY QUESTIONS

1. There is a downward force on the jumper equal to his or her weight and a larger upward force applied by the bungee cord.

2. The jumper is at the lowest position when the acceleration is positive and at a maximum.

3. The acceleration is about +15 m/s^2, directed upward.

4. The highest position the jumper reached is in the middle of the second free-fall section, or a little past 9 s.

5. The magnitude of the acceleration when the jumper was at the top of the first bounce was -9.8 m/s^2 (directed downward).

6. Length of cord = 20 m. Since the time of the fall is about 2.0 seconds, $d = ½at^2$ ($d = ½ \times 9.8 \times 2^2 = 20$ m).

ANSWERS TO PROCEDURE QUESTIONS

7. Acceleration should be zero while the jumper is at rest.

8. Acceleration is -9.8 m/s^2 during free fall.

9. The maximum upward acceleration occurs when the jumper is at the lowest point in the motion.

ANSWERS TO ANALYSIS QUESTIONS

1. See the graph and Data Table in the Sample Results section.

2. The jumper was at the lowest point at about 1.5 s, and the acceleration was about 18 m/s^2 directed upward. We can see this because the upward force is at a maximum when the bungee cord is fully stretched. The jumper reached the highest position in the middle of the second free-fall period, or about 2.4 s. The acceleration is downward and about -9.8 m/s^2. The acceleration changed from negative to positive at about 1.1 s. At this time the jumper was still falling, but the tension in the bungee cord had just matched the magnitude of the weight.

3. The laboratory jump takes place over a shorter time period than the real jump. The qualitative shape is very similar, showing a zero acceleration at the start, a free-fall period, and large positive acceleration as the bungee cord is stretched.

4. To improve the correlation, the length of the lab bungee cord would have to be increased to many meters, just like the real bungee cord.