Weightless Wonder

Background

This problem is part of a series that applies algebraic principles to the U.S. Space Exploration Policy.

Exploration provides the foundation of our knowledge, technology, resources, and inspiration. It seeks answers to fundamental questions about our existence, responds to recent discoveries and puts in place revolutionary techniques and capabilities to inspire our nation, the world, and the next generation. Through NASA, we touch the unknown, we learn and we understand. As we take our first steps toward sustaining a human presence in the solar system, we can look forward to far-off visions of the past becoming realities of the future.

The U.S. Space Exploration Policy includes returning the space shuttle safely to flight, completing the International Space Station, developing a new exploration vehicle and all the systems needed for embarking on extended missions to the Moon, Mars, and beyond.

In our quest to explore, humans will have to adapt to functioning in a variety of gravitational environments. Earth, Moon, Mars and space all have different gravitational characteristics. Earth's gravitational force is referred to as one Earth gravity, or 1 *g*. Since the Moon has less mass than the Earth, its gravitational force is only one sixth that of Earth, or 0.17 *g*. The gravitational force on Mars is equivalent to about 38% of Earth's gravity, or 0.38 *g*. The gravitational force in space is called microgravity and is very close to zero-*g*.

When astronauts are in orbit, either in the space shuttle or on the International Space Station, they are still affected by Earth's gravitational force. However, astronauts maintain a feeling of weightlessness, since both the vehicle and crew members are in a constant state of free-fall. Even though they are falling towards the Earth, they are traveling fast enough around the Earth to stay in orbit. During orbit, the gravitational force on the astronauts relative to the vehicle is close to zero-*g*.

The C-9 jet is one of the tools utilized by NASA to simulate the gravity, or reduced gravity, astronauts feel once they leave Earth (Figure 1). The C-9 jet flies a special parabolic pattern that creates several brief periods of reduced gravity. A typical NASA C-9 flight goes out over the Gulf of Mexico, lasts about two hours, and completes between 40 and 60 parabolas. These reduced gravity flights are performed so astronauts, as well as researchers and their experiments, can experience the gravitational forces of the Moon and Mars and the microgravity of space.

By using the C-9 jet as a reduced gravity research laboratory, astronauts can simulate different stages of spaceflight. This can allow crew members to practice what might occur during a real mission. These reduced gravity flights provide the capability for the development and verification of space hardware, scientific experiments, and other types of research (Figure 2). NASA scientists can also use these flights for crew training, including exercising in reduced gravity, administering medical care, performing experiments, and many other aspects of spaceflight that will be necessary for an exploration mission. A flight on the C-9 jet is the next best thing to blasting into orbit!

Figure 1: C-9 jet going into a parabolic maneuver.

Figure 2: Astronaut crew training onboard the C-9 aircraft in preparation for the Microgravity Science Laboratory missions flown on the Space Shuttle Columbia in April and July of 1997.

For more information about the U.S. Space Exploration Policy, NASA's Weightless Wonder, and reduced gravity research, visit www.nasa.gov.

To view a video on NASA's Weightless Wonder and reduced gravity research, go to http://microgravityuniversity.jsc.nasa.gov/video/RGSFOP_video.mpg.

Instructional Objectives

- You will solve quadratic equations and evaluate and graph quadratic functions.
- You will find the maximum, the *y*-intercept, the *x*-intercepts, and interpret their significance.
- You will determine the effects of parameter changes on the graph of a quadratic equation.

1 – Weightless Wonder Video

Please answer the following questions about the Weightless Wonder video.

1. In the flight of the C-9 what part of one maneuver is a true parabola and why?

2. What else can this type of flight simulate besides zero-*g*?

3. What changes might occur to the body during this type of flight?

4. What types of experiments do you think might be performed in the reduced gravity environment of a parabolic flight?

5. What do the students do to prepare themselves for the reduced gravity flight?

6. What are other instances where one might feel reduced gravity on Earth?

2 – Interpreting Graphs of Quadratic Functions

The graph below shows the altitude of a C-9 jet during one parabolic maneuver. Use this graph to answer the questions below:
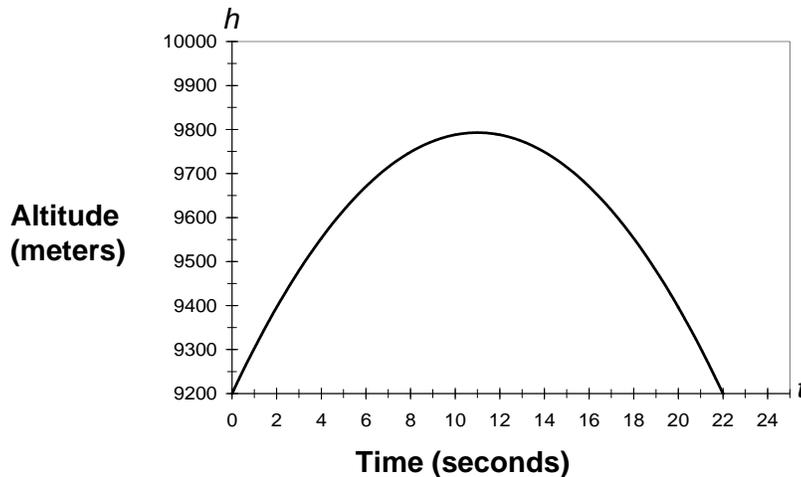
Figure 3: Altitude of C-9 During one parabolic maneuver

1. What does 9200 meters represent in this situation?

2. When does the C-9 first reach an altitude of 9400 meters? How long does the plane remain above 9400 meters? Justify your answer.

3. Between what two whole number seconds was the plane at 9600 meters?

4. What is the approximate vertex of the parabola? What does this vertex tell you about this part of the flight?

5. What is a reasonable domain for this part of the flight? What does the domain tell you about the flight?

6. What is a reasonable range for this part of the flight? What does the range tell you about the flight?

3 – Weightless Wonder Problem

To prepare for an upcoming mission, an astronaut participated in a C-9 flight simulating microgravity, or close to zero-*g*. The pilot flew out over the Gulf of Mexico, dove down to increase to a maximum speed then climbed up until the nose was at a 45° angle with the ground. To go into a parabolic maneuver, the pilot then cut the thrust of the engine letting the nose of the plane continue to rise then come back down at a -45° angle with the ground. Ending the maneuver, the pilot throttled the engine back up and began another dive to prepare for the next parabola. The pilot completed 50 parabolas during the 2 hour flight.

The figure below shows the movement of the plane during a typical flight. The parabolic maneuver, where microgravity is felt, is highlighted. This is the part of the flight that you will focus on for the following questions.

The function $h = -4.9\,t^2 + 87.21\,t + 9144$ describes the altitude (*h*) in meters (m) of the plane in relation to the time (*t*) in seconds (s) after it started the parabolic maneuver. You will use this function to analyze the parabolic flight of the C-9. Round all answers to the nearest tenth.
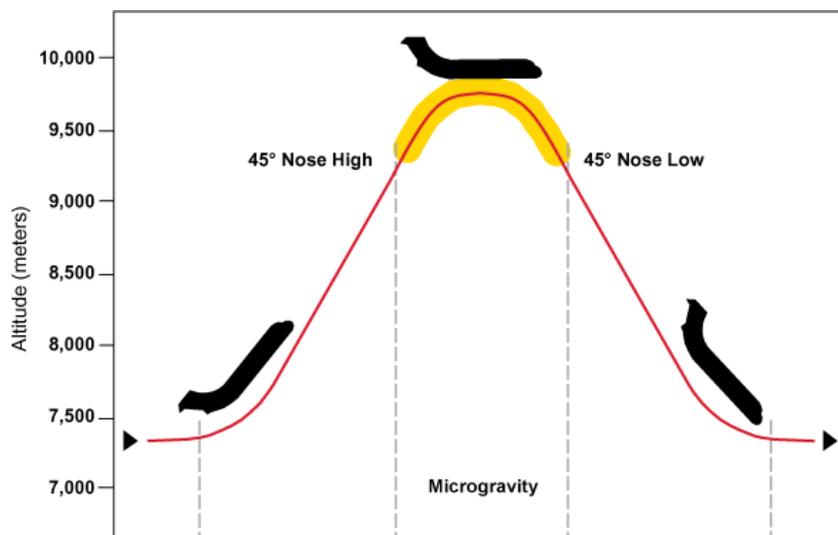
Figure 4: A typical microgravity maneuver.

1. Using the defined function, at what altitude did the astronaut first start to feel microgravity?

2. Consider the first parabolic maneuver to examine its beginning and end.

   a. Use algebra to find the times when microgravity began and ended during this one maneuver.

   b. What was the length of time the astronaut experienced microgravity during this one maneuver? Explain your answer.

   c. Use the graphing calculator to graph $y_1 = -4.9\,x^2 + 87.21\,x + 9144$ and $y_2 = 9144$.
       Note: Using a graphing calculator y represents the altitude (h), and x represents the time (t). Set your **WINDOW** to show only the first parabolic maneuver and write these values on the **WINDOW** screen below. Then sketch the two graphs on the blank screen.

   ```
   WINDOW
    Xmin=
    Xmax=
    Xscl=
    Ymin=
    Ymax=
    Yscl=
    Xres=
   ```

   d. How many times do the graphs intersect? Find the x and y values of the point(s) of intersection. Explain what these x and y values represent.

3. Consider the first parabolic maneuver to examine its maximum altitude.

    a. Use algebra to find the maximum altitude of the plane during this one parabolic maneuver.

    b. Use the graphing calculator to find the maximum altitude and when it occurs.

4. What percent of the astronaut's total flight was spent in microgravity?

4 – Changing the Parameters of Quadratic Functions

The function $f(t) = \frac{1}{2} a\, t^2 + v_0 t + h_0$ describes the altitude of the C-9 plane during one of its parabolic maneuvers with respect to the time (t) in seconds. This is an equation often used in physics and can be applied to any object in free fall. The variable a is the acceleration due to gravity. The variable v_0 is the vertical velocity of the airplane when it starts the parabolic maneuver. The variable h_0 is the altitude of the airplane when it starts the maneuver.

- The acceleration due to gravity is approximately -9.8 m/s^2.

- The vertical velocity the C-9 plane travels when starting a parabolic maneuver ranges between 90 and 115 m/s.

- The altitude at which the plane starts the maneuver ranges between 8600 and 9200 meters.

Changes in initial altitude:

1. Duringanother reduced gravity flight, the C-9 plane starts a parabolic maneuver at a velocity of 100 m/s and an altitude of 9000 meters.

    a. Write an equation to describe its altitude after t seconds. Note: Using a graphing calculator y represents the altitude (h), and x represents the time (t).

    b. Graph the equation with a graphing calculator and sketch it in the space provided.
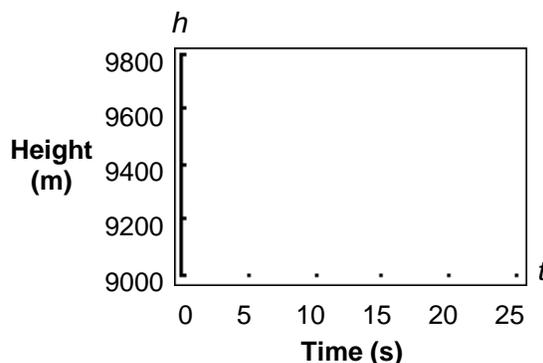
2. Refer to the graph.

    a. Describe what is happening with the plane.

    b. Estimate the maximum altitude reached.

    c. Approximately how long does the parabolic maneuver last?

3. For the next parabola the velocity is the same but the altitude is 9200 meters when the plane starts the maneuver.

   a. Write a new equation to describe this flight.

   b. Predict how the graph of this equation will change. How will the maximum altitude be affected? How will the time be affected?

4. Now check your predictions on the graphing calculator. How do your predictions compare with the changes you see on the graph?

5. How will the equation and the graph change if the plane starts at 8700 meters?

Changes in velocity:

6. If the plane's starting velocity is 90 m/s when it performs the maneuver, how will this change the equation in Question 1? Predict how this will affect the graph.

7. Now graph the equation in a graphing calculator to check your prediction.

   a. What is the maximum altitude reached?

   b. How long does the parabolic maneuver last?

   c. How does your prediction compare with the changes you see in the graph?

8. If the plane is able to start the parabolic maneuver at 115 m/s, how will this change the graph? Check your answer by graphing the equation.

9. Given the equation of the parabola is $y = a\,x^2 + b\,x + c$, summarize how changes in *a*, *b*, and *c* affect the graph of a parabola.

   a. What can you say about the value of *a*? Explain your answer.

   b. How do changes in *b* affect the graph?

   c. What does the value of *c* represent? Explain your answer.

5 – Weightless Wonder: Wrap Up
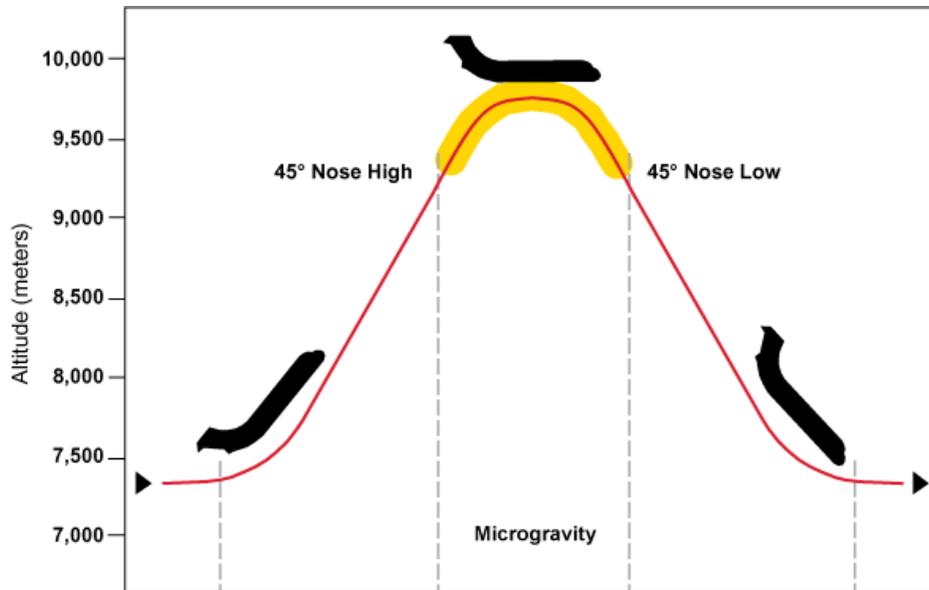
Figure 4: A typical microgravity maneuver.

1. Enter into the graphing calculator, $y_1 = -4.9\,x^2 + 91.68\,x + 8940$ and $y_2 = 8940$. Set your **WINDOW** to show only the first parabolic maneuver. Note: Using a graphing calculator y represents the altitude (h), and x represents the time (t). Use the calculator to find the x and y values of the point of intersection that is on the right. Explain what these x and y values represent.

2. Find the maximum altitude of the plane during one parabolic maneuver and when it occurs.

3. If the pilot flew for 2.5 hours and did 60 parabolas, what percent of the total flight was spent in microgravity?

4. If the equation changes to $y_1 = -4.9\,x^2 + 91.68\,x + 8600$, explain how the graph changes?

5. In the previous question, if the velocity changes to 84.19 m/s, explain how the graph changes?