



# MATH AND SCIENCE @ WORK

AP\* PHYSICS Student Edition



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## WEIGHTLESS WONDER – Reduced Gravity Flight

### Background

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.

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  $1g$ . Since the Moon has less mass than the Earth, its gravitational force is only one sixth that of Earth, or  $0.17g$ . The gravitational force on Mars is equivalent to about 38% of Earth's gravity, or  $0.38g$ . The gravitational force in space is called microgravity and is very close to zero- $g$ .



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.

When astronauts are in orbit, either in the space shuttle or on the International Space Station (ISS), Earth's gravitational force is still working on them. 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 travels 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 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!

### 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  $45^\circ$  angle with the ground. At this point the velocity of the plane was 444 kilometers per hour (about 275 mph) and the altitude was 9,144 meters (about 30,000 ft). 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  $-45^\circ$  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.

Figure 3 shows the movement of the plane during a typical flight. The parabolic maneuver, where microgravity is felt, is highlighted.

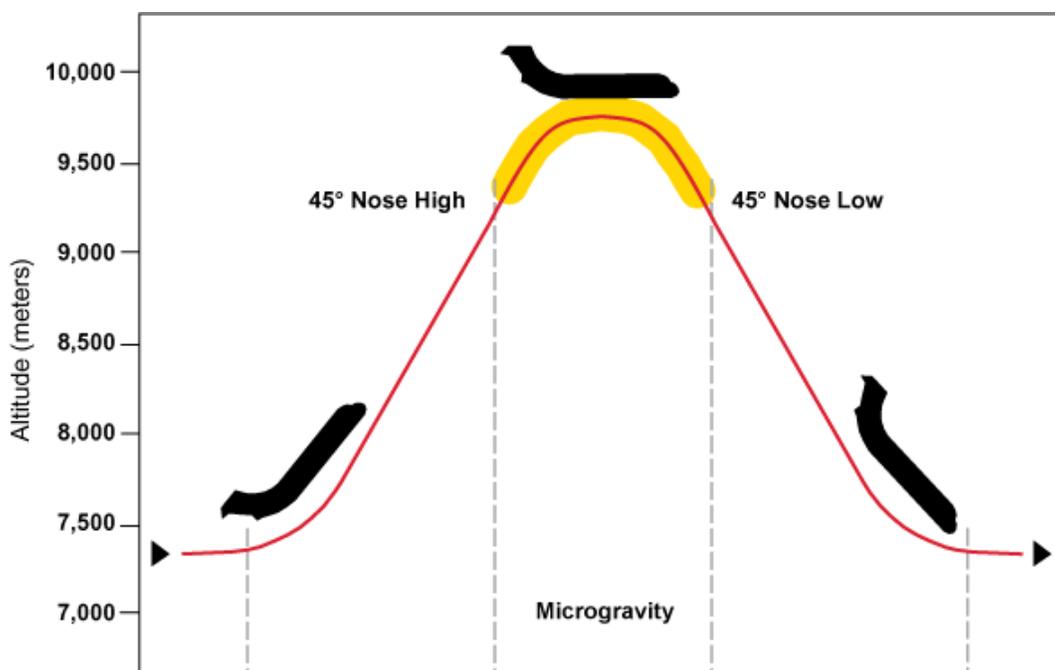


Figure 3: A typical microgravity maneuver. (Not to scale.)



*Note: Acceleration due to gravity is approximately  $-9.8 \text{ m/s}^2$ . For this problem we will be ignoring other influences such as air resistance.*

*Round all answers to three decimal places.*

- A. Find the initial and final vertical and horizontal velocities during one parabolic maneuver.
  
  
  
  
  
  
  
  
  
  
- B. Find the time elapsed, in seconds, of one parabolic maneuver.
  
  
  
  
  
  
  
  
  
  
- C. Find the maximum altitude, in meters, the plane reached. For students in Physics C, verify the maximum point using calculus.
  
  
  
  
  
  
  
  
  
  
- D. Find the horizontal displacement, in meters, of the plane during one parabolic maneuver.
  
  
  
  
  
  
  
  
  
  
- E. What percentage of the total flight was spent in microgravity?
  
  
  
  
  
  
  
  
  
  
- F. How many parabolas would the pilot need to complete in order for the astronaut to have had at least 15% of his flight in microgravity?