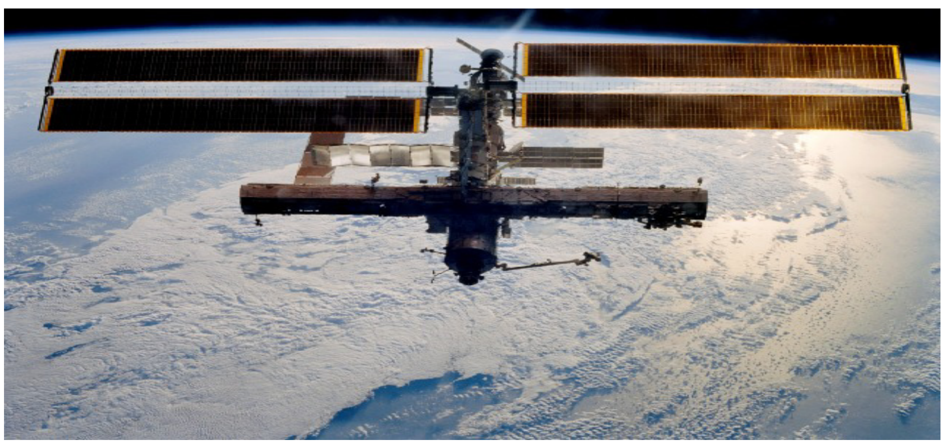
Weightlessness

Goals: Solve problems as a group. Create visual aids for oral presentation. Manipulate equations as part of a presentation. Interpret and apply graphical data.

PROBLEM

We've probably all seen video of astronauts floating weightless in their space vehicle. Studies of phenomena in a weightless environment are among the most important parts of research in space. The International Space Station (ISS) performs many of these experiments in low orbit around the earth (picture NASA).



The ISS orbits about 200 km above the surface of the Earth, or about 6600 km from the center of the Earth. Ideally the ISS stays in a circular orbit at a constant altitude. Even though the Earth provides a gravitational force on the mass in the ISS, the orbital acceleration results in a weightless condition.

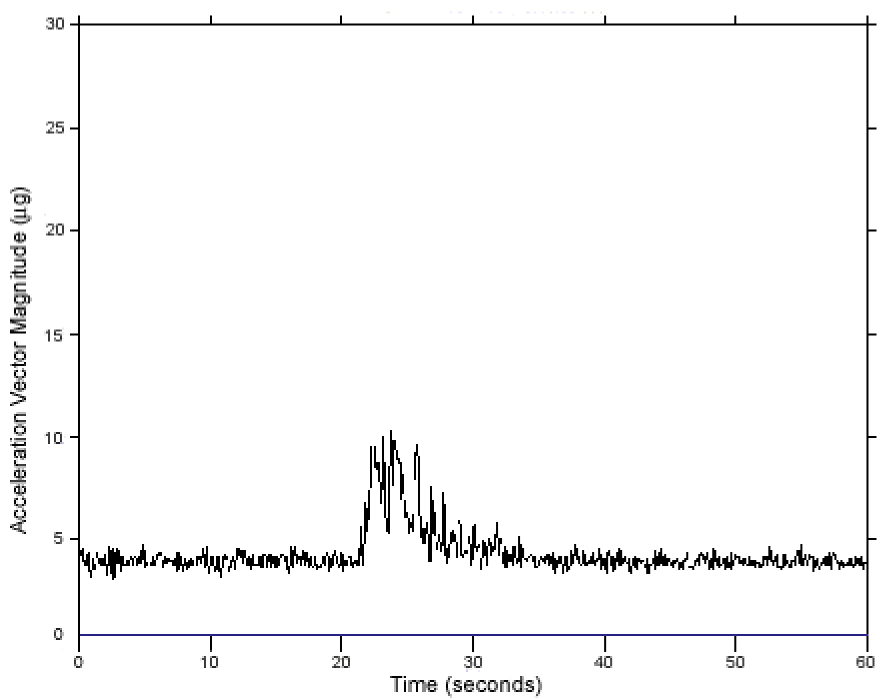
However, even at the altitude of the ISS, there is still a little bit of atmosphere that causes a small amount of drag on the ISS. That drag produces a force that results in a small acceleration. Experiments to test weightless conditions may be sensitive to small amounts of weight, so the ISS has sensitive instruments that can measure accelerations equal to a millionth of the acceleration due to gravity on Earth's surface.

PROBLEM SKILLS

Data for problems is expressed both in numbers and in graphs. Graphs have the advantage of presenting a lot of data in one image. Graphs also are useful for identifying the relationships between different parts of a set of data.

One common type of graph measures some quantity compared to time. The time measurement appears on the horizontal (x) axis and the physical quantitiy on the vertical (y) axis. Both axes are labeled with their units and tick marks to show the scale. On many time plots there is a baseline measurement before a specific event happens. The baseline may not be zero, and it may show small fluctuations due to measurement error. When the event occurs there is a change in the measurement larger than the typical error.

The following graph was measured by the Microgravity Acceleration Measurement System (MAMS) aboard the ISS. The MAMS measures the acceleration aboard the ISS in micro-g, where *g* is the gravitational acceleration on the Earth. During the period of measurement, a space shuttle docked with the ISS, and the effect of the docking was detected by the MAMS.



BACKGROUND INFORMATION

Gravity is a fundamental force of attraction between masses. It is a central force because it is directed toward the center. The magnitude of the attraction between two masses M and m separated by a distance r is given by Newton's law of universal gravitation

$$F = \frac{GMm}{r^2} \qquad \text{(EQ 1)}$$

where G = 6.67 x 10^{-11} N m^2 / kg^2 is the gravitational constant. At Earth's surface, a distance of about r_E = 6400 km, the gravitational acceleration, $GM/r_E^2 = g = 9.8$ m/s^2.

An orbit is the path an object follows due to the actions of force. A circular orbit of radius r has a path length equal to the circumference of the circle $2\pi r$. The period T associated with a circular orbit of radius r and speed v is

$$T = \frac{2\pi r}{v} \qquad \text{(EQ 2)}$$

In a circular orbit there is a constant centripetal acceleration. The acceleration is always directed toward the center of the circle and has a constant magnitude of

$$a = \frac{v^2}{r} \qquad \text{(EQ 3)}$$

In a perfect orbit around the Earth the acceleration in orbit is entirely due to the gravitational force. Since the space station and objects within are all accelerated at the same rate there is no force exerted that is felt as weight. This is the same as if the object were in free fall at the surface of the Earth.

PROBLEM SOLVING

Part A. Gravity at the Station

1. Assign group members to be persons A, B (and C). The assignments should be different than in previous oral presentation labs.
2. Draw a force diagram of the space station in orbit on the white board. Label the radius (r), the radius of the Earth (r_E) and the height above the Earth (h). Identify the forces on the ISS.
3. Use EQ 1 to create an expression for force of gravity on the ISS in terms of h and r_E.
4. Use the expression from step 3 to derive an expression for the ratio of the force of gravity at the ISS compared to the force of gravity at the surface of the Earth.
5. Use your ratio from step 4 to find the gravitational force on a 60 kg astronaut on the ISS. If there was no centripetal acceleration this would be the weight of the astronaut on the ISS.
6. Use EQ 3 to find the orbital speed of the ISS around the Earth. Use EQ 2 to find the period of revolution of the ISS and convert the time to hours and minutes.
7. Place your expression from step 4 and the numeric results from steps 4 through 6 on the white board in a way that separates them and makes them clear. Use an appropriate number of significant figures on the numeric data.

8. Make a presentation of the figure, steps and results (person A); Record your results and those of the other groups (person B); Ask questions of other presenters (person C).

Part B. Microgravity Measurement

9. After recording your results, erase your board.
10. Look at the graph of the MAMS data from the shuttle docking. Discuss with your group any important features on the graph.
11. From the baseline values on graph, estimate the typical magnitude of the acceleration on the ISS and the error.
12. Find the time that the shuttle docked with the ISS, and the additional acceleration caused by the docking.
13. Estimate the length of time the vibrations due to the shuttles' docking changed the accelerations detected by the MAMS from the baseline.
14. Write the equation for the change in position of an object subject to a constant 1-dimensional acceleration.
15. Use the graph and the results of steps 13 and 14 to estimate the deflection of a dart tossed beginning as the shuttle docked. Assume the dart is tossed at 0.5 m/s toward a target inside the ISS at a distance 3.0 m away with a diameter of 2 cm.
16. Find the appropriate errors on the deflection.
17. Draw a diagram on the white board to illustrate the trajectory and deflection of the dart. Add your equation from step 14 and results from steps 15 and 16.
18. Make a presentation of the steps and results (person B); Record your results and those of the other groups (person A); Ask questions of other presenters (person C).

ASSIGNED QUESTION

19. Your TA will assign an additional question or two to answer in a report.
20. Each student should assemble their own separate report. The report should include a summary of the data and diagrams from the groups and use them to answer the assigned question.