National Aeronautics and Space Administration

NASA's Real World: Mathematics

Educator Guide

"Preparing for a Soft Landing"

Educational Product	
Educators & Students	Grades 6-8

NP-2008-09-106-LaRC

www.nasa.gov

Preparing For A Soft Landing

NASA's REAL WORLD MATHEMATICS

Grade Level: 6-8

Subjects:
Middle School Mathematics
Physical Science

Teacher Preparation Time:
1 hour

Lesson Duration:
Five 55-minute class meetings

Time Management:
Class time can be reduced to three 55-minute time blocks if some work is completed at home.

National Standards

National Science Education Standards (NSES)
- Science as Inquiry
- Physical Science
- Science and Technology

National Council of Teachers of Mathematics (NCTM)
- Measurement
- Data Analysis and Probability
- Representation

International Society for Technology in Education: National Educational Technology Standards (ISTE/NETS)
- Research and Information Fluency

Lesson Overview:
Students are introduced to the Orion Crew Exploration Vehicle (CEV) and NASA's plans to return to the Moon in this lesson. Thinking and acting like engineers, they design and build models representing Orion, calculating the speed and acceleration of the models.

This lesson is developed using a 5E model of learning. This model is based upon constructivism, a philosophical framework or theory of learning that helps students connect new knowledge to prior experience. In the ENGAGE section of the lesson, students learn about the Orion space capsule through the use of a NASA eClips video segment. Teams of students design their own model of Orion to be used as a flight test model in the EXPLORE section. Students record the distance and time the models fall and make suggestions to redesign and improve the models.

During the EXPLAIN section, students answer questions about speed, velocity and acceleration after calculating the flight test model's speed and acceleration.

Working in teams, students redesign the flight test models to slow the models by increasing air resistance in the EXTEND section of this lesson.

Students assess their understanding and abilities throughout the lesson and revisit the Essential Questions in the EVALUATE section.

Icons flag five areas of interest or opportunities for teachers.

- TECHNOLOGY highlights opportunities to use technology to enhance the lesson.
- MODIFICATION denotes opportunities to differentiate the lesson.
- RESOURCES relates this lesson to other NASA educator resources that may supplement or extend the lesson.
- CONNECTIONS identifies opportunities to relate the lesson to historical references and other topics or disciplines.
- CHECK FOR UNDERSTANDING suggests quick, formative assessment opportunities.

Enduring Understandings:
These *Project 2061 Benchmarks for Science Literacy* guide teachers as they work to improve science literacy for all students.
- An unbalanced force acting on an object changes its speed or direction of motion, or both.
- Technology is essential to science for such purposes as exploration of outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

Essential Questions:
- How is the challenge of returning people to the Moon driving scientific and technological advancement?
- What affects the speed of a falling object?

Instructional Objectives:

Students will

- measure and calculate speed and acceleration;
- use the design process to create, test, and improve Orion flight test models;
- document the design process using instructional technology; and
- increase their understanding of past and future human travel to the Moon.

NASA Background:

America will send a new generation of explorers to the Moon aboard NASA's Orion Crew Exploration Vehicle (see Figures 1 and 2). Making its first flights early in the next decade, Orion is part of the Constellation Program to send human explorers back to the Moon, and then onward to Mars and other destinations in the solar system.

Figure 1: Exploded view of Orion. ***Image Credit:*** *Lockheed Martin Corp*

Orion will be capable of carrying crew and cargo to the space station. It will rendezvous with a lunar landing module and an Earth departure stage in low-Earth orbit to carry crews to the Moon and, one day, to Mars-bound vehicles assembled in low-Earth orbit. Orion will be the Earth entry vehicle for lunar and Mars returns. Orion's design borrows its shape from the capsule of the past, but takes advantage of 21st century technology in computers, electronics, life support, propulsion, and heat protection systems.

Orion will be similar in shape to the Apollo spacecraft, but significantly larger. The Apollo-style heat shield is the best understood shape for re-entering Earth's atmosphere, especially when returning directly from the Moon. Orion will be 5 meters (16.5 feet) in diameter and have a mass of about 22.7 metric tons (25 tons). Inside, it will have more than two-and-a-half times the volume of an Apollo capsule. The larger size will allow Orion to accommodate four crew members on missions to the Moon, and six on missions to the International Space Station or to low-Earth orbit in order to transfer to a Mars-bound spacecraft.

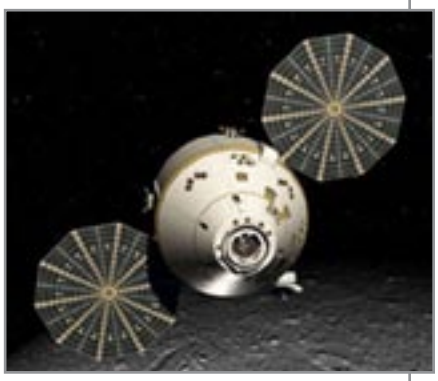

Figure 2: Orion orbits the Moon with disc-shaped solar arrays tracking the sun to generate electricity. ***Image Credit:*** *Lockheed Martin Corp*

A launch abort system atop the Orion capsule will be capable of pulling the spacecraft and its crew to safety in the event of an emergency on the launch pad or at any time during ascent.

For missions to the Moon, NASA will use two separate launch vehicles, each derived from a mixture of systems with heritage rooted in Apollo, space shuttle and commercial launch vehicle technology.

Landing on the Moon

An Ares V cargo launch vehicle (see Figure 3) will precede the launch of the crew vehicle, delivering to low-Earth orbit the Earth departure stage and the lunar module that will carry explorers on the last leg of the journey to the Moon's surface. Orion will dock with the lunar module in Earth orbit, and the Earth departure stage will propel both on their journey to the Moon. Once in lunar orbit, all four astronauts will use the lunar landing craft to travel to the Moon's surface, while the Orion spacecraft stays in lunar orbit.

Figure 3: A concept image shows the Ares V cargo launch vehicle launching from NASA's Kennedy Space Center, Florida. ***Image Credit:*** *NASA/MSFC*

Once the astronauts' lunar mission is complete, they will return to the orbiting Orion vehicle using a lunar ascent module. The crew will use the service module main engine to break out of lunar orbit and head to Earth.

Landing on Earth

Orion and its crew will reenter Earth's atmosphere using a newly developed thermal protection system. Parachutes will further slow Orion's descent through the atmosphere.

Orion will follow the traditions of Mercury, Gemini, and Apollo by landing in the ocean. A secondary landing location for Orion may be on dry ground. This would allow for easier retrieval and vehicle reusability. "It's much easier to refurbish a spacecraft from a land landing as opposed to a water landing," said the lead test engineer, Richard Boitnott.

Figure 4: The gantry is receiving a fresh coat of protective paint as part of the summer renovations. Other upgrades include a new bridge, a new elevator, floor repairs and a new parallel winch system. ***Image Credit:*** *NASA/Sean Smith*

Tests have been conducted at Langley Research Center in Hampton, VA, using NASA's gantry. The gantry is a large drop-testing platform (see Figure 4). The gantry was built to train Apollo astronauts to land on the Moon. Now it helps researchers test the possibility of landing Orion on land.

Engineers and technicians at the gantry have conducted three types of tests for this dry landing option, progressing to more realistic models with each new test.

Testing began by dropping a test article – a framework used to represent the future capsule that was a half-size model of Orion. For the second round of testing, engineers added a welded structure, representing Orion's intended shape, to examine the article's tendency to flip or to remain upright. The third round of testing included two different sets of airbags under a flat-bottomed test article, that was approximately 3,175 kilograms (7,000 pounds), with a full-scale model of Orion.

"Future testing will reduce risk associated with using airbags and will gather more information about possible failure modes," said Boitnott. "We learn from one generation of airbag testing to the next and make improvements to give NASA a more reliable landing system."

Sources: NASA Website:
http://www.nasa.gov/mission_pages/constellation/orion/index.html and
http://www.nasa.gov/mission_pages/constellation/orion/orion-gantry.html

For more information about Orion and the Constellation Program, visit
http://www.nasa.gov/mission_pages/constellation/main/index.html

5E Inquiry Lesson Development
ENGAGE (20 to 30 minutes)

1. Post and discuss the first Essential Question: How is the challenge of returning people to the Moon driving scientific and technological advancement?
2. Use a KWL chart to organize what students already KNOW and what students WANT TO LEARN about exploring the Moon. These questions may guide discussion:
   a. What do you KNOW about past and future exploration of the Moon and how do you know this? *(Answers vary.)*
   b. When was the last time Americans stepped foot on the Moon? *(Apollo 17 mission – 1972)*
   c. What are some of the challenges NASA engineers and technicians face in sending people back to the Moon? *(safety, effects of reduced gravity on humans, travel needs, launching, landing, life support, etc.)*
   d. What would you like to LEARN about traveling to the Moon? *(Answers vary.)*
   e. How could you find out more? *(Answers will vary, but should include designing experiments, doing Internet research, etc.)*
3. TECHNOLOGY Show the NASA eClips video segment *Lunar Landing Crash Test Designs* featuring the gantry and tests of the Orion space capsule. This segment may be found at NASA eClips You Tube™,
   http://www.youtube.com/watch?v=tmpJ9K9ftlw&feature=PlayList&p=887C1C3BAAD53F17&index=0

4. Organize students into small groups to continue discussions about lunar exploration.
   MODIFICATION For groups that need more structure, these questions may focus discussion:
   a. What is the gantry and how was the gantry used to prepare for the Apollo missions?
      (A tall structure used as a test drop facility that was built to train Apollo astronauts to land on the Moon.)
   b. How has the gantry been used to improve airplane safety?
      (Airplanes have been dropped from the gantry to test their construction and safety.)
   c. How will the gantry be used to prepare for America's return to the Moon?
      (The gantry is being used for tests using the Orion space capsule.)
   d. What are some other tests that might be performed using the gantry? *(Answers vary.)*
   e. What skills are engineers and technicians modeling throughout this video segment?
      (Planning, testing, experimenting, building, gathering data, recording data, making models, simulating, measuring, etc.)
5. CHECK FOR UNDERSTANDING Summarize small group discussions through a class discussion focused around the essential question: How is the challenge of returning people to the Moon driving scientific and technological advancement? *(Answers vary. Based upon the NASA eClips video segment, students see that NASA's interest in returning to the Moon pushes scientists and engineers to improve spacecraft designs.)*

EXPLORE (two 55-minute class meetings)

After completing a mission and returning to Earth, Orion may land on dry ground rather than landing in water as the Mercury, Gemini, and Apollo spacecraft did. As shown in the NASA eClips segment, engineers and technicians conduct tests for this dry landing option using the gantry. Dropping flight test models from the gantry allows engineers to improve Orion's design. During this design challenge, students think and act like engineers as they design and create flight test models to protect cargo for a dry landing.

MODIFICATION Class time may be reduced by assigning sections to be completed as homework. Some homework suggestions: view the NASA eClips video segment; complete Internet research; and/or sketch or construct the flight test model.

1. Post and discuss the second Essential Question: What affects the speed of a falling object?
2. TECHNOLOGY Learn more about Orion and flight test models by viewing the NASA eClips video segment *21st Century Crew Exploration Vehicle*. This segment may be found at NASA eClips You Tube™, ***www.youtube.com/watch?v=kfuibrk22RU&feature=PlayList&p=D7BEC5371B22BDD9&index=0***
3. Organize students into Design and Engineering Teams.
   RESOURCES Find out more about how to organize these teams and the design process from *NASA's Lunar Nautics Educator Guide,* ***http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Lunar_Nautics_Designing_a_Mission.html*** This guide contains activities that lead to designing a mission to live and work on the Moon. Pages 118 – 119 offer tips for forming and implementing design teams.
4. TECHNOLOGY Prior to construction, guide each team to find out more about Orion and the Constellation Program. These websites are a beginning point for research:
   a. Constellation: ***http://www.nasa.gov/mission_pages/constellation/main/index.html***
   b. Exploration Systems Mission Directorate: ***http://www.nasa.gov/directorates/esmd/csd/index.html***
   c. NASA 101: ***http://www.nasa.gov/externalflash/nasa101/index.html***
5. TECHNOLOGY The design challenge has three parts. Encourage students to document each part with digital images. If possible, videotape or digitally record the drop tests.

A. Part One: Each team will create an Orion flight test model. Ask students to complete the Design Process Sheets to document the design process. More specific directions for each section may be needed based upon the needs of your students. For example, on Design Sheet C you may help students develop the procedure showing them step-by-step directions.

1. The model may be no larger than 20 cm x 20 cm x 20 cm (8 in x 8 in x 8 in) and must hold a raw egg sealed inside a plastic bag. The egg represents an astronaut.
2. It must have a working door that can be opened and closed to inspect the capsule's contents.
3. Students may add any gathered materials to the model to protect their egg-astronaut. As seen in the video segment, students may consider adding air bags.
4. Students may NOT add parachutes or other aerobraking devices to slow the descent of the payload.
5. Encourage students to use the evaluation rubric to guide their construction.
6. Some suggested materials for the flight test model include:

• cardboard boxes	• construction paper	• cups	• straws	• paper towels
• cotton balls	• plastic bags	• bubble wrap	• balloons	• string
• tape	• cloth	• tissue paper		

B. Part Two: Identify a drop test location. Try to find a SAFE location with a height of at least 9 meters or 30 feet (e.g., the second story of a building). It may be necessary for an adult to drop the flight test models for safety reasons. For consistency, be sure that the height is constant for all test drops. Mark a target landing site on the ground.
MODIFICATION Data charts included may be used to help students record data. This activity will be more challenging if students design their own data collection tables.

1. Record the height (meters) of the drop locations.
2. Drop each flight test model two times without the egg-astronaut cargo.
3. Add the egg-astronaut to the model for the third drop.
4. Record the time (seconds) for each flight test model to fall.
   TECHNOLOGY Texas Instruments, Vernier, and Casio produce graphing calculators and motion sensors that can obtain accurate drop-test times.

C. Part Three: Discuss ways to improve the designs. Use these questions to guide discussion:

1. The Orion capsule will carry four to six astronauts. How might you modify your model to carry more egg-astronauts? *(Answers vary. Students will need to consider ways to protect the eggs from each other inside the model. This may lead to a discussion of the model's volume.)*
2. Compare your simulated landing to the NASA eClips segment. How is your simulation similar to the testing shown in the video segment? In what ways did it differ? *(Answers vary.)*
3. How would you redesign your flight test model for different environments (aquatic, high heat)? *(Answers vary.)*
4. How would you modify the design if the model lands in water? *(Answers vary. Students may discuss ways to "waterproof" the model.)*
5. How would you modify the design to land the model on the Moon? *(Answers vary. This question should lead to a discussion of the Moon's reduced gravity and minimal atmosphere. On the Moon, heat is not created by "atmospheric friction". Since there is no atmosphere, there is no slowing down of the spacecraft by friction thus parachutes will not work and retrorockets are needed. The terminal speed at hitting the Moon is greater than at hitting the Earth.)*

EXPLAIN (20 to 30 minutes)

Scientists and engineers working at the gantry study relationships between force and motion. As we've seen, the pull of gravity on objects is one of the forces affecting the motion of the Orion capsule as it returns to Earth.

Measuring Gravitational Force

All objects that have mass exert a gravitational force on all other objects with mass. The strength of this force is affected by the objects' masses and the distance between objects.

An understanding of the following basic force and motion vocabulary will be developed as students analyze data gathered in the EXPLORE section.

speed: The time it takes an object to travel a certain distance.
This formula calculates speed: **speed=distance/time or** $s = d / t$

velocity: The speed and the direction of travel of an object. Direction becomes important when dealing with navigation of boats, aircraft, wind and water currents, etc.

acceleration: Any change in speed or velocity (when an object speeds up, slows down, or changes direction.) Acceleration can be described as positive or negative (e.g., speeding up is positive acceleration, slowing down is negative acceleration)

g: The force of Earth's gravity is 1 *g.*

1. Guide students to calculate the mean time and average speed for data collected in the EXPLORE section using the Drop Times Table.
2. Direct students to analyze the drop times data by answering questions on the Student Handout.
   TECHNOLOGY Segment the digital video recording into second intervals. Discuss how the digital recording allows for more precision in gathering data.

   Compare the distance the model falls each second as it falls. This represents acceleration due to gravity. Your students will discover that the force of gravity causes an object to fall faster as it falls further.

   When an object on Earth is dropped off a building or tower, the relationship between Earth's gravitational force *(g)*, the distance *(d)* the object falls, and the time *(t)* it takes to fall is given by the following formula:

$$g = d / t^2$$

One Earth gravity *(g)* is measured as the acceleration of an object affected only by Earth's gravity. This acceleration is approximately 9.8 meters/second squared (9.8 m/s^2) or 32 feet/second squared (32 ft/s^2). Ignoring air resistance, the speed of an object falling freely near Earth's surface increases by 9.8 meters per second every second.

MODIFICATION Challenge students to create graphs representing speed from different heights. This would require creating more data points by using more drop heights.
RESOURCES See the *NASA CONNECT* educator guide,
http://connect.larc.nasa.gov/programs/2002-2003/micro_gravity/guide.html, for more information.

CONNECTIONS Early experiments conducted by Galileo Galilei over 360 years ago helped formulate some of today's understanding of Earth's gravitational pull on objects. One of Galileo's students, Vincenzo Viviani, described how Galileo dropped a cannon ball and a musket ball from the top of the Leaning Tower of Pisa and hypothesized that both objects would hit the ground at the same time, no matter the difference in weight. Viviani reported that the balls hit the ground at nearly the same time, disproving Aristotle's earlier belief that heavier objects fall faster than lighter objects. Because the drop was short, air resistance wasn't a strong influence. If the balls had fallen a longer distance, air resistance would have had a more pronounced effect, slowing the larger ball.

While on the Moon during the Apollo 15 mission, David Scott performed a similar experiment to Galileo's. He dropped his geology hammer and a feather from the same height, at the same time.

1. Ask students what they think will happen if a golf ball and a feather are dropped from the same height on Earth. After students make their predictions, run the test. What forces affect these objects when they are dropped? *(gravity and air resistance)*
2. On the Moon, what forces affect these objects when they are dropped? *(gravity)*
3. The Moon has almost no atmosphere and about 1/6 Earth's gravity. How do these differences affect the objects when they're dropped on the Moon? *(The objects fall at the same rate, but both fall at a slower speed than on Earth. The fall rates on the Moon won't be affected by air resistance because the Moon has almost no atmosphere.)*

4. TECHNOLOGY Show students a video segment of this historic event found at: ***http://www.lpi.usra.edu/lunar/missions/apollo/apollo_15/surface_opp/***
5. If both objects fell at the same speed and landed on your foot, why would the geology hammer hurt more? *(An object's mass doesn't change on the Moon, only the weight. The geology hammer has the same mass on the Moon as on Earth. However, because the force of gravity is less [the Moon has less mass than the Earth] it shouldn't hurt as much as if it hit your foot on Earth – and hopefully not at all if you're wearing protective boots!)*

EXTEND (one 55-minute class meeting)

Air resistance can counteract the force of gravity. Following the same procedure outlined in the EXPLORE section, students redesign their flight test models to increase air resistance and reduce their model's speed.

MODIFICATION Class time may be reduced by assigning sections to be completed as homework. Some homework suggestions: Redesign the flight test model, design data tables, questions and/or rubric. Complete calculations and questions.

1. Ask students to redesign their model adding parachutes or other aerobraking devices to increase air resistance, slow the descent, and protect the egg-astronaut.
2. Be sure students accurately record data. They may recreate the data tables from the Drop Test Tables or design their own table or spreadsheets for the modified flight test models. Ask students to revisit and revise the evaluation rubric.
3. Ask students to develop their own questions to compare the performance of their flight test model WITH aerobraking and WITHOUT aerobraking. Guide them to discuss how the forces of gravity and air resistance affect the flight test models as they fall.

EVALUATE (30 to 40 minutes)

These activities may be used to evaluate your students' understanding.
MODIFICATION Class time may be reduced by assigning sections to be completed as homework.

1. Scientists observe, predict, measure, test, and discover the workings of the natural world. Engineers extend an understanding of the natural world to design, build, and test innovations for the designed world. Mathematicians use numbers to help quantify and make predictions within the natural and designed worlds.

   Ask students to reflect on times throughout this lesson when they were thinking and acting like engineers, mathematicians, and scientists.

2. Ask students to return to the KWL chart from the ENGAGE section to complete what they've LEARNED throughout this experience.
3. Use questions, discussions, student handouts, and the grading rubric from the lesson to assess students' understanding.
4. Ask students to revisit the Essential Questions and write a paragraph organizing their learning from this lesson.
   - What effects the speed of falling object?
     (Answers vary. Students should discuss the effects of gravity and air resistance on the motion of the models.)
   - How is the challenge of returning people to the Moon driving scientific and technological advancement?
     (Answers vary. Returning to the Moon challenges scientists and engineers to design faster, safer space capsules; and smaller, lighter equipment to obtain data.)
5. TECHNOLOGY Challenge students to create a digital collage or multimedia presentation to document their work during the EXPLORE and EXTEND design challenge.

Problem, Constraints, and Brainstorming

Identify the problem, identify criteria and constraints, and brainstorm possible solutions.
List them below. Include sketches and/or diagrams.

STEP 1

Identify the Problem

STEP 2

Identify Criteria and Constraints

STEP 3

Brainstorm Possible Solutions

Ideas, Possibilities, and Design Choice

Select two or three optimal ideas from the brainstormed list on Design Sheet A. Make a detailed sketch of each design. Select one design to construct. List reasons for your choice. Sketches should be labeled with dimensions and materials for each part.

STEP 4

Generate Ideas

STEP 5

Explore Possibilities - Sketches

STEP 6

Select a Design; Justify your Choice

Model or Prototype

List the materials used to construct your selected model from Design Sheet B, or redesign of an existing model, and write a detailed procedure for its construction. You may continue the procedure on additional paper if needed.

STEP 7

Build a Model or Prototype - Materials and Procedures

Refine the Design

STEP 8

Testing

Hypothesize about your design's performance during testing. Strive to use an If.., then... format.
For example, "If the redesigned model has increased in size (change in the independent variable), then it will fall at a faster speed (change seen in the dependent variable)."

Evaluation
List the strengths and weaknesses of your apparatus' design here or on a separate sheet.

Redesign
If you were to build this apparatus again, what would you do differently and why?

Design Challenge Evaluation Rubric

Group Members: _____

_____

Rubric Category	Score
Identify the Problem, Constraints, and Brainstorming • The problem is identified and explained in detail. • All criteria and constraints are listed and clarified. • Possible solutions are listed following brainstorming session. • Evaluation criteria/predictions are closely connected to the problem.	
Generate Ideas, Possibilities, and Design Choice • Two or three ideas are selected from brainstormed list. • Detailed sketches are created for selected ideas. • Sketches are labeled with dimensions and materials for each part. • One design is selected to construct with reasons for your choice.	
Build the Model or Prototype • Detailed list of materials is included. • Detailed procedures are included and followed. • Scale and details mimic the original design. • Drop test data tables are complete and well organized.	
Refine the Design • Hypothesis following an “if.., then…” format is developed for the design. • Strengths and weaknesses of the design are listed. • Modifications to improve the design are documented. • Reflections show great insight and understanding of process and goals of project.	
Evaluate Performance • Model or prototype performs with intended results. • Results are repeated in additional trials.	
Present Findings • Presentation is very well-organized. • Presentation covers all areas of the design process. • Presentation is clearly communicated (verbally or visually) with appropriate data, sketches, or graphs. • Presentation highlights all team members contributions.	
TOTAL (out of 24 pts possible)	

4 (Excellent) = All criteria (procedures, steps, and details) are met or followed with rare mistakes.
3 (Good) = Most criteria are met with only a few mistakes.
2 (Fair) = Many criteria are not met and/or there are many mistakes.
1 (Poor) = Most criteria are not met.
0 (No effort) = No effort to meet criteria.

Essential Questions:

- How is the challenge of returning people to the Moon driving scientific and technological advancement?
- What affects the speed of a falling object?

Background:

America will send a new generation of explorers to the Moon aboard NASA's Orion Crew Exploration Vehicle (CEV) (see Figures 1 and 2). Making its first flights early in the next decade, Orion is part of the Constellation Program to send human explorers back to the Moon, and then onward to Mars and other destinations in the solar system.

Figure 1: Exploded view of Orion. ***Image Credit:*** *Lockheed Martin Corp*

Orion and its crew will reenter Earth's atmosphere using a newly developed thermal protection system. Parachutes will further slow Orion's descent through the atmosphere. Orion will follow the traditions of Mercury, Gemini, and Apollo by landing in the ocean. A secondary landing location for Orion may be on dry ground. This would allow for easier retrieval and vehicle reusability.

Figure 2: Orion orbits the Moon with disc-shaped solar arrays tracking the sun to generate electricity. ***Image Credit:*** *Lockheed Martin Corp*

Tests have been conducted at Langley Research Center in Hampton, VA, using NASA's gantry. The gantry is a large drop-testing platform (see Figure 3). Scientists and engineers working at the gantry study relationships between force and motion. The pull of gravity on objects is one of the forces affecting the motion of the Orion capsule as it returns to Earth.

Early experiments conducted by Galileo Galilei over 360 years ago helped formulate some of today's understanding of Earth's gravitational pull on objects. One of Galileo's students, Vincenzo Viviani, described how Galileo dropped a cannon ball and a musket ball from the top of the Leaning Tower of Pisa and hypothesized that both objects would hit the ground at the same time, no matter the difference in weight. Viviani reported that the balls nearly hit the ground at the same time, disproving Aristotle's earlier belief that heavier objects fall faster than lighter objects. Because the drop was short, air resistance wasn't a strong influence. If the balls had fallen a longer distance, air resistance would have had a more pronounced effect to slow the larger ball.

Figure 3: The gantry is receiving a fresh coat of protective paint as part of the summer renovations. Other upgrades include a new bridge, a new elevator, floor repairs and a new parallel winch system. ***Image Credit:*** *NASA/Sean Smith*

Sources: NASA Website:
http://www.nasa.gov/mission_pages/constellation/orion/index.html and
http://www.nasa.gov/mission_pages/constellation/orion/orion-gantry.html
For more information about Orion and the Constellation Program, visit
http://www.nasa.gov/mission_pages/constellation/main/index.html

VOCABULARY

acceleration - Acceleration is any change in speed or velocity (when an object speeds up, slows down, or changes direction). Acceleration can be described as positive or negative (e.g., speeding up is positive acceleration, slowing down is negative acceleration).

constellation - The definition of constellation you may be familiar with is a group of stars that can be connected together to form a pattern such as the "Big Dipper." NASA's mission which includes building a new vehicle, the Orion, capable of going to the Moon for lunar exploration and research, is called the Constellation Program.

constraint - Any limit or restriction of the design process is called a constraint.

criteria - Criteria are specifications or rules guiding the design process, such as size, type of material, or dollar limit to build the model.

design process - The design process is a series of steps in designing something (see Figure 4).

drop test - An experiment that measures speed, velocity or acceleration of a falling object, or the results of a fall or the impact of the fall, is called a drop test.

force - A force is whatever can cause an object with mass to accelerate (change its direction or speed). Force may be expressed with both magnitude (speed or velocity) and direction making it a vector quantity.

g - The force of Earth's gravity.

gantry - NASA's gantry is a large apparatus in Hampton, Virginia that was built to test Apollo space capsules. Now it helps researchers test the Orion space capsule (see Figure 3).

gravity - Gravity is a force between objects based on their masses and the distance between the objects. The force of gravity of large objects, such as moons and planets, is strong enough to cause objects to be "caught in an orbit" around them. The force of gravity on the Moon is less than the force of gravity on Earth because the Moon has only 1/6 the mass of the Earth.

mass - The amount of matter in an object is the object's mass. Objects are made up of atoms containing varying numbers of protons, neutrons, and electrons which determine their masses.

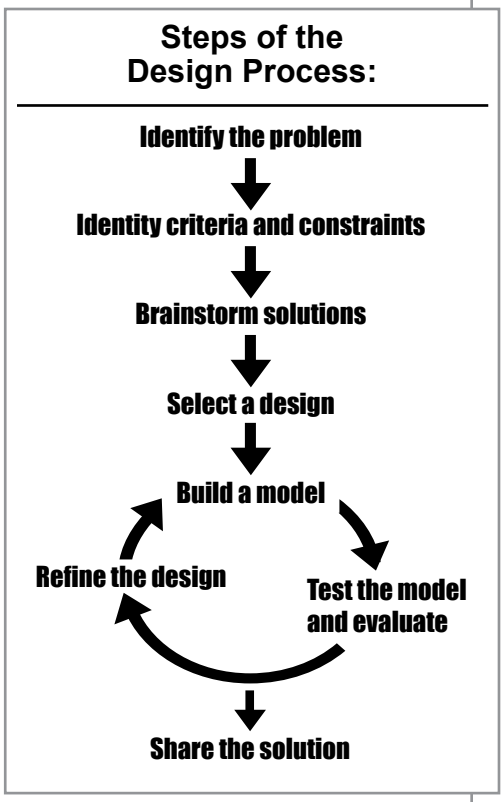

Figure 4: Steps of the Design Process

model - A model represents something else. A model might be a drawing or a 3-D object. Models are smaller than the original object or made out of less expensive materials than the actual object. Many iterations (repetitions or versions) of models are often needed before the actual object (for instance, the Orion spacecraft) can be built. The first version is often a drawing scaled down to fit on a piece of paper. The next may be a series of structures made out of paper, cardboard, plastic, or other readily available materials.

prototype - A prototype is an original or model on which something is based.

simulation - A simulation is something that substitutes for the real thing. For instance, flight simulators are mockups for pilots to practice so they do not crash real aircraft under different weather and equipment emergencies. A simulation can have many qualities of the authentic experience without all the expenses, dangers, and etc. A model simulates - or is a simulation of - a real object or event.

speed - Speed is the time it takes an object to travel a certain distance. Speed equals distance divided by time or $s = d / t$.

variable - A letter that represents a group of numbers is called a variable. Variables are italicized. That's how you can tell them apart from units such as grams (g). An example of some variables used in this activity: s = speed, d = distance, t = time or $s = d / t$. Two variables you use all the time to plot points on a graph are the x and y coordinates [e.g., Plot point (x, y)].

vector quantity - A vector quantity is any force that has both size and direction. For example, speed becomes a vector once you give it a direction.

velocity - The speed and the direction of travel of an object is the object's velocity. Velocity is similar to speed, but whereas an example of speed would be, "the wind was blowing at 40 miles per hour," velocity would be expressed as "40 miles per hour from the SE." Direction becomes important when dealing with navigation of boats, aircraft, wind and water currents, etc.

EXPLORE – Gathering and Analyzing Data

A. Gathering Data

1. Your teacher will identify a drop test location. Each flight test model will be dropped two times without the egg-astronaut cargo.
2. Measure and record the mass of each model in Table 1.
3. The height for all tests should be kept constant. Measure it and record below.
4. Record the time it takes for each model to fall.
5. Add the egg-astronaut to the model for the third drop.
6. Record the time for the third drop.
7. Enter all results in Table 1.

Drop Test Height (meters): _____

Table 1. Drop Time

	Model Mass (grams)		**Time (seconds)**		
	without egg-astronaut	with egg-astronaut	Trials		
			1 (without egg)	**2** (without egg)	**3** (with egg)
Flight test model 1					
Flight test model 2					
Flight test model 3					
Flight test model 4					
Flight test model 5					
Flight test model 6					
Flight test model 7					
Flight test model 8					

B. EXPLAIN – Analyzing Data

1. Using the times for all three trials, calculate the mean time for each flight test model drop. Enter results in Table 2.

Table 2. Mean Drop Times

	Mean Drop Time (seconds)
Flight test model 1	
Flight test model 2	
Flight test model 3	
Flight test model 4	
Flight test model 5	
Flight test model 6	
Flight test model 7	
Flight test model 8	
Class mean	

speed: The time it takes an object to travel a certain distance.
This formula calculates speed: **speed=distance/time or** $s = d / t$

velocity: The speed and the direction of travel of an object. Direction becomes important when dealing with navigation of boats, aircraft, wind and water currents, etc.

acceleration: Any change in speed or velocity (when an object speeds up, slows down, or changes direction). Acceleration can be described as positive or negative (e.g., speeding up is positive acceleration, slowing down is negative acceleration).

g: The force of Earth's gravity

1. What did you do to measure the motion of flight test models?

2. Which of the vocabulary terms above best describes the motion of the models?

3. Calculate the speed of your team's model.

4. How does the speed of all flight test models compare?

5. TECHNOLOGY If you videotaped or recorded the drops, segment the video recording into one-second intervals. What do you observe when you compare the segmented footage? How does the distance the ball falls each second change over time? Which of the vocabulary terms above best describes this change in motion?

   Compare the distance the model falls each second as it falls. This represents acceleration due to gravity. When an object is dropped and pulled to Earth's surface, there is a relationship between the distance *(d)* and time *(t)* the object travels to Earth's gravity *(g)*. The relationship is given in this equation: $g = 2 d / t^2$

6. One Earth gravity (1 *g*) is measured as the acceleration of an object affected only by Earth's gravity. This acceleration is approximately 9.8 meters/second squared (9.8 m/s^2) or 32 feet/second squared (32 ft/s^2). Ignoring air resistance, the speed of an object falling freely near Earth's surface increases by 9.8 meters per second every second.

   a. Enter the calculated mean time and average speed for your flight test model into Table 3.
   b. Calculate the model's acceleration due to gravity and place your answer in the last column below.
   c. How close to 9.8 m/s^2 is your calculated value for *g*?

Table 3. Acceleration due to gravity.

	Height (meters)	Mean drop time (seconds)	**Speed** (distance/time)	**Acceleration due to gravity** (m/s^2)
Flight test model #_____				

7. What more would you like to know?

EXPLORE – Gathering and Analyzing Data

A. Gathering Data

1. Your teacher will identify a drop test location. Each flight test model will be dropped two times without the egg-astronaut cargo.
2. Measure and record the mass of each model in Table 1.
3. The height for all tests should be kept constant. Measure it and record below.
4. Record the time it takes for each model to fall.
5. Add the egg-astronaut to the model for the third drop.
6. Record the time for the third drop.
7. Enter all results in Table 1.

Drop Test Height (meters): *(Answers Vary)*

Table 1. Drop Time

	Model Mass (grams)		Time (seconds)		
	without egg-astronaut	with egg-astronaut	Trials		
			1 (without egg)	**2** (without egg)	**3** (with egg)
Flight test model 1					
Flight test model 2					
Flight test model 3					
Flight test model 4					
Flight test model 5					
Flight test model 6					
Flight test model 7					
Flight test model 8					

B. EXPLAIN – Analyzing Data

1. Using the times for all three trials, calculate the mean time for each flight test model drop. Enter results in Table 2.

Table 2. Mean Drop Times *(Answers Vary)*

	Mean Drop Time (seconds)
Flight test model 1	
Flight test model 2	
Flight test model 3	
Flight test model 4	
Flight test model 5	
Flight test model 6	
Flight test model 7	
Flight test model 8	
Class mean	

ANSWER KEY

speed: The time it takes an object to travel a certain distance.
This formula calculates speed: **speed=distance/time or** $s = d / t$

velocity: The speed and the direction of travel of an object. Direction becomes important when dealing with navigation of boats, aircraft, wind and water currents, etc.

acceleration: Any change in speed or velocity (when an object speeds up, slows down, or changes direction). Acceleration can be described as positive or negative (e.g., speeding up is positive acceleration, slowing down is negative acceleration).

g: The force of Earth's gravity

1. What did you do to measure the motion of flight test models? *(Recorded the distance the models fell and the time it took for them to travel this distance.)*
2. Which of the vocabulary terms above best describes the motion of the models?*(If you describe how fast an object travels, you are describing speed. If you also include the direction the balls travel, you are describing velocity.)*
3. Calculate the speed of your team's model. *(Answers vary. Average speed is calculated by dividing the distance the model fell by the mean drop time.)*
4. How does the speed of all flight test models compare? *(Depending upon the design of the flight test models, answers may vary. The shape of the models may increase air resistance and slow down the drops.)*
5. TECHNOLOGY If you videotaped or recorded the drops, segment the video recording into one-second intervals. What do you observe when you compare the segmented footage? How does the distance the ball falls each second change over time? Which of the vocabulary terms above best describes this change in motion? *(The model falls a greater distance for each second it falls. The model is accelerating as it falls.)*

Compare the distance the model falls each second as it falls. This represents acceleration due to gravity. When an object is dropped and pulled to Earth's surface, there is a relationship between the distance *(d)* and time *(t)* the object travels to Earth's gravity *(g)*. The relationship is given in this equation: $g = 2 d / t^2$

6. One Earth gravity (1 *g*) is measured as the acceleration of an object affected only by Earth's gravity. This acceleration is approximately 9.8 meters/second squared (9.8 m/s^2) or 32 feet/second squared (32 ft/s^2). Ignoring air resistance, the speed of an object falling freely near Earth's surface increases by 9.8 meters per second every second.

   a. Enter the calculated mean time and average speed for your flight test model into Table 3.
   b. Calculate the model's acceleration due to gravity and place your answer in the last column below. *(Following the formula $g = 2 d / t^2$)*
   c. How close to 9.8 m/s^2 is your calculated value for *g*? *(Answers vary. If there is no air resistance and the distance and time are accurately measured, the calculated value for g should be close to 9.8 m/s^2).*

Table 3. Acceleration due to gravity. *(Answers vary)*

	Height (meters)	Mean drop time (seconds)	**Speed** (distance/time)	**Acceleration due to gravity** (m/s^2)
Flight test model #_____				

7. What more would you like to know? *(Answers vary. You may want to guide students to wonder what would happen if you dropped objects of different weight or dropped the objects from different heights. Encourage students to create their own experiments based upon some of their questions.)*

ANSWER KEY