



Spacecraft Structures

DESCRIPTION

This activity challenges your students to solve a real-world problem that is part of the space program using creativity, cleverness, and scientific knowledge, while learning about forces, structures, and energy transfer.

OBJECTIVES

Students will

- Accurately measure drop heights and compute average heights
- Observe a design before testing and pick out the “key features”
- Observe a model during and after testing and document precisely what happens to the model
- Apply the engineering design process
- Record observations and organize data so that they can be exchanged with others and referred to later

NASA SUMMER OF INNOVATION UNIT

Engineering

GRADE LEVELS

7 – 9

CONNECTION TO CURRICULUM

Science, Math, Technology, and Engineering

TEACHER PREPARATION TIME

4 to 8 hours

LESSON TIME NEEDED

Six 45-minute sessions

Level: Moderate

NATIONAL STANDARDS

National Science Education Standards (NSTA)

Science as Inquiry

- Understanding of scientific concepts
- Understanding of the nature of science
- Skills necessary to become independent inquirers about the natural world
- Dispositions to use the skills, abilities, and attitudes associated with science

Physical Science Standards

- Position and motion of objects

Common Core State Standards for Mathematics (NCTM)

Expressions and Equations

- Represent and analyze quantitative relationships between dependent and independent variables
- Solve real-life and mathematical problems using numerical and algebraic expressions and equations
- Understand the connections between proportional relationships, lines, and linear equations

ISTE NETS and Performance Indicators for Students

Creativity and Innovation

Students:

- Apply existing knowledge to generate new ideas, products, or processes
- Create original works as a means of personal or group expression
- Use models and simulations to explore complex systems and issues
- Identify trends and forecast possibilities

Critical Thinking, Problem Solving, and Decision Making

Students:

- Identify and define authentic problems and significant questions for investigation
- Plan and manage activities to develop a solution or complete a project
- Collect and analyze data to identify solutions and/or make informed decisions
- Use multiple processes and diverse perspectives to explore alternative solutions

MANAGEMENT

To prepare yourself and your classroom for this Engineering Design Challenge, you should use the Background Information section in this guide, and the Engineering Design Challenge Web site at <http://edc.nasa.gov>.

Become familiar with the spacecraft structures used by NASA and the science and engineering concepts you will be introducing. Notify parents about the project using the flier included in the “Masters” section.

If students discover the beginning stages of a design failure before they have successfully launched three times, they can be allowed to stop testing and repair their design.

Mass reduction is not the only goal in spacecraft design. Engineers must also strive to lower costs.

CONTENT RESEARCH

Compressive Forces: As students think about the forces on their model, they will realize that the main force on it during launch is compression, the direct result of the bottle pressing down and the lever pressing up on the thrust structure. Thinking about these compressive forces offers an opportunity for learning more about what is actually going on before, during, and after launch. Before launch, as the thrust structure and rocket rest on the launch lever, the forces are balanced and, therefore, there is no acceleration. During launch, there clearly is acceleration, and, therefore, there must be unbalanced forces on the thrust structure and the rocket because they accelerate. After launch, there is, again, acceleration (or deceleration, depending on the frame of reference) as the rocket gradually slows down and stops at its apogee. So, there must be unbalanced forces causing this acceleration. Acceleration would continue (downwards) if the catcher did not catch the rocket and prevent it from falling.

If students have done static testing, they will have an idea of the amount of force exerted on the thrust structure during launch. This will be the weight that they determined the thrust structure had to support. This is the force that the bottle experiences during launch. Force can be calculated using the following formula: $F = ma$. Using $a = F/m$, they can calculate the acceleration the bottle experiences. This is the so-called g-force.

Forces on the Thrust Structure: When the thrust structure rests by itself on the lever, there is no compressive force on the structure. The structure presses down on the lever with a force equal to its weight, for example, 0.1 N (0.022 pound-force), and the lever exerts a matching force of 0.1 N upwards on the structure. There is a force pressing up on the bottom of the structure, but no force pressing down on its top, so there is no compressive force on the whole thrust structure. When a force is exerted down on an object that is resting on a surface, the compressive force on the object is the size of that downward force.

Forces During Acceleration: When forces of different strengths are exerted on opposite sides of an object: the compressive force on the object is the size of the smaller force; and the object is accelerated by the difference between the two forces (also called the net force on the object). While a nonaccelerating object (that is not deformed) transmits all of the force exerted on one side of it to the object on the other side of it, accelerating objects transmit only some of the force exerted in the direction of their acceleration.

Energy Transfer: Gravitational potential energy is the stored energy an object has due to its position and kinetic energy is energy of motion. As the sandbag falls it loses height and simultaneously accelerates. It gains kinetic energy and loses potential energy. When it hits the launch lever, some of its kinetic energy is transferred to the lever, which transfers energy to the thrust structure. The thrust structure accelerates and gains kinetic energy. It pushes on the bottle, which accelerates and also gains kinetic energy. As the bottle rises, it slows down and reaches a maximum height of about 39 inches (1 meter). (It slows down because gravity decelerates it.) At its apogee (highest point), it has no kinetic energy and has its maximum gravitational potential energy (PE). $PE = mgh$; where m = the mass of the object; g = the acceleration due to gravity; h = the height above the Earth. In the case of the sandbag, if it has a mass of 10 kilograms and is about 0.5 meters above the Earth, and if g is approximately 10 m/sec/sec, then $PE = 10 \times 0.5 \times 10 = 50$ joules (1 joule = 1 kg · m²/sec²).

The Significance of Mass: Every pound that is carried to space requires fuel to do so, regardless of whether that pound is cargo, crew, fuel, or part of the spacecraft itself. The more the vehicle and fuel weigh, the fewer passengers and smaller payload the vehicle can carry. Designers try to keep all the parts of the vehicle, including the skeleton (or structure), as light as possible. To design a lightweight structure is very difficult, because it must be strong enough to withstand the tremendous thrust (or force) of the engines during liftoff. Throughout the history of space vehicles, engineers have used various strategies for the structure. To make the Ares spacecraft as light as possible, NASA engineers are constructing them of lightweight yet strong materials such as Al-Li 2195, an aluminum-lithium alloy, which is less dense and stiffer than pure aluminum. NASA engineers also design structures that use as little material as possible to achieve the strength and rigidity they need. For example, they make use of a network of hollow tubular struts (called a truss) rather than use more compact, but heavier solid beams.

Engineering Design Process: Identify a problem/challenge, brainstorm, design, test and evaluate, share solutions, redesign, test, and continue to repeat testing, sharing solutions, and redesigning until the best possible solution to the problem or challenge is found.

LESSON ACTIVITIES

- Session 1: Introducing the Challenge and Getting Started: Overview of NASA's Spacecraft Structures, demonstrate the launch stand with teacher's poorly designed thrust structures, explain data recording sheets, journals, and culminating activity.
- Session 2: Design 1: Review safety issues found in the guide, introduce the materials, design, build, test, record, and share solutions.
- Sessions 3 and 4: Designs 2, 3, 4, and 5 and repeat cycle
- Session 5: Construct a storyboard or poster of final design testing results, sketches, steps throughout development, and journals.
- Session 6: Student Presentations Linking Design Strategies and Observations to Science Concepts.
http://www.nasa.gov/pdf/221640main_EDC_Spacecraft_Structures.pdf

ADDITIONAL RESOURCES

Spacecraft Design:

<http://www.sti.nasa.gov/sscg/18.html>

Order a classroom activity kit from NASA CORE Catalog:

<http://corecatalog.nasa.gov/item.cfm?num=300.0-41A>

NASA Career Corner for Grades 5–8

<http://www.nasa.gov/audience/forstudents/5-8/career/index.html>

Discover Engineering Online

<http://www.discoverengineering.org>

Marshall Space Flight Center

<http://www.nasa.gov/centers/marshall/home/>

NASA Education Home Page

<http://education.nasa.gov>

DISCUSSION QUESTIONS

- Why is it important to make the launch vehicle as lightweight as possible? *Every pound that is carried to space requires fuel to do so, regardless of whether that pound is cargo, crew, fuel, or part of the spacecraft itself. The more the vehicle and fuel weigh, the fewer passengers and smaller the payload the vehicle can carry.*

- What are some ways NASA engineers could make the Ares launch vehicles as lightweight as possible? *NASA engineers can construct them of lightweight yet strong materials such as Al-Li 2195, an aluminum-lithium alloy, which is less dense and stiffer than pure aluminum. NASA engineers also design structures that use as little material as possible to achieve the strength and rigidity they need.*
- If it costs \$10,000 to lift a pound (half a kilogram) of payload into orbit aboard the International Space Station, calculate the cost of sending yourself into space. How much would it cost to send yourself, your family, and your pets into space? *Answers vary.*
- How much mass is your group launching to orbit? *Answers vary.*
- What is the source of the propulsive force? *22 pounds or a 10 kilogram bag of sand.*
- What forces are acting on the bag of sand when it is suspended in the air before the drop? *Gravity and the student's muscles.*
- What forces are acting on the bag when it is released? *Gravity.*
- How does the sandbag have energy? *By virtue of its position.*
- How does it get its energy? *From the pull of gravity on it.*
- Does it have energy when it is sitting on the ground or only when it is held aloft? *It has useful energy with respect to the launch lever only when it is held aloft.*
- Would it have more energy if it were more massive? *Yes.*
- Would it have more energy if it were held higher? *Yes.*
- Where does the energy come from that moves the sandbag from the floor to its position above the launch lever? *Human muscles, which are powered by chemical reactions.*
- Would the sandbag have the same energy if it were positioned the same height above the surface of the Moon? *No, because the gravitational field of the Moon is less than that of the Earth. It would also take less muscular effort to lift the sandbag into position on the Moon.*
- If you replicated the whole launch on the Moon, would the bottle rocket rise to the same height? What would be different on the Moon? What would be the same? *Answers will vary. The mass of the bottle and the sand would be the same, but the acceleration due to gravity would be different, therefore the amount of stored energy would be different.*
- What do we call the kind of energy that the sandbag has due to its position? *Potential energy (PE).*
- How does the sandbag transfer energy to the thrust structure and the rocket? *Students may be able to explain that as the sandbag falls, it loses height and simultaneously accelerates. It gains kinetic energy and loses potential energy. When it hits the launch lever, some of its kinetic energy is transferred to the lever, which transfers energy to the thrust structure. The thrust structure accelerates and gains kinetic energy. It pushes on the bottle, which accelerates and also gains kinetic energy. As the bottle rises, it slows down and reaches a maximum height of about 39 inches (1 meter). It slows down because gravity decelerates it. At its apogee (highest point) it has no kinetic energy and has its maximum gravitational potential energy.*
- How did the launch structure transmit the force of launch from the lever to the bottle? *When forces of different strengths are exerted on opposite sides of an object, the compressive force on the object is the size of the smaller force; and the object is accelerated by the difference between the two forces (also called the net force on the object).*
- What happened to each part of the thrust structure during the testing? *Answers vary.*
- Did any parts of the design seem to fail before the rest? Why? *Answers vary.*
- Which design features were most effective? What made the designs effective? *Answers vary.*

ASSESSMENT ACTIVITIES

Use a rubric to evaluate student's work on the storyboards, journals, and student presentations of their test results, designs, and solutions to the challenge. Criteria for evaluation are included in the educator guide.

ENRICHMENT

Increasing the Rocket Mass

Add additional design constraints to increase the challenge. The most obvious modification would be to add mass to the rocket.

Changing the Cardboard Plate

You may also wish to use a different shape, size, or thickness of cardboard or give students the option of modifying the cardboard. Doing away with the cardboard altogether will make the challenge much more difficult.