Thermal Protection Systems Challenge

DESCRIPTION
This activity challenges students to solve a real-world problem that is part of the space program while learning about heat and heat transfer.

OBJECTIVES
Students will

- 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
- Record observations and organize data so that they can be exchanged with others and referred to later
- Apply the design process to a problem

NASA SUMMER OF INNOVATION

UNIT
Engineering—Challenges

GRADE LEVELS
7 – 9

CONNECTION TO CURRICULUM
Science, Math, Technology, and Engineering

TEACHER PREPARATION TIME
4 to 8 hours

LESSON TIME NEEDED
Seven 45-minute sessions *Complexity: Advanced*

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
- The dispositions to use the skills, abilities, and attitudes associated with science

Physical Science Standards
- Transfer of energy

Common Core State Standards for Mathematics (NCTM)

Geometry
- Solve real-life and mathematical problems involving angle measure, area, surface area, and volume

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, familiarize yourself with the Background Information section in the Engineering Design Challenges: Thermal Protection Systems Educator Guide. Try out the activity yourself and notify parents using the flier included in the back of the guide. Students should work in cooperative groups of 3 to 4.

CONTENT RESEARCH

Heat and Heat Transfer: Heat is a form of energy. Heat always flows from a hotter place to a cooler place. The hotter place is sometimes called a heat source and the cooler place is sometimes called a **heat sink**. Heat transfer occurs in three ways.

Different Sources of Heat

Conduction: Heat moves by conduction when it flows through a solid substance or when heat flows between solid substances that are in direct contact. For example, when you touch your hand to a cold water pipe, heat flows from your hand to the pipe by conduction. Materials that conduct heat well are called thermal conductors, while those that conduct heat poorly are called thermal insulators. Metals are good conductors while wood, glass, cork, ceramic, and plastic foam are good insulators. Air is an insulator. Small pockets of air in wool, fur, and feathers keep heat from passing through, making these materials good insulators. Air spaces are also used to insulate buildings—for example, between double pane windows.

Convection: Heat moves by convection when it flows through a liquid or gas because the liquid or gas particles move. In the winter when you feel a draft coming off a cold window, you are feeling a convection current of air. When a “warm front” of weather moves in, the warmth is brought by hot molecules of air traveling across the Earth, in a huge convective stream. When you see “heat” rising over a radiator or over any hot surface, you are seeing a convective current of warm air.

Radiation: Heat moves by radiation when it flows through empty space or a transparent medium without heating the space or the medium. Heat reaches Earth from the Sun by means of radiation. When you feel the heat of glowing coals or of a hot wood stove, you are feeling radiated heat. Radiated heat travels as electromagnetic waves. Most of the thermal energy is in the infrared portion of the spectrum, which is not visible.

MATERIALS

- A propane torch
- Copper, aluminum, or brass screening
- Aluminum foil
- Wooden dowels
- Hot melt glue pot or glue gun and glue
- Brass machine screws, nuts, and washers
- Plywood
- Poster paper
- Markers
- Safety goggles
- Ring stand and clamps
- Fire extinguisher

How Thermal Protection Systems (TPS) Work: Different methods can be utilized to enable a TPS to keep heat from reaching the inside of a spacecraft. One method is to use a covering material that will absorb the heat and radiate it back into space, away from the spacecraft. All materials radiate heat when they get hot. You can feel this whenever you put your hand near something hot like a radiator, a hot stove, or the coals of a campfire. However, only certain materials can radiate heat so efficiently that the heat does not build up within the material and pass it into the spacecraft or possibly melt the body of the spacecraft. Another way a TPS works is to let small bits of itself actually burn and fall away from the spacecraft. These materials neither absorb nor radiate much heat, so when the surface becomes very hot, the material starts to burn and erode. The term “ablation” describes this process of material being eroded by heat.

Keeping the TPS Light: A launch vehicle’s engines can lift a certain amount of weight into orbit. That weight is divided between two parts: the weight of the vehicle itself (including the fuel) and the weight of the passengers and the payload. The more the structure of the vehicle weighs, the fewer passengers and smaller the payload it can carry. Engineers try to keep all the parts of the vehicle, including the thermal protection system, as light as possible so that more of the weight can be used for passengers and payload.

LESSON ACTIVITIES

- Session 1: Introducing the Challenge and Getting Started: Overview of NASA's Thermal Protection Systems, review safety procedures, demonstrate the test assembly with basic rocket models without TPS to establish the baseline average protection time for system (glue) failure, explain data recording sheets, journals, and culminating activities.
- Session 2: Design 1: Review safety issues found in the guide, introduce the materials, and design, build, test, record, and share solutions.
- Sessions 3 and 4: Designs 2, 3, 4, and 5: 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

ADDITIONAL RESOURCES

Space Shuttle Thermal Protection Systems
http://www.youtube.com/watch?v=RJzyB_qEWyU

NASA Career Corner for Grades 5–8
http://www.nasa.gov/audience/forstudents/5-8/career/index.html

Discover Engineering Online
www.discoverengineering.org

NASA Education Home Page
http://education.nasa.gov

DISCUSSION QUESTIONS

- What are two sources of heat that NASA engineers are protecting against? *Heat from friction between the atmosphere and the speeding spacecraft and heat from the combustion of fuel.*
- Name two different approaches to providing thermal protection. How does each type work? *Radiation and ablation. Materials that protect by radiation radiate heat very efficiently; as soon as they start to absorb heat they release it very efficiently. They also have a high thermal capacity; they can absorb a lot of heat without heating up very much themselves. Materials that protect by ablation do not absorb or conduct heat very well. Heat erodes them; their surfaces burn and fall away, carrying heat away from the spacecraft.*
- How does the heat from the flame reach the glue? *Convection and conduction.*
- What made this design last so long? *Answers will vary.*
- How does this model simulate the thermal protection problems faced by a spacecraft such as the Ares? *Using the figure in the guide students should make comparisons to the figure of the Ares Rocket.*
- How are they similar? How are they different? *Answers will vary.*
- The spacecraft has an "inside" that must be protected. What part of the model represents the inside? What is it that must be protected on the model? *Glue.*
- What part of the model represents the "skin" of the spacecraft? *The screw.*
- How did the TPS keep the heat of the flame from reaching the glue? *Answers will vary.*
- What happened to each part of the TPS during the testing? *Answers will vary.*
- Did any parts of the design seem to heat up more than the rest? How could you tell? *Answers will vary.*
- Which model designs were most effective? What made these designs effective? *Answers will 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

Turning up the Heat:

The simplest way to make the challenge more difficult is to increase the flame length. You may also want to test the same design with different flame lengths and then plot the data. Students can thus find a relationship between flame length and protection time.

Limiting Designs by Mass:

The Ares TPS must weigh as little as possible. To achieve this, engineers use the lightest weight materials that can provide the protection needed. Challenge students to build the lightest weight TPS that still achieves a minimum protection time. Have students plot mass versus protection time. You will want to determine in advance whether the washers and nuts are a mandatory or optional part of the TPS as removing them dramatically reduces the TPS mass.

Limiting Designs by Size

Students may find that a long thin TPS extending toward the flame will be very effective. However, it would be unrealistic for a spacecraft to employ a TPS that would significantly increase its size. You might add the challenge that the TPS be as small as possible. Alternatively, you may add the design constraint that the TPS must be “smaller than an egg” or “smaller than a lemon” or a similar object. You might also construct a box into which the TPS must fit before testing, similar to the box used for carry-on bags at the airport.

Designing on a Budget

One goal of the Constellation program is to have a low cost way of getting to space. This means that cost must be a design constraint in every aspect of the design.

Designing With Additional Materials

The brass screw, copper screen, and aluminum foil have been chosen for their high conductive ability. This keeps the protection time fairly low and avoids long waits during testing, which can adversely affect student engagement. You may wish to experiment with materials that are more heat resistant.

Measuring Where the Heat is With a High-Temperature Probe

If you have a high temperature probe, you can use it to show students where the hottest part of the flame is and how the heat travels from the flame.

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