Thermal Protection Systems
(Adapted from NASA Educator Guide "Thermal Protection Systems")

Objectives

Students Will:

- Identify factors that determine the conduction rate of heat through a solid
- Identify several materials that are good conductors and several materials that are good insulators
- Research how NASA uses thermal protection systems on their space vehicles
- Build a structure what will protect a model of a designed spacecraft vehicle from the heat of a propane torch for as long as possible

Suggested Grade Level

6^{th} – 9^{th}

Subject Areas

Science, Engineering

Timeline

120 minutes

Standards

- MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.
- MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- MS-PS1-6. Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.

21^{st} Century Essential Skills

- critical thinking/problem solving, collaboration and teamwork, communication, information literacy, carrying out investigations, constructing explanations, designing solutions, obtaining/evaluating/communicating ideas

Background

Perhaps the biggest challenge faced when designing reusable spacecraft technology is how to keep the vehicle from burning up on launch and when it re-enters the Earth's atmosphere. The tremendous heat caused by friction with the Earth's atmosphere must be kept from reaching the skin of the spacecraft. This is the purpose of the Thermal Protection System (or TPS).

The Space Shuttle Thermal Protection System, as shown in this image, protected the Space Shuttle orbiter during the 3,000-degree heat of the atmosphere during re-entry! The TPS also protected the shuttle from the extreme hot and cold temperatures of space while in orbit. The Shuttle had surface materials with capabilities to withstand high temperatures, along with an underlying thermal insulation to minimize heat conduction to the interior of the space vehicle.

Conduction is the process by which heat is directly transmitted through a substance when there is a difference of temperature between adjoining regions, without movement of the material. Insulation uses a material to prevent or reduce the passage, transfer, or leakage of heat. The thermal conductivity of a material is measured in Watts per meter per degree Kelvin (W/mK). Examples of metals that are thermally conductive are copper, silver, gold, aluminum, and silicon carbide.

Thermal Protection Systems are vital for space vehicles in order to maintain acceptable temperatures. Engineers must design lightweight, cost-efficient, yet effective, reusable thermal protection systems in order to protect these valuable space assets. Thermal Protection Systems are found in items here on Earth as well; some examples include cell phones, NASCAR racecars, and SCUBA diving equipment.

Vocabulary

Thermal, heat, heat transfer, conduction, convection, radiation, thermal conductors, thermal radiators, specific heat, heat capacity

Materials

- Propane torch
- Copper, aluminum, or brass screening
- Aluminum foil
- Wooden dowels
- Hot glue gun
- Brass machine screws, nuts, and washers
- Safety goggles

Revised: May/2020

- Thermal gloves
- Fire extinguisher
- Poster paper
- Markers
- Ring stand and clamps (optional)

Lesson

(Prepare a test assembly of a thermal protection system before the lesson. You may also choose to hot glue the wooden dowels to the screws in advance of the lesson).

1. Explain to students that they will take on the role of engineers for this lesson. They will attempt to solve a problem that engineers face when developing reusable spacecraft technology. Use the background information, and pictures, videos, or models of the Space Shuttle to introduce the concept of a reusable launch vehicle.
2. Introduce the term "Thermal Protection System" and ask students what they think it means. Ask students to think of examples of thermal protection in everyday items.
3. Have students research the conductive properties of copper, aluminum, and brass screening, as well as aluminum foil. These are the materials they will be using to design their TPS.
4. Explain to students that their challenge is to build the best possible thermal protection system for a model of a reusable spacecraft vehicle that you will test in the classroom.
5. Pass around the prepared test assembly and explain that it will simulate a portion of the spacecraft. Discuss the relationship between the test assembly and the spacecraft using the below questions.
    a. How does the model test assembly simulate the thermal protection problem faced by designers of reusable spacecraft vehicles?
    b. How are the test assembly model and the spacecraft similar?
    c. What part of the test assembly model represents the inside of the spacecraft that must be protected? Students should recognize that the glue represents the inside of the spacecraft while the screw represents the outside.
    d. What part of the test assembly model represents the "skin" of the spacecraft?
6. Explain that the test assembly will be held over the flame of a propane torch until the glue melts and the screw falls off. Explain that their goal is to keep the screw from falling off for as long as possible.
7. Explain that engineers always face design constraints and restrictions. Sometimes they are restricted by how much it would cost to build something. Other times they are restricted by how long it may take to build, along with many other constraints.

Discuss why the TPS cannot touch the dowel or the glue (because they represent parts inside the spacecraft). Explain the design constraints for students:
   a. Use only the specified materials to construct the TPS.
   b. No glue may be used in the TPS design itself.
   c. No part of the TPS may touch the dowel.
   d. No part of the TPS may touch the glue.
8. Discuss potential design ideas and strategies.
9. Have the students complete the Design Results sheet (located on page 75).
10. Provide students ample time to discuss design ideas with their team and build a thermal protection system, using the specified materials, that protects the model for the longest possible time.
11. The teacher will test each team's design by holding the TPS over a flame of a propane torch. Time how long the TPS remains intact (i.e. how long until the glue melts and the screw falls off). Teacher should wear protective clothing and eye protection during the tests. Have a fire extinguisher readily available in case of emergency.
12. After all teams have tested their design, discuss the results with students. The post-test discussion is critical to expanding students' learning beyond the design and construction techniques and connecting their design work with the science concepts underlying their work. Encourage students to hold their model TPS (after it has sufficiently cooled) and use it to illustrate their point when they discuss a particular design feature.
    a. For each model, pose any of the following questions:
        i. i) How did the TPS keep the heat of the flame from reaching the glue?
        ii. ii) What happened to each part of the TPS during the testing?
        iii) Did any parts of the design seem to heat up more than the rest? How could you tell?
        iii. iv) Which model designs were most effective? What made these designs effective?
13. Record (or have students record) the most successful design features on a wall chart. This list should be expanded and revised throughout the discussion.

Extensions

- Students document their designs with sketches and written descriptions.
- Assign monetary value to the materials and propose a second challenge that the team who designs the most protective TPS, while having the lowest budget, is the winner.
- As a culmination, students compile their results into a poster and present them to the class.

Resources

- Conduction. (n.d.). Retrieved May 21, 2020, from https://www.dictionary.com/browse/conduction?s=t
- Dunbar, B. (2009, July 13). Engineering Design Challenges: Thermal Protection Systems Educator Guide. Retrieved May 20, 2020, from https://www.nasa.gov/stem-ed-resources/edc-thermal-protection.html
- Space Shuttle thermal protection system. (2019, December 19). Retrieved May 19, 2020, from https://en.wikipedia.org/wiki/Space_Shuttle_thermal_protection_system
- Thermal Protection. (n.d.). Retrieved May 21, 2020, from https://www.sciencedirect.com/topics/engineering/thermal-protection