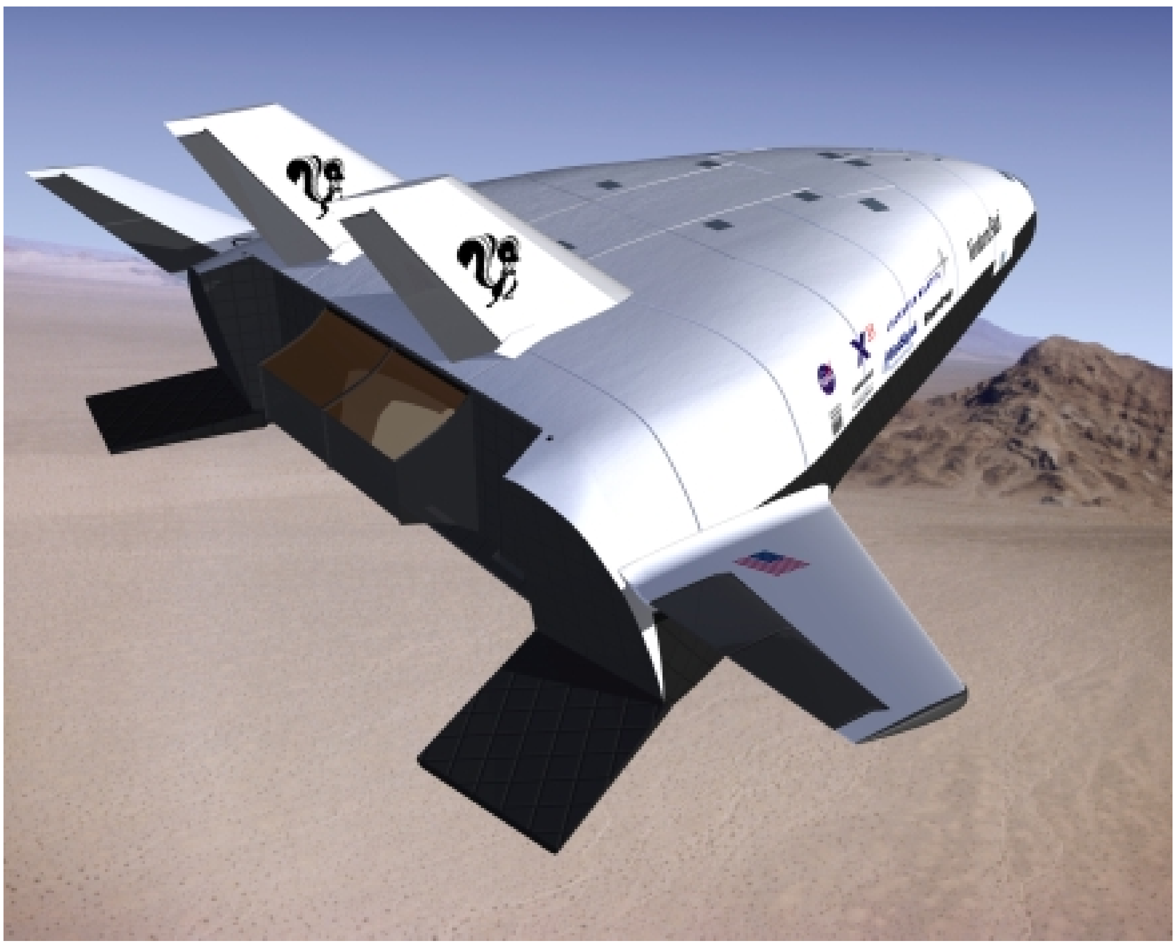
National Aeronautics and
Space Administration

| Educational Product | |
|---|---|
| Educators | Grades 6-9 |

# NASA Earth-to-Orbit Engineering Design Challenges

## Thermal Protection Systems



Sponsored by

NASA Marshall Space Flight Center, Huntsville, AL

NASA Dryden Flight Research Center, Edwards, CA

Designed by

TERC, Cambridge, MA

# Table of Contents

# NASA Earth-to-Orbit Engineering Design Challenges

## Thermal Protection Systems

## Overview

### Space Transportation

NASA Engineers at Marshall Space Flight Center, Dryden Flight Research Center, and their partners at other NASA centers and in private industry are currently developing X-33, a prototype to test technologies for the next generation of space transportation. This single-stage-to-orbit reusable launch vehicle (SSTO RLV) may replace the Space Shuttle Orbiter and greatly reduce the cost of putting people, satellites, and scientific experiments into space.

### Connect to Engineering and Science

The Earth-to-Orbit Engineering Design Challenges connect students with the work of NASA engineers by engaging them in related design challenges of their own. With some simple and inexpensive materials, you can lead an exciting unit that focuses on a specific problem that NASA engineers must solve and the process they use to solve it. In the classroom, students design, build, test, and revise their own solutions to problems that share fundamental science and engineering issues with the challenges facing NASA engineers.

### The Design Challenge

You will present students with a challenge: build a structure from aluminum foil and copper screening that will protect a model of the X-33 from the heat of a propane torch for as long as possible. Students first measure the "protection time" of an unprotected model. Then they design, build, test, and revise their own thermal protection systems. They document their designs with sketches and written descriptions. As a culmination, students compile their results into a poster and present them to the class.

### Materials

You will need a few simple and inexpensive materials:

- A propane torch
- Some copper, aluminum, or brass screening
- Some aluminum foil
- Some wooden dowels
- A hot melt glue pot or glue gun and some glue (try a craft store)
- Some brass machine screws, nuts, and washers
- Some scraps of plywood
- Poster paper
- Markers
- Safety goggles
- A ring stand and clamps
- A fire extinguisher

## Time Required

The design challenge can be carried out in seven 45-minute class periods, but you could easily extend it for twice that long. We give some ideas for Extensions at the end of the guide.

You will need to invest 4-8 hours gathering the materials, building the test stand, trying out your own designs, reading the guide, and preparing the classroom.

## Value to Students

These activities help students achieve national goals in science, math, and thinking skills. In the pilot testing of the design challenge, students embraced the design challenge with excitement. The value of this activity to your students is the opportunity to solve a challenge based on a real-world problem that is part of the space program and to use creativity, cleverness, and scientific knowledge in doing so. Students have many opportunities to learn about heat and heat transfer during the activities. The culminating activity gives students an opportunity to develop their presentation and communication skills.

## Student Research Opportunities

The Resources section of this guide includes many web sites where students can obtain additional information.

## Parent Involvement

The Masters section of this guide includes a reproducible flyer to send home to inform parents about the activity and includes suggested activities students and parents can do at home together.

## Safety

These activities meet accepted standards for laboratory science safety.

# How to Use This Guide

This guide is divided into several sections:

- National Science Education Standards
- Math Connections
- Thinking Skills
- Background material
- Preparation for the challenge
- Day-by-day procedures
- Detailed materials list
- Extensions
- Resources
- Masters

## National standards

If you have questions about how this activity supports the national science education standards, math connections, and thinking skills, read these sections that follow immediately. Otherwise, refer to those sections as you need them.

## Suggested order of reading

First, skim through the entire guide quickly to see what is included.

Next, read through the Classroom Sessions that describe what happens in each of the seven sessions. Give special attention to the last part: "Linking Design Strategies and Observations to Science Concepts." This gives explicit suggestions on how to help students understand the science in their designs. Review this section once you start classroom work with your students.

Be sure to read the last two sections in the Teacher Preparation section: "Teaching Strategies for an Engineering Design Challenge" and "Helping Students Understand the Design Process." These will help you understand what is distinctive about an engineering design challenge and how your students can get the most out of it.

When you understand the session-by-session flow and the pedagogical approach on which it is based, read the Background section. This will provide you with information you will want to have in mind to "set the stage" for students and to link their classroom work with the work of NASA engineers. It focuses on one of the challenges faced by NASA engineers in developing a reusable launch vehicle: the thermal protection system (TPS). You will find information here about thermal protection systems in general, about the system used on the Space Shuttle, and about the new design for the X-33. An overview of the concepts of heat and heat transfer follows the section on thermal protection systems.

Further resources for you and your students can be found in the Resources section.

The reproducible masters you need are in the Masters section.

Finally, read the remainder of Teacher Preparation to find out how to prepare your classroom and yourself to conduct the engineering design challenge. It contains safety guidelines, lists of materials, suggestions for organizing the classroom, and teaching techniques.

# National Science Education Standards

This Earth-to-Orbit Engineering Design Challenge supports the following Content Standards from the National Research Council's National Science Education Standards.

## Science as inquiry

All students should develop abilities necessary to do scientific inquiry.

### Fundamental abilities and concepts

- Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables
- Students should use appropriate tools and techniques, including mathematics, to gather, analyze, and interpret data
- Students should base their explanation on what they observed; providing causes for effects and establishing relationships based on evidence
- Students should think critically about evidence, deciding what evidence should be used and accounting for anomalous data.
- Students should begin to state some explanations in terms of the relationship between two or more variables
- Students should develop the ability to listen to and respect the explanations proposed by other students
- Students should become competent at communicating experimental methods, following instructions, describing observations, summarizing the results of other groups, and telling other students about investigations and explanations
- Students should use mathematics in all aspects of scientific inquiry

All students should develop understandings about scientific inquiry.

### Fundamental abilities and concepts

- Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables
- Mathematics is important in all aspects of scientific inquiry
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations
- Scientific explanations emphasize evidence
- Scientific investigations sometimes generate new procedures for investigation or develop new technologies to improve the collection of data

## Physical science

All students should develop an understanding of transfer of energy.

### Fundamental concepts and principles

- Energy is a property of many substances and is associated with heat and light
- Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature

**Students respond positively to the practical, outcome orientation of design problems before they are able to engage in the abstract, theoretical nature of many scientific inquiries.**
**–National Science Education Standards, National Research Council**

**Complete text of the National Science Education Standards http://books.nap.edu/html/nses/html/**

**Complete text of Benchmarks for Science Literacy http://watt.enc.org/online/ENC2299/2299.html**

**Through design and technology projects, students can engage in problem-solving related to a wide range of real-world contexts. By undertaking design projects, students can encounter technology issues even though they cannot define technology. They should have their attention called to the use of tools and instruments in science and the use of practical knowledge to solve problems before the underlying concepts are understood.**

**–Benchmarks for Science Literacy, AAAS**

## Science and technology

All students should develop abilities of technological design.

### Fundamental concepts and principles

1. Design a solution or product
   a. Consider constraints
   b. Communicate ideas with drawings and simple models
2. Implement a design
   a. Organize materials
   b. Plan work
   c. Work as collaborative group
   d. Use suitable tools and techniques
   e. Use appropriate measurement methods
3. Evaluate the design
   a. Consider factors affecting acceptability and suitability
   b. Develop measures of quality
   c. Suggest improvements
   d. Try modifications
   e. Communicate the process of design
   f. Identify stages of problem identification, solution design, implementation, evaluation

The challenge satisfies the following criteria for suitable design tasks:

- Well defined, not confusing
- Based on contexts immediately familiar to students
- Has only a few well-defined ways to solve the problem
- Involves only one or two science ideas
- Involves construction that can be readily accomplished by students without lengthy learning of new physical skills or time-consuming preparation or assembly

All students should develop understandings about science and technology.

- Difference between scientific inquiry and technological design
- Technological designs have constraints
- Technologies cost, carry risks, provide benefits
- Perfectly designed solutions don’t exist; engineers build in back-up systems

# Math Connections

This Earth-to-Orbit Engineering Design Challenge offers the opportunity to integrate a variety of math skills described in the following table. Some of the applications listed are part of extension activities.

| Skillf | Application |
|---|---|
| Reading and writingf time measurements | Recording protection times |
| Performing operationsf with decimal numbersf | Protection time, size of TPS, quantities of materials |
| Roundingf | Rounding protection time to the second, tenth of a second, etc. |
| Calculating averagesf | Calculating average, mean, median, mode, or range for multiple tests of the same design, for all designs by one team, or for the entire class |
| Graphingf | Creating line graphs, bar graphs, circle graphs, or scatterplot of protection time<br>Graphing protection time vs. mass of TPS<br>Graphing protection time vs. size (width, length, diameter) of TPS |
| Measuring percentage improvementf | Comparing designs by one team, calculating improvement for the entire class |
| Calculating ratiosf | Determining the relationship between the quantity of materials used and protection time; between the flame length and protection time |
| Using a budgetf | See the extension activity: Designing on a Budget |

# Thinking Skills

This Engineering Design Challenge provides an opportunity to assess students' development of critical thinking skills in a context in which these skills are applied throughout the task. Students are often asked to perform critical thinking tasks only after they have mastered such lower-level thinking skills as making simple inferences, organizing, and ranking. In this learning activity various levels of thinking skills are integrated. The following rubric is designed to assist you in assessing students mastery of thinking skills.

**Cognitive memory skills**

1. Students accurately measure the protection time and compute the average time?
2. Students observe a design before testing and pick out the "key features"
3. Student observe a model during and after testing and document precisely what happens to the model
4. Students record observations and organize data so that they can be exchanged with others and referred to later

**Structuring, organizing, relating skills**

5. Students can classify designs
6. Students can rank designs according to various criteria, i.e., protection time, mass
7. Students can create diagrams, charts and graphs of the results
8. Students can visualize relationships such as part-whole, cause-effect
9. Students can interpret such information as test results and design documentation
10. Students can compare and contrast different design solutions

**Convergent and generalizing skills**

11. Students can demonstrate that they understand the challenge
12. Students can draw conclusions and generalize
13. Students can converge on a solution by choosing from alternatives

**Divergent thinking skills**

14. Students can apply ideas and concepts of heat transfer to their designs
15. Students can make inferences and predictions about the performance of a design
16. Students can invent and synthesize a solution
17. Students can devise an experiment to test a particular theory
18. Students can balance trade-offs between cost, quality, safety, efficiency, appearance, and time

**Evaluation skills**

19. Students can evaluate designs based on given criteria
20. Students value new knowledge

- Includes test results and description of what happened to the design during the test
- Includes conclusion about the most effective thermal protection system
- Uses scientific vocabulary
- Has an appealing layout with a title
- Correct grammar and spelling

You may optionally assign additional research or invite students to do research on their own initiative. Research findings could also be included on the storyboard. See the resource list in the back of the guide for suggested starting points. Students could investigate:

- Thermal protection systems used in rockets
- Thermal protection systems used in other devices and vehicles
- Properties of materials
- Properties of a propane flame

## 3. Create the storyboards

Give students an entire class session to create their storyboards. You might take this opportunity to encourage students to practice sketching detail and section views of the models as described in Session 2.

**See the Math Connections section earlier in this guide for additional suggestions for graphing and analysis that could be included on the final posters.**

You might also want to assign several students to prepare a "results" poster for the entire class. This poster would make use of the charts on which you recorded data from each test session. The overall improvement of the class could be calculated and displayed.

### Optional extension:

Students may create their storyboards electronically using digital photographs of their models and may post their presentations on a school web site.

# Session 7

## Student Presentations

When all storyboards have been completed, put them on display in the classroom. Allow students time to browse among the posters. Encourage conversation. Then reconvene the class and allow each team a few minutes to present their storyboard.

Another option is to conduct a poster session as might occur at a professional conference. Half the teams would remain with their posters to answer questions while the other teams browse. After about 15 minutes, the browsing teams stand by their posters while the other teams browse. Browsing teams should ask questions and engage the presenting teams in conversation.

The poster session provides an opportunity to invite parents, other teachers, and students from other classes in to view student work.

### Learning goals

- Communicate results to an audience

# Linking Design Strategies and Observations to Science Concepts

An important opportunity for science learning through this Engineering Design Challenge comes from the connections that students make between their design solutions, their observations, and the underlying scientific principles. As you observe students designing, as you conduct the testing, and as you discuss the test results, there will be numerous opportunities to draw connections between what the students are doing and the science principles of heat energy and heat transfer. This section provides suggestions and background information to help you draw those connections at the moment they arise, the "teachable moment," when students are highly engaged and receptive to new information. The section is organized according to design strategies and observations made during pilot testing of this unit.

## Observation: Changes in the foil and copper screen

Encourage students to watch carefully for changes in the TPS materials during and after testing. Careful observation of changes in the material can help determine how hot it got. When copper screen is exposed to high heat for a length of time, it first glows, then turns black, and eventually it disintegrates. If the copper screen is folded it will tend to unfold. Aluminum foil becomes faintly multihued, gets thinner, turns black, and eventually disintegrates.

The changes in the TPS materials exposed to heat are evidence of chemical activity. Many other good examples of chemical changes caused by heat occur in the cooking of food. For example, foods change color when they are cooked because there's chemical activity going on during cooking. The changes you see in the copper and aluminum are due to rapid oxidation driven by the high temperatures. Both copper and aluminum oxidize at room temperature, but the high temperatures caused by the torch increase the speed of these reactions. Students can think about how engineers must anticipate how TPS materials will react at high temperatures. Engineers also must think about the environment in which the TPS is operating. For example, at orbital altitudes there is almost no oxygen present; hence materials do not readily oxidize. But when high temperatures are encountered during reentry, oxygen is present, and oxidation reactions do occur.

Interestingly, the melting point of aluminum is higher than its combustion point. Therefore, aluminum will burn before it melts if there's oxygen present (not in space).

## Observation: Glowing

**Glowing metal is first absorbing and then radiating heat.**

Students may notice parts of the TPS, such as the copper screen and the aluminum foil, glowing. Materials glow because they are emitting electromagnetic radiation in the visible portion of the spectrum. This radiation carries away energy, so in the absence of further energy input, a glowing material gradually cools and stops glowing. Think about taking a glowing piece of hot metal from a furnace. At first, it may glow white hot, then yellow, then red, and finally stop glowing. The changes of color indicate a shift in the spectrum of light it is emitting. The spectral “signature” corresponds to the temperature of the metal. When it stops glowing, it is still warm, and still emitting radiation, but now the radiation is no longer in the visible portion of the spectrum. It is in the infrared.

Students may notice that only some parts of the TPS glow. The glowing parts are at a higher temperature than the non-glowing parts. The glowing can show students where heat is building up on the model, i.e. where the “hot spots” are. Students may notice that after a while, parts of the TPS that were glowing begin to deteriorate. Parts of the copper screen and the aluminum foil may vaporize. These “burn-throughs” destroy the structural integrity of the TPS and may allow the convective stream of hot gas from the torch to reach the glue joint. This is analogous to a “burn-through” on the TPS of a spacecraft and is to be avoided.

Compare the TPS test to what happens when you turn on the burner of an electric stove. If you put your hand above the burner, you can feel the heat radiating from it long before it starts to glow. As the coil gets hotter, it begins to glow. Where the TPS is glowing it is hottest. By observing where the model is glowing, you can tell where the largest amount of heat energy is going.

Why do hot metals glow? Metal atoms have free electrons that can be boosted into a higher energy state by an inflow of energy. When these electrons return to the lower energy state they emit photons as radiating energy. Atoms absorb heat energy and then give some of it back as electromagnetic radiation, some of which is visible light. As the material heats up, its atoms give off more and more radiating energy. As the temperature increases, more of the radiating energy is emitted as waves of shorter and shorter wavelengths. Still, most of the energy is emitted in the infrared spectrum. Only when the temperature gets high enough do the wavelengths become short enough to be visible as light.

If the TPS is glowing, then some of the heat energy it has absorbed is radiating into space rather than conducting to the screw. It’s not just conducting the heat back to the screw. Radiation actually cools the TPS.

Parts of the TPS that aren’t glowing are, obviously, not as hot, probably because they are not in the path of the hot air coming from the torch. This does not mean that those parts of the TPS are entirely ineffective; they may still be blocking some of the hot air and they may be radiating energy in the non-visible portion of the spectrum. Another possibility is that those parts of the TPS may be absorbing heat, but are conducting that heat on to something behind.

## Observation: How the heat gets to the glue

Encourage students to compare the conduction paths of various TPS designs. Trace backward, from the glue to the flame. Find the path along which heat energy flows. Which model had a more direct path? Which model had a longer path? Which model had air gaps or other insulators in the path? How does this information compare to the test results for the TPS?

## Design Strategy: Cover the tip of the screw

No matter what kind of shield you build, if the tip of the screw is exposed to the flame, the TPS will not be very successful. Shielding the screw against the hot blast of air flowing from the torch is an effective strategy. Students must come to the realization that they need to protect the tip of the screw rather than just the glue.

**Many of the kids are wrapping the screw with copper screen or aluminum foil. Some are still leaving the screw tip exposed. When asked why they wrap the screw, they say that it forms a "heat sink."**

## Design Strategy: A long conduction path

Students should understand that they can increase protection time by creating the longest and most tenuous path of conduction. You can visualize this in terms of heat flowing like a river. Just as a broad deep river will carry a lot more water than a shallow narrow stream, a wide conduction path will allow more heat to flow along it.

In constructing a long conduction path, the cooler areas of the shield might suggest locations on the TPS where connections between materials should be made in order to reduce conduction. For example, if you will be layering two pieces of foil, it will be more effective to attach the two pieces to one another as far from the flame as possible, where they stay the coolest. See the section on glowing above.

**One team created what they called "the battering ram," a tightly folded and coiled piece of aluminum foil attached to the front of the screw. They expected the thick wad of foil to take a long time to heat up.**

## Design Strategy: Wrap the screw

Students may have seen hot water pipes or tanks wrapped in a fiberglass blanket or foam sheath. The fiberglass blanket may have a backing that looks like aluminum foil. The fiberglass acts as an insulator while the aluminum foil serves to protect the fiberglass by keeping moisture out. (It also reflects some radiating energy.)

Wrapping the screw will prove a rather ineffective strategy because it ignores the issue of conduction. Because the aluminum foil or copper screen is in contact with the screw in so many places, heat energy absorbed by the wrapping will easily conduct into the screw.

## Design Strategy: Large mass of material at the end of the screw

Like wrapping the screw, this strategy does not overcome the problem of conduction. A (relatively) large mass of material in front of the screw will take longer to heat up but eventually the heat will conduct through it. Even while it is heating it will conduct heat back to the screw that it is touching. The hotter the TPS gets, the more heat will be conducted back to the screw. If you put a mass of thermally conductive material in front of but touching the screw, it will take a while for it to heat up, but the heat will eventually be conducted back to the screw.

This provides an opportunity to discuss specific heat. Materials with a lower specific heat will conduct heat energy faster. Copper will conduct heat energy 2.5 times faster than aluminum. Ask students to put their hands on different materials in the classroom to tell which ones have a lower specific heat.

## Observation: Do the holes in the copper screen matter?

Compare the performance of two similar shields, one made from copper screen and one made from aluminum foil. Because the aluminum foil is much more effective at blocking the hot air, it should protect the glue for much longer.

## Design Strategy: Reflect the heat

Students may attach a mirror-like shield of aluminum foil designed to “reflect” the heat. This would be a more appropriate description if the heat energy was radiating. But the amount of radiating energy is a negligible amount in this situation compared to the amount of energy in the hot air flowing up and away from the area around the flame. The effectiveness of a “reflecting” shield is actually found in its ability to block the hot air from reaching the screw. If the torch was pointed *down* at the TPS, the protection time would be much longer because much of the hot air would flow upward because it is less dense.

You might ask students about using aluminum foil in baking. Does it make a difference if a dish in a conventional oven is covered with foil with the shiny side up or down? No, because the aluminum is *conducting* the heat from the air inside the oven into the food. Heat in an oven is not radiating energy and therefore the reflective side of the foil will have no different effect than the dull side. This contrasts with the silvered thermal bottle which reflects radiated heat. This heat comes from the contents if they are hot and from the outside of the bottle if the contents are cold.

## Design Strategy: Deflect the heat

Students may design a flat or cone shaped heat shield to deflect the heat. It would be useful for students to think about the stream of hot gas emanating from the area around the torch. They could visualize it as a stream of water. Having in mind something like a stream will give them something to think about blocking. You might introduce the term “air convection.”

A convex shield will deflect the flow around the screw. Attaching the tip of the cone to the tip of the screw will provide a conduction path that defeats the purpose of the shield.

Some students may design a concave shield intended to deflect the heat that actually functions as a heat collector. You can compare this to a satellite dish or radar reflector. If you have a concave shape that blocks the air moving from the torch then it might cause the air to stay around the tip of the screw and heat it up even more.

## Design Strategy: Multiple layers

A TPS made of many layers can be effective in at least two ways.

If students choose to construct a TPS using multiple layers, encourage them to experiment with the amount of space they leave between layers. Layers that are tightly packed will still allow heat transfer by conduction. Loosely packed layers will create a longer conduction path and will incorporate air pockets as insulating spaces.

Layers also block heat transfer by radiation. Each layer reflects some heat back so each successive layer back is at a lower temperature. The more layers, the longer it will take before the layer connected to the screw heats up enough to conduct heat back to the screw.

## Design Strategy: Air pockets

An air pocket can serve as an effective insulator for the glue. Air pockets may be created by shaping the foil into a tube or bag shape. A loose layering of materials will trap air between the layers. Thinsulate, fiberglass insulation, down parkas, and double pane windows all use this strategy for insulation. In order to travel through an air space, heat energy must radiate from air molecule to air molecule which are much farther apart than atoms in a solid or liquid. This is why it takes much longer for heat to pass through an air space.

## Design Strategy: Increasing surface area of shield

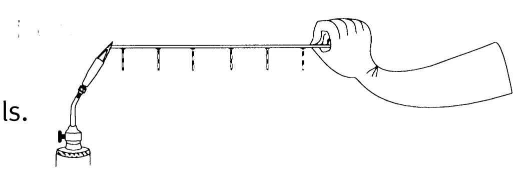
Increasing the surface area of the shield will increase the amount of heat transferred by conduction. The larger the surface area of the shield, the better it cools by conduction because more air comes into contact with the shield.

A larger surface area can be created simply by making the shield bigger, or by accordion pleating to get fins as in a radiator. Because of the materials constraints in this engineering design challenge, a large shield will need to be thinner. A smaller shield with finer fins can be just as effective as a larger flat one.

---

## Conduction Demonstration

Use this demonstration to show how heat travels gradually through a solid. This may help students understand how heat conducts through the brass screw.



To do this demonstration, you will need:

- 6-8 brass screws glued to the rod at 2-inch intervals.

- A hot melt glue gun or glue pot

- A brass or steel rod about one foot long

### Test station

Ask students to predict what will happen when you hold one end of the rod in the flame of the propane torch. If they suggest that the screws will fall off, ask them to be more specific. Will the screws drop off at equally spaced intervals of time? Will they drop off at an accelerating rate? Why or why not.

Light the torch and hold the rod by one end so that the other end is in the flame. Hold the rod in the flame until all the screws have dropped off or until the heat conducting up the rod reaches your hand.

Ask students what this demonstration can tell us about the way heat moves through the metal rod.

To illustrate different thermal conductivities, try the demonstration with rods made of different materials.

# Extensions

You may find, especially with advanced students, that students achieve protection times of over 4 minutes. At this stage, you may want to add additional design constraints to increase the challenge.

## 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 plot the data. Students can then find a relationship between flame length and protection time.

## Limiting designs by mass

The X-33 TPS must weigh as little as possible. To achieve this, engineers use thin layers of metal combined with lightweight insulating material. 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.

## Limiting designs by cost

**You can find information about the Space Shuttle at http://www.nasa.gov/qanda/space_shuttle.html**

A primary goal of the X-33 project is to design a low cost way of getting to space. This means that cost must be a design constraint in every aspect of the design.

Ask students to brainstorm about what NASA engineers must do to reduce the cost of getting to space. Holding up a model of the space shuttle or referring to a poster will be useful in stimulating student ideas. You might want to discuss such facts about the Space Shuttle as how much fuel it uses, which parts are reusable and which are not, what needs to be done to the Space Shuttle to prepare it for launch, etc. Possible answers include: Make sure all the parts can be reused, make the vehicle lighter so it uses less fuel, use less expensive materials, make it more durable so you don't need to do much to it to prepare for the next launch, make a better engine that uses less fuel, make the engine more powerful so you can carry more on a single launch, use less expensive fuel. Students are less likely to come up with ideas for cutting costs such as designing faster and testing more efficiently.

# Masters:
# NASA Earth-to-Orbit Engineering Design Challenges

## Thermal Protection Systems

# NASA Earth-to-Orbit Engineering Design Challenges

Dear Parent:

Your child is beginning an exciting unit in science class entitled the NASA Earth-to-Orbit Engineering Design Challenge. This unit will connect students with the work of NASA engineers by engaging them in a related design challenge in their classroom. Students will design, build, and test their own solutions to a design problem similar to one faced by NASA engineers.

## Thermal Protection Systems

NASA is currently developing the X-33, a reusable spacecraft technology demonstrator that may one day replace the Space Shuttle as a low-cost way to put people and satellites into orbit. The X-33 is undergoing testing at Marshall Space Flight Center in Huntsville, AL, and at Dryden Flight Research Center in Edwards, CA. One challenge faced by designers of the X-33 is how to keep the vehicle from burning up when it re-enters the 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 a Thermal Protection System.

## The Challenge

Your child's challenge in class is to build a thermal protection system for a model of the X-33. He/she will use such common materials as nuts, washers, screening, and aluminum foil to build a protective shield that will keep the model from melting. The design will be tested and then the student will have the opportunity to revise the design based on the test results. Designs will go through a number of revisions to try to improve the amount of time the model is protected. As a culminating activity, students will create posters documenting their design process and results.

## Questions to Ask Your Child About the Project

This is an inquiry-based activity. This means that much of your child's learning depends on hands-on experimentation. It's important, however, that your child reflects on the hands-on work and tries to understand why certain design features were or were not successful. You can encourage this reflection by asking your child to:

- Explain the challenge and the design constraints.
- Describe the design and how it survived the testing.
- Explain why the design did or didn't work well.
- Explain whether other students in the class tried different designs and how those designs tested
- Explain the next design and why it will be an improvement.

## Some Activities to do at Home

There are many examples around home of thermal protection systems in action.

- Winter clothing, such as coats, mittens, and hats is designed to prevent the loss of body heat. Discuss whether the clothes create heat or just retain the body's heat.
- Cooking provides a way to examine the thermal properties of materials. Look for the following:
  - Pot holders: Cloth potholders contain a layer of insulating material.
  - Cooking utensils: When stirring hot food, what kind of utensil do you use? Wood is a poor conductor, so the heat from hot food does not easily travel up a wooden spoon to your hand. Metal is a good conductor, it heats up quickly when placed in hot food.
  - Pots and pans: What are your pots and pans made of? Do they have a different type of metal on the bottom? Is the bottom thicker than the sides? Aluminum and copper are popular materials for cooking pots because they are good conductors. Do the handles of your pots get as hot as the pots or do they stay cooler? What are the handles made from? How are they attached?
- Fans: Moving air carries heat away from hot objects by *conduction* and *convection*. When the air contacts the hot surface, heat moves from the hot surface to the air molecules by conduction. When the air moves away from the hot surface, it takes the heat with it. When heat is carried away by a moving gas or liquid it is called *convection*.
- Double or triple pane windows: air is a good insulator that can protect your house from hot weather in the summer and cold in the winter. The air pocket trapped between the two panes of glass (some windows have two air pockets and three panes) prevents heat from passing through the window in either direction. Air serves as an insulator.
- Deep eaves: Roofs with large overhangs serve to keep a house cooler because they shade the house and prevent the radiant heat energy from the sun from reaching the walls and windows of the house. Heat energy from the sun is called radiation or radiating heat. Radiating heat can pass through empty space, air, and other transparent media such as glass. But radiating heat can't pass through opaque materials such as the roof of a house. Instead the roof absorbs the heat energy. If the roof is a light color, it will reflect some of the radiation as well.
- Fiberglass blankets: check your hot water tank or your water pipes if they are visible. Wrapping a tank or pipe in a fiberglass blanket prevents heat from hot water pipes from escaping into the air. If you discover asbestos wrapping, do not disturb it.
- Insulation: The walls of your home probably have some type of insulation such as fiberglass batting, rigid foam boards, or blown-in insulation like cellulose. All of these materials are good insulators because they trap many air pockets in them to make it difficult for heat energy to pass through by conduction or convection.
- Thermal bottles: contain a double-walled container with a vacuum between the two walls. Heat does not travel easily through a vacuum. Another space between the bottle and the outer covering also prevents heat from passing through because air is a good insulator. The inner surface of the bottle is mirrored to reflect heat inward.

## Resources for Further Exploration

***About the Space Shuttle***

http://www.nasa.gov/qanda/space_shuttle.html

***About the Space Shuttle Thermal Protection System***

NASA Facts On Line, John F. Kennedy Space Center
http://www-pao.ksc.nasa.gov/kscpao/nasafact/tps.htm

Space Shuttle News Reference Manual, detailed information about every part of the Space Shuttle.
http://www.ksc.nasa.gov/shuttle/technology/sts-newsref/sts_sys.html#sts-tps

Introduction to the Space Shuttle: Shuttle Systems
http://163.206.3.4/processing/m1/s1-8a_tps.html

***About the X-33 Thermal Protection System***

Mission Update: X-33's Innovative Metallic Thermal Shield "Ready for Flight"
http://www.venturestar.com/pages/missupd/pressrel/1999/02049901.html

***About Other Places You Find Thermal Protection Systems***

NASCAR, http://www.bsrproducts.com/fp1.htm

SCUBA Diving, http://www.diveboulder.com/layerz.htm

Whales, http://pbs.org/oceanrealm/intheschool/school5.html

***About Thermal Protection Materials***

Thermal Protection Systems Expert and Material Properties Database (detailed description and contact person for every thermal protection material)
http://kauai.arc.nasa.gov/cgi-bin/tpsx/unrestrict/V2/tpsx-frame.pl

***About New Space Vehicles***

"The Way to Go in Space" by Tim Beardsley. *Scientific American*, February 1999, pp. 80-97. Further reading: www.sciam.com/1999/0299issue/0299beardsleybox1.html

http://www.venturestar.com/

At this web site you can follow the progress of the X-33 as it progresses through the stages of development.

***About Engineering and Careers***

www.discoverengineering.org

A new web site, Discover Engineering Online, lets adolescents investigate a host of engineering achievements. Aimed at inspiring interest in engineering among America's youth, the site is a vast resource. Among the many features of the site is information on what engineers do and how to become one. Designed specifically for students in grades six through nine, the site has links to games, downloadables, and powerful graphics, as well as to web sites of corporations, engineering societies, and other resources. One section, for example, lists several “cool” things tied to engineering, such as the mechanics of getting music from a compact disc to the ears of a teen, how to make a batch of plastic at home, or learning how to fold the world’s greatest paper airplane.

***CD-ROMs about Space Transportation***

Space Transportation: Past, Present and Future
Available from NASA Marshall Space Flight Center

An Interactive Guide to the X-34 Program’s History, Technology & Achievements
Available from NASA CORE

Venturestar: The Odyssey Begins
Available from Lockheed Martin

***Some NASA Web Sites***

http://spacelink.nasa.gov
An Aeronautics and Space Resource for Educators

http://core.nasa.gov
The worldwide distribution center for NASA-produced multimedia materials

http://education.nasa.gov
A link to the many education resources provided by NASA

http://www.nasa.gov
NASA home page

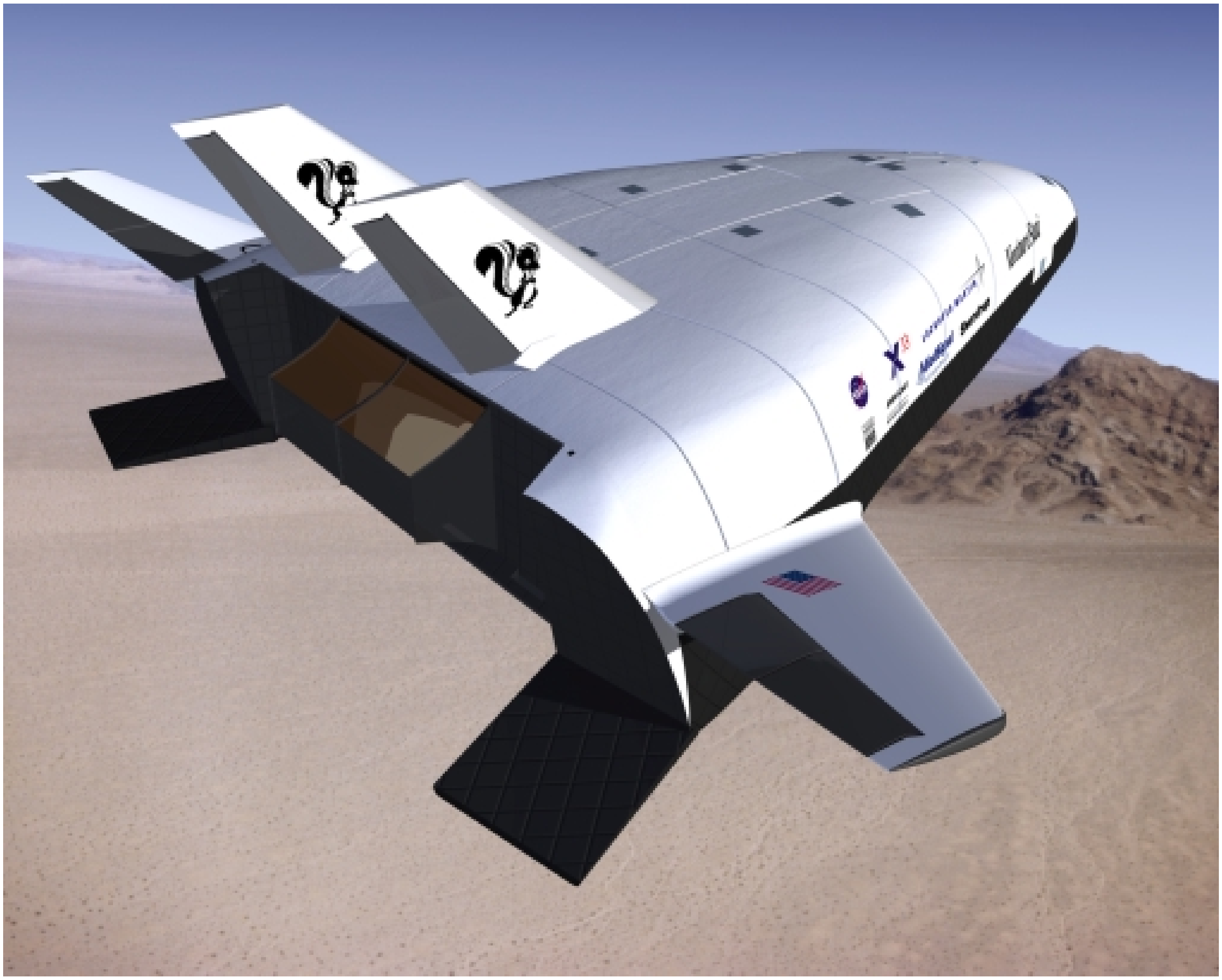
http://www.dfrc.nasa.gov/
Dryden Flight Research Center Home Page
Learn about the X-33 and other “X-planes.” Includes a photo gallery of more than 1,000 digital images of research aircraft

http://www1.msfc.nasa.gov/
Marshall Space Flight Center Home Page

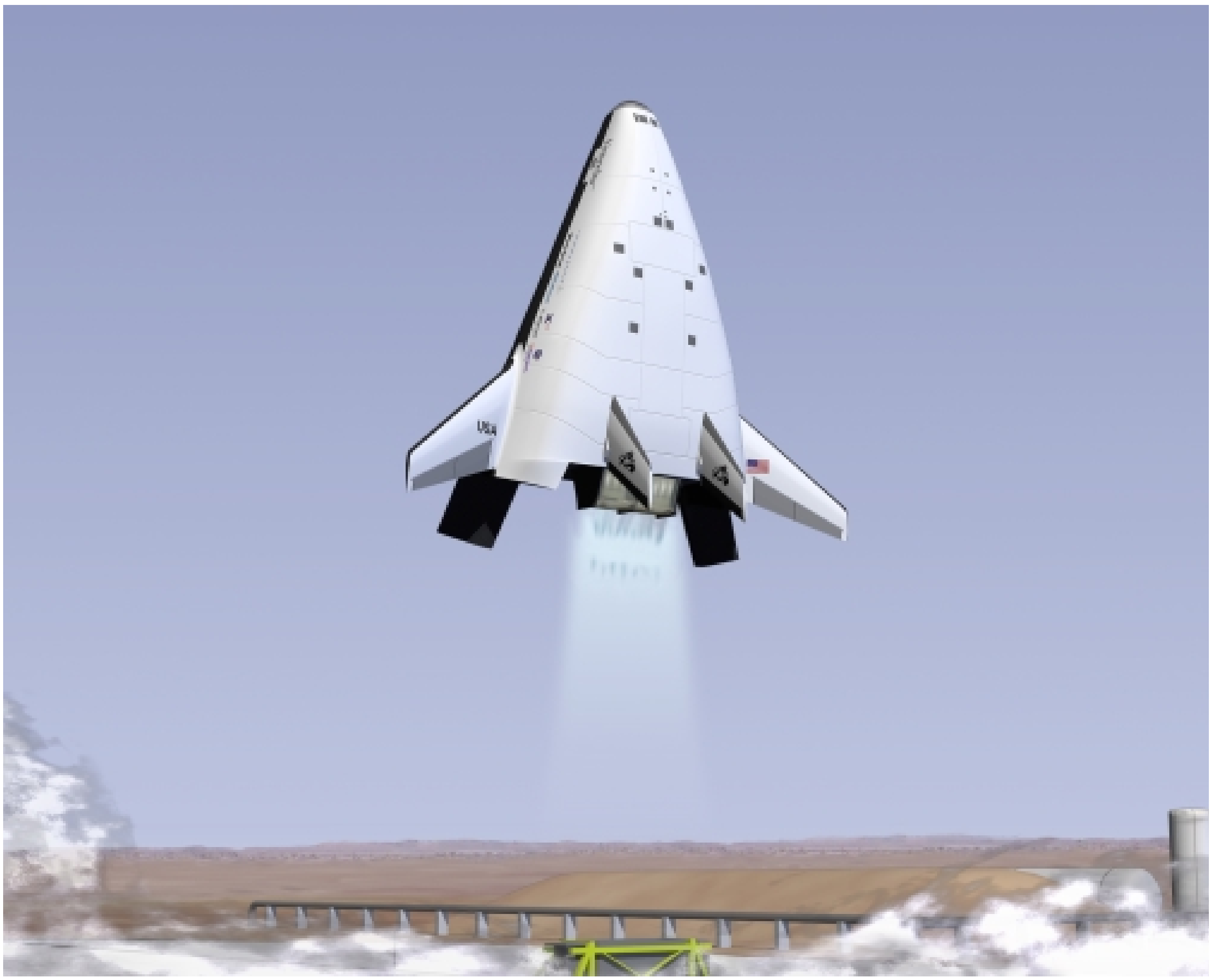
***Career Information***

http://spacelink.nasa.gov/Instructional.Materials/Curriculum.Support/Careers/.index.html

# The X-33



# X-33 Lift off



# NASA Earth-to-Orbit Engineering Design Challenges

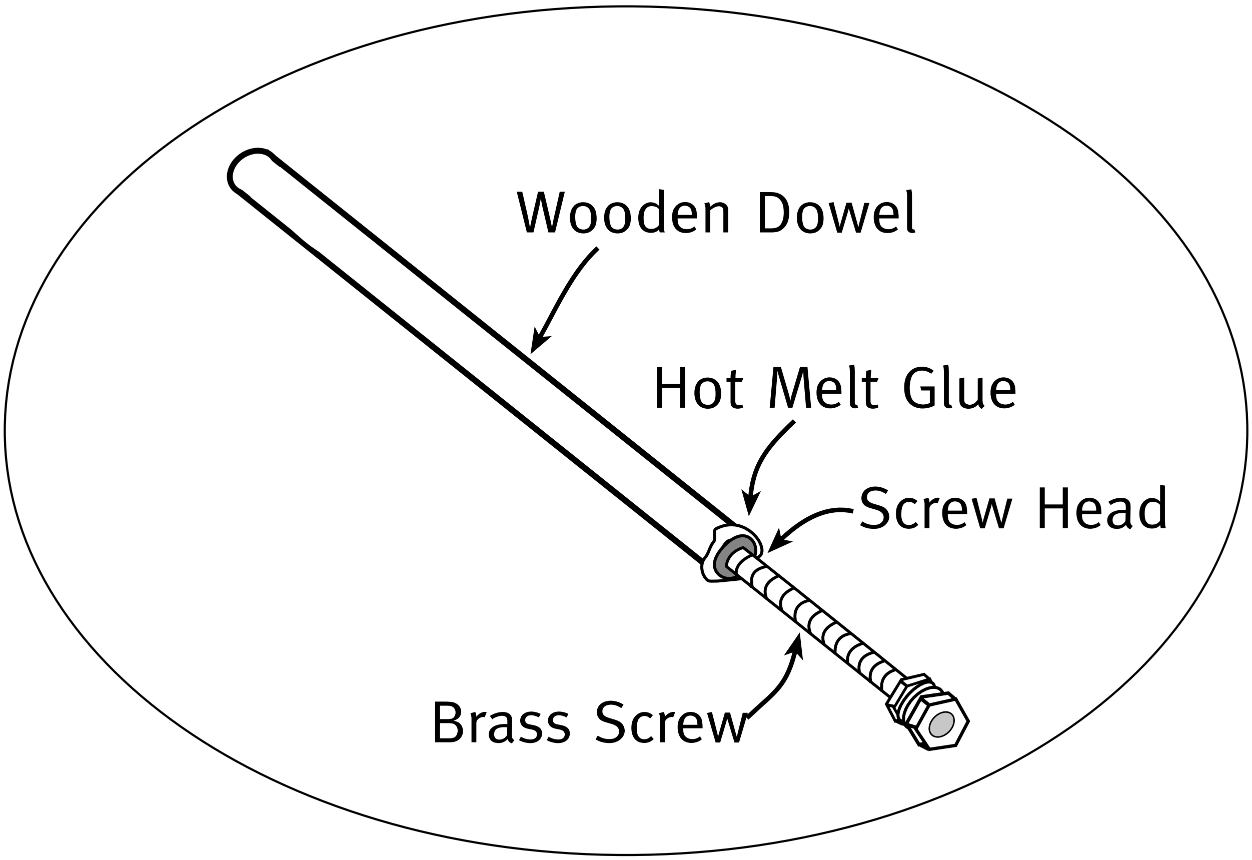
**The Challenge:**

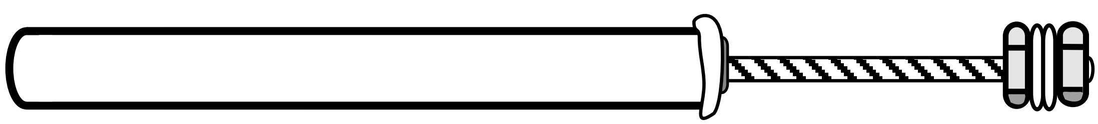
Build a thermal protection system (TPS), using the specified materials, that protects the model for the longest possible time.

**Design Constraints:**

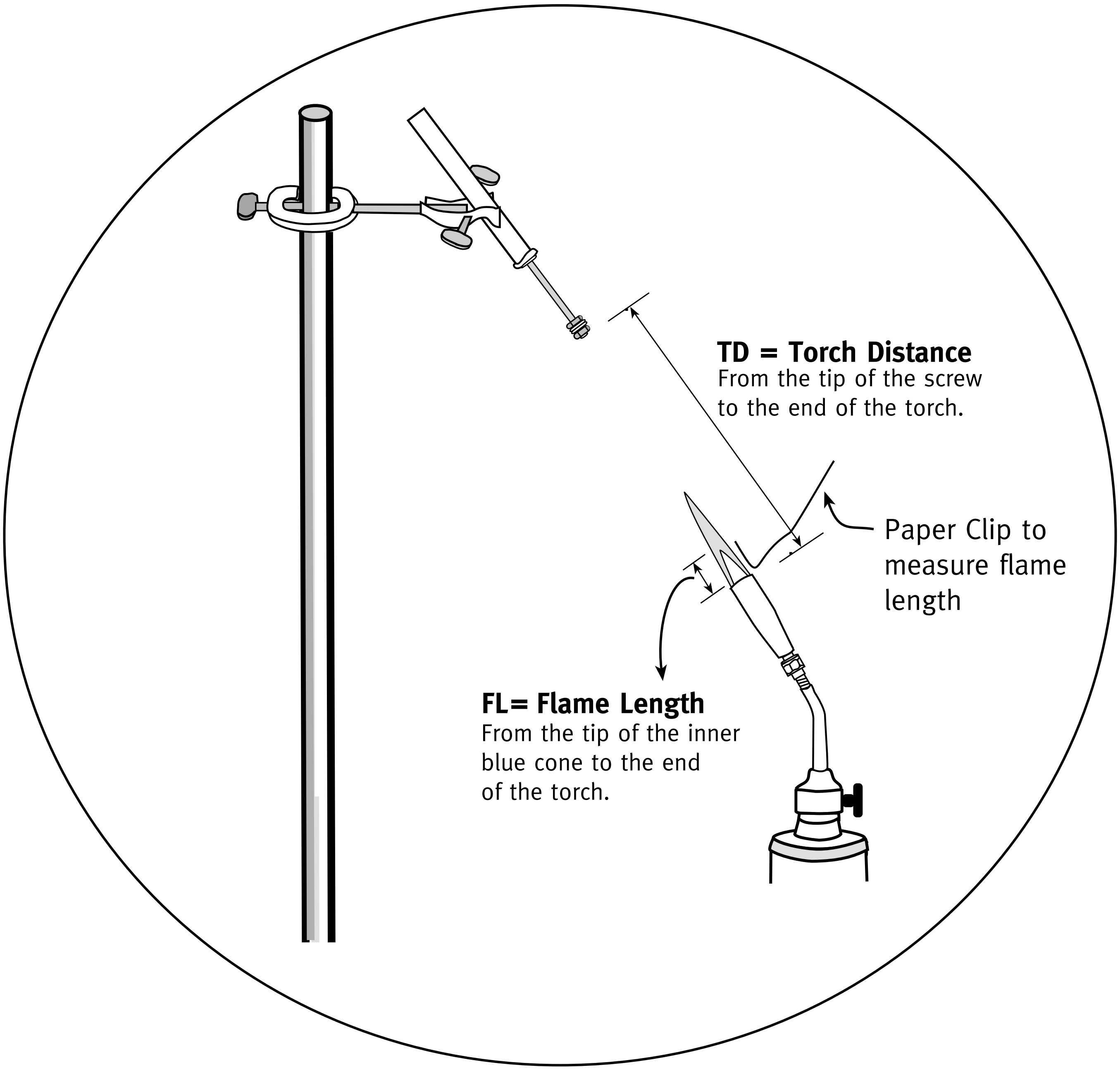
- Use only the specified materials to construct the TPS.
- No glue may be used in the TPS itself.
- No part of the TPS may touch the dowel.
- No part of the TPS may touch the glue.

# The TPS Test Assembly

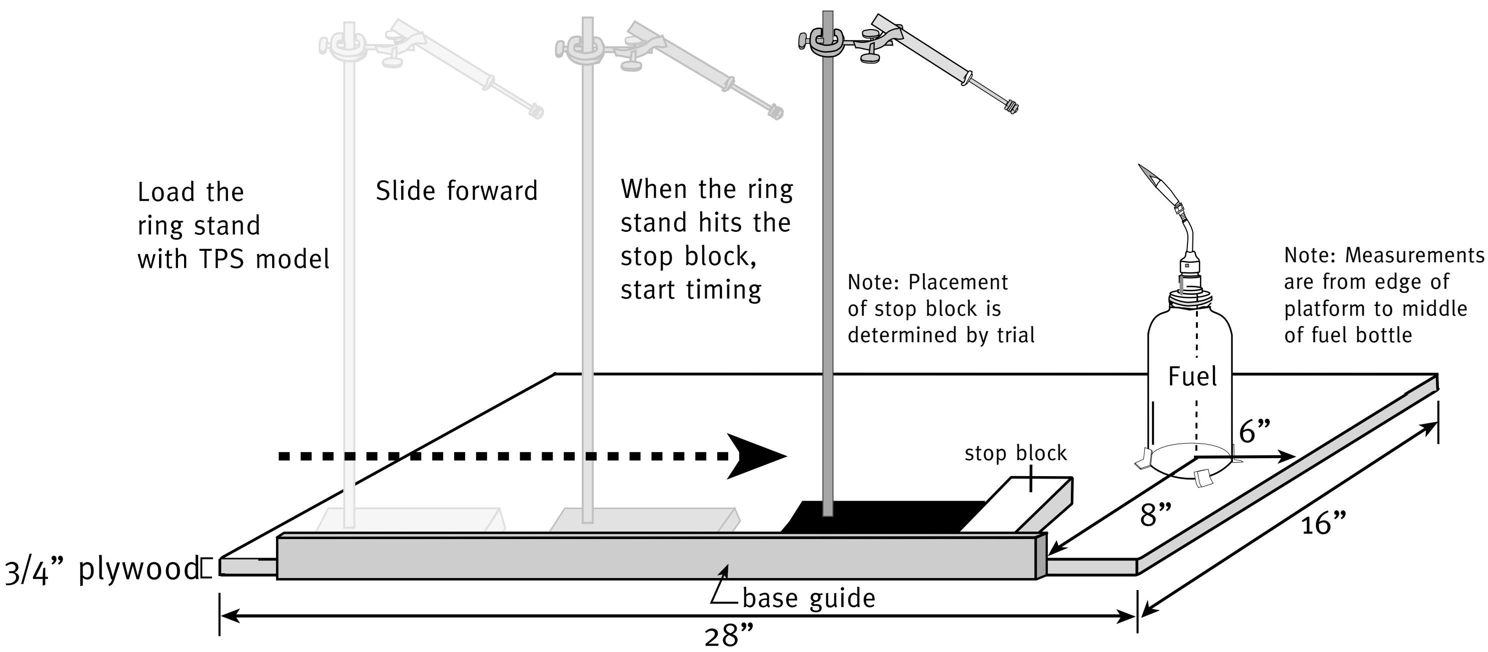


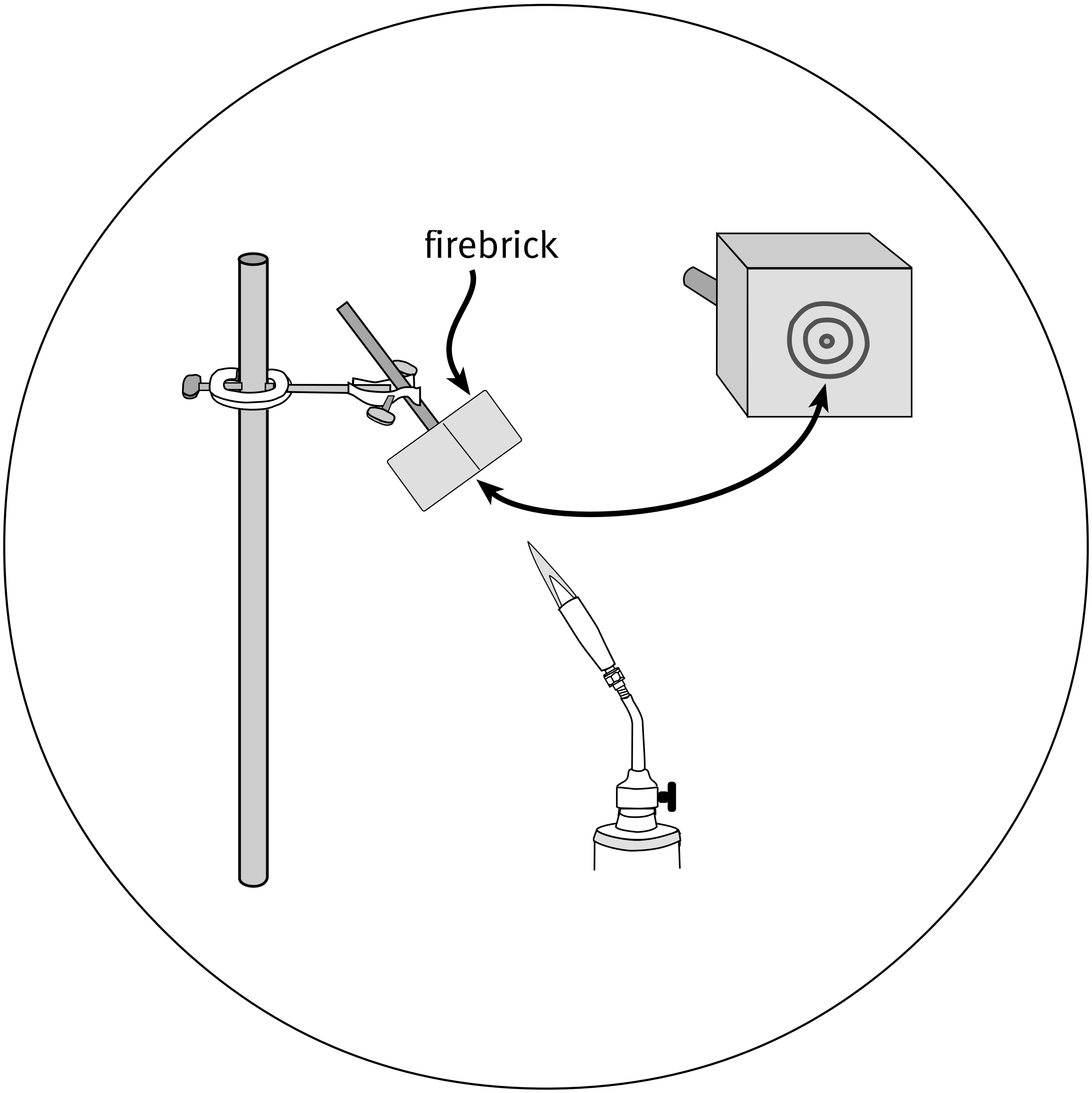
# The TPS Test Stand



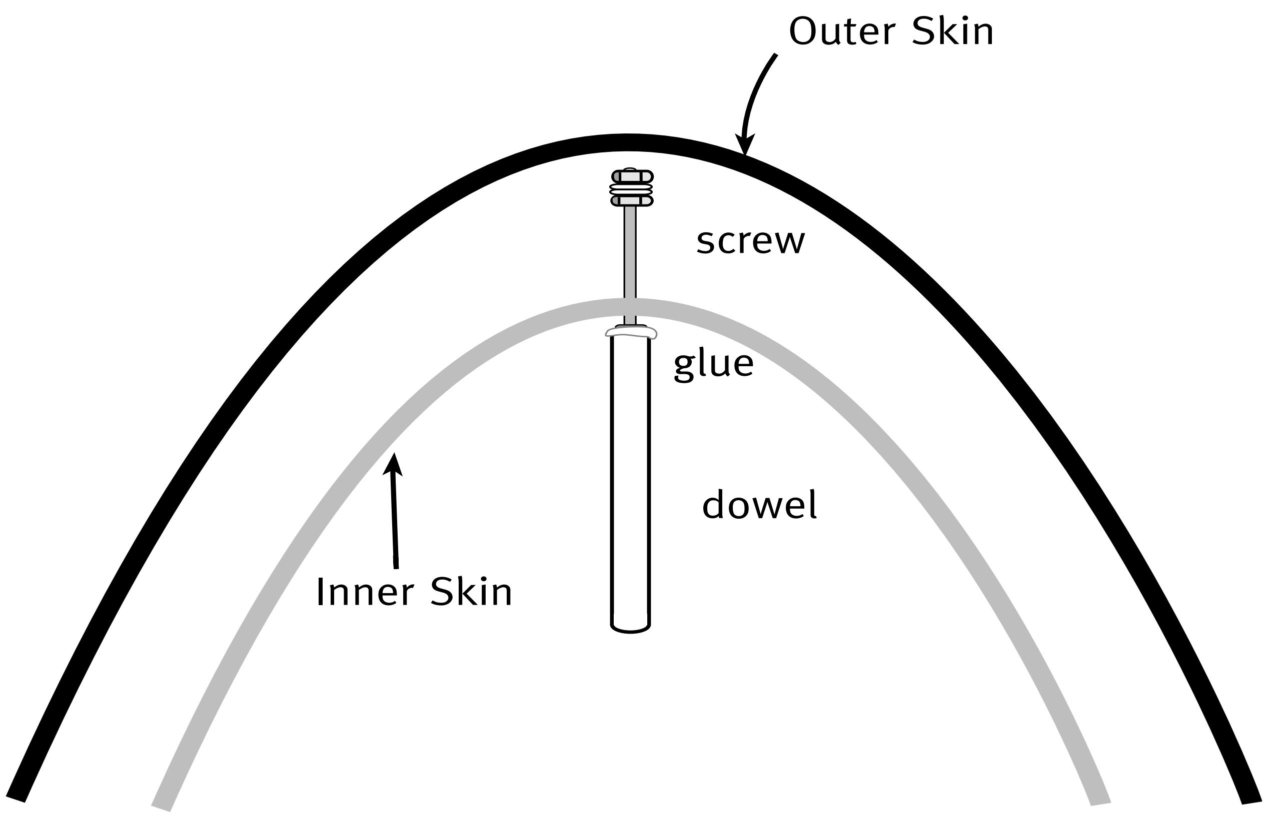
# Using the TPS Test Stand



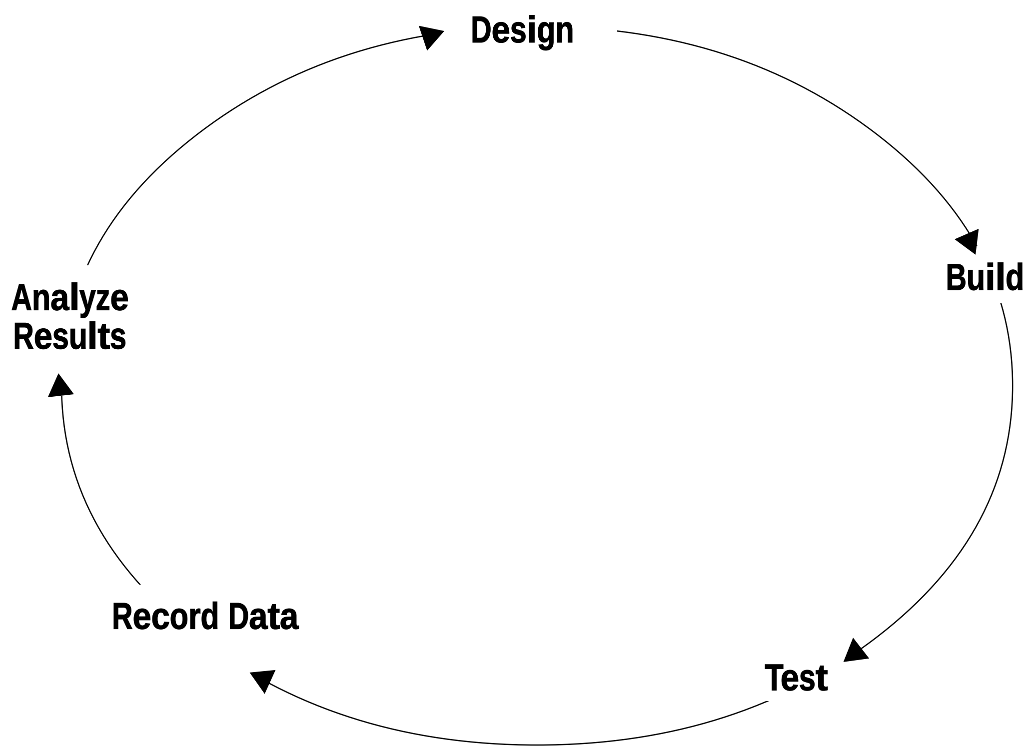
# Alignment Fixture



# Relationship of the TPS Model to a Spacecraft




# The Design Process



# TPS Design Specifications and Test Results Sheet

Design Number: ____

Protection Time in seconds: ____

**Date:** ____________ **Class:** ____________________ **Team:** ______________________________

**Designer Names:** ______________________________________________

Sketch your design below. Check that you have drawn and labeled the following:

☐ Dowel ☐ Screw ☐ Glue joint ☐ Hex nuts ☐ Washers ☐ Other materials

**Describe the key features of your design:**

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

**Describe what happened during the test:**

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________

______________________________