National Aeronautics and
Space Administration

21st Century Community Learning Center
NASA Engineering Design Challenge

Parachuting Onto Mars

STEM Facilitation Guide

NASA: Why We Explore

Humanity's interest in the heavens has been universal and enduring. Humans are driven to explore the unknown, discover new worlds, push the boundaries of our scientific and technical limits, and then push further.

Human space exploration helps address fundamental questions about our place in the universe and the history of our solar system. Through addressing the challenges related to human space exploration, we expand technology, create new industries, and help foster peaceful connections with other nations. Curiosity and exploration are vital to the human spirit. Accepting the challenge of going deeper into space will invite the citizens of the world today and the generations of tomorrow to join NASA on this exciting journey.

The United States is a world leader in the pursuit of new frontiers, discoveries, and knowledge. The National Aeronautics and Space Administration, more commonly known as NASA, performs a unique role in America's leadership in space. NASA has landed people on the Moon, sent spacecraft to the Sun and every planet in the solar system, and launched robotic explorers to travel beyond the solar system. NASA's vision is to discover and expand knowledge for the benefit of humanity.

NASA was formed in 1958 and has amassed a rich history of unique scientific and technological achievements in human space flight. From John Glenn's 1962 orbit around the Earth in Mercury Friendship 7, through the Apollo missions and the space shuttle years, to today's orbiting International Space Station (ISS), NASA is on the forefront of manned space flight.

Figure 1. Illustration of the Orion spacecraft, a multi-purpose crew vehicle designed to carry astronauts into deep space. (NASA)

NASA is leading the next steps into deep space near the Moon, where astronauts will build and begin testing the systems needed for challenging missions to deep space destinations, including Mars. This area of space near the Moon offers a true deep space environment to gain experience for human missions that push farther into the solar system, yet astronauts will be close enough to access the lunar surface for robotic missions and, if needed, return to Earth in days rather than weeks or months.

NASA's future success and global leadership will be determined largely by the investments and innovations we make today in scientific research, technology, and our workforce. NASA's focus has always been, and always will be, to discover, invent, and demonstrate new technologies, tools, and techniques that will allow our Nation to explore space while improving life on Earth.

Career Connection

What is an engineer? An **engineer** is a person who works on a team to solve a problem that humans want to solve or make better. Engineers are at the heart of every engineering challenge. Engineers design and build things we use every day. The NASA for Kids video "Intro to Engineering" explains the role of an engineer and can be shared with your students: http://youtu.be/wE-z_TJyzil. After viewing the video, have students discuss what they learned about what an engineer does.

Figure 2. Aerospace Engineer Chris Randall tests rocket parts and life support systems to ensure they work as planned. (NASA)

Some examples of NASA-engineered products include the following:

Figure 3. Simulation System Engineer Debbie Martinez works on developing general aviation flight simulation software. (NASA)

- Portable x-ray machines: NASA engineers worked to create a small, low-radiation x-ray machine so medical professionals can examine people's injuries at accident scenes.
- Infrared ear thermometers: NASA engineers developed infrared temperature sensors for space missions, and these sensors were adapted to create a faster and easier way to take someone's body temperature.
- Food processing control: NASA engineers worked with food production companies to create a process to identify the critical points where food could be contaminated.
- Airplanes: NASA engineers work with private companies to design and develop aircraft that are safer, quieter, lighter, more fuel efficient, and more reliable.

Engineers help to improve society. Women and men of all races, ethnicities, and walks of life can become engineers. Encourage students to explore NASA engineer career profiles at https://www.nasa.gov/audience/forstudents/careers/profiles/index.html

Table of Contents

Introduction to the Engineering Design Challenge

Figure 4. Artist's rendering of the Space Launch System. (NASA)

Facilitator's Overview

NASA has created an **engineering design challenge (EDC)** that involves students in using the **engineering design process (EDP)** to develop solutions to authentic NASA mission-centered challenges.

The EDC serves as an authentic, standards-driven investigation that allows students to engage in the process of answering questions and solving problems like today's scientists and engineers do. This EDC provides students with opportunities to gain tangible skills that are essential in science, technology, engineering, and mathematics (STEM) careers. This guide is organized into three sections:

1. **Introductory Materials** establish a basic level of understanding about the EDP and the EDC and provide tools to support students through the challenge.
2. **Facilitator Instructions** provide instructions for facilitators to use throughout the design challenge and include tools to assess student understanding throughout each step.
3. **Student Team Challenge Journal** contains prompts and tools to guide students through the cycle of steps in the EDP while documenting their work for each step. It is suggested that each student have a copy of this journal.

What is the Engineering Design Process?

The EDP is a systematic practice for solving problems. Engineers work through the process to solve problems and create new technologies and systems that enhance our lives. All EDP models begin by identifying a need or problem, but there is no defined or fixed path toward the end goal. The EDP model allows problem solvers the flexibility to move between steps as appropriate for the challenge faced.

What is an Engineering Design Challenge?

The EDC is a learner-centered instructional approach that organizes learning around a shared goal or challenge. Students are presented with a challenge or problem and, using the EDP, work in teams to complete activities and experiments to develop solutions toward solving that problem. These challenges facilitate teamwork and engage students in problem-solving practices used by real-world engineers.

Engineering Design Process

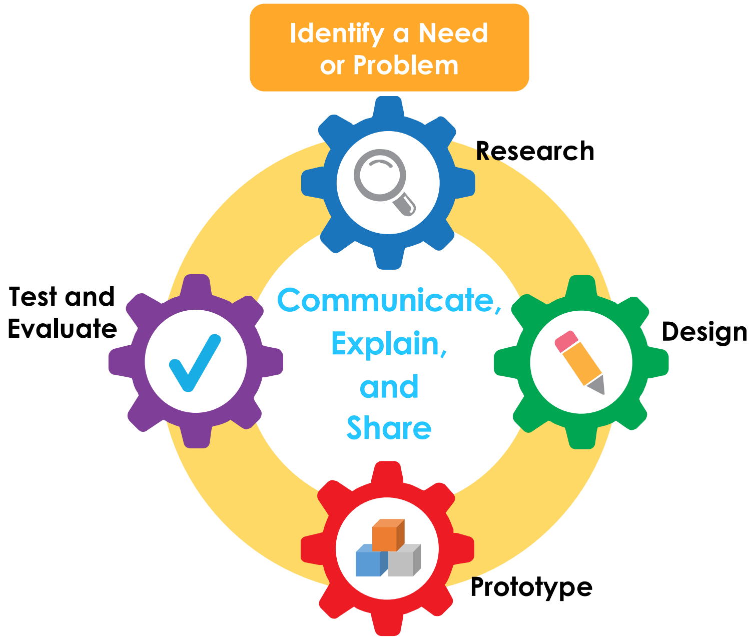


Figure 5. Engineering design process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.

Identify a Need or Problem. Identify a need or problem to be solved, improved, or fixed. Identify the criteria and constraints that will need to be met to solve the problem.

Research. Use resources from the internet, the library, or discussions with NASA scientists and engineers to learn more about the need or problem and possible solutions. Investigate how this problem is currently being solved or what efforts scientists and engineers are making to find a solution.

Design. Use all information gathered to create the design(s). Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. Construct a prototype, or physical model, based on the design model(s). Prototypes are used to test proposed solutions.

Test and Evaluate. Test prototype to determine how effectively it solves the need or problem. Collect data to use as evidence of success or need for improvement. Redesign and refine prototypes to continue looking for possible solutions.

Communicate, Explain, and Share. Communicating, explaining, and sharing the solution and design is essential to tell others how it works, how it solves (or does not solve) the identified need or problem, and how it meets (or fails to meet) the criteria and constraints. Determining how to communicate and act on constructive criticism is critical.

Engineering Design Challenge: Parachuting Onto Mars

As NASA plans new robotic missions and human expeditions to Mars, it becomes more important for spacecraft that carry payloads to be able to accommodate heavier and larger payloads to support an extended stay on the Martian surface. NASA seeks to use atmospheric drag as a solution for planetary atmospheric decelerations, deploying next-generation drag devices at high supersonic speed to safely land crew, cargo, and vehicles. NASA is currently conducting full-scale, stratospheric testing of breakthrough technologies high above Earth to test their value for future missions to Mars.

Figure 6. The Low-Density Supersonic Decelerator (LDSD) test vehicle is one of several drag devices NASA has engineered for landing large payloads on Mars. (NASA/JPL–Caltech)

The Challenge

Because spacecraft that land on the surface of Mars travel at extremely high speeds, they need some sort of drag device to slow them down to prevent them from crashing into the planet and becoming damaged. As missions increase in complexity, landers and rovers become heavier and require even more effective drag devices. Engineers must work within the limits (or constraints) of mass, weight, and space on a rocket to successfully accomplish the mission. Students will work in teams to design and construct a drag device that will slow down the team-built cargo bay when it is dropped from a consistent height.

Criteria and Constraints

1. The drag device must connect to a team-built cargo bay that is assembled using the template provided in this guide.
2. The entire device must be deployed from 2 m and remain intact throughout the drop.
3. The cargo bay must hold 10 g.
4. The overall mass cannot exceed 50 g.

Pacing Guide

The Pacing Guide offers a suggested timeline for each phase of the engineering design process (EDP). Facilitators may condense or expand the schedule to accommodate the needs and explorations of their student teams. This challenge may be completed in an estimated 20 sessions, with each session approximately 1 hour. At the completion of each EDP phase, students will communicate, explain, and share their discoveries, successes, and understandings.

Activity	Sessions
Introduction • Complete the Team Building activities • Explore NASA Mission Background and careers • Complete the STEM Investigations • Investigate each phase of the EDP	2 sessions
Identify a Need or Problem • Explore the challenge scenario and watch the introductory video • Identify the criteria and the constraints of the challenge	2 sessions
Research • Brainstorm research questions related to the challenge scenario • Complete a KWL chart • Connect with a NASA scientist or engineer	3 sessions
Design • Complete an individual drawing of the prototype based on the challenge scenario, criteria, and constraints • Evaluate each of the individual drawings for strength and unique ideas • Combine all of the individual drawings and ideas into a team drawing	3 sessions
Prototype • Construct a prototype using the team drawing • Evaluate the prototype against the criteria and constraints • Create a budget worksheet that will record and calculate the material costs • Demonstrate the ability to work effectively and respectfully with a team	3 sessions
Test and Evaluate • Complete the tests on the prototype according to the criteria and constraints of the challenge • Collect and analyze data from each of the tests • Determine how to best improve the prototype	3 sessions
Student Team Presentation • Collect photos and videos that will illustrate the process the team followed to complete the challenge • Represent all phases of the EDP in the student team presentation • Summarize each of the team's successes and challenges in the presentation	4 sessions

Learning Outcomes

Education Standards

The engineering standards addressed here are tailored for 6th–8th grade students based on Next Generation Science Standards. Even if your state has not adopted these standards, similar core ideas are likely found in other terms in your state's standards.

Standards Addressed

Next Generation Science Standards
Engineering Design
• **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–ETS1–3** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.
• **MS–ETS1–4** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
• **MS–PS2–1** Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.
• **MS–PS2–2:** Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

Connected Concepts

Common Core State Standards	
Mathematics	***English Language Arts***
• **MP.2** Reason abstractly and quantitatively. • **MP.4** Model with mathematics. • **6.RP.1** Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. • **6.RP.3** Use ratio and rate reasoning to solve real-world and mathematical problems. • **7.RP.2** Recognize and represent proportional relationships between quantities. • **7.EE.3** Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies.	• **RST.6–8.2** Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. • **RST.6–8.7** Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). • **WHST.6–8.7** Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. • **WHST.6–8.8** Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard format for citation. • **WHST.6–8.9** Draw evidence from informational texts to support analysis, reflection, and research. • **SL.6–8.5** Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest.

Evidence of Learning

This guide uses a number of tools to indicate student progress, including the following:

- Accessing of existing knowledge and assessment of level of understanding
- Supporting Science Investigations, Data Collection Sheets, and post-investigation discussions
- Sample guiding questions to assist in facilitating discussions
- A final assessment, including creation of a video or slide presentation explaining the iterative design process, challenges encountered, and how decisions were made based upon the concepts learned

Student Team Challenge Journal

The engineering design process (EDP) that each team uses will vary from team to team. Prior to starting the engineering design challenge, print and assemble enough copies of the Student Team Challenge Journal into three-ring or loose-leaf binders so that each student receives a complete journal. Included in the journal are the EDP practices students will use to record their progress. Print extra copies of these EDP sheets and make them available for students. Students will select the appropriate sheets as they move through the process. Instruct students to work page-by-page through their journals, documenting the challenges they faced and the steps they took. This documentation will help students prepare their final presentations.

Solution Presentation Criteria

Student teams should use the Student Presentation Rubric to guide them as they work through the challenge. The Student Presentation Organizer and the Team Progress Chart are tools students can use to help them create a final product that clearly communicates the team progress through the engineering design challenge.

Once the video or slide presentation is complete, submit according to the guidelines on the Y4Y (You for Youth) website.

Team Presentation Rubric

Student name ____________________ **Team name** ______________________

The Team Presentation Rubric will be used to evaluate the student team presentations (video, student presentation, and/or slide presentation).

1. In the introduction, the team name, the challenge name, and the title of the presentation were all included. Personal or identifying information was NOT given in the introduction.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

2. The team explained the challenge, including the criteria and the constraints.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

3. The team described the results of their research, including the STEM career they explored and the information they collected from the virtual connection with the NASA scientist or engineer.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

4. The team explained how they used the engineering design process to design and construct their final prototype or model.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

5. As a conclusion, the team described the challenges and successes they experienced as they built, tested, and improved their prototype or model.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

Comments and Encouragement

Facilitator Instructions

Recommended Materials

The following materials are required to complete this challenge. The quantity will depend on the number of students participating. Alternatives and additional materials can be used if desired, but be mindful of safety when allowing students to bring in or handle materials that could potentially be dangerous.

Figure 7. Household supplies that could be used as construction materials for the challenge.

Each team will require the following items:

- Digital scale or balance
- Stopwatch
- Measuring tape
- Ruler
- Thin string (e.g., embroidery thread, twine, or yarn)
- Small sealable plastic storage bag to hold payload inside capsule
- Washers, marbles, or pennies to serve as mass
- Hole reinforcements or stickers with holes
- Each team should have a copy of the cargo bay template provided in this guide. It can be copied on any weight of paper, but all copies need to be the same paper weight.

Examples of additional materials that may be used:

- Aluminum foil
- Balloons
- Binder clips
- Bubble wrap
- Cardboard or cardstock
- Clothespins
- Cloth
- Coffee filters
- Cotton balls
- Craft sticks or tongue depressors
- Glue sticks
- Mini aluminum foil pie plates
- Modeling clay
- Paper bags
- Paper clips
- Paper towel or toilet paper tubes (empty)
- Pennies
- Plastic eggs
- Plastic wrap
- Rubber bands
- Skewers or stirrers
- Staplers and staples
- Straws
- String
- Tape (masking, electrical, transparent, duct)

Safety

Safety, an important issue for all curricular areas of education, is of special concern for STEM-based activities and courses. Many national and state academic standards address the need for schools and subject areas to promote development of student knowledge and abilities in a safe learning environment.

School administrators, teachers, and facilitators are responsible for providing a learning environment that is safe, suitable, and supportive. Facilitators are also responsible for their students' welfare in the classroom and laboratory.

Facilitators should

- Approve all drawings before students start building their designs.
- Look for flimsy structure designs and potentially hazardous combinations of materials.
- Ensure that resources are clean and dry, with no sharp edges exposed.
- Make sure all materials are undamaged and in good repair.
- Prohibit students from bringing in or using additional materials for their designs without prior approval.

Students should

- Make safety a priority during all activities.
- Wear safety goggles when conducting all investigations and the challenge.
- Demonstrate courtesy and respect for ideas expressed by others in the group.
- Use tools and equipment in a safe manner.
- Assume responsibility for their own safety and the safety of others.

Team Building

Begin by dividing students into teams of no more than four to give all students an opportunity to contribute. By working as members of a team, students develop skills such as trust, cooperation, and decision making. Working as a team member, however, can be challenging for some students. The following exercises are recommended to help teams begin to work together effectively.

Figure 8. This Apollo 11 patch depicts an eagle landing on the Moon with a view of the Earth in the background. (NASA)

Establish a team name. Many NASA teams are named based on the work they do.

Design a mission patch. Teams that work on NASA missions and spacecraft are unified under a mission patch designed with symbols and artwork to identify the group's mission.

Create a vision statement. This is a short inspirational sentence or phrase that describes the core goal of the team's work. NASA's current vision statement is "*To discover and expand knowledge for the benefit of humanity.*"

As students begin to work together, their individual strengths will become apparent. Students can volunteer or be assigned tasks or responsibilities that are vital to completing the challenge. Team jobs can also be rotated throughout the team members to give all students an opportunity to improve their team skills. The following list includes examples of jobs that student teams will need to complete. Feel free to come up with others, and remember that all team members should serve as builders and engineers for the team.

Design engineer. Sketches, outlines, patterns, or plans the ideas the team generates

Technical engineer. Assembles, maintains, repairs, and modifies the structural components of the design

Operations engineer. Sets up and operates the prototype to complete a test

Technical writer/videographer. Records and organizes data and prepares documentation (text, pictures, and/or video) to be reported and published

NASA Mission Background

Mars

Mars is the fourth planet from the Sun and is approximately 228 million km away from it. Mars is the next planet beyond Earth and is about one-half the size of Earth. Known as the "Red Planet," Mars gets its red color from the iron in its soil.

Mars is very cold and has an average temperature of –62 °C (–79.6 °F), far below the freezing point of water. Its rocky and dusty red surface is covered with canyons, inactive volcanoes, and craters. Although the Martian atmosphere is considerably different than Earth's, Mars does have clouds, wind, and dust.

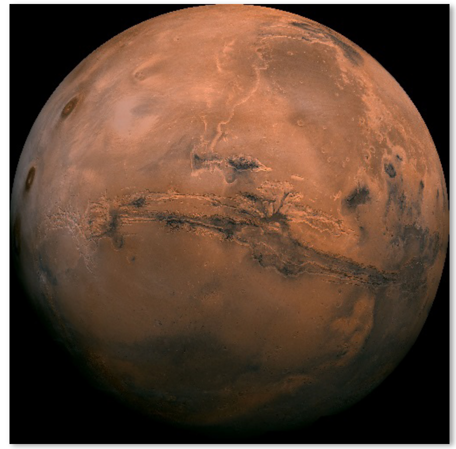


Figure 9. Photograph pieced together from 102 Viking Orbiter images of Mars. (NASA)

The characteristics of Mars and Earth are very different. The gravitational pull on Mars is less than the gravity on Earth, meaning that a rock dropped on Mars would fall more slowly than a rock dropped on Earth. A person who weighs 45 kg (about 100 lb) on Earth would weigh only about 17 kg (37 lb) on Mars because of the reduced gravity. The atmosphere of Mars is about 100 times thinner than Earth's. The Martian atmosphere has much less oxygen and far more carbon dioxide than the Earth's atmosphere. It is very difficult for NASA to land spacecraft on the surface of Mars because there are fewer molecules of air for the parachute to "catch."

How is NASA exploring Mars today?

The spacecraft orbiting Mars today use tools to collect scientific information, such as the temperature and the kinds of minerals on Mars. These spacecraft take images and search for water.

NASA has also landed rovers named Sojourner, Spirit, Opportunity, and Curiosity on the surface of Mars. These rovers are robots that move around taking images, conducting scientific experiments, and collecting data about the planet's soil and rocks.

NASA uses the images and information gathered by the orbiting spacecraft and the rovers on the planet's surface to help determine if life could ever have existed on Mars. Opportunity and Curiosity are still providing images and data to NASA.

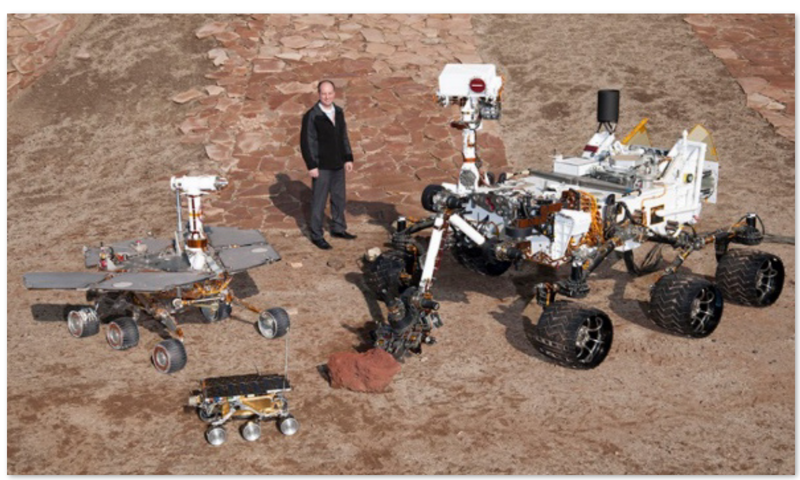


Figure 10. Replicas of successful Mars rovers, showing size relation. (NASA)

How will NASA explore Mars in the future?

NASA is working to send astronauts to the Red Planet. To accommodate heavier loads needed for longer missions, NASA continues to develop drag devices to safely land the spacecraft on the Martian surface. NASA plans to send more robots to Mars to collect Martian soil and rocks and return them to Earth to be studied.

How do spacecraft land on the Martian surface?

Devices that slow down moving objects by creating drag come in many shapes, sizes, and materials. NASA has used a basic parachute design as a drag device to land vehicles on the surface of Mars since 1976, when the first Viking lander touched down.

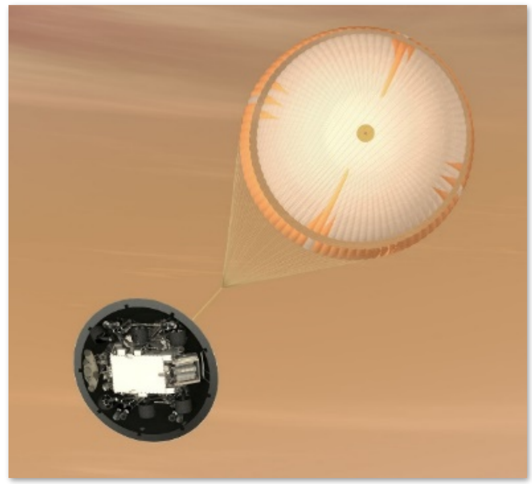


Figure 11. Artist's concept of the parachute system for the Mars Science Laboratory's Curiosity rover. (NASA)

To conduct advanced exploration missions and safely land heavier spacecraft on Mars in the future, NASA must improve the technology of decelerating (slowing down) large payloads traveling at supersonic speeds. NASA is developing new large, sturdy, and lightweight systems to deliver next-generation rovers and landers on Mars. These new technologies will be able to slow down larger, heavier landers from supersonic speeds to the slower speeds that are necessary for a safe landing on Mars.

Engagement: Accessing Existing Knowledge

Prior to starting the engineering design challenge, it will be useful to identify students' existing knowledge and level of understanding using a series of guided questions related to this specific challenge. This discussion will allow facilitators to tailor the challenge and the Supporting Science Investigations to the group, maximizing the educational benefit.

The following questions provide a starting point from which additional topics may be discussed.

- How is Mars different from Earth?
- Could we live on Mars today? Why or why not?
- What is a parachute?
- Where have you seen parachutes in use?
- What is drag?
- Can you name some things that create drag?

STEM Vocabulary

Engineering design challenges and the engineering design process (EDP) are concepts that may be unfamiliar to your students. Younger students in particular may not have heard words like "criteria" or "constraints," which are commonly associated with engineering design.

A list of related STEM vocabulary words is included in this guide. If practical or appropriate, a vocabulary wall can be created to assist in familiarizing students with these words.

Student Team Challenge Journal

Before moving on to the Supporting Science Investigations, provide students with the Student Team Challenge Journal. Additional sheets should be made available as students work through the challenge. Where possible, engage students by relating the information to their everyday lives.

Exploration: Supporting Science Investigations

The following pages contain two Supporting Science Investigations to help with students' understanding of the background material. Ideally, students will perform both of the Supporting Science Investigations, but facilitators should ensure that at least one of these investigations is completed prior to commencing the engineering design challenge. These investigations will explore the primary concepts used during the challenge.

This section includes the following Supporting Science Investigations and their respective concepts:

- Investigation 1: It's a Drag
  - Drag is a force.
  - Drag is created as an object interacts with the air.
  - The amount of drag created is directly proportional to the object's surface area.

- Investigation 2: Touchdown
  - Drag is a force.
  - Drag negatively affects acceleration.

Supporting Science Investigation 1: It's a Drag

Concept

Every object that falls due to gravity will ultimately fall at a constant speed. In order to stop an object or to slow it down, a certain amount of drag needs to be applied to oppose the acceleration. As drag increases, an object will slow its rate of fall.

In this activity, students will see the effects of drag on a falling object by shaping a large sheet of paper and measuring the time it takes to fall from a fixed distance.

Figure 12. Space Shuttle Endeavour's drag chute deploys to slow the orbiter as it lands at Edwards Air Force Base at the conclusion of the STS–111 mission to the International Space Station in 2002. (NASA)

Materials

For each pair of students:

- Meter stick
- Large sheet of paper
- Stopwatch
- Table

Procedure

1. Divide the class into pairs. Students will take turns dropping and timing the falling object.
2. Students place the meter stick on top of the table so that it stands upright. The meter stick should be placed at the edge of the table. The top of the stick (approx. 2 m above the floor) will be the designated drop point for each iteration of the test.
3. One student in each group folds the paper in half and holds the sheet of paper horizontally at the top of the meter stick.
4. The student releases the paper while the other team member times how long it takes to fall to the floor.
5. Students record the time on their Data Collection Sheets.
6. Students repeat this drop two more times for a total of three iterations, recording the time for each drop on their Data Collection Sheets.
7. Students calculate the average of the three drops and record it on their Data Collection Sheets.
8. Students fold the sheet of paper into quarters, once in each direction.

9. Students drop the paper three times using the method described in steps 3 and 4, recording all of the times and the average on their Data Collection Sheets. Remind students to switch dropper and timer roles so each gets a chance to time.
10. Instruct students to repeat this experiment multiple times with various reshaping of the paper. There is no constraint as to how the paper is folded or unfolded. Tell students their goal is to discover the shape that causes the most drag and therefore the slowest fall time.
11. Have students answer the questions on their Data Collection Sheets.

Options for Differentiating Instruction

The following suggestions may be used when modifying this investigation for students outside of the designated age range or ability levels.

Modification

- Consider prescribed folds for the investigation.

Enrichment

- Consider allowing students to use different weights of paper.

Supporting Science Investigation 2: Touchdown

Concept

The Mars 2020 rover mission is part of NASA's Mars Exploration Program. The mission is not only seeking signs of habitable conditions on Mars but is also searching for signs of past microbial life. The mission will gather information to aid future human expeditions to Mars. This includes improving landing techniques; identifying resources to enable human habitation; and characterizing weather, dust, and other environmental conditions that could affect how future astronauts live and work on Mars.

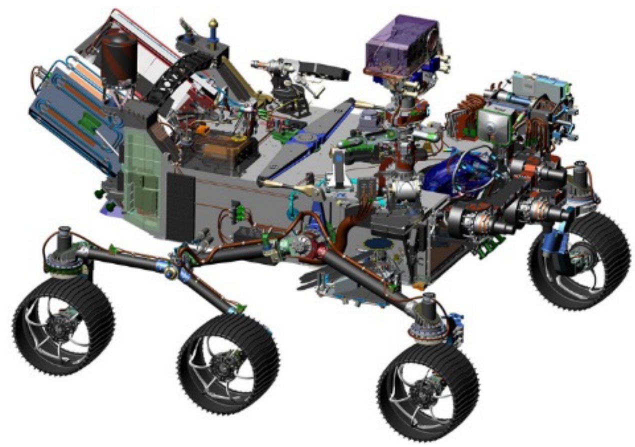


Figure 13. Computer-assisted design of NASA's 2020 Mars rover. (NASA/JPL–Caltech)

NASA will use the proven landing system used to land the Curiosity rover. However, with heavier science equipment, the spacecraft will need to have a way to absorb the extra energy of impact from the landing while also protecting the cargo.

Each team will design and build a vehicle imitating the Mars 2020 rover landing vehicle. Teams will develop a shock-absorbing system that will keep marshmallows (cargo) inside a cup (cargo hold) upon landing during a drop test. Teams will not be allowed to secure the cargo with tape. The challenge is to make a shock-absorbing system that absorbs the transfer of energy so the marshmallows stay in the cup on landing. Teams can only use the materials they are given.

Materials

For each pair of students:

- Piece of stiff paper or cardboard, approximately 10 x 13 cm (4 x 5 in.)
- Small paper or plastic cup
- 4 small index cards
- Tape measure
- 2 regular-size marshmallows
- 10 miniature marshmallows
- 3 rubber bands
- 8 plastic straws
- Scissors
- Tape

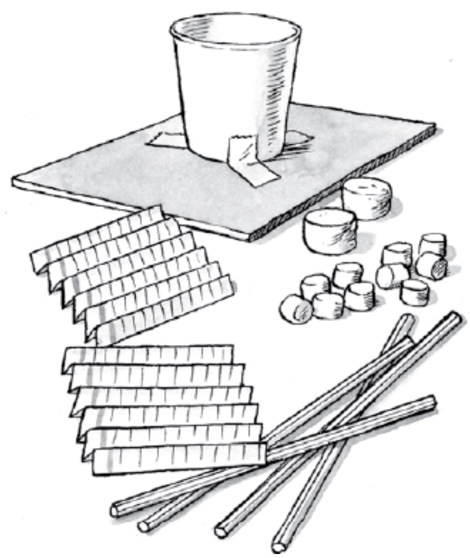


Figure 14. Materials used in the "Touchdown" investigation.

Procedure

1. Secure the cargo hold (cup) on the lander (cardboard). Students draw a circle around the bottom of the cup. They can either leave the cup in place during the design and build, or they can remove it to assist in the construction of the shock-absorbing system. In either case, the cargo hold must be secured prior to testing.
2. Students work in pairs to design a shock-absorbing system with the materials provided.
3. Students build their designed shock-absorbing system and attach it to the cardboard lander.
4. With the cargo hold secured to the lander, put two pieces of cargo (the large marshmallows) in the cargo hold.
5. Students drop the lander from heights of 50 cm, 100 cm, and 150 cm.
6. If the cargo does not stay in the cup, students redesign the shock-absorbing system as time allows.

Notes

- If a lander tips over as it falls through the air, make sure it is level when released. Check that the cup is centered on the cardboard. Check that the weight is evenly distributed.
- If the cargo bounces out of the cup during testing, add soft pads or change the number or position of the shock absorbers.

Options for Differentiating Instruction

The following suggestions may be used when modifying this investigation for students outside of the designated age range or ability levels.

Modification

- Consider giving students a picture of one of the current Mars rovers and suggest they model their design after it.

Enrichment

- Consider increasing the mass of the cargo by adding pennies or other small objects, such as washers.

Explanation: Supporting Science Investigations Discussion

The following investigation discussions are designed to reinforce students' understanding of the specific concepts learned during the Supporting Science Investigations.

Each discussion is based on the standard Think–Pair–Share strategy, which encourages individual participation, collaborative learning, and higher-level thinking. This strategy consists of three parts:

- **Think**: Students think independently about the question that has been posed.
- **Pair**: Students are paired to discuss their thoughts.
- **Share**: Students share their ideas with the whole class.

Focus on one question at a time. When students are done sharing their thoughts and ideas on the first question, move to the second question and repeat the process.

Procedure

1. Discussion Questions for each Supporting Science Investigation are included in this guide.
2. Ask one of the Discussion Questions to begin the Think–Pair–Share process.
3. Provide approximately 5 minutes for students to think independently.
4. Next, provide approximately 5 minutes for the students to share in pairs.
5. Finally, have students share their ideas in a class discussion.

Investigation Discussion 1: It's a Drag

Concepts Learned

The following scientific concepts should have been realized by performing this investigation:

- Drag is a force.
- Drag is created as an object interacts with the air.
- The amount of drag created is directly proportional to the object's surface area.

Discussion Questions

It's a Drag used falling paper to simulate the effects of drag on a moving object.

If we were to perform the same activity on Mars

1. Would the results be the same, faster, or slower than here on Earth? Why?
2. If the goal was to produce as much drag as possible, how could you achieve this?
3. How will you apply what you learned in this investigation to your design?

Investigation Discussion 2: Touchdown

Concepts Learned

The following scientific concepts should have been realized by performing this investigation:

- A falling object has energy.
- A falling object hitting the ground transfers that energy to the ground.
- Materials can absorb energy on impact.

Discussion Questions

The Touchdown activity showed that an object gains energy (speed) as it falls due to gravity pulling downward on the object. To prevent the cargo from being damaged as it landed, it had to be protected using energy-absorbing materials.

1. If this experiment were performed on Mars, would the outcome be different?
2. Which of the available materials performed best in this challenge? Would this material work in space? Why or why not?
3. Guide students to help them make the connection between this investigation and the engineering design challenge.

Elaboration: The Engineering Design Challenge

Using the Engineering Design Process

Discuss the engineering design process (EDP) with students and explain how students will use this process to work through the engineering design challenge. The following pages explain how each step of the EDP relates to the challenge and how to facilitate the process. Regardless of the step being undertaken by each team, it is important that they work in a scientific manner. Explain the EDP sheets and how to use the appropriate pages for recording group ideas. It is important for students to understand that they may choose any path through the EDP, but they should be able to communicate why they selected a particular path.

Discuss with your students the information covered within the engineering design challenge. Using the background information, talk about current NASA missions and how those relate to this challenge. As a class, discuss the individual components of this challenge. Explain the specific criteria and check with students for understanding. Discuss with students what the constraints mean, how and why they are important, and how they relate to their everyday experiences.

Consider using a budget sheet with students as an optional real-world component. Suggestions include the following:

- Provide students with a price sheet that lists the cost of the items they have used to complete the challenge.
- Have teams use the Budget Reporting Data Sheet included here to determine the cost of their solution as tested.
- For enrichment, advise students that NASA plans to mass-produce their design for use as a delivery vehicle for monthly supply trips to Mars, but due to financial constraints, the annual budget has been reduced. Students will be required to redesign their prototype to reduce costs, but without reducing performance.

Engineering Design Process

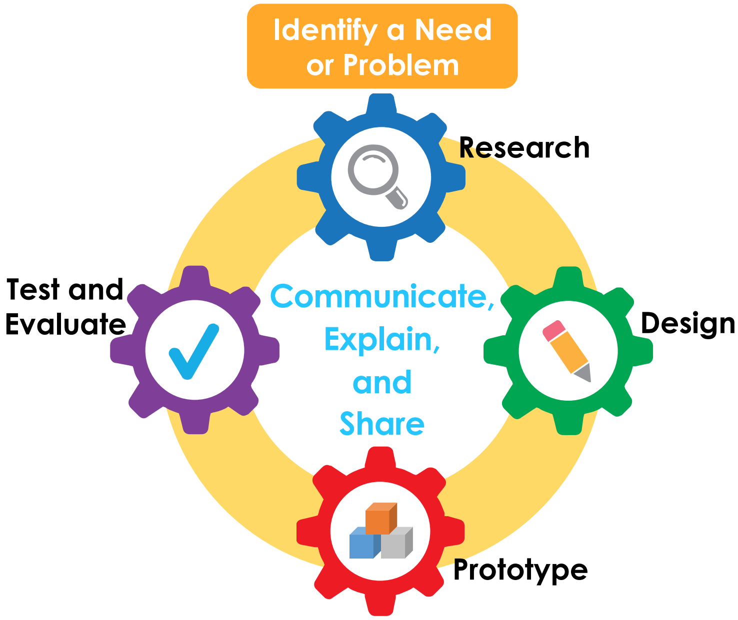


Figure 15. Engineering Design Process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.

Identify a Need or Problem. Identify a need or problem to be solved, improved, or fixed. Identify the criteria and constraints that will need to be met to solve the problem.

Research. Use resources from the internet, the library, or discussions with NASA scientists and engineers to learn more about the need or problem and possible solutions. Investigate how this problem is currently being solved or what efforts scientists and engineers are making to find a solution.

Design. Use all information gathered to create the design(s). Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. Construct a prototype, or physical model, based on the design model(s). Prototypes are used to test proposed solutions.

Test and Evaluate. Test prototype to determine how effectively it solves the need or problem. Collect data to use as evidence of success or need for improvement. Redesign and refine prototypes to continue looking for possible solutions.

Communicate, Explain, and Share. Communicating, explaining, and sharing the solution and design is essential to tell others how it works, how it solves (or does not solve) the identified need or problem, and how it meets (or fails to meet) the criteria and constraints. Determining how to communicate and act on constructive criticism is critical.

The Engineering Design Challenge

The Challenge

Because spacecraft that land on the surface of Mars travel at extremely high speeds, they need some sort of drag device to slow them down to prevent them from crashing into the planet and becoming damaged. As missions increase in complexity, landers and rovers become heavier and require even more effective drag devices. Engineers must work within the limits (or constraints) of mass, weight, and space on a rocket to successfully accomplish the mission. Students will work in teams to design and construct a drag device that will slow down the cargo bay when it is dropped from a consistent height.

Figure 16. The Low-Density Supersonic Decelerator (LDSD) test vehicle is one of several drag devices NASA has engineered for landing large payloads on Mars. (NASA/JPL–Caltech)

Criteria and Constraints

1. The drag device must connect to a team-built cargo bay that is assembled using the template provided in this guide.
2. The entire device must be deployed from 2 m and remain intact throughout the drop.
3. The cargo bay must hold 10 g.
4. The overall mass cannot exceed 50 g.

Options for Differentiating Instruction

The following suggestions may be used when modifying the engineering design challenge for students outside of the designated age range or ability level.

Modification

- Consider assembling the cargo bay for students.

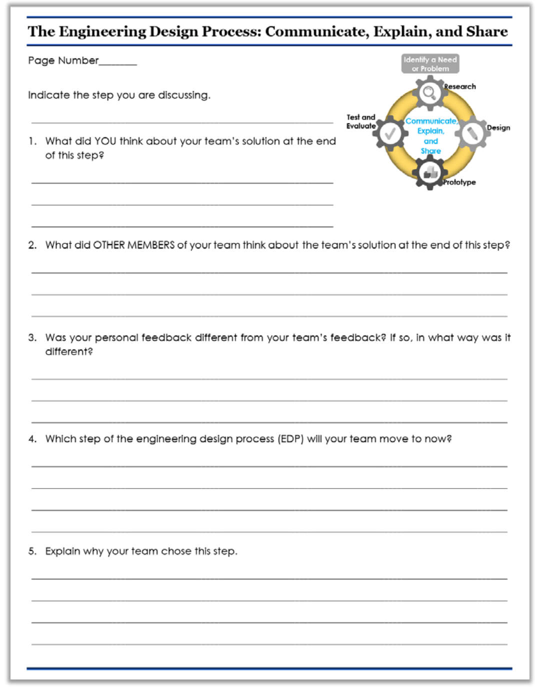
Enrichment

- After students have mastered the drag device with a 10-g payload, increase that weight to 15 g and then 20 g to test the device with more mass.

Student Team Challenge Journals

Students will be creating their Student Team Challenge Journals as they move through the engineering design process (EDP) to solve the challenge. Take time prior to starting the challenge to explain the best way for students to document their work and what the goals are for completing the challenge. The pages should document how student teams moved through the EDP. Students should be instructed to use as many sheets as needed to document each step of the process.

1. Always fill in the page number. This will help keep the pages in order.
2. Direct students to collaborate within their teams and use the five questions on the Communicate, Explain, and Share page to think about where they are in the process before they move on to the next step. Allow for extra copies of this section if needed. Here is an example: "We are moving back to the design phase because the prototype failed to meet the criteria. It was 50 g over the limit."
3. When documenting the prototype stage, remind students to make note of any challenges they faced in building the design and how those challenges were resolved.



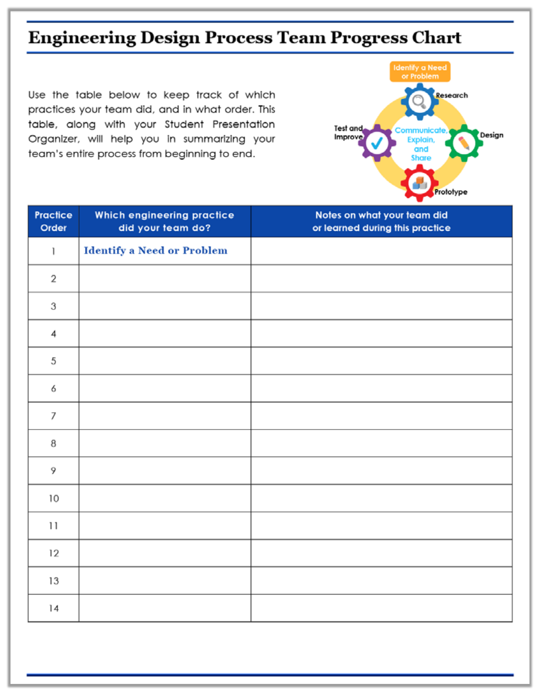
The Engineering Design Process: Communicate, Explain, and Share

Page Number______

Indicate the step you are discussing.

1. What did YOU think about your team's solution at the end of this step?
2. What did OTHER MEMBERS of your team think about the team's solution at the end of this step?
3. Was your personal feedback different from your team's feedback? If so, in what way was it different?
4. Which step of the engineering design process (EDP) will your team move to now?
5. Explain why your team chose this step.

As students proceed through the process, they should record steps accomplished on the Team Progress Chart, found at the back of the Student Team Challenge Journal. Think of this chart as a Table of Contents for the journals that are being created as students move through the process.



Engineering Design Process Team Progress Chart

Use the table below to keep track of which practices your team did, and in what order. This table, along with your Student Presentation Organizer, will help you in summarizing your team's entire process from beginning to end.

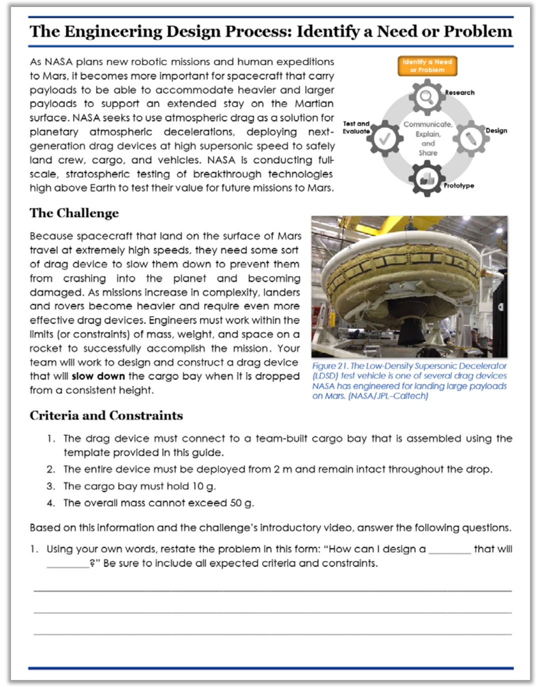
Practice Order	Which engineering practice did your team do?	Notes on what your team did or learned during this practice
1	Identify a Need or Problem	
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

In order to successfully complete the engineering design challenge, teams must use the EDP. As they work the steps of the EDP, students will be engaging in authentic engineering practices.

Identify a Need or Problem

Students complete the Identify a Need or Problem page from the Student Team Challenge Journal.

Engineering design begins by identifying a need or problem that an attempt can be made to solve, improve, and/or fix. This typically includes articulation of criteria and constraints that will define a successful solution.



The Engineering Design Process: Identify a Need or Problem

As NASA plans new robotic missions and human expeditions to Mars, it becomes more important for spacecraft that carry payloads to be able to accommodate heavier and larger payloads to support an extended stay on the Martian surface. NASA seeks to use atmospheric drag as a solution for planetary atmospheric decelerations, deploying next-generation drag devices at high supersonic speed to safely land crew, cargo, and vehicles. NASA is conducting full-scale, stratospheric testing of breakthrough technologies high above Earth to test their value for future missions to Mars.

Identify a Need or Problem
Research
Design
Prototype
Test and Evaluate
Communicate, Explain, and Share

The Challenge

Because spacecraft that land on the surface of Mars travel at extremely high speeds, they need some sort of drag device to slow them down to prevent them from crashing into the planet and becoming damaged. As missions increase in complexity, landers and rovers become heavier and require even more effective drag devices. Engineers must work within the limits (or constraints) of mass, weight, and space on a rocket to successfully accomplish the mission. Your team will work to design and construct a drag device that will **slow down** the cargo bay when it is dropped from a consistent height.

Figure 21. The Low-Density Supersonic Decelerator (LDSD) test vehicle is one of several drag devices NASA has engineered for landing large payloads on Mars. (NASA/JPL–Caltech)

Criteria and Constraints

1. The drag device must connect to a team-built cargo bay that is assembled using the template provided in this guide.
2. The entire device must be deployed from 2 m and remain intact throughout the drop.
3. The cargo bay must hold 10 g.
4. The overall mass cannot exceed 50 g.

Based on this information and the challenge's introductory video, answer the following questions.

1. Using your own words, restate the problem in this form: "How can I design a ________ that will ________?" Be sure to include all expected criteria and constraints.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- How can our team design a _____ that will _____?
- What needs to be solved or improved?
- What are we trying to accomplish?

Instructional Procedure

1. Review the engineering design process with students.
2. Show the NASA Beginning Engineering Science and Technology (BEST) video titled "Repeatability," found at https://www.youtube.com/watch?v=-2Az1KDn-YM.
3. Ask students to identify the specific criteria and constraints of the design challenge.
4. Have students fill out the Identify a Need or Problem page in the Student Team Challenge Journal.

Differentiation Suggestions

Modifications

- Allow students extra time to discuss the challenge itself, the problem that needs to be solved, and how the problem could be solved.
- Introduce criteria and constraints one at a time. Allow student designs to meet one challenge requirement successfully before introducing additional requirements.

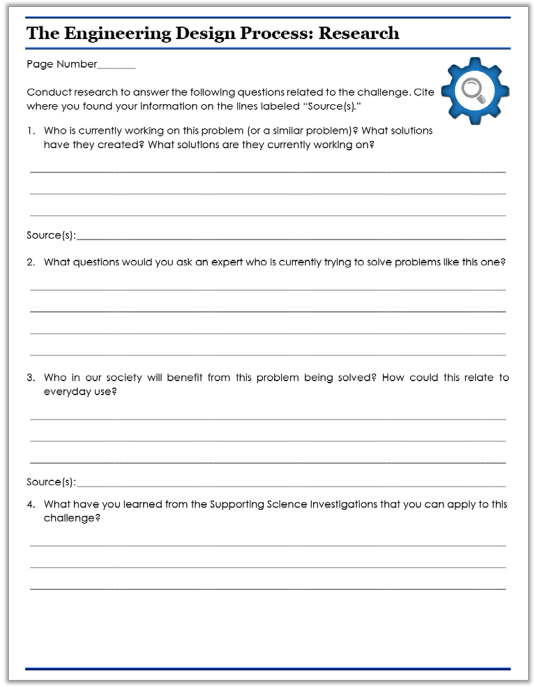
Enrichment

- Require students to write a letter or an email to a friend as if they were explaining their first job as a newly hired NASA engineer.

Research

Students complete the Research page from the Student Team Challenge Journal.

Research is done to learn more about the identified need or problem and potential solution strategies. Students can use resources from the internet, the library, or discussion with experts to examine how this problem or similar problems are currently being solved.



The Engineering Design Process: Research

Page Number______

Conduct research to answer the following questions related to the challenge. Cite where you found your information on the lines labeled "Source(s)."

1. Who is currently working on this problem (or a similar problem)? What solutions have they created? What solutions are they currently working on?

Source(s):

2. What questions would you ask an expert who is currently trying to solve problems like this one?

3. Who in our society will benefit from this problem being solved? How could this relate to everyday use?

Source(s):

4. What have you learned from the Supporting Science Investigations that you can apply to this challenge?

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- Where can you find more information about the topic?
- What questions would you ask an expert or an engineer who is currently working on this problem?
- Who in our society will benefit from this problem being solved?

Instructional Procedure

1. Help students answer any questions they have about the challenge. Use the internet or a school library to research answers.
2. Write down any unanswered questions and save them to ask the NASA subject matter expert (SME) during live connections.
3. Have team members fill out the Research page in the Student Team Challenge Journal.

Differentiation Suggestions

Modifications

- Provide a list of reputable online resources students can use.
- Arrange a visit to a library.
- Pair up students to complete their research together.

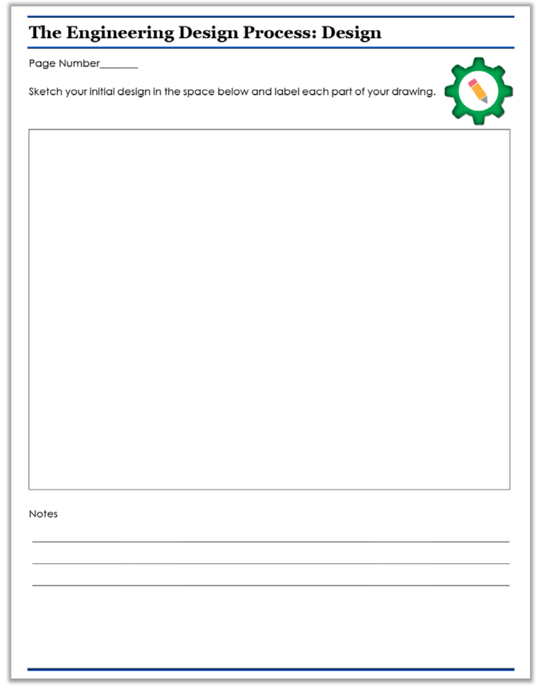
Enrichment

- Have students provide a properly formatted citation for one or more resources.

Design

Students complete the Design pages from the Student Team Challenge Journal.

The design stage includes modeling possible solutions, refining the models, and choosing the model that best meets the original need or problem.


The Engineering Design Process: Design

Page Number______

Sketch your initial design in the space below and label each part of your drawing.

Notes

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What are all the different ways each member of the team can imagine to solve the problem?
- What do we need to add to the design?
- What could go wrong if we add to the design?
- Do the drawings address all the criteria and constraints?

Instructional Procedure

1. Ask each team member to brainstorm individually and make sketches representing ideas for a solution. Students must clearly label and identify each part of their drawing.
2. Each team member should make sure that designs meet all constraints and criteria.
3. Have students sketch their ideas on the Design page in the Student Team Challenge Journal.
4. Ask team members to discuss their ideas and drawings with the rest of the team.
5. Have students record the strengths of each of the designs.
6. Have students fill out the Best Possible Solution page in the Student Team Challenge Journal.

Differentiation Suggestions

Modifications

- Encourage students to create a series of storyboards rather than a single complete drawing.
- Show students the building materials to help them visualize their sketch prior to beginning the drawing.

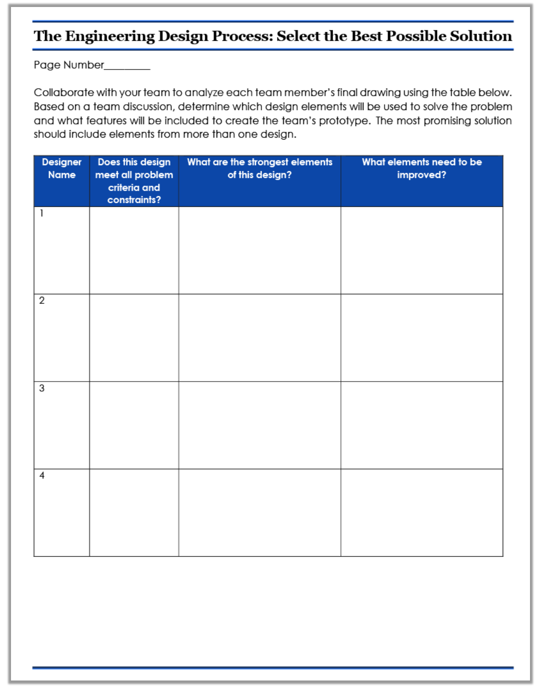
Enrichment

- Require students to specify measurements.

Analyzing the Designs

Team members analyze each member's final drawing using the table provided in the Student Team Challenge Journal.

Based on a team discussion, team members will determine which design elements will be used to solve the problem and what features will be included to create the team's prototype. The most promising solution should include elements from more than one design.



The Engineering Design Process: Select the Best Possible Solution

Page Number_______

Collaborate with your team to analyze each team member's final drawing using the table below. Based on a team discussion, determine which design elements will be used to solve the problem and what features will be included to create the team's prototype. The most promising solution should include elements from more than one design.

Designer Name	Does this design meet all problem criteria and constraints?	What are the strongest elements of this design?	What elements need to be improved?
1			
2			
3			
4			

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What is one strength of each student's individual design?
- How can that be incorporated into a group design?
- Are the strengths in each design related to the criteria and constraints of the challenge?
- Are elements from each team member's design represented in the final design?

Differentiation Suggestions

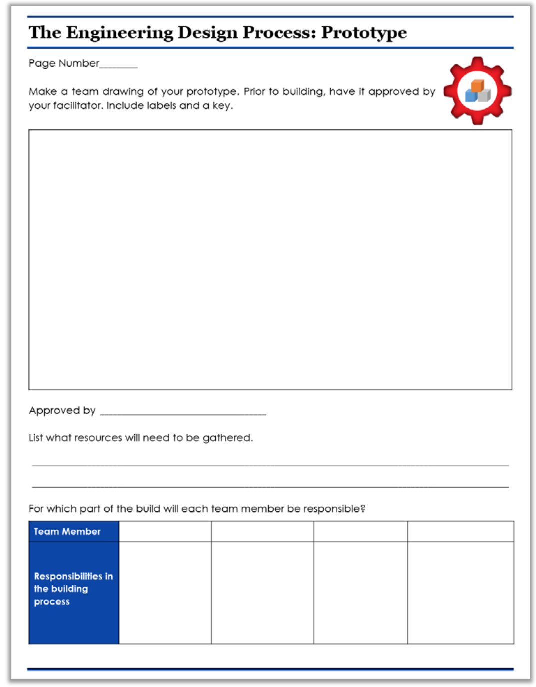
Modification

- Have students pick one aspect or characteristic at a time from each team member's drawing to discuss in the group.

Enrichment

- Require students to draw one or more parts of the design to scale.

Prototype


The Engineering Design Process: Prototype

Page Number_______

Make a team drawing of your prototype. Prior to building, have it approved by your facilitator. Include labels and a key.

Approved by ______________________

List what resources will need to be gathered.

For which part of the build will each team member be responsible?

Team Member				
Responsibilities in the building process				

Students complete the Prototype page from the Student Team Challenge Journal.

A prototype is constructed based on the design model and used to test the proposed solution. A final design should be drawn precisely and labeled with a key. Facilitators should approve final drawings before building begins. Facilitators are expected to assist students as necessary to ensure classroom safety.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What resources does your team need to gather?
- What is the plan?
- Who is doing what?

Instructional Procedure

1. Ask each team to identify the design that appears to solve the problem.
2. A final diagram of the design should be drawn precisely and labeled with a key.
3. Have each team determine what materials they will need to build their design and assign responsibilities to team members for prototype completion.
4. Be sure to approve the final drawings before building begins.
5. After teams receive their materials to build their prototype, have them complete a budget sheet showing their building material costs.
6. Have teams construct their prototypes using their drawings.
7. Have teams fill out the Prototype page in the Student Team Challenge Journal.

Differentiation Suggestions

Modification

- Give students extra time to explore various materials prior to building the model.

Enrichment

- Limit materials to add complexity (e.g., only 1 m of duct tape).

Test and Evaluate

Students complete the Test and Evaluate pages from the Student Team Challenge Journal.

Student teams should test their prototypes to determine how effectively they addressed the need or problem and collect data to serve as evidence of their success or need for improvement. Remind students that they must test their prototypes a minimum of three times for each iteration to ensure the validity of their results.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- Did the team collect enough data to analyze the design?
- How did the prototype perform when tested?
- Did the design meet or exceed the criteria and constraints?

Instructional Procedure

1. Visit each team and test their designs to ensure they meet all challenge criteria and constraints.
2. Have teams fill out Test and Evaluate pages in the Student Team Challenge Journal.

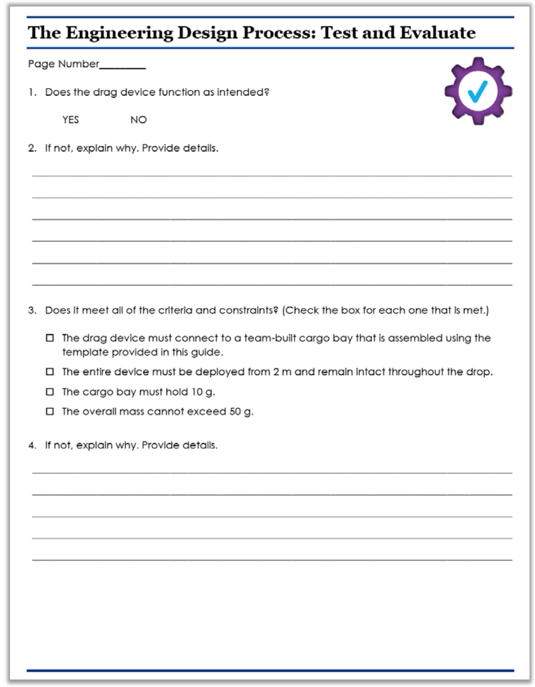
Differentiation Suggestions

Modification

- Encourage students to test only one criteria or constraint at a time rather than all of them at once.

Enrichment

- Create a scatter plot of test results.



The Engineering Design Process: Test and Evaluate

Page Number_______

1. Does the drag device function as intended?

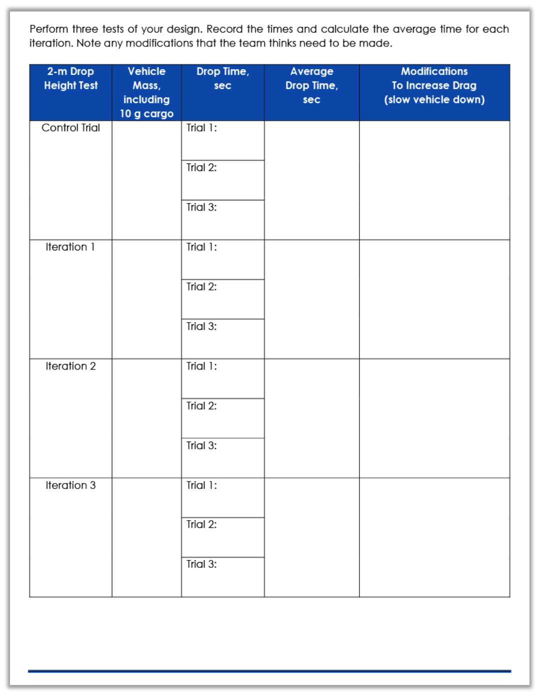
YES NO

2. If not, explain why. Provide details.

3. Does it meet all of the criteria and constraints? (Check the box for each one that is met.)

- ☐ The drag device must connect to a team-built cargo bay that is assembled using the template provided in this guide.
- ☐ The entire device must be deployed from 2 m and remain intact throughout the drop.
- ☐ The cargo bay must hold 10 g.
- ☐ The overall mass cannot exceed 50 g.

4. If not, explain why. Provide details.



Perform three tests of your design. Record the times and calculate the average time for each iteration. Note any modifications that the team thinks need to be made.

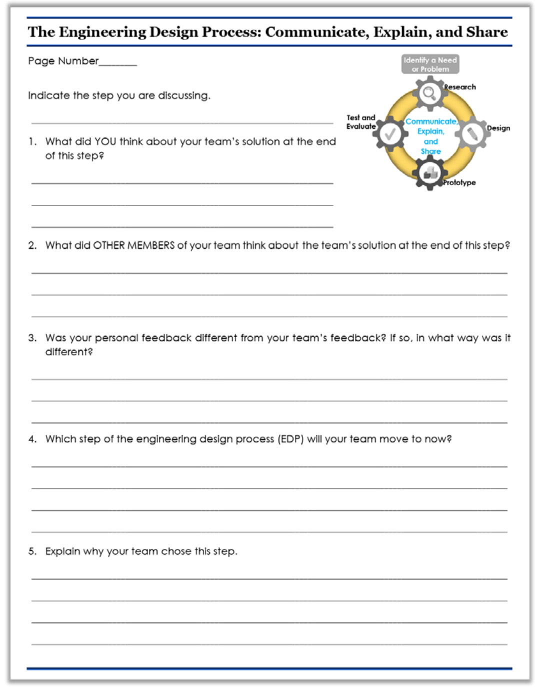
2-m Drop Height Test	Vehicle Mass, including 10 g cargo	Drop Time, sec	Average Drop Time, sec	Modifications To Increase Drag (slow vehicle down)
Control Trial		Trial 1:		
		Trial 2:		
		Trial 3:		
Iteration 1		Trial 1:		
		Trial 2:		
		Trial 3:		
Iteration 2		Trial 1:		
		Trial 2:		
		Trial 3:		
Iteration 3		Trial 1:		
		Trial 2:		
		Trial 3:		

Communicate, Explain, and Share

Students complete the Communicate, Explain, and Share pages from the Student Team Challenge Journal.

Throughout the process, students will take time to reflect on their progress and consider what steps should be taken next. For this challenge, students will share with their peers, both one-on-one and as a classroom. Oral and written peer feedback will help students improve their solutions and designs. It is important for students to learn the peer-review process and to be accepting of others' suggestions.

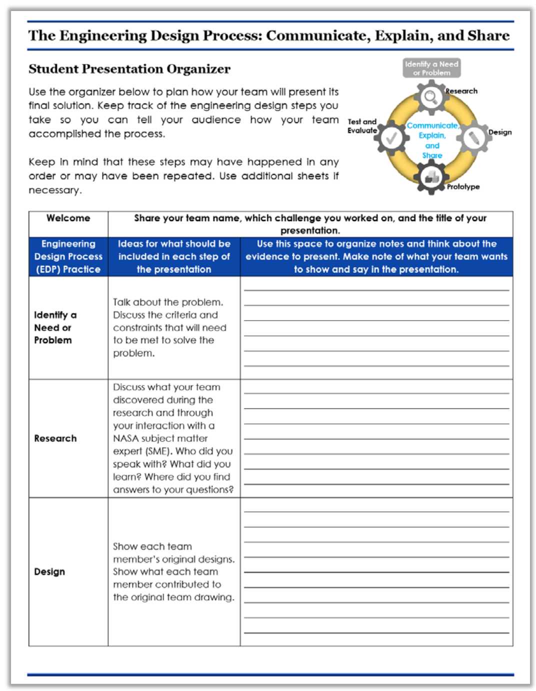
Students will complete the Communicate, Explain, and Share pages after each step to maintain direction and focus during the engineering design process (EDP). Communicating, explaining, and sharing the solution and design is essential to conveying how it works, how it solves the identified need or problem, and how it meets the criteria and constraints. Using the Student Presentation Organizer will help students create the presentation that will be submitted when the challenge has been completed.


The Engineering Design Process: Communicate, Explain, and Share

Page Number______

Indicate the step you are discussing.

1. What did YOU think about your team's solution at the end of this step?
2. What did OTHER MEMBERS of your team think about the team's solution at the end of this step?
3. Was your personal feedback different from your team's feedback? If so, in what way was it different?
4. Which step of the engineering design process (EDP) will your team move to now?
5. Explain why your team chose this step.


The Engineering Design Process: Communicate, Explain, and Share

Student Presentation Organizer

Use the organizer below to plan how your team will present its final solution. Keep track of the engineering design steps you take so you can tell your audience how your team accomplished the process.

Keep in mind that these steps may have happened in any order or may have been repeated. Use additional sheets if necessary.

Welcome	Share your team name, which challenge you worked on, and the title of your presentation.	
Engineering Design Process (EDP) Practice	Ideas for what should be included in each step of the presentation	Use this space to organize notes and think about the evidence to present. Make note of what your team wants to show and say in the presentation.
Identify a Need or Problem	Talk about the problem. Discuss the criteria and constraints that will need to be met to solve the problem.	
Research	Discuss what your team discovered during the research and through your interaction with a NASA subject matter expert (SME). Who did you speak with? What did you learn? Where did you find answers to your questions?	
Design	Show each team member's original designs. Show what each team member contributed to the original team drawing.	

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What did or did not work in the latest iteration of the design? Why or why not?
- What are the pros and cons of this solution?
- Did each team show that they used all of the processes of the EDP?

Instructional Procedure

1. Ask team members to document and report the results of their designs.
2. Have students identify what changes were made with each iteration of the design and what the team believed caused the design to succeed or fail.

3. Students should complete the corresponding sheets in the Student Team Challenge Journal to help them think about how they completed each step of the EDP.
4. Students should use the Team Progress Chart to document progress as they work on their solutions.
5. Teams should use the Student Presentation Organizer to guide them through the creation of the team video or slide presentation.

Differentiation Suggestions

Modification

- Provide a few basic yes/no questions for students to answer to determine whether their design was successful or not.

Enrichment

- Have student teams use a variety of media to create their presentations.

Evaluation: Student Debriefing Questions

The following questions are designed to help start a discussion with your students. After the design challenge is complete, have teams work together to answer these questions.

1. Why did your team use this approach to solve the problem?
2. How did your research help you decide that this was the best solution?

   Encourage students to talk about their thought processes. How did they make their decisions? Was their approach logical and well reasoned? Do they understand the goals?

3. What changes did you make to your design during your iterations of redesign?
4. How could you further improve on your design?

   Questions 3 and 4 will confirm that students have correctly identified the flaws in their designs and are working to correct them.

5. What were the greatest challenges for your team throughout this process?

   Emphasize to students that even the most successful engineers have setbacks.

6. What strategies did your team use that proved effective in overcoming challenges?

   Have students elaborate on why they chose certain options or strategies. Did collaborative discussion or debate help them generate more or better ideas?

7. How did you use the engineering design process (EDP) to help with your design?

   Make sure students talk about each practice and discuss how the process helped them complete the challenge.

8. What concerns must be considered in constructing a quality drag device?

   Emphasize safety and meeting the criteria and constraints. Encourage students to utilize proper scientific terminology and the vocabulary embedded in this guide.

9. What specific problems did you have to address in designing the drag device?

   This could include technical problems as well as interpersonal problems. Emphasize how the students worked to find a solution to each problem. Was test data consistent? Have students describe any unusual results and tell what might have happened to cause them.

10. If you were an astronaut heading to Mars, would you trust your team's drag device to safely land supplies during an extended stay on the planet? Why or why not?

    This question can serve two purposes. One allows students to visualize themselves as astronauts as a way to evaluate their solution in a real-world context. The other allows students to consider various career pathways such as electrical or mechanical engineer, repair technician, or payload scientist.

Creating Solution Presentations

For the final stage of the challenge, students will document their progress in a video or slide presentation to share with other groups who have completed this engineering design challenge. The Student Team Challenge Journal was designed to help document each stage of the engineering design process (EDP). Encourage students to use their journals to help build the presentation.

Submission Guidelines

The finished presentation must meet the following guidelines:

- The introduction must say this: "This is team (team name) and we worked on the (name of challenge). The title of our presentation is (presentation title)."

  Do not identify by name any student, teacher, school, group, city, or region in your presentation. Submissions that do not follow these directions will be disqualified.
- The presentation should document every step students took to complete the challenge, including the Supporting Science Investigations.
- Identify any information provided by NASA subject matter experts (SMEs) that helped you in your design or testing.
- Explain which characteristics of the design provided the most reliable results and why.
- The total length of the presentation should be 3 to 5 minutes.

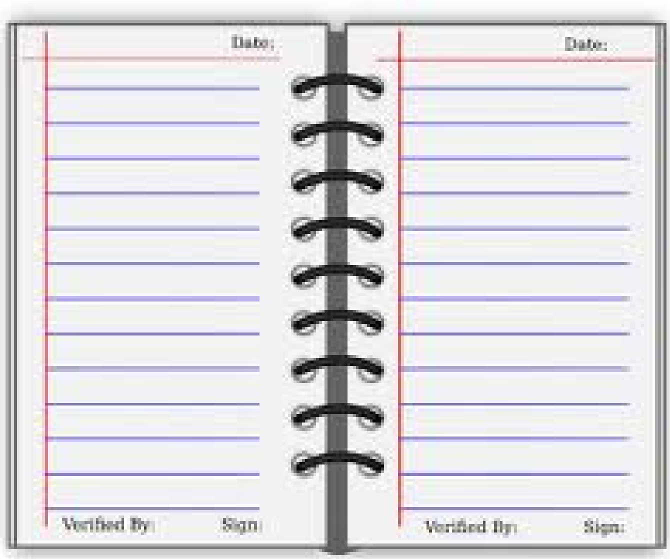
Once the video or slide document is complete, submit the presentations using the process explained on the Y4Y (You for Youth) website.

Budget Reporting Worksheet

Directions: As a team, complete the cost sheet below. Be sure to include all materials needed, unit cost, quantity, and the item total needed to complete your design. At the end, total up the entire cost of your solution.

Line Item Number	Material	Unit Cost	Quantity	Item Total
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
			Total Cost:	

Student Team Challenge Journal



Supporting Science Investigation 1: It's a Drag

Concept

Every object that falls due to gravity will ultimately fall at a constant speed. In order to stop an object or to slow it down, a certain amount of drag needs to be applied to oppose the acceleration. As drag increases, an object will slow its rate of fall.

In this activity, you will see the effects of drag on a falling object by shaping a large sheet of paper and measuring the time it takes to fall from a fixed distance.

Figure 17. Space Shuttle Endeavour's drag chute deploys to slow the orbiter as it lands at Edwards Air Force Base at the conclusion of the STS–111 mission to the International Space Station in 2002. (NASA)

Materials

For each pair of students:

- Meter stick
- Large sheet of paper
- Stopwatch
- Table

Procedure

1. Working with a partner, take turns dropping or timing the falling object.
2. Place the meter stick on top of the table so that it stands upright. The meter stick should be placed at the edge of the table. You will drop the paper from the top of the meter stick to the floor.
3. One student in each group folds the paper in half and holds the sheet of paper horizontally at the top of the meter stick.
4. Release the paper while your partner times how long it takes to fall to the floor.
5. Record the time on your Data Collection Sheet.
6. Repeat this drop two more times for a total of three iterations. Record the times on your Data Collection Sheet.
7. Calculate the average of the three drops and record it on your Data Collection Sheet.
8. Fold the sheet of paper into quarters.
9. Drop the paper three times using the method described in steps 3 and 4. Record all of the times and the average on your Data Collection Sheet.
10. Repeat this experiment multiple times, trying different shapes of paper. There is no constraint as to how the paper is folded or unfolded.
11. Answer the questions provided on the Data Collection Sheet.

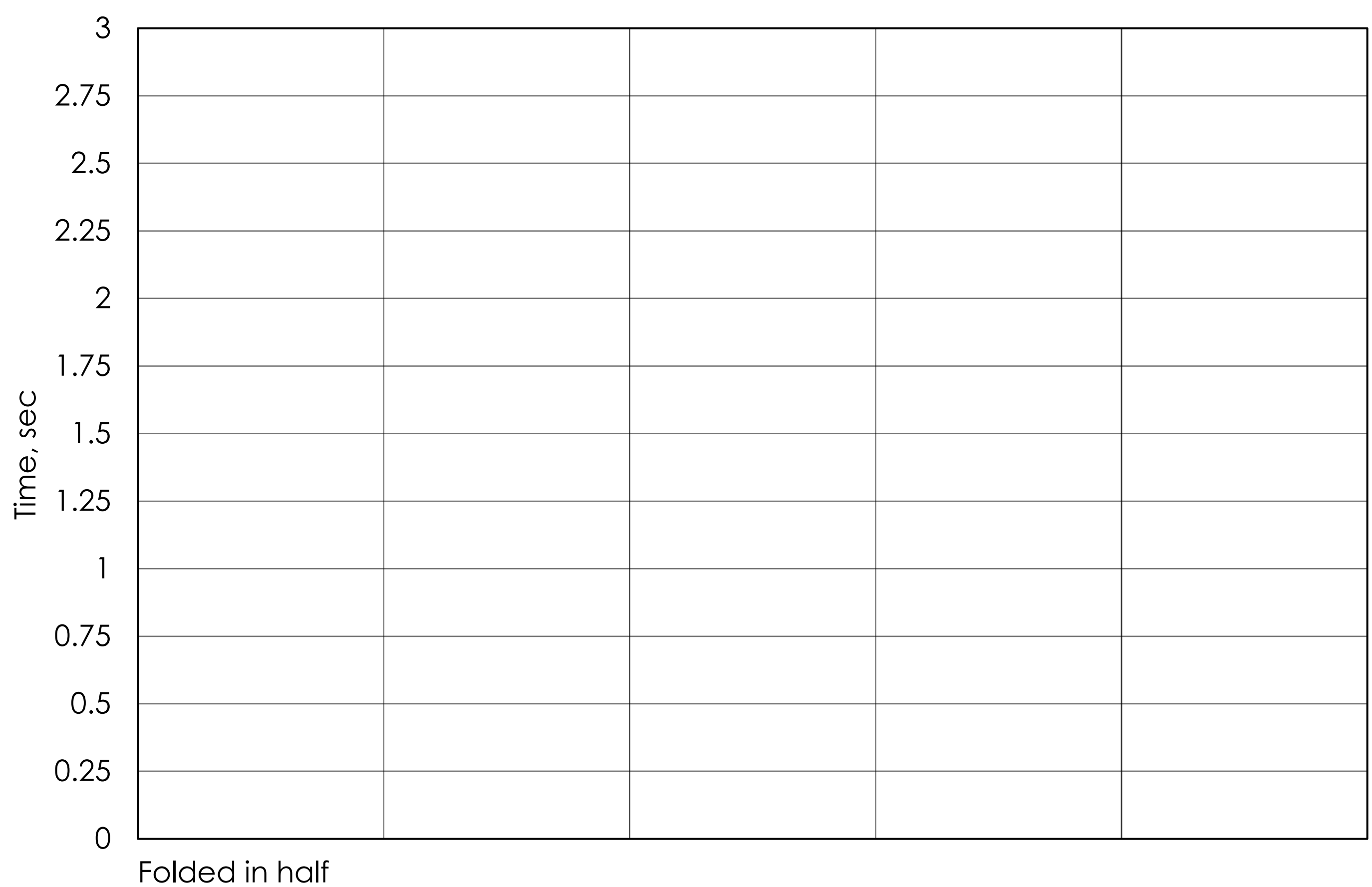
Data Collection Sheet

Complete the table below using the results from your experiments.

Paper shape	Drop 1 time, sec	Drop 2 time, sec	Drop 3 time, sec	Average drop time, sec	Observations
Folded in half					

Using a different color for each test, create a bar graph of the average results from your experiments below. Remember to label each bar at the bottom.

Title:____



Parachuting Onto Mars

1. Describe the graph. How did the shape of the paper affect the speed at which it fell? Use the data in your answer.

____

____

____

____

____

2. Why do you think that happened?

____

____

____

____

____

Discussion Questions

It's a Drag used different shapes of paper to simulate the effects of drag on a moving object.

1. If we were to perform the same activity on Mars, would the results be the same, faster, or slower than here on Earth? Why?

____

____

____

2. If the goal was to produce as much drag as possible, how could you achieve this?

____

____

____

3. How will you apply what you learned in this investigation to your design?

____

____

____

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____

Supporting Science Investigation 2: Touchdown

Concept

The Mars 2020 rover mission is part of NASA's Mars Exploration Program. The mission is not only seeking signs of habitable conditions on Mars but is also searching for signs of past microbial life. The mission will gather information to aid future human expeditions to Mars. This includes improving landing techniques; identifying resources to enable human habitation; and characterizing weather, dust, and other environmental conditions that could affect how future astronauts live and work on Mars.

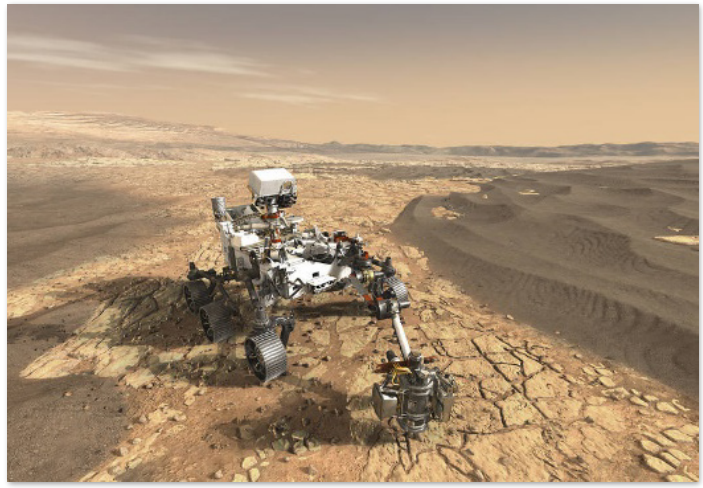


Figure 18. Artist's rendering of the Mars 2020 rover on the surface of Mars. (NASA/JPL–Caltech)

NASA will use the proven landing system used to land the Curiosity rover. However, with heavier science equipment, the spacecraft will need to have a way to absorb the extra energy of impact from the landing while also protecting the cargo.

Each team will design and build a vehicle imitating the Mars 2020 rover landing vehicle. Your team will develop a shock-absorbing system that will keep marshmallows (cargo) inside a cup (cargo hold) upon landing during a drop test. Teams will not be allowed to secure the cargo with tape. The challenge is to make a shock-absorbing system that absorbs the transfer of energy so the marshmallows stay in the cup on landing.

Materials

For each pair of students:

- Piece of stiff paper or cardboard, approximately 10 x 13 cm
- Small paper or plastic cup
- 4 small index cards
- Tape measure
- 2 regular-size marshmallows
- 10 miniature marshmallows
- 3 rubberbands
- 8 plastic straws
- Scissors
- Tape

Procedure

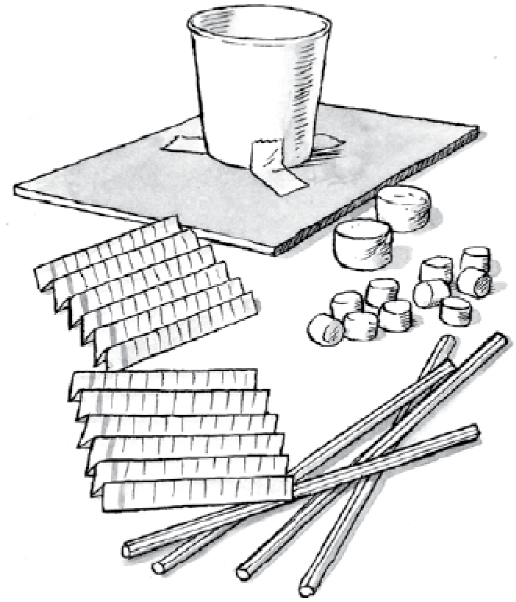


Figure 19. Materials used in the "Touchdown" investigation.

1. Secure the cargo hold (cup) on the lander (cardboard). Draw a circle around the bottom of the cup. You can either leave the cup in place during the design and build or you can remove it to assist in the construction of the shock-absorbing system. In either case, the cargo hold must be secured prior to testing.
2. Work in pairs to design a shock-absorbing system with the materials provided.
3. Build your designed shock-absorbing system and attach it to the cardboard lander.
4. With the cargo hold secured to the lander, put two pieces of cargo (the large marshmallows) in the cargo hold. They cannot be secured with tape.
5. Drop the lander from heights of 50 cm, 100 cm, and 150 cm.
6. If the cargo does not stay in the cup, work with your team to redesign the shock-absorbing system as time allows.

Data Collection Sheet

	Cargo protected? Yes/No	Modifications Needed
50 cm		
100 cm		
150 cm		

1. Describe the team's test results. Did your initial design meet the criteria? If not, describe the modifications your team had to make to continue working on the problem.

____

____

____

____

____

2. Was your team able to create a shock-absorbing system that held together for a 150-cm drop? If not, what prototype ideas did you have to revisit to try to meet the criteria?

____

____

____

____

Discussion Questions

1. Touchdown used a shock-absorbing system to protect the cargo in a landing vehicle. What do you think would happen if this investigation was performed on Mars?

___

___

___

2. Would the results be the same, better, or worse than here on Earth? Why?

___

___

___

___

3. How will you apply what you learned in this investigation to your design?

___

___

___

___

The Engineering Design Process

The engineering design process (EDP) consists of a series of steps, each designed to help you develop a solution to a problem. Start with "Identify a Need or Problem" and use the EDP diagram shown here to help solve this challenge.

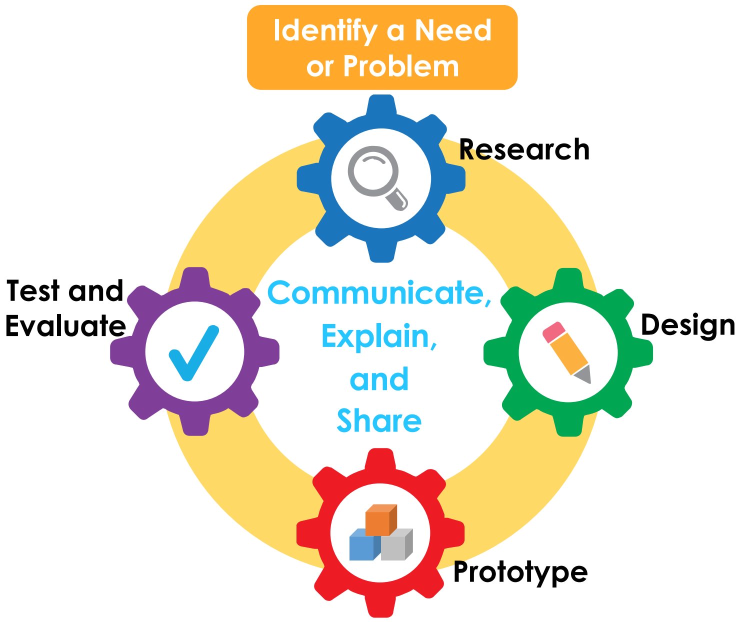


Figure 20. Engineering design process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.

Identify a Need or Problem. Identify a need or problem to be solved, improved, or fixed. Identify the criteria and constraints that will need to be met to solve the problem.

Research. Use resources from the internet, the library, or discussions with NASA scientists and engineers to learn more about the need or problem and possible solutions. Investigate how this problem is currently being solved or what efforts scientists and engineers are making to find a solution.

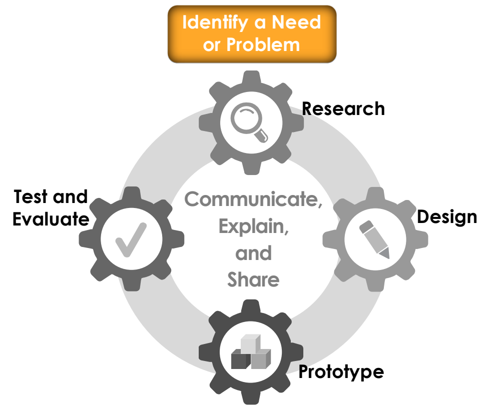
Design. Use all information gathered to create the design(s). Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. Construct a prototype, or physical model, based on the design model(s). Prototypes are used to test proposed solutions.

Test and Evaluate. Test prototype to determine how effectively it solves the need or problem. Collect data to use as evidence of success or need for improvement. Redesign and refine prototypes to continue looking for possible solutions.

Communicate, Explain, and Share. Communicating, explaining, and sharing the solution and design is essential to tell others how it works, how it solves (or does not solve) the identified need or problem, and how it meets (or fails to meet) the criteria and constraints. Determining how to communicate and act on constructive criticism is critical.

The Engineering Design Process: Identify a Need or Problem



As NASA plans new robotic missions and human expeditions to Mars, it becomes more important for spacecraft that carry payloads to be able to accommodate heavier and larger payloads to support an extended stay on the Martian surface. NASA seeks to use atmospheric drag as a solution for planetary atmospheric decelerations, deploying next-generation drag devices at high supersonic speed to safely land crew, cargo, and vehicles. NASA is conducting full-scale, stratospheric testing of breakthrough technologies high above Earth to test their value for future missions to Mars.

The Challenge

Because spacecraft that land on the surface of Mars travel at extremely high speeds, they need some sort of drag device to slow them down to prevent them from crashing into the planet and becoming damaged. As missions increase in complexity, landers and rovers become heavier and require even more effective drag devices. Engineers must work within the limits (or constraints) of mass, weight, and space on a rocket to successfully accomplish the mission. Your team will work to design and construct a drag device that will **slow down** the cargo bay when it is dropped from a consistent height.

Figure 21. The Low-Density Supersonic Decelerator (LDSD) test vehicle is one of several drag devices NASA has engineered for landing large payloads on Mars. (NASA/JPL–Caltech)

Criteria and Constraints

1. The drag device must connect to a team-built cargo bay that is assembled using the template provided in this guide.
2. The entire device must be deployed from 2 m and remain intact throughout the drop.
3. The cargo bay must hold 10 g.
4. The overall mass cannot exceed 50 g.

Based on this information and the challenge's introductory video, answer the following questions.

1. Using your own words, restate the problem in this form: "How can I design a ________ that will ________?" Be sure to include all expected criteria and constraints.

____

____

____

2. What general scientific concepts do you and your team need to consider before you begin solving this need or problem?

___

___

___

The Engineering Design Process: Research

Page Number_________

Conduct research to answer the following questions related to the challenge. Cite where you found your information on the lines labeled "Source(s)."

1. Who is currently working on this problem (or a similar problem)? What solutions have they created? What solutions are they currently working on?

____

____

____

Source(s): ____

2. What questions would you ask an expert who is currently trying to solve problems like this one?

____

____

____

____

3. Who in our society will benefit from this problem being solved? How could this relate to everyday use?

____

____

____

____

Source(s): ____

4. What have you learned from the Supporting Science Investigations that you can apply to this challenge?

____

____

____

The Engineering Design Process: Design

Page Number_________

Sketch your initial design in the space below and label each part of your drawing.

Notes

____

____

____

____

The Engineering Design Process: Select the Best Possible Solution

Page Number_________

Collaborate with your team to analyze each team member's final drawing using the table below. Based on a team discussion, determine which design elements will be used to solve the problem and what features will be included to create the team's prototype. The most promising solution should include elements from more than one design.

Designer Name	Does this design meet all problem criteria and constraints?	What are the strongest elements of this design?	What elements need to be improved?
1			
2			
3			
4			

The Engineering Design Process: Prototype

Page Number________

Make a team drawing of your prototype. Prior to building, have it approved by your facilitator. Include labels and a key.

Approved by ______________________________

List what resources will need to be gathered.

____

____

For which part of the build will each team member be responsible?

Team Member				
Responsibilities in the building process				

The Engineering Design Process: Test and Evaluate

Page Number_________

1. Does the drag device function as intended?

   YES NO

2. If not, explain why. Provide details.

3. Does it meet all of the criteria and constraints? (Check the box for each one that is met.)

   - ☐ The drag device must connect to a team-built cargo bay that is assembled using the template provided in this guide.
   - ☐ The entire device must be deployed from 2 m and remain intact throughout the drop.
   - ☐ The cargo bay must hold 10 g.
   - ☐ The overall mass cannot exceed 50 g.

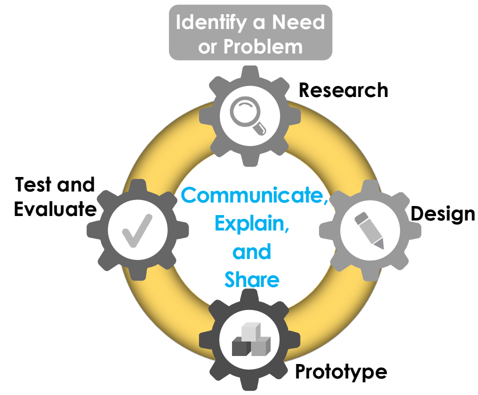
4. If not, explain why. Provide details.

Perform three tests of your design. Record the times and calculate the average time for each iteration. Note any modifications that the team thinks need to be made.

2-m Drop Height Test	Vehicle Mass, including 10 g cargo	Drop Time, sec	Average Drop Time, sec	Modifications To Increase Drag (slow vehicle down)
Control Trial		Trial 1:		
		Trial 2:		
		Trial 3:		
Iteration 1		Trial 1:		
		Trial 2:		
		Trial 3:		
Iteration 2		Trial 1:		
		Trial 2:		
		Trial 3:		
Iteration 3		Trial 1:		
		Trial 2:		
		Trial 3:		

The Engineering Design Process: Communicate, Explain, and Share

Page Number_______



Indicate the step you are discussing.

____

1. What did YOU think about your team's solution at the end of this step?

____

____

____

2. What did OTHER MEMBERS of your team think about the team's solution at the end of this step?

____

____

____

3. Was your personal feedback different from your team's feedback? If so, in what way was it different?

____

____

____

4. Which step of the engineering design process (EDP) will your team move to now?

____

____

____

____

5. Explain why your team chose this step.

____

____

____

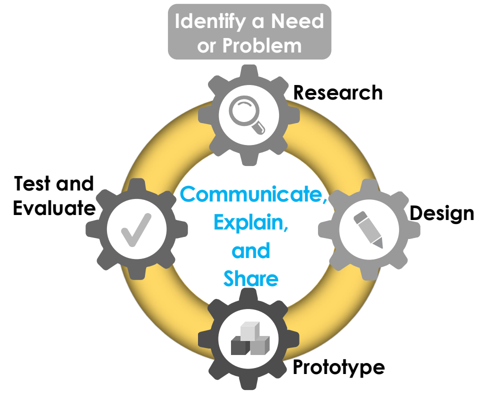
____

The Engineering Design Process: Communicate, Explain, and Share

Student Presentation Organizer

Use the organizer below to plan how your team will present its final solution. Keep track of the engineering design steps you take so you can tell your audience how your team accomplished the process.

Keep in mind that these steps may have happened in any order or may have been repeated. Use additional sheets if necessary.

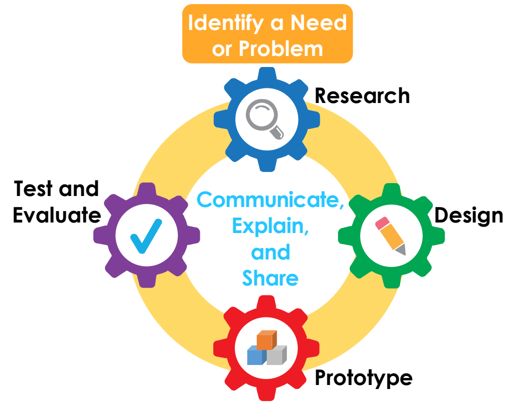


Welcome	Share your team name, which challenge you worked on, and the title of your presentation.	
Engineering Design Process (EDP) Practice	**Ideas for what should be included in each step of the presentation**	**Use this space to organize notes and think about the evidence to present. Make note of what your team wants to show and say in the presentation.**
Identify a Need or Problem	Talk about the problem. Discuss the criteria and constraints that will need to be met to solve the problem.	
Research	Discuss what your team discovered during the research and through your interaction with a NASA subject matter expert (SME). Who did you speak with? What did you learn? Where did you find answers to your questions?	
Design	Show each team member's original designs. Show what each team member contributed to the original team drawing.	

Prototype	Show materials used and how you put the prototype together.	
Test and Evaluate	Talk about how your team tested the design and discuss the results. Using the data, discuss the strengths and weaknesses of your team prototype.	
Communicate, Explain, and Share	Talk about your data. Was your team able to solve the problem or not? What improvements did your team make to reach your final solution? Discuss any further action your team would take to improve this solution. Describe how your team members communicated with each other to improve the solution. Also describe how you discussed options with people outside your group.	

Engineering Design Process Team Progress Chart

Use the table below to keep track of which practices your team did, and in what order. This table, along with your Student Presentation Organizer, will help you in summarizing your team's entire process from beginning to end.



Practice Order	Which engineering practice did your team do?	Notes on what your team did or learned during this practice
1	**Identify a Need or Problem**	
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Solution Presentation

The final stage of the challenge is to document your progress for sharing with other groups who have completed this engineering design challenge. Your journey may be documented using video or slide presentations.

The finished presentation must meet the following guidelines:

- The introduction must say this: "This is team (team name), and we worked on the (name of challenge). The title of our presentation is (presentation title)."

  Do not identify by name any student, teacher, school, group, city, or region in your presentation. Submissions that do not follow these directions will be disqualified.

- The presentation must document every step you took to complete the challenge, including the Supporting Science Investigations. Use every page of your Student Team Challenge Journal to help complete this presentation.
- Identify any information provided by NASA subject matter experts (SMEs) that helped you in your design or testing.
- Explain which characteristics of the design provided the most reliable results and why.
- The total length of the presentation should be 3 to 5 minutes.

Team Presentation Rubric

Student name ______________________ **Team name** ________________________

The Team Presentation Rubric will be used to evaluate the student team presentations (video, student presentation, and/or slide presentation).

1. In the introduction, the team name, the challenge name, and the title of the presentation were all included. Personal or identifying information was NOT given in the introduction.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

2. The team explained the challenge, including the criteria and the constraints.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

3. The team described the results of their research, including the STEM career they explored and the information they collected from the virtual connection with the NASA scientist or engineer.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

4. The team explained how they used the engineering design process to design and construct their final prototype or model.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

5. As a conclusion, the team described the challenges and successes they experienced as they built, tested, and improved their prototype or model.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

Comments and Encouragement

Vocabulary List

Aerodynamics. The qualities of an object that affect how easily it is able to move through the air

Capsule. A pressurized modular compartment of an aircraft or spacecraft, designed to accommodate a crew or to be ejected

Cargo. Freight carried by an aircraft or other transportation vehicle

Constraints. Limits placed on a design due to available resources and environment

Criteria. Standards by which something may be judged or decided

Decelerator. A mass or object that decreases the speed of another object

Descent. The downward incline or passage of an object

Drag. Resistance to motion through the air

Exploration. Systematic investigation for the purpose of discovery

Fragile. Easily broken or damaged

Gravity. The force that attracts a body toward the center of the Earth or toward any other physical body having mass

Iteration. One cycle of a repetitive process

Launcher. A device for firing rockets

Mass. A unified body of matter without any specific shape

Model. A small object, usually built to scale, that represents another larger object

Observation. The act of noting and recording something with an instrument

Orbit. The path of a celestial body or artificial satellite as it revolves around another object

Payload. Things carried by a spacecraft

Template. A pattern used to guide in making something accurately

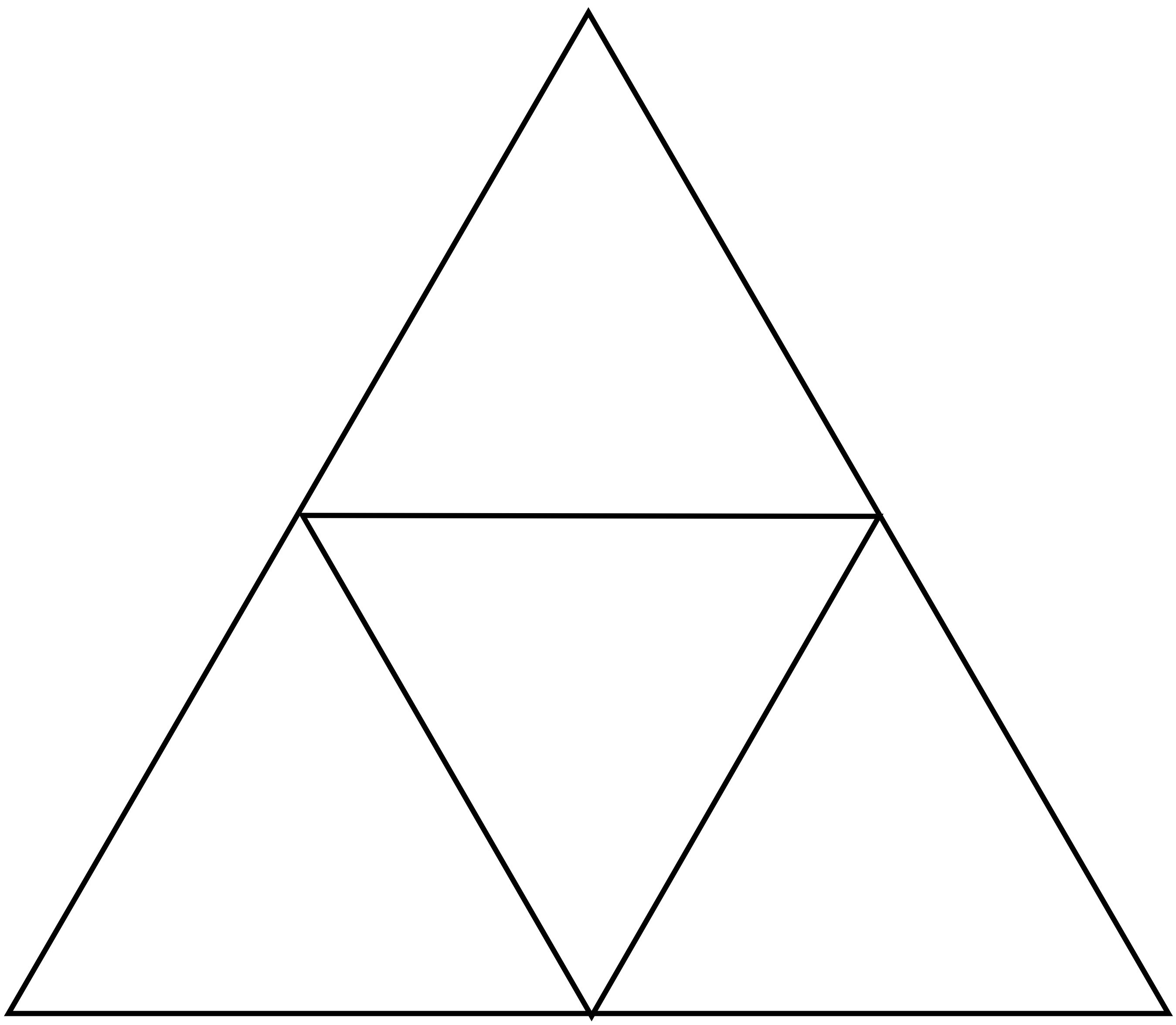
Volume. The quantity of three-dimensional space enclosed by some closed boundary; for example, the space that a substance (solid, liquid, gas, or plasma) or shape occupies or contains

Weight. The force on an object due to gravity

Appendix

Cargo Bay Template

Cut out the larger triangle and fold on the inner lines to create a pyramid shape. Put the simulated payload inside the pyramid and tape up the sides. Because you might need to adjust the weight of your capsule during testing, use a minimal amount of tape so it can be opened easily.



NASA Resources

Online Resources

To learn more about NASA's Orion spacecraft:
http://www.nasa.gov/exploration/systems/orion

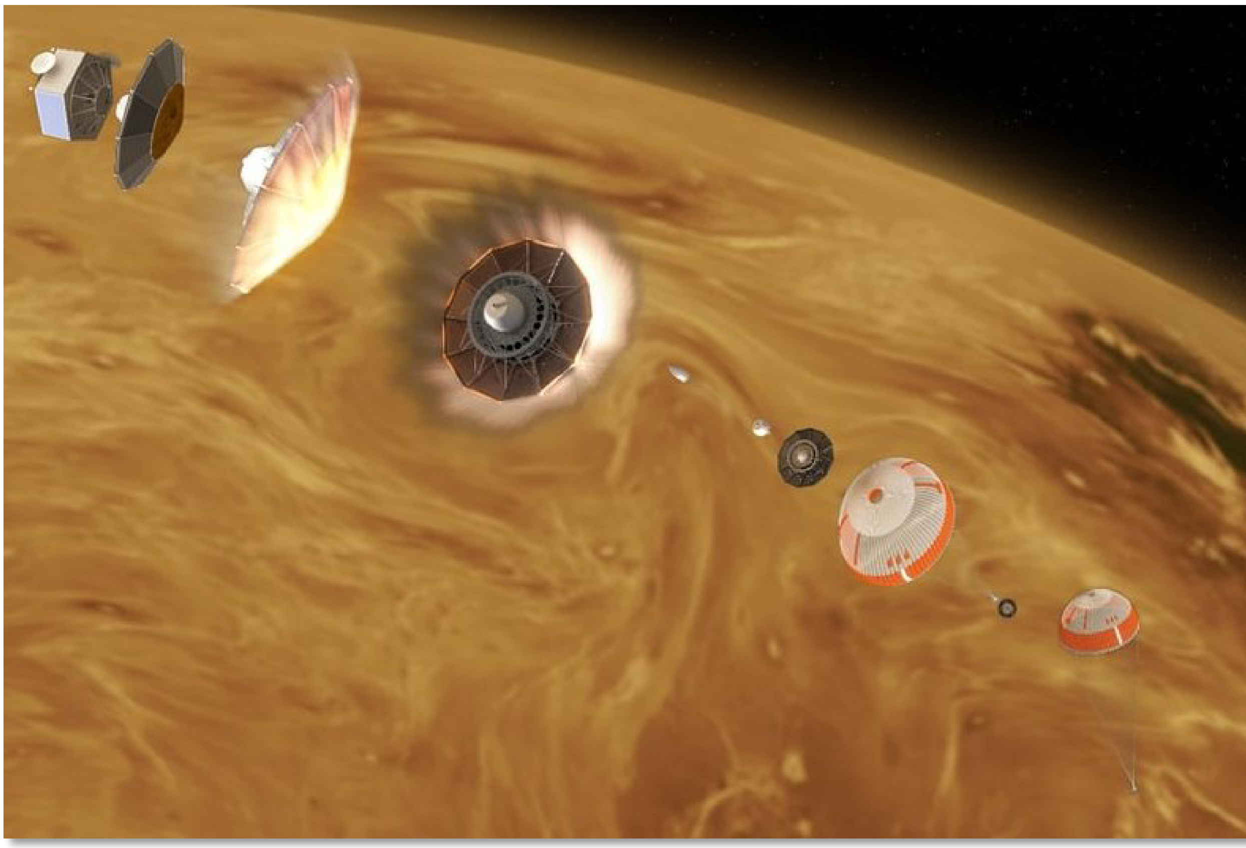
To learn more about NASA's Space Launch System:
http://www.nasa.gov/exploration/systems/sls

To watch an exciting NASA video about Orion's development:
https://www.youtube.com/watch?v=KyZqSWWKmHQ

To learn more about NASA's historic Voyager missions:
http://voyager.jpl.nasa.gov/

To learn more about NASA's New Horizons spacecraft exploration of Pluto:
http://pluto.jhuapl.edu/

Back cover: Artistic rendering of an entry, descent, and landing system concept to safely deploy scientific payloads or enable long-term human exploration to other planets. (NASA)



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