FUTURE U.

Mars Landing

Objectives

Students wil be able to:

- **Research** and **explain** the factors and challenges that affect a Mars landing.
- **Design** and **create** a spacecraft prototype that takes these factors into consideration.
- **Analyze** the results of their prototype testing and **develop** a plan for optimization.

Lesson Overview

As landing engineers in Boeing's Beyond Earth division, students are challenged with creating a landing system for the world's first crewed Martian-bound spacecraft. Students will explore the various factors that affect a Mars landing, including spacecraft speed, atmospheric pressure, and planetary surface dust. After creating a model of their design, students will simulate testing as they consider how their design would fare in deep space and how they may be able to optimize it.

This lesson focuses on

Engineering Design Process

- Defining the Problem
- Designing Solutions
- Refine or Improve

21st Century Skills

- Communication
- Collaboration
- Critical Thinking
- Creativity

Timing

Three 45–60-minute class periods

Materials

ALL DAYS

- Computer or device with the ability to project, one for the instructor

DAY 1

- Video to project: 7 Minutes of Terror: The Challenges of Getting to Mars
- Video to project: Fly Over NASA InSight's New Mars Home
- Image to project: CST-100 Starliner webpage

- Image to project: Space Launch System webpage
- Mars Landing Research handout, enough for half the class
- Devices with internet access, at least enough for half the class

DAY 2

- EDL Planning handout, enough for one-quarter of the class
- Prototype materials:
    - Hardboiled eggs or water balloons (pre-filled), 2*
    - Various building materials for the class to share, which may include:
        - Cardboard
        - Rubber bands
        - Marshmallows
        - Aluminum foil
        - Plastic wrap
        - String
        - Plastic bags
        - Coffee filters
        - Bubble wrap
        - Tape
        - Scissors

*If you will be completing the drop indoors, hard-boiled eggs are recommended. If you will be completing the drop outside, either eggs or water balloons may be used. See the Instructor Prep section for more details.

DAY 3:

- Hardboiled eggs or water balloons (pre-filled), enough for one-third of the class
- EDL Testing and Optimization handout, one per student
- Remaining protype materials, left over from Day 2
- NASA's *Mars in a Minute* video

Have you ever wondered…

Have there been successful trips to Mars?

Yes! However, every trip has been unmanned. Never has a spacecraft with a crew inside orbited or landed on Mars. NASA's Mariner 4 completed the first successful fly-by in 1965. Since this date, four space agencies have made it into Mars' orbit: NASA, the former Soviet Union, the European Space Agency, and the Indian Space Research Organization[1]. In addition to this fly-by, the United States has had eight successful Mars landings. The first occurred in 1976 and the most recent occurred in 2018.2 The Soviet Union also had two successful Mars landings during the 1970s. Imagery and data collected during each trip has allowed humans to better understand Mars' atmosphere, climate, and habitability[2].

When will humans be able to visit Mars?

NASA predicted in 2018 that it will be ready to send humans to Mars within 25 years. In order to make this a reality, solutions must be developed to protect astronauts from cosmic rays, intense radiation, and solar flares. The spacecraft must also be able to safely land and take off from Mars while carrying humans and cargo. And, once on the planet, astronauts must be prepared to deal with extreme weather conditions and dust storms. Once these challenges are solved, humans will be able to take the 34 million-mile (and about one year in length!) trip to Mars[3].

Make Connections

How does this connect to students?

Though the last human walked on the Moon in 1972, an emphasis on human space travel (to both the Moon and Mars) has returned in full force. The United States' renewed focus on its space program means that there are growing funds and resources being dedicated to space exploration. Students will be entering university and the workforce during a crucial time as researchers and scientists work to tackle the many challenges that currently inhibit a manned Martian-bound spacecraft. Not only are students likely to have a wider scope of related job opportunities, but deep space travel is likely to be possible within their lifetime!

How does this connect to careers?

GIS Technician: GIS technicians interpret maps and analyze geographical data. GIS technicians who work on planetary datasets help process information from NASA missions, including drafting maps based on imagery from Mars.

Launch Vehicle Control Engineer: One role of launch vehicle control engineers is to develop and execute procedures related to flight avionics hardware and electrical ground support. This career could help design and build a fully-automated launch and landing system for a Mars-bound flight![4]

Mechanical Engineers: Mechanical engineers may design, develop, manufacture, and install mechanical systems. In relation to Mars landings, one role of a mechanical engineer could be to develop and test spacecraft heatshield materials in order to determine which materials can withstand the temperature changes that occur when entering new atmospheres.[5]

How does this connect to our world?

Space travel is a worldwide endeavor. Though only the United States and the former Soviet Union have been able to land on Mars successfully, other countries (and companies) have their eyes set on it as well. China, for example, hopes to implement its first Mars mission in 2020 in order to take steps toward their goal of collecting Martian rock and soil and bringing it back to Earth.[6]

International collaboration also plays an important role in the success of space exploration. Launched in 1998, the International Space Station (ISS) is a partnership between the U.S., Russia, Canada, Japan, and participating countries from the European Space Agency. According to NASA, it "is one of the most ambitious international collaborations ever attempted."[7] Aboard the ISS, astronauts are able to prepare for longer trips to deep space as scientists study everything from how the body reacts to long-term space flight to how systems critical for Mars missions perform![8]

Sources

[1] Howel, Elizabeth. "A Brief History of Mars Missions." Space.com. space.com/13558-historic-mars-missions.html.
[2] "Mars Exploration Fast Facts." CNN Library. cnn.com/2013/10/21/world/mars-exploration-fast-facts/index.html.
[3] May, Ashley. "Humans Could Be heading to Mars in 25 years, NASA Says." USA Today. usatoday.com/story/news/nation-now/2018/11/14/nasa-humans-space-travel-mars-25-years/1997627002/.
[4] Gelber, Mack. "5 Jobs That Will Take You to Mars—Kind of." Monster. monster.com/career-advice/article/mars-jobs-nasa-wanted-posters.
[5] "Spacecraft Design." NASA. nasa.gov/centers/ames/research/2007/faq-shuttlereentry.html
[6] Mosher, Dave. "China Wants to Launch to Mars Next Year…" Business Insider. businessinsider.com/china-mars-spacecraft-launch-2020-rover-sample-return-2019-1.
[7] "International Cooperation." NASA. nasa.gov/mission_pages/station/cooperation/index.html.
[8] "Top 10 Ways ISS is Helped Us Get to Mars." NASA. nasa.gov/mission_pages/station/research/news/iss_helps_get_to_mars.

Blueprint for Discovery

Instructor Prep: Before Days 2 and 3, you will need to determine where students will complete their test drop. This location can be indoors or outdoors, but try to make the drop occur from a point at least one story high. Stairs may be the easiest option!

Once you have a drop site selected, decide which type of test cargo will work best: water balloons or hardboiled eggs. As noted in the Materials section, hard-boiled eggs are recommended for indoor locations!

DAY 1

1. Begin class by showing the first section of this video from the NASA Jet Propulsion Laboratory: 7 Minutes of Terror: The Challenges of Getting to Mars. Stop the video at 1 minute 5 seconds, and ask students to think-pair-share* their initial reactions about why landing a vehicle on Mars is called "7 minutes of terror".

   **Note:* During a think-pair-share, encourage students to first think about the question independently, discuss their thoughts with a partner, and then share with the larger class.

2. Draw a circle on the board and write "Vehicle Landing" in the middle of it. Challenge the class to brainstorm factors that may need to be considered when landing vehicles—both on Earth and in outer space. For each idea, draw a new circle, write the idea in the center, and then draw a connecting line to the "Vehicle Landing" circle.

3. Tell students that they are about to further investigate these ideas, as they are now going to pretend that they are landing engineers who have just been transferred to Boeing's Beyond Earth division. As you play this flyover video of Mars (using the Fly Over NASA InSight's New Mars Home video) explain that their division's next project is to work toward a successful crewed Mars landing mission.

4. Brief students on a couple Boeing innovations that could make Mars exploration possible:

   - Project and scroll through this CST-100 Starliner webpage, and explain that Boeing's CST-100 Starliner is a new space capsule that will take people to and from the International Space Station. It will fly autonomously from launch to landing. The last time Americans took off for outer space was in 2011, so it is important that Americans continue this space exploration! Being able to ferry people to the International Space System is an important step toward exploring Mars—because it could serve as an outpost to launch missions into deep space.
   - Next, project this Space Launch System webpage and explain that NASA has partnered with Boeing to build the Space Launch System (SLS). The SLS is the size of a 38-story building, and it will be the most powerful rocket ever built. When completed, it will help astronauts explore far into the solar system and deep space, beginning a new era of space exploration.

5. Conclude by acknowledging that while Mars exploration is becoming much more possible, a plan has not yet been developed to land a crewed spacecraft on Mars…which is where the Beyond Earth division comes in!

6. Divide students into pairs and distribute one Mars Landing Research handout to each pair. Review the research questions provided and explain students will research these questions for the rest of the class period in order to better understand what landing on Mars entails and what spacecrafts must be equipped for. Instruct students to begin their research using the websites provided on the handout but explain that they may also perform additional research if time allows.

Tell students that next class they will apply what they have learned to create a Mars landing system, so it is important that they perform careful and thorough research today!

DAY 2

1. Begin class by reviewing the key findings that students discovered in their research during the previous class period. As students share, encourage anyone who is missing information to record it on their Mars Landing Research handout. For each research category, ensure students have learned the following:
    - **Heat Considerations:** Spacecrafts need a heat shield to protect itself and its passengers from the heat and friction created when it collides with Mars' atmosphere.
    - **Speed Reduction:** In those seven minutes after it reaches Mars' atmosphere, the spacecraft must quickly slow down from a speed of 13,000 miles per hour in order to land safely. Mars' atmosphere will help it slow down considerably, but not enough!
    - **Surface Conditions:** Extreme weather and dust storms have the potential to damage spacecrafts, so precautions must be taken.
2. Write the letters "EDL" on the board and explain that EDL stands for *Entry, Descent, and Landing* System. Further explain that *Entry* refers to entry into the Martian atmosphere, *Descent* refers to when the vehicle prepares for landing, and *Landing* refers to the period during which the vehicle touches down on the new planet!
3. Match each pair of research partners with another group of two, so students are now in groups of four. Then distribute an EDL Planning sheet to each group. As you read through the handout's instructions, be sure to include the following:
    - Tell students if they will be using water balloons or hardboiled eggs as their cargo. Explain that today you brought a couple model water balloons/hardboiled eggs for the class to refer to as they build their space vehicle and EDL system. At the start of the next period, each group will receive their own for testing.
    - Show students where they can find the building materials, and review the materials that are available.
4. Remind students how much time remains in the class period and tell them that their goal is to have *Step 3: Create* complete by the end of class! Rotate around the classroom as students work, ask questions, and provide help as needed. Provide warnings when there are 10 minutes and five minutes left in the class period.
5. When the period comes to a close, help students place their prototypes in a safe place. Wrap up by previewing that students will be testing their protypes next class session!

DAY 3

1. As class begins, instruct students to sit with their group members. Distribute a water balloon or hardboiled egg to each group, and tell students that they will have 10 minutes to prepare their prototype for its drop test now that they have their cargo!
2. Once 10 minutes have passed, distribute one EDL Testing and Optimization handout to each student and instruct them to bring this handout, a writing utensil, and their prototype to the drop location.
3. Welcome students to the Beyond Earth division's Deep Space Landing Trial, and review the following testing protocols:

- Instruct each group to share how their prototype addresses the deep space issues of heat, speed reduction, and planetary surface conditions before they test their model. The rest of the division will then count down from 3 to 0, and the protype can be dropped!

  Note: Once the prototype has landed, remove the "cargo" from the spacecraft so students can see if it landed safely (if it's not otherwise clear).

- Explain that those who are not testing should listen carefully to each presentation and use their handout to record at least one idea from each model that they think is particularly innovative. These ideas can be noted in their handout's "design" and "reasoning" columns. Once the model is dropped, students should quickly record whether this particular design element seemed to be successful and jot any ideas the test may have sparked for optimization*.

  *Tip: If needed, define optimization as the process of making modifications in order to improve performance.

4. Once every group has tested their model, bring students back to the classroom. Explain that they are about to use the results of their testing to optimize their EDL system design, but first they are going to hear a quick presentation from NASA that will summarize some of this agency's own learnings! As you play this NASA *Mars in a Minute* video, encourage students to think about how their own design compares to the EDL system used in video's un-manned spacecraft.

5. Then instruct students to reassemble with their groups and complete Step 5 on their EDL Testing and Optimization handout. Deduct about five minutes from the time remaining in class and tell students they will have about this amount of time to optimize their design.

6. When there are five minutes left in class, encourage groups to share one optimization idea that they think has the power to be most impactful.

7. Finally, conclude by thanking the Beyond Earth division for their creativity and hard work over the past few class periods. Instruct students to "come back" to the present, and explain that if deep space exploration intrigues them, there are a multitude of fields in which they can make a difference! Future missions to Mars will require ongoing collaboration among many, many careers—including engineers, physicists, astronauts, computer scientists, technicians, assembly inspectors, etc.—to just name a few. Encourage students to consider an aerospace career in the future if they want to play a bigger role in our mission to Mars!

EXTEND

Students can prepare a presentation for Boeing's Executive Council that explains why significant funds should be allotted toward building and optimizing a CST-100 Starliner landing system in order for it to explore deep space.

Soft Landing: Students can explore a variation of this activity by engaging in an egg-drop challenge. Invite students to devise a way to protect an astronaut during a landing by designing and testing a capsule for a spacecraft. As part of the design challenge, students design a drop tower and control circuit to test their spacecraft capsule designs. As students work to solve the design problem, they develop a deep understanding of the forces involved in safely landing a spacecraft. Students also develop an initial understanding of electricity and magnetism as they design and test an electromagnetic release system for the drop tower. Students test their ideas and assumptions and consider alternative approaches to optimize their spacecraft capsule and drop tower designs.

National Standards

Next Generation Science Standards

Engineering Design

- MS-ETS1-1: Defining and Delineating Engineering Problems
  The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.
- MS-ETS1-4 Developing Possible Solutions
  A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.

Physical Science

- MS-PS2-2. Motion and Stability: Forces and Interactions
  The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.

Common Core English Language Arts Standards

Science & Technical Subjects

- RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts.

Speaking & Listening

- SL.1 Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

Mars Landing Research Notes

Atmosphere: Heat Considerations

Research Question: Why and when does heat play a role in a Mars landing?

Suggested research starting point:
European Space Agency: tinyurl.com/y3paqc67
(esa.int/Our_Activities/Space_Science/Mars_Express/Landers_feel_the_heat_on_space_missions)

Atmosphere: Speed Reduction

Research Question: Why is speed reduction an important factor in a Mars landing? Be sure to explain the effects of the Martian atmosphere!

Suggested research starting points:
HowStuffWorks: science.howstuffworks.com/landing-on-mars1.htm
NASA Jet Propulsion Laboratory: mars.nasa.gov/mer/spotlight/challengesRover01.html

Surface Conditions

Research Question: What surface conditions exist on Mars that a spacecraft would have to keep in mind?

Suggested research starting point:
Space.Com: space.com/16903-mars-atmosphere-climate-weather.html

EDL Planning handout

Step 1: Brainstorm

If you were to create a Martian EDL system for a new crewed spacecraft, what would you include to ensure that it lands safely? Keep the following goals in mind and then work with your group to jot ideas in the space below:

1. Heat protection
2. Speed reduction
3. Protect the spacecraft from the challenges of Mars' surface
4. Additional strategies/ideas (e.g. how to reduce the landing impact, further protect the passengers inside, etc.)

Step 2: Design

Now think about how your ideas could be incorporated into a spacecraft. What would a spacecraft look like if it had all of the design ideas that your group brainstormed? Sketch a model design below. Then label your ideas and briefly explain how they will help with Mars' forces and conditions.

Step 3: Create

Create a prototype of a spacecraft and its EDL system using the materials available. Your prototype must protect your fragile cargo and also take the mission's heat, speed, and planetary surface conditions into consideration!

EDL Testing and Optimization

Step 4: Test

Design Element	Design Reasoning	Success? (Yes, No, So-So)	Optimization Ideas

Step 5: Optimize

Once you have completed your testing, learned from your peers, and heard from NASA, work with your group to analyze how you can use your learnings to optimize your design and make it even more successful. Then sketch a new and improved prototype design. Be sure to label your improvements!