

NEXT ENGINEERS



ENGINEERING DISCOVERY

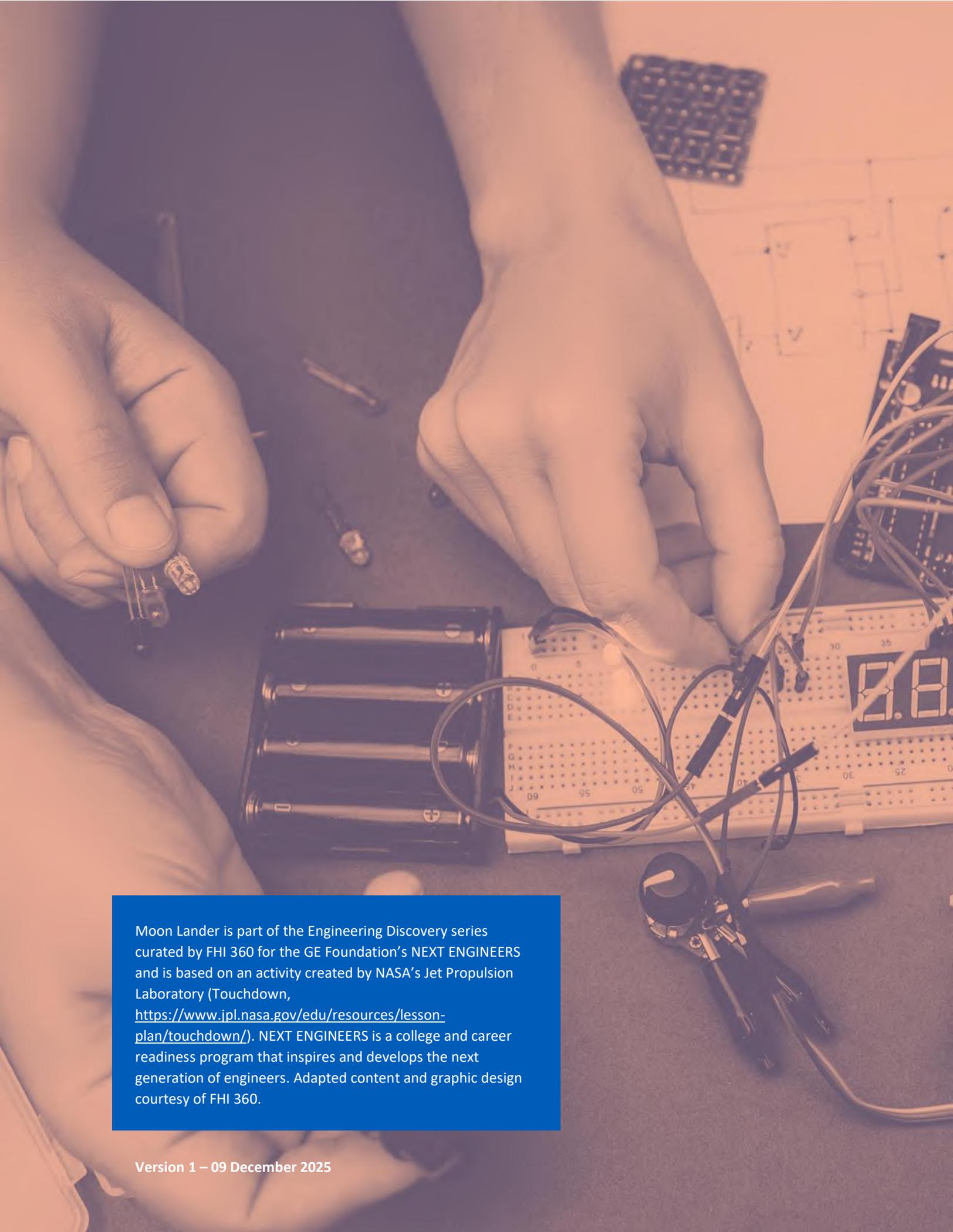
Difficulty Level **1**

Moon Lander

Aeronautical Engineering
Mechanical Engineering



NEXT ENGINEERS



Moon Lander is part of the Engineering Discovery series curated by FHI 360 for the GE Foundation's NEXT ENGINEERS and is based on an activity created by NASA's Jet Propulsion Laboratory (Touchdown, <https://www.jpl.nasa.gov/edu/resources/lesson-plan/touchdown/>). NEXT ENGINEERS is a college and career readiness program that inspires and develops the next generation of engineers. Adapted content and graphic design courtesy of FHI 360.



Moon Lander

HANDS-ON ACTIVITY

Time	Ages	Cost	Group size (teams)	Activity type
45 minutes	8 - 15	Medium	3 - 4 students	Hands-on Activity
Engineering Areas				
<ul style="list-style-type: none"> Mechanical Engineering Aeronautical Engineering 				

Activity Description

Landing on moons and other planets is a tricky challenge, especially when there are astronauts involved. Part of the solution is to design spacecraft with special shock absorbing systems that can absorb and dissipate as much of the energy of impact as possible. Sometimes these systems are structural where certain parts of the landing system are designed to bend, compress or stretch. Other times mechanisms like springs, dampers, and crushable materials are used.

In this challenge, students will get to design their own lander to protect two marshmallow “astronauts” by ensuring that they remain safely inside their cockpit when the lander is dropped. The aim is to achieve a successful landing from the greatest drop height possible.

About the Engineering Design Challenge

In this challenge, teams design, build, and test a shock-absorbing lander to protect two marshmallow “astronauts” as they land after being dropped from the greatest height possible.

Success Criteria

- The marshmallow “astronauts” must remain safely in the lander cockpit upon impact.
- Teams should drop their lander from the greatest height possible.
- Teams may cut, bend, twist, poke, or fold any of their materials.

Constraints

- Teams may only use the materials provided but they don’t have to use all of them.
- Teams must place the cup on the cardboard platform, right side up to form the cockpit in which the “astronauts” will sit.
- The “astronauts” must remain free to move around inside the cockpit i.e., they may not be tied, glued, or wedged into the cup.
- Teams may not cover the top of the cup.



STUDENT DISCOVERIES

Students will:

- Know more about engineering and engineering careers
- Learn the about the Engineering Design Process
- Participate in a team-based learning experience
- Learn about how to absorb and dissipate the forces experienced on impact.
- Have fun experiencing engineering



Materials

Students will need blank paper and pens/pencils to draw their designs.

The following materials will be required **per team** for this activity:

- 1 plastic cup (about 350 ml (12 oz))
- 1 cardboard rectangle (10 cm x 13 cm (4 in x 5 in))
- 3 rubber bands
- 3 index cards (8 cm x 13 cm (3 in x 5 in))
- 8 drinking straws
- 2 marshmallows (the astronauts)
- 10 mini marshmallows
- 1 m (40 in) of tape
- Scissors
- 1 copy of the **Engineering Design Process Summary** (below)
- 1 copy of the **Student Handout** (below)

The following additional materials will be required for **testing** the landers:

- A measuring tape

Facilitation Principles

Working with Youth: Facilitation Tips

(<https://www.nextengineers.org/resource/working-youth-facilitation-tips>) is a handy summary of the key facilitation principles that volunteers need to keep in mind when demonstrating any activity with students.

Facilitator Preparation

1. Read the step-by-step instructions.
2. Collect the materials and place each team's materials in separate bags for easy distribution.
3. Practice doing the activity yourself to identify where students may struggle.
4. Plan when and how any volunteers will share their story and career journey in a relevant and personal way. Try to integrate these stories into the demonstration as much as possible. Volunteers may find the following resources useful:
 - a. *I'm an Engineer! Storytelling Worksheet*
(<https://www.nextengineers.org/resource/im-engineer-storytelling-worksheet>)
 - b. *I Work with Great Engineers! Storytelling Worksheet*
(<https://www.nextengineers.org/resource/i-work-great-engineers-storytelling-worksheet>)
5. Practice asking and answering questions students may ask. See **Frequently Asked Student Questions** (<https://www.nextengineers.org/resource/frequently-asked-student-questions>).
6. Print out copies of the **Student Handout** for each group.
7. Prepare the room and set out the materials before the activity begins.



EXTENSION

One of the ways in which to extend this challenge is to require teams to also build as efficiently as possible by imposing a cost on each material and/or requiring them to purchase from a central store with a budget.



KEY WORDS

- Cantilever
- Center of gravity
- Constraints
- Criteria
- Damper
- Engineering Design Process (EDP)
- Engineering Habits of Mind (EHM)
- Engineers
- Iteration
- Pliable
- Prototype
- Tripod



Step-by-Step Instructions

Time	Instructions	Materials
5 min	<p>Welcome & Introductions</p> <ul style="list-style-type: none"> • Welcome students to the activity and briefly introduce yourself. • Have any volunteers introduce themselves. As appropriate, have any volunteers share their stories and career journeys with the group. 	
5 min	<p>Pre-Challenge Exploration</p> <ul style="list-style-type: none"> • Ask the group if anyone knows when astronauts first landed on the moon. • Say that it was 11 July 1969 and at that time very little was known about what the moon's surface was actually like. • Explain that whenever we send spacecraft to the moon (or other planets like Mars) it is very important that they land gently without injuring the astronauts or damaging the spacecraft or instruments. • Often, this involves slowing the spacecraft down from speeds of up to 29,000 km/h (18,000 mph) as well as using shock absorbers. • Ask for a volunteer to stand on a chair and then jump to the ground. As they do, ask the rest of the group to watch and then describe what this student does. • Explain, that whenever we jump down from something like a step or chair, we bend our back and knees to help absorb some of the energy or shock of landing. Hence the term shock absorber. • Show the group an index card folded into a concertina and how such a structure can also act as a shock absorber. • Explain that soft materials (like mini marshmallows) or flexible or pliable structures (like an index card concertina spring) can be effective shock absorbers. 	Activity Background



TIPS FOR WORKING WITH STUDENTS

- **Be prepared** by practicing the activity beforehand. Being prepared is the best start to leading confidently and having fun.
- **Facilitate like an engineer** by reflecting during and after each session. What worked? What could be improved? How could you do things differently next time?
- **Teamwork is critical** in engineering so encourage it among students. Make sure no one dominates and everyone gets to play.
- **Give one instruction at a time** to keep a large group on task and doing what you need them to do.
- **Give regular time updates** to keep students on track.



5 min	<p>Challenge Overview</p> <ul style="list-style-type: none"> • Explain that students are going to work as teams of engineers to design a shock absorbing lander to protect two marshmallow “astronauts” as they land on the moon. • Show the group the materials that each team will get. • Explain that the two “astronauts” must remain safely inside the cockpit upon landing, that the lander that achieves a successful landing from the greatest height will be the winner and that teams may cut, bend, twist, poke, or fold any of their materials. These are the success criteria. • Explain the constraints: <ul style="list-style-type: none"> ○ Teams may only use the materials provided. ○ Teams must place the cup on the cardboard platform, right side up to form the cockpit where the “astronauts” will sit. ○ The “astronauts” must remain free to move around inside the cockpit i.e., they may not be tied, glued, or wedged onto the bottom of the cup. ○ Teams may not cover the top of the cup. • Note that the two key design considerations teams should think about are how to create a shock absorbing mechanism and how to keep their lander from tipping over during flight. • Tell students that they will have 25 minutes to design and test their landers. Within this time, each team will get two official test opportunities to record their greatest successful drop height. • If necessary, briefly describe the engineering design process that teams will follow using the Engineering Design Process Summary (below). • Divide the group into teams of three or four and provide each team with its equipment and materials. 	<p>Building Materials</p> <p>Engineering Design Process Summary</p> <p>Student Handout</p>
25 min	<p>Engineering Design Challenge</p> <ul style="list-style-type: none"> • Have students work through the Student Handout. • As teams work, circulate around the room encouraging teams and answering any questions they might have. • As teams work on their designs have them consider the following questions: <ul style="list-style-type: none"> ○ Should their lander be symmetrical? ○ Should it be tall or short? ○ How many shock absorbers will it have? ○ How will these be made and how will they work? 	<p>Student Handout</p>



TIPS FOR MAKING CONNECTIONS

1. **Give constructive feedback** to help students grow and improve.
2. **Ask open-ended questions** to better understand what and how students are thinking.
3. **Be respectful** by listening actively and responding openly and authentically. Give students your undivided attention and the respect you want them to give you.
4. **Be honest** about what you know. Say if you don’t know something. Encourage students to keep trying by sharing some of your own failures and the lessons you learned.



	<ul style="list-style-type: none"> ○ Where will they be located? ○ How will they be attached? ● Make sure that after about 15 minutes each team has done the first of their official tests. ● If a team's lander keeps tipping over, suggest that they adjust the position of the cockpit of their shock absorbers to balance the weight better and get the lander's center of gravity closer to its middle. If a team's lander bounces on impact, suggest that they change the number, size, and position of the shock absorbers or find other ways to absorb more of the impact energy. ● Encourage teams to continue testing, refining and improving their designs to achieve the highest successful drop height possible before they return for their second formal test. ● Remind groups that any failures they encounter are simply an opportunity to learn and improve. 	
5 min	<p>Reflection and Closing</p> <ul style="list-style-type: none"> ● If possible, give teams a few minutes to discuss the reflection questions in the Student Handout. ● After this bring students back together to discuss their experience of the activity, including challenges they had and one thing they learned. 	Student Worksheet



FACILITATION TIP

To help you manage the official test process, allow teams to conduct an official test with any of the activity facilitators or volunteers. Just make sure that the drop height of each successful landing is recorded for each team. If there is a whiteboard available, it is a good idea to record successful drop heights here so that all teams know the latest height to beat.

Extension

This activity can be extended in the following ways:

- Require teams to protect three or more marshmallow "astronauts".
- Impose a minimum drop height.
- Add a budget constraint to require teams to consider cost-efficiency in their design as well. Have them purchase the materials from a central store with a fixed budget.

Key Words

- **Cantilever:** a rigid structure, like as a beam or slab, anchored at only one end while the opposite end remains unsupported and extends horizontally.
- **Center of gravity:** The single point where an object's entire weight seems to act, or the balance point where it would rest if unsupported.
- **Damper:** A device that dissipates the energy from an oscillating system, causing its vibrations to decrease over time.
- **Pliable:** The property of a substance that allows it to bend, fold, or twist easily without breaking or cracking.
- **Tripod:** A three-legged stand used to support and stabilize equipment and structures.



- **Constraints:** Limitations of materials, time, budget, size of team, etc.
- **Criteria:** Conditions that the design must satisfy to be considered successful.
- **Engineering Design Process (EDP):** The iterative process of researching, designing, prototyping, and testing engineers use to solve problems and design solutions.
- **Engineering Habits of Mind (EHM):** Six unique ways that engineers think.
- **Engineers:** Inventors and problem-solvers of the world. Twenty-five major specialties are recognized in engineering (have a look at the infographic at https://tryengineering.org/wp-content/uploads/18-EA-381-InfographicEngineering_R2-6.pdf).
- **Iteration:** The process of repeated design, testing, and redesign.
- **Prototype:** A working model of the solution to be tested.

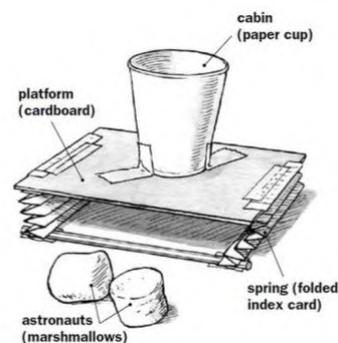
Activity Background

Landing manned or unmanned spacecraft on other moons and planets is hard. Landers like the Apollo Lunar Lander perform slow and controlled “soft landings”. This helps ensure that any astronauts are not harmed and that the lander itself or any scientific equipment onboard is not damaged.

Spacecraft travel at enormous speeds but then need to slow right down to be able to land safely. Braking from 29,000 km/h (18,000 mph) to just 3,6 km/h (2.2 mph) is no mean feat and requires special decent engines.

Then even at low landing speeds, it is necessary for the lander to employ mechanisms able to absorb and dissipate as much of the energy of the landing as possible. These mechanisms can be of various types:

- **Crushable materials:** Structures like aluminium honeycombs in footpads or other structural elements absorb energy through irreversible deformation and crushing. This is a lightweight and effective technique but can only be used once. This kind of mechanism was used in the Surveyor landers.
- **Telescopic dampers:** These are fluid or gas-filled cylinders that provide damping. They are often used for individual equipment or as primary landing struts. Their stiffness can be adjusted for different conditions.
- **Spring-dampers:** These combine springs to store elastic energy and dampers for energy dissipation.
- **Magnetorheological (MR) Fluid Dampers:** These are a promising new kind of semi-active damper. The dampers are filled with a fluid containing micron-sized ferrous particles. Ordinarily this is a low viscosity fluid. However, in the presence of a magnetic field (generated by passing a current through a coil), the ferrous particles align into chain-like structures and greatly increase the viscosity of the fluid. The greater the current, the stronger the field, the higher the viscosity.



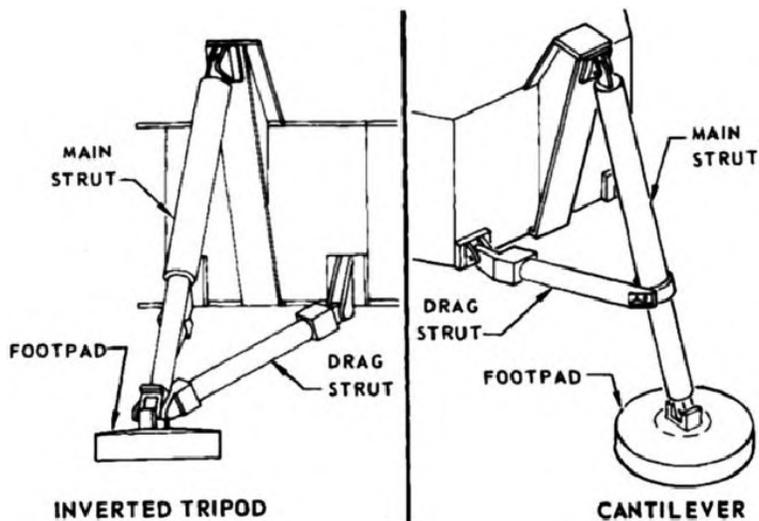
A possible Moon Lander design by NASA is used under fair use <https://www.jpl.nasa.gov/edu/resources/lesson-plan/touchdown/>



The structure of the lander's legs can also offer shock absorption. There are two basic designs:

- **Cantilever Legs:** This is a very simple design that involves a primary strut connected to the lander with a fixed secondary strut. On impact, the primary strut experiences a bending load.
- **Inverted Tripod Legs:** This is a common design. Several struts (usually three) all join together at a footpad. All struts experience compressive forces on impact.

The differences between these are illustrated below.



Inverted Tripod and Cantilever Leg Configurations by Marc Briere is used under fair use.

https://www.researchgate.net/figure/Inverted-Tripod-and-Cantilever-Leg-Configurations-4_fig7_232382018

Finally, some lunar landers incorporate footpads. These can help protect the main shock absorbing structures by dissipating energy as well. Sometimes they include crushable honeycombs.

While sophisticated systems like MR fluid dampers are obviously not possible, teams can experiment with different spring or material damper systems as well as leg structures like those described above, possibly even including tiny marshmallow footpads.

Additional Resources

- **Moon landing**
[https://en.wikipedia.org/wiki/Moon_landing#Human_Moon_landings_\(1969–1972\)](https://en.wikipedia.org/wiki/Moon_landing#Human_Moon_landings_(1969–1972))
- **Apollo Lunar Module**
https://en.wikipedia.org/wiki/Apollo_Lunar_Module
- **The Surveyor Shock Absorber**
<https://ntrs.nasa.gov/api/citations/19690002490/downloads/19690002490.pdf>
- **Moon lander structural design using Truss Me!** (6:31)
<https://www.youtube.com/watch?v=ZGrQHq6cjdI>



References

This activity is based on **Touchdown** originally created by NASA's **Jet Propulsion Laboratory** and available at: <https://www.jpl.nasa.gov/edu/resources/lesson-plan/touchdown/>.

Visit the **JPL Education website** (<https://www.jpl.nasa.gov/edu/>) for a host of other great engineering activities and resources.



Jet Propulsion Laboratory
California Institute of Technology





Moon Lander

STUDENT HANDOUT

Design and build a lander able to protect two marshmallow 'astronauts' when dropped from the greatest height possible.

1 IDENTIFY AND DEFINE THE PROBLEM

Criteria

- The marshmallow "astronauts" must remain safely in the lander cockpit upon impact.
- You should attempt a successful landing from the greatest height possible.
- You may cut, bend, twist, poke, or fold any of their materials.

Constraints

- You may only use the building materials provided.
- You must place the cup on the cardboard platform, right side up to form the cockpit in which the "astronauts" will sit.
- The "astronauts" must remain free to move around inside the cockpit i.e., they may not be tied, glued, or wedged into the cup.
- You may not cover the top of the cup.

2 GATHER INFORMATION

Materials

- A plastic cup and cardboard rectangle
- 2 marshmallows (the astronauts)
- 3 rubber bands and index cards
- 8 drinking straws and 10 mini marshmallows
- 1 m (40 in) of tape and scissors

You need to achieve a successful landing from the greatest drop height possible in 2 official tests within 25 minutes.

? Ask yourself

- What might cause your astronauts to fall out of their cup cockpit?

7 PRESENT OR COMMUNICATE THE SOLUTION

Within 25 minutes you must do at least one official test to demonstrate how well your lander works. The team able to complete a successful landing from the greatest drop height will be the winners!

6 5 TEST, EVALUATE AND REDESIGN YOUR PROTOTYPE

Before you do any official tests, you should do many of your own flight tests. Start testing at lower heights and make small adjustments as you go.

? Ask yourself

- What did you observe during the test?
- How did your lander behave as it fell and when it hit the ground? Did it tip over? Did it bounce? What can you do to keep it from tipping over or bouncing?
- Did your lander break on impact?
- What changes can you make to improve the performance of your lander?
- What materials have you not used yet? How might you use these materials?

4 CREATE A PROTOTYPE

Now it's time to build your lander.

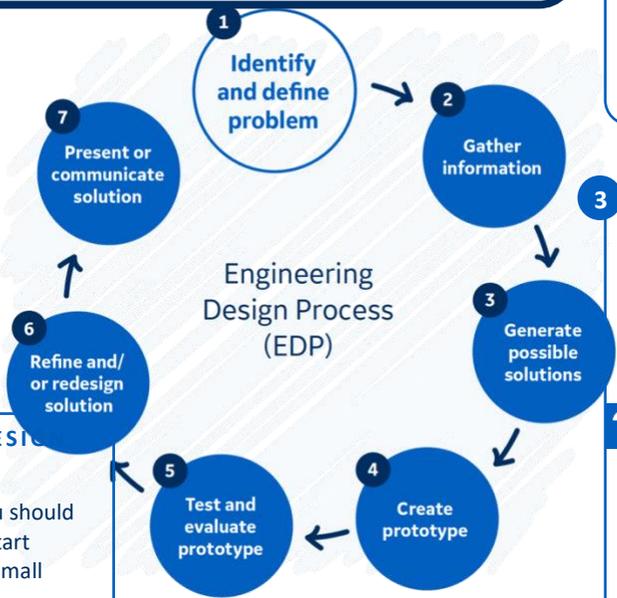
Test early and often. It is a good idea to try lots of different ideas and approaches to see which ones work best. Remember, failure is a necessary part of the process.

3 GENERATE POSSIBLE SOLUTIONS

Take some time to look at the materials you have and think about how you can use them to build a lander. Then draw some of your ideas.

? Ask yourself

- Is there air on earth? How will this effect your design?
- How can you change the shape of some of your materials to change their properties?
- How big and strong should your lander be?
- Should it be tall or short?
- Does it have to be symmetrical? Why or why not?
- Will you make shock absorbers? If so, how will you make them, how many will you make and where will you attach them?
- How can you keep your lander stable during flight and on impact so the marshmallows don't fall out?



TEAM DISCUSSION AND REFLECTION



1. Did you succeed in creating a lander that could protect the “astronauts”? What features made your lander a success?
2. How did your final design differ from the one you started with? What lessons did you learn while testing?
3. What feature of your lander are you most proud of or think is the most unique?
4. How did the winning design differ from your own (if you didn’t win, of course!)?
5. If you could have used one additional material in your lander, what would it be? Why?
6. Do you think that this activity was more rewarding to do as a team, or would you have preferred to work alone on it? Why?
7. What did you learn about engineering?
8. How do you think the activity relates to a career in engineering?

AT HOME



When you get home today, tell your family about the Moon Lander you built? Describe and explain the process you followed to design and test different ideas and how you decided on the best design.

Explain how your lander stayed stable during its descent and how it was able to absorb the force of the impact of landing to keep the astronauts safely in their cockpit.

Also describe how you worked in a team to design, build, and test your lander and what you learned about teamwork and the process of engineering doing this.

Tell them what you liked or didn’t like about doing this activity and what you would change or add to it. If you like, you can also discuss some of the reflection questions with them.





The Engineering Design Process

STUDENT HANDOUT

The engineering design process (EDP¹) is the key process engineers follow when they solve problems and design solutions.

1. Identify and define the problem

Engineers start by asking lots of questions. What problem must be solved? Who has the problem? What do we want to accomplish? What are the project requirements? What are the limitations? What is the goal? Through this process, engineers start to identify the **criteria** (the conditions the solution must satisfy to be considered successful) and the **constraints** (the limitations they need to design within).

2. Gather information

Engineers dig deep into the problem by collecting **information and data** about the problem and any existing solutions that might be adaptable. They talk to people from many different backgrounds and specialties to assist with this research.

3. Generate possible solutions

Now the fun really starts! Engineers start to **brainstorm** ideas and develop as many solutions as possible, sometimes even crazy ones. This is the time for wild ideas and deferred judgment. It is important to build on the ideas of others while staying focused on the core problem and keeping the criteria and constraints in mind. For example, if there is a budget, can the potential solution be developed within that budget?

4. Create a prototype

Engineers choose one or more of the most promising solutions to **prototype**. A prototype is a working model to be tested.

5. Test and evaluate the prototype

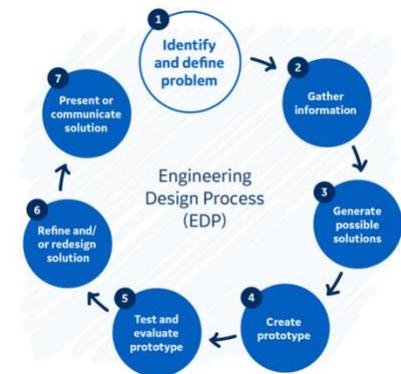
Most prototypes **fail**, but that is good. It tells engineers which ideas they should focus on. Engineers also need to decide if the design really does solve the original problem.

6. Refine and/or redesign the solution

After learning through testing, engineers **redesign and retest** until they have the best solution possible – one that balances the criteria and constraints.

7. Present or communicate the solution

Finally, engineers reach a point where they are satisfied with their solution. It does not need to be perfect, but it should '**satisfice**' - meet the criteria within the constraints. Engineers now communicate their solution to others.



¹ Adapted from <https://www.teachengineering.org/design/designprocess>





Moon Lander Volunteer Guide

This guide highlights some important information, questions, and principles to help you support teams in this challenge. Start by watching a video that explains some of the *Principles for Supporting Young Engineers* (9:40) and then *An Introduction to the Design Challenges* (6:08). You can also read about some general *facilitation tips* about working with youth.

The design challenge

In this challenge, teams design, build, and test a shock-absorbing lander to protect two marshmallow “astronauts” as they land after being dropped from the greatest height possible.

- Success criteria
 - The marshmallow “astronauts” must remain safely in the lander cockpit upon impact.
 - Teams should attempt a successful landing from the greatest height possible.
 - Teams may cut, bend, twist, poke, or fold any of their materials.
- Constraints
 - Teams may only use the materials provided but they don’t have to use all of them.
 - Teams must place the cup on the cardboard platform, right side up to form the cockpit in which the “astronauts” will sit.
 - The “astronauts” must remain free to move around inside the cockpit i.e., they may not be tied, glued, or wedged into the cup.
 - Teams may not cover the top of the cup.

Possible design solutions

This challenge is about impulse and the forces experienced by an object during a collision due to changes in momentum. When a cup containing marshmallows is dropped and hits the ground, the upward force applied by the ground to change the momentum of the cup to zero is transferred to the marshmallows which tend to fly out of the cup. In addition, the cup invariably also bounces and tips over, spilling the marshmallows.

Therefore, in designing their lander, teams should be encouraged to explore two approaches to protect their marshmallow “astronauts” and keep them safely inside the lander:

1. Find ways to reduce the impulse of the collision by extending its time (and thus reducing its force) by designing some sort of shock-absorbing system.
2. Find ways to keep their cup from rolling when falling through the air and/or bouncing and toppling over when it lands.



FACILITATION NOTE

While there is no atmosphere on the moon, there is one on Earth and many teams are likely to find that their landers roll and pitch during descent causing their marshmallows to fall out even before impact. Be on hand to assist teams with this by helping them to think about the weight distribution of their lander and also ways to change it that minimise this action.



Key design questions

As teams get started, it will be very tempting for them to jump straight into building. However, encourage them to slow down and to share, discuss, and draw their designs on paper first. The more ideas, the better—and crazy ideas are welcome! Explain that sketches are a great way to test out different designs quickly and cheaply, and to share their ideas with each other.

Here are some questions you can ask teams to help them think through their designs.

- What are you trying to accomplish with your design?
- Is there air here on earth? How will this effect your design?
- What materials do you have and what are the properties of each one? How might each material assist you in your design? How can you change the shape of these materials to change their properties?
- How big will your lander be? How strong should your lander be, and how can you make it stronger?
- Does your lander have to be symmetrical? Why or why not?
- Should your lander be tall or short?
- Will you make shock absorbers? If so, how will you make them, how many will you make and where will you attach them?
- How can you keep your lander stable during flight and on impact, so the astronauts don't fall out?

Key testing questions

As teams build, encourage them to test early and often to make sure that each part of their lander works as intended. Remind teams that failure is an essential part of engineering so any failures they experience need to be seen as opportunities to learn and improve. As teams test, encourage them to start low but then to test their lander with higher and higher drops.

In some cases, you may need to suggest that teams try a completely new design. In this case, spend some time with them to help them think through what an alternative design might look like.

Here are some other questions you can ask while teams test and iterate:

- What did you observe during the test?
- How did your lander behave as it fell and when it hit the ground? Did it tip over? Did it bounce? What can you do to keep it from tipping over or bouncing?
- Have you been able to reduce the force of impact on the “astronauts”?
- Did your lander get damaged on impact?
- What changes can you make to improve the performance of your lander?
- What materials have you not used yet? How might you use these materials?



FACILITATION NOTE

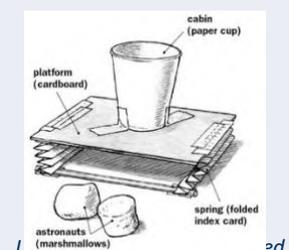
Strongly encourage teams to draw their design ideas on paper in as much detail as possible before they start building anything. Failing ‘on paper’ is much faster and cheaper than failing while constructing something.

If possible, explain why engineers draw sketches of their designs before they build by relating your own experience.



FACILITATION NOTE

An internet search for “lunar lander design ideas” returns many different design ideas that you could suggest to teams. Here is one from NASA’s JPL.



under fair use.
<https://www.jpl.nasa.gov/edu/resources/lesson-plan/touchdown>

