Crash(less) Landing

The Design Process and Apollo 11

From the USS Hornet Museum Education Department

Alissa Doyle, June 2018

Alissa.Doyle@uss-hornet.org

About This Document

The Apollo 11 engineers faced countless obstacles in their attempt to successfully get a human to and back from the moon. Iteration upon iteration of capsules and lunar landers led to the best end solutions that would launch America into the history books. Through hands-on challenges, students will learn the importance of the design process as they explore the physical forces faced by the Apollo engineers. This document contains three focused lessons, each relating to a different aspect of the Apollo 11 lunar mission. While this program is designed for 3rd through 8th grade students, the concepts and activities can easily be adjusted and expanded to suit older students.

Alissa Doyle, Lead Education Instructor

USS Hornet Museum Education Department

PO Box 460, Alameda CA 94501

uss-hornet.org

✉ edu@uss-hornet.org

f facebook.com/USSHornetMuseumEDU

Table of Contents

Goals 3

Objectives 3

Big Questions…and Answers 3

- How do engineers go about solving a problem?” 3
- What were some of the challenges facing the Apollo engineers? 3

Program Overview 3

Background Reference Material 8

Next Generation Science Standards 12

Appendix: Reference Materials 13

Links and Credits 13

Goals

In this program, students will:

- Engage directly in the design process
- Collaborate and come up with creative solutions to solve problems

Objectives

In this program, students will learn:

- How engineers solve a problem
- The importance of the test phase to engineering and the general creative process
- How the Apollo engineers designed the capsule to safely reenter Earth's atmosphere
- How the engineers designed the most effective lunar module for landing and functioning on the moon

Big Questions…and Answers

How do engineers go about solving a problem?"

Engineers first come up with an idea, they build their idea, and then test its viability. After observing the results of the initial test, they repeat the process indefinitely until they are satisfied with the end product. This process of reiteration, remaking, and improvement defined the Apollo 11 program. Potential space capsules and lunar modules went through endless tests and variations to ensure the astronauts landed on and returned safely from the Moon.

What were some of the challenges facing the Apollo engineers?

The weight limitations and pressure in space, the effects of Earth's atmosphere upon departure and reentry, the immense speed of the capsule upon reentry, just to name a few.

Program Overview

Activity 1- focused on Center of Mass- 3rd – 5th grade

<u>Approximate Program Timeline-</u>

40 minutes total:

-Overview of Apollo mission, STEM concepts- 20-25 minutes

-Activity- 10-15 minutes

-Debrief- 5-10 minutes

<u>Suggested materials-</u>

-pipe cleaner

-Popsicle stick

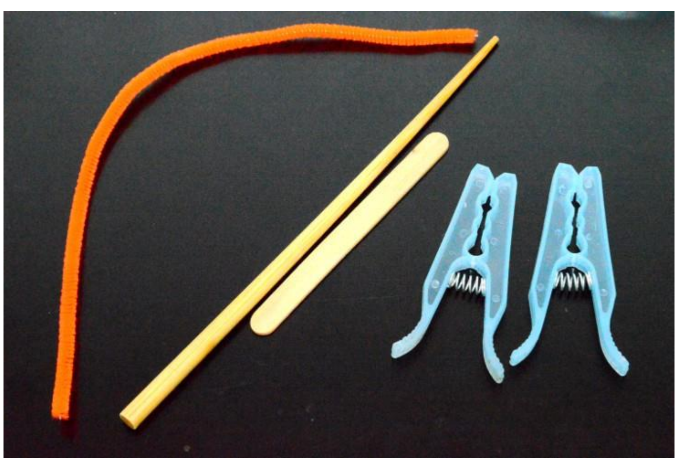
-binder clips or clothespins

-chopstick or dowel or ruler

-large heavy book or tape- for holding the chopstick/dowel/ruler steady and in place on a table

Divide students into teams of 3-5. Have students tape their chopstick to the table, with at least half of it sticking off the table.

Challenge students to balance the Popsicle stick upright on its end on the chopstick so that ONLY the Popsicle stick is touching the chopstick. Use



only the 3 materials provided.

Once all teams have succeeded in getting their stick to balance, debrief as a group. Suggested questions:

- Further discuss the idea of center of mass and how it can be manipulated.
- What would they have to change if the Popsicle stick was a foot tall? What if it weighed 20 pounds?
- What would make this activity easier? Harder?
- Where have students seen this concept illustrated in everyday life? Think- tight rope walker, ice-skating, cat movement, game of Jenga, riding a bike.

Activity 2- focused on the Design Process and the Lunar Module- 3rd grade and above

Approximate Program Timeline-

45 minutes total:

-Overview of Apollo mission, STEM concepts- 20-25 minutes

-Activity- 15-20 minutes

-Debrief- 5-10 minutes

Suggested materials-

-index cards

-tape

-loose recycled parts- straws, cups, bottle caps, egg cartons, etc.

-puff balls

-graph paper and pencils- for planning designs first

-optional- measuring tape/yard stick for measuring height of drop

Divide students into teams of 3-4. Allow them to choose any combination of the materials they wish. Give them 3 puff balls- these are the "astronauts". Challenge them to build a lunar lander with the provided materials. Their lander will be dropped from a predetermined height- a student's arm height to the ground should suffice- and the "astronauts" must "survive" the fall, i.e. stay on the lander. Allow students to first design their capsule on graph paper if desired. This is especially helpful if students struggle to begin building their capsules. Test the durability of all landers, increase the drop height if desired, allow students to make modifications if desired.

Debrief as a group. Suggested questions:

- (If they began with a drawing) How did your final product compare with your initial design? –This is a great opportunity to show the engineering plans for the original Apollo 11 lunar module, and discuss why engineers create plans of their designs.
- What was successful about your design? What was not? How would you change it if you could do it over?
- What would you have to change about your design if you were landing on the lunar surface? In water?
- Discuss the importance of shock absorption and weight distribution in the students' designs, and to the actual lunar module.

Activity 3- Demo- focused on Pressure and Surface Area- 3rd grade and above

Approximate Program Timeline-

40 minutes total:

-Overview of Apollo mission, STEM concepts- 20-25 minutes

-Demo- 10-15 minutes

-Debrief- 5-10 minutes

Suggested materials:

-1 inch thick piece of Styrofoam or plywood, approximately 8″x10″

-several dozen nails (2 ½ inch flat head nails)

-several balloons

-piece of wood or a book, approximately 8″x10″

For the instructor:

Insert or hammer about two dozen nails in a uniform, closely-spaced pattern across the Styrofoam or plywood. Save 2 or 3 nails.

Blow up 2-3 balloons.

Demo 1

Ask students: What do you think will happen if the balloon is pressed into just two nails?

Press the balloon against the two nails, applying enough force to make the balloon pop.

Ask students: Why did the balloon pop? Encourage students to identify the force vector and the area where the force is applied.

Demo 2

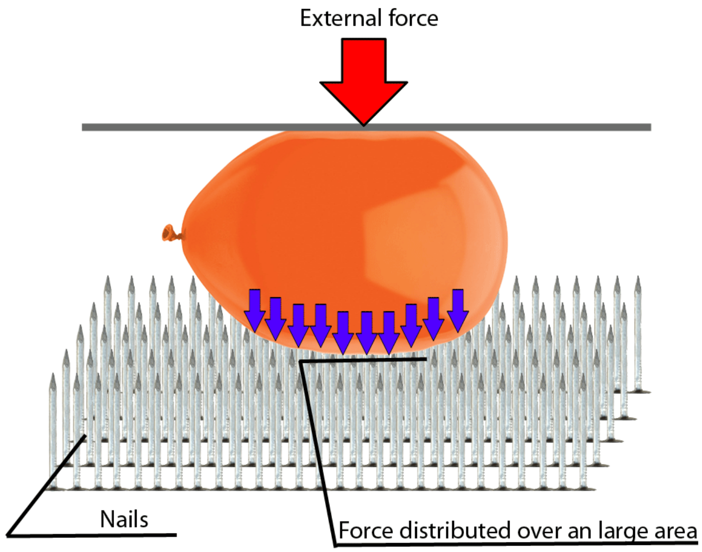
Ask students: What do you think will happen if I press the balloon against the board with several dozen nails?

Place the balloon onto the board with several dozen nails. Place the piece of wood or other hard, flat material on top of the balloon and apply force. (The balloon will not break unless a great deal of force is applied.)

Ask students: Why does the balloon not break on the bed of nails?

Debrief what happened:

Nails are sharp because they have a point with very little surface area. One nail point has much less surface area than ten or more nail points. To pop a balloon, a nail has to exert a lot of pressure on the balloon (p=F/A). Pressure = force / area, thus, the smaller the area, the more pressure is exerted by the same amount of force. On a board with nails, the force is distributed over all those nail points, so the pressure is lower and the balloon doesn't pop as easily.



<u>Demo 3</u>

Have students get in the push-up position. Have them do a standard push-up using both hands. Now have them continue to do push- ups, but slowly decrease the number of fingers they use.

- What did they notice changed?
- On what part of their body did they feel the most strain? Why?

This is an excellent exercise because students can physically feel the change in pressure as they reduce the number of fingers they use.

Suggested concluding topics-

- Link the three pressure demonstrations to the shape of the re-entry capsule. Discuss how other shapes would have fared upon re-entry, taking into consideration surface area and materials used.
- Discuss the concept of biomimicry. Prior to even the Apollo engineers, scientists observed meteors to learn about the effects of re-entry on a spherical body.

Background Reference Material

The spacecraft itself must be strong enough to slow down quickly, must endure extremely high and low temperatures, and must survive the landing. When the space capsule comes close to a planet's or moon's surface, it has to slow down at a very exact rate. If it slows down too quickly, everything in the capsule will be crushed. If it doesn't slow down quickly enough, it will crash into the surface and be destroyed. There are additional requirements for atmospheric reentry. If the angle of attack is too shallow, the capsule may skip off the upper surface of the atmosphere. If the angle of attack is too steep, the deceleration forces may be too high or the heat of reentry may exceed the tolerances of the heat shield.

<u>The Design Process-</u>

Begin with an idea, create the idea, and then test it out. Repeat.

While especially applicable to engineering, everyone uses this process when problem solving. This process is repeated indefinitely until the person is satisfied with the outcome, and their idea effectively solves their initial problem. Simplified, it can be seen as THINK → MAKE → TRY, and repeat the process over again. Engineers also record their process in a set of detailed instructions, with visuals, so others can replicate their design. The engineers on the Apollo mission were constantly making and remaking their designs following each testing stage.

The Lunar Module-

Grumman Aerospace designed the lunar module for Apollo 11. There were numerous redesigns to save weight, improve safety, and fix problems. First to go were the heavy cockpit windows, and the seats; the astronauts would stand while flying the module, supported by a cable and pulley system, with smaller triangular windows giving them sufficient visibility of the landing site. Later, the redundant forward docking port was removed, which meant the Command Pilot gave up active control of the docking to the Command Module Pilot; he could still see the approaching CSM through a small overhead window. These changes resulted in significant weight savings. Egress while wearing bulky Extra-Vehicular Activity (EVA) spacesuits was also facilitated by a simpler-opening forward hatch (32 x 32 inches).

Power was initially to be produced by fuel cells built by Pratt and Whitney similar to the CSM, but in March 1965 these were discarded in favor of an all-battery design, which saved weight and increased reliability.

The initial design had three landing legs. As any particular leg would have to carry the weight of the vehicle if it lands at any significant angle, three legs was the lightest configuration. However, it would be the least stable if one of the legs were damaged during landing. The next landing gear design iteration had five legs and was the most stable configuration for landing on an unknown terrain. That configuration, however, was too heavy and the designers compromised on four landing legs.

The Lunar Module was the first manned spacecraft to operate exclusively in the airless vacuum of space. It was the first, and to date only, crewed vehicle to land anywhere beyond Earth, capable of operation only in outer space. Structurally and aerodynamically it was incapable of flight through the Earth's atmosphere, and fully fueled, not even able to support its own weight.

Boilerplate-

A nonfunctional craft used to test various configurations and basic size, load, and handling characteristics of rocket launch vehicles. It is far less expensive to build multiple, full-scale, non-functional boilerplate spacecraft than it is to develop the full system (design, test, redesign, and launch). In this way, boilerplate spacecraft allow components and aspects of cutting-edge aerospace projects to be tested while detailed contracts for the final project are being negotiated. These tests may be used to develop procedures for mating a spacecraft to its launch vehicle, emergency access and egress, maintenance support activities, and various transportation processes.

<u>STEM concepts to consider in relation to the Apollo 11 mission:</u>

Center of mass- the point on an object where if a force were applied, the object would move in the direction of the force without rotating. The distribution of mass is balanced around the center of mass.

To compensate for the extreme effects of reentry- heat, drag, increased speed- and to give the astronauts some directional control, the capsule’s center of mass was offset. With the help of rotational thrusters, the astronauts were able to somewhat steer the craft to a safe water landing.

Lift- a force acting perpendicular to a fluid moving past an object.

Lift is used to control the trajectory of the capsule, allowing reduced g-forces on the crew, as well as reducing heat transfer into the capsule itself.

Drag- a force acting opposite to the relative motion of any object moving with respect to a surrounding fluid.

The immense speed coupled with reentering Earth's atmosphere meant the capsule encountered extreme drag and thus exposed its exterior to temperature nearing 2700 F.

As it descended to lower altitudes, a trio of parachutes deployed, increasing drag around the capsule and slowing its descent.

Honeycomb structure- the geometry of honeycomb structures relies on an array of hollow cells formed between thin vertical walls. The cells are often columnar and hexagonal in shape. They provide a material with minimal density and a high strength-to-weight ratio.

When made from aluminum, as in the space capsule, such a design minimized material usage, weight, and cost, all paramount to Project Apollo and the capsule's overall functionality.

Pressure- the force applied perpendicular to the surface of an object per unit area over which that force is distributed.

Following extensive testing, the engineers landed on a spherical blunt-body shape for the final Apollo 11 re-entry capsule. Such a shape distributed the heat buildup during atmospheric re-entry across a larger surface area and allowed it to ablate around the sides of the capsule.

Biomimicry- applying the models, systems, and elements found in nature to human problems.

As early as 1920, scientists began studying the effects of re-entry on meteors' change in shape and temperature; the blunt body capsule and ablative heat shield directly resulted from these observations.

<u>Engineering Plans-</u>

SEE "REFERENCE IMAGES" FOR PLANS

Next Generation Science Standards

Grade Level	Standards
3-5	*Engineering Design:* 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem. 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
3	*Motion and Stability: Forces and Interactions:* 3-PS2-1Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.
5	*Motion and Stability : Forces and Interactions:* 5-PS2-1 Support an argument that the gravitational force exerted by Earth on objects is directed down.
6	*Energy:* MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.
8	*Motion and Stability: Forces and Interactions* 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.
5-8	*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.

Appendix: Reference Materials

SEE "REFERENCE IMAGES" FOLDER FOR SUPPLEMENTAL MATERIAL

Links and Credits

Docent Scott Zirger has created a wiki for the ship containing a wealth of information:
https://en.wikipedia.org/wiki/User:Szirger/Books/USS_Hornet_Reference_Material

This program was created in conjunction with a grant from the Office for Naval Research, and expanded upon concepts addressed in the following lesson plans:
http://www.ussnautilus.org/education/pdf/stemlessons/dive-the-cartesian-way.pdf

http://www.ussnautilus.org/education/pdf/stemlessons/THEGREATESCAPE_MEZICK_activityTwo.pdf

Special thanks to USS Hornet Docent and Helicopter Restoration Specialist Joe Martinez for his expertise, guidance, and review of this curriculum.