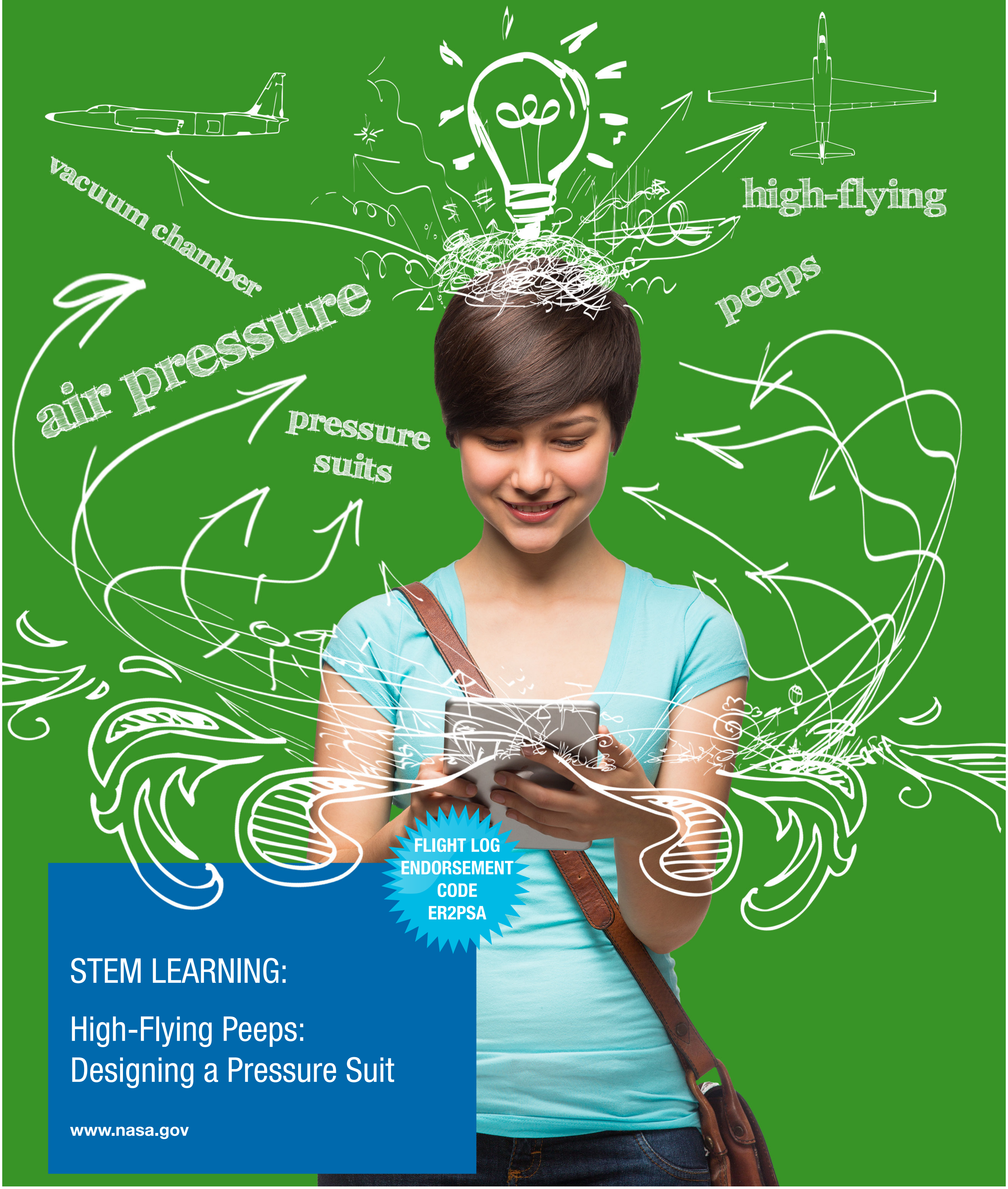
National Aeronautics and Space Administration



STEM LEARNING:

High-Flying Peeps: Designing a Pressure Suit

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BACKGROUND INFORMATION

Air Pressure in the Atmosphere

Earth is surrounded by layers of gases which together are known as the atmosphere. These gases are held near the plant by Earth's gravity. But, as you move further from Earth's surface, gravity decreases. As a result, there is more air close to Earth's surface than there is higher in the atmosphere.

Pilots flying airplanes at low altitudes usually do not have to worry about whether there is enough air for them to breathe. At low altitudes, the atmosphere is thick enough that it provides plenty of air for humans to breathe normally. As altitude increases, air pressure decreases. So, when pilots fly at high altitudes, the low pressure makes it impossible for them to survive without some sort of humanmade enclosure.

In most airplanes, internal cabins or cockpits are pressurized to help humans function. Commercial airliners, for example, usually cruise at altitudes near 12 kilometers (40,000 feet), but they are pressurized so that the air inside is equal to the atmosphere at about 1.5 kilometers (5,000-6,00 feet). This makes it safe for pilots and passengers. Some airplanes, like NASA's Airborne Science ER-2, fly at extremely high altitudes. These planes do have pressurized cockpits, but the pressurization is lower than commercial planes. The high-altitude pilots who fly these planes are trained to understand the effects of low oxygen levels and respond quickly to potential problems when in lower-pressure environments. But they must wear pressure suits to protect themselves.

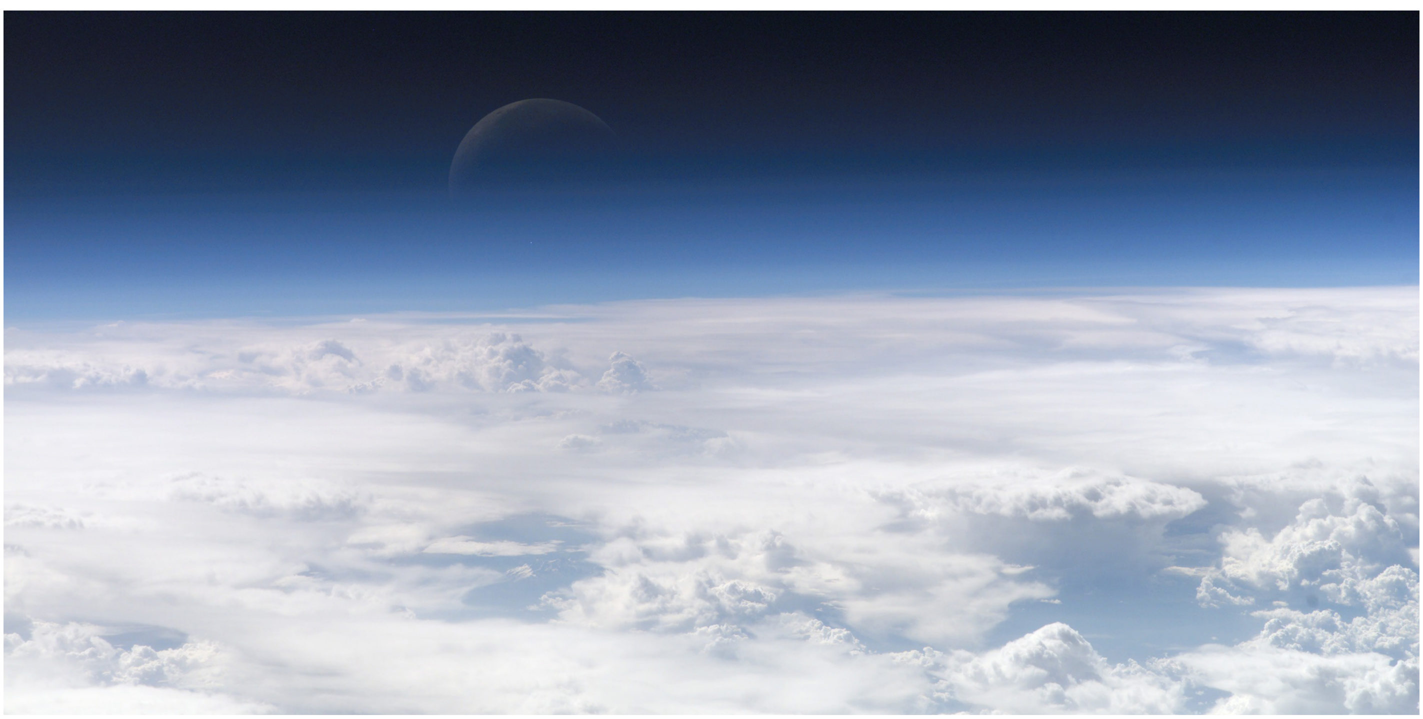


Figure 1. High in the atmosphere, very little air is found. Image credit: NASA.

High-Altitude Aircraft

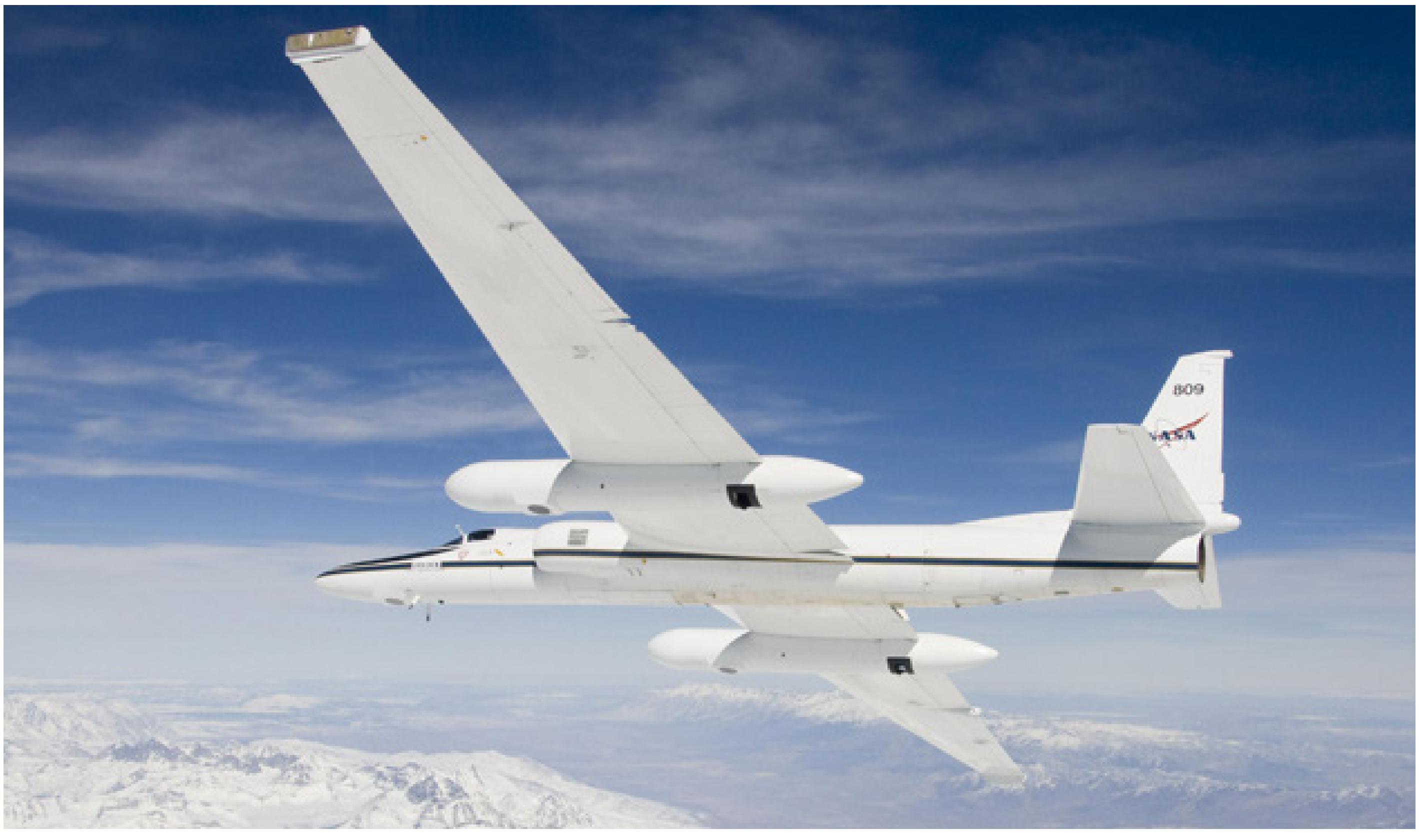


Figure 2. NASA ER-2 airplane flies at 70,000 feet. Image credit: NASA / Carla Thomas.

Throughout aeronautics history, there have been many planes that have flown at high altitudes, requiring pilots to wear specially designed pressure suits. Some of these planes include the SR-71; the U-2; and the U-2's sister aircraft, the ER-2.

NASA's ER-2 airplanes fly at an altitude of about 21 kilometers (about 70,000 feet) and have historically kept cockpit pressurization equal to 9.5 kilometers (30,000 feet). To prevent hypoxia, a dangerous medical condition caused by inadequate air, from occurring, high-altitude pilots breathe oxygen throughout the flight. This helps prevent the buildup of nitrogen in their blood, which can lead to nitrogen narcosis, or "the bends."

Early high-altitude pilots had no formal training for flying at these altitudes and only wore partial pressure suits. Now, cockpit conditions are improved to include more pressurization, helping to prevent decompression sickness and helping the aircraft and sensors last longer. Pilots now wear full pressure suits and participate in an intensive training program that includes sessions in the high-altitude pressure chamber which simulates atmospheric conditions at very high altitudes.

Protecting High-Altitude Pilots

There are two types of pressure suits commonly used by pilots: partial pressure suits and full pressure suits. In a partial-pressure suit, the counter-pressure is not as complete as in a full-pressure suit, but it is placed so that shifts in body fluids are kept within reasonable limits. On the other hand, a full-pressure suit creates an artificial environment for the pilot.

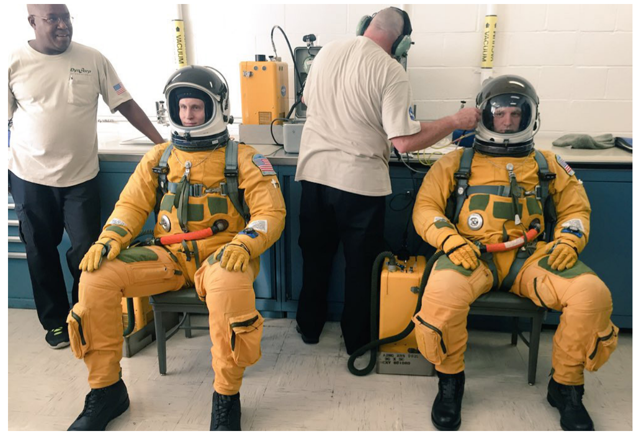


Figure 2. NASA ER-2 airplane flies at 70,000 feet. Image credit: NASA.

Partial pressure suits are basically form-fitting garments that cover the body from the neck to the wrists and ankles. Inflatable tubes, called capstan tubes, inflate to provide additional pressure when necessary. The added pressure provides just enough counterpressure to allow pilots to breathe at very high altitudes and when performing extreme maneuvers. The pressure suit does not provide oxygen for the pilot to breathe, however; that is supplied through an attached helmet and mask.

Full pressure suits are self-contained living environments for pilots. Everything needed for survival—breathing oxygen and pressure exerted on the body—exists within the suit. Along with providing protection, these suits must also be functional. Cockpit controls and other equipment must still be useable while wearing large gloves and fully pressurized suits. For high-altitude pilots, the suits are pressurized with air instead of pure oxygen to reduce the dangers associated with the flammability of oxygen. There is a seal surrounding the pilot's face that prevents that air from escaping the suit. The resulting face cavity, which is the face area of the pilot's helmet, is the only area to have nearly pure oxygen for pilots to breathe.

Effects of Low Air Pressure on the Human Body

If a human being were to be subjected to an extremely low-pressure environment without protection, there would be a lack of air to breathe and a lack of air pressure to help our bodies function as they were meant to. Hypoxia, an inadequate oxygen supply to the cells and tissues of the body, would occur. Very low oxygen levels result in impaired judgment, inability to concentrate, lack of night vision acuity, shortness of breath, nausea, and fatigue. High-altitude pilots are trained to react quickly to try to help themselves in these situations because they would lose consciousness within a few seconds.

In extremely low-pressure environments, your body would swell without a pressure suit because liquid in your soft tissues and, to a lesser extent, water in your circulatory system would begin to vaporize. Contrary to some existing myths, you would not explode – your skin is too strong for that to happen.

Your blood would not immediately boil in your veins. But within about a minute, blood would no longer circulate. Gas and vapor would flow out of airways, cooling the mouth and nose to near-freezing temperatures. The water in your nose and on your tongue would begin to boil. Soon after that, the water that lines your lungs would also boil. Lungs are perhaps the most vulnerable part of the body if decompression occurs. Since the lungs contain a large volume of air and the lungs are made up of intricate airways, air's expansion within low pressures and/or the vacuum of space would most definitely affect the lungs.

Because of the human body's vulnerability in low-pressure environments, there has been years of research and development of methods to help humans both survive and function in low-pressure situations. A properly fitted pressure suit can protect a pilot in these environments. The degree to which the effects described above would occur depends on the altitude. The higher the altitude, the more serious the effects on the human body.

OVERVIEW & ACTIVITY INSTRUCTIONS

Three activities are included that help students understand what happens to the human body in a reduced-pressure and/or near vacuum environment. The first two demonstrations simulate the effects of pressure (or lack of pressure) on the human body, lungs, and the water in our bodies using marshmallows or marshmallow Peeps, balloons, and bottled water. In the third hands-on activity, teams of students will design and build a pressure to protect their "pilot" while in a vacuum chamber that simulates a high-altitude environment.

Materials:

- Large marshmallows or marshmallow Peeps (Peeps make a much more dramatic demonstration)
- Small balloons
- Plastic bottle of water
- Various materials for students to develop a pressure suit for their marshmallows (items could include tape, latex or nitrile gloves, and small plastic containers or water bottles)
- Student worksheets
- Vacuum pump and bell jar (see safety notes below)
  Note: There are several alternatives to using a more-expensive vacuum pump for this activity. Science supply companies also sell less-expensive vacuum pump options such as hand-operated vacuum pumps and microscale bell jar and vacuum sets. Both options create a partial vacuum environment, which would be suitable for this experiment. Alternatively, you could use a food sealer with a plastic container attachment instead of the more-expensive vacuum pump.

Important Safety Notes:

- For safety considerations, we recommend using a Nalgene bell jar instead of a glass bell jar.
- If you have never used a vacuum pump and chamber before, use caution when placing objects in the vacuum chamber. Objects can break when exposed to vacuum conditions, potentially damaging the chamber in the process. Always check to make sure the chamber is in good condition (no cracks or signs of excessive wear), that seals and gaskets are clean, and that you know how to properly use it. When you repressurize the chamber following an activity, items in the chamber will not stay where they are when air floods back in (for example, the marshmallows or Peeps may bounce around inside the chamber), so use care. Also take into consideration that many of your students' pressure suit designs for activity three may not hold up in a vacuum chamber, so be aware of what materials they are using for their suits.
- Following this activity, particularly if testing multiple Peeps, the vacuum pump oil will most likely be dirty from the sugar coating of the Peep. Pump oil should be changed at the conclusion of this activity to extend the life of the vacuum pump.
- As a component of good safety practices, advise students that they should never eat their experiments, even if the materials are candy.

Extension/Modification Ideas:

- Students can personalize their Peeps by naming them, drawing on them, etc. If they use marshmallows rather than Peeps, they can draw a face on their marshmallow.
- You can place a cup of water in the vacuum chamber to demonstrate how it can boil when the pressure is lowered, even though the temperature does not change much.
- This activity can also be used to simulate the environment astronauts experience in the vacuum of space.

ACTIVITY ONE: SIMULATING THE HUMAN BODY IN EXTREMELY LOW PRESSURE

Soft tissue of the human body, when exposed to the extremely low pressures encountered at high altitudes, will swell if not contained in a pressure suit or pressurized cabin or environment. Similarly, marshmallows and marshmallow Peeps will also expand in a near-vacuum environment, so this demonstration is a good simulation of what the human body would do without a suit or pressurized aircraft cabin.

Materials:

- Vacuum pump and bell jar
- Peeps (large marshmallows can also be used instead)
- Optional) Empty large-mouth plastic container that allows a Peep to be placed inside

Directions:

1. Ask students what they think will happen when the Peep is placed in a vacuum and why. Have them record their answers on their student worksheets.

2. Place a Peep in the vacuum chamber (you can put more than one in the vacuum chamber at once).

3. Turn on the vacuum pump and have students observe how the Peep changes and ask them why they think the changes are happening.

4. When finished, turn off the pump and repressurize the chamber. Have students observe what happens to the Peep. You can explain that the air has been forced out of the Peep when the pressure decreased in the vacuum chamber. And because they are made of marshmallow, a very sticky material, the air pockets within the Peeps cannot refill.

5. On their worksheets, have students record what they observed and why they think the Peeps changed.

*The concept of air pressure affecting us so dramatically can be a difficult concept to grasp. A second demonstration can be done using two Peeps—one in the vacuum chamber unprotected and the other placed in the chamber within a plastic bottle with a lid secured tightly. This demonstrates the protective effect that air pressure has on one of the Peeps in the closed bottle.

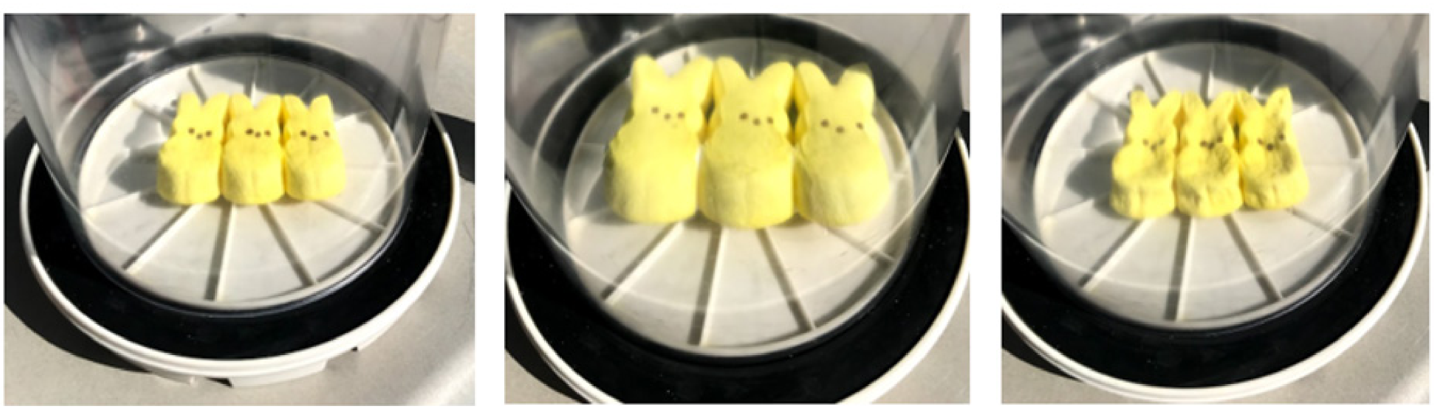


Figure 4. From left to right: Peeps are shown at normal sea-level pressure, in a vacuum, and after being subjected to a vacuum. Image credit: NASA / Steve Kirsche.

ACTIVITY TWO: SIMULATING LUNGS (AND LIQUIDS) IN EXTREMELY LOW PRESSURE

Like the Peeps in Activity One, balloons will also expand in a near-vacuum environment. Your skin and your lungs, which are somewhat like a balloon, can expand and stretch, but only to a certain point. Placing a small, partially inflated balloon inside the vacuum chamber will show students what would happen to your lungs if you were in a near-vacuum environment. An optional addition to this demonstration is to show what happens to room-temperature water in the same environment, simulating the liquids in the human body.

Materials:

- Vacuum pump and bell jar
- Small balloon
- (Optional) Plastic bottle of water

Directions:

1. Ask students to explain how a partially inflated balloon is a good model for a lung and record their explanation on their worksheets.

2. Have students predict what will happen to the balloon when the pressure inside the vacuum pressure is lowered with the balloon inside. They should record their predictions on their worksheets.

3. Partially inflate a small balloon and place it inside the vacuum chamber. Be careful not to overinflate the balloon or place too large of a balloon in the chamber. The balloon will expand to several times its normal size, so leave plenty of room for expansion.

4. Turn on the vacuum pump and ask students to observe what is happening to the balloon in the vacuum.

5. Talk with the students about what would happen if the balloon expanded too much. They should record their predictions on their worksheets. Explain that this is similar to what lungs would do in a near-vacuum environment.

6. Optional: For an extension to this activity, place a plastic bottle half filled with water (lid removed) in the chamber. Water in the bottle will start to boil at room temperature since the air pressure typically pushing down on the surface of the water, keeping it from boiling, has been removed. You can also place a second bottle of water, with the cap on, in the chamber at the same time—this water will not boil since air pressure is still present inside the bottle. This demonstrates what will happen to liquids in our bodies in a near-vacuum situation. *During a 1965 pressure suit test at Johnson Space Center, a leak resulted in the subject feeling the water on his tongue beginning to boil. The large chamber was repressurized and he recovered quickly. The accident helped NASA understand more about vacuum environments and their effects on the human body.*

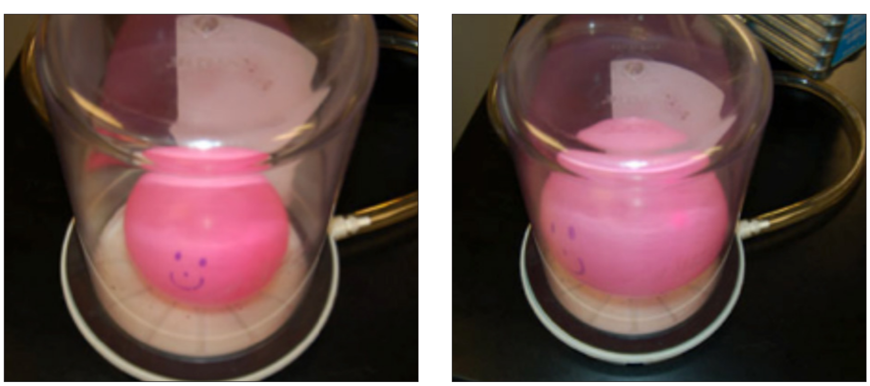


Figure 5. A balloon is shown at normal sea-level air pressure (left) and in a partial vacuum (right). Credit: NASA

ACTIVITY THREE: DESIGNING A PRESSURE SUIT

Activities one and two focused on the effects of low pressure on objects that simulate the human body. The final hands-on activity asks students to work in pairs or teams to design a pressure suit for a Peep that will keep the Peep from expanding in a low-pressure environment.

Materials:

- Peeps or large marshmallows (as before, Peeps make a more dramatic activity; in this case, they also better simulate fitting a pressure suit around a person or animal)
- Vacuum pump and chamber
- Various materials for students to develop a pressure suit for their marshmallows (Items could include various types of tape, latex or nitrile gloves, sealable sandwich bags, and small plastic containers such as yogurt containers and small plastic water bottles, aluminum foil, straws, etc.)

Directions:

1. Review the background information about pressure suits and why humans need to have the suit or pressurized chamber to function at high altitudes.

2. Tell students that they will need to design a pressure suit for their Peep that will keep it from expanding like it did in the earlier demonstration.

3. Have students plan and sketch out their suit. Their design should utilize the supplies you have made available to them.

4. Once the students have designed their pressure suits, have them construct their suits from available materials.

5. Test student designs in the vacuum chamber. Use an unprotected Peep as a control inside the chamber as well.

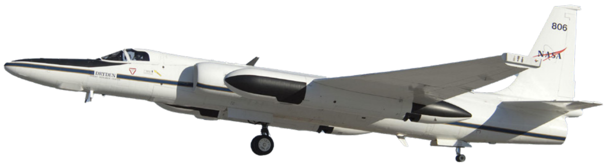
6. Allow students to refine their designs and retest, using a new Peep.

7. Finally, if time allows, have the students present their pressure suit prototypes to the class. Encourage the students to explain and share their designs, along with any challenges, hurdles, or failures along the way.

Tips, Tricks, and Extension ideas:

- Redundancy, layers, and careful construction are keys to a successful “suit.”
- Create a “budget” for materials
- It is highly recommended to provide enough time for teams to rebuild their suits. Oftentimes teams who were not successful the first time are the second time and vice versa (unsuccessful teams improve their designs and/or material choices, while oftentimes successful teams rush through their second build resulting in leaks). Explain that good engineering design works well **EVERY** time.
- For another extension or challenge, add a suit requirement: this could include a window the Peep can see out of, moveable parts, etc. These complexities mimic the real needs of suits for both pilots and astronauts (pilots need to see out of their helmets and turn their heads, for example!).

Name: ____ Date: __________________



HIGH-FLYING PEEPS: DESIGNING A PRESSURE SUIT

Activity One:

1. Make a prediction: What do you think will happen to the Peep when it is exposed to a near-vacuum environment? Why?

2. Draw or describe what the Peep looked like before and after being exposed to the near-vacuum environment. If creating a drawing, label what you draw.

3. Why do you think the Peep changed like it did?

Activity Two:

1. In what ways do you think a partially inflated lung is a good model for a lung?

2. Make a prediction: How do you think the balloon will change when it is exposed to a near-vacuum environment?

3. What do you think would happen if the balloon expanded too much? *Bonus question: do you think it would be better to hold your breath with your lungs full or not if you were thrust into a near-vacuum situation? Why?*

Activity Three:

1. Sketch out the design for your pressure suit. Label it to show what materials you plan to use to make the suit. If you have a budget for materials, include the cost of your materials.

2. After you test you suit, you are likely to find some things that work well and others that do not work very well. For your suit, what worked well and what did not?

3. How would you modify your design to work better?

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