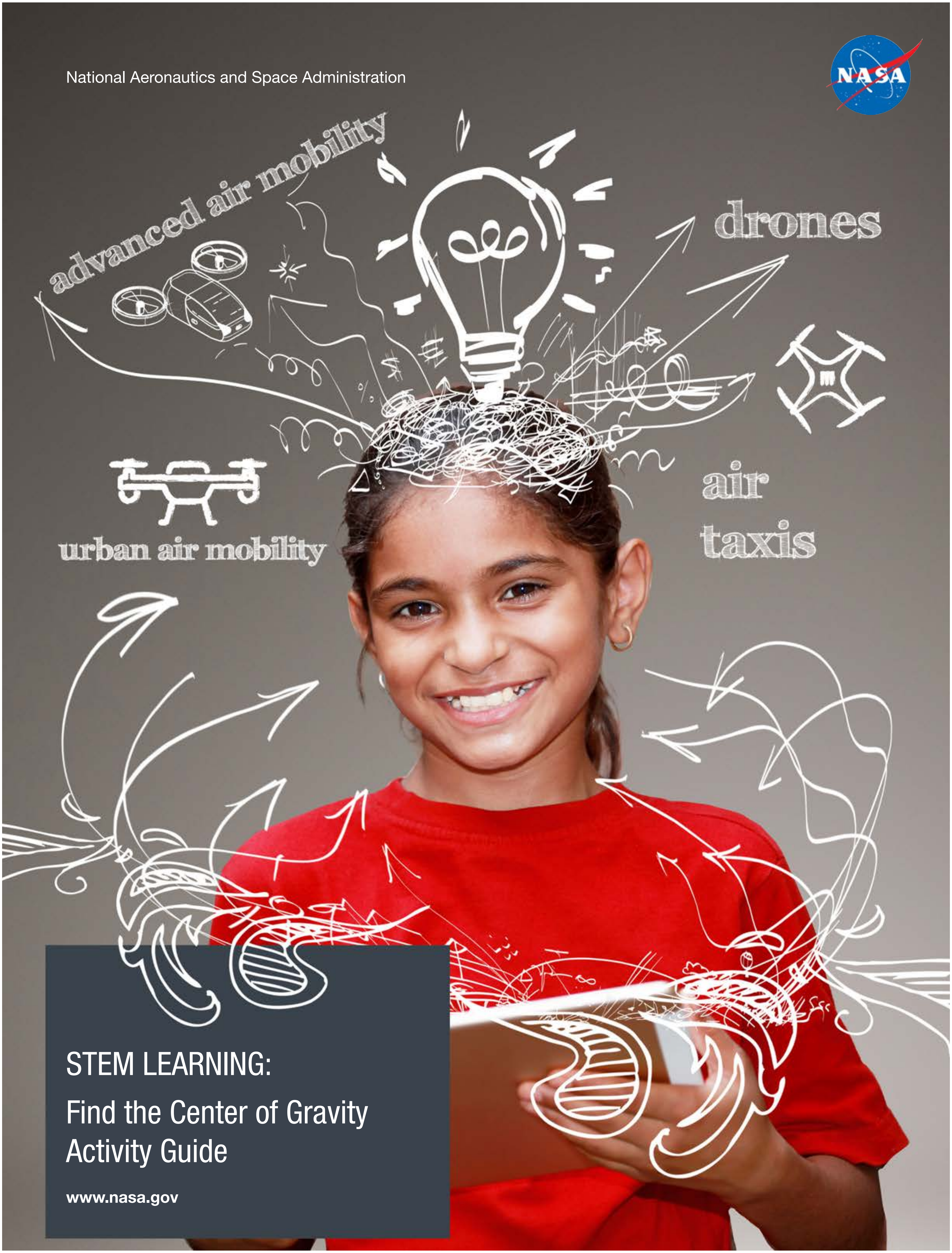
National Aeronautics and Space Administration



STEM LEARNING:

Find the Center of Gravity Activity Guide

www.nasa.gov

OVERVIEW

In this lesson, students learn about an object's center of gravity and why it's important when designing Unmanned Aerial Vehicles, or UAVs. Using multiple methods, students determine the center of gravity of simple and complex shapes.

Objectives

Students will be able to:

- Use a variety of simple objects to:
  - practice estimation and create hypotheses about the location of objects' centers of gravity
  - observationally determine the center of gravity by balancing objects
  - combine strategies to determine the center of gravity
- Calculate the center of gravity for complex shapes

Student Prerequisite Knowledge

Before beginning this lesson, students should be familiar with:

- What a center of gravity is (can be taught as a warm-up activity)

Standards

Next Generation Science Standards

NGSS.MS.PS2.A: Motion and stability: forces and interactions

- 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.

Crosscutting Concepts

- Systems and system models

Science and Engineering Practices

- Developing and using models
- Planning and carrying out investigations

Materials

- A variety of simple-shaped objects (included in appendix 1 of this guide) such as squares, triangles, rectangles, and circles, along with a cutout of a basic aircraft shape (one set per student pair or group)
- Three colors of markers or pens (per student pair or group)
- Paper clips (to be used in activities 3 and 4; in activity 3, other objects such as coins, erasers, etc. can be used)
- Rulers (one per student pair or group)
- Tape
- Blank cardstock (one piece per student pair or group)
- Scissors (one per student pair or group)
- String (two pieces, approximately 24 inches in length, per student pair or group)
- Weight to attach to string so it will hang straight down (roll of tape, etc. can be used)
- Hole punch

Preparation

- ☐ Print out a student reflection sheet for each student. Alternately, you can post the questions to save on copies.
- ☐ Gather required materials.
- ☐ Prepare simple-shaped objects (available in appendix 1), printed on cardstock. If desired, these can be laminated, which allows students to adjust their findings as needed, and also allows you to reuse the shapes.
- ☐ Print out the real-world objects included in appendix 1.

Background Information

Advanced Air Mobility (AAM)

When most people think of aircraft, they usually think about airplanes that travel at great speeds and cover long distances while flying routes between airports. More and more, however, new types of aircraft are transporting people and equipment to urban and rural locations where traditional airplanes cannot access. These new aircraft range in size from small cargo carrying drones to passenger-carrying air taxis, and carry out short range missions.

Figure 1. Air traffic in the future will include a higher quantity of smaller vehicles than today's air traffic. Credit: NASA

NASA is leading the nation to quickly open this new era in air travel called Advanced Air Mobility, or AAM. The vision of AAM is that of a safe, accessible, automated, and affordable air transportation system for passengers and cargo capable of serving previously hard-to-reach urban and rural locations.

According to recent NASA-commissioned market studies, by 2030 there will be as many as 500 million flights per year for package delivery services and 750 million flights per year for air metro services. AAM will help ensure this new airspace is properly managed.

Compared to airplanes and helicopters, the aircraft that fly in this new airspace are small. This, along with where they fly, makes it unrealistic to continuously track or control these aircraft using radar or satellite technology. Many of these aircraft are Unmanned Aerial Vehicles, or UAVs, meaning they are self-flying or autonomous.

Center of Gravity

An object's center of gravity is the point around which the weight is evenly distributed. When suspended at this point, the object is balanced. For regular shapes, the center of gravity might be the actual center of the object, while for irregular or uneven shapes, the center of gravity may be in a completely different location.

Engineers need to calculate the center of gravity of different objects for many reasons. Aeronautical and aerospace engineers are particularly concerned with centers of gravity because they affect the stability and operation of aircraft and spacecraft. In order to make sure aircraft can fly safely through the air, or that spacecraft will launch and fly properly, engineers must first calculate the center of gravity for their projects.

Calculating the center of gravity for air and space vehicles can be particularly challenging. Instead of being simple shapes, some engineering projects can be quite complex in design and shape. While an empty aircraft or spacecraft has its own initial center of gravity, adding cargo, passengers, fuel, or anything else will change where the center of gravity is located. Even after this initial calculation, both aircraft and spacecraft use up fuel as they fly, constantly changing mass and center of gravity as they move. Engineers use a specific set of calculations that allow them to determine the changes in center of gravity during flight, making sure that the vehicle will remain stable throughout the entire flight.

The center of gravity is also important when engineering an Unmanned Aerial Vehicle, or UAV, especially when accounting for the torques created by the propellers. The UAV's frame has an initial center of gravity that needs to be calculated, then recalculated as electronic components and other pieces of equipment are added. UAVs operate on battery power, so the center of gravity remains constant during flight because fuel isn't consumed.

Other Resources

- Exploring the Extreme: An Educator's Guide, Lesson 1: Finding the Center of Gravity Using Rulers Grades K–4, available at *https://www.nasa.gov/pdf/382710main_ETE_Lesson_1.pdf*
- Exploring the Extreme: An Educator's Guide, Lesson 2: Finding the Center of Gravity Using Plumb Lines Grades 3–4, available at *https://www.nasa.gov/pdf/382714main_ETE_Lesson_2.pdf*
- Exploring the Extreme: An Educator's Guide, Lesson 3: Center of Gravity, Pitch, Yaw Grades 5–8, available at *https://www.nasa.gov/pdf/382718main_ETE_Lesson_3_Center_Gravity.pdf*

Steps

1. Use a warm-up or other method to review or teach the center of gravity concept. A search of the internet will provide you with many possible demonstrations to engage students.
2. Give each student or group several simple-shaped objects (squares, triangles, rectangles, circles, ovals). Examples of these can be found in appendix 1.
3. Each student or group also needs an additional piece of cardstock with which they can create their own irregular shape to use. Their irregular shape needs to be symmetric. To ensure their object's symmetry, have them follow these steps:
    a. Fold the piece of cardstock in half.
    b. Draw a shape on one side. This shape needs to include the fold line as one side on the shape.
    c. Cut out the shape while the cardstock is still folded.
    d. Unfold to reveal the symmetric, yet irregular shape.
4. **Activity 1: Hypothesize**—Ask students to hypothesize where the center of gravity might be for each of the objects without manipulating it or using measurement devices such as rulers. Have them mark the hypothesized location with one color marker or pen. Then, have them write the reason they believe it is at the location they chose on their student reflection sheet.
5. **Activity 2: Trial and Error Balance Method**—This method is the simplest as the centers of gravity are determined through experimentation and observation. You may need to demonstrate this method for students (the directions are given in step 6). Students need to complete this method with the assigned simple-shaped objects. Note: They should not use the irregularly shaped object they created, as this will be used in activity 4.
6. Have students adjust the location of a shape atop a finger (or small, fixed object) until it remains balanced on its own. This location should be marked with a second color marker or pen.

7. **Activity 3: Changing the Center of Gravity**—Have students change the center of gravity for an object by attaching paper clips to it in random locations. Use the balance method to determine the new center of gravity and mark this location with a third color marker or pen. Repeat with as many differently shaped objects as time allows.
8. **Activity 4: Gravitational Balance Method**—This method is most useful when determining the center of gravity of an irregularly shaped symmetric object. For this method, students will use the irregularly shaped object they created and follow these steps:
    a. Unfold a paperclip as shown in figure 2.
    b. Attach weight to one end of a piece of string.
    c. Attach the other end of the string to the bottom of the paperclip.
    d. About 2.5 centimeters (1 inch) from the edge of the irregularly shaped object, use the hole punch to make a hole. This hole should not be on the object's fold line.
    e. Put one end of the paperclip through the hole so the object hangs freely next to the string.
    f. Mark the point where the fold line on the object meets the hanging string.
    g. Remove the object and use the trial and error balance method test to confirm that this is the center of gravity.
9. **Activity #5: Real-World Examples**—Provide each student or group one or more of the real-world objects provided in appendix 1. Have them find a way to use the gravitational balance method to determine the center(s) of gravity. One way of doing this:
    a. Punch two different holes in the object.
    b. Hang the object and the weighted string from one of the holes.
    c. On the object, draw a line where the string hangs.
    d. Repeat steps (b) and (c) using the second hole.
    e. Where the two lines intersect is the center of gravity.
10. **Activity #6: Reflection**—Have students reflect on this activity using the "Student Reflection Sheet" found in appendix 2.

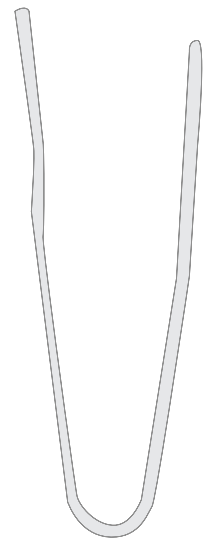
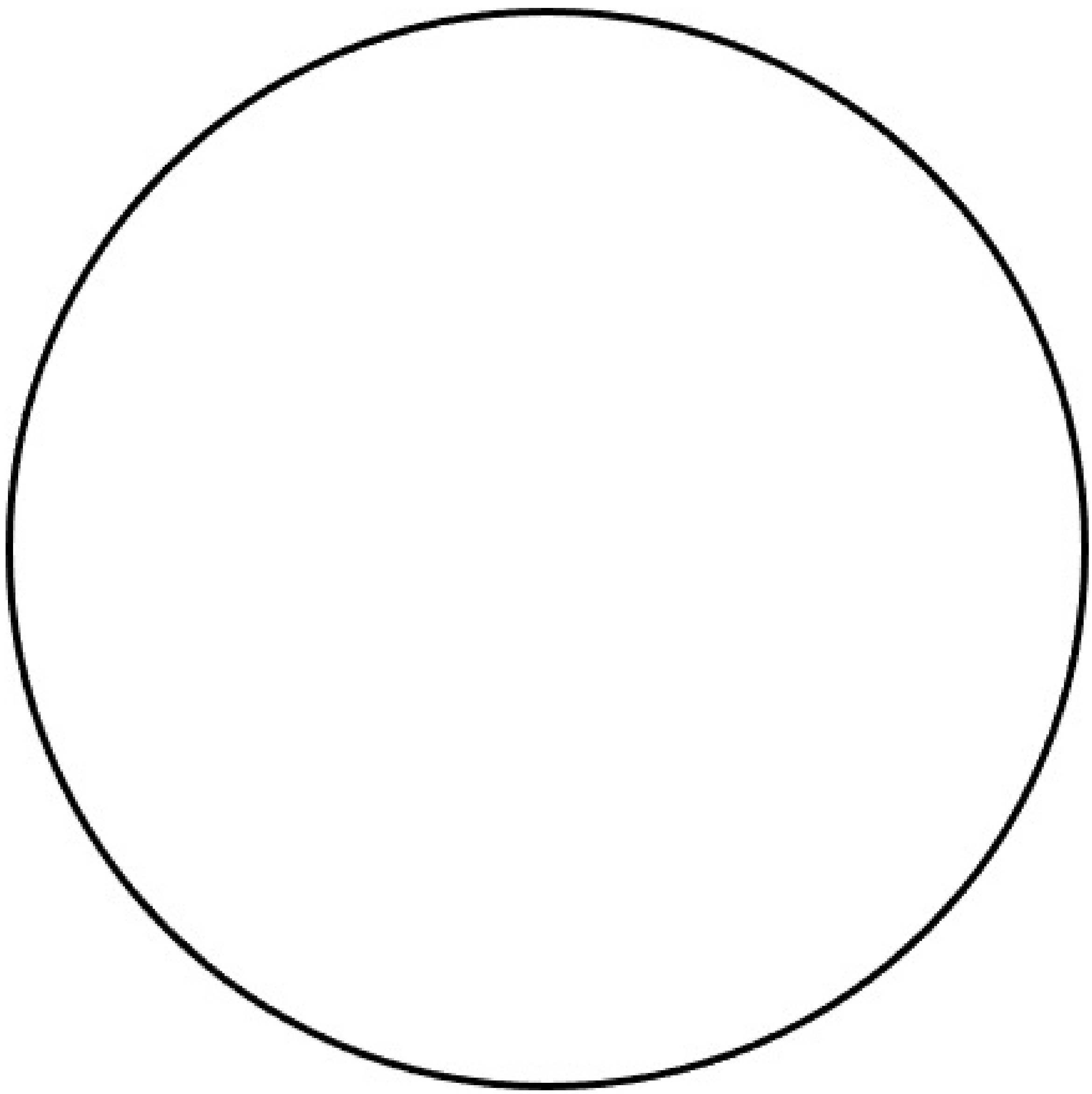
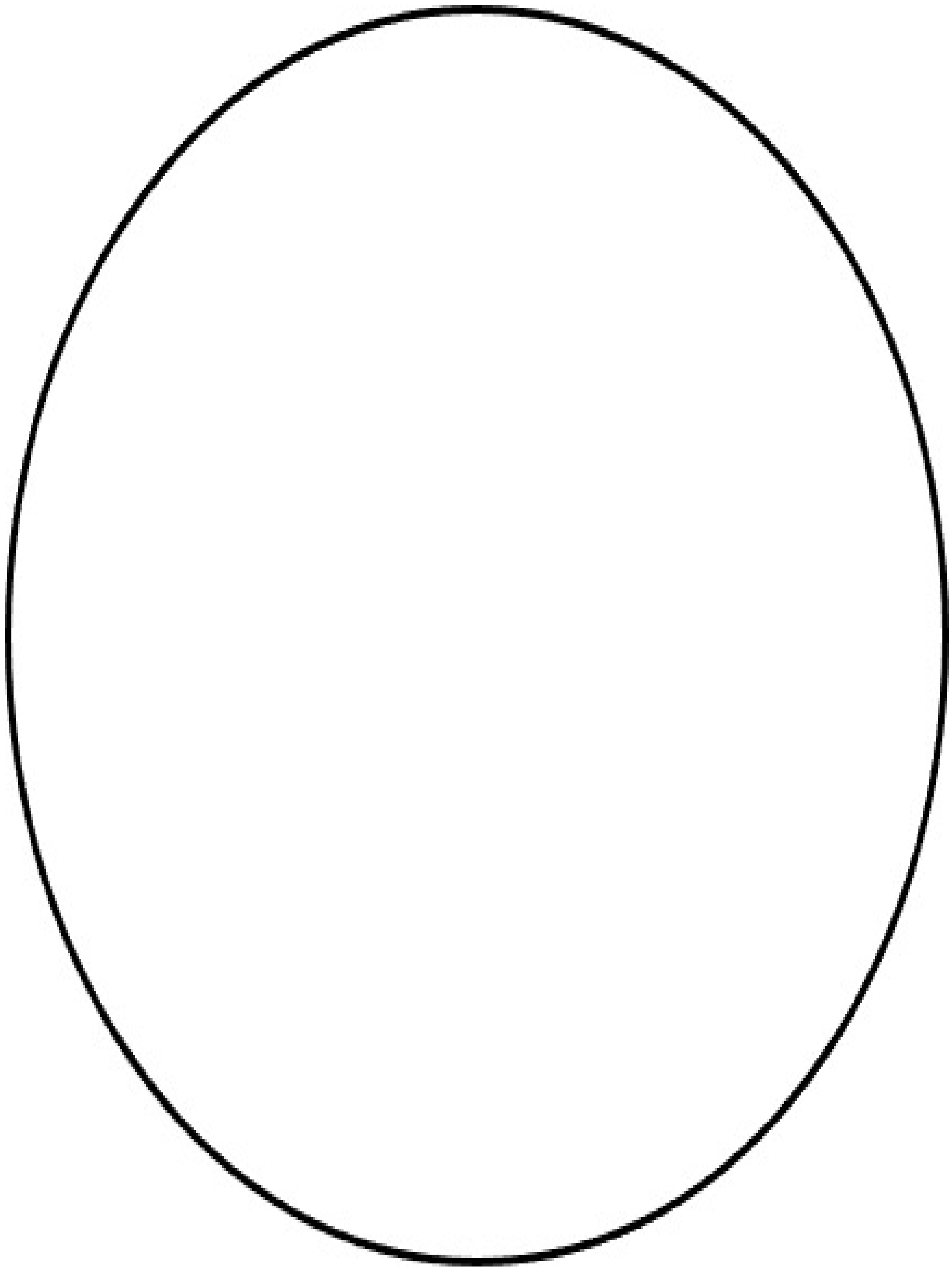


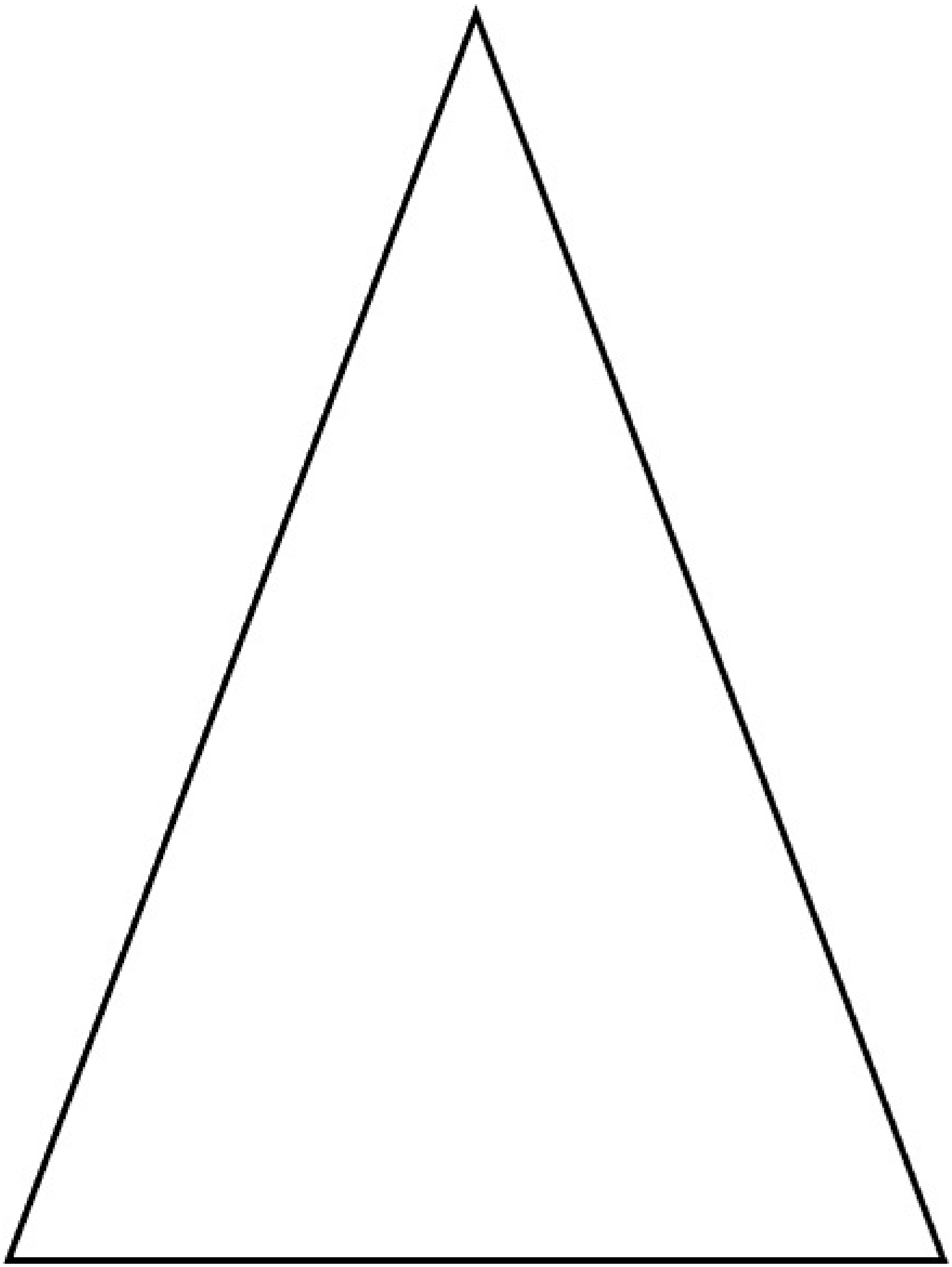
Figure 2. Paper clip unbent into a u shape.

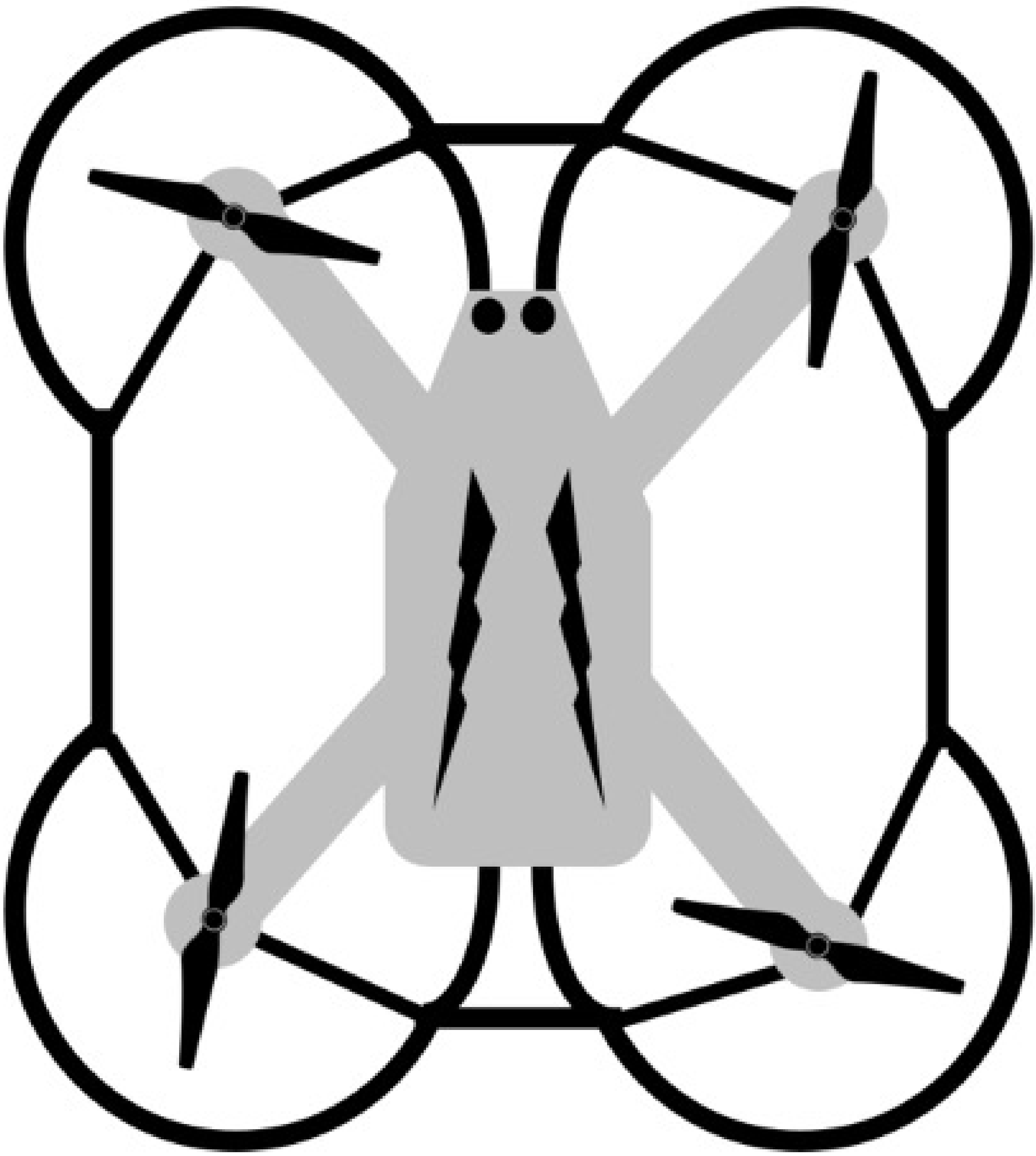
APPENDIX 1

Objects to use for Determining Centers of Gravity

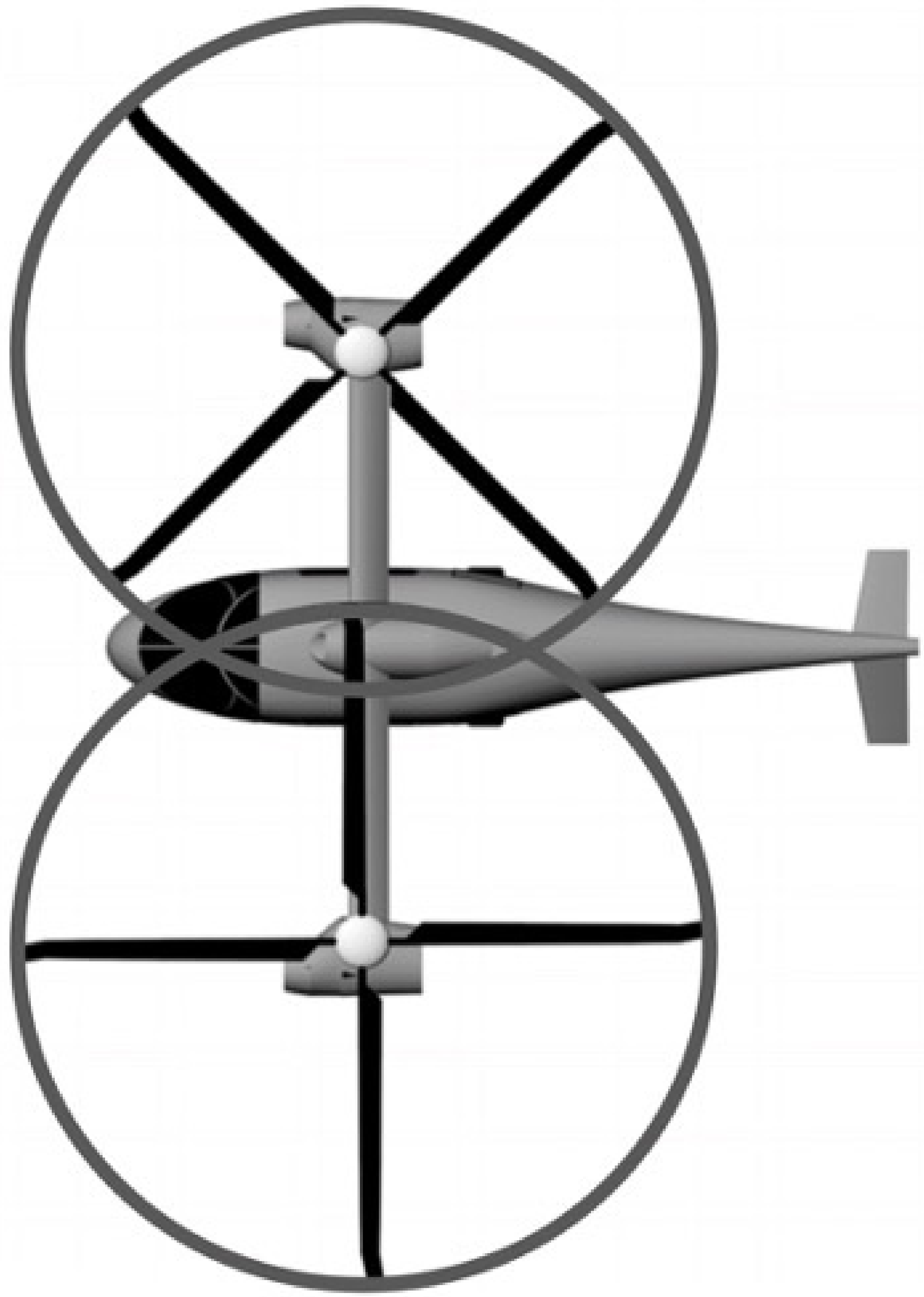




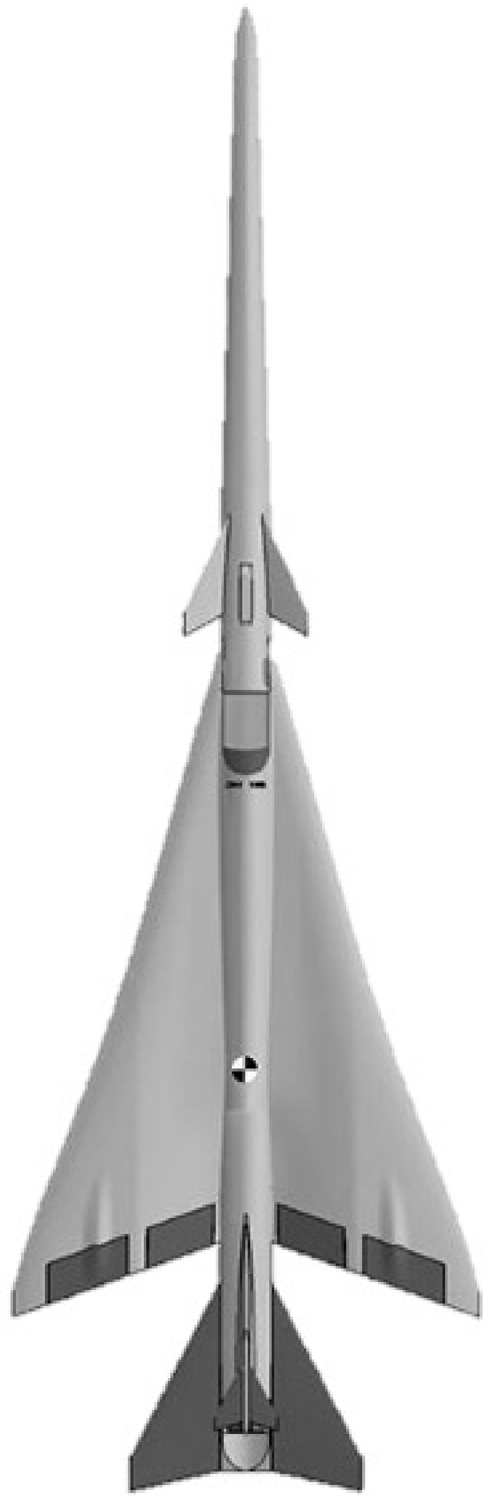




UAV – print on cardstock



Air taxi – print on cardstock



X-59 aircraft – print on cardstock

Note: This aircraft does not operate in the airspace AAM controls. It is provided as an extra example of a complex shape for which to find the center of gravity.

APPENDIX 2

Student Reflection Sheet

Name: ____

Hypothesis:
You chose a location for the center of gravity on the simple shape. Explain why you hypothesized this as the location:

Answer the following:

1. You hypothesized the location of the centers of gravity for the simple-shaped objects before determining them using the gravitational balance method. Did the locations differ from your hypothesized locations? Did your experiment confirm your hypothesis? Explain.

2. When you attached weight to the shapes, how did it affect the centers of gravity? How did you know whether it had moved?

3. How did you find the center of gravity for the real-world object(s) provided?

4. Aeronautical engineers help design airplanes. Why do you think it's important for aeronautical engineers to be able to determine the center of gravity for an airplane?

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