NATIONAL MUSEUM OF THE UNITED STATES AIR FORCE™

FINDING THE CENTER OF GRAVITY

Students will learn about the history of airlift missions (both humanitarian and combat) as well as to learn about the center of gravity (CG) of an aircraft and ways in which the CG can be determined. The U. S. Air Force's Global Reach is emphasized! Center of gravity lessons derived in most part from NASA's Exploring the Extreme Educator Guide.

Learning Objectives

The students will:

- Learn about the importance of the center of gravity (CG) with respect to a cargo aircraft's flight
- Learn how to determine the center of gravity of an object, with each member of the class (or group) working with their own demonstration/experimental items
- Experiment with meter sticks and plumb lines to determine the CG of a two-dimensional model of a C-17
- Learn about the history of both humanitarian and combat airlift missions around the world
- Learn about the variety of cargo and refueling aircraft which have been used throughout recent history
- Learn about the U. S. Air Force's successful development of "Global Reach and Global Power"

Grade Level: 5—6

Ohio Learning Standards/Science (2018)

Expectations for Learning
Nature of Science
Cognitive Demands for Science

Physical Science - Forces and Motion
5.PS.1: Change in movement of an object
6.PS.1. Matter has properties of mass and volume

Ohio Learning Standards/Social Studies (2018)
History Topics:
Historical Thinking and Skills
Heritage
Geography Topics:
Spatial Thinking & Skills

Ohio Learning Standards/Mathematics (2017)
5.MD: Measurement and Data
6.G: Geometry

Materials Required:

- White board, projector
- Slide presentation
- Laptop, monitor, digital projector
- Two cardboard cut-outs of aircraft per team
- One meter stick per team
- One pair scissors per team
- Pencils
- Paper clips
- String
- Push pins
- Large needle and thread

Background

Airlift and transport missions were not a real priority during the early years of flight, primarily because the small aircraft at the time were not conducive to large cargo loads or multi- passenger movement. As airplanes developed and their size and capacity increased, airlift operations became a reality. The United States developed transports known as C-47 Skytrains and C-54 Skymasters, based on commercial airliners. C-47s were affectionately called "Gooney Birds," and the Army Air Corps first ordered these cargo airplanes in 1940. By the end of World War II, over 9,300 Skytrains had been procured. C-54 Skymasters could carry much heavier loads than the C-47s (28,000 pounds of cargo versus 6,000 pounds) and the U. S. military (the Army Air Corps and Navy) began using C-54s in 1942.

From 1942 through 1947, the Army Air Corps procured 1,164 C-54 Skymasters. In 1947, the U. S. Air Force became a separate branch of the U. S. military. From its very beginnings, the Air Force has also used its airlift capabilities for humanitarian purposes. Humanitarian airlift efforts have always been a key component and top priority for the Air Force, and these missions have made an extremely positive impact on the lives of countless individuals around the world.

For example, in June 1948, when the Air Force was still in its infancy, the Soviet Union decided to block all roads, railways and rivers going into the city of West Berlin (which was still in ruins after World War II). They cut all power as well, so the 2.5 million inhabitants of West Berlin faced certain starvation. There were, however, three narrow air corridors

left open, as the Soviets thought the Allies' airlift capabilities would be negligible. The United States, Britain and France agreed to join forces to keep West Berliners supplied with coal and food, and above all, to keep them free from Soviet rule. The Berlin Airlift, nicknamed "Operation Vittles'" lasted for fifteen months, and nearly 2.3 million tons of supplies were flown into Berlin during 277,000 flights. The workhorses for this incredible humanitarian airlift were C-47s and C-54s, and that is what makes this whole airlift operation so amazing—none of the gigantic cargo aircraft of today, such as the C-17 Globemaster III, the C-5 Galaxy and the C-130 Hercules, were in existence! More recently, the Air Force has been heavily involved in global humanitarian airlift missions, which provide relief and assistance to victims of civil war, famine, floods, earthquakes, wildfires, harsh winter weather, etc. Some of the countries that have benefitted from these humanitarian operations include Somalia, Bosnia, Kosovo, Greece, Peru, Ecuador, Venezuela, the former Soviet Republics, Rumania, Rwanda, Iraq, Turkey, Mozambique, Madagascar, Pakistan, India, Japan, Haiti, Honduras, El Salvador, Nicaragua, Afghanistan and Indonesia! Some of our states that have benefitted from the Air Force's humanitarian efforts include Oklahoma, Kansas, South Dakota, Louisiana, Hawaii, California and Florida.

With regard to air refueling operations, the two primary aircraft that allow the Air Force to have such amazing global reach are the KC-135 Stratotanker and the KC-10 Extender. They extend the range of our tactical fighters and strategic bombers during overseas operations, and they also provide refueling support to the Navy, the Marine Corps and many aircraft of our allied nations. Not only do these aircraft play a key role in the mobilization of our military assets, they are also capable of transporting patients during aeromedical evacuations. Regarding modern cargo aircraft, such as the C-17 and the C-5, their inherent performance and flexibility greatly improve the ability of the Air Force's 'total airlift system' to fulfill its global air mobility requirements. These requirements have increased significantly, since the size and weight of U. S. mechanized firepower and equipment have grown in response to the improved capabilities of our potential adversaries. Finally, the ultimate measure of airlift value is the ability to rapidly project and sustain an effective combat force in close proximity to a potential theater of war. Most assuredly, the U. S. Air Force has that ability, and its proficiency in providing humanitarian aid is beyond repute.

Procedures:

- Before class: create a 2-d aircraft model by printing the attached aircraft outline on heavy cardstock and cutting out the shape – one for each student or group of students.
- Begin with a discussion of cargo aircraft. Use as little or as much from the background information as desired. A slide presentation is available to assist.
- Next discuss the importance of balance/symmetry (stability) in everything that flies, including birds, kites, aircraft, etc. Ask the students what this means in terms of cargo aircraft (cargo inside the plane must also be balanced and knowledge of the location of the CG is crucial in loading the plane to maintain balance).
- Balance a small, three-dimensional model of an airplane on your index finger, and tell the students that the center of gravity is the point from which an airplane could be suspended and remain completely balanced—it is the center of mass of the aircraft.
- As you draw an airplane on the board, tell the students that the CG can also be defined as the average location of the weight of an aircraft (place a dot on your airplane's fuselage at the wings' leading edge).
- For each team of students (recommend two or three students per team), distribute one of the two-dimensional aircraft cutouts, a meter stick, a pencil, masking tape and scissors.
- Hold up your C-17 cutout, balance it flat on your index finger and ask students to try it themselves, giving them plenty of time to experiment and to have a bit of fun.
- Tell the class that aerospace engineers have to know the exact location to balance a real airplane, just like they have done with their model aircraft.
- Hold up your model again, and tell students that this seems to be a very stable position. If you give it a little push, it will wobble back and forth, but it will return to a stable position without falling. Tell the class that aerospace engineers utilize mathematics, science and engineering to find the exact center of gravity of a plane.
- Ask the students to brainstorm some ideas as to how they might be able to find the approximate CG mechanically. Then tell them that you will show them one way.

- Demonstrate to the class how to affix a meter stick to the edge of a desk or table—most of the stick should be past the edge of the table; then fasten the small part of the stick that is still on the table with masking tape. Have each team of students do the same thing with their sticks and tape.
- Show the students how to place their cardboard aircraft model on top of the meter stick in a longitudinal direction, with the nose of the airplane pointing toward the table. Draw a line down the center of the model with a pencil and have the class perform the same operation.
- Show the class how to place the model on top of the stick in a lateral direction, with the fuselage of the plane parallel to the table and perpendicular to the stick. Draw a line across the wings corresponding to the direction of the stick. Tell the students that the point of intersection of the two lines is the approximate CG.
- Punch a small hole in each of the aircraft models at the CG, using a large needle and thread. Tie a large knot on the bottom of the thread, ensuring that the knot is large enough so that it won't go through the hole. Hold the model by the top of the thread to see how well it balances.
- At a later time, you may wish to hang all the models from the ceiling, using paperclip hooks or similar items.
- Announce to the students that it is now time to find a model airplane's center of gravity by using plumb lines.
- Pass out a new cardboard two-dimensional model that you printed on cardstock and cut out.
- Pass out paper clips, 15-inch lengths of string and pushpins (one per team of students).
- Tell the class to attach the paperclip to one end of the string, and to use a pushpin to attach the other end of the string to a wall. Demonstrate this process and tell students that this is the plumb line.
- Continue to demonstrate by punching a hole anywhere on your model, and by putting another pushpin through the hole, allowing the model to dangle from the pushpin until it settles in a stable position.
- Place the pushpin and the stabilized model right over the plumb line, then use a meter stick to draw a line on the model, carefully following the 'path' of the plumb line.
- Punch another hole somewhere else on your model, and repeat the steps (place pushpin through hole, allow model to stabilize, place pushpin and model over plumb line, draw a line on model which follows plumb line).
- Repeat a third and final time, punching yet another hole, placing a pushpin through third hole, allowing the model to stabilize, placing a pushpin and model over plumb line and drawing a line that follows plumb line.
- Tell the class that, where the three lines intersect on the model, is its center of gravity!
- Have each team of students perform the three hole/three intersecting line process to find the CG of their models using the plumb line method. Compare both models' CG.

Assessment/Evaluation

The students should be evaluated on their class participation, listening skills and ability to follow verbal instructions, especially when they are involved with cooperative learning activities and class discussions.

Extension:

Have students find the CG of other shapes (a state, a rhombus, etc.).

Resources:

USAF Humanitarian missions:

https://www.airforce.com/mission/american-airmen/humanitarian

https://www.airforce.com/mission/history

National Museum of the USAF relevant resources:

https://www.nationalmuseum.af.mil/Visit/Museum-Exhibits/Fact-Sheets/Display/Article/196271/douglas-c-47d-skytrain/

https://www.nationalmuseum.af.mil/Visit/Museum-Exhibits/Fact-Sheets/Display/Article/196682/c-47-hospital-ship/

https://www.nationalmuseum.af.mil/Visit/Museum-Exhibits/Fact-Sheets/Display/Article/197518/berlin-city-held-hostage/

https://www.nationalmuseum.af.mil/Visit/Museum-Exhibits/Fact-Sheets/Display/Article/617087/global-reach-gallery-introduction/

https://www.nationalmuseum.af.mil/Visit/Museum-Exhibits/Global-Reach-Gallery/

https://www.nationalmuseum.af.mil/Visit/Museum-Exhibits/Fact-Sheets/Display/Article/195851/boeing-c-17-globemaster-iii/

Center of Gravity resources:

https://www.grc.nasa.gov/www/k-12/airplane/cg.html

https://www.grc.nasa.gov/WWW/k-12/BGA/Melissa/center_of_gravity_act.htm

https://www.grc.nasa.gov/WWW/K-12/airplane/acg.html

NASA's *Exploring the Extreme* Educator Guide:

https://www.nasa.gov/stem-ed-resources/exploring-the-extreme-guide.html