NATIONAL MUSEUM
OF THE UNITED STATES AIR FORCE™

CHANGING 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) and ways in which the CG can be calculated and changed. 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
- Discover that the center of gravity can be changed by adding weights to a balanced object with each member of the class (or group) working with their own demonstrational items
- Learn how to calculate moment arms using weights on a meter stick
- 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"

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.

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/Mathematics (2017)
5.OA: Operations and Algebraic Thinking
5.MD: Measurement and Data
6.NS: The Number System
6.EE: Expressions and Equations

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

Materials Required:

- Slide presentation
- Laptop, monitor, digital projector
- One meter stick per team
- One 12 inch/30 cm ruler
- Flat sinkers/washers/standard weights of 30, 60, and 90 grams
- Pencils
- String
- One copy of included worksheet per team

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:

- After learning as little or as much of the above background information as the teacher prefers, explain to students that the center of gravity of an aircraft – crucial to its balance and stable flight – changes constantly. This is due to fuel consumption, changes in the amount and location of cargo/passengers, and other circumstances.

- Students will be tasked with learning how to change the center of gravity and to learn how – working in teams of three students – to calculate a moment arm using weights on a meter stick.

- Distribute the following items to each team of students: a meter stick, a rubber band, a long string, masking tape, a ruler, fishing sinkers of 30, 60 and 90 grams, and a copy of the chart on the last page of this lesson.

- Have each group perform the following tasks: wrap the rubber band around their meter stick; tie the string to the rubber band; suspend their meter stick from the ceiling or anywhere appropriate. Have each group move the rubber band until the meter stick is hanging level and balanced.

- Tell the groups that the rubber band is at the ZERO (0) point, and measurements will be made in both directions (called 'moment arms') starting from this point.

- Tell students that a 'moment arm' is equal to weight times moment arm (distance).

- Tell the groups to place a 30 gram weight 5 cm from the 0 point and tape it to the meter stick. The meter stick will be unbalanced at this point. Ask the students to find out how much weight needs to be placed at 2.5 cm on the opposite side of the 0 point to make the 'system' balanced (*they will find that it is 60 grams, or two units of weight* as 30 times 5 equals 150 and 150 divided by 2.5 equals 60). Have them record their findings on their chart.

- Lead a quick class discussion: ask if the larger weight is closer or farther away from the 0 point, and if it is closer, will that always be the case? [*Yes, the larger weight will always be closer to the 0 point*]

- Tell the students to place two units of weight (60 grams) at 15 cm from the 0 point; ask them to find what weight needs to be added at 10 cm from the 0 point on the other side (*they will find that it is 90 grams, or three units of weight as 60 times 15 = 900 and 900 divided by 10 = 90*). Have them record their findings on the chart.

- Explain that the distance the weight is from the 0 point is called the 'moment arm.' Label one side weight A on moment arm A; the other side weight B on moment arm B.

- Tell the class to place three units of weight (90 grams) 10 cm from the 0 point (three units of weight at 10 cm moment arm). Ask them where they think they could place a one unit – 30 grams – weight to make the meter stick balance, and have them record their answer (*they should have discovered it is 30 cm*).

- Have them put two units of weight on one side to make their meter stick balance (it would be easier if students use even measurements). Have them record their answer (refer to completed chart below).

- Discuss: ask students if they notice a correlation between moment A and moment B; ask how they would find moment; ask what the difference is between moment and moment arm (*moment equals weight times arm distance; moment arm equals moment divided by weight*).

A **Weight x Moment Arm = Moment**	**B** **Weight x Moment Arm = Moment**
1. 30 x 5 = **150**	1. **60** x 2.5 = **150**
2. 60 x 15 = **900**	2. **90** x 10 = **900**
3. 90 x 10 = **900**	3. 30 x **30** = **900**
4.	4.
5.	5.
6.	6.

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 team activities and class discussions.

Extension

Have students experiment with weights to get other moments; challenge students to add weights to two different locations on the same side of the meter stick

($weight_{A1}$ x $moment\ arm_1$ + $weight_{A2}$ x $moment\ arm_2$ = $weight_B$ x $moment\ arm_B$).

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

University of Colorado Boulder Interactive Simulations for Science and Math:

https://phet.colorado.edu/en/simulation/balancing-act

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MOMENT STUDENT WORKSHEET

Students: Please show your math

A	B
Weight times moment arm = moment	Weight times moment arm = moment
① 30 x 5 = _____	① ? x 2.5 = _____
② 60 x 15 = _____	② ? x 10 = _____
③ 90 x 10 = _____	③ 30 x ? = _____
④	④
⑤	⑤
⑥	⑥