NATIONAL MUSEUM
OF THE UNITED STATES AIR FORCE

AIRLIFT MISSION—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!

LESSON PLAN (D)

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 rulers 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"

Introduction/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 very first successful airlift was accomplished by Germany in 1936, when they transported 20,000 stranded Spanish troops across the Strait of Gibraltar and on to Seville, Spain. It took the Germans 677 flights (sorties) using their modified Junkers Ju.52 trimotor aircraft. After hearing the news of this successful, initial airlift, other countries began developing their own cargo/transport Aircraft. The British utilized transport-bombers, such as Their Vickers Victoria airplane. The United States developed transports that were actually Douglas DC-3 and Douglas DC-4 commercial airliners, and with modifications, these two aircraft became C-47 "Skytrains" and C-54 "Skymasters," respectively. The conversions included removing the airliner interiors, adding heavier floors and creating large cargo doors. 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.

Grade Level: 4—6

National Science Education Standards:
Science as Inquiry, Science and Technology, Physical Science, Science in Personal and Social Perspectives and History and Nature of Science

National Standards for History:
Chronological Thinking and Historical Comprehension

National Standards for Mathematics:
Data Analysis and Probability, Problem Solving, Communication and Measurement

Materials Required:

- Magic board and markers
- PowerPoint presentation
- Laptop, monitor, digital projector
- Demo items as listed within lesson plan

Resources:

- General Information:

http://www.amc.af.mil/library/factsheets/factsheet.asp?id=229 and id=239 and http://www.centennialofflight.gov/essay/Air_Power/cargo/AP19.htm and http://www.futurefirepower.com/us-air-force-airlift-global-us-military-aircraft and http://www.theaviationzone.com/factsheets/c5.asp (and c17.asp and c130.asp) and www.konnections.com/airlift/berlin.htm and www.caa.govt.nz and http://www.grc.nasa.gov/WWW/k-12/WindTunnel/Activities/balance_of_forces.html and http://avstop.com/technical/weightbal.htm and http://www.dod.mil/execsec/adr96/airforce_report.html and http://www.af.mil/information/factsheets/index.asp and http://www.Airforce.com/learn-about/history/part4/ and http://www.answers.com/topic/air-mobility-command and http://www.grc.nasa.gov/WWW/K-12/airplane/acg.html and www.nationalmuseum.af.mil/education

From 1942 through 1947, the Army Air Corps procured 1,164 C-54 “Skymasters.” Special Note: the U. S. Air Force was not a separate branch of the U. S. military until 1947. However, from its very beginnings as a distinct entity, the Air Force has NOT just used its airlift capabilities to transport combat troops and supplies into, and out of, theaters of war (as exemplified by Operation Desert Storm, one of the largest strategic airlifts since World War II). 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 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 straight months, and nearly 2.3 million tons of supplies (4.6 billion pounds) were flown into Berlin during 277,000 flights (there was one flight every three minutes)! 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. In 1992, the Military Transport Service (airlift division) merged with Strategic Air Command’s refueling operations to form the Air Mobility Command (AMC). AMC is a major command which is headquartered at Scott Air Force Base in Illinois, and it provides worldwide cargo and passenger delivery, air refueling and aeromedical evacuation. It is also the command which is the focal point for all Air Force humanitarian airlift operations. 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 litter and ambulatory patients utilizing patient support pallets 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 efficacy 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:

NOTE: Teachers may use as much of the information contained within the “Intro/Background” section as they deem appropriate for their students; similarly, teachers may wish to pick and choose items within this “Procedures” section. Teachers may wish to cover center of gravity (CG) and finding the center of gravity of a two-dimensional model using both ruler and plumb line methodology on one day, then cover changing the center of gravity using moment arms on a different day. Background PowerPoint is at http://www.nationalmuseum.af.mil/shared/media/document/AFD-121218-021.pdf.

- Write (on board) the things that will be covered/discussed/reviewed in class, including: the center of gravity of an object, the center of gravity of an airplane, determining the CG of an object and/or airplane, the history of airlift operations, the types of aircraft used for airlift missions and a PowerPoint presentation.
- Hook: balance a small, three-dimensional model of an airplane on your index finger, and tell the students that, by definition, 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, or the ‘theoretical’ point at which the entire weight of the airplane is (presumably) concentrated.
- **Special Note:** National Science Academic Standards/Science As Inquiry/Evidence, Models and Explanation: models correspond to real objects and help both scientists and students understand how things work!

Procedures (continued)

NOTE: A two-dimensional 'model' of a C-17 "Globemaster III" is included on page 5 (to copy and cut out)!

- 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).
- Pass out items to each student (or to each group of three students, if you prefer a cooperative learning scenario): a two-dimensional cutout of a C-17 (which you will have already copied on cardstock and precut), a ruler, a crayon, masking tape and scissors—or, you may wish to have your students cut the airplanes out!
- Have one of each item at the front of the classroom/at your disposal for demonstration/instructional purposes.
- 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 (and again, this is known as the center of gravity, or CG).
- 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.
- Demonstrate to the class how to affix a ruler to the edge of a desk or table—most of the ruler should be past the edge of the table; then fasten the small part of the ruler that is still on the table with masking tape. Have each student, or group of students, do the same thing with their rulers and tape.
- Show the students how to place their flat C-17 model on top of the ruler 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 crayon, and have the class perform the same operation.
- Show the class how to place the model on top of the ruler in a lateral direction, with the fuselage of the plane parallel to the table and perpendicular to the ruler. Draw a line across the wings corresponding to the direction of the ruler. Tell the students that the point of intersection of the two lines is the CG!
- Punch a small hole in each of your students' C-17 model at the CG, using a 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.
- 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 new C-17 two-dimensional models you've copied on cardstock, and allow students to cut them out.
- Pass out paper clips, 15-inch lengths of string and pushpins (one per student or per group 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 ruler 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 pushpin through third hole, allowing the model to stabilize, placing 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 student or group of students perform the 'three hole/three intersecting line process' to find the center of gravity of their C-17 models using the plumb line method. Compare both models' CG!
- Announce to the class that it is now time to learn how to <u>change</u> the center of gravity, and to learn how to calculate 'moment arms' using weights on a yardstick (groups of three students each work best here)!
- Pass out the following items to each cooperative learning group: a yardstick, a rubber band, a long string, masking tape, a ruler, fishing sinkers of 1, 2 and 3 ounces and a copy of the chart on page 5 of the lesson plan.
- Have each group perform the following tasks: wrap the rubber band around their yardstick; tie the string to the rubber band; suspend their yardstick from the ceiling (it would be best if you have already done this for each group due to safety concerns—unless there are lower places to suspend things inside your classroom); have each group move the rubber band until the yardstick 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 'arms') starting from this point.
- Tell students that a 'moment' is equal to weight times moment arm (distance).

Procedures (continued)

- Tell the groups to place a one ounce weight two inches from the 0 point and tape it to the yardstick. The yardstick will be unbalanced at this point. Ask the students to find out how much weight needs to be placed at one inch on the opposite side of the 0 point to make the 'system' balanced (they will find that it is two ounces, or two units of weight). 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 (two ounces) at six inches from the 0 point; ask them to find what weight needs to be added at four inches from the 0 point on the other side (they will find that it is three ounces, or three units of weight). Have them record their findings on the chart.
- Lead another quick discussion: the distance that the weight is from the 0 point is called the 'moment arm.' One side is called weight A on moment arm A; the other side is weight B on moment arm B.
- Tell the class to place three units of weight (three ounces) four inches (10.16 cm) from the 0 point (three units of weight at four inches or 10.16 cm moment arm). Ask them where they think they could place a one unit weight to make the yardstick balance, and have them record their answer (they should have discovered it is twelve units).
- Have them put two units of weight on one side to make their yardstick balance (it would be easier if students use even measurements). Have them record their answer (refer to completed chart below).
- Lead yet another quick discussion: 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)!

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A	B
1. 1 x 2 = 2	1. 2 x 1 = 2
2. 2 x 6 = 12	2. 3 x 4 = 12
3. 3 x 4 = 12	3. 1 x 12 = 12
4. 2 x 3 = 6	4. 3 x 2 = 6 (poss. ans.)
5. 2 x 6 = 12	5. 3 x 4 = 12 (poss. ans.)
6. 2 x 9 = 18	6. 3 x 6 = 18 (poss. ans.)

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 I: have students experiment with weights to get other moments; challenge students to add weights to two different places on same side of yardstick (weight A1 x moment arm 1 + weight A2 x moment arm 2 = weight B x moment arm B). **Extension II**: have students find the CG of other shapes (a state, a rhombus, etc.).

References

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TEACHER ADDENDUM / PAGE 5