NATIONAL MUSEUM OF THE UNITED STATES AIR FORCE™

Engineering Design Challenge – Aircraft Structure

Students will learn about the history of airlift missions (especially humanitarian) as well as learn about aircraft structures and the engineering mindset that is needed to properly design them. The U. S. Air Force's Global Reach is emphasized.

LESSON PLAN

Learning Objectives

The students will

- Learn about cargo aircraft structures and about the importance of creative engineering to ensure safe and functional design of those structures
- Learn about the dynamics of working within a team, while assisting their team with specific engineering design concepts and processes
- Learn to solve problems while working within a group
- 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 in Technology (2017)
Design and Technology
3-5.DT.2.b.: Plan and implement a design process
3-5.DT.2.c.: Generate, develop and communicate design ideas and decisions
6-8.DT.1.c.: Define and categorize the requirements of a design as either criteria or constraints.
6-8.DT.2.a.: Apply a complete design process to solve a problem
6-8.DT.2.d.: Consider multiple factors, including criteria and constraints, (e.g., research, cost, time, materials, feedback, safety) to justify decisions when developing products and systems to solve problems.
6-8.DT.3.a.: Collaborate to solve a problem as an interdisciplinary team modeling different roles and functions.

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

Ohio Learning Standards for Science (2018)
Expectations for Learning
Nature of Science

Physical Science
5.PS.1: Force and Motion

Materials Required:

- Laptop, monitor, digital projector, Internet access
- Books or other support system (see procedure section)
- About 10 sheets per team of 8.5 by 11 inch copy paper of any color
- Several boxes of large paper clips per team
- One ruler per team
- Pencils
- One roll cellophane tape per team
- 3-d Model of a C-17 if available

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 teaching as little or as much of the above background information as the teacher prefers, explain to students that they will be working in teams to compare and contrast older aircraft structures with newer designs and will learn about engineering design challenge teams/solutions, the history of airlift operations, and the types of aircraft used for airlift missions.

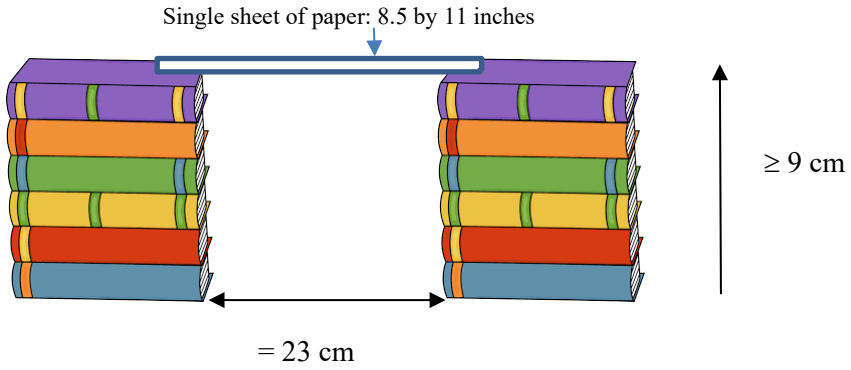
- If available, show the students a model of a C-17 Globemaster III cargo airplane. If not available, show the students photos and/or the video (both available at the web sites in the resources section below). Explain that the aircraft has a huge cargo capacity (170,900 pounds maximum payload). Ask them how they think such huge airplanes can hold so much cargo and still take off, fly and land successfully.

- Explain that, during the early years of aviation, airplanes were constructed of wood and cloth. Point to the basic aircraft structures on your model as you tell them that, originally, the wings, fuselage (body) and tail were given structure by using wooden spars and framework and then by stretching and stitching cloth over those spars and wooden frame elements to make a lightweight skin. Show the students the photos of a WW I aircraft, the Standard J-1, without its fabric covering to show the internal structure. Show the photos of the same type of aircraft with its covering for perspective. These photos are available at the web sites listed in the resource section below.

- Tell the students that more modern technology for an aircraft's 'airframe' includes the use of metal spars, frames and ribs, as well as lightweight sheet metal for the skin—quite a contrast from the cloth and wood construction of over 100 years ago.

- Tell them that the fuselage is the main body of the aircraft to which all parts are connected, and it is the primary carrier of the airplane's payload/cargo. The wings provide lift and control for the aircraft, and many times there are fuel tanks inside them (which saves a lot of space for other systems and cargo). The primary function of the tail of the airplane is to provide stability and control during take-off, flight and landing.

- Before beginning the hands-on portion, explain that changing the shape of an object can dramatically increase its overall strength so that it can be used for safer and stronger aircraft structures. Students will be challenged to work as a team (as real engineers do) to "engineer" a piece of paper in such a way that it will support an increasing amount of weight. Each team will need a large box of large paperclips and multiple sheets of plain 8.5 inch by 11 inch copy paper of any color. Each team will also need two stacks of books or two boxes or any other objects that will allow for two vertical "towers" that can be staged 23 cm apart (creating a "bridge) and are the same height (at least 9 cm tall).



- Demonstrate to the entire class that the paper, when placed between the objects lengthwise, will not even support its own weight. It will droop down and most likely fall off the structure completely. It will therefore definitely not hold the weight of even one paperclip on top of the paper.

- Their challenge is to work as a team to engineer a way to make one sheet of paper strong enough to stay supported over the "bridge" as well as to be able to hold the weight of as many paperclips as possible. Tell the class that this correlates with the lightweight material strength and rigidity that needs to be engineered into modern aircraft structures and components.

- Introduce the concept of criteria (the bridge must support itself and as many paperclips as possible) and constraints (time; materials available – can only use one sheet of paper and nothing else other than tape – the tape cannot be used to attach the paper to the towers). Also have the students assign responsibilities to each team member (suggestions: the commander is responsible for making sure the team works together and gets the job done, the loadmaster is responsible for putting the paperclips on the bridge and counting them, the public affairs officer is responsible for explaining the design solution and results to the class as a whole, etc.).

- Allow the teams 30 to 45 minutes to work as a team to devise a paper bridge capable of holding lots of paperclips. Extra credit if they can come up with more than one solution! Students should count the number of paperclips their structure could support before collapsing.

- One possible solution is to fold the paper length-wise twice so as to form a "W" (the distance between each fold will be slightly over two inches). Place the folded sheet so that the "W" is upside down on the bridge. This structure will be able to support itself, plus teams will be able to add a large number of paperclips until the paper eventually collapses.

- A similar solution to the "W" is to make accordion-style folds.

- The "W" and the accordion are similar to the corrugated sheets of metal which are found inside some aircraft wings. A similar structure can be seen inside the heavy cardboard sides of many packing boxes.

- Another solution is to roll the sheet of paper into a tube and use tape so it will hold its shape. When placed over the bridge structure, the tube will be able to hold its own weight plus a substantial number of paperclips before collapsing. This structure is similar to the fuselage of an airplane. Also, the tube structure is the same principle as that used in column supports in buildings.

- At the end of the allotted time, have each team share their solution(s) with the entire class. Compare how many paperclips they were able to support with their design.

Assessment

The students should be evaluated on their class participation, team work skills, listening skills and ability to follow verbal instructions

Resources

C-17 resources:
https://www.af.mil/About-Us/Fact-Sheets/Display/Article/1529726/c-17-globemaster-iii/
https://www.boeing.com/defense/c-17-globemaster-iii/
https://www.youtube.com/watch?v=kbbKz7ecoRc

Photos of a Standard J-1 showing internal structure (wood/cloth):
https://www.nationalmuseum.af.mil/Visit/Museum-Exhibits/Fact-Sheets/Display/Article/197398/standard-j-1-fabric-removed/

Photos of a Standard J-1 with fabric covering in place:
https://www.nationalmuseum.af.mil/Visit/Museum-Exhibits/Fact-Sheets/Display/Article/198093/standard-j-1/

Photo showing structure of a more modern wing (page 4):
https://mae.ufl.edu/haftka/structures/FAA.pdf

USAF Humanitarian missions:
https://www.airforce.com/mission/american-airmen/humanitarian
https://www.airforce.com/mission/history

Other 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/