NATIONAL MUSEUM OF THE UNITED STATES AIR FORCE™

Weight and Balance Forces: Expanding Applications

Students will learn about weight and balance forces and how they act upon an aircraft in flight.

LESSON PLAN

Learning Objectives:

The students will:

- Learn about basic weight and balance forces and how they affect cargo aircraft in flight
- Learn about the dynamics of working within a cooperative learning team, while assisting their team with solutions to math problems/scenarios related to the science of torques and moments

Purpose:

Students will work in teams to learn about basic weight and balance forces and how those apply to an aircraft. Students will learn how to solve problems in teams and how to delegate problem solving. They will learn about different topics that affect an airplane's ability to fly. Students will also learn about the four forces of flight.

Introduction:

Airframes all abide by scientific theories that are still difficult to comprehend but scientists speculate that there are certain reasons as to why this occurs. They speculate that laws, effects, and principles of nature all make up this scientific theory of flight. First we want to discuss the four forces that effect flight. These are thrust, drag, weight, and lift. Thrust is a force that moves an aircraft in the direction of the motion, drag is the force that acts opposite of motion, weight is the force caused by gravity, and lift is the force that holds the airplane in the air. There are numerous other scientific phenomena that play into flight. For more information regarding the science behind flight look for page 4 titled '**information sheet**.'

Grade Level: **6 – 8**

Ohio Learning Standards/Science (2018)
Expectation of Learning
Nature of Science

Physical Science
6.PS.2: Change of state
6.PS.3: Energy: kinetic & potential
7.PS.4: Energy can be transferred
8.PS.2: Force can act to change motion of objects

Ohio Learning Standards/Mathematics (2017)
Expressions & Equations
6.EE.2: Write, read & evaluate expressions
6.EE.3: Apply properties of operations
7.EE.4: Use variables to represent quantities

Number System
7.NS.1: Apply previous understandings of addition & subtraction
7.NS.2: Apply previous understandings of multiplication & division

Materials Required:

- Attached worksheets
- Pencils
- Calculators

Procedure:

A. Warm-Up

1. Review all attached pages that explain definitions, problems and equations
2. Balance airplane model on finger and explain the concepts of center of gravity
3. Students should be put into scenario teams of three, four or five members (depending on size of class)

B. Procedure

1. Establish teams and hand out student information worksheets
2. Review student information worksheet with the class
3. Students have 10 minutes to review the topics being discussed
4. Hand out first student exercise sheet
5. Students have 25 minutes to solve Problem #1
6. Explain the solution to Problem #1
7. Hand out second student exercise sheet
8. Students have 15 minutes to solve Problem #2

C. Wrap-up

1. Each team should write down all of their solutions and explanations on the whiteboard at the same time
2. Reveal correct answers to the class and display different methods of solving exercises
3. Discuss that cooperative learning, as well as working within the framework of a dynamic team are important skills that will serve them well, both as future students and in their adult working lives.

Assessment/Evaluation

The students should be evaluated on their class participation, listening skills and ability to follow verbal instructions, especially when they are involved as cooperative learning/math-science scenario team members.

Resources/References:

Science behind flight

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

Airplane center of gravity

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

https://www.grc.nasa.gov/www/k-12/VirtualAero/BottleRocket/airplane/acg.html

Torque or Moment

https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/12_phak_ch10.pdf

https://www.experimentalaircraft.info/articles/aircraft-engine-performance-1.php

http://ffden-2.phys.uaf.edu/webproj/211_fall_2016/Collin_Lasley/collin_lasley/torque.html

Information Sheet

- Center of gravity is the point at which an aircraft would balance if suspended OR the imaginary point where the total weight involved with an aircraft is concentrated (mathematically, it is the pivotal point about which the 'nose-heavy' and 'tail-heavy' moments are of equal magnitude).

- A moment (or a torque) is the weight of an item multiplied by the arm (or moment arm or distance) of its position; since a moment (or a torque) is the product of the arm (in inches) and the weight (in pounds) it is usually expressed in pound-inches (lb-in)—and it may have either a positive or negative value.

- Center of gravity limits are the forward (left) and aft (right) points within which the center of gravity must fall if the aircraft is to operate normally and safely (and the distance between these limits is the center of gravity range).

- Datum (or the reference datum) is an imaginary vertical line from which all horizontal center of gravity measurements are made—usually it is located in the vicinity of the nose or firewall of an aircraft, although for a C-17, it is 85 inches out in front of the nose (see page 5 for visual)—this is actually a popular location for the datum, as all arms are then positive, and computational errors are minimized.

- An arm (or moment arm) is the horizontal distance from the datum to the center of gravity of the aircraft, or to any item in it—a plus sign indicates measurement aft (to the right) of the datum, and a minus sign indicates measurement forward (left) of the datum.

- A station is a location in the airplane that is identified by a number designating its distance (in inches) from the datum—in the case of C-17s, the station numbers get fairly large, since the tip of the nose of this huge cargo airplane is already "station 85".

- Maximum all up weight is the maximum weight allowable for an aircraft (includes the airplane, the fuel, the passengers, every piece of cargo...everything).

Further explanation as to how terms relate to each other:

- A moment (or a torque) is caused by a force acting upon an object at some distance (moment arm) from the center of gravity.

- A torque (or a moment) is equal to the force times the moment arm OR a moment (or a torque) is equal to the weight times the moment arm OR the moment arm equals the moment (or torque) divided by the weight.

- The force involved always acts perpendicular (at a 90-degree angle) to the moment arm.

    - Weight and balance problems/scenarios are based on the physical law of the lever:
      A lever is balanced when the weight on one side of the fulcrum (or datum) multiplied by its arm is equal to the weight on the opposite side multiplied by its arm.

- This is when the positive moments (those which try to rotate the lever clockwise) are equal to the negative moments (those which try to rotate the lever counterclockwise).

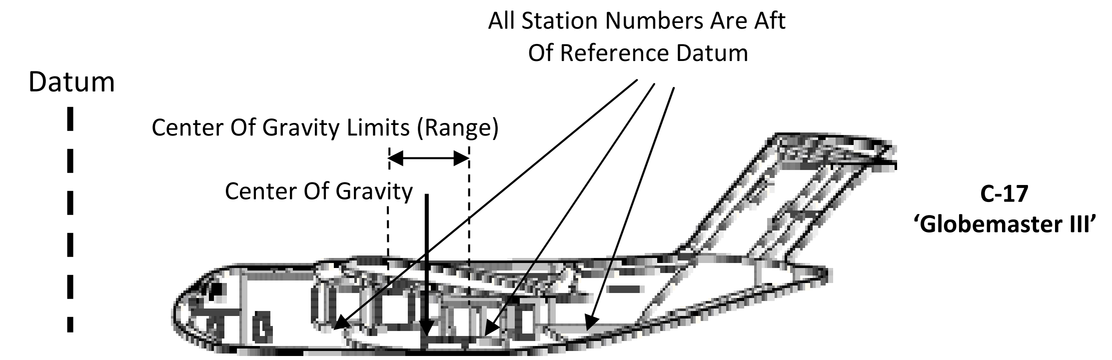
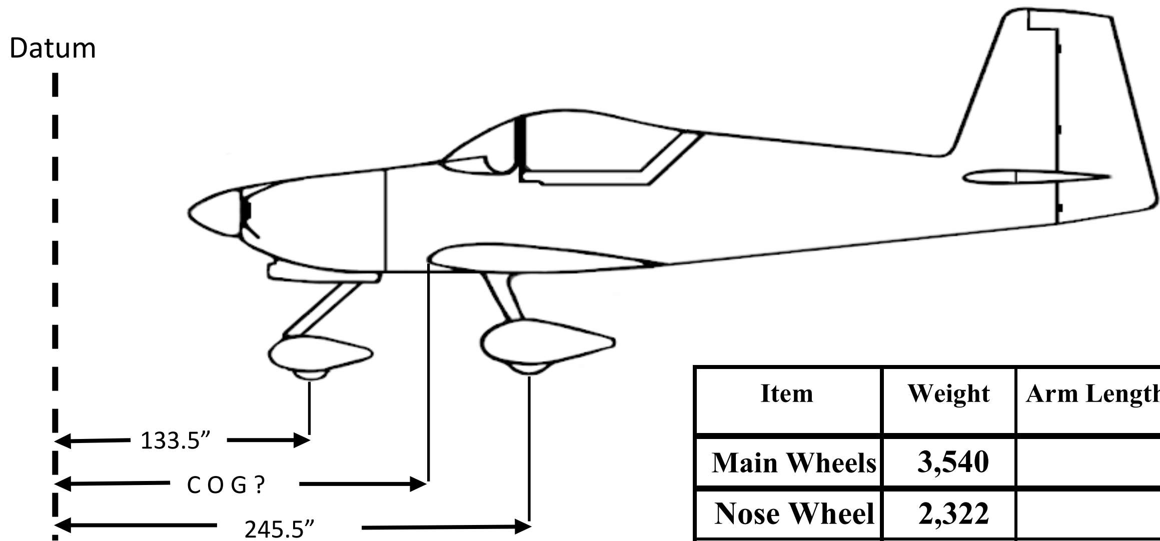


Figure 1

Student Info & Practice Worksheet I



Item	Weight	Arm Length	Moment
Main Wheels	3,540		
Nose Wheel	2,322		
Total			
C O G ?			

Figure 2

- Determining the center of gravity of an aircraft is done in the same manner as determining the center of gravity of a board/lever.
- Example airplane is placed on three scales to determine both the nose wheel weight and the weight of the two main wheels—this will give us the empty weight of the aircraft.
- One nuance: the weight of any device used to hold the airplane on the scales, or to level it, is called tare weight and that will be subtracted from the scale readings.
- The arms (or moment arms) of the weighing points have already been specified in the diagram.

Practice Problems:

What is the total weight for both the main and nose wheels?

Given:

Main wheels = 3,540 pounds Nose wheels = 2,322 pounds

Solution:

MW + NW = Total 3,540 + 2,322 = **5,862 pounds**

What are the arm lengths for both wheel types?

Given:

Main wheels = **245.5 inches** Nose wheels = **133.5 inches**

What is the moment (or torque) for each wheel type?

Given:

Main wheels = 3,540 pounds Nose wheels = 2,322 pounds

Main wheels = 245.5 inches Nose wheels = 133.5 inches

Solution:

Weight * Arm Length = Moment

Main wheels:

3,540 pounds * 245.5 inches = **869,070 pound-inches**

Nose wheels:

2,322 pounds * 133.5 inches = **309,987 pound-inches**

Total moment (or torque) = 869,070 + 309,987

1,179,057 pound-inches

Where is the center of gravity located?

Given:

Total Moment = 1,179,057 pound-inches Total weight = 5,862 pounds

Solution:

Total Moment / Total Weight = Center of Gravity

1,179,057 / 5,862 = 201.1 inches aft (to the right of) the datum

Student Exercise Worksheet II

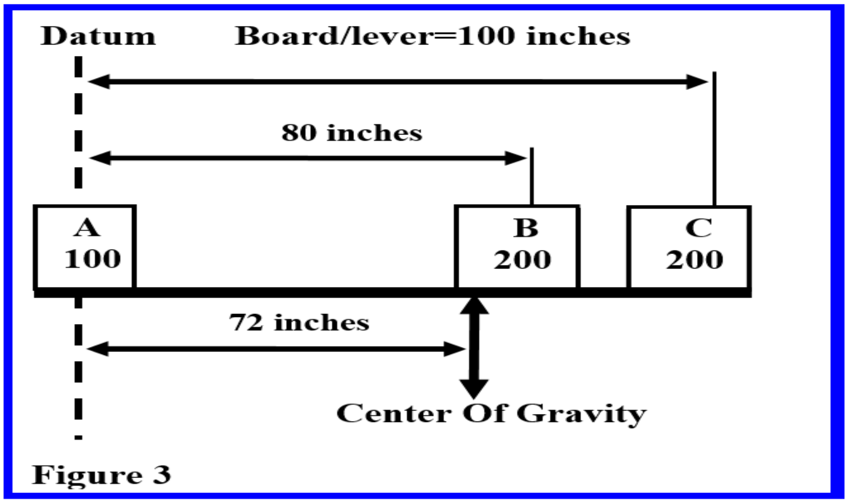


Figure 3

For this example, the board/lever is loaded with the three weights:

It balances at a point 72 inches from the 100 pound weight 'A' to the center of gravity.

NOTE: The center of gravity CAN be moved by shifting weights.

Given:

Item 'A' weight = 100 pounds   Arm & Station = 0   Moment = 0

Item 'B' weight = 200 pounds   Arm & Station = 80 inches   Moment = 16,000 pound-inches

Item 'C' weight = 200 pound   Arm & Station = 100 inches   Moment = 20,000 pound-inches

Problem #1

With the chart and figure provided, determine where weight 'B' needs to be relocated so that the board/lever will balance about its center (*HINT: first step, determine the arm of weight 'B' that will allow three weights to equal 0)*

ITEM	WEIGHT	ARM / STATION	MOMENT
WEIGHT 'A'	100	-50	-5,000
WEIGHT 'B'			
WEIGHT 'C'	200	+50	+10,000
			+5,000

Given Equations:

$$Arm\ of\ an\ object = \frac{Moment}{Weight} \qquad Distance\ of\ an\ object\ shifted = \frac{Total\ weight * change\ in\ COG}{Weight\ Shifted}$$

Show all work below:

Problem #2

How would you rearrange the *'Distance of an object shifted'* equation so it can be:

(A) Used to determine the amount of weight that will have to be shifted from station 80 to station 25, and to move the center of gravity from station 72 to station 50.

(B) Used to determine the amount the center of gravity shifted when a given amount of weight is moved for a specified distance—to determine the amount the center of gravity will be shifted when 200- pound weight 'B' is moved from station 80 to station 25.

Show all work below:

Answer Sheet

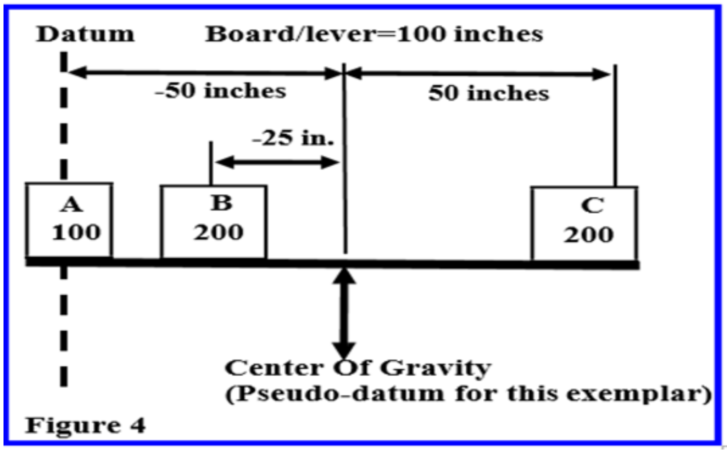


Figure 4

ITEM	WEIGHT	ARM / STATION	MOMENT
WEIGHT ‘A’	100	-50	-5,000
WEIGHT ‘B’	200	-25	-5,000
WEIGHT ‘C’	200	+50	+10,000
			0

Problem #1

Weight B Moment needs to equal **-5,000 pound-inches** to make the board/lever balance

Arm & Station of weight ‘B’ $= \frac{Moment}{Weight} = \frac{-5{,}000}{200} = \mathbf{-25}$

This means that weight ‘B’ will have to be located so that its own ‘center of gravity’ is **25 inches to the left of the balance point/center of gravity of the board/lever**.

The center of gravity was 72 inches from the datum on Figure 3. We shifted the center of gravity to the center of the board/lever by moving weight ‘B’

We moved that 200-pound weight **55 inches to the left**, which shifted the center of gravity from **72 inches** to **50 inches** (a distance of 22 inches to the left)

Distance weight ‘B’ is shifted $= \frac{Total\ weight * change\ in\ COG}{Weight\ shifted} = \frac{500 * -22}{200} =$ **-55 inches**

Problem #2

'Changing the location of the center of gravity' from different perspectives, one can rearrange the basic equations given

Weight shifted $= \frac{Total\ weight * change\ in\ COG}{Distance\ weight\ is\ shifted} = \frac{500 * 22}{55} =$ **200 pounds**

Change in COG $= \frac{Weight\ shifted * distance\ it\ is\ shifted}{Total\ weight} = \frac{200 * 55}{500} =$ **22 inches**