NATIONAL MUSEUM OF THE UNITED STATES AIR FORCE™

Weight and Balance Forces

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 and/or act upon 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 title '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 concept 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 the student exercise sheet
5. Students have 30 minutes to solve the two exercises

C. Wrap-up

1. Each team should write down 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 learning and 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:

Science behind flight

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

https://www.hq.nasa.gov/office/aero/pdf/four_forces_5_8.pdf

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 of an aircraft is the point from which it could be suspended and remain completely balanced. It is the center of mass of the airplane—the theoretical point at which the entire weight of the aircraft is concentrated.
- Another way to explain is that gravity multiplied by an object's mass produces a force called weight.
- Although the force of the object's weight pulls downward on every part of that object, it acts as a single force through the center of gravity.
- If an object's weight is distributed equally throughout the object, its balance point/center of gravity is located at its geometric center, but if there is unequal distribution of weight, then the balance point will most probably not be located at the geometric center of the object.
- It is very important that the location of the center of gravity be within the limits specified by the engineers and airframe designers of that particular airplane—if it falls outside of those parameters, there could be an adverse effect on how the aircraft flies.
- Moment or torque is caused by a force acting upon an object some distance from the center of gravity and that distance is called a moment arm. Its formula is: torque = force x moment arm.
- Other ways to state the formula is that a moment is equal to weight times moment arm, or moment arm equals moment divided by weight.
- The force involved always acts ***perpendicular*** to the moment arm (distance).
- When the counterclockwise torque equals the clockwise torque, the aircraft will be balanced along that geometric plane.
- Any moment (or torque) *in front of* the center of gravity is considered a ***negative*** value (having a negative moment arm) and the torque (or moment) *behind* the center of gravity is considered to be a ***positive*** value (with a positive moment arm).

Student Info & Practice Worksheet

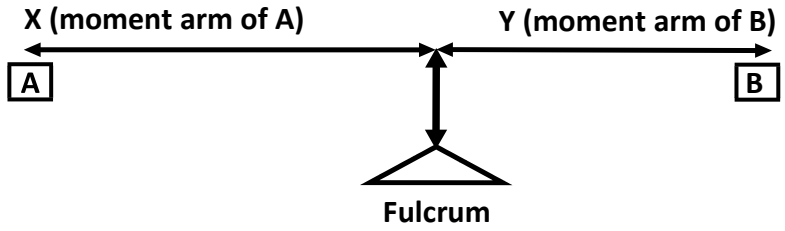
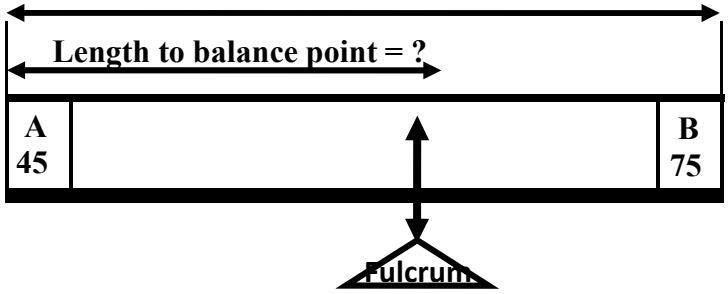


Figure 1

- Item 'A' is at distance 'X' from the fulcrum/pivot point/center of gravity
- Item 'B' is at distance 'Y' from the fulcrum
- If the system is balanced, then the product of 'A' and 'X' must equal the product of 'B' and 'Y'
- The product of the weight of 'A' and its distance ('X') from the fulcrum creates a counterclockwise torque
- The product of the weight of 'B' and its moment arm 'Y' produces a clockwise torque (the force always acts perpendicular to the moment arm).



Item	Weight	Arm Length	Moment
A	45	0	0
B	75	80	6000
Total	120		6000
Bal. Pt.		50	

Figure 2

Practice problem:

Where is the balance point for this diagram (or where to locate the fulcrum)?

The overall length of the beam is 80 inches and, for this problem, is considered weightless.

Set up an arbitrary zero reference point to calculate the balance point (Can be located anywhere on linear beam/for this instance 'A' is reference point).

Given:

Item 'A' weight = 45 pounds Item 'A' arm length = zero (0) (reference point)

'Item A' (Weight * Arm length) = Moment **therefore** 45 * 0 = **0 pound-inches**

Item 'B' weight = 75 pounds Item 'B' arm length = 80 inches (full length of beam)

Item B Moment = 75 pounds * 80 inches = **6,000 pound-inches**

Unknown:

Find balance point/fulcrum

Total weight = 120 Total Moment = 6,000 pound inches

(Moment/Weight) = Arm length

(6,000/120) = **50 inches to the right of 'A'** (or since 80 – 50 =30, **it is also 30 inches left of 'B'**)

Moment arm of 'A' is a negative number:

A's torque equals force * distance = 45 pounds x –50 inches = -2,250 pound-inches (counterclockwise torque)

B's torque equals force * distance = 75 pounds x +30 inches = +2,250 pound-inches (clockwise torque)

Student Exercise Worksheet

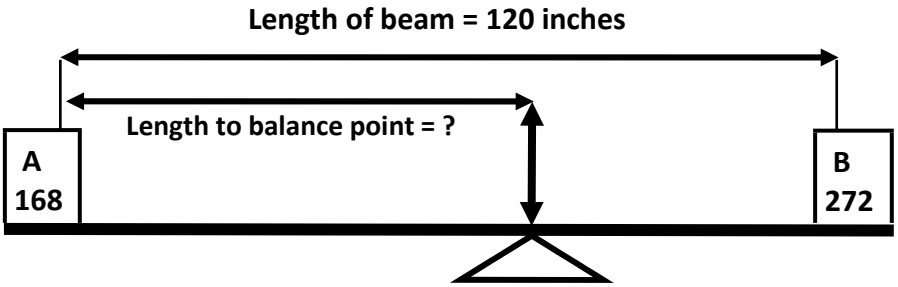


Figure 3

Problem #1

Look at the figure on your papers:

Where is the center of gravity (where the fulcrum should be placed) in regards to Item 'A'?

Given:

Item 'A' weight = 168 pounds

Item 'B' weight = 272 pounds

'Weightless' beam = 120 inches long

Show work below:

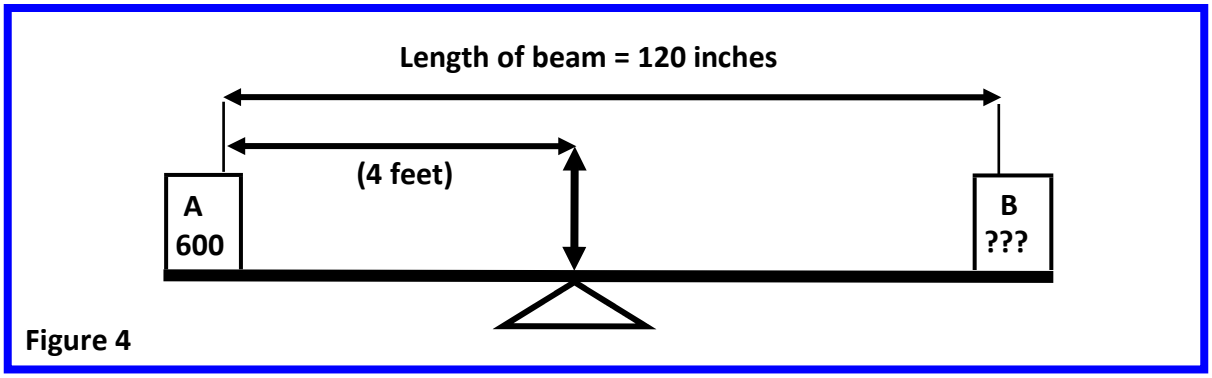


Figure 4

Problem #2

Look at the figure on your papers:

a. What is the weight needed at 'B' to produce system equilibrium/balance?

Given:

'Weightless' beam = 120 inches in length

Item 'A' weight = 600 pounds

Center of gravity is located four feet to the right of 'A' (HINT: length and moment have inch units)

Show work below:

b. Find the torque for both Item 'A' and 'B'

Show work below:

Answer sheet

Problem #1

Given:

Item 'A' weight = 168 pounds

Item 'B' weight = 272 pounds

'Weightless' beam = 120 inches long

Solution:

Item 'A' Moment = 168 pounds * 0 inches (starting point) = 0 pound-inches

Item 'B' Moment = 272 pounds * 120 inches = 32,640 pound-inches

Total Moment = 32,640 pound-inches

Find balance point/fulcrum:

Total weight = 440 Total Moment = 32,640 pound-inches

(Moment/Weight) = Arm length

(32,640/440) = **~74.18 inches to the right of 'A'**

Problem #2

a. What is the weight needed at 'B' to produce system equilibrium/balance?

Given:

'Weightless' beam = 120 inches in length

Item 'A' weight = 600 pounds

Center of gravity is located four feet to the right of 'A' (HINT: length and moment have inch units)

Show work below:

(Moment/Weight) = Arm length

48 inches = $\frac{0+120x}{600+x}$

48 *(600+x) = 120x 28,800 + 48x =120x

-48x -48x

28,800 = 72x $\frac{28,800}{72} = \frac{72x}{72}$

x = 400 pounds

Item 'B' weight = 400 pounds

b. Find the torque for both Item 'A' and 'B'

Show work below:

Moment arm of 'A' is a negative number:

'A's torque equals force * distance = 600 pounds x –48 inches = **-28,800 pound-inches** (counterclockwise torque)

'B's torque equals force * distance = 400 pounds x +72 inches = **+28,800 pound-inches** (clockwise torque)