WEIGHT AND BALANCE OF AN AIRPLANE

INTRODUCTION

This series of lessons focuses on exposing high school math students to relevant applications in the aviation industry. Students will explore the concept of the weight and balance of an airplane to determine whether or not a plane could successfully fly.

This is the first in the series for Integrated Math 3 and can be taught alone or in conjunction with Unit 2 Lesson 2 – Aviation Performance.

LEARNING OUTCOMES

- Students will calculate the Weight and Balance of an airplane.
- Students will articulate the importance of correctly calculating the weight and balance of a plane and the ramifications of incorrectly calculating it.
- Students will explain how this skill is used in an aviation career.

CURRICULUM ALIGNMENT

COMMON CORE STANDARDS - MATHEMATICS

Standard 1: Make sense of problems and persevere in solving them.

Standard 2: Reason abstractly and quantitatively.

High School Numbers & Quantities: Reason quantitatively and use units to solve problems.

HSN-Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

HSN-Q.A.2: Define appropriate quantities for the purpose of descriptive modeling.

CLASSROOM TIME REQUIRED

One or more 90-minute block periods or two or more 45-minute class periods

TEACHER PREPARATION

- Try the paper airlines activity.
- Make sure your email address can handle all of the large files that the students are going to send you. Set up a free account with Gmail or Hotmail if you need it.
- Work through the problems so you understand the steps.

MATERIALS NEEDED

- 3-4 paperclips for each group
- Blank white paper
- Tape measure (optional)
- Weight and Balance 1 Worksheet
- Weight and Balance 2 Worksheet
- Cessna 152 and 172 information

TECHNOLOGY RESOURCES

- digital camera
- email address capable of receiving images by email
- calculators
- computer, projector and speakers for showing the digital video

ACTIVITIES

PART 1

1. Divide the class into student pairs and go outside or find a long hallway. The gym or cafeteria would be a good option for a rainy or cold day.
2. Give each group a blank piece of paper, paperclips (5 or 6), and a tape measure (optional).
3. Have them build their favorite type of airplane and launch it. Record their observations on the Paper Airplane Data Sheet.
4. Have them place first one paperclip, then multiples, in various locations on their airplane and relaunch the planes. Record their observations.
5. Challenge the students to find the optimal arrangement of 3 or 4 paperclips to allow the plane to fly the farthest.
6. Have the students take a picture of their plane with their cell phone or digital camera and email it to you.
7. (Optional) Offer a prize for the group whose plane goes the furthest or with the best design.

PART 2

Return to the classroom for a discussion based on the script below:

"What happened when you put all the paperclips on the front of your plane?"

"This is called being nose heavy. If an actual plane has all of its weight up front, it will crash nose-first."

"What happened when you put all the paperclips at the back of your plane?"

"This is called being tail heavy. If an actual plane has all of its weight at the back of the plane it will go into a stall and crash."

"Where was the best arrangement of paperclips?"

"Let's talk about real planes. When they load bags onto an airplane, do they just toss them in there or do they anchor them down?"

"Have you ever been on a mostly empty plane and a flight attendant asked you to move seats?"

"They do that so the weight of the plane will be properly balanced and won't crash."

"There are actual calculations that each pilot is supposed to do every time before they take off. They need to find the center of gravity of the loaded plane and make sure it falls into a specified range or the plane will not fly correctly. These calculations are called finding the weight and balance of a plane."

Have the students label their planes with the critical vocabulary terms. Keep the airplanes accessible during the rest of the lesson so students have a concrete example for reference.

PART 3

Lead the class through the first example of the Weight and Balance Worksheet and then let the students work through the rest of the problems in their groups.

PART 4

There is a National Geographic series called "Air Crash Investigations". One episode deals with a plane crash in Charlotte in 2003 where a pilot had incorrect information to calculate his CG envelope and consequently, the plane was not correctly balanced and crashed shortly after takeoff. The following links take you to the five parts of the episode.

Season 5 – Dead Weight Episode 5

http://www.youtube.com/watch?v=f5x5F94iiBo – part 1

http://www.youtube.com/watch?v=bHdXPoJfbZE&feature=related – part 2

http://www.youtube.com/watch?v=_kxekbpWgfU&feature=related – part 3

http://www.youtube.com/watch?v=K2zY7YDk8CA&feature=related – part 4

http://www.youtube.com/watch?v=5XsmEAvFIgU&feature=related – part 5

If you don't have enough time to watch the Air Crash Investigations episode, you could discuss the background information of the crash and then show the NTSB recreation of the flight.

http://www.youtube.com/watch?v=UllYdX5Nk1E – NTSB recreation, Charlotte USAir flight

GUIDED PRACTICE

Have students complete the Weight and Balance 2 worksheet on their own in class or for homework. Discuss the worksheet at the end of class or the next day to check for understanding.

ASSESSMENT

Administer the Unit 2 Quiz or have the class complete the Weight and Balance 2 worksheet instead.

CRITICAL VOCABULARY

Basic Empty Weight: the weight of the plane with all of its equipment but no fuel or payload.

Payload: passengers, crew, baggage, and cargo

Reference Datum: an imaginary vertical line in the plane that all calculations are based on.

Arm: the distance from the datum to a weight in the plane (forward of the datum is negative and aft of the datum is positive)

Moment: caused by a weight on the end of an arm. Calculated by multiplying the weight of an object times the length of the arm (units are pounds-inches)

CG arm: the length from the center of gravity to the datum. Calculated by dividing the sum of the weights by the sum of the moments.

WEBSITES AND RESOURCES

- Center of Gravity of an Airplane background information
  http://en.wikipedia.org/wiki/Center_of_gravity_of_an_aircraft
- Directions for building different types of paper airplanes
  http://www.1opaperairplanes.com/
- Convert videos into a file that can be downloaded and saved onto a computer
  http:/www.zamzar.com

COMMENTS

Make sure there is room to spread out for the paper airplane activity. Consider requiring the students (and teacher) to wear eye protection.

AUTHOR INFORMATION

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Audrey Floyd is the Department Chair of the Aviation Management / Career Pilot Technology Program at Guilford Technical Community College. She was an Air Force pilot with over 2600 hours of flight time. Audrey was also a high school physics teacher in Davidson County before she began at Guilford Tech.

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KENAN FELLOWS PROGRAM

SMT

North Carolina Science, Mathematics, and Technology Education Center

Paper Airplane Data Sheet

Sketch	Flight Length

Optimal Arrangement:

WEIGHT AND BALANCE OF AN AIRPLANE

Remember

- If the plane is overweight, it won't fly. Check the total weight before you do the rest of the calculations so you don't waste your time.
- Aviation gasoline weighs 6 lbs per gallon. Make sure you convert gallons to pounds before you plug it into your table.

Examples: (Refer to your info about the Cessna 152 for arms, maximum weight limits, CG moment envelope, etc)

1. Basic Empty Weight is 1194 lbs with a moment of 40,000 lb-in
   The pilot weighs 180 lbs
   The plane has 24.5 gal of fuel.
   Baggage area #1 has 40 lbs in it and baggage area #2 has 10 lbs in it.

Is the plane overweight? _____

CG arm= _____lb-in_ = in
lb

Is the CG arm within the CG limits? _____

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW			
Pilot			
Fuel			
BA #1			
BA #2			
Total		n/a	

2. Basic Empty Weight is 1194 lbs with a moment of 40,000 lb-in
   The pilot and passenger weigh 380 lbs
   The plane has 24.5 gal of fuel.
   Baggage area #1 has 40 lbs in it and baggage area #2 has 10 lbs in it.

Is the plane overweight? _____

CG arm= _____lb-in_ = in
lb

Is the CG arm within the CG limits? _____

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW			
Pilot			
Fuel			
BA #1			
BA #2			
Total		n/a	

3. Basic Empty Weight is 1194 lbs with a moment of 40,000 lb-in
The pilot weighs 180 lbs
The plane has 13 gal of fuel.
Baggage area #1 has 120 lbs in it and baggage area #2 has 40 lbs in it.

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW			
Pilot			
Fuel			
BA #1			
BA #2			
Total		n/a	

Is the plane overweight? _____

CG arm= _____lb-in_ = in
lb

Is the CG arm within the CG limits? _____

4. Basic Empty Weight is 1660 lbs with a moment of 66,000 lb-in
The pilot and front seat passenger weighs 360 lbs and are of average height
The rear passenger weighs 180 lbs and is also average height.
The plane has 31 gal of fuel.
Baggage area #1 has 70 lbs in it and baggage area #2 has 30 lbs in it.

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW			
Pilot & FP			
RP			
Fuel			
BA #1			
BA #2			
Total		n/a	

Is the plane overweight? _____

How much fuel can the plane carry? _____

Redo your calculations with the new fuel amount.

CG arm= _____lb-in_ = in
lb

Is the CG arm within the CG limits? _____

5. In the situation above, the pilot and front seat passenger are both very tall and have to slide their seats all the way back to sit comfortably. How does that affect the CG arm?

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW			
Pilot & FP			
RP			
Fuel			
BA #1			
BA #2			
Total		n/a	

CG arm= _____lb-in_ = in

lb

WEIGHT AND BALANCE OF AN AIRPLANE – ANSWER KEY

Remember:

- If the plane is overweight, it won't fly. Check the total weight before you do the rest of the calculations so you don't waste your time.
- Aviation gasoline weighs 6 lbs per gallon. Make sure you convert gallons to pounds before you plug it into your table.

Examples: (Refer to your info about the Cessna 152 for arms, maximum weight limits, CG moment envelope, etc)

1. Basic Empty Weight is 1194 lbs with a moment of 40,000 lb-in
The pilot weighs 180 lbs
The plane has 24.5 gal of fuel.
Baggage area #1 has 40 lbs in it and baggage area #2 has 10 lbs in it.

Is the plane overweight? __NO_____

CG arm= __56,620_lb-in_ = 36.02 in
1572 lb

Is the CG arm within the CG limits? _Yes_____

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW	1194		40,000
Pilot	180	39	7020
Fuel	147	42	6200
BA #1	40	64	2560
BA #2	10	84	840
Total	1572	n/a	56, 620

2. Basic Empty Weight is 1194 lbs with a moment of 40,000 lb-in
The pilot and passenger weigh 380 lbs
The plane has 24.5 gal of fuel.
Baggage area #1 has 40 lbs in it and baggage area #2 has 10 lbs in it.

Is the plane overweight? __YES_____

CG arm= _____lb-in_ = in

lb

Is the CG arm within the CG limits? _____

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW	1194		40,000
Pilot	380	39	14,820
Fuel	147	42	6200
BA #1	40	64	2560
BA #2	10	84	840
Total		n/a	

3. Basic Empty Weight is 1194 lbs with a moment of 40,000 lb-in
The pilot weighs 180 lbs
The plane has 13 gal of fuel.
Baggage area #1 has 120 lbs in it and baggage area #2 has 40 lbs in it.

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW	1194		40,000
Pilot	180	39	7,020
Fuel	78	42	3,276
BA #1	120	64	7,680
BA #2	40	84	3,360
Total	1612	n/a	61,336

Is the plane overweight? _NO_____

CG arm= ___61,336 lb-in_ = 38.0 in
1612 lb

Is the CG arm within the CG limits? _NO_____

4. Basic Empty Weight is 1660 lbs with a moment of 66,000 lb-in
The pilot and front seat passenger weighs 360 lbs and are of average height
The rear passenger weighs 180 lbs and is also average height.
The plane has 31 gal of fuel.
Baggage area #1 has 70 lbs in it and baggage area #2 has 30 lbs in it.

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW	1660		66,000
Pilot & FP	360	48	13,320
RP	180	73	13,140
Fuel	186 (150)	48	8928 (7,200)
BA #1	70	95	6,650
BA #2	30	115	3,450
Total	2486 (2450)	n/a	111,488 (109,760)

Is the plane overweight? __YES_____
How much fuel can the plane carry? __25 gal____
Redo your calculations with the new fuel amount. (in parenthesis)

CG arm= _109760 lb-in_ = 44.8 in
2450 lb

Is the CG arm within the CG limits? ___YES_____

5. In the situation above, the pilot and front seat passenger are both very tall and have to slide their seats all the way back to sit comfortably. How does that affect the CG arm?

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW	1660		66,0000
Pilot & FP	360	46	16560
RP	180	73	13,140
Fuel	150	48	7,200
BA #1	70	95	6,650
BA #2	30	115	3,450
Total	2450	n/a	113,000

CG arm= __113,000 lb-in_ = 46.1 in
2450 lb

WEIGHT AND BALANCE 2

Use the Cessna 172 data for these situations.
The following two situations have the same total weight, yet their CG arms are almost 3 inches different.

Situation #1

The Basic Empty Weight is 1660 lbs with a moment of 66,000 lb-in.
Pilot and front passenger together weigh 360 lbs and are short so their seats are in the front position.
The plane has a full load of fuel, 31 gallons.
Baggage area #1 has 140 lbs of cargo and baggage area #2 has 100lbs.

CG arm= _____ $\frac{\text{lb-in}}{\text{lb}}$ = in

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW			
Pilot & FP			
RP			
Fuel			
BA #1			
BA #2			
Total		n/a	

Situation #2

The Basic Empty Weight is 1660 lbs with a moment of 66,000 lb-in.
Pilot and front passenger together weigh 360 lbs and are short so their seats are in the front position.
The plane has a full load of fuel, 31 gallons.
The rear passenger weighs 240 lbs and there is no cargo.

CG arm= _____ $\frac{\text{lb-in}}{\text{lb}}$ = in

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW			
Pilot & FP			
RP			
Fuel			
BA #1			
BA #2			
Total		n/a	

Why do these situations have the same weight but different CG arms?

Is it simply enough to know whether your plane is under the maximum weight or does where those weights are located make a difference?

WEIGHT AND BALANCE 2 – ANSWER KEY

Use the Cessna 172 data for these situations.
The following two situations have the same total weight, yet their CG arms are almost 3 inches different.

Situation #1

The Basic Empty Weight is 1660 lbs with a moment of 66,000 lb-in.
Pilot and front passenger together weigh 360 lbs and are short so their seats are in the front position.
The plane has a full load of fuel, 31 gallons.
Baggage area #1 has 140 lbs of cargo and baggage area #2 has 100lbs.

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW	1660		66,000
Pilot & FP	360	34	12,240
RP	0		0
Fuel	186	48	8,920
BA #1	140	95	13,300
BA #2	100	115	11,500
Total	2446	n/a	111,968

CG arm= $\frac{111,968 \text{ lb-in}}{2446 \text{ lb}}$ = 45.78 in

Situation #2

The Basic Empty Weight is 1660 lbs with a moment of 66,000 lb-in.
Pilot and front passenger together weigh 360 lbs and are short so their seats are in the front position.
The plane has a full load of fuel, 31 gallons.

The rear passenger weighs 240 lbs and there is no cargo.

	Weight (lbs)	Arm (in)	Moment (lb-in)
BEW	1660		66,000
Pilot & FP	360	34	12,240
RP	240	73	17,520
Fuel	186	48	8,920
BA #1	0		0
BA #2	0		0
Total	2446	n/a	104,688

CG arm= $\frac{104,688 \text{ lb-in}}{2446 \text{ lb}}$ = 42.80 in

Why do these situations have the same weight but different CG arms?
The weight is distributed differently in the two situations.

Is it simply enough to know whether your plane is under the maximum weight or does where those weights are located make a difference?

Where the weights are located makes a huge different and can determine whether or not the plane is safe to fly.