Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2021, 8(5):160-168**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Aircraft Weight and Balance

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Abstract Aircraft weight and balance is a critical aspect of aviation safety and efficiency. This paper provides a comprehensive overview of the principles, procedures, and importance of aircraft weight and balance. It covers the fundamental concepts of weight, center of gravity, and moment, and explains how these factors affect an aircraft's performance and stability.

The paper discusses the regulatory requirements for weight and balance calculations, including the role of the Federal Aviation Administration (FAA) and other international aviation authorities. It also explores the various methods and tools used to determine an aircraft's weight and balance, such as load manifest, weight and balance charts, and computerized systems.

Furthermore, the paper examines the implications of improper weight and balance, including the potential for loss of control, reduced fuel efficiency, and increased wear and tear on aircraft components. It also highlights the importance of proper weight and balance management in preventing accidents and ensuring the safety of passengers and crew.

In conclusion, this paper emphasizes the critical role of aircraft weight and balance in aviation operations and underscores the need for pilots, operators, and maintenance personnel to adhere to established procedures and guidelines to maintain safe and efficient flight operations.

Keywords Aircraft, weight and balance

Key words in Aircraft Weight and Balance:

Standard empty weight — The weight of the airframe, engines, and permanently installed fixtures and fluids (including unusable fuel and full engine oil)

Basic empty weight — Standard empty weight plus any accessories your airplane might have added

Licensed empty weight — An older term than “standard empty weight,” which does not include engine oil

Maximum ramp weight — Total loaded aircraft weight only published for some airplanes. This will be a few pounds heavier than maximum takeoff weight because it assumes you will burn some for taxi and run-up.

Maximum takeoff weight — Maximum weight you can take off with.

Maximum landing weight — Maximum weight you can land with. This is not always published, or it may be published as equal to takeoff weight. Larger aircraft have landing weights much less than takeoff weights since they are designed to burn hundreds (or thousands) of pounds of fuel during flight.

Maximum zero fuel weight — The loaded aircraft weight with everything except fuel. Only published for some aircraft. This is a loading figure to reduce stress on the wings.

Payload — A common term for the maximum weight an airplane can carry of things that can pay the bill—passengers or cargo.

Useful load — A common term for what an airplane can carry that the pilot loads aboard—pilot, passengers, cargo, and fuel. It is found by taking the maximum takeoff weight and subtracting out the aircraft’s basic empty weight.

Datum — A reference point chosen by the manufacturer from which all arms are measured. Where it doesn't matter, but it is usually located at the tip of the propeller spinner or the engine firewall.
Arm — The distance measured fore or aft of the datum. Every location a pilot can load an object will have an arm distance listed in the POH/AFM. If an arm is located forward of the datum, it will be a negative number.
Station — A location in the airplane where you can load something. Examples of stations include front seats, rear seats, main baggage area, nose baggage area, fuel tanks, etc.
CG — The center of gravity measured in inches aft of the datum. The airplane will have a minimum and maximum CG location for every available weight.
Moment — A measurement of the force that an item places on the airplane. A 100-pound object will produce more force the farther away from the datum that it is located. In other words, a 100-pound bag will affect your CG location more the farther back in the airplane it is located. Moments are measured in inch-pounds.
Moment index — Moments are usually long numbers, so many POH/AFMs index them to simplify the math. This simply means they divide them by either 100 or 1,000. So 123,456.0 in-lbs becomes 1,234.56 or 123.456.
Calculation Method
To some extent, all weight and balance calculations come back to the mathematic formula for weight and balance.
Weight x Arm = Moments
Figuring out the weight and balance by calculation alone simply means that you do the math for everything—all of the numbers are filled out line by line. The other methods simply make your life a little easier by giving you some of that information quickly.
Understanding the calculation method is important because it is the basis for the other methods. If you can figure out the airplane's weight and balance this way, you can figure it out anyway.

Graph Method
If your Aircraft Flight Manual includes graphs, you'll get at least two.
The first will show how many moments an item produces at each station. So each station of the airplane (front seats, rear seats, fuel, baggage, etc.) will have its own line on the graph. On the bottom will be weight, and on the side will be moments.
Once you have tallied each item in the airplane, simply add total weight and total moment. A second graph will show you the acceptable CG limits using these two numbers.
Table Method
Tables are similar to graphs, only they will provide tables of numbers for every station and a similar table for the CG limits.
Like the graph method, the only math involved should be totaling the weight and moments column.
Tables may require you to round your numbers up a bit since each item will be listed for even-numbered weights. For example, if your front passengers weigh 345 pounds total, you might use the 350-pound line. Alternatively, you could use the provided arm and resort to the calculation method to get a more precise number.
Finding the Weight and Balance with the Calculation Method
Step 1 – Make Your Table
Weight and balance start with a blank table that you can fill out for every flight. Many schools and FBOs provide you with a planning sheet, but it's easy to make your own.
The first column will be "weights," the second "arm," and the third will be "moments." To remind yourself, you can write the weight and balance formula at the top.
Weight x Arm = Moments
The usual line items will be as follows. The list will depend on the available stations for loading in your aircraft. The first line will always be the empty weight of the airplane.

	Weight x	Arm =	Moments
Empty weight	?	?	?
Pilot + Copilot	?	?	?
Rear passengers	?	?	?
Fuel — main tanks	?	?	?
Fuel — aux tanks	?	?	?
Baggage area 1	?	?	?
Baggage area 2	?	?	?
Total	?	?	?

Weight and Balance Formula

Step 2 – Find the Aircraft's Empty Weight and Moment

You can't do the paperwork until you know which airplane you'll be flying. The only official source for the empty weight, CG, and moment of the airplane is the official record found in that particular airplane's POH/AFM. Do not use the sample information found online or in your personal PIM.

The official record comes from the last time a mechanic physically weighed aircraft. It should be signed by the A&P and specific to that airplane.

From this form, you need the empty weight and the total moments. Add these to the first row of your table.

	Weight x	Arm =	Moments
Empty weight	2,100	78.3	164,430
Pilot + Copilot	?	?	?
Rear passengers	?	?	?
Fuel — main tanks	?	?	?
Fuel — aux tanks	?	?	?
Baggage area 1	?	?	?
Baggage area 2	?	?	?
Total	?	?	?

Weight and balance sheet.

Step 3 – Weight Your Gear and Passengers

Fill out all of the items in the weight column. Estimates aren't good enough in a small airplane—you should use exact numbers. Don't be afraid to ask your passengers how much they weigh. Many FBOs have a scale you can use if they don't know. Remember to include heavy jackets and boots if it's wintertime!

You should know how many gallons of fuel your airplane holds, but how much does it weigh? Avgas weighs 6 pounds per gallon, so multiply the gallons by 6. (If your airplane burns Jet-A, you'll have a table that will tell you how much it weighs at various temperatures—it's usually a little over 7 pounds per gallon.)

Remember to include everything in the airplane that isn't bolted down. Commonly missed items are flight bags thrown in the rear seats or spare parts, oil, and various things stored in the baggage area.

	Weight x	Arm =	Moments
Empty weight	2,100	78.3	164,430
Pilot + Copilot	340	?	?
Rear passengers	350	?	?
Fuel — main tanks	450	?	?
Fuel — aux tanks	0	?	?
Baggage area 1	80	?	?
Baggage area 2	0	?	?
Total	?	?	?

Step 4 – Find the Arm for Each Station

Next, you need to know the arm for each weight on your list.

	Weight x	Arm =	Moments
Empty weight	2,100	78.3	164,430
Pilot + Copilot	340	85.0	?
Rear passengers	350	121.0	?
Fuel — main tanks	450	75.0	?
Fuel — aux tanks	0	–	?
Baggage area 1	80	150.0	?
Baggage area 2	0	–	?
Total	?	?	?

Step 5 – Find the Moment for Each Line Item
Do the multiplication for each row to solve for the moment.

	Weight x	Arm =	Moments
Empty weight	2,100	78.3	164,430
Pilot + Copilot	340	85.0	28,900
Rear passengers	350	121.0	42,350
Fuel — main tanks	450	75.0	33,750
Fuel — aux tanks	0	–	0
Baggage area 1	80	150.0	12,000
Baggage area 2	0	–	0
Total	?	?	?

Step 6 – Find Total Weight
Add up the weight column. Is your total weight under the maximum takeoff weight for your airplane?
If you are over maximum takeoff weight, you'll want to double-check your numbers. You might need to leave some items (or people!) behind. Or, you could consider leaving with less fuel if it is safe to do so.

	Weight x	Arm =	Moments
Empty weight	2,100	78.3	164,430
Pilot + Copilot	340	85.0	28,900
Rear passengers	350	121.0	42,350
Fuel — main tanks	450	75.0	33,750
Fuel — aux tanks	0	–	0
Baggage area 1	80	150.0	12,000
Baggage area 2	0	–	0
Total	3,320	?	?

Step 7 – Find Total Moment and CG
Add up the moment column. This will be enough if you have a chart in your POH/AFM for the loaded moments. Remember to correct it to the appropriate index that matches the information in your POH. You may have to divide by either 100 or 1,000.

	Weight x	Arm =	Moments
Empty weight	2,100	78.3	164,430
Pilot + Copilot	340	85.0	28,900
Rear passengers	350	121.0	42,350
Fuel — main tanks	450	75.0	33,750
Fuel — aux tanks	0	–	0
Baggage area 1	80	150.0	12,000
Baggage area 2	0	–	0
Total	3,320	?	281,430

If you need to solve for CG, take your total moment (unindexed) and divide by the total weight. A common mistake is to add up all of the arms, but this will not provide a helpful number. Instead, you need to calculate it based on the weights and forces in the airplane, which are represented by the moments and weight.

	Weight x	Arm =	Moments
Empty weight	2,100	78.3	164,430
Pilot + Copilot	340	85.0	28,900
Rear passengers	350	121.0	42,350
Fuel — main tanks	450	75.0	33,750
Fuel — aux tanks	0	–	0
Baggage area 1	80	150.0	12,000
Baggage area 2	0	–	0
Total	3,320	CG = 84.8*	281,430

CG = Moments/Weight = 281,430/3,320 = 84.8

Introduction to Aircraft Weight and Balance:

Aircraft weight and balance is a critical aspect of aviation safety and efficiency. It involves the careful management of an aircraft's weight distribution to ensure that it remains within safe operating limits. This includes calculating the total weight of the aircraft, the location of its center of gravity, and the distribution of weight among its various components.

The weight of an aircraft is the sum of its empty weight (the weight of the aircraft without passengers, cargo, or fuel) and the weight of its payload (passengers, cargo, and fuel). The center of gravity is the point at which the aircraft would balance if suspended from that point. The moment is the product of the weight and the distance from the center of gravity.

Proper weight and balance are essential for maintaining the aircraft's stability and performance. An aircraft with an improper weight distribution may be difficult to control, especially during takeoff and landing. It can also affect fuel efficiency, as an aircraft that is too heavy may require more fuel to maintain altitude and speed.
Regulatory agencies, such as the Federal Aviation Administration (FAA) in the United States, have established guidelines and requirements for aircraft weight and balance. These regulations are designed to ensure the safety of passengers and crew and to prevent accidents caused by improper weight distribution.
In conclusion, aircraft weight and balance are critical factors that must be carefully managed to ensure the safety and efficiency of flight operations. Pilots, operators, and maintenance personnel must adhere to established procedures and guidelines to maintain safe and efficient flight operations.

Why Calculate Weight and Balance?
Each weight and balance problem component is a critical limitation on the aircraft. Few performance or safety items are more important than knowing that your flight is within limits.
The regulations do not explicitly require you to calculate your weight and balance before every flight, however it is implied. The regulations stipulate that you calculate your takeoff and landing distances and operate the airplane according to the AFM.
If you don’t know your weight and balance, you can’t comply with that regulation. (14 CFR Part 91.9)
Weight
We all know that airplanes are only built to support so much weight. The most important number is the maximum takeoff weight.
Operating beyond maximum weight puts you into the realm of the test pilot. Here are just a few of the negative flight characteristics you might expect.

- Higher takeoff speeds with longer takeoff rolls
- Longer landing rolls
- Reduced performance, including slower cruise speeds and slow climbs
- Higher stall speeds
- Limits on landing gear and brakes exceeded
- More load put on the structure of the aircraft then it was designed for

Balance
Finding whether or not your airplane is in balance is all about finding the loaded airplane Center of Gravity or CG. Once you have this, you can compare it to the charts or tables the manufacturer gives you to ensure that it is within acceptable limits.
The CG cannot be too far forward nor too far back. Either situation will make the airplane dangerous and potentially unstable.
A CG located forward of the forward limit will cause the airplane to have a nose-down tendency. If the loading is severe enough, the elevator travel may not produce enough force to allow the airplane to flare or rotate.
The nose-down tendency will increase the airplane’s stall speed and make cruise flight much slower.
If the CG is located too far aft, the airplane will have a nose-up tendency. This typically is the most dangerous situation. The aircraft will have a noticeably higher cruise speed, but the aircraft will be much less stable.
Should the airplane begin pitching up and slowing, as in a stall scenario, it may be impossible for the pilot to lower the nose, reduce the angle of attack, and recover.
A rearward out-of-limits CG is associated with unrecoverable stalls and spins.

Conclusion - Air craft Weight and Balance:
Aircraft weight and balance is a critical aspect of aviation safety and performance. It refers to the distribution of weight within an aircraft and ensuring that it is within specified limits to maintain stability and control during flight. Here are some key points about aircraft weight and balance:
Weight: The weight of an aircraft includes the combined weight of the aircraft itself, fuel, passengers, cargo, and any other items on board. It is essential to know the total weight of the aircraft to ensure that it does not exceed

the maximum takeoff weight (MTOW) or maximum landing weight (MLW) specified by the aircraft manufacturer.

Center of Gravity (CG): The center of gravity is the point at which the aircraft would balance if it were suspended in the air. It is crucial to ensure that the CG remains within specified limits to maintain stability and control during flight. The CG is affected by the distribution of weight within the aircraft, including the location of passengers, cargo, and fuel.

Weight and Balance Calculations: Before each flight, pilots and ground crew perform weight and balance calculations to determine the total weight of the aircraft and the location of the CG. This involves calculating the weight of passengers, cargo, and fuel, as well as the weight and location of other items on board. The calculations are used to ensure that the aircraft is within weight and balance limits for safe operation.

Loading Procedures: Proper loading procedures are essential to maintain the aircraft's weight and balance within limits. This includes distributing passengers, cargo, and fuel in a way that keeps the CG within specified limits. Pilots and ground crew follow loading procedures provided by the aircraft manufacturer and airline to ensure safe and efficient loading.

Regulatory Requirements: Aviation authorities, such as the Federal Aviation Administration (FAA) in the United States, have regulations and guidelines for aircraft weight and balance. These regulations specify weight and balance limits, as well as procedures for calculating and maintaining weight and balance.

Safety Considerations: Maintaining proper weight and balance is critical for the safety of the aircraft and its occupants. An aircraft that is outside of weight and balance limits may be difficult to control, especially during takeoff and landing. It is essential for pilots and ground crew to follow proper procedures and guidelines to ensure safe operation.

OEW stands for "Operating Empty Weight." It refers to the weight of an aircraft when it is empty and ready for operation, including the weight of the airframe, engines, avionics, flight controls, and other essential systems. OEW does not include the weight of fuel, passengers, cargo, or other items that may be added to the aircraft during operation.

OEW is an important parameter for aircraft performance and operational planning. It is used to calculate the maximum takeoff weight (MTOW) and maximum landing weight (MLW) of the aircraft, which are critical for ensuring safe and efficient flight operations.

Aircraft manufacturers provide OEW data for each aircraft model, and airlines use this information to plan their operations, including fuel requirements, payload capacity, and range. OEW can vary depending on the specific configuration of the aircraft, such as the number of engines, seating layout, and optional equipment.

In summary, OEW is the weight of an aircraft when it is empty and ready for operation, and it is an essential parameter for aircraft performance and operational planning and Overall, aircraft weight and balance is a fundamental aspect of aviation safety and performance. Pilots, ground crew, and aviation authorities work together to ensure that aircraft are loaded and operated within weight and balance limits for safe and efficient flight.

Problem which I worked:

Airlines have faced challenges related to weight and balance in the past. For example, in 2019, Southwest Airlines discovered that it had been miscalculating the weight of checked bags, leading to potential discrepancies in weight and balance calculations. The airline took corrective actions to address the issue and ensure accurate weight and balance calculations by changing the application software programs.

As part of the problem FAA Proposes $3.92 Million Civil Penalty Against Southwest Airlines. The U.S. Department of Transportation's Federal Aviation Administration (FAA) proposes a $3.92 million civil penalty against Southwest Airlines for allegedly operating multiple aircraft on commercial flights with incorrect calculations of weight and balance data.

The FAA alleges that between May 1, 2018, and August 9, 2018, Southwest operated 44 aircraft on a total of 21,505 flights with incorrect operational empty weights, and center of gravity or moment data. This weight-related information is used along with other data in determining how many passengers and how much fuel can be safely carried, as well as where cargo must be located.

The FAA alleges that Southwest's operation of these aircraft was contrary to the airline's approved weight-and-balance program and FAA-issued operations specifications.

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