Mass and Balance

Mass definitions

- **Basic empty mass (BEM)**: aircraft mass + standard fix equipment + unusable fuel + full oil + other elements used for every flight of that particular aircraft (ex. Fixed ballast)

- **Empty mass**: BEM with only unusable oil (not full oil)

- **Dry operating mass (DOM)**: ZFM – Traffic load | BEM + VL
Total mass of the aircraft ready for a specific type of operation (includes special operational equipment), excluding usable fuel and traffic load. The Operator establishes the items to include in the DOM

- **Gross mass (All-up mass)**: Total mass of the aircraft and all its content at any given time.
It must never exceed MTOM or MLM. Its increase will cause stall speed and longer takeoff and landing run

- **Zero fuel mass (ZFM)**: Gross mass – usable fuel | It doesn't influence the total amount of fuel we can load

- **Maximum zero fuel mass (MZFM)**: It is a regulatory limitation. It ensures the value of max bending of the wing at the wing root is not exceeded at the max load factor of 2.25 G under the assumption that fuel is firstly consumed from the center wing tank.

- **MTOM**: Maximum mass at the start of the takeoff run

- **MLM:** Maximum mass upon landing. For light aircraft MTOM ≈ MLM

- **Maximum ramp mass**: quantity of fuel that may exceed MTOM to take into account the fuel used during the taxi phase. It is a fixed value in the Flight manual

- **RTOM**: Regulated takeoff mass | Minimum between PLTOM and MSTOM

- **RLM**: Regulated landing mass: minimum between PLLM and Structural limited landing mass

- **Maximum structural takeoff mass (MSTOM)**: maximum permissible total airplane mass on takeoff in normal circumstances

- **Maximum structural landing mass (MSLM)**: maximum permissible total airplane mass on landing in normal circumstances

- **Performance limited takeoff mass (PLTOM)**: takeoff mass subject to departure aerodrome limitation

- **Performance limited landing mass (PLLM)**: landing mass subject to arrival aerodrome limitation

- **Variable load (VL)**: crew, their baggage and any removable equipment that is required for that flight (catering, pax service equipment, food and beverages, potable water and lavatory chemicals).

- **Passenger mass** includes hand baggage mass. If it is evident the standard mass is too low, each pax have to be weighed. Pax have to be weighed if number of seats < 10.
If passenger seats < 10, mass of individual passenger can be obtained by verbal statement.

Fuel definitions

- **Start and taxi fuel**: Used in starting and operating the APU and the main engines and taxiing to the runway threshold for takeoff

- **Trip fuel**: Required to complete takeoff run + climb + cruise + descent + arrival + approach + landing at the designated airport

- **Contingency fuel**: To account for unforeseen circumstances (bad weather, extended hold,…) and is given as a 5% of the trip fuel (or 3% if ERA is available) or 5 min hold speed flow

- **Alternate fuel**: required to carry out a missed approach at the destination airfield up to the landing at the alternate

- **Final reserve fuel**: minimum fuel in the tanks on landing [45 min piston | 30 min jet]

- **Additional fuel**: fuel as required by the crew for any reason

- **Block fuel:** fuel before engine start

Other definitions

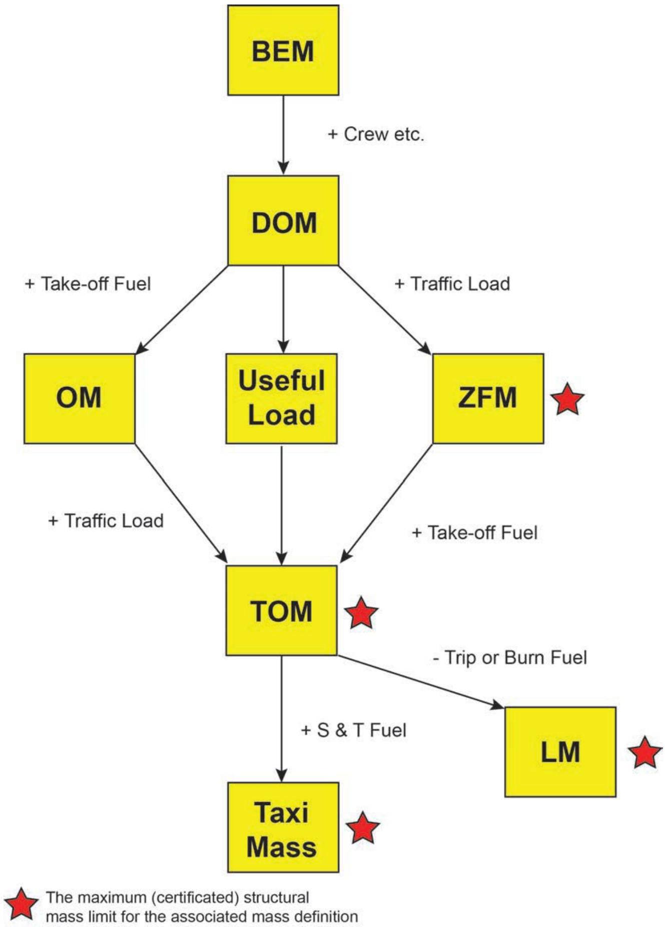
- **Traffic load (TL)**: TOM – DOM. Passengers + baggage + cargo, including any non revenue load | it is limited on short flights by MZFM and on long flights by MTOM

- **Usable fuel (UF)**: total mass of the fuel on board (like block fuel)

- **Useful load**: Traffic load + Useful fuel | Traffic load + Takeoff fuel

- **Loading index**: A moment divided by a constant to reduce the magnitude for a more practical use

- **New weight calculation**:
  - Upon initial entry to fleet
  - if the CG position deviates +/- 0.5% of the MAC
  - Whenever the <u>cumulative</u> changes to the DOM > ± 0.5% of the MLM. It should be done in an enclosed building
  - Every 4 years (48 months) for individual aircraft mass | every 9 years if fleet masses are used
  - If there were modifications done to the aircraft and the M&B calculations have not been done



Effects of overloading

Fatigue is a permanent loss of the physical properties of the materials comprising the structure. It is cumulative and non-reversible and the higher the fatigue level the greater the risk of premature structural failure.

The **Design ultimate load** (DUL) is the minimum load the structure must be able to absorb in an emergency without collapsing. Loads in excess of DUL is likely to result in permanent damage or collapse.

Some limits are never to be exceeded during normal operations and are determined by the manufacturer:

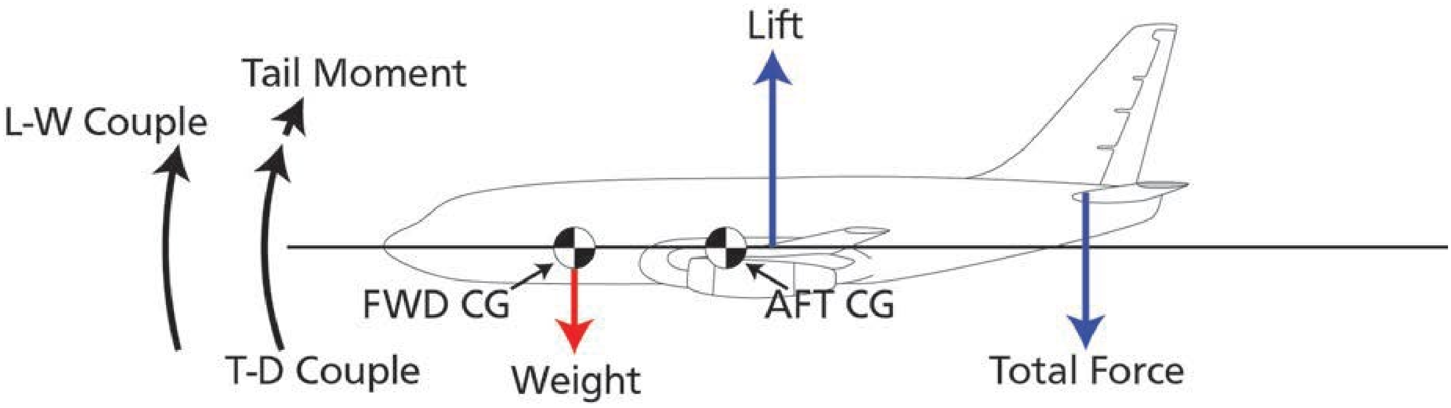
- maximum taxi mass (MTM)
- maximum structural takeoff mass (MSTOM)
- maximum zero fuel mass (MZFM)
- maximum structural landing mass (MSLM)

Effect of CG position

The location of the CG with respect to the neutral point determines the longitudinal stability of the airplane.

The center of pressure is the point of application of the forces and when CP ≠ CG a moment is generated.
The CP moves towards the leading edge when the AOA increases.

- FWD CG determines stall speeds
- AFT CG determines minimum control speeds



CG ON FWD LIMIT		CG ON AFT LIMIT	
STABILITY	↑	STABILITY	↓
STICK FORCES	↑	STICK FORCES	↓
MANOEUVRABILITY	↓	MANOEUVRABILITY	↑
DRAG	↑	DRAG	↓
V_S (STALLING SPEED)	↑	V_S	↓
V_R (ROTATION SPEED)	↑	V_R	↓
RANGE	↓	RANGE	↑
FUEL CONSUMPTION	↑	FUEL CONSUMPTION	↓
ABILITY TO ACHIEVE		**ABILITY TO ACHIEVE**	
1. CLIMB GRADIENT	↓	CLIMB GRADIENT	↑
2. GLIDE SLOPE	↓	GLIDE SLOPE	↑

- **CG outside of the FWD limit**: [equivalent to having a heavier aircraft]

- Longitudinal stability increased: higher stick force to be applied by the pilot
- Maneuverability reduced
- Drag increased
- Tail down force increased is equivalent to an increase of weight, so stall speed will increase
- Takeoff speeds will increase [$V_1 - V_R - V_{MU}$]

- **CG outside of the AFT limit**:

- Longitudinal stability reduced: if too far AFT, the aircraft will became very unstable
- Maneuverability increased
- Range and endurance increased
- Glide angle difficult to sustain due to pitch up tendency

Static margin is the distance between the CG and the neutral point (NP, where the aircraft is neutrally stable) and is a direct measure of the longitudinal (static) stability.
A small static margin gives reduced pitch stability and vice-versa.

$$staticmargin(\%) = \frac{CG - NP}{MAC} * 100$$

CG position as % MAC

It is common practice to use this method for swept wings. The length of the MAC is constant and it is at a fixed distance from the datum. The CG is located at some point along the MAC.
It is calculated as the difference in distance between (datum – CG) and the (datum – leading edge), divided by the MAC.

$$MAC(\%) = \frac{CG - Leadingedge}{MAC} * 100$$

Repositioning of the CG

It may be achieved in 2 ways:

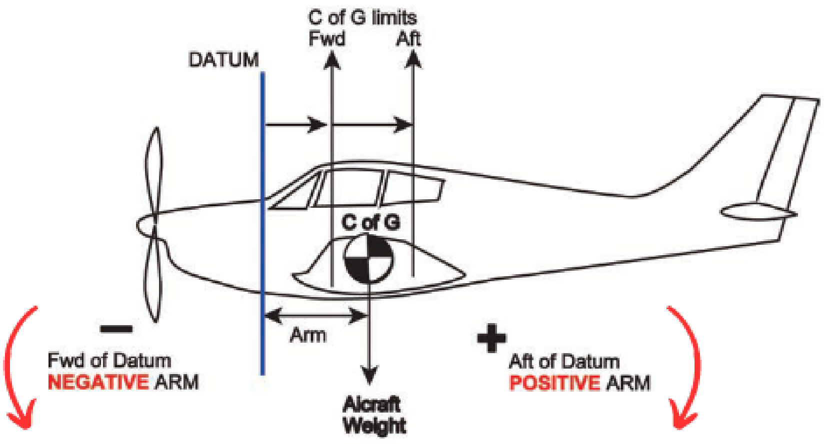
- by repositioning a mass which is already on board the aircraft
- by adding or removing mass (ballast)

When he amount o mass adjustment has been calculated, it must be ascertained that this makes the aircraft safe for both takeoff and landing.

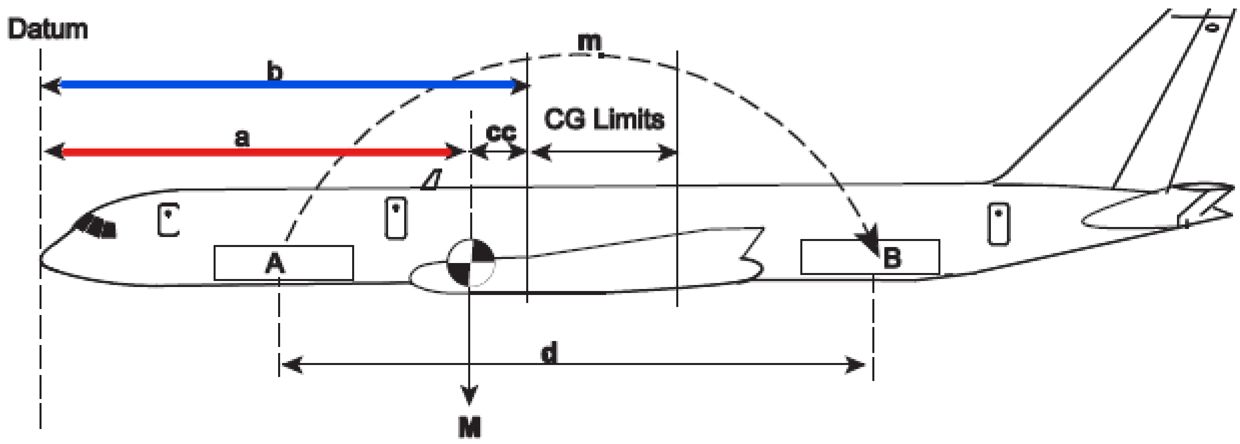
When taking in consideration the moment of the aircraft given by each mass, this is the convention used:

- Each mass FWD of datum generates a negative moment (pitch down)

- Each mass AFT of datum generates a positive moment (pitch up)



Repositioning of the CG by repositioning mass



$$m * d = M * cc$$

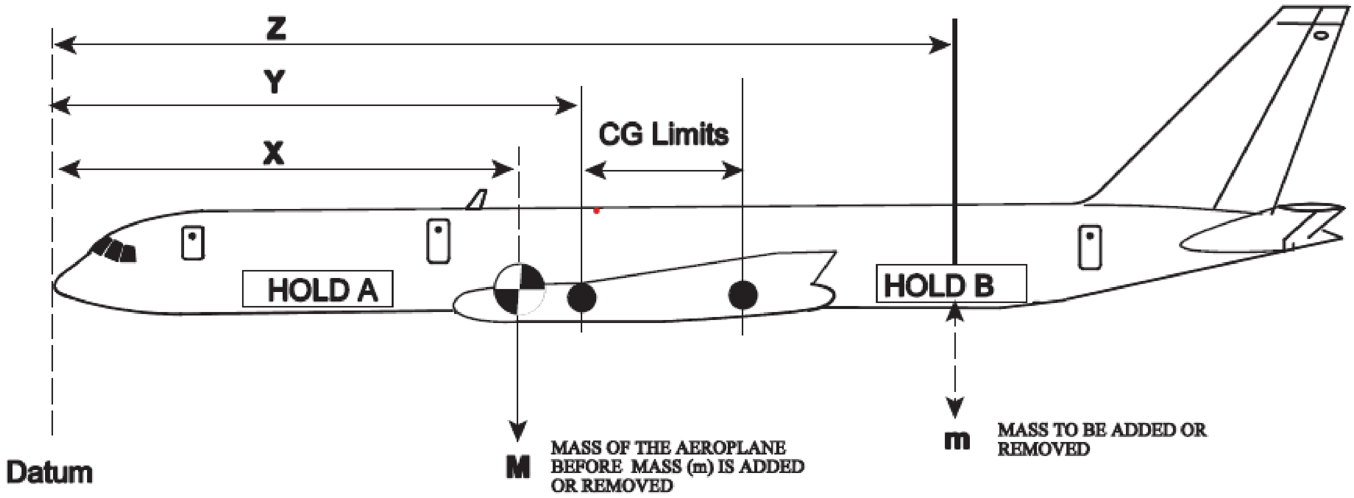
- m: mass to be repositioned

- M: total mass of the aircraft

- d = B-A: displacement (distance through which “m” moves)

- cc = b-a = ΔCG: distance the CG moves through (actual – desired position)

Repositioning of the CG by adding or subtracting mass (ballast)



$$\underbrace{(M+m)*Y}_{\text{NEW MOMENT}}=\underbrace{(M*X)}_{\text{OLD MOMENT}}\pm\underbrace{(m*Z)}_{\text{CARGO MOMENT}}$$

$$\frac{Masschange}{Oldmass}=\frac{\Delta CG}{Distance(Mass-NewCG)}$$

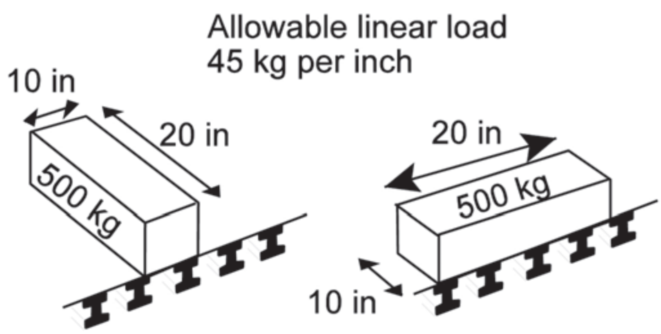
- M: total mass of the aircraft
- m: ballast mass

-X: actual CG position from datum
-Y: desired CG position from datum
- Z: ballast arm from datum

Cargo Handling

Linear/running load (underfloor protection)

The linear (or running) loading limitation (lb per linear foot or kg per linear inch) protects the aircraft underfloor frames from excessive loads.
The least linear loading occurs when the longest lengths is placed at 90° to the floor beams.



(a) 50 kg/in (b) 25 kg/in

- Maximum running load = Load / shortest length
- Mid running load = Load / mid length
- Minimum running load = Load / longest length

Area Load Limitation (floor protection)

The area load limitation (kg/m^2 or lb/ft^2) protect the aircraft floor panels.
The 2 permissible intensities of pressure are "Uniformly Distributed" (UD) and "Concentrated" loads.
UD is the general floor loading limitation for cargo (distribution load intensity).

- Maximum distribution load on the floor = Load / smallest area
- Mid distribution load on the floor = Load / medium area
- Minimum distribution load on the floor = Load / largest area

Maximum Floor Load: Load per unit area, meaning that each m^2 has a limit of weight or load.

Bulk Cargo is used to carry late arrival bags, pilots or cabin crew baggage, live animals, freight, mail or items with uneven and individual shape.

Conversion factors

Volume: Gal (US) – Gal (Imp) – Liter

1 Gal (US) = 3.785 L 1 Gal (Imp) = 4.546 L 1 Gal (Imp) = 1.2 Gal (US)

Mass: kg – lbs

1 kg = 2.205 lbs 1 Gal (US) = 6,67674 lbs

Fuel density (specific gravity – SG)

SG = kg / L SG = lbs / 10*Gal (Imp) Avgas SG: 0.73

Mass of fuel = Volume * SG

Area:

1 lb/ft^2 = 4.88 kg/m^2

Load / Trim sheet

Underload = Maximum Traffic load – Actual Traffic load = Actual TOM – OM – Actual Traffic load

The Allowed Traffic load is the lowest of the following:

• Structural Limited Traffic Load = MZFM – DOM

• Take-off Limited Traffic Load = RTOM – DOM – Take-off fuel

• Landing Limited Traffic Load = RLM – DOM – Fuel remaining

The Allowable Take-off Mass is the lowest of:

• MZFM + Take-off Fuel

• MTOM | Regulated Take-off Mass

• MLM + Trip Fuel | Regulated Landing Mass + Trip Fuel