Mass and Balance

Edition 1.1

1/2/3 Aerodynamic Principles, Basic Empty Mass & Centre of Gravity

AERODYNAMIC PRINCIPLES

LIFT FORMULA

- $L = \frac{1}{2} \rho TAS^2 S C_L$
- When **mass** is **increased**, **lift** must also be

MASS LIMITATIONS

- Found in the **Aircraft Flight Manual** **(AFM)**
- Drawn up by the **designer**
- Approved by the **state**
- **Must not** be **exceeded**

EFFECTS OF INCREASED MASS

- **Reduced** **Manoeuvrability** (V_{MC} ↑)
- **Longer** **Take Off Run**
- **Lower** **Angle of Climb**
- **Reduced** **Rate of Climb**
- **Increased** **Fuel Consumption**
- **Increased** **Tyre Wear**
- **Increased** **Landing Speed**
- **Increased** **Angle of Glide**
- **Increased** V_{MU} (Minimum Unstick Speed)
- **No effect** on **Glide Range**

STALL SPEED AND MASS

- $V_{S1} = V_{S0} \times \sqrt{W_1/W_0}$
- i.e an **increase** in **weight** will **increase** **stall speed**

BASIC EMPTY MASS (BEM)

METHOD

- Weighed on a **minimum** of **3 points**
- Small aircraft use **scales**
- Large aircraft use **electronic pressure pads**
- In an **enclosed building** with **no A/C**

RESPONSIBILITY

- The **Operator** must establish the BEM from the **manufacturer** or an **AMO**
- Recorded in the **Weighing Schedule**
- Weighed every **4 years** (**9 years** if using **fleet masses**)
- **Modifications** may be recorded rather than re-weighing the aircraft
- Aircraft are weighed **fully equipped** (standard role)

FULLY EQUIPPED (STANDARD ROLE)

- A **fully equipped** aircraft includes:
  - Declared quantities of unusable fuel/oil
  - Other operating fluids
  - Fire extinguishers
  - Pyrotechnics
  - Emergency oxygen
  - Supplementary electronics
- Also referred to as the **BEM**
- *If MTOM <5700kg* ***all oil*** *can be included*

CENTRE OF GRAVITY (COG)

BASICS

- **Centre of Gravity –** The point through which gravity will act on a body
- **Moment = Mass x Arm**
- This can be used to determine if a body is in **equilibrium**
- Gear deployment **will** move the COG
- Tailwheel aircraft must be measured in the **flight position**

CALCULATING COG POSITION

- **COG (arm)= Total Moment/Total Mass**
- **Clockwise** Moment = **Positive** = **Aft** (*Right* as Drawn)
- **Anticlockwise** Moment = **Negative** = **Forward** (*Left* as Drawn)
- This will give the distance from the selected datum to the actual COG
- If no datum is given, pick one
- Actual datum position and limits are found in the **AFM**

4/7/6/8 CG on Stability, Load Definitions, Structural Limits & MAC

POSITION OF CG ON STABILITY

MOVING CG FORWARD (-)

- Increased **Fuel Consumption**
- Decreased **Range** and **Endurance**
- Increased **Elevator Control Loads**
- Increased **Longitudinal Stability**
- Increased **Stall Speed**
- Decreased **Absolute Ceiling**
- Decreased **Rate of Climb**
- *Same effects as a **heavier** aircraft*

MOVING CG AFT (+)

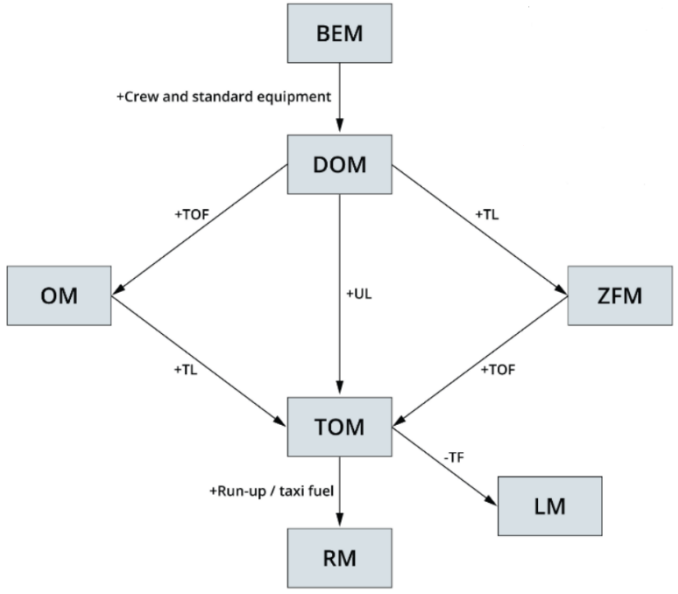
- Decreased **Longitudinal Stability**
- Light Pitch **Stick Forces** (could overstress)
- Difficult **Spin Recovery**
- Increased **Range** and **Endurance**
- Decreased **Stall Speed**
- *Same effects as a **lighter** aircraft*

LOAD DEFINITIONS

MASS DEFINITIONS

- **BEM –** Basic Empty Mass
  - No **additional** equipment
- **DOM –** Dry Operating Mass
- **LM –** Landing Mass
- **OM –** Operating Mass
- **RM –** Ramp Mass
- **TL –** Traffic Load
- **TF –** Trip Fuel
- **TOF –** Take-Off Fuel
- **TOM –** Take-Off Mass
- **ZFM –** Zero Fuel Mass
- **VL –** Variable Load – Role equipment, crew and crew baggage (=DOM-BEM)
- **UL –** Useful Load – Pilots, pax, baggage, cargo, operating items and usable fuel

MASS RELATIONSHIPS



STRUCTURAL LIMITS

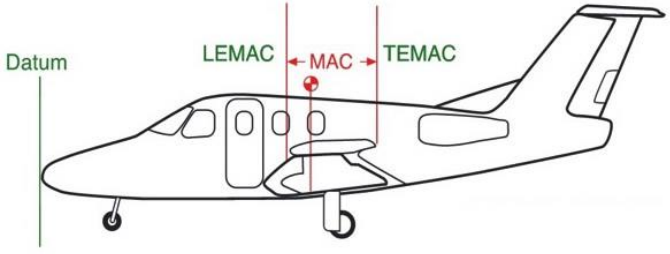
DEFINITIONS

- Set by the **manufacturer** in the **AFM**
- **Cannot** normally be exceeded (MSLM may be exceeded in emergencies)
- **MSTOM –** Max. Structural Take-Off Mass
- **MSLM –** Max. Structural Landing Mass
- **MZFM –** Max. Zero Fuel Mass
  - **Limited** by **wing root strength**
  - Calculated for a **+2.5G load factor**
- **MSTM –** Max. Structural Taxi Mass
- **RTOM –** Regulated TOM (**Lower** of **MSTOM** and **PLTOM**)
- **RLM –** Regulated LM (**Lower** of **MSLM** and **PLLM**)

MEAN AERODYNAMIC CHORD (MAC)

BASICS

- Defined by the **manufacturer**
- **CoG** can be referenced:
  - Relative to the **Datum**
  - **%** of **MAC**
- **LEMAC – Leading Edge MAC**
- **TEMAC – Trailing Edge MAC**
- **% MAC = $\frac{\text{CoG - LEMAC}}{\text{MAC}}$ x 100**
  where MAC = TEMAC – LEMAC



9/10/12 Cargo Considerations, Load Addition/Removal/Shift & EU-OPS

CARGO CONSIDERATIONS

FLOOR LOADING

- **Floor Loading = $^{Mass}/_{Area}$**
- Use the **2 largest sides** to work out the area to get the lowest possible floor loading
- *Remember to keep the same units!*

RUNNING LOAD

- **Running Load = $^{Mass}/_{Length}$**
- Use the **longest side** as the length to get the lowest possible running load

CARGO LOADING

- **Palletised** Cargo – Individual pieces on standard pallets secured by nets
- **Bulk** Cargo – Late Baggage/Crew Bags
- **Containerised** Cargo – Normal baggage placed into standard size containers
- **Baggage –** Personal belongings

LOAD ADDITION/REMOVAL/SHIFT

BASICS

- **CoG** moves **to** where the mass is **added**
- **$^{d}/_{D} = {}^{m}/_{M}$**

LOAD TRANSFER

- **m =** Mass being **moved**
- **M =** Mass of **aircraft**
- **d =** **Old** CoG to **New** CoG
- **D =** Hold **Out** to Hold **In**

KNOWN COG MOVEMENT

- **m =** Mass **added**/**removed**
- **M =** **Old** mass of **aircraft**
- **d =** **Old** CoG to **New** CoG
- **D =** Hold **In**/**Out** to **New** CoG

KNOWN LOAD MOVEMENT

- **m =** Mass **added**/**removed**
- **M =** **New** mass of **aircraft**
- **d =** **Old** CoG to **New** CoG
- **D =** Hold **In**/**Out** to **Old** CoG

EU-OPS

AIRCRAFT WEIGHING

- *See Chapter 2 – BEM*
- If **cumulative** changes exceed **±0.5%** of **MSLM** or **±0.5%** of **MAC**, **recalculation** of mass/CoG is necessary
- For **fleet masses**, **DOM** and **CoG**'s may not differ by more than **±0.5%**
- **Sample** of the fleet weighed **every 4 years:**

Fleet Size	Formula
2-3	n
4-9	$n + {}^{3}/_{2}$
10+	$n + {}^{51}/_{10}$

*Where **n** is the **fleet size***

- Each **individual** aircraft weighed every **9 yrs**

CG LIMITS

- Specified in the **AFM**
- **Safety margin** applied for **crew/pax movement** and **fuel consumption**

CREW MEMBER MASSES

- **Actual** masses, or **standard** masses of:
  - **Flight Crew – 85kg**
  - **Cabin Crew – 75kg**
- **Includes** a **hand baggage allowance**

PASSENGER MASSES

- See **CAP, Section 1 Page 5**
- **Actual** masses, or **standard** masses and:

MOPSC <19:

- **No hand baggage = -6kg**

MOPSC <10:

- **Statement** from each person
- **+6kg hand baggage**, **+4kg clothing**

DEVIATION FROM STANDARD MASSES

- **Operator** must complete a **detailed weighing survey**
- Approved by the **competent Authority**

WEIGHING MACHINE ACCURACY

- **Capacity** of **150kg**
- **Graduations** of **500g**