MASS AND BALANCE IN AIRCRAFT

KADİR BUHARALI
MASS AND BALANCE
INTRODUCTION

✓ Deals with the loading of aircraft
✓ Ensure that they are not overloaded or misloaded
The specific gravity of Jet A1 is greater than for AvGas, and will vary slightly with temperature.
For the mass and balance JAA exam, assume the SG of AvGas to be 0.72, and Jet A1 as 0.8.
**MASS AND BALANCE THEORY**

**DEFINITION:**

- **MASS**: THE AMOUNT OF AN ITEM INSIDE A BODY
- **CENTER OF GRAVITY (C.G)**: THE POINT THROUGH WHICH THE FORCE OF GRAVITY IS SAID TO ACT ON A MASS.
- **BALANCE OF ARM (BA)**: THE DISTANCE FROM THE DATUM TO THE CENTRE OF GRAVITY OF A MASS
- **MOMENT**: THE PRODUCT OF THE MASS AND THE BALANCE ARM
  
  \[ \text{MOMENT} = \text{MASS} \times \text{ARM} \]
• **DATUM OR REFERENCE DATUM:**

• (RELATIVE TO AN AEROPLANE) IS THAT (VERTICAL) PLANE FROM WHICH THE CENTRES OF GRAVITY OF ALL MASSES ARE REFERENCED

*Figure 2-8. Determining the CG of an airplane whose datum is ahead of the airplane.*

*Figure 9-2. Weight and balance.*
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

•  THE EFFECT OF CG LOCATION VS. CP LOCATION:
  ✓ When the CG is forward of the CP, there is a natural tendency for the aircraft to want to pitch nose down.
  ✓ If the CP is forward of the CG, a nose up pitching moment is created. This increases AoA, causing the CP to move further forward and can lead to a stall.
  ✓ For natural longitudinal stability, the CG should be in front of the CP.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• **THRUST AND DRAG:**

  ✓ The forces are arranged so that lift acts behind weight and thrust acts below drag.

  ✓ Ideally, the pitching moments should cancel each other out, but in practice, a secondary method of balancing is used.

  ✓ It is normally done by the tailplane.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

- **TAILPLANE:**
  - It supplies the force necessary to balance any residual pitching moment.
  - Long Moment Arm requires smaller aerodynamic surface.
  - It creates either a down force or up force. At slow speed the force is insufficient to balance.
  - In these cases, the elevator is deflected to increase or reduce the forces. It creates drag, which is referred to as **Trim Drag**.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• CG CONSTRAINTS:

To ensure that the aircraft is correctly controllable and stable, the manufacturer places front and rear constraint or limits for the location of CG, both on the ground and in flight.

If the aircraft’s CG falls on or within these lines, the CG is in limits.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

- **FORWARD LIMIT:**

  - The forward limit is determined by the authority that the tailplane has to trim out the increased nose down pitching moment created by the location of the CG.
  - This authority is determined by the range of the elevator, the airspeed of the aircraft, and the size of the tailplane and the lever arm.
As the CG is located rearward, there is a reduction in the nose down pitching moment. This reduces down force requirement and large elevator deflections.

It allows for extra control surface deflection to be used to alter pitch attitude of the aircraft. There is also a reduction in trim drag and stick fixed force making it easier for the pilot to move the controls.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• NEUTRAL POINT:

As the CG moves further aft, the controllability increases with the decrease in stability. The rear limit is set to maintain sufficient stability.

The rear limit is set forward of the neutral point. The neutral point occurs on a point termed the aerodynamic center, which in subsonic aircraft is normally located at the $\frac{1}{4}$ chord point behind the leading edge.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

- AERODYNAMIC CENTER:
  
  - For calculation, the AC is considered to be located at 25% chord. In reality, it moves between 23-27% of the chord for a subsonic aircraft.
  
  - If the CG is located on the AC, there is no net pitching moment (increased controllability, neutral stability) – not desirable
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• AERODYNAMIC CENTER:

Since it is not desirable in an air transport aircraft, the CG rear limit is set forward of this point. This gives the aircraft longitudinal static stability.

The distance between the neutral point and the CG is termed the static margin or CG margin. Therefore, in real terms, the real limit is forward of the neutral point, and the CG is not allowed to get this far aft.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• FACTORS AFFECTING THE LONGITUDINAL CG POSITION IN FLIGHT:

✓ Fuel consumption
✓ Flap extension / retraction
✓ Gear extension / retraction
✓ Cargo movement
✓ Passenger / crew movement
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• FUEL CONSUMPTION:

• In flight, the mass of the aeroplane reduces through consumption of fuel.
• If the aircraft has fuel tanks with varying arms, as the trip fuel is burnt off, the CG position varies due to this consumption and the drop in aircraft mass.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• FOWLER FLAPS:

- Transport aircraft frequently use Fowler flaps as trailing edge flaps. These flaps translate rearward on extension, moving rearward as well as lowering the trailing edge.
- This results in the CG moving rearward with the flaps’ extension and forward with the flaps’ retraction.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• LANDING GEAR DESIGN:

• Most aircraft have main gears that retract laterally (no effect on the longitudinal CG). However, the raising of a forward retracting nose gear moves the CG forward and vice versa.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• **CARGO:**
  • When an aircraft is loaded, The CG and mass must be within prescribed limits of the aeroplane. If the cargo should shift in flight, the aircraft can become either too stable or uncontrollable.
  • Additionally, cabin crew and passenger movements have an effect on the trim of the aeroplane.
• **THREE CG POINTS THAT MUST BE CALCULATED:**
  • If the aircraft is not overloaded, The CG may fall on or between the CG limits. However, as the aircraft’s CG location moves with the consumption of fuel, prior to any flight,
    • the aircraft’s calculated Take-Off Mass (TOM),
    • Landing Mass (LM),
    • Zero Fuel Mass (ZFM)
  • and corresponding CGs must be compared to the limits.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT – CARGO LOADING
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• SUMMARY:
• As the CG moves toward the forward limit:
  - Stability increases and controllability decreases.
  - On take-off, the nose is heavy requiring more elevator deflection to rotate the aircraft.
  - The climb is suppressed, as the nose wants to pitch down.
  - Greater deflection of the elevators, which results in an increase in trim drag.
  - Greater down force requires greater lift, which results in a higher stalling speed.
  - The increase in trim drag requires more thrust to maintain a given airspeed.
  - The increase in thrust results in more fuel being burned (shorter range)
  - Strong longitudinal stability reduces the effectiveness of the elevator.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• As the CG moves toward the aft limit:
  - Stability decreases and controllability increases.
  - On take-off, the nose is lighter, requiring less elevator deflection. The aircraft rotates more rapidly than expected.
  - The down force required from the elevator reduces. (less drag)
  - The reduction in drag, requires less thrust.
  - Less thrust results in fuel flow reducing and range increase.
  - The decreased down force, which results in a lower stalling speed.
  - In the event of a landing climb (go around), the aircraft’s nose rotates more easily.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT
MASS AND BALANCE

- An Aircraft Accident:
- March 21, 1980
- Piper PA-31-350 with a pilot, a pilot-in-command trainee and 8 passengers
- MTOM: 7000lbs
- Actual TOM: 7280 lbs!
- No baggages in the forward cargo compartment!
- Center of Gravity 3 in beyond the rear limit!(138 in instead of 135 in max.)
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

• Desirable CG Position in Flight
  ➢ A slightly aft location for the optimum CG position.
  ➢ Sufficiently stable but more manoeuvrable.
  ➢ Less drag
  ➢ Less thrust
  ➢ More efficient cruise
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

- **EFFECT OF OVERLOADING:**
  - If Maximum Take-off Mass (MTOM) is exceeded, but the CG is located within the safe range, it results in:
    - A greater take-off run, because it requires a greater speed for required lift.
    - Reduced climb performance
    - A reduction in airspeed for a given power setting.
    - *Higher stalling speed. If it is heavier than calculated, it is more likely to stall.* (no stall safety margin)
    - Reduced excess power means reduced service ceiling.
    - Increase in fuel consumption.
    - A decrease in range.
    - A higher landing speed due to stall risk. Longer landing run.
    - Heavy braking, damaged tyres.
    - A mass above the maximum structural landing mass will result in failure.
FACTORS AFFECTING MASS AND BALANCE IN AIRCRAFT

- **Basic Empty Mass - BEM (Basic Mass - BM)**:
  - is the mass of an aeroplane plus standard items such as:
    - Unusable fuel and other unusable fluids
    - Lubricating oil in the engine and auxiliary units
    - Fire extinguishers
    - Emergency oxygen equipment
MASS DEFINITIONS AND LIMITATIONS

- **Variable Load**
  - Crew and crew baggage
  - Catering and removable passenger service equipment
  - Potable water and lavatory chemicals
  - Food and beverages
  - $\text{BEM} + \text{Variable Load} = \text{Dry Operating Mass}$
MASS DEFINITIONS AND LIMITATIONS

- **Traffic Load**
  - The total mass of passengers, baggage, and cargo, including any non-revenue load.

- **Pay Load**
  - This is defined as that part of the traffic load from which the revenue is earned.
Fuel Definitions:
- Block Fuel (Bulk Fuel) or Ramp Fuel
- Start, Run-up, and Taxi Fuel
- Take-Off Fuel
- Trip Fuel
- Landing Fuel (reserve fuel)

To summarise:

\[
\text{Landing Fuel} + \text{Trip Fuel} = \text{Take-Off Fuel}
\]

\[
\text{Take-Off Fuel} + \text{Start Fuel} = \text{Ramp Fuel}
\]
Fuel Definitions

- **Operating Mass (OM)**
  - is the DOM plus fuel but without traffic load.
  - \( \text{DOM} + \text{TOF} = \text{OM} \)
  - \( \text{BEM} + \text{VL} + \text{TOF} = \text{OM} \)

- **Zero Fuel Mass (ZFM)**
  - is DOM plus traffic load but excluding fuel.
  - \( \text{DOM} + \text{Traffic Load} = \text{ZFM} \)
  - \( \text{BEM} + \text{VL} + \text{Traffic Load} = \text{ZFM} \)
STRUCTURAL LIMITATIONS:
- Maximum Structural Taxi Mass (MSTM)
  ✓ is the structural limitation on the mass of the aeroplane at the commencement of taxi. (Maksimum Taxi/Ramp Mass)
- Maximum Structural Take-Off Mass
  ✓ The maximum permissible total aeroplane mass at the start of the take-off run. (Maximum Take-off Mass – MTOM)
MASS DEFINITIONS AND LIMITATIONS

- **STRUCTURAL LIMITATIONS:**
  - **Maximum Structural Landing Mass**
    - The maximum permissible total aeroplane mass on landing under normal circumstances. (Maximum Landing Mass – MLM)
  - **Maximum Zero Fuel Mass (MZFM)**
    - The maximum permissible mass of an aeroplane with no usable fuel.
MASS DEFINITIONS AND LIMITATIONS

- PERFORMANCE LIMITATIONS:
  - The altitude of the airfield (density)
  - The air temperature (density)
  - The length of the runway
  - The topography of the area

- Performance Limited Take-off Mass (PLTOM)
  ✓ is the take-off mass subject to departure airfield limitations.
MASS DEFINITIONS AND LIMITATIONS

- PERFORMANCE LIMITATIONS:
  - The altitude of the airfield (density)
  - The air temperature (density)
  - The length of the runway
  - The topography of the area

- Performance Limited Landing Mass (PLLM)
  - Is the mass subject to the destination airfield limitations.

![Diagram showing non-obstacle clearance and effective runway length with obstacle clearance highlighted.](image-url)
MASS DEFINITIONS AND LIMITATIONS

REGULATED LIMITATIONS:

Regulated Take-off Mass (RTOM)
✓ Is the lowest of Performance Limited and Structural Limited Take-Off Mass. (Maximum Allowable Take-Off Mass (MATOM)
✓ Regulated Landing Mass (RLM)
✓ Is the lowest of Performance Limited and Structural Limited Landing Mass. (Maximum Allowable Landing Mass) (MALM)
The maximum mass at which an aeroplane can take-off is the most restrictive (lowest) of the three limitations below:

1. The regulated take-off mass RTOM, which is the more restrictive (lower) of the performance limited take-off mass and the maximum structural take-off mass.

2. The regulated landing mass RLM (which is the more restrictive of the performance limited landing mass and the maximum structural landing mass) plus the trip fuel.

MASS DEFINITIONS AND LIMITATIONS
CALCULATING THE MAXIMUM TAKE-OFF MASS

Example
Given the following calculate the maximum take-off mass.
Maximum Structural Take-off Mass 78 000 kg
Maximum Structural Landing Mass 71 500 kg
Maximum Zero Fuel Mass 63 000 kg
Maximum Performance Limited Take-off Mass 85 000 kg
Maximum Performance Limited Landing Mass 67 000 kg
Fuel at take-off 13 800 kg
Trip fuel 5200 kg

<table>
<thead>
<tr>
<th>RTOM</th>
<th>RLM</th>
<th>MZFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>78 000 kg</td>
<td>67 000 kg</td>
<td>63 000 kg</td>
</tr>
<tr>
<td>+ 5 200 kg</td>
<td>+ 13 800 kg</td>
<td></td>
</tr>
<tr>
<td>78 000 kg</td>
<td>72 200 kg</td>
<td>76 800 kg</td>
</tr>
</tbody>
</table>

The maximum take-off mass is therefore the lowest of the above masses, 72 200 kg.

MTOM
- **Cargo Compartments:**
  - Compartments in the lower deck accommodate baggage and cargo.
  - All compartments have a maximum floor loading (kg/m²) and maximum running load value (kg/m).
- **Containerised Cargo**
- **Palletised Cargo**
- **Bulk Cargo**
**AIRCRAFT FLOOR LOADING**

- **FLOOR LOADING:**
- Lightweight panels are supported on crossbeams (blue).
- These are attached to the longerons (red) and the frames (yellow).
- In the passenger cabin, seat rails (dark yellow) carry the passengers.
- Limitations are;
  - **Running Loads**
  - **Static Loads**
EXAMPLE FOR CARGO COMPARTMENT LIMITATIONS:

The hold has an overall length of 280 inches and is located between balance arms 220 to 500 in. The hold is sub-divided into three separate sections: from 220 to 280 in, from 280 to 340 in, and from 340 to 500 in.

<table>
<thead>
<tr>
<th></th>
<th>BA – IN 220</th>
<th>280</th>
<th>340</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAXIMUM COMPARTMENT RUNNING LOAD IN KG PER INCH</td>
<td>10.5</td>
<td>8.9</td>
<td>15.12</td>
<td></td>
</tr>
<tr>
<td>MAXIMUM DISTRIBUTION LOAD INTENSITY KG PER SQUARE FOOT</td>
<td></td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAXIMUM COMPARTMENT LOAD KG</td>
<td>630</td>
<td>534</td>
<td>2419.2</td>
<td></td>
</tr>
<tr>
<td>MAXIMUM TOTAL LOAD KG</td>
<td></td>
<td></td>
<td>3583.2</td>
<td></td>
</tr>
<tr>
<td>HOLD CENTROID B.A.- IN</td>
<td></td>
<td></td>
<td>374</td>
<td></td>
</tr>
</tbody>
</table>
AIRCRAFT FLOOR LOADING

- **PRINCIPLE OF RUNNING LOAD:**
  - If a container 10 in wide, 20 in long, weighing 200 kg is placed in the fwd compartment (max. Running load is 10.5 kg/in), the running load is: $200/20 = 10 \text{ kg/in}$

- If the container is rotated through 90 degree, the container’s running load increases to $200/10 = 20 \text{ kg/in}$ which is over the limit.
AIRCRAFT FLOOR LOADING

• LOAD SPREADERS:
• Used to increase the surface area over which a mass can act.
LOAD SHIFTING, LOAD ADDITION, AND LOAD SUBTRACTION

• LOAD SHIFTING:
  ✓ The act of transferring a mass from one location to another within an aircraft has a double effect on the total moment.

![Diagram of a plane with load shifting calculations]

Where:
- \( m \) = the mass to be moved
- \( M \) = the total mass of the aircraft
- \( d \) = the distance the CG will move from its original position
- \( D \) = the distance that the mass \( m \) is moved
LOAD SHIFTING, LOAD ADDITION, AND LOAD SUBTRACTION

• LOAD ADDITION:

Where:

- $m$ = the mass **to be** moved
- $M$ = the total mass of the aircraft
- $d$ = the distance the CG **will** move from its original position
- $D$ = the distance that the mass $m$ **is** moved
LOAD SHIFTING, LOAD ADDITION, AND LOAD SUBTRACTION

- LOAD SUBTRACTION:

Where:
- \( m \) = the mass to be moved
- \( M \) = the total mass of the aircraft
- \( d \) = the distance the CG will move from its original position
- \( D \) = the distance that the mass \( m \) is moved
**Light aircraft** predominantly use straight wings that are either tapered or semi-tapered. These wings are mounted at right angles to the fuselage. (90 degree). This means that the CG safe range runs across the span of the wings.

**Modern transport aircraft**, due to their higher speeds and efficiencies, use swept-back wings. Here, the leading edge (Le) of the wing at the tip is behind the junction of the leading edge at the wing root and in some designs (as shown below) behind the wing root trailing edge (Te).
The safe range on a straight wing can easily be visualised as a band running from one wing tip to the other and be seen to fall within the lifting area. For a swept-back wing, if the safe range band were to pass through the wing tips (as per band A in the diagram above), the CG would be behind the Centre of Pressure.

To ensure that the CG safe range is ahead of the CG, the safe range is located forward on the wing and is shown below as band B.

To rationalise this, a system called the **Mean Aerodynamic Chord (MAC)** is used.
MEAN AERODYNAMIC CHORD:

- The mean aerodynamic chord of a wing, is the chord of a rectangular wing, with the same span, and having similar pitching moment characteristics.
- The MAC is the primary reference for longitudinal stability considerations.
- For mass and balance purposes, the aircraft can be considered to have a straight wing of this chord. It is considered that the lift generated by the wings comes from this chord. The length of the chord is referred to as MAC.
MEAN AERODYNAMIC CHORD

✓ For mathematical computation, whatever the actual length of the chord, it is discussed in the terms of percentage. LeMAC is always 0% MAC, and TeMAC is 100% MAC whatever the distance.
✓ This allows the fwd and aft CG limits to be given as percentages of MAC.
✓ For example, to find the linear distance that 20% of Mac represents, divide the chord length of MAC by 100 and multiply it by 20.

✓ 15 ft/100 = 0.15 ft
✓ 0.15 ft * 20 = 3 ft
As all components are given in relation to the aircraft's datum, the leading edge of MAC has to be given as a linear distance from the datum. The CG can be given as a linear distance from the datum that requires converting to a percentage of MAC.
MEAN AERODYNAMIC CHORD

- **CG LIMITS AS PERCENTAGES:**
  - In the diagram below, the fore and aft CG limits can be seen and would normally be given as a percentage of MAC, in the case 10% and 40%.
  - Example: Express the CG as a lineer distance from the datum.
    - a) 33 ft    c) 34 ft
    - b) 33.5 ft   d) 34.5 ft
  - Solution:
    - 15 ft*0.23 = 3.45 ft
    - 30 ft + 3.45 ft = 33.45 ft = 33.5 ft
MASS VALUES FOR CREWS:

Operators are required to account for the mass of their crew members and baggage as part of determining the dry operating mass. The operator can use:

- The actual mass of the crew members and their baggage
- The standard mass of 85 kg for flight crew and 75 kg for cabin crew (regardless of gender or build)
- Any other standard mass acceptable to the Aviation Authority
- The operator must correct the DOM and its CG position if the crew has additional baggage.
**TABLE 1 — PASSENGER MASS VALUES FOR UP TO 20 OR MORE SEATS**

<table>
<thead>
<tr>
<th>Passenger Seats</th>
<th>20 and more</th>
<th>30 and more</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>All flights except</td>
<td>88 kg</td>
<td>70 kg</td>
</tr>
<tr>
<td>holiday charters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holiday charters</td>
<td>83 kg</td>
<td>69 kg</td>
</tr>
<tr>
<td>Children</td>
<td>35 kg</td>
<td>35 kg</td>
</tr>
</tbody>
</table>

Where the total number of passenger seats in an aeroplane is between 20 and 29, the operator is to use the gender-based masses for 20 and more, as per table 1, for determination of the passenger load. If the aircraft has 30 or more seats, the operator is to use the all adult masses.

- All flights except holiday charters: Schedule service, etc.
- Holiday charters: Part of holiday package travel
- All adult: Adult mass regardless of gender
For aircraft with 19 passenger seats or less, table 2 applies (see above). The smaller the seating capacity, the greater the standard adult passenger’s mass becomes. Within these masses is an allowance for hand baggage. On flights (table 2 only) where no hand baggage is carried in the cabin or where the hand baggage is accounted for separately, 6 kg may be deducted from the adult mass. Articles such as small cameras, overcoats, umbrellas, and small handbags are not considered hand baggage.
# Loading Manifests, Sep 1

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass</th>
<th>Arm (in)</th>
<th>Moment / 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Basic Empty Condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Front Seat Occupants</td>
<td></td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>3. Third and Fourth Seat PAX</td>
<td></td>
<td>117</td>
<td></td>
</tr>
<tr>
<td>4. Baggage Zone ‘A’</td>
<td></td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>5. Fifth And Sixth Seat PAX</td>
<td></td>
<td>152</td>
<td></td>
</tr>
<tr>
<td>6. Baggage Zone ‘B’</td>
<td></td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>7. Baggage Zone ‘C’</td>
<td></td>
<td>180</td>
<td></td>
</tr>
</tbody>
</table>

**Sub-total = Zero Fuel Mass**

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass</th>
<th>Arm (in)</th>
<th>Moment / 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Fuel Loading</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sub-total = Ramp Mass**

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass</th>
<th>Arm (in)</th>
<th>Moment / 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Subtract Fuel for Start, Taxi and Run Up (see Note)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sub-total = Take-off Mass**

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass</th>
<th>Arm (in)</th>
<th>Moment / 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Trip Fuel</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sub-total = Landing Mass**

**NOTE:** Fuel for start taxi and run up is normally 13 lb at an average entry of 10 in the column headed **Moment / 100**
**LOADING MANIFESTS, SEP 1**

- **EXAMPLE FOR SEP1:**
  - Pilot of 140 lb
  - 200 lb of cargo in Zone A
  - Passengers with a total mass of 120 lb in seats 5&6
  - 100 lb in baggage Zone C
  - Fuel load of 50 US gal, of which 40 US gal will be burnt as trip fuel 1 US gal = 6 lb
  - 50 US gal * 6 = 300 lb
  - Moment * 100
  - If the ZFM, TOM, and LM masses and CG positions are in limits (Check SEP 1 data) the A/C is safe to fly.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>MASS (lb)</th>
<th>ARM (in)</th>
<th>MOMENT X 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Basic Empty Condition</td>
<td>2415</td>
<td>77.7</td>
<td>1876.46</td>
</tr>
<tr>
<td>2. Front Seat Occupants</td>
<td>140</td>
<td>79</td>
<td>110.6</td>
</tr>
<tr>
<td>3. Third &amp; Fourth Seat Pax</td>
<td>0</td>
<td>117</td>
<td>0</td>
</tr>
<tr>
<td>4. Baggage Zone A</td>
<td>200</td>
<td>108</td>
<td>216</td>
</tr>
<tr>
<td>5. Fifth &amp; Sixth Seat Pax</td>
<td>120</td>
<td>152</td>
<td>182.4</td>
</tr>
<tr>
<td>6. Baggage Zone B</td>
<td>0</td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td>7. Baggage Zone C</td>
<td>100</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td><strong>Sub–Total = ZERO FUEL MASS</strong></td>
<td>2975</td>
<td>86.2</td>
<td>2565.46</td>
</tr>
<tr>
<td>8. FUEL Loading</td>
<td>300</td>
<td>75</td>
<td>225</td>
</tr>
<tr>
<td><strong>Sub–Total = RAMP MASS</strong></td>
<td>3275</td>
<td>85.2</td>
<td>2790.46</td>
</tr>
<tr>
<td>9. Subtract Fuel for Start, Taxi, and Run Up (see Note)</td>
<td>-13</td>
<td>SEE NOTE ON SEPI PAGE 3</td>
<td>-10</td>
</tr>
<tr>
<td><strong>Sub–Total = TAKE-OFF MASS</strong></td>
<td>3262</td>
<td>85.2</td>
<td>2780.46</td>
</tr>
<tr>
<td>10. TRIP FUEL</td>
<td>-240</td>
<td></td>
<td>-180</td>
</tr>
<tr>
<td><strong>Sub–Total = LANDING MASS</strong></td>
<td>3022</td>
<td>86.4</td>
<td>2610.46</td>
</tr>
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MEDIUM RANGE JET TRANSPORT (MRJT)

FUSELAGE PLUGS (BOEING 737)

Table to Convert Body Stations to Balance Arm (Figure 4.2)

<table>
<thead>
<tr>
<th>Body Station</th>
<th>Conversion</th>
<th>Balance Arm-in</th>
</tr>
</thead>
<tbody>
<tr>
<td>500A</td>
<td>348 + 22 in</td>
<td>370</td>
</tr>
</tbody>
</table>
MEDIUM RANGE JET TRANSPORT (MRJT)

- PASSENGERS (PAX) AND PERSONNEL:

### Passenger and Personnel Data

<table>
<thead>
<tr>
<th>ZONE</th>
<th>NO. PAX</th>
<th>B.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15</td>
<td>284</td>
</tr>
<tr>
<td>B</td>
<td>18</td>
<td>386</td>
</tr>
<tr>
<td>C</td>
<td>24</td>
<td>505</td>
</tr>
<tr>
<td>D</td>
<td>24</td>
<td>641</td>
</tr>
<tr>
<td>E</td>
<td>24</td>
<td>777</td>
</tr>
<tr>
<td>F</td>
<td>18</td>
<td>896</td>
</tr>
<tr>
<td>G</td>
<td>18</td>
<td>998</td>
</tr>
</tbody>
</table>

**Figure 4.7 Balance Arms (in)**

**Figure 4.8 Table of Passenger Zones, Number of Passengers and Balance Arms**

5.3 Passenger Mass

Unless otherwise stated, passenger mass is assumed to be 84 kg (this includes a 6 kg allowance for hand baggage).

5.4 Passenger Baggage

Unless otherwise stated, a baggage allowance of 13 kg may be made per passenger.

5.5 Personnel

Standard Crewing

<table>
<thead>
<tr>
<th>No.</th>
<th>BA</th>
<th>Standard Mass (kg) each</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>Flight Deck</td>
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<tr>
<td></td>
<td>2</td>
<td>78.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cabin Staff Forward</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>162.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cabin Staff Aft</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1,107.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
</tr>
</tbody>
</table>
## MEDIUM RANGE JET TRANSPORT (MRJT)

### Loading Manifest – MRJT 1

Max Permissible Aeroplane Mass Values:
- **TAXI MASS** - 63 060 kg
- **ZERO FUEL MASS** - 51 300 kg
- **TAKE-OFF MASS** - 62 800 kg
- **LANDING MASS** - 54 900 kg

<table>
<thead>
<tr>
<th>ITEM</th>
<th>MASS (kg)</th>
<th>BA IN</th>
<th>MOMENT kg in/1000</th>
<th>CG %MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. DOM</td>
<td>34 500</td>
<td>649.00</td>
<td>22 390.5</td>
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<tr>
<td>2. PAX Zone A</td>
<td>840.00</td>
<td>284.00</td>
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</tr>
<tr>
<td>3. PAX Zone B</td>
<td>1 512</td>
<td>386.00</td>
<td>583.60</td>
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</tr>
<tr>
<td>4. PAX Zone C</td>
<td>2 016</td>
<td>505.00</td>
<td>1018.1</td>
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<tr>
<td>5. PAX Zone D</td>
<td>2 016</td>
<td>641.00</td>
<td>1292.3</td>
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<td>6. PAX Zone E</td>
<td>2 016</td>
<td>777.00</td>
<td>1566.4</td>
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<tr>
<td>7. PAX Zone F</td>
<td>1 512</td>
<td>896.00</td>
<td>1354.8</td>
<td></td>
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<td>8. PAX Zone G</td>
<td>1 092</td>
<td>998.00</td>
<td>1089.8</td>
<td></td>
</tr>
<tr>
<td>9. CARGO HOLD 1</td>
<td>650.00</td>
<td>367.9</td>
<td>239.10</td>
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</tr>
<tr>
<td>10. CARGO HOLD 4</td>
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<td>884.5</td>
<td>1875.1</td>
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<tr>
<td>11. ADDITIONAL ITEMS</td>
<td>NIL</td>
<td>N/A</td>
<td>NIL</td>
<td></td>
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<tr>
<td><strong>ZERO FUEL MASS</strong></td>
<td>48 274</td>
<td>655.60</td>
<td>31 648.3</td>
<td>22.30</td>
</tr>
<tr>
<td>12. FUEL TANKS 1 &amp; 2</td>
<td>9 084</td>
<td>650.70</td>
<td>5911</td>
<td></td>
</tr>
<tr>
<td>13. CENTRE TANK</td>
<td>4 916</td>
<td>600.40</td>
<td>2951.6</td>
<td></td>
</tr>
<tr>
<td><strong>TAXI MASS</strong></td>
<td>62 274</td>
<td>650.50</td>
<td>40 510.9</td>
<td>18.50</td>
</tr>
<tr>
<td>LESS TAXI FUEL</td>
<td>-2 600</td>
<td>600.40</td>
<td>-156.10</td>
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</tr>
<tr>
<td><strong>TAKE-OFF MASS</strong></td>
<td>62 014</td>
<td>650.70</td>
<td>40 354.8</td>
<td>18.70</td>
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<tr>
<td>LESS FLIGHT FUEL</td>
<td>4 844</td>
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<tr>
<td><strong>EST. LANDING MASS</strong></td>
<td>52 514</td>
<td>655.20</td>
<td>34 407.3</td>
<td>22.53</td>
</tr>
</tbody>
</table>

**Note:** The balance point for the zero fuel mass is 31 648.3 inches from the front of the aircraft. The balance point for the take-off mass is 40 510.9 inches from the front of the aircraft.
MEDIUM RANGE JET TRANSPORT (BOEING 737)

• CENTER OF GRAVITY LIMITS:
MEDIUM RANGE JET TRANSPORT (MRJT)

- TAKE-OFF HORIZONTAL STABILISER TRIM SETTING:
MEDIUM RANGE JET TRANSPORT (MRJT)

- TAKE-OFF HORIZONTAL STABILISER TRIM SETTING CALCULATION:
- ON BOARD PERFORMANCE TOOL (OBT)
MEDIUM RANGE JET TRANSPORT (MRJT)

- LOAD AND TRIM SHEET:
MEDIUM RANGE JET TRANSPORT (MRJT)

• LOAD AND TRIM SHEET FOR BOEING 777:
MEDIUM RANGE JET TRANSPORT (MRJT)

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Addresses</th>
<th>Originator</th>
<th>Recharge Date/Time</th>
<th>Initials</th>
<th>Flight</th>
<th>Date</th>
<th>Registration</th>
<th>Version</th>
<th>Crew</th>
<th>Date</th>
<th>ALL MASSES IN KILOGRAM</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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**DRY OPERATING MASS**

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<th>Take-off Fuel</th>
<th>+</th>
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**MAXIMUM MASSES FOR**

<table>
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<th>Zero Fuel</th>
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**OPERATING MASS**

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<th>=</th>
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</table>
### MEDIUM RANGE JET TRANSPORT (MRJT)

**Section 3**

<table>
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<th>Description</th>
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<td>TOTAL</td>
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<td>Passenger Mass</td>
<td>10920</td>
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<tr>
<td>TOTAL TRAFFIC LOAD</td>
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<tr>
<td>Dry Operating Mass</td>
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<td>Max.</td>
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**Part A**

**LAST MINUTE CHANGES**

<table>
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<tr>
<th>Dest</th>
<th>Specification</th>
<th>CI/Cpt</th>
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<th>minus</th>
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**Prepared by:**

**Approved by:**
MEDIUM RANGE JET TRANSPORT (MRJT)

- Trim Sheet (Top section)
**MEDIUM RANGE JET TRANSPORT (MRJT)**

<table>
<thead>
<tr>
<th>Fuel Mass (kg)</th>
<th>Index Units</th>
<th>Fuel Mass (kg)</th>
<th>Index Units</th>
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<tbody>
<tr>
<td>500</td>
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<td>9,330</td>
<td>-0.3</td>
</tr>
<tr>
<td>750</td>
<td>-1.5</td>
<td>9,580</td>
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</tr>
<tr>
<td>1,000</td>
<td>-1.9</td>
<td>9,830</td>
<td>-1.5</td>
</tr>
<tr>
<td>1,250</td>
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<td>-2.1</td>
</tr>
<tr>
<td>1,500</td>
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<td>10,330</td>
<td>-2.7</td>
</tr>
<tr>
<td>1,750</td>
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<td>-3.3</td>
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<tr>
<td>2,500</td>
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<td>-4.5</td>
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</tr>
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<td>-6.3</td>
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<tr>
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<td>-6.9</td>
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<td>-8.1</td>
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<td>-16.3</td>
</tr>
<tr>
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<td>16,080</td>
<td>-17.1</td>
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<tr>
<td>tanks 1 and 2 full</td>
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<td>centre tank full</td>
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</tr>
<tr>
<td></td>
<td>+0.3</td>
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<td>-173</td>
</tr>
</tbody>
</table>

* Usable fuel quantities in lines = 20 kg (included in the tables). Interpolation not necessary!

* Fuels in pipelines between tanks and engines
**MEDIUM RANGE JET TRANSPORT (MRJT)**

- **EXAMPLE - ADJUSTING THE CG LOCATION:**
- Use the worked example to relocate the CG from its current position to a new location of 18% MAC. After drawing the two vertical lines, it would be necessary to:

  - Add 100kg to the fwd hold, or
  - Remove 100kg from the aft hold, or
  - Add 1 Pax to Cpt Oa, or
  - Alterations in Cpt Od have no effect
  - Remove 1 Pax from Cpt Oe, or

Any single alteration from the above list causes the CG to relocate to 18% MAC.
COMPUTERIZED WEIGHT AND BALANCE SYSTEM FOR BOEING 777
COMPUTERIZED WEIGHT AND BALANCE SYSTEM FOR BOEING 777

Boeing Laptop Tool / Onboard Performance Tool

Weight Inputs:
- PAX (243)

CARGO:
- Pax Zone 1 (30) 27
- Pax Zone 3 (40) 32
- Pax Zone 5 (40) 40
- Pax Zone 7 (35) 35

OTHER:
- Pax Zone 2 (40) 36
- Pax Zone 4 (40) 33
- Pax Zone 6 (40) 40

FUEL:
- Pax Zone 2 (40) 36
- Pax Zone 4 (40) 33
- Pax Zone 6 (40) 40

WT AND BALANCE
- Taxi (293835) 156870
- Takeoff (293837) 156870
- Land (250000) 156870
- ZFW (195044) 156870

Operating Envelope:
- MTOW
- MLW
- MZFW
- GFW
COMPUTERIZED WEIGHT AND BALANCE SYSTEM FOR BOEING 777
COMPUTERIZED WEIGHT AND BALANCE SYSTEM FOR BOEING 777
COMPUTERIZED WEIGHT AND BALANCE SYSTEM FOR BOEING 777

**Boeing Laptop Tool / Onboard Performance Tool**

**Takeoff Weight:** 252922

**CG (%):** 25.2

Calculated takeoff weight and CG will be used in the takeoff performance calculations.
COMPUTERIZED WEIGHT AND BALANCE SYSTEM FOR BOEING 777
REFERENCE

- JAA ATPL Theoretical Knowledge Manual, 031 00 MASS AND BALANCE, Oxford Aviation Services, Published by Jeppesen GmbH, Frankfurt, Germany
- www.pdpilot.co.uk
- www.captainpilot.com