**WEIGHT & BALANCE:**

The ability to check the loading of an aircraft by means of weight and balance calculation is crucial to the safety of a flight.

Weight is typically checked first and then the longitudinal centre of gravity (CG) balance. The aircraft weight and CG must fall within manufacturer determined limits for safe flight.

**Example:**

**You aircraft, VH-RAQ, will be loaded as follows:**

Pilot: 78kg, passenger (pax): 85kg, passenger:60kg, cargo: 20kg, fuel: 120L

Determine if the aircraft weight and balance falls within the acceptable limits for safe flight.

1. **Start With Weight**

   You can choose to use either imperial or metric units. Insert the aircraft's Basic Empty Weight (BEW), and decide where each passenger will sit. In the example, the Pilot and 85kg pax will sit in Row 1 (the front two seats).

   BEW is found by referring to an aircraft's load sheet. Every aircraft has a unique load sheet outlining its weight and CG.

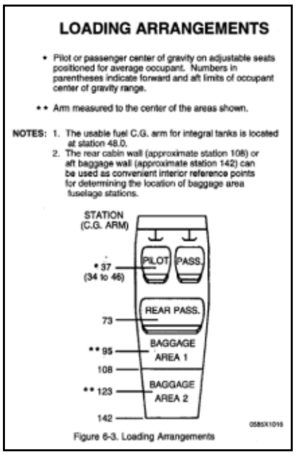
   The specific gravity (SG) of fuel is 0.72. This means that 1 litre of fuel weighs 0.72kg. 120L x 0.72SG = 86.4kg

| Item | Weight | | Arm | | Moment / 1000 | Aircraft Balanced |
|---|---|---|---|---|---|---|
| | kg | lbs | mm | inches | | |
| Basic Empty Weight | 782.4 | | | | | |
| Row 1 | 78+85 | | | | | |
| Row 2 | 60 | | | | | |
| Row 3 | | | | | | |
| Baggage 1 | 20 | | | | | |
| Baggage 2 | | | | | | |
| Zero Fuel Weight | 1025.4 | | | | | ✓ |
| Main Fuel Tanks | 86.4 | | | | | |
| Aux Fuel Tanks | | | | | | |
| Take-off Weight | 1111.8 | | | | | ✓ |

   A take-off weight of 1111.8kg is less than the maximum take-off weight specified in the POH Section 2.

2. **Determine The Arm For Each Station**

   Refer to C172 POH diagram "Loading Arrangements". It outlines the 'arm', or distance from the firewall that each station is located.




   In the POH data, Row 1 is shown to lie 37 inches behind the firewall. If you've chosen metric for weights, you'll have to convert 37 inches to mm.

   37 inches x 25.4 = 940mm. Write this on the table. The aircraft BEW arm is found on the load sheet, write this on the table also.

3. **Calculating The Moment**

   In order to plot the weight and balance data onto a graph, we need to convert our weights and arms into a common unit called a 'moment'. The formula is as follows:

   Weight x Arm = Moment (/1000)

   Dividing the moment by 1000 simply makes the number more manageable.

   782.4 x 1044 = 816.8 kg/mm

   Calculate the remaining arms and moments for: Row 2, Baggage and Main Fuel Tanks.

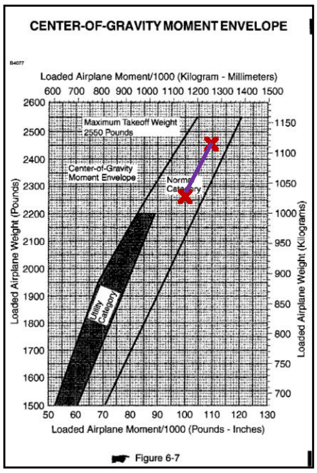
4. **Adding It Together**

   Once the moments are calculated, they can be added together to fill in the 'Zero Fuel Weight' (ZFW) row. Next, add the ZFW moment and the 'Main Fuel Tanks' moment to determine the 'Take-off Weight' (TOW) moment.

| Item | Weight | | Arm | | Moment / 1000 | Aircraft Balanced |
|---|---|---|---|---|---|---|
| | kg | lbs | mm | inches | | |
| Basic Empty Weight | 782.4 | | 1044 | | 816.8 | |
| Row 1 | 78+85 | | 940 | | 153.2 | |
| Row 2 | 60 | | ??? | | ??? | |
| Row 3 | | | | | | |
| Baggage 1 | 20 | | ??? | | ??? | |
| Baggage 2 | | | | | | |
| Zero Fuel Weight | 1025.4 | | | | 1129.5 | ✓ |
| Main Fuel Tanks | 86.4 | | ??? | | ??? | |
| Aux Fuel Tanks | | | | | | |
| Take-off Weight | 1111.8 | | | | 1234.8 | ✓ |

5. **Plotting To Check Balance**

   We now have a weight and moment for both the ZFW and TOW, which can be plotted onto the Moment Envelope to check balance.




   Mark the envelope at two points and draw a straight line to intersect them.

   This line represents the balance of the aircraft throughout the flight as fuel is burned to nil. If the entire line remains inside the envelope, the aircraft is considered safely balanced for flight.

6. **Practice Exercise #1**

   Using the weights in the example scenario, complete a second calculation to observe how the balance would change if both passengers were seated in Row 2.

7. **Practice Exercise #2**

   With four persons on board, each weighing 80kg, how much fuel could be added without exceeding max take-off weight or moment envelope?

## PRESSURE & DENSITY HEIGHT:

A driver is cruising at 80km/h. This could be considered too fast or slow depending on the context. In order to definitively state if the driver's speed is fast or slow, a reference datum, or in this case, a speed limit should be used for comparison. This is the same concept for aircraft performance.

In order to accurately determine if our aircraft will perform well or poorly, we must adopt a datum or standard conditions to compare against. These are called the International Standard Atmosphere (ISA).

**International Standard Atmosphere:**
QNH @ MSL = 1013hPa
Temp @ MSL = 15°C
Pressure lapse rate = 1hPa / 30ft
Temperature lapse rate = 2°C / 1000ft
Temperature lapse rate (constant hPa) = 1°C / 120ft

**Example:**
**Calculate density height, given the following conditions:**
QNH: 1007hPa, Temperature: 28°C, Location: Kingaroy

8. **Start with Pressure Height (PH)**
   Ask yourself: Is 1007hPa better or worse performance than a standard day? Knowing this will allow you to crosscheck your final answer. 1007hPa is less pressure than 1013hPa, so performance will be reduced.

9. **Calculate Deviation from ISA**
   ISA QNH – Actual QNH = Deviation
   1013hPa – 1007hPa = +6hPa

10. **Convert Pressure Deviation into Height**
    Deviation x pressure lapse rate
    +6hPa x 30ft = +180ft

11. **Factor Aerodrome Elevation into the Calculation**
    Height Variance + Elevation
    +180ft +1492ft = +1672ft
    **Pressure Height = +1672ft**

In the given conditions, an aircraft taking off at YKRY (1492ft) will experience performance characteristics the same as an aircraft taking off at 1672ft on an ISA day. That is, it will experience a slight loss of performance, when pressure alone is considered. However, an aircraft's performance is ultimately determined by the density, which factors in both pressure and temperature.

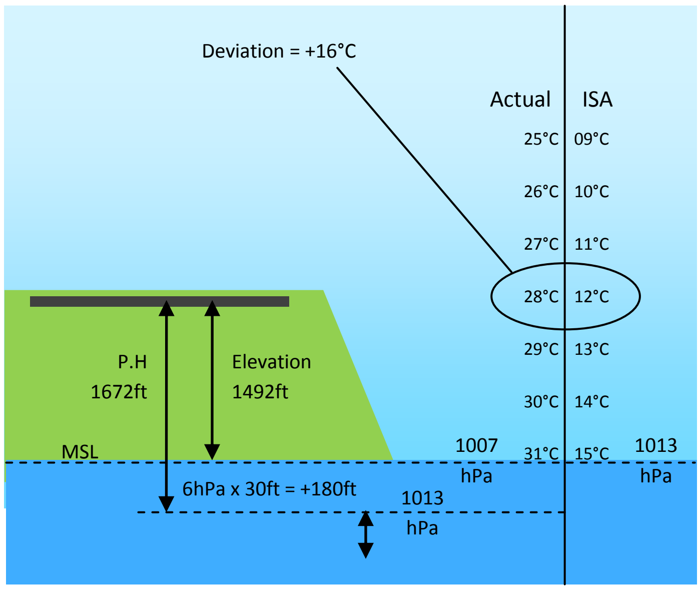
12. **With PH Calculated, Work out Density Height (DH)**
    To determine the temperature deviation from ISA, we must first ensure we're making a direct comparison. The question gives temperature (28°C) which is at PH 1672ft, not MSL. The 15°C ISA figure is at MSL, so we must calculate an equivalent ISA temperature for 1672ft.
    Based on the 2°C / 1000ft lapse rate, the ISA temperature at 1500ft would be 12°C. (PH can be rounded to the nearest 500ft). Eg: ISA temp at 3877ft = 7°C (rounded 4000ft)

13. **Consider Deviation from ISA**
    ISA @ 1500ft = 12°C and Actual @1500ft = 28°C
    28°C - 12°C = +16°C Deviation
    The Actual temperature is 16°C warmer than ISA.

14. **Factor Elevation into the Calculation**
    Temperature Deviation x temp lapse rate (constant hPa)
    +16°C x 120ft = +1920ft

15. **Combine Pressure and Temperature:**
    Temperature Calc ± Pressure Height = Density Height
    +1920ft +1672ft = 3592ft
    **Density Height = 3592ft**

In the given conditions, an aircraft taking off at YKRY (1492ft) will experience performance characteristics the same as an aircraft taking off at 3592ft on an ISA day. That is, it will experience a significant loss of performance, when pressure and temperature are considered.




## SUMMARY OF FORMULAS:

**Pressure Height =** (1013 – Actual QNH) x 30ft + Elevation
**Density Height =** (Temp Deviation x 120ft) ± Pressure Height

## PRACTICE QUESTIONS:

Find Density Height for:
1 – Kingaroy, QNH 1020hPa, Temp 16°C
2 – Redcliffe, QNH 1001hPa, Temp 24°C
3 – Toowoomba, QNH 1006hPa, Temp 32°C
4 – Archerfield, QNH 1017hPa, Temp 5°C

Answers:
1 – PH = 1282ft, DH = 1762ft
2 – PH = 367ft, DH = 1567ft
3 – PH = 2296ft, DH = 4936ft
4 – PH = -55ft, DH = -1255ft

**TAKE-OFF & LANDING DISTANCE:**

Calculating pressure and density height is purely academic unless we use the data for a practical purpose. Pilots must be able to accurately calculate PH and DH, as aircraft take-off and landing performance charts require this data in order to extract a takeoff or landing distance required.

**Scenario:** You have calculated the following for your operations at Kingaroy aerodrome:
Pressure Height = +1672ft
Density Height = +3592ft
Aircraft Weight = 2380lbs
The ambient conditions are as follows:
Wind: 050°M/10kt
Temperature: 28°C
Surface: Grass (smaller runway)
Determine the take-off and landing distance required.

1. **Consult the POH Take-off Tables**
   The Cessna 172S POH offers three take-off tables based on increasing aircraft weight (2250lbs, 2400lbs, 2550lbs). You should round your calculated aircraft weight up to the next highest weight table. eg: Given weight is 2380lbs, so the 2400lb performance table will be used.

2. **(Method A) Enter the Table using PH & Temp**
   Using your calculated pressure height of +1672ft, enter the table on the left column. 1672ft should be rounded up to the nearest 500ft, which will take us to 2000ft.

   If the PH happened to be 1450ft and was rounded to 1500ft, an interpolation of the 1000ft and 2000ft data would be required.

   Interpolating is the same as averaging:
   Ground Roll: (1010ft + 1110ft) / 2 = 1060ft
   Total to 50ft: (1720 + 1890) / 2 = 1805ft

   The ambient temperature is 28°C, so rounding up to the 30°C column is suitable. Temps can be interpolated to the nearest 5°C.

3. **(Method B) Enter the Table using Declared DH only**
   If you've obtained DH using a declared density chart (PPL students), you will not have a PH to enter the table. This is okay, because PH and DH are the same if the temperature is at ISA. To use the performance table, you must determine the ISA temperature at the DH of +3592ft, which is 8°C.

   Enter the table using the given DH of +3592ft in the PH column (rounding to 4000ft). The temp will be 10°C, which is the ISA 8°C rounded up.

   Note the answer obtained in 'Method B' is virtually the same as 'Method A', with a slight inaccuracy due to rounding. Both methods are a valid option based on the data you have available.

| Press Alt In Feet | 0°C Grnd Roll Ft | 0°C Total Ft To Clear 50 Ft Obst | 10°C Grnd Roll Ft | 10°C Total Ft To Clear 50 Ft Obst | 20°C Grnd Roll Ft | 20°C Total Ft To Clear 50 Ft Obst | 30°C Grnd Roll Ft | 30°C Total Ft To Clear 50 Ft Obst | 40°C Grnd Roll Ft | 40°C Total Ft To Clear 50 Ft Obst |
|---|---|---|---|---|---|---|---|---|---|---|
| S. L. | 745 | 1275 | 800 | 1370 | 860 | 1470 | 925 | 1570 | 995 | 1685 |
| 1000 | 810 | 1390 | 875 | 1495 | 940 | 1605 | 1010 | 1720 | 1085 | 1845 |
| 2000 | 885 | 1520 | 955 | 1635 | 1030 | 1760 | 1110 | 1890 | 1190 | 2030 |
| 3000 | 970 | 1665 | 1050 | 1795 | 1130 | 1930 | 1215 | 2080 | 1305 | 2230 |
| 4000 | 1065 | 1830 | 1150 | 1975 | 1240 | 2130 | 1335 | 2295 | 1430 | 2455 |
| 5000 | 1170 | 2015 | 1265 | 2180 | 1360 | 2355 | 1465 | 2530 | 1570 | 2715 |
| 6000 | 1285 | 2230 | 1390 | 2410 | 1500 | 2610 | 1610 | 2805 | 1725 | 3015 |
| 7000 | 1415 | 2470 | 1530 | 2685 | 1650 | 2900 | 1770 | 3125 | 1900 | 3370 |
| 8000 | 1560 | 2755 | 1690 | 3000 | 1815 | 3240 | 1950 | 3500 | 2095 | 3790 |

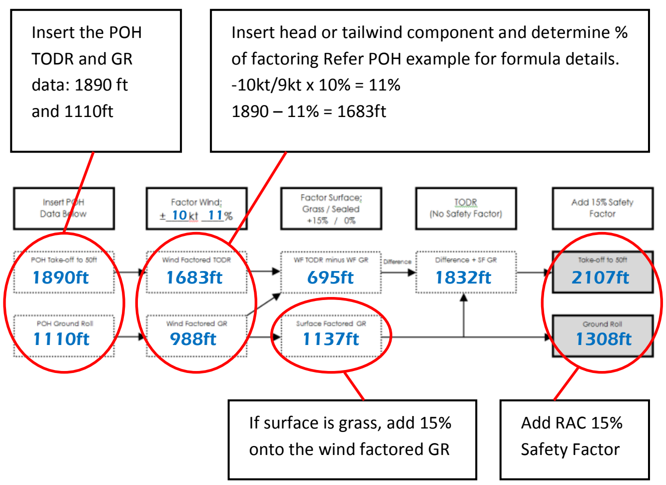
4. **Factoring The POH Data**
   Now that we have a basic take-off distance required (TODR) of 1890ft and ground roll of (GR) of 1110ft, we need to factor these answers for any variables that may affect the distance such as runway surface and wind. The POH specifies the factoring as a percentage and is written below the Performance Tables.

**NOTE**

- Short field technique as specified in Section 4.
- Prior to takeoff from fields above 3000 feet elevation, the mixture should be leaned to give maximum RPM in a full throttle, static runup.
- Decrease distances 10% for each 9 knots headwind. For operation with tail winds up to 10 knots, increase distances by 10% for each 2 knots.
- For operation on dry grass runway, increase distances by 15% of the "ground roll" figure.

Figure 5-5. Short Field Takeoff Distance (Sheet 2)

Use the attached 'Take-off Distance Required Flow Chart' to factor for ambient conditions.




5. **Comparison Against Runway Length**
   Once you've obtained a final TODR, convert to meters and make a comparison of the actual runway length in ERSA. If the calculation is less than the runway length, the operation is considered safe.

   Calculations made with actual ambient data are valid for 15 minutes. Declared conditions are valid for the season of operation.

| **Aircraft Weight & Balance** | |
|---|---|
| Aircraft Type: | Aircraft Rego: |
| Pilot: | Date of Flight: |

| Item | Weight | | Arm | | Moment / 1000 | Aircraft Balanced |
|---|---|---|---|---|---|---|
| | kg | lbs | mm | inches | | |
| Basic Empty Weight | | | | | | |
| Row 1 | | | | | | |
| Row 2 | | | | | | |
| Row 3 | | | | | | |
| Baggage 1 | | | | | | |
| Baggage 2 | | | | | | |
| Zero Fuel Weight | | | | | | ✓ |
| Main Fuel Tanks | | | | | | |
| Aux Fuel Tanks | | | | | | |
| Take-off Weight | | | | | | ✓ |

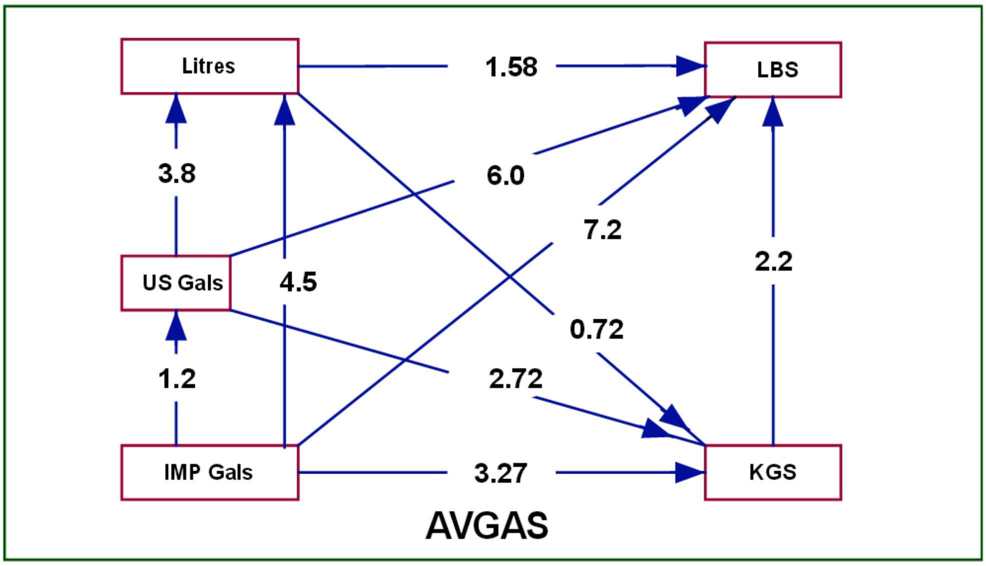
| **Take-off Distance Required** | | Location: |
|---|---|---|
| Pressure Height: | Temperature: | Density Height: |

| Insert POH Data Below | Factor Wind: ±____kt ____% | Factor Surface: Grass / Sealed + % | TODR Factored for Wind and Surface | Add RAC 15% Safety Factor |
|---|---|---|---|---|
| POH Take-off to 50ft → | Wind Factored TODR → | +__% of Ground Roll → | → | Take-off to 50ft |
| POH Ground Roll → | Wind Factored GR → | +__% of Ground Roll → | → | Ground Roll |

| **Landing Distance Required** | | Location: |
|---|---|---|
| Pressure Height: | Temperature: | Density Height: |

| Insert POH Data Below | Factor Wind: ±____kt ____% | Factor Surface: Grass / Sealed + % | LDR Factored for Wind and Surface | Add RAC 15% Safety Factor |
|---|---|---|---|---|
| POH Take-off to 50ft → | Wind Factored LDR → | +__% of Ground Roll → | → | Take-off to 50ft |
| POH Ground Roll → | Wind Factored GR → | +__% of Ground Roll → | → | Ground Roll |

| From | Into | Factor (multiply or divide) |
|---|---|---|
| Inches | Centimeters | x 2.54 |
| Inches | Millimeters | x 25.4 |
| Feet | Meters | x 0.3048 |
| Pounds | Kilograms | / 2.2046 |
| Kilometers | Nautical Miles | / 0.539 |
| US Gallons | Litres | x 3.79 |
| Litres of AVGAS | KG of Avgas | x 0.72 |
| US Gallons of AVGAS | KG of Avgas | x 2.72 |
| | | |




1. To convert:
   **multiply** by the factor in the "balloon" when moving in the direction of the arrow, or
   **divide** by that factor if converting in the opposite direction.

2. Fuel SG (0.8 AVTUR and 0.72 AVGAS) is based on ISA temperature at MSL.
   Therefore, fuel weights will be approximate for other than 15DEG Celsius.