Importance of Weight and Balance

• Controllability
  – Longitudinal Stability requires center of gravity to be within limits
  – Elevator may not have enough authority for abnormal loadings

• Structural
  – Max gross weight is typically limited by airframe stress in turbulence

• Performance with higher weights
  – Stall speed increases
  – Takeoff distances increase
  – Climb rate reduced
  – Cruise speeds decrease
  – Fuel Economy is reduced
  – Landing distance increase
  – Over-gross: test pilot territory! (but military does it and round-the-world pilots)
Weight Terms

- **Empty Aircraft**
  - **Standard Empty Weight** – weight of a standard airplane including unusable fuel, full operating fluids and full oil
  - **Basic Empty Weight** – Standard Empty Weight plus optional equipment
    - Starting Point of Weight and Balance

- **Fuel**
  - **Usable Fuel** – fuel which can be used for flight planning
  - **Unusable Fuel** – fuel which cannot be use in flight due to fuel tank design
  - **6 lbs per gallon for gasoline (6.7 for Jet A)**

- **Weight**
  - Force that acts straight down to the center of the Earth
  - Decreases with fuel burn

- **Loaded Aircraft**
  - **Maximum Ramp Weight**
    - Maximum allowable mass for ground operations
    - Assures ground maneuverability
    - Includes fuel for taxi, run-up and start
  - **Maximum Takeoff Weight**
    - Maximum allowable mass for initiation of takeoff roll
  - **Maximum Landing Weight**
    - Maximum allowable mass at touchdown
    - Generally limitation of landing gear and associated structure
  - **Baggage Compartment Limits**
    - Structural limitation to prevent bracket/bulkhead/floor failure
Weight Terms

• **Useful Load – total usable fuel, passengers, and cargo**
  - Maximum Ramp Weight – Basic Empty Weight = Useful Load

• **Payload – passengers and cargo**
  - What essentially could be generating revenue

• **Zero Fuel Weight – Weight of aircraft without fuel**
  - Typically a limitation for jets

\[
\begin{align*}
\text{Basic Empty Weight} & \quad + \quad \text{Payload} \\
\text{} & \quad = \quad \text{Zero Fuel Weight} \\
\text{Zero Fuel Weight} & \quad + \quad \text{Usable Fuel} \\
\text{} & \quad = \quad \text{Ramp Weight} \\
\text{Ramp Weight} & \quad - \quad \text{Fuel used for start, taxi and run-up} \\
\text{} & \quad = \quad \text{Takeoff Weight} \\
\text{Takeoff Weight} & \quad - \quad \text{Fuel used for flight} \\
\text{} & \quad = \quad \text{Landing Weight}
\end{align*}
\]

Balance Terms

• **Arm**
  - Distance from the datum measured along the longitudinal axis
  - If located in front of datum, negative
  - If located in back of datum, positive

• **Moment**
  - Weight multiplied by its arm
  - Tendency of a mass to cause a rotation about the Center of Gravity

• **Reference Datum ("pivot point")**
  - Reference base for location of components
  - Imaginary vertical plane
  - Location specified from manufacturer
  - Lies on longitudinal axis
  - Warrior – 78.4 inches from wing leading edge

• **Center of Gravity (CG)**
  - Point of a mass through which gravity acts
  - Point where aircraft would balance if suspended
  - Point where all three axis intersect
  - Divide total moment of aircraft by weight of aircraft
Basic W&B Math

- Moment = Weight X Arm
- Location of the Center of Gravity

\[
\text{Location}_{CG} = \frac{\text{Sum of All Moments}}{\text{Gross Weight}}
\]

- For the next few examples...
  - The seesaw is synonymous with the aircraft
  - The people are synonymous with the weight of fuel, equipment, passengers, etc...
  - The fulcrum can be thought of as lift, supporting the entire mass
  - The datum can be considered the nose of the aircraft

See-Saw Example

- Where should we put the Green weight to balance the See-Saw
- Moment on Right
  - 5*10+20*20=450
  - Moment = 450
- Moment on Left
  - Moment must = 450
  - 8*X=450
  - X = 56.25 inches
Finding Center of Gravity

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight</th>
<th>Arm 10 inches</th>
<th>Arm 20 inches</th>
<th>Arm 50 inches</th>
<th>Arm 62 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple</td>
<td>5</td>
<td>10</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lavender</td>
<td>3</td>
<td>20</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>8</td>
<td>50</td>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>10</td>
<td>62</td>
<td>620</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Board</td>
<td>15</td>
<td>35</td>
<td>525</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Weight: 41 lbs, Total Moment: 1655 lb-inches

Center of Gravity: 1655/41 = 40.37 inches

Once we know where the CG is, we can support the entire board there and it will balance.

Basic W&B Relationships

- Center of Gravity Limits
Results of Aircraft Overloading

- Stall Speed ➔ Increases
- Takeoff and Landing Distance ➔ Increases
- Climb Rate ➔ Reduced
- Cruise Speed ➔ Reduced
- Fuel Consumption ➔ Greater
- Range and Endurance ➔ Reduced
- Stability ➔ Increased

- Overweight aircraft no longer certified as structurally sound throughout its flight envelope. You become a test pilot!

Results of a Forward CG

- Static Longitudinal Stability becomes excessive
  - Rotation and Flare are more difficult
- Takeoff Roll ➔ Increased
- Cruise Speed ➔ Decreased
  - A greater tail down force must be produced. For a given angle of attack, this requires elevator deflection and increases drag.
- Climb Rate ➔ Reduced
- Range and Endurance ➔ Reduced
- Stall Speed ➔ Increased
Effects of an Aft CG

- Longitudinally Stability ➔ Reduced
- Takeoff Roll ➔ Reduced
  - Tendency to Over-Rotate
- Landing Roll ➔ Reduced
  - Tendency to Over-Flare
- Cruise Speeds ➔ Increased
  - Less tail down force, is less drag
- Climb Rates ➔ Increased
- Fuel Consumption ➔ Decreased
- Range and Endurance ➔ Increased
- Stall Speeds ➔ Reduced
  - Recovery hindered due to reduced longitudinal stability

SECTION 6
WEIGHT & BALANCE/EQUIPMENT LIST

LOADING ARRANGEMENTS

- Pilot or passenger center of gravity on adjustable seats positioned for average occupant. Numbers in parentheses indicate forward and aft limits of occupant center of gravity range.

**Baggage area center of gravity.

NOTES:
1. The usable fuel C.G. arm is located at station 43.0.
2. The aft baggage wall (approximate station 166) can be used as a convenient interior reference point for determining the location of baggage area fuselage station.

Figure 6-3. Loading Arrangements
Calculating Weight and Balance

- For each flight, the PIC is required to calculate weight and balance of the aircraft
- The Pilot Operating Handbooks of aircraft contains the information required to calculate weight and balance
- [http://trumpetb.net/alph/wb172N.html](http://trumpetb.net/alph/wb172N.html)
  - Note: uses 7 lb/gal instead of 6 lb/gal
- In the Warrior POH, section 6 contains...
  - Weight and Balance Calculation procedure for the aircraft
  - Basic Empty Weight and Moment of the aircraft
  - Changes to the Weight and Balance

Computation Method

- This method uses the basic weight and balance formula to determine center of gravity
  - Can be used for most aircraft
  - Extremely accurate, fewer arithmetic errors
- Example: Piper Warrior (PA-28-161)

- Procedure
  1. Determine the Basic Empty Weight of the aircraft
  2. Find the moment of each weight to be carried
  3. Add all moments and all weights
  4. Divide the total moment by the total weight. This number is your Center of Gravity
  5. Compare this number to the CG limits for the aircraft
Weight and Balance

Piper Warrior

For our first problem, we use a weight and balance form for a Piper Warrior.

Piper Warrior

<table>
<thead>
<tr>
<th>Weight (lbs.)</th>
<th>Arm (in.)</th>
<th>Moment (lbs.-in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Empty Weight</td>
<td>1,500</td>
<td>128,850</td>
</tr>
<tr>
<td>Pilot, Front Passengers</td>
<td>340</td>
<td>80.5</td>
</tr>
<tr>
<td>Rear Passengers</td>
<td>340</td>
<td>118.1</td>
</tr>
<tr>
<td>Baggage (200 lb. Max)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero Fuel Condition</td>
<td>2,180</td>
<td>196,374</td>
</tr>
</tbody>
</table>

Next, check ramp condition.
Piper Warrior

<table>
<thead>
<tr>
<th>Weight (lbs.)</th>
<th>Arm (in.)</th>
<th>Moment (lbs.-in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Empty Weight</td>
<td>1,500</td>
<td>128,850</td>
</tr>
<tr>
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<td>118.1</td>
</tr>
<tr>
<td>Baggage (200 lb. Max)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero Fuel Condition</td>
<td>2,180</td>
<td></td>
</tr>
<tr>
<td>Fuel (48 gallons max)</td>
<td>267</td>
<td>95</td>
</tr>
<tr>
<td>Ramp Condition</td>
<td>2,447</td>
<td></td>
</tr>
<tr>
<td>Taxi, start, runup fuel</td>
<td>- 7</td>
<td>95</td>
</tr>
<tr>
<td>Takeoff condition</td>
<td>2,440</td>
<td>90.6</td>
</tr>
</tbody>
</table>

Go for Take-Off!
Check Landing Condition

<table>
<thead>
<tr>
<th>Weight (lbs.)</th>
<th>Arm (in.)</th>
<th>Moment (lbs.-in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff condition</td>
<td>2,440</td>
<td>90.6</td>
</tr>
<tr>
<td>Cruise fuel (30 gallons)</td>
<td>-180</td>
<td>95.0</td>
</tr>
<tr>
<td>Landing condition</td>
<td>2,260</td>
<td>90.25</td>
</tr>
</tbody>
</table>

Private Pilot Ground School
Use App

- N707WT Cirrus SR20:
  - Empty weight 2124.02
  - CG 140.49 in
  - Moment 298,414
- Pilot: 200; Copilot: 80; Rear seat: 190; Baggage: 50
- Fuel: 50 gallons at start; 15 to burn

Web and Spreadsheets

- West Valley Flying Club: [example SR20](http://example.com)
- [Journeys Aviation](https://journeysaviation.com) (Colorado)
- [A spreadsheet for an SR20](https://example.com/spreadsheet)
- Fltplan.com offers a tool
Chart Method

1. Find the tabular data provided in Section 6 of the POH. (These may or may not be provided)
2. Correlate the weight to the appropriate tables to determine the moment. (interpolate if necessary)
3. Add the moments determined from the tables and correlate them to the CG Limit chart.

Table Method

• Procedure
  1. Find the tabular data provided in Section 6 of the POH. (These may or may not be provided)
  2. Correlate the weight to the appropriate tables to determine the moment. (interpolate if necessary)
  3. Add the moments determined from the tables and correlate them to the CG Limit chart.
The empty weight and moment of the airplane at the time of delivery are shown on the airplane Empty Weight and Balance form. Useful load items which may be loaded into the airplane are shown on the Useful Load Weights and Moment tables. The minimum and maximum moments are indicated on the Moment Limits vs Weight table. These moments correspond to the forward and aft center of gravity limits for a particular weight. All moments are divided by 100 to simplify computations.

PILOT & F. PASS | F.S. | PWD POS | 85 | AFT POS | 118

MAXIMUM WEIGHT 270 POUNDS INCLUDING EQUIPMENT AND BAGGAGE.
MAXIMUM WEIGHT 200 POUNDS FORWARD OF REAR SPAR INCLUDING EQUIPMENT AND CARGO WITH REAR SEAT REMOVED.
MAXIMUM WEIGHT 270 POUNDS AFT OF REAR SPAR INCLUDING EQUIPMENT AND CARGO WITH REAR SEAT REMOVED.

ALL BAGGAGE/CARGO MUST BE SECURED

USEFUL LOAD WEIGHTS AND MOMENTS

<table>
<thead>
<tr>
<th>Weight</th>
<th>Front Seats</th>
<th>Rear Seat</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOM/100</td>
<td>ARM 89</td>
<td>ARM 89</td>
</tr>
<tr>
<td>120</td>
<td>102</td>
<td>107</td>
</tr>
<tr>
<td>130</td>
<td>110</td>
<td>116</td>
</tr>
<tr>
<td>140</td>
<td>115</td>
<td>125</td>
</tr>
<tr>
<td>150</td>
<td>128</td>
<td>124</td>
</tr>
<tr>
<td>160</td>
<td>136</td>
<td>142</td>
</tr>
<tr>
<td>170</td>
<td>144</td>
<td>151</td>
</tr>
<tr>
<td>180</td>
<td>153</td>
<td>160</td>
</tr>
<tr>
<td>190</td>
<td>163</td>
<td>169</td>
</tr>
<tr>
<td>200</td>
<td>170</td>
<td>178</td>
</tr>
</tbody>
</table>

NOTE: OCCUPANT POSITIONS FOR ADJUSTABLE SEATS ARE SHOWN AT THEIR EXTREME POSITIONS. INTERMEDIATE POSITIONS WILL REQUIRE INTERPOLATION OF THE MOMENT/100 VALUES.

BAGGAGE (Continued)

<table>
<thead>
<tr>
<th>Weight</th>
<th>Moment/100</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>14</td>
<td>70</td>
</tr>
<tr>
<td>20</td>
<td>26</td>
<td>60</td>
</tr>
<tr>
<td>30</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>66</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>60</td>
<td>84</td>
<td>120</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weight</th>
<th>Moment/100</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>14</td>
<td>70</td>
</tr>
<tr>
<td>20</td>
<td>26</td>
<td>60</td>
</tr>
<tr>
<td>30</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>66</td>
<td>100</td>
</tr>
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<td>70</td>
<td>110</td>
</tr>
<tr>
<td>60</td>
<td>84</td>
<td>120</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>Moment/100</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>14</td>
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<td>30</td>
<td>42</td>
<td>50</td>
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<tr>
<td>40</td>
<td>66</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>70</td>
<td>110</td>
</tr>
<tr>
<td>60</td>
<td>84</td>
<td>120</td>
</tr>
</tbody>
</table>
Questions?

Back-up
Weight & Balance – Cessna P210

- Basic Empty Weight: 2,632 lbs. (Moment 109,000)
- Front Seat (170 lbs.)
- Center Seat (160 and 150 lbs)
- Aft Seat (200 and 170 lbs)
- Baggage Area A (150 lbs)
- Baggage Area B (0)
### Zero Fuel Condition

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight</th>
<th>Arm</th>
<th>Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEW</td>
<td>2632</td>
<td></td>
<td>109000</td>
</tr>
<tr>
<td>Front Seat</td>
<td>170</td>
<td>37</td>
<td>6290</td>
</tr>
<tr>
<td>Center Seat</td>
<td>310</td>
<td>71</td>
<td>22010</td>
</tr>
<tr>
<td>Aft Seat</td>
<td>370</td>
<td>102</td>
<td>37740</td>
</tr>
<tr>
<td>Baggage A</td>
<td>150</td>
<td>138</td>
<td>20700</td>
</tr>
<tr>
<td><strong>Zero-Fuel</strong></td>
<td><strong>3632</strong></td>
<td><strong>53.89</strong></td>
<td><strong>195740</strong></td>
</tr>
</tbody>
</table>

### Ramp Condition

- Add 64 gallons of fuel

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight</th>
<th>Arm</th>
<th>Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Zero-Fuel</strong></td>
<td>3632</td>
<td>53.89</td>
<td>195740</td>
</tr>
<tr>
<td>Fuel</td>
<td>384</td>
<td>43</td>
<td>16512</td>
</tr>
<tr>
<td><strong>Ramp Weight</strong></td>
<td><strong>4016</strong></td>
<td><strong>52.85</strong></td>
<td><strong>212252</strong></td>
</tr>
</tbody>
</table>
Takeoff Condition

- Run-up: minus 16 lbs of fuel

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight</th>
<th>Arm</th>
<th>Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp Weight</td>
<td>4016</td>
<td>52.85</td>
<td>212252</td>
</tr>
<tr>
<td>Run-up</td>
<td>-16</td>
<td>43</td>
<td>-688</td>
</tr>
<tr>
<td>Takeoff</td>
<td>4000</td>
<td>52.89</td>
<td>211564</td>
</tr>
</tbody>
</table>
Shift a Passenger

- Move the 200 lb passenger from the aft seat to the front seat

- Equation:

\[
\frac{\text{WEIGHT MOVED}}{\text{WEIGHT OF AIRPLANE}} = \frac{\text{DISTANCE CG MOVES}}{\text{DISTANCE BETWEEN ARMS}}
\]
**Fuel Burn**

- 2.5 hour flight at 20 gallons per hour

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight</th>
<th>Arm</th>
<th>Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff</td>
<td>4000</td>
<td>49.64</td>
<td>198560</td>
</tr>
<tr>
<td>Fuel Burn</td>
<td>(2.5 x 20 x 6) -300</td>
<td>43</td>
<td>-12900</td>
</tr>
<tr>
<td>Landing</td>
<td>3700</td>
<td>50.18</td>
<td>185660</td>
</tr>
</tbody>
</table>
Questions?