Performance Characteristics We Want to Predict

Airplanes:
- Takeoff Distance: Ground Roll/Over 50’ Obstacle
- Climb Rate
- Time, Distance, Fuel to Climb
- Cruise Speed, Fuel Consumption
- Time, Distance, Fuel to Descend
- Landing Distance Ground Roll
- Landing Distance Over 50 ft Obstacle

• Helicopters
  - Ability to hover in/out of ground effect
Importance of Performance

91.103 — Preflight action.
• Each pilot in command shall, before beginning a flight, become familiar with all available information concerning that flight. This information must include:
  – ... information appropriate to the aircraft, relating to aircraft performance under expected values of airport elevation and runway slope, aircraft gross weight, and wind and temperature.

Reminder: Thrust and Drag

• As the aircraft produces lift, it also creates drag
  – “Induced drag”
  – Decreases as airspeed increases
• As the aircraft moves through the air, there is friction between the air and the skin of the aircraft
  – “Parasitic drag”
  – Increases as airspeed increases
• The sum of the two curves gives total drag of the aircraft
  – In order to maintain airspeed, the thrust provided by the aircraft must equal the total drag
• “Back Side of the Power Curve”
  – A decrease in airspeed requires an increase in power

(Note: To get the power curve, multiply Drag And Thrust by airspeed)
Climb Performance

• Best Angle of Climb ($V_A$):
  – Greatest gain in altitude over the shortest distance
    • Increases with altitude (TAS)
    • Wind changes climb angle, but $V_A$ calculated for calm wind

• Best Rate of Climb ($V_Y$)
  – Greatest gain in altitude over the shortest time
    • Decreases with altitude (TAS)
    • Independent of wind

• Cruise Climb
  – Increases Ground Speed
  – Increases Forward Visibility
  – Better Engine Cooling
  – 87 Knots in Warrior (79 Vy); 105 for Cirrus SR20 (96 Vy); 150 for PC-12 (120 Vy)

Climb Thrust and Power

• Thrust is the forward acting force created by the propeller
  – As airspeed increases, the thrust created by the propeller decreases
  – The more excess thrust an aircraft has, the steeper it can climb (i.e. higher angle of climb)

• Power is defined as $\text{thrust} \times \text{speed}$
  – Roughly constant with airspeed for piston aircraft
  – The more excess power available, the higher the RATE at which an aircraft can climb
Best Glide Ratio

- What airspeed would you fly when you lost your engine? Why?

- \((L/D)_{MAX}\) is the airspeed at which the aircraft covers maximum distance for a given altitude loss.

Effects of Weight on Performance

- As weight increases...
  - Takeoff distances increase
  - Cruise speeds decrease
  - Fuel Economy is reduced
  - Landing distance increase

- Remember...
  - Any increase in weight results in a needed increase in lift, thus less thrust available.
Effects of Wind on Performance

**Headwind**
- Better takeoff performance
- Better climb angle
- Decreased cruise range (lower ground speed)
- Better landing performance (shorter ground roll)

**Tailwind**
- Worse takeoff performance (need to roll farther to build up required airspeed)
- Worse climb angle (being pushed into trees)
- Better cruise range
- Worse landing performance (higher ground speed requires more time/distance for braking)

Center of Gravity

**Forward Center of Gravity**
- Increased Stability
- Longer Takeoff Distance
- Decreased Climb Rates
- Slower Cruise Speeds
- Decreased Range
  - More tail down force

**Aft Center of Gravity**
- Decreased Stability
- Shorter Takeoff Distances
- Increased Climb Rates
- Faster Cruise Speeds
- Increased Range
  - Less tail down force

Source: Public Domain
Atmospheric Pressure

Effect of Temperature on Atmospheric Pressure

A Simple “Mental Model” of Atmospheric Pressure

Source: Public Domain

Effect of Atmospheric Pressure

- Aircraft performance is primarily affected by changes in air density
  - Air density in turn is primarily affected by pressure, temperature and humidity
- For each flight, performance needs to be calculated under the prevailing conditions
  - Conditions are usually referenced to the international standard atmosphere (ISA)
- As air density decreases:
  - The engine cannot take in as much air for combustion
  - The propeller cannot grab as much air for thrust
  - Drag is reduced

<table>
<thead>
<tr>
<th>Standard Atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude (ft)</td>
</tr>
<tr>
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</tr>
<tr>
<td>1,000</td>
</tr>
<tr>
<td>2,000</td>
</tr>
<tr>
<td>3,000</td>
</tr>
<tr>
<td>4,000</td>
</tr>
<tr>
<td>5,000</td>
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<tr>
<td>18,000</td>
</tr>
<tr>
<td>19,000</td>
</tr>
<tr>
<td>20,000</td>
</tr>
</tbody>
</table>
Pressure Altitude

- **Pressure Altitude**
  - Height above the Standard Datum Plane (29.92 in. Hg)
- **To calculate pressure altitude at an airport:**
  - Standard Lapse Rate: 1000’ per 1” Hg
  - Standard atmospheric pressure: 29.92” Hg

\[(29.92 - \text{altimeter setting}) \times 1000 + \text{Field Elevation} = \text{Airport Surface Pressure Altitude}\]

Determining Pressure Altitude

- **Elevation 3563’;**
  - Altimeter 29.96
- **Interpolate between 29.92 and 30.00**
  - \(-\frac{73}{2} = 36.5\)
- **3563 - 36.5 = 3526.5’**
- **Or use formula:** \((29.92 - 29.96) \times 1000 + 3563 = 3523’\)

Source: Public Domain
Density Altitude

• Density Altitude
  – Pressure Altitude corrected for non-standard temperature (15° C)
• Big performance impact
• The temperature / density relationship is nonlinear.
  – A simple formula to calculate Density Altitude does not exist
• To calculate Density Altitude:
  – Performance Charts
  – E6B
  – Electronic Flight Computer
  – Web/App

Determining Density Altitude

• Determine density altitude
  – Airport elevation 5250 MSL
  – Altimeter Setting 29.25
  – Temperature 81 F

1. Interpolate between 29.2 and 29.3 on Conversion Factor chart (+626 ft)
2. Convert airport elevation to pressure altitude (5250+626 = 5876 ft)
3. Use graph to determine density altitude from pressure altitude (8250 ft)
4. Flight Computer demo (if time)
Density Altitude (cont’d)

• When are Density Altitude and Pressure Altitude the same?

• Answer: If the temperature distribution of the atmosphere is the same as that of the standard atmosphere

Humidity: Another Enemy

• Relative humidity: ratio of water in the air to the water that the air could hold

• Higher Humidity -> Higher Density Altitude

• Smaller effect than temperature, but very high humidity can reduce engine output by 7 percent.
Experiment with Humidity: change dewpoint to 10°C -> 7735'
Computing Density Altitude
Pilot Operating Manual

Density Altitude “baked in” to many performance charts

Other Factors affecting Performance

- Turbulence
  - Decreases maneuverability and controllability
  - Requires reduced airspeed
- Pilot technique:
  - Rotation speed
  - Proper/constant pitch attitude
  - Aircraft Configuration: think about a go-around
    - Flaps
    - Landing Gear
    - Cowl Flaps (Beriev Be-103)
    - Spoilers (AA 965)
Runway Condition

- Best numbers: Dry, Paved Runway
- Dry Grass
  - +20% ground roll (Cirrus SR20)
- Wet Grass
  - +30% ground roll takeoff (Cirrus SR20)
  - +60% ground roll landing (SR20)
- Gravel Runways
  - Slight reduction in performance
- Wet Grooved Runways
  - Similar to Dry, Paved

Cessna Mustang* numbers for “adverse runway conditions”:
- Dry: 3000’
- Wet: 4240’
- 0.2 inches water: 4800’
- 0.2 inches slush or wet snow: 4950’
- 0.1 inches dry snow: 5100’
- Compact snow: 5300’
- Wet ice: off chart (16,600’ if dry number is 2200’)

* turbojet that lands at Baron speeds.

Runway Slope and Ground Roll

- Up
  - Increased takeoff (SR20: 22% at sea level for every 1%; 43% at 10,000’)
  - Decreased landing (SR20: 9% for every 1%)
- Down
  - Decreased takeoff (SR20: 7% at sea level for every 1%; 14% at 10,000’)
  - Increased landing (SR20: 27% for every 1%)
Ceiling

- **Absolute Ceiling**
  - Altitude where the aircraft will no longer climb
    - Altitude where $V_x$ and $V_y$ are the same
- **Service Ceiling:**
  - Where maximum rate of climb is 100 feet per minute (fpm) at max weight and ISA (13,500’ for Cessna 172R)
- Determined using the Maximum Rate of Climb Chart

Range vs. Endurance

- **Range:** greatest distance an aircraft can travel
- **Max-range airspeed** depends on:
  - Weight
  - Wind
- **Endurance:** time the aircraft can remain aloft
  - Minimum fuel consumption to maintain altitude
  - Useful if waiting one’s turn for Oshkosh, waiting for a runway to reopen, loitering for surveillance, lost
- Robinson R44 helicopter: 100 knots max-range; 55 knots max endurance.
Max endurance = minimum fuel consumption per hour.

Max range = minimum fuel consumption per mile.

Power = thrust * velocity

PREDICTING PERFORMANCE FOR ALL FLIGHT PHASES
Landing and Takeoff Performance

- **Terms**
  - Ground Roll
  - Distance with 50’ Obstacle: static start to 50’ AGL

![Diagram showing ground roll and distance to clear a 50' obstacle.](image-url)
Landing Performance
Additional Factors

- Pilot Technique
  - Braking
  - Stabilized Approach

- Turbulence
  - Increase approach speed
  - During gusty conditions, increase approach speed by 1/2 the gust factor (rule of thumb). With METAR wind 35015G25KT
    - Gust Factor: 25 – 15 = 10
    - 1/2 of Gust Factor: 10/2 = 5
    - Approach at 80 knots instead of 75 (Cirrus SR20)

- Flaps:
  - Approach Speed reduced
  - Approach Angle increased

Takeoff/Landing Performance Charts

- Charts differ based on configuration and desired performance value. Piper Warrior POH includes...
  - 0° Flaps Takeoff Ground Roll
    - Used for Normal Takeoff
  - 0° Flaps Takeoff Performance (50’ Standard Obstacle)
  - 25° Flaps Takeoff Ground Roll
    - Used when necessary to leave runway surface sooner
  - 25° Flaps Takeoff Performance (50’ Standard Obstacle)
    - Used when obstacle clearance is necessary

- Flight school renters: remember that they made the charts with a new aircraft and engine!
- Everyone: remember that a professional test pilot demonstrated those numbers. (FAR 121 and 135 add margins)
Wind Components

- Note Headwind: shortens takeoff and landing distances
- Check Tailwind: stay within limitations for high-performance aircraft
- Check Crosswind: ensure sufficient rudder authority (increases with airspeed so maybe adjust flap use)

Wind 26040KT; Rwy 29

Heavy Crosswind?
- Check Limitations
- Check Max Demonstrated
- Consider reduced flaps

Philip's Anecdote:
You can get a jet type rating at FlightSafety even if you can’t use this chart.
Takeoff Performance

Example:
- OAT: 15°C (59°F)
- Pressure altitude: 5,800 feet
- Takeoff weight: 2,500 lb
- Headwind component: 90 knots

Ground run:
- Total distance over a 50-foot obstacle: 2,200 feet
- Takeoff speed at 50 feet: 96 knots (110 mph)

Associated conditions:
- Power: Full throttle 2,600 rpm
- Mixture: Lean to appropriate fuel pressure
- Flaps: Up
- Landing Retract after positive gear established
- Crawl: Open

Table: Takeoff speed

<table>
<thead>
<tr>
<th>Weight</th>
<th>Lift-off</th>
<th>50 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,950</td>
<td>66</td>
<td>73</td>
</tr>
<tr>
<td>2,800</td>
<td>64</td>
<td>70</td>
</tr>
<tr>
<td>2,600</td>
<td>61</td>
<td>66</td>
</tr>
<tr>
<td>2,200</td>
<td>58</td>
<td>63</td>
</tr>
</tbody>
</table>

Pilatus PC-12, Flaps 15

Table: Takeoff total distance - Flaps 15°

<table>
<thead>
<tr>
<th>WEIGHT</th>
<th>V1</th>
<th>V2</th>
<th>VREF</th>
<th>XREF</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,000</td>
<td>64</td>
<td>73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7,000</td>
<td>67</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8,000</td>
<td>71</td>
<td>84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9,000</td>
<td>75</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10,000</td>
<td>74</td>
<td>95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10,000</td>
<td>81</td>
<td>103</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Why Cirrus is the best seller

Takeoff Distance: 3000 LB

<table>
<thead>
<tr>
<th>PRESS ALT FT</th>
<th>DISTANCE</th>
<th>TEMPERATURE °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>SL Gnd Roll</td>
<td>1297</td>
<td>1300</td>
</tr>
<tr>
<td>50 ft</td>
<td>1848</td>
<td>1988</td>
</tr>
<tr>
<td>1000 Gnd Roll</td>
<td>1412</td>
<td>1526</td>
</tr>
<tr>
<td>50 ft</td>
<td>2022</td>
<td>2175</td>
</tr>
<tr>
<td>2000 Gnd Roll</td>
<td>1552</td>
<td>1676</td>
</tr>
<tr>
<td>50 ft</td>
<td>2214</td>
<td>2381</td>
</tr>
<tr>
<td>3000 Gnd Roll</td>
<td>1706</td>
<td>1842</td>
</tr>
<tr>
<td>50 ft</td>
<td>2426</td>
<td>2609</td>
</tr>
</tbody>
</table>

Rate of Climb?

Gross Weight 1,670 lbs
Press. Alt at Takeoff 2,000 ft
Temperature 68° F (20° C)
Rate of Climb?
Climb Speed?
### POH Table

<table>
<thead>
<tr>
<th>Weight lbs</th>
<th>Press alt ft</th>
<th>Climb Speed kias</th>
<th>Rate of climb - fpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1670</td>
<td>S.L. 2000</td>
<td>67</td>
<td>835 765 700 630</td>
</tr>
<tr>
<td></td>
<td>4000</td>
<td>68</td>
<td>735 670 600 535</td>
</tr>
<tr>
<td></td>
<td>6000</td>
<td>65</td>
<td>635 570 505 445</td>
</tr>
<tr>
<td></td>
<td>8000</td>
<td>65</td>
<td>635 570 505 445</td>
</tr>
<tr>
<td></td>
<td>10,000</td>
<td>63</td>
<td>535 475 415 355</td>
</tr>
<tr>
<td></td>
<td>12,000</td>
<td>62</td>
<td>440 380 320 265</td>
</tr>
<tr>
<td></td>
<td></td>
<td>61</td>
<td>340 285 230 175</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>245 190 135 85</td>
</tr>
</tbody>
</table>

**Conditions:** Flaps up, Full throttle

**Note:** Mixture leaned above 3000 feet for maximum rpm.

---

### Maximum Rate of Climb

- **Gross Weight:** 1,670 lbs
- **Press. Alt at Takeoff:** 2,000 ft
- **Temperature:** 68° F (20° C)
- **Rate of Climb?** 600 fpm
- **Climb Speed?** 66 KIAS
ASSOCIATED CONDITIONS:
- GROSS WEIGHT: 2440 lb.
- POWER: FULL THROTTLE
- MIXTURE: FULL RICH
- FLAPS: UP
- AIRSPEED: 79 KIAS

MAXIMUM RATE OF CLimb
- PRESSURE ALTITUDE: 5000FT
- OAT: 16°C (ISA + 11°C)
- MAX RATE OF CLIMB: 374 FPM

CLIMB PERFORMANCE

Cruise Charts – Tabular Example

<table>
<thead>
<tr>
<th>PRESSURE ALTITUDE (FEET)</th>
<th>ISA - 15°C</th>
<th>ISA</th>
<th>ISA + 10°C</th>
<th>ISA + 20°C</th>
<th>ISA + 30°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>628</td>
<td>555</td>
<td>574</td>
<td>554</td>
<td>534</td>
</tr>
<tr>
<td>2000</td>
<td>578</td>
<td>545</td>
<td>524</td>
<td>504</td>
<td>485</td>
</tr>
<tr>
<td>3000</td>
<td>528</td>
<td>495</td>
<td>475</td>
<td>455</td>
<td>436</td>
</tr>
<tr>
<td>4000</td>
<td>478</td>
<td>446</td>
<td>425</td>
<td>405</td>
<td>386</td>
</tr>
<tr>
<td>5000</td>
<td>429</td>
<td>398</td>
<td>378</td>
<td>358</td>
<td>337</td>
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<tr>
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<td>379</td>
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<td>99</td>
<td>79</td>
<td>59</td>
<td>40</td>
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<tr>
<td>12000</td>
<td>83</td>
<td>48</td>
<td>29</td>
<td>9</td>
<td>-10</td>
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<tr>
<td>13000</td>
<td>33</td>
<td>0</td>
<td>-21</td>
<td>-41</td>
<td>-60</td>
</tr>
</tbody>
</table>

Cruise power settings

<table>
<thead>
<tr>
<th>PRESS ALTITUDE (FT)</th>
<th>ISA - 20°C (-56°F)</th>
<th>Standard day (ISA)</th>
<th>ISA +25°C (+36°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press Alt. (FT)</td>
<td>IOAT</td>
<td>Engine Speed</td>
<td>MAN. press</td>
</tr>
<tr>
<td>Ave. 2,500</td>
<td>19</td>
<td>2,400</td>
<td>66</td>
</tr>
<tr>
<td>Ave. 2,500</td>
<td>17</td>
<td>2,400</td>
<td>66</td>
</tr>
<tr>
<td>Ave. 2,500</td>
<td>15</td>
<td>2,400</td>
<td>66</td>
</tr>
<tr>
<td>Ave. 2,500</td>
<td>13</td>
<td>2,400</td>
<td>66</td>
</tr>
<tr>
<td>Ave. 2,500</td>
<td>11</td>
<td>2,400</td>
<td>66</td>
</tr>
<tr>
<td>Ave. 2,500</td>
<td>9</td>
<td>2,400</td>
<td>66</td>
</tr>
<tr>
<td>Ave. 2,500</td>
<td>7</td>
<td>2,400</td>
<td>66</td>
</tr>
</tbody>
</table>

Note:
1. Full throttle manifold pressure settings are approximate.
2. Shaded area represents operation with full throttle.

Source: Public Domain
Landing Performance Example

8. (Refer to Figure 40.) Determine the total distance required for takeoff to clear a 50-foot obstacle.

OAT.................................Std
Pressure altitude................Sea level
Takeoff weight....................2,700 lb
Headwind component..............Calm

☐ A. 1,000 feet.
☐ B. 1,400 feet.
☐ C. 1,700 feet.
The Easy Way

- Runway numbers for low performance aircraft: using POH remains common
- Apps are available and, in the turbine world, standard.
- Everyone: Web or app for calculating time and fuel requirements.
Gyronimo (not free)

PC-12 AFM (free/$5 million)

Note: Accelerate-Stop based on chopping power at roughly 80 knots and pulling condition lever back to Ground Idle (good luck remembering that!).
Questions?