Performance and Limitations

Objective

Gain an intuitive understanding of how atmospheric conditions affect aircraft performance, and how to use our airplane's performance charts to compute specific performance numbers.

Motivation

Altitude, temperature, and pressure affect all aspects of our airplane's performance. All pilots need to understand how these factors affect the capabilities of the airplane and how that affects the safety of flight.

Overview

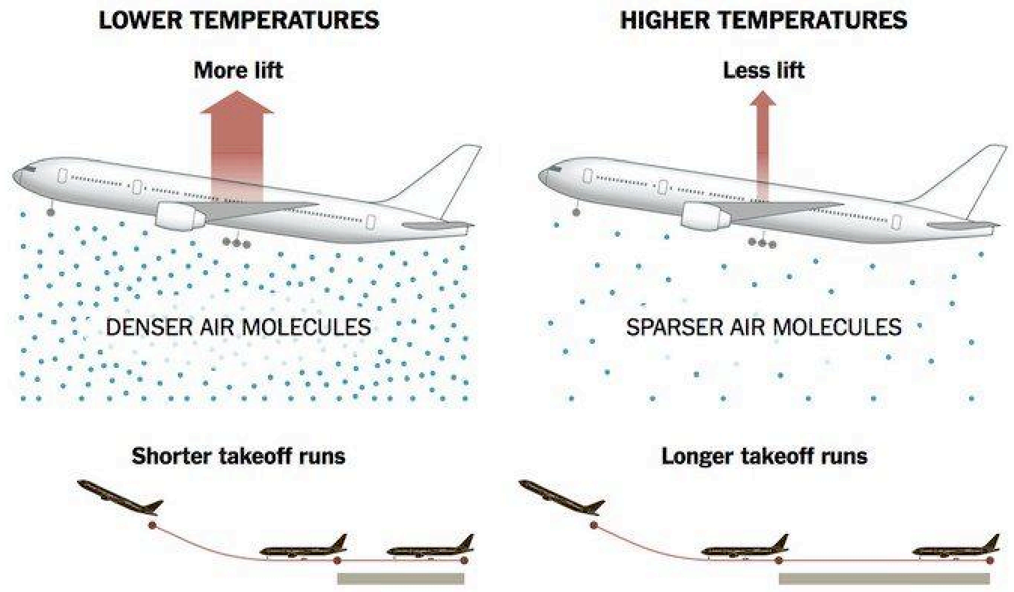
- Air and density
  - International Standard Atmosphere
  - Types of Altitude
  - Types of Airspeed
  - How density affects performance
- Airplane performance charts
  - Performance scenario using Cessna charts
  - Other chart styles

Performance Concepts

Air and Density

- Air has mass
- Our airplane swims through the air, air molecules bounce off the airplane
  - As these air molecules are deflected downward, our airplane is forced upward
  - Our propeller pushes air backwards which pushes us forwards
  - Our engine "breaths" air from outside, burns that air with fuel to produce power

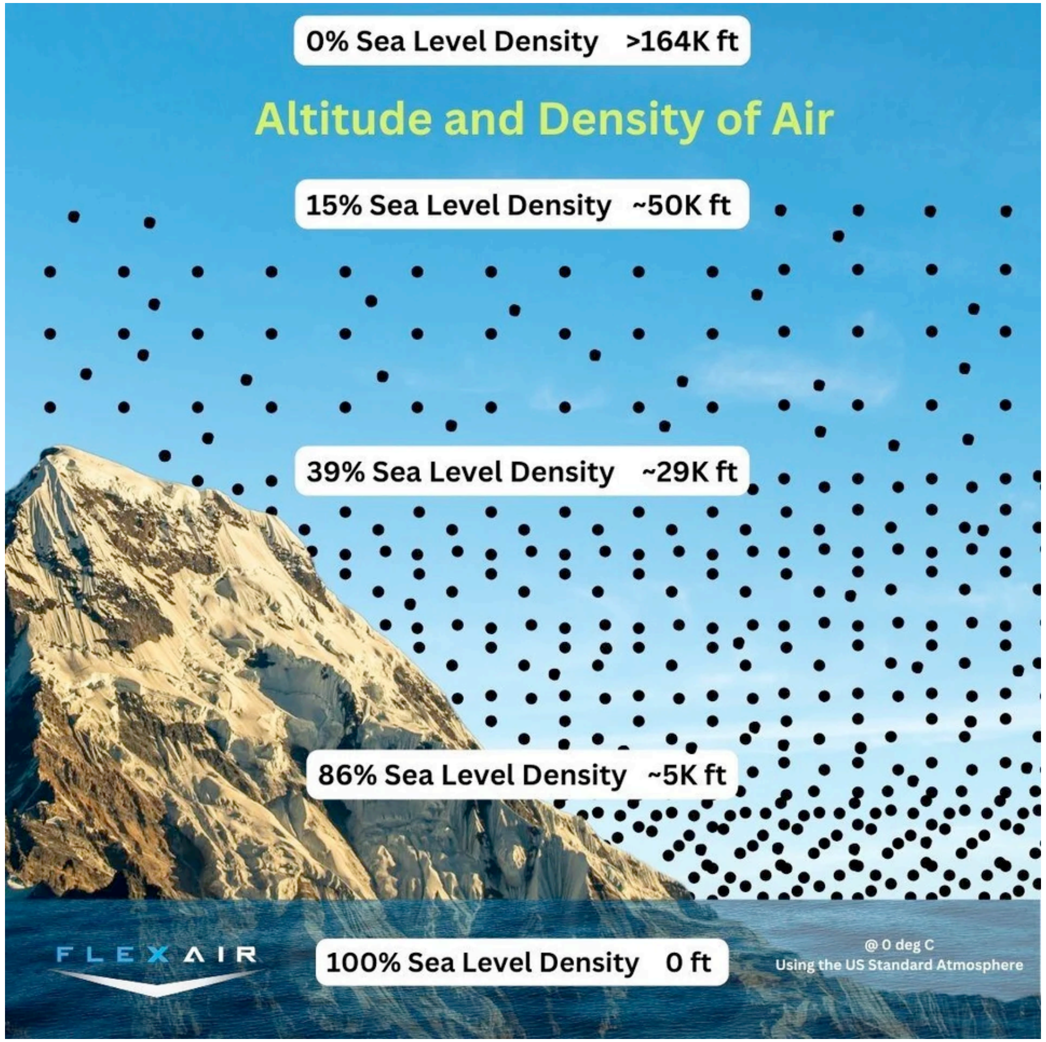
High and Low Air Density



Source: National Oceanic and Atmospheric Administration | By The New York Times

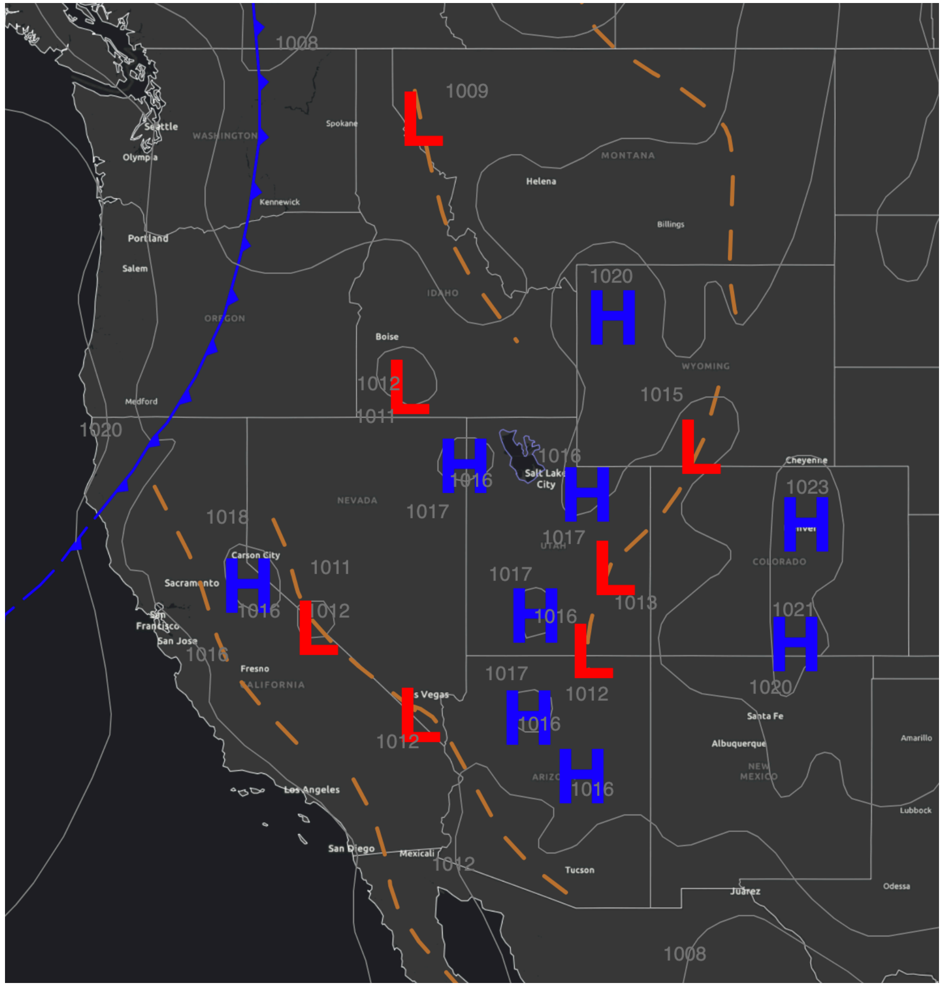
- All of this depends on how close the air molecules are together
- Tightly spaced = more air to grab on to
    - Wings can produce more lift
    - Propeller can produce more thrust
    - Engines has more air molecules to burn, just like a campfire
- Sparely spaced = less air to grab on to
    - Wings produce less lift
    - Propellers can't produce as much thrust
    - Engine has less air molecules to burn

Things That Affect Density: Altitude (Variable #1)



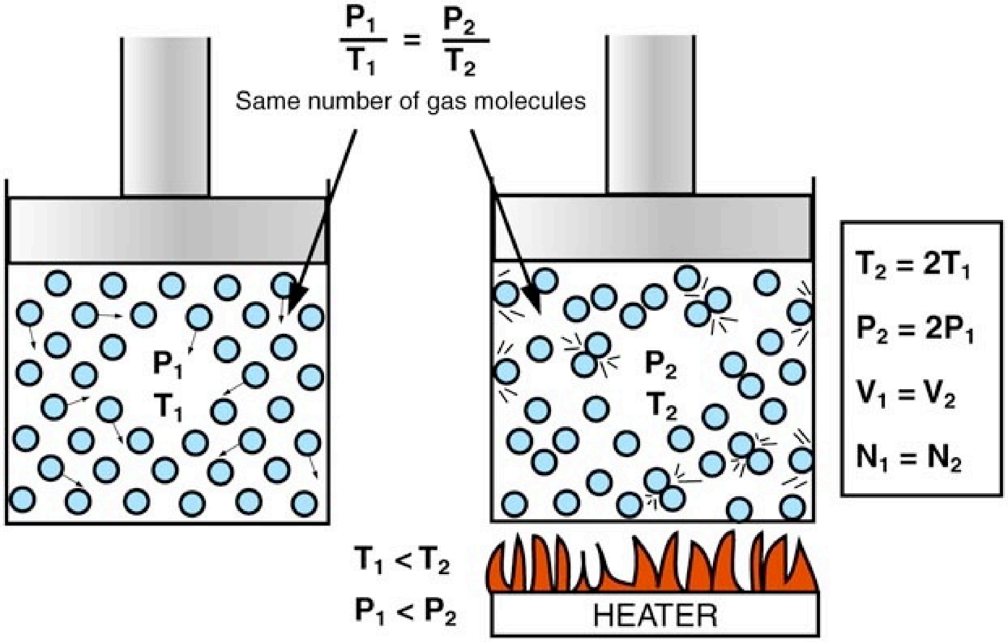
- Density decreases as we get farther from the Earth's surface due to gravity
- The rate at which this occurs is called the pressure *lapse rate*
- The average lapse rate is 1" Hg per 1000 ft.

Thing That Affect Density: Ambient Pressure (Variable #2)



- The pressure outside varies from day to day
- On high pressure days, the air is more dense
- On low pressure days, the air is less dense

Things That Affect Density: Temperature (Variable #3)

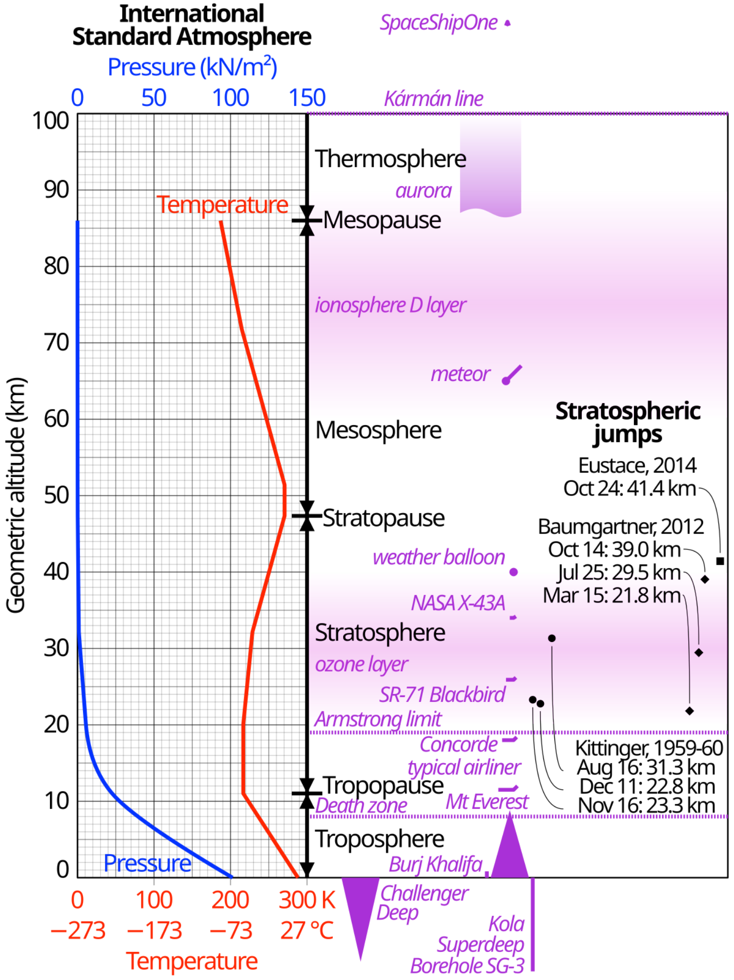


- Hot air molecules bounce off each other more energetically
- This causes the molecules to spread out and become less dense
- Likewise, cold air molecules are less excited become more dense

Rolling it All Up

- That's a lot of variables to consider
- What if there was a magic "density" number which could combine:
  - Altitude
  - Ambient pressure
  - Temperature
- Then give us one number which represents the density of the air

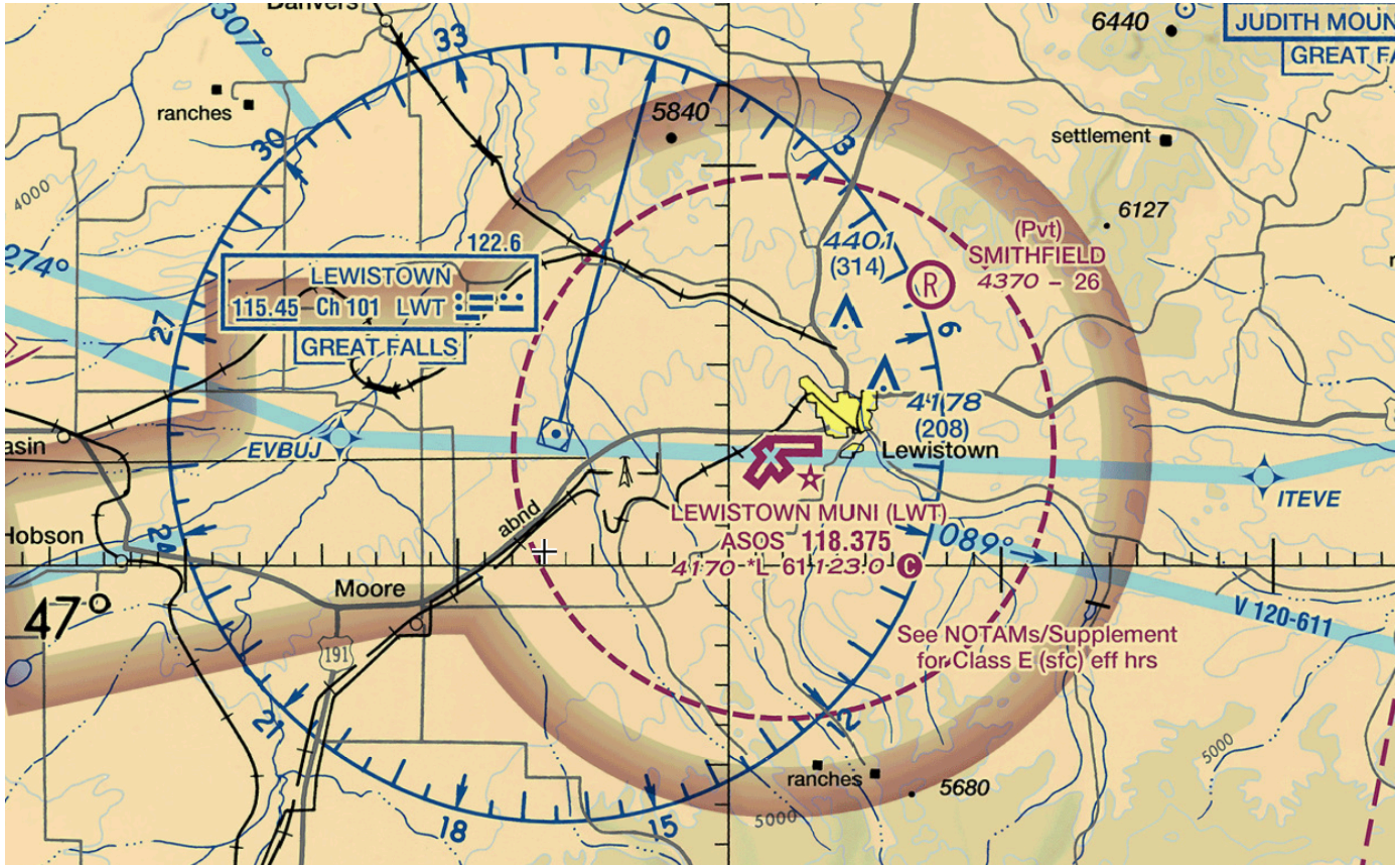
International Standard Atmosphere (ISA)



- A fake atmosphere with ideal conditions
  - Our "magic" density number is a height in this atmosphere
  - This height would have an *equivalent* density to the real conditions
- ISA Definitions
  - At sea level, the pressure is 29.92" Hg (1013.2 millibars)
  - Pressure lapses (reduces) at 1" Hg per 1000'
- The higher the altitude, the lower our airplane's performance

How do we compute this magic density number?

First, gather your information:



- Field elevation **4170 ft.**
- Temperature **84° F, 29° C**
- Pressure **29.88" Hg**

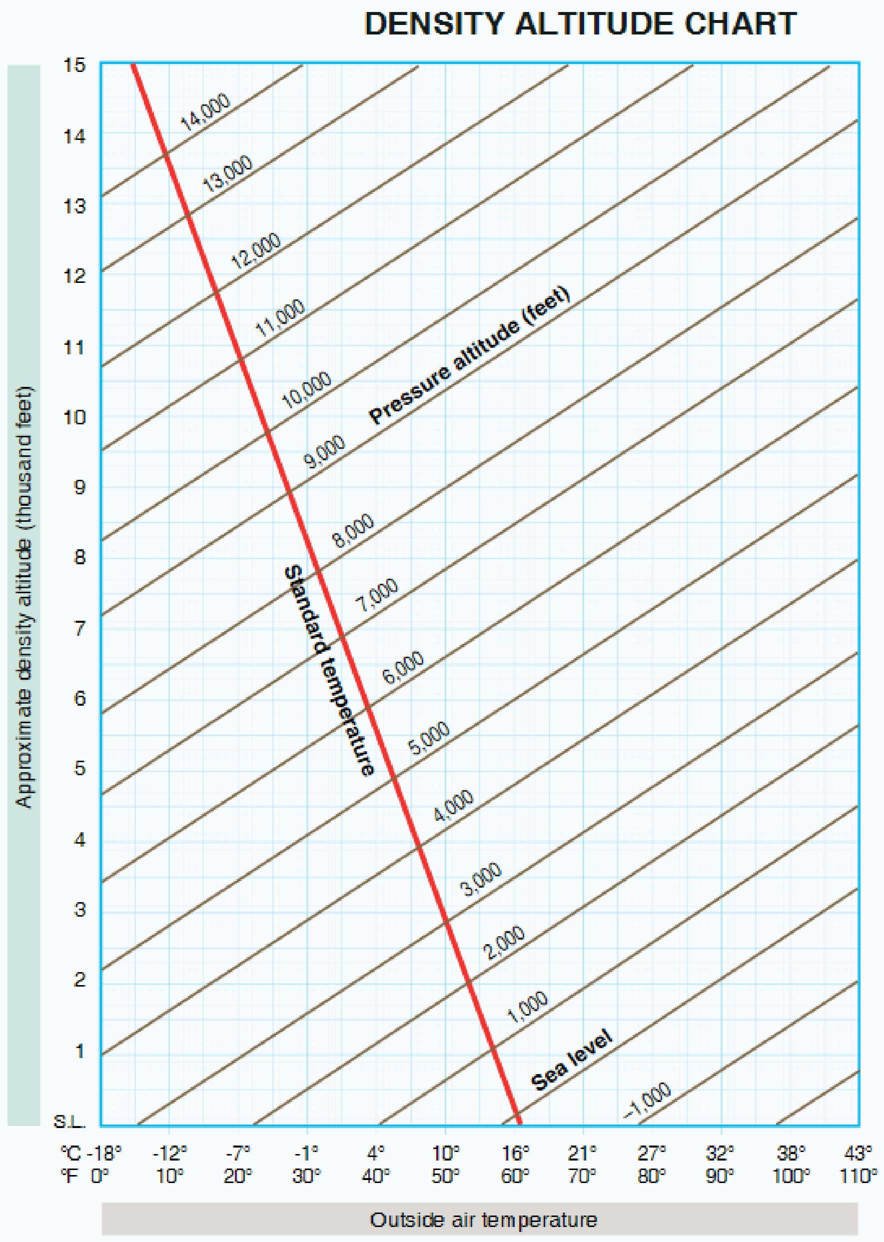
Start with variable #1: Altitude

- Start with the field elevation
- If we were in the airplane we'd read this directly off the altimeter, what we call *indicated altitude*

Correct for Variable #2: Ambient Pressure

1. We get this from the current altimeter setting
   - Subtract the S.L. pressure of 29.92" Hg
   - $(29.92 - 29.88) = 0.04\text{” Hg}$
2. Since we know the standard atmosphere lapses at 1" per 1000':
   - Multiple this by 1000 to get the change in feet
   - $0.04 * 1000 = 40$
3. Add this difference to our field elevation:
   - $4170 + 40 = 4210$
   - The altitude in the standard atmosphere where the current *pressure* is found
4. This is called **pressure altitude**

Pressure Altitude Chart



Altimeter setting ("Hg)	Pressure altitude conversion factor
28.0	1,824
28.1	1,727
28.2	1,630
28.3	1,533
28.4	1,436
28.5	1,340
28.6	1,244
28.7	1,148
28.8	1,053
28.9	957
29.0	863
29.1	768
29.2	673
29.3	579
29.4	485
29.5	392
29.6	298
29.7	205
29.8	112
29.9	20
29.92	0
30.0	−73
30.1	−165
30.2	−257
30.3	−348
30.4	−440
30.5	−531
30.6	−622
30.7	−712
30.8	−803
30.9	−893
31.0	−983

Figure 8. Density Altitude Chart.

Pressure altitude another way: Have the altimeter do the math

- As you rotate the Kollsman window the altimeter moves up and down at that same rate 1" per 1000'
- If we set our altimeter to 29.92" (the pressure of S.L. in the standard atmosphere), it will give us pressure altitude

Correct for Variable #3: Temperature

- The temperature in the standard atmosphere decreases as we ascend:
  - Temperature is 15°C at sea level
  - The temperature lapse rate is 2° per 1000'
  - We care about the different between *actual* temperature and *standard* temperature
- At a pressure altitude of 4210'
  - $15^{\circ}C - 2 * (4210/1000) = 6.58^{\circ}C$
- If the pressure outside is 29°C
  - $29 - 6.58 = 22.4^{\circ}C \text{ above standard}$

Correct for Variable #3: Temperature

- Now need factor this temperature difference into our density altitude
- Apply the formula:
  - $\text{Pressure altitude} + 118.8 * (\text{Temperature difference from standard})$
  - $4210 \text{ ft} + 118.8 * 22.4^{\circ}C = 6871 \text{ ft}$
- This is our magic number: **density altitude**
  - If our airplane were flying in the standard atmosphere, it would feel like it's flying at **6871** feet

Review of Altitude Types

- Ambient pressure/Altimeter setting: Set in the Kollsman window
- Indicated altitude: Read directly off the altimeter
- Pressure altitude: Height in the ISA where current pressure is found
- Density altitude: Height in the ISA where the current pressure is found, plus any correction for temperature

Pitot Tube As A Molecule Counter

- More forward movement: More molecules we hit
- More air density: Molecules tightly spaced so more to hit

Imagine an Airplane Traveling 100 Feet

- Plane travels 100 feet at the same speed:
  - If the air density is high, it's going to hit 200 molecules - higher airspeed shown
  - If the air density is low, it's going to hit 100 molecules - lower airspeed shown
- Which is going to produce more lift force?

Types of Airspeed: Indicated Airspeed

- How many molecules are hitting the pitot tube
- Really a measure of pressure:
  - $\text{Airspeed} = \text{RAM air pressure} - \text{Static air pressure}$

Types of Airspeed: Calibrated Airspeed

- The pitot tube is attached at a certain angle
- This might not be directly into the relative wind
- With a high angle of attack, the relative wind will be at a steeper angle
- To account for this, we compute **calibrated airspeed**
  - This is usually given in a table in the POH

Computing Calibrated Airspeed

AIRSPEED CALIBRATION

NORMAL STATIC SOURCE

CONDITIONS:
Power required for level flight or maximum power descent.

FLAPS UP													
KIAS	50	60	70	80	90	100	110	120	130	140	150	160	170
KCAS	61	65	72	80	89	99	109	118	128	138	147	157	167
FLAPS 20°													
KIAS	40	50	60	70	80	90	95	---	---	---	---	---	---
KCAS	54	58	63	71	80	89	94	---	---	---	---	---	---
FLAPS FULL													
KIAS	40	50	60	70	80	90	95	---	---	---	---	---	---
KCAS	52	57	63	71	80	90	95	---	---	---	---	---	---

- Examples
  - Indicated airspeed of 120 means a calibrated airspeed of 118
  - Indicated airspeed of 60 means a calibrated airspeed of 65
- Notice how the error increases the slower we are

Types of Airspeed: True Airspeed

- Similar to altitude, we can account for non-standard temperature and pressure in airspeed
- This adjusts the "molecule count" based on the air density
  - Uses the same 3 variables: Altitude, pressure, temperature
- True airspeed in the speed you're moving through the *air mass*

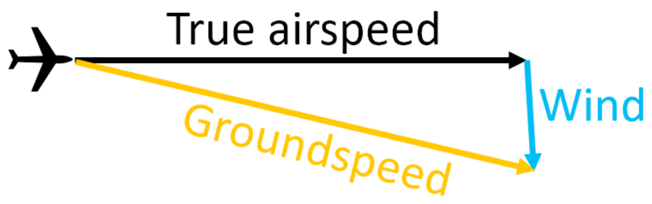
True Airspeed: Example

- Pressure altitude (PALT): 4210'
- Outside air temperature (OAT): 29°C
- Calibrated airspeed (CAS): 118 knots

Using an E6B computer, we compute true airspeed (TAS) as **130.1 knots**

- This means we're flying *faster* through the air mass than the airspeed indicator would have us believe.
- With no wind, we'd be moving 130 knots over the ground

Types of Airspeed: Ground Speed



- The air mass itself might be moving due to wind
- We add wind velocity to our true airspeed to get our speed over the ground
- With zero wind: Ground speed = true airspeed

Types Of Airspeeds

- Indicated airspeed (IAS): Read from altimeter
- Calibrated airspeed (CAS): Calibrated for position/instrument errors
    - At slow airspeeds this may be several knots off
- True airspeed (TAS): CAS corrected for altitude and nonstandard temperature
- Ground speed (GS): Actual speed over the ground
    - TAS adjusted for wind

Knowledge Check

- Assuming all other variables are the same:
  - Where will an airplane have a longer takeoff roll, in Denver or in Orlando?
  - Where will an airplane have a longer landing roll, when the temperature is 2° C or 30° C?
  - Which aircraft will have a higher ground speed on takeoff, when the pressure is 20.79" or 30.44" Hg?
  - When will our (normally-aspirated) airplane produce the most power, on the ground or at 8000 feet?

Performance Planning

Performance

On a cross-country flight we want to know:

- How long the flight will take
- How much fuel we will burn
- How mush landing distance we will use
- How much runway distance we will use

CRUISE PERFORMANCE
PRESSURE ALTITUDE 2000 FEET

CONDITIONS:
3100 Pounds
Recommended Lean Mixture
Cowl Flaps Closed

NOTE
For best fuel economy, operate at the leanest mixture that results in smooth engine operation or at peak EGT.

		20°C BELOW STANDARD TEMP -9°C			STANDARD TEMPERATURE 11°C			20°C ABOVE STANDARD TEMP 31°C		
RPM	MP	% BHP	KTAS	GPH	% BHP	KTAS	GPH	% BHP	KTAS	GPH
2400	25	---	---	---	78	137	14.8	74	137	14.0
	23	74	131	14.0	70	131	13.3	66	130	12.6
	21	65	125	12.4	62	124	11.8	59	123	11.3
	19	57	117	10.9	54	116	10.5	51	115	10.0
2300	25	78	135	14.9	74	135	14.1	71	134	13.4
	23	70	129	13.3	67	128	12.7	63	128	12.1
	21	62	122	11.8	59	121	11.3	56	120	10.8
	19	54	114	10.4	51	113	10.0	49	112	9.6
2200	25	75	132	14.2	71	132	13.5	67	131	12.8
	23	67	126	12.7	64	126	12.1	60	125	11.5
	21	59	119	11.3	56	118	10.8	53	117	10.3
	19	51	111	9.9	49	110	9.5	46	108	9.1
2100	25	71	129	13.5	68	129	12.9	64	129	12.2
	23	64	123	12.1	60	123	11.5	57	122	11.0
	21	56	116	10.7	53	115	10.3	50	114	9.8
	19	48	108	9.5	46	106	9.1	43	104	8.7
	17	41	97	8.2	39	95	7.8	37	91	7.5

Aircraft Performance Charts

- Published in our POH/AFM
- Based on a new airplane, engine, and propeller
- Based on a test pilot flying with excellent technique (airspeed control, proper leaning)
- Formatted in a variety of ways
  - Some use pressure altitude + temperature (Cessnas)
  - Some use density altitude only

Performance Scenario

- Depart: Lewiston Municipal (KLWT)
  - Elevation: 4170'
  - Altimeter: 29.88" Hg
  - Temperature: 29°C
- Cruise at 8500 ft.
- Arrive: Harve City County (KHVR)
  - Elevation: 2591'
  - Altimeter: 29.95" Hg
  - Temperature: 25° C
- Aircraft
  - 50 gallons of fuel aboard
  - Max gross weight (3100 lbs)

Takeoff Distance

TAKEOFF DISTANCE

MAXIMUM WEIGHT 3100 LBS

SHORT FIELD

CONDITIONS:
Flaps 20°
2400 RPM and 31 Inches Hg Prior to Brake Release
Mixture Full Rich
Cowl Flaps Open
Paved, Level, Dry Runway
Zero Wind

NOTES:
1. Short field technique as specified in Section 4.
2. Decrease distances 10% for each 9 knots headwind. For operation with tailwinds up to 10 knots, increase distances by 10% for each 2 knots.
3. For operation on a dry, grass runway, increase distances by 15% of the "ground roll" figure.

WEIGHT LBS	TAKEOFF SPEED KIAS		PRESS ALT FT	32°F 0°C		50°F 10°C		68°F 20°C		86°F 30°C		104°F 40°C	
	LIFT OFF	AT 50 FT		GRND ROLL	TOTAL TO CLEAR 50 FT OBS	GRND ROLL	TOTAL TO CLEAR 50 FT OBS	GRND ROLL	TOTAL TO CLEAR 50 FT OBS	GRND ROLL	TOTAL TO CLEAR 50 FT OBS	GRND ROLL	TOTAL TO CLEAR 50 FT OBS
3100	49	58	S.L.	700	1310	760	1415	820	1535	890	1665	960	1805
			1000	750	1390	810	1505	880	1630	950	1770	1025	1925
			2000	800	1475	870	1600	940	1735	1015	1885	1100	2050
			3000	855	1570	930	1700	1005	1850	1090	2010	1175	2190
			4000	920	1670	995	1815	1080	1970	1165	2145	1260	2345
			5000	985	1780	1070	1935	1155	2110	1250	2300	1355	2510
			6000	1055	1900	1145	2070	1245	2260	1345	2465	1455	2700
			7000	1135	2035	1235	2220	1335	2425	1450	2650	1565	2910
			8000	1220	2180	1325	2385	1440	2605	1560	2855	1685	3140

Headwind: 4 knots

Pressure altitude: 4210

Temperature: 29°C

30° line, 4000':

1165' ground roll

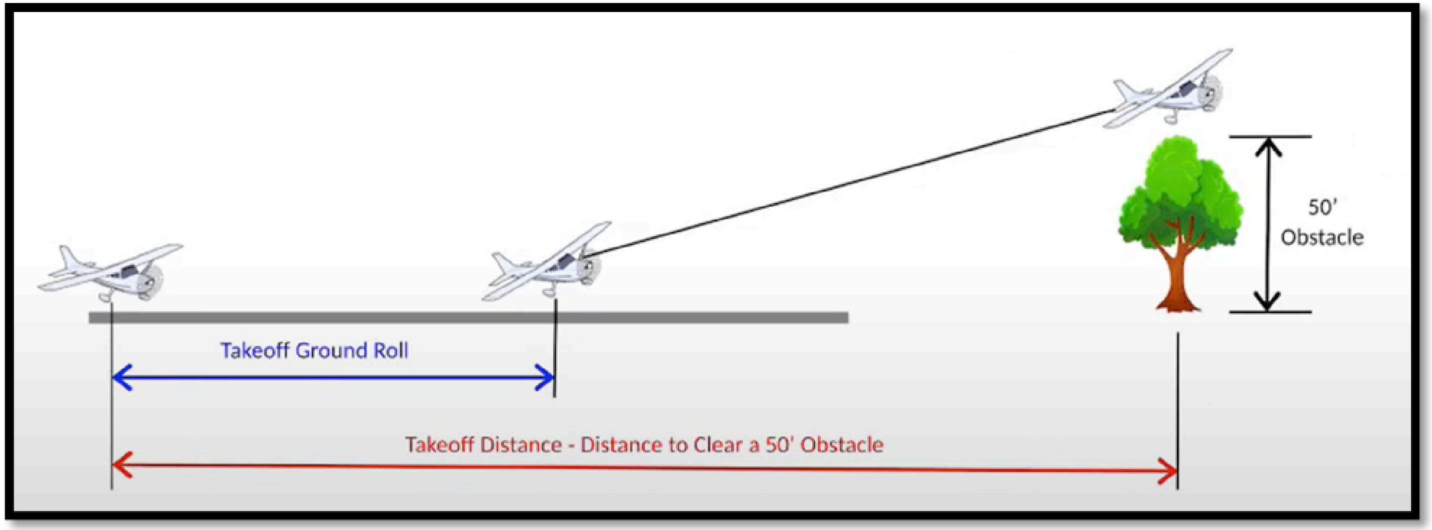
2145 over 50' obstacle

4 kts headwind, -5%:

$1165 * 0.95$ = **1107 ft.**

$2145 * 0.95$ = **2137 ft.**

Takeoff Distance - Safety Factor



Ground roll = **1107 ft.**

Over 50' obstacle = **2137 ft.**

With 50% safety factor:

$1107 * 1.5$ = **1660 ft.**

$2137 * 1.5$ = **3205 ft.**

Time, Distance, Fuel to Climb (Normal Climb)

TIME, FUEL, AND DISTANCE TO CLIMB

NORMAL CLIMB - 95 KIAS

CONDITIONS:
Flaps Up
2400 RPM
24 Inches Hg
Mixture Full Rich
Cowl Flaps Open
Standard Temperature

NOTES:
1. Add 2.0 gallons of fuel for engine start, taxi and takeoff allowance.
2. Increase time, fuel and distance by 10% for each 7°C above standard temperature.
3. Distances shown are based on zero wind.

WEIGHT LBS	PRESSURE ALTITUDE FT	TEMP °C	RATE OF CLIMB FPM	FROM SEA LEVEL		
				TIME MIN	FUEL USED GALLONS	DISTANCE NM
3100	S.L.	15	500	0	0	0
	2000	11	500	4	1.4	6
	4000	7	495	8	2.8	13
	6000	3	485	12	4.3	20
	8000	-1	470	16	5.7	27
	10,000	-5	450	21	7.3	35
	12,000	-9	425	25	8.9	44

Airport: 4170'

Cruise: 8500'

Above standard: 22 ° C

8000' line: 16 minutes, 5.7 gal, 27m

4000' line: 8 minutes, 2.8 gal, 13nm

16 - 8 = 8 minutes

5.7 - 2.8 = 2.9 gallons

27 - 13 = 14nm

Time, Distance, Fuel to Climb (Normal Climb)

TIME, FUEL, AND DISTANCE TO CLIMB

NORMAL CLIMB - 95 KIAS

CONDITIONS:
Flaps Up
2400 RPM
24 Inches Hg
Mixture Full Rich
Cowl Flaps Open
Standard Temperature

NOTES:
1. Add 2.0 gallons of fuel for engine start, taxi and takeoff allowance.
2. Increase time, fuel and distance by 10% for each 7°C above standard temperature.
3. Distances shown are based on zero wind.

WEIGHT LBS	PRESSURE ALTITUDE FT	TEMP °C	RATE OF CLIMB FPM	FROM SEA LEVEL		
				TIME MIN	FUEL USED GALLONS	DISTANCE NM
3100	S.L.	15	500	0	0	0
	2000	11	500	4	1.4	6
	4000	7	495	8	2.8	13
	6000	3	485	12	4.3	20
	8000	-1	470	16	5.7	27
	10,000	-5	450	21	7.3	35
	12,000	-9	425	25	8.9	44

8 minutes, 2.9 gallons, 14nm

22 / 7 = 3.14

3.14 * 10% = 31% increase

8 * 1.31 = **10.5 minutes**

2.9 * 1.31 = 3.8 gallons

14 * 1.31 = **18.3nm**

+2 gal start/taxi/takeoff

3.8 + 2 = **5.8 gallons**

Cruise Performance (8000 ft.)

CRUISE PERFORMANCE

PRESSURE ALTITUDE 8000 FEET

CONDITIONS:
3100 Pounds
Recommended Lean Mixture
Cowl Flaps Closed

NOTE
For best fuel economy, operate at the leanest mixture that results in smooth engine operation or at peak EGT.

		20°C BELOW STANDARD TEMP -21°C			STANDARD TEMPERATURE -1°C			20°C ABOVE STANDARD TEMP 19°C		
RPM	MP	% BHP	KTAS	GPH	% BHP	KTAS	GPH	% BHP	KTAS	GPH
2400	25	---	---	---	79	146	15.1	75	145	14.3
	23	76	140	14.4	72	140	13.7	69	139	13.0
	21	68	134	13.0	65	133	12.4	62	132	11.8
	19	61	126	11.6	58	126	11.1	55	124	10.6
2300	25	80	143	15.2	76	143	14.5	72	143	13.7
	23	73	137	13.8	69	137	13.1	66	136	12.5
	21	65	131	12.4	62	130	11.9	59	129	11.3
	19	58	123	11.1	55	123	10.6	52	121	10.1
2200	25	77	141	14.6	73	140	13.9	69	140	13.1
	23	70	135	13.2	66	134	12.6	63	133	12.0
	21	62	128	11.9	59	127	11.3	56	126	10.8
	19	55	121	10.6	53	120	10.2	50	118	9.7
2100	25	73	138	13.9	70	138	13.2	66	137	12.6
	23	66	132	12.6	63	131	12.0	60	130	11.4
	21	59	125	11.3	56	124	10.9	54	123	10.4
	19	52	117	10.2	50	116	9.7	47	114	9.3
	17	46	108	9.0	43	106	8.6	41	102	8.3

13° C above standard

2200 RPM

21" manifold pressure

KTAS: 126 and 127 = 127 KTAS

% BHP: Interpolate 59% and 56%, or take higher value.

Fuel flow: Interpolate 11.3 and 10.8 BHP, or take higher value.

Cruise Performance - Interpolation

CRUISE PERFORMANCE

PRESSURE ALTITUDE 8000 FEET

CONDITIONS:
3100 Pounds
Recommended Lean Mixture
Cowl Flaps Closed

NOTE
For best fuel economy, operate at the leanest mixture that results in smooth engine operation or at peak EGT.

		20°C BELOW STANDARD TEMP -21°C			STANDARD TEMPERATURE -1°C			20°C ABOVE STANDARD TEMP 19°C		
RPM	MP	% BHP	KTAS	GPH	% BHP	KTAS	GPH	% BHP	KTAS	GPH
2400	25	---	---	---	79	146	15.1	75	145	14.3
	23	76	140	14.4	72	140	13.7	69	139	13.0
	21	68	134	13.0	65	133	12.4	62	132	11.8
	19	61	126	11.6	58	126	11.1	55	124	10.6
2300	25	80	143	15.2	76	143	14.5	72	143	13.7
	23	73	137	13.8	69	137	13.1	66	136	12.5
	21	65	131	12.4	62	130	11.9	59	129	11.3
	19	58	123	11.1	55	123	10.6	52	121	10.1
2200	25	77	141	14.6	73	140	13.9	69	140	13.1
	23	70	135	13.2	66	134	12.6	63	133	12.0
	21	62	128	11.9	59	127	11.3	56	126	10.8
	19	55	121	10.6	53	120	10.2	50	118	9.7
2100	25	73	138	13.9	70	138	13.2	66	137	12.6

Interpolate between 11.3 and 10.8 GPH

$$(10.8 - 11.3)/(19 - -1) = -0.025$$

$$(13 - -1) = 14$$

$11.3 - 0.025 * 14 =$ **11.0 gph**

Interpolate between 59% and 56% BHP

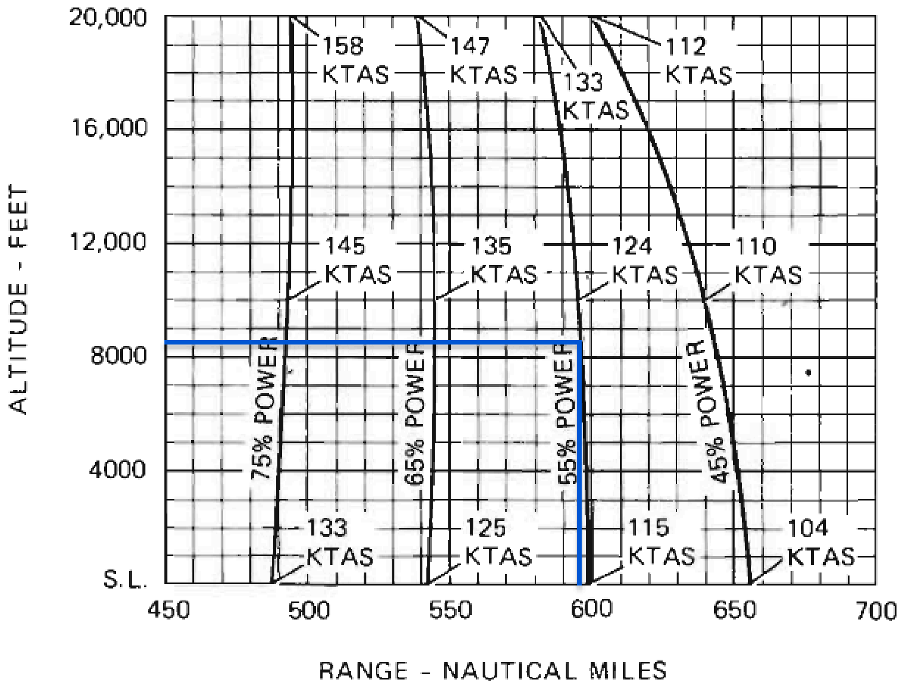
$$(56 - 59)/(19 - -1) = -0.15$$

$59 - 0.15 * 14 =$ **58 % bhp**

RANGE PROFILE
45 MINUTES RESERVE
65 GALLONS USABLE FUEL

CONDITIONS:
3100 Pounds
Recommended Lean Mixture for Cruise
Standard Temperature
Zero Wind

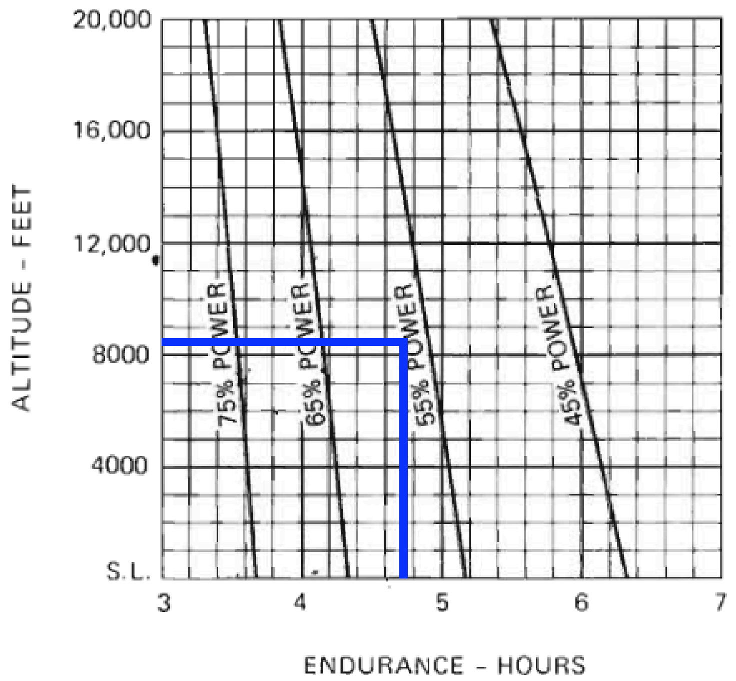
NOTE:
This chart allows for the fuel used for engine start, taxi, takeoff and climb, and the distance during a normal climb up to 12,000 feet and maximum climb above 12,000 feet.



ENDURANCE PROFILE
45 MINUTES RESERVE
65 GALLONS USABLE FUEL

CONDITIONS:
3100 Pounds
Recommended Lean Mixture for Cruise
Standard Temperature

NOTE:
This chart allows for the fuel used for engine start, taxi, takeoff and climb, and the time during a normal climb up to 12,000 feet and maximum climb above 12,000 feet.



Landing Distance (Short Field)

LANDING DISTANCE

SHORT FIELD

CONDITIONS:
Flaps FULL
Power Off
Maximum Braking
Paved, Level, Dry Runway
Zero Wind

NOTES:
1. Short field technique as specified in Section 4.
2. Decrease distances 10% for each 9 knots headwind. For operation with tailwinds up to 10 knots, increase distances by 10% for each 2 knots.
3. For operation on a dry, grass runway, increase distances by 40% of the "ground roll" figure.
4. If a landing with flaps up is necessary, increase the approach speed by 9 KIAS and allow for 40% longer distances.

68°F

WEIGHT LBS	SPEED AT 50 FT KIAS	PRESS ALT FT	0°C		10°C		20°C		30°C		40°C	
			GRND ROLL	TOTAL TO CLEAR 50 FT OBS	GRND ROLL	TOTAL TO CLEAR 50 FT OBS	GRND ROLL	TOTAL TO CLEAR 50 FT OBS	GRND ROLL	TOTAL TO CLEAR 50 FT OBS	GRND ROLL	TOTAL TO CLEAR 50 FT OBS
2950	61	S.L.	560	1300	580	1335	600	1365	620	1400	640	1435
		1000	580	1335	600	1365	620	1400	645	1440	665	1475
		2000	600	1370	625	1405	645	1440	670	1480	690	1515
		3000	625	1410	645	1445	670	1485	695	1525	715	1560
		4000	650	1450	670	1485	695	1525	720	1565	740	1600
		5000	670	1485	695	1525	720	1565	745	1610	770	1650
		6000	700	1530	725	1575	750	1615	775	1660	800	1700
		7000	725	1575	750	1615	780	1665	805	1710	830	1750
		8000	755	1625	780	1665	810	1715	835	1760	865	1805

Headwind: 4 knots

Pressure altitude: 2500

Temperature: 20°C

Average 1440 and 1485 = 1462 ft.

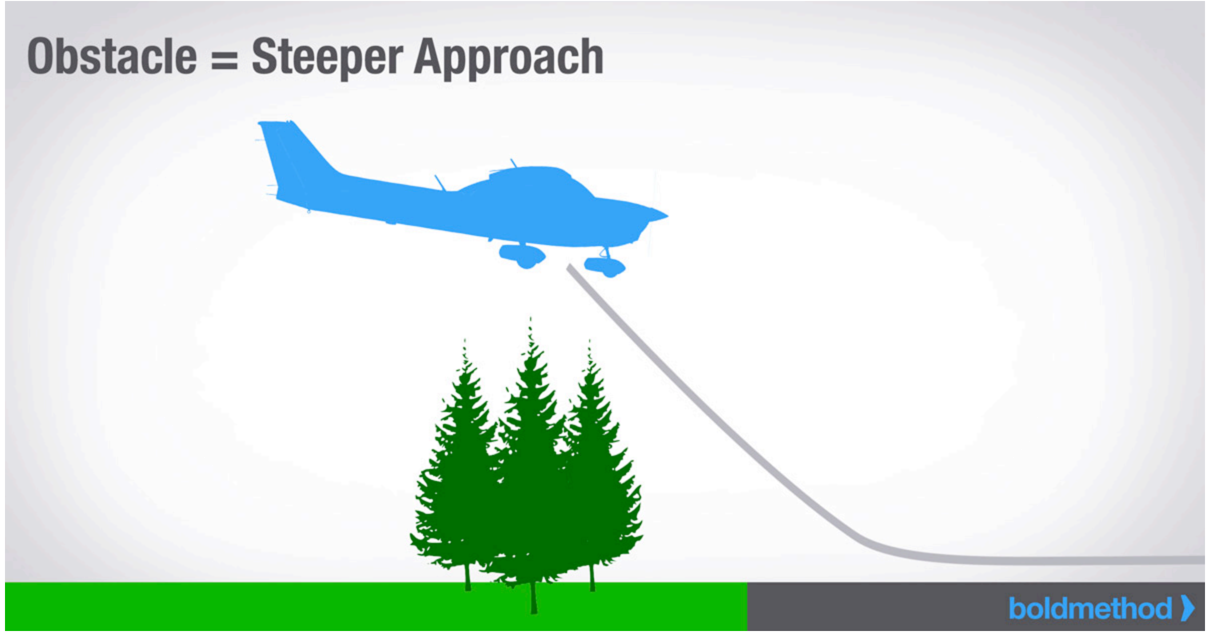
Average 645 and 670 = 658 ft.

4° / 9° = 0.44, decrease 4.4%

0.95 * 1462 = **1389 ft. over 50' obs.**

0.95 * 658 = **625 ft. ground roll**

Landing Distance (Short Field) - Safety Factor



1389 ft. over 50' obs.

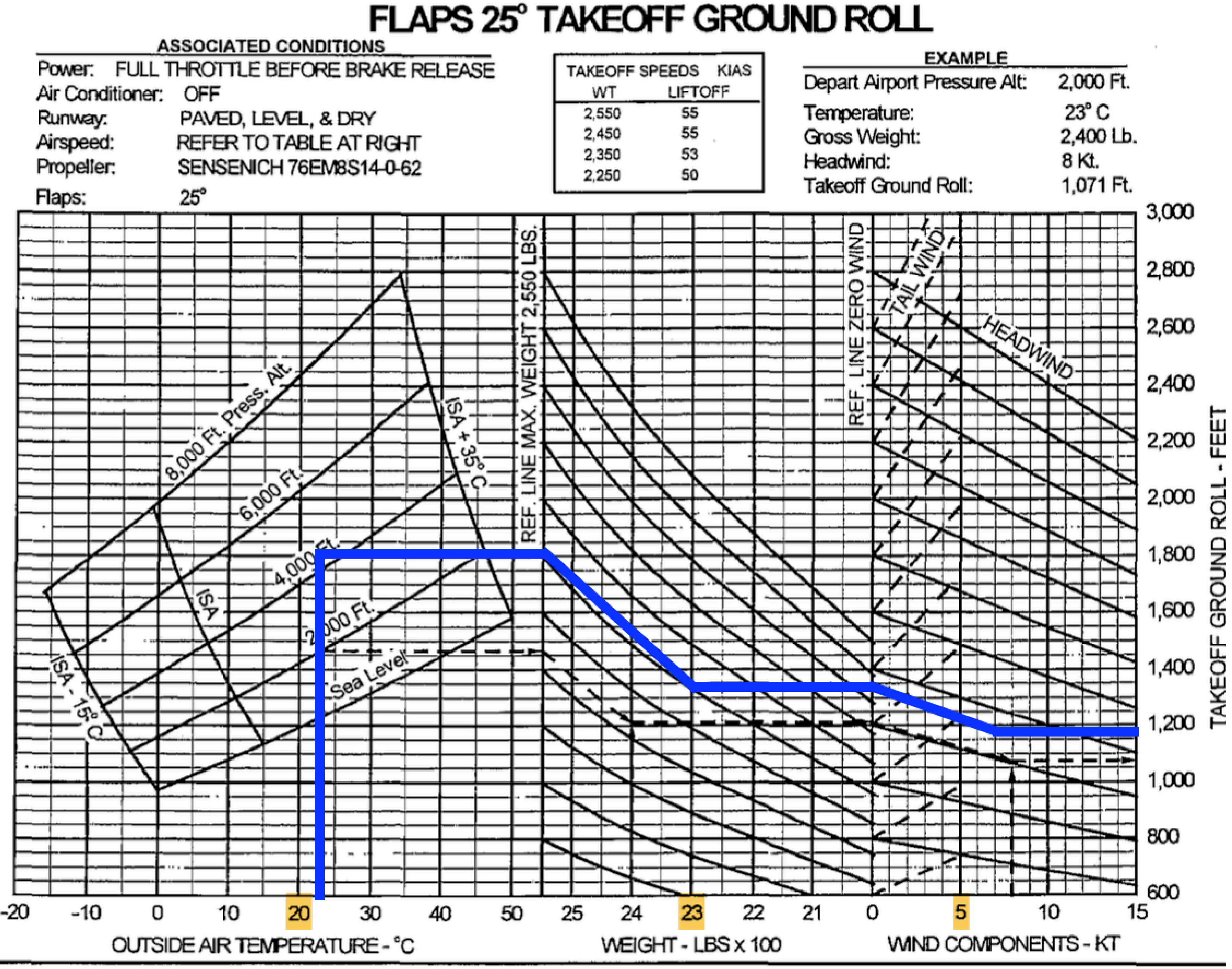
625 ft. ground roll

Over 50' obstacle:

$$1389 * 1.5 = 2084 \text{ ft}$$

Ground roll:

$$625 * 1.5 = 938 \text{ ft}$$



4100' press. altitude

22° C

2300 lbs.

7 knots headwind

~1150 ft.

Summary

- Air and density
  - International Standard Atmosphere
  - Types of Altitude
  - Types of Airspeed
  - How density affects performance
- Airplane performance charts
  - Computing performance values using Cessna charts