Lesson 2

Non standard Atmosphere

MIL-STD-210A

Hydrostatic Equation (review)

$$dp = -\rho g_0 \, dh$$

p is pressure
h is geopotential altitude
g_0 is gravity
ρ is density

With the ideal gas equation of state

$$p = \rho R T$$

So,

$$dp = -\frac{p}{RT} g_0 \, dh$$

But $T = T(h)$ (a function of height)

We could solve analytically (as in lesson 1) or numerically.

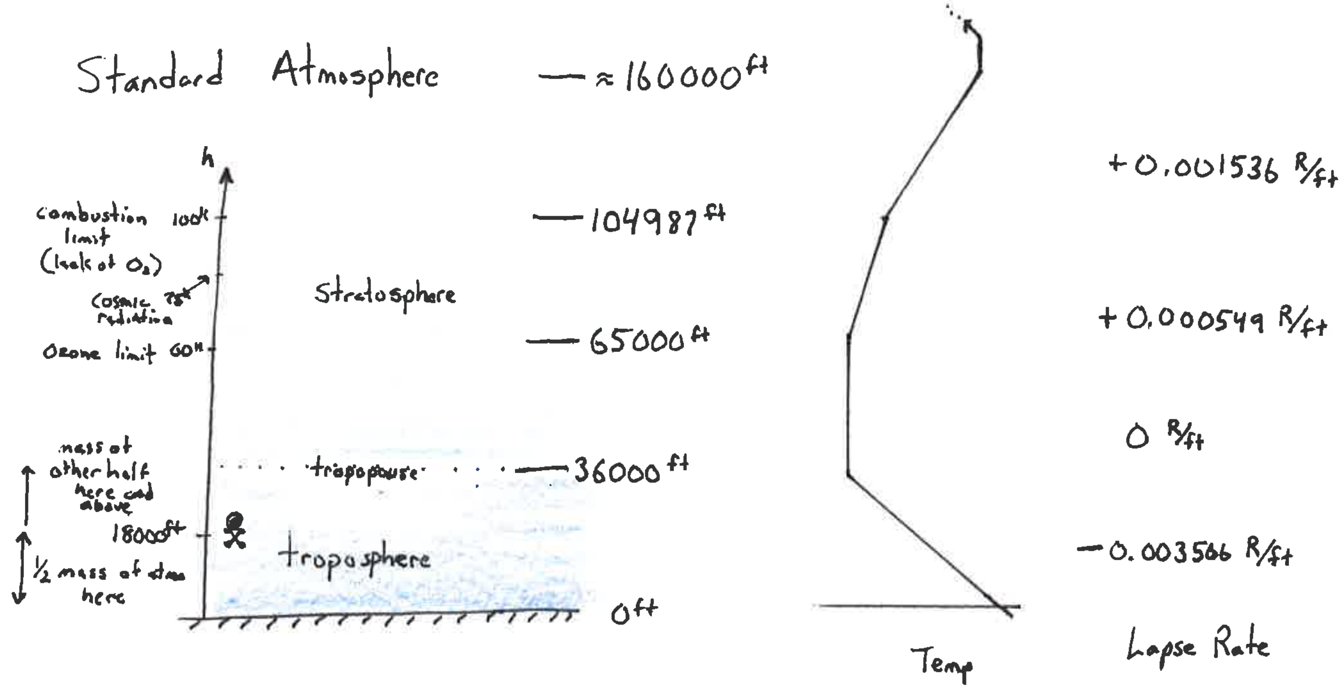
$$\Delta p = -\frac{p}{RT} g_0 \, \Delta h \quad \Rightarrow \quad \underbrace{P(h_1) = P(h_0) - \frac{\left(P(h_1) - P(h_0)\right)}{R\left(T(h_1) - T(h_0)\right)} g_0 \left(h_1 - h_0\right)}_{\text{one possible integration method}}$$

Units:

$$dp = -\frac{p}{RT} g_0 \, dh$$

$$\underbrace{\frac{lbf}{in^2}}_{dp} = \underbrace{\frac{\cancel{lbf}}{in^2}}_{p} \underbrace{\frac{\cancel{R} \ \cancel{slug}}{1716.5 \ \cancel{ft} \ \cancel{lbf}}}_{\frac{1}{R}} \underbrace{\frac{}{\cancel{R}}}_{1/T} \underbrace{\frac{32.174 \ \cancel{ft}}{\cancel{s^2}}}_{g_0} \underbrace{\frac{\cancel{ft}}{}}_{dh} \frac{lbf \ \cancel{s^2}}{\cancel{slug} \ \cancel{ft}} \quad \checkmark$$

Standard Atmosphere



We are lucky to live at the bottom of an ocean of protective air.

- Death zone for humans begins around 20^{kft} or so...
- Half the mass of air is below 18^{kft}
- Ozone above 60^{kft} prevents use of outside air for humans.
- Cosmic radiation becomes significant around 75^{kft}.
- Normal jet combustion fails around 100^{kft}. (Not enough O_2)
- The positive lapse rate around 65^{kft} makes the atmosphere stable. Convection is minimal.

Non-dimensional P, T, ρ ratios

$$\delta = \frac{P}{P_{ssl}} \qquad \theta = \frac{T}{T_{ssl}} \qquad \sigma = \frac{\rho}{\rho_{ssl}} = \frac{\delta}{\theta}$$

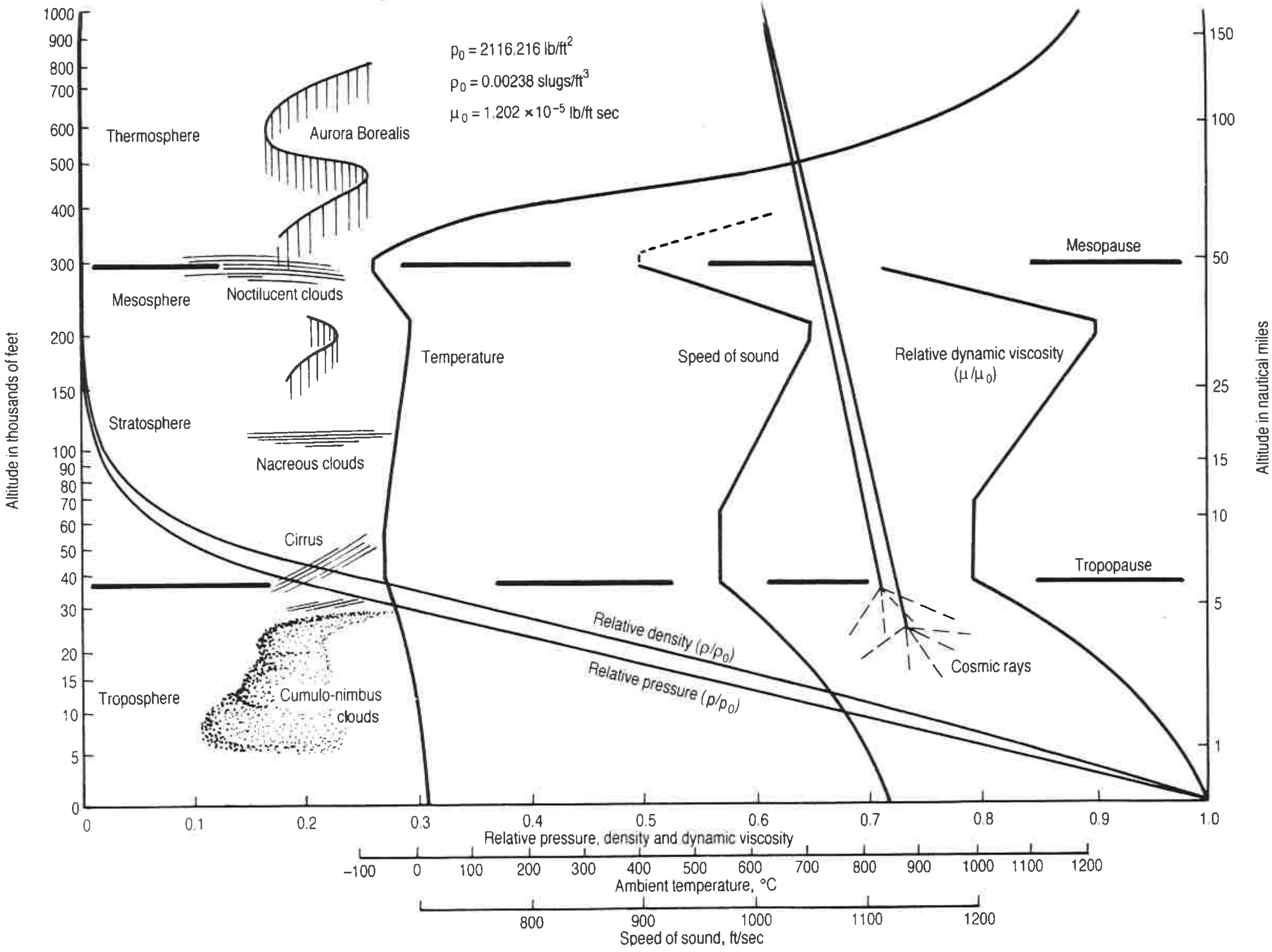
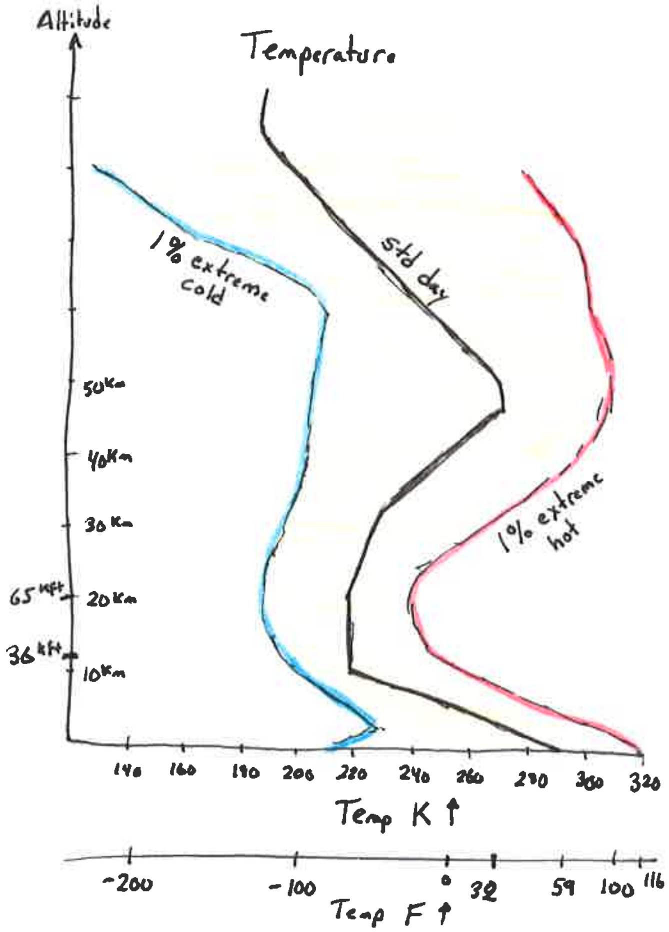


Fig. 1.2 General characteristics of the atmosphere (based upon ICAO and US Standard Atmosphere 1962).

Source: The Anatomy of the Airplane
Stanton

The atmosphere is not, has not, and never will be standard.



See:

U.S. Standard Atmosphere 1976
(NASA-TM-X-74335)

for details (241 pages!)

Non Std Atmosphere Models. (MIL-STD-210A)

Std

h [ft]	λ [R/ft]
0	-0.003566
36089	0
65617	+0.000549
104987	+0.001536
154199	0

$T_0 = 59°F$

Hot

h [ft]	λ [R/ft]
0	-0.003840
39370	+0.000439
67 257	+0.000768

$T_0 = 103.28°F$

Tropic

h [ft]	λ [R/ft]
0	-0.003840
52493	+0.002085
68898	+0.001361

$T_0 = 90.086°F$

Cold

0	+0.013716
3281	0
9843	-0.003292
31 168	0
4 2651	+0.004872
50853	0
60696	+0.002524
73819	-0.000425

$T_0 = -59°F$

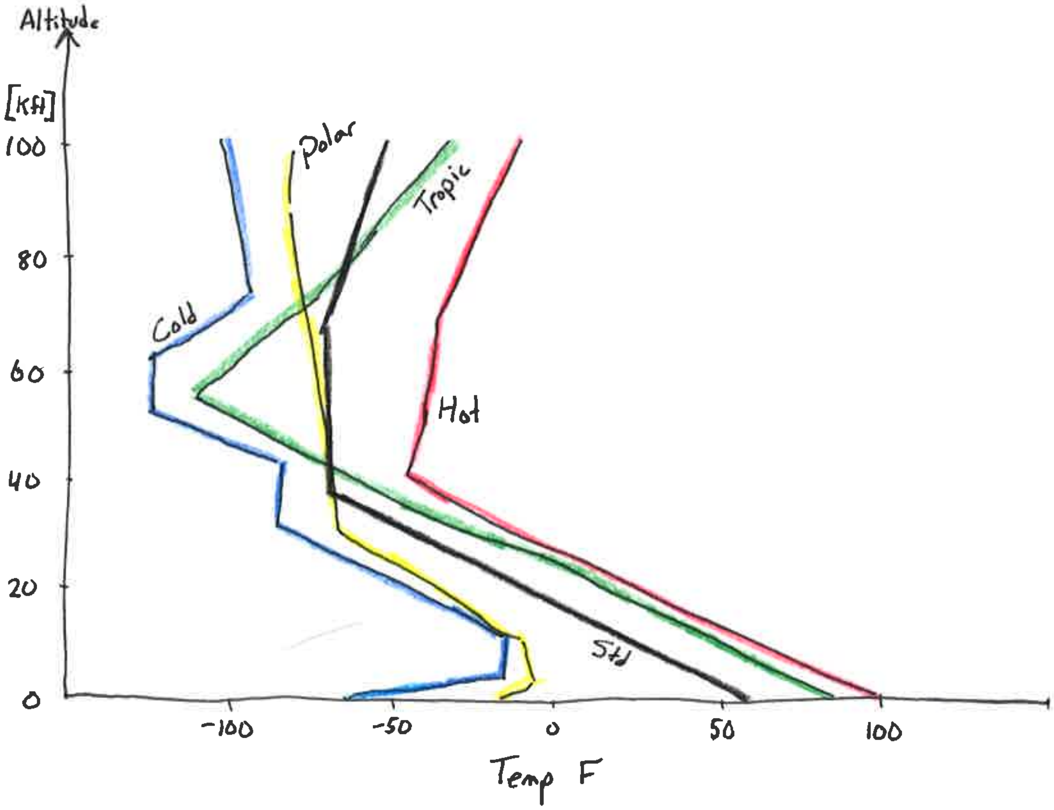
Polar (warning: reverse engineered from data!)

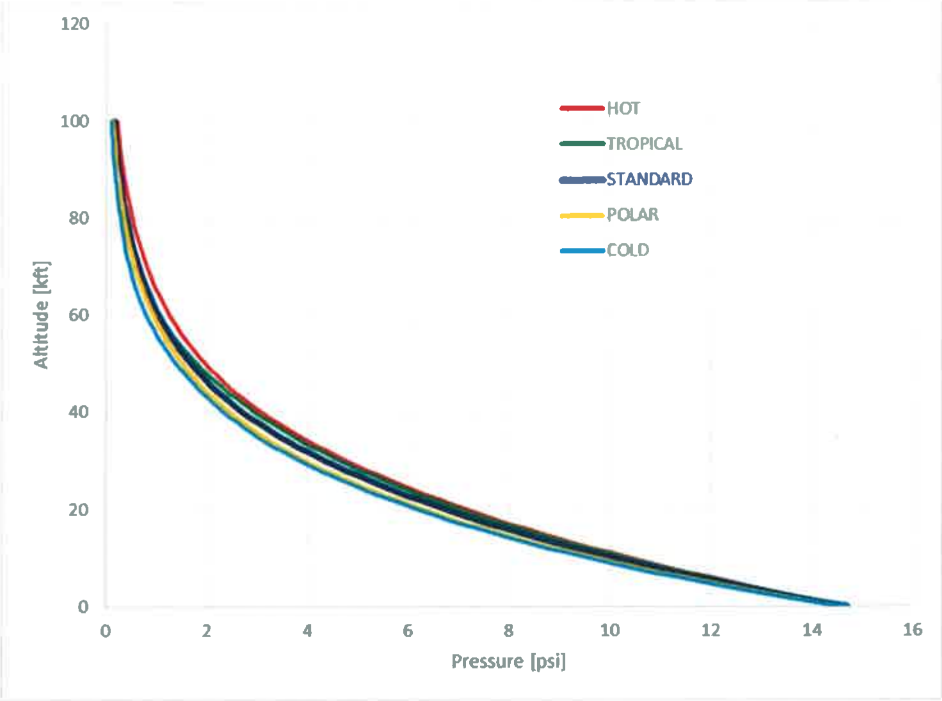
0	0.003
3281	-0.00055
9843	-0.0028
31 168	-0.0003
88000	0

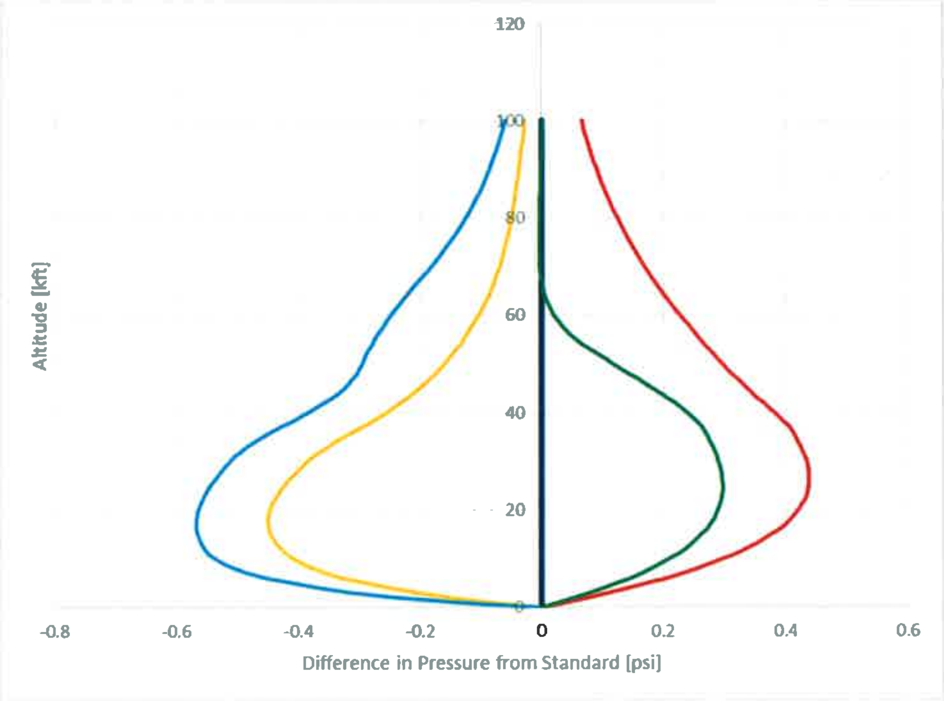
$T_0 = -15.67°F$

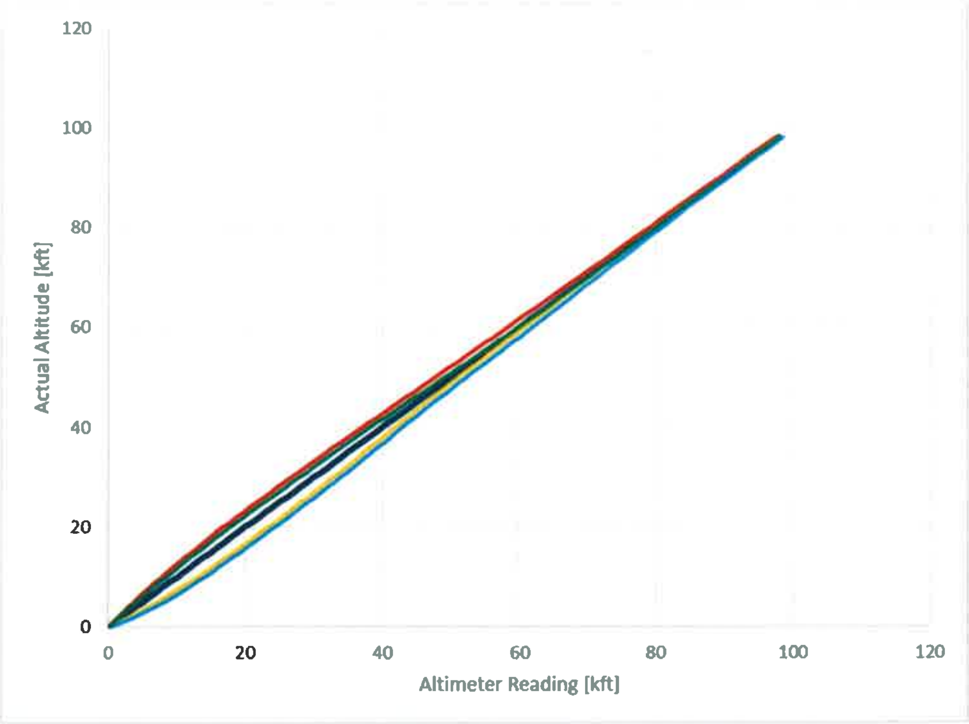
ISA + X

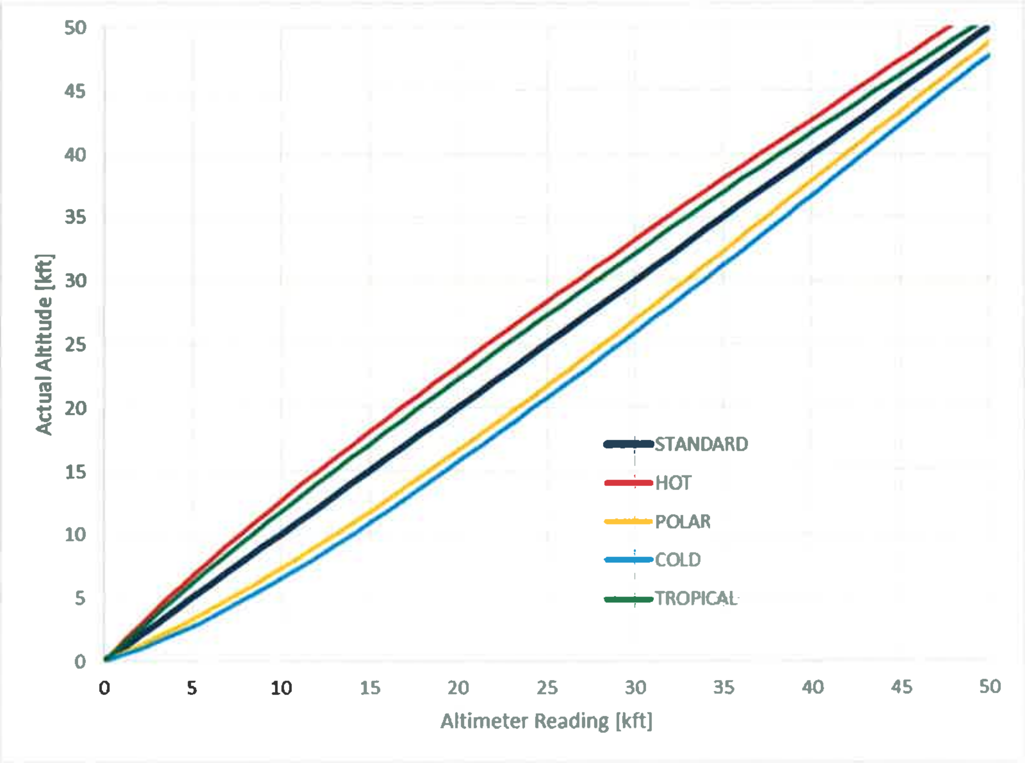
Add X to temp of std day




120
100
80
60
40
20
0
Altitude [kft]
0
2
4
6
8
10
12
14
16
Pressure [psi]
HOT
TROPICAL
STANDARD
POLAR
COLD


120
100
80
60
40
20
0
Altitude [kft]
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Difference in Pressure from Standard [psi]


120
100
80
60
40
20
0
Actual Altitude [kft]
0
20
40
60
80
100
120
Altimeter Reading [kft]


50
45
40
35
30
25
20
15
10
5
0
Actual Altitude [kft]
0
5
10
15
20
25
30
35
40
45
50
Altimeter Reading [kft]
STANDARD
HOT
POLAR
COLD
TROPICAL

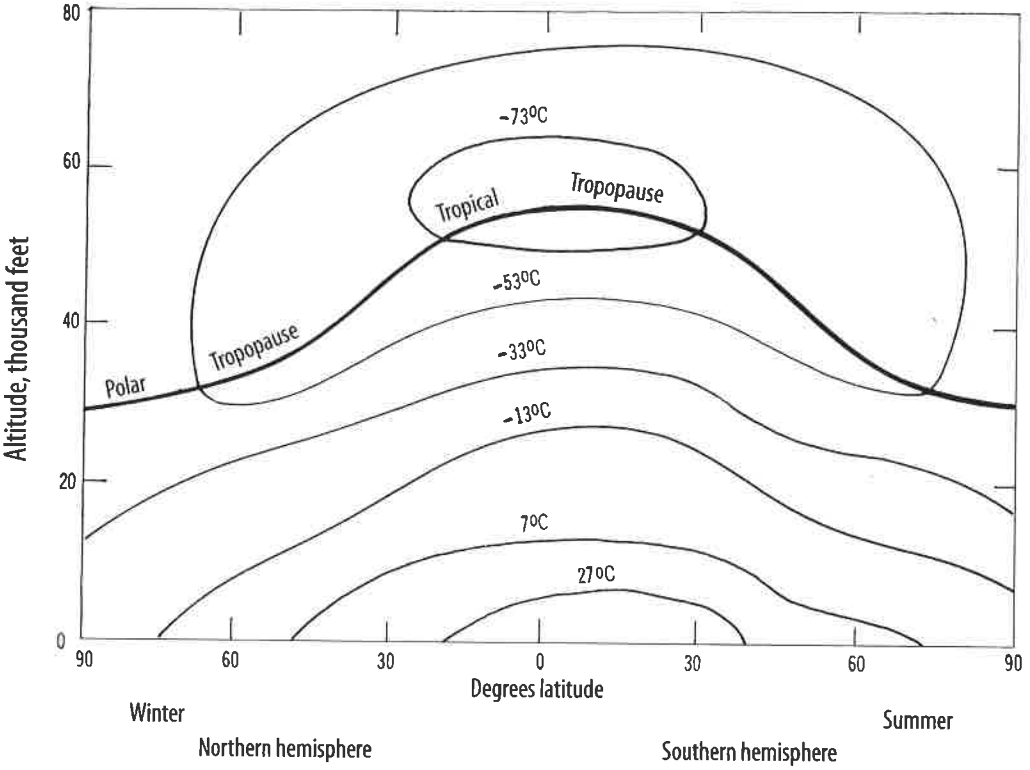


Fig. 1.1 Typical variation in atmospheric temperature along a meridian of longitude, summer in the Southern Hemisphere.

Source: TA of the Airplane, Stinton

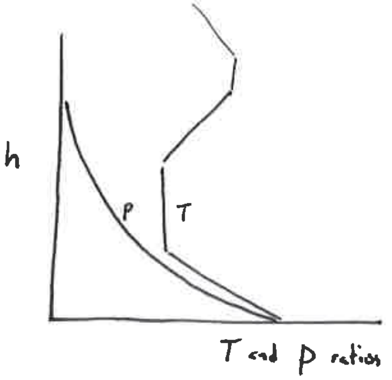
Fact: Cold temperature testing of a/c is often done at high altitudes in the tropics!

Why? We need to know some meteorology.

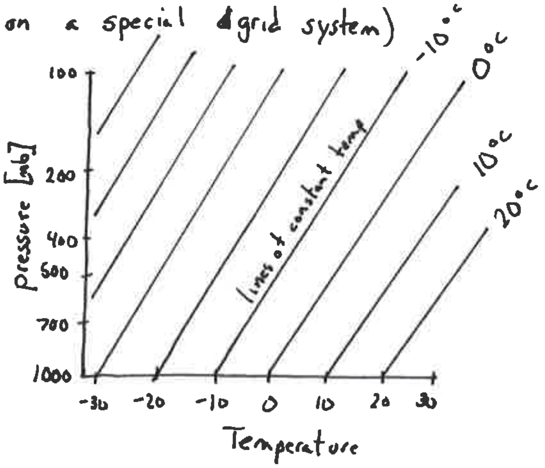
Why Clouds Form:

So far, we discussed only the dry-air lapse rate. Actual air has moisture.

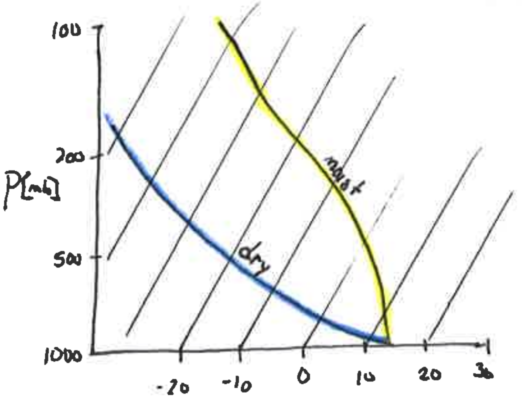
Skew T - Log P (draw height Pressure and Temp profiles on a special ~~d~~ grid system)



⟹



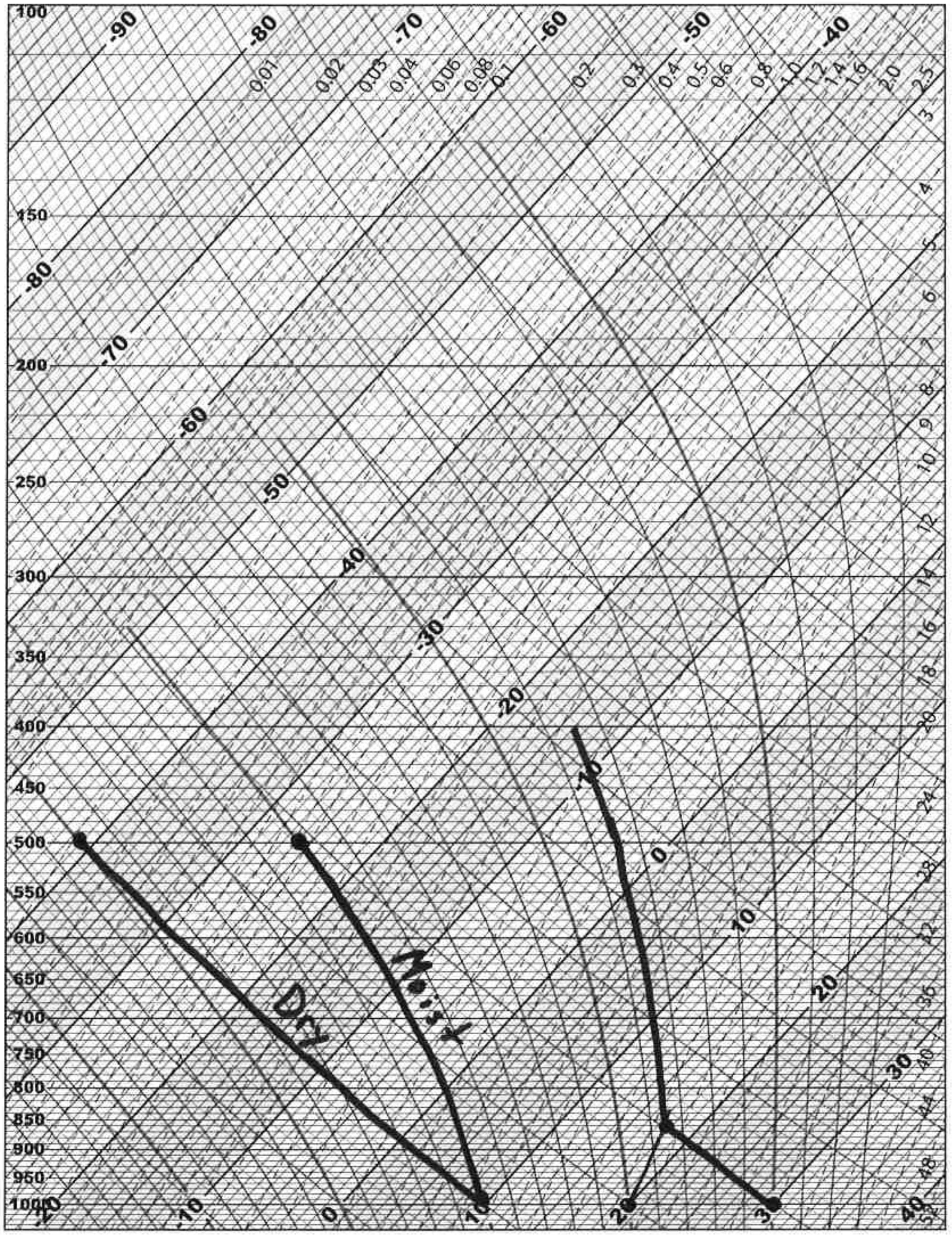
Using a skewT - log p plot, lets look at ~~the~~ standard day ~~lapse~~ rate (dry)



Changing the height to a log scale of pressure and tilting the temperature grid/coordinate allows us to see more of the atmosphere

Now, with water, the latent heat of water moving from ~~liquid~~ vapor to ~~vapor~~ liquid allows a slower cooling rate (Moist/Saturated lapse rate)
Once the moisture is condensed out (see previous Arden-Buck equ) as the pressure drops, the moist lapse rate approaches the dry lapse rate.

Air assends at the dry lapse rate until it becomes saturated (condenses), at which it ascends at the moist lapse rate



Skew-T / log p diagram for use with *A First Course in Atmospheric Thermodynamics* ©2008 by G.W. Petty

www.sundogpublishing.com

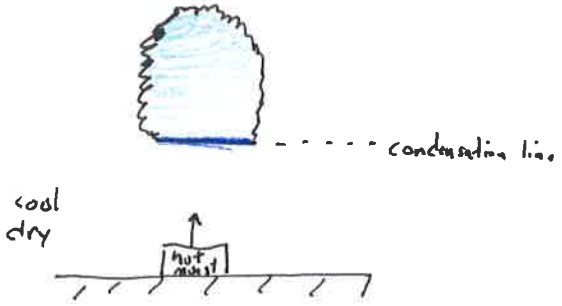
Example ① Lift moist vs dry air from $\underbrace{1000\text{ mb}}_{\approx SSL}$ to $\underbrace{500\text{ mb}}_{18000\text{ft}}$

Example ② Surface temp 30°C, Dew point 20°C
Clouds form when condensation begins at intersection of dewpoint and dry lapse around 850 mb ≈ 4500 ft

Atmospheric Stability

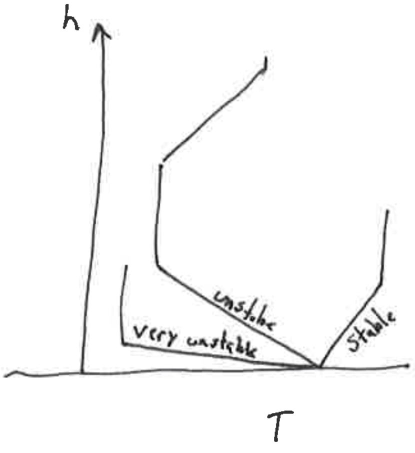
The driving force for cloud generation is density induced buoyancy. The hot moist air has a lower density and tends to rise within a cooler dry mass of air.

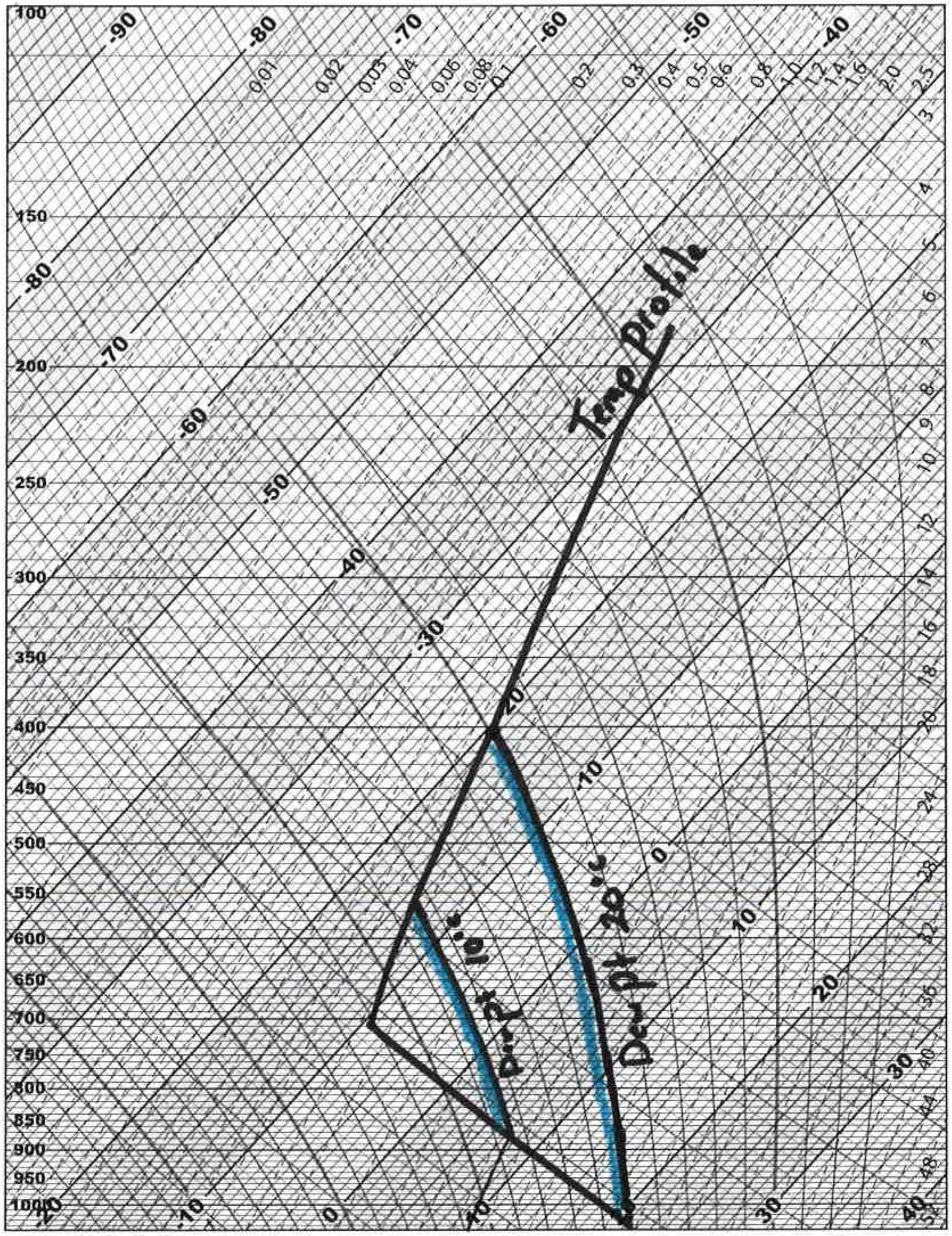
We saw that moist air rising has more energy (warmer) than dry air moved to the same height. This becomes an unstable system; As the moist air rises it tends to increase the driving force (density lowers).



For the standard atmosphere, where does the cloud stop rising? When the lapse rate changes to be more positive and eventually the density variation (and momentum) go to zero. The std atmosphere is naturally unstable to at least 36000 ft!

In reality, the convection/motion from the surface warms the upper atmosphere and reduces the lapse driving rate. Clouds are a visible sign of moving energy up!



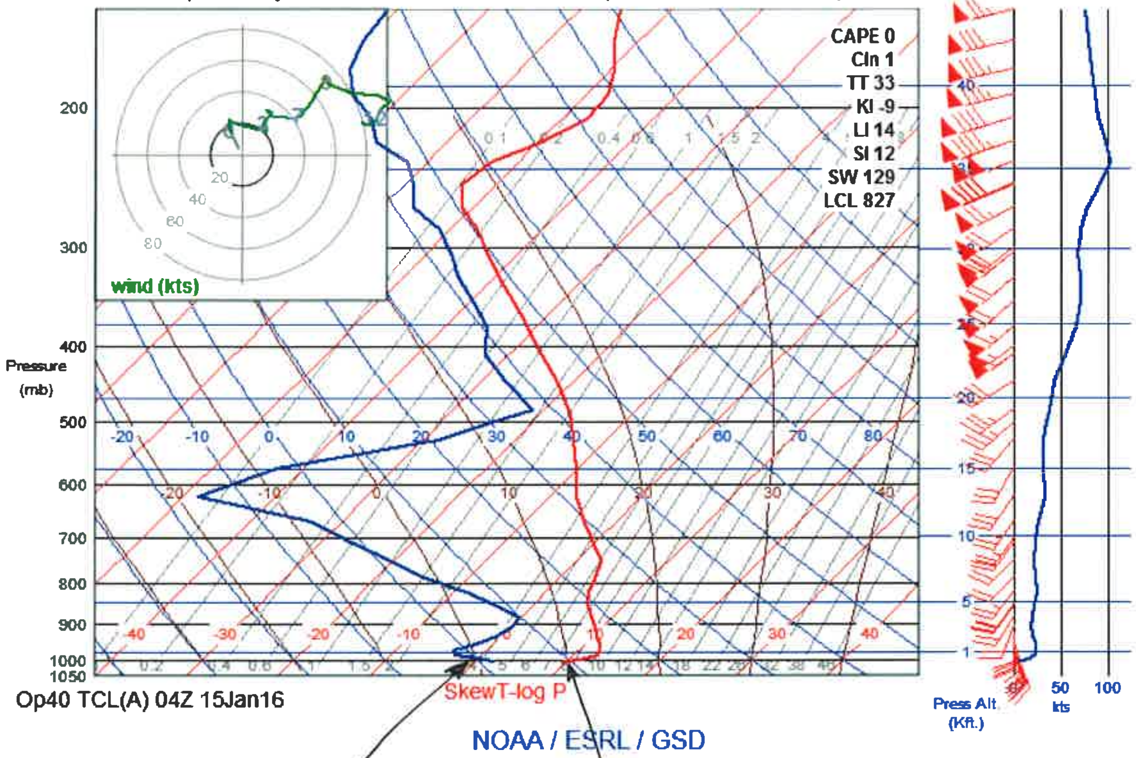


Skew-T / log p diagram for use with *A First Course in Atmospheric Thermodynamics* ©2008 by G.W. Petty

www.sundogpublishing.com

Tuscaloosa

Op40 Analysis, valid 15-Jan-2016 04:00:00 (10.3nm/355° from TCL)



Dew Point °C

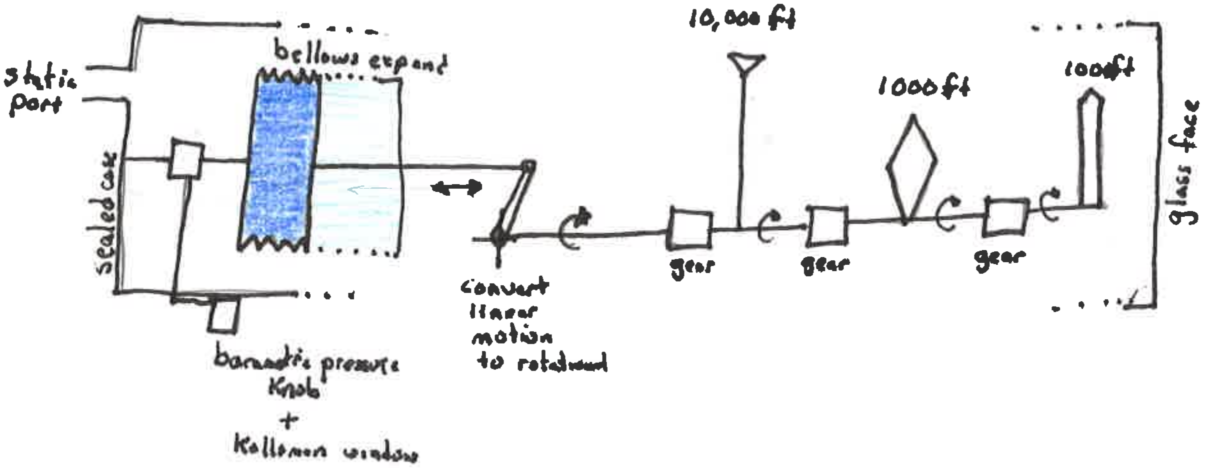
Temp °C

Altimeter (pressure type)

A sensor used to measure altitude. Uses local static pressure

Reading 13 700 ft

Inside (cartoon, not to scale)



Calibrated to SSL and Standard Atmosphere.

- Given a standard day, the altimeter reads a geometric altitude
- Given a non standard day, the altimeter reads pressure altitude (if 29.92 setting)
- The Knob corrects for local pressure differences such that the altimeter reads the airport's elevation. Obviously, a non standard pressure profile combined with airport approach and departures makes knowing the correct Kollsman window setting critical. "Altimeter setting two niner eight two"

Flight Level (FL):

When set to 29.92 in Hg, the altimeter's reading is a convienent reference for high altitude aircraft. Read as hundreds of feet. FL350 = 35000 ft

Q: why not low altitude?

Q: Why is a reference needed?

RVSM (Reduced Vertical Separation Minima)

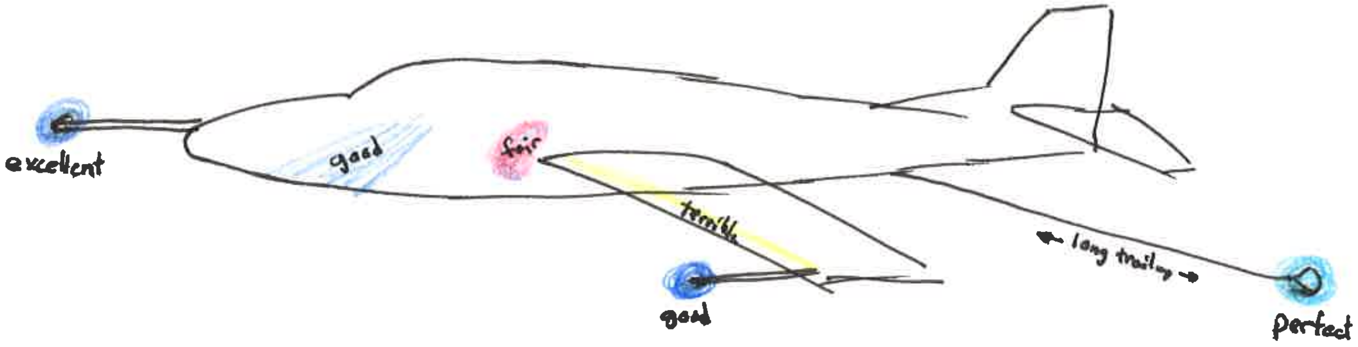
To increase the number of aircraft operating (safely) between FL290 and FL410, the verticle spacing between aircraft was reduced from 2000 ft to 1000 ft.

Aircraft operating in that region require special certification. In particular, the static pressure source becomes critical.

Easy Right?!? No. Placing the static port(s) can be a challenge.

Given that an aircraft creates a pressure distribution to generate lift and that a fuselage impacts the pressure distribution, the static sources must be placed in a region such that minimum deviation occurs during $\underbrace{\text{cruise}}_{\text{low } \alpha}$ and $\underbrace{\text{App/Dep}}_{\text{high } \alpha}$.

So, where?! Usually...



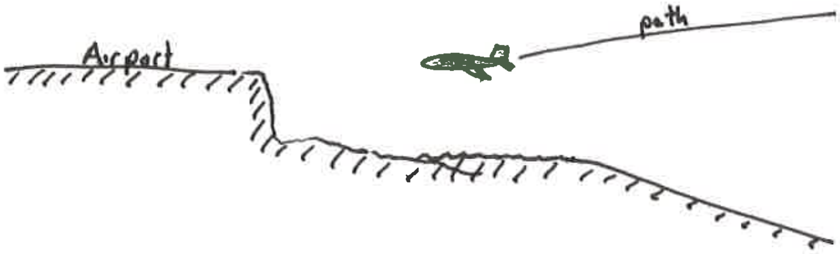
Radar Altimeter

Measure altitude based on time of flight.

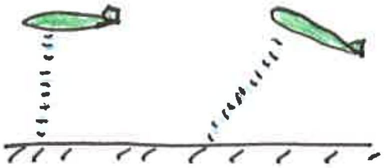
Ideal for high precision landing

problems:

- Not all airports are on flat level ground.



- Some models sensitive to tilt angle



Solution: Mount at angle where altitude is most critical. App/Dep. for most AC.

- Limited maximum altitude.

- Non passive signature (i.e. bad guys can find you).

More later... stay tuned.