Meteorology 433

Barometry

Spring 2022

Basics Revisited

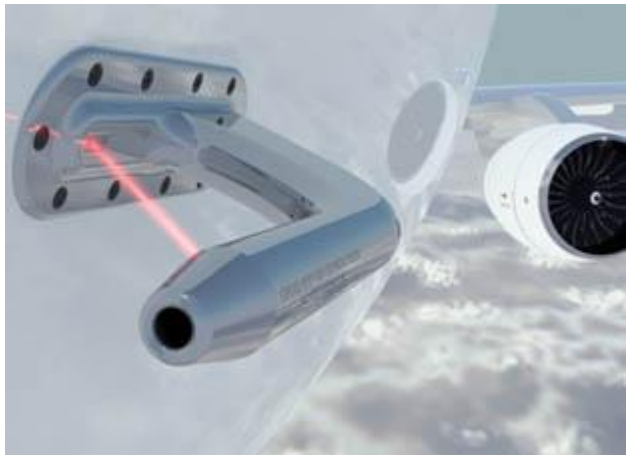
- Objective: Measure the static pressure exerted by the atmosphere.
- Static Pressure: Force per unit area in the absence of air motion.
- In this case, pressure is just the weight (per unit area) of the column of air above you.

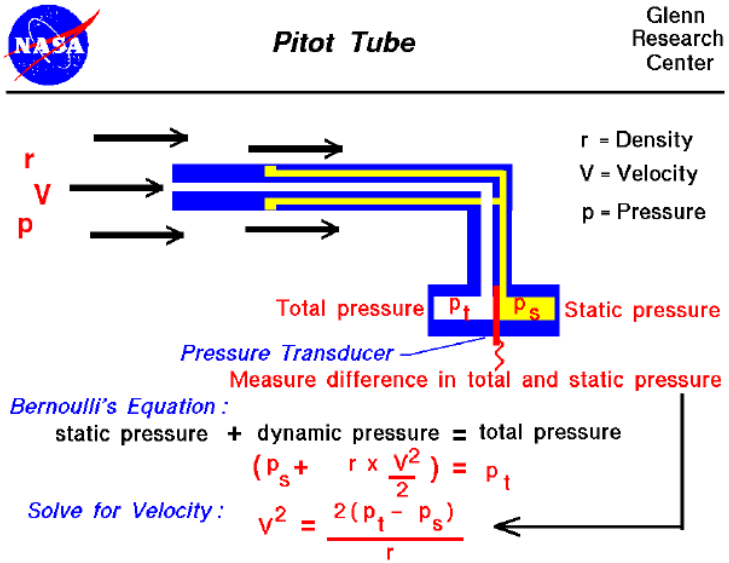
Dynamic Pressure

- Pressure exerted by wind flow.
  - Momentum transfer air particles impinging on a surface of unit area.

- $\Delta P = \frac{1}{2} C \rho V^2$
  - ΔP = pressure error from static conditions
  - C = coefficient whose magnitude is close to unity.
  - ρ = air density
  - V = wind speed

Pitot Tubes




Pitot Tube
Glenn Research Center
r = Density
V = Velocity
p = Pressure
r
V
p
Total pressure
p_t
p_s
Static pressure
Pressure Transducer
Measure difference in total and static pressure
Bernoulli's Equation :
static pressure + dynamic pressure = total pressure
$(p_s + r \times \frac{V^2}{2}) = p_t$
Solve for Velocity :
$V^2 = \frac{2(p_t - p_s)}{r}$

Direct/Indirect

- Direct measurement of pressure
  - Instruments that balance the force of the atmosphere against something.
  - Liquid column.
  - Spring (aneroid barometer).
  - Pressure transducer or digital barometer

- Indirect measurement of pressure
  - Boiling point of liquid exposed to atmospheric pressure.

Direct Measurement

- Manometer
  - Differential measurement.
  - Absolute measurement.
  - Measure the difference in height of the two columns.
  - Requires two measurements of height.

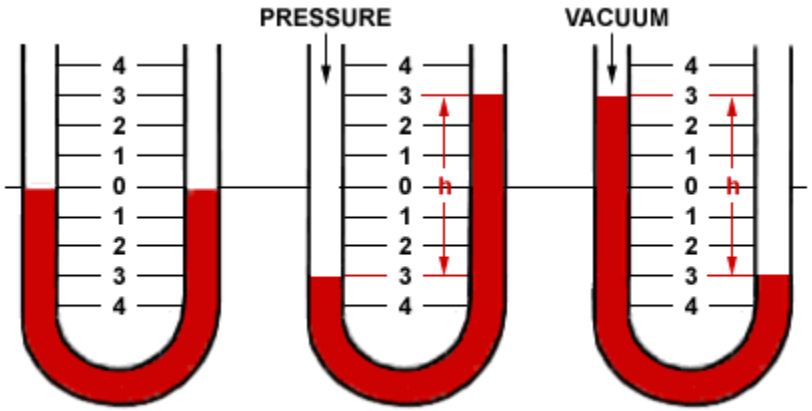


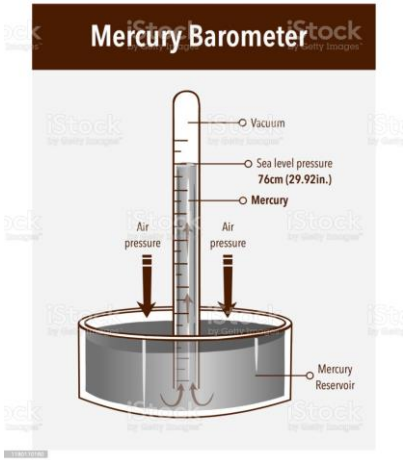
Fig. 2-1 Fig. 2-2 Fig. 2-3

Direct Measurement

- Mercury barometer
  - Column of mercury in a glass tube with a reservoir of mercury at the bottom and is sealed at the top (near vacuum).
  - Weight of column is balanced against the force of the atmosphere.
  - Height of the column relative to the surface of mercury in the reservoir is determined by the attached scale.

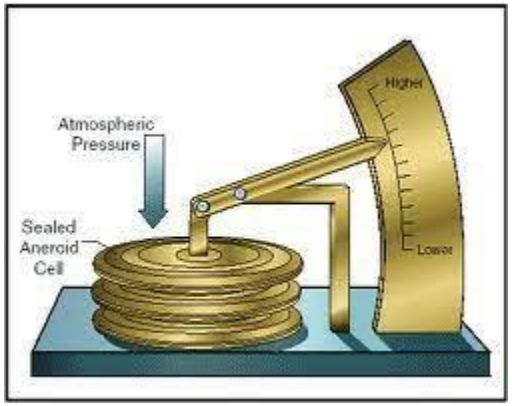
Why Mercury?

- High Density
  - 13534 kg/m^3
  - Allows column to be of reasonable length.
- Low vapor pressure
  - Has little impact on the vacuum at the top.
- Easily purified and is chemically stable
  - Vapor is toxic – Extreme care must be used.
- Is liquid between ~ -39 ºC to 357 ºC.



Aneroid Barometer

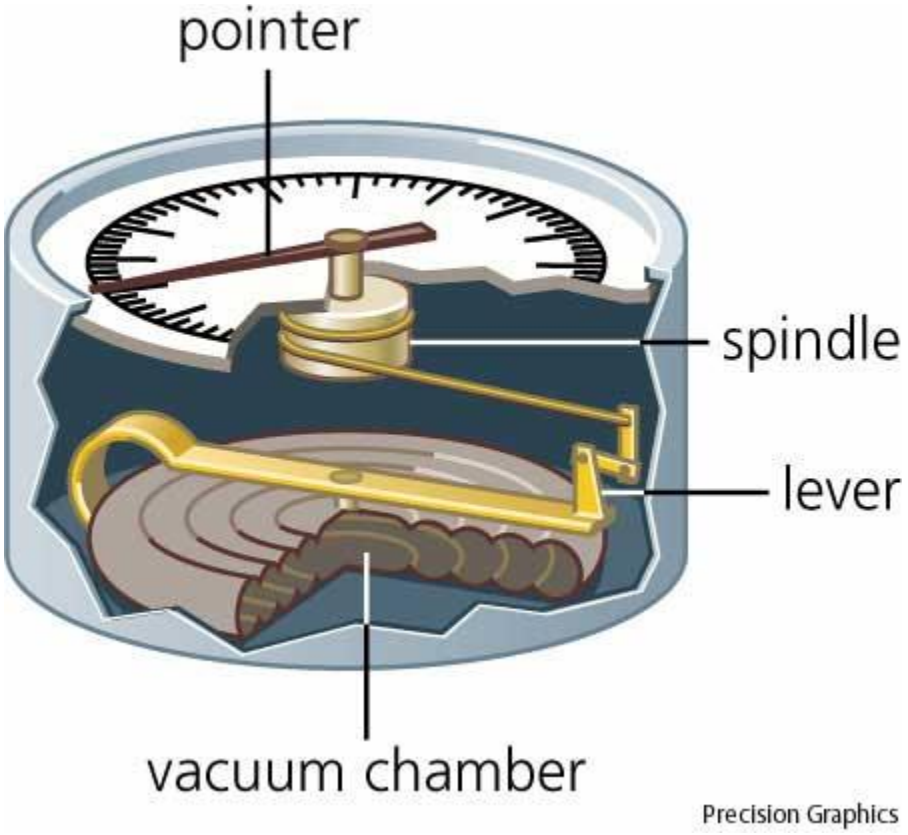
- Aneroid: Without fluid.
- Evacuated chamber with a flexible diaphragm that moves in response to applied pressure.
  - Somewhat similar to pressure transducer.
- The restoring force is a spring or may be part of the diaphragm itself.



Real Aneroid

- Corrugated diaphragms.
  - Simple fix that makes the static sensitivity nearly constant.
  - Nearly a linear sensor.
- Two corrugated diaphragms welded together.
  - Space between diaphragms is evacuated.
- Deflection of diaphragm either drives a dial display or provides an electric output.

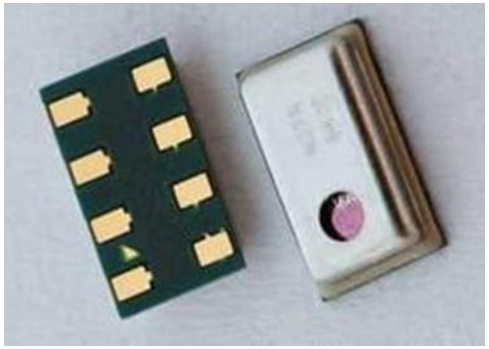

Nassau
Outdoor Environments, LLC.
U.S.A.


pointer
spindle
lever
vacuum chamber
Precision Graphics

Modern Barometers

- Digital barometers or pressure transducers

- Cell is sensitive to atmospheric pressure
  - Pressure changes the cells capacity to conduct/relay electricity
  - This change is easily measure by a data logger.



Modern Barometers

Accuracy	
Calibration Uncertainty	±0.15 hPa
Uncertainty	±0.3 hPa (at 20°C)
Total Uncertainty	±0.5 hPa (at -40° to +60°C)
Long-Term Stability	±0.1 hPa/yr
Power Supply Rejection	Negligible
Measurement Noise	0.05 hPa (RMS)
Resolution	0.1 hPa

Sources of Error in Mercury Barometers

- Dynamic wind pressure
  - Can be several hPa.
  - How do you overcome this?
- Density of mercury is a function of temperature.
  - Make temperature correction (C_T).
- Local Gravity must be known correctly.
  - Make gravity correction (C_G).
- Air or water vapor at top of tube (not vacuum).
- Barometer must be kept vertical.
- Mercury must be pure.
- In small tubes, surface tension will cause a meniscus
  - For 5mm tube, ~200 Pa (~0.2% of standard atmosphere).
  - For 13mm tube, ~27 Pa
  - Index Correction (C_I)

Corrections

- Ideal barometer: static pressure as the only input.

- Reality: static pressure, dynamic pressure, and temperature are inputs
  - This results in errors that need to be corrected.

- To convert a raw barometer reading (p_1) to station pressure (p_s), we need to apply an index correction (C_x), temperature correction (C_T), and gravity correction (C_G).

Index Correction (C_x)

- Obtained by comparison with a reference barometer.
- Usually is included on a card that comes with the barometer.
- If no index correction is given, assume is zero.
  - Quote this as being “unknown”, and set it equal to zero.

Temperature Correction (C_T)

- Developed from known thermal expansion coefficients for mercury *and* for the scale.
  - Volume change in mercury reservoir.
  - Length change of scale.

- $C_T = - P_1 (\beta - \alpha) T$
  - β = volume expansion coefficient of mercury (p. 21).
  - α = linear expansion coefficient of the scale.

- By introducing this correction, we effectively reduce our pressure measurement to 0˚C

- For a brass scale, $C_T = -1.63 \times 10^{-4} P_1 T$.

Gravity Correction (C_G)

- Let the index and temperature corrected pressure be P_2.
  - $P_2 = P_1 + C_x + C_T$
  - $P_s = P_2 + C_G$
- If we are at a place with standard gravity ($g_o = 9.80665\ m/s^2$), P_2 is final true pressure.
- If g deviates from g_o, we need to make a gravity correction.
  - If you go north, gravity increases.
    - Your weight increases by 0.5% as you go from equator to pole, this is approximately one pound for the average person.
  - If you go up, gravity decreases.

Gravity Correction

- $C_G = \frac{g_L - g_o}{g_o} P_2$.

- Where:
- g_0 = standard gravity = 9.80664 m/s^2
- Φ = barometer latitude
- z = barometer elevation in meters
- z'= mean elevation within a 150 km radius

- $g_\Phi = 9.80616 (1 – 2.6373x10^{-3} \cos(2\Phi) + 5.9x10^{-6} \cos^2(2\Phi))$
- $g_L = g_\Phi – 3.086x10^{-6} z + 1.118x10^{-6} (z-z')$

- WMO, 1983

How accurate do we need to be?

- How accurately must the latitude and elevation be determined?
  - Do we need to measure the exact height and latitude of the barometer?

- For an error of 0.05 hPa, how close do we need to be?
  - ±169m in height, and
  - ±0.6° in latitude
  - These are determined by $\frac{\partial C_G}{\partial z}$ and $\frac{\partial C_G}{\partial \emptyset}$

Reading a Fortin Barometer

Procedure

Read the Fortin barometer

(a) Open the barometer case and read the thermometer immediately to the nearest 0.1°C. The desired temperature is that of the barometer; after you open the case, convection currents may affect the thermometer reading.

(b) Use the bottom screw to adjust the level of mercury in the cistern until the mercury just touches the fiducial point.

(c) Gently tap the cistern to move any mercury sticking to the glass. Check the level and repeat (b) as necessary.

(d) Adjust the scale index to the top of the mercury column. Keep your eye level with the mercury meniscus in the tube. The zero line should be tangent to the uppermost point of the mercury.

(e) Read the pressure p_1 using the vernier, to 0.1 hPa.

(f) Lower the level of mercury in the cistern until the mercury is no longer touching the fiducial point, turn off the light, and close the barometer case.

Apply correction to the Fortin barometer reading

(a) Index correction. The index correction C_I is stated in the barometer certificate. It was obtained by comparison with a standard barometer.

(b) Temperature correction. Use eq. 2.4a or 2.4b or look up the correction in tables. Apply the index and temperature correction: $p_2 = p_1 + C_\kappa + C_T$.

(c) Gravity correction. Determine the height and latitude of the barometer and compute C_G using eq. 2.5. Show this calculation. The station pressure is given by $p_s = p_2 + C_G$.

Read other barometers

Read the microbarograph, the aneroid, and other barometer, if available. Convert readings to hPa and compute the correction relative to the Fortin barometer.

Assignment

- Take a reading on the Fortin barometer before class on Wednesday
  - Each group member will take their own reading.
- Record:
  - Time of reading, pressure, and temperature
  - Readings from two external sources for comparison (time, pressure, temperature).
- We will use this data in class on Wednesday.