# Measuring Pressure Loss in Underground Airways- Webinar

SRK Consulting – Ventilation Group

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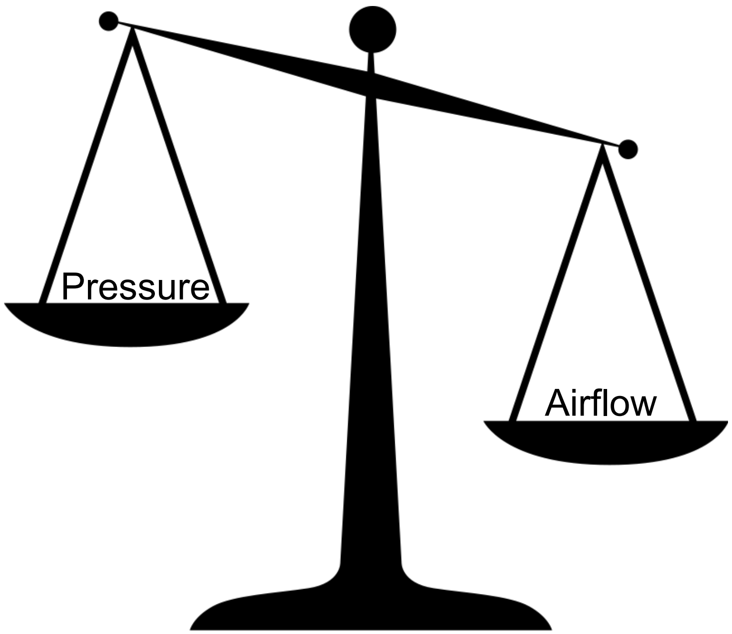
# Introduction

## The importance of ventilation survey pressure measurements.

- Necessary for calculation of airway resistance
- Significant impact on ventilation modeling accuracy
- Can be used to monitor ventilation system.
- Identify areas of high loss.

# Balance of Measurements




Survey measurement emphasis heavily weighted toward airflow.

Results in negative impact  when one measurement type is favored.

# Square Law

$$P = RQ^2 \text{ or } R = \frac{P}{Q^2}$$

$R$ = Resistance (Practical Unit or $Ns^2/m^8$)

$P$ = Pressure Drop (milli in. w.g. or Pa)

$Q$ = Quantity (kcfm or $m^3/s$)

# Atkinson's Friction Factor Equation

$$R = \frac{P}{Q^2} = \frac{kLPer}{A^3}$$

or

$$k = \frac{RA^3}{LPer}$$

Atkinson's Equation

$R$ = Resistance (Practical Unit (P.U.) or Ns2/m8)

$k$ = Friction factor (lbf min$^2$/ft$^4$ x $10^{-10}$ or kg/m$^3$) [and is a function of air density]

$L$ = length of airway (ft or m)

$Per$ = flow perimeter (ft or m)

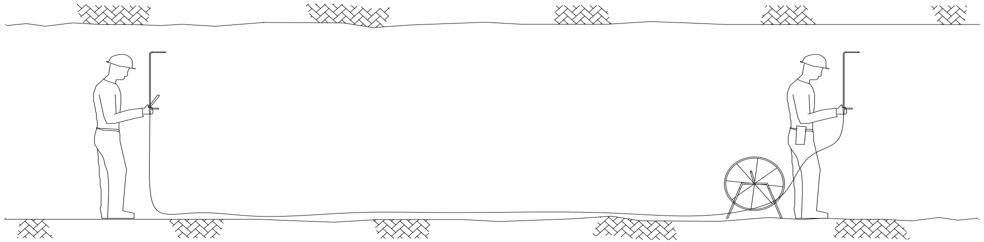
$A$ = cross-sectional area (ft2 or m2)

$a$ = 52 in imperial units and 1 in SI units.

# Types of Pressure Measurements

- Barometric/Altimeter


- Gauge and Tube/Direct Measurement



# Barometric/Altimeter Measurements

Barometer/Altimeter Measurement Survey Techniques

1. Roving
2. Base Station

Measurements Required

- Barometric Pressure
- Elevation (survey)
- Dry Bulb Temperature and Wet Bulb temperature or Relative Humidity
- Air Velocity

# Barometers/Altimeters

Setra Barometer


Laboratory quality measurements in a portable unit (high resolution) +/- 10 Pa

Wallace and Tiernen or Paulin

Non battery powered/safe for use in return airways (coal) – intrinsically safe


Kestral
Small pocket size less accuracy, lower resolution
+/- 20 Pa



Druck or Vaisala
+/- 10 Pa

# Other Survey Equipment


RH/Temp

Anemometer

Sling Psychrometer


Barometer

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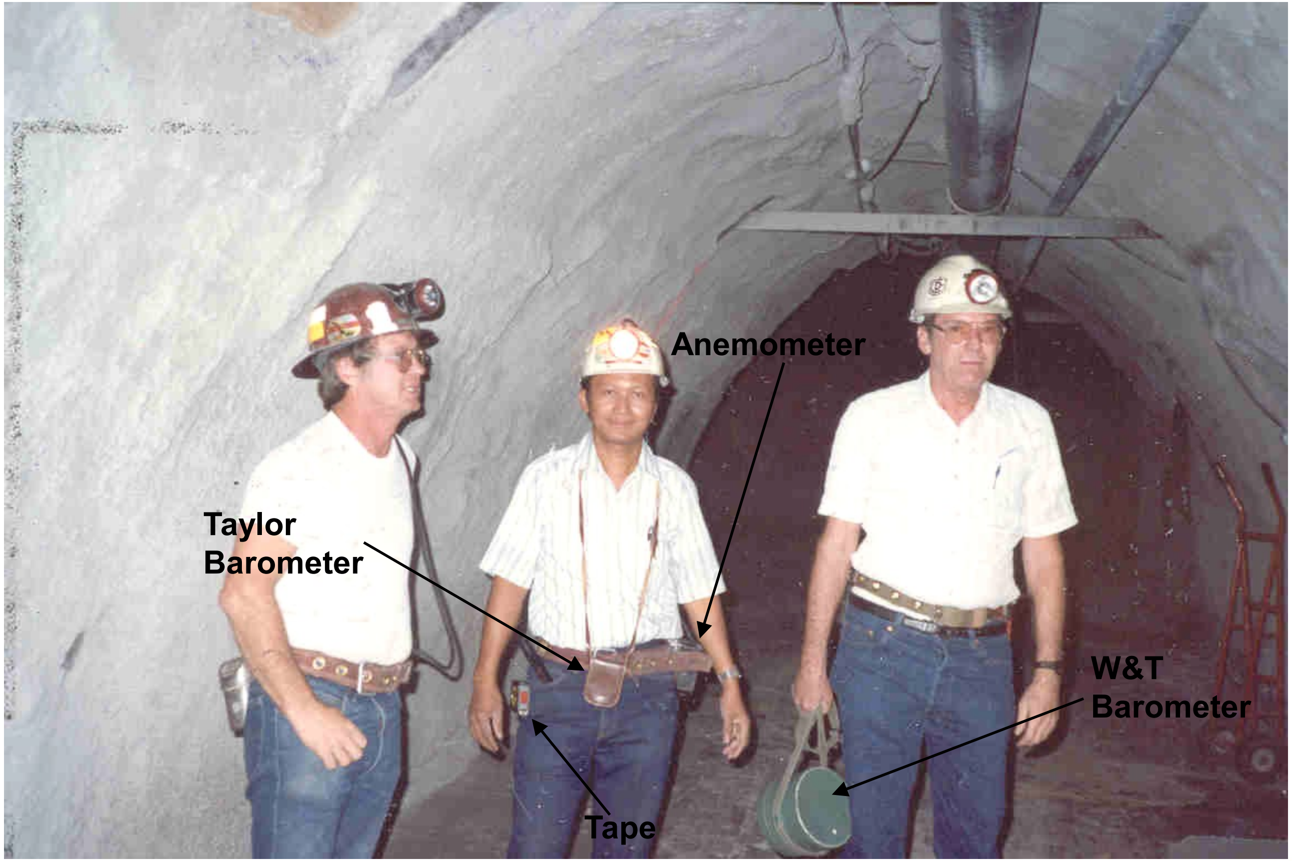
# Barometer Survey Team



# Barometer Survey – Two Ways

Roving

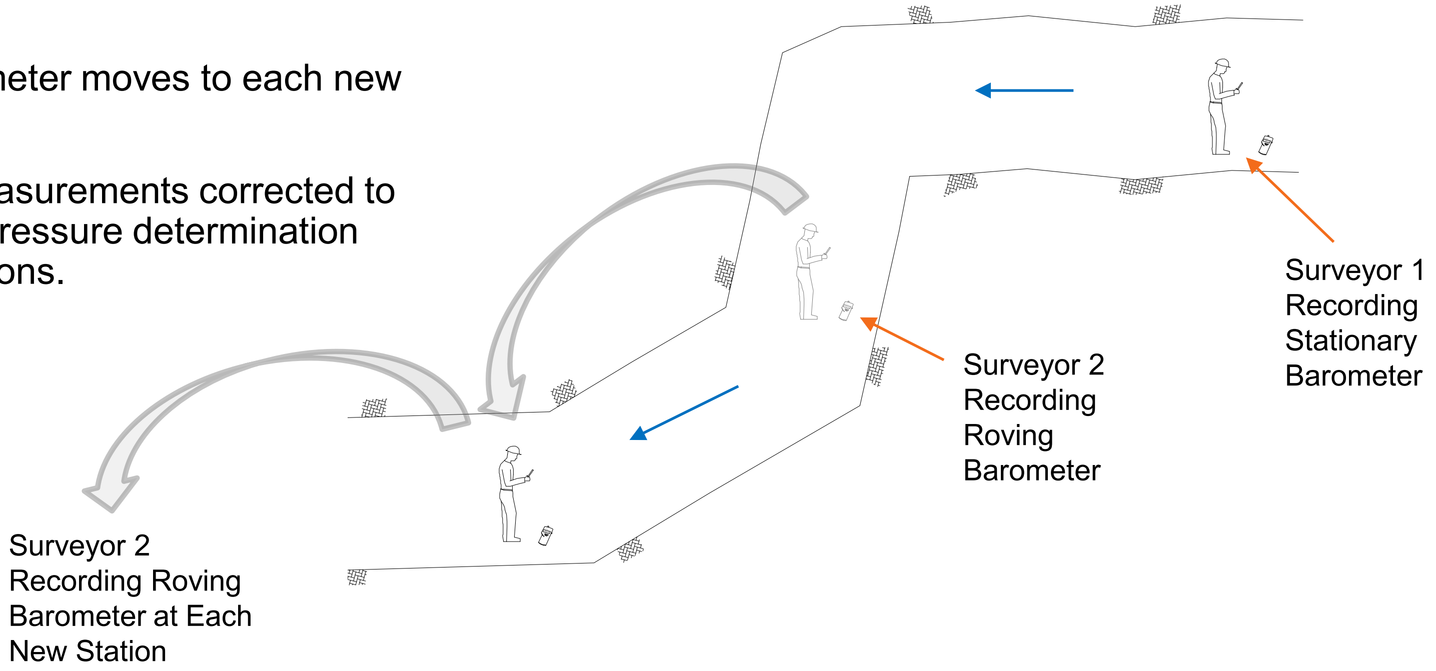
&

Leapfrog

- Roving - single surveyor traverses the airways; second stationary barometer continuously records.
- Leapfrog - two surveyors traverse the underground; measurements are recorded simultaneously.

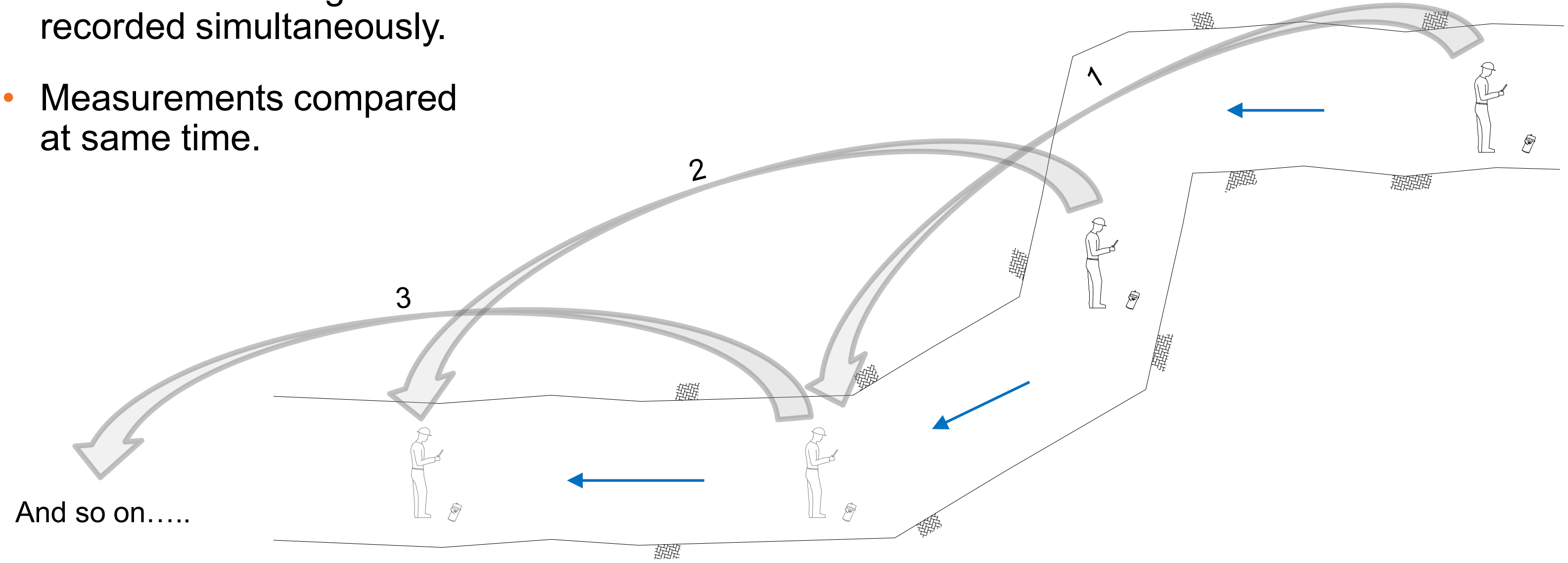
# Barometer Survey - Roving Method

- Stationary barometer used for correction.
- Roving barometer moves to each new station.
- Individual measurements corrected to baseline for pressure determination between stations.



# Barometer Survey – Leap Frog Method

- Barometer readings recorded simultaneously.
- Measurements compared at same time.



# Reduced form of Steady Flow Energy Equation (*SFEE*) - SI Units

$$F_{12} = \frac{u_1^2 - u_2^2}{2} + (Z_1 - Z_2)g - R(T_2 - T_1)\frac{\ln(P_2/P_1)}{\ln(T_2/T_1)}$$

- F = work done against friction (J/kg)
- P = barometric pressure (kPa)
- T = absolute temperature (Kelvin)
- Z = elevation of barometer location (m)
- u = air velocity at the barometer location (m/s)
- R = mean gas constant (J/kg·K)
- g = gravitational acceleration (9.81 $m/s^2$)

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# Solving for the gas constant in the *SFEE*

- Velocity (u) is from anemometer readings.
- Elevations (Z) need to be from *accurate* survey data.
- Gas constant is the average computed at each station from:

$$R = \frac{\text{P}}{\rho \, \text{T}} 1000 \quad (J / kg°C)$$

- T is absolute temperature in Kelvin (°C + 273.15)
- P is barometric pressure (kPa)

# Barometer Survey Data Reduction: Determine Pressure Loss from *SFEE*

$$p_{12} = \rho_a F_{12}$$

- $p_{12}$ = frictional pressure drop (Pa)
- $F_{12}$ = work done against friction (J/kg)
- $\rho_a$ = average actual density (between the two stations)

# Barometer Survey Data Reduction: Alternative Thermodynamic Methods

## Steady Flow Energy Equation

$$F_{12} = \frac{u_1^2 - u_2^2}{2} + (Z_1 - Z_2)g - R(T_2 - T_1)\frac{\ln(P_2 / P_1)}{\ln(T_2 / T_1)} \qquad (1)$$

Where:
- F - Work done against friction (J/kg)
- P - Barometric pressure (kPa)
- T - Absolute temperature (Kelvin)
- Z - Elevation of barometer location (m)
- u - Air velocity at the barometer location (m/s)
- R - Mean gas constant (J/kg K)
- g - Gravitational acceleration (9.81 m/s²)

$$p_{12} = \rho_a F_{12} \qquad (2)$$

Where:
- $p_{12}$ - Frictional pressure drop (Pa)
- $\rho_a$ - Average density of air between two stations (kg/m³)

## Burrows, 1989

$$p_{12} = -(P_2 - P_1) - g\int wdZ$$

$$\int wdZ = \frac{1}{2}(\rho_1 + \rho_2)(Z_1 - Z_2)$$

## Hall, 1981

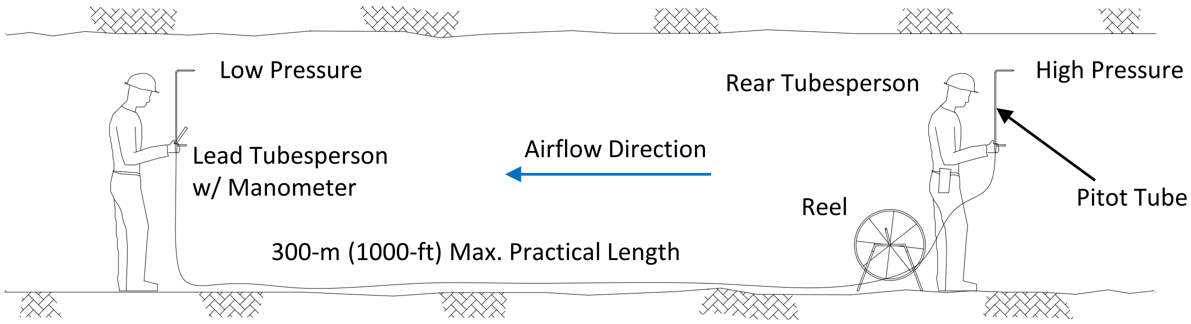
$$P_{2calc} = P_2\left(\frac{2P_1 + Dg\,\rho_1}{2P_2 - Dg\,\rho_2}\right)$$

Where: D - Depth below datum (m)

$$p_{12} = P_{2calc} - P_2$$

# Gauge and Tube/Direct Measurement

- Two people with 1000 ft tube, manometer, and pitots.
- Great for measurements without extreme elevation changes



# Gauge and Tube Measurements

Surveyor with pitot tube and manometer.

Survey Station Marker

1000' Pressure Tube

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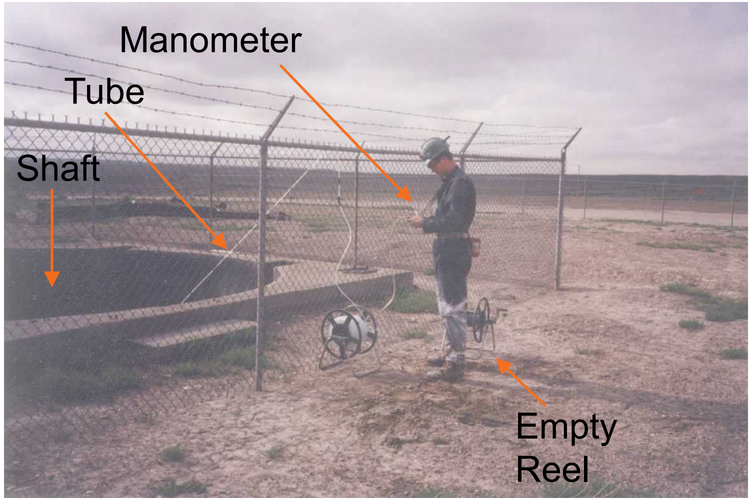
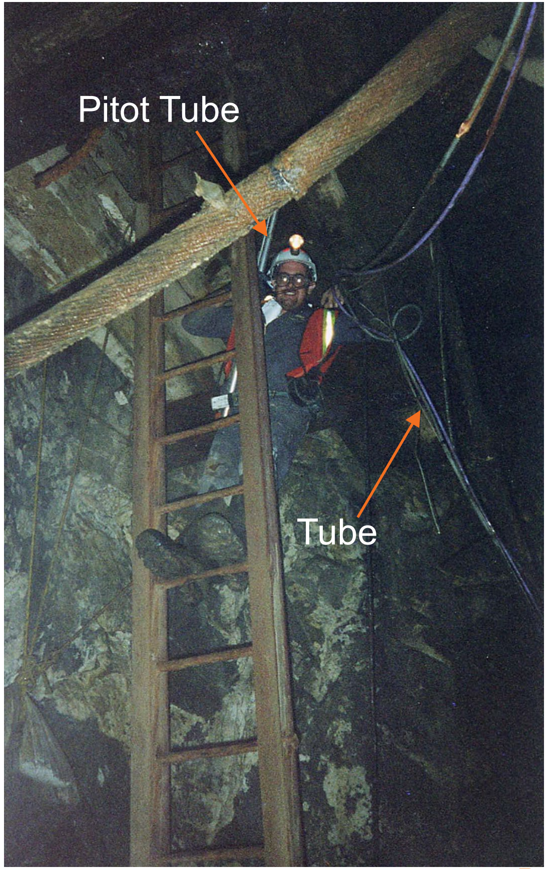
# Shaft Measurements



# Raise Measurements

Gauge and tube measurements in internal raises of shafts can be physically demanding.



# Data Reduction for Raises and Shafts

- Vertical elevation changes greater than 300 meters require additional measurements to calculate corrections accounting for changes in density.

$$p_{12} = \Delta P \times \frac{P_m}{P_L}$$

$p_{12}$- Frictional pressure drop from point 1 to point 2

$P_m$- Mean barometric pressure in the shaft

$P_L$ - Barometric pressure at measurement location (at either point 1 or point 2)

$\Delta P$- Raw differential pressure measurement

# Which Is Better?

Depends on Application

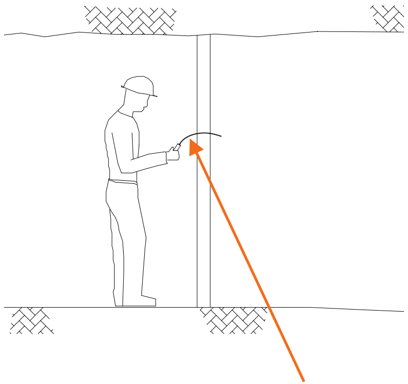
**Gauge and Tube**

- Measurements along levels
- Measurements along ramps
- Level raises
- Measurement of small differential pressures

**Barometer/Altimeter**

- Deep shafts/raises
- Across gob areas
- Evaluation of "black box" areas
- Where there are personnel constraints – flooding, poor ground conditions

# Differential Pressure Measurements



Tube connected to manometer through bulkhead

<u>Equally Important  and Complimentary to Gauge and Tube Measurements</u>

- Uses either precision manometer or magnehelic and length of tubing
- Measures pressure differential across regulators, doors, bulkheads, curtains, and fans.

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# Conclusion

- Full ventilation survey usually combines both barometer and gauge and tube techniques.
- In older “historic” areas of the mine, elevation data may not be available, but often represent integral parts of the ventilation system.
- Barometric survey techniques can shorten a survey, but don’t omit the need for gauge and tube.
- Pressure measurements are critical to fully understand ventilation system.

# References

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McPherson, M.J 1993. Subsurface Ventilation and Environmental Engineering. New York, New York: Chapman & Hall