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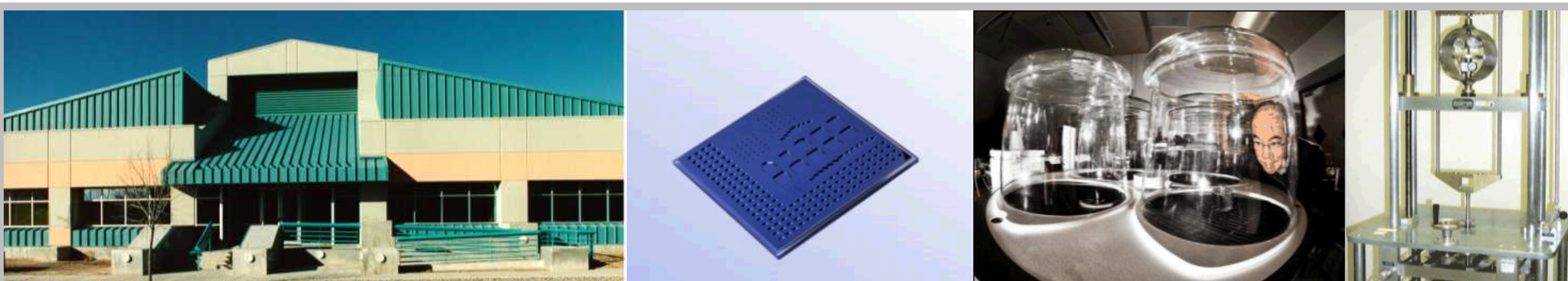

Uncertainty of Conventional Mass Conversion

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Outline

- Metrology
- Mass measurement
- What is conventional mass?
- Measurement uncertainty
  - Monte Carlo simulation
- Results
- Thermometer Calibration

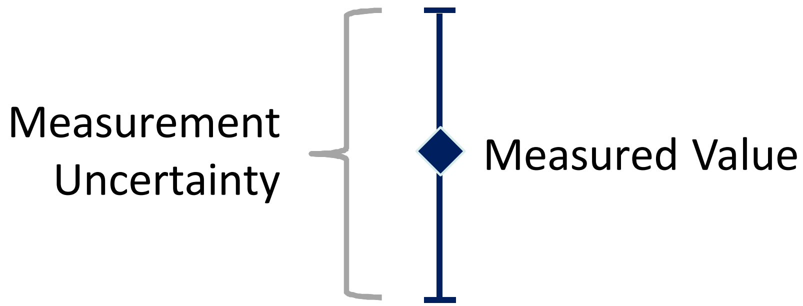
Metrology

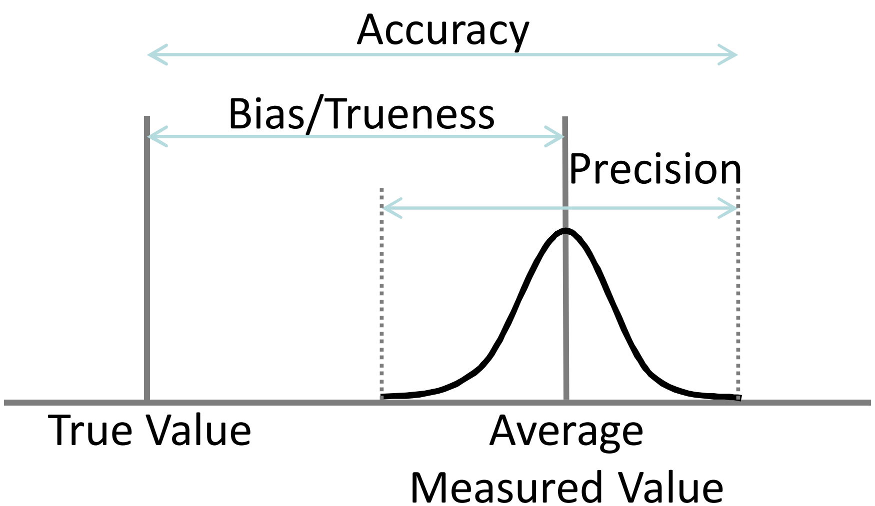
- Study of measurement
- Important in science, technology, and commerce
- Length/Mass/Force Lab

- Accuracy
- Traceability

Mass Measurement

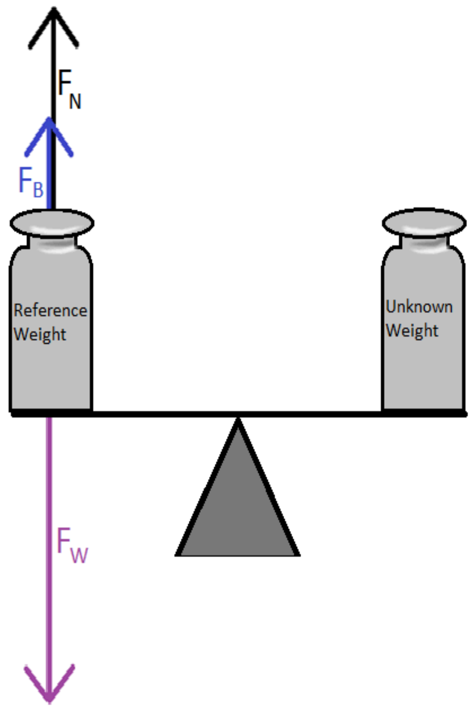
- Comparison between known reference and unknown unit under test
- Mass of unit under test is mass of reference weight that balances it, with corrections applied
- Uncertainties – estimate of range of values about the measured value in which the true value is believed to lie





Conventional Mass

- "Conventional result of weighing in air if:
  - $t_0 = 20\ ^{o}C$
  - $\rho_R = 8000\ kg/m^3$
  - $\rho_a = 1.2\ kg/m^3$
- "True mass" (mass in a vacuum)
  - Mass measurement, without the effect of buoyancy
- Corrections required from other air conditions



$$m_{CUUT} = m_{UUT} \frac{1 - \frac{1.2}{\rho_R}}{1 - \frac{1.2}{8000}}$$

Measurement Uncertainty

- Task: Find which has lower uncertainty
- First converting to true mass, then to conventional

$$m_{CUUT} = \frac{m_{(ABQ)UUT} * \rho_{UUT}}{(\rho_{UUT} - \rho_{(ABQ)a})} * \frac{(\rho_{UUT} - \rho_0)}{\rho_{UUT}}$$

- Converting directly to conventional

$$m_{CUUT} \approx m_{(ABQ)UUT} + \frac{m_{(ABQ)UUT}}{\rho_{UUT}} * (\rho_{(ABQ)a} - \rho_0)$$

- Equation valid in conditions other than Albuquerque's
- Use Monte Carlo random number simulation for uncertainty

5.1.2 The combined standard uncertainty $u_c(y)$ is the positive square root of the combined variance $u_c^2(y)$, which is given by

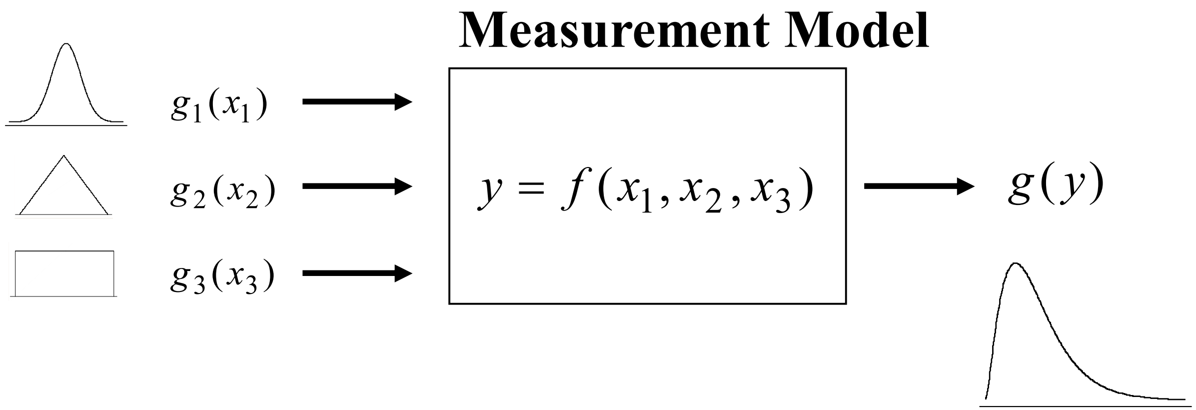
$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) \tag{10}$$

where f is the function given in Equation (1). Each $u(x_i)$ is a standard uncertainty evaluated as described in 4.2 (Type A evaluation) or as in 4.3 (Type B evaluation). The combined standard uncertainty $u_c(y)$ is an estimated standard deviation and characterizes the dispersion of the values that could reasonably be attributed to the measurand Y (see 2.2.3).

Equation (10) and its counterpart for correlated input quantities, Equation (13), both of which are based on a first-order Taylor series approximation of $Y = f(X_1, X_2, ..., X_N)$, express what is termed in this *Guide* the *law of propagation of uncertainty* (see E.3.1 and E.3.2).

Monte Carlo Simulation

- Possible to simulate many measurements
- Define all input variables and uncertainties
- Simulate many random values for each variable
  - Normal distribution
- Calculate output from each set
- Uncertainty of result = standard deviation of all calculated values of result



Results

- Direct conventional mass uncertainty always less than conventional mass through true mass uncertainty

$$u(m_{CUUT\_direct}) < u(m_{CUUT\_throughTrue})$$

  - Less than uncertainty of true mass

$$u(m_{CUUT\_direct}) < u(m_{UUT})$$

Uncertainty (k=2) in mg of true mass and conventional mass as a function of density and density uncertainty

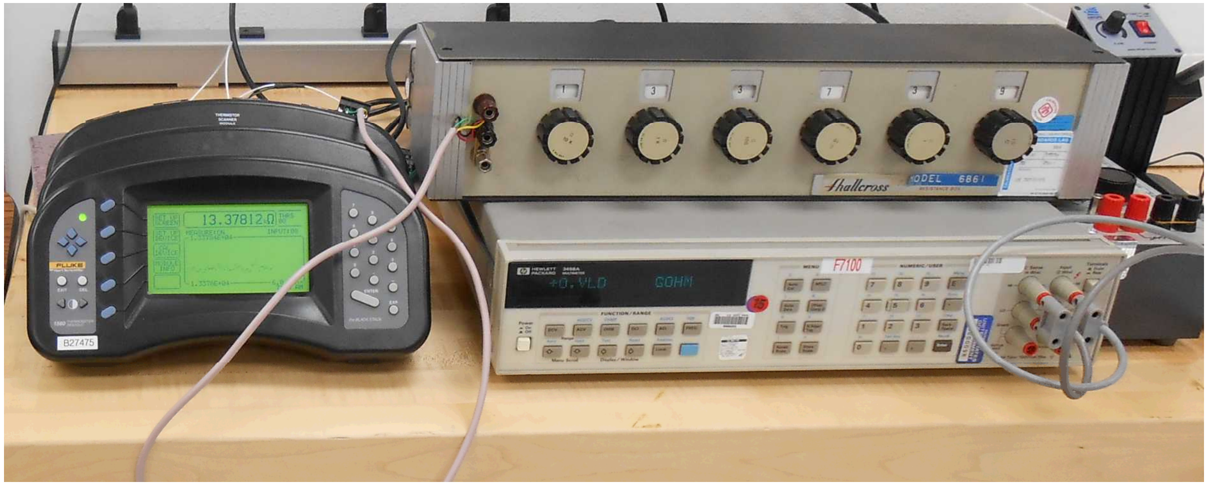
		UUT Density Uncertainty											
		0.05% $U(m_{UUT})$	0.05% $U(m_{CUUT})$	0.14% $U(m_{UUT})$	0.14% $U(m_{CUUT})$	0.23% $U(m_{UUT})$	0.23% $U(m_{CUUT})$	0.29% $U(m_{UUT})$	0.29% $U(m_{CUUT})$	0.41% $U(m_{UUT})$	0.41% $U(m_{CUUT})$	0.50% $U(m_{UUT})$	0.50% $U(m_{CUUT})$
UUT density	7810 kg/m³	0.14	0.057	0.36	0.093	0.58	0.14	0.73	0.17	1.0	0.24	1.3	0.29
	7910 kg/m³	0.13	0.057	0.35	0.092	0.57	0.14	0.72	0.17	1.0	0.23	1.2	0.28
	8010 kg/m³	0.13	0.058	0.35	0.093	0.57	0.14	0.71	0.17	1.0	0.23	1.2	0.28
	8110 kg/m³	0.13	0.058	0.34	0.092	0.56	0.14	0.70	0.17	0.99	0.23	1.2	0.28
	8210 kg/m³	0.13	0.057	0.34	0.090	0.55	0.13	0.69	0.16	0.98	0.23	1.2	0.27

Based on Stainless Steel Standards

Thermometer Calibration

Sandia National Laboratories

- Calibration Procedure for Black Stack 2564 Thermometer
  - Resistance
  - Temperature



Resistance

- Resistance affected by temperature, used to determine temperature
- Used resistance box and certified ohmmeter to find differences between displayed and actual resistance
  - Within likely temperature range

Temperature

- Connected thermometer to one thermistor probe, “master” probe
- Compared readings to certified thermometer
  - Found offset of probe readings
- Connected thermometer to all probes
  - Same environment
  - Found offset of each probe from master
  - Added to master offset to find offset of each probe

Learning Experience

- Interesting problems to solve
- Importance of measurements
- Effects of small changes
- Difference between results of different methods
- Useful contribution to metrology

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Sources and Further Information

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