SAND2009-6801C

Infrasound Calibration

NCSLi Albuquerque Sectional Meeting

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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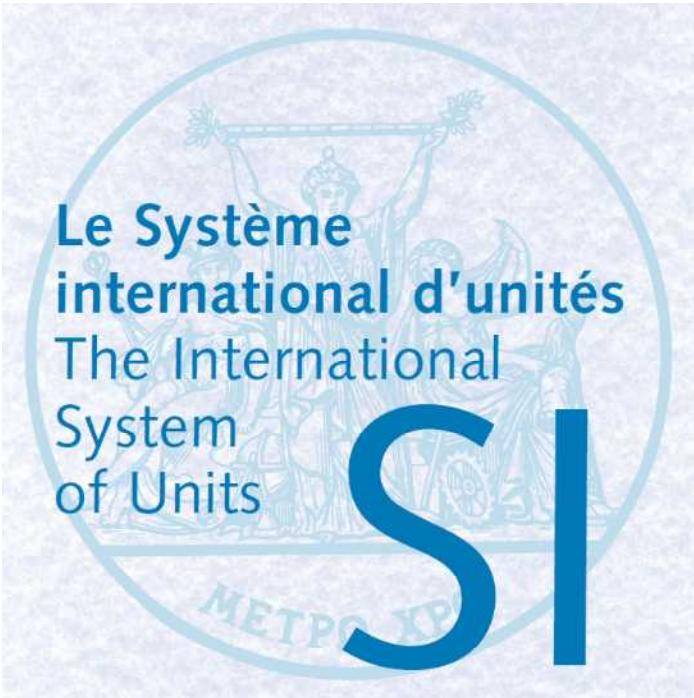


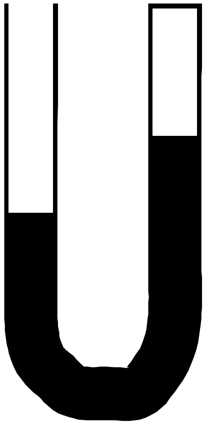
From the cover of the SI Brochure
http://www.bipm.org/en/si/si_brochure/

Pa (m^{-1} kg s^{-2})

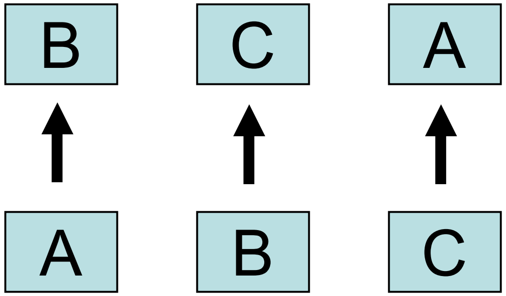
Pressure Traceability

DC

Sandia Ultrasonic Manometer
Transferred to NIST in 2008



> 30 Hz



An Infrasonic Pistonphone

Photo courtesy of Rod Whitaker
Los Alamos National Laboratory

The Measurement Equation

$$\text{Sensor Cal Constant } (c) = \frac{\text{Sensor Output } (r)}{\text{Chamber Pressure } (p)}$$

If p is calculated from the chamber dimensions:

$$p = -\frac{gP_0 v}{V_0} + Corrections$$

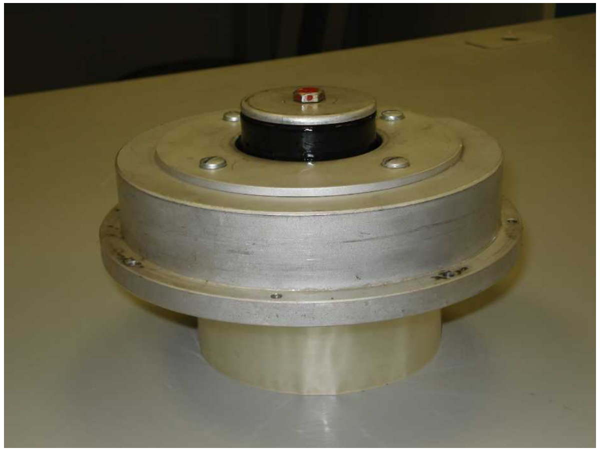
Where P_0 is the ambient pressure, V_0 is the chamber volume, v is the piston displacement, and g is a function of frequency and is equal to γ in the adiabatic limit and 1 in the isothermal limit.

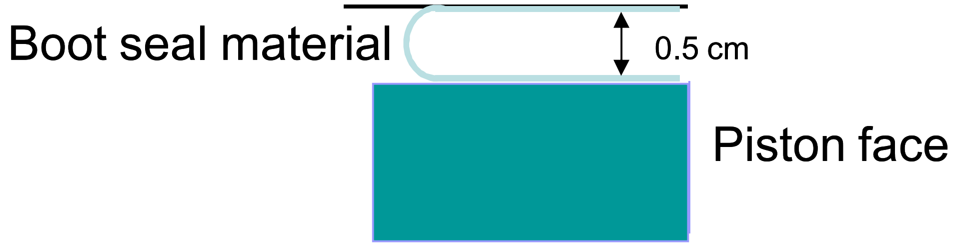
So:

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

Piston Displacement

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$





Take the standard (1σ) uncertainty to be: 1.6%.

Standard uncertainty in the piston stroke 0.3% out of 1.30 cm.

Chamber Volume

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

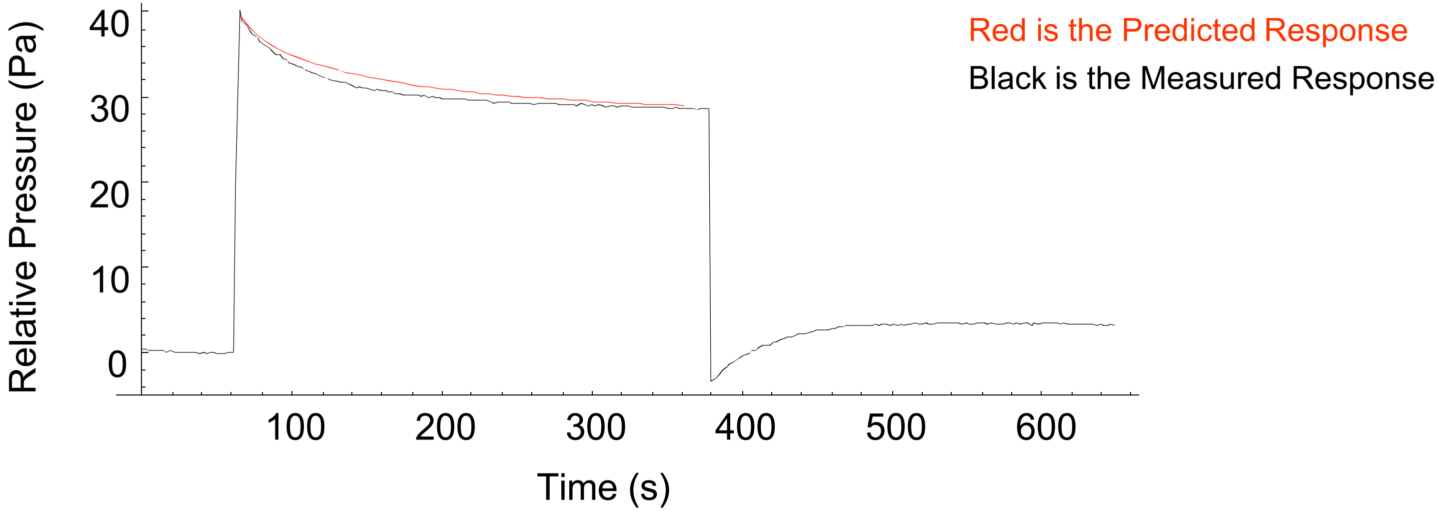
Standard uncertainty of the volume of the empty chamber: 0.1% out of 994 L.

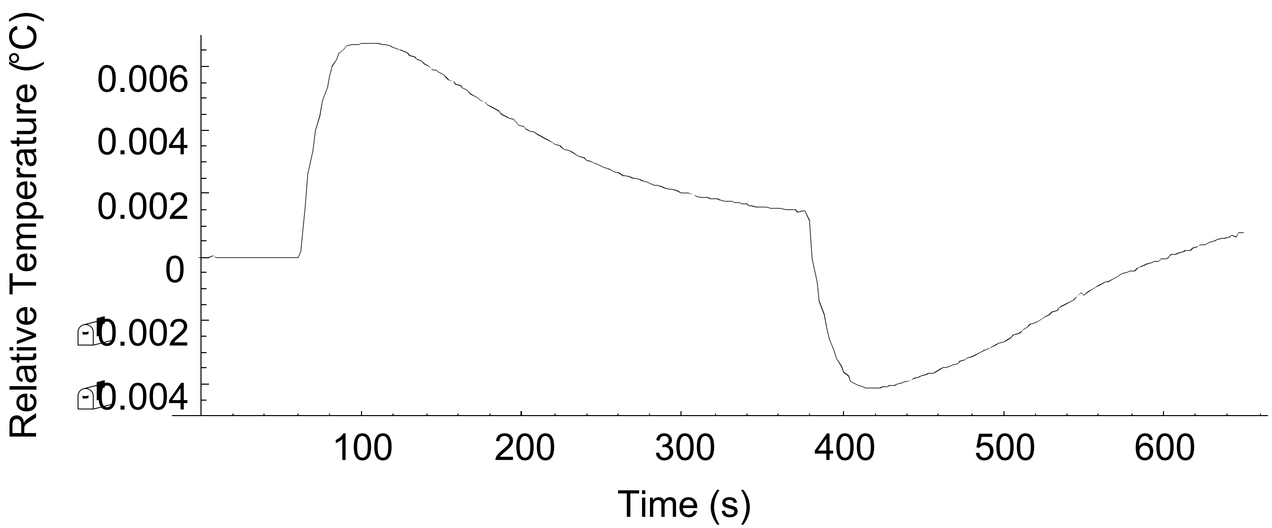
Volume taken by the Unistrut supports, wires, …: ~0. 4%

Volume of one Chaparral 25: ~ 0.5%

Volume of one Chaparral 50: ~ 2%

Step Volume Change Response of an 80 L Chamber



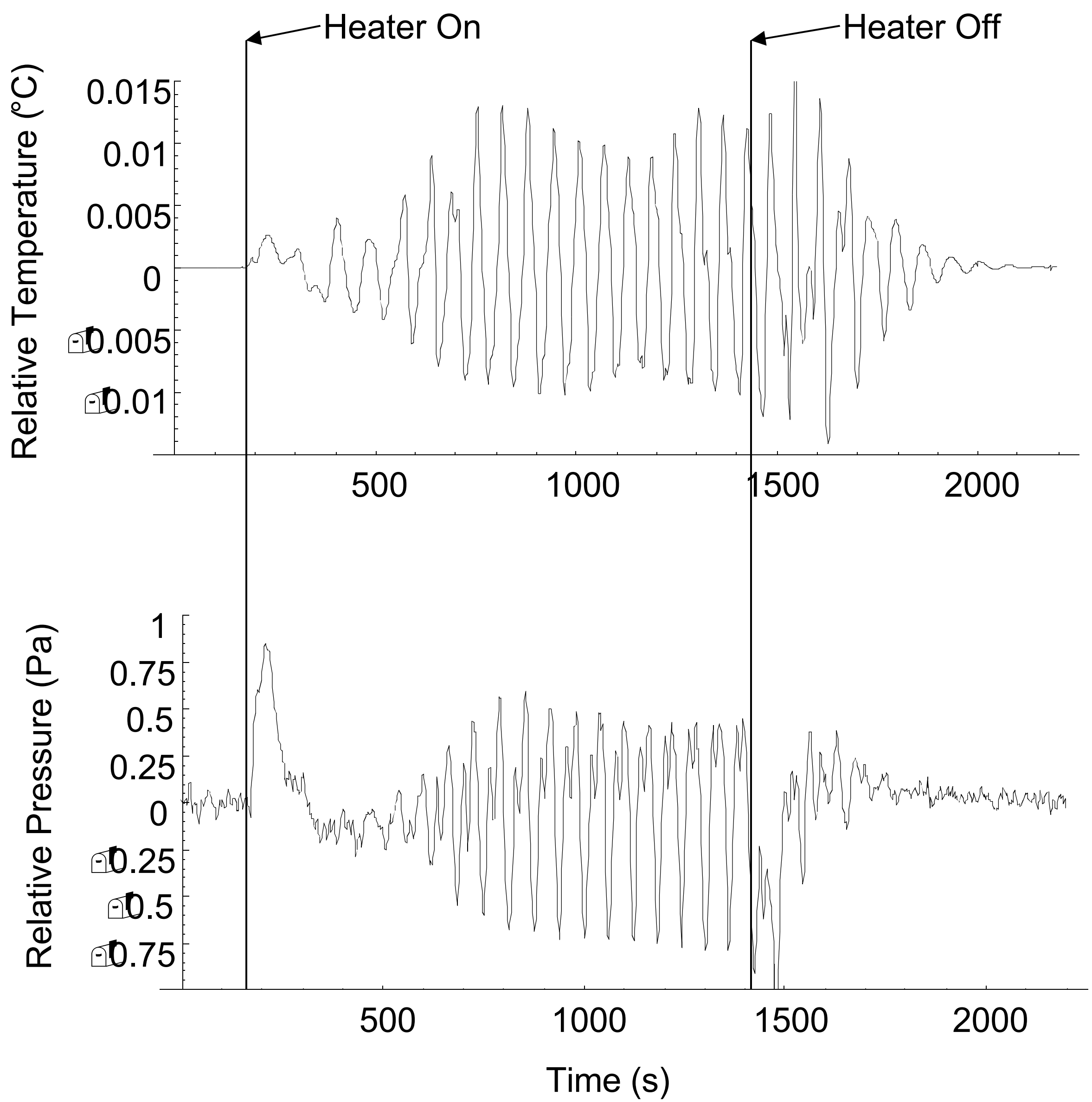


(The response time of the thermistor is too slow to catch the full air temperature rise. Linear drift is removed from the temperature plot.)

Convective Noise: 3W of power in an 80 L Chamber

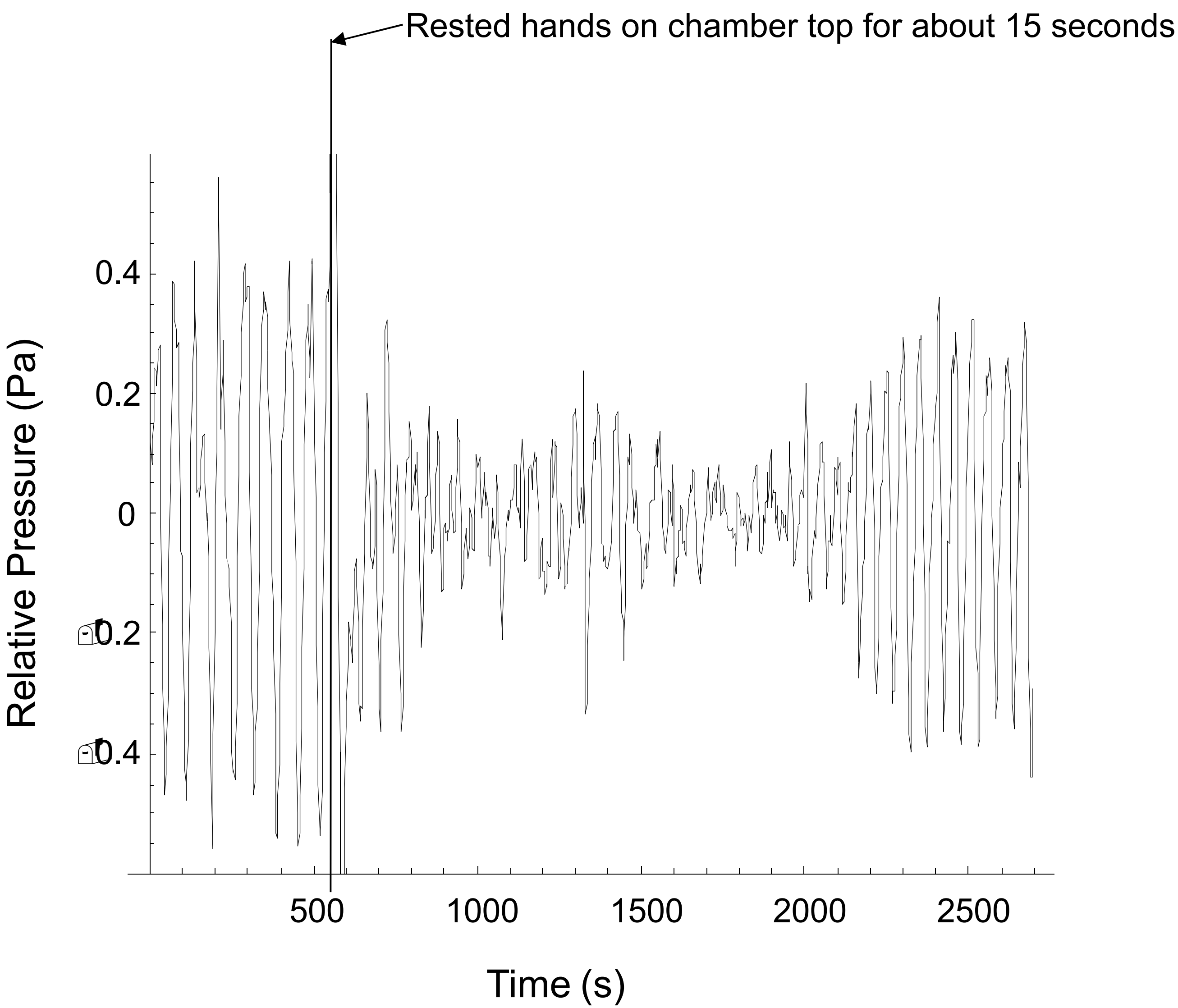
Data is filtered with a 0.01 Hz high pass filter

Thermistor is about 4 inches above the heater.



A 3 point moving average is taken for the pressure data.

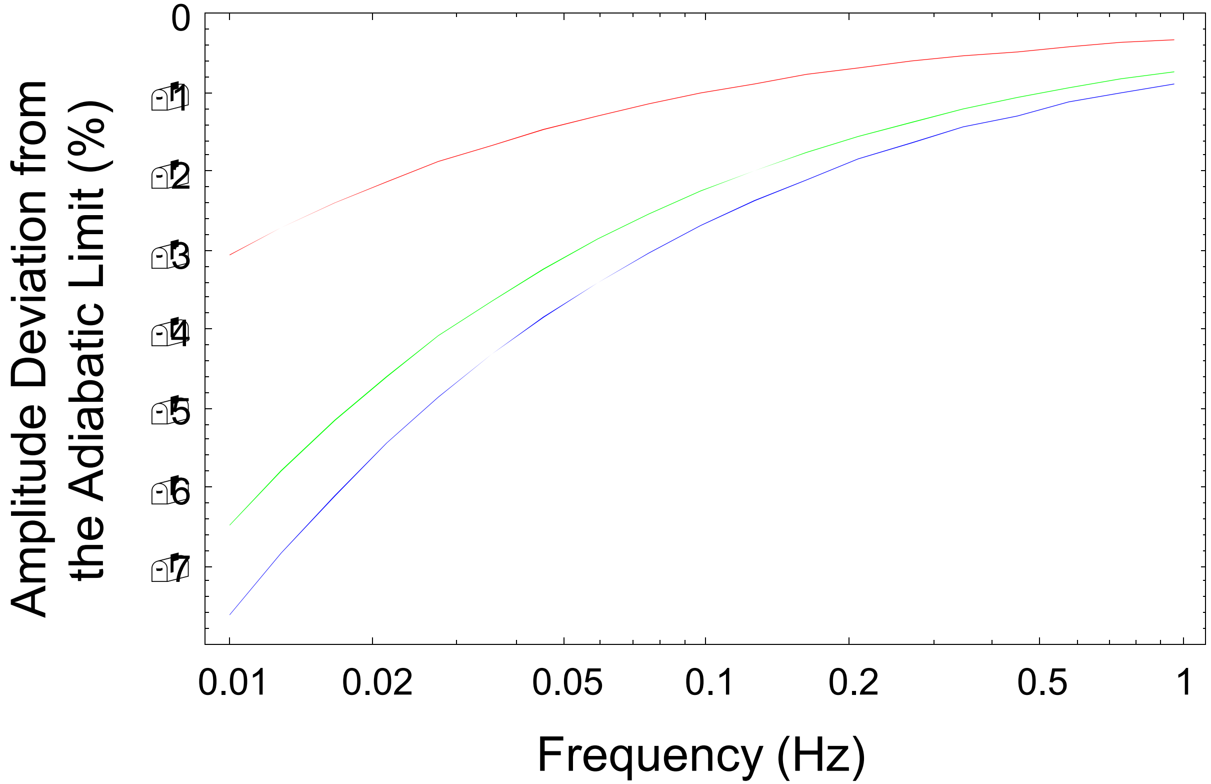
Effect of Heating the Chamber Top



Data is filtered with the 0.01 Hz high pass filter and a 3 point moving average is taken.

Chamber Amplitude Response as a Function of Frequency

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$



Red (Top) is the 1000 L LANL Chamber Prediction

Green (Middle) is the 80 L Chamber Prediction

Blue (Bottom) is the 80 L Chamber (Roughly) Fit to the Measured Data

Wall Stiffness

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

The correction due to pressure driven wall flexing is roughly proportional to the square of the area and inversely proportional to the thickness.

Modeling each side as a thin simply supported plate with a thickness of 4.5 in. and a Young's Modulus of 30 GPa, the correction due to wall flexing is 0.03%. As the exact composition on the LANL chamber walls is not known we take this standard uncertainty component to be 0.1%.

Note: Because the correction due to wall flexing is strongly dependant on the size, it is possible to design a chamber where this error is significant.

Other Sources of Uncertainty

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

Error due to the ideal gas approximation: 0.2%

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

Observed noise in the signal: 0.1%

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

Humidity correction to γ: 0.1%

Other Sources of Uncertainty (Cont.)

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

Leaks in the chamber: <0.1%

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

Measurement of the ambient pressure: <0.1%

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

Calibration of the digitizer: <0.1%

Summary of the LANL Chamber Error Budget

Cal Constant From Chamber Dimensions

Component	Uncertainty (1σ)
Piston Area	1.6%
Piston Travel	0.3%
Chamber Empty Volume	0.4%
Sensor Volume Displacement	0.2%
Heat Conduction Correction	0.1% at 1 Hz 2% at 0.02 Hz
Wall Stiffness	0.1%
Non-Ideal Gas Corrections	0.2%
Humidity Correction	0.1%
Noise in the Signal	0.1%
Ambient Pressure	<0.1%
Digitizer Calibration	<0.1%
Chamber Leaks	<0.1%
Total Standard Uncertainty	1.7-2.6%

Expanded Uncertainty at a 95% confidence level: 3.4% at 1 Hz and 5.2% at 0.02Hz

Chamber Calibration Against a DC Pressure Sensor

Alternatively, the chamber can calibrated against a pressure sensor which has itself been calibrated at DC. In this case, we directly determine v/V_0 and most of the corrections at the calibration frequency.

$$c = \frac{r}{-\frac{gP_0 v}{V_0} + Corrections}$$

However, since g is a function of frequency, it still contributes to the total uncertainty.

Summary of the LANL Chamber Error Budget

Cal Constant From DC Pressure Sensor

Component	Uncertainty (1σ)
DC Pressure Standard Linearity	1.5%
DC Pressure Standard Calibration	0.5%
DC Standard Frequency Response	2%
Heat Conduction Correction	2%
Sensor Volume Displacement	0.2%
Humidity Correction	0.1%
Noise in Sensor Output	0.1%
Ambient Pressure	<0.1%
Digitizer Calibration	<0.1%
Chamber Leaks	<0.1%
Total Standard Uncertainty	3.2%

What is not included in this error budget:

- Sensor dependence on environmental conditions (ambient pressure, temperature, supply voltage,…)
- Shifts in the sensor response over time.
- The effect of hoses and site location when in the field.

A drive up to Sandia Peak…