Reference Sound Source Calibration at Different Temperatures and Altitudes.

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Compensation for environmental variables in the calibration and the application of Reference Sound Sources.

*** Atmospheric temperature (site sound velocity).**

*** Barometric Pressure (site altitude)**

Introduction

- Sound power, $\mathcal{P}$, is calculated from sound pressure, P, measurements on a surface, S, as
- $\mathcal{P} = SP^2/(\rho c)$.

- Calibrated Sound power is expressed for the standard environmental conditions of 101.325 kilopascals and a standard temperature such as 15 degrees Celsius.

Real Life

- Calibration laboratories may not be at sea level or standard temperature.

- Practical test sites (where sound power emitted by a device under test is to be determined by the comparison method via an RSS) can be at higher elevations and outdoors at uncontrolled temperatures.

What This Means

- The sound pressure level (SPL) varies inversely with altitude.
- The air density varies inversely with altitude
- For constant temperature, the sound power (being pressure squared divided by air density) varies inversely with altitude.

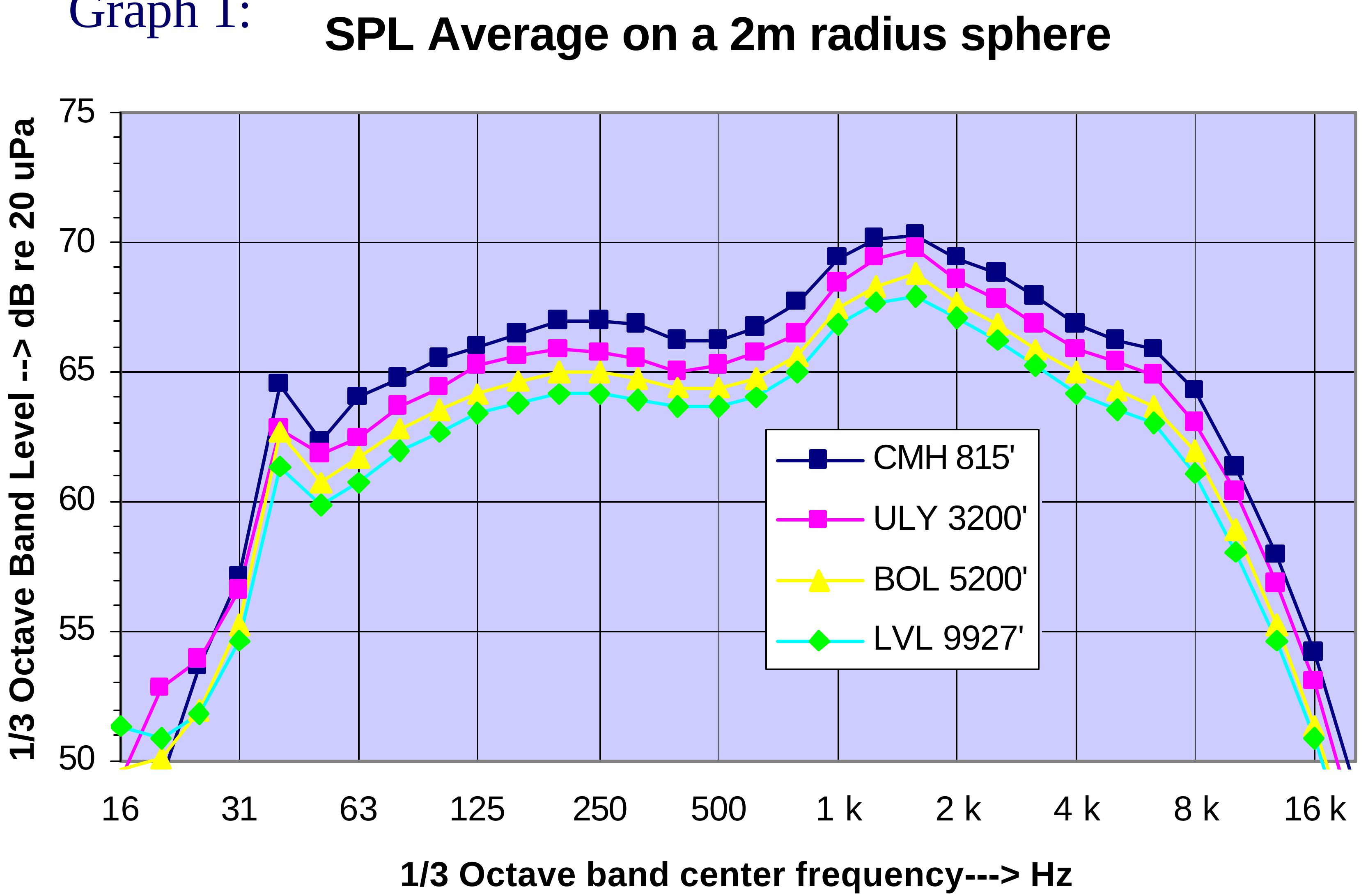
Barometric Pressure Experiment:

- Barometric Pressure, B, directly affects the emitted sound pressure level, P.
- By Experiment as B decreases, so does P (Graph 1), and so also does ρ. Graph 2 shows that P µ B .
- Altogether, P^2**/** ρ, or P **,** reduces linearly with B:
- P = $SP^2/(\rho c)$: P µ B: 20log P µ 20logB
- P is directly measured. Sound power P is computed.
- **We want to predict** the sound pressure P expected at B from a source of known (“calibrated”) P_o.
- We return to this “representation” problem later.

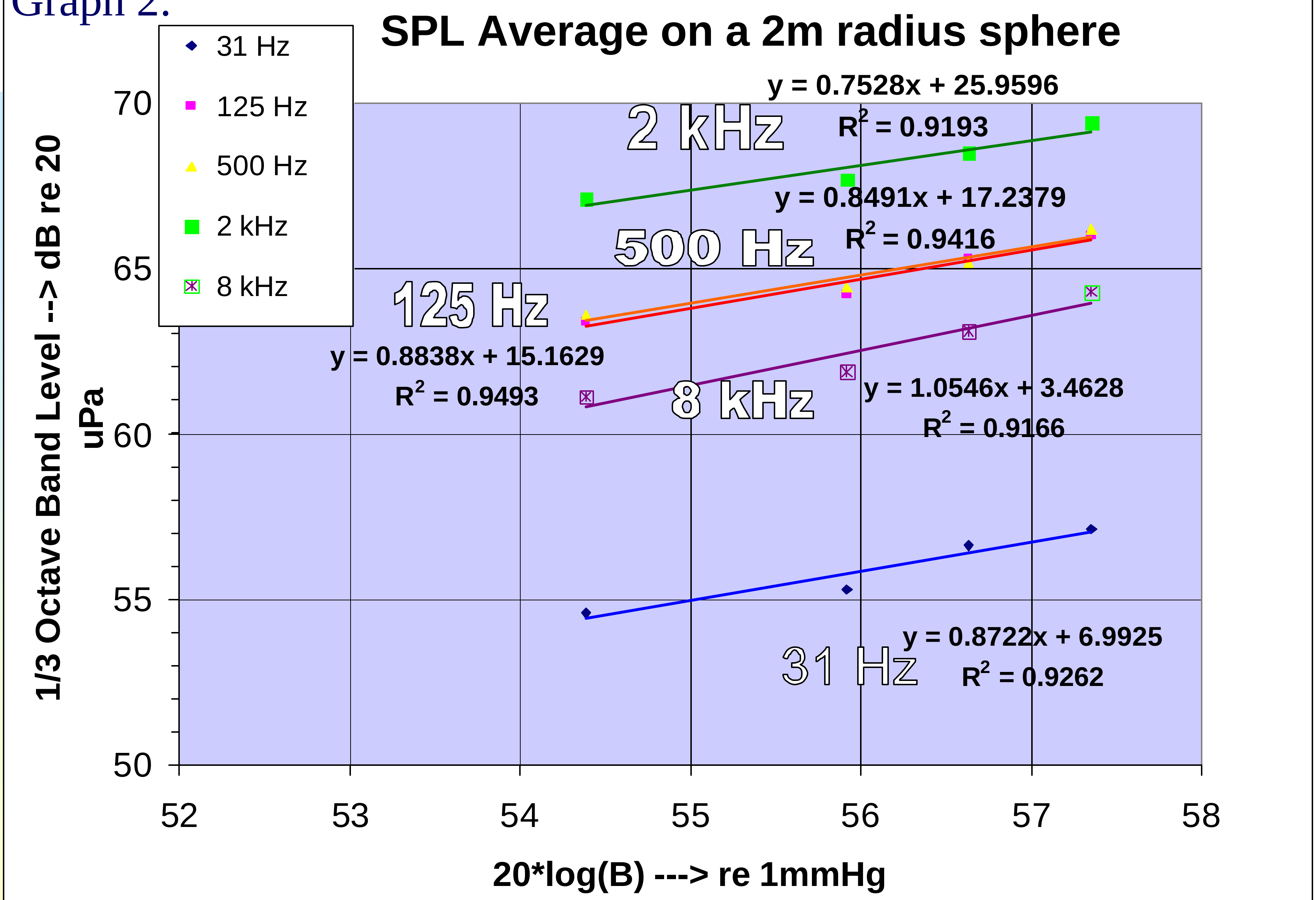
Barometric Pressure (Altitude) Test

- A single RSS 400 unit was transported to and calibrated at the original and three higher elevation sites, June 09-30, 2000.
- Columbus,OH 815’ (CMH)
- Ulysses, KS 3,067’ (ULY)
- Boulder, CO 5,288’ (BOL)
- Leadville, CO 9,927’ (LVL)
- Graphs 1& 2 show SPL variation with barometric pressure. Table 1 shows pistonphone calibration of unadjusted measurement microphone system.

Graph 1:


SPL Average on a 2m radius sphere
1/3 Octave Band Level --> dB re 20 uPa
75
70
65
60
55
50
16
31
63
125
250
500
1 k
2 k
4 k
8 k
16 k
1/3 Octave band center frequency---> Hz
CMH 815'
ULY 3200'
BOL 5200'
LVL 9927'

Graph 2:



SPL Average on a 2m radius sphere
31 Hz
125 Hz
500 Hz
2 kHz
8 kHz
y = 0.7528x + 25.9596
R2 = 0.9193
y = 0.8491x + 17.2379
R2 = 0.9416
y = 0.8838x + 15.1629
R2 = 0.9493
y = 1.0546x + 3.4628
R2 = 0.9166
y = 0.8722x + 6.9925
R2 = 0.9262
1/3 Octave Band Level --> dB re 20 uPa
20*log(B) ---> re 1mmHg
70
65
60
55
50
52
53
54
55
56
57
58

Table 1: Pistonphone microphone calibration (monopole):

1/2" random incidence microphone LD type 2238
LD2900 SLM Voltage Response was fixed.

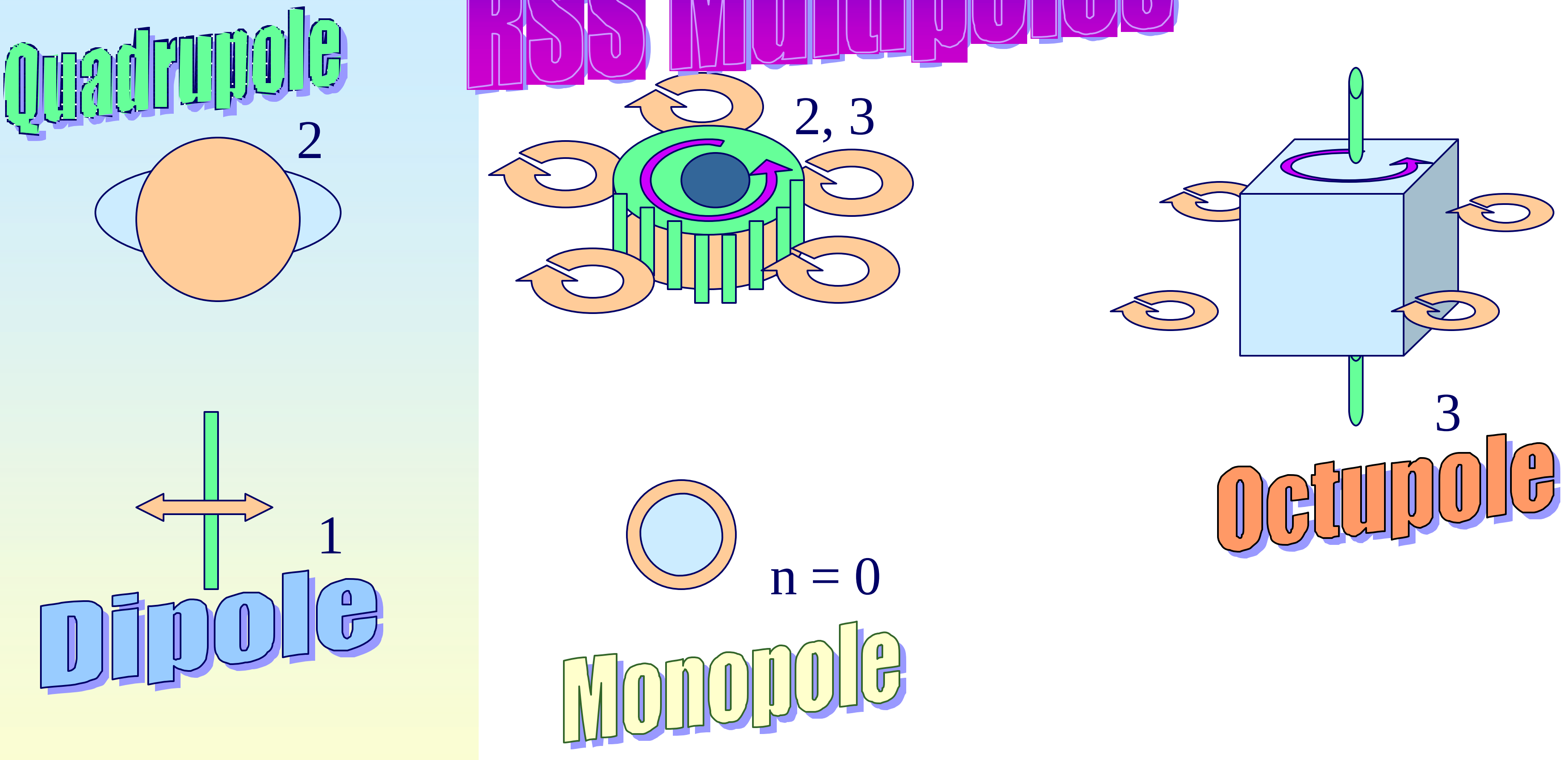
Expected & actual B&K 4220 pistonphone signals:

Site:	Columbus	Ulysses	Boulder	Leadville
Elevation =	815'	3,067'	5,288'	9,927'
B =	738mmHg	679	625	524
Expected =	123.85 dB	123.24	122.42	120.88
Obtained =	123.9	123.32	122.48	121.10
deviation =	+.05dB	+.08	+.06	+.22

Site Air Temperature Effect:

- Air temperature directly affects the velocity of sound, c, via air density, ρ
- $$c \propto \rho^{-1/2} \propto T^{1/2}$$
- For the aerodynamic Reference Sound Source, sound is generated as **multipole** radiation by turbulent eddies from a rotating and stalled fan.
- Analyses by Lighthill and by Powell suggest that at a constant fan velocity, multipole radiation sound intensity, I, varies as c^{-2n}. “n” depends on the multipole order: 0 (monopole), 1(dipole), 2 (quadrupole) or 3 (octupole).

RSS Multipoles



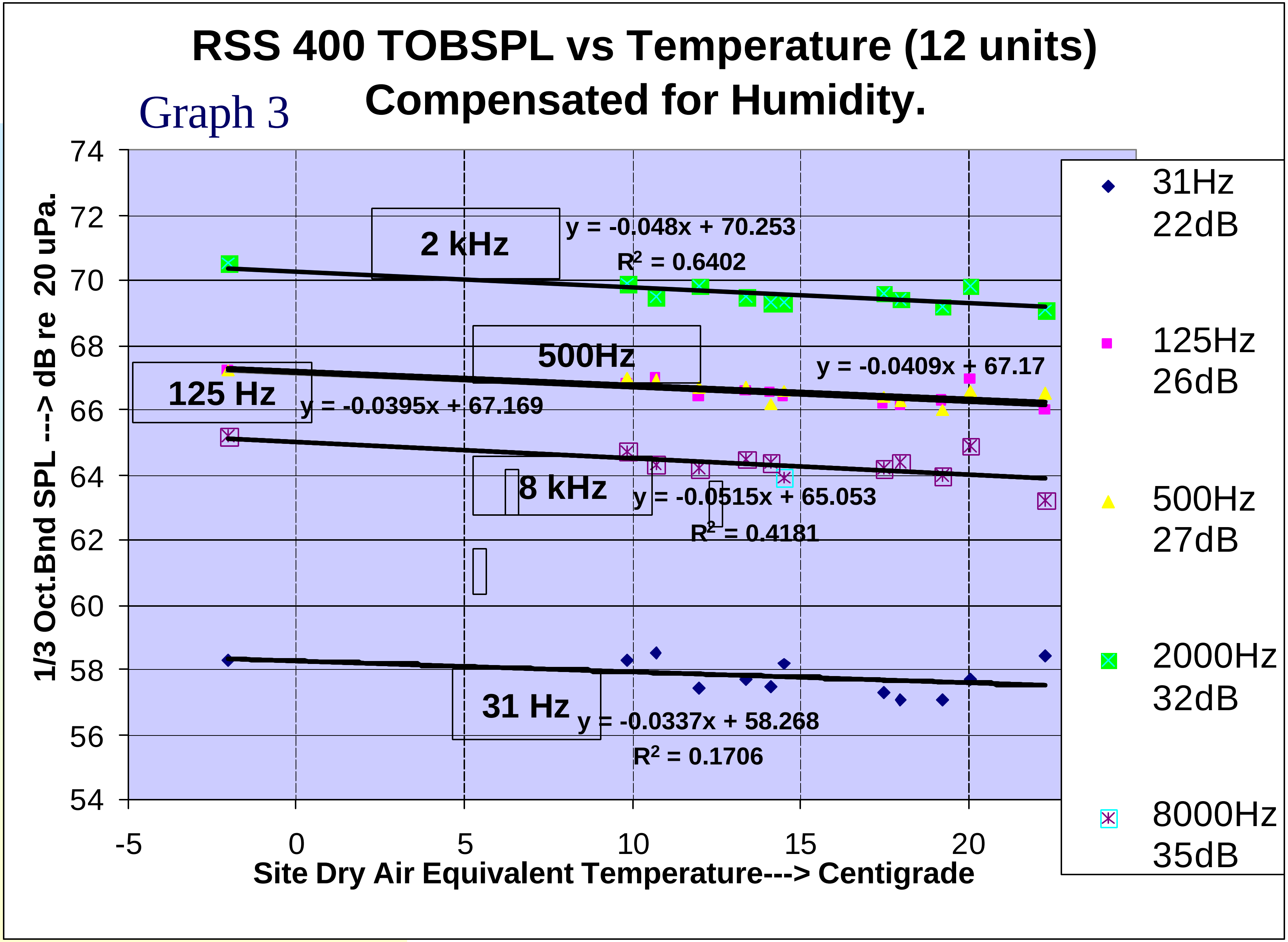
Suggested Powell - Lighthill predictions:

- For a constant acoustic-velocity source, emitted sound power Π is, dependent on multipole order; (Mono-, Di-, Quadru-, Octu- pole):
- $\Pi \propto P^2/(\rho c)$, $P^2/(\rho c)[1/c^2]$, $P^2/(\rho c)\ [1/c^4]$, $P^2/(\rho c)\ [1/c^6]$
- Sound pressure, P, varies with barometric pressure, B, and sound velocity as [$P \propto B$, B/c, B/c^2, B/c^3.]
  - But $c \propto T^{1/2}$, and $\rho \propto 1/B$, so that sound pressure P is
    - $P \propto B$, $B/T^{1/2}$, B/T, $B/T^{3/2}$
    - $\Pi \propto B/T^{1/2}$, $B/T^{3/2}$, $B/T^{5/2}$, $B/T^{7/2}$
- **Quadrupole** sound pressure P in dB varies as **20logP µ 20logB - 20logT**.
- **Quadrupole** power Π as **10log** Π µ **10logB - 25logT**.

Temperature Experiment:

Sound Pressure behavior with temperature at nearly constant barometric pressure was tested with 12 production RSS400 units calibrated at an outdoor site with calm air from -2C to +22C. Graph 3 shows the sound pressure squared average over a ***2 meter radius hemisphere*** for the 31.5, 125, 500, 2000 and 8000 Hz 1/3- octave bands.

In Graph 3, the ***empirical*** dB rate of P vs T is observed as the P-regression coefficient; at each frequency). RSS Quadrupole ("20") P-agreement occurs at 31.5 Hz. At 125 and 500 Hz, RSS P-agreement is a Quadrupole-Octupole mix (25±). RSS Octupole ("30") P-agreement occurs at 2000 Hz. [Microphone resonance vs temperature may compromise the 8 kHz ("35") P data.]


RSS 400 TOBSPL vs Temperature (12 units)
Compensated for Humidity.
Graph 3
2 kHz
y = -0.048x + 70.253
R2 = 0.6402
500Hz
y = -0.0409x + 67.17
125 Hz
y = -0.0395x + 67.169
8 kHz
y = -0.0515x + 65.053
R2 = 0.4181
31 Hz
y = -0.0337x + 58.268
R2 = 0.1706
1/3 Oct.Bnd SPL ---> dB re 20 uPa.
Site Dry Air Equivalent Temperature---> Centigrade
74
72
70
68
66
64
62
60
58
56
54
-5
0
5
10
15
20
31Hz 22dB
125Hz 26dB
500Hz 27dB
2000Hz 32dB
8000Hz 35dB

What This Means:

- Emitted sound power P increases directly with barometric pressure B, but decreases with increased temperature T.
- B and T effects are computed separately for test convenience.
- The degree of P diminishment by T depends on the multipole order of emission mechanism of the source under test. For the mechanical fan sound source, the temperature effect on sound ***power*** P is rounded to be a quadrupole(25)-octupole(35) mix.
    - **Empirical Conclusions** (for each sound frequency) **:**
- The **RSS** mixed-pole site sound ***power*** P in dB may vary as:

  10logP µ **10logB - 30logT** (compare, Graph 4)

  The **RSS** mixed-pole site sound ***pressure*** P in dB may vary as:

  20logP µ **20logB - 25logT** (compare, Graph 3)

Three Representation Situations:

- A- To **report the actual** sound *power* P emitted on the test site, the measured site-sound *pressure* is adjusted with site barometric pressure as 10*logB.
- B- To report the **normalized** sound power, P_o**,** that would be emitted by the test source under "standard conditions" (STP), the site ***sound pressure*** is adjusted according to 10*log B and the temperature adjustment, q1, shown in Table 2. Graph 4 shows good agreement when these are applied to normalize the four separate Barometric Pressure "Calibration" data sets.
- C- To **predict the actual** ***sound power*** P that would be emitted at a remote site, the expected site barometric pressure is applied as 10*logB. Table 2 shows the temperature adjustment according to the multipole nature of the source under test. The RSS is a mix of a quadrupole and an octupole.
- The relation above Table 2 applies to **predict the sound pressure P' on surface S'** from source P_o at B' and T'.

Example of Temperature Corrections, q for Computing P & P

Graph 4 shows four RSS site results (r=2m) normalized to P_o @ STP as

$$10*\log P_o = 10*\log P^2 + 20*\log(r) + 7.98 - 10*\log(B/B_o) + 30*\log(T/T_o)$$

=====*Predictive* Field calculations for the RSS:=======

RSS Site PWL: $10*\log P = 10*\log P_o + 10*\log(B/B_o) - 30*\log(T/T_o)$

------------------------ **Device Under Test** ------------------------------

(P is found by averaging P^2 over the test surface of S m^2)

The rated (sea level) ***sound power*** P_o for a device of ***known multipole nature*** is calculated from test site SPL, P, with q1 selected from Table 2:

$$10*\log P_o = 10*\log P^2 + 20*\log S - 10*\log(B/Bo) + q1*\log(T/To)$$

------------------------ **Device in use elewhere** ------------------------------

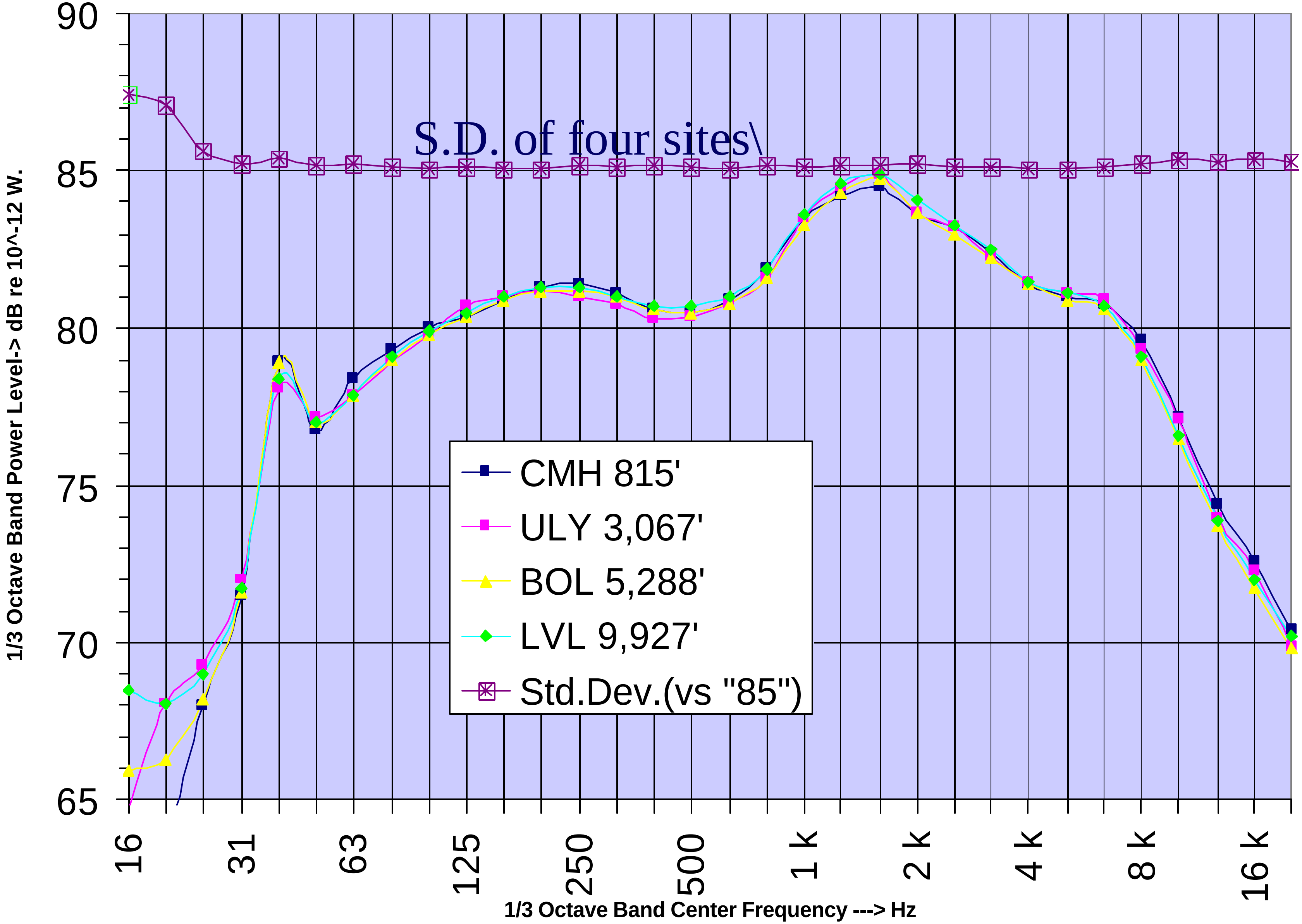
New application site ***sound pressure*** P' on S' at B' & T' for that same device P_o of ***known multipole nature*** is calculated from q2 as:

Site SPL: $20*\log P' = 10*\log P_o - 10*\log S' + 20*\log(B'/Bo) - q2*\log(T'/To)$

------------------**Table 2: Values for q1 and q2** ------------------------------

Source Nature:		Monopole	Dipole	Quadrupole	Octupole
Example		(pistonphone)	(speaker)	(bell,LF-RSS)	(HF-RSS)
P	q1	5	15	25	35
P	q2	- 0 -	10	20	30

Graph 4: **Normalized Sound Power 815'-9,927' El.**



“Representation”

By Angelo Campanella: **This is a plan for the futu**

Compensation For Test Site Altitude & Temperature (for Comparison Tests; ISO 3747, ANSI S12.8, AMCA 300 etc)

- ISO 6926 Section 7.6 (“Calculations”) should be reviewed. Measurements near sea level may be affected within precision of method. Sound power determinations at higher altitudes will be affected beyond the precision of this method.
- Research should be conducted in the effect of gas sound velocity on radiated sound power for aerodynamic reference sound sources.

Next Steps

- Institute these recommendations in the RSS instruction manual.
- Implement these corrections in ANSI and ISO standards (under development).
  - REV 10 MAR'08.