Overview of Multi-Point Ground Flares

- Developed in the 1970's, Multi-Point Ground Flares derive their name from their physical layout.

- Instead of the flare flame being on an elevated structure, the flame is spread out in a grade mounted field of multiple pressure assisted flare tips.

- The tips are then arranged in stages that open as the upstream pressure and gas flow increases and close as pressure and flow decreases.

What is Noise?

- Noise can be defined as excessive or unwanted sound. In general, any sound that is annoying, interferes with speech, damages the hearing, or reduces concentration or work efficiency may be considered noise.

- It is often characterized by its intensity which is measured in decibels.

- A decibel (dB) is a log base scale developed to quantify sound.

- There are two common uses of decibel levels. One is sound power (PWL) and the other is sound pressure (SPL).

What is Noise?

- Sound power (PWL) or acoustic power is the rate at which sound energy is emitted, reflected, transmitted or received, per unit time.

- Sound pressure (SPL) or acoustic pressure is the local pressure deviation from the ambient atmospheric pressure, caused by a sound wave.

- The sound pressure scale usually ranges from 0 to 140 dB. The 0 value of the scale occurs when sound pressure equals the threshold of human hearing.

What is Noise?

- Many times noise values are A-Weighted, which means the noise level has been modified to de-emphasize the low and very high frequencies which pose less of a risk to hearing.

- In this presentation, all noise values will be shown as unweighted unless stated otherwise.

- In addition, when a noise varies over time, the "Leq" is the equivalent continuous sound which would contain the same sound energy as the time varying sound. In essence, this is the average measurement over a duration of time.

Test Setup

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Test Setup

- Testing was conducted at Zeeco's test facility in Broken Arrow, Oklahoma on one MPGF flare tip.

- Noise measurements were recorded at distances of 100'-0" and 200'-0" to the East of the flare tip using two Norsonics NOR140 Type I noise meters.

- One meter was placed at each distance to measure simultaneously during the test points.

- Each measurement point lasted 60 seconds.

- In order to minimize the amount of background noise, testing was conducted at night with all non-essential equipment (compressors, forklifts, etc.) shut off to avoid contamination of the noise results.

Test Setup

- The test fuels used were Tulsa Natural Gas (TNG) and Propane.

- Gas flow was measured using a 4-inch orifice run.

- Tip pressure and gas temperature were also recorded for secondary flow measurement verification.

- All data was recorded simultaneously using a data acquisition system (DAQ).

- A weather station was also connected to the DAQ that measured wind speed, wind direction, ambient temperature, barometric pressure, and relative humidity throughout the entire test, which allowed for accurate accounting of atmospheric attenuation in the analysis.

Background Noise

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Background Noise

- To ensure accuracy of the test data, background noise points were taken before and after testing.

- The average ambient sound pressure level was approximately 64 dB.

- Ambient noise was dominated by low frequencies.

- While every action was taken to reduce ambient noise, proximity to city streets and highways were uncontrollable factors that likely led to the slightly elevated levels of low frequency sound.
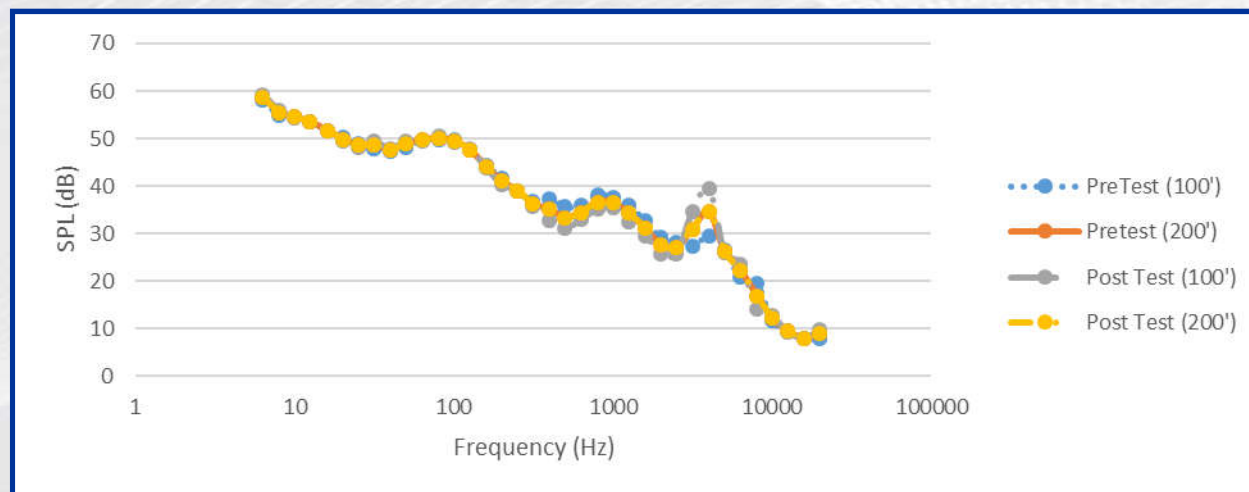
Sound Power Levels as a Function of Sonic and Subsonic Flows
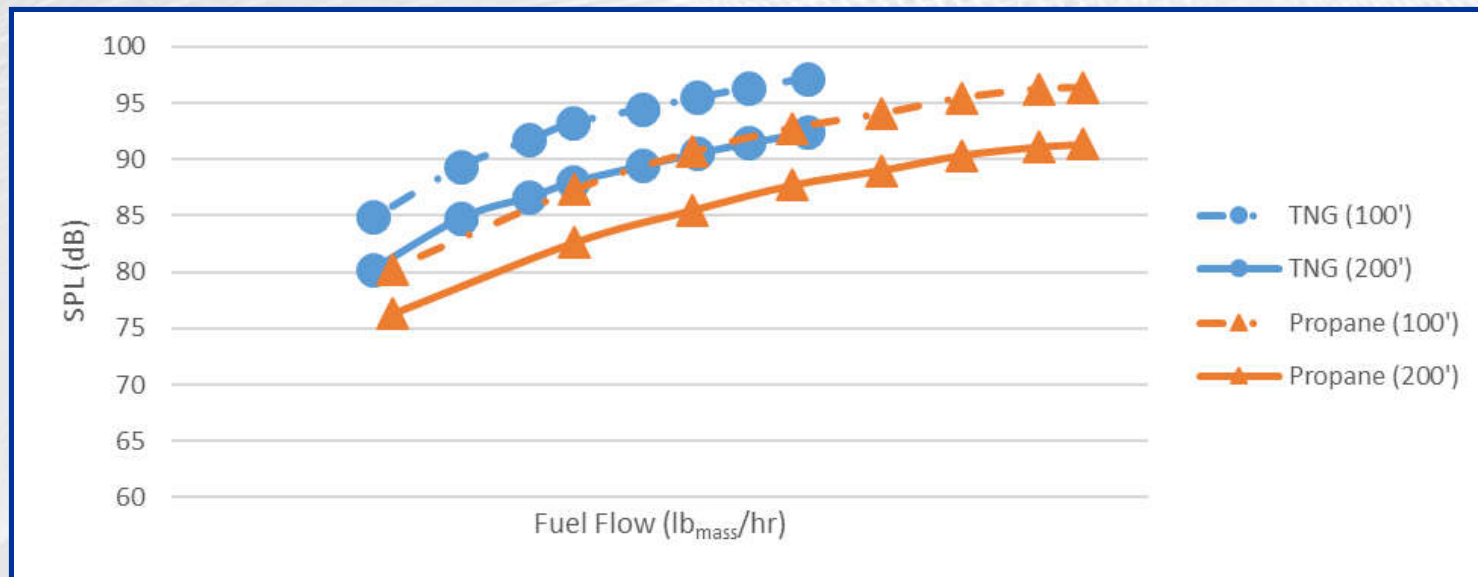
Sound Power Levels as a Function of Sonic and Subsonic Flows

- All resulting noise data was analyzed on an unweighted basis as sound pressure levels in 1/3 octave bands at 1-second intervals.

- The data presented in this presentation are the computed 60-second Leq 1/3 octave band spectra or the overall (or total) level derived from these 1/3 octave band spectra.
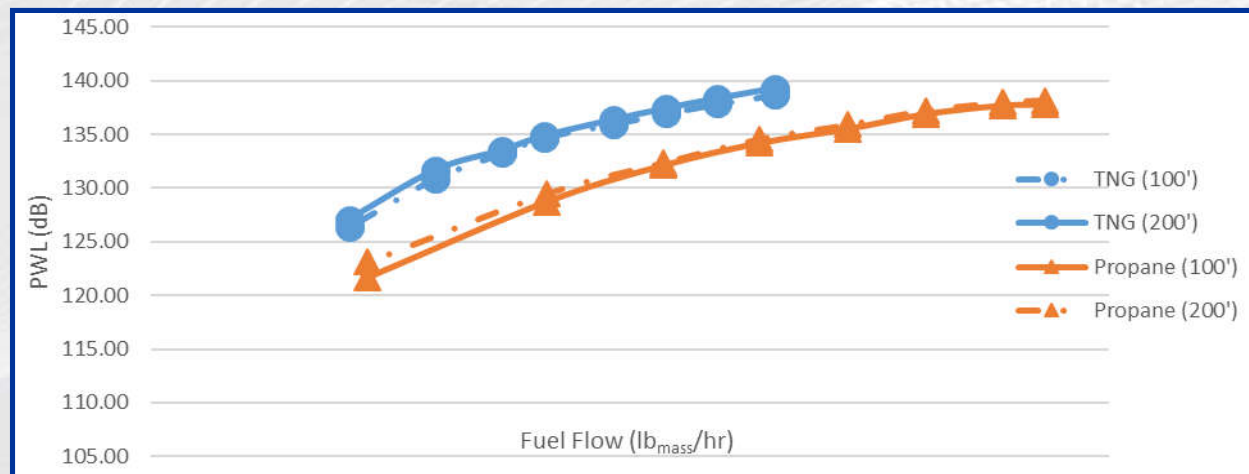
Sound Power Levels as a Function of Sonic and Subsonic Flows

- The sound pressure level for each test point was converted to a sound power level using the equation below.

$$PWL = SPL + 20Log(r) + 0.5$$

- Variable "r" is the direct distance in feet from the noise source to the noise measurement location.

- When converting to sound power level, atmospheric attenuation was taken into account using onsite meteorological data.

Sound Power Levels as a Function of Sonic and Subsonic Flows

- Computed Sound Power Level (PWL) – Tulsa Natural Gas

TP#	PWL - 60 Second Log Average			
	100'	200'	Δ dB	% Diff
1	138.7	139.3	0.6	0.4
2	137.9	138.4	0.5	0.4
3	137.0	137.4	0.5	0.3
4	136.0	136.4	0.4	0.3
5	134.7	134.9	0.1	0.1
6	133.2	133.5	0.3	0.2
7	130.9	131.7	0.8	0.6
8	126.3	127.1	0.8	0.6
Average % Difference			0.5	0.4

- Computed Sound Power Level (PWL) – Propane

TP#	PWL - 60 Second Log Average			
	100'	200'	Δ dB	% Diff
9	137.8	138.2	0.4	0.3
10	137.7	138.0	0.3	0.2
11	136.9	137.2	0.3	0.2
12	135.5	135.9	0.4	0.3
13	134.2	134.6	0.4	0.3
14	132.1	132.4	0.3	0.2
15	128.7	129.5	0.8	0.6
16	121.7	123.1	1.5	1.2
Average % Difference			0.5	0.4

# Sound Power Levels as a Function of Sonic and Subsonic Flows

- The graph below shows sound power levels versus tip static pressure. The critical pressures were calculated from the specific heat ratio of the fuel gas at their respective flowing temperatures per the equation below and correspond to the point at which the fuel gas reaches sonic velocity.

$$p_c = p_2 \left(\frac{k+1}{2}\right)^{\frac{k}{k-1}}$$

$P_c = Critical\ Pressure, psia$

$P_2 = Ambient\ pressure. psia$

$k = Ratio\ of\ Specific\ Heat$
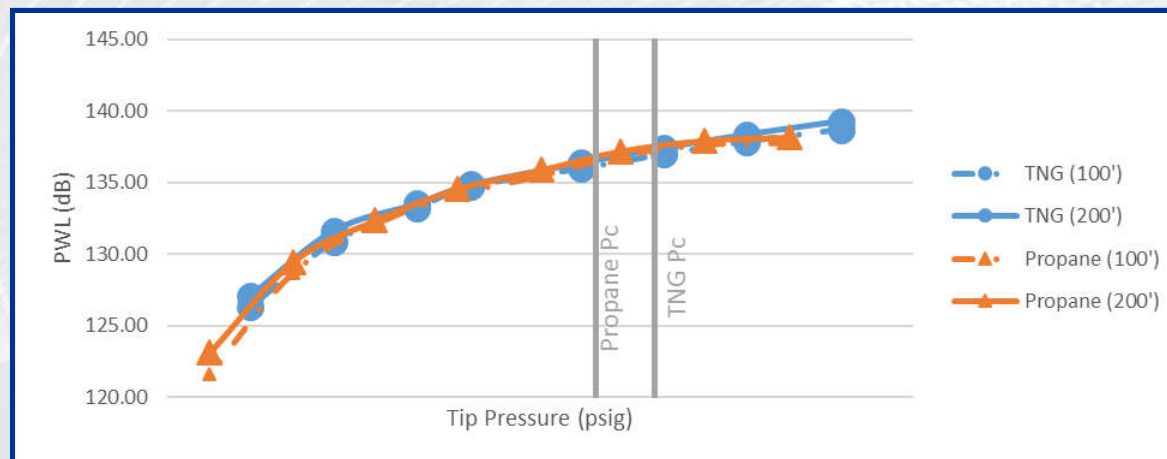
10Log vs 20 Log Analysis

10Log vs 20Log Analysis

- Previous information debates using a 10Log versus 20Log relationship to calculate the overall PWL.

- For each case, a reference fuel mass flow rate and corresponding power level is used to determine a sound power level over a range of fuel mass flow rates.

$$PWL_{calculated} = PWL_{reference} + 10Log\left(\frac{G}{Go}\right)$$

$$PWL_{calculated} = PWL_{reference} + 20Log\left(\frac{G}{Go}\right)$$

$$PWL_{Calculated} = Sound\ Power\ Level\ at\ Desired\ Flow\ Rate, dB$$

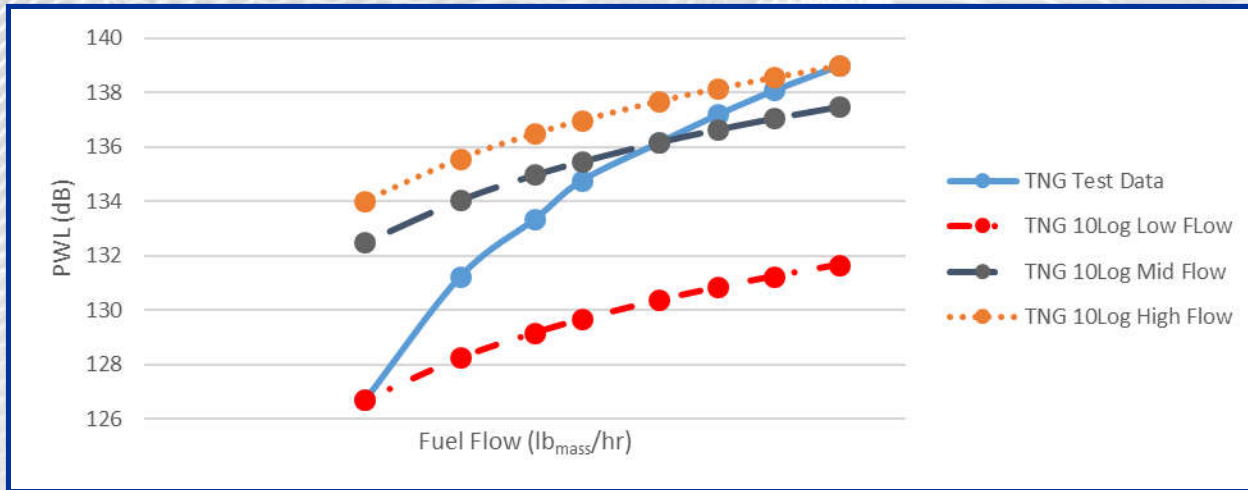$$PWL_{reference} = Sound\ Power\ Level\ at\ Empirical\ Reference\ Point, dB$$

$$G = Desired\ Fuel\ Flow\ Rate, \frac{lb_{mass}}{hr}$$

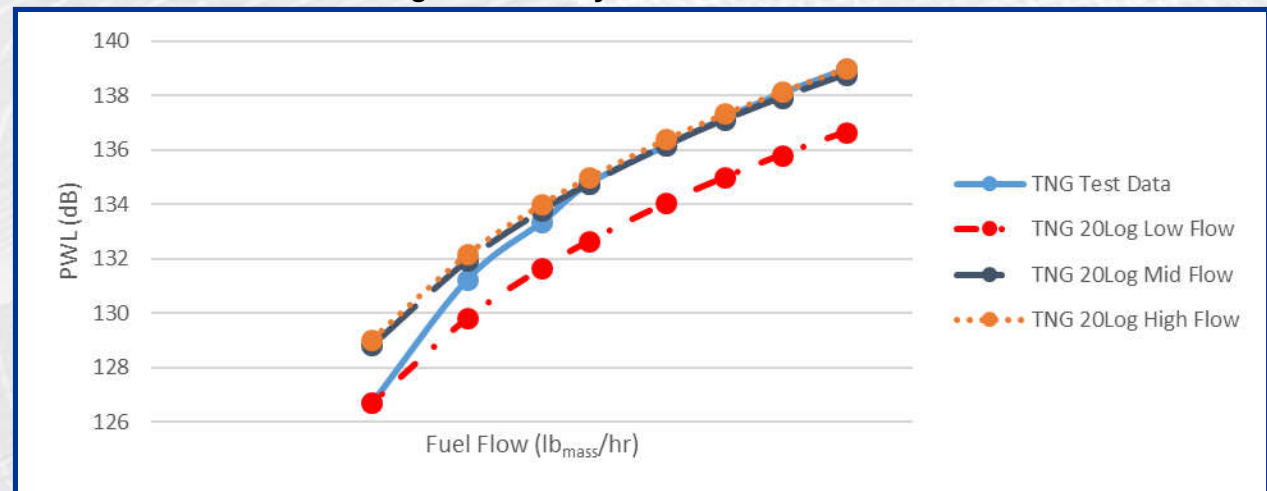$$G_0 = Fuel\ Flow\ Rate\ at\ Empirical\ Reference\ Point, \frac{lb_{mass}}{hr}$$

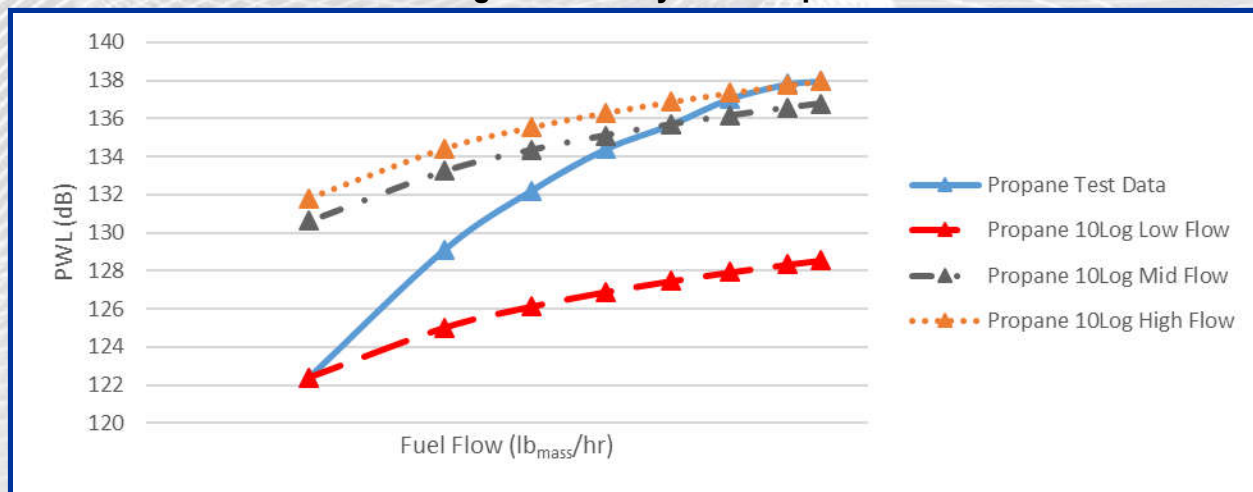# 10Log vs 20Log Analysis

10Log Trend Analysis – Tulsa Natural Gas
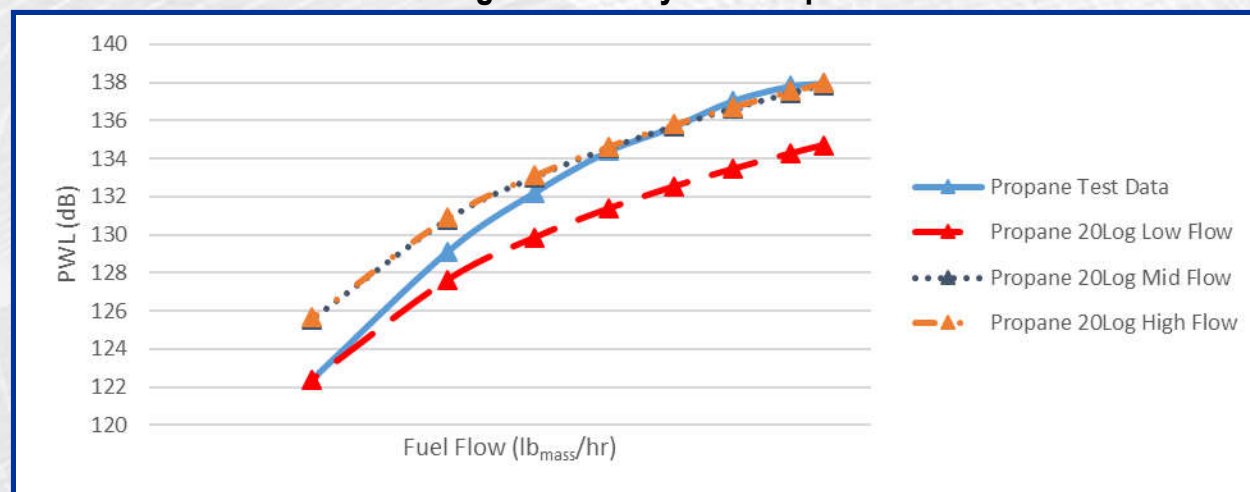

20Log Trend Analysis – Tulsa Natural Gas

10Log vs 20Log Analysis

10Log Trend Analysis – Propane

20Log Trend Analysis – Propane

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10Log vs 20Log Analysis – Further Testing

- While the 10Log vs 20Log analysis shows a more accurate trend correlation when analyzing by means of a 20Log function, testing including higher fuel flow rates would provide a better understanding of the error involved when extrapolating noise values outside of a small range away from the referenced empirical data.

- A larger range of fuel flow rates would also allow a better understanding of optimal fuel flow rates to use as an empirical reference.

Acoustical Efficiency

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Acoustical Efficiency

- Multiple reference articles include discussions about acoustical efficiencies, but several discrepancies exist between these articles.

Reference Article	Acoustical Efficiency for a Typical Hydrocarbon
"Predict Flare Noise and Spectrum" (Cunha-Leite, 1988)	$5(10^{-8})$
"Predict Flare Noise" (Narasimhan, 1986)	$1(10^{-6})$
"Noise Generation by Open Turbulent Flames" (Smith, 1963)	$1.23(10^{-8}) - 8.20(10^{-8})$
"Ecological Aspects of Combustion Devices (with Reference to Hydrocarbon Flaring)" (Swithenbank, 1972)	$1(10^{-7}) - 1(10^{-9})$

Acoustical Efficiency

- Using the empirical sound power level, fuel flow rate, and fuel composition, the acoustical efficiency was calculated for each test point.

- A trend was observed that shows as the fuel flow rate increases, the acoustical efficiency increases for a constant exit area.
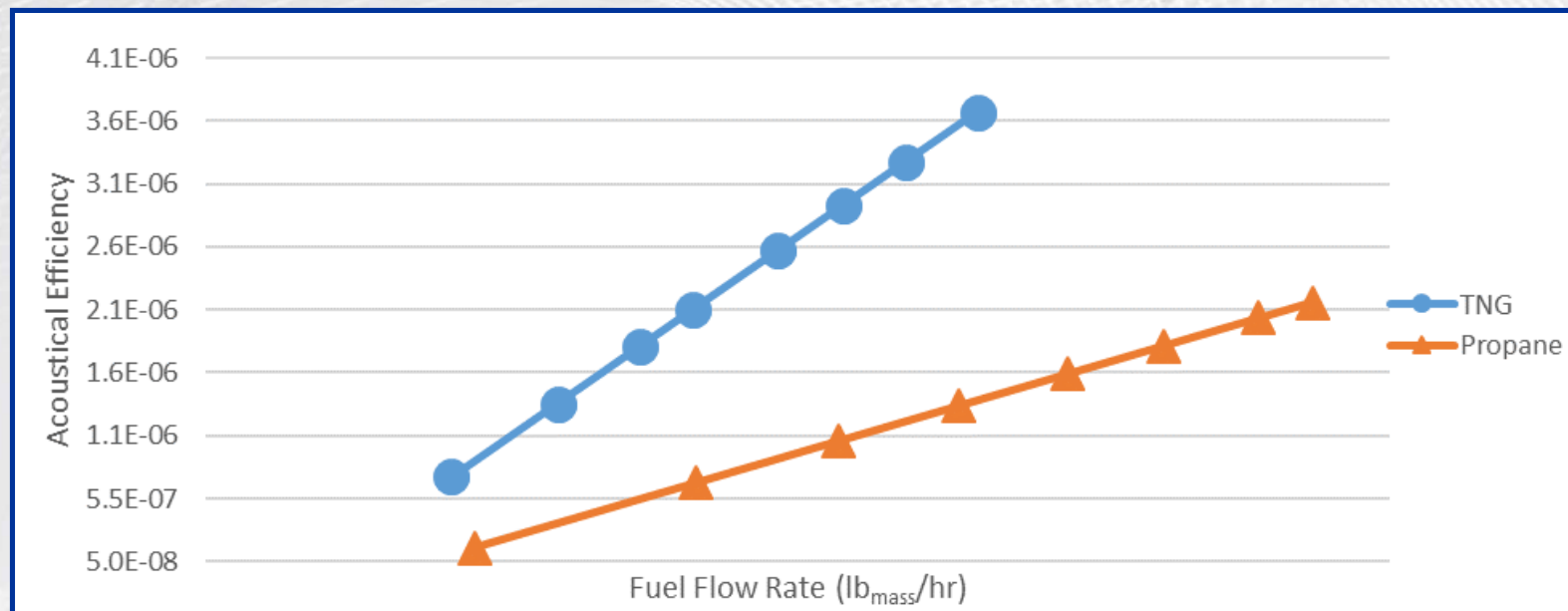
➤ Acoustical Efficiency – Further Testing

- With the observance of increasing acoustical efficiencies associated with increasing fuel flow rate for a constant exit area, further testing is required to determine actual causation.

- Testing of the same format with a multitude of fuel gases would be beneficial and would provide more evidence to analyze trends present between fuel gases with different heating values and molecular weights.

- In addition, fuel blends and inert mixtures would add additional understandings to the phenomena observed.

- The aforementioned acoustical efficiency testing could potentially yield a more accurate method of predicting multipoint ground flare noise levels.

Combustion vs. Venting

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Combustion vs. Venting

- Two sets of data points were tested to compare venting jet noise to combustion noise.

- Venting without combustion produced an average 20 dB decrease in sound power level of TNG and an average 23 dB decrease for propane.

| Test Point	PWL (Leq dB) at Respective Meter Locations		
	100' (dB)	200' (dB)	Δ (dB)
TNG Sonic - Combustion	139	139	20
TNG Sonic - Venting	119	119	
TNG Subsonic - Combustion	136	136	20
TNG Subsonic - Venting	116	116	
Propane Sonic - Combustion	138	138	23
Propane Sonic - Venting	114	117	
Propane Subsonic - Combustion	136	136	23
Propane Subsonic - Venting	112	114	

Combustion vs. Venting

- A further analysis of individual 1/3 octave bands indicates that combustion noise predominantly occurs at frequencies below approximately 500 Hz and jet noise predominantly occurs at frequencies above approximately 2500 Hz.

- It is important to note that the venting test point low frequency noise could be influenced by the proximity to city streets and highways.

- The higher trends of the venting case for low frequencies less than 1000 Hz does not appear to correlate to noise mechanisms of the flare, but when compared to background noise frequency appears to be originating from test site surroundings.

- At these lower frequencies for the venting case, the ambient noise pressure level is higher than that of the flare tip.

- When analyzing the data as sound power level, the calculation is not applicable to these lower frequencies due to the measured sound pressure level being from ambient surroundings and not the venting point source.
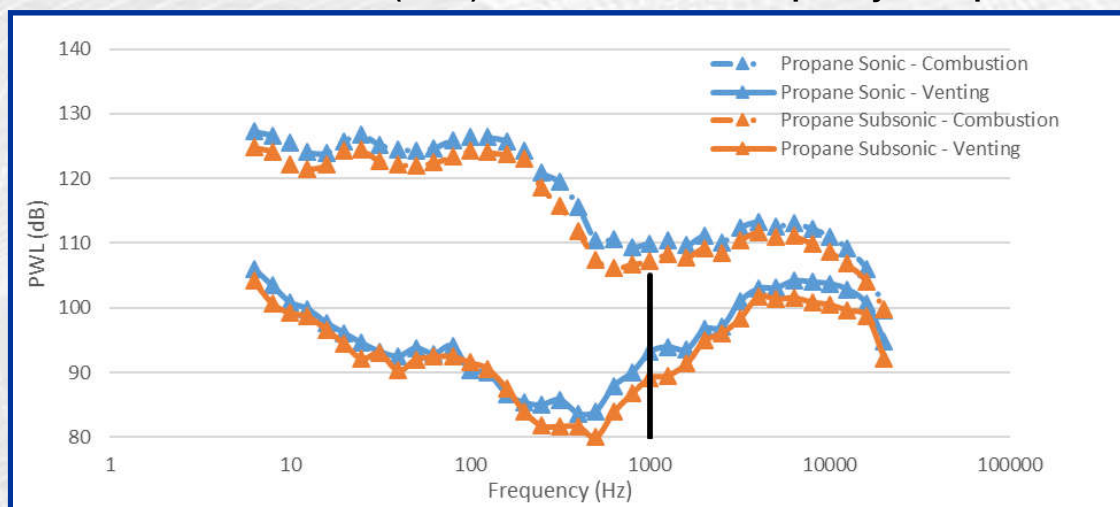
Combustion vs. Venting

Sound Power Level (PWL) as a Function of Frequency – Tulsa Natural Gas
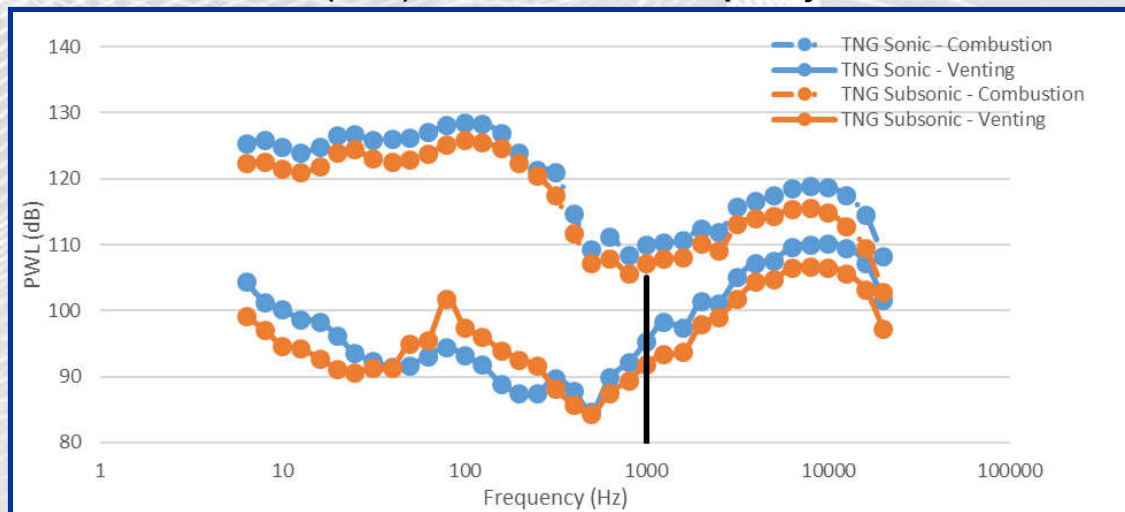
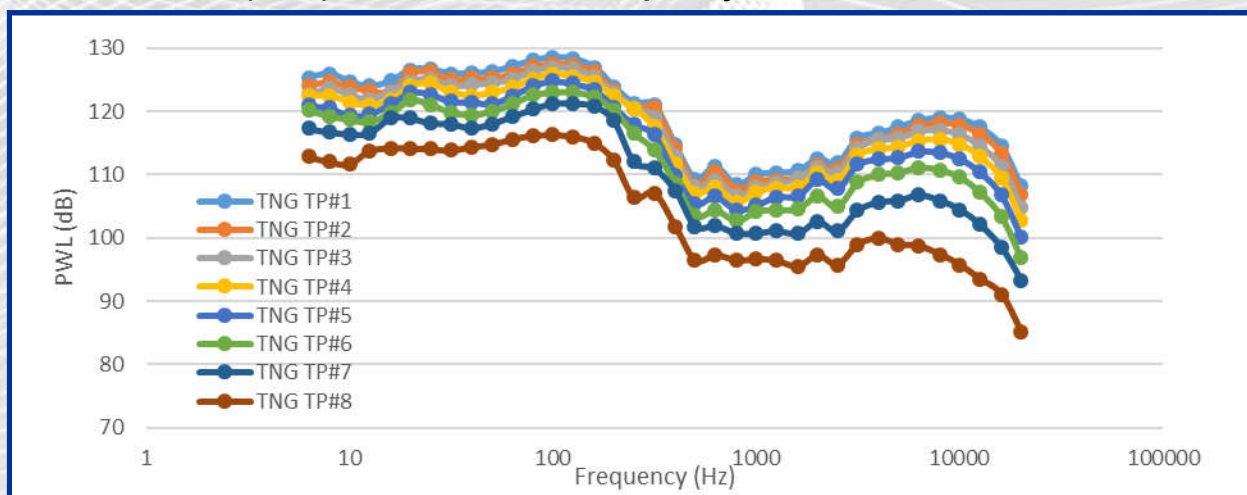**Sound Power Level (PWL) as a Function of Frequency – Propane**
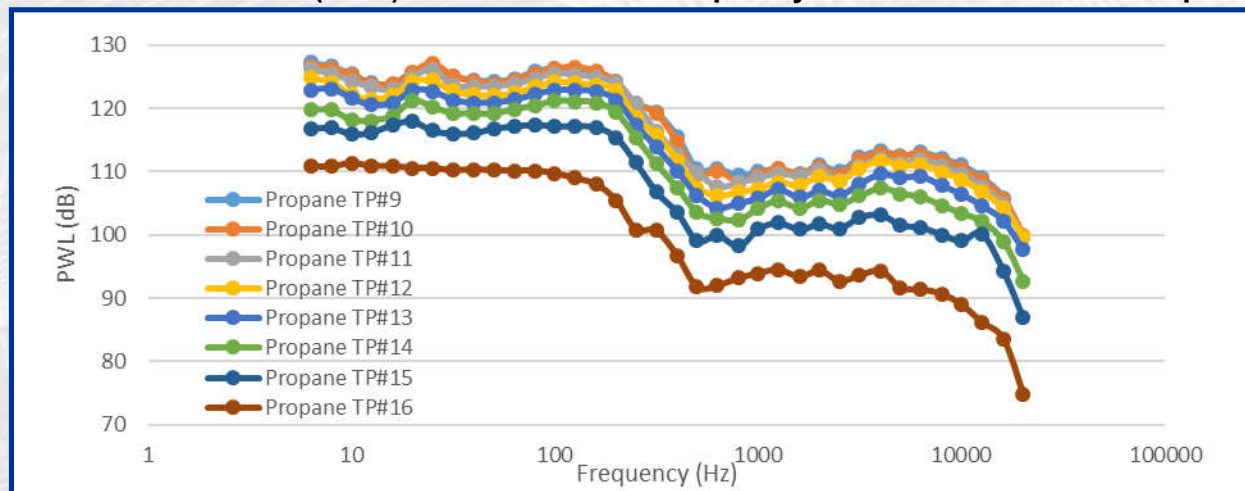
► Combustion vs. Venting

Sound Power Level (PWL) as a Function of Frequency and Fuel Flow Rate – Tulsa Natural Gas

Sound Power Level (PWL) as a Function of Frequency and Fuel Flow Rate – Propane

Combustion vs. Venting – Further Testing

- While the combustion versus venting tests provide insight into which frequency ranges are dominated by respective noise mechanisms, it would be beneficial to test a multitude of fuel gases of differing molecular weights and sonic velocities.

- Adjusting fuel exit areas while maintaining a constant fuel flow rate would yield a better understanding of the driving noise mechanisms of combustion versus venting and would allow a better understanding of the magnitude of impact from combustion noise.

  - This would be facilitated by incrementally decreasing the fuel exit velocity and respective jet noise, while maintaining constant combustion.