Minimizing Noise

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Photo courtesy of El Paso Pipelines

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  - Dresser Rand
  - Atmos Energy
  - Siemens
  - Williams Gas Pipeline

Presentation Overview

Focus of presentation = In-pipe noise and source control

- Background on Pipeline / Station Noise
- GMRC Project and Objectives
- Test Case #1:
  - GMRC sponsored field site for a reciprocating compressor station
- Test Case #2:
  - Turbulent flow excitation of an acoustic resonance for a PSV line
- Closing Comments

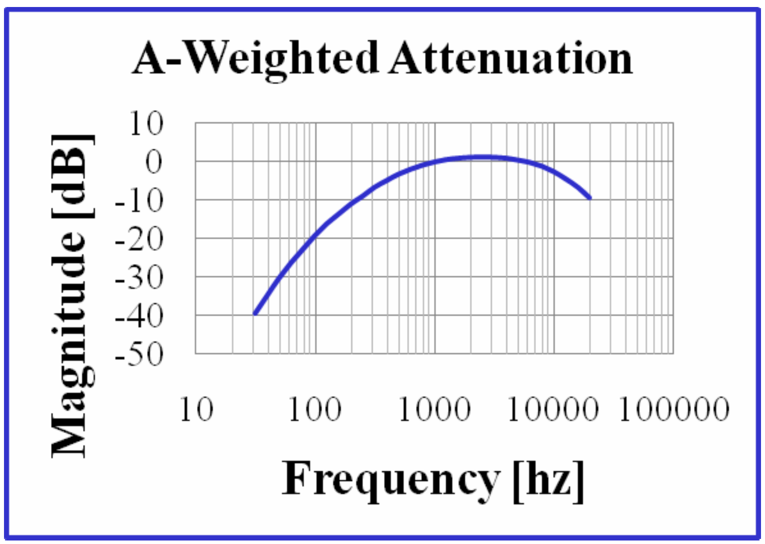
Why is Compressor Station Noise Important?

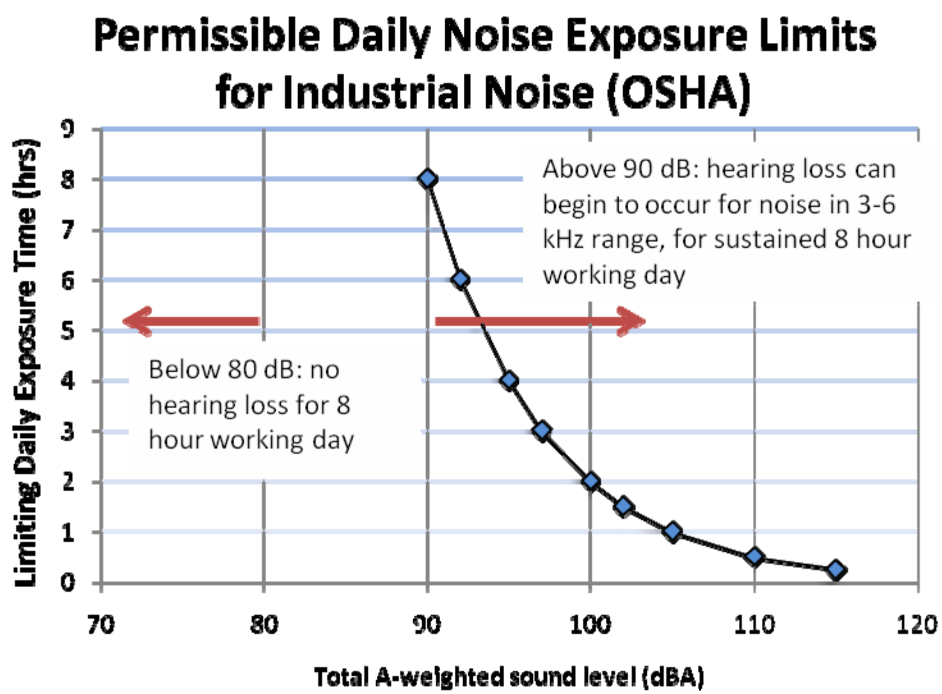
- Occupational safety limits for personnel
- Environmental noise is bad (bad for public relations, gas industry image, etc.)!
- Can be an indication of high vibrations (structural, acoustically-induced or other) and potential for fatigue
- Proper design and analysis, in the up-front stages of a project, can reduce cost of "retroactive" fixes.

Photos courtesy of Mueller Environmental Designs

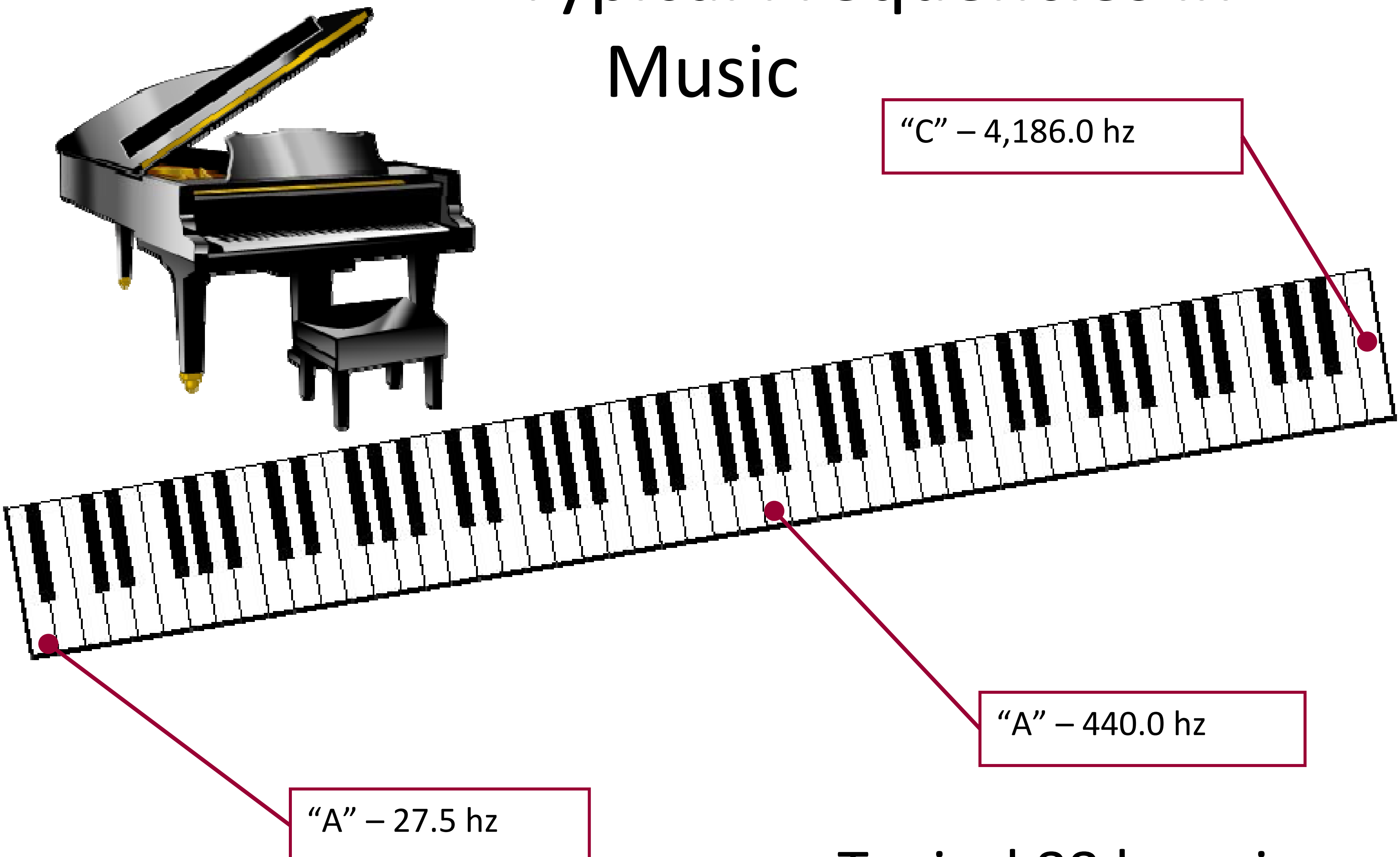
Human Hearing / Occupational Limits

- Human hearing ranges from about 20 to 20,000 hz
- Most Sensitive to 500 – 10,000 hz (based on dBA). Hearing loss will occur if noise above 90 dB sustained in the 3000-6000 Hz range.
- Threshold of hearing is about 20 μPa or 0 dB.
- A-weighted attenuation scale developed for human hearing sensitivity.





Typical Frequencies in Music



Typical 88 key piano

Compressor / Pipeline Station Noise Sources

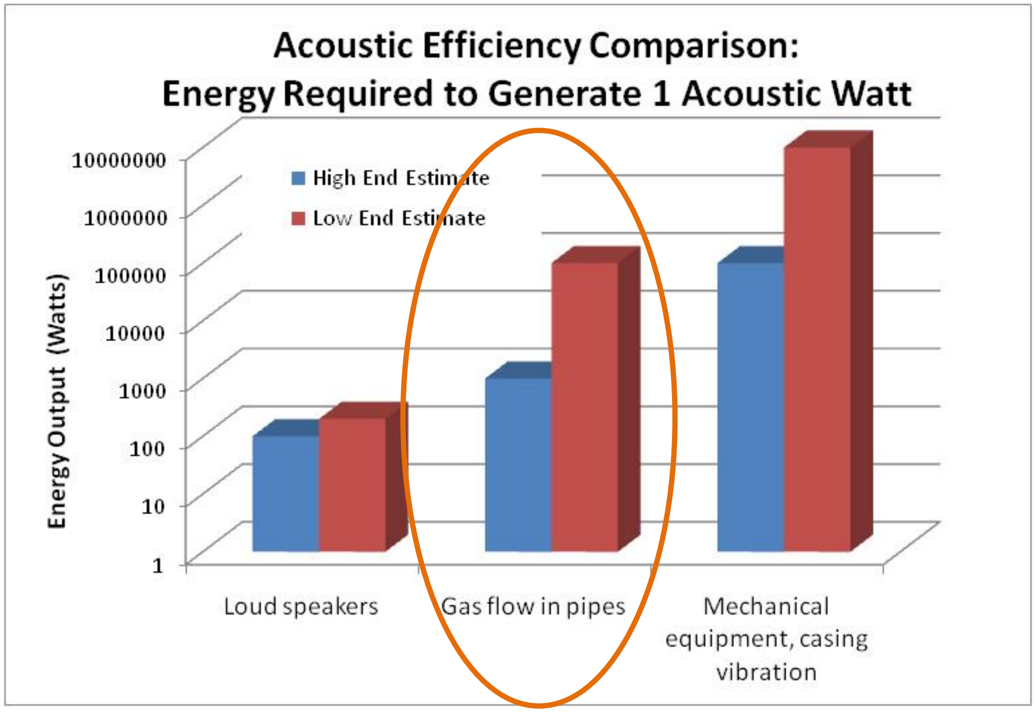
Acoustic Efficiency is the efficiency of mechanical power conversion to acoustic power:

$$\eta = W_a / W_m$$

To minimize this conversion efficiency, fundamentally the pressure or flow must be reduced.

(For a valve, $W_m = \Delta P * Q$)

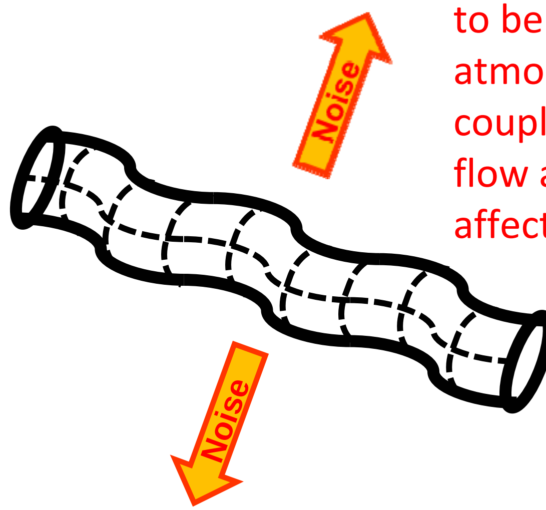
- Machinery noise: Compressors, gas turbines, engines, motors, gas / water coolers, smaller oil / water pumps, etc.
- Gas flow noise: Turbulent gas flow is more efficient acoustically, than machinery generated noise.
  * Gas flows also cause substantial related valve noise*
- Structure-born noise: Transmitted as vibrations from machinery, support structures, piping.

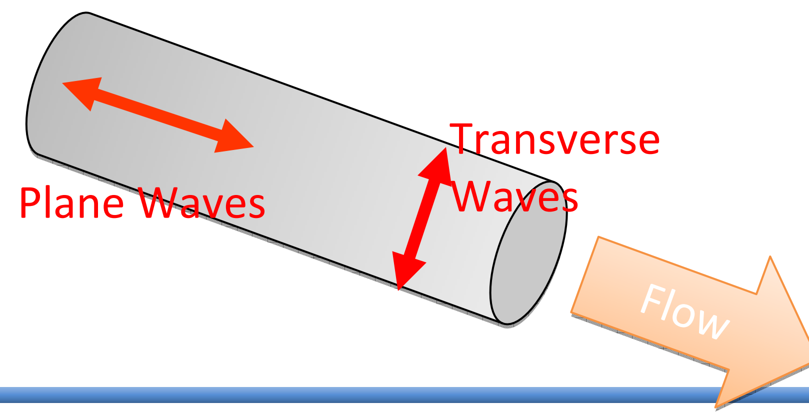


Noise Mechanisms for Pipeline / Compressor Station Piping

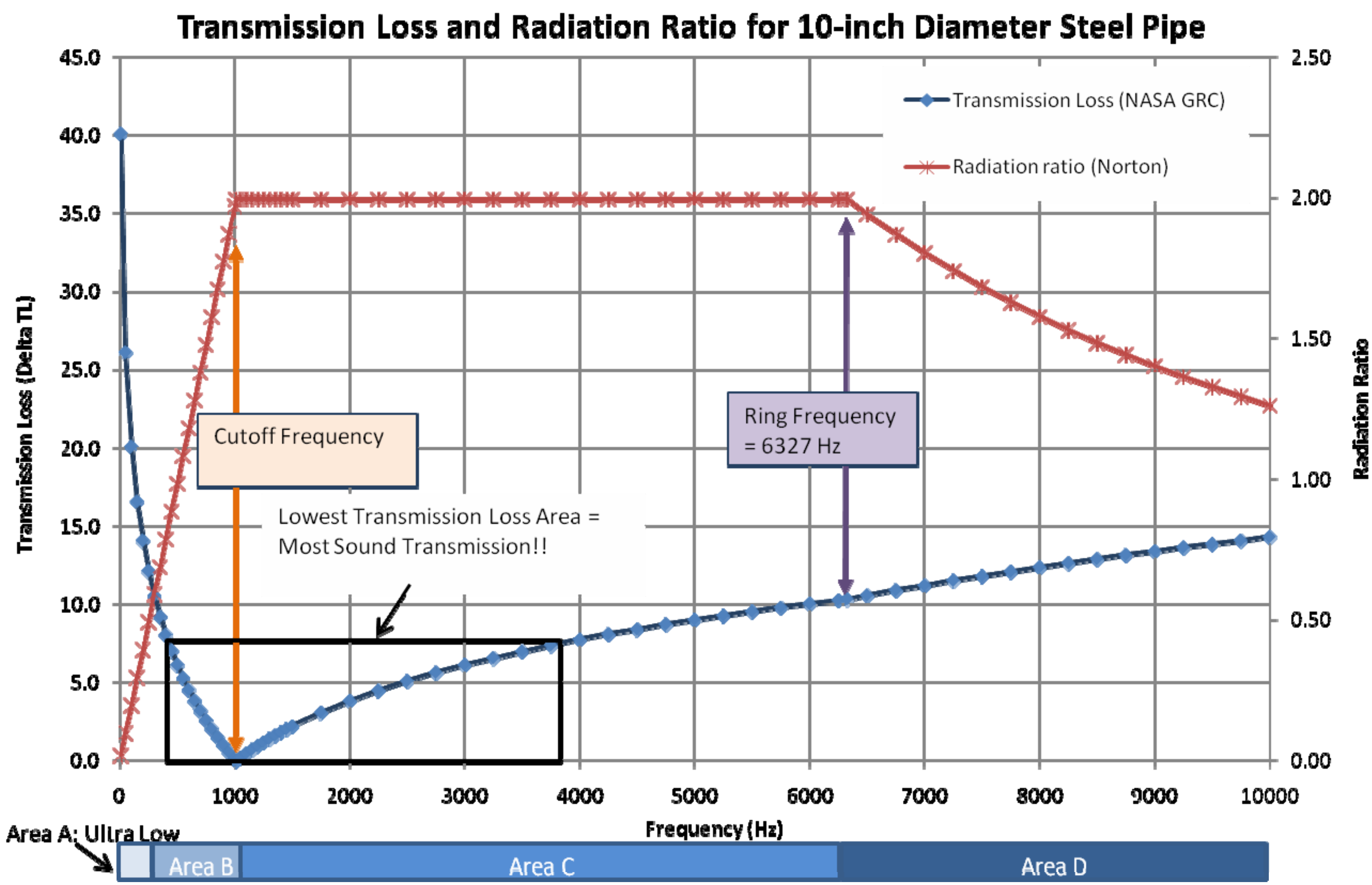
1. Turbulent flow: Straight fully developed flow will produce a certain noise level, apart from any piping vibration or flow stream interference. (up to 10k Hz)
2. Major and minor pipeline obstructions, elbows, valves, tees, etc.
3. Turbulent excitation of acoustic / mechanical resonances (typically 300-700 Hz range)
4. Vibration of the pipe: additional noise term due to flow, planar and traverse waves (100-400 Hz)
5. Pulsation-induced noise: Generally from planar waves resonant with compressor running speeds in low frequencies (20-300 Hz range)

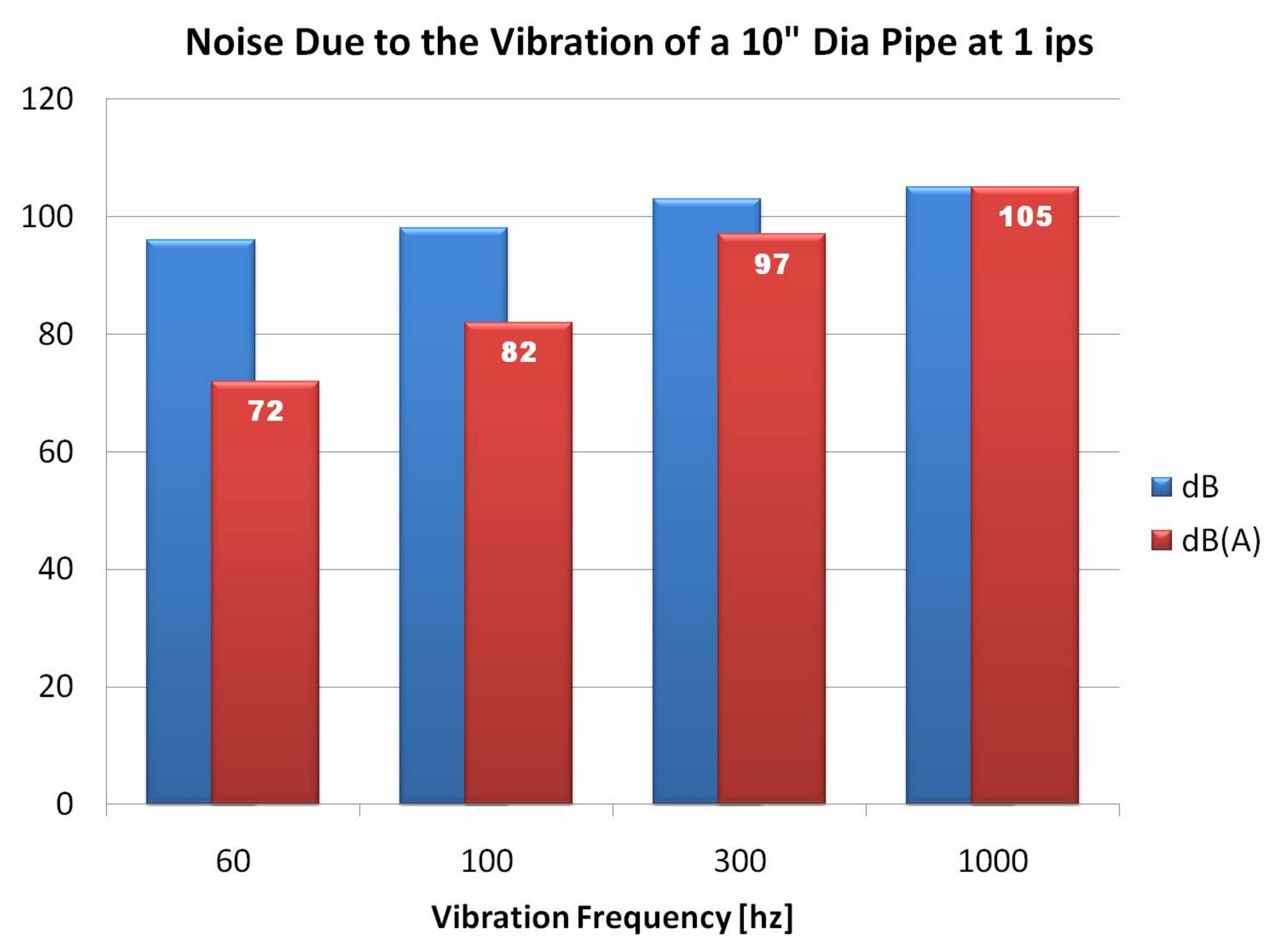
For internal pipe noise to be transmitted to atmosphere – need coupling between gas flow and pipe: this affects transmission loss





Importance of Flow to Pipe Coupling / Transmission Loss




Noise Due to the Vibration of a 10" Dia Pipe at 1 ips
120
100
80
60
40
20
0
72
82
97
105
dB
dB(A)
60
100
300
1000
Vibration Frequency [hz]

The GMRC 2009-2010 Station Noise Research

- Objective in work is to develop engineering tools, based on laboratory, field test data, and simulations that allow the prediction and control of in-pipe generated and transmitted noise in compression stations.
- 2010 effort focuses on the development of a guideline document that provides design rules and methods to predict noise transmission and generation in gas pipe.
- Noise transmission from reciprocating compressors and in-pipe generated noise sources are considered. Potential to enlarge body of work to include centrifugal and screw compressor installations.

TEST CASE # 1
(RECIPROCATING COMPRESSOR, DISCHARGE PIPING SYSTEM)

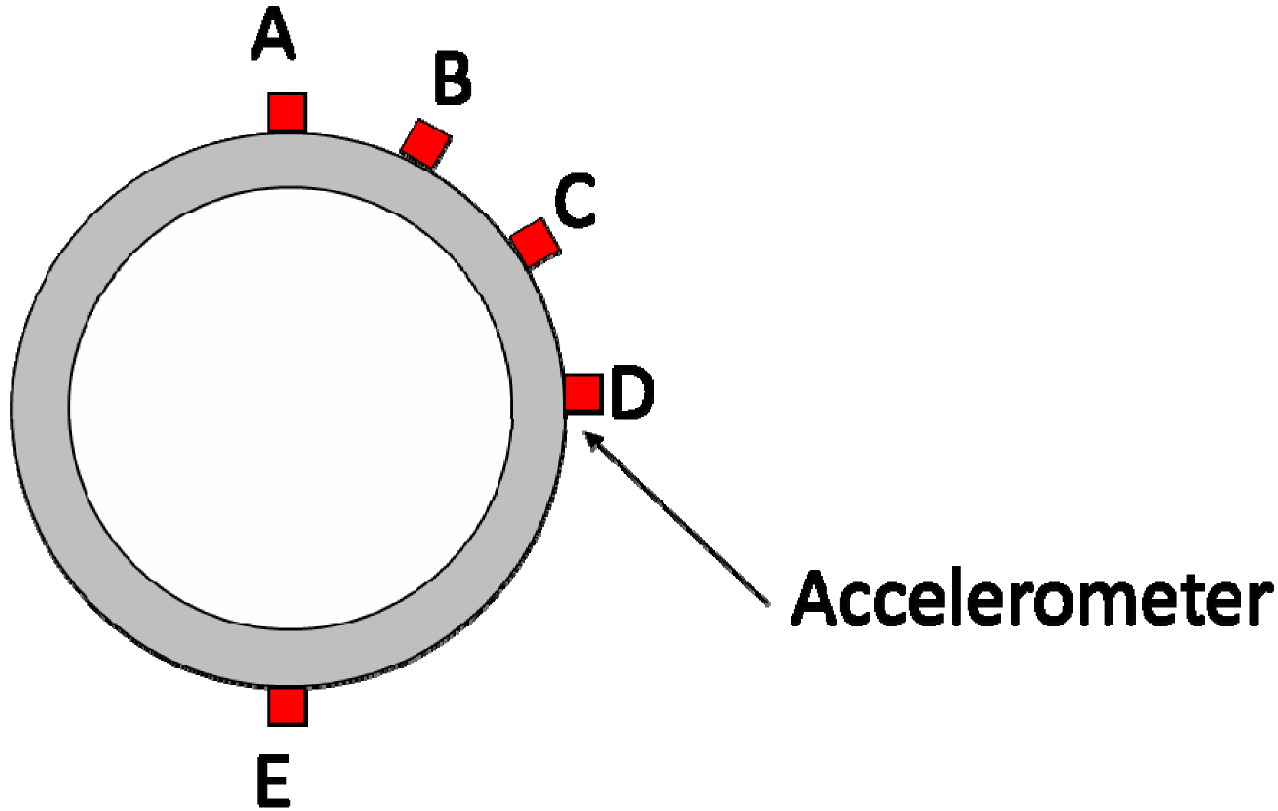
Station Description

- Unit composed of Cat 3612 driver and Ariel JGC-6 reciprocating compressor.
- Single-stage operation (up to 3,550 HP) with operating speeds between 800 and 1,000 rpm.
- Testing occurred on the discharge side between the bottle and the cooler on 10” diameter piping with 0.5” thick walls (two discharge pipes).
- The fluid was natural gas at about 750 psi and 130°F and total flow through the unit was about 144 MMSCFD.

Instrumentation

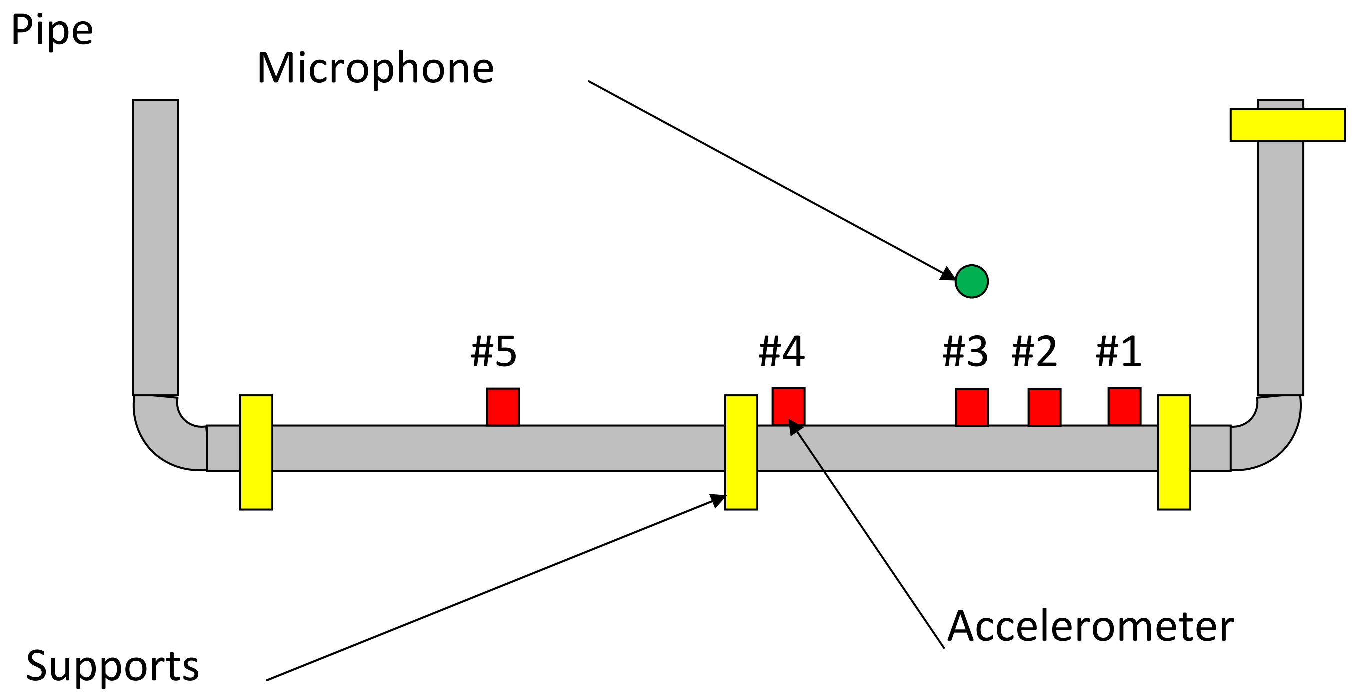
- Accelerometers were used to measure vibration.
  - Attached to piping using magnets
  - Top recommended frequency ~ 4000 hz
- Single pressure transducer mounted in flow to detect pressure fluctuations, at tap near cooler.
- Three external microphones were used.
  - Presented data is shown for microphone near center of piping section.
  - Microphones measure sound pressure level.
  - Likely picked up background noise from exhaust and cooler fans.

Accelerometer Location (Radial Shell Modes)



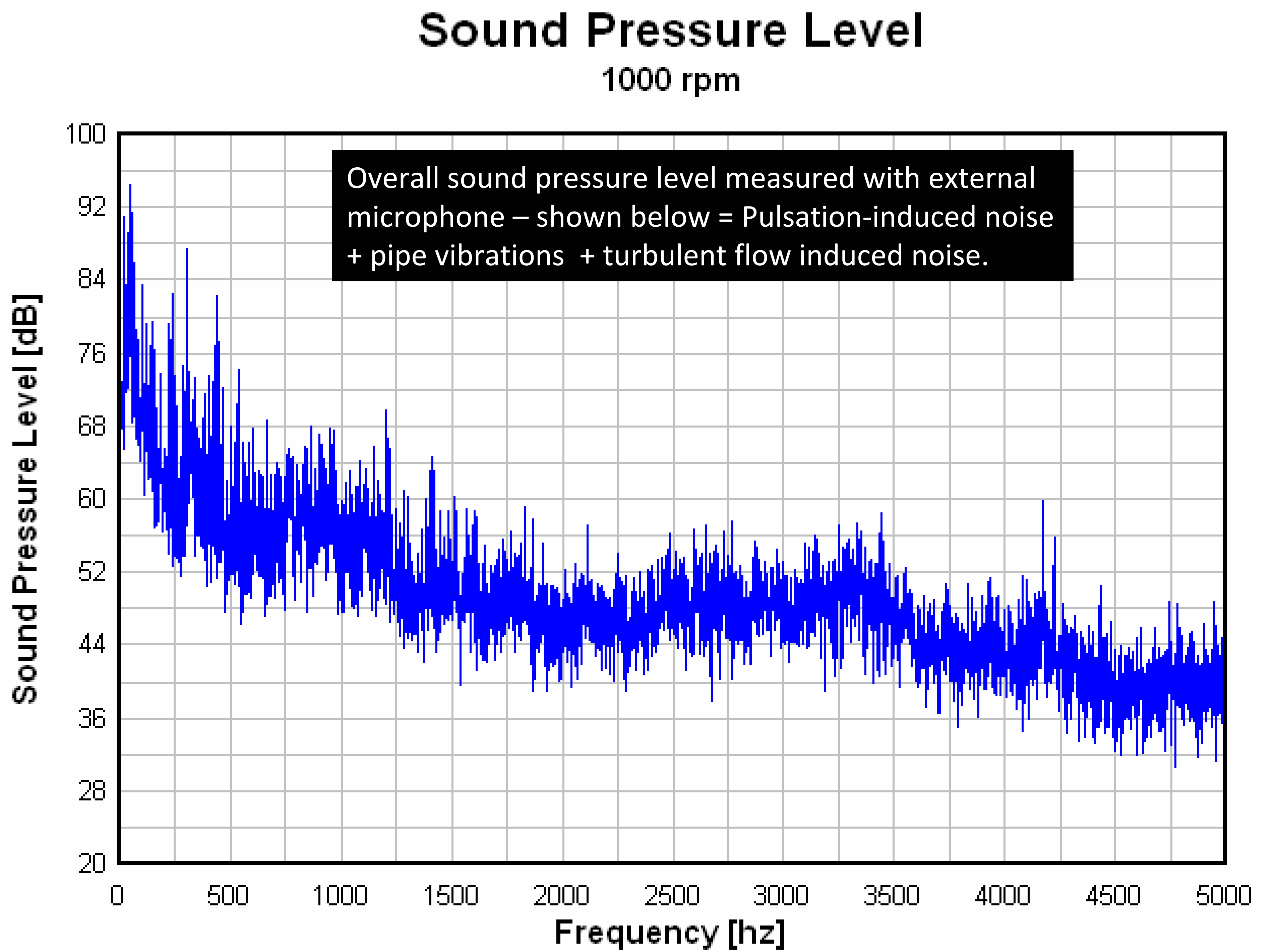
Pipe Cross-Section

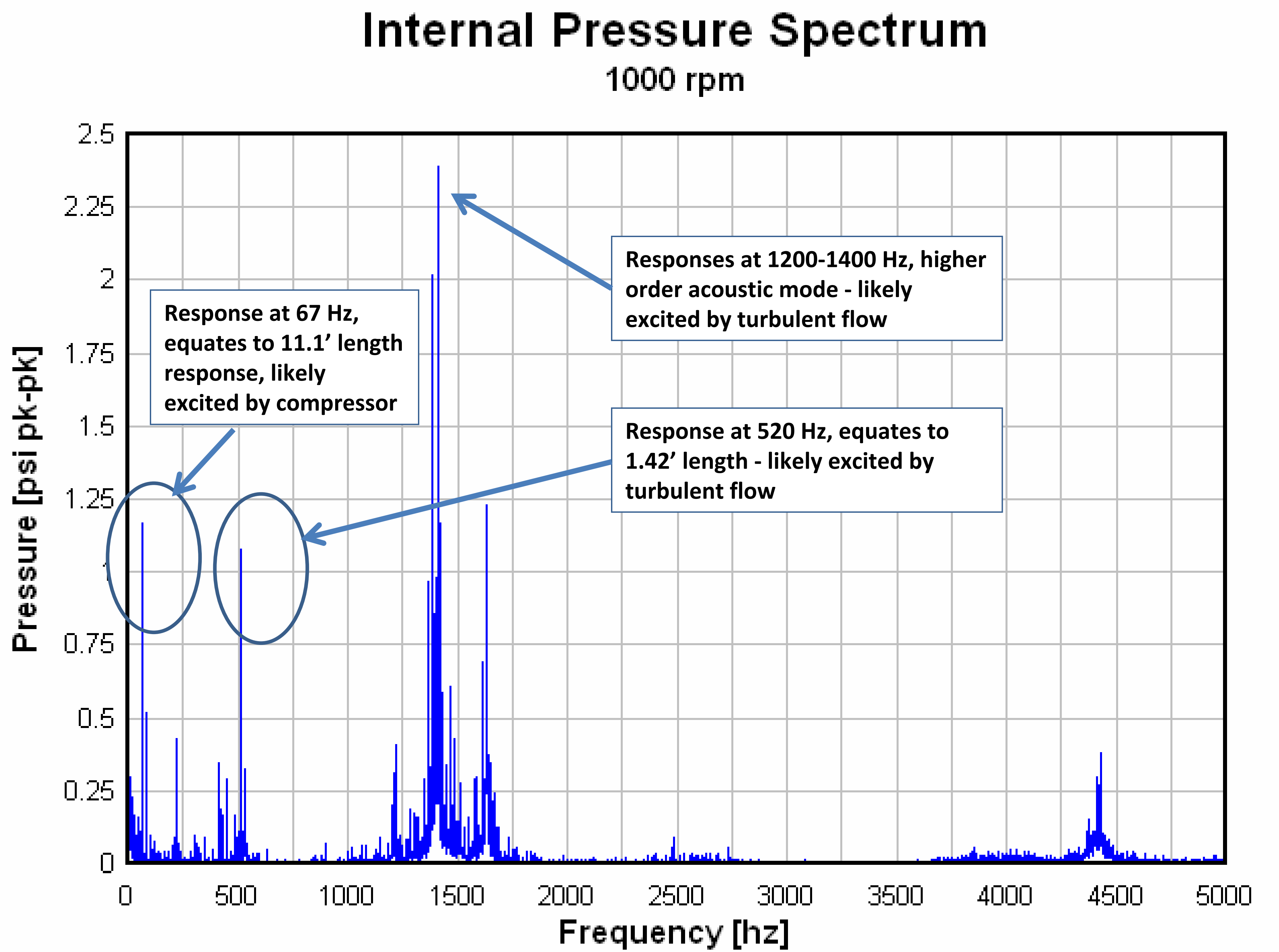
Accelerometer Locations (Axial Shell Modes)



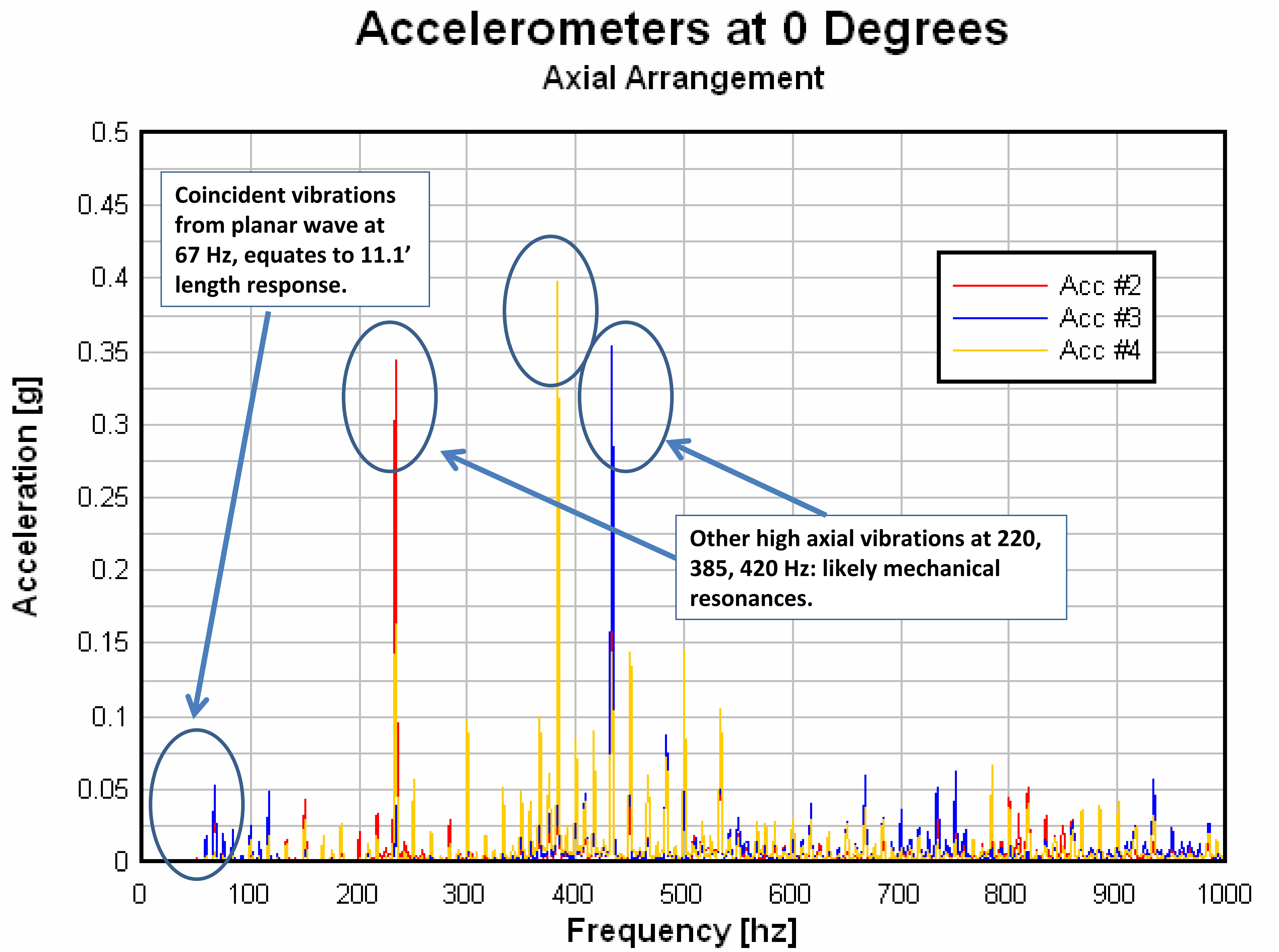

Microphone
Axial Accelerometer Positions


Radial Accelerometer Positions

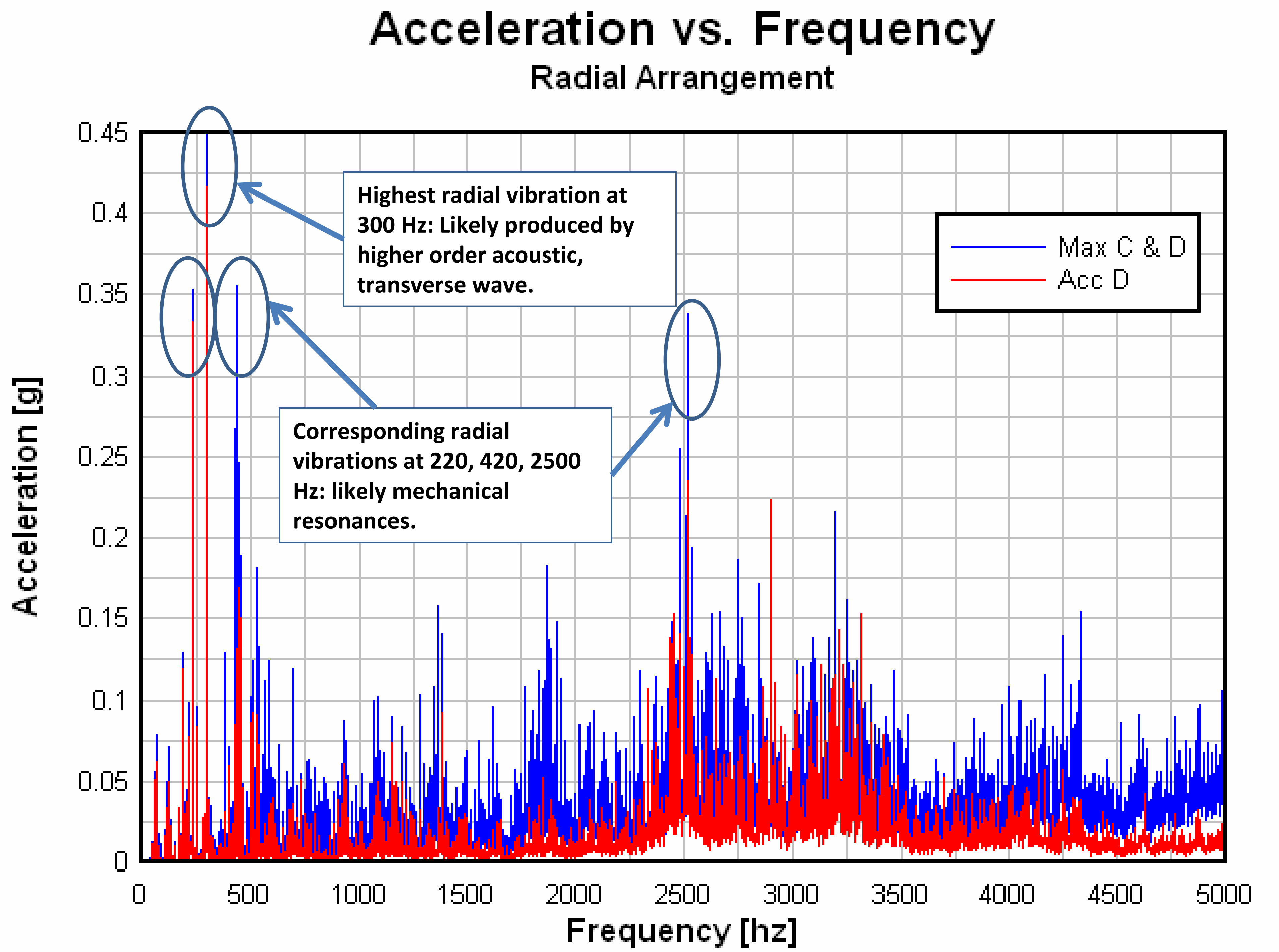

Sound Pressure Level
1000 rpm
Overall sound pressure level measured with external microphone – shown below = Pulsation-induced noise + pipe vibrations + turbulent flow induced noise.
Sound Pressure Level [dB]
100
92
84
76
68
60
52
44
36
28
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency [hz]



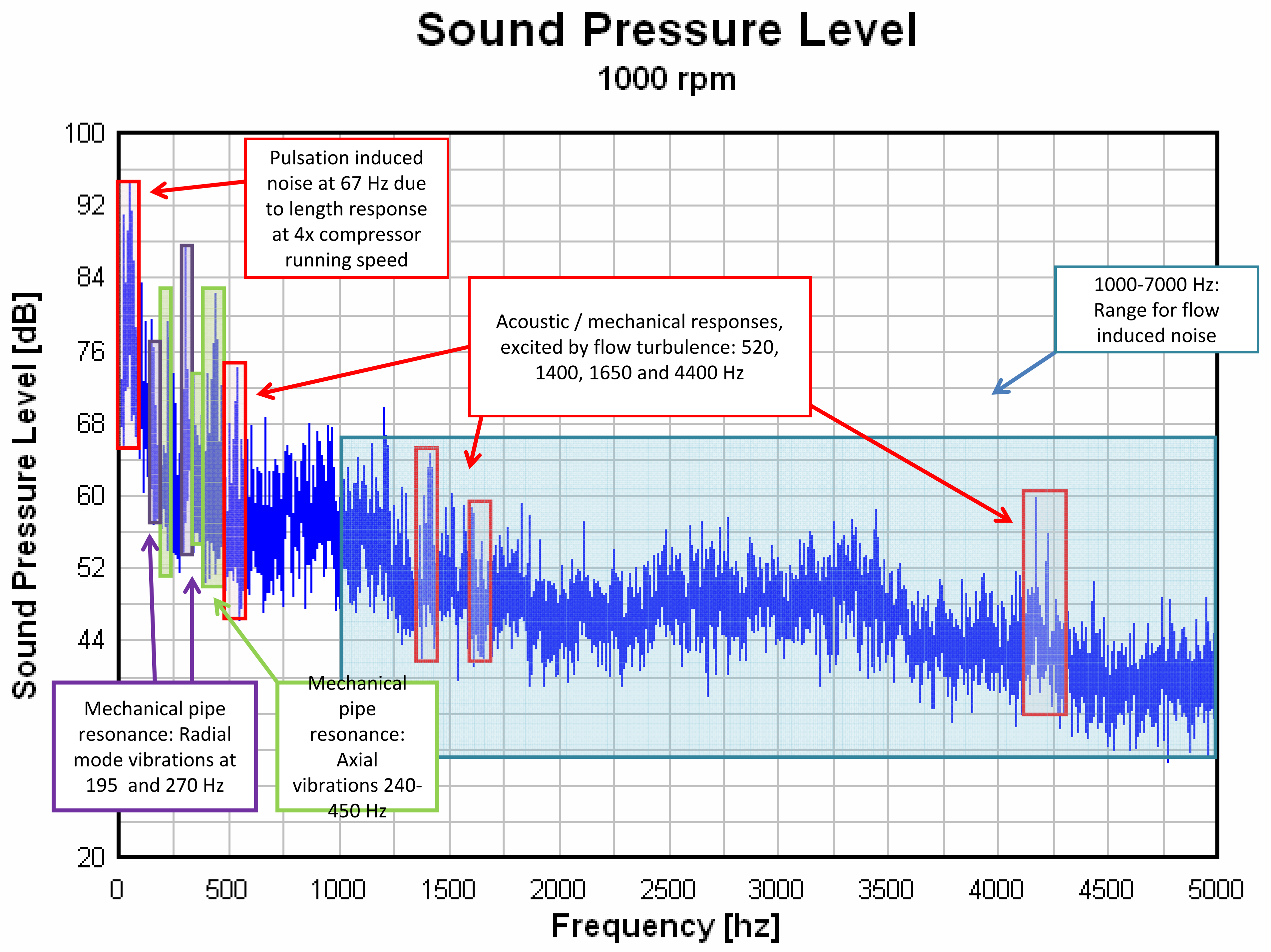
Internal Pressure Spectrum
1000 rpm
Pressure [psi pk-pk]
Frequency [hz]
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Response at 67 Hz, equates to 11.1' length response, likely excited by compressor
Responses at 1200-1400 Hz, higher order acoustic mode - likely excited by turbulent flow
Response at 520 Hz, equates to 1.42' length - likely excited by turbulent flow



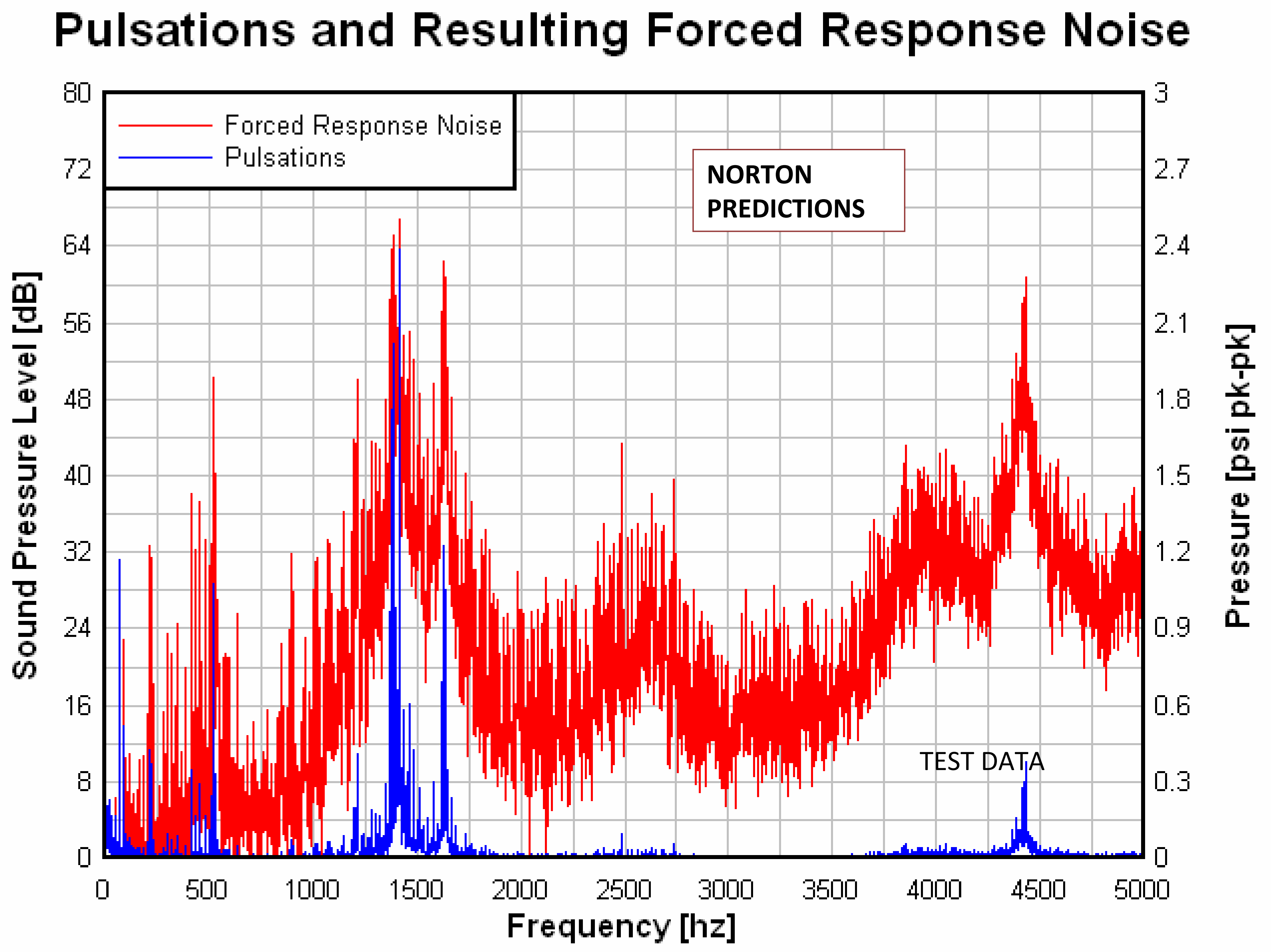
Accelerometers at 0 Degrees
Axial Arrangement
Coincident vibrations from planar wave at 67 Hz, equates to 11.1' length response.
Other high axial vibrations at 220, 385, 420 Hz: likely mechanical resonances.
Acc #2
Acc #3
Acc #4
Acceleration [g]
Frequency [hz]
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
100
200
300
400
500
600
700
800
900
1000



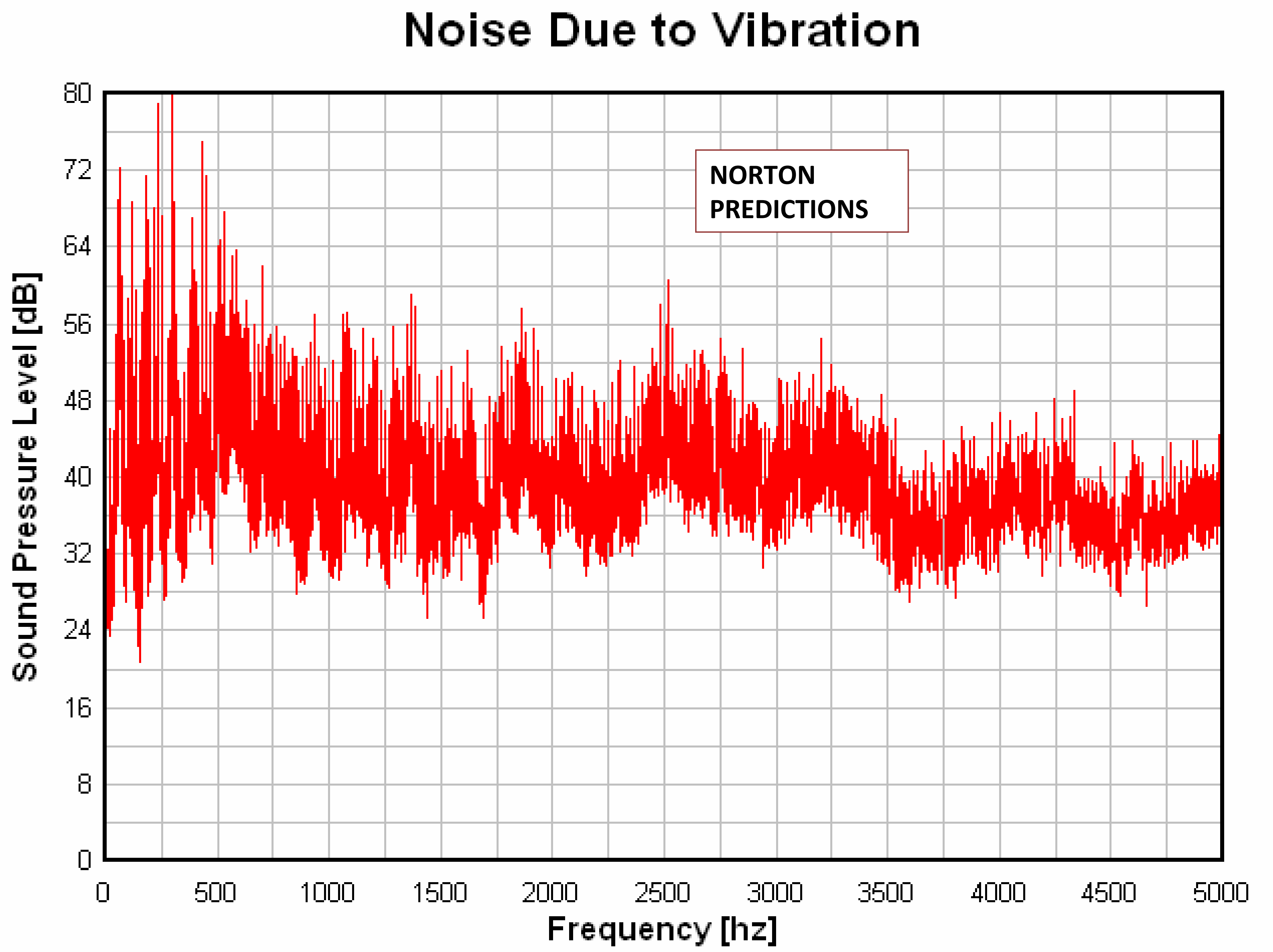
Acceleration vs. Frequency
Radial Arrangement
Highest radial vibration at 300 Hz: Likely produced by higher order acoustic, transverse wave.
Corresponding radial vibrations at 220, 420, 2500 Hz: likely mechanical resonances.
Max C & D
Acc D
Acceleration [g]
Frequency [hz]
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000



Sound Pressure Level
1000 rpm
Pulsation induced noise at 67 Hz due to length response at 4x compressor running speed
Acoustic / mechanical responses, excited by flow turbulence: 520, 1400, 1650 and 4400 Hz
1000-7000 Hz: Range for flow induced noise
Mechanical pipe resonance: Radial mode vibrations at 195 and 270 Hz
Mechanical pipe resonance: Axial vibrations 240-450 Hz
Sound Pressure Level [dB]
Frequency [hz]
100
92
84
76
68
60
52
44
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000



Pulsations and Resulting Forced Response Noise
Forced Response Noise
Pulsations
NORTON PREDICTIONS
TEST DATA
Sound Pressure Level [dB]
80
72
64
56
48
40
32
24
16
8
0
Pressure [psi pk-pk]
3
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency [hz]


Noise Due to Vibration
NORTON
PREDICTIONS
Sound Pressure Level [dB]
80
72
64
56
48
40
32
24
16
8
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency [hz]

Preliminary Recommendations

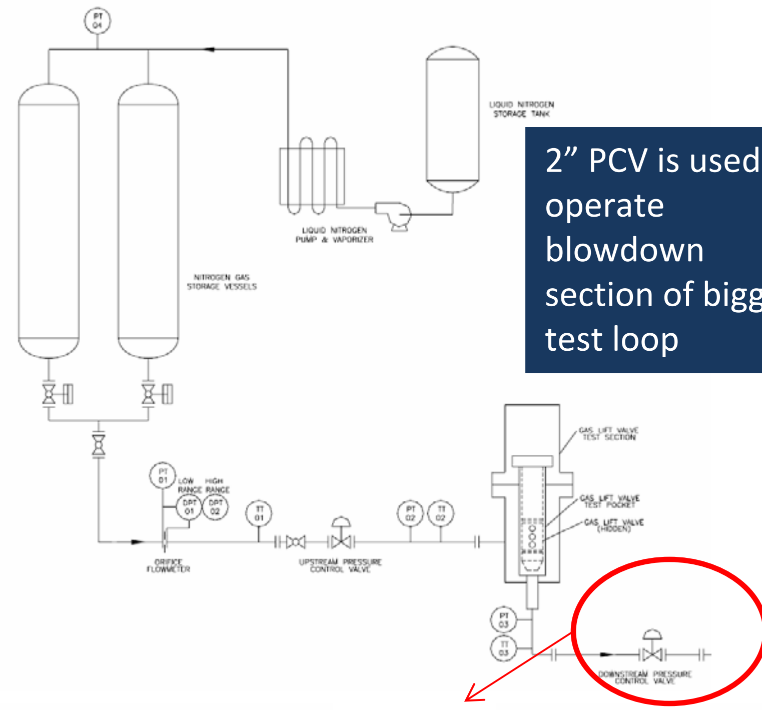
1. Mechanically-Induced Noise:
   - Mechanical vibration noise tends to occur in the 0-500 Hz range and can be at relatively high dB (up to 90 dB) levels.
   - Can be controlled with good supports and restraints on piping.
2. Pulsation-Induced Noise:
   - Pulsations will produce high noise at key frequencies, tending to be higher amplitude at lower frequencies below 300 Hz.
   - Best practice is to avoid resonance through design.
3. Flow-induced Noise:
   - Flow-induced noise <u>is highly installation dependent</u> - but will reach peak amplitudes in 1000-6000 Hz.
   - **This is typically going to drive "noise complaints" because of frequency content.**
   - Must try to avoid flow-excitation of mechanical and acoustic resonances (400-800 Hz) – leading to high acoustic-induced vibrations in relief valves, blowdown valves.
   - Can be avoided by minimizing velocities, selecting gradual bends, staging pressure cuts.

- For accuracy, prediction methods should combine forced-response analysis, vibration noise estimates and turbulent flow excitation analysis.

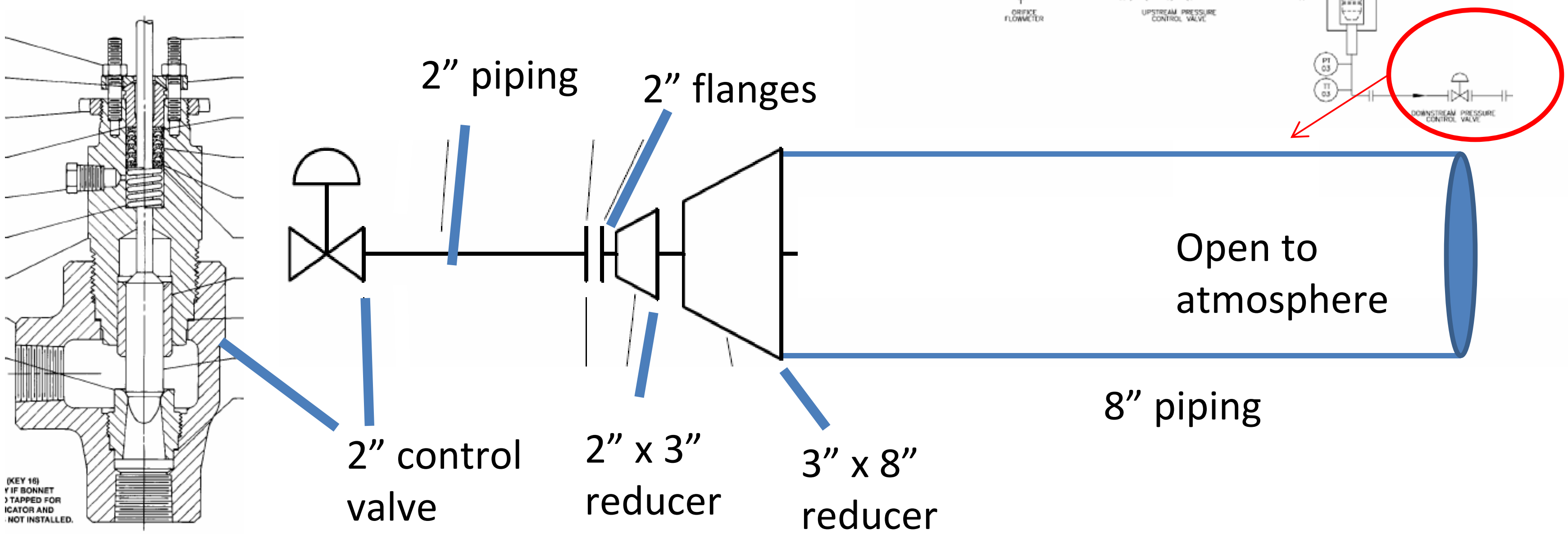
TEST CASE # 2
(PRESSURE CONTROL VALVE LINE, TURBULENT EXCITATION OF ACOUSTIC RESONANCE)

Pressure Control Valve Noise

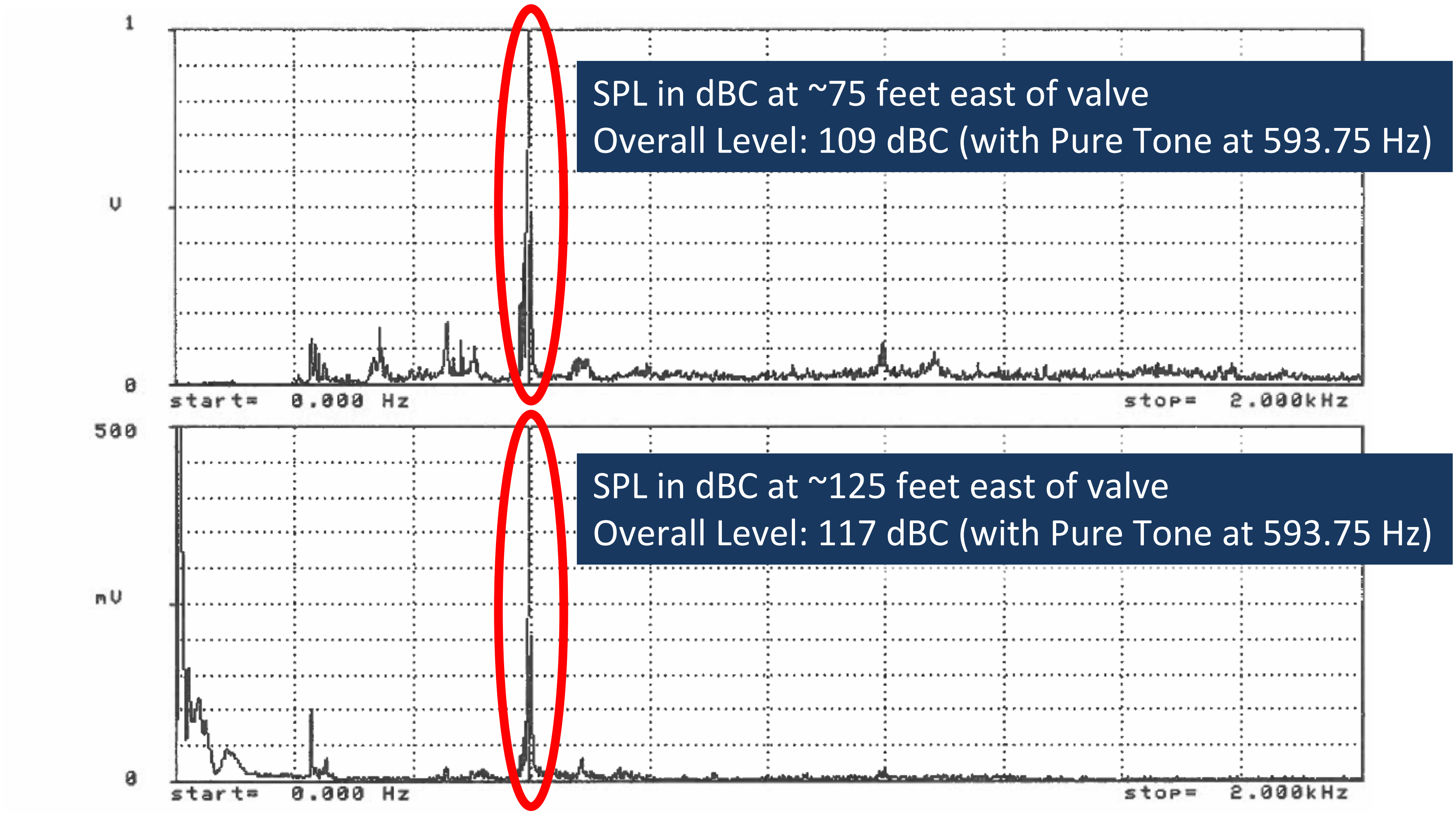
- Noise problem was in the vicinity of a blow down line which utilizes a 2-inch pressure control valve (PCV)
- Operator had not determined frequency content or root cause of high noise: over 110 dBA at certain flow rates.



2” PCV is used to operate blowdown section of bigger test loop



PCV Noise Problem – Sound Pressure Level Field Measured (C-weighted scale)

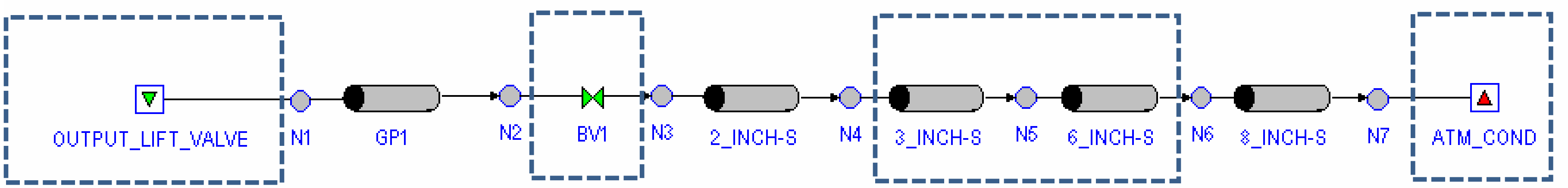


FLUID MODEL OF THE PCV LINE

- Known system operating conditions (upstream of the 2” valve) modeled in Stoner (transient hydraulic modeling software) to predict the downstream conditions.
- Additional transient modeling performed in SwRI acoustic software to determine resonant responses.

4 MMSCFD,
1539 psia, 102ºF

2 “ Equal percentage
Valve characteristic



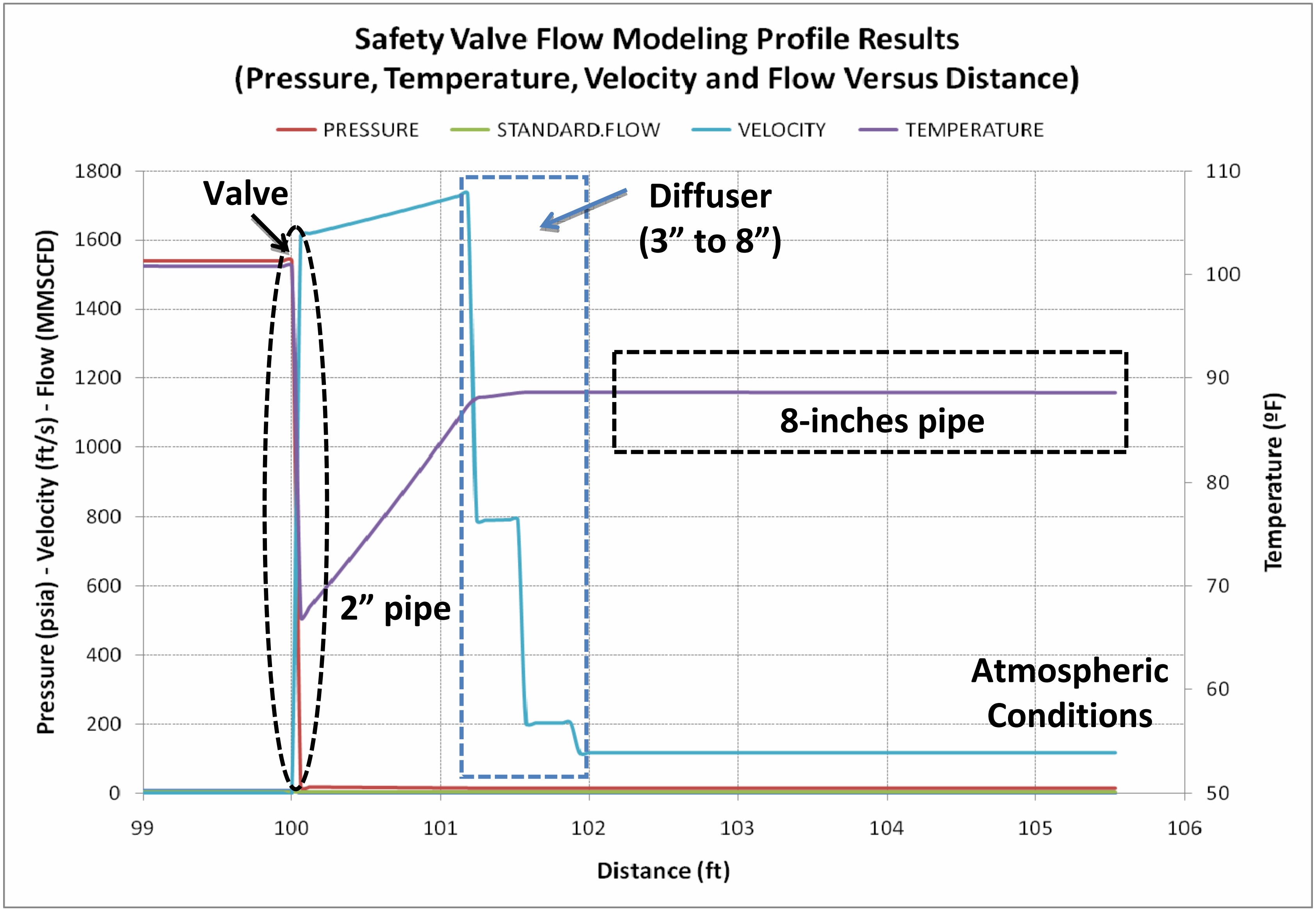
Flow -Boundary Condition (100% Nitrogen)

Safety Valve

Diffuser (3 to 8 inches)

Pressure Boundary Condition (Atmospheric)

FLUID MODEL RESULTS

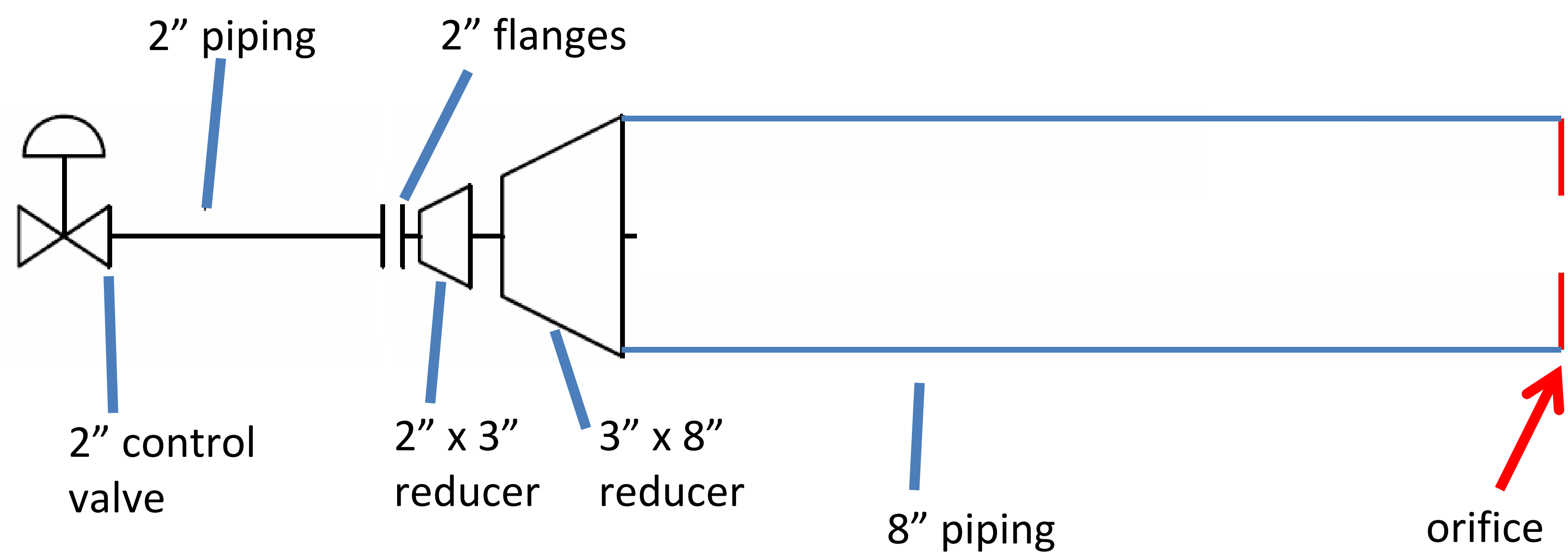


PCV Noise: Modeling Results

- Selection of "model" conditions downstream:
  - Pressure dropped 1540 psia to ~30 psia immediately downstream of the valve, gradual decrease to atmospheric pressure downstream of the valve.
  - Temperature dropped from 101 degF to 65 degF downstream of valve, but quickly increased to approximately 87 degF.
  - SwRI parametrically studied system in various model runs to determine realistic conditions which simulated downstream temperature and pressures, on the back side of the 2" PCV.
- A system acoustic response (multiple of the fundamental mode of the piping) was predicted to be very near the field measured 594 Hz.
- Acoustic resonance was likely excited by flow turbulence through the PCV.

PCV Noise Problem - Solution

- Options presented to client:
  - Install an orifice at the exit of the 8" piping to damp the acoustic resonance, at velocity maximum for acoustic response
  - Select a different valve with noise attenuating trim, will help to control turbulent excitation.
  - Redesign downstream leg (and hope to avoid excitation of new resonant condition)



Closing Remarks

- Station noise levels are often a combination of machinery, structural and flow noise due to turbulence and excited acoustic / mechanical resonances.
- Gas flows are acoustically efficient and will generate high noise over broad frequency range easily.
- In-pipe noise can be controlled with good design practice (avoiding abrupt transitions, 90deg bends, etc.), resonance avoidance, and <u>in-pipe</u> controls.
- Sound pressure level measurements can help to identify root cause, dominating sources of noise and low cost solutions for noise control within the pipe.