VAC Webinar March 2, 2022

Flow Noise of Perforated Concentric Tubes

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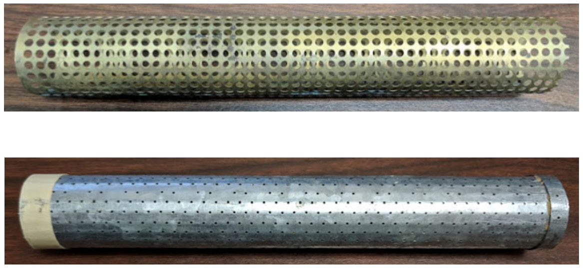
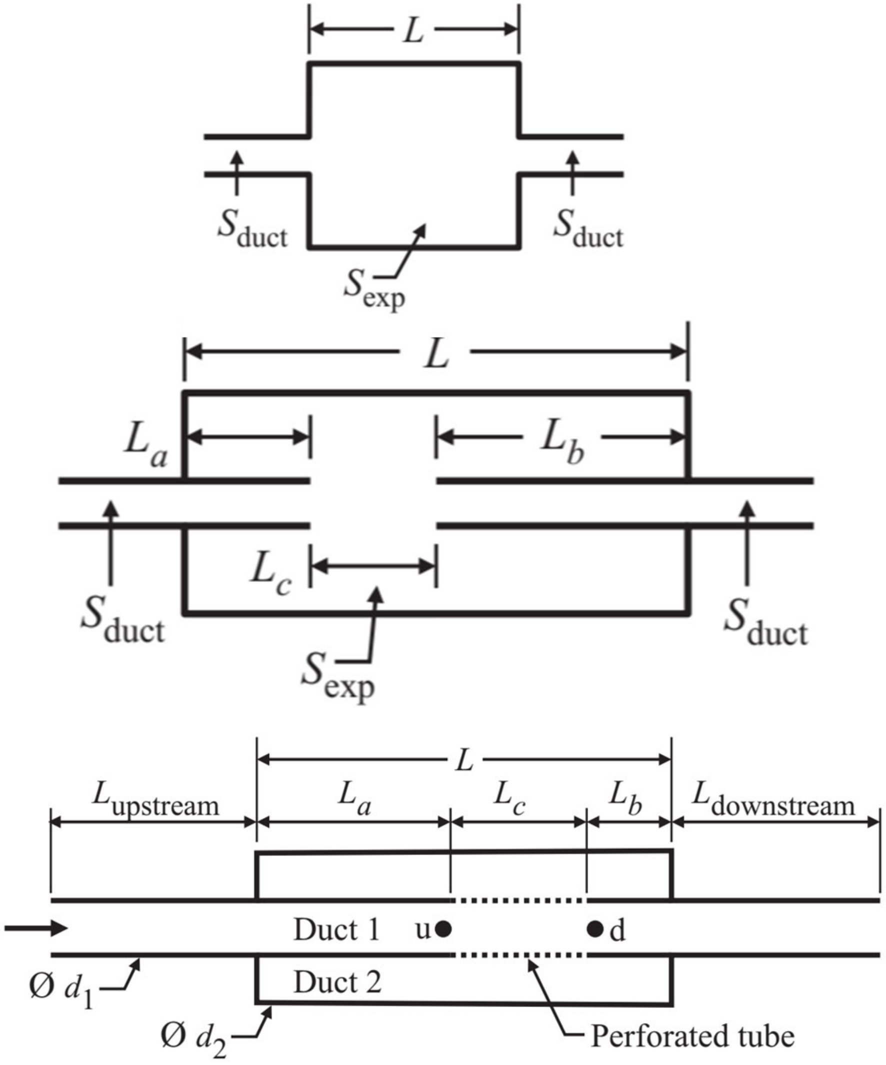
Background Perforate Tubes

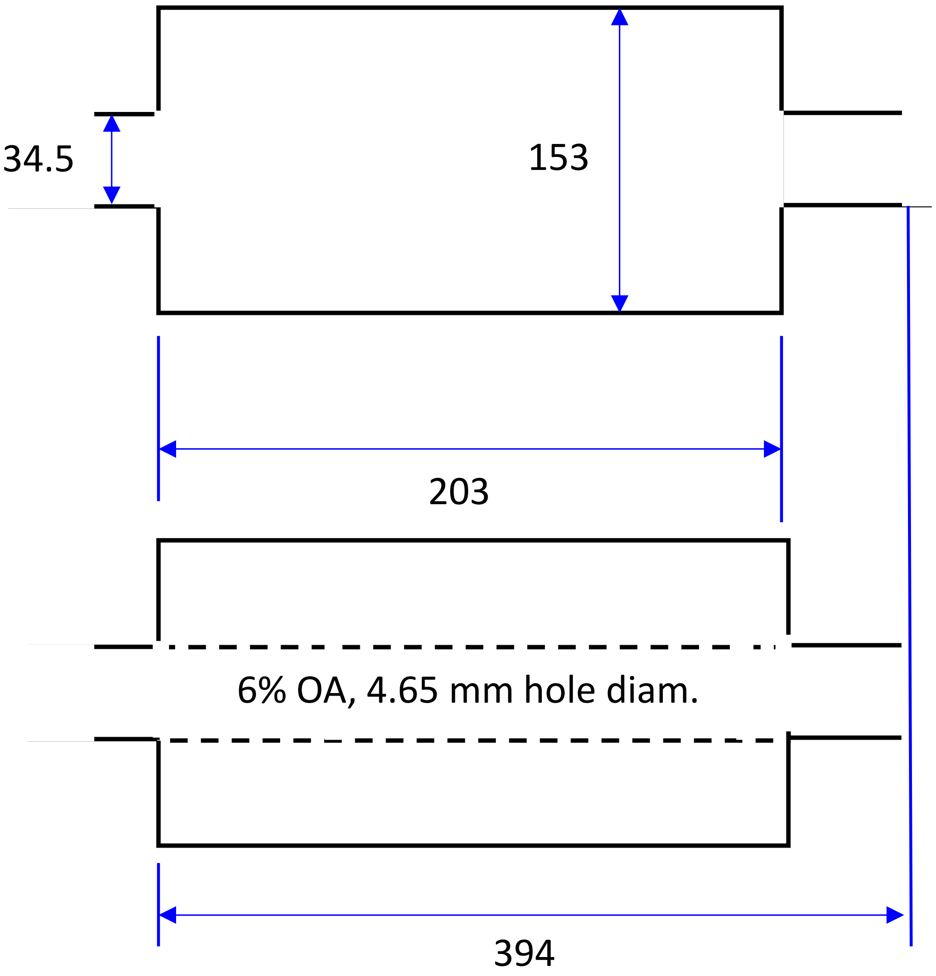
- Sudden expansions provide broadband attenuation but have significant pressure drop.
- Pressure drop can reduce efficiency of the source.
- Perforated tubes can be used to
  - Limit the amount pressure drop
  - Protect absorption
  - Provide additional attenuation



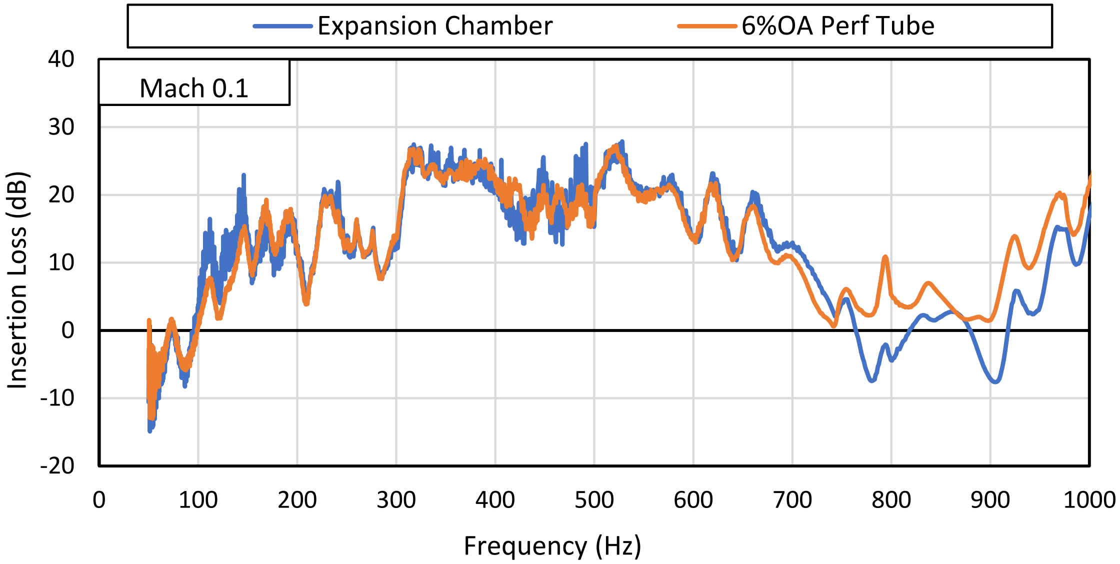


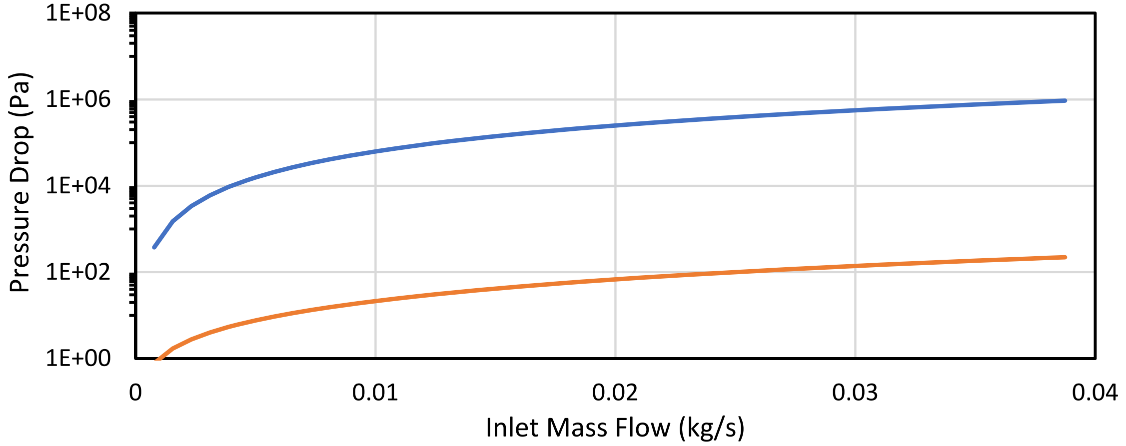
(Bies [2])

Background Perforate Tubes

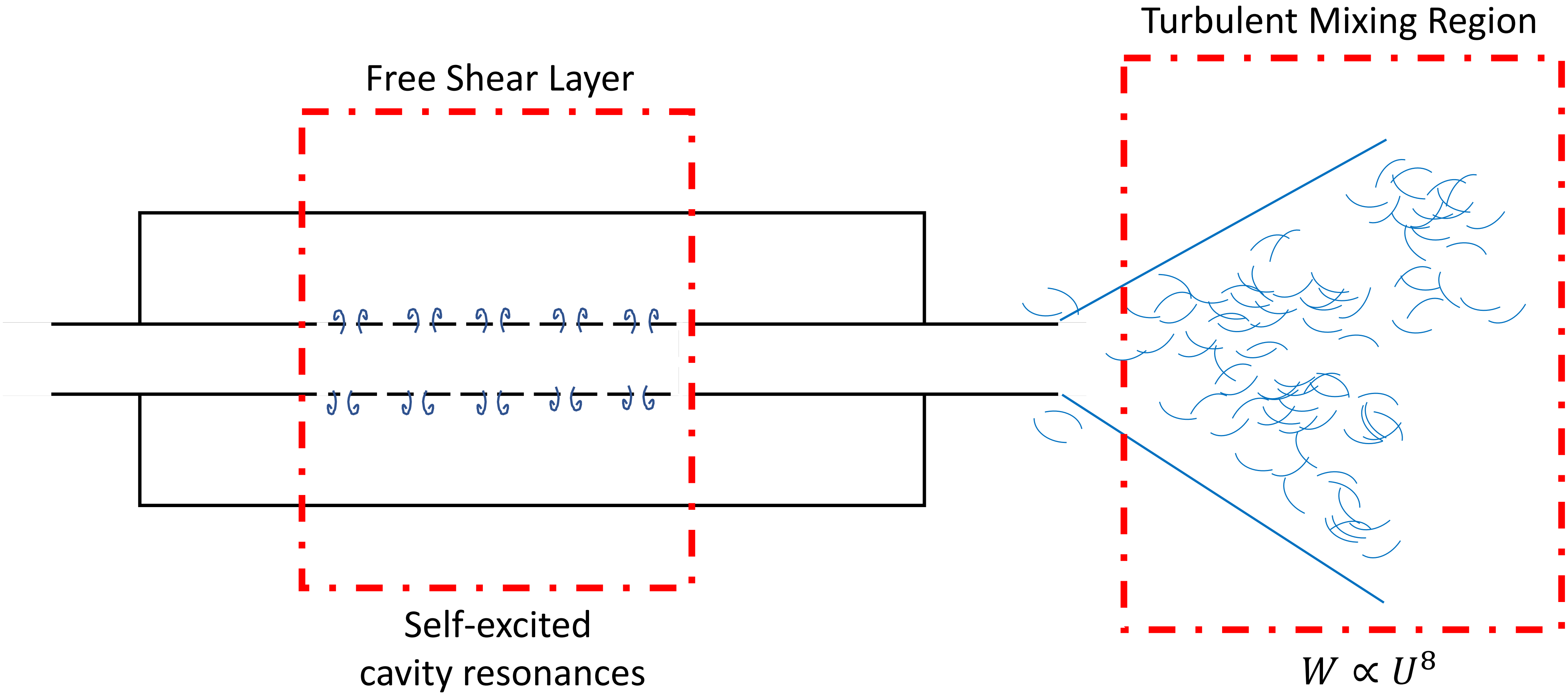


*Dimensions in mm





Background Flow Noise Sources



Turbulent Mixing Region

Free Shear Layer

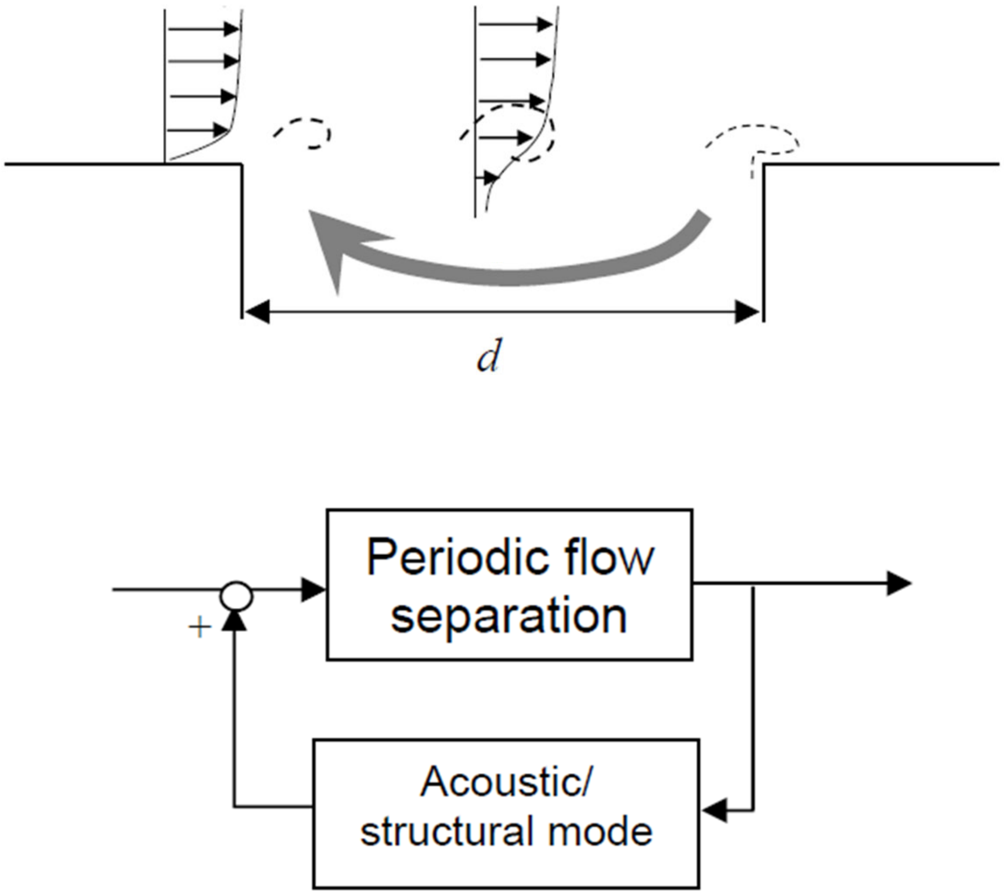
Self-excited
cavity resonances

$W \propto U^8$

(Lighthill [5])

Background Cavity Resonance

- Created by flow instabilities
- Depend on the coupling of fluid dynamics and the acoustic characteristics of cavity.
- Resonance is self-sustained by a fluid-resonator feedback loop



Periodic flow separation

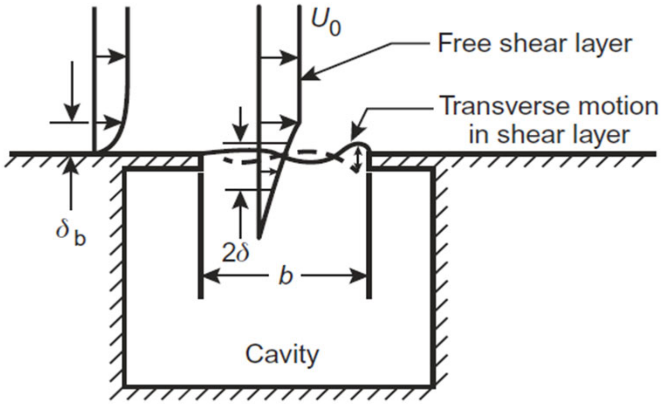
Acoustic/ structural mode

(Åbom [5])

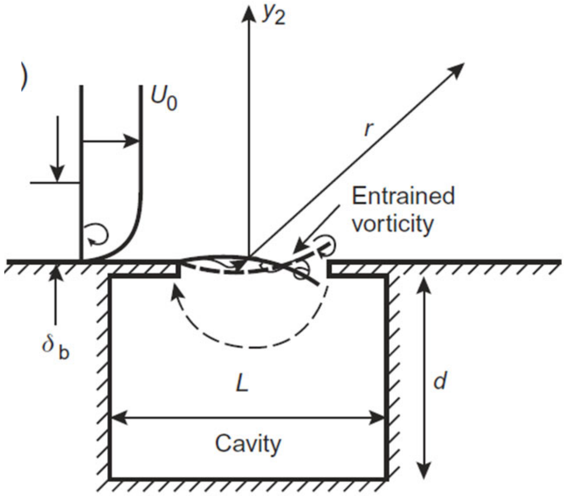
Background Cavity Resonance

Frequency of tone depends on:

1. Upstream turbulent boundary layer, δ_b
2. Mean fluid velocity, U_o
3. Opening size, b
4. Cavity volume
5. Cavity geometry



Geometry of the shear layer in the opening



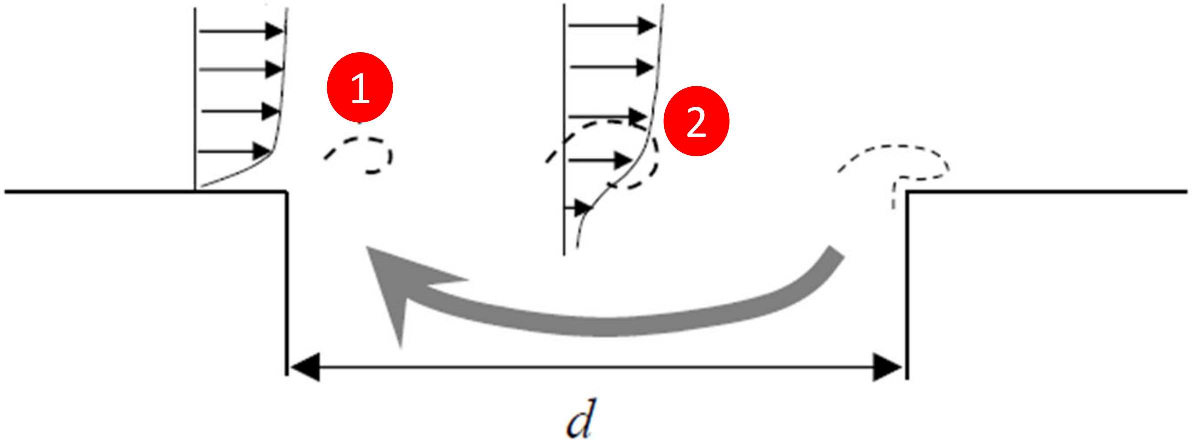
Deep cavity with small opening, $d > L > b$

(Blake [3])

Background Cavity Resonance

Fluid-resonator feedback loop:

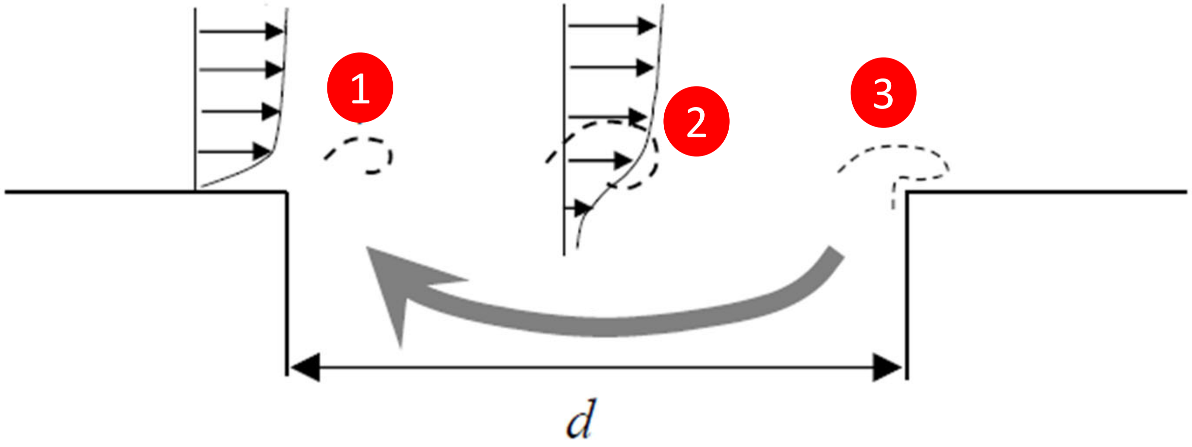
1. Upstream edge causes separation of a vortex
2. Vortex is amplified across the opening as it travels downstream



Background Cavity Resonance

Fluid-resonator feedback loop:

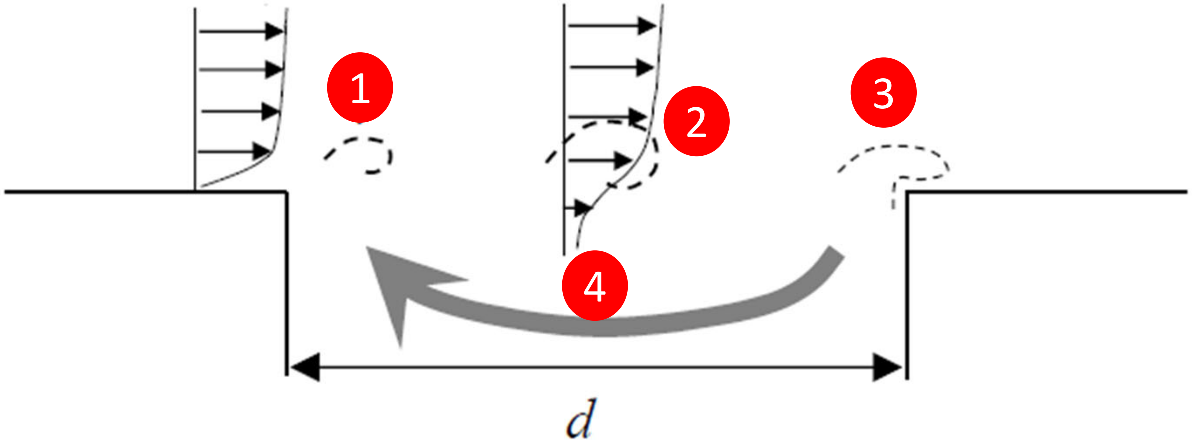
1. Upstream edge causes separation of a vortex
2. Vortex is amplified across the opening as it travels downstream
3. Vortex reaches the downstream edge and creates an unsteady pressure pulse.



Background Cavity Resonance

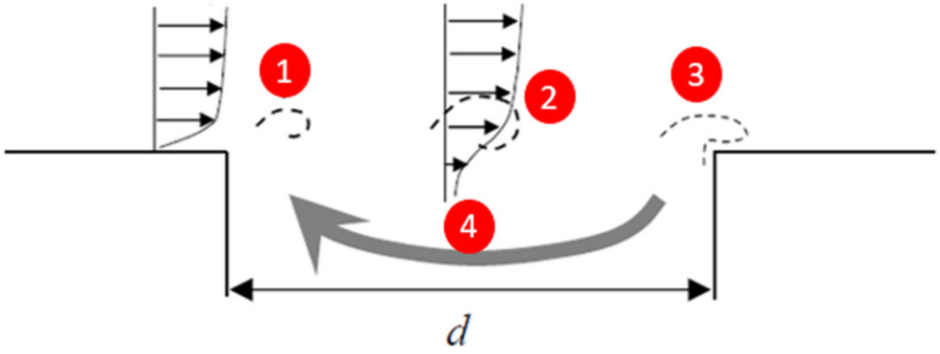
Fluid-resonator feedback loop:

1. Upstream edge causes separation of a vortex
2. Vortex is amplified across the opening as it travels downstream
3. Vortex reaches the downstream edge and creates an unsteady pressure pulse.
4. The pressure pulse propagates back upstream through the cavity and triggers a new vortex.



Background Cavity Resonance

- Tones frequency can be estimated using Rossiter modes
- ϕ phase correction
  - most flow tones, $\phi = \frac{\pi}{4}$
- $\gamma = \frac{\mathrm{U_c}}{\mathrm{U_0}}$
  - U_c – convection speed of vortex
  - U_0 – mean flow velocity

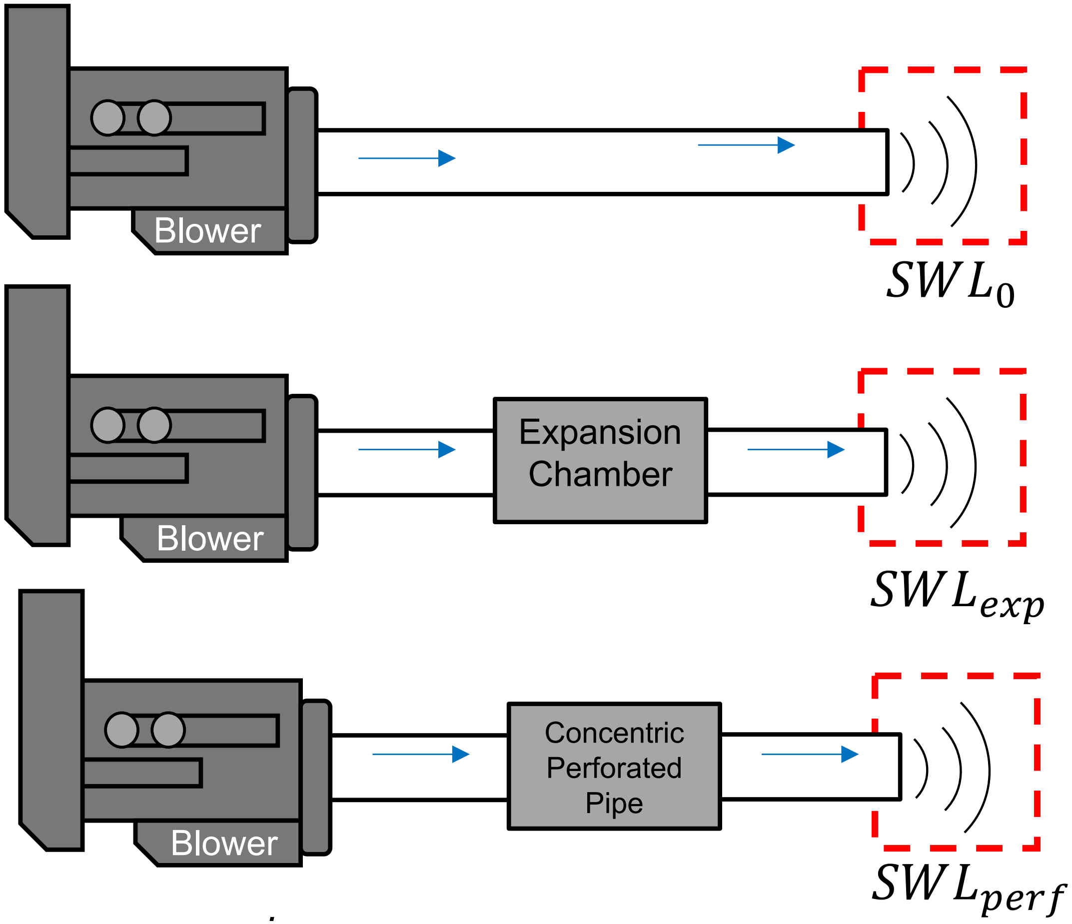


$$\frac{f_n d}{U_0} = \frac{n - {}^{\phi}/_{2\pi}}{{}^{1}/_{\gamma} + M}$$

$$n = 1,2,3, \ldots$$

Experimental Methods

- Additional flow noise generated by the perforated pipe determined using methods resembling insertion loss measurement.
- Straight pipe and simple expansion chamber are the baseline references.



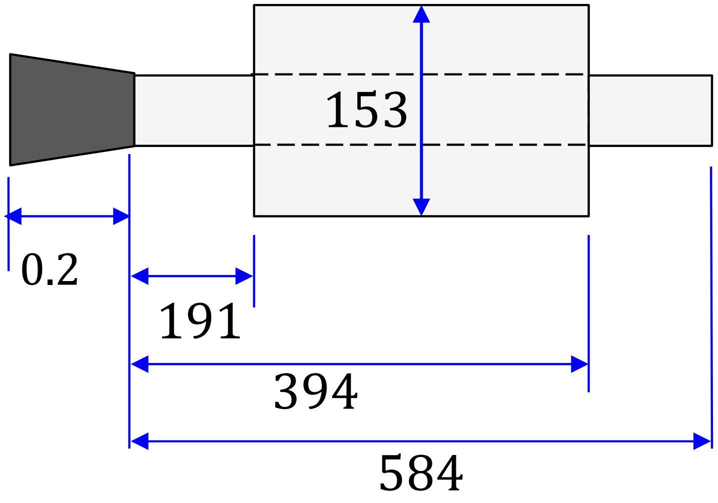
$$IL_{flow}^{pipe}(dB) = SWL_0 - SWL_{perf}$$

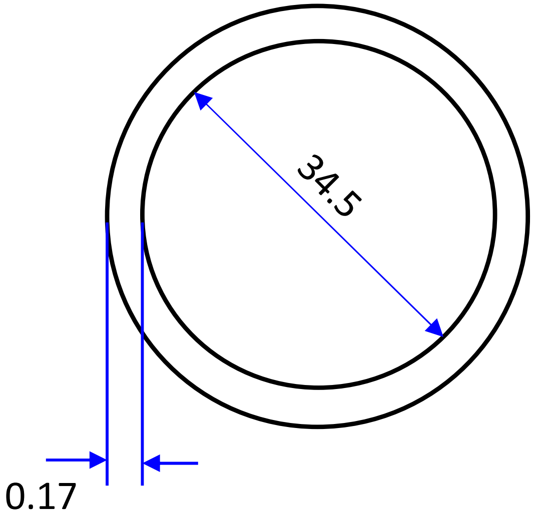
$$IL_{flow}^{exp}(dB) = SWL_{exp} - SWL_{perf}$$

Experimental Methods Test Cases

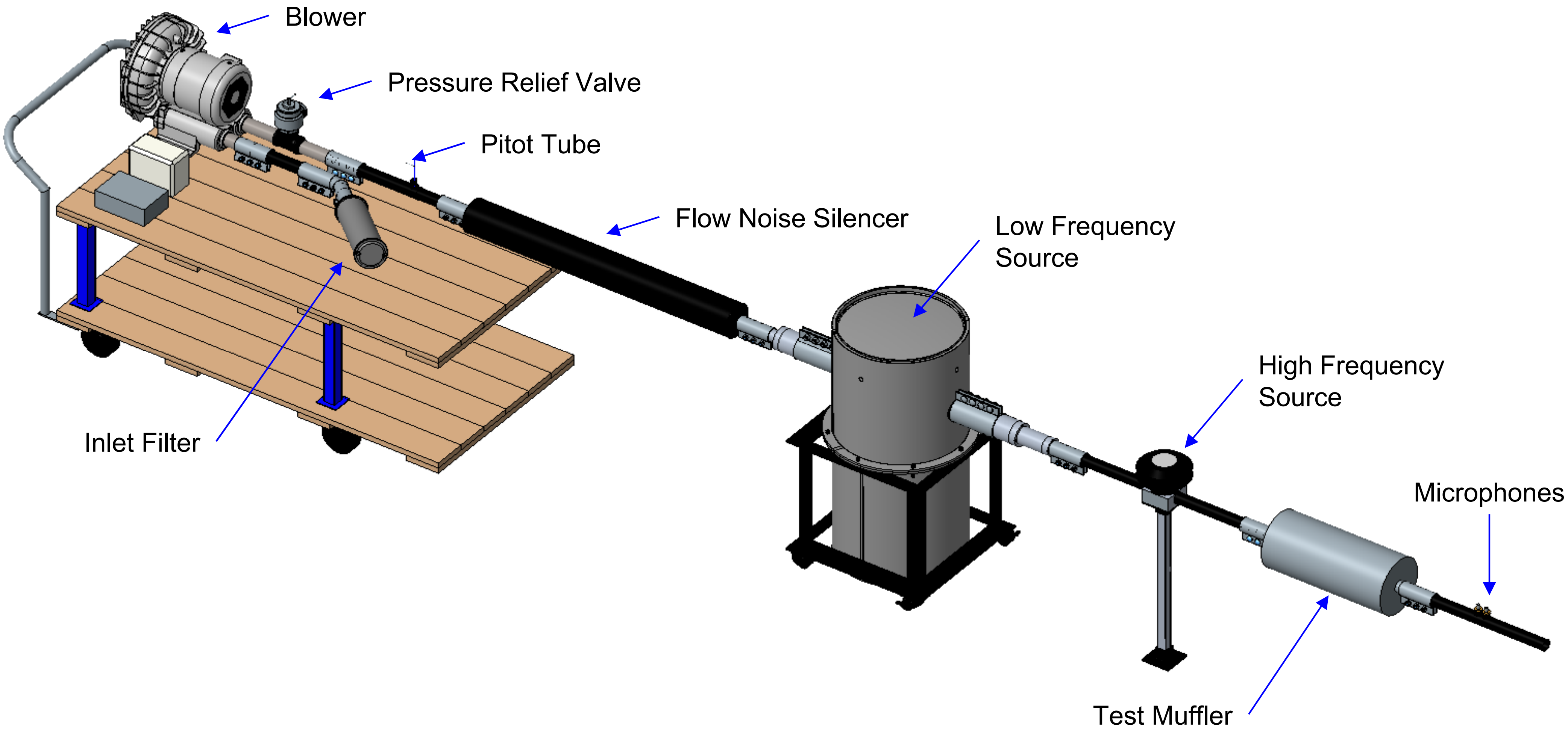
Case	Description	Hole Pattern	Hole Diameter (mm)	Grid Spacing (mm)	OA (%)
1	Straight Pipe	N/A	N/A	N/A	N/A
2	Expansion Chamber	N/A	N/A	N/A	N/A
3	Perf 1	Square	4.7	17.2	6
4	Perf 2	Square	3.2	20.2	2
5	Perf 3	Square	3	9.5	8
6	Perf 4	Square	3	6	20
7	Perf 5	Square	3.5	4.6	45
8	Perf 6	Hex	0.8	4.2	3

Mach Number	Velocity (m/s)
0.1	34.3
0.12	41.2
0.14	48.0
0.16	54.9
0.18	61.7
0.2	68.6
0.22	75.5
0.24	82.3
0.26	89.2
0.28	96.0

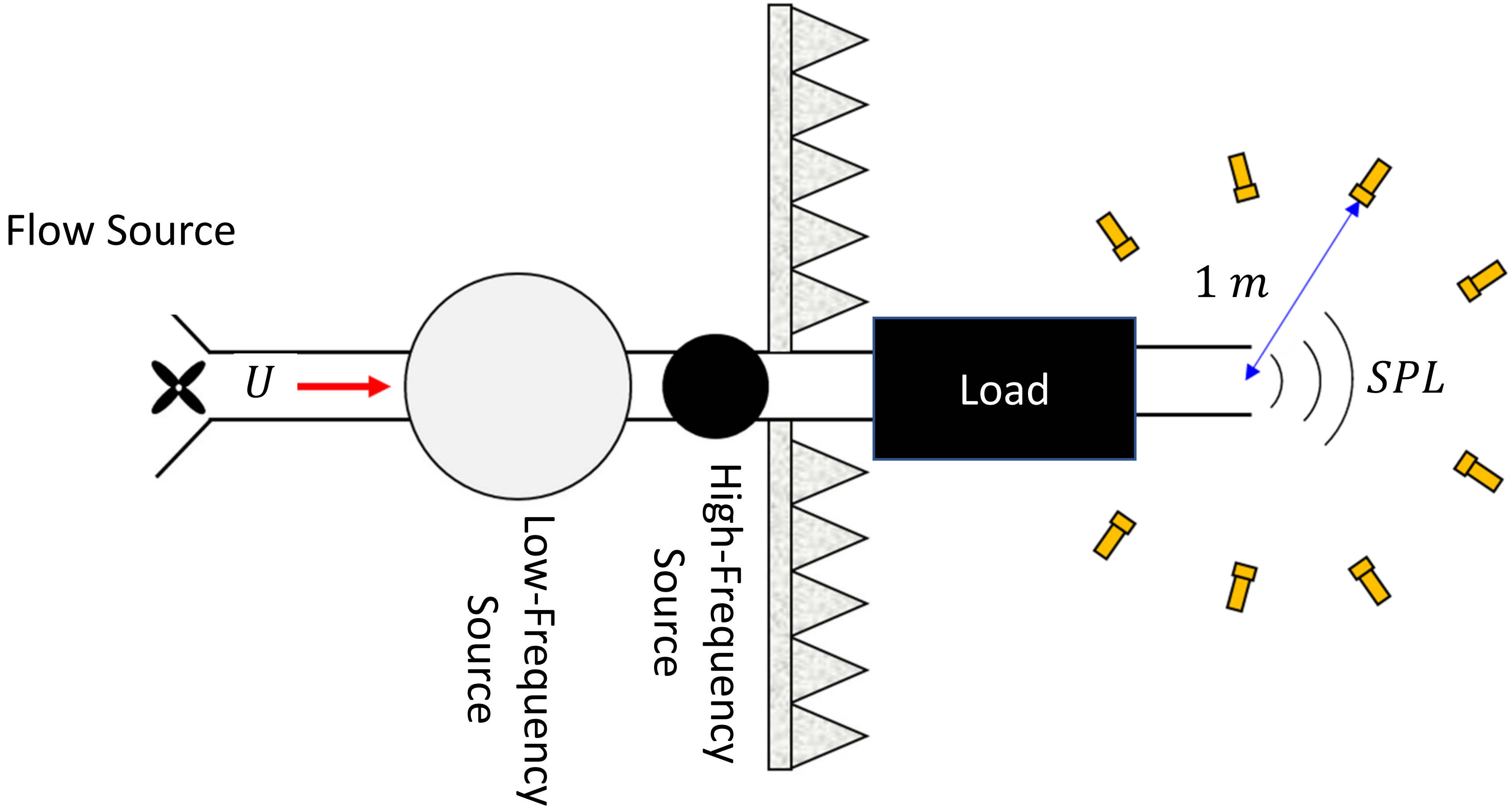




Experimental Methods Measurement Rig

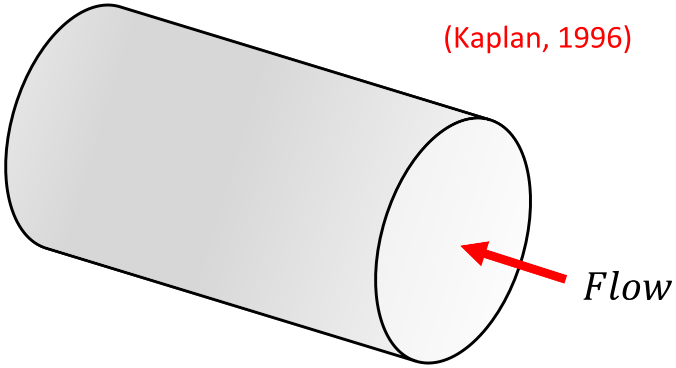


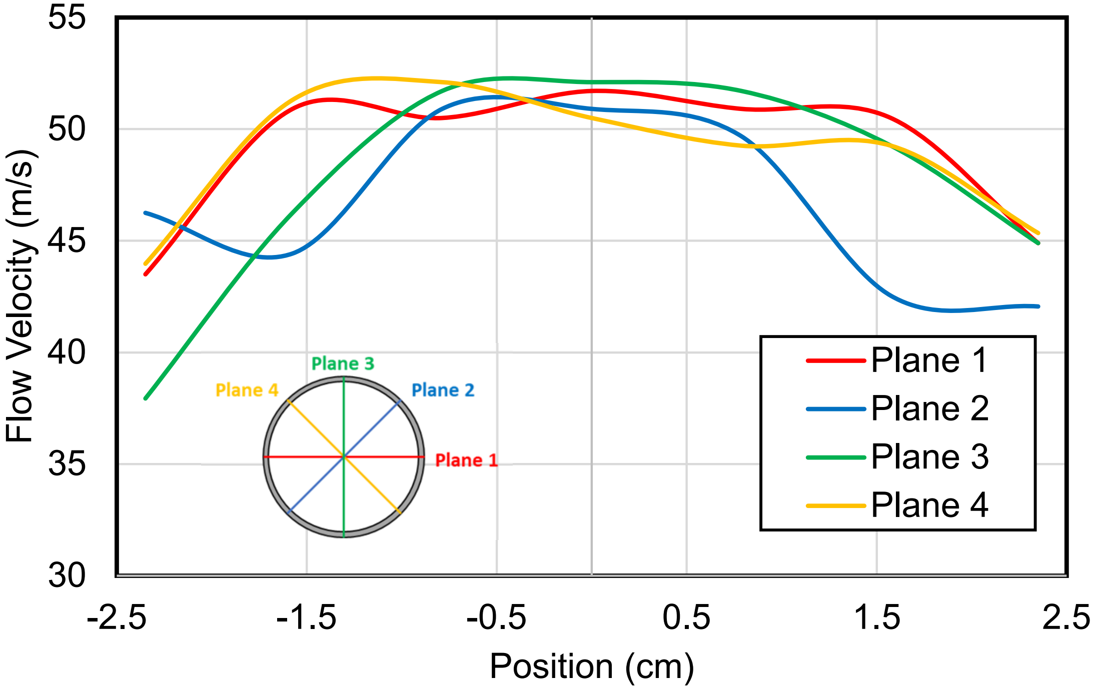
Experimental Methods Measurement Rig



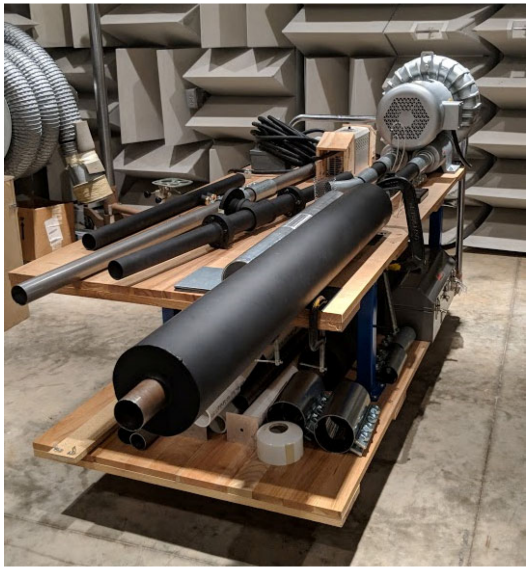
Experimental Setup Flow Source

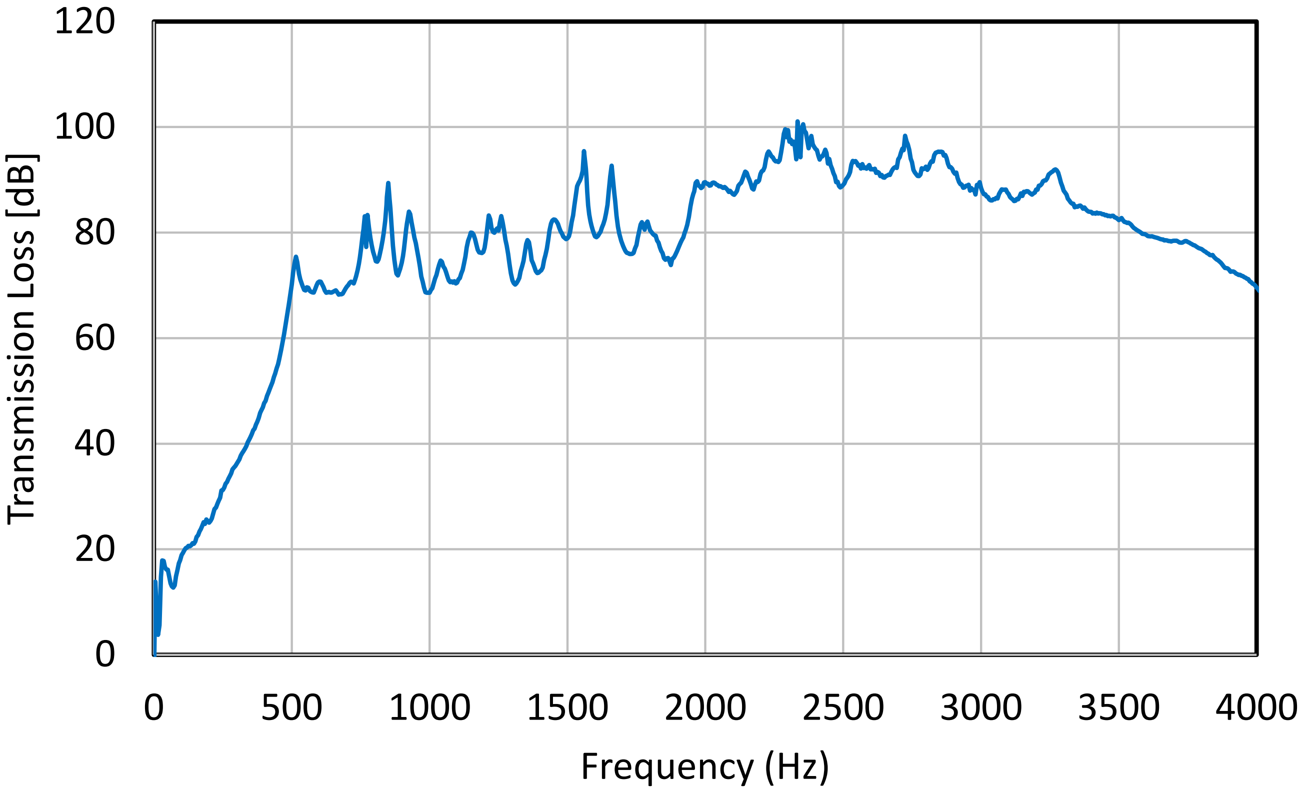
Flow Conditioner



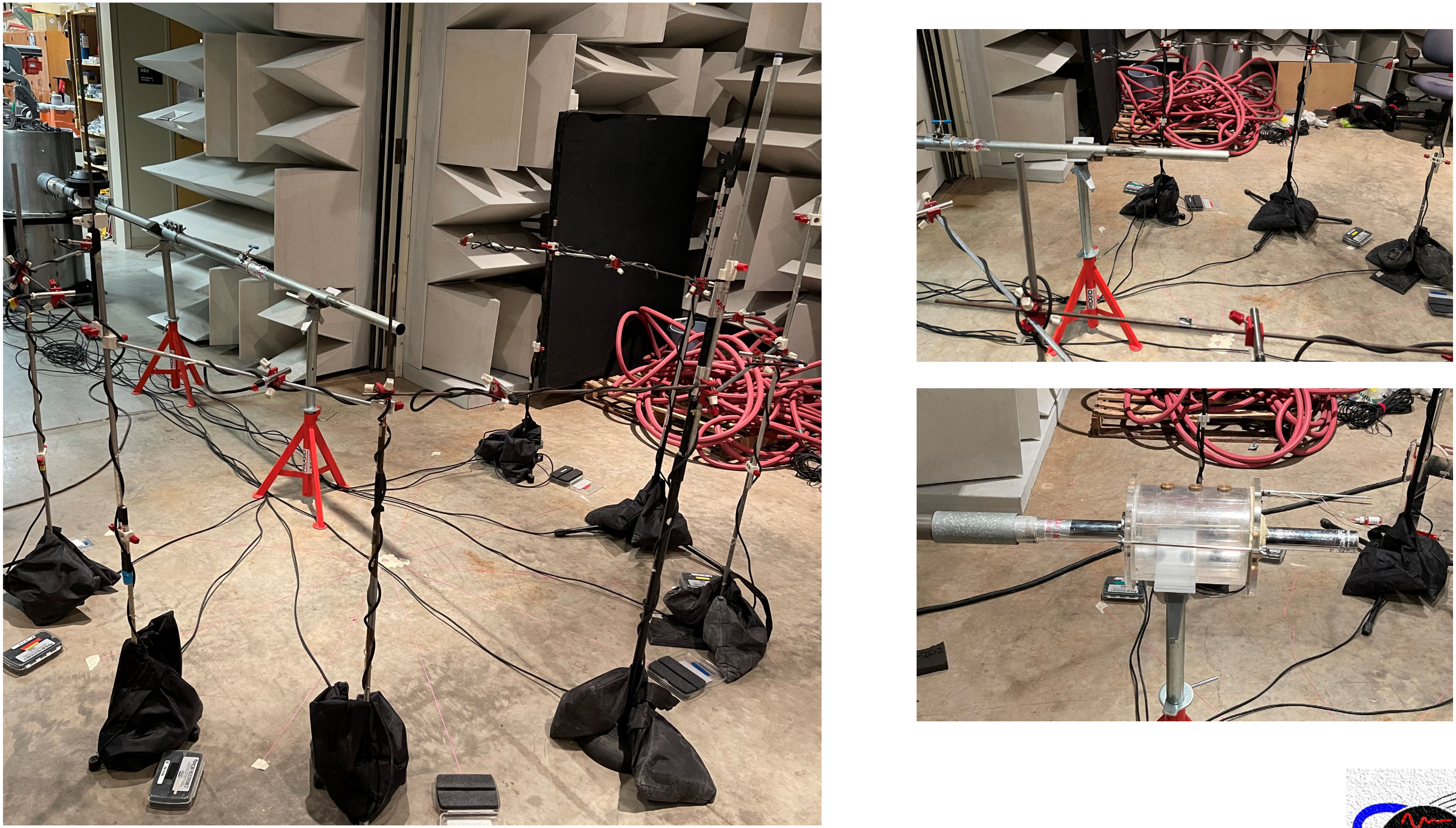


Experimental Setup Blower Silencer



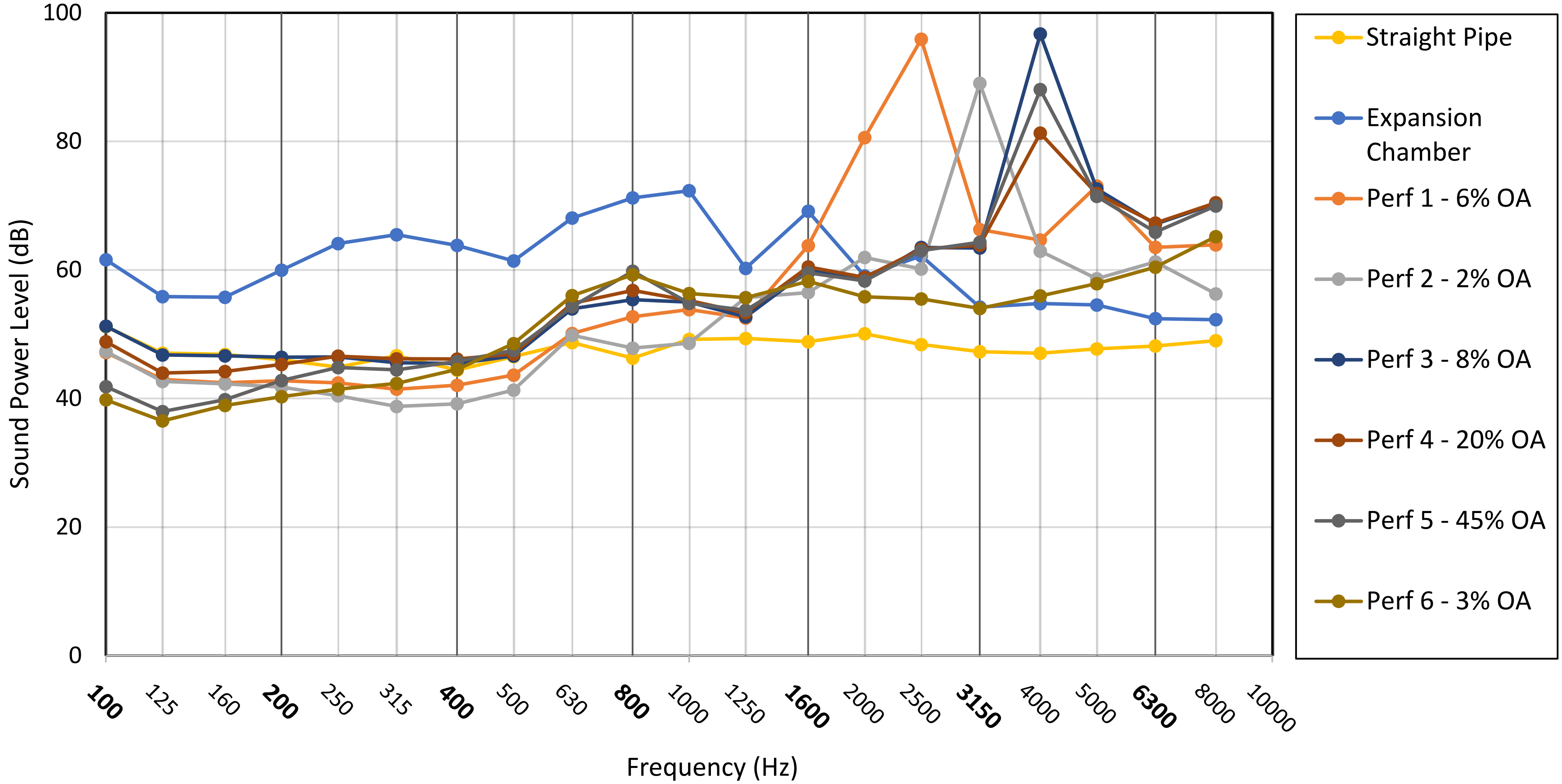


Experimental Setup

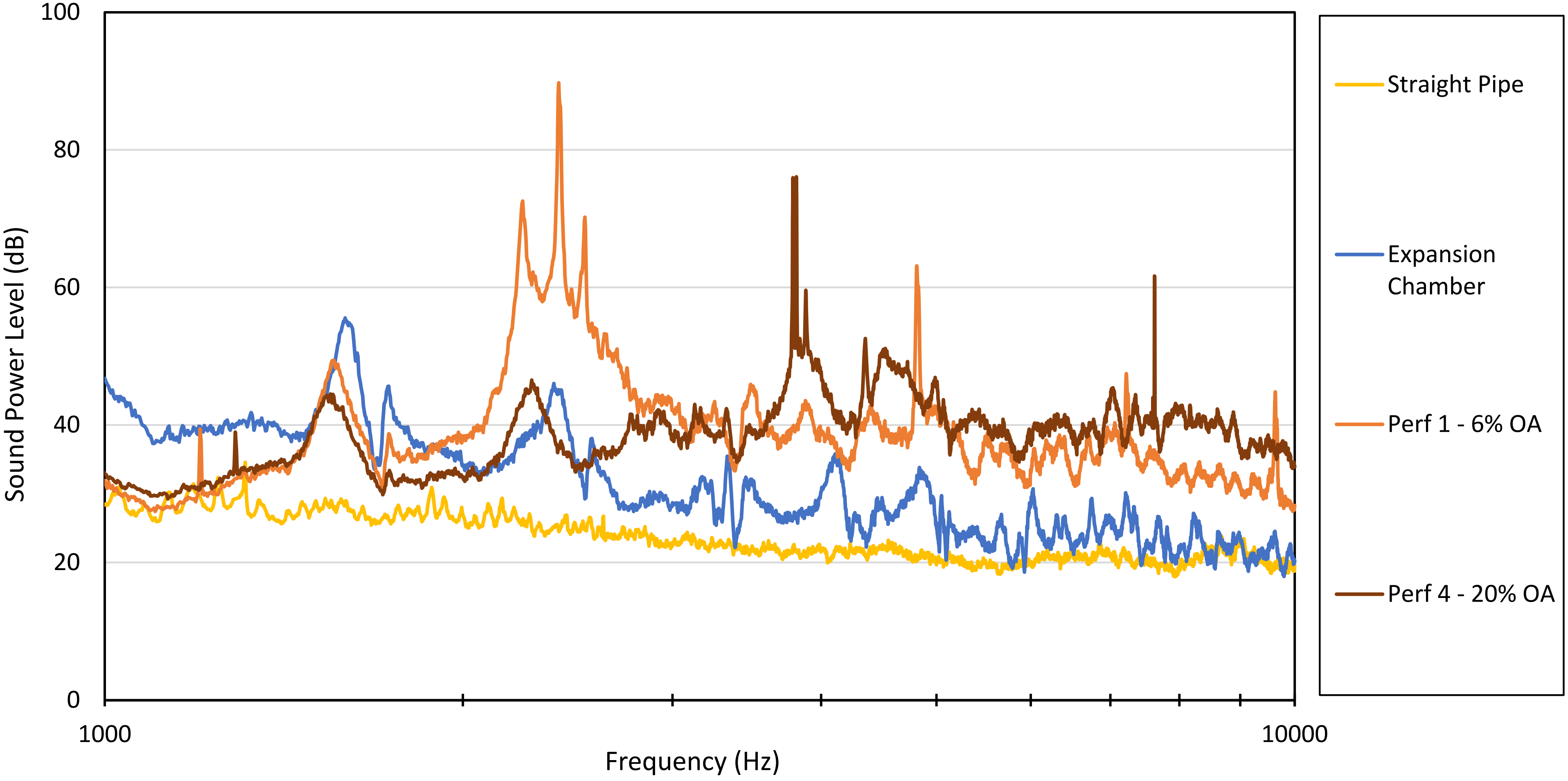


Experimental Setup

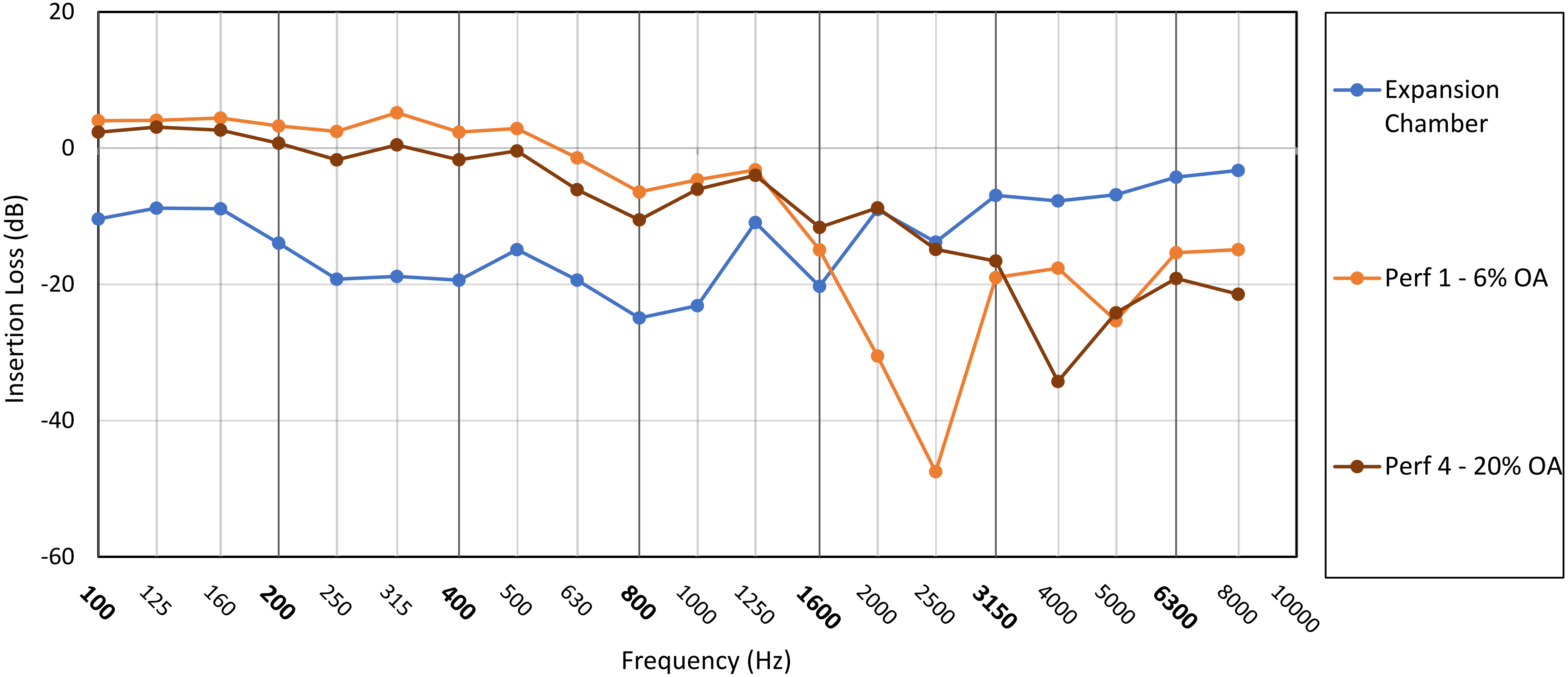
Results SWL Mach 0.14



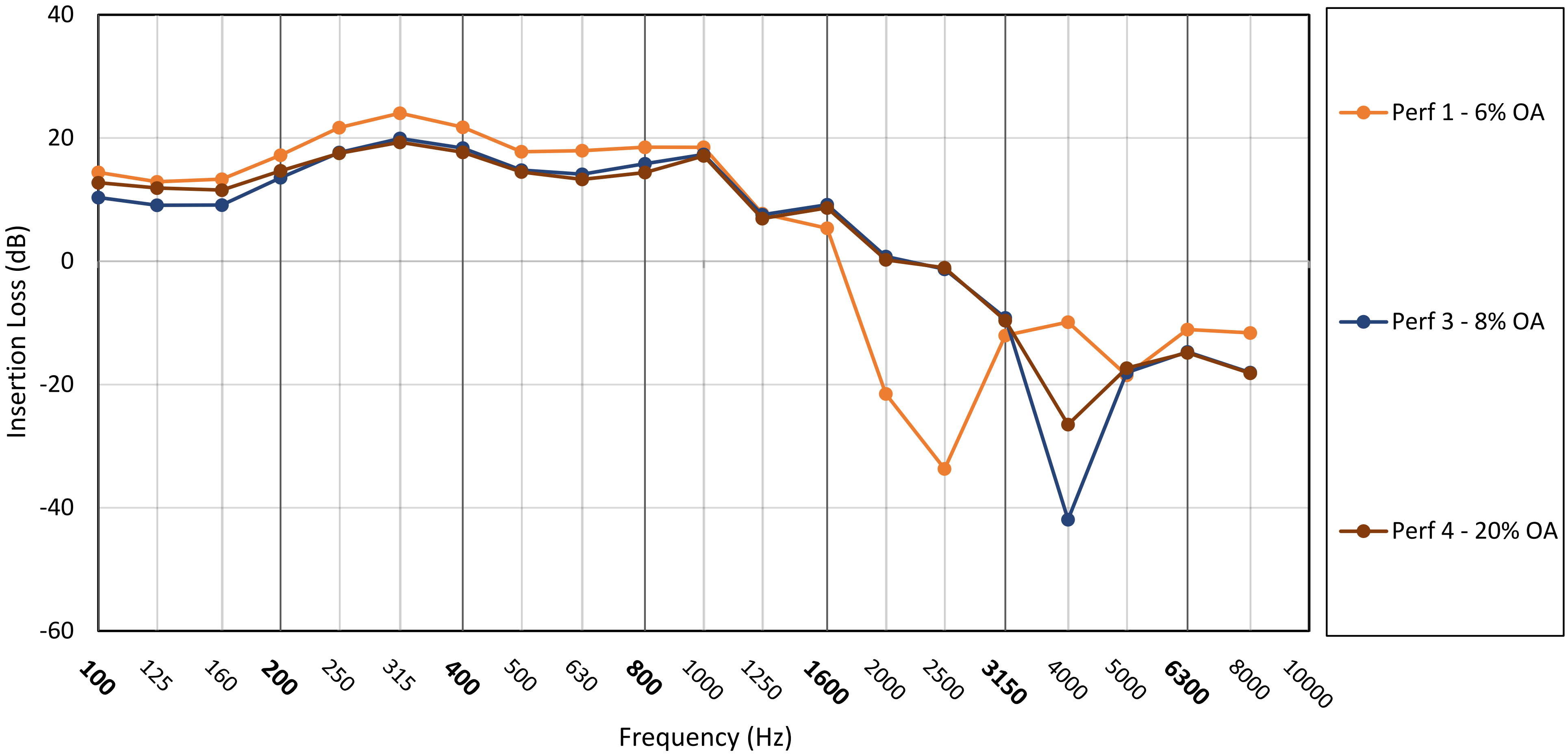
Results SWL Mach 0.14



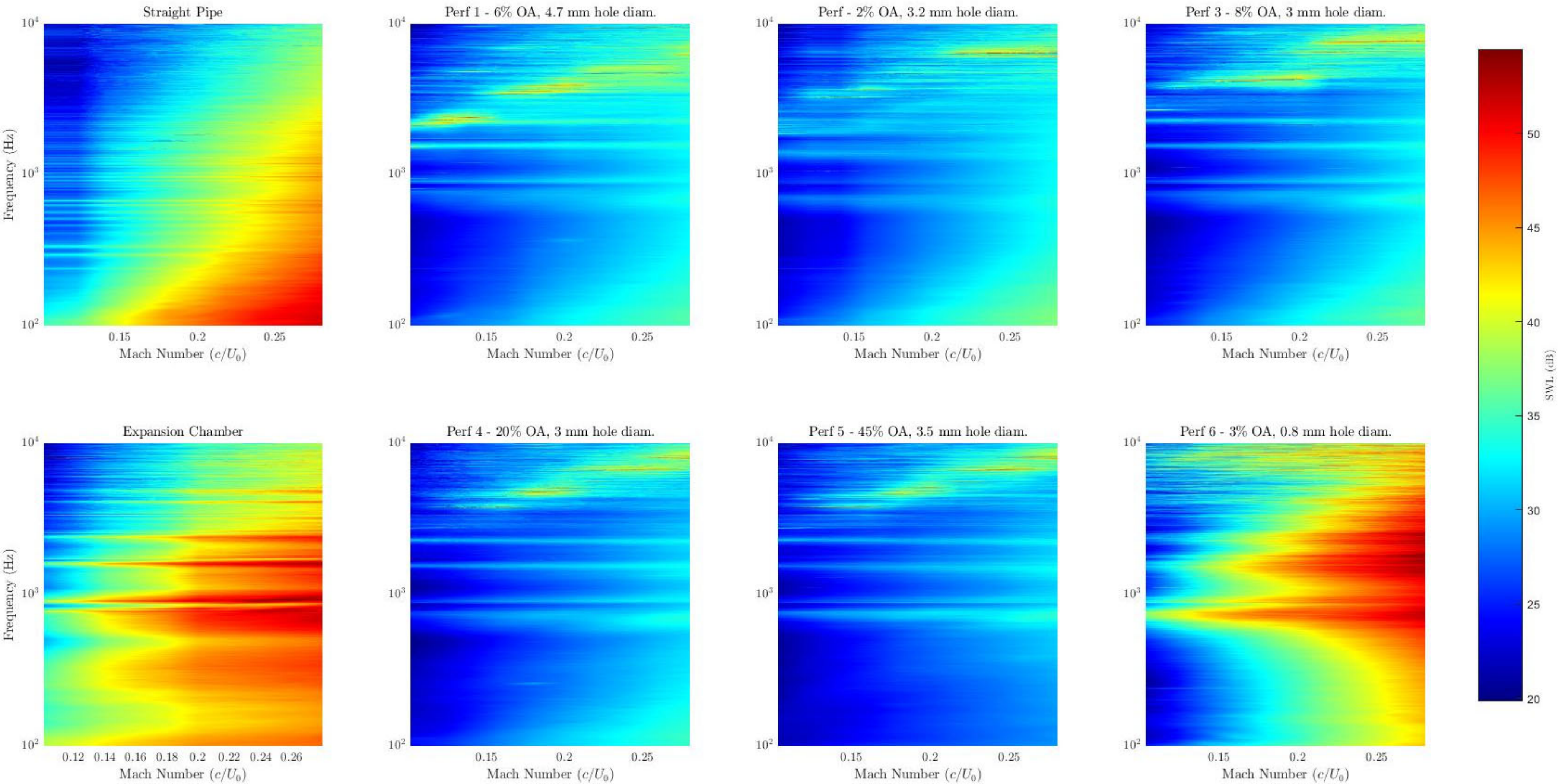
Results Insertion loss Mach 0.14 – Ref. Straight Pipe



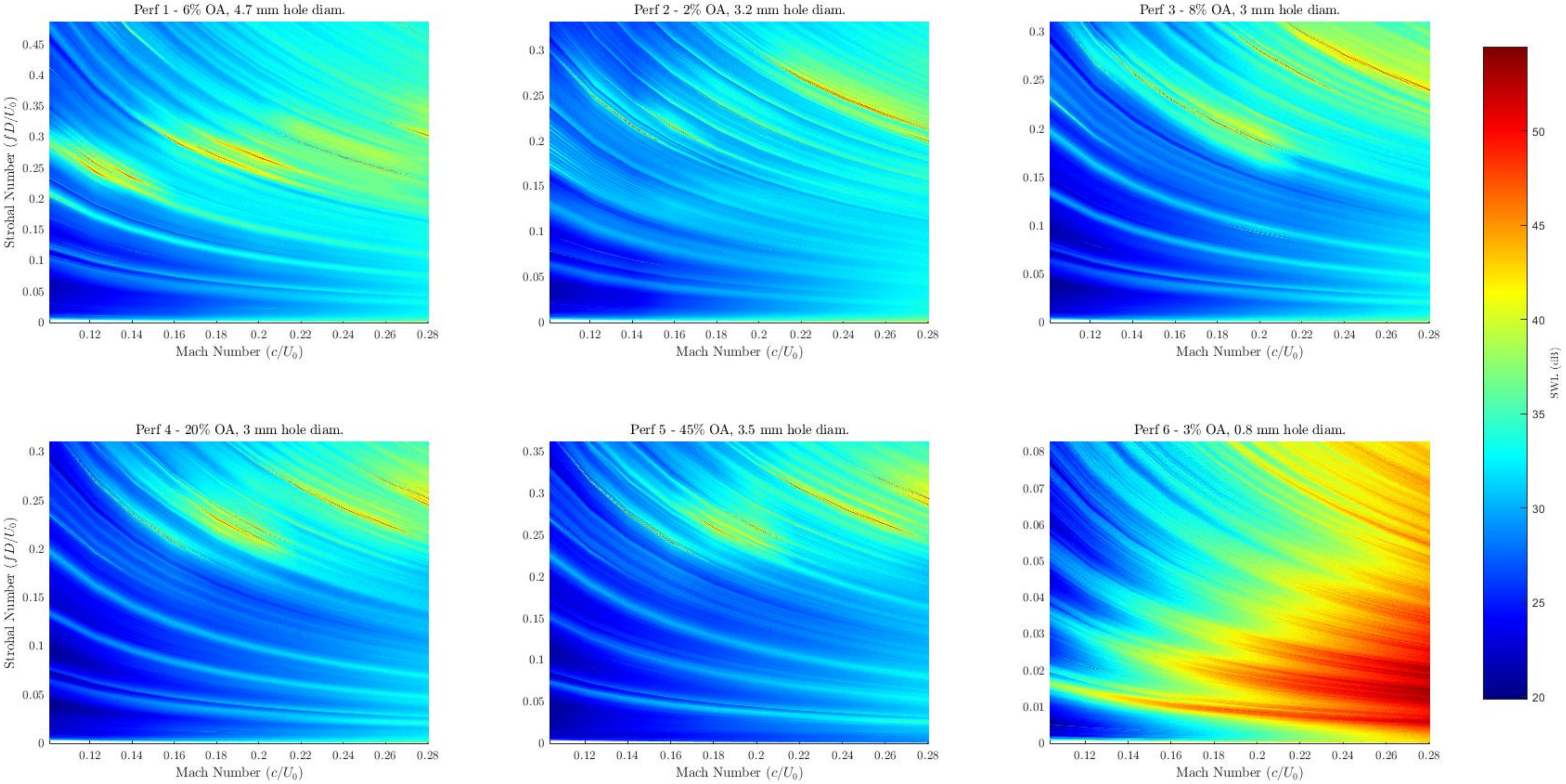
Results Insertion loss Mach 0.14 – Ref. Expansion Chamber



Results Mach Number vs Frequency of Tone



Results Mach Number vs Strouhal Number


Perf 1 - 6% OA, 4.7 mm hole diam.

Perf 2 - 2% OA, 3.2 mm hole diam.

Perf 3 - 8% OA, 3 mm hole diam.

Perf 4 - 20% OA, 3 mm hole diam.

Perf 5 - 45% OA, 3.5 mm hole diam.

Perf 6 - 3% OA, 0.8 mm hole diam.

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Next Steps

- Measure pressure drop for all cases.
- Check for repeatability of measurements by repeating at least one more time.
- Test methods for modifying perforation to control the generated flow noise on Perf. 1.
- Check for impacts on mufflers performance with modifications to perforation.

References

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Overview

1. Background on perforate tubes in mufflers and silencers
2. Background on flow noise and cavity resonances
3. Experimental approach
4. Measurement Setup
5. Results
6. Next steps