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Study of an Axial Fan Combined with a Microperforated Duct

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INTER-NOISE 15, SAN FRANCISCO, USA

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Acknowledgement

- **3M Company, USA**

  - **The authors acknowledge the support of 3M Corporation through the provision of materials for the fan noise experiments and for the financial support of this work.**

Objective

- Two main fan types of HVAC

	Noise Level	Air Volume	Static Pressure
Axial Fans	Low	High	Low
Centrifugal Fans	High	Low	High

- By adopting the microperforated duct for the HVAC system using an axial fan, it is expected to have benefits in the reduction of noise level while maintaining similar volume flow rate performance and static pressure capabilities of the impermeable duct.

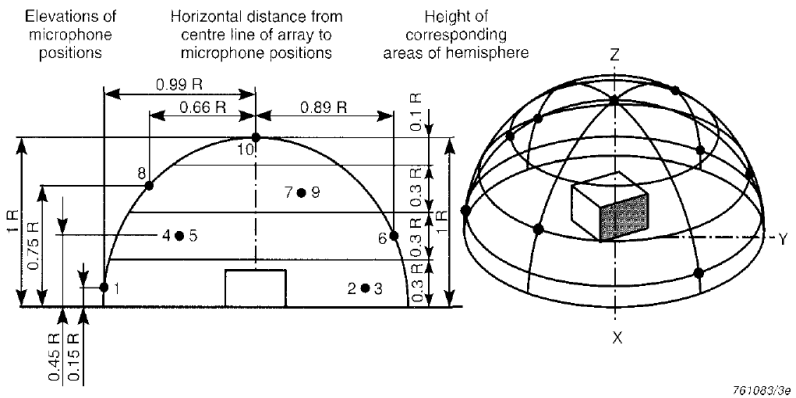
- **Noise reduction performance of the microperforated duct will be studied experimentally by measuring the sound power radiated from the ducted fan.**

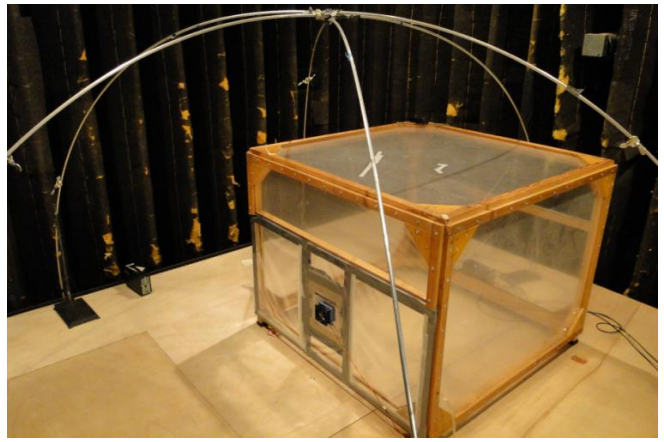
- **Sound field around the microperforated ducted fan will be visualized by using the nearfield Acoustic Holography method.**

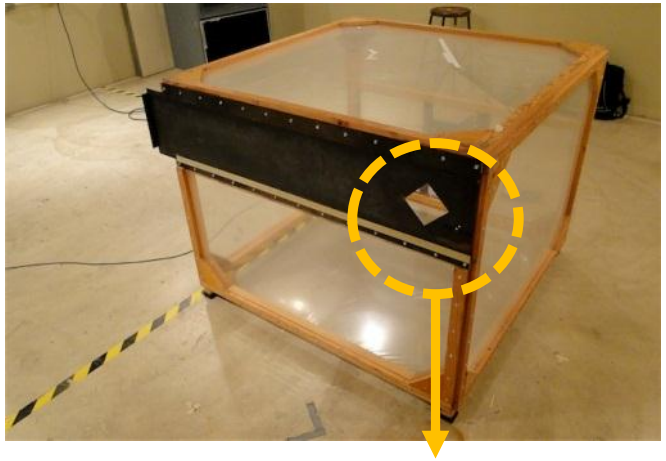
Experimental setup

9-12 AUGUST 2015
inter.noise 2015
SAN FRANCISCO, CALIFORNIA USA

Hemispherical Frame Configuration for Sound Power Level measurement.

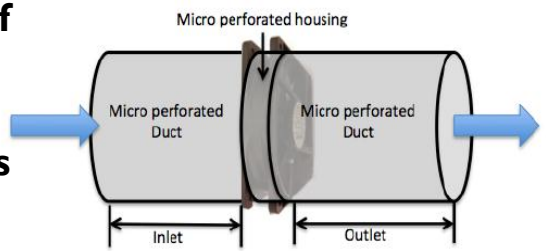






Controllable opening

- Plenum designed based on ISO 10302.
- The test plenum is intended for measuring the flow rate and the fan static pressure.
- 10 Microphone positions on equal areas on the surface of a hemisphere to measure sound power. [ISO 3744]
- Radius of hemispherical frame is 5.5 ft.
- Test equipment including the hemispherical frame was set up in the anechoic chamber at Herrick Laboratories.



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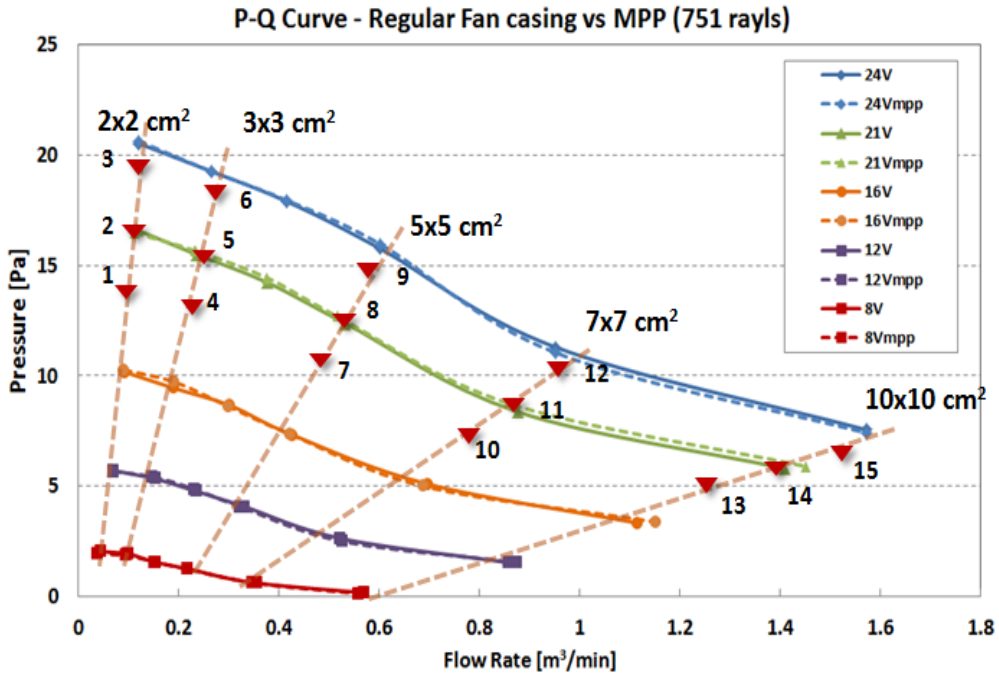
P-Q curve and operating points

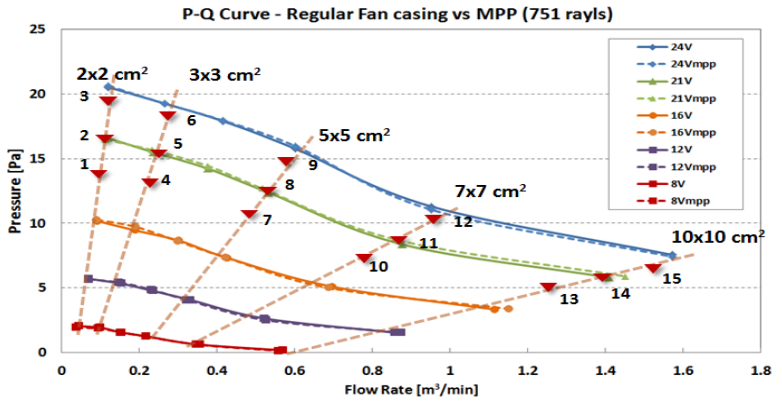


- **Fan operation condition for comparison**
  - ✓ Rotation speed was controlled by giving different input voltage 19V, 21V and 23V of input voltage
  - ✓ Flow exit area was varied from 2 x 2 to 10 x10 cm²

Pt.	Pressure [Pa]	Opening Area [cm²]	Flow Rate [m³/min]	Flow Vel. [m/s]	Rotation Speed [RPM]
1	12.0	2x2	0.1	3.8	1474.7
2	15.2	2x2	0.1	4.6	1599.3
3	17.8	2x2	0.1	5.4	1716.7
4	11.9	3x3	0.2	3.7	1492.7
5	14.1	3x3	0.2	4.1	1618.7
6	16.4	3x3	0.2	4.4	1736.7
7	9.5	5x5	0.4	2.8	1542.7
8	11.6	5x5	0.5	3.4	1676.0
9	13.4	5x5	0.6	3.9	1806.0
10	6.7	7x7	0.8	2.7	1606.0
11	8.2	7x7	0.9	2.9	1748.0
12	9.2	7x7	1.0	3.3	1882.0
13	4.5	10x10	1.3	2.2	1580.7
14	5.4	10x10	1.4	2.4	1712.0
15	6.3	10x10	1.6	2.6	1850.0

Testing procedures

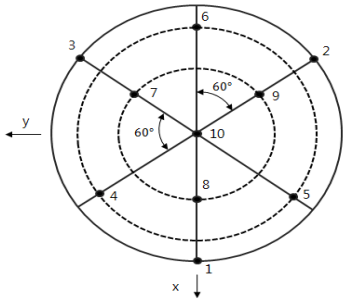
1. **Operate a fan at different operating conditions selected from the fan's performance curve.**



2. **Measure the signals at the surface of hemispherical array.**

Position #	z-dir.	Position #	z-dir.
1	0.15 R	6	0.45 R
2	0.15 R	7	0.75 R
3	0.15 R	8	0.75 R
4	0.45 R	9	0.75 R
5	0.45 R	10	1 R

R: Radius of Hemispherical frame



3. **Calculate sound power level according to ISO 3744**

$$L_w = L_p + 10\log_{10}\frac{S}{S_{ref}}$$

L_p : Space – averaged sound pressure level

S_{ref} : Reference area, 1 m²

S : Surface area of the hemisphere

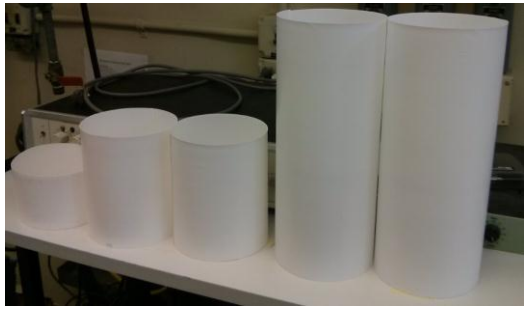
Duct dimensions and material properties

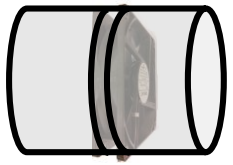
❑ Duct Lengths

	Inlet Length [cm]	Outlet Length [cm]	Total Length [cm]
Duct Short	6.00	6.00	12.0
Duct Long	27.8	27.8	55.6

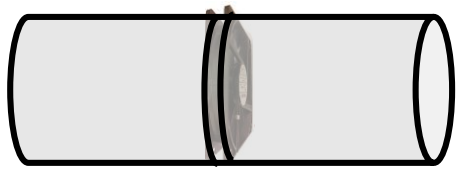
❑ MPP properties

	Hole Diameter [μm]	Thickness [m]	Flow Resistance [Rayls]
MPP 751	150.50	0.00035	751





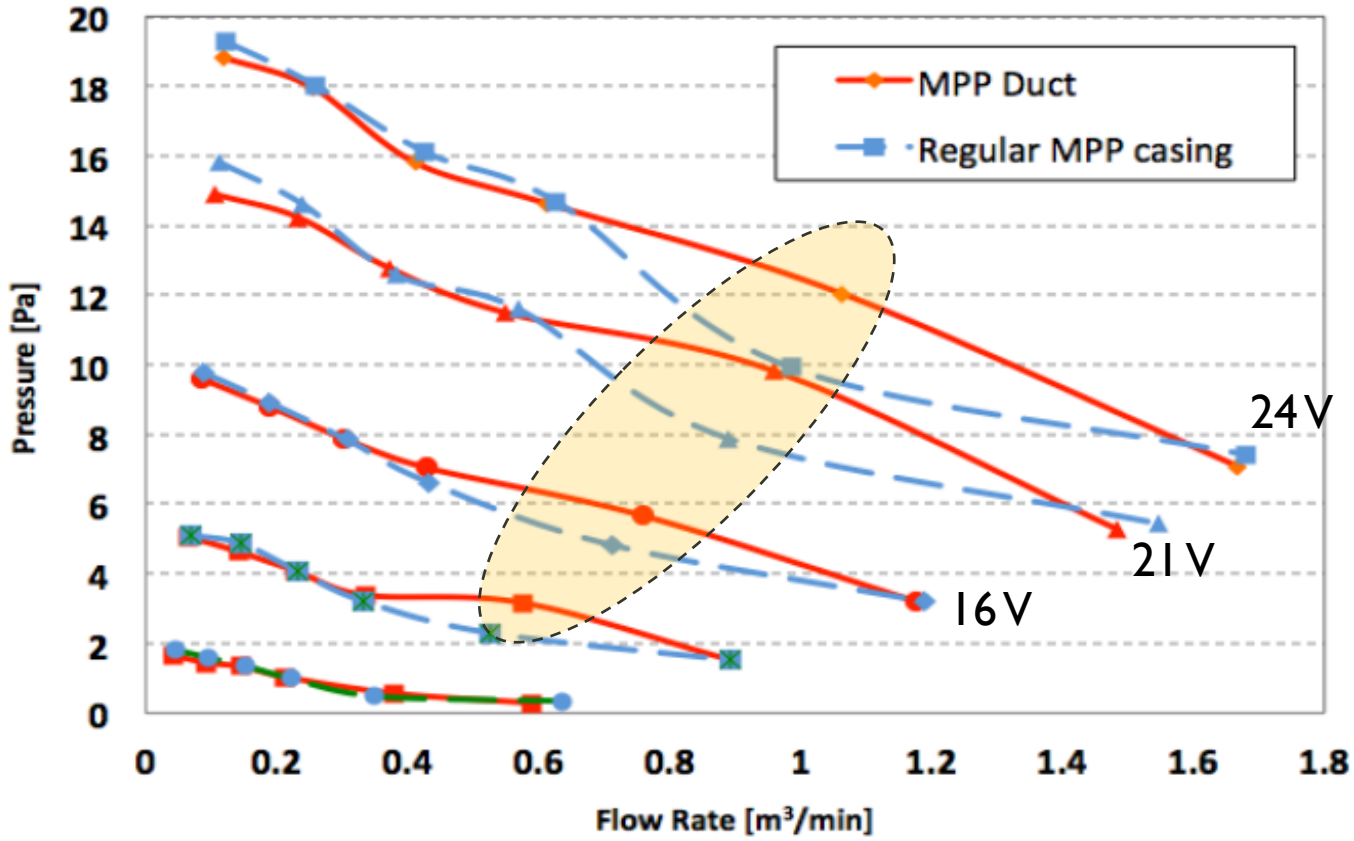
Duct Short MPP 751



Duct Long MPP 751

Performance of extended housing

P-Q Curve – MPP (751 Rayls) Duct Casing vs MPP (751 Rayls) Regular Fan



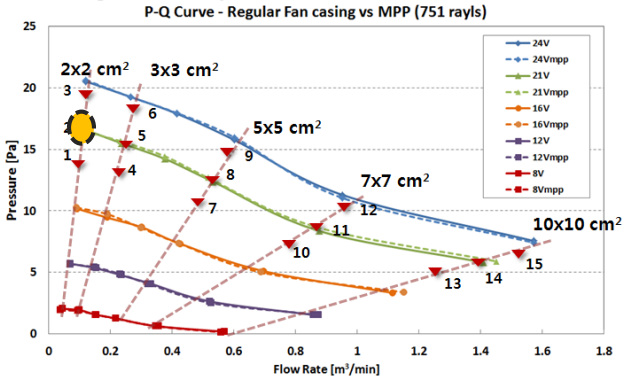
- MPP duct casing generates more static pressure and flow rate at less operating voltage!!
- Regular MPP casing results were from Noise-con 13, Denver, CO, USA

Short ducts test results

- Comparison

Duct short Not-Perf. | **Duct short MPP 751**

- Operating Point



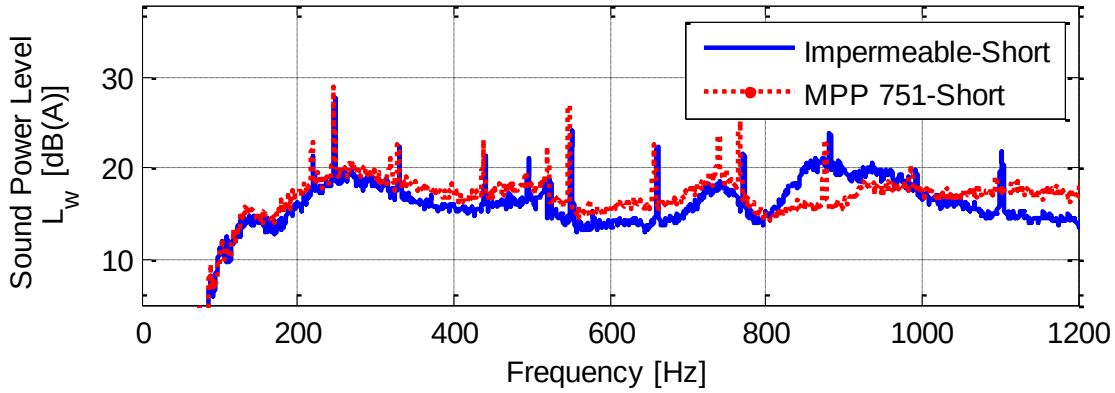
- Blade Passage Tone [dB(A)]

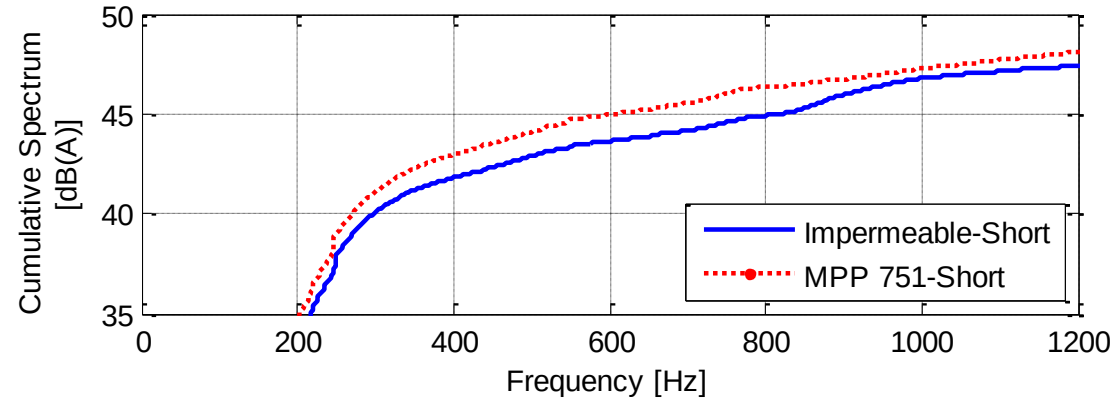
DUCT REG.	DUCT 751
27.7	29.0

- Overall Sound Power Level [dB(A)]

DUCT REG.	DUCT 751
50.4	51.1

Measurement at operating condition #2





Short ducts test results

❑ Blade passage tone levels comparisons at all operating points.

OP #	Blade Passage Tone Level [dBA]		OP #	Blade Passage Tone Level [dBA]		OP #	Blade Passage Tone Level [dBA]	
	Impermeable	MPP 751		Impermeable	MPP751		Impermeable	MPP751
1	23.5	24.9	6	30.6	30.8	11	32.3	32.6
2	27.7	29.0	7	25.7	23.0	12	34.4	33.5
3	29.2	31.6	8	28.8	26.4	13	33.0	33.5
4	25.6	24.6	9	30.7	29.1	14	37.6	37.5
5	27.8	28.7	10	28.5	29.2	15	38.4	39.4

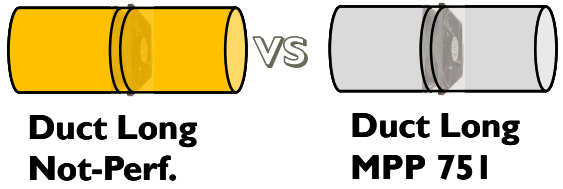
❑ Overall sound power levels comparisons at all operating points.

OP #	Overall Sound Power Level [dBA]		OP #	Overall Sound Power Level [dBA]		OP #	Overall Sound Power Level [dBA]	
	Impermeable	MPP 751		Impermeable	MPP751		Impermeable	MPP751
1	48.5	49.1	6	51.7	52.3	11	51.0	51.4
2	50.4	51.1	7	49.0	49.3	12	52.4	52.8
3	51.7	52.4	8	50.3	50.9	13	49.7	49.9
4	48.6	49.0	9	51.7	52.4	14	52.0	52.1
5	50.3	50.9	10	49.0	49.4	15	53.4	53.6

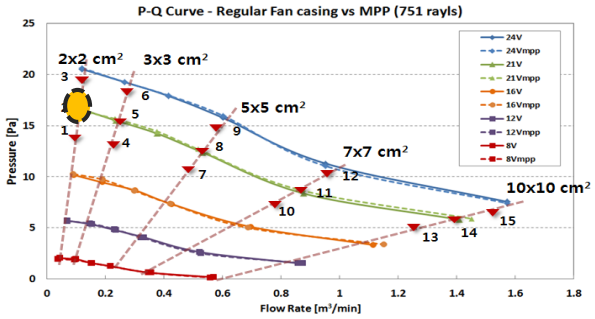
✓ Short microperforated duct does not have beneficial effects compare to impermeable duct.

Long ducts test results

- **Comparison**



- **Operating Point**

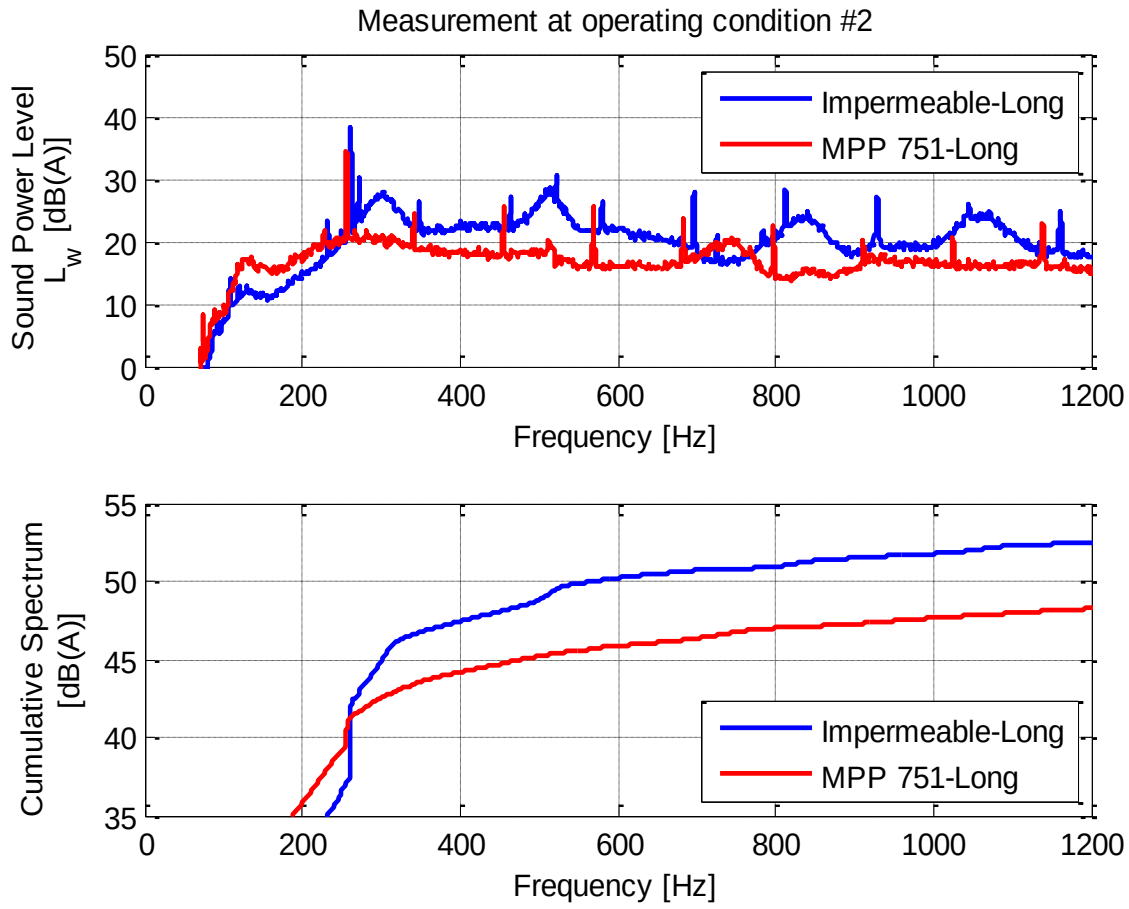


- **Blade Passage Tone [dB(A)]**

DUCT REG.	DUCT 751
38.3	34.4

- **Overall Sound Power Level [dB(A)]**

DUCT REG.	DUCT 751
53.8	50.7



Long ducts test results

❑ Blade passage tone levels comparisons at all operating points.

OP #	Blade Passage Tone Level [dBA]		OP #	Blade Passage Tone Level [dBA]		OP #	Blade Passage Tone Level [dBA]	
	Impermeable	MPP 751		Impermeable	MPP751		Impermeable	MPP751
1	30.4	29.7	6	45.6	36.3	11	33.1	30.4
2	38.3	34.3	7	29.9	26.4	12	39.7	35.2
3	43.6	37.2	8	37.8	32.0	13	27.7	25.7
4	30.4	28.3	9	43.6	35.8	14	32.3	29.6
5	39.8	33.0	10	25.3	25.3	15	36.1	31.6

❑ Overall sound power levels comparisons at all operating points.

OP #	Overall Sound Power Level [dBA]		OP #	Overall Sound Power Level [dBA]		OP #	Overall Sound Power Level [dBA]	
	Impermeable	MPP 751		Impermeable	MPP751		Impermeable	MPP751
1	54.9	48.9	6	56.1	52.1	11	54.3	52.8
2	53.8	50.7	7	53.4	49.6	12	56.6	54.5
3	55.9	52.1	8	52.8	50.9	13	51.0	48.3
4	57.3	48.9	9	55.0	52.8	14	52.9	52.5
5	53.5	50.6	10	59.8	54.1	15	54.1	53.9

✓ Long microperforated duct has beneficial effects compare to impermeable duct.

Pressure generated by the long ducts

- Pressures generated by the long ducted fan was measured with the micromanometer (Dwyer Model 1430) repeatedly and then the results were averaged.
- The accuracy of micromanometer : ± 0.06 Pa

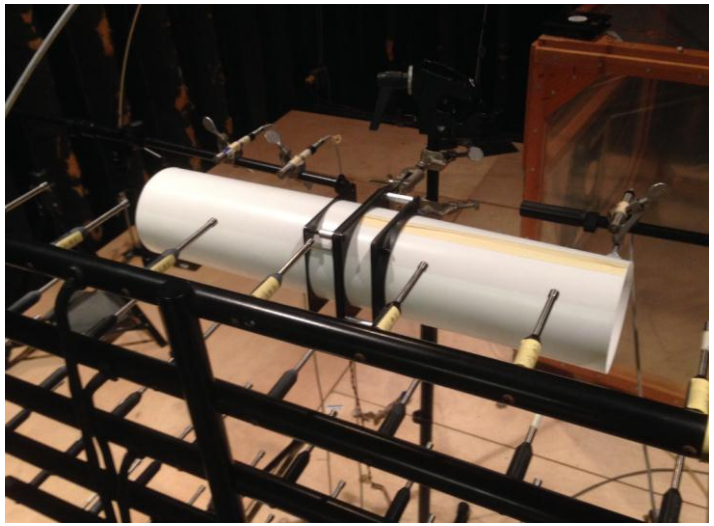
Short ducts comparison

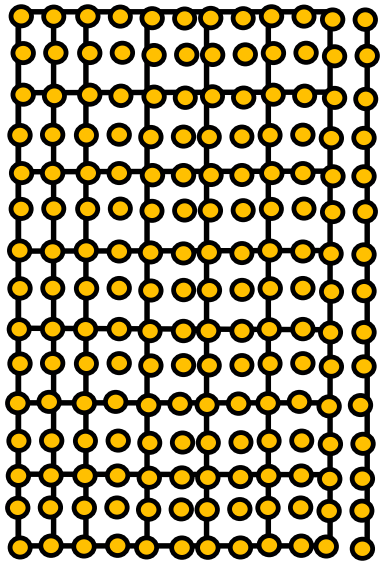
	REG [Pa]	Duct 751 [Pa]		REG [Pa]	Duct 751 [Pa]		REG [Pa]	Duct 751 [Pa]
1	11.3	11.8	6	15.8	16.4	11	9.7	9.8
2	14.8	15.8	7	7.9	8.9	12	10.8	10.8
3	17.3	17.5	8	10.8	11.8	13	4.1	4.1
4	10.8	10.8	9	12.8	13.5	14	5.1	5.1
5	13.8	13.8	10	6.9	6.9	15	6.0	6.0

Long ducts comparison

	REG [Pa]	Duct 751 [Pa]		REG [Pa]	Duct 751 [Pa]		REG [Pa]	Duct 751 [Pa]
1	9.8	10.3	6	14.4	14.9	11	8.8	9.0
2	12.8	13.2	7	8.2	8.5	12	10.6	10.8
3	15.1	15.8	8	10.9	11.3	13	4.1	4.1
4	9.2	9.8	9	12.8	13.3	14	5.5	5.7
5	12.1	12.8	10	6.5	6.8	15	6.8	7.0

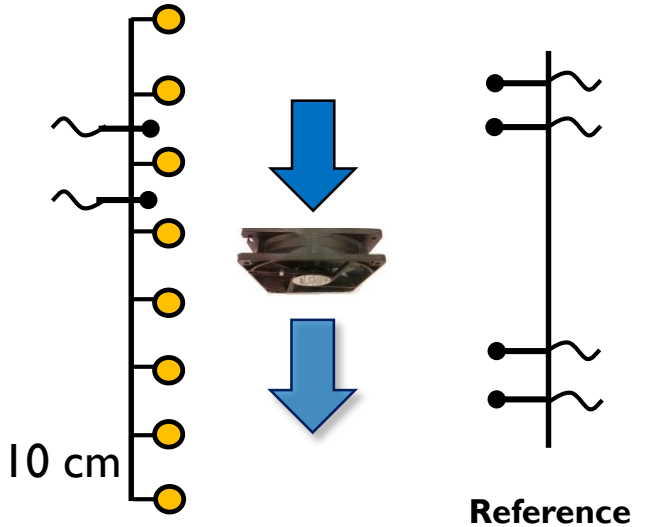
Noise Field Studies – Nearfield Acoustic Holography





Side-View

16 x 12 Microphone Array



Top-View

Reference Microphones

- Distance between the array microphones were filled by physical interpolation of the array.

Multi-reference Nearfield Acoustic Holography procedure

1. Measure the pressure field with array Microphones.

$$\mathbf{p} = \mathbf{H}_{pr}\mathbf{r}$$

$$\underbrace{\begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_N \end{bmatrix}}_{\mathbf{p}} = \underbrace{\begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1M} \\ h_{21} & h_{22} & \cdots & h_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N1} & h_{N2} & \cdots & h_{NM} \end{bmatrix}}_{\mathbf{H}_{pr}} \underbrace{\begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_M \end{bmatrix}}_{\mathbf{r}}$$

N: Number of signals on the measurement surface
M: Number of reference signals

2. Cross-spectra between measurement surface and reference signals

$$\mathbf{S_{pr}} = \mathbf{pr}^{\mathbf{H}} = \mathbf{H}_{pr}\mathbf{S}_{rr}$$

3. Decompose reference cross-spectra $\mathbf{S}_{rr}$ using Singular Value Decomposition method

$$\mathbf{S}_{rr} = \mathbf{V}\sum\mathbf{V}^{\mathbf{H}} \qquad \mathbf{V}: \text{Unitary matrix}$$

$$\mathbf{H}_{pr} = \mathbf{S}_{rp}^{\mathbf{H}}\mathbf{V}\sum^{-1}\mathbf{V}^{\mathbf{H}} \rightarrow \mathbf{S}_{pp} = \mathbf{H}_{pr}\mathbf{S}_{rp} = \mathbf{H}_{pr}\mathbf{S}_{rr}\mathbf{H}_{pr}^{\mathbf{H}}$$

4. Partial field

$$\mathbf{p} = \mathbf{H}_{pr}\mathbf{V}\sum^{1/2} = \mathbf{S}_{rp}^{\mathbf{H}}\mathbf{V}\Sigma^{-1/2}$$

5. Planar Nearfield Acoustic Holography method & Wavenumber filtering applied

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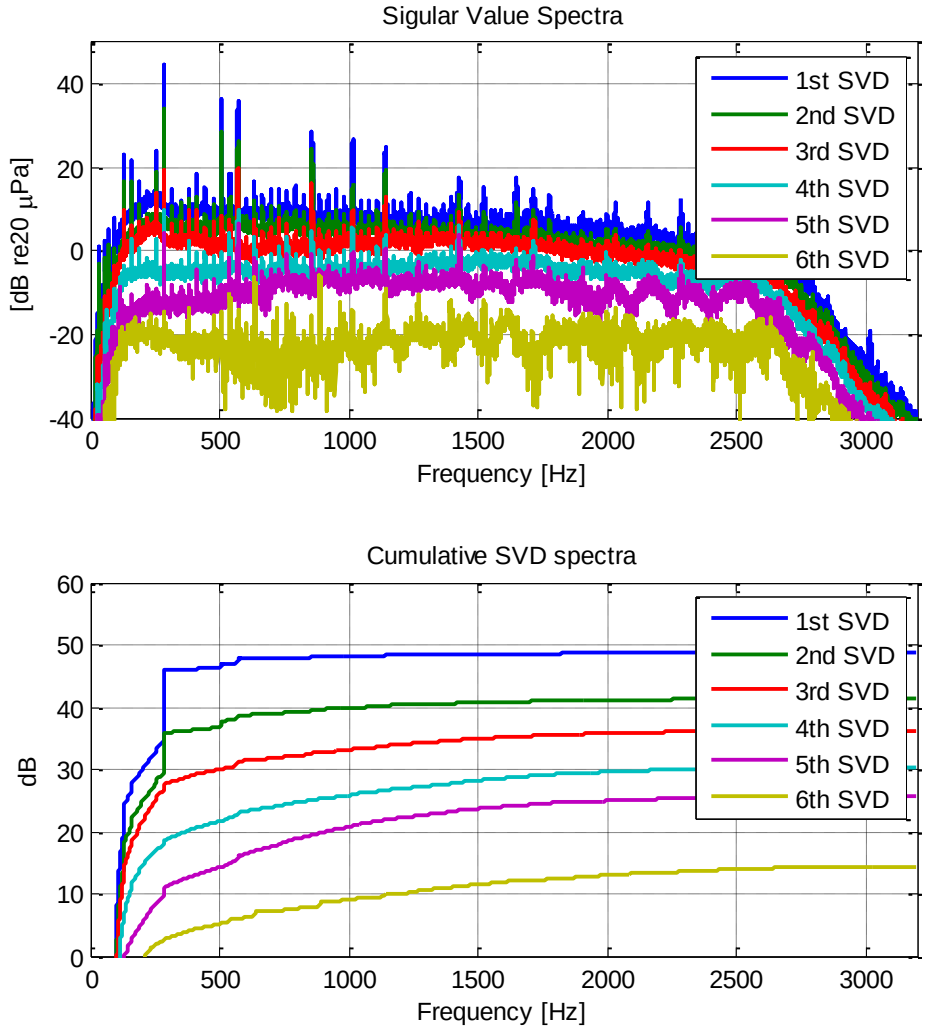
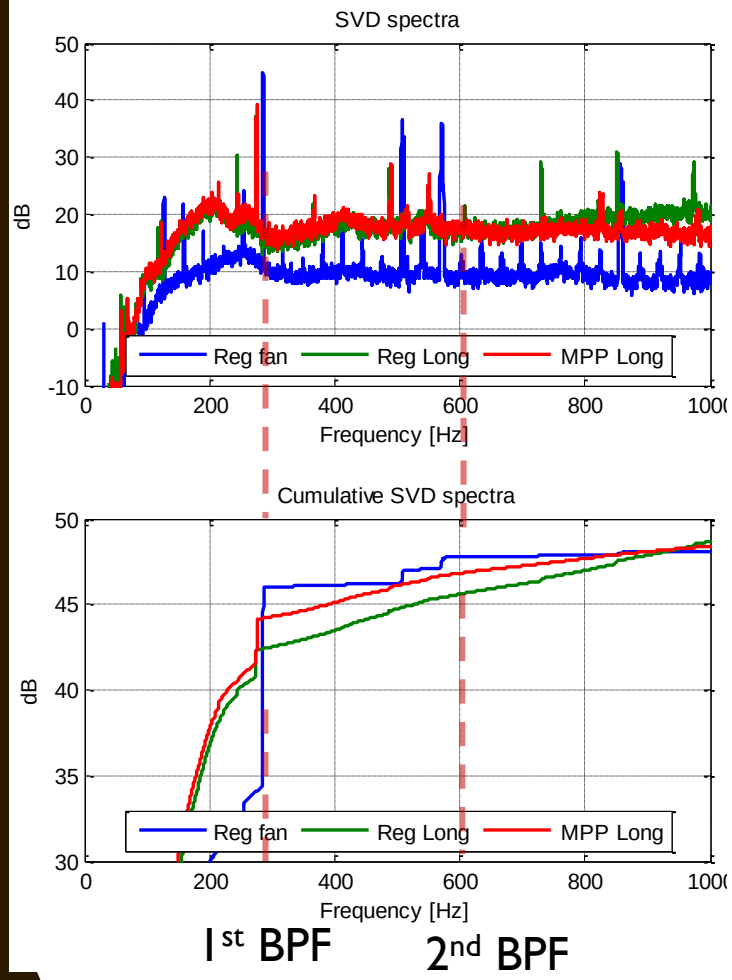
Singular Value Spectra

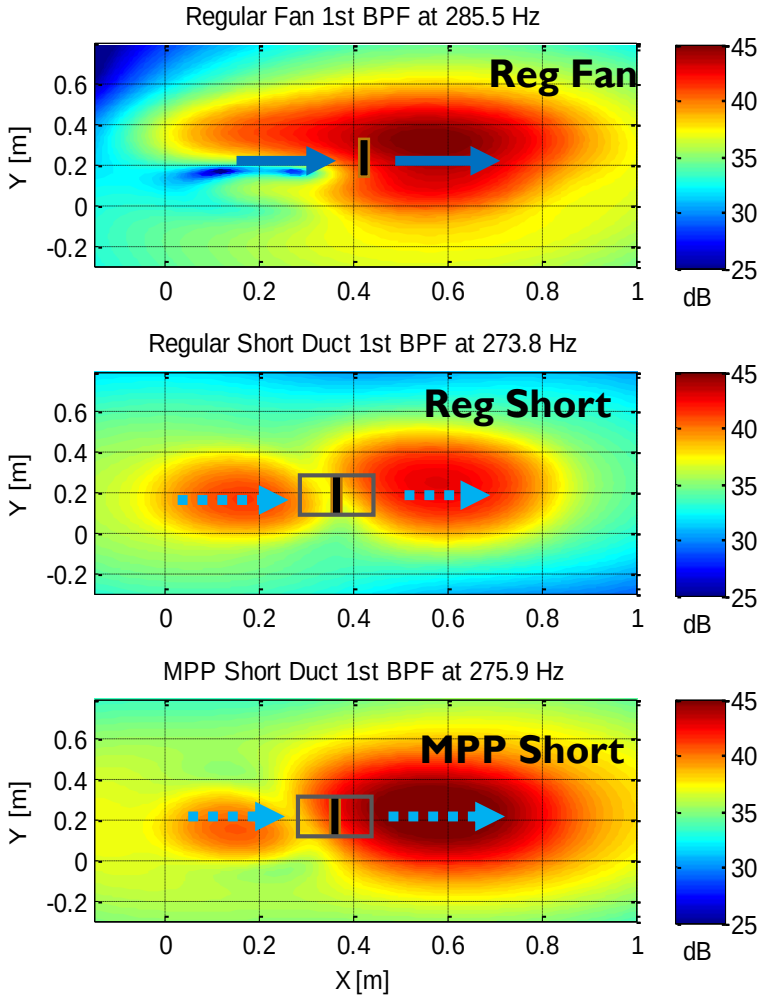


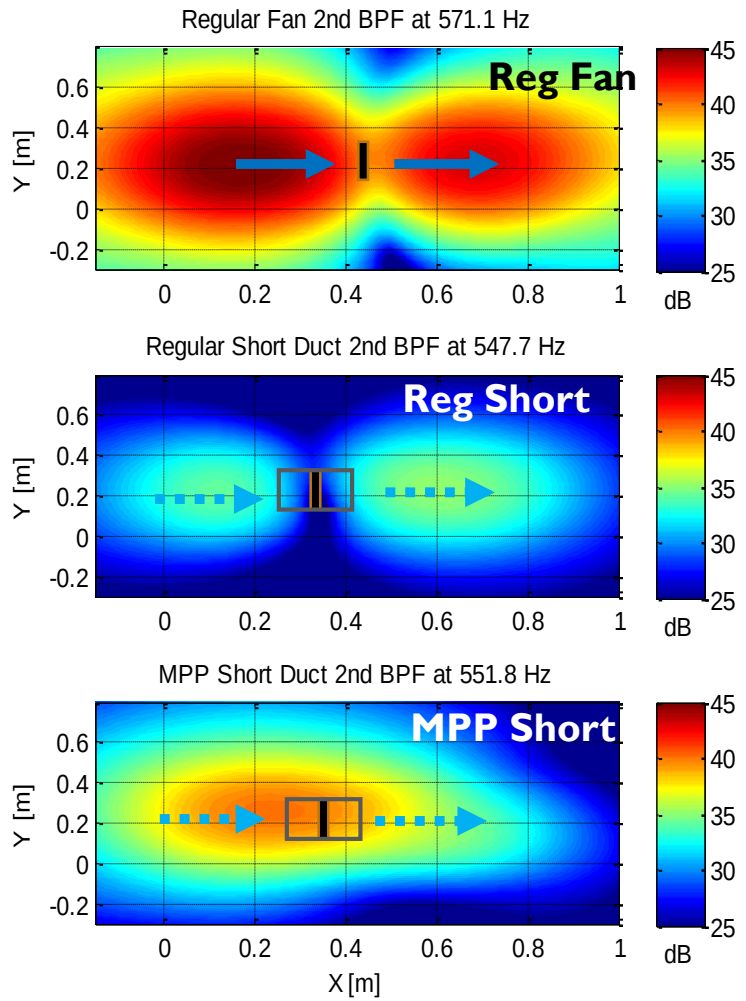
- Singular Value Spectra of Regular Fan.
- Dominant 1st SVD spectrum.
- Partial Noise Field will be provided using 1st SVD Spectra for each duct casing.

Short ducts at Blade Passage Frequencies

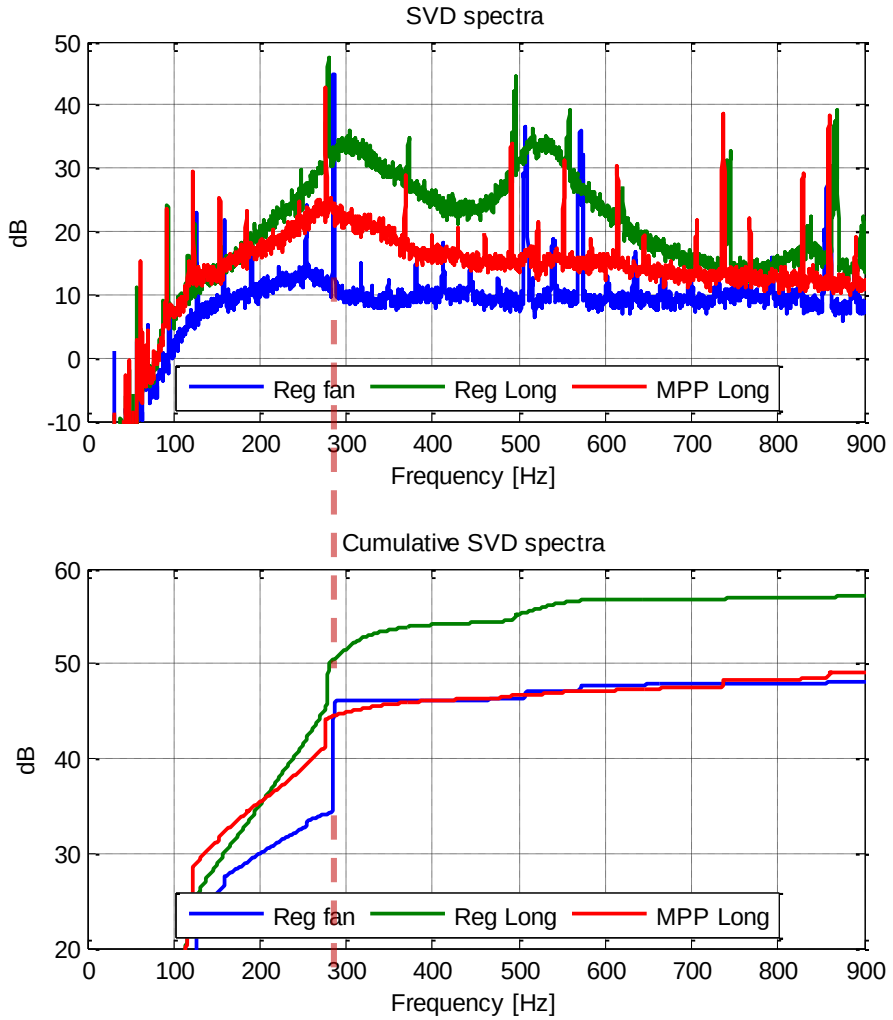


1st BPF 2nd BPF

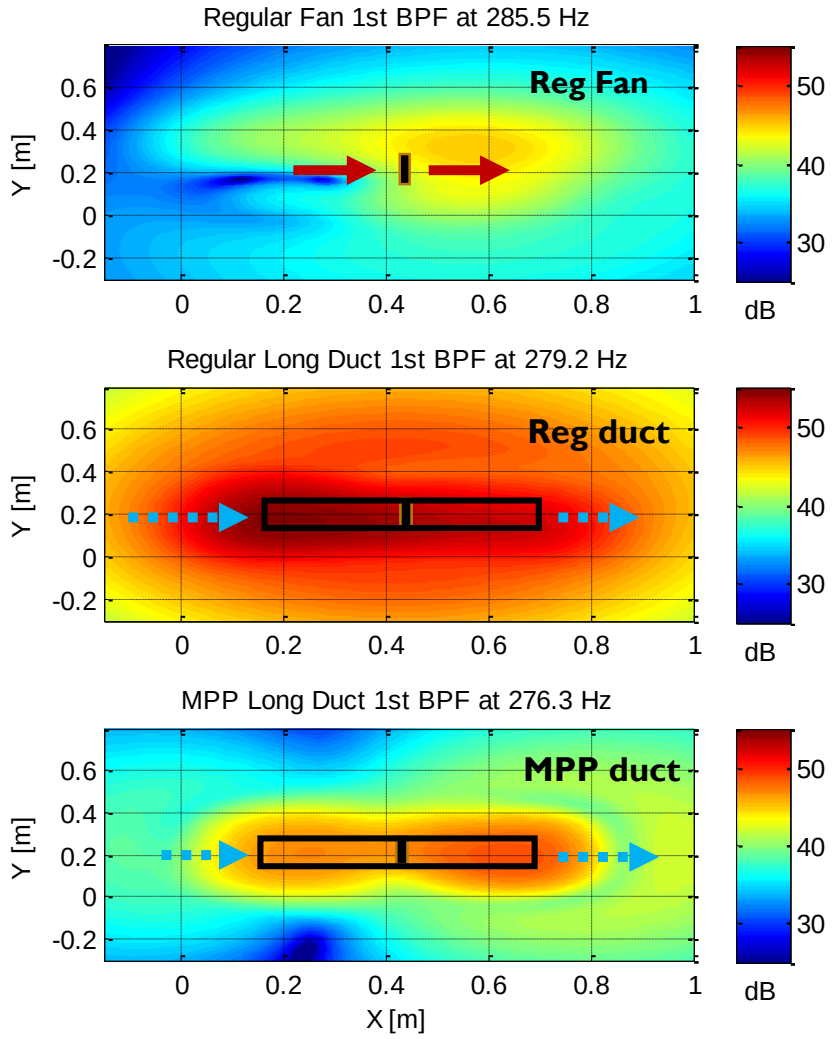




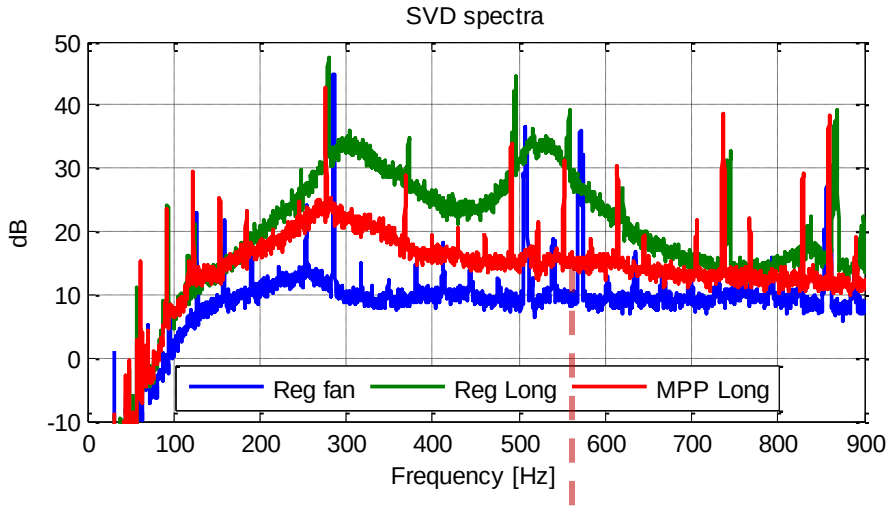
Sound fields of Long ducts at 1st BPF

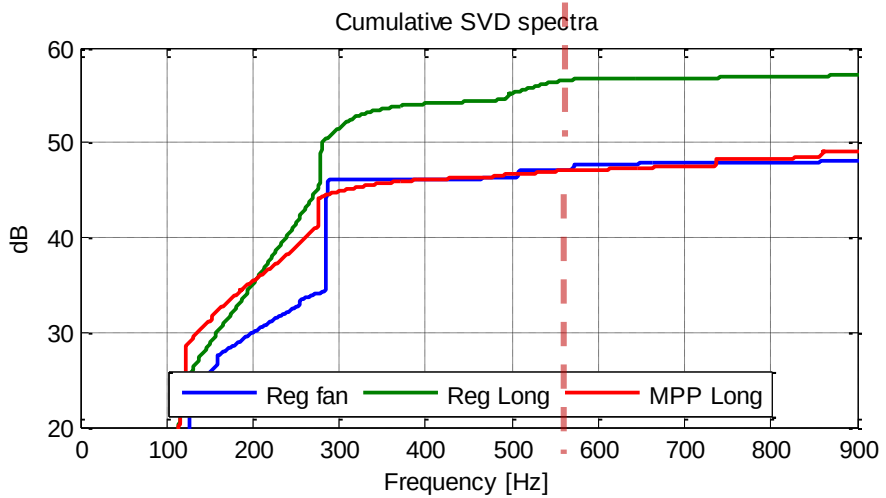


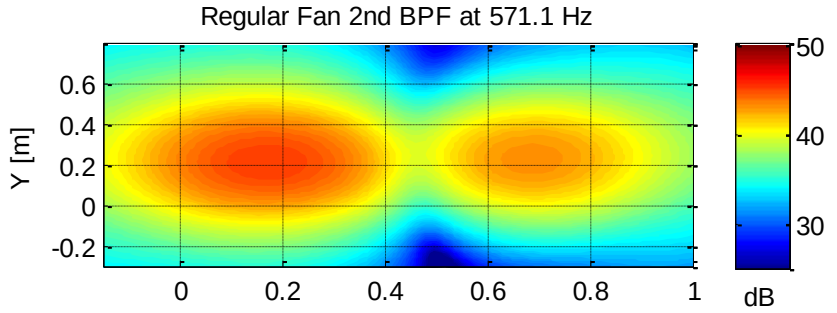
1st BPF

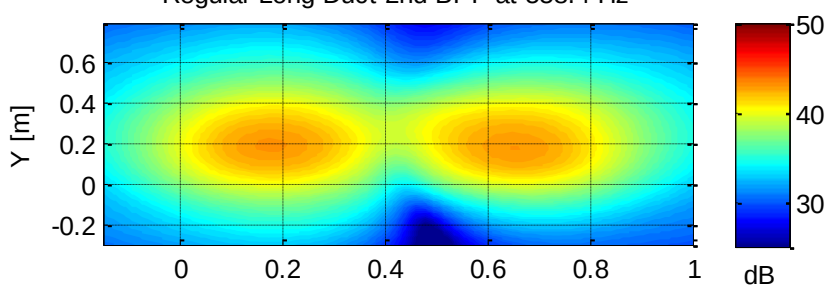


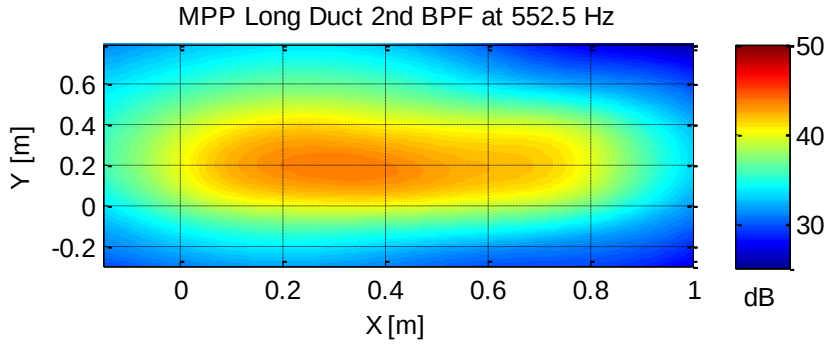
Sound fields of Long ducts at 2nd BPF





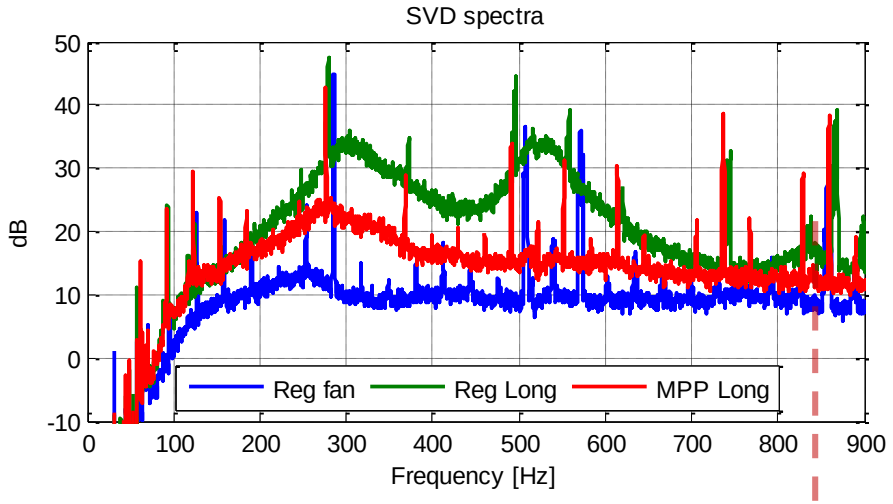


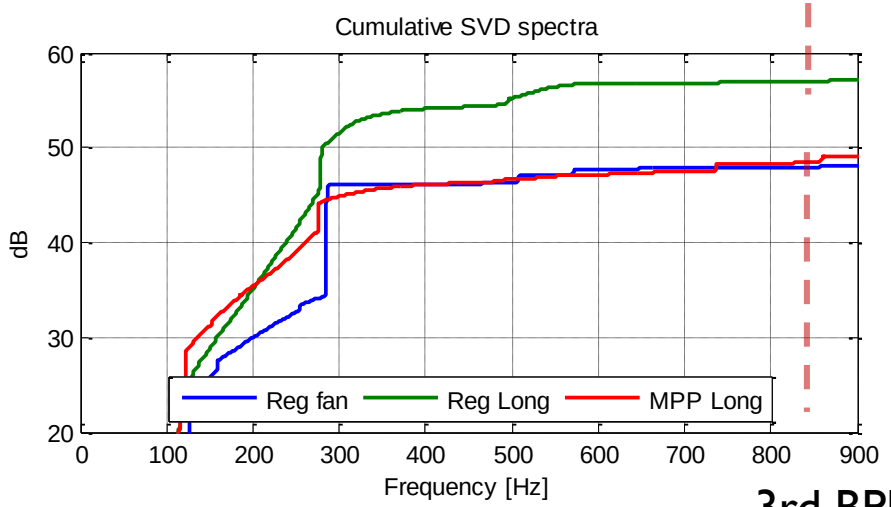




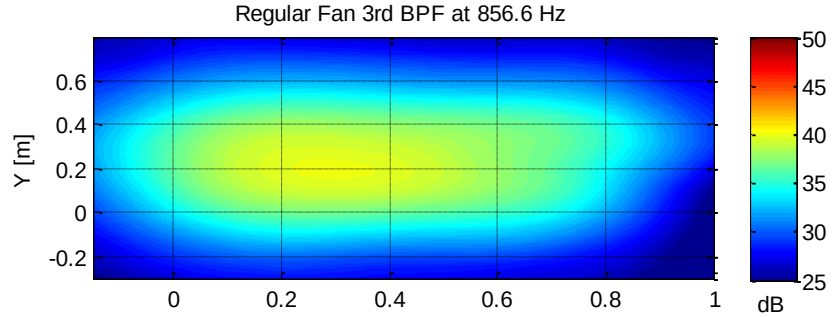
2nd BPF

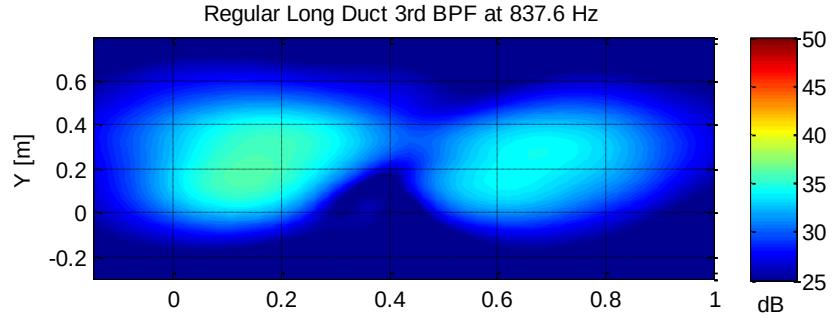
Sound fields of Long ducts at 3rd BPF

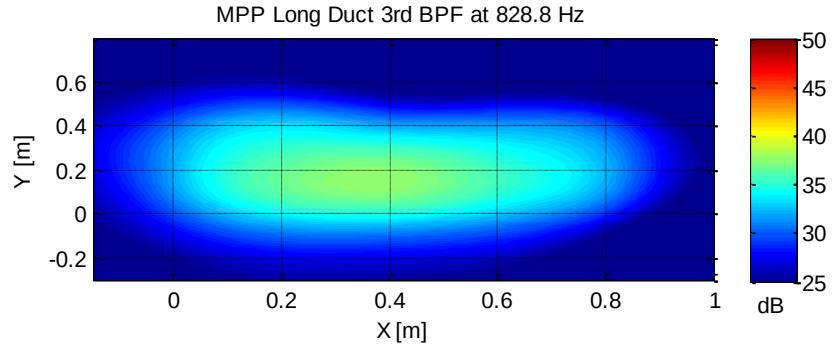




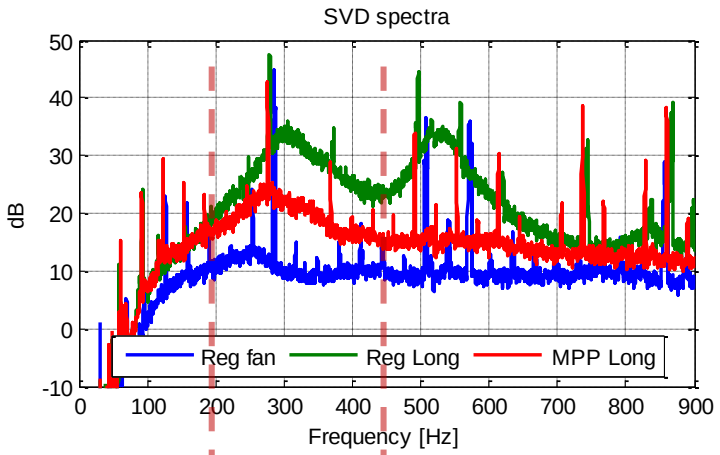
3rd BPF

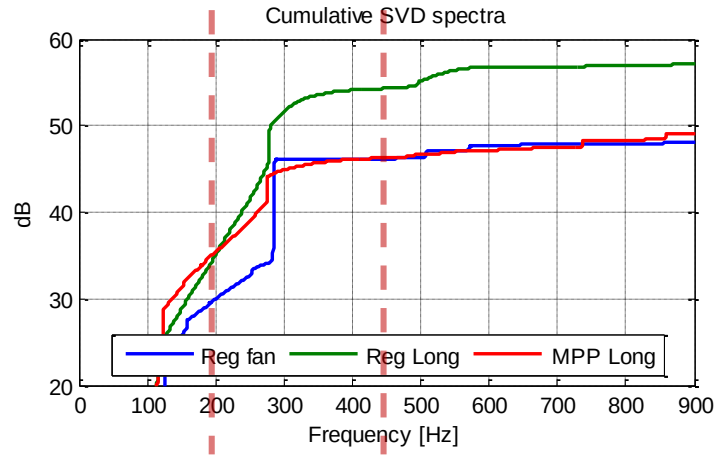






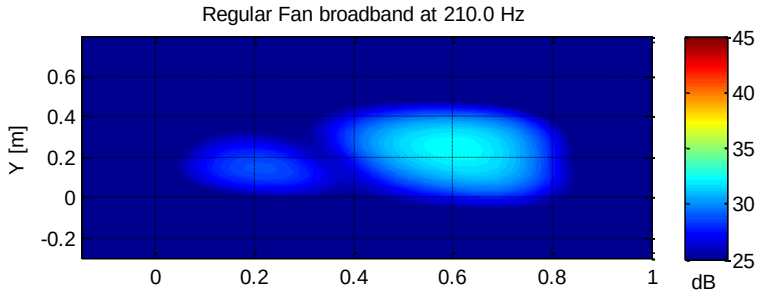
Broadband regions of Long ducts

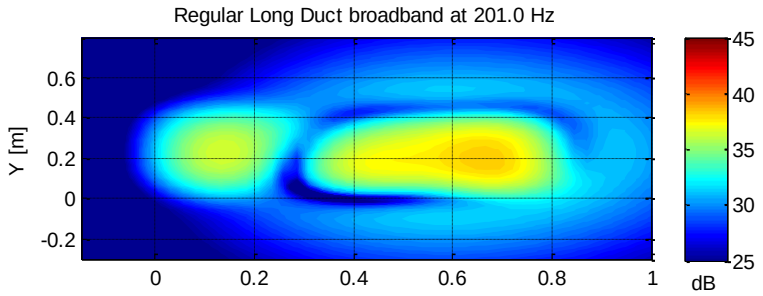


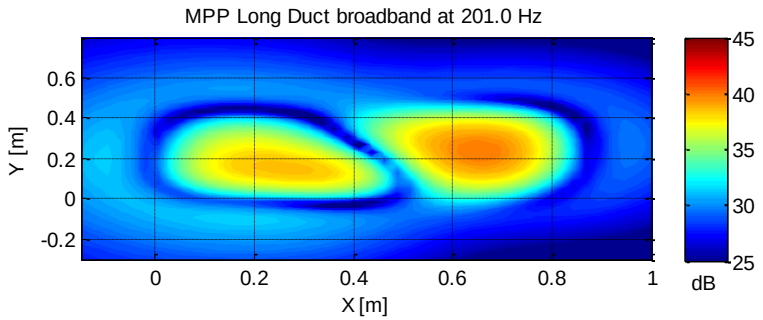


200 Hz 420 Hz

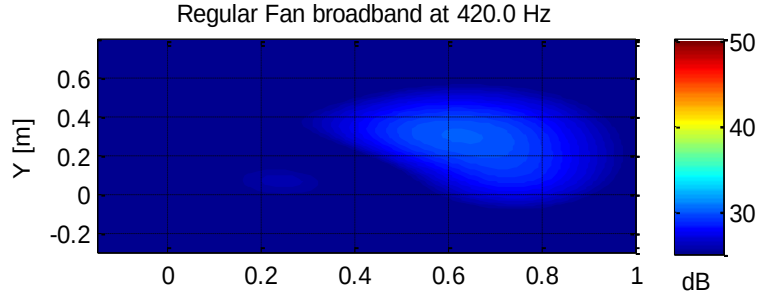
200 Hz

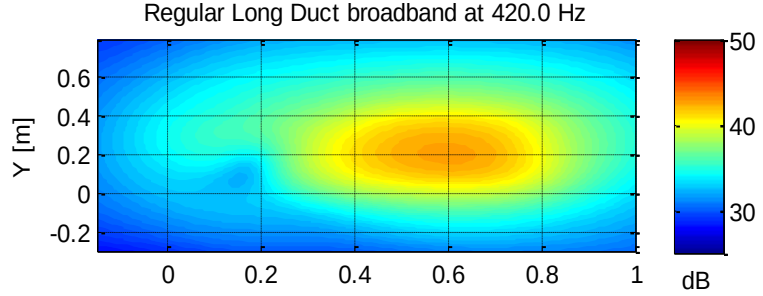


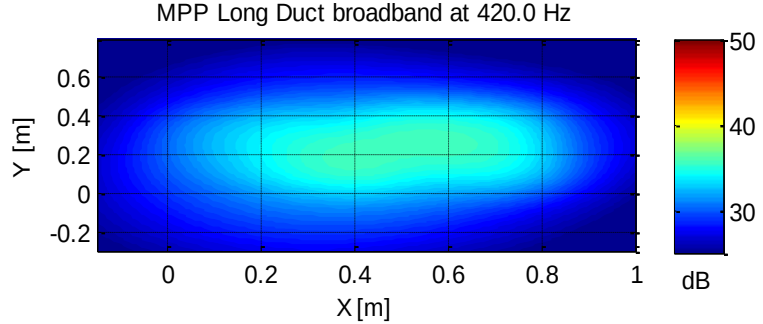




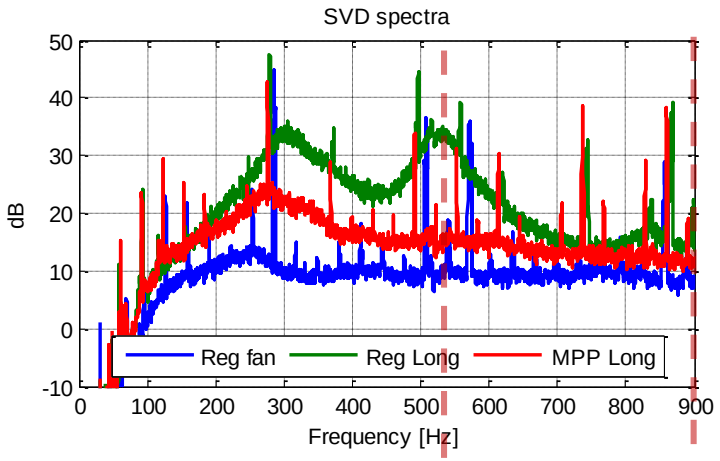
420 Hz

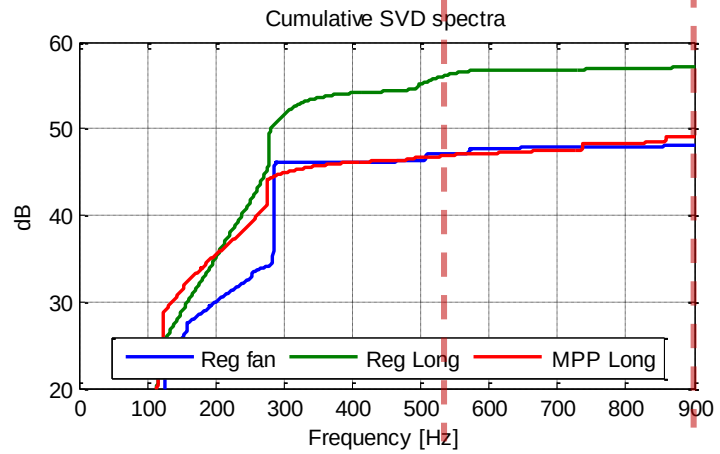






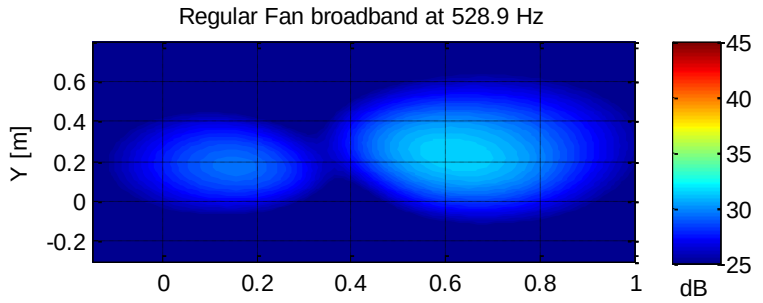
Broadband regions of Long ducts

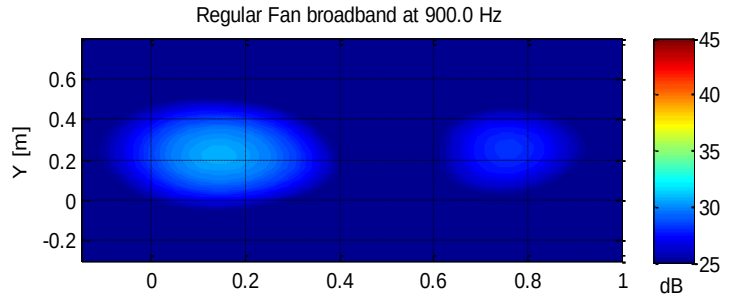


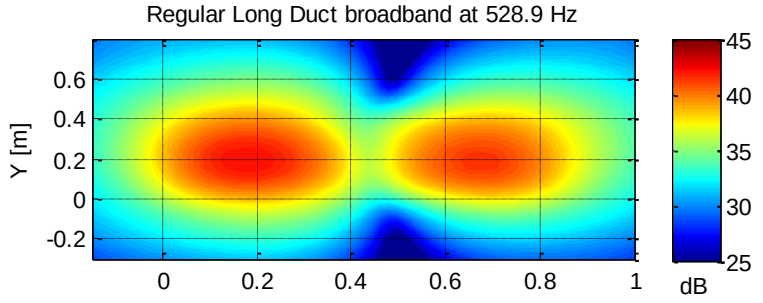


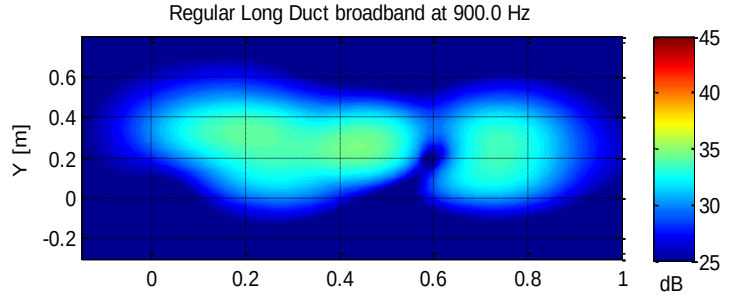
528.9Hz

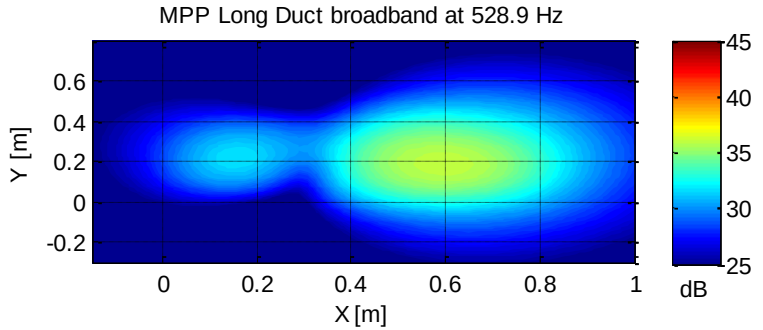
900 Hz

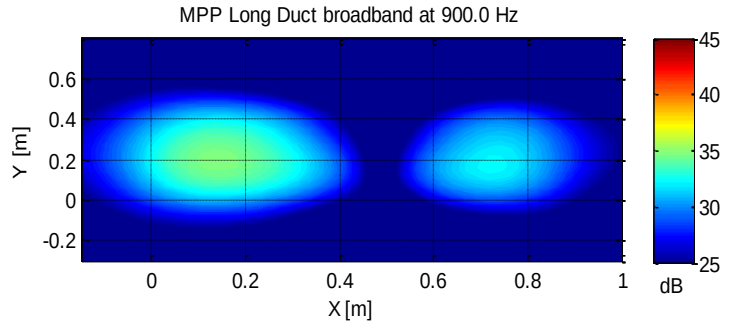












Conclusion & Future Plan

- Sound power radiation from the fans with impermeable duct and microperforated duct were measured and compared. Moreover, the sound field around the ducted fans with different materials were visualized using the nearfield acoustic holography method.

- Proper length should be selected when using microperforated material as a duct material because there should have enough distance to dissipate sound wave as the wave travel through the duct.
  - Long impermeable duct increased the noise level of the regular fan but this noise level can be reduced by replacing the duct with the same length of long MPP duct.

- The microperforated duct could provide better performance in flow transfer and static pressure generation compared to the impermeable duct.

- Different inlet and outlet length combinations of the ducted fan will be considered.

- Resonant fan scroll housing will be considered.