4-2015

The application of microperforated material to control axial fan noise

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ACKNOWLEDGEMENT

- **3M Company, MN, USA**

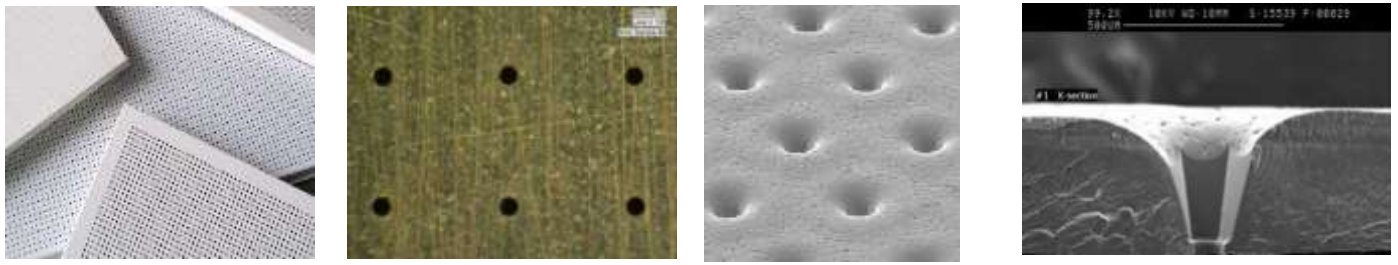
  - **The authors acknowledge the support of 3M Corporation through the provision of materials for the fan noise experiments and for the financial support of this work.**

Herrick Laboratories PURDUE UNIVERSITY

PURDUE ENGINEERING

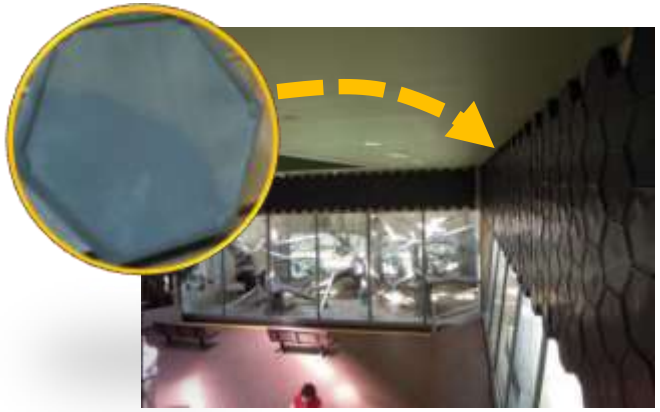
MICROPERFORATED MATERIAL

- **Microperforated panel introduced**
  - **Maa (1975, 1987, 1998)**
  - **Perforated panel:**
    - The dissipation of sound energy into heat occurs due to visco-thermal losses inside the perforations.
    - Hard to obtain wide frequency range of sound absorption.



MICROPERFORATED MATERIAL

- Advantages of MPP
  - Can be used alone as sound absorbing material unlike perforated panel.
  - Clean, Hygienic, Light-weight, Resistive to fire, etc.
- Applications of MPP



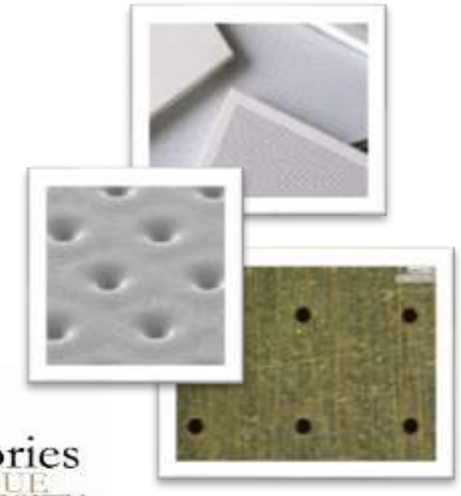
Buildings

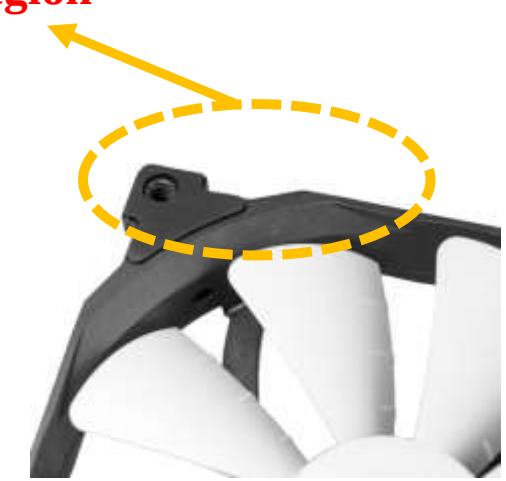
Vehicle

OBJECTIVE

- To reduce the blade passage tone level of axial cooling fan (120 mm)
  - Focusing on reducing tip clearance noise.
- Tip noise can be reduced by installing a finite flow resistance strip in the housing around the fan circumference.
  - Finite level of flow resistance created by the slightly

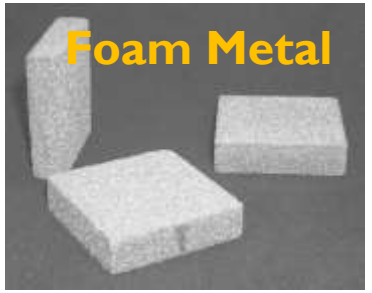
  Permeable housing may reduce turbulence levels in the tip region.
- The fan noise was quantified on the basis of the blade passage tone level.





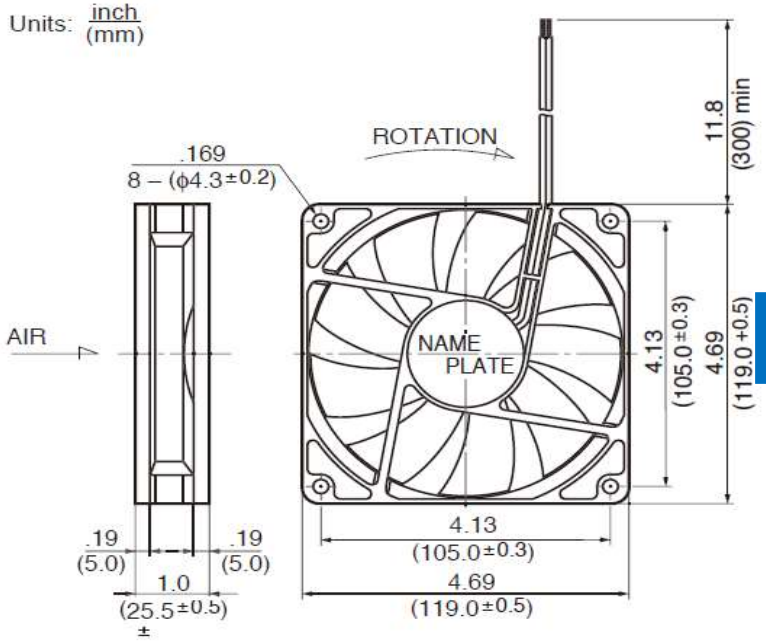
RELATED RESEARCH

- Structural Design of the Fan: Strut designs, etc.
  - W. M. Gresho (1985); J. Wang and L. Huang (2005); S. Lee, G-S Lee, S. Heo and C. Cheong (2005)
- Structural Design of the fan: Impact of the guard grille design
  - A. Gregor, M. Hocevar and B. Sirok (2009)
- Active noise control
  - D. A. Quinlan (1992); K. L. Gee and S. D. Sommerfeldt (2003); J. W. Schulz, W. Neise and M. Moser (2006)
- Tip Clearance region
  - Blade design: G. Jin, H. Ouyang, Y. Wu and Z. Du (2011),
  - Perofrated resonator in the housing: L. Gorny, G. L. Koopmann, W. Neise and O. Lemke (2011)
  - D. L. Sutliff and M. G. Jones (2009):
    - Beneficial effect of foam metal liner in turbine blade-tip.

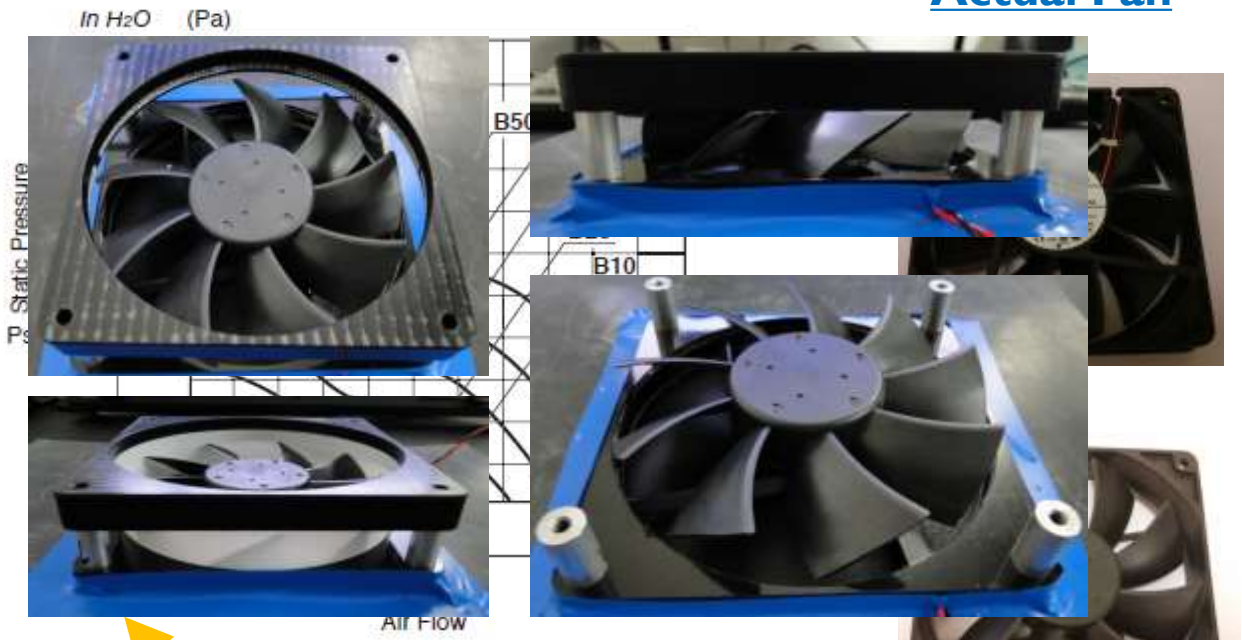


FAN SPECIFICATION

Model: 4710KL-05W-B20



Characteristic Curve



Actual Fan

Manufacturer provided Specification

Rated Volt [V]	Operating Voltage [V]	Current [A]	Input Power [W]	Speed [RPM]	Max Air Flow [m³/min]	Max Static Pressure [Pa]	Noise [dB]	Mass [g]
24	10.0 ~27.6	0.10	2.40	1900	2.15	24.8	31.0	180

Microperforated casing attached !

FANS AND MATERIALS

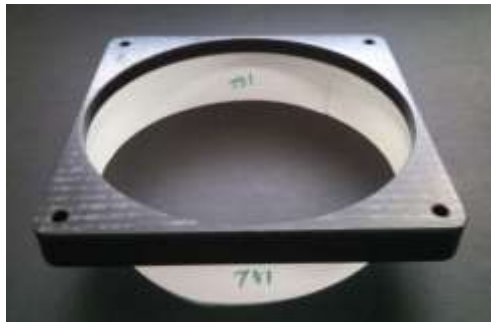
- **Material properties**

	MPP 751	MPP 1204	MPP 1759
Hole diameter [μm]	150	97.1	75.5
Thickness [mm]	0.3	0.3	0.3
Flow resistance [Rayls]	751	1204	1759

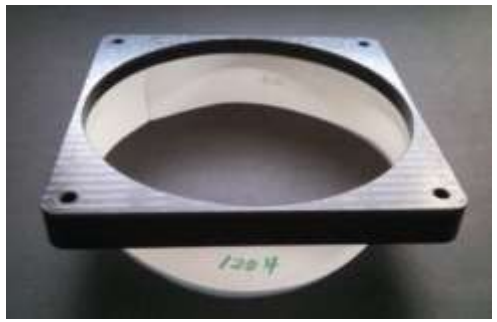
*** In SI unit, Rayls = N·s/m³**

Impermeable (Regular)

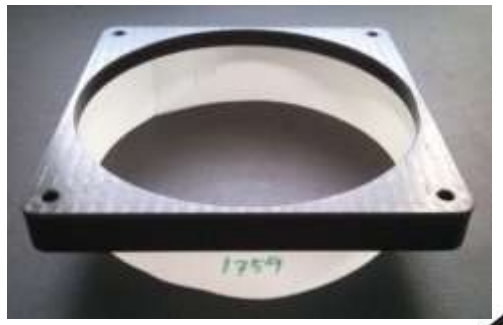
MPP 751 Rayls



MPP 1204 Rayls

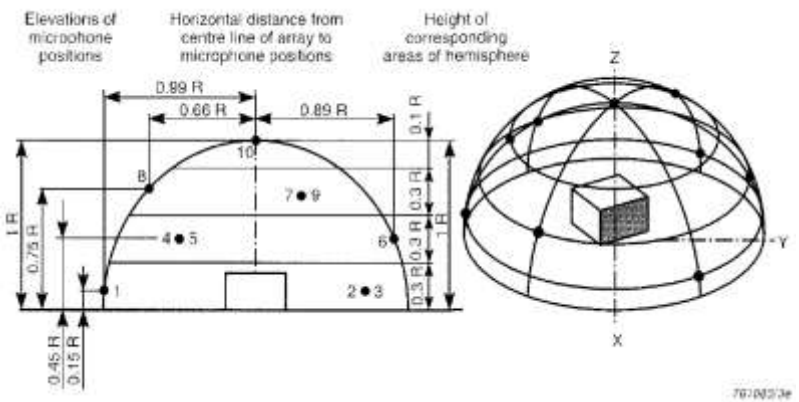


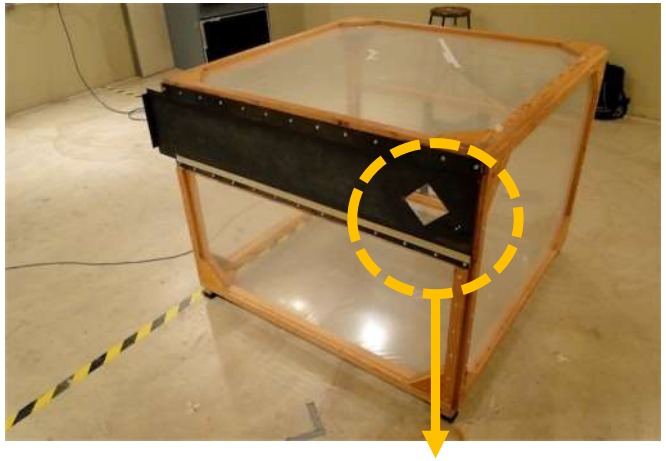
MPP 1759 Rayls



EXPERIMENTAL SETUP

Hemispherical Frame Configuration for Sound Power Level measurement.

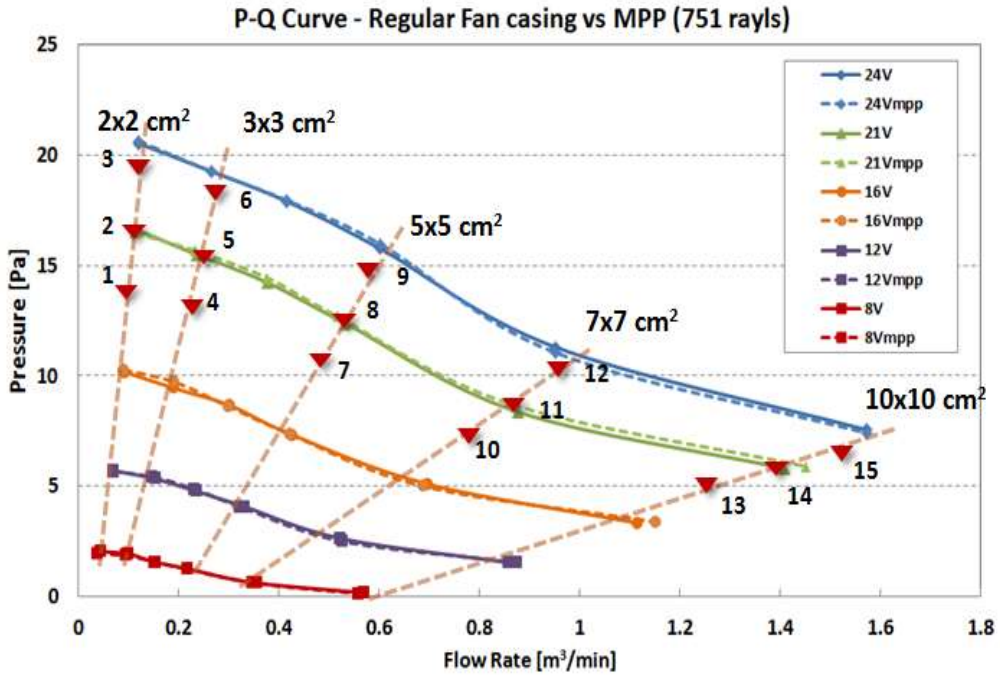




Controllable opening

- 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.

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

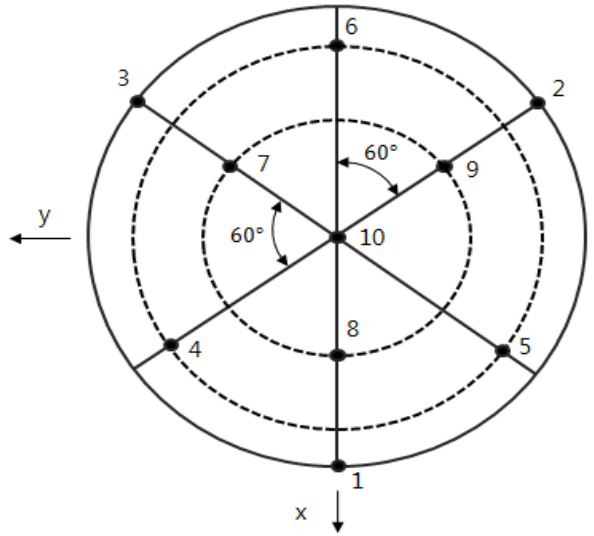
Pt.	Pressure [Pa]	Opening Area [cm²]	Flow Rate [m³/min]	Flow Vel. [m/s]	Rotation Speed [RPM]
1	12.00	2x2	0.09	3.75	1474.7
2	15.29	2x2	0.11	4.58	1599.3
3	17.80	2x2	0.13	5.41	1716.7
4	11.98	3x3	0.20	3.70	1492.7
5	14.18	3x3	0.22	4.07	1618.7
6	16.41	3x3	0.24	4.44	1736.7
7	9.582	5x5	0.43	2.80	1542.7
8	11.64	5x5	0.51	3.40	1676.0
9	13.43	5x5	0.58	3.87	1806.0
10	6.752	7x7	0.78	2.65	1606.0
11	8.231	7x7	0.85	2.89	1748.0
12	9.285	7x7	0.98	3.33	1882.0
13	4.498	10x10	1.32	2.20	1580.7
14	5.432	10x10	1.42	2.37	1712.0
15	6.278	10x10	1.55	2.58	1850.0

MEASUREMENT PROCEDURE

- Pick a measurement point from P-Q curve
- Operate the fan attached to plenum at required voltage (speed).
- Acquire noise signals from 10 different microphone positions.
  - Sampling time: 80 sec; Sampling rate: 25.6 kHz
  - 10 microphone arrays for the sound power level estimation [ISO 3744]

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



- Calculate sound power level according to ISO 3744
  - The Sound Power Level estimation from the sound pressure level

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

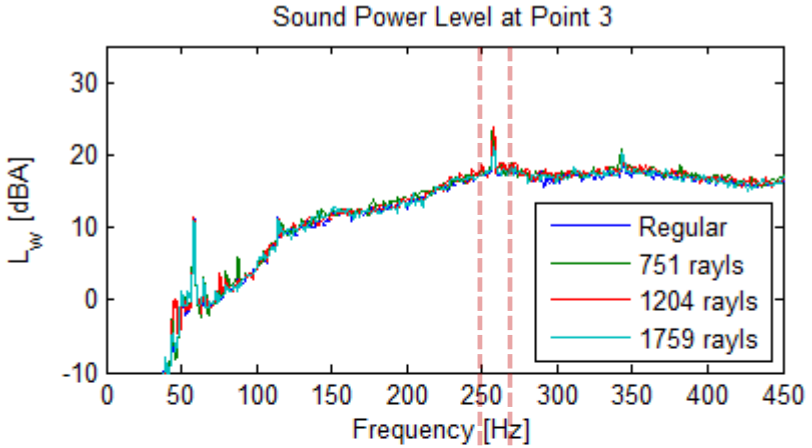
L_p : Space – averaged sound pressure level

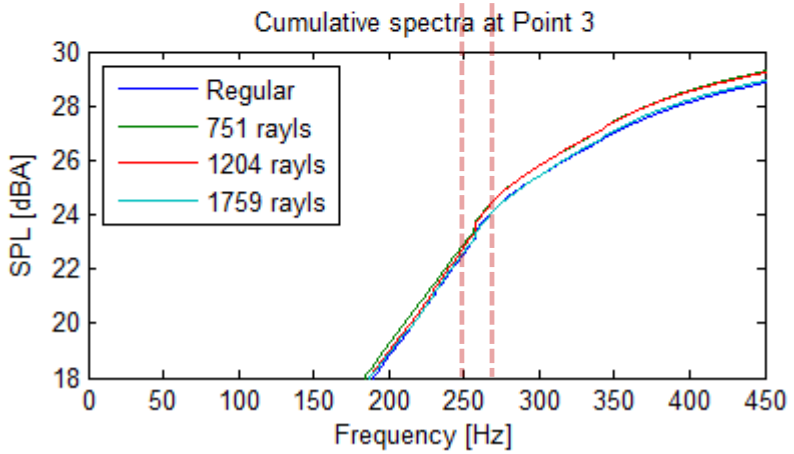
S_{ref} : Reference area, 1 m^2

S : Surface area of the hemisphere

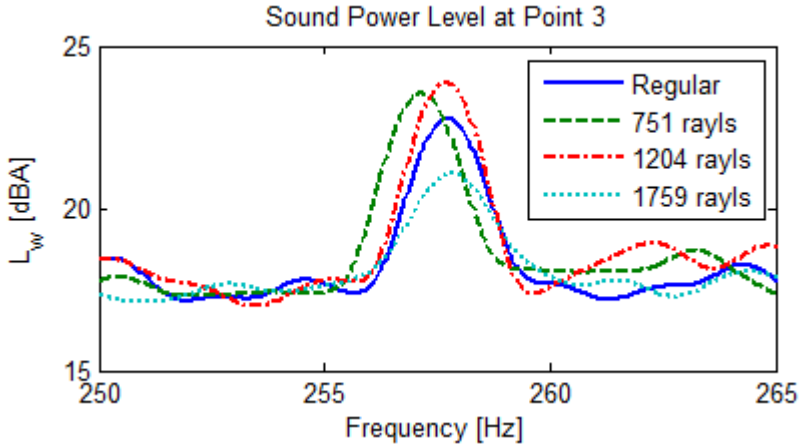
RESULTS BLADE PASSAGE TONE REDUCTION

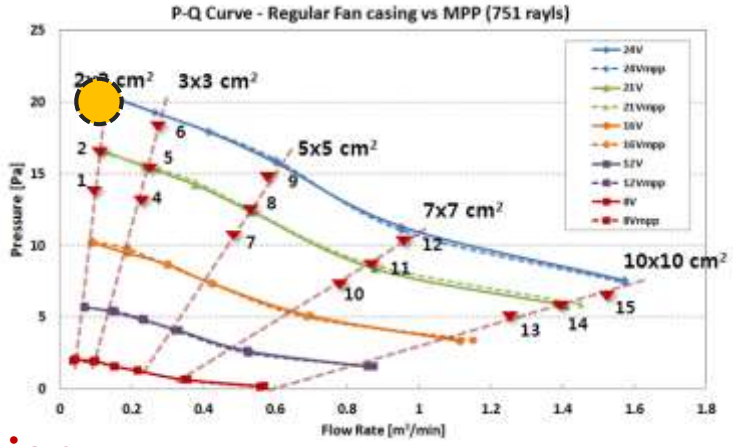
- **2x2 cm² Opening Area**
- **High Pressure (17.8 Pa) / Low Flow Rate (0.05 m³/min)**





At Blade Passage Frequency Region

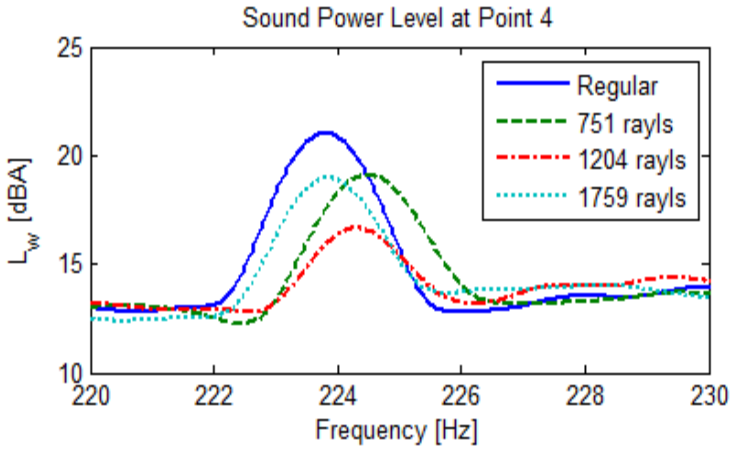


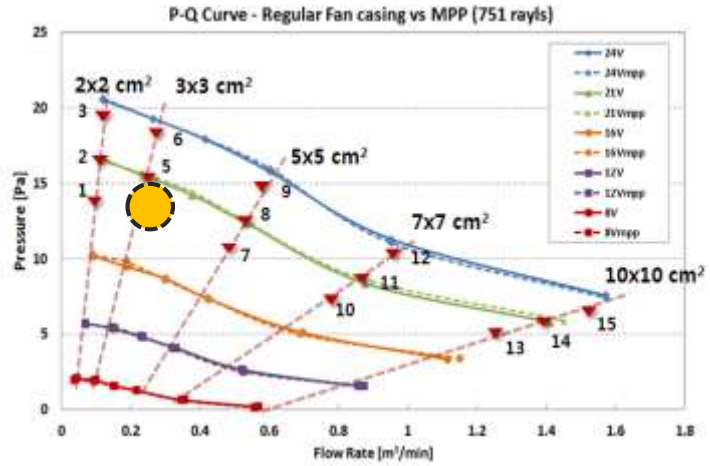


Blade Passage Frequency Region

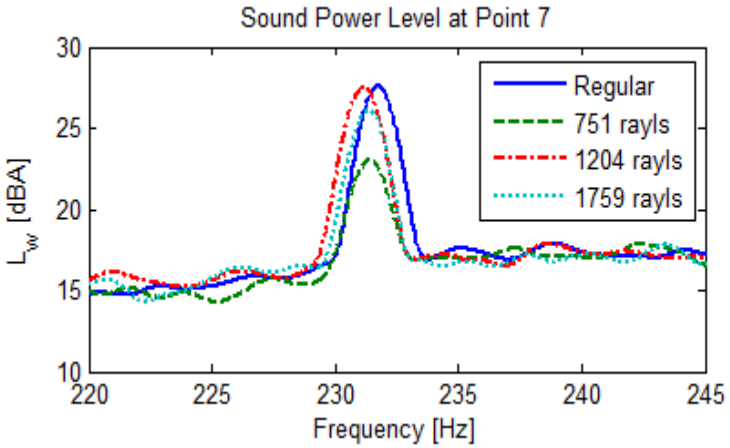
RESULTS BLADE PASSAGE TONE REDUCTION

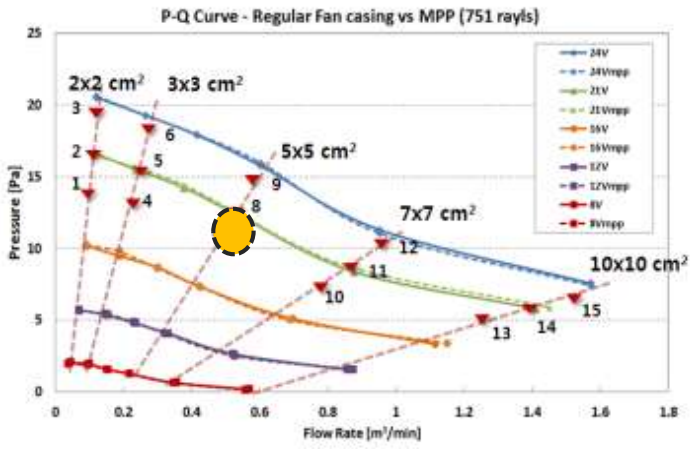
- 3x3 cm² Opening Area
- Mid Pressure (12.03 Pa) /
- Low Flow Rate (0.21 m³/min)



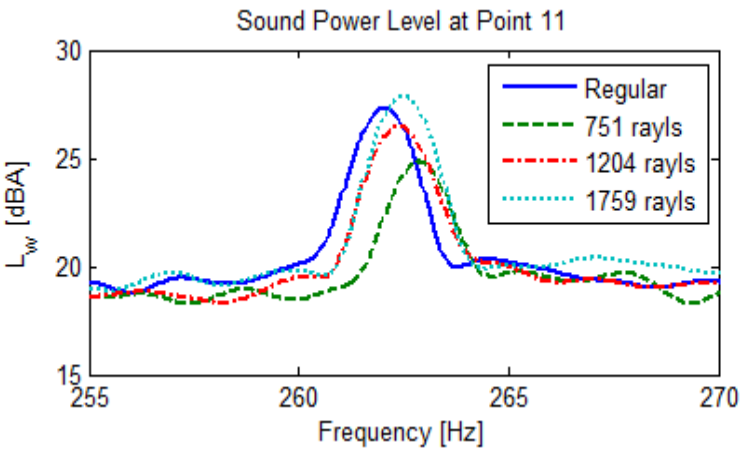


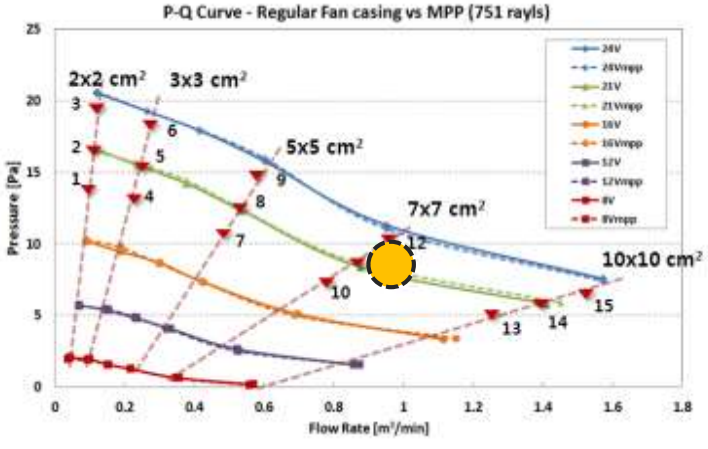
- 5x5 cm² Opening Area
- Mid Pressure (9.58 Pa) /
- Low Flow Rate (0.49 m³/min)





- 7x7 cm² Opening Area
- Mid Pressure (8.23 Pa)
- Mid Flow Rate (0.88 m³/min)





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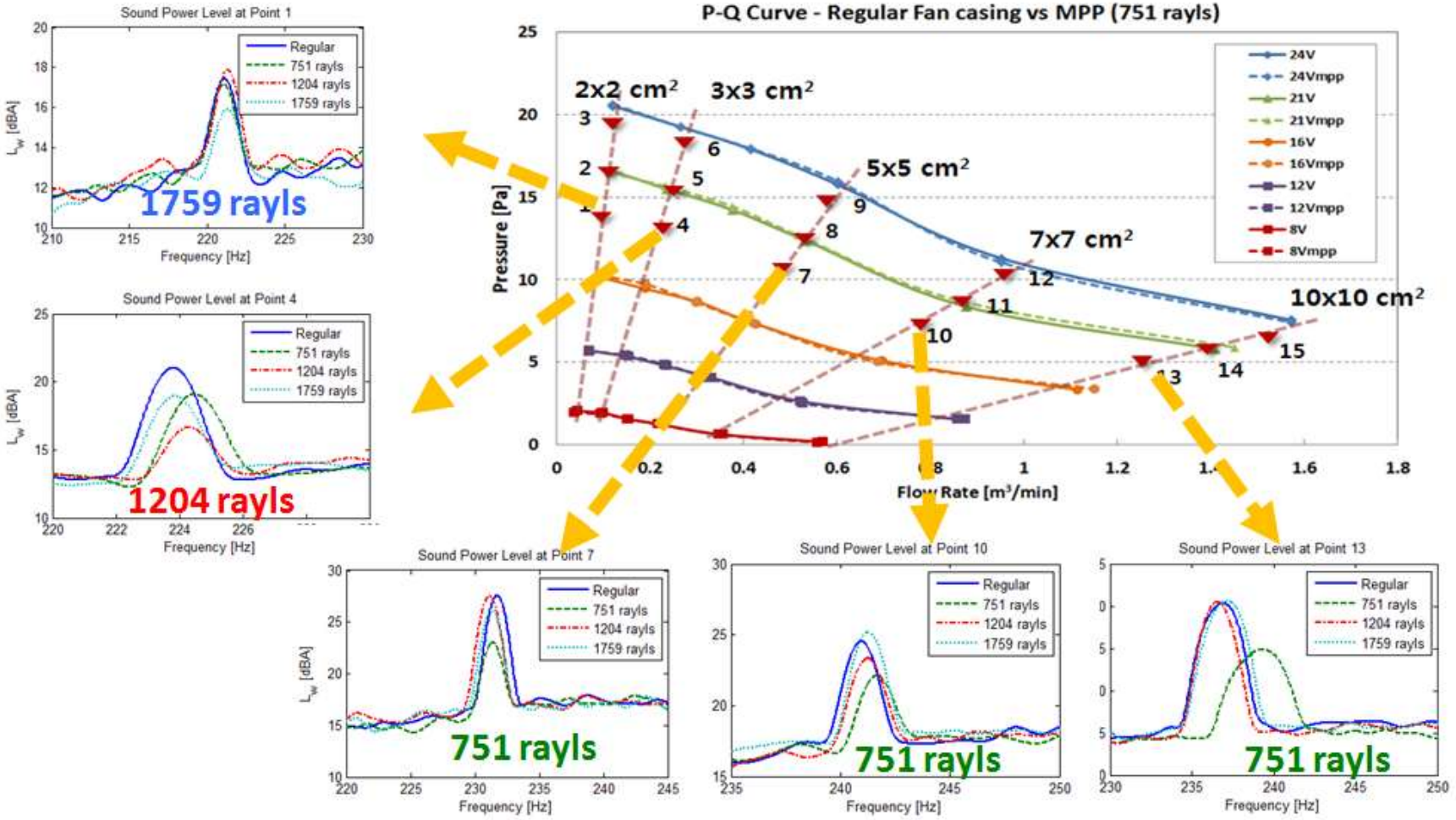
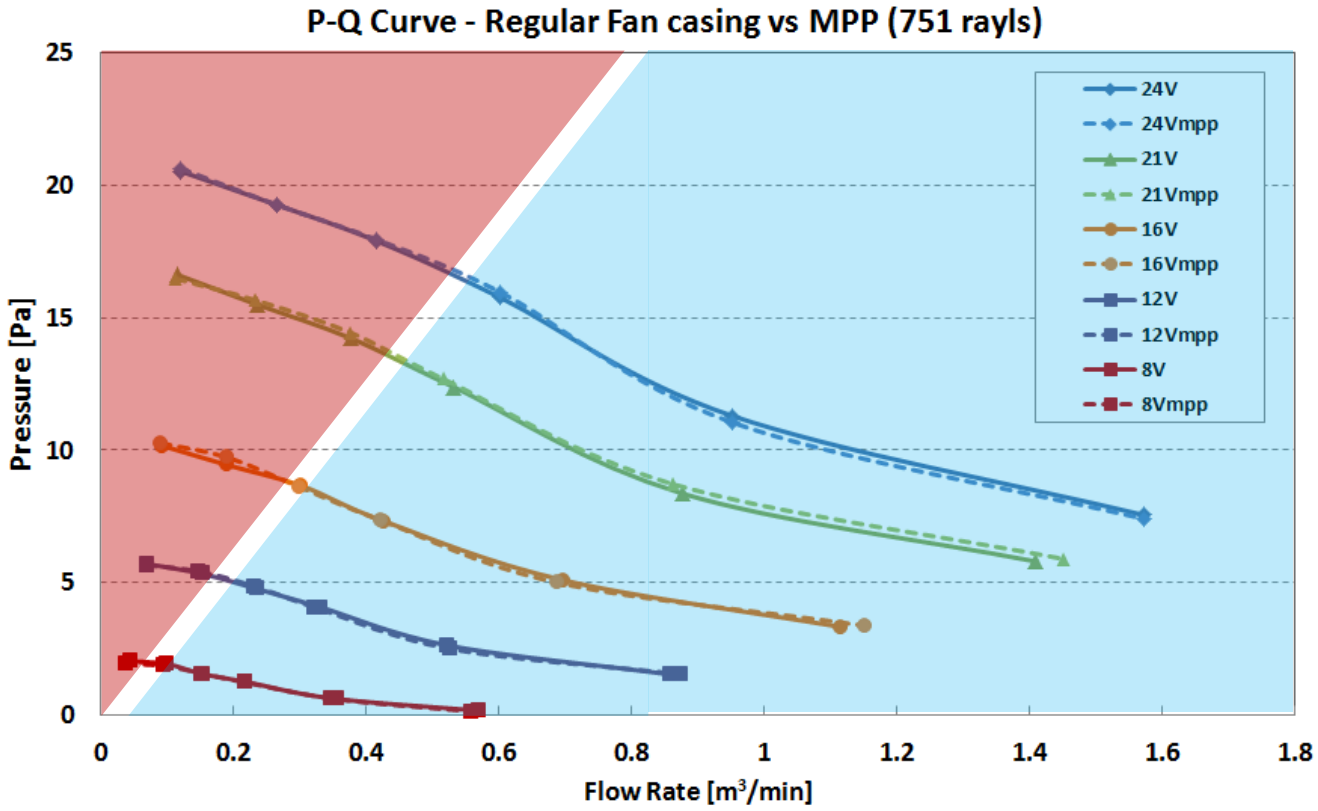
BLADE PASSAGE TONE REDUCTION OVER P-Q CURVES



BLADE PASSAGE FREQUENCY TONES

Area [cm²]	Point	BPF [Hz]	Regular [dB(A)]	MPP751 [dB(A)]	MPP1204 [dB(A)]	MPP1759 [dB(A)]
2 x 2	1	221.2	17.45	17.14	17.86	15.89
	2	239.9	20.59	20.54	21.15	19.03
	3	257.5	22.76	23.54	23.89	21.09
3 x 3	4	223.9	21.02	19.11	17.33	18.95
	5	242.8	24.01	23.32	21.24	21.50
	6	260.5	27.06	26.18	23.42	24.57
5 x 5	7	231.5	27.59	23.03	27.51	26.09
	8	242.8	29.58	26.19	30.46	27.85
	9	260.5	31.26	28.09	32.35	29.70
7 x 7	10	240.9	24.54	22.11	23.33	25.19
	11	262.2	27.30	24.82	26.47	27.84
	12	282.3	29.16	27.09	27.24	29.38
10 x 10	13	237.1	30.34	24.86	30.48	34.75
	14	256.8	31.37	29.63	34.26	35.71
	15	277.5	34.50	31.28	34.81	37.32

COMMENTS ON THE RESULTS

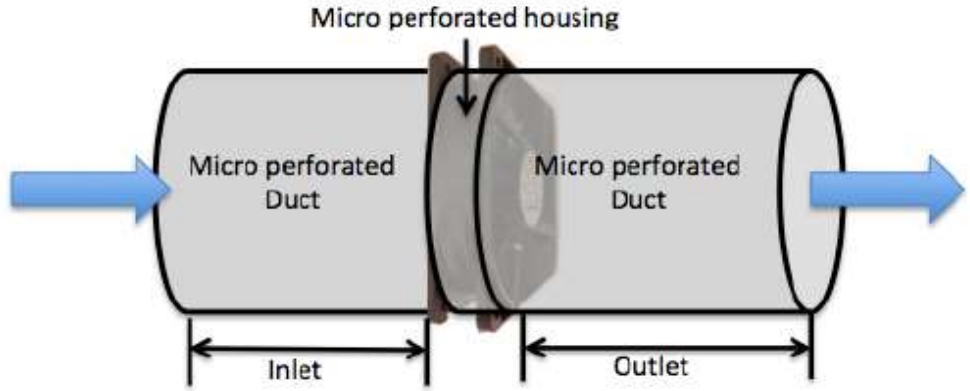


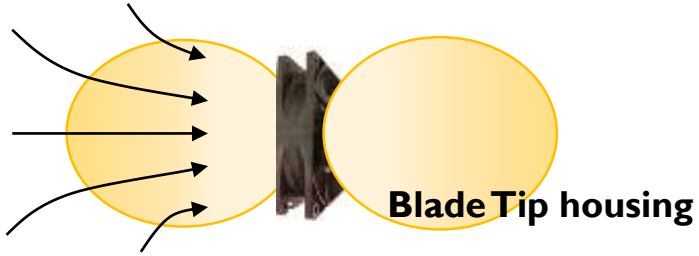
Red : MPPs with **High** flow resistivity showed better performance in reducing BPF tone

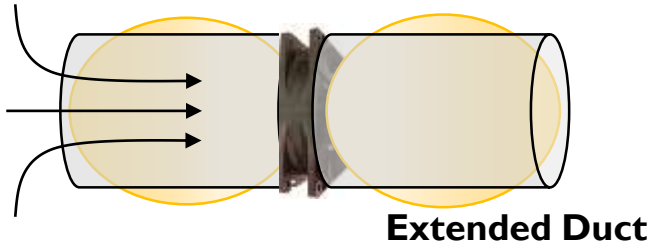
Blue : MPPs with **Low** flow resistivity showed better performance in reducing BPF tone

AXIAL FAN WITH THE DUCT CASING

- **MPP casing was extended in the direction of inlet-end and outlet-end of the fan.**
  - Expecting the duct to suppress dipole-like source of the axial fan.
  - Control the flow to improve the flow performance from the regular blade-tip housing.







DUCT DIMENSIONS AND MATERIAL PROPERTIES

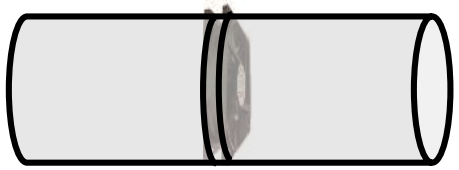
- **Duct Lengths**

	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



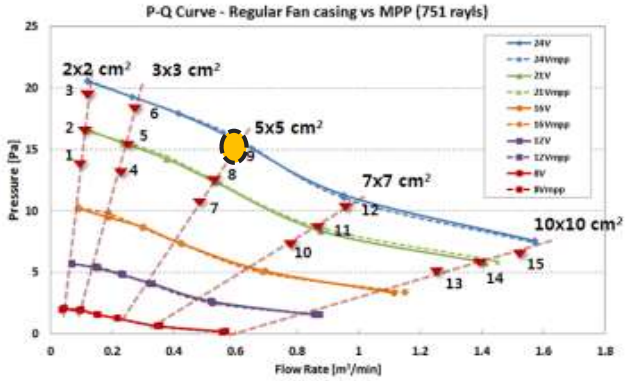
Duct Long MPP 751

EXTENDED HOUSING RESULT

- Comparison

Blade-Tip **Duct Short Casing**

- Operating Point

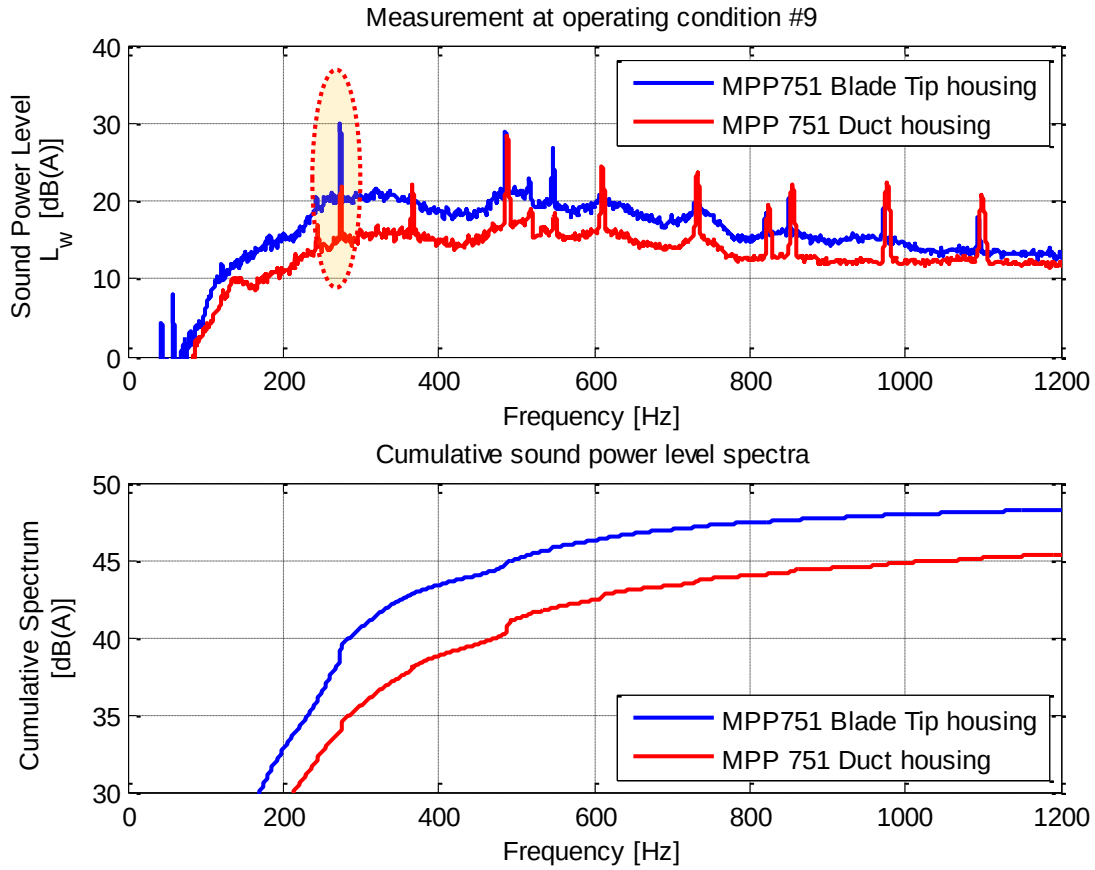


- Blade Passage Tone [dBA]

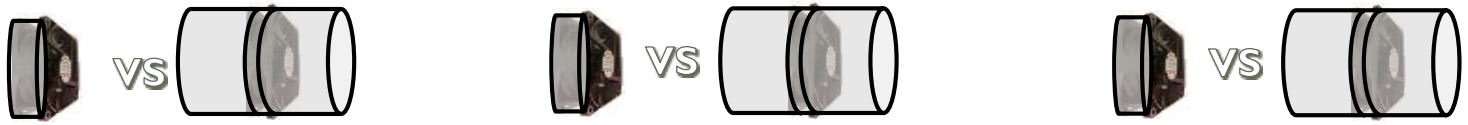
MPP 751	DUCT 751
30.40	21.89

- Overall Sound Power Level [dB(A)]

DUCT REG.	DUCT 751
48.86	46.53

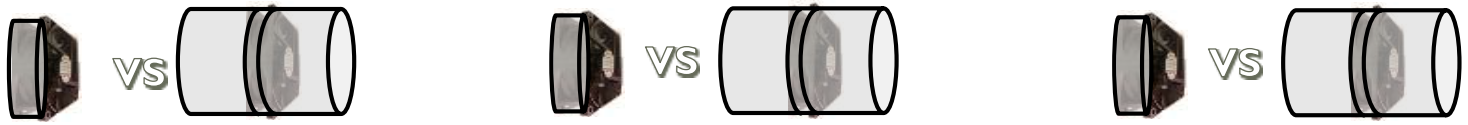


BLADE PASSAGE FREQUENCY TONE



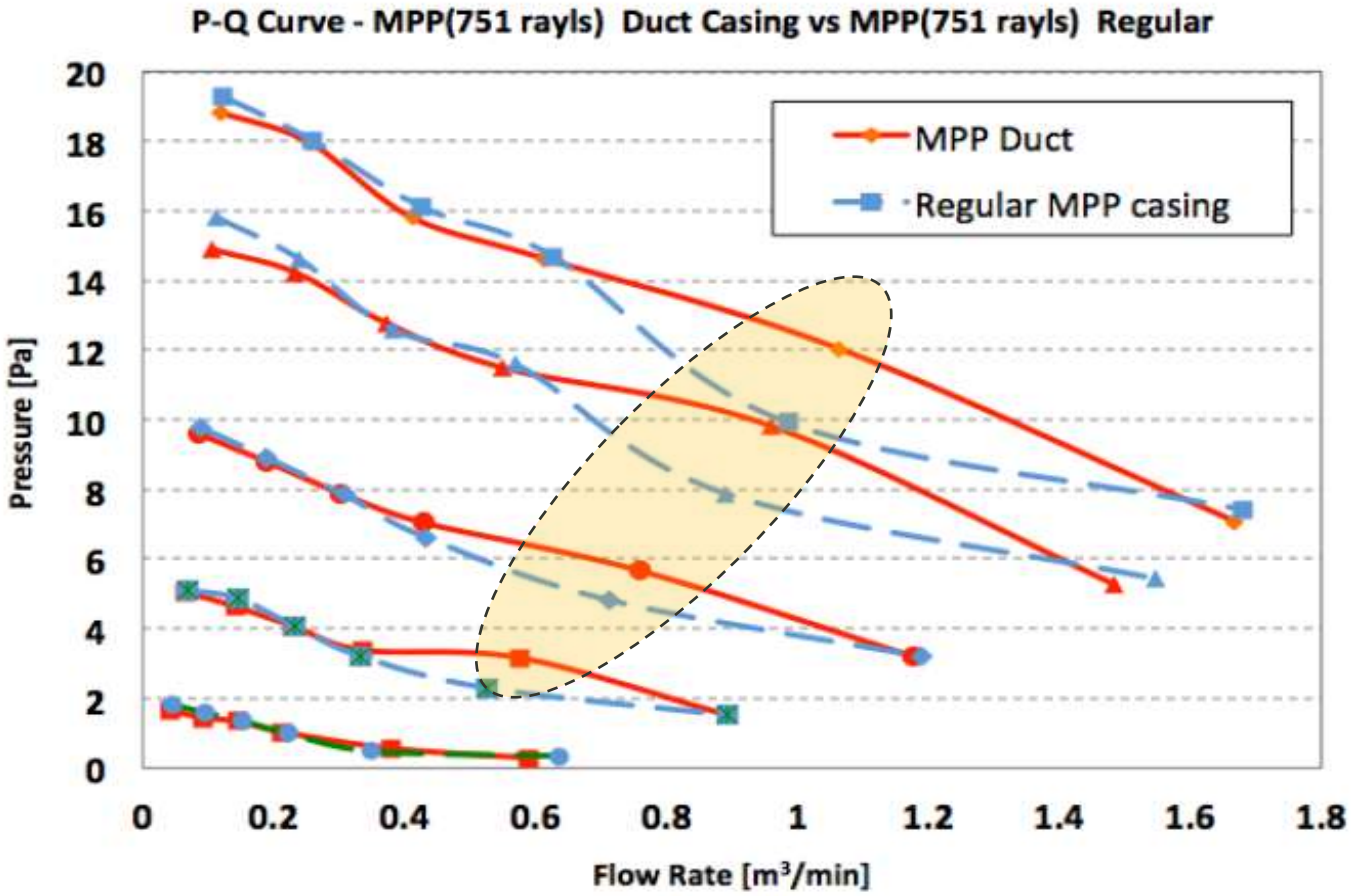
Op #	REG 751 [dB (A)]	Duct 751 [dB (A)]	Op #	REG 751 [dB (A)]	Duct 751 [dB (A)]	Op #	REG 751 [dB (A)]	Duct751 [dB (A)]
1	20.09	18.32 ↓	6	26.75	23.51 ↓	11	24.51	21.04 ↓
2	23.67	21.94 ↓	7	24.86	16.71 ↓	12	26.67	24.43 ↓
3	26.98	23.78 ↓	8	27.90	18.81 ↓	13	29.57	21.73 ↓
4	20.93	17.95 ↓	9	30.40	22.29 ↓	14	32.19	24.29 ↓
5	24.46	20.59 ↓	10	24.37	18.53 ↓	15	27.66	27.56 ↓

OVERALL SOUND POWER LEVEL



Op #	REG 751 [dB (A)]	Duct 751 [dB (A)]	Op #	REG 751 [dB (A)]	Duct 751 [dB (A)]	Op #	REG 751 [dB (A)]	Duct751 [dB (A)]
1	43.55	42.91 ↓	6	47.40	46.33 ↓	11	47.37	44.96 ↓
2	45.55	44.79 ↓	7	49.75	47.42 ↓	12	50.54	46.93 ↓
3	43.89	46.53 ↓	8	46.71	44.54 ↓	13	45.80	49.86 ↑
4	43.88	43.13 ↓	9	48.86	46.62 ↓	14	48.08	45.51 ↓
5	45.61	44.58 ↓	10	45.21	48.59 ↑	15	54.47	47.45 ↓

PERFORMANCE OF EXTENDED HOUSING



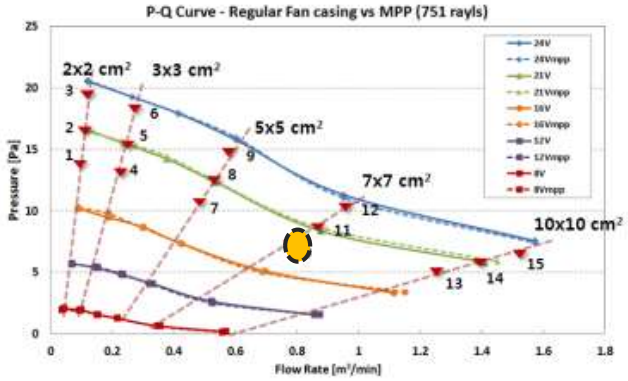
- **MPP duct casing generates more static pressure and flow rate at less operating voltage!!**

MOTOR NOISE AT OP# 10 AND 13

- Comparison

Blade-Tip Duct Short Casing

- Operating Point

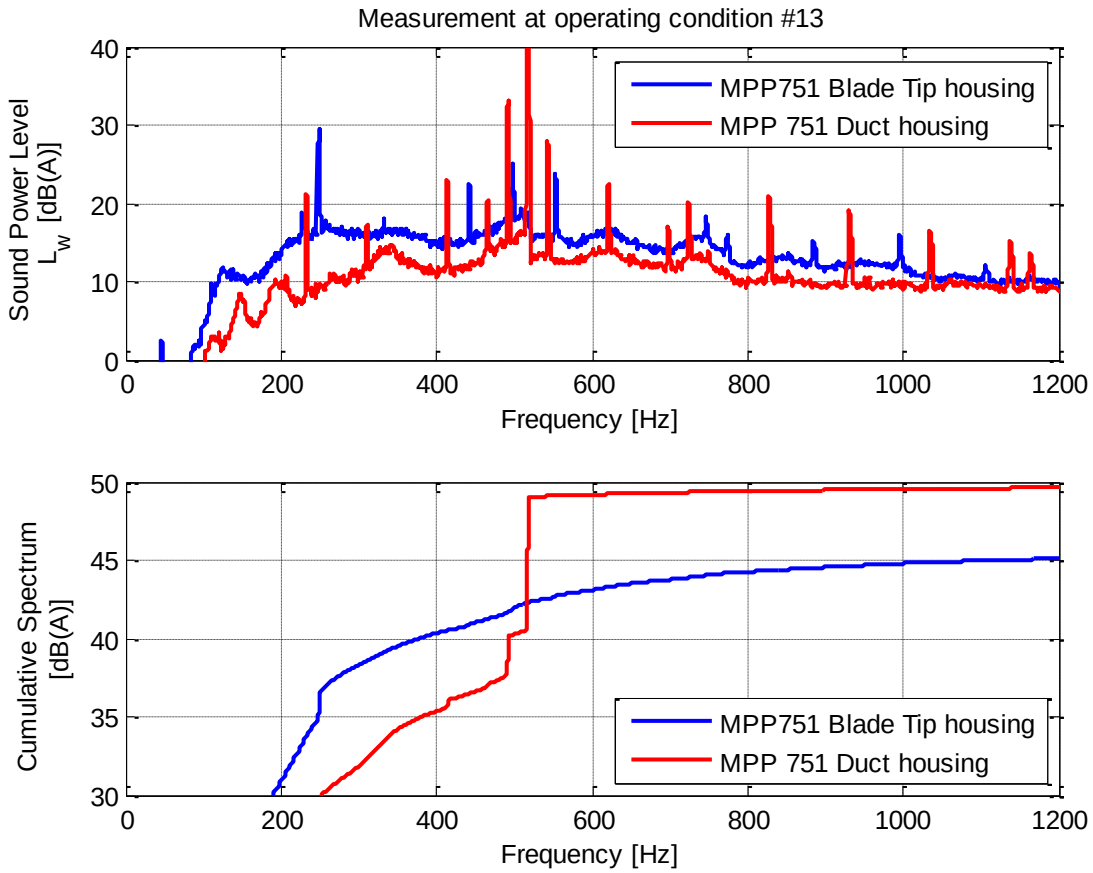


- Blade Passage Tone [dB(A)]

MPP 751	DUCT 751
29.57	21.73

- Overall Sound Power Level [dB(A)]

DUCT REG.	DUCT 751
45.80	49.86



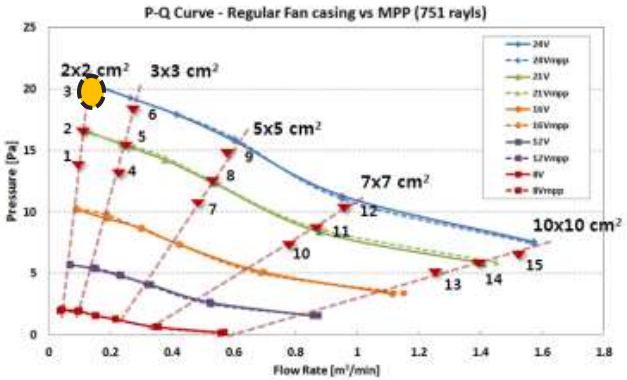
Fan needed to be operated at lower voltage to meet the operating points

SHORT DUCTS COMPARISON AT OP#3

- Comparison

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

- Operating Point

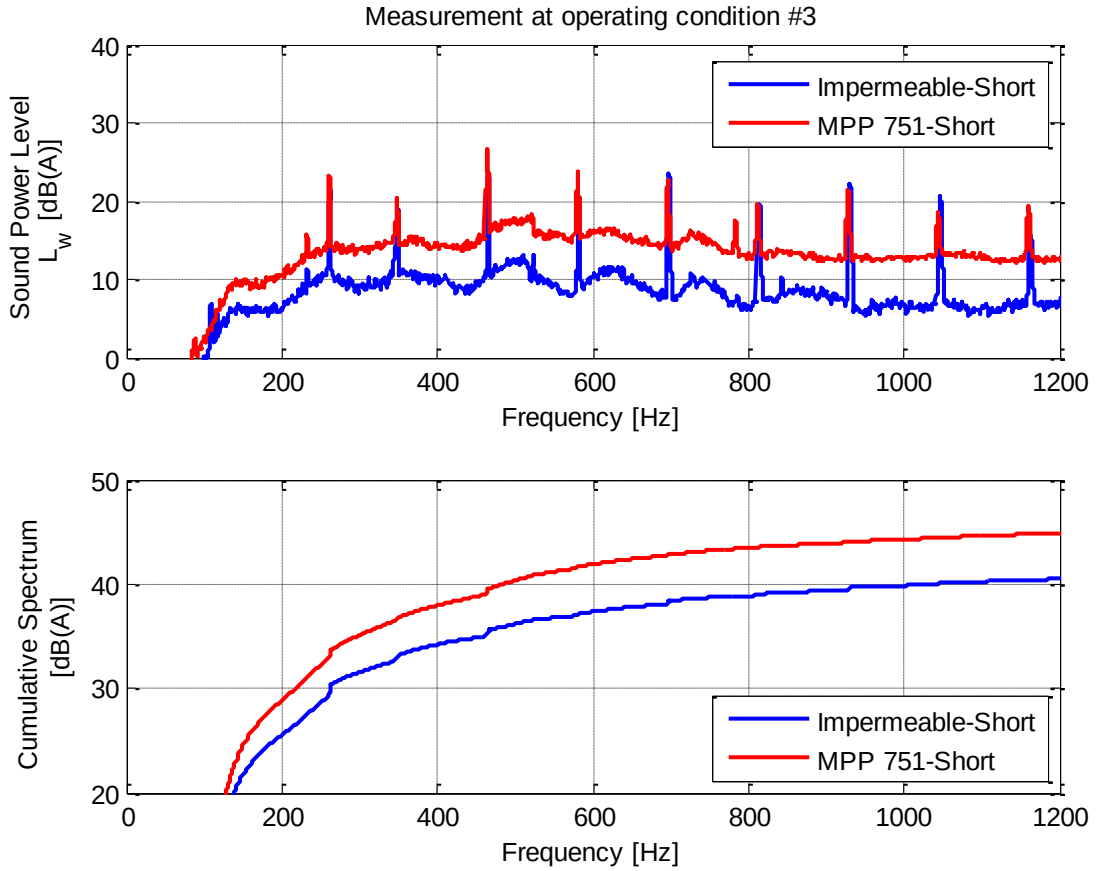


- Blade Passage Tone [dB(A)]

DUCT REG.	DUCT 751
21.34	**23.78**

- Overall Sound Power Level [dB(A)]

DUCT REG.	DUCT 751
41.91	**46.53**



BLADE PASSAGE TONE COMPARISON

op #	No Perf [dB(A)]	Duct Short [dB(A)]	op #	No Perf [dB(A)]	Duct Short [dB(A)]	op #	No Perf [dB(A)]	Duct Short [dB(A)]
1	17.43	18.32 ↑	6	21.90	23.51 ↑	11	18.18	21.04 ↑
2	19.66	21.94 ↑	7	9.88	16.71 ↑	12	21.54	24.43 ↑
3	21.35	23.78 ↑	8	12.60	18.81 ↑	13	20.09	21.73 ↑
4	16.86	17.95 ↑	9	15.22	22.29 ↑	14	23.04	24.29 ↑
5	18.44	20.59 ↑	10	16.85	18.53 ↑	15	25.66	27.66 ↑

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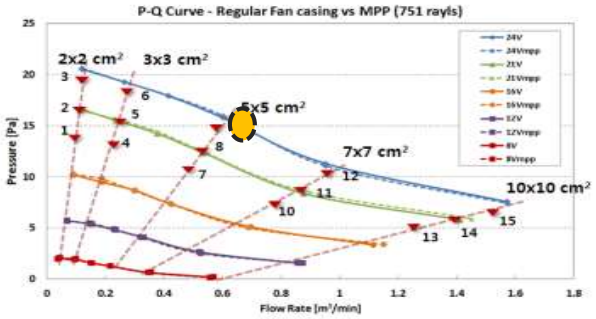
LONG DUCT RESULTS AT OP #9

- **Comparison**

Duct Long Not-Perf. **Duct Long MPP 751**

- **Operating Point**

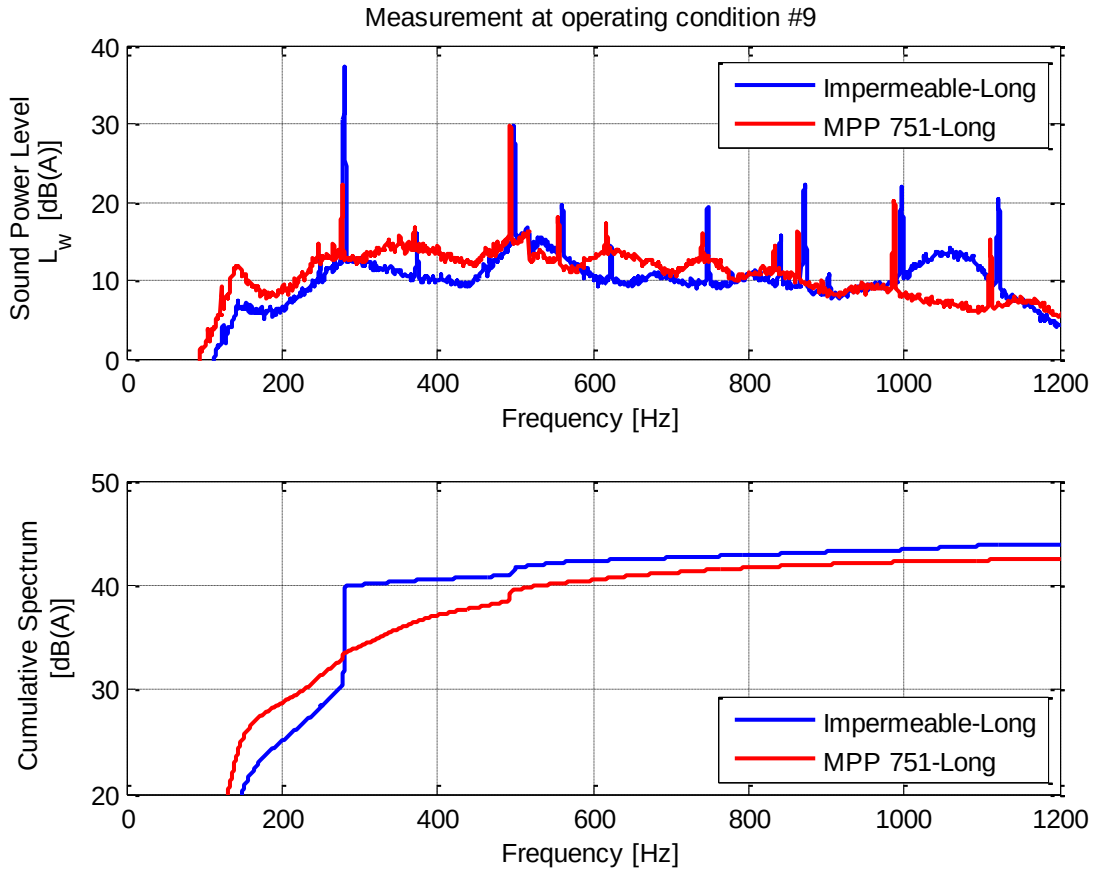


- **Blade Passage Tone [dB(A)]**

DUCT REG.	DUCT 751
37.31	22.28

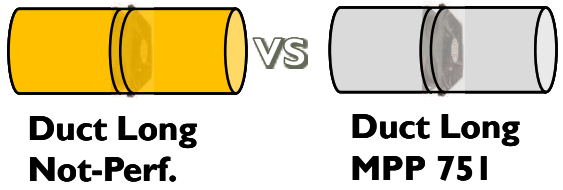
- **Overall Sound Power Level [dB(A)]**

DUCT REG.	DUCT 751
44.51	43.25

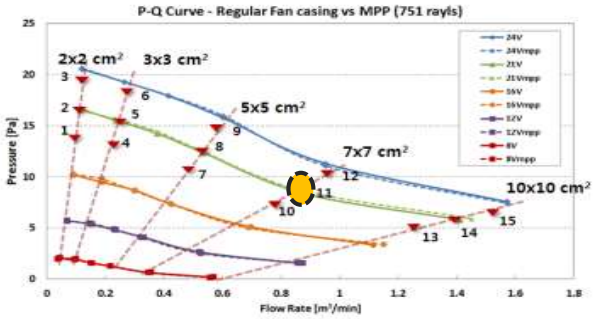


LONG DUCT RESULTS AT OP #11

- **Comparison**



- **Operating Point**

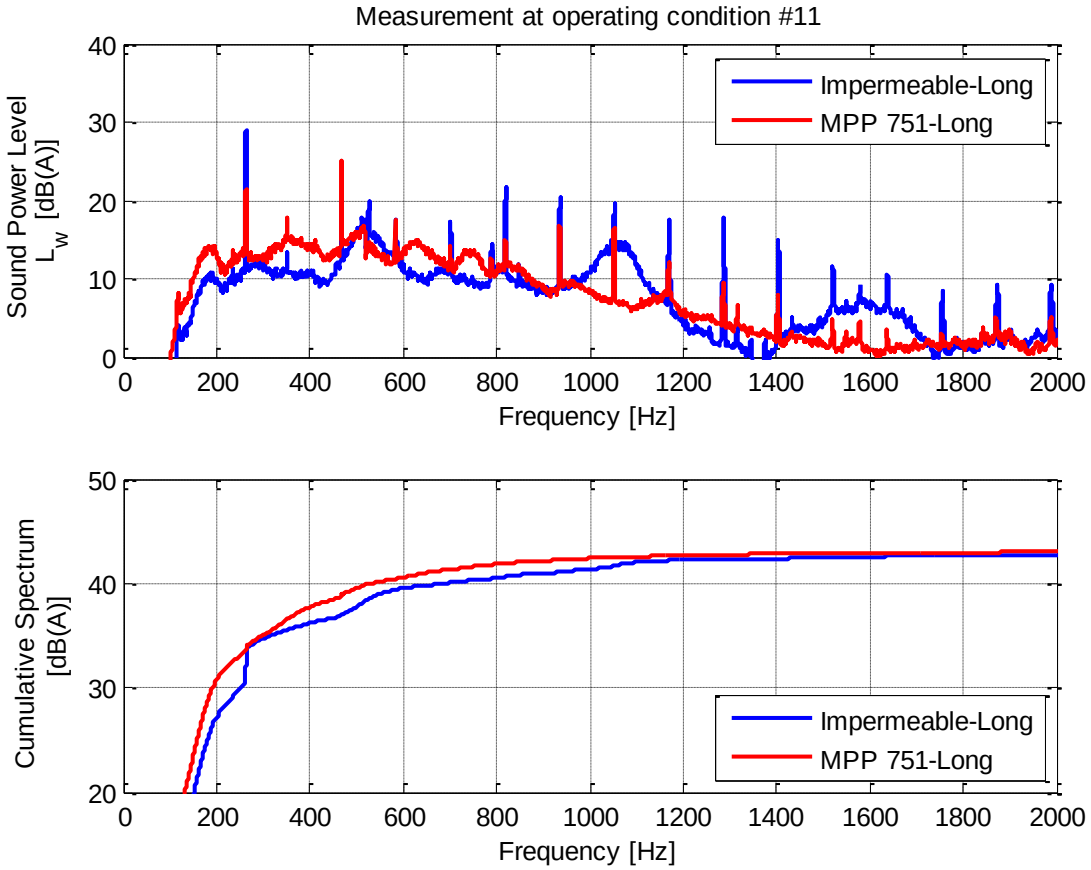


- **Blade Passage Tone [dB(A)]**

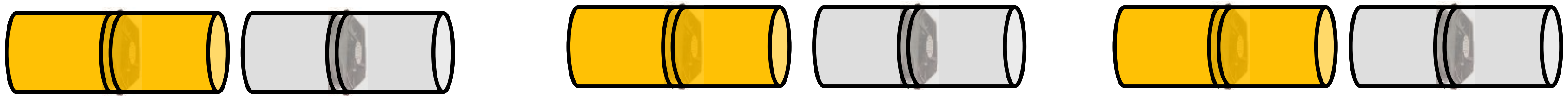
DUCT REG.	DUCT 751
29.06	21.35

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

DUCT REG.	DUCT 751
43.15	43.34



BLADE PASSAGE TONE COMPARISON
OVERALL SOUND POWER LEVEL



op #	No Perf [dB(A)]	Duct Long [dB(A)]	op #	No Perf [dB(A)]	Duct Long [dB(A)]	op #	No Perf [dB(A)]	Duct Long [dB(A)]
1	43.32	42.72 ↓	6	44.57	42.93 ↓	11	43.15	43.34 ↑
2	41.85	40.96 ↓	7	40.04	40.03 ↓	12	45.81	45.61 ↓
3	44.54	42.92 ↓	8	41.60	41.22 ↓	13	46.87	41.19 ↓
4	43.16	43.10 ↓	9	44.51	43.25 ↓	14	44.14	43.14 ↓
5	41.69	40.96 ↓	10	41.50	41.29 ↓	15	46.98	45.11 ↓

STATIC PRESSURE PERFORMANCE

- Measured using pressure gauge SETRA 264 model
- Pressure measured by maintaining the operating voltage of the fans with different duct materials the same.

- Pressures generated by the short duct (Total length = 12cm) [Pa]

	REG	Duct 751		REG	Duct 751		REG	Duct 751
1	12.8	11.29 ↓	6	16.8	16.2 ↓	11	9.2	9.03 ↓
2	15.7	15.14 ↓	7	9.78	9.4 ↓	12	10.9	10.8 ↓
3	18.0	17.03 ↓	8	11.6	11.1 ↓	13	4.64	4.14 ↓
4	11.9	11.51 ↓	9	13.7	13.0 ↓	14	5.37	5.10 ↓
5	14.5	14.16 ↓	10	7.90	7.78 ↓	15	6.78	6.40 ↓

- Pressures generated by the long duct (Total length = 55.6cm) [Pa]

	REG	Duct 751		REG	Duct 751		REG	Duct 751
1	10.1	10.8 ↑	6	13.5	15.2 ↑	11	7.97	8.26 ↑
2	11.8	12.9 ↑	7	8.78	9.45 ↑	12	9.83	10.7 ↑
3	13.9	15.8 ↑	8	10.9	11.1 ↑	13	4.27	4.27 ↑
4	9.80	10.8 ↑	9	12.6	13.2 ↑	14	5.06	5.06
5	11.6	12.8 ↑	10	6.69	6.92 ↑	15	6.14	6.03 ↓

CONCLUSION & FUTURE PLAN

- It was found that the tip noise of an axial fan could be reduced by using microperforated housings.
- Flow resistance of microperforated housing should be carefully determined depending on the operation environment of the fan.
- Extension of microperforated housing to inlet and outlet of the fan was also considered.
- The microperforated duct could provide better performance in flow transfer and static pressure generation compared to the impermeable duct.
- More microperforated materials will be tested in the microperforated ducted fan along with different inlet and outlet length combinations.
- The sound field generated by the fan with different housings will be studied.
- Resonant fan scroll housing will be considered.

APPENDIX – MOTOR NOISE MOVIE