8-1-2012

CFD Modeling of Tapered Hole Microperforated Panels

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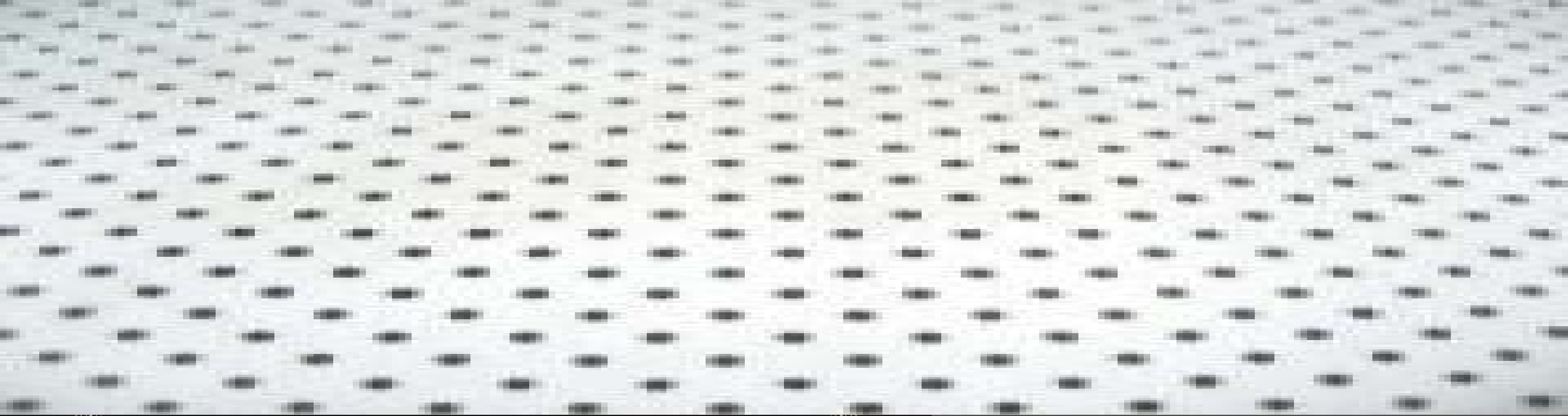

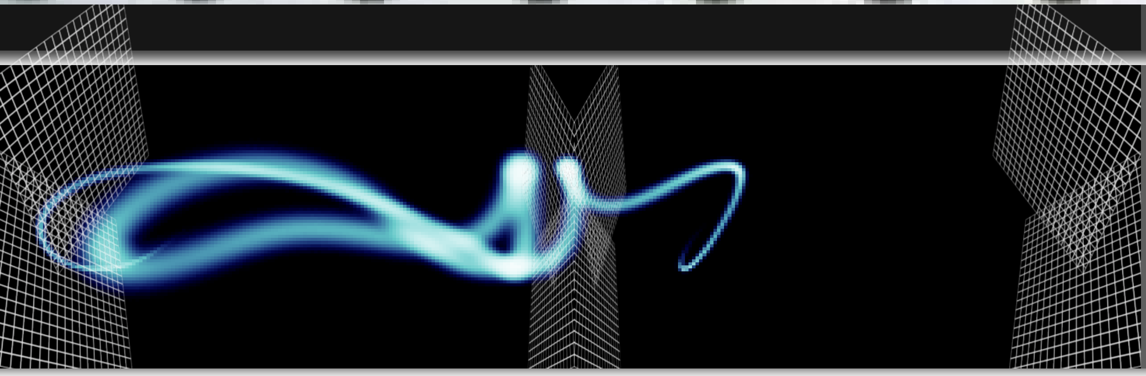

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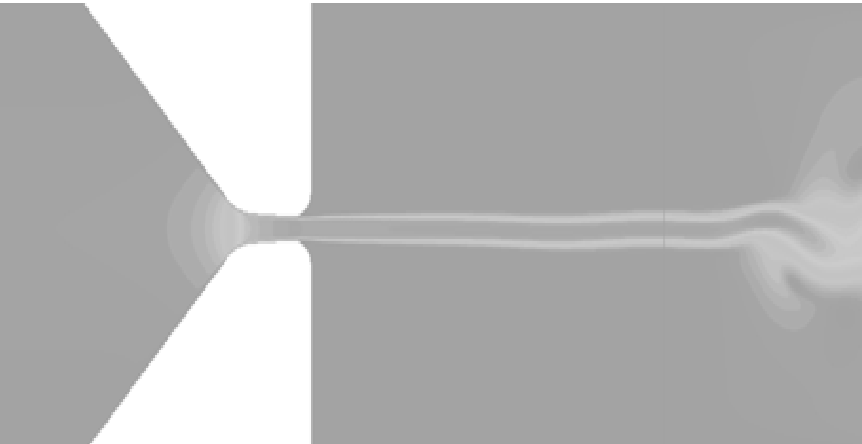

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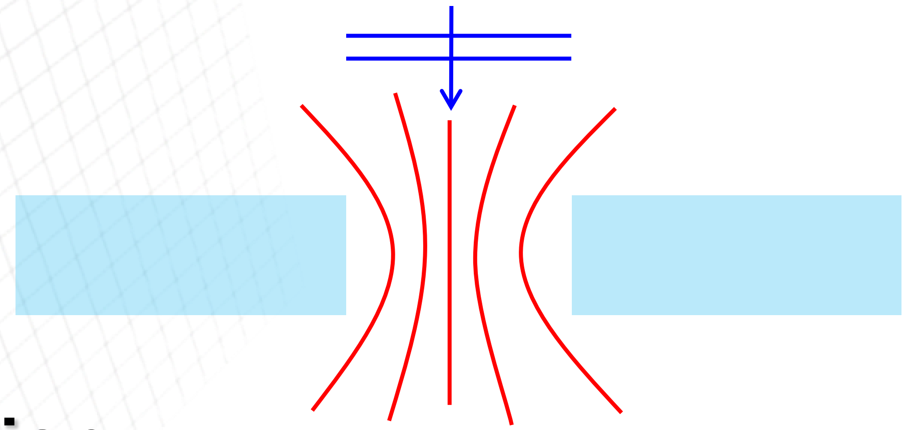
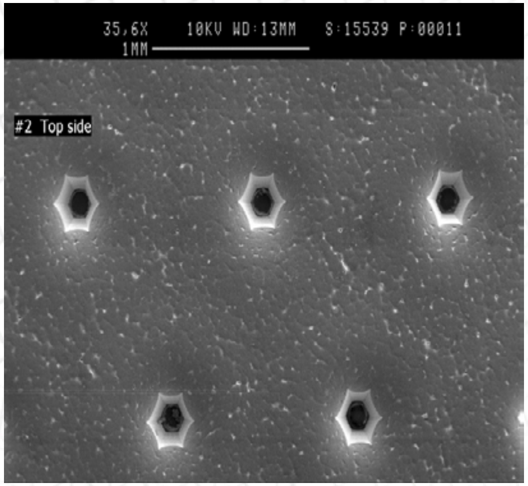
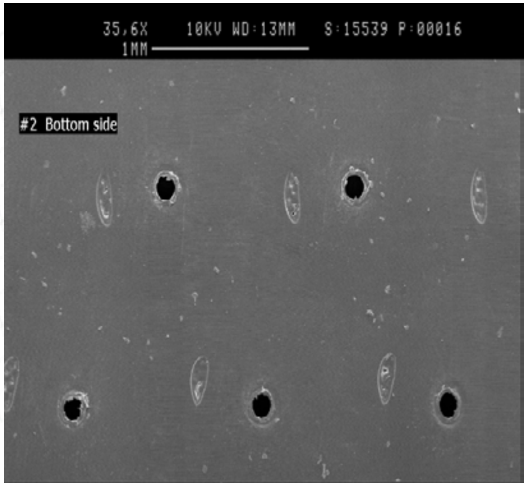
Internoise 2012
Aug 21, 2012

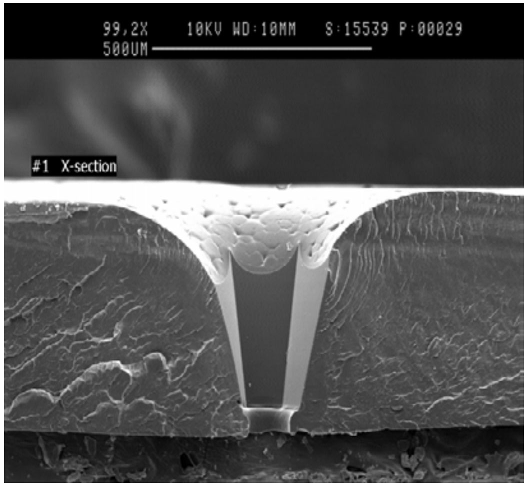
- **Microperforated material**



- **Dissipation**
  - In hole
  - Along outer surface
  - Within shearing fluid
- **Analytical models**
  - Maa (1975) and Guo *et al.* (2008) account for first two





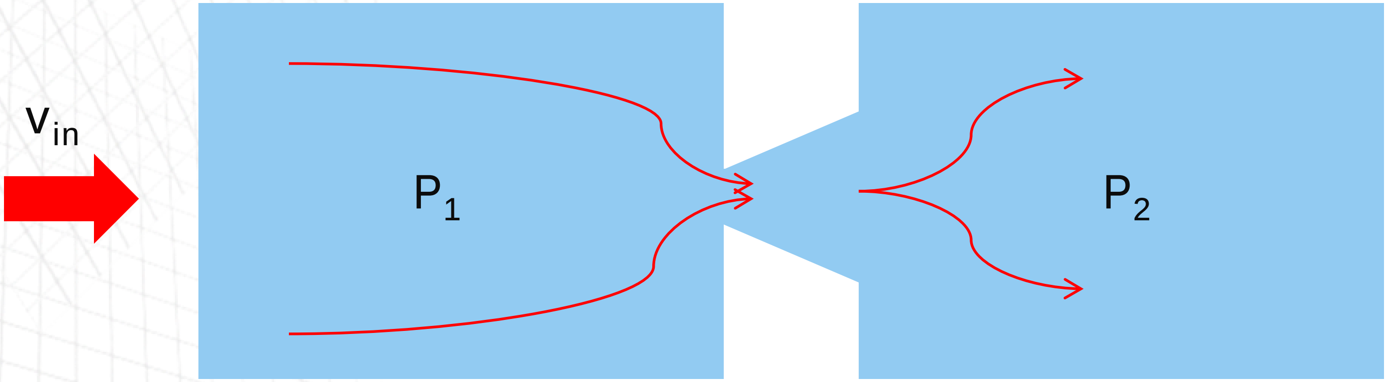


Microperforated panel

Real materials do not have regular hole shapes and so are not suitable for analytical treatment

Objective

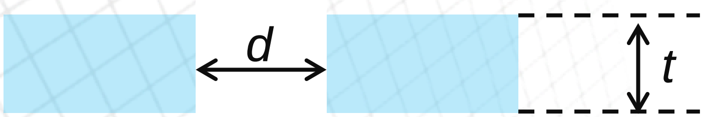
By using computational fluid dynamics approach, calculate dynamic flow resistance for tapered hole microperforated panel considering flow through one hole and compare with existing formulation



$$R_f = \frac{P_1 - P_2}{v_{in}}$$

Guo's Model

Guo Model



Properties

t : thickness of panel
d : diameter of hole
σ : porosity
ω : frequency
R_s : surface resistance

Cylinder | Surface

$$R = \left(Re\left\{ \frac{j\omega t}{\sigma c}\left[1 - \frac{2}{k\sqrt{-j}}\frac{J_1(k\sqrt{-j})}{J_0(k\sqrt{-j})}\right]^{-1} \right\} + \frac{\alpha 2R_s}{\sigma\rho c} \right) \times \rho c$$

$$k = d\sqrt{\frac{\omega\rho_0}{4\eta}} \qquad R_s = \frac{\sqrt{2\omega\rho_0\eta}}{2}$$

$\alpha = 2$ when smooth end

$\alpha = 4$ when sharp end

Dynamic Flow resistance (R) is function of *t, d, σ*

Note that $R_s \rightarrow 0$ as $\omega \rightarrow 0$

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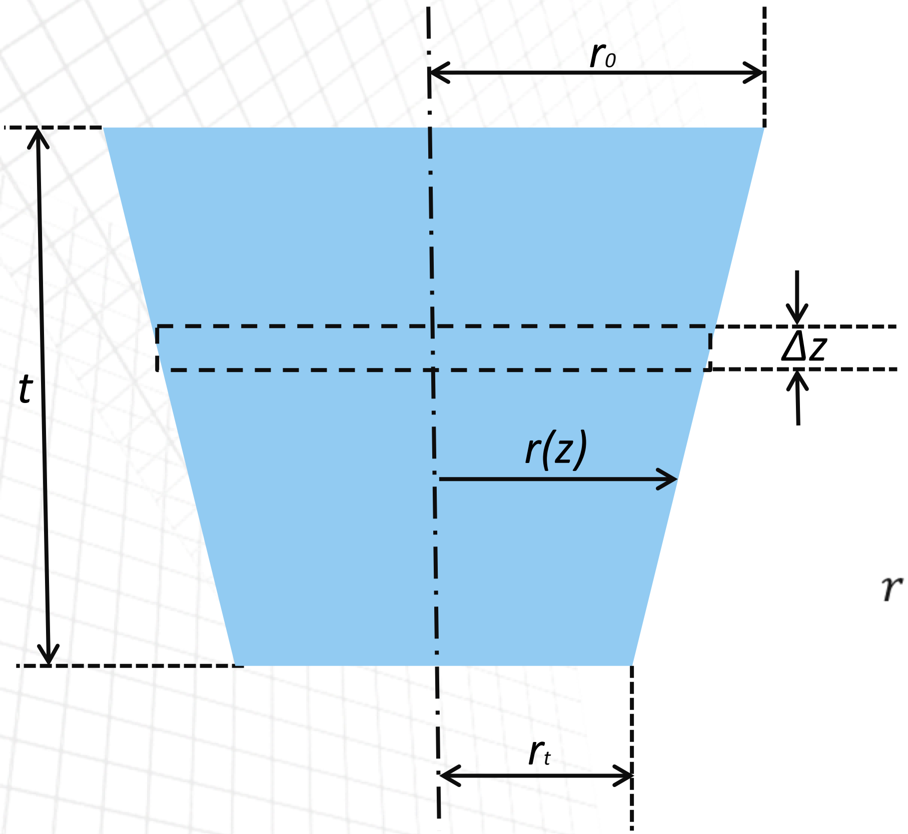
Analytical Solution (Randeberg, 2000)

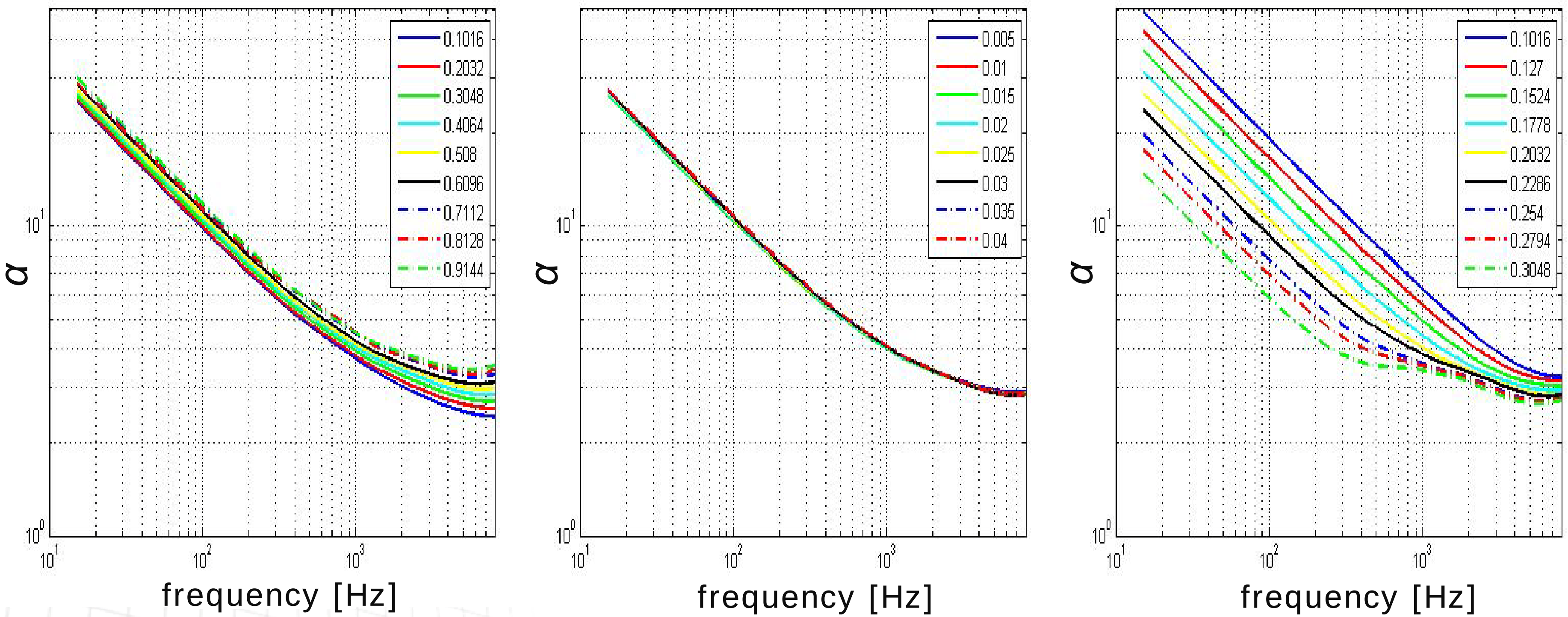


Based on Guo's model, Randeberg used integration method. (used *α = 4 for sharp edged)*

$$r = Re\left\{\sum_{n=1}^{N}\frac{j\omega\Delta z}{\sigma_n c}\left[1-\frac{2}{k_n\sqrt{-j}}\frac{J_1\left(k_n\sqrt{-j}\right)}{J_0\left(k_n\sqrt{-j}\right)}\right]^{-1}\right\} + \frac{\alpha R_s}{\sigma_1 \rho c} + \frac{\alpha R_s}{\sigma_N \rho c}$$

Previous work (sharp-edged hole)

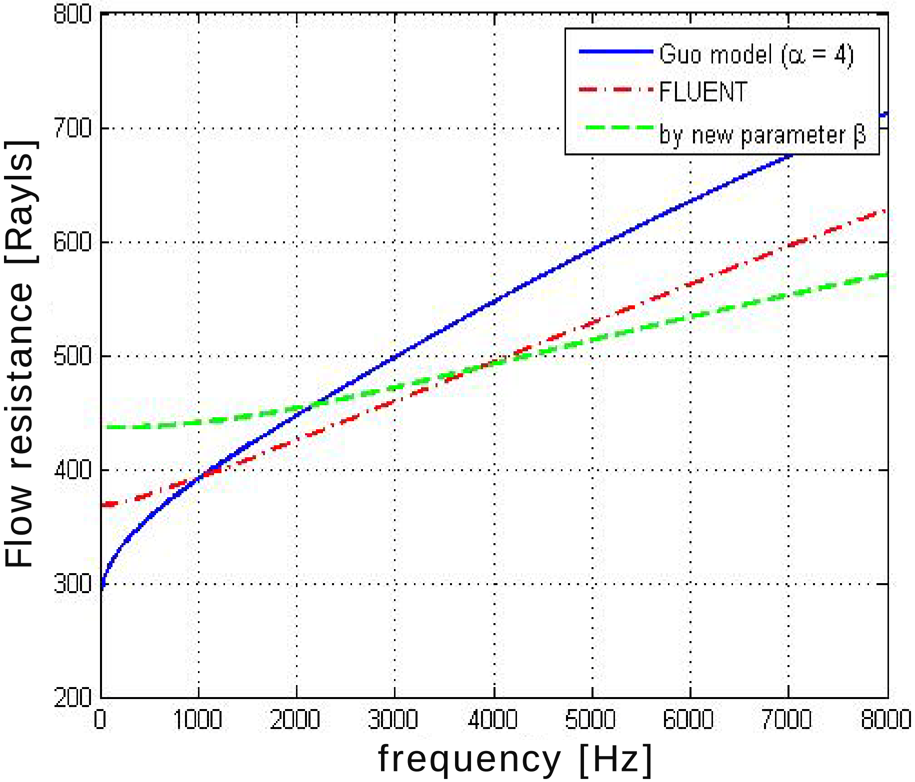
The value of α vs. Frequency



In these graphs, it is shown that α is a function of frequency, thickness, and hole diameter

Previous work (sharp-edged hole)

Flow resistance computed by Fluent vs. β



(at t = 0.4064 mm, d = 0.2032 mm, σ = 0.02)

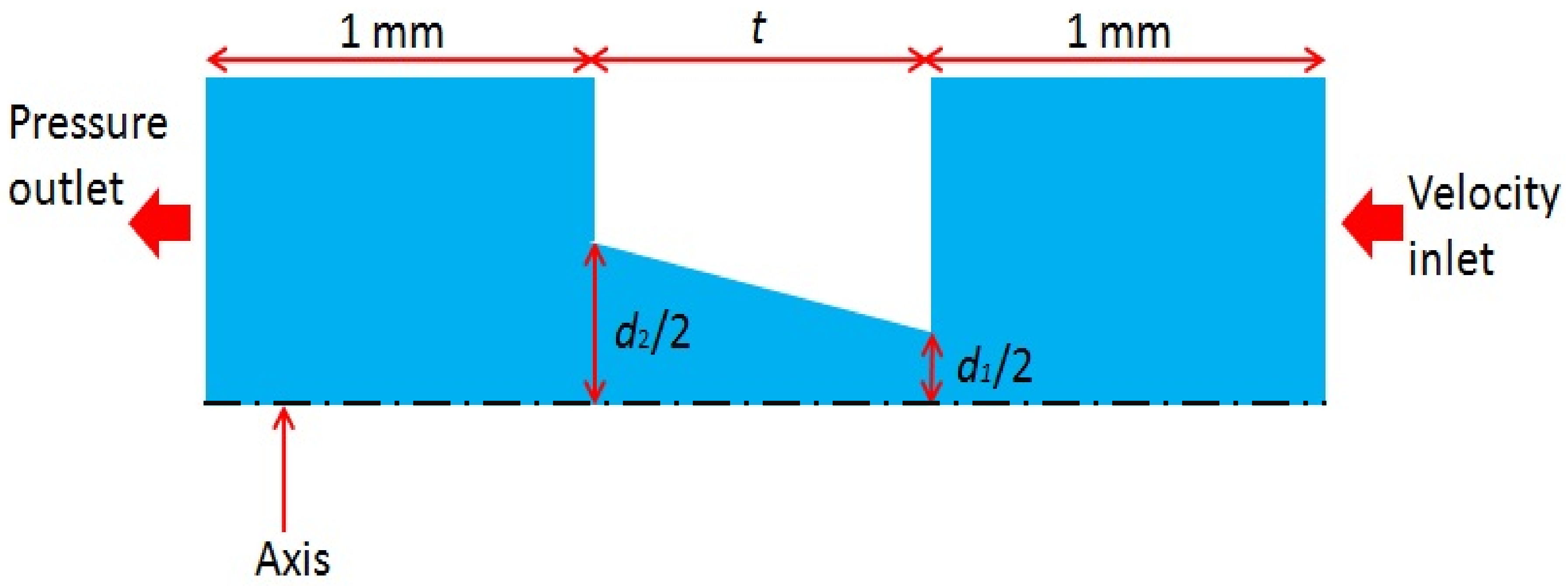
α, end correction coefficient in Guo model, is dependent on frequency.

$$\alpha = \beta f^{-0.5}$$

β is function of thickness, hole diameter, and porosity.

$$\beta = 16.9\frac{t}{d} + 152.8$$

Geometry of CFD model



Mesh size : 0.005 mm, calculating time : 3-8 hours

CFD Parameters

36 Cases with 9 different thicknesses

(t = 0.1016 mm – 0.9144 mm)

	d_1 [mm]	d_2 [mm]		d_1 [mm]	d_2 [mm]		d_1 [mm]	d_2 [mm]
Case1	0.1016	0.127	**Case13**	0.127	0.254	**Case25**	0.1778	0.2794
Case2	0.1016	0.1524	**Case14**	0.127	0.2794	**Case26**	0.1778	0.3048
Case3	0.1016	0.1778	**Case15**	0.127	0.3048	**Case27**	0.2032	0.2286
Case4	0.1016	0.2032	**Case16**	0.1524	0.1778	**Case28**	0.2032	0.254
Case5	0.1016	0.2286	**Case17**	0.1524	0.2032	**Case29**	0.2032	0.2794
Case6	0.1016	0.254	**Case18**	0.1524	0.2286	**Case30**	0.2032	0.3048
Case7	0.1016	0.2794	**Case19**	0.1524	0.254	**Case31**	0.2286	0.254
Case8	0.1016	0.3048	**Case20**	0.1524	0.2794	**Case32**	0.2286	0.2794
Case9	0.127	0.1524	**Case21**	0.1524	0.3048	**Case33**	0.2286	0.3048
Case10	0.127	0.1778	**Case22**	0.1778	0.2032	**Case34**	0.254	0.2794
Case11	0.127	0.2032	**Case23**	0.1778	0.2286	**Case35**	0.254	0.3048
Case12	0.127	0.2286	**Case24**	0.1778	0.254	**Case36**	0.2794	0.3048

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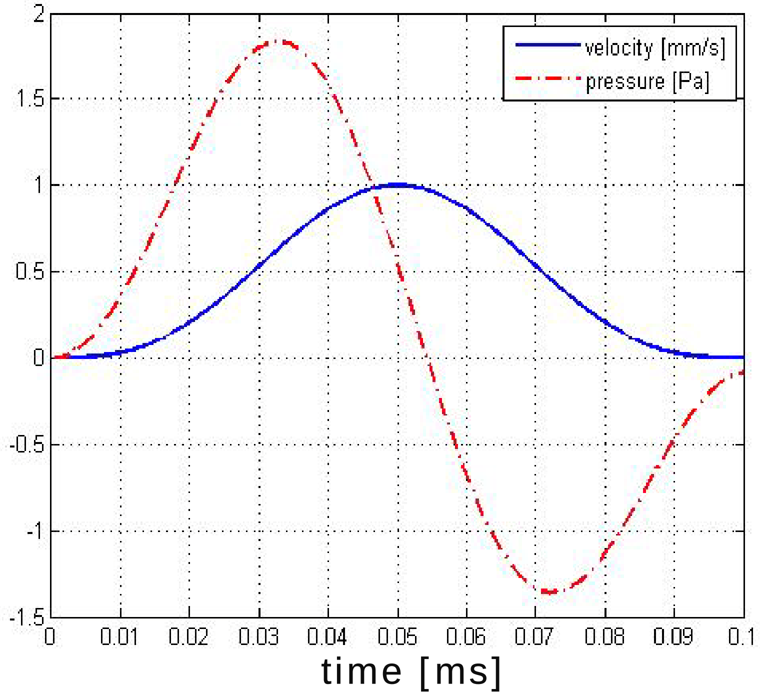
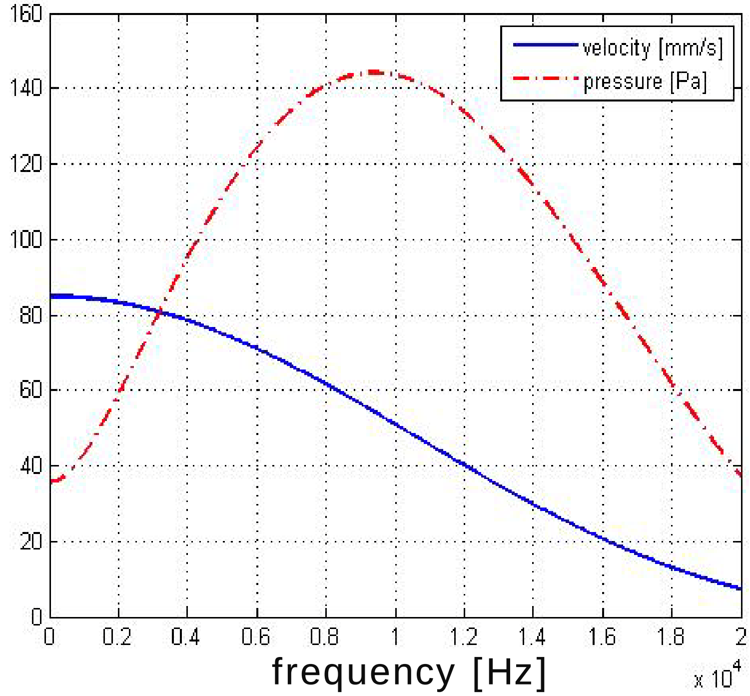
Input velocity and pressure

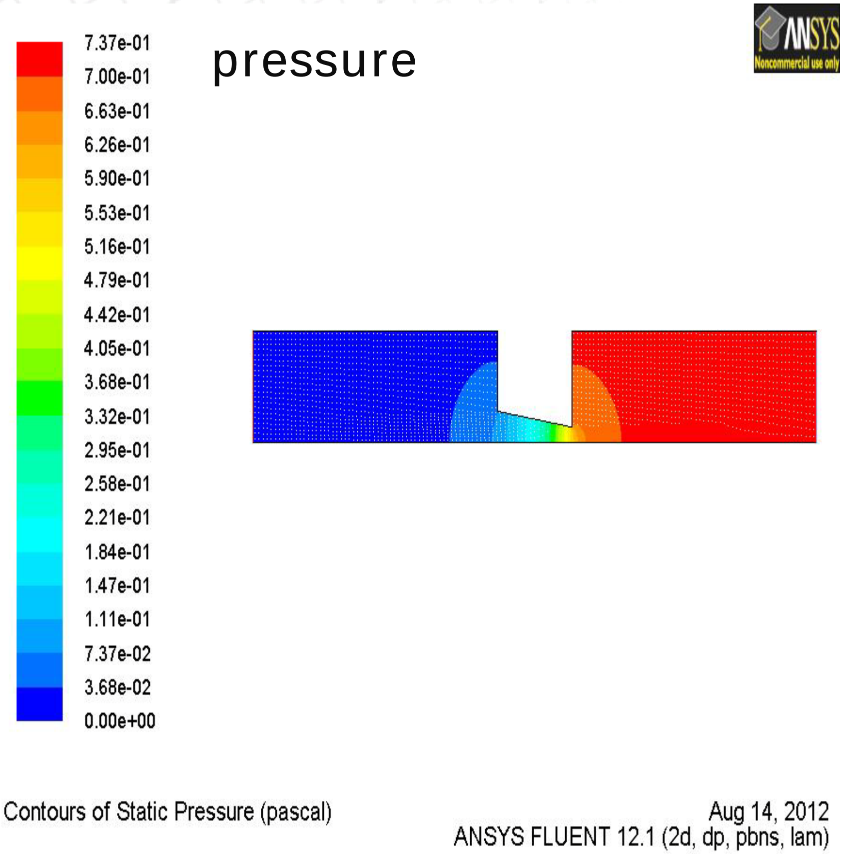


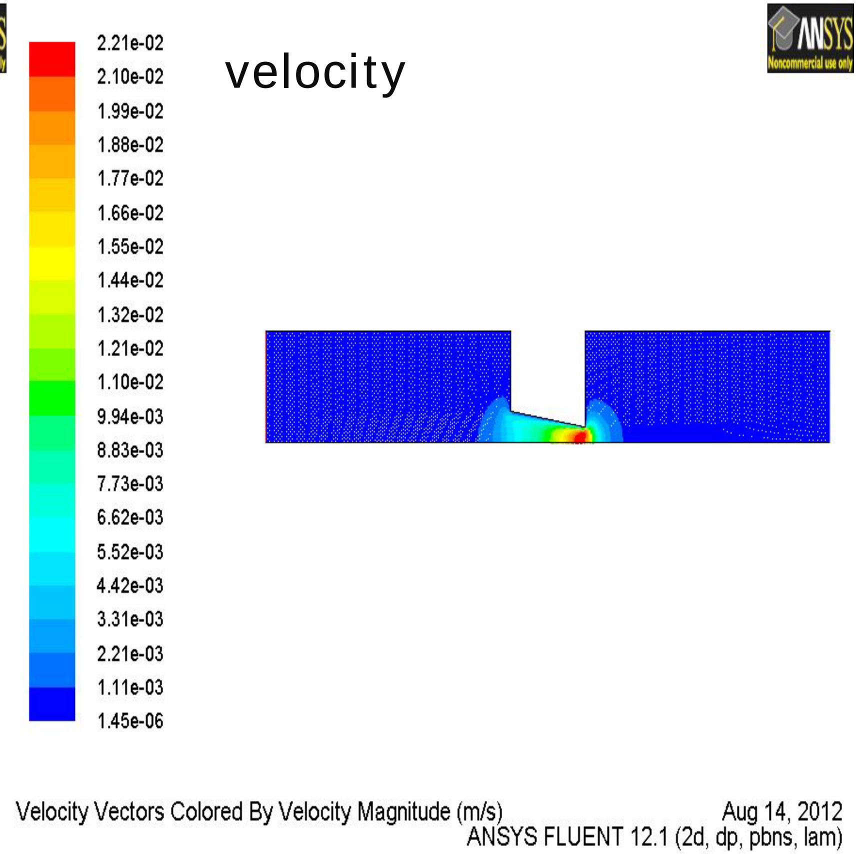


Inlet velocity was chosen to be a Hann windowed, 5 kHz half-sine wave having a maximum value of 1 mm/s in order to cover the frequency range up to 10 kHz

Pressure & velocity results from simulation

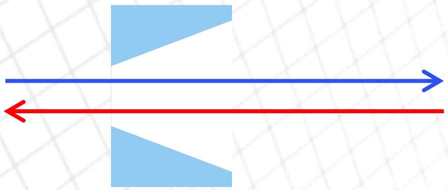
t = 0.4064 mm, d_1= 0.1016 mm, d_2= 0.2032 mm, σ = 0.02



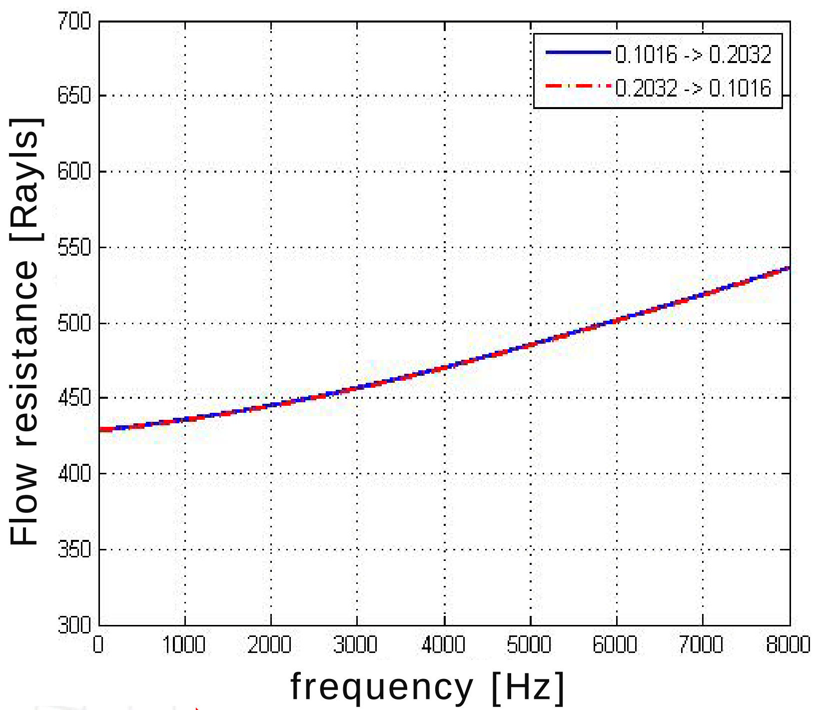


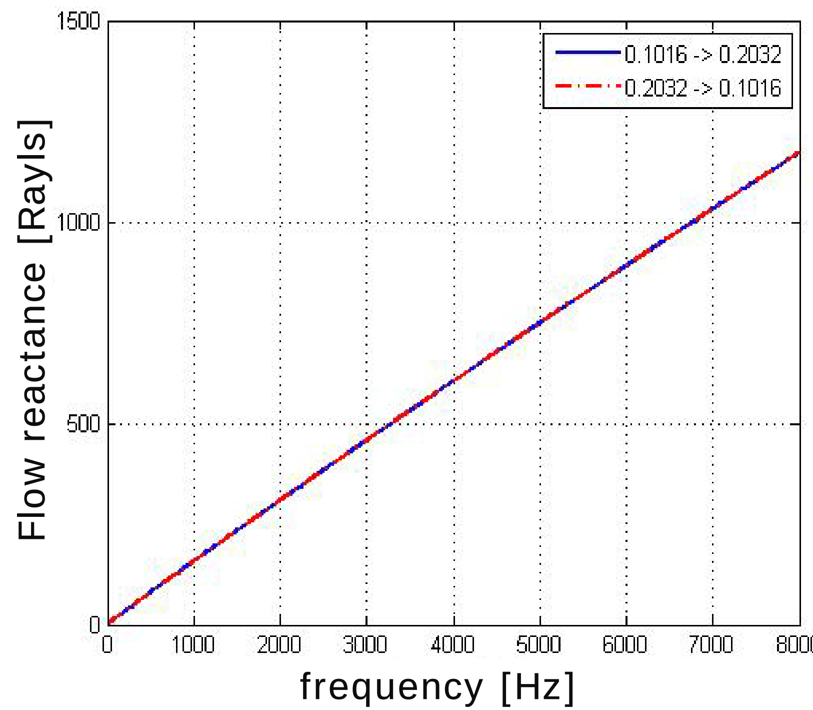
Flow resistance & reactance

(t = 0.4064 mm, σ = 0.02, d_1 = 0.1016 mm, d_2 = 0.2032 mm)



flow direction



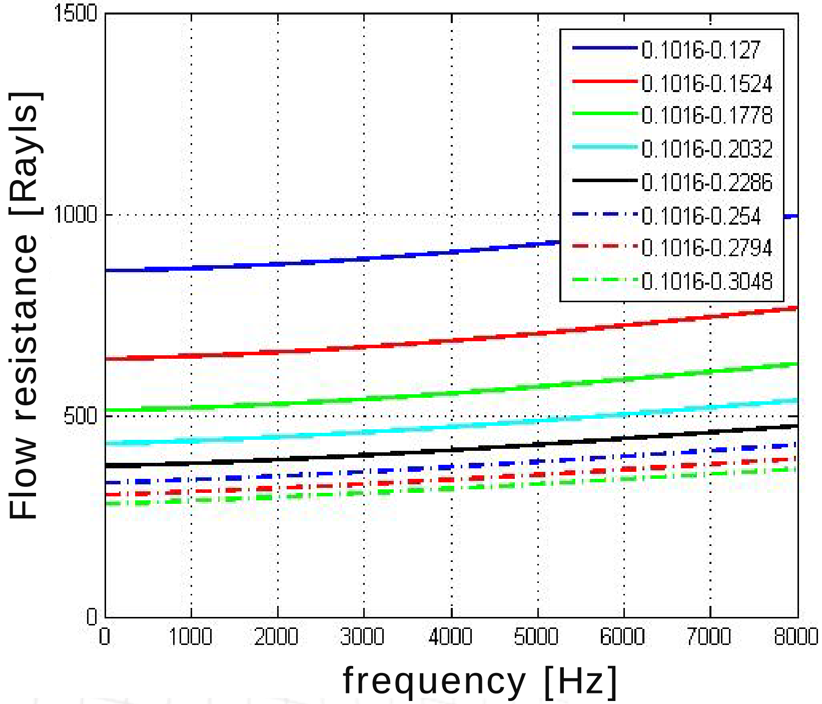


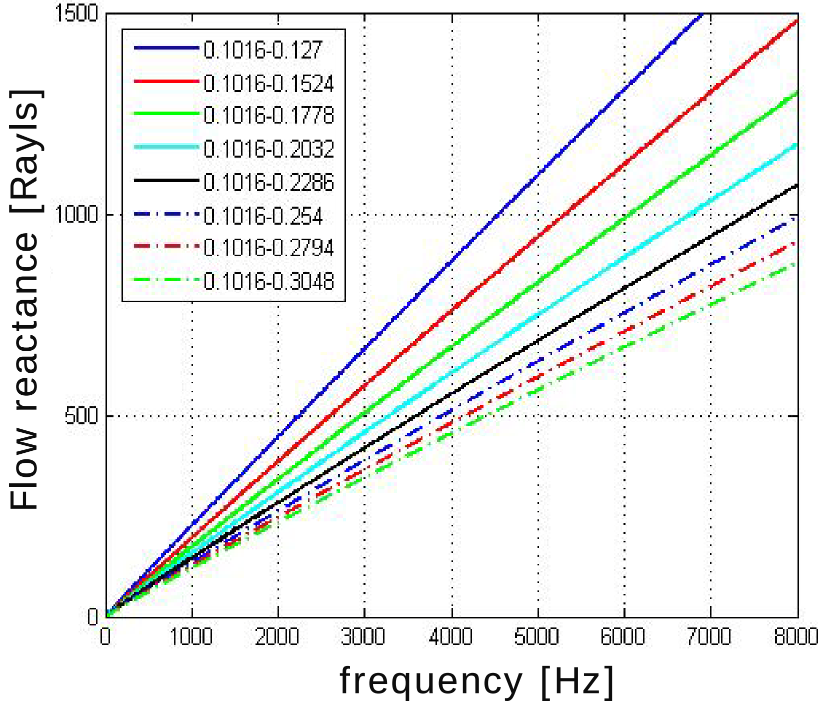
Flow direction does not affect resistance or reactance

Dynamic flow resistance and reactance

Fixed diameter of inlet hole

(t = 0.4064 mm, σ = 0.02, d_1 = 0.1016 mm)

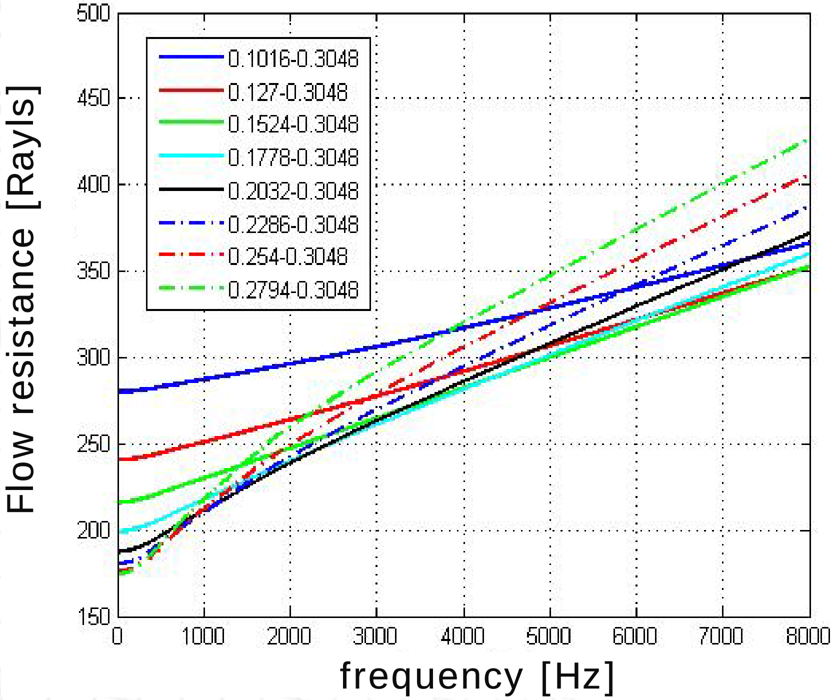


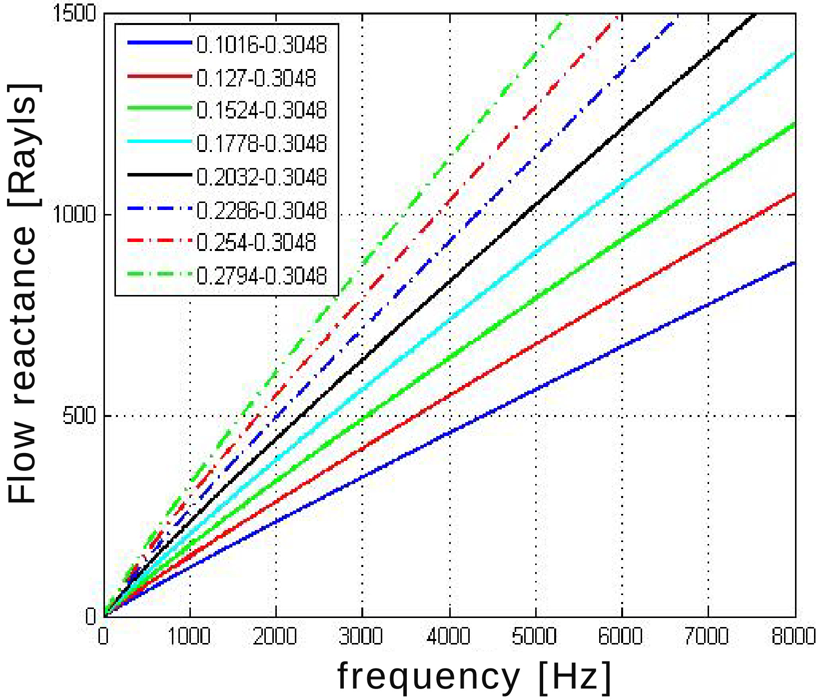


Dynamic flow resistance and reactance

Fixed diameter of outlet hole

(t = 0.4064 mm, σ = 0.02, d_1 = 0.3.48 mm)

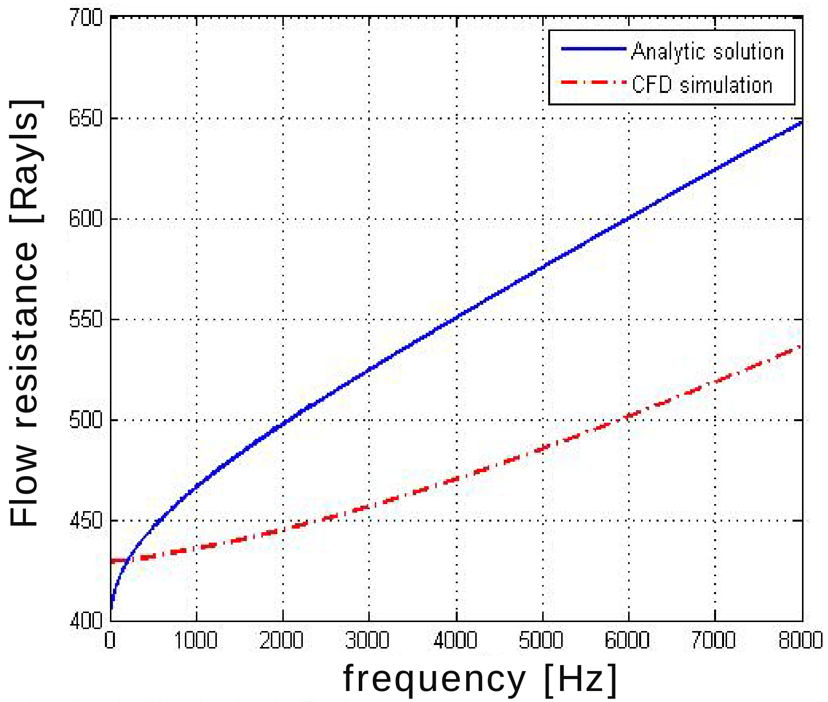


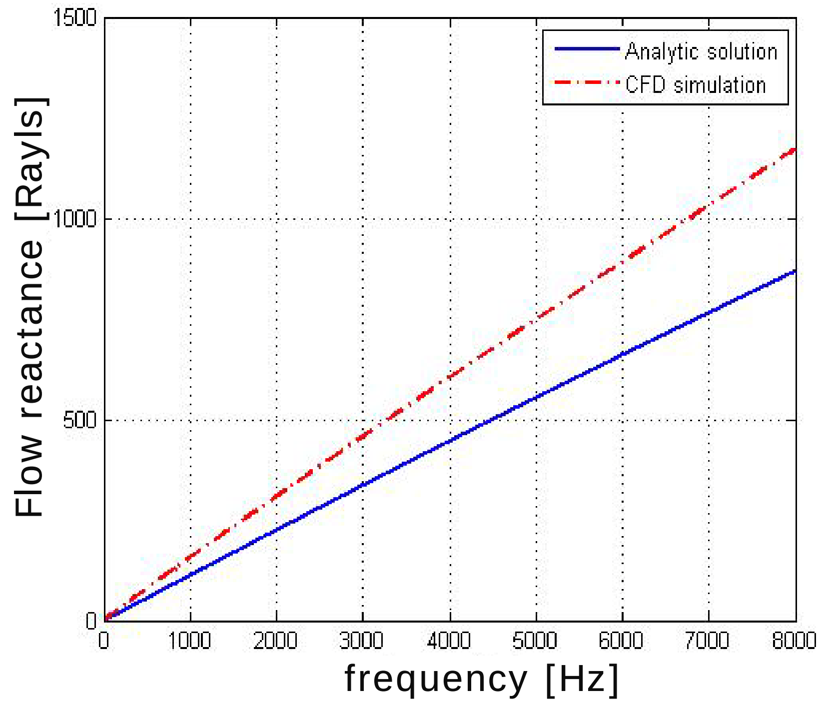


Compared CFD Result with Guo Model

Flow resistance & reactance

(t = 0.4064 mm, σ = 0.02, d_1 = 0.1016 mm, d_2 = 0.2032 mm)





Make α, which is defined by Guo *et al.*, function of frequency to fit with CFD results

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Error correction factor α

In the previous work (sharp-edged cylindrical hole)

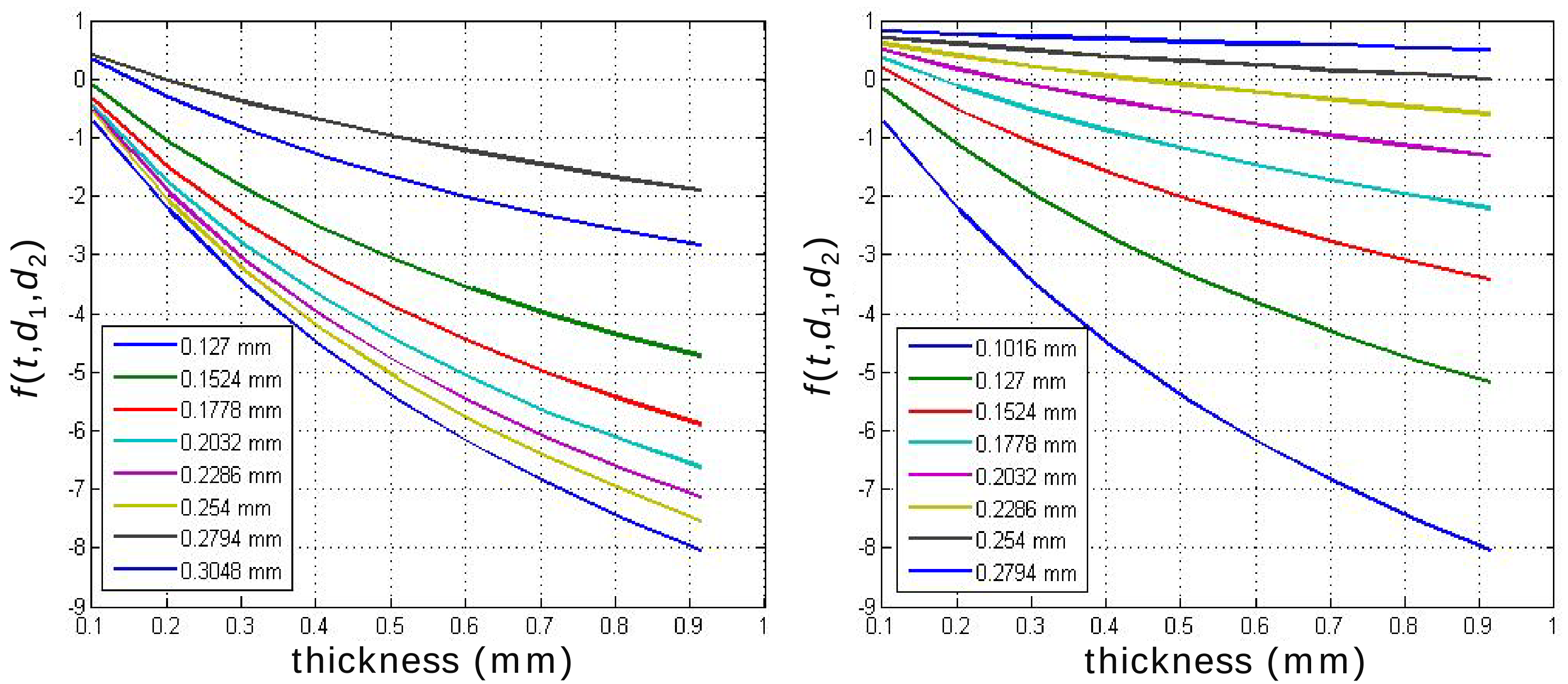
$$\alpha = (16.9\frac{t}{d} + 152.8)f^{-0.5}$$

$$\alpha = \beta f^{-0.5}$$

Make β a function as thickness, inlet diameter, and outlet diameter.

$$\beta = \left(16.9\frac{t}{d_1} + 153\right)f(t, d_1, d_2)$$

Define $f(t, d_1, d_2)$



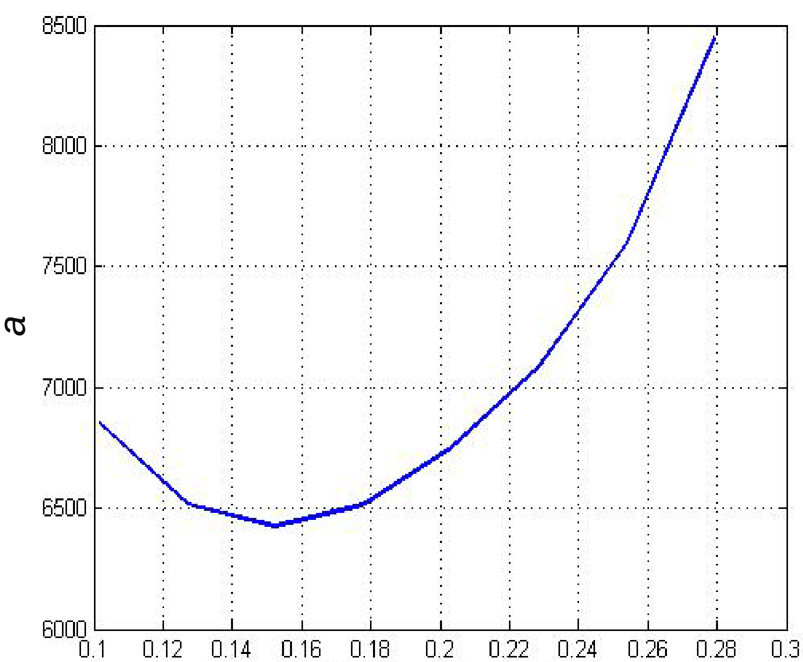
(left is fixed by d_1 = 0.1016 mm, and right is fixed by d_2 = 0.3048 mm)

Inversely proportional to thickness and almost linear

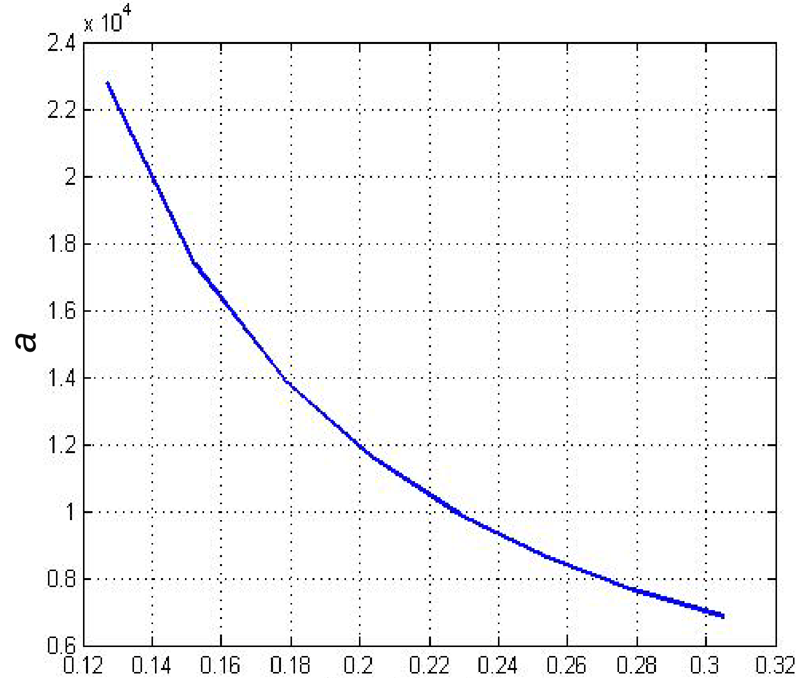
$$\Rightarrow f(t, d_1, d_2) = a\left(1 - \frac{d_2}{d_1}\right)t + 1$$

The value of a vs. Frequency

Define slope *a*



inlet hole diameter (mm)



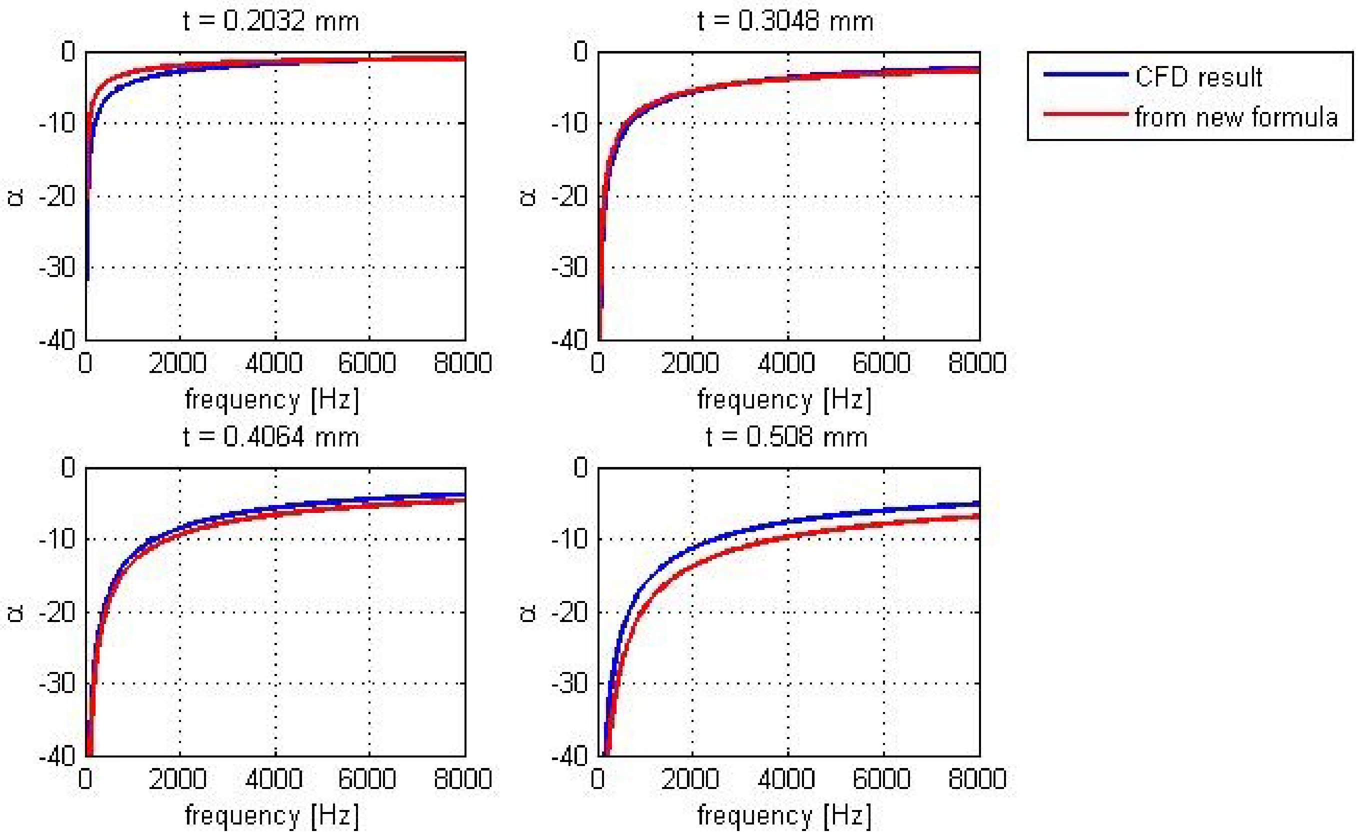
outlet hole diameter (mm)

By second order Newton interpolation

$$a = \left(6.66\left(\frac{d_1}{d_2}\right)^2 - 7.07\left(\frac{d_1}{d_2}\right) + 3.06\right) \times 10^4$$

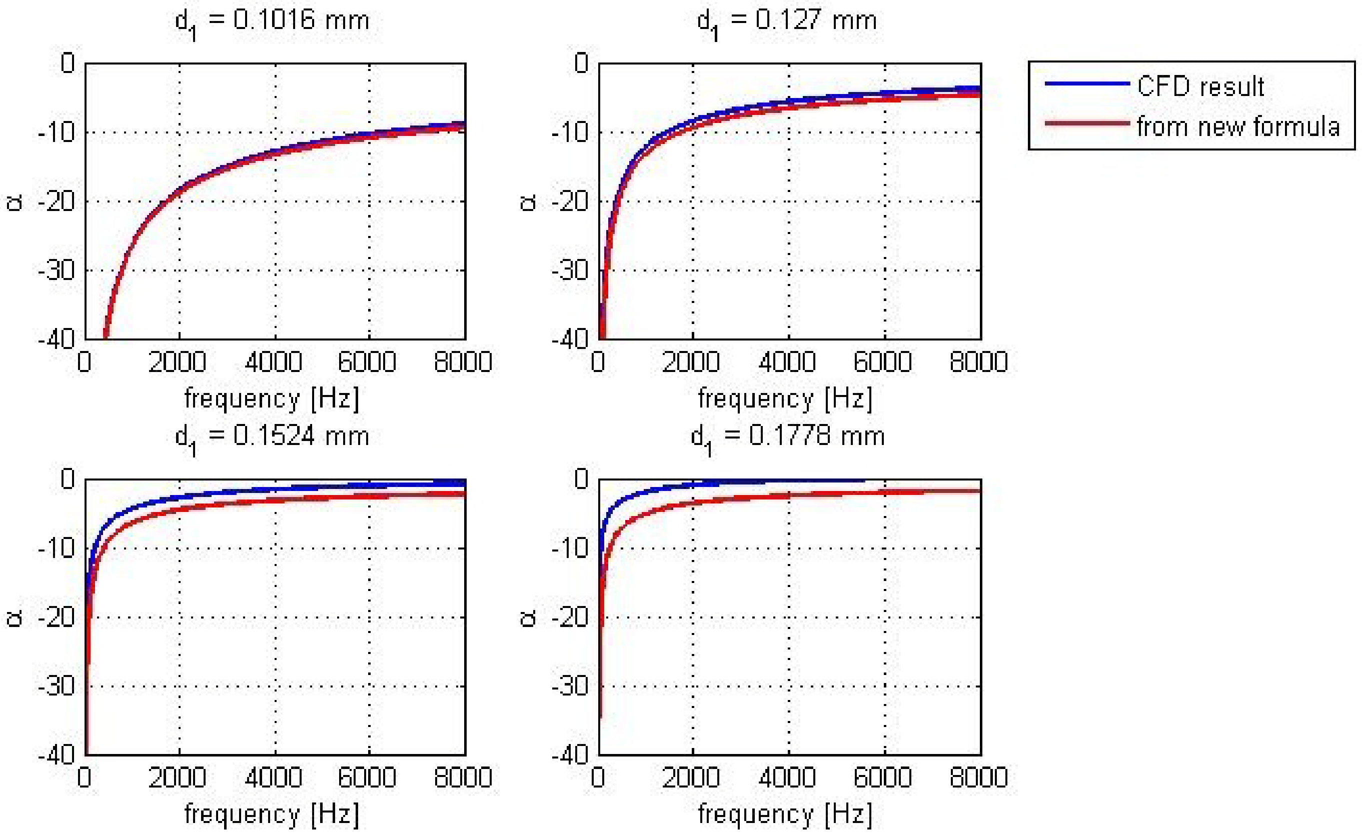
The value of α vs. Frequency

d_1 = 0.1016 mm, d_2 = 0.2032 mm, σ = 0.02



The value of α vs. Frequency

t = 0.4064 mm, d_2 = 0.2032 mm, σ = 0.02



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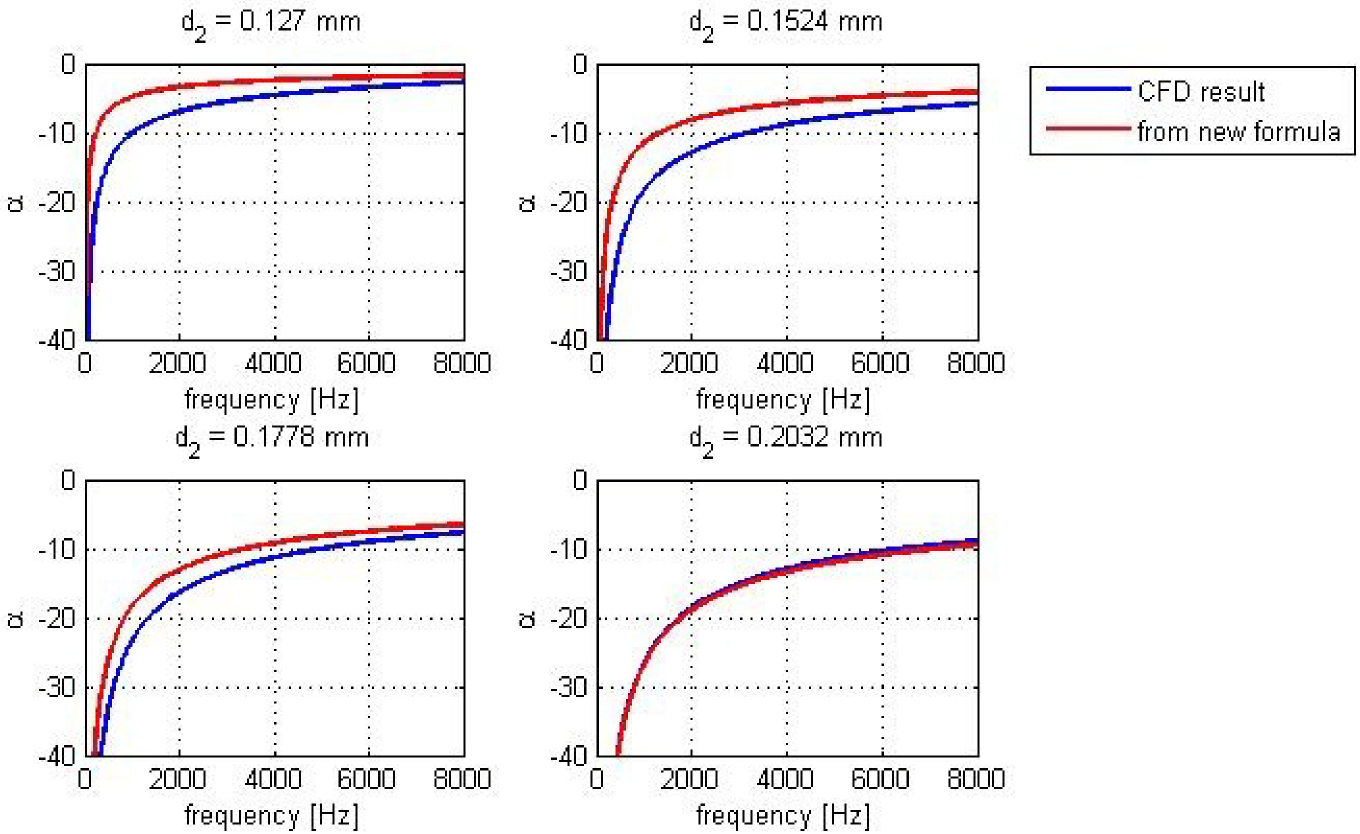
The value of α vs. Frequency

t = 0.4064 mm, d_1 = 0.1016 mm, σ = 0.02



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Conclusion

- By changing the definition of α, which is defined by Guo *et al.*, accuracy can be improved

- By making β a function of thickness, inlet hole diameter, and outlet hole diameter (as below), we can define dynamic flow resistance for any tapered hole.

$$\beta = \{\left(6.66\left(\frac{d_1}{d_2}\right)^2 - 7.07\left(\frac{d_1}{d_2}\right) + 3.06\right) \times 10^4 \times \left(1 - \frac{d_2}{d_1}\right)t + 1\}(16.9\frac{t}{d_1} + 152.8)$$

- Future : Make complete definition of α and an examination of the effect of square or slit hole geometry

Acknowledgements

Thanks to :

- Thomas Herdtle of 3M Corporation, St. Paul, Minnesota, for his useful, practical advice at an early stage of this work.