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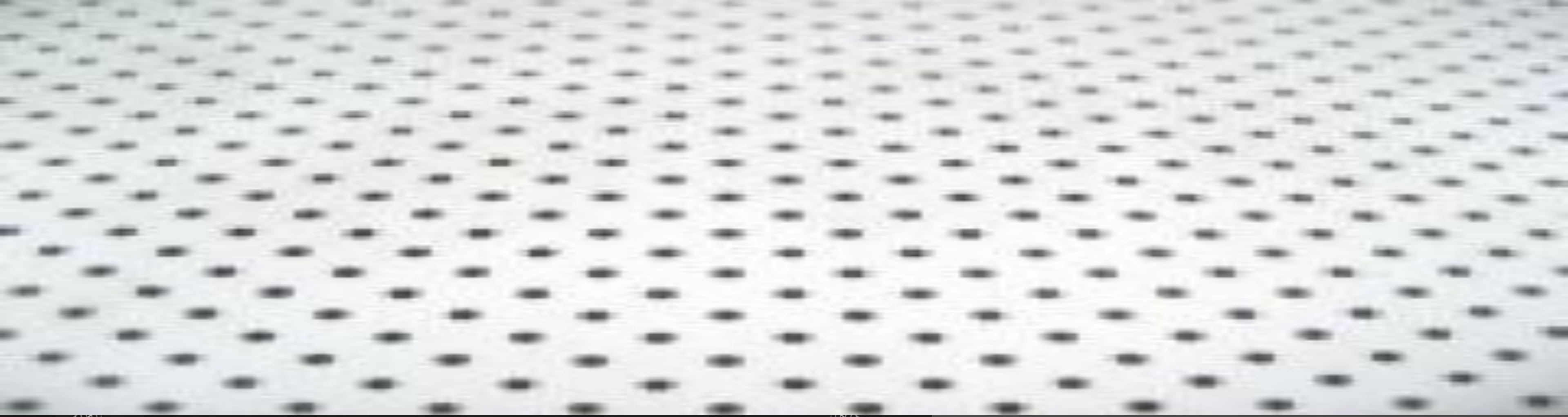

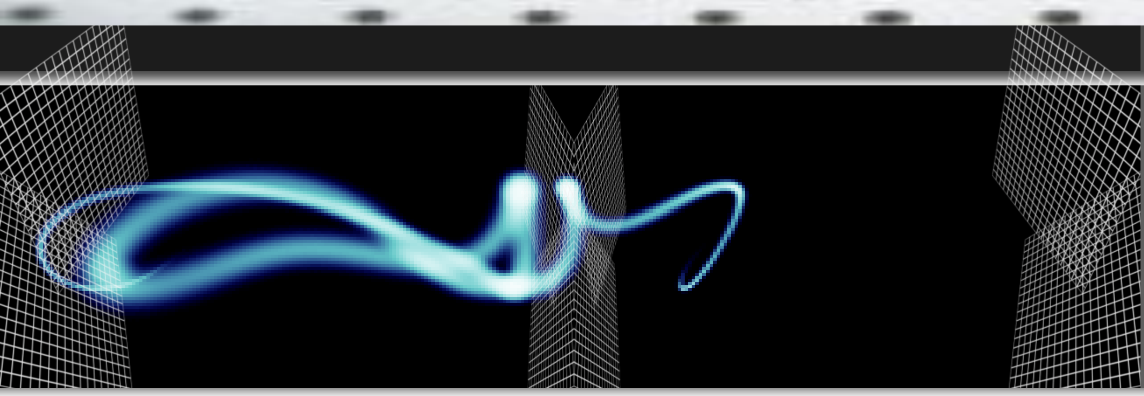

Use of CFD to calculate the dynamic resistive end correction for microperforated materials

J. Stuart Bolton and Nicholas Kim
Ray W. Herrick Labs
Purdue University

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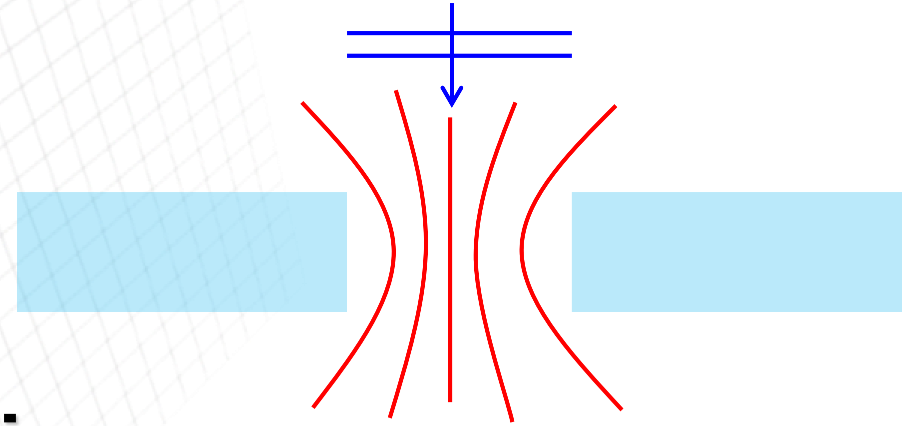
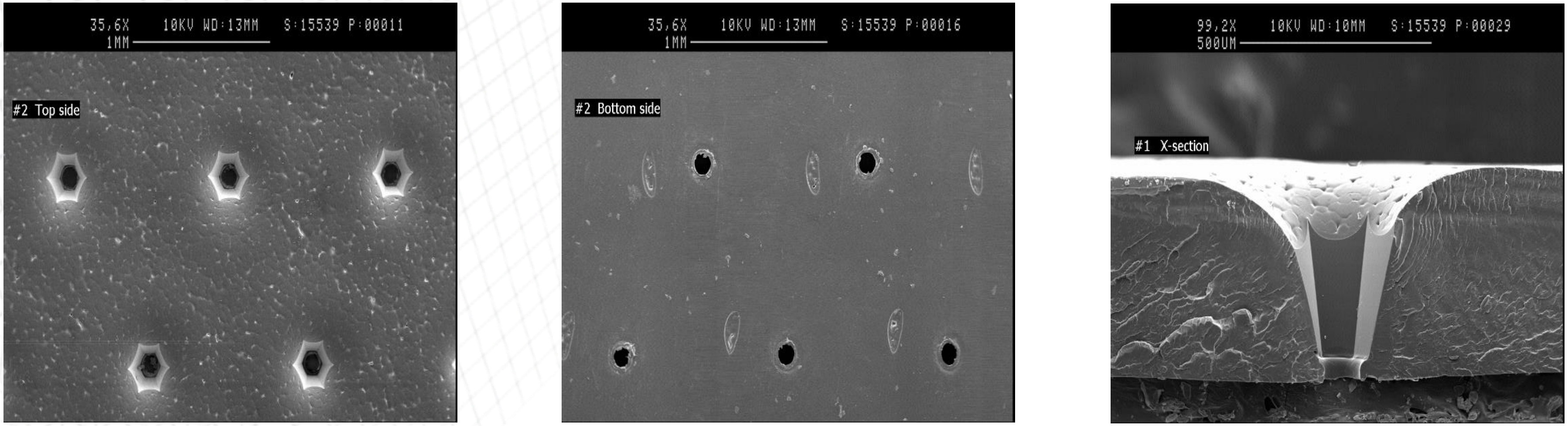
Introduction

- **Microperforated material**



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

Introduction



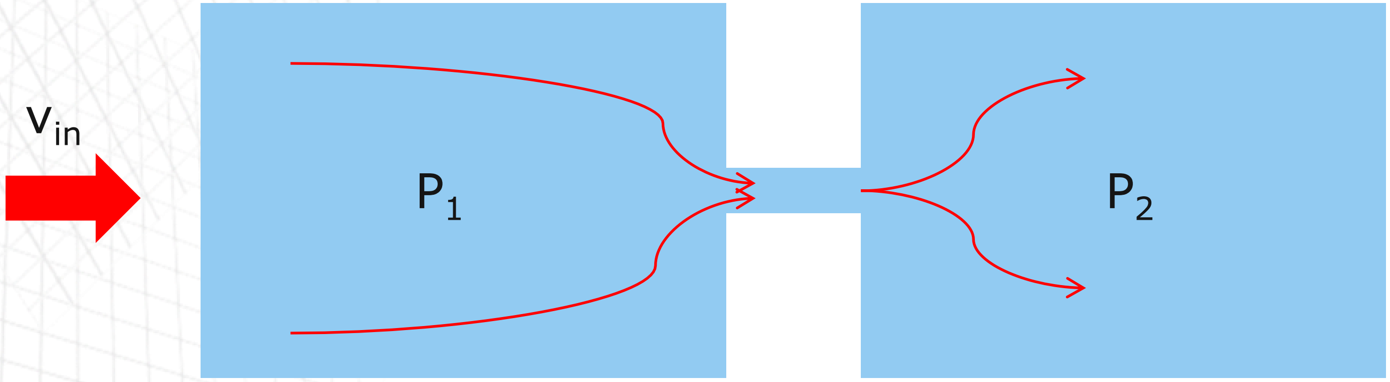
Microperforated panel

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

Introduction

Objective

By using computational fluid dynamics approach, calculate dynamic flow resistance for 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

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

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

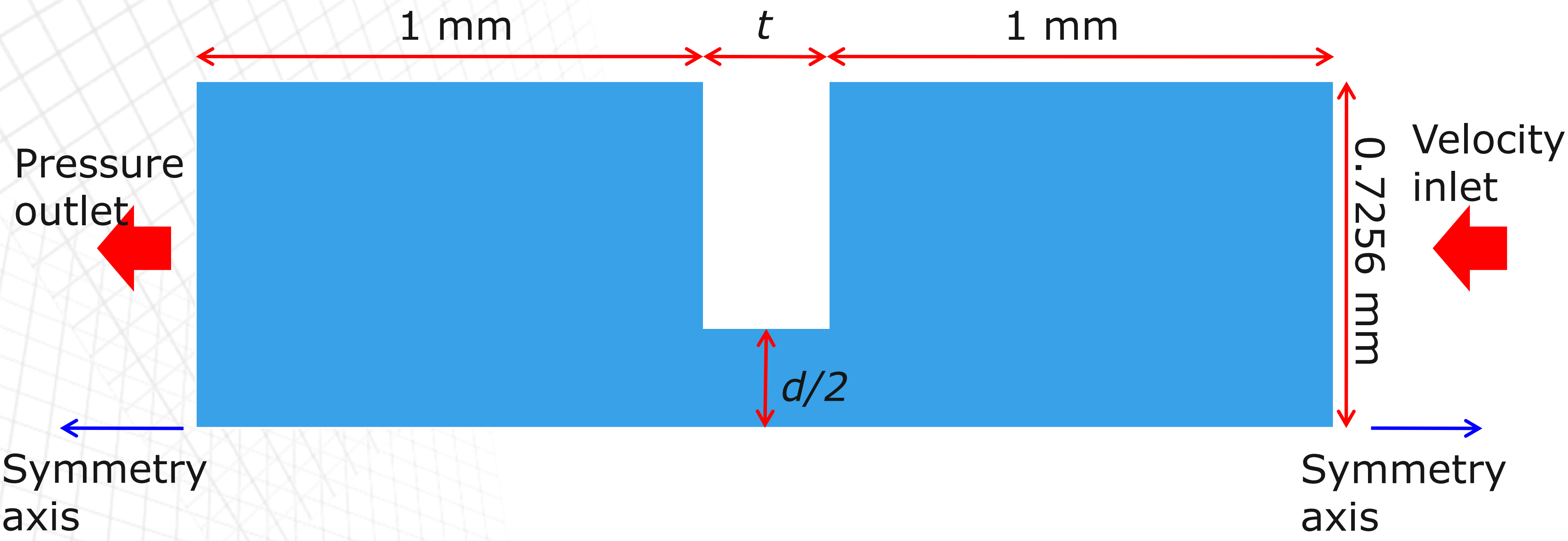
$$R_s = \frac{\sqrt{2\omega\rho_0\eta}}{2}$$

$\alpha = 2$ 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 $\omega \rightarrow 0$**

Geometry of CFD model



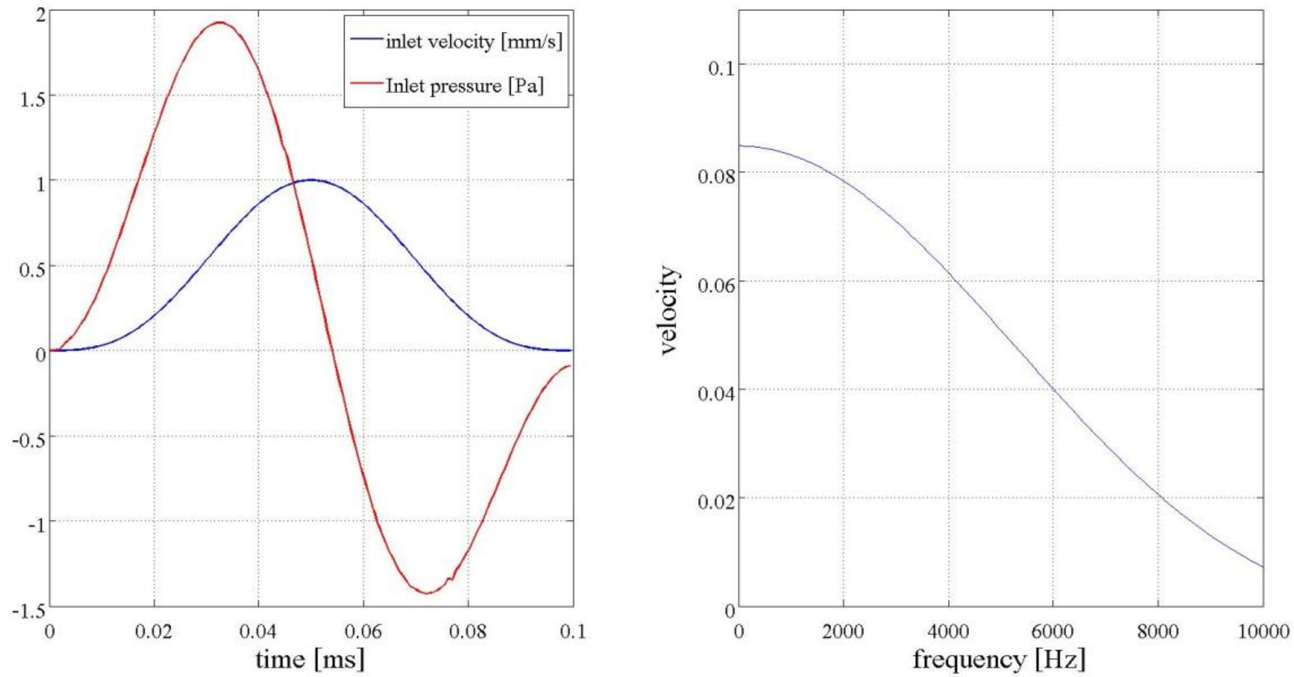
Mesh Interval : 0.005 mm, pressure-based, implicit formulation
the Green-Gauss node-based method
SIMPLE for the pressure-velocity coupling method
STANDARD for pressure
SECOND-ORDER UPWIND for momentum

CFD parameters

- **Three different sets**
  - Panel thickness (*t*)
  - Hole diameter (*d*)
  - Porosity (*σ*)

Set 1. Thickness			Set 2. Diameter			Set 3. Porosity		
t (mm)	*d* (mm)	*σ*	*t* (mm)	*d* (mm)	*σ*	*t* (mm)	*d* (mm)	*σ*
0.1016	0.4064	0.02	0.4064	0.1016	0.02	0.4064	0.2032	0.005
0.2032	0.4064	0.02	0.4064	0.2032	0.02	0.4064	0.2032	0.01
0.3048	0.4064	0.02	0.4064	0.3048	0.02	0.4064	0.2032	0.015
0.4064	0.4064	0.02	0.4064	0.4064	0.02	0.4064	0.2032	0.02
0.508	0.4064	0.02	0.4064	0.508	0.02	0.4064	0.2032	0.025
0.6096	0.4064	0.02	0.4064	0.6096	0.02	0.4064	0.2032	0.03
0.7112	0.4064	0.02				0.4064	0.2032	0.035
0.8128	0.4064	0.02				0.4064	0.2032	0.04
0.9144	0.4064	0.02						

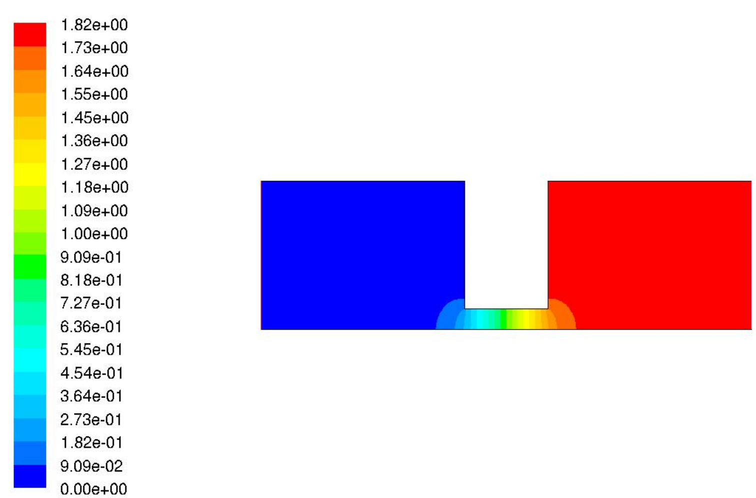
Inlet Velocity and Pressure



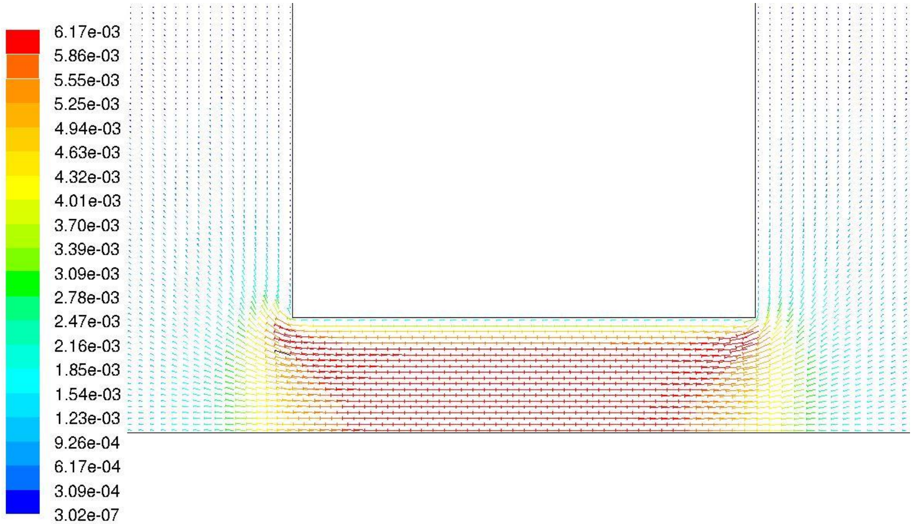
Inlet velocity was chosen to be a Hann windowed, 5 kHz half-sine wave having a maximum value of 1 mm/s in order to cover the frequency range up to 10 kHz

Pressure and Velocity distribution in simulation

t **= 0.4064 mm,** ***d*** **= 0.2032 mm,** ***σ*** **= 0.02**



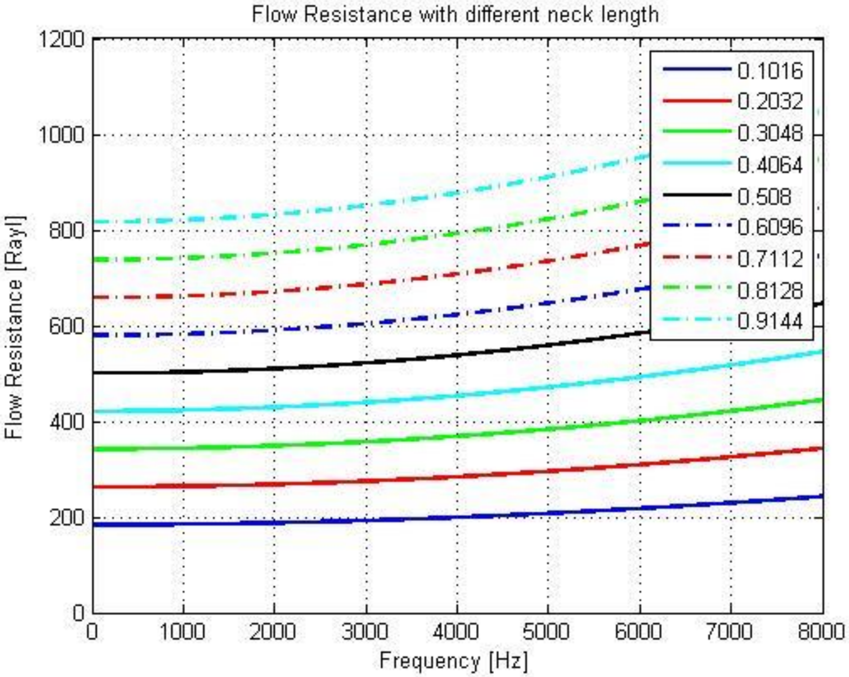
Contours of Static Pressure (pascal) (Time=3.1000e-05) Jun 08, 2010
FLUENT 6.2 (axi, dp, segregated, lam, unsteady)



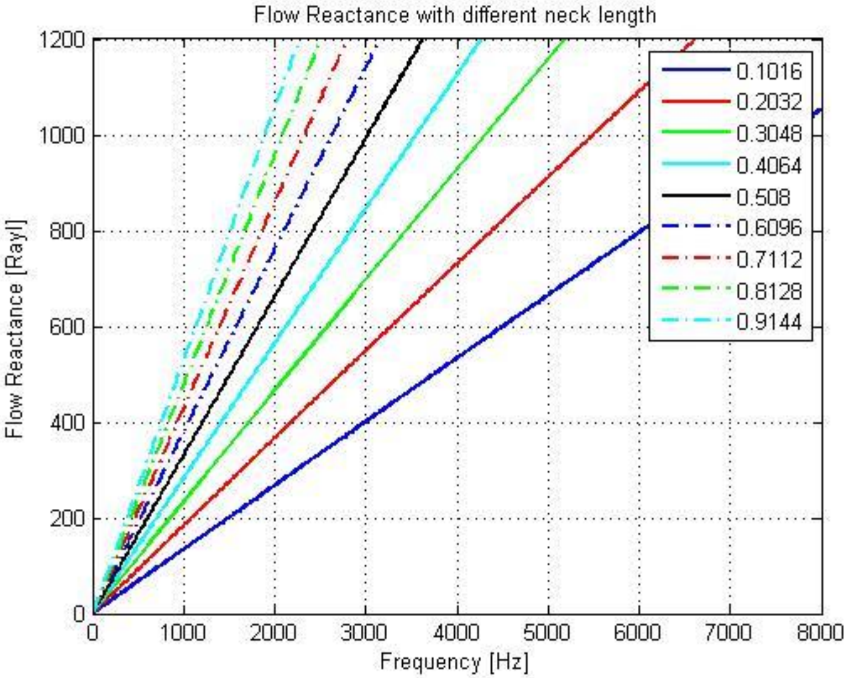
Velocity Vectors Colored By Velocity Magnitude (m/s) (Time=1.5500e-05) Jun 09, 2010
FLUENT 6.2 (axi, dp, segregated, lam, unsteady)

Dynamic flow resistance and reactance

Set 1. (different thicknesses)



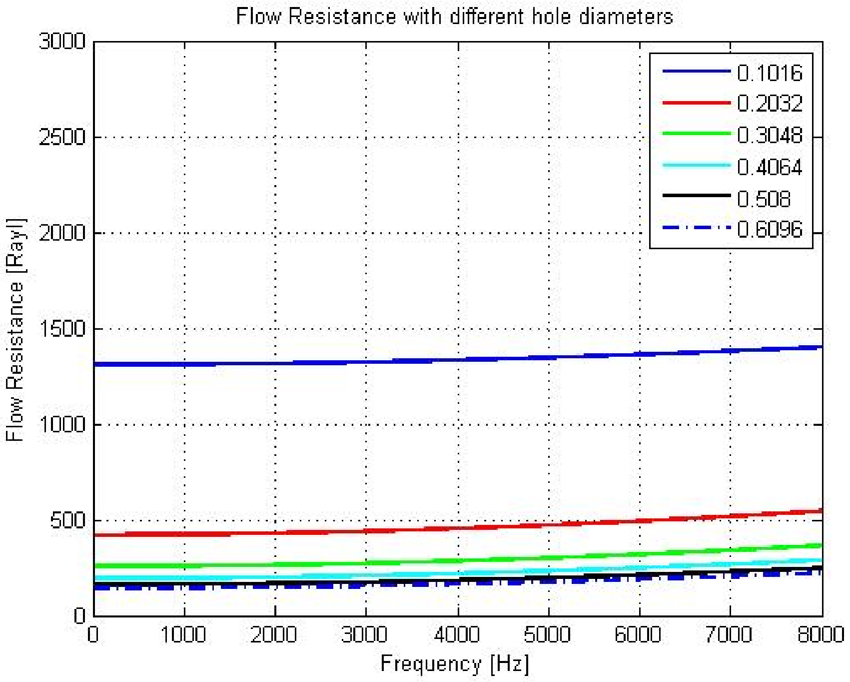
Flow Resistance with different neck length

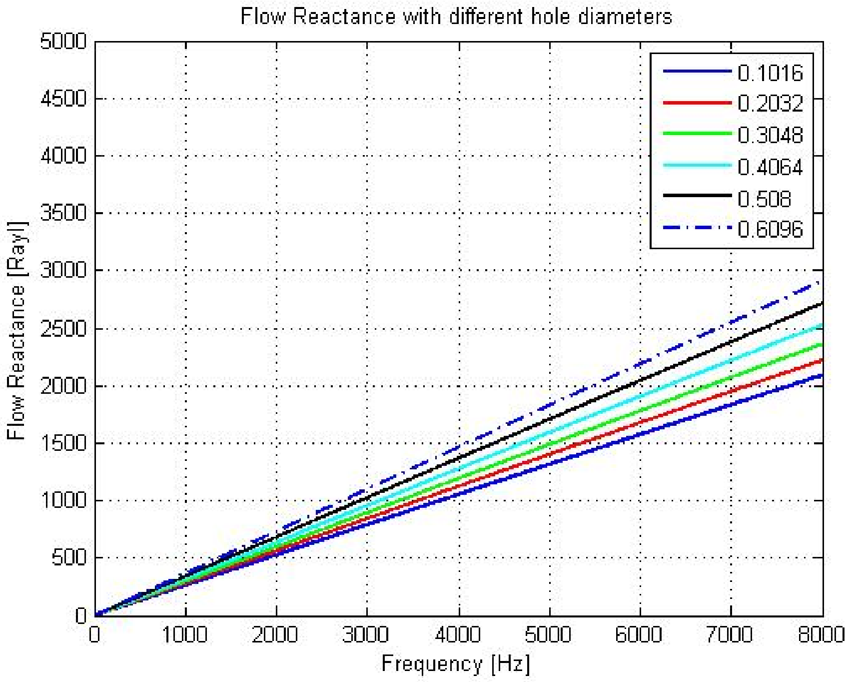


Flow Reactance with different neck length

Dynamic flow resistance and reactance

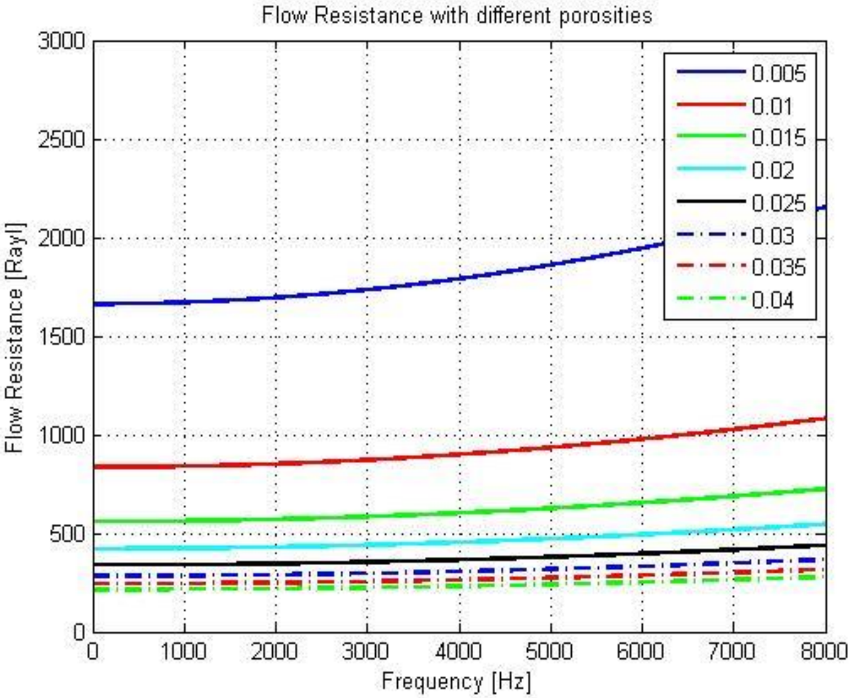
Set 2. (different hole diameters)

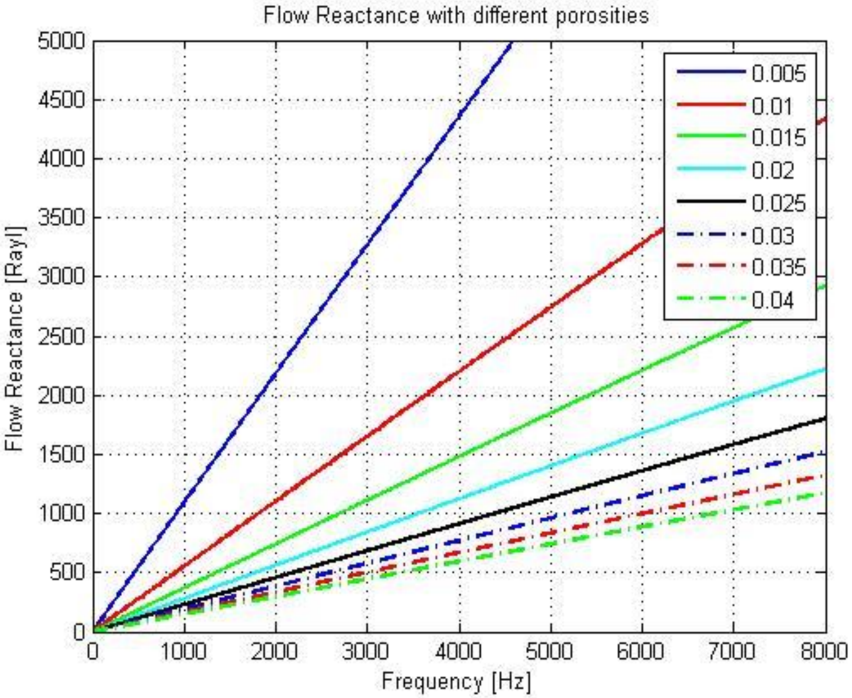




Dynamic flow resistance and reactance

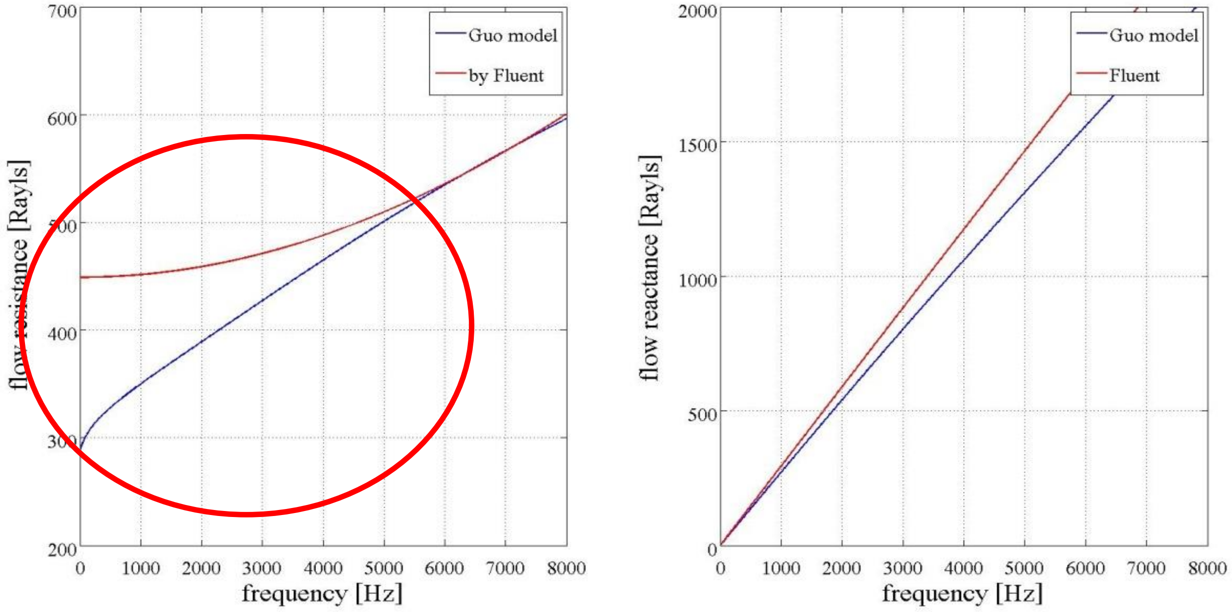
Set 3. (different porosities)


Flow Resistance with different porosities


Flow Reactance with different porosities

Comparison of CFD Result with Guo Model

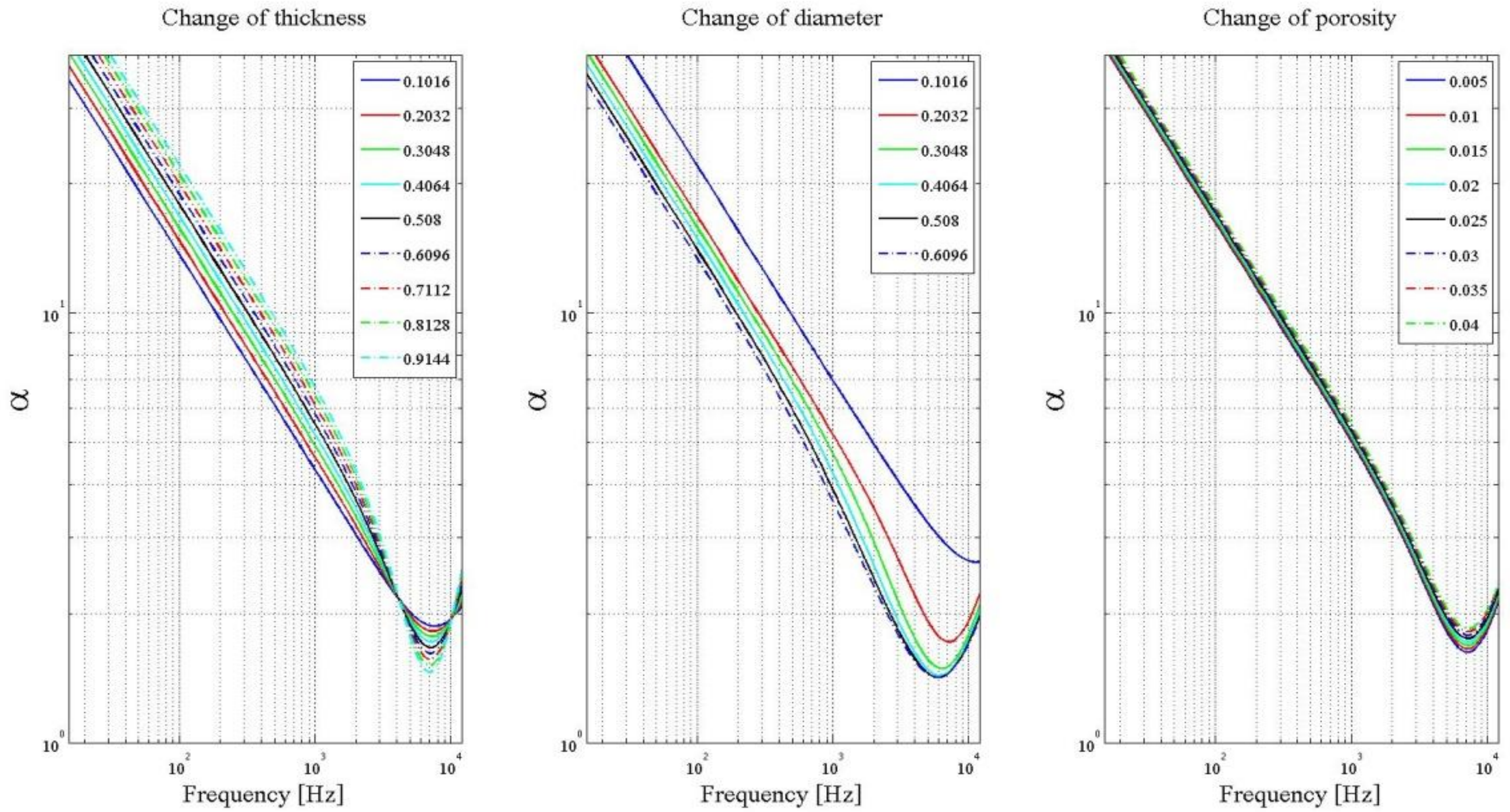
Dynamic flow resistance and flow reactance
(d=0.4064 mm, t=0.4064 mm, σ=0.02)



Large difference in flow Resistance in low frequency range

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

The value of α vs. Frequency



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

Especially all plot lines are almost parallel below 2 kHz, so we can say that α is approximately proportional to $f^{-0.5}$

Revised formulation

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

as before

but

α should be a function of *ω*, *t*, *d*, and *σ*

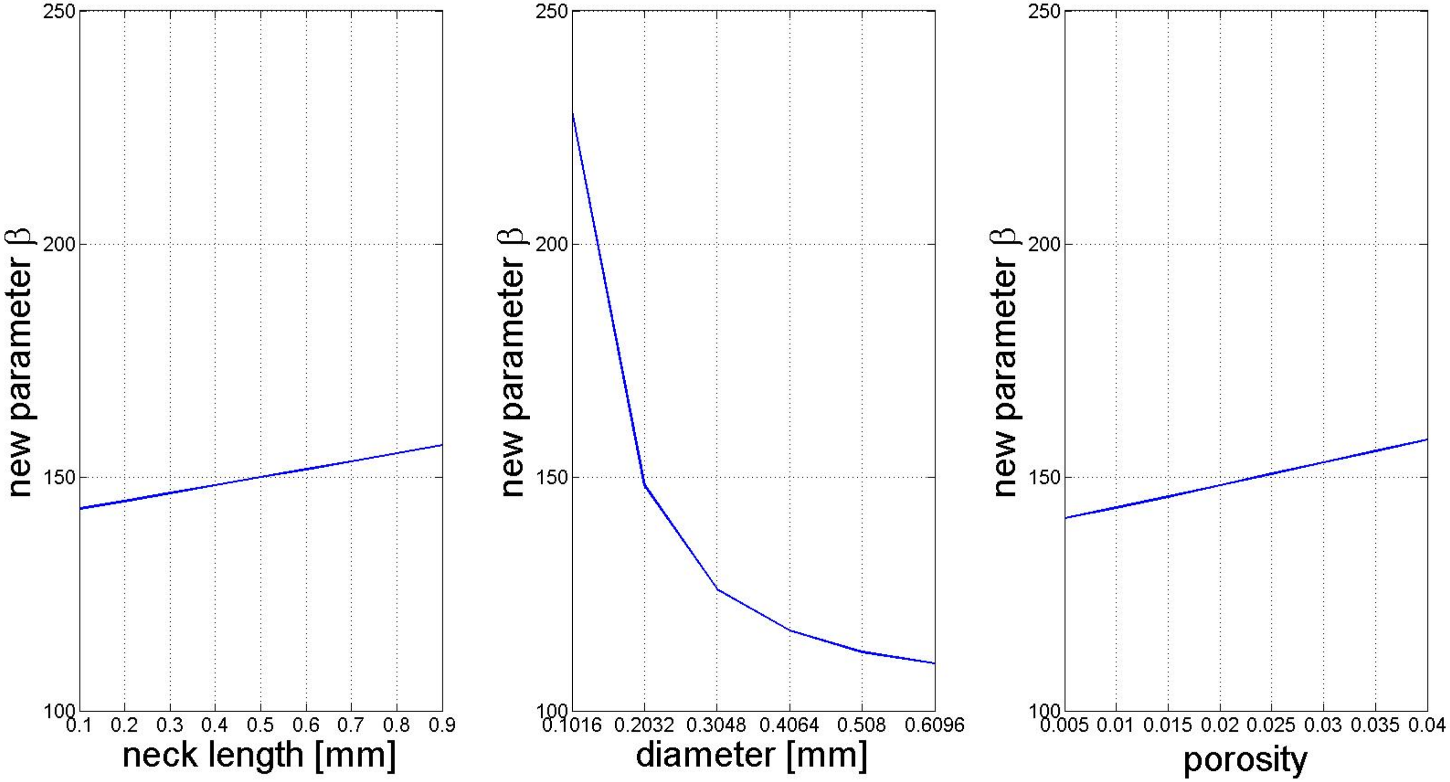
- **Express α as**

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

So that

$$\beta = \alpha f^{0.5} = f(t, d, \sigma)$$

β vs. thickness, diameter, and porosity



- **In these graphs, *β* is proportional to thickness and porosity, and inverse proportional to hole diameter.**

Define the new parameter β

- **Define new parameter *β***

$$\beta = (a + b\sigma)\frac{t}{d} + c \qquad (a, b, \text{and } c \text{ are constants})$$

Using least square method to calculate the constants, *a*, *b*, and *c*

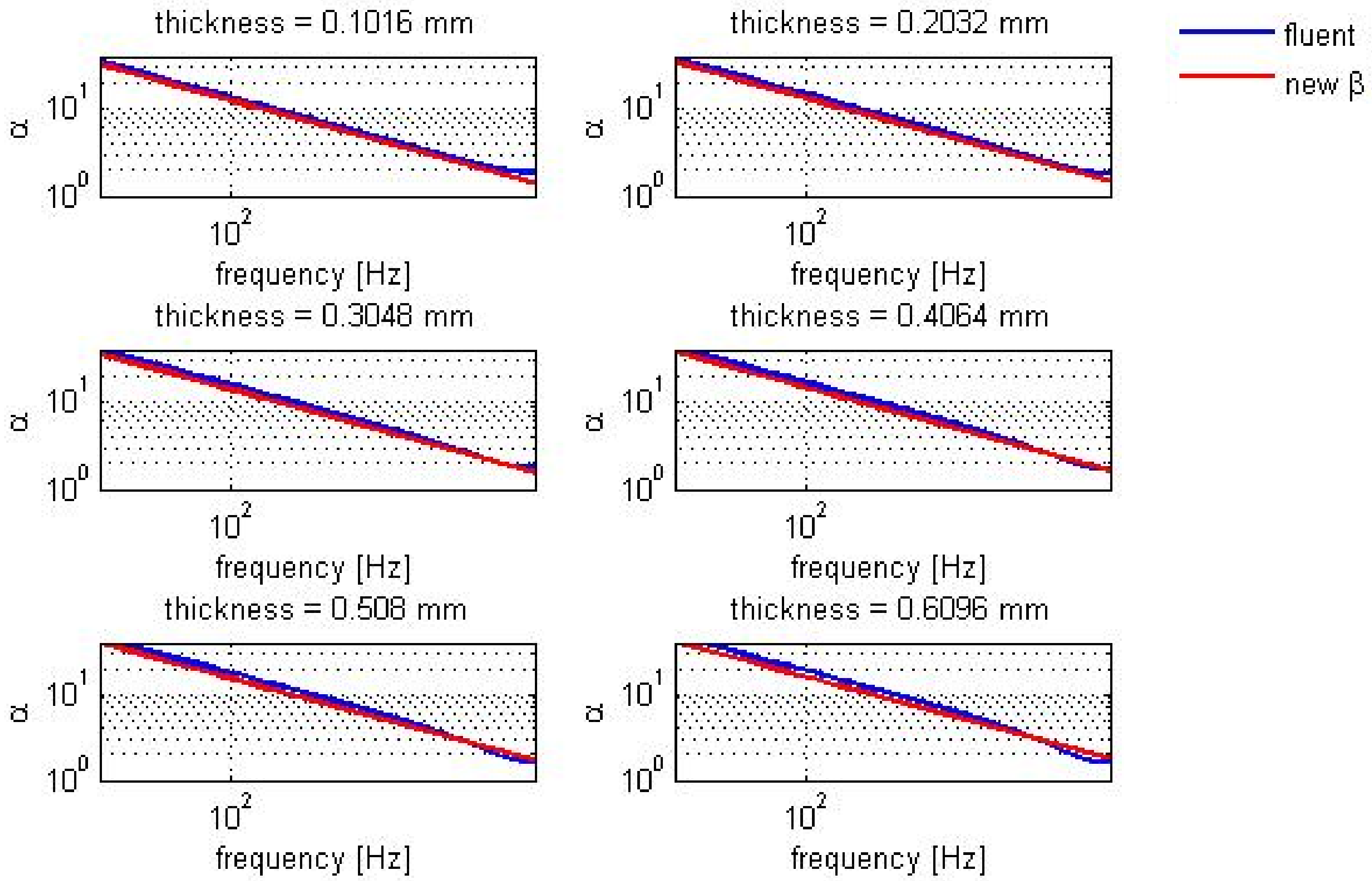
$$\beta = (14.1 + 0.059\sigma)\frac{t}{d} + 117.33$$

$\sigma < 1$, $0.059\sigma << 14.1$, so we can ignore σ *terms*

$$\boxed{\beta = 14.1\frac{t}{d} + 117}$$

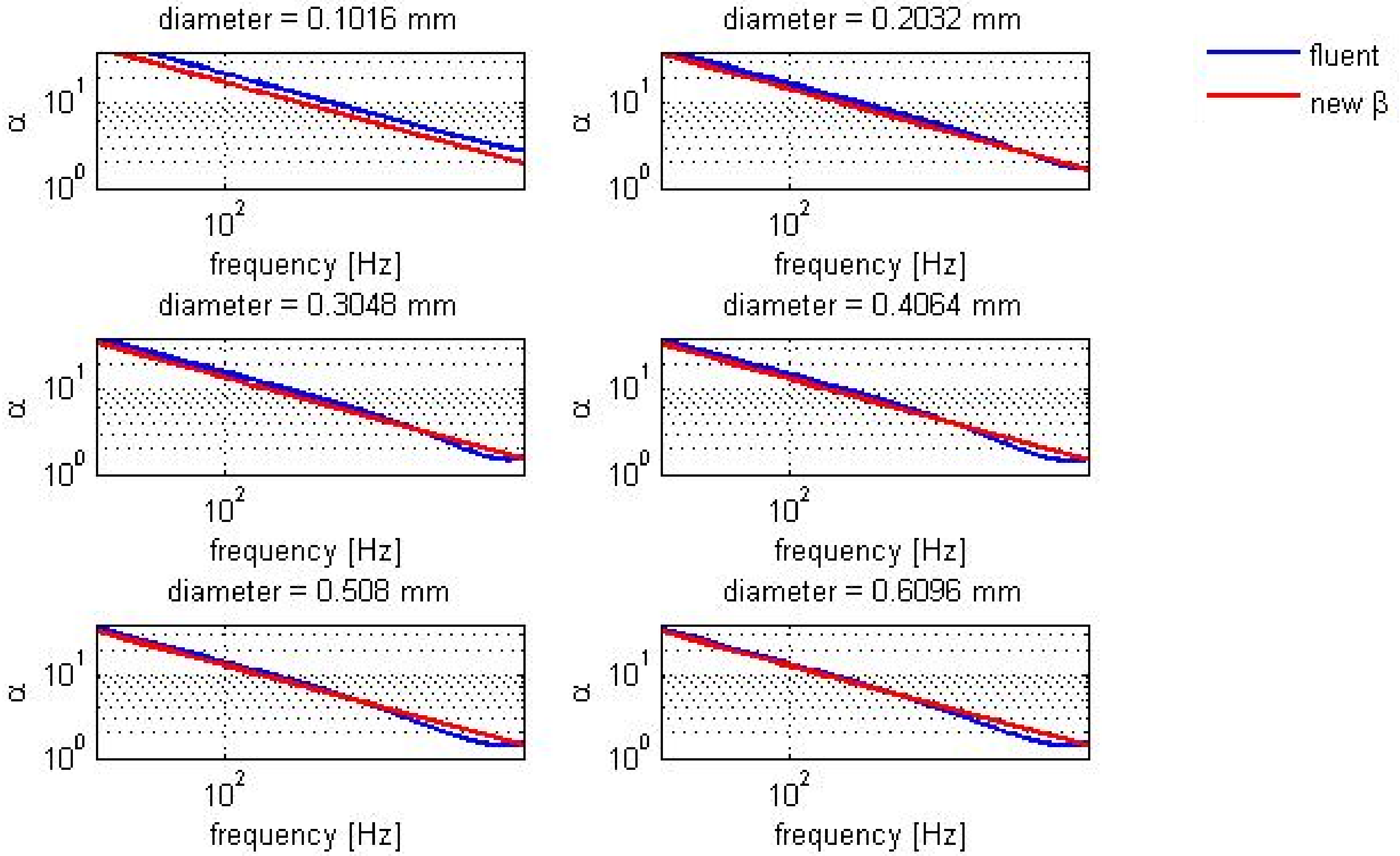
The value of α

Set 1. (different thicknesses)



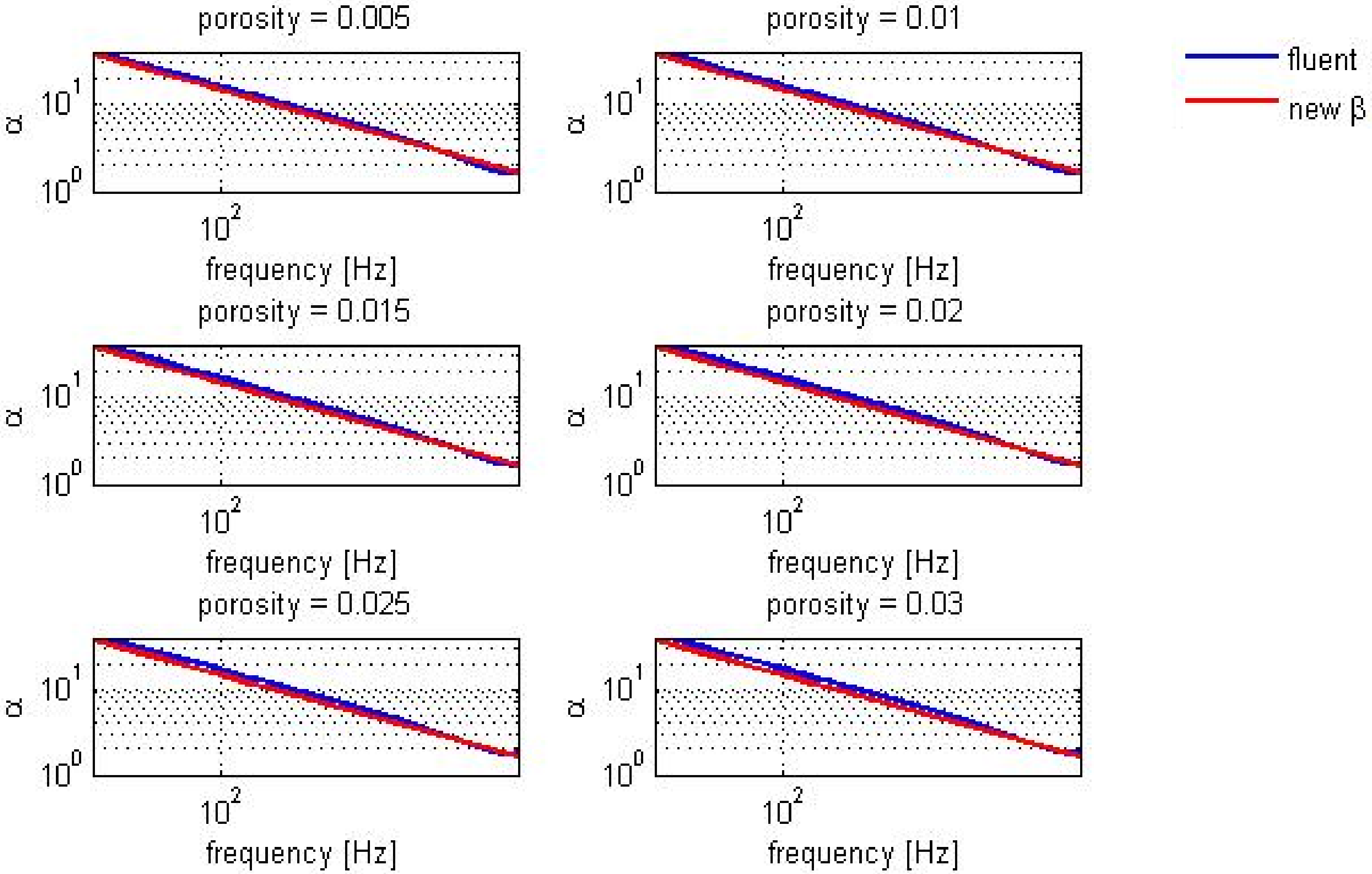
The value of α

Set 2. (different hole diameter)



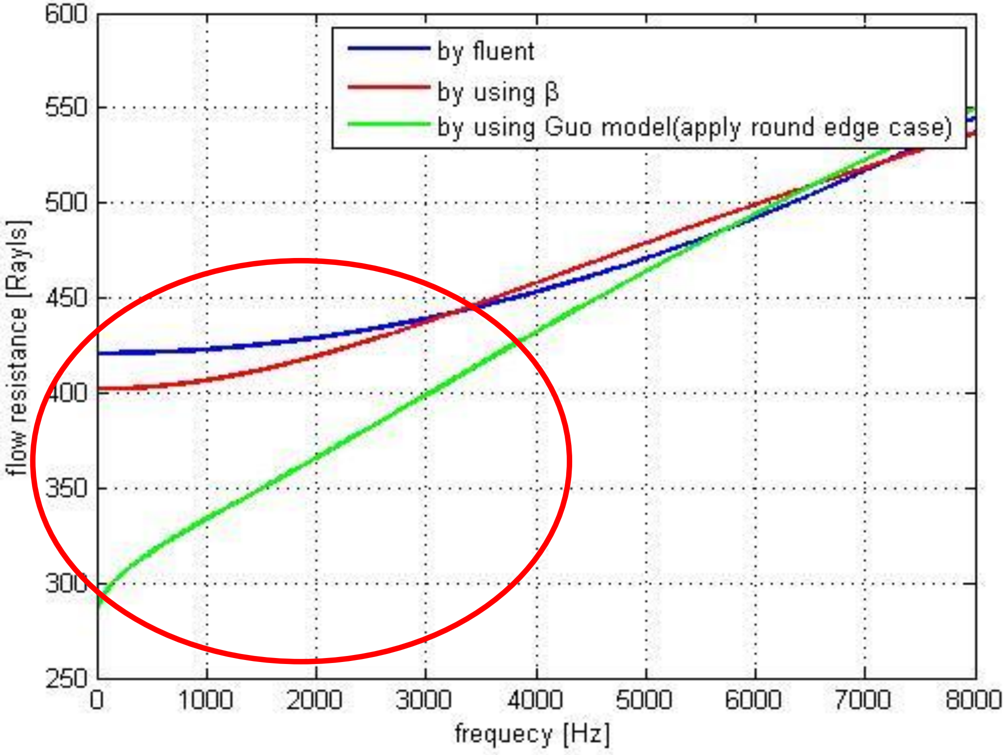
The value of α

Set 3. (different porosity)



Flow resistance computed by Fluent Vs. β

Dynamic flow resistance (d=0.2032 mm, t=0.4064 mm, σ=0.02)



- **When using the new parameter *β*, the accuracy is improved compared to the Guo model.**

Conclusions

- Classic theoretical model of microperforated panel differs significantly from CFD result especially in the low frequency range.

- By changing the definition of α, as defined by Guo et al., accuracy can be improved in low frequencies.

- Define $\alpha = \left(14.1\frac{t}{d} + 117\right) f^{-0.5}$ where ***t*** is thickness, ***d*** is hole diameter, and ***f*** is frequency

- Future : Determine α when the flow is compressible and explore effect of hole shape

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