

Acoustics Forum

small room acoustics

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Flow Resistance of Panel Absorbers

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Flow Resistance of Panel Absorbers

by [jonessy](#) » Fri Feb 27, 2009 11:25 am

Hi all,

Been away for a while. Sorry 'bout that.

I'm trying to model the behavior of solid panel absorbers using a transfer matrix, and could use some help.

For a simple panel<-->air<-->rigid-back construction:

The complex impedance at the panel layer is function of 1) the mass-spring reactance term (imaginary) and 2) the flow resistance term (real).

According to Long* this is:

$$z = r_f + j[\omega m - (\rho c^2 / \omega d)]$$

Where r_f is the flow resistance, and all the rest are pretty self explanatory.

I have two questions regarding the approximation of r_f :

[1]

For an airtight construction the flow resistance is really high, so one can assume that the r_f term approaches infinity.

This in turn means that at least theoretically speaking, at resonance the absorption coefficient is infinity.

Obviously this is not the case in real life.

So if I wanted to model this behavior, would it be safe to normalize the absorption coefficients across the frequency range so at resonance α becomes 1 (highest absorption is 1 instead of highest absorption is infinity)?

[2]

Assuming a non-airtight construction, such as an unboxed membrane distanced from a rigid wall, what would be the best way to approximate the flow resistance?

My hunch is that this has something to do with diffraction around the membrane, but I couldn't find any documentation to support this.

Any ideas?

Thanks 😊

Cheers,
Jon.

* Long, M. (2005). *Architectural acoustics*. Amsterdam: Elsevier/Academic Press.

Bert is still my hero.

What d'ya know.

[jonessy](#)

Posts: 580

Joined: Wed Jan 04, 2006 3:39 pm

Location: Israel

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Re: Flow Resistance of Panel Absorbers

▣ by [Terry Montlick](#) » Fri Feb 27, 2009

3:07 pm

I think there's something very fishy about Long's inserting the term r_f due to resistance from a spring air force **behind** the panel, and implying that this is the same as a flow resistance **through** the panel. 🙄

I'll look at this later today and see if I can determine a correct formulation.

Regards,

Terry

Terry Montlick Labs

Tweeters tweaked. Woofers neutered.

[Terry Montlick](#)

Posts: 1143

Joined: Mon Apr 12, 2004 9:31 pm

Location: Rhode Island, USA

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Re: Flow Resistance of Panel Absorbers

by [jonessy](#) » Fri Feb 27, 2009 3:31 pm

Thanks Terry, that would be great.

I'm going to re-read the chapter too - now that you've mentioned this, it does seem strange.

Cheers, 😊

Jon.

Bert is still my hero.

What d'ya know.

[jonessy](#)

Posts: 580

Joined: Wed Jan 04, 2006 3:39 pm

Location: Israel

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Re: Flow Resistance of Panel Absorbers

by [bert stoltenborg](#) » Fri Feb 27, 2009 5:29 pm

Quick & dirty (obvious that I don't know exactly what you're talking about):

isn't this comparable with a speaker in a box or vented enclosure?

If you view life with the knowledge that there are no problems, only opportunities, you are a marketing manager.....this is my personal philosophy

[bert stoltenborg](#)

Posts: 4520

Joined: Sun Apr 18, 2004 11:03 am

Location: Achterhood, Netherlands

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p

Re: Flow Resistance of Panel Absorbers

by [jonessy](#) » Fri Feb 27, 2009 7:09 pm

I guess...

Only the driving force is not the electro-mechanical system, and the membrane is rectangular and not conical..

Does this mean that the membrane's flow resistance is equivalent to the mechanical resistance of the driver ?

I'm confused...

Bert is still my hero.

What d'ya know.

[jonessy](#)

Posts: 580

Joined: Wed Jan 04, 2006 3:39 pm

Location: Israel

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Re: Flow Resistance of Panel Absorbers

by [Terry Montlick](#) » Fri Feb 27, 2009 7:30 pm

Okay, Jon. Page 273 of Long is pretty fucked up. It looks like *my* math at the end of a really bad day. 🤖

Here's the **right** way to derive this. 😊 Consider the transfer matrix of just the thin panel. Remember that a transfer matrix simply relates pressure and velocity on one side of something to the pressure and velocity on the other side of the same something:

$$p_{i+1} = T_{11} * p_i + T_{12} * v_i$$

$$v_{i+1} = T_{21} * p_i + T_{22} * v_i$$

where T is the 2x2 transfer matrix that I can't show neatly in ASCII! 🤖

So what is T for an ideal thin panel with mass per unit area M ?

We have [Kuttruff p. 43] the simple relation between the pressure on each side of a thin panel:

$$p_{i+1} - p_i = M \, dv/dt = j\omega Mv$$

And for velocity the relation is completely trivial, because motion on one side of the rigid panel is exactly the same as the motion on the other:

$$v_{i+1} = v_i = v$$

This gives us a transfer matrix with the following elements:

$$T_{11} = 1$$

$$T_{12} = j\omega M$$

$$T_{21} = 0$$

$$T_{22} = 1$$

How do we add the air layer? From the magic of transfer matrices, we just multiply the transfer matrix of the panel times the transfer matrix of the air layer against a solid wall.

From Cox and D'Antonio, p. 149, we know that the impedance of such an air layer is:

$$-jz_0 \cot(k_{\text{air}}l)$$

where

$$k_{\text{air}} = \omega/c$$

$$z_0 = c\rho_0$$

l = thickness of the air layer

In transfer matrix form, the impedance gets plugged into T_{12} :

$$T_{11} = 1$$

$$T_{12} = -jz_0 \cot(k_{air}l)$$

$$T_{21} = 0$$

$$T_{22} = 1$$

So just multiply these two transfer matrices (remember, first row times first column = first element, etc.), and you've got the solution!

Regards,

Terry

Terry Montlick Labs

Tweeters tweaked. Woofers neutered.

[Terry Montlick](#)

Posts: 1143

Joined: Mon Apr 12, 2004 9:31 pm

Location: Rhode Island, USA

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Re: Flow Resistance of Panel Absorbers

by [ionessy](#) » Fri Feb 27, 2009 8:27 pm

Thanks Terry for looking into it.

However, there is still no answer for the mysterious resistive component...

Multiplying the two transfer matrices gives a new 2x2 matrix:

$$T_{11} = 1$$

$$T_{12} = -jz_0 \cot(\omega d / c_0) + j\omega m$$

$$T_{21} = 0$$

$$T_{22} = 1$$

So from that we derive:

$$z = -j\rho_0 c_0 \cot(\omega d / c_0) + j\omega m$$

Since we know that $k(\text{air}) = \omega / c_0$ we can rewrite the equation:

$$z = j[\omega m - \rho_0 c_0 \cot(kd)]$$

Which is the same as eq 7.1 from Long's book (p.273 with the messy math...).

Still, this is only the reactive part of the impedance. Where is the resistive part (or what he calls r_f) accounted for

? 🤔 🤔 🤔

Cheers, 😊

Jon.

Bert is still my hero.

What d'ya know.

[jonessy](#)

Posts: 580

Joined: Wed Jan 04, 2006 3:39 pm

Location: Israel

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[Re: Flow Resistance of Panel Absorbers](#)

by [Terry Montlick](#) » Fri Feb 27, 2009

9:05 pm

jonessy wrote:...

Since we know that $k(\text{air}) = \omega / c_0$ we can rewrite the equation:

$$z = j[\omega m - \rho_0 c_0 \cot(kd)]$$

Which is the same as eq 7.1 from Long's book (p.273 with the

messy math...).

Still, this is only the reactive part of the impedance. Where is the resistive part (or what he calls r_f) accounted for? 🤔🤔🤔

He added a general r_f resistance term and called it flow resistance of the panel. But panels (either sealed or infinite) don't have flow resistance unless they are perforated! [And perforated panels aren't talked about until the next section, with different math 🤔] So r_f appears to be a catch-all resistance term. It would more typically be due to the resistance of a porous absorber placed **behind** the panel. You can of course add this as another layer to the transfer matrix. 😊

Regards,
Terry

Terry Montlick Labs

Tweeters tweaked. Woofers neutered.

[Terry Montlick](#)

Posts: 1143

Joined: Mon Apr 12, 2004 9:31 pm

Location: Rhode Island, USA

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[Re: Flow Resistance of Panel Absorbers](#)

by [jonessy](#) » Fri Feb 27, 2009 9:21 pm

Terry wrote:He added a general r_f resistance term and called it flow resistance of the panel. But panels don't have flow resistance unless they are perforated!

Exactly my point. Well to be more accurate, panels don't have airflow through them, so they should have a flow resistance of infinity, no?

Long further elaborates:

Marshall Long, p.273 wrote: If the panel is impervious to flow, the flow resistance is infinite and the absorption is theoretically infinite at resonance. Above and below resonance the absorption coefficient falls off.

So far so good. Sort of. I can live with infinity, and that's where my question originated from (can I normalize infinity at resonance to $\alpha = 1$).

But wait, just as things start to make (a little) sense, he writes:

Marshall Long, p.274 wrote: In this model the sharpness of the peak is determined by the amount of flow resistance provided by the panel.

What freaking *amount* of flow resistance ???

You (he) just wrote that for a solid panel the flow resistance is infinity 🤔🤔🤔 . What gives?

I looked up nearly every acoustic text I have, Kuttruff, Bies & Hansen, Kinsler & Frey, et al. Nobody goes near this stuff.

I didn't check Morse & Ingard, though. That book scares the shit out of me. 🤖

Help (!)

Cheers, 😊

Jon.

Bert is still my hero.
What d'ya know.

[jonessy](#)

Posts: 580

Joined: Wed Jan 04, 2006 3:39 pm

Location: Israel

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Re: Flow Resistance of Panel Absorbers

by [Terry Montlick](#) » Fri Feb 27, 2009

9:30 pm

jonessy wrote:What freaking flow resistance ???

Exactly. 🤖

He sticks in a term that doesn't really belong, doesn't define it, talks around it (badly) for a bit, and just ends up confusing the reader, which is you!! 🤖

Regards,

Terry

Terry Montlick Labs

Tweeters tweaked. Woofers neutered.

[Terry Montlick](#)

Posts: 1143

Joined: Mon Apr 12, 2004 9:31 pm

Location: Rhode Island, USA

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Re: Flow Resistance of Panel Absorbers

by [Eric.Desart](#) » Sat Feb 28, 2009

6:33 am

A bit off-topic

Higini has made a model to predict the behavior of panel absorbers (he's a PhD)

As I understood it's published in one of his Spanish books about acoustics. (Never bought it since I don't speak the language). I don't know this model.

Maybe you can email him.

It's a very nice, warm and humble man with an enormous knowledge.

He's one of Spain's top acousticians.

Maybe you can email him. (He speaks some, but not good English)

I once had some extensive email contact with him.

Arau Acustica Higini Arau Puchades

Travessera De Dalt, 118-3^o-1, Barcelona, 08024

t: 932845016 f: 932850895

<http://www.arauacustica.com>

info -at- arauacustica.com

He's the one who designed the Arau Puchades RT formula
Higini Arau Puchades "An improved reverberation
formula," H. Arau-Puchades, Acustica 65, 163-180 (1988)

divinely-inspired

[Eric.Desart](#)

Moderator

Posts: 2461

Joined: Tue Feb 10, 2004 4:29 am

Location: Antwerp, Belgium

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Re: Flow Resistance of Panel Absorbers

by [jonessy](#) » Sat Feb 28, 2009 2:18 pm

Eric -

Thanks for the tip. I'll contact him, maybe he has some answers.

Terry -

I think I'm making some progress.

I modeled our solution to the transfer matrix and it seems incorrect. Alpha values always turn out to be 0, in all frequencies.

This kinda makes sense because systems naturally resonate at zero reactance, so if we don't have energy dissipated due to resistance - we are left with 0 losses.

This lead me to re-think about the rf-term that now seems crucial for the solution.

From p.166 in Cox & D'Antonio:

Cox & D'Antonio wrote: Consider a simple absorber formed by a cavity with a covering sheet. The sheet could either be perforated to form a Helmholtz design, **or solid but flexible to form a membrane absorber.**

It could even be a flexible perforated membrane, which is a combination of the two.

In the first two cases, the impedance of the cavity given in Equation 5.25 will **simply be altered by the addition of mass ($j\omega m$) and resistance (r_m) terms.** These are the acoustic mass and resistance respectively, arising due to the perforated

sheet or membrane. The surface impedance of the resonant system is:

$$z_1 = r_m + j[\omega m - \rho c \cot(kd)]$$

This matches the Long solution, which is the same of ours, only with the mysterious resistance term.

I still don't get it. 🤔

Is this the acoustic resistance of the panel *itself*? And if yes, then how on earth do I go about calculating it?

Any thoughts?

Cheers, 😊

Jon

Bert is still my hero.
What d'ya know.

[ionessy](#)

Posts: 580

Joined: Wed Jan 04, 2006 3:39 pm

Location: Israel

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Re: Flow Resistance of Panel Absorbers

by [krasmuzik](#) » Sat Feb 28, 2009
2:35 pm

Terry Montlick wrote: Okay, Jon. Page 273 of Long is pretty fucked up. It looks like *my* math at the end of a really bad day. 🤔

Here's the **right** way to derive this. 😊 Consider the transfer matrix of just the thin panel. Remember that a transfer matrix simply relates pressure and velocity on one side of something to

the pressure and velocity on the other side of the same something:

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$$v_{i+1} = T_{21} * p_i + T_{22} * v_i$$

where T is the 2x2 transfer matrix that I can't show neatly in ASCII! 🙄

So what is T for an ideal thin panel with mass per unit area M?

Terry

Salford uses the Transmission matrix $T = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$ which is the input as function of outputs because then the chain multiply is a blackbox T for the entire system. More commonly used in RF theory but applicable to acoustic duct/transformer/layer networks because it is easy to create the matrix chain by transmission chains of series/parallel impedance in two port form rather than going back to the equations - let matlab do all the hard work of chained matrix multiplies.

a random .edu link - wish my class notes were as fancy as this!

[http://www.ittc.ku.edu/~jstiles/723/han ... ackage.pdf](http://www.ittc.ku.edu/~jstiles/723/han...ackage.pdf)

in the acoustic impedance analogue p is V and U is I.

Last edited by [krasmuzik](#) on Sat Feb 28, 2009 2:50 pm, edited 2 times in total.

Kevin R. Shank

[krasmuzik](#)

Posts: 165

Joined: Tue Feb 10, 2004 1:49 am

Location: Newport, VA

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Re: Flow Resistance of Panel Absorbers

▣by [krasmuzik](#) » Sat Feb 28, 2009

2:47 pm

jonessy wrote:

Is this the acoustic resistance of the panel *itself*? And if yes, then how on earth do I go about calculating it ?

Any thoughts ?

Cheers, 😊

Jon

An ideal panel does not exist - think about the damped modal analysis of plates for thin panels. Bit more complicated than room modes...don't forget to include the radiation load of the plate on top of your modal analysis.

Kevin R. Shank

[krasmuzik](#)

Posts: 165

Joined: Tue Feb 10, 2004 1:49 am

Location: Newport, VA

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Re: Flow Resistance of Panel Absorbers

▣by [Terry Montlick](#) » Sat Feb 28, 2009

3:46 pm

krasmuzik wrote:

jonessy wrote:

Is this the acoustic resistance of the panel *itself*? And if yes, then how on earth do I go about calculating it ?

Any thoughts ?

Cheers, 😊

Jon

An ideal panel does not exist - think about the damped modal analysis of plates for thin panels. Bit more complicated than room modes...don't forget to include the radiation load of the plate on top of your modal analysis.

Correct. And neither does an ideal layer of air, with no frictional losses. 😊

Regards,

Terry

Terry Montlick Labs

Tweeters tweaked. Woofers neutered.

[Terry Montlick](#)

Posts: 1143

Joined: Mon Apr 12, 2004 9:31 pm

Location: Rhode Island, USA

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[Re: Flow Resistance of Panel Absorbers](#)

by [ionessy](#) » Sat Feb 28, 2009 3:50 pm

I think I lost you guys here... 🤔

Bert is still my hero.

What d'ya know.

[ionessy](#)

Posts: 580

Joined: Wed Jan 04, 2006 3:39 pm

Location: Israel

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Re: Flow Resistance of Panel Absorbers

by [Terry Montlick](#) » Sat Feb 28, 2009

3:52 pm

krasmuzik wrote:Terry

Salford uses the Transmission matrix $T = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$ which is the input as function of outputs because then the chain multiply is a blackbox T for the entire system. More commonly used in RF theory but applicable to acoustic duct/transformer/layer networks because it is easy to create the matrix chain by transmission chains of series/parallel impedance in two port form rather than going back to the equations - let matlab do all the hard work of chained matrix multiplies.

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in the acoustic impedance analogue p is V and U is I.

Kevin,

This looks suspiciously like a transfer matrix. I don't understand the difference. 🤔

- Terry

Terry Montlick Labs

Tweeters tweaked. Woofers neutered.

[Terry Montlick](#)

Posts: 1143

Joined: Mon Apr 12, 2004 9:31 pm

Location: Rhode Island, USA

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Re: Flow Resistance of Panel Absorbers

by [krasmuzik](#) » Sat Feb 28, 2009
4:04 pm

Terry Montlick wrote:Kevin,

This looks suspiciously like a transfer matrix. I don't understand the difference. 🤔

- Terry

chaining upstream vs. downstream or backwards vs. forwards or in vs. out...

Don't remember what version Cox used in his book so just noting the conventions we used at Salford. There are after all many different circuit analogues and many different two-port modeling conventions (not counting these two different ways of T matrixes) - and that don't count CGS vs. MKS units to make it even more confusing 🤔

Kevin R. Shank

[krasmuzik](#)

Posts: 165

Joined: Tue Feb 10, 2004 1:49 am

Location: Newport, VA

T
o
p

Re: Flow Resistance of Panel Absorbers

by [bert stoltenborg](#) » Sat Feb 28, 2009 4:28 pm

Is this flow resistance something like the acoustical impedance you have with speaker membranes?

If you view life with the knowledge that there are no problems, only opportunities, you are a marketing manager.....this is my personal philosophy

[bert stoltenborg](#)

Posts: 4520

Joined: Sun Apr 18, 2004 11:03 am

Location: Achterhood, Netherlands

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Re: Flow Resistance of Panel Absorbers

▣ by [Terry Montlick](#) » Sat Feb 28, 2009
4:32 pm

jonessy wrote: I think I lost you guys here... 😬

Let me see if I can find a more detailed (non-ideal) 2-port (just air pressure and particle velocity) thin panel model for you which has vibrational loss in it, Jon. Detailed enough so that I can see how some loss gets generated, but not so detailed that I can't understand it. 🤖

BTW, if you add any porous absorber (modeled with Delany/Bazley, etc.), you will of course add loss from the resistive flow.

Regards,

Terry

Terry Montlick Labs

Tweeters tweaked. Woofers neutered.

[Terry Montlick](#)

Posts: 1143

Joined: Mon Apr 12, 2004 9:31 pm

Location: Rhode Island, USA

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