EDITORIAL

Interesting Paradoxes of Airborne Sound Insulation

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Alexander Pushkin (1799-1937), the great Russian poet, expressed his admiration for science in a beautiful verse translated by me to English:

Many a wonderful invention
shall rise from hard experiment,
The power of education,
The genius, paradox's friend,
and luck of a divine occasion

Sometimes vibro-acoustic engineers encounter puzzling and, at first glance, paradoxical problems. A paradox used to be defined as a result or statement that sounds contradictory or absurd but may in fact be true.

In science, most paradoxes come from the inability to interpret the differences between the observed and theoretically (or intuitively) expected data. Such anomalies can be solved with a new theory or breakthrough experiment, which may not be easy but moves people forward in theory and practice (the genius, paradox's friend). Fortunately, apparent anomalies in vibro-acoustics have been sooner or later resolved. Let's describe some apparent paradoxes in airborne sound transmission.

Abnormally low sound insulation of multiple partitions with no sound absorption in air gaps. By analogy to thermal insulation, some engineers believe that good sound insulation afforded by double or triple partitions is enhanced mainly by the number of air gaps. Such a mistake may result in misleading conclusions – the more air gaps, the higher the direct sound transmission loss of a partition. However even at high frequencies (where the mass-spring-mass resonances can be neglected), this opinion proved wrong for the ideal partition consisting of N similar infinite panels separated by equal air gaps:

$$TL = TL_0 + 10\log(N)$$

where TL_0 is the transmission loss for a single panel.[1] In particular, even for a partition consisting of 10 panels, the calculated transmission loss exceeds that for one panel by just 10 dB. This paradox rose from a deliberate assumption of no sound absorption in the air cavities and panels. (The former is more important than the latter, since in practical cases, the sound energy dissipation inside solid panels is notably below that occurring on its surfaces.)

This is why sound absorption layers in the cavities are more important for multilayer partitions than many solid panels. A notable role of sound absorption in the air cavity for double partitions was theoretically proved earlier[2] (in the classical theory,[3] published 17 years before[2] the effect had not been clearly interpreted).

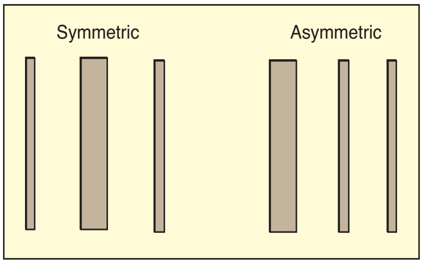

Figure 1. Symmetric and asymmetric partition configurations.

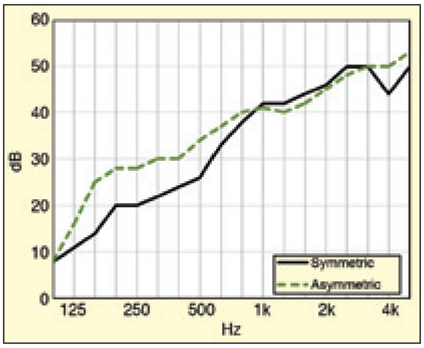

Figure 2. Sound transmission loss of symmetric and asymmetric partition configurations.

Massive middle panes in a triple window can notably reduce transmission loss at low frequencies. A theoretical result, looking paradoxical, was derived for a symmetric infinite triple partition (with similar external panels and equal air gaps, Figure 1).[4] The airborne sound transmission at low frequencies does not increase with the surface density of the middle panel. Such an effect is caused by two mass-spring-mass resonances where the role of masses and springs is played by the panels and air gaps.

For a symmetric triple partition, the natural frequencies are close together and get even closer if the middle panel gets more massive. Two nearby resonances mutually amplify each other and therefore reduce the sound transmission loss in this frequency region. For asymmetric triple partitions consisting of the same three panels but with the lightweight panel in the middle, the natural frequencies are not as close, and the low-frequency transmission loss is higher.

A similar trend was observed experimentally. As seen from the one-third-octave transmission loss spectra for the symmetric and asymmetric, double-spaced glass units with 10-mm panes and two 3-mm panes and 20-mm air gaps (Figure 2), in the range 160 - 500 Hz, the average difference exceeds 8 dB. The adjacent pane edges were connected along the whole perimeter by a 20-mm hollow aluminum profile. It is noteworthy that the mass-spring resonances commonly govern the airborne sound transmission loss of lightweight partitions and glazing at low frequencies, while the indirect sound transmission (in particular, via the edge "sound bridges") dominates at high frequencies.

Can the transmission loss of real single partitions notably overdo the Mass Law? The Mass Law is one of the main relationships of the theory of airborne sound transmission. It was first derived for infinite single partitions at normal sound incidence. For diffuse sound incidence, it is correct well below the coincidence frequency.

According to the Mass Law, the airborne sound transmission loss grows with the logarithm of the product of sound frequency and partition's surface density. (At normal sound incidence, it is 5-6 dB over that for diffuse sound incidence.) However, in 1954 V. Peutz published a paper declaring his paradoxical experimental findings: the transmission loss of thin plates at low frequencies can notably (by 10-15 dB) exceed Mass Law predictions, even those for normal incidence.

He noted the thicknesses of the plates but not their length and width. However, those non-reported dimensions are important at low frequencies, where they control the sound radiation coefficient – the smaller the partition, the lower its sound radiation ability.

The effect described by V. Peutz can occur if the length and width of the plates tested did not exceed 0.5-0.6 m. Possibly, this is why the paradox, much discussed in 1954, did not later attract noteworthy attention.

Do the loss factor, stiffness, size, and edge conditions affect the Mass Law at low frequencies? It does not for infinite partitions. For real finite partitions, it does. The partition can resonate at its natural frequencies of bending vibration. In particular, this effect "rejects" the Mass Law at very low frequencies.

Now that we obtained multiple experimental data, this limitation does not seem too important. But in the beginning of sound transmission science, the effect looked like a formidable restriction for the Mass Law. This is why the asymptotic law derived by Schoch in 1937 played the role of a good paradox; with frequency, the acoustic impedance of a single finite partition approaches that of the infinite partition. Even though Schoch's result was obtained only for normal sound incidence, it helped Cremer to develop his classical theory of sound transmission via single partitions.[7]

Conclusions. There might be two important proverbs for all engineers and scientists: "Most often, new used to be well-forgotten old" and "Don't step on the same rake twice." From this viewpoint, the forgotten paradoxes can help. In Alexander Pushkin's drama Boris Godunov, the Russian tsar, tells his sun Fyodor (my translation):

"*Peruse, my son: the learning shortens trialsin our life, that goes so fast . . .*"

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3. London, A., "Transmission of Reverberant Sound Through Double Walls," *Journal of the Acoustical Society of America*, 22, pp. 270-279, 1950.
4. Vinokur, R. Y., "Transmission Loss of Triple Partitions at Low Frequencies," *Applied Acoustics*, 29, pp. 15-24, 1990.

5, Peutz, V., "Some Fundamental Measurements On Single and Double Plate Structures", *Acustica*, 4, pp. 281-284, 1954.

6. Schoch, A., "Über Ein Asymptotisches Verhalten Von Erzwungenen Plattenschwingungen Bei Hohen Frequenzen," *Akust. Zeits*, 2, pp. 113-128, 1937.

7 Cremer, L., "Theorie Der Schalldämmung Wände Bei Schrägem Einfall," *Akust. Zeits*, 7, pp. 81-104, 1942.

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