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2pED2. Popular papers with short case stories on acoustics and vibration for practical engineers and students

Roman Vinokur*

*Corresponding author's address: Engineering, ResMed Motor Technologies, 9540 De Soto Avenue, Chatsworth, CA 91311, romanv@resmed.com

One of the reasons for using foam wedges or cones in hemi-anechoic rooms is a gradual change of the acoustical impedance in order to reduce the reflection of incident sound waves from the sound absorbing walls. By analogy, popular papers on science (in particular, in acoustics and vibration) facilitate a smooth introduction to new theories because of their small cognitive "impedance" to understanding the written information. Such papers are relevant mostly for extramural reading but they help engineers and students to promptly perceive important effects and applications via interesting case stories and simplified physics and mathematics. Generally speaking, this approach is not new: in particular, it was successfully applied by Y. Perelman in his book "Physics for Entertainment". But in author's opinion, for better effectiveness such texts should be limited in size and include 3-4 related short case stories from actual engineering or consulting practice, history, news, or literature. To illustrate this method, several one-page papers published in the "Sound and Vibration" magazine will be briefly discussed: "Haunted Buildings and Other Acoustical Challenges", "Vibroacoustic Measurements without Transducers", and "Only the Best Will Do".

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SHORT ENTERTAINING STORIES AS A STIMULUS TO SELF-IMPROVEMENT

Short entertaining stories on physics (in particular, acoustics and vibration) published by practical specialists on Internet or in popular magazines may be recommended for extramural reading for young people, entering the profession, to activate their pursuit of solving practical problems. The cognitive effect will increase if the paper contains several consistent case stories with an interesting introduction and clear pictures. For prompt accessibility, the stories are to be published on Internet.

In particular, a good collection of such stories is Yakov Perelman’s “Physics for Entertainment” [1]: first published in 1913, this book was translated from Russian into many languages and influenced science students around the world. To describe his approach, Perelman wrote: *I have quoted extensively from Jules Verne, H. G. Wells, Mark Twain and other writers, because, besides providing entertainment, the fantastic experiments these writers describe may well serve as instructive illustrations at physics classes.*

Many topics of the book were devoted to acoustics and vibration: “Sound and Bullet,” “If the Speed of Sound Were Less,” “The Train Whistle Problem,” “Acoustical Clouds and Aerial Echo, etc. Yakov Perelman (he died from starvation in 1942, during the German Siege of Leningrad) was not related to the famous Russian mathematician Gregory Perelman (born in 1966), who solved the Poincare conjecture but rejected the Fields Medal and the Millennium Prize of one million dollars for this extraordinary achievement. But Gregory’s interest in science, particularly mathematics, was inspired by his father who gave him *Physics for Entertainment*. Moreover, at least two generations of the engineers were inspired but this book.

A much similar approach was utilized by J. Walker [2]. However, the case stories in books [1, 2] do not fit all the requirements that in author’s opinion are important:

- Three-five interesting case stories, devoted to the same problem or method, are published in the same paper by vibroacoustic engineers and consultants based on their practical experience.
- The paper is short (approximately one page).
- The case stories are written in entertaining manner.
- There should be no complicate equations in the paper. The goal is to inspire the readers to get back to their science books and do a deep study on their own.
- This is a big plus, if the paper can be accessed on Internet for free.

A few examples of such case stories are described in the next chapter.

EXAMPLES OF THE CASE STORIES DESCRIBED ABOVE

Acoustical Ghosts

Many tales have been told of haunted houses – doors exploding off the hinges, lights spinning on their own, inexplicable sounds of a crying woman or heavy footsteps. But some of them are real as described in paper [3].

The Case of a Haunted Building

The main objectives are to inspire the students in studying:

- Theory of aeroacoustics and Helmholtz’s resonator.
- Psychoacoustics as the science of sound perception.

At the end of the 19th century, a devious contractor hired a team of workers to build a rental building in Moscow, Russia. After the building had been completed, the rogue took advantage of the verbal agreement with the workers (they were illiterate) and paid them just half of what had been promised. In response to their protest, he called the police and made the workers improve the roof just for food and vodka. However, tenants did not stay long in the new building because of a mysterious nocturnal roaring, the ‘haunted’ house did not provide sufficient rental income and creditors appeared with written contracts in hand. The contractor tried to ‘fix’ the problem using illegal methods but finally went to prison. The new owner, a railroad engineer, hired the workers who had built the house to eliminate the source of the evil noise. They showed him the empty vodka bottles vengeancefully embedded in the roof and loft with the open necks outward. The air in the bottles resonated and ‘wailed’ when a strong wind blew across the open necks (FIGURE 1). Using a Helmholtz resonator model, the engineer evaluated
the frequency of this noise as about 100 Hz. This low-frequency sound penetrated into the rooms through the ceiling and windows. During the day, the ‘ghost’ roaring was partly masked by the street noise, but the local winds were strong at night. Such a nocturnal noise, both tonal and intermittent, proved too annoying even for those tenants who did not believe in poltergeists. After the cheerful workers removed the glass ‘ghosts,’ the rental house became profitable.

**Two involuntary Ghosts**
The main objective is to acquaint the students with some of the structural and airborne noise “mysteries” quickly resolved by acoustical consultants.

Good neighbors do not enjoy rock music with their windows fully open and do not have noisy parties late at night. However, the following stories show that even good neighbors sometimes turn their dwellings into ‘haunted’ houses. In both cases, those complaining were elderly women living in multistory concrete buildings. The ghost was a noise allegedly coming from an upper-floor apartment. The first case happened to a colleague of mine. The complainant lived on the second floor. A chronic low-frequency noise occurred from 9:00 a.m. to 6:00 p.m. while the third-floor neighbor was not at home. My colleague visited the neighbor on the fourth floor. She was a typist working at home. The vibration from her mechanical typewriter was conveyed through the desk to the linoleum floor, and the thin linoleum layer was not a good isolator of low-frequency vibrations (FIGURE 2). All the floor slabs and the internal and external walls were similar concrete panels. The fundamental frequency of the bending vibration for such panels was calculated to be about 60 Hz, which was consistent with the spectrum measured at the apartment on the second floor. The typist willingly agreed to have rubber isolators placed under her desk and the ‘ghost’ problem was solved to the satisfaction of all parties.

The other story involved a woman complaining of TV noise. The woman called on her neighbor but found his TV to not be excessively loud. So, she suggested that the ghost noise could be emanating from another apartment – but from which one? At her landlord’s request, I visited an upper apartment. A young Ph.D. student had recently moved in with his mattress, TV set, computer and many books – all resting on the floor. I had previously measured the airborne sound transmission loss of the concrete floor in two opposite directions – with the testing sound source (a loudspeaker) on the floor of the lower room and with the source on the floor of the upper room. In the second case, the sound insulation proved notably worse. By my proposal, he elevated the TV just by one foot using his books as the supports. This temporary solution worked to some extent and the young man promised to buy a TV table the next day to fully solve the problem.

**FIGURE 1.** The air in the bottles resonated and ‘wailed’ when a strong wind blew across the open necks.
FIGURE 2. The vibration from a mechanical typewriter as a source of low-frequency structural noise propagating via the concrete floor and walls to the other apartments. The effect proved notable at the resonance frequency of the panels (about 60 Hz).

Vibroacoustic Measurements without Transducers

The importance of modern devices for vibroacoustic measurements is difficult to overestimate. However, sometimes we may have to do without high-precision transducers and sophisticated analyzers – because they are not available at that time, or they can be damaged or they cannot be used directly for a particular application. One of the four case stories published in paper [4] is presented below.

The objective is to demonstrate to students that low-frequency vibration may be sometimes measured without high-precision accelerometers and laser-vibrometers.

Angular Deflection of a Fan

FIGURE 3. The red light beam from the laser pointer was reflected by the mirror moving together with the fan core.
I was working for a large company making air-circulating and ventilating fans. The quality control manager wanted to test the angular deflection of ceiling fans from the vertical axis under the imbalance force.

The rotational speed of the fan was 180 RPM (3 Hz). Our small accelerometers didn’t operate at such low frequencies, and it wasn’t clear how to protect the accelerometer cable from the rotating blades. But I found a simple solution by arranging a pen-shaped red laser pointer (on the floor), a small magnet-backed mirror (on the steel fan core) and a piece of graph paper (on the floor) as shown above. The red light beam from the laser pointer was reflected by the mirror moving together with the fan core. The red circle, illuminated by the reflected beam on the graph paper, was a magnified image of the fan precession (FIGURE 3).

The angle of the fan deflection \( \alpha \) from the vertical was calculated by the equation \( \alpha = \frac{R}{2H} \), where \( R \) is the radius of the red circle and \( H \) is the height of the fan core over the floor. The quality control manager was satisfied with the results obtained.

“We wanted the best, but it turned out not good”

As distinct from engineers, politicians make “high-flying” mistakes, not only in their papers and implementations, but also when they talk to a broad audience. The objective is to acquaint the students with some typical mistakes in the practice of noise and vibration reduction.

Vibration Isolation with a Resilient Pad.

It is a common knowledge that flexible mountings isolate machine vibrations. Very often, manufacturing engineers implement such solutions without consulting the specialists. As a result, the vibration is not reduced enough and sometimes even increased because vibration created by the operating machine at frequencies lower than its mounted resonant frequency is not isolated at all. Vibration at a resonance frequency may be amplified. The resonant frequency of the machine on its resilient mountings must be well below the frequencies of the vibration to be isolated. If the mountings are steel springs, the resonant frequency is typically low, and the chances for success are commonly higher. With a rubber pad under the machine (Figure 4), the resonant frequency may be relatively high and can coincide with one of the main vibration frequencies (in particular, with the motor speed of rotating machinery). I have seen quite a few of such failures. In some cases, the machines were big and heavy, so the remounting procedure was costly.

![FIGURE 4. Vibrating machine on a rubber layer.](image)

Sound Insulating Wall

A large fan in the utility room of a commercial building created a terrifying low-frequency noise that propagated to a nearby office via the adjacent wall. To reduce the noise, an acoustical consultant recommended erecting an extra single drywall partition 0.6 m (2 feet) away from the fan (FIGURE 5a). However, the manufacturing engineer reduced this distance to 0.05 m (2 inches) to save the utility room area for new equipment. He thought that with the same wall, the recommendation should work anyway. Post-construction reality proved harsh – the drywall “roared” more loudly than the fan itself. The acoustical consultant returned, looked at the design, and quickly explained what happened. If the air gap between the drywall and fan is narrow, a 1-DOF vibration system is created where the air...
gap works as a spring and the drywall plays the role of a lumped mass (FIGURE 5b). The resonant frequency of this system is given by equation

$$f_{\text{res}} = \frac{\sqrt{\rho c^2 / (M d)}}{2 \pi} \approx 85 \text{ Hz}$$

where the surface density of the drywall $M = 10 \text{ kg/m}^2$, the gap thickness $d = 0.05 \text{ m}$, air density $\rho = 1.3 \text{ kg/m}^3$, and sound speed in air $c = 330 \text{ m/s}$. Such a low-frequency resonance amplified the noise of the fan at the same frequency.

![Figure 5a: Machine with Air gap and Drywall](image)

**FIGURE 5.** If the air gap between the drywall and fan is narrow, a 1-DOF vibration system is created where the air gap works as a spring and the drywall plays the role of a lumped mass

**CONCLUSION**

In author’s opinion, the short entertaining papers described above may be helpful to the future vibroacoustic engineers.

**REFERENCES**