## Is my room large enough?

Every pianist was, at some point or another, unsettled by the question: how large shoud a music room be to provide satisfactory experience? Or, to put it in another way: what piano sizes would musically suit a specific room?

The question relies on acoustics, from the production of sound inside the instrument to the way it interacts with the environment. The problem is plagued by too many variables for a simple answer to be formulated. Variables such as humidity, temperature and air density all have important effects on sound quality and, even under the most drastic control, different voicing or hammer wear would produce vastly disparate sounds. In addition to the previous variables, a variety of acoustic phenomena occurs when the sound waves interact with furniture and walls, which makes any exhaustive modeling, and thus satisfactory answer, impossible.

## Lewis Lipnick's recommendations

The only useful element of response that I found is provided by Lewis Lipnick in Larry Fine's Piano Buyer ${ }^{1}$, and is based on the extensive experience of the author and of his impressive network of technicians. I attempt to summarize it by the following points:
(i) Rooms with non-parallel walls perform better than those with parallel walls
(ii) Room lengths (including height) should not be multiples of one another
(iii) The room total wall length should be at least 10 (resp. 15) times the size of the piano for solo (resp. ensemble) playing

The intuitive reason behind point $(i)$ is relatively simple. In a room with parallel walls, some of the acoustic wave is trapped bouncing perpendicularly to the walls in a way that it returns frequently to the same location. This creates a standing wave, resulting in dead areas where the air pressure does not vary (the pitch cannot be heard) next to live areas where the air pressure oscillates with maximum amplitude (the pitch is heard with maximum intensity). As these dead and live areas are different for different frequencies, this phenomenon leads to an imbalanced perception of the music where, depending on the location of the listener, certain pitches dominate over others. Non-parallel walls make the waves bounce at an angle and make their return to the same position less frequent, thus preventing the creation of some otherwise dangerous standing waves. Unfortunately, as most rooms have parallel walls, point ( $i$ ) cannot always be met and point (ii) is then recommended to palliate the emergence of standing waves. For example, rooms with two equal lengths, or with one length being the double of another, should be avoided. The rationale behind this recommendation is that rooms with such aspectratios might favor the build-up of the same frequencies in at least two directions and, thus, of strong multi-dimensional standing waves.

## Further criteria

We now turn to point (iii). The recommendation provides a criterion on the room total wall length, not on its volume. It assumes a standard room height of approximately 8 feet, or about

[^0]2.44 m . In this essay, I provide some further calculations to convert the total wall length criterion into criteria on the piano size and on the room dimensions.

Let us consider rectangular rooms. Rooms with more complex (polygonal) shapes usually possess more wall length per unit volume (see the fractal coastline problem ${ }^{2}$ ) and, thus, focusing on the simplest shape provides an upper bound for the room surface area criterion ${ }^{3}$. Actual room dimensions can then be compared with the criteria obtained for rectangular rooms: if the criteria are met, then the room is unarguably large enough. A similar argument holds for piano sizes.

We denote by $S$ the piano size, by $l$ the width of the room and by $\alpha \geq 1$ its aspect-ratio, such that the length of the room is $L=\alpha l$. This notation is illustrated in figure 1 .


Figure 1: Sketch of the piano room of width $l$, length $L=\alpha l$, where $\alpha$ is the aspect-ratio of the room. The piano is a grand piano of size $S$.

For practicality, we also denote by $c$ the coefficient given in point (iii): $c=10$ (resp. $c=15$ ) for solo (resp. ensemble) playing corresponding to the minimum recommended total wall length expressed in units of piano size. The total wall length is $2(l+L)=2(1+\alpha) l$, so we get:

$$
\begin{equation*}
2(1+\alpha) l \geq c S \tag{1}
\end{equation*}
$$

From this, one can express a criterion for the piano size $S$ :

$$
\begin{equation*}
S \leq \frac{2(1+\alpha) l}{c} \tag{2}
\end{equation*}
$$

This way of reformulating point (iii) is of particular interest to those wanting to place a grand piano in a given room but not knowing which size they should consider.

Example: What grand piano sizes can one consider for solo playing in a 7 m by 4 m room? Replacing $\alpha=7 / 4, l=4 m$ and $c=10$ in equation (2) reveals $S \leq 2.2 m$, such that a grand piano of up to 2.2 m can be placed in this room without compromising on acoustics.

The surface area of the room is given by:

$$
\begin{equation*}
\Sigma=L l=\alpha l^{2} \tag{3}
\end{equation*}
$$

[^1]so to get a criterion for the surface area, we need to obtain one for either $l$ or $\alpha$ from equation (1). The former criterion seems more useful than the latter, which will thus be discussed in a separate section. The criterion for $l$ is:
\[

$$
\begin{equation*}
l \geq \frac{c S}{2(1+\alpha)}, \tag{4}
\end{equation*}
$$

\]

which gives:

$$
\begin{equation*}
\Sigma \geq \alpha \frac{c^{2} S^{2}}{4(1+\alpha)^{2}} \tag{5}
\end{equation*}
$$

This criterion will be of interest to those designing a music room.

Example: How to design a music room for solo playing $(c=10)$ on a 214 cm grand piano ( $S=2.14 m$ )? Following point (ii), we choose a non-rational aspect-ratio $\alpha=\sqrt{2}$. The minimal surface area that the room should possess is given by equation (5): $\Sigma \geq 27.8 m^{2}$. To get the minimal dimensions of the room, we use equation (4): the width is $l \geq 4.43 \mathrm{~m}$, giving the length $L=\alpha l \geq 6.27 \mathrm{~m}$.

From expression (5), one can also get a criterion for the piano size:

$$
\begin{equation*}
S \leq \frac{2(1+\alpha)}{c} \sqrt{\frac{\Sigma}{\alpha}} \tag{6}
\end{equation*}
$$

This criterion is similar to criterion (2), but uses the surface area of the room instead of its width $\left(\Sigma=\alpha l^{2} \Longleftrightarrow l=\sqrt{\Sigma / \alpha}\right)$.

Example: What piano size should one get to play chamber music $(c=15)$ in a room $\overline{\text { of surface area } \Sigma=40 \mathrm{~m}^{2} \text { and of aspect ratio } \alpha=\sqrt{3} \text { ? Using criterion (6), we }}$ obtain $S \leq 1.75 \mathrm{~m}$, so that pianos of up to 1.75 m would suit ensemble playing in this room.

## Limitations

These recommendations come with obvious limitations. Large aspect-ratio rooms can easily satisfy any of the above criteria but not be able to host a piano. For example, a room with aspect-ratio $\alpha=15$ and width $l=1 \mathrm{~m}$, gives a total wall length of 32 m . Point (iii) tells us that the room is large enough for a typical concert grand piano, however, the width of most grand pianos is about 1.55 m , making it impossible to fit the piano into the room, except tipped... This is an extreme example, but it illustrates the fact that the recommendations discussed here become less relevant when larger room aspect-ratios are considered.

Another limitation resides in the room height. If pianos could be modeled as unobstructed pointwise sources, sound would be produced in spherical waves and propagate indiscriminately in all three directions. The volume of the room (together with its aspect-ratios) would then undeniably be the quantity of interest. However, the actual physics is substantially more complex. An open lid, for example, would transfer some of the energy from vertical acoustic waves to horizontal ones, hereby increasing the importance of the horizontal dimensions of the room and decreasing that of its height. As such, it is difficult to provide a correction to the presented criteria that takes into account the room height.

Nowhere in this discussion has the room content been discussed. It is important to realize that carpets or tapestry substantially dissipate acoustic energy compared to more reflective surfaces such as floor tiles and glass windows. I believe that the original piece of advice is based on technicians' experience and should be understood in the following way: any room that complies with the recommendations, if not satisfactory as is, can be treated to yield satisfactory acoustic performance.

## Alternate criterion

From equation (1), one can also express a criterion for the room aspect-ratio $\alpha$ :

$$
\begin{equation*}
\alpha \geq \frac{c S}{2 l}-1 \tag{7}
\end{equation*}
$$

for which we need to bear in mind that $\alpha \geq 1$, by definition. The surface area criterion then reads:

$$
\begin{equation*}
\text { if } \quad \frac{c S}{2 l}-1 \geq 1, \quad \text { then } \quad \Sigma \geq\left(\frac{c S}{2 l}-1\right) l^{2} \tag{8}
\end{equation*}
$$

The condition in criterion (8) relies on $S / l$ not being too small. Small values of this ratio implies that the piano is small comparatively to the width of the room. In this were to be the case, then the room would be perfectly suitable to host a piano and no further criterion would be needed.

## Closing remarks

The purpose of these notes is to help the pianist community. If you spot an error, typo, or for any remark or question, please let me know at: ced.beaume@gmail.com.


[^0]:    ${ }^{1}$ https://www.pianobuyer.com/article/how-to-make-a-piano-room-sound-grand/

[^1]:    ${ }^{2}$ https://en.wikipedia.org/wiki/Coastline_paradox
    ${ }^{3}$ We will not consider triangular rooms, which are not as common as rectangular ones

