PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Acoustics inside a gypsum sphere with 7 m of diameter

Ernesto ACCOLTI [1]; Fernando DI SCIASCIO; Daniel GANDOLFO

Instituto de Automática, National University of San Juan and National Scientific and Technical Research Council, Argentina

ABSTRACT

Concave surfaces are known to focalize or diffuse sound depending on the curvature and the source position regarding the surface. Spherical rooms are frequently found as theoretical cases in the literature. In this work, results from models and measurements of the acoustics inside a 7-m-diameter gypsum sphere are compared.

Keywords: concave surfaces, spherical rooms, architectural acoustics

1. INTRODUCTION

That concave surfaces are likely to focus sound energy is a well-known problem in room acoustics (1, 2, 3). Whisperings gallery is frequently presented as a theorical case (3).

In this article the acoustics of a 360° cinema inside a gypsum truncated sphere is studied and a project for the acoustic conditioning is proposed. The study has two goals: giving support to theory and identifying acoustic conditioning needs.

The 360° cinema was constructed at the same time the present study was being carried out. Thus, the main conditioning is not yet implemented, but acoustical measurements of the unconditioned cinema were taken in order to improve the proposals.

Schemes of the cinema are shown in Figure 1 and Figure 2. Figure 1 shows an elevation cross section joint to three proposals of loudspeakers configuration. Figure 2 shows the floor plan joint to measurements points.

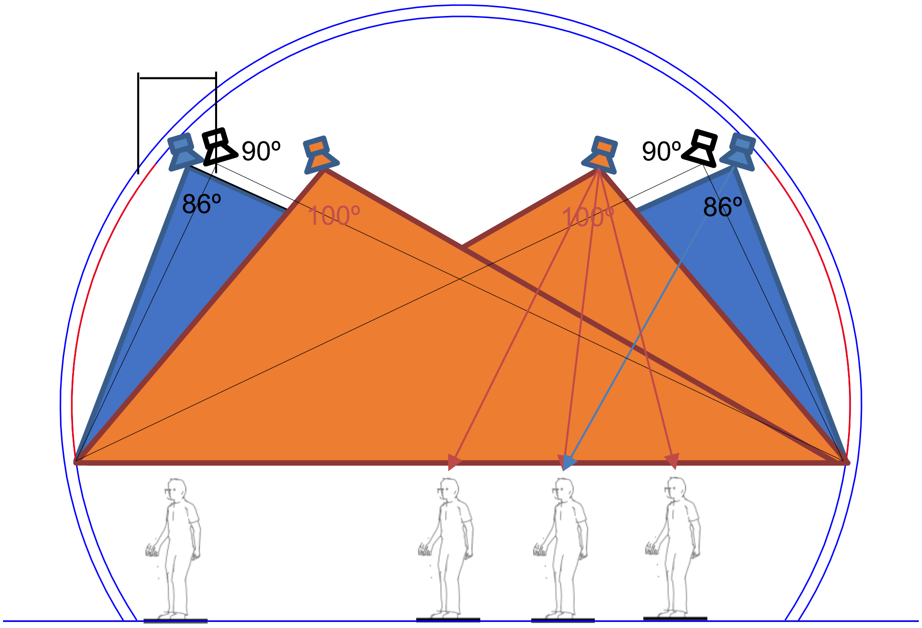

Figure 1 – Scheme with directive loudspeakers from above

[1] eaccolti@inaut.unsj.edu.ar

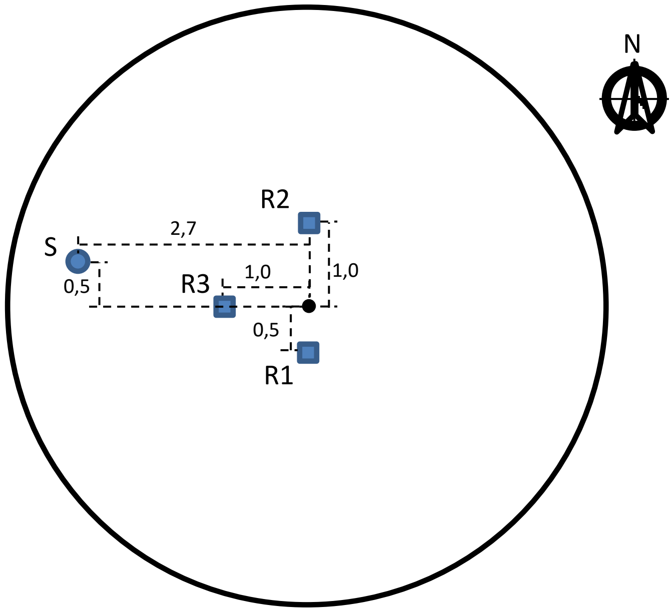

Figure 2 – Scheme with source S and measurements points R1, R2, and R3.

2. PREDICTIONS

The main method for predictions is the Kirchhoff integral applied to spherical surfaces as in Vercammen pp. 50 (2).

$$p(A,\varpi) = \frac{p_{\mathrm{i}}R}{4\pi} \int_{\theta=\theta_M}^{\theta_m} \int_{\phi=0}^{2\pi} \sin\theta \left(\frac{1+ku}{u}\cos\varphi + \frac{1+jks}{s}\cos\alpha\right)\frac{e^{-jk(u+s)}}{su}\,\mathrm{d}\theta\mathrm{d}\phi \tag{1}$$

where $p(A,\omega)$: is the sound pressure at a receiver point A, for the angular frequency $\omega=2\pi f$, linear frequency f, wave number k, p_{i} is the source sound pressure measured at 1 m in free field, s is the surface differential distance to source, u is the surface differential distance to receiver, R is the surface differential distance to the center of the sphere, θ is the elevation angle of the surface differential, ϕ is the azimuth angle of the surface differential, α is the local angle from the receiver to the center of the sphere at surface differential, and φ is the local angle from the source to the center of the sphere at surface differential.

In order to include all the first order reflections, the reflection in the floor was added using the image source method (3)

$$p_{\mathrm{f}}(A,\varpi) = p_{\mathrm{i}}\frac{e^{j\varpi d/c}}{d} + p(A,\varpi) \tag{2}$$

where p is the sound pressure including all first order reflections,

Equation (2) was implemented in a mathematical software to calculate the sound pressure. The surface was discretized in 100 steps of elevation and in 900 steps of azimuth. Receivers were modeled in two categories: surface receivers and punctual receivers.

Surface receivers were located in a plane located 1.4 m above the floor. The surface was sampled using a squared grid of 40 cm side. For this category of receivers, the sound pressure was estimated with equation (2) at the center frequency of the 1/1 octave bands.

Figure 3 shows the sound pressure due to first order reflections for the 125 Hz frequency. The figure shows the source position with a red truncated pyramid. The floor is the gray surface. Every 10 elevation elements a black circle is shown. The blue pyramids are other loudspeakers.

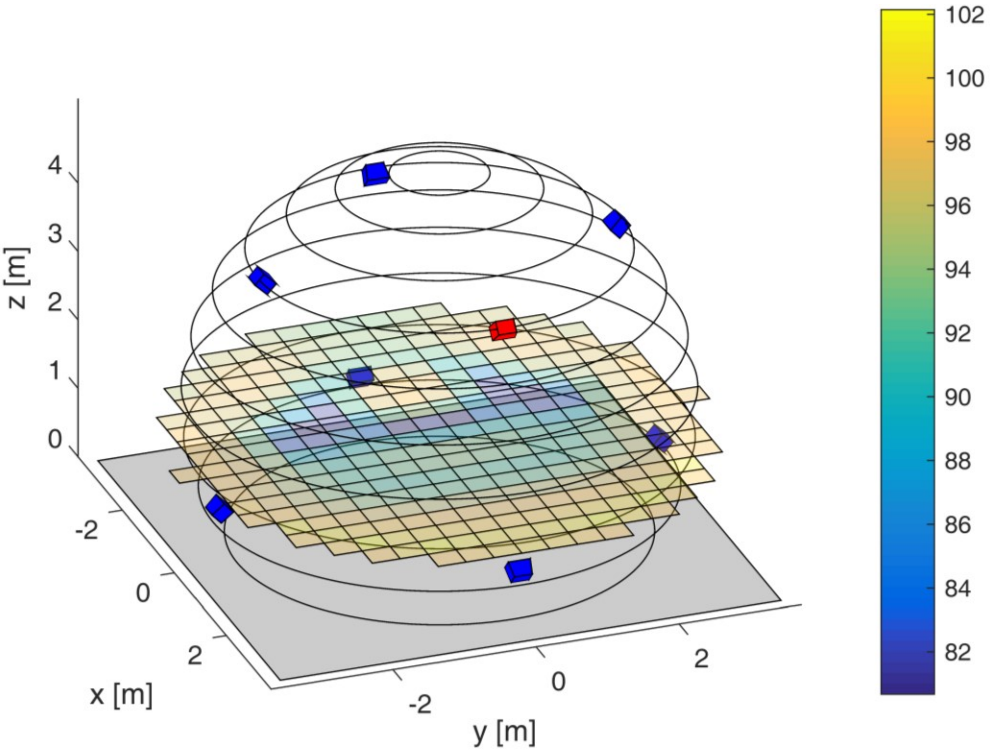

Figure 3 – Sound pressure distribution. Surface receivers and one source located at 4 m high

Punctual receivers were located at positions R1, R2 and R3 at 1.4 m high. These receivers were used to estimate the impulse response corresponding to one reflection in the concave surface. For this category of receivers, the sound pressure was estimated with equation (2) at 4 096 linearly spaced frequencies in the range from 0 Hz to 6 kHz. Then, using the inverse Fourier Transform, the impulse response was calculated.

Figure 4 shows the impulse responses of the first order reflections calculated with this method.

3. MEASUREMENTS

In order to both validate the proposed model and carry out a diagnosis of the room a number of acoustical measurements were taken. For that purpose, the impulse responses were measured using both balloon bursts and sweeps.

The source position *S* as well as the receivers' positions R1, R2 and R3 are shown in Figure 2. The source was located at a height of 4 m and receivers were located at a height of 1.4 m. Three bursts were used for each receiver.

Figure 5 shows the absolute value of one of the impulse responses for each receiver estimated from the sweeps eliminating the effect of the signal as in ISO 18233 (4). The impulse responses are limited up to about the octave frequency band of to 4 kHz (0 Hz to 6 kHz). Each row is scaled by the amplitude of the direct sound and time shifted by the time the direct sound requires to reach the corresponding receiver.

Finally, using the balloon bursts, the reverberation time was estimated for each burst. The estimators are EDT, T10, T20, and T30 as defined in ISO 3382 (5). Figure 6 shows the average of the estimations for the 9 bursts corresponding to the 3 repetitions for each of the 3 receivers.

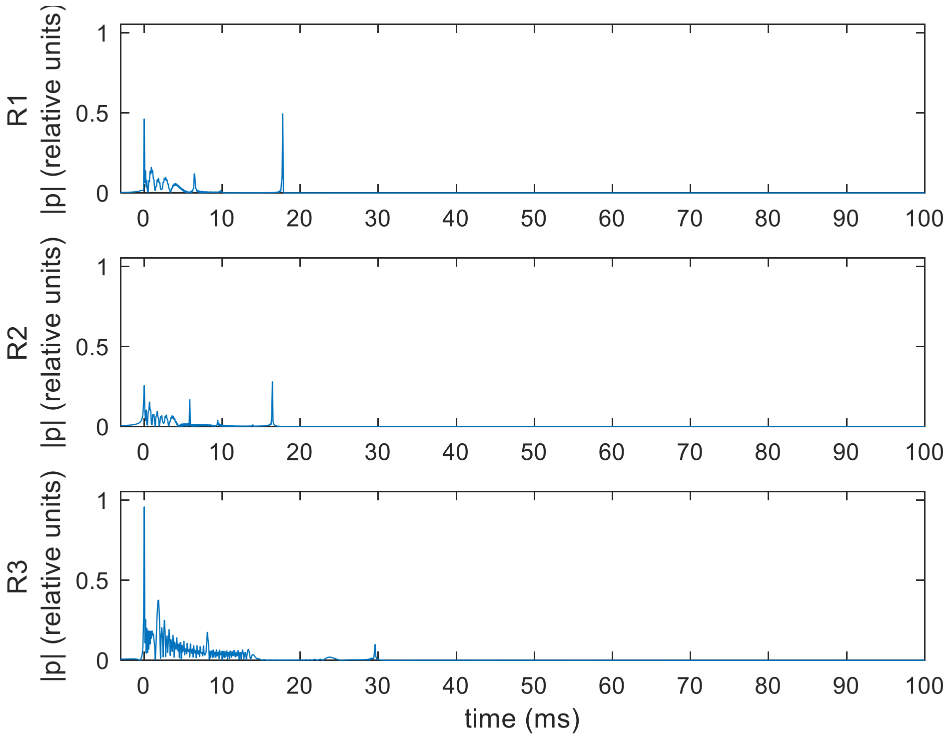

Figure 4 – Calculated impulse responses at punctual receivers located at R1, R2, and R3

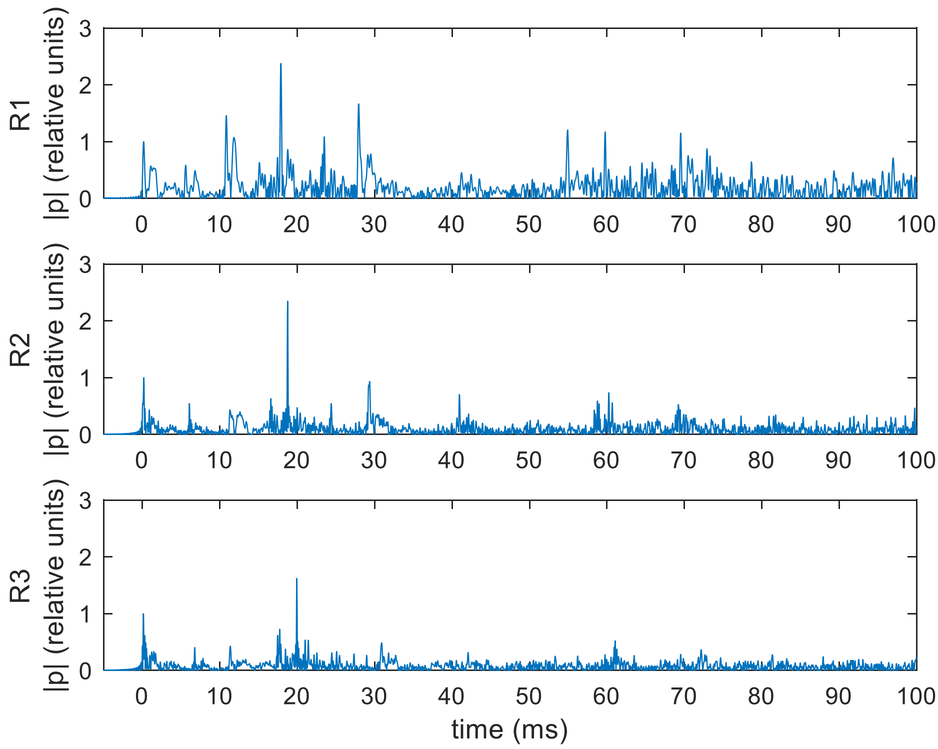

Figure 5 – Measured impulse responses for receivers at R1, R2, and R3.

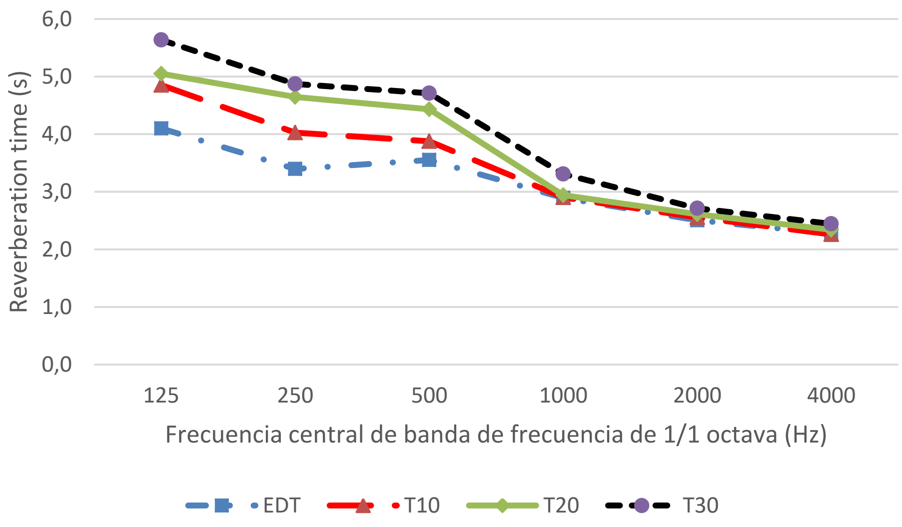

Figure 6 – Reverberation time estimations.

4. DISCUSSION

This article shows an application of numerical calculation of reflected sound pressure due to concave surfaces models. The predicted results are in accordance with measurements and expected behavior for concave surfaces.

The time of the calculated first order reflections is very similar to that of measured reflections. However, the amplitude is not exactly the same possibly due to directivity of loudspeakers or propagation of the discretization errors. In the measured impulse responses several additional reflections are present. These additional reflections are likely to appear due to higher order reflections.

The focalization of sound energy shown in Figure 3 is one of the expected results. Differences of about 20 dB are present in the receiver surface. This effect was not measured with electronic equipment but was perceived aurally by the authors.

A consequence of such a focalization is that the sound field is not diffuse. This conclusion can also be drawn by analyzing the reverberation time estimations in figure 6. In case of diffuse sound fields, the estimations of EDT, T10, T20 and T30 tend to be similar.

Even the focalizations are relatively small problems compared with the main problem: perceivable echoes. These echoes can be distinguished from data shown in Figure 4 and Figure 5 as those reflections comparable in amplitude to the direct sound and delayed about 20 ms or more. A change in the direction of arrival of the echoes was also perceived by the authors as they walked throw the room.

The red line in Figure 1 shows the screen of the cinema. The intention of the commissioner is to avoid acoustics materials in the screen zone. With the model used in this work it is possible to evaluate several configurations such as those shown in Figure 1 affecting the coverage angle of loudspeakers or acoustic treatment in several surfaces.

ACKNOWLEDGEMENTS

The authors acknowledge the support from the following Argentine institutions: the *Secretaría de Estado de Ciencia Tecnología e Innovación de la Provincia de San Juan* (Secretary of State for Science Technology and Innovation of the Province of San Juan), the National Scientific and Technical Research Council, and the National University of San Juan.

REFERENCES

1. Vercammen M. Sound concentration caused by curved surfaces. Proceedings of Meetings on Acoustics, 2013; 19:015053.
2. Vercammen M. Sound concentration caused by curved surfaces. Doctoral thesis, Eindhoven University of Technology, 2012.
3. Kuttruff H. Room acoustics. Elsevier Science Publ.,1973, (fourth ed., Taylor & Francis, London, 1999)

4. ISO 18233:2006. Acoustics – Application of new measurement methods in building and room acoustics. InternationalOrganization for Standardization, Geneva, 2006.
5. ISO, International Standard Organization. ISO 3382-1: Acoustics. Measurement of room acoustic parameters. Part 1: Performance spaces, Geneva, 2009