The extended model to simulate the Quetzal echo at the Mayan pyramid of Kukulkan at Chichen Itza in Mexico

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Introduction

It is well known [1-8] that a handclap in front of the staircase of the pyramid produces an echo that sounds similar to the chirp of the Quetzal bird. This phenomenon occurs due to diffraction. There exist some publications concerning this phenomenon and even some first attempts are reported to simulate it. Recently, it has been shown [Declercq et al, J. Acoust. Soc. Am. 113(4), 2189, 2003] that it is possible to reproduce the echo by means of a simulation which is based on the theory of the diffraction of plane waves and which takes into account continuity conditions. The latter theory is the building block for a theory that tackles the diffraction of a spherical sound pulse. By means of these principles it is possible to simulate the echo following a handclap in front of the staircase. This paper shows results obtained by means of an extension of the model where also reflections on the ground in front of the staircase are taken into account as well as different kinds of incident pulses, such as a delta like pulse and a real handclap.

Theoretical background

The staircase is seen as a periodically corrugated (infinite) surface, being sawtooth shaped (see Figure 1).

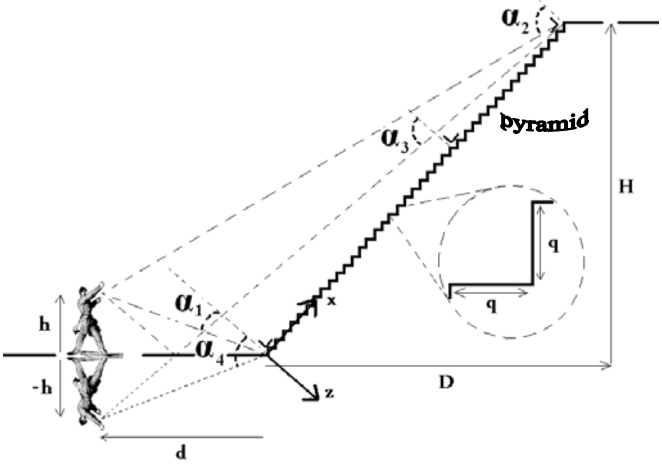

Figure 1: Depiction of the pyramid's staircase with and observer in front of it.

This is only true within the interval of the physical staircase. This infinite mathematical model is matched to reality by modeling a handclap not by a truly spherical wave, but by a wave that only contains propagation directions from the emitter directly to the staircase within the angular interval $[\alpha_1, \alpha_2]$ that assures impingement on the staircase and within the interval $[\alpha_3, \alpha_4]$ if, in addition, reflections on the ground are considered as well. Hence, the handclap is only spherical if observed on the staircase. The diffraction theory of Claeys et al that is applied here can be found in the literature [9-11]. The theory is based on the decomposition of the diffracted acoustic field into pure plane waves. Basically, each of the reflected and transmitted wave fields are decomposed into a series of plane waves, each plane wave of order *m* having a wave vector

$$\mathbf{K}^m = k_x^m \mathbf{e}_x + k_z^m \mathbf{e}_z \qquad (1)$$

with

$$k_x^m = k_x^{inc} + m \frac{2\pi}{\sqrt{2}q} \qquad (2)$$

and k_z^m determined by k_x^m, the material properties of the considered medium and the dispersion relation $k^2 = \omega^2 / v^2$, omega being the angular frequency and *v* being the plane wave velocity. The sign of k_z^m is chosen such, as to fulfill the necessity of plane waves to propagate away from the interface and, whenever k_z^m is purely imaginary, the amplitude must decay away from the interface. The continuity conditions demand continuity of normal stress and normal particle displacements on each spot of the pyramid's staircase. It can be found in Claeys et al [9-11] that this leads to a set of equations that is periodical in *x*, whence the discrete Fourier transform can be applied, resulting in an equal number of equations and unknown amplitudes of all diffracted orders. It can also be found in Claeys et al [9-11] that this discrete infinite set of equations and unknowns can be chopped to a square linear matrix equation that can be solved by a computer.

Numerical simulations vs experiments

The fact that an echo appears that sounds like a Quetal bird, in front of the stairs of the pyramid at Chichen Itza, is widely known [1-8]. It is also known that diffraction is involved. Thanks to the work of David Lubman [13], we have got to know the dimensions of the pyramid, the stairs and the position of the observer, as well as some .wav files that enabled us to compare our simulations with experiments. The calculated echo coming from an incident delta like

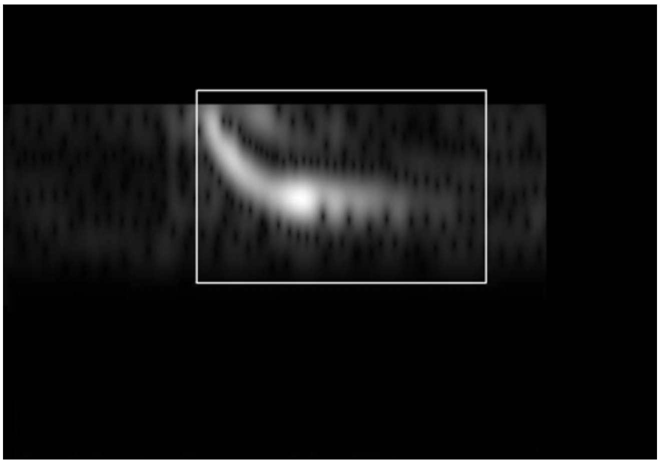

Figure 2: Sonogram of the calculated direct echo coming from a delta pulse. In all sonograms presented here, the white rectangle is a reference window and the horizontal axes run from 0s to 0.2 s whereas the vertical axes run from 0Hz to 5kHz (at the position of the upper side of the reference window).

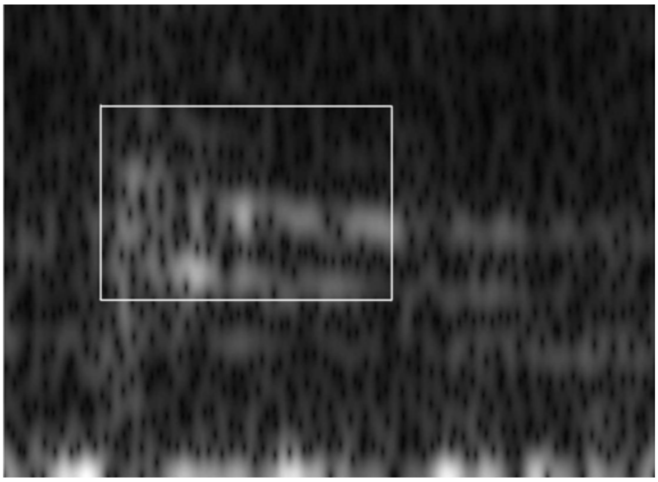

Figure 3: Sonogram of the recorded echo coming from the pyramid [13].

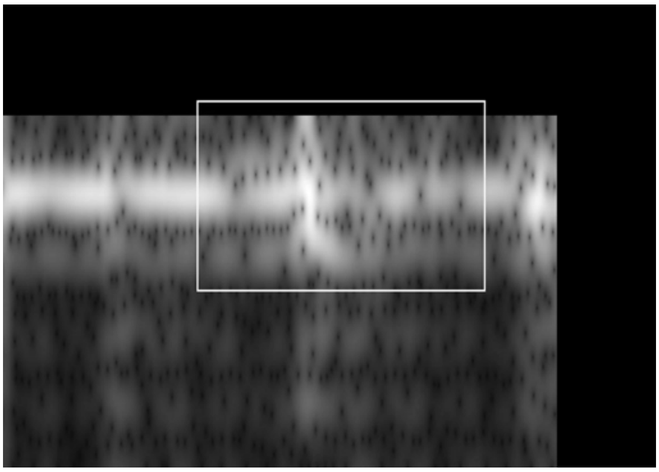

Figure 4: spectrogram of the calculated direct and indirect echo coming from a real handclap

pulse, can be found in Figure 2. Whereas the measured echo is seen in Figure 3. The difference is due to the shape of the incident handclap. In Figure 4, the calculated echo, coming from a simulated handclap, is depicted. The lower frequency bands which were not present in Figure 2, can now be seen as well, just as in Figure 3. Actually here also reflections on the ground are taken into account, but there is only small difference if compared with the case where a real handclap is incident on the stairs without consideration of reflections on the ground.

Conclusions

This paper, together with the presentation, shows that the echo that is produced by a handclap at the pyramid of Chichen Itza, is the result of diffraction and is pretty much determined by the frequency contents of the incident handclap itself. This is in contrast to what many people previously believed. It is also shown that the presence of reflections on the ground does not alter the echo very much.

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