How The Mound Got Its Quack

What follows is a brief write-up of the 26th New College Conversation, delivered in Hilary 2018.

The artificial hill in the middle of the New College gardens—affectionately known as 'The Mound'—has a remarkable property. Standing a few yards from the steps, and clapping, the echo returned has its own character different to the sound of the original clap. The echo lies somewhere between a duck's *quack*, a mouse's *squeak*, and a bird's *chirp*. While The Mound has been in place for hundreds of years (*cf.* the 27th New College Conversation, delivered by Robin Lane Fox in Trinity 2018), it only got its quack in 1993.

This is the story of how it happened.

The story begins with that famous explainer of natural phenomena, Lord Rayleigh. The natural phenomena he famously explained include the fact of why the sky is blue. In brief, Rayleigh showed that when light scatters off particles far smaller than the light's wavelength, different wavelengths have different likelihoods of scattering. The likelihood (strictly, the *cross section*) goes as the inverse fourth power of the wavelength. That is, shorter wavelengths, like blue, scatter far more frequently than longer wavelengths such as red. As a result, blue takes a very indirect route through the atmosphere to our eye, giving a diffuse blue colour to the entire sky.

In an 1873 letter to *Nature*,[1] Rayleigh details a range of fascinating auditory phenomena reported from around the world. Highlights include the lakes of Killarney in Ireland, which render 'an excellent second to any simple air played on a bugle', and an echo at Bedgebury Park in which 'The sound of a woman's voice was returned from a plantation of firs, situated across a valley, with the pitch raised an octave. . . . With a man's voice, we did not succeed in obtaining the effect'. He concludes that: 'It is difficult to believe that these descriptions are accurate, but that they have a basis of truth there can be little doubt'.

Rayleigh proceeds to explain that these effects derive from the acoustic version of Rayleigh scattering: the outgoing sound scatters off objects significantly smaller than the sound's constituent wavelengths (presumably the plantation of firs in the example above), and the different tones scatter in inverse proportion to the fourth power of their wavelength. The precise details of how this works, and why a woman's voice is affected but not a man's, he does not discuss.

So is Rayleigh scattering how the mound got its quack? Rayleigh thinks not. For, in a further letter to *Nature* a couple of months later,[2] he writes the following, presumably in response to a claim of observation of the phenomena just mentioned:

> I believe the echo observed by W. J. M. is of a different nature from mine and more analogous to one described by Oppel. Each bar of the railing, when struck by the aerial pulse, diverts a small portion, which is scattered in all directions, much as if the bar were itself the source of sound. These derived pulses reach the ear of the observer at approximately equal intervals, and accordingly blend into a musical note, whose pitch, however, may not be quite constant.

With reference to The Mound, it would seem the effect is as follows. The ingoing clap echoes off each step individually, such that a train of claps returns. Any brief sound repeated periodically at sufficiently short intervals forms a tone. This is illustrated in Fig. 1.

[1] Rayleigh, 'Harmonic Echoes', *Nature* 8 (199) (21 August 1873), pp. 319-20.
[2] Rayleigh, 'Harmonic Echoes', *Nature* 8 (208) (23 October 1873), p. 528.

ISSN 2517-6935

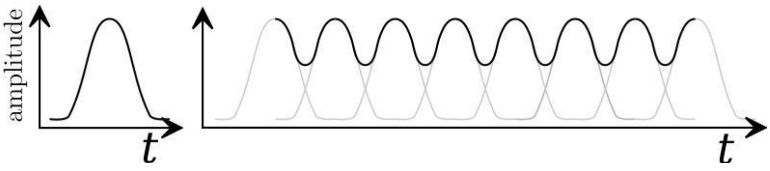

Figure 1: Any brief-duration sound, such as a clap (left), repeated periodically with a sufficiently brief interval (right, grey), sounds like a pure tone to our ear. The black curve on the right shows the approximate total amplitude as a function of time, which can be seen to be approximately sinusoidal (a perfect sine wave would be a pure note).

It is this tone which sounds to us like a quack. In fact, the echoes will not return with exactly equal spacing in time; the actual spacing of the returned claps can be found by applying Pythagoras's theorem to find the distance to each step. This is shown in Fig. 2. For practical purposes, however, they form a close enough approximation to a pure tone as to be indistinguishable by ear.

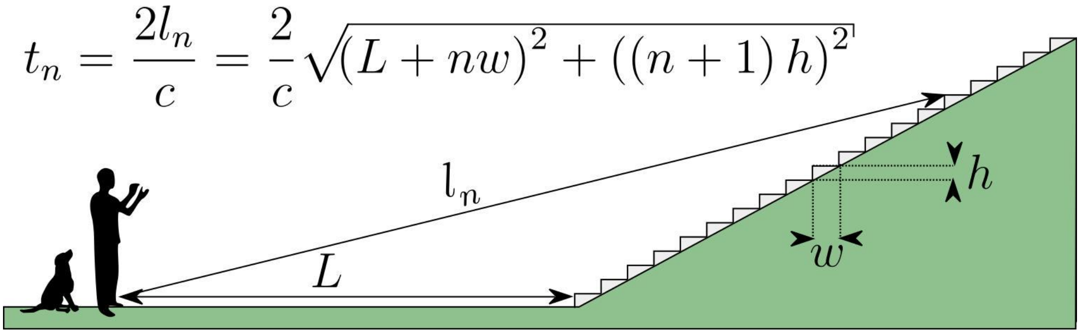

Figure 2: The Mound gets its quack from the fact that each step returns a separate echo. The time t_n taken for the n^{th} step's echo to return is given by $2l_n/c$, where l_n is the direct distance to step n, and c=330ms^{-1} is the speed of sound in air. This can be found using Pythagoras's theorem. Call the step width w (30cm) and height h (16cm), and label L the (variable) distance to the bottom step (which we'll number n=0). Approximating the echo to return from the top corner of each step, the formula is as stated in the image.

The Mound has 47 steps, each 30cm wide and 16cm high. If we put these numbers into the formula in Fig. 2 we find that, stood 3m from The Mound, our claps return as a very good approximation to a 497Hz tone: almost a perfect middle-B. Standing 30m away, approximately at the gate, we expect a 536Hz tone: a rather sharp C.

That, then, is how The Mound got its quack.

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ISSN 2517-6935