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# THE TUNED SINGING BURROW OF MOLE CRICKETS

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## Introduction

Mole crickets are large insects that burrow. The song of the male is produced from a singing burrow which extends to the surface. The song can be loud (Bennet-Clark, 1970) but has pure tones and a relatively constant carrier frequency. The sound output can be mapped and it has been estimated that the efficiency of production is about 35 per cent. The sound producing parts of the wings are small in area and so have a small radiation resistance. The singing burrow has two main regions, between which the sound producing wings are placed: an outer exponential horn about ½ wavelength long and an inner bulb. It has been proposed (Bennet-Clark, 1970) that the burrow acts as a tuned acoustic transformer to increase the radiation resistance of the wings and hence the sound power output of the song.

This paper describes an experimental re-investigation of this problem, addressing particularly the gain of the burrow, its tuning and the way it is constructed by the insect.

Material and methods. The research described here was carried out in the University of Florida, Gainesville. The mole cricket species used was *Scapteriscus acletus*, which is abundant in the area. Singing males were collected in the field and were transferred to 10 L buckets of sand. Burrow acoustics was investigated using a purpose-built electret doublet source, 10 mm in diameter, based on a Tandy (Radioshack) microphone type 270-090. This source could be inserted into the singing burrow as a model mole cricket. The source was fed from a sine-wave oscillator via a tone-burst gate and amplifier which allowed integer cycles of tone to be fed to the doublet source. Measurements of the acoustic output of the source were always made by comparing the sound pressure with that of the same source, at the same distance, with the same microphone.

## Results

The normal song. The range of the carrier frequency is 2.5 to 2.8 kHz and the pulse rate is around $60.s^{-1}$. At a range of 150 mm from the mouth of the burrow, the s.p.l. is about 70 dB, with only ± 1 dB variation.

Construction of the singing burrow. About 15 minutes after lights-out, the insect breaks a hole from its subterranean burrow through the sand surface. The insect then turns and positions itself so that its wings are about 50 mm in from the surface opening. It then gives a 2 to 5 second chirp, during which it walks to and fro through about 10 mm. It then walks to the inside of the burrow where it digs, for 30 to 45 s, in the bulb region of the burrow (fig. 1). It then turns, comes out and shapes the horn-like outer part of the burrow. The inner part, near the bulb, is kept narrow but, as the insect

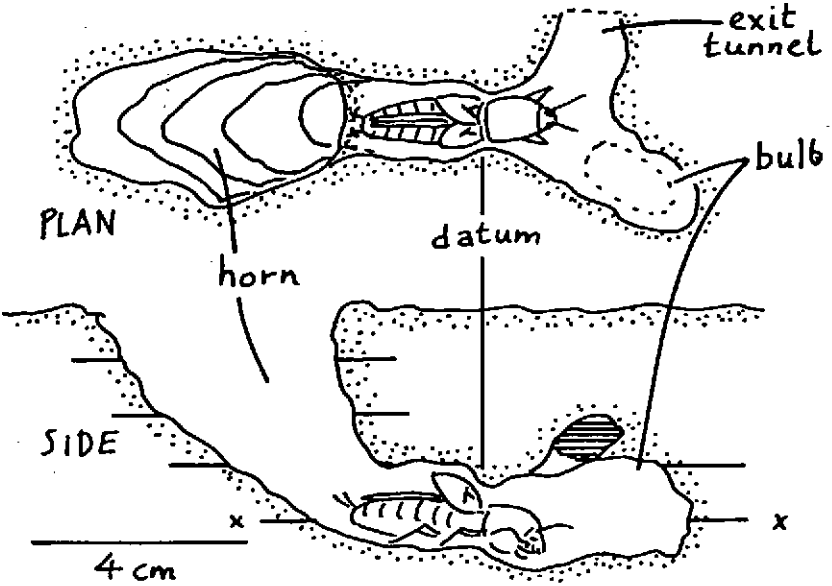

Fig. 1. Scale drawing of the singing burrow of Scapteriscus acletus. The horn flares exponentially from 20 mm outside the datum. The position of the singing insect is shown. The datum line is drawn at the constriction. The plane of the subterranean plan is shown as x - x in the side view.

moves further out towards the surface, the digging movements are accompanied by spreading and extension of the fore-limbs so that the outer part of the horn is expanded. After 30 to 45 s, the insect turns and, as before, gives a short chirp. The cycle of bulb digging, horn digging and chirping is repeated with a 1 to 2 minute period for up to 50 minutes, after which the animal (normally) settles down to continuous singing, during the early part of which it may move up to 5 mm up or down the burrow.

The burrow is remarkably constant in shape. It has been described, but with different terminology, by Nickerson et al. (1979): I follow here my earlier terminology (1970) for the burrows of Gryllotalpa vineae. The horn has a nearly exponential flare. The insect's wings are held raised to about 45° above the body and the insect is positioned so that the wings extend across a constriction just outside the bulb. At the level of the wings, the burrow is somewhat expanded. The bulb is blind and somewhat variable in shape but is to the left or right of the axis of the horn while a 12-14 mm diameter tunnel extends inwards from the opposite side of the burrow (fig. 1).

During the half-hour of burrow construction, both the amplitude and the quality

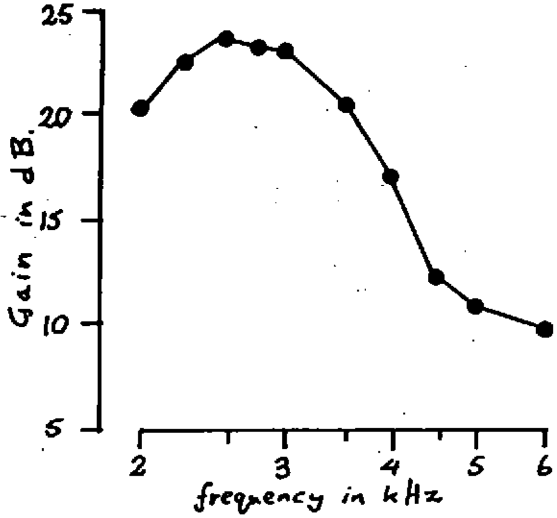

Fig. 2. Gain of singing burrow measured at a plane 5 mm outside (to the left) of the datum shown in fig. 1.

of the short song chirps change. The sound power output rises steadily, at the end being 10 dB higher than the initial s.p.l. The song also becomes purer: the 2nd harmonic is -20 dB at the start and -25 dB finally. It thus appears that, in the construction process, the properties of the burrow as a sound radiator are greatly improved.

Acoustic properties of the singing burrow. The sound pressure level in the free field was measured at 50 mm from the doublet source. The source was then inserted into a finished singing burrow and the s.p.l. 50 mm above the sand surface was measured. Readings were taken between 2 and 5 kHz and with the source moved in 5 mm steps from the mouth of the horn into the bulb region of the burrow. The relative sound pressure between that recorded with the source outside and then inside the burrow, regarded as the gain of the burrow, is shown in fig. 2.

The gain varies with frequency, reaching a maximum of about 24 dB at 2.5 to 3 kHz. The gain also varies with the distance of the source, from the mouth of the burrow, being maximal at 2.75 kHz around 5 mm from the datum (fig. 3) which is just outside the constriction, where the insect's wings are normally placed. At other frequencies, the position of maximum gain is different but the overall gain is always lower. It thus appears that the burrow acts as an acoustic transformer with an acoustic power gain of 250.

Between 2 and 6 kHz, the doublet source shows negligible ringing. When it is inside the burrow, at the position of maximum output, there is an exponential

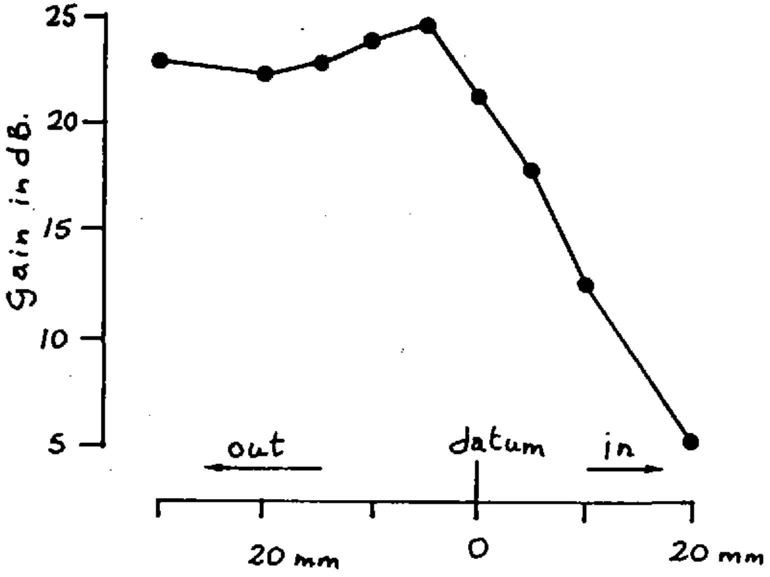

Fig. 3. Gain of singing burrow at 2.75 kHz measured against distance from the datum plane of fig. 1. The insect's wings are placed during singing at a plane 5-10 mm out from the datum.

build up and decay of the tone burst. The burrow thus acts as a resonant system. The Q of the tuning has been calculated from:

$$Q = \frac{\pi}{\ln\text{ (amplitude ratio of successive cycles)}}$$

For different burrows, Q values between 2.8 and 3.3 have been calculated.

The Tuning Mechanism. It has been suggested (Bennet-Clark, 1970) that the horn throat inductance is tuned by an acoustic capacitance to form a series resonant circuit with, at resonance, a resistive throat impedance. The measured Q factor of 3 agrees moderately well with the 10 dB increase in the sound power output between the early and late, presumably tuned, stages of burrow construction.

Other experiments support this interpretation. If one wing is painted with cellulose paint, the sound power output decreases by 3 dB. If the tips and lateral regions of the wings are cut off, so that there is a considerable gap, of at least 2 mm, between the edges of the wings and the sides of the burrow, the operated insect sings with a power output that is within 1 dB of that before the operation: a close fit at the throat of the horn is not necessary, though it is with a simple horn.

The bulb is a crucial part of the system. If the bulb region is pushed in from outside, the song becomes erratic and quieter, before singing stops.

The role of the bulb in horn tuning has been examined by Klipsch (1941). The relationship between the volume, V, of the bulb and the dimensions of the horn is given by: $V = 2.9\ AR$ where A is the throat area and R is the axial distance in which the throat area doubles. For both *Gryllotalpa* spp. and *Scapteriscus* horns, the measured volume of the bulb is close to that predicted by Klipsch' equation. The horn is finite in length and so will show resonances. The frequency of the lowest of these, Fn, can be calculated from:

$$Fn = \frac{c}{2Lp} \cdot \sqrt{n^2 + \left(\frac{Lp}{\pi h}\right)^2} \qquad \text{(Morse, 1948)}$$

where Lp is horn length + 0.6 mouth radius, h is the distance over which diameter increases by e, n is the order of resonance (1, 2 etc.) and c is the velocity of sound in air. For typical *Scapteriscus* horns, this gives values for Fn of 3.2 to 3.5 kHz which is close to the measured value of 2.75 kHz.

It is not clear how the insect monitors the properties of the burrow. If the resonant frequency of the burrow is different from that of the wings, the acoustic load will be reactive and there will be either a change in the resonant frequency of the wings due to the change in the effective system mass or compliance or a gross mismatch between the two resonances which will make the wing resonance difficult to sustain. The resonant frequency of isolated wings has been measured by placing cork powder on the harp region of the wings and exciting the wing with sound. Harp vibration is seen between 2.5 and 3 kHz.

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