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AUSTRALIAN ABORIGINAL MUSICAL INSTRUMENTS — THE BULLROARER

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1 INTRODUCTION

The “bullroarer” is a simple instrument that has been developed in several different environments, ranging from the Inuit of Canada and inhabitants of ancient Egypt in about 3,000 BC to the Aboriginal inhabitants of Australia, who may have used it for far longer. Of course, it is not called a “bullroarer” in Australia Aboriginal languages, and there are many words for it, but most are deemed to be “sacred-secret” and are used only by initiated male members of the tribe.

The instrument itself is a simple slat of wood or other hard material, 20 to 30 cm in length, about 5 cm wide, and a few millimetres in thickness, whirled around on the end of a thin cord about a metre long. During the school days of many of us, such a bullroarer was made from a wooden ruler tied to a piece of string passing through a hole drilled near one of its ends. The Australian Aboriginal instrument is much more carefully made and is decorated with the tribal or family totem symbol, usually some animal drawn in abstract skeletal form. When the slat is whirled around on the end of its cord at about one revolution per second, it emits a loud pulsating growl, and it is easy to appreciate its power in important ceremonies in early tribal environments.

The aim of the study to be discussed here was to measure the sound output, to see how it depends upon the physical variables involved, and to attempt to understand the aerodynamics underlying the sound-production mechanism. The detailed investigation has been reported in a recent paper by the authors,[1] and the present paper will give a more qualitative discussion of the matters involved.

2 EXPERIMENTAL RESULTS

The obvious major experimental variables are the dimensions of the slat, the length of the string, and the rate of rotation, and the resulting acoustic quantities of interest are the sound frequency and the acoustic power output. These were all investigated, mostly in hand-whirled experiments conducted in quiet conditions outdoors.

Close examination shows that the pulsating sound has two envelope frequency components, one at the arm rotation frequency or about 1 Hz, and a slower one at about 0.2 Hz or less that is associated with the fact that the slat rotates for a few seconds in one direction, then slows, stops, and reverses its rotation direction. The reason for this is clear: the rotation of the slat twists the string and this provides a steadily increasing torque that finally overcomes the aerodynamic torque driving the rotation. Since, for a symmetrical slat, there is no preferred rotation direction, the rotation then builds up in the opposite sense and the whole cycle repeats. Observation also shows that the path traced out by the string is not planar, but rather conical, with the hand driving the rotation near the apex. When the rotation direction reverses, so does the axial orientation of the cone. In the case of a symmetrical slat, there is no dependence of sound output on rotation direction, but an actual bullroarer is slightly asymmetrical in cross-section and one direction of rotation gives a greater sound output than the other.

For all slats, the sound is primarily sinusoidal, with the second harmonic about –30 dB relative to the fundamental. This fundamental frequency is typically in the range 20 – 150 Hz for slats of width 40 to 100 mm rotated at arm speeds of 1 to 2 Hz. If W is the width of the slat and V the speed of its centroid through the air, then the experimental results for the sound frequency f can be expressed, in the case of a flat rectangular slat, by the regression

$$f \approx 0.25\, V^{0.9}\, W^{-1.3}, \tag{1}$$

where V is related to the rotational frequency F of the arm and length L of the string by $V = 2\pi LF$. In the expression (1), in which SI units are used, the exponents have an uncertainty of about ± 0.2, and the numerical factor 0.25 has an uncertainty of about ± 20%. The relation (1) was established experimentally over an airspeed range of 5 to 10 m/s and a range of slat widths from 40 to 100 mm. The uncertainty in the values of the exponents suggests that (1) may actually be an experimental approximation to a simpler law of the form

$$f \approx 0.25\, V / W\,. \tag{2}$$

Measurements were also made of the total radiated acoustic power, this being simplified by the fact that the radiation appeared to be isotropic to better than 3 dB. This radiated power was found to increase sharply with the arm rotation speed F, and the regression could be well fitted by the expression

$$P = \text{const.} \times F^{5.4}\,, \tag{3}$$

with an uncertainty of perhaps ± 1 in the value of the exponent. There is apparently no dependence of the radiated power upon the width of the slat. The variation of radiated power with slat length L was not examined, but one might expect P to be proportional to L^2 for reasons that will be discussed below.

3 THEORETICAL TREATMENT

To derive an approximate expression for the behaviour of the slat, we first consider a simple rotating slat of width W and length L in an airstream of speed V. Suppose that the slat is rotating at an angular speed ω, and evaluate the separate components of the torque acting. (This will not be a rigorous analysis, because many of the influences are nonlinear.)

First there is a drag force slowing the rotation that is proportional to the square of the speed of the edge of the slat, $(W\omega)^2$, and to the square of the width of the slat (to get the moment), giving a torque proportional to $-LW^4\omega^2$. This torque would be present even in the absence of motion of the slat through the air. Then there is a torque that comes from the interaction between the rotational and translational motions because one edge of the slat is moving through the air at speed $V + W\omega/2$ and the other at $V - W\omega/2$. Squaring these to get the aerodynamic force and multiplying by LW^2 to get the moment gives a torque proportional to $LW^3\omega V$, so that the total aerodynamic torque looks like

$$\Gamma = \alpha LW^3\omega V - \beta LW^4\omega^2 , \tag{4}$$

where α and β are constants, the values of which need not concern us. In the absence of any torque from the twisted string, the slat will rotate with angular speed ω such that the nett torque Γ is zero. This means that

$$\omega = (\alpha/\beta)\, V/W , \tag{5}$$

which is in agreement with the form of the modified experimental result (2). This treatment can be extended to allow for the torque generated by the twisting string, and it is also straightforward to include the general lift force on the rotating slat that gives rise to the conical path of the supporting string.

4 SOUND GENERATION

When the slat moves through the air with an attack angle θ and velocity V, the aerodynamic lift force is proportional to $V^2Wg(\theta)$, where $g(\theta)$ is an odd function of θ that behaves to a first approximation as $\sin 2\theta$. This force is due to a pressure dipole across the slat, the separation between the poles being about W, so that the magnitude of the dipole is

$$\mu \approx \alpha V^2W^2L , \tag{6}$$

where α is the lift coefficient for the slat profile, which has a value of order unity. Because $\theta = 2\pi ft$, where f is the slat rotation frequency, the sound radiated by the dipole has frequency $2f$ or $\omega = 4\pi f$. The sound power radiated by such an oscillating dipole is[2]

$$P \approx \omega^4\rho\mu^2/24\pi c^3 \approx 3\rho L^2V^6/c^3 , \tag{7}$$

where ρ is the density of air and c the velocity of sound in air. The radiated sound power is thus predicted to be independent of the slat width (because rotation speed is inversely proportional to slat width) and to vary as the 6th power of the rotational speed of the arm. This theoretical prediction is in good agreement with the experimental result (3).

An alternative treatment of sound radiation, based upon the properties of the vortices generated by the rotating slat, gives very similar results.[1] Because it is a more complex treatment, however, it will not be discussed here.

5 CONCLUSIONS

This brief discussion of what is, in fact, a very complex aeroacoustic system shows that a great deal of understanding can be gained by applying quite simple physical principles. It also shows that there is a wealth of interesting investigation to be done on even apparently trivially simple musical instruments. We cannot claim that the results are of commercial or industrial significance, but they do serve to enlighten us about at least one aspect of indigenous culture. It supplements an investigation that extends previous work[3,4] on the acoustics of the didjeridu, that is now in progress as a cooperative venture between Melbourne University, The University of New South Wales, and the Australian National University.

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