Dick Sillitto's involvement with Acoustics

1 The McClure Organ

1.1 From a report by RMS to Professor Sidney Newman, Faculty of Music

The present tuning of the organ embodies a temperament which is a "mean tone" temperament, in the sense that there is only one size of whole tone in the scale, but the major third is slightly narrower than the true major third of the early mean tone temperament. As we know from Dr McClure's article in *The Organ* of January 1951, his first experiments in mean tone tuning employed the temperament described in 1769 by Dr Robert Smith, Master of Trinity College, Cambridge; this temperament, based on a division of the octave into 50 equal parts, had a noticeably flattened third. In 1691 the Dutch scientist Christiaan Huygens had described a mean tone temperament based on the division of the octave into 31 equal parts. This temperament uses a sharpened major third. The present tuning of Dr McClure's organ lies between the tunings of Smith and of Huygens, with the thirds slightly flatter than true. This tuning is of course implicit in the tuning scheme of which you have copies, obtained I believe from Messrs Harrison and Harrison who built the organ. The last notes left by Dr McClure, and now in the possession of Father Lawrence Bévenot, seemed to show that in the last months of his life, Dr McClure had come to favour a temperament whose thirds are even sharper than those of the Huygens temperament. (The sharper temperaments are probably more "melodious", but less "harmonious" than the flatter ones.)

Since Huygens temperament can be heard on Professor A.D. Fokker's organ at Haarlem (described in the *Archives du Musée Teyler*, Series III, Vol. X, No. 3, 1951), and since the logical end to this process of sharpening the temperament is our modern equal temperament, there would seem to be no good reason for us to retune the McClure organ to the temperament described in Dr McClure's last notes.

1.2 BBC – – Third Programme 6.30 – 7.00 p.m. Thursday 6/11//52

" The McClure organ, etc"

Richard Sillitto:

I think we should regard the musician's scale as a related set of musical intervals, and this is how an unaccompanied singer makes his scale. However, when keyboard instruments were introduced, it became necessary to define the scale as a series of notes, each with its own particular pitch.

But then certain well-known difficulties arose. Twelve perfect fifths, for example, add up to a little more than 7 octaves; 4 perfect fifths add up to a little more than 2 octaves and a true major third. We can reduce these difficulties if we adjust or temper some of the intervals, and we can do this in several ways.

The modern division of the octave into 12 equal semitones, from which larger intervals are then built up, gives reasonably harmonious intervals, but in this equal temperament all the harmonies are imperfect in greater or less degree.

Historically, this rather intellectual scale came after the mean tone temperament of the 17th and early 18th centuries. In mean tone temperament the major thirds are true, but true thirds can be accommodated on the keyboard only if the fifths are narrow and the semitones are appreciably broadened.

Up to the time of Bach, practically all organ music was written by composers who thought in terms of this temperament, and wrote with its special character and limitations in mind. Bach himself wrote almost all his organ music for mean tone temperament. But the 48 preludes and fugues which were his great manifesto for equal temperament, were written for the clavichord, or harpsichord.

Mean tone temperament has now fallen into disuse, but it's been recreated in a small chamber organ, designed by the late Dr A. R. McClure. Listen to this Noèl: *Les Bourgeois de Chatre* by the 17th century French composer, Le Begue; it's played on the McClure organ by Herrick Bunney. Notice the smoothness of the harmonies provided by this old temperament.

(McClure organ: "Les Bourgeois de Chatre") 2 min. approx.

The McClure organ is an experimental instrument, of very simple design. It has no reed pipes, only one manual, and no pedal stops, the pedal board being coupled permanently to the manual. So it provides the organist with little opportunity for using subtle registrations, or weaving intricate textures. Everything is subordinated to throwing into bold relief the special character of the temperament, and it's for this that we ask you to listen during this programme.

In mean tone temperament, pairs of notes such as D sharp and E flat, E sharp and F flat, and so on, differ in pitch. This means that, within the compass of each octave, there are many more notes than the 12 which can be played from our familiar keyboard. So from these many notes we must choose 12, and then we can use only a limited range of key signatures – six major and three minor keys in fact. In this limited range the harmonies, as on this record, are smoother – and perhaps duller – than those we nowadays hear.

(Chordal passage on McClure organ) – 10"

Another interesting feature of the temperament is that the broad semitones makes leading notes sound rather flat when considered melodically,

(melodic illustration) – 10"

but, on the other hand when when this is harmonised the transition from leading note to tonic sounds unusually pleasing and positive.

(Same melody, harmonised) –10"

It's interesting to compare the McClure organ, which uses this early temperament, with the baroque organ in the chapel of Frederiksborg Castle, in Denmark. This organ, [which was built in 1616 by Compenius, is constructed as a concert, rather than as a church organ, and] is untempered – that is, it's tuned to the diatonic scale. It is then, more severely limited in its choice of keys than is a mean tone tempered organ. Here is a record of the *Fantasia Tertii Toni* by Tomas de Santa Maria, a mid-16th century Spanish composer, played on the Frederiksborg organ.

(*Fantasia Tertii Toni* by Tomas de Santa Maria)
(Compenius Organ, Frederiksborg Castle.) – 1'7"
Now here's the same work played on the McClure organ.
(*Fantasia Tertii Toni* by Tomas de Santa Maria)
(McClure organ) – 1'7"

This mean tone temperament seems to be particularly suitable for accompanying early choral music. We've found that, once they are accustomed to its unfamiliar demands, singers feel that mean tone temperament provides a very natural accompaniment for Tudor music, and the result is very refreshing.

Here, for example, is a recording of the Orlando Gibbons anthem *This is the record of John* made by the Edinburgh University singers accompanied at the McClure organ by their conductor Herrick Bunney. Notice in particular the smoothness and coolness of the blend of voice and organ in the tenor solo passages.

(Orlando Gibbons: *This is the record of John*) 4 min. approx
(Edinburgh University singers and McClure organ)

But despite its charm, mean tone temperament died out [and, as with most living things, the gradual process of dying occupied most of its life.] The limitation to six major and three minor keys imposed on harmonic music a restriction which was foreign to its very nature – a restriction of the power to modulate. Attempts were made to overcome this limitation by providing additional notes. The Father Smith organs at Durham and at the Temple had two of the black keys in each octave split in half, and extra pipes were provided. By using either the front or the back half of the split key the organist could select, in the one case either E flat or D sharp, and in the other case either G sharp or A flat. Later there were many other attempts to extend the harmonic resources available to composers of keyboard music; always these involved complication of the keyboard, and always they were successfully resisted by the players. In time, the escape from the restrictions of the mean tone temperament was found in the adoption of equal temperament, with its broad thirds and narrow fifths and semitones. In this way music gained complete freedom to modulate, in particular through the medium of enharmonic changes.

Now the transition from mean tone to equal temperament was a gradual process extending over about 200 years. The very gradualness of the process, by the way, suggested the initial stimulus to change came not so much from a frustrated desire for greater harmonic freedom as from dissatisfaction with the melodic properties of the mean tone scale. And when the change was finally made, the stiffest opposition came – on harmonic grounds – from organists. The sustained notes of the organ show up the roughness of the equally tempered harmonies more clearly than do the transient notes of the other keyboard instruments. To illustrate this I'd like to play part of a recording of the *Veni Redemptor* by Thomas Tallis. It's played on the equally tempered organ of St Giles Cathedral in Edinburgh,

(*Veni Redemptor* by Thomas Tallis)
(St Giles's organ. Record C/MGW 17490) 2'2"
now listen to the same passage played on the McClure organ.
(*Veni Redemptor* by Thomas Tallis)
(McClure organ. Record C/MGW 17490) 2'2"

Equal temperament was established on the continent early in the 19 century and on British organs it came into general use between 1854 and 1890. Once composers had begun to exploit the freedom of equal temperament, organists and organ builders were bound to come into line.

This might suggest that the mean tone organ of the present day is an anachronism, or at best, is of interest only to musical historians. And that would be true of the McClure organ were it merely a reproduction of the earlier mean tone instruments. But in fact it has resources of modulation that didn't exist in the organs of two or three hundred years ago. Following a suggestion made in a treatise on *Harmonics* written in 1759 by Robert Smith, Master of Trinity College, Cambridge, Dr McClure designed his organ to give 19 notes to each octave; the keyboard is quite normal, but a set of seven switches, whose effect is to change certain sets of pipes for others, allows pitches of seven notes to be altered. Thus, drawing one of these switches substitutes E sharp pipes for the E flat pipes, and makes available the key of E minor, which could not be played on the normal mean tone instrument. In fact, all the single sharp or single flat notes except E sharp and B-flat can be produced, and this allows a range of 15 major and 13 minor keys, although it still doesn't allow a closed cycle of modulations.

The question then arises: is this a worthwhile contribution to musical resources? The answer can be given only by musicians. Scales, said Parry, are made in the process of endeavouring to make music. A number of composers have been experimenting with microtonal music, in the search for greater subtlety of expression than they've had before. It may be that the microtonal distinctions of the mean tone temperament, (which arise from harmonic sources) are more meaningful than the microtones obtained by dividing the octave with mathematical precision into 24 equal parts.

The McClure organ raises these questions, and at the same time offers a means to search out the answers. I'd like to finish by asking you to listen to a new work for the McClure organ, written by John Buckland. Buckland based this work on two old chorales, by Johann Walther and by Johann Ahle, but he uses a combination of notes which couldn't be produced on an orthodox mean tone organ, and in this way he's able to employ unusual harmonies.
(Buckland: Two Bach chorales, with fugal link) 4' approx
(McClure organ)

2 The Caprington horn

2.1 Summary of results of acoustical investigation

This note presents briefly the results of an investigation, carried out at the suggestion of Professor Stuart Piggott, into the acoustical properties of the Caprington horn.

Introduction

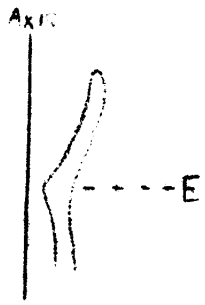
Preliminary qualitative observations showed the horn to have a warm, pleasant tone – comparable with that of the horn bugle – and to sound four notes.

Measurements were made of the frequencies and waveforms of the four natural notes of the horn, and the results have been compared with the predictions of a rather idealised theory in which the wall of the horn is assumed quite rigid and unyielding.

A less detailed examination of the acoustic properties of the replica in the possession of the National Museum of Antiquities of Scotland showed the properties of the replica to be somewhat different.

Description of the Horn

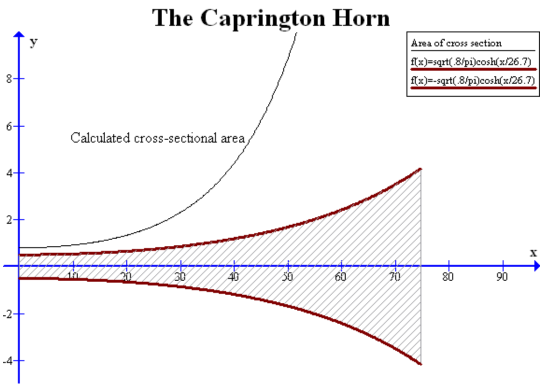
The mouthpiece of the horn (see sketch) is of a form intermediate between that of a trumpet and a French horn, although the rapid widening of the tube beyond the constriction is characteristic of none of the modern mouthpiece forms.



The internal diameter of the tube at the constriction is about 1/2 cm, compared with a diameter of 2 cm at the lip; the depth from lip to constriction is about 1.8 cm.

Along almost the whole of the 74.7 cm length from the constriction to the open end, at which the average diameter is 9.3 cm, the horn opens out rapidly; the area of cross-section (in square centimetres) at any distance x cm from the constriction being given with remarkable accuracy by the relation

$$S = 0.8 \cosh^2(x/26.7)$$



In this expression the factor 0.8 is the area of cross-section which the tube would have at the point E on the sketch if the constriction were absent, while the figure 26.7 cm measures the rate of flare. The rate of flare varies inversely as this value. Such a rapid flare along the whole length of the horn would be expected to make the series of natural notes markedly inharmonic, the intervals between successive notes being less than the intervals between the corresponding members of a harmonic series.

Measurements of frequency and waveform

The waveforms given by the instrument, when sounding in turn each of its four natural notes, were displayed on a cathode ray tube screen, and photographed by a high-speed moving film camera. Comparison with the simultaneous record on the same film of a 750 cycle note from a standard frequency oscillator gave a measurement of the frequency of each note. The amplitudes of the partials of the several notes were found by a numerical analysis of the waveform records. The results are presented in the following table:

Freq	Approx	Relative amplitude of partial tones.										
of note	pitch	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
253	b+	100	148	48	58	15	18	8	10	13	5	8
466	a’	100	21	16	7	7	2	3	0	0	0	0
714	f”+	100	6	4	2	0	0	0	0	0	0	0
970	b”-	100	22	7	0	0	0	0	0	0	0	0

The relative pitches of the notes may be described in another way. The octave may be divided into 300 equal intervals, these intervals being called savarts; one savart is approximately the smallest change of pitch that can be detected by the ear. The intervals between successive pairs of notes in the above table measure respectively 64, 185 and 133 savarts. The intervals between the corresponding members of the familiar series – octave, fifth, fourth, given by modern brass instruments, would be 300, 175 and 125 savarts.

Discussion

Although it is possible to predict with some confidence the resonant characteristics of the air column in a horn of this shape, the use of such a horn as a musical instrument introduces other factors not amenable to calculation. One cannot, for instance, evaluate the effect of damping and resonances due to vibrations in the metal wall; nor can one calculate the end correction to be applied to the mouthpiece end of the horn, since this correction depends on the interaction between the air column and the players lips.

The relation

$$\nu_n = \frac{c}{2l_p}\left\{n^2 + (\frac{l_p}{\pi h})^2\right\}^{1/2}$$

(in which $\nu_n$is the frequency of the nth natural note,
c is the velocity of sound in air,
h is the flare constant, = 26.7 cm,
and l_p is the speaking length of the horn)

gives the frequencies if the speaking length l_p is known, that is to say, if the geometrical length is known and the end-corrections have been calculated. The end-corrections must themselves be frequency dependent, as one can readily show by calculating the frequencies from the above formula while assuming the speaking length to be constant. In the following table the first column gives the observed frequencies, and the second column gives the frequencies calculated on the assumption of a constant speaking length of 72.6 centimetre.

Observed frequency	calculated frequency if $l_p = 72.6\,\text{cm}$*	calculated speaking length
253	312	116 cm
466	516	82.3
714	737	75.3
970	970	72.6

*(cf.total geometrical length of horn = 76.5 cm)

The lack of agreement, except at one arbitrary point in the series, shows the necessity of assuming a variable speaking length, that is, a frequency dependent end correction. In the third column are shown the values of l_p obtained by inserting the observed frequencies into the above formula and solving for l_p. It will be seen that the first two of these values are greater than the geometrical length, while the third and fourth require a negative end correction.

It was remarked by the trumpeter that the lowest note of the horn was exceedingly difficult to obtain satisfactorily, and considerable variations in pitch and waveform were noticed before he pronounced himself satisfied. In the case of the replica, on the other hand, the lowest note (of frequency 245 cycles) is the easiest to produce, and is very definite, both in pitch and quality. The second notes of the two instruments differ in frequency by less than one cycle, but the trumpeter who assisted in the tests of the replica could find only a suggestion of the third note and no trace of a fourth. The replica was of course intended to simulate the external rather than the internal form of the Caprington instrument.

The shallowness of the mouthpiece probably contributed to the difficulty of producing the lowest note. Modern practice would incline towards a mouthpiece depth of 28 millimetres, rather than 18 millimetres, for a bottom note in the neighbourhood of middle C. The shallower mouthpiece will require a rather lower blowing pressure than is customary, and this will tend to make it difficult to supply enough energy to sustain the heavily damped vibrations. Although not acoustically significant, the sharp rim of the mouthpiece makes the instrument uncomfortable to play.

The results of the harmonic analysis show features characteristic of many of the brass instruments. In the lowest note the first partial is weaker than the second, as is the case with, among others, the French horn and the tuba; it is interesting that the odd partials tend to be weaker than the even ones. The higher notes have a relatively short series of partials, and their tone is singularly clear and beautiful.

Acknowledgements

The writer is indebted to Professor Stuart Piggott for interesting him in this investigation; to Mr R. B. K. Stevenson and his staff at the National Museum of Antiquities of Scotland, whose careful measurements of the dimensions of the horn were the basis of many of the considerations recorded above; to his wife for her help with the acoustic measurements and the harmonic analysis; and to Dr MAS Ross for helpful and stimulating discussions on the treatment of the results.

8th December, 1950

Richard M. Sillitto,
Department of Natural Philosophy,
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Edinburgh.

2.2 Letter to RMS from Stuart Piggott

As from: Priory Farm, Rockbourne, Hants.
20 April 1950

Dear Mr Sillitto,

You may remember that you made a rash suggestion that you might be able to record the waveforms of some of the Bronze Age trumpets (about 500 BC) from Ireland, when we were having that entertaining morning with the Caprington horn. When in London recently I discussed this in very general terms with the British Museum authorities, and they were delighted that anyone should be sufficiently interested to think of doing such a thing. They have a number of Irish trumpets of the sort I mentioned to you, and if you ever like to follow up this line of research, they are at your disposal.

I also talked the matter over with the President of the Prehistoric Society, and we felt that it would be a very good idea if any work done in this way was put before the Society and published by them. I don't know whether you have access to any sound recording apparatus in the Department, but it would be most interesting if recordings could be made, and then played over at a meeting of the Prehistoric Society in London, with a commentary by you on the technical results of the study of the sounds. I am getting in touch with a trumpeter in London who could do the initial blowing for us.

I'd like to know whether you are interested in carrying on this line of research, and if so, to offer you all the necessary cooperation from the archaeological side. For my part, I would be delighted to think that something was at last being done in this direction. If you're interested, I don't see why I couldn't fix you a grant from some source in the University to cover expenses for such recording etc. outside the Department. Let me know what you feel about it, and I'll go ahead. In the meantime my very warm thanks for all you did with the Caprington experiment.

Yours sincerely,
Stuart Piggott.

[Work in the HT Lab took priority; I wonder whether anyone else has tackled the Irish trumpets? WS, Ed.]

2.3 Extract from *Scotland's Music*

John Purser (1992; ISBN1 85158 426 9) writes:

> Whatever the date, the sound is magnificent, but not easy to produce – the mouthpiece, which is an integral part of the casting, is sharp rimmed and hard on the lips of modern players used to a more gentle bed for their mouths. That said, the four or five notes obtainable from it are of a clarity and resonance that no one could criticise and the instrument is particularly responsive to rapid tounging – a feature which would make it suitable for signalling....
>
> ...Clearly an instrument used in battle, as the carnyx was and as the Caprington horn probably was, is going to be played with volume and vigour and may be called upon for practical purposes, as trumpets and horns have been through the centuries, using rhythm and pitch to create distinctive signals. The much older Bronze Age horns are far less suited to such tasks, for their mouthpieces do not encourage articulation and the pitch of the end-blown horns is limited and of the side-blown ones undefined, because within three octaves or so the range is infinite. In the rigours of battle any note might come out of the side-blown horn, and signalling requires guaranteed precision.