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Edited by
Peter Williams

Laaber
PIPE-DIAMETER SCALING ACCORDING TO THE
ANNOTAZIONI OF THE ORGAN BUILDER
LUIGI MONTESSANTI (MANTUA, 1806)

Patrizio Barbieri (Rome)

Pietro Ferroni, a Florentine physicist-mathematician and engineer, published a paper in 1804 on organ-building practice, in which he proposed (or, rather, re-proposed) the use of a particular mathematical tool, the sector, to provide the builder immediately with the precise length of each pipe in a given rank.\(^1\) Two years later, the Mantuan organ-builder Luigi Montessanti published anonymously a pamphlet, very rare nowadays, containing his critical notes on the said paper.\(^2\) In it, he also provides the sole written record, starting with Alhanasius Kircher (1650), on the diameter scaling adopted by Italian organ-builders.\(^3\) There is no record of Ferroni’s ever writing a response to this pamphlet.\(^4\) This event also provides the umpteenth testimony of the great scepticism — or better, mistrust — with which makers of musical instruments, generally speaking, greeted physicists and mathematicians who attempted to stray onto their preserves.\(^5\) Such scepticism in this particular case by Montessanti was, as we shall see, wholly justified.

Abbreviations

\(^{M}\) = [Luigi Montessanti,] Annotazioni d’un artefice d’organi sopra la logistica proposta dal matematico Sig. Pietro Ferroni per la costruzione di tali strumenti. 14-page pamphlet, published anonymously without any publisher’s name, dated ‘Mantova 15 Gennaio 1806’. The last page of a photocopy of the pamphlet in my possession bears the manuscript annotation: ‘Del Sig: Luigi Montessanti Mantovano’.

1 Pietro Ferroni’s ‘logarithmic sector’ (1804)

Although the scientific academies of the time invited their research correspondents to avoid shows of learning, one notes immediately that Ferroni’s style is pompous and his paper literally stuffed with what are mostly superfluous bibliographical references; this is amazing, consider-
ing that the author was also a professor of mathematics (University of Pisa). The title of the said work, 'Memoir on the use of the *logistica* in organ building', starts with the fact that the top end of the pipes in a register, ranged in chromatic order, describe with reasonable approximation a curve, at that time termed *logistica* or, as we would say today, *logarithmica* (logarithmic): see M, 4 and in Figure 1.

![Logistica curve](image)

**Figure 1** *Logistica* (= logarithmic) curve assumed by the tops of the pipes in an organ rank when arranged in chromatic order (M, 2). Their length $L$ appears on the vertical axis, matching each note $n$ on the horizontal axis. Assuming that $L = 1$ for the lowest pipe, for the entire range we thus have $L = 2^{-n/12}$, where $n = 0, 1, 2, 3, \ldots$. Since this expression is equal to $n = -12 \log_2 L$, it follows that the relation between $L$ and $n$ is of the kind known as 'exponential' or 'logarithmic'. Such a progression, however, is accurate only if the pipes are equally spaced, their temperament is equal, and the end corrections are overlooked.

Stripped of its useless verbosity, Ferroni’s dissertation proposes the use of a *compresso di proporzione* (a sector) calibrated in geometric pipe lengths, calculated precisely according to the temperament adopted, so as to facilitate operations for less skilful builders by eliminating the difficult final tuning operations (*F*, pp. 390-95). The instrument must consequently have been accurate to fractions of a comma. The sector was, in actual fact, a sort of pantograph which, opened along the length of the lowest pipe in a given octave, would automatically provide the corresponding decreasing lengths for the successive semitones (see Figure 2). For the division of the monochord, this instrument had moreover been prescribed since the early decades of the seventeenth century; the scales marked on the models
that have come down to us, however, show that their accuracy was decidedly inadequate for their intended use. In particular, Ferroni appears to have been inspired by the sector used by a compatriot of his, the Tuscan Count Francesco Rigi. The latter had calibrated his instrument according to the 2/7-comma, a temperament invented two centuries earlier by Gioseffo Zarlino (F, p. 407):

Come i numeri e logaritmi sono segnati sopra le righe o scale Gunteriane, non altramente la piattaforma per gli organi potrebbe con facilità convertirsi in una specie di compasso-disproporzione a nocella piana per uso degli artefici meno addestrati o più speditivi. Il conte Francesco Rigi di San Sepolcro in Etruria costruiti di legno di bosso questo compasso nel 1764. Ciascuna delle due gambe era lunga intorno ad uno e mezzo pè di Parigi. Parecchie linee rette, tutte centrali, v'erano incise nelle due faccie, colle divisioni armoniche corrispondenti a IV ottave, compresi i punti dei semitoni cromatici. E finalmente portava in fronte scolpito il titolo Canon geometricus Organi Pythagralici ad quintam diminutam 2/7 commatis 81 ad 80 accomodatus. Ei non sapeva, quell'abile fabbricatore e restauratore d'organi consecrati specialmente alla liturgia ed innologia, d'esser stato di circa un secolo e un terzo prevenuto da Giovanni Beaugrand col suo compasso geometrico-armonico-temperato.

Like the numbers and logarithms marked above the lines or Gunter scales [reference to the first calculating device, by Edmund Gunter], the scale for organs could also be easily converted into a sort of flat-hinged sector for the use of less skilful or more expedientous craftsmen. Count Francesco Rigi of San Sepolcro in Tuscany constructed such a box-wood sector in 1764. Each of the two axes was about one-and-a-half Peri feet [about half-a-metre]. Many straight lines, all centred [= starting from the central hinge] were marked on the two faces, with harmonic divisions corresponding to four octaves, including chromatic semitone points. Lastly, it bore engraved on the front the title Canon geometricus Organi Pythagralici ad quintam diminutam 2/7 commatis 81 ad 80 accomodatus. The skilful builder and restorer of organs dedicated specifically to liturgy and hynology was unaware that he had been preceded by about one-and-a-half centuries by Giovanni Beaugrand with his geometric-harmonic-tempered sector.

Jean de Beaugrand's sector, described by Mersenne in his Harmonie universelle (1636–37) and subsequently in the Harmonicorum libri XII (1648), was however designed for arranging the keys on the neck of the lute. In fact, Rigi and Ferroni's idea had already been aired in a treatise on mathematical instruments published at Leipzig in 1727 by the Mathematicus und Mechanicus Jacob Leupold: after illustrating the use of the proportional-Zirckel for arranging lute frets (§ 192), he proposes to use a similar sector not only for the length of the pipes, but also their diameter.⁵

As far as the organ-building activities of Count Francesco Rigi are concerned, little is known.⁶ Ferroni also mentions a mathematical manuscript by Rigi dated 1773 containing what is not further described as
'physical-harmonic propositions' (F, p. 408). There also exists a manuscript letter by one Federigo Rigi — addressed to the Paris Académie des Sciences and dated Città S. Sepolcro, 12 novembre 1774 — in which the sender announces that his brother 'now deceased, a good mathematician' as well as 'organ amateur', maintained that 'it was necessary to give a geometric proportion to the diameters' of the said instruments. Although the latter died without announcing his discovery, Federigo states that he has managed to reconstruct the said diameter scaling and offers to travel to Paris to illustrate the results to the Académie. In §3 we shall see that the logarithmic scaling criterion for diameters was put forward by Giordano Riccati (1767) and Sorge (1773): according to what we have seen, the name of Francesco Rigi should thus be added to those of the said authors. Nor can it be excluded that the said scaling had already been employed on some of the 'many straight lines' engraved on the sector of 1764.

Figure 2 Functional drawing of a sector (Barbieri, 'Il mesolabio', p. 208). The instrument comprises two metal or wooden plates, hinged on O. As far as their musical application is concerned, the subdivisions corresponding to the vibrating string lengths of a given temperament are marked on both OC lines (those in the figure are, for example, C, C#, D, ... C'). For the corresponding placing of the frets on the neck of a lute of any particular length, the similarity of triangles OCC, OCG, ..., OCC' is used, from which it follows that OC : OC' : ... : OC' = CC : CCG : ... : C'C'. With L as the length of the open string, the opening of the sector is adjusted — once and for all — so that CC = L. That being done, the portion of vibrating string from the bridge to the first fret is given by CCG, for the second fret by DD, etc. The said lengths are taken with the aid of an ordinary compass. With regard to the use now described, the instrument thus acts as a pantograph. A similar procedure can be used to obtain the lengths of the pipes of any given organ rank; in this case, however, the task is more complicated because the lengths marked for the various notes have to take the end corrections into account.
Let us return however to the sector of Ferroni, whose project was upset by experiments published in 1636-37 by Mersenne, with which we shall deal in § 2.1. Indeed, he recalls that, according to the latter, the frequency of the note emitted by an organ pipe depends not only on its geometrical length — as provided for by Euler’s formula, the only one then known — but also on its diameter. Furthermore — again contradicting the said formula — by halving the length of a pipe, it loses a semitone or even a tone in the higher octave, unlike what happens with vibrating strings. Therefore (F, pp. 405–06),

He consequently invites ‘talented physicists [...] to solve this difficulty by repeating the two experiments described above’ (i fisici valorosi [...] a sciogliere questo nodo ripetendo le due suddescritte esperienze).

2 Luigi Montesanti’s Annotazioni (1806) and the problem of the ‘end corrections’

2.1 The sector

At the end of his pamphlet, Montesanti concludes that in describing the phenomena, he is drawing solely on his ‘consummate practice’ as an organ-builder, leaving it to physicists to provide a rational explanation (M, p. 14). It is quite easy for him to demonstrate the uselessness of the sector ingenuously proposed by Ferroni. Even leaving aside the dependency of frequency on diameter, he observes that once mounted on the wind chest the pipes lie in each other’s ‘acoustic shadow’, especially at the mouth; this finds confirmation in the fact that their tuning varies simply by making them turn on the spot (M, pp. 6–7). They are also impacted by the length and section of the windchest groove from which the air is received (M, p. 13).
On the temperament used, Montesanti merely says (M, pp. 8–9):

we know that to make the tuning bearable in the chromatic keys — when the enharmonic ones i.e. the quarter-tones are no longer in use, [in a footnote: D#/Eb, G#/Ab] — it is necessary to narrow the fifths and to stretch the thirds in the diatonic keys.

The description is fairly vague, although clearly pointing to a 'circulating' type of tuning. The fact that the fifths are narrowed 'in the diatonic keys' seems to be an indirect reference to a Vallotti-type temperament.

<table>
<thead>
<tr>
<th>Increase in diameter</th>
<th>Mersenne (original)</th>
<th>Mersenne (from Montesanti)</th>
<th>Montesanti</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.33 : 1</td>
<td>–</td>
<td>–</td>
<td>semitone</td>
</tr>
<tr>
<td>2 : 1</td>
<td>tone or minor 3rd</td>
<td>minor or major 3rd</td>
<td>about minor 3rd, but not major 3rd</td>
</tr>
<tr>
<td>3 : 1</td>
<td>–</td>
<td>–</td>
<td>major 3rd</td>
</tr>
<tr>
<td>4 : 1</td>
<td>4th or augmented 4th</td>
<td>augmented 4th</td>
<td>narrow 5th</td>
</tr>
<tr>
<td>8 : 1</td>
<td>minor 6th</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>little over 16 : 1</td>
<td>diminished octave</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 1 Results obtained by the organ-builder Luigi Montesanti on the drop in frequency observed in a flue pipe, keeping the length constant and progressively increasing the diameter (4th column). He compares them with the corresponding data which according to him comes from Mersenne (3rd column, with some inaccuracy). Montesanti adds that the said value is greatly influenced by the size of the mouth, which he has kept 'analogous to the proportion of the pipe' (analoga alla proporzione della canna, M, 9–10). The second column shows the original data taken from Mersenne, Harmonie universelle, pp. 331–2. Mersenne's survey shows that, by keeping the length constant and progressively widening the diameter, it is almost possible to descend to the next octave below, but no further.

With regard to frequency varying according to pipe diameter, Montesanti took up Ferroni's challenge and carried out a series of experiments: Table 1 shows that they substantially confirm those published by Mersenne in 1636–37. The latter's data are the result of a series of experiments performed on pipes of the same length and varying diameter, commissioned by him from a certain Cornu, a 'skilled surveyor' and sound mathematician. Mersenne also wished to know to what extent the frequency oscillations in Table 1 depended on the width of the mouth, to ascertain which, as early as 1635, Christophe de Villiers had
offered to construct two pipes of equal diameter, provided with mouths of highly different width.\textsuperscript{13} Montesanti too, like every good organ-builder, was well aware that frequency varies with mouth width (see the caption to Table 1).

On the fact that halving the length of a pipe does not make it jump one octave higher, Montesanti was able to correct an error made by Ferroni, revealing the latter’s lack of familiarity with the organ-building sector. Since the said operation would produce ‘roughly the seventh’, to obtain the octave one should not – as Ferroni affirmed – ‘narrow slightly the mouth of the higher and shorter [pipe] and widen the mouth of the lower and longer one’, but do exactly the opposite.\textsuperscript{14} Montesanti states that, in order to obtain the octave from the same pipe, it should be cut, not in half, but at 7/16 of its original length.

2.2 Digression on the two ‘end corrections’

Based on what we have seen, Ferroni has at least the merit of being one of the first theorists to call attention to a problem that, albeit well-known to organ-builders at least since the Middle Ages, had up to then been ignored by almost all physicist-mathematicians: that of the two ‘end corrections’.

In this connexion, Giordano Riccati (1767) and Johann Heinrich Lambert (1775) had already established that the geometric length of a pipe does not coincide with its acoustic length.\textsuperscript{15} We shall now see that the problem would take nearly two centuries for both an analytical and experimental solution to be found.

1848. On the basis of laboratory results, Wilhelm Wertheim manages for the first time to quantify the value both for the mouth and for the upper-end correction, finding, for the latter, a value of around 0.6 times the pipe radius.\textsuperscript{16}

1860. In a paper still known by organ-builders today, Aristide Cavaillé-Coll provides the first empirical formulae establishing the ‘correct’ length of a pipe.\textsuperscript{17} In the very same year, Hermann Helmholtz makes the first theoretical calculation for the upper-end correction.\textsuperscript{18} In the said calculation, however, the top end of the pipe is assumed to be fitted with an extensive flange, thus limiting to the upper hemisphere the sound radiation, which leads to a decided simplification for the calculation. The addition of the said flange increases the value of the end correction, which Helmholtz calculated as 0.785\(a\) (\(a\) = pipe radius).
1871. Although later acknowledging Helmholtz's priority in discovering the 'correct theory of the open organ pipe', Lord Rayleigh reaches similar results by means of a totally innovative method, assuming an analogy between acoustic- and electric-current.\textsuperscript{19}

1877. By means of experiment, Rayleigh finds that the flange contribution is circa $0.2a$, thus confirming the mean value of the upper-end correction for an unflanged tube already empirically pointed out by the above-mentioned Wertheim (circa $0.6a$).\textsuperscript{20}

1948. The calculation models of Helmholtz and Rayleigh are valid only for wavelengths much greater than the radius. Consequently in the same pipe they are not valid for top harmonics. It was therefore necessary to find a more general method of calculation. An analytical solution was in any case required: as early as the mid-nineteenth century, experimental measurements on (i) pipes of equal diameter but different length, and on (ii) the overtones of the same pipes, produced sometimes conflicting results. The question was solved only exactly one hundred years after the first experimental measurements by Wertheim, by the analytical study of Levine and Schwinger: they found that the value $0.6a$ assumed for the upper-end correction to the lower frequencies drops progressively as the latter rise.\textsuperscript{21} This has major repercussions in practice. Since the correction value is empirically established by the organ-builder to match the fundamental harmonic (i.e. the note emitted, which he tunes by ear, without making use of the above formula), it proves excessive for the overtones, which consequently seem progressively stretched as compared to those emitted by the mouth jet. The vibration frequency of the latter is — owing to the rigorously periodic pipe-end wave reflections — periodic and therefore characterised by strictly harmonic partials. The displacement of resonator harmonics increases in passing from narrow-scale pipes to large-scale ones (i.e. from viola to flute ranks), so that the latter are poorer in overtones, since the resonance of those emitted by the mouth jet is less and less enhanced by the tube as frequency increases.

1960. Utilising a different method of calculation, Nomura, Yamamura and Inawashiro solved the problem from a general point of view, i.e. even in the case where the top end of the cylindrical pipe is fitted with an infinite flange (the same case as Helmholtz, 1860). Like Levine and Schwinger for the unflanged tube, they too found that the upper-end correction falls with increased frequency.\textsuperscript{22} The said correction assumes a value very important in proportion to the short depth of the tone holes of wind instruments, which can be considered as very short pipes with both ends flanged.
With this last study, the analytical theory of pipes with vibrating air column can be deemed complete, after about 230 years of gestation. For organ pipes all that remained was a rigorous quantification of the mouth correction value, a factor that is, however, rather complicated to reduce to a calculation, since it depends on the conformation assumed by the mouth in the various pipe ranks and according to different builders. In this connection, various formulae, all clearly approximate, were put forward in the first half of the twentieth century.\textsuperscript{23}

3 Pipe-diameter scaling

It is on diameter scaling that Montesanti provides the most interesting information (M, pp. 7–8). To Ferroni’s statement that in order to optimise sound emission, the pipe diameter:length ratio must be between 1/12 and 1/15 (F, p. 401), Montesanti replies that, in the same rank, the said ratio would in fact vary according to the tessitura. In this connection, he attaches the measurements indicated in Table 2, which he states were taken ‘from various ancient and classical authors and which even nowadays are observed approximately’ (da diversi autori antichi e classici, e che anche da moderni vengono ad un dipresso osservate). Table 2 refers to the 16’ Principal extended to as many as eight octaves: since Montesanti states that he is referring to a keyboard with 62 keys (some organs of that period have a CC–f’’’ range, with short bottom-octave), the said measurements must clearly be deemed to extend to the ripieno ranks. As far as the Flute stops are concerned, he states that the said ratios are much higher, starting from 1/9 in the low notes and reaching 1/5 or even 1/4 in the high ones.

<table>
<thead>
<tr>
<th>Octave</th>
<th>16’</th>
<th>8’</th>
<th>4’</th>
<th>2’</th>
<th>1’</th>
<th>1/2’</th>
<th>1/4’</th>
<th>1/8’</th>
</tr>
</thead>
<tbody>
<tr>
<td>D/L</td>
<td>1/18</td>
<td>1/16</td>
<td>1/14</td>
<td>1/12</td>
<td>1/10</td>
<td>1/9</td>
<td>1/7.5</td>
<td>1/7</td>
</tr>
<tr>
<td>L (feet/10)</td>
<td>160</td>
<td>80</td>
<td>40</td>
<td>20</td>
<td>10</td>
<td>5</td>
<td>2.5</td>
<td>1.25</td>
</tr>
<tr>
<td>D (feet/10)</td>
<td>8.89</td>
<td>5.00</td>
<td>2.86</td>
<td>1.67</td>
<td>1.00</td>
<td>0.56</td>
<td>0.33</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Table 2  Pipe-diameter scaling, according to Luigi Montesanti (M, p. 8). The second row shows the ratio of diameter $D$ to length $L$ of the pipes of the Principale and of the ripieno, for the octaves in the first row. In actual fact, for octave 1/4’ the original text indicates $D/L = 1/8 + 1/2$. In the last two rows, the said data have been translated into the respective measurements for $L$ and $D$, used to plot the graph in Figure 3.
Figure 3  Diameter scaling, according to Luigi Montesanti (continuous line). As compared to the dashed line (representing a linear scaling), we see that the one indicated by Montesanti is similar to no. 5 in Figure 4. Data taken from Table 2.

Figure 4  Various typologies of historically used diameter scaling.

The data in Table 2 can be plotted on the graph in Figure 3. We know that scaling rules are manifold, since each confers particular nuances of timbre to the various tessituras of the stop. Over the centuries they have consequently developed according to the aesthetics of the period. To see what Montesanti describes in its historic perspective, we shall glance at the five typologies traced in Figure 4, in connexion with which the following remarks can be made.  

1 Diameter could be kept constant only in some mediaeval organs with a limited keyboard, since, for ranges of more than two or three octaves,
(i) the low notes would assume a timbre increasingly rich in harmonics, even presenting the bottom notes that overblow at higher partials, and (ii) the high notes would behave in contrary fashion, until they no longer emitted any sound at the upper end: the pipe, being too large-scaled, no longer satisfying the condition that its wavelength should be much greater than its diameter ($\lambda >> D$), i.e. that its geometric length should be much greater than its radius ($L >> D/2$).

2 Starting from the thirteenth century, the said problem was sometimes solved using this second type of scaling, which kept $D$ proportional to $L$. Although all the pipes in the rank were thus similar to each other, high note emission was overly weak compared to the low notes. For such reasons, it has been abandoned in modern times. Montesanti too observes that, in adopting the said scaling rules, 'after the third octave of 4 feet, the force of the tone would diminish increasingly in ascending to the high notes, as well as having a defective and delayed sound'.

3 Such a scale 'with addition constant' (the added constant is indicated by $k$) did not provide a constant ratio, but on the contrary provided pipes progressively wider (relatively) in ascending to the high notes, thus avoiding the defect seen in no. 2.

4 Scales 2 and 3 produced also the defect of over-wide diameters in the bass range, with consequent negative impact on timbre and space. Starting from the early seventeenth century, this was partly corrected by utilising two addition constants (the second of which — not shown in the figure, but located higher than $k$ — restrained diameter expansion toward the lower notes). An even more effective correction, in the work of e.g. the Dutch organ-builder Jan van Heurn (1804--05), consisted of introducing new constants, increasingly smaller in ascending to the high notes, for every octave of the scale. Montesanti's progression, seen in Figure 3, is also of this latter type.

5 Starting in 1739 the physicist-mathematicians take over, introducing logarithms to the calculations, deposing the old empirical criteria, based on rational ratios: curves of the continuous type thus replace broken ones. They proposed new constant scaling ratios, from semitone to semitone, following a law of the type $D \propto L^x$ (where $x<1$); since $x < 1$, halving the diameter occurs beyond the octave (in type 2 scaling, just dealt with, $x = 1$). The basis for their assumption was that loudness must remain constant throughout the rank, although such an assumption was based on considerations of a purely energetic nature, physio- and psy-
chological acoustics being still to come. The first of these is Leonhard Euler, who in his Tentamen, in order that the ‘different pipes emit similar and equally loud sounds’, proposed keeping the $S/L$ ratio constant (where $L =$ pipe length, $S =$ its cross-section area); this resulted in the law $D \propto L^{1/2}$, i.e. in halving the diameters after two octaves (the same as saying that the octave diameters have a ratio of $1:2^{1/2} = 1:1.41$). In the mid-eighteenth century, however, such a progression was very far from common practice, so that Euler’s suggestion was not acted upon (the related curve would have a shape like the one in 5, but would be much more ‘swollen’ toward the top). The first operational progressions are thus those of Giordano Riccati (1767) and Georg A. Sorge (1773), who calculated scaling ratios in which the halving of the diameter occurred after 16 equal-tempered semitones (for $D \propto L^{3/4}$) or just 15 (for $D \propto L^{3/2}$), corresponding to curve 5. The law $D \propto L^{3/4}$ — requiring the scaling of the octave diameters according to the ratio of $1:2^{3/4} = 1:1.68$, or $1:2^{3/2} (=1.81/2)$ if the $S$ areas are referred to — was independently re-proposed by Johann Gottlob Töpfer in 1833 and, since then, is one of those most employed. In §1 we saw that, in the very years in which Riccati and Sorge were publishing their proposals on the subject, the Tuscan Francesco Rigi also reached the same conclusions.

On the basis of what we have just noted, we can see that the scaling in Figure 3 has a decided trend like no. 5 in Figure 4, i.e. a logarithmic-type scaling. In this connection, Montesanti goes on to say (M, p. 11):

Although his reference to ‘any ancient or modern organ’ is decidedly exaggerated, his statement proves that logarithmic-type scaling was beginning to gain ground, albeit unacknowledged. To match this requirement more effectively, however, his graph should be slightly more arched: indeed, it may be noted that in the bass range the halving of diameters occurs at an interval between the ninth and minor tenth, and that in the successive octaves the said ratio is not kept perfectly constant.

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Diameter scaling in actual North-Italian organs

On the scaling actually adopted on organs of the Montesanti family, no data is so far available. For this period we do however possess several measurements taken during the recent restoration of instruments located in central and northern Italy. Rather illuminating are the following cases, which cast some light on the still badly-defined transitional phases between linear and logarithmic scaling.

Up to the second half of the eighteenth century, organ-builders of the so-called scuola veronese-gardesana (i.e. of the Verona area) utilised linear, or approximately linear, scales, i.e. very similar to no. 3 in Figure 4. In the pipe ranks of Carlo Prati (+1700), Giuseppe Bonatti (1668–1752) and Giacomo Benedetti (with his own workshop from 1744), recent research by Maurizio Isabella has shown that the number of additional constants is very low and the difference between two consecutive ones is rather limited. In some ranks, the said constants are even totally absent (Figure 5).

Figure 5  Organ at Acquanegra sul Chiese. Scaling of the XV 2′ (top) and XIX 1 1/3′ (bottom) stops, both the work of Giacomo Benedetti. As compared to the graphs in Figures 3–4, the scale of the abscissae is inverted. From Isabella, 'Giacomo Benedetti', pp. 68–69, adapted.

A little later on, however, scaling of the type shown in Figure 3 starts to appear. The Principale of an organ attributed to Giuseppe Fedeli, built in
1790 at his workshop at Camerino (Macerata), provides the diagram given in Figure 6. It shows numerous and fairly accentuated changes of direction; even if the scaling ratio is not constant throughout the entire register. Marco Valentini, who restored the instrument in 2010, also points out the trend shown in Figure 7, for the stop Flauto in V: although not logarithmic, the measurements taken pipe by pipe show that it has the progression of a true curve, highly unusual for the period (Figure 7).  

Figure 6  Organ attributed to Giuseppe Fedeli, Camerino, 1790. Pipe diameter scaling of the ripieno rank. For clarity's sake, only the first two addition constants are shown (fainter lines), omitting the two from the high tessitura. From Valentini, L'organo della chiesa di Santa Maria della Pietà in Prei, p. 152.

Figure 7  Organ attributed to Giuseppe Fedeli, Camerino, 1790. Pipe diameter scaling of the 'Flauto in V' stop. From Valentini, L'organo della chiesa di Santa Maria della Pietà in Prei, p. 154.

Figure 8 refers to the scaling of the Principale I of an organ built in 1816 by Giuseppe Antonio Serassi, of the famous Bergamo family. As we can see, it shows four decided changes of direction, i.e. angles. With the aid of the table indicating the diameter measurements for this stop, we see that for its whole range, their halving provides a fair approximation for the minor tenth. This confirms Montesanti's statements and is a further sign that, at least as early as 1816, there was a clear trend toward logarithmic scaling ratios.  

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Figure 8  Organ built by Giuseppe Antonio Serassi, Bergamo, 1816. Diameter scaling of Principale I; measurements by Maurizio Isabella. From Bertagna, Rodì, Gli organi Serassi di S. Filippo Neri a Genova, p. 57.

Progressions like the one in Figure 3 are however still encountered in the second half of the nineteenth century, as for example in the instrument built in 1874 by the Bernasconi brothers for Mombello, on Lake Maggiore. Scaling with a fair approximation in the halving of diameters for the major tenth interval is also found at Cesi (Terni), in the organ built by Francesco Pasquetti in 1836, exactly three years after the publication of Töpfer's famous treatise.
The data available to us is still insufficient to draw any conclusions of a general nature. In Italy, the situation in this field of research appears very similar to what was happening in about 1970–80 with regard to the study of temperament. It is to be hoped that the research of Isabella and Valentini will continue and be extended to the south of the Peninsula in future organ restoration.

Translated by Dr Ken Hurry

Notes


3 See the measurements for the reed stop known as the Vox humana, which Kircher maintains he received from Roman organ-builders: Patrizio Barbieri, 'Cembali enarmonici e organi negli scritti di Kircher. Con documenti inediti su Galeazzo Sabbatini', Enciclopedismo in Roma barocca, eds Maristella Casciato, Maria Grazia Ianniello, Maria Vitale (Venezia: Marsilio, 1986), pp. 111-128: 114-5 + Fig. 11 (also at www.patriziobarbieri.it/pdf/cembali.pdf).


5 Patrizio Barbieri, Enharmonic instruments and music 1470-1900 (Latina: Il Levante, 2008), p. 529 (with reference to the making of flutes).

On this subject, see Barbieri, ‘Il mesolabio e il compasso di proporzione’, pp. 211-213.

Jacob Leupold, Theatrum arithmetico-geometricum; das ist: Schau-Platz der Rechen- und Mess-Kunst (Leipzig: Zunke, 1727), p. 95: §193. Wie verhâlt es sich mit den Orgelpfeiffen? Mann eine der selbigen mit der Menschlichen Stimme übereinstrellen solle, so muss ihre höhe 1½ Schuh lang seyn, nach welcher die anderen Pfeiffern ihre Proportion bekommen; Also müssen auch die Dicken der Pfeiffern ihre Proportion haben.


Correspondance du P. Marin Mersenne [...] V, p. 148: Christophe de Villiers (Sens) to Mersenne (Paris), 1.5.1635: Partant pour veoir si cela [the frequencie] depend de la bouche, j’en fervois qui auroit la bouche bien grande et un autre qui l’auroit bien petite de mesme grosseur. Et voyant qu’il y eust distinction des tons divers, sera ayse d’en faire d’autre qui ayent la bouche moyennement grande.


24 For the main bibliographic references, see Christhard Mahrenholz, The calculation of organ pipe scales from the middle ages to the mid-nineteenth century, trans. by Andrew H. Williams (Oxford: Positif Press, 1975), passim.

25 Mersenne, Harmonie universelle […] ‘Traité des instrumen a chordes’, pp. 333-4, as a result of experimental tests, states that le tuyau different en sa seule longueur peut monter de deux ou trois octaves.

26 M, p. 11: ne verrebbe che dopo la terza ottava di 4 piedi; si minorebbe la forza della voce sempre più che si ascendesse alla parte acuta, oltre d’aver un suono difettoso, e tardo.

27 J. van Heurn’s scale in his book De Orgelmaaker […] in Volledige beschrijving van alle Konsten, ambachten, handwerken […] is mentioned by Mahrenholz in The calculation, pp. 28, 61.


29 Leonhard Euler, Tentamen novae theoriae musicae (St. Petersburg: Typographia Academiae Scientiarum, 1739), p. 22: Quo autem plures tibiae sonos edant similis et aeque vehementes, sportet tibiae amplitudinem seu basin tubi sicut chordae crassitiem proportionalem esse longitudini. (On the identity of crasities = S, i.e. equal to the cross-section area, see also what Euler says at p. 11). For pipe crassities, Euler proposes a law similar to the one he has already expounded (pp. 10-12) for the strings of keyboard instruments. For the latter, Riccati, Delle corde, p. 134 would also propose a different law, noting that Euler had overlooked craftsmen practice. It should be added that this ratio, applied however just to the octaves and without any scientific justification, had already been put forward in previous centuries: Mahrenholz, The calculation, pp. 39-40.

31 'It appears to be the most generally adopted by both German and French organ builders, including Schulze and Cavaille-Coll': George Ashdown Audsley, *The art of organ-building*, II (New York: Dodd, Mead & Co., 1905), p. 568.

32 In this connexion, we are rather unlucky. We have for example the instrument built in 1790 by Andrea and Luigi Montesanti for the basilica of Sant’Andrea at Mantua; over the years, however, it has been tampered with, and a recent restoration shows that it even contains Renaissance pipes: Michel Formentelli, ‘Il restauro dell’organo’, *L’organo Montesanti 1790-1828 della parrocchiale di San Erasmo già nella basilica mantovana di Sant’Andrea. La storia. Il restauro* (Mantova: Parrocchia di Governolo, 2001), pp. 43-9. Another Montesanti instrument too, dated 1813, incorporates pipes from the previous organ, built by Giacomo Benedetti, an author to whom we shall refer later on: Maurizio Isabella, ‘Giacomo Benedetti: misure e segnature delle canne ad Acquanegra sul Chiese’, *L’organo Luigi Montesanti 1813 della chiesa di San Tommaso in Acquanegra sul Chiese*, ed. Federico Lorenzani (Acquanegra sul Chiese, Mantova: Parrocchia di Acquanegra sul Chiese, 2009), pp. 56-74.


