Definition

SCALING is the relationship of the width of a pipe resonator to its length

It is one of the primary determinants of power and tonal quality for both flue pipes and reed pipes. In principle, the narrower the scaling of a pipe, the less power and foundational tone it produces and the more higher harmonics are present. Conversely, the wider the scaling the more foundational tone is produced and fewer or weaker harmonics are present. Broadly speaking, narrow-scaling in flue-stops produces string tone, wide-scaling, flutes, and between these is the middle ground from which Principals are derived. Mouth characteristics of flue pipes, particularly mouth width and cut-up, but nicking, wind supply and wind quality can also make marked changes to the final tonal results and contribute to the effects of scaling. The width of the opening at the foot of the pipe can also be quite critical in this connection. In reeds similar principles apply relating to resonator scalings and shapes as well as further relevant factors e.g. shallot design and reed tongue thickness.

to c12thc

Up to the 12thc about 75 still extant texts deal with this. Some duplicate material in others - often later copies or fragments. They are typically titled *mensura fistularum, logissimam, cognita omnia consonantia* or similar names, usually taken from their latin first lines (2 are in Hebrew). Many are anonymous tracts (e.g. Anonymous of Bern), others have identifiable authors or scribes (e.g. Hucbald, Gerbert of Aurillac, Aribo). In this context they deal mainly with pipe-lengths, since the earliest ranks of organ pipes - 9th to 12thc - were constructed with the same diameters (constant scaling). They became shorter, but not narrower, from bass to treble. This made them sound like thin Principals in the bass (the technology was not yet available to create string-tone), Principals in their mid-ranges and Flutes in the treble. It placed limits on the ranges of ranks since pipes using early technology (i.e without ears, beards, rollers, nicking or even an acceptably malleable metal around pipe mouths) cannot usefully produce sounds if they are too narrow-scaled. With excessively wide-scaling another set of problems is encountered. For these reasons ranks were initially just an octave or two of pipes (e.g. the hydraulis, Aquincum). It was a simple corollary to this that separate stops of uniform tonal colour were not available.

13th/14thc

Constant scaling persisted at least into the early 14thc. Although as early as the 10thc there might be some hints that alternatives were being sought, Hans Hickmann only finds evidence for varying flue pipe scales "by the 14thc". Mahrenholz believes that scaling at least became "wider" in the 11th and 12th centuries, that is than the "pigeon's egg" measurements given in the Anonymous of Berne (Berne Codex). Certainly by about the 13thc, partly promoted by a switch from copper to lead as pipe material, empirical organ building methods of scaling had to be developed to achieve both wider ranges of available notes and to create perceptions of consistency in tone from bass through to treble (variable scaling). It has been argued that variable scaling was introduced as early as the 13thc by Conrad von Scheyern at Scheyern

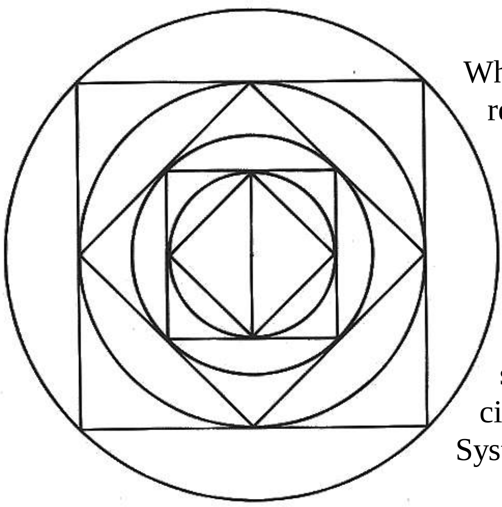
Abbey, 1245. While this relies heavily on conjecture when interpreting early documents, variable scalings were definitely attempted in different contexts before they became the norm in the 15^{th}c. Monochord theory persisted in pointing one way ahead, and the octave ratio of 1:2 (exactly proportioned lengths to diameters - e.g. half diameter for half length) was tried. However this was found to reverse the bass-treble characteristics, that is the treble became thin and the bass thick. Differences arising from tin or lead pipes began to be perceived and noted in early texts such as *Circa latitudinem* (of uncertain dating but transmitted through English 14^{th} and 15^{th}c scribes).

15^{th}c

In the 15^{th}c Arnaut de Zwolle suggested a method whereby the shape for the flat metal plate (before it was rolled into pipe forms) was drawn and marked off according to the 1:2 ratio, with the width of the plate now being $^{1}/_{6}{}^{th}$ or $^{1}/_{7}{}^{th}$ the length. (formerly under monochord theory it had typically been $^{1}/_{5}$). An addition constant was then derived, e.g. by taking $^{2}/_{5}{}^{th}$, $^{1}/_{3}{}^{rd}$, or $^{3}/_{10}{}^{th}$ the width of the longest pipe, adding this value throughout the entire range. It produced scaling values between the two earlier extremes (constant scaling and 1:2) and thus achieved a somewhat better degree of tonal consistency from bass to treble. It also allowed a corresponding increase in the available musical range to about $3^{1}/_{2}$ or 4 octaves. Even so, too high an addition constant value gave dominant trebles, too low produced dominant basses, and if a value was chosen that satisfied treble and bass, then the middle suffered. This led to each octave being treated as a slightly separate entity. Indeed there was often no attempt to mark off the individual pipes in a logarithmic/parabolic manner, just 12 equal spacings in each separate octave. One early tract even allows pairs of adjacent pipes to have the same diameter.

The 15^{th}c was the point at which stop-separation began in earnest. New technology appeared which allowed single ranks with flutey trebles, stringy basses and mid-range “Principals” to be converted into separate ranks which consistently showed one of these properties throughout their ranges, even if still limited to a few octaves. Individual (separated) stops could now be given descriptive names indicating their tonal class. Perhaps one of the more elusive meanings of the word *Diapason* is underscored here: “(consistent) over the entire range”?

16^{th}c/17^{th}c



De Caus: deriving octave scalings (the circles)

When reed ranks were introduced (c15^{th}c) their resonators were soon found to need different scaling principles to flues. Around the Renaissance a long quest was begun to establish scaling ratios for all pipe types, forms, metals and woods. For flues, ratios such as 2:3, 3:5 and 4:7 were tried. 3:5 became the most workable for Principals at this stage. Experiments were made with geometric solutions - squares, triangles, and pentagons drawn within circles: the circles representing octave diameter ratios. Systems were developed and reported by 16^{th}c; in 17^{th}c theorists such as Salomon de Caus, Athanasius Kircher, Marin Mersenne, Andreas Werckmeister (in his Orgel-Probe of 1681), and Johann Philipp Bendeler (Arp Schnitger's son-in-law, friend of Werckmeister) in *Organopoeia* of 1690, contributed ideas on scaling.

"This business has up to now caused musicians and good organ makers as many and wonderful thoughts as Mercurius of the philosophers did to the alchemists. It is [now] commonly held that the scaling of pipes cannot and may not be carried out according to the musical proportions; thus some other basis is sought. Some think that the basis of scaling is to be found in solid geometry and not in the musical proportions, and therefore have not been afraid to attack the musical proportions as old and deceptive inventions of Pythagoras; it is much to be desired that this dispute be sorted out." Bendeler

At this time some of Germany's leading organ builders were setting voicing and scaling standards which have endured to this day. Their work was still driven by empiricism, but the scientific aspects reflected the *Zeitgeist* of the Enlightenment era in which they lived. Scaling ratios could now be applied differently to ranks of various tonal qualities - Flutes, Principals, Quintadenas, reeds, early String stops - so that tonal perception remained uniform for each register from bass to treble.

18th c

Throughout the 18th c pipe technology was further explored and scaling practice refined. Narrower scalings were successfully ventured and string stops began their final stages of development. The application of logarithms brought new understanding and the ability to deal ever more scientifically with this blend of art and science. Sorge was particularly involved in promoting these aspects in the mid-18th c. For one thing logarithms led to a more exactly-proportioned approach to the values within the separate octaves than before - a perfectibility important to the philosophies of their epoch. Jacob Adlung also made important contributions in his 1768 (posthumous) publication, *Musica mechanica organoedi*.

19th c

In the early 19th c J.G. Töpfer finally derived a mathematical formula that could be applied to ensure any rank of pipes would sound true to its tonal designation consistently from lowest - even 32' - to highest pitches, with tiny pipes of only a few centimeters length. He produced the following formula giving the width for the octave above any given pipe:

$$WIDTH:\ UPPER\ PIPE = \frac{1}{\sqrt[4]{8}}\ LOWER\ PIPE$$

- which is 1:1.6818.

Later in the 19th c a somewhat new *lingua franca* evolved alongside the specific ratios of 1:2, 3:5, 1:1.6818 etc.: this was to take the point at which a rank's diameter halved, expressed according to its place in a chromatic musical scale. What is known as halving ratios grew out of this. British-American culture used e.g. "halving at the 15th" (or 14th or 19th etc.) - "halving on the 17th" was fairly standard for Principals in both British and German traditions. Semitones were the unit of measurement here. In Germany actual diatonic intervals were used e.g. "halving on the 10th (- 11th, 12th etc.)" which was equivalent to 17th (18th 19th etc.)

respectively in the other system. Even so, the different tonal classes - principals, flutes, strings, reed resonators - were all found to need differing halving ratios. Tolerances were projected - e.g. the "slowest" Principal tone increment was estimated by one authority (Audsley) as halving on the 19th.

20th c

During the 19th and 20th cs extended scaling options were further pursued, creating some very narrow strings and reeds in one direction (e.g. the 19th/20th c Dulciana, Aeolina), and very wide flues and reeds in the other (e.g. Tibia, Tuba). Using Töpfer's formula a rank of any tonal quality could be produced maintaining the perception of that quality from the lowest to the highest pipe, the fulfillment of 1000 years of control over tonal production probably starting in the 10th c and continuing through the 20th c.

Reeds

With reed pipes, resonator scales have varied significantly from those used with flue-pipes. Either a 1:2 octave ratio has been applied as basis, but with a much larger addition-constant than flues, or using another ratio, typically varying between 4:5 and 10:13. Dom Bédos de Celles adopted differing resonator ratios between bass (4:5) and treble ranges (5:7) of the same reed rank. A 5:7 ratio was suggested by 20th c organ reform leaders Christhard Mahrenholz and Paul Smets as being ideal for conical reed resonators, and 5:6 for cylindrical.

20th c/21st c

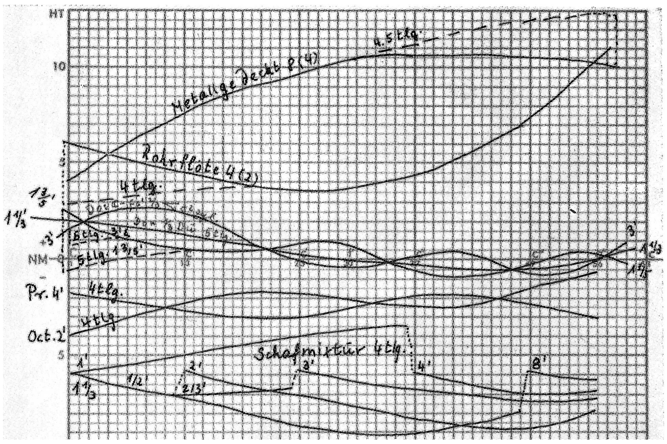
Töpfer's work rightly took cross-sectional areas into consideration as well as diameters, thus he could include e.g. rectangular wooden pipes. Arising from this a standard scaling, called in German *Normalmensur*, was projected in Germany during 1927 by Johannes Biehle (after the 1926 Freiburg Organ Reform Movement conference). Most organ builders and consultants nowadays eschew using *Normalmensur*, although it is useful in making comparisons. A "normal scaled" - abbreviated NS or NM in German - 8' Principal pipe was then set at the following values (slightly larger than Töpfer's):

	C	c^0	c^1	c^2
Circumference	489	290	173	102
Diameter	155.5	92	54.9	32.6
Mouth width ($^1/_4$)	122	72.5	43	26
Cut-up ($^1/_4$)	31	18	11	6.4

From this, increments of a semitone (abbreviated as HT in both English - half-tone - and German - *Halbton*) are now sometimes used in talking about scaling. Thus 1 semitone under normal scaling (-1HT) is achieved when a C pipe has the (smaller) diameter of its adjacent C♯ companion. When a pipe of a certain length has a (larger) diameter, e.g. the same as one octave lower should have, then it is 12 semitones over normal scaling (+12HT).

Conclusion

Whilst theoretically this point might seem to mark the end of the long era of empirical organ building, since pipe tone could now be “designed”-created-controlled “scientifically”, the human ear nevertheless always was and always remains the final arbiter. Conformity to norms by some builders, mass-production, and other 19th and 20thc trends in organ building, including the cinema organ and even the electronic organ, arguably retrained ears in certain instances, causing shifts in aesthetic paradigms.



A 20thc organ builder’s scaling curves

Use is still often made of “addition constants”: in modern contexts, essentially a blend of Töpfer’s system, historical and modern practices. Here each pipe is designed with a small scaling change - a few millimeters or so - added or subtracted to its theoretical “scientific” or standard diameter as the rank ascends in pitch. This creates a “scaling curve” with e.g. the low range, mid-range and high range using slightly differing scaling parameters to create subtle “blooming” or “thinning” effects. Reeds have a natural affinity to “blooming” in the bass - a characteristic given notable encouragement in the French classical traditions but suppressed in others through these means. Such techniques always return us to an empirical system, since they are deliberately used to create subtle but important changes in “flutiness” or power as the pipe-lengths get smaller or larger. In this way scaling can encourage a rank to “sing” or “bloom” in its trebles rather than sound thin, however perfect that might seem to be in theory.

Addition constants may be negative as well as positive and applied variously to different parts of the range - achieving this successfully in a given situation is the art and skill of the good organ builder, although even here the final arbiter is taste. There are also fine historic organs where fixed scalings were used, e.g. Thal, Neu St. Johann 1690/1 by Matthäus Abbrederis.

Yet even all this is too simplistic for the ultimate complexities of organ building: e.g. lead pipes need to be scaled two to three HT smaller than their corresponding tin-alloy counterparts; Flutes are better halving “later” than principals - on the 22nd, for instance, rather than around the 17th. The varied acoustic properties of buildings all ideally need tailor-made scalings. Satisfactory instruments cannot be built by simply using *Normalmensur* or formulas of this kind. Human perception of music seems to prefer scalings that deviate from the “straight line” implied by Töpfer’s system and its derivatives, one of the mistakes of some builders and consultants in the early days of the organ reform movement. What also had to be learned over these 10 centuries of scaling development was how to balance total perfection (which fringes on being boring), and allow just sufficient variety - “imperfection” (in a sense creating interest and hence musicality).

The varying manners in which scaling has been applied over the centuries has created national schools, romantic and classical instruments, and the suitability of organs to play a specific repertoire or sound well in a given ensemble, building, or when accompanying congregations. This gets back to the semantics and etymology of the definition of an organ as being a (musical) “tool” for a specific job (Werk).

Examples

Some examples of scalings for classical French Bourdons -

Dom Bédos:

	Actual Pipe Length (ft.)	Ø
Bourdon (Large)	4	85
	2	48
	1	30
	$^1/_2$	22
Bourdon (normal)	4	73
	2	41
	1	26
	$^1/_2$	19

Clicquot:

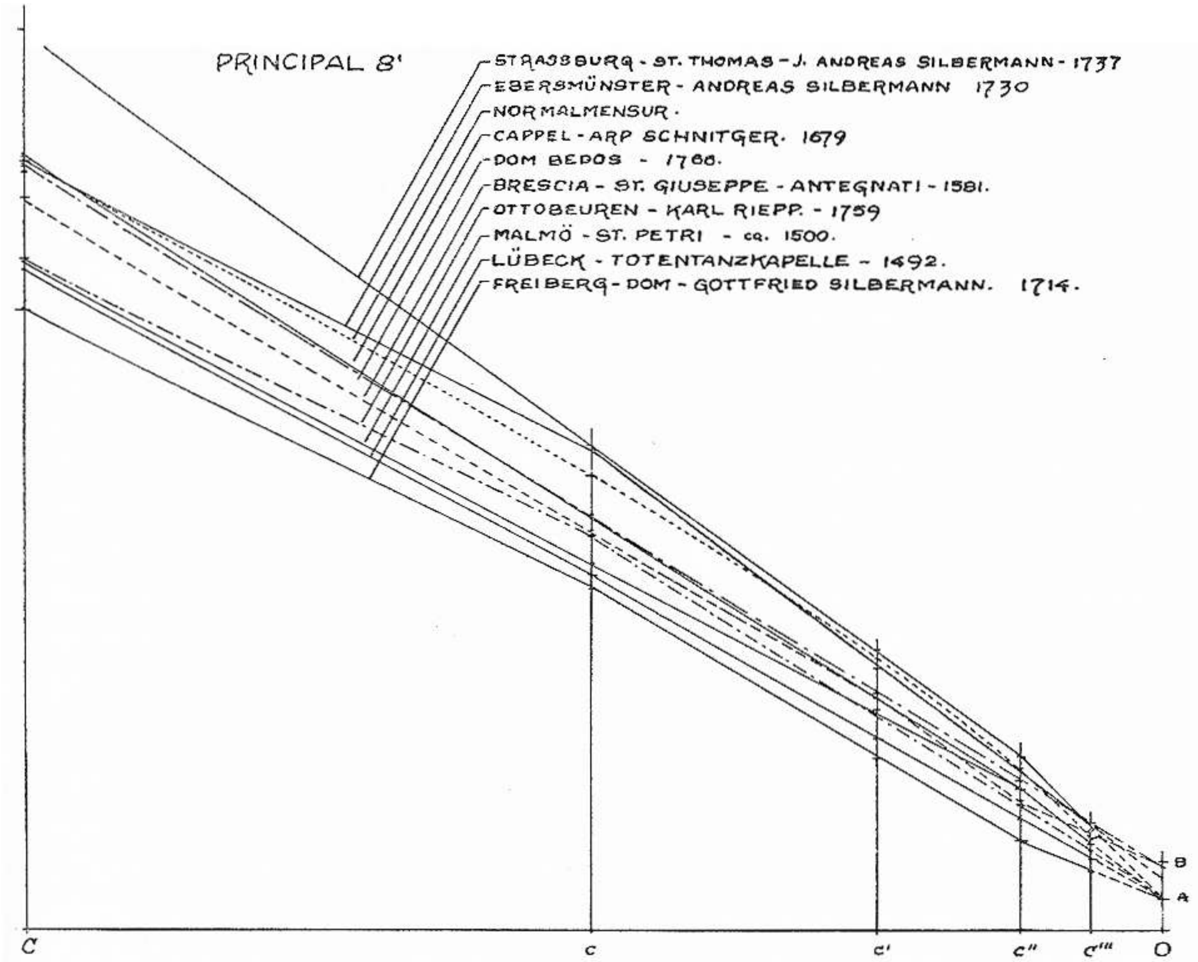
Stop	Actual Pipe Length (ft.)	Ø
Bourdon (GO)	4	78.5
	2	46
	1	30
	$^1/_2$	21
Bourdon (Pos)	4	66.5
	2	46
	1	30
	$^1/_2$	22

Some of the differences between French and German schools for two mutation ranks may be seen from the following table:

Scalings of pipes at c^1:

	Ø ($2^2/_3$)	Ø ($1^3/_5$)
"FRENCH"		

Souvigny GO (F.-H. Clicquot)	29	23
Souvigny Réc	28	22
Nazard/Tierce, wide-scaled, open pipe (Dom Bédos)	28	20
Nazard/Tierce, "Menue" (Dom Bédos)	23	17.5
Tierce $3^1/_5$ (Dom Bédos)		27
Cornet GO (Dom Bédos)	33.5	24
(average)	28.3	22.3
"GERMAN"		
Dresden, Hofkirche (G. Silberrmann 1750)	29	21
Ochsenhausen (Gabler 1755)	18	12
Rot-an-der-Rot Manual I (Holzhey)	23	16
Rot-an-der-Rot Manual II	23	15
Weingarten, Benediktiner Abtei (Gabler 1737-)	15.5	12
(average)	21.7	15.2



Some 18th c Principal scalings (after P.G. Andersen in Orgelbogen)

[Back to Index]
[to David Rumsey's home page]
[to David Rumsey's mediæval page]

See also on this site:
[Glossary of medieval organ topics]
[Explanation of Gothic-mediæval organ types]
[A general background to Gothic-mediæval organ culture]