CAVAILLÉ-COLL AND SOME EXPERIMENTS ON ORGAN PIPES

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Some time ago I had the opportunity of buying some old books on the organ from a book-dealer in Brussels. There was also a notebook containing various manuscripts, in particular concerning experiments made on organ pipes by Aristide Cavaillé-Coll (4.2.1811–13.10.1899)[1]. The first part of these experimental studies had been read to the Académie des Sciences at Paris on Saturday, February 15th, 1840 and published at Paris in 1849.

In previous activities of this academy, the physicists Bernoulli, Sarti and Savart had already demonstrated the vibrations of air in an organ pipe, going on to publish their work which had been completed respectively by 1762, 1706 and 1825[2]. Others eminent in physics and mathematics had also by then worked on musical acoustics, including Joseph Sauveur (1653–1716, the Father of Acoustical Sciences), Leonhard Euler (1707–1783), F. W. Marpurg (1718–1795), Baron Gaspard de Prony (1755–1839), Ernest Chladni (1756–1826), Jean-Baptiste Biot (1774–1862) and Baron Charles Cagniard de la Tour (1777–1862)[3]. A few months after Cavaillé-Coll's report, the French physicist Antoine-Philibert Masson (1806–1858) published in the journal *L'Institut* (Nos 332–3) the substance of this *mémoire* as something originating from Savart's course, Masson's work appearing on May 7th and 14th, 1840. Twenty years later, after intense work in Paris, Béziers, Perpignan, Toulouse, Rouen, Narbonne and elsewhere, Cavaillé-Coll presented to the same academy on Monday, January 23rd, 1860 a further study: *De la détermination des dimensions des tuyaux en rapport avec l'intonation des mêmes tuyaux*[4]. This seems to have been a sequel to that read in February, 1840.

It is this second part that is published hereafter (with an English translation); a transcription of the manuscript has not been published before.

The present article is written in memory of Dom Joseph Kreps OSB (Antwerp 23.v.1886–Louvain 13.7.1965), 'le plus savant organologue de Belgique et sans doute de France et d'ailleurs' (Ernest Closson).

Aristide Cavaillé-Coll

Paris, January 23rd, 1860

In another series of experiments on cylindrical metal pipes we were able to recognise that the law applying to prismatic pipes on a square base relates also to cylindrical pipes. It is always the double 'depth' of the pipe added to its length which equals the wavelength of the pitch concerned. We must nevertheless point out that there should be no confusion between the depth of a pipe and its diameter, as one might suppose on the analogy with wooden pipes on a rectangular base. In such pipes the depth is the same as the size of the side perpendicular to the line of the pipe-mouth, while in cylindrical pipes the depth is smaller than the diameter. The flattening at the mouth, which is usually a quarter of the circumference of the pipe, makes a line subtending an arc equal to three-quarters of the same circumference. It is the 'height' or *sagitta* ('arrow') of this arc that must be understood as the depth of the pipe. This sagitta is very nearly five sixths of the diameter. If in calculating cylindrical pipes one preferred to employ the expression of the diameter to that we have called P (as representing the depth), it should be remembered that $P = \frac{5}{6}D$, where D = diameter, and one would then have:

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and hence $L = V/N - \frac{5}{3}D$

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There follows a table of our first experiments with cylindrical pipes.
Three pipes of tin with thick walls having approximately the same diameter, all

cut on the *diapason* of 880 vibrations per second and at the octave to each other, gave the following figures:

Longueur Length	*Diamètre* Diameter	*Profondeur* Width	*Hauteur des bouches* Height of mouth	*Observations* Observations
0·643	0·028	0·025	0·0055	Vibrations deduced from the formula given.
0·297	0·028	0·025	0·0050	*Les nombres de vibrations ont été déduits au moyens de la formule citée*
0·122	0·029	0·0256	0·0045	

These pipes were set up with a view to understanding the relationship between the lengths of pipes of the same diameter and thus to determine the nodes in harmonic pipes. In comparing lengths, I noticed that the difference between b^{I} and b^{II} was double that between b^{II} and b^{III}, which led me to see that in harmonic pipes the length of the vibrating parts from the open end of the pipe was in inverse ratio to the number of vibrations, and that shortening the column of air in the pipe had effect only on the parts next to the mouth.

I looked then to understand the influence the mouth could have on the length of pipes, and in comparing the part next to the mouth with those which gave the harmonics, I saw that the difference was twice the depth of the pipe, as I had already discovered to be the case with prismatic wooden pipes on a rectangular base.

In reducing the pipes indicated in the above table to the same pitch, one obtains the dimensions of three pipes whose diameters are in the relation of 1–2–4 and whose lengths differ in comparison with the wavelength always by twice the interior depth of the pipe.

The following table makes it possible to judge the results.

$$\left.\begin{array}{l} 1-(25\text{mm}\times 2) = 0{\cdot}693\text{mm} \\ 2-(25\ \ \times 4) = 0{\cdot}694 \\ 4-(25.6\ \ \times 8) = 0{\cdot}6928 \end{array}\right\} \begin{array}{l} l'Onde\ sonore \\ \text{Wavelength} \end{array} = \frac{340\text{m}}{490\,\text{V}} = 0{\cdot}6938\text{mm}$$

Experiments in March 5th, 1840. In my researches to discover the influence of pipe-depth on pipe-length, I set up a wooden pipe on a rectangular base, having a length of 1 metre, a cross-section of 10 × 30 cm, a double pipe-wall opposite the mouth side provided with a parallelogram system allowing it to be brought nearer to or farther away from the mouth as required (by means of a screw). I could therefore vary the depth of the pipe without changing any of the other dimensions.

J'ai conservé une séries d'expériences faites a St-Denis le 5 mars 1840 et que j'indique dans le tableau ci après. Sa pression du vent était de 10 cm de colonne d'eau. La température de + 3° centigrades. Le temps était sec.
Les observations ont été faites avec une sirenne de Mr le baron Cagniard-Latour et chacune d'elles a duré une minute.

I	II	III
Profondeur du tuyau	*Hauteur de la bouche*	*Epaisseur de la lumière*
Depth of pipe	Height of mouth	Thickness of flue
0·22m	0·027m	0·001m
0·20	0·027	0·001
0·15	0·027	0·001
0·10	0·027	0·001
0·05	0·025	0·001

La concordance remarquable des nombres trouvés par l'observation avec leurs déduits de notre formule est une nouvelle preuve de l'exactitude de notre théorie. Les nombres des 5 premières colonnes avait été determines expérimentalement le 5 mars 1840 avant que nous ayons trouvés notre formule ce n'est qu'environ une année plus tard que nous avons calculé les chiffres de la 6e colonne et à cause de la basse température dans laquelle nous avions operée, nous avons supposé la vitesse du son V à 0 degré = 332·3 m.

I noted a series of experiments made at St-Denis on March 5th, 1840 and show them in the following table. The wind-pressure was 10 cm in a column of water; the temperature was 3° centigrade; the weather was dry. The observations were made with a *sirenne* made by M. le baron Cagniard-Latour, and each lasted a full minute.

IV	V	VI	VII
Nombre de vibrations par seconde — *Observations*	*Moyennes*	*Longueurs calculés selon la formule*	*Différences de vibrations au calcul*
Number of vibrations a second — By observation	Mean	Lengths calculated from the formula	Difference in calculated vibrations
112·20	111·45V	115·0V	÷3·55V
110·95			
111·20			
114·75	116·50	118·70	+2·20
115·75			
115·90			
117·33			
118·70			
116·57			
128·00	127·21	127·80	+0·59
125·47			
126·43			
128·30			
127·87			
138·50	139·37	138·45	−0·92
138·30			
142·93			
143·10			
137·70			
137·73			
152·95	153·12	151·05	−2·07
153·28			
153·78			
152·77			
152·80			

The remarkable agreement between numbers found by observation and those calculated from the formula is new proof of the exactness of our theory. The numbers in the first five columns were determined experimentally on March 5th, 1840 before I established the formula. Only a year later were the figures in the sixth column calculated, and in view of the low temperature in which we were working, I supposed the speed of sound V at zero centigrade to be 332.3m.

Some other experiments made on cylindrical pipes of tin reported below offer a new example of the exactness of the theory. A flute pipe of good pipe-metal and strong walls, tuned to a = 880, voiced to a steady wind-pressure of 10 cm of a column of water, in a temperature of 4° cent., with a length of 32.5cm and diameter of 3.2cm. The mean of a series of ten experiments very precisely measured with the *sirenne* gave pitches of 444.25 and 888.50. In submitting the pipe to calculation, by means of the formula

$$N = \frac{V}{L \times \frac{5}{3} D}$$

(where V at a temperature of 4° = 335m), the number of vibrations for such a pipe is 885.6. Three other pipes, tin, cylindrical, 1m long, all voiced to a wind-pressure of 10cm in a column of water, in the same temperature of 4°, gave the following figures:

Diamètre Diameter	*Nombres de vibrations* *Expérimentés* Number of vibrations Experimental	*Calculés* Calculated
0·09m	145·39V	145·65
0·08	146·70	147·85
0·068	151·11	150·50

Once again these observations prove the exactness of the theory, confirmed moreover in practical experience during twenty years of building large organs.

The ease of making calculations from my formula has allowed me to put in the hands of the simplest workmen tables and rules indicating the real length of soundwaves and through which, with a simple arithmetical operation or even by a pair of compasses, they can determine directly and most exactly the true length of the pipes for the fundamental tone, even the position of the nodes in harmonic pipes.

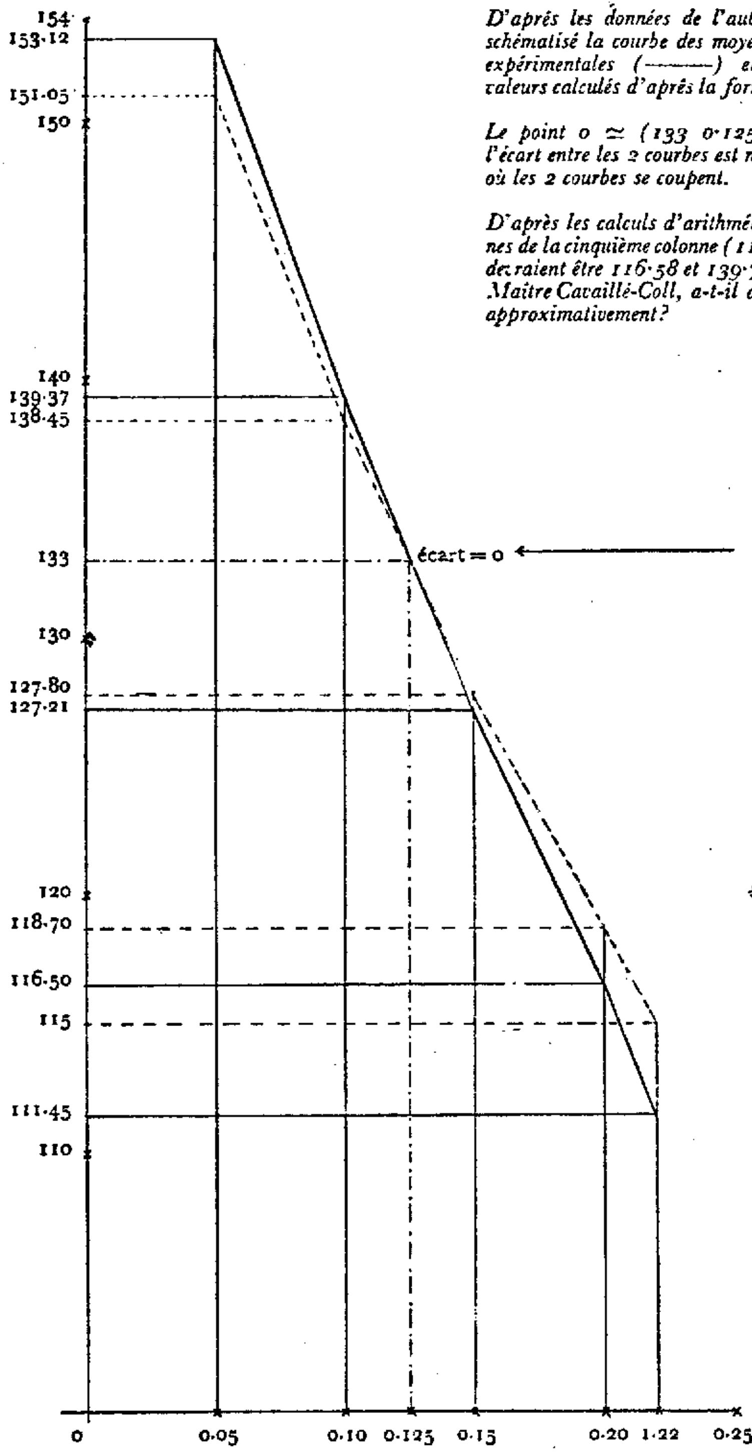
The author puts himself at the disposition of the Academy to make in its presence any experiments it may consider necessary in support of his theoretical and practical solution of the problem he has just had the honour of presenting.

Translated by editor

D'après les données de l'auteur, nous avons schématisé la courbe des moyennes des valeurs expérimentales (———) et la courbe des valeurs calculés d'après la formule (- - - -).

Le point o ≃ (133 0·125) est celui, où l'écart entre les 2 courbes est nulle, c'est-à-dire où les 2 courbes se coupent.

D'après les calculs d'arithmétique, les moyennes de la cinquième colonne (116·50–139·37), devraient être 116·58 et 139·71.
Maître Cavaillé-Coll, a-t-il donné ces chiffres approximativement?



From the author's data we have drawn the curve of the mean values obtained experimentally (———) and the curve of the values calculated on the formula (-----).

The point o ≃ (133×0·125) is that where the variant between the two curves is nil, i.e. where the two curves cross.

Calculated mathematically, the mean measurements in the fifth column (116·50–139·37) are 116·58 and 139·71. Did Cavaillé-Coll give approximations?

Notes

1 Cavaillé-Coll's dates are often given wrongly

2 Daniel Bernoulli (1700–1782) occupied the chair of mathematics, anatomy, botany, physics and philosophy at the University of Basel from 1725 to 1732 and was responsible for developing the kinetic theory of gas. His publications include *Mémoire sur l'inclination des orbites planétaires* (1734), *Traité sur les marées* (1740) and *Traité d'hydrodinamiqe* (1738). Guiseppe Sarti (1729–1802), composer and organist, held positions (mostly as *Maestro di cappella*) in Faenza, Copenhagen, Venice, Milan, St Petersburg and Mingotti, wrote about eighty operas and published articles on acoustical matters in scientific reviews. Félix Savart (1791–1841), physician, translated the *De Arte medica* of Aulus Cornelius Celste, returning to Paris in 1819 where he presented his mémoire on the construction of string and bowed instruments. He invented various scientific instruments, becoming professor of physics at the College de France. His publications include *Sur la communication des mouvements vibratoires entre les corps solides* (1820), *Sur les vibrations de l'air* (1823), *Sur la voix humaine* (1825), *Sur la communication des mouvements vibratoires par les liquides* (1826) and *Sur la voix des oiseaux* (1826).

3 See *Orgue de l'église royale de Saint-Denis. Rapport fait à la société libre des Beaux Arts par Adrien de la Fage* (Paris, 2nd., 1846), pp33, 56, 75–7, 78–9

4 Other publications of Aristide Cavaillé-Coll include:

Rapport sur les travaux du grand orgue de l'église de la Madelaine à Paris (Paris 1846). See also J. H. Burn, *Dictionary of Organs and Organists* (2nd edn., 1921)

Études expérimentales sur les tuyaux d'orgues. Ie partie (Paris, 1849), also in *Projet d'orgue monumental pour la Basilique de St-Pierre de Rome*. (Bruxelles, 1875), pp47–52. See C. & E. Cavaillé-Coll, *Aristide C-C* (Paris, 1929), pp149–151, and *Encyclopédie de la musique et dictionnaire du conservatoire*, ed. A. Lavignac & L. de la Laurencie, Pt. II (Paris, 1926), pp1103–4, 'Tuyauterie'. Also *De la Détermination des dimensions des tuyaux par rapport à leur intonation* (Paris, 1895)

De l'Orgue et de son Architecture. 1st edn., *Revue générale de l'architecture et des travaux publics*, 1856; 2nd edn. enlarged, *ibid.*, 1872

De la détermination du ton ou du diapason pour l'accord des instruments de musique. (Paris, 1859). See C. & A. Cavaillé-Coll, *op.cit.*, pp165–181

Notes sur une soufflerie de précision. (Paris, 1863). This and the previous paper were read to the Académie on 23.ii. 1863 and 5.ii.1859 respectively.

Rapport de l'Académie des Beaux Arts sur le Grand-Orgue de St-Sulpice (Versailles, 1863). See also L'Abbé Lamazou, *Étude sur l'orgue monumentale de St-Sulpice et la facture d'orgue moderne* (Paris, 1863), especially pp90–3

Le grand orgue de l'église métropolitaine Notre-Dame de Paris (Paris, 1868)

Le grand orgue de la nouvelle salle de concert de Sheffield (Paris, 1874)

'Note sur la détermination des dimensions des tuyaux a bouche', 'Moteur pneumatique à simple effet pour le tirage des claviers' and 'Moteur pneumatique à double effect pour opérer la traction des registres' in C. M. Philbert, *L'Orgue du palais de l'Industrie d'Amsterdam* (Amsterdam, 1876)

Note sur la détermination des tuyaux coniques (1887, read to the Académie des sciences, 21.v.1877)

See also *Catalogue de la Bibliothèque de F. J. Fétis* (Paris, Libraire de Firmin-Didot et Cie. Ao. 1877), nos 4116. 4118, 4119, 7227; A. Peschard, *Notice biographique sur A.C-C et les orgues électriques* (Paris, 1899); G. A. Audsley, *The Art of Organ-Building* (New York, 1905); Dom Joseph Kreps, 'Le Tuyau à bouche–ses pressions, longeur, diamètre, volume et matériau', *Mélanges Ernest Closson* (Bruxelles, 1948), pp110-138; and Grove's *Dictionary of Music and Musicians*, 'Aristide Cavaillé-Coll'.