The Paradigm of Industrial Thinking in Brass Instrument Making during the Nineteenth Century

Ignace De Keyser

It would be an exaggeration to say that industrialization completely changed musical instrument making in the nineteenth century. Brass instrument making was not the first branch of musical instrument production to turn to industrial procedures, nor was it the most important. The most important industrial plants by far, in size as well as in industrial applications, were the piano factories and the organ and harmonium builders. The use of iron and steel in piano making is well documented, and many innovations by Erard, Pape, Debain, Alexandre, and others relate to details of the production of pianos and reed organs.[1] However, despite the growth of larger factories, a great number of small workshops emerged that specialized in segments of the market, and continued to supply parts to the larger factories.

Industrialization and craftsmanship went hand in hand in the Parisian musical instrument factories. An average workshop of a brasswind maker in the years 1830-50 employed eighteen workers. In general, in the 1860s there were roughly equal percentages of single-artisan workshops (35%), workshops with two to ten workers (32.5%), and factories with more than ten workers (32.5%). At the end of the century, 50% of the brasswind instrument makers were workshops with fewer than five workers, 32% were factories with between five and fifty workers, and 18% were factories with more than fifty workers.[2]

In brass instrument making, the Industrial Revolution served as an example—a paradigm—on four different levels. Technically, it occurred in the choice of materials and industrial solutions being adopted from other fields in the manufacture of musical instruments; economically, in the division of labor, the mechanization of production, and in mass production; sociologically, in the development of mass culture; and ideologically, as a continuous search for progress. In this study these four paradigms will be examined specifically in relation to brass instrument making in Belgium, France, and Germany, and also in their relationship to other branches of the musical instrument industry.

Technical aspects: the choice of materials and adoption of industrial solutions to the manufacture of musical instruments

The choice of materials

Although musical instrument making had always taken advantage of the opportunities provided by the presence of new raw materials, especially in the case of exotic woods, no dramatic change occurred in the use of metals in the nineteenth century. Brass had been used as a basic material for some lip-vibrated musical instruments since the Middle Ages, and this remained so. However, the use of brass for lip-vibrated instruments in the nineteenth century was not exclusive. Aluminum, for instance, was available by the middle of the century. In 1845 Friedrich Wöhler had prepared enough aluminum to determine its density and to establish that it was ductile, stable, and easily melted. In 1854 Henri Sainte-Claire Deville was able to produce larger quantities of aluminum, and public interest was at once aroused. Emperor Napoleon III, for example, wondered if it might be used for helmets and armor. By 1857 aluminum was being sold at $20 a pound—one twentieth of its price five years earlier.[3] So, why did makers of brasswind instruments not convert to aluminum? The same question can be asked of steel.

As a matter of fact, some brasswind instrument makers did use, or had intended to use, aluminum for at least some parts of their instruments. Besson patented aluminum valve mechanisms in 1857.[4] He used them to reduce the weight of the pump mechanism and thus of the instrument itself. Pretending to be the first to use aluminum, he claimed the right to use it in other applications involving wind instruments.[5] It was also Besson who made steel mandrels to shape brasswind instrument bores, thereby achieving more accuracy and consistency.[6]

Other parts, such as clarinet mouthpieces, were frequently made of metal, and some writers praised the "acoustical" merits of metal mouthpieces.[7] In so far as decoration and finalization were concerned, brasswind instrument makers were more open to innovation when it came to the use of new materials or new alloys such as *maillechort* (cobalt-copper-tin-iron-nickel-zinc), *argentan* (cobalt-copper-nickel-zinc), and "German silver" (copper-nickel-zinc).[8]

In this context the work of Theobald Boehm, the great reformer of the flute, is quite typical. As early as 1832-34, Boehm and his friend Carl Emil von Schafhäutl (1803-90) performed iron-melting experiments. These experiments led to Schafhäutl's patent (BP No. 6837) of 13 May 1835 for the "improvement in the mode of manufacturing malleable iron." Four years later, Schafhäutl obtained a British patent for "an improved method of smelting copper ore."[9]

To my knowledge, however, even the most progressive brass instrument makers of the nineteenth century continued to use brass as the basic material for instrument bodies. Since aluminum and steel have very different proper densities as compared to brass, sheets of these metals are different in section when used to make bodies for lip-vibrated instruments. This reminds me of the answer given to me by a foreman at Yamaha fifteen years ago, when I asked why they did not use the high-tech materials applied to aerospace vehicles to make saxophones. He said, "We did, but since the sheets were extremely thin, tone color changed dramatically and we abandoned our experiments."

Industrial processes

The paradigm of adaptation of industrial solutions for the production of musical instruments is implicitly present in various aspects of the manufacture of wind instruments. One of them is the soldering together of pieces. In the nineteenth century brass instrument parts were no longer fitted together with wire or wax, but soldered. In this domain as well, some makers tried to innovate production methods. In 1866 Adolphe Sax patented a method of fitting parts of brasswind instruments together by electrolysis[10]—he called it *par voie galvanique* (see Figure 1). In this patent he proposed using non-covered rims, points, or hooks, which could be fixed by depositing a metal on them by electrolysis. However, there is no evidence that this procedure ever worked.

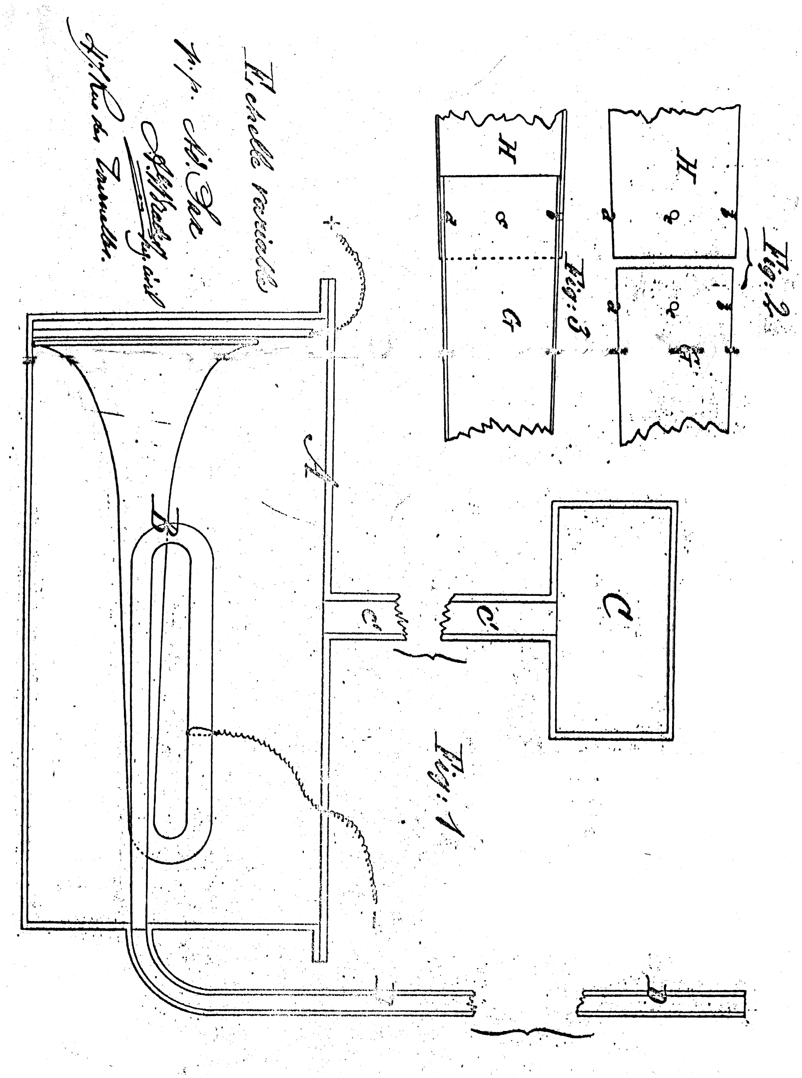


Figure 1
Drawing from French patent BF 70025, by Adolphe Sax, dated 9 January 1866.

Another application of industrial methods in the manufacture of musical instruments is the use of copy machines to make the wing joints of bassoons. Mahillon was already using copy machines in 1885.[11]

Steam engines were used to supply the energy necessary for relatively large factories. It is worth noting that the first branch of Parisian industry to use steam engines was the piano industry. Of all categories of musical instrument makers, piano, accordion, and organ makers used steam engines most intensely.[12] On the other hand, only the larger wind-instrument factories used them: Adolphe Sax (from 1847), Gautrot, and Lecomte in France, and Mahillon (from 1874) in Belgium. At the end of the nineteenth century in France, twelve brasswind factories used steam engines, with a total capacity of 118 horsepower.[13] Used as mere suppliers of power, these engines were not specific for the kind of industry in which they were employed. Charles Mahillon stated in an introductory notice to the catalogue of the National (Belgian) Exhibition of 1880:

> In the workshop of a wind instrument maker, the steam engine is there only to replace brute power. The quality of an instrument depends, for the largest part, on the skill of intelligent workers.[14]

More indirectly, industrial installations were used for some specific aspects of the production of musical instruments—for instance, to dry the wood (see Figure 2).[15]

The paradigm of industrial solutions from other fields for musical problems is symbolically present in the case of valve mechanisms. As Herbert Heyde notes, the original valve had been developed as an imitation of wind valves in the furnaces of the steel industry of Silesia.[16]

Here again it is worth noting the attitude of Theobald Boehm. In 1834 Boehm temporarily abandoned flute making and turned his attention to manufacturing. With Faber du Four he patented a method for evacuating furnace gasses (1836).[17] This attitude reflects the state of mind of this famous reformer of the flute, working for the improvement of industrial processes as well as for innovation in musical instrument making.

Economic aspects: division of labor and mass production

Mass production

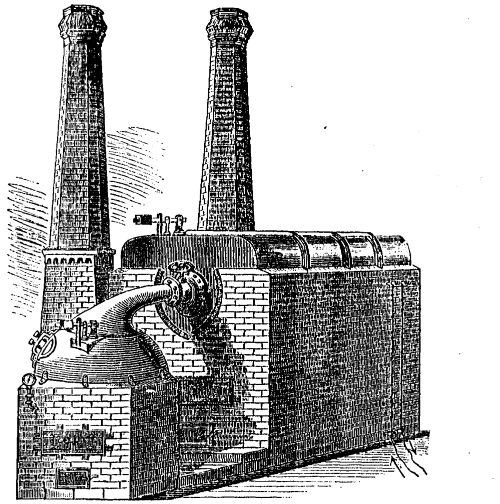
Only a few brass instrument makers on the Continent in the nineteenth century employed a large number of workers and realized large production figures, but the production figures they advertised were very often exaggerated. It is not necessary to go into detail on this matter. There is already sufficient literature, notably on the factories of Sax, Gautrot, Besson, Lecomte, Thibouville-Lamy, and others.[18]

— 233 —

Beschreibung des Präparations-Verfahrens für Hölzer,

insbesondere Resonanzbodenhölzer durch Einwirkung von ozonisirtem Sauerstoffe. Veranschaulichung des hierzu nöthigen Apparates und der Thätigkeit desselben. Patentgesetzlich vor Nachahmung geschützt.

Von **Carl Alfred René** in Stettin.



Der Zweck der Erfindung besteht in dem Verfahren durch Einwirkung des mässig erhitzten und vermittelst Durchleitung electrischer Funken ozonisirten Sauerstoffes den zum Clavierbau zu verwendenden Hölzern ihren Gehalt an Harz- und Fétttheilen zu entziehen, denselben zu zersetzen und in der Weise zu präpariren, dass sie befähigter sind, die Schwingungen der Saiten aufzunehmen und dadurch eine erheblich volltönendere Resonanz hervorzubringen, hauptsächlich dem Holze dadurch die Eigenschaften des Alters zu verleihen.

Durch dieses Verfahren wird feuchtes, resp. junges, nicht abgelagertes Holz, welches bisher nicht zum Bau von Instrumenten und namentlich nicht zur Anfertigung von Clavier-Resonanzböden verwendet werden konnte, so präparirt, dass es dem Jahre lang gelagerten und gepflegten Holze nicht nur gleichkommt, sondern dasselbe bei Weitem übertrifft.

Die Erfindung ist für den Clavier-, Geigen- und im Allgemeinen für den Instrumentenbau, ferner für die Möbel-Industrie von grösster Wichtigkeit und ist anwendbar in jedem Industriezweige, wo nur trockenes, abgelagertes Holz Verwendung findet. Der Sauerstoff allein für sich, namentlich aber der erhitzte und durch Electricität ozonisirte, übt die eigenartigen nachweisbaren Wirkungen auf Holz aus, dass er die Harz- und Fetttheile desselben vollständig zersezt und das Holz gewissermaassen alt macht.

Eine bekannte und in meinem Fache als Clavierfabrikant erprobte Thatsache ist es, dass solches Holz, welches lange Zeit den Einwirkungen der atmosphärischen Luft und dadurch auch den Einwirkungen des Sauerstoffes ausgesetzt ist, welcher nur circa den fünften Theil derselben ausmacht, zum Bau von Instrumenten ausserordentlich brauchbar gemacht wird, je länger also das Holz dem geringen Einflusse des in der Atmosphäre enthaltenen Sauerstoffes preisgegeben ist, desto besser ist es zu verwenden; namentlich gilt dies für Resonanzbodenhölzer und haben aus diesem Grunde die Geigenbauer stets das am längsten gelagerte Material zum Bau der nöthigen Resonanzböden gesucht.

Hieraus ist nun der Schluss zu ziehen, dass, wenn der geringe Sauerstoffgehalt der Atmosphäre in langer Zeit diese wichtigen Veränderungen bewirkt, diesen Prozess in bedeutend umfangreicherer Weise und in viel kürzerer Zeit der durch chlorsaures Kali hergestellte Sauerstoff erzeugen muss. Ich habe bei meinen Versuchen die Wahrnehmung gemacht und zugleich die Erfahrung gewonnen, dass grade ozonisirter Sauerstoff in mässig erhitztem Zustande, diesen ganz besonderen Einfluss auf Holz bedeutend activer und schnellwirkender geltend macht, indem er die Harz- und Fetttheile desselben vollständig zersetzt, die Vorzüge des abgelagerten Holzes verleiht und durch dieses Resultat einem bisher fühlbaren Mangel am nöthigen für Claviere geeigneten Holzmateriale abhilft.

Um nun Holz in genannter Weise zu präpariren, ist also zunächst ein hermetisch zu verschliessender Raum erforderlich, in welchen das dem Prozesse zu unterwerfende Holz hineingeführt und darin so aufgelagert wird, dass der hineinzuleitende Sauerstoff die Oberflächen desselben überall bestreichen und dadurch seine intensive Wirkung möglichst erweitern kann.

In diesen Raum wird sodann der Sauerstoff, — nach Entleerung der in demselben befindlichen atmosphärischen Luft vermittelst einer Luftpumpe — hineingeleitet und nach hermetischer Schliessung des Raumes der Sauerstoff vermöge eines electrischen Stromes und durch das Ueberspringen von

Figure 2

Carl Alfred André, "Beschreibung des Präparations-Verfahrens für Hölzer," in *Zeitschrift für Musikinstrumentenbau* 1/17 (June 1881): 233-34.

Division of labor

The facts are well known. I limit myself to providing new statistics on the division of labor in the Mahillon factory, and to comparing them with those of a large brasswind factory in France at the end of the nineteenth century.

A document of the Syndicate of Belgian Musical Instrument Makers dated 20 June 1897 gives us detailed information about the categories of workers in a Belgian musical instrument factory.[19] The managers at that time distinguished fourteen categories of brass instrument makers. I list them below in decreasing order of the wages they earned.

Instrument factory workers in Belgium:

- bell maker (*pavillonneur*), with a salary of 0.70 franc/hour
- fitter (*monteur*) and valve maker/fitter (*pistonneur-monteur*), with salaries of 0.65 franc/hour

Figure 3

Brasswind makers in the Mahillon factory 1885. Litho by Klitzsch & Rochlitzer in *L'écho musical*, 14 May 1885, 115.

- embosser *(repousseur*), with a salary of 0.60 franc/hour
- turner (*tourneur*), brazer (*braseur*), and folder (*plieur-ceintreur*) with salaries of 0.55 franc/hour
- filer (*limeur*), scraper (*gratteur*), hammerer (*débosseleur*), finisher (*rodeur*), polisher (*polisseur*), repairer (*réparateur*), with salaries of 0.45 franc/hour
- general worker *(homme de peine*), with a salary of 0.40 franc/hour

These salaries are relatively high. Masons, plumbers, stucco workers, painters, and woodworkers employed by the Brussels City Authority in 1897 earned 0.50 franc per hour. These amounts must be reduced by twenty percent for the so-called "employer taxes," paid directly by the employer. A general worker earned only 0.35 franc per hour, without deduction of these employer taxes.[20]

One large brasswind factory in Paris, probably Lecomte, used the following categories of workers at the end of the nineteenth century:[21]

Instrument factory workers in France (payment on an hourly basis):
- 7 foremen (*contremaître*), with a salary of 5.5 to 7 francs
- 5 valve makers (*pistonniers*), with a salary of 6 to 9 francs
- 6 bell makers (*pavilloneurs*), with a salary of 4.5 to 8 francs
- 2 pumice stoners (*ponceurs*), with a salary of 5 to 8.5 francs
- 18 makers or fitters (*facteurs*), with a salary of 5 to 7.5 francs
- 11 makers or fitters (*luthiers*), with a salary of 5 to 7.5 francs
- 8 controllers (*vérificateurs*), with a salary of 4.25 to 7 francs
- 13 finishers (*finisseurs*), with a salary of 5 to 5.5 francs

Instrument factory workers in France (payment on a per-unit basis):
- 18 valve makers (*pistonniers*), with a salary of 8.5 to 10 francs
- 2 valve makers (*pavillonneurs*), with a salary of 6.5 to 8.5 francs
- 14 pumice stoners (*ponceurs*), with a salary of 6 to10 francs
- 25 makers or fitters (*facteurs*), with a salary of 4.25 to 8 francs

Thus Belgian manufacturers finely segmented the division of labor, while French manufacturers showed a greater concern with quality control and finishing.

Mass culture

In the nineteenth century mass culture in music was a matter of participation, not of consumption as it is today, and this participation clearly focused on the workers in mines and mills. One of the first important movements of mass culture in the field of music in France were the choral societies, or *Orphéons,* founded by Guillaume-Louis Bocquillon, alias Wilhem (1781-1842), in Paris in October 1833. Jane Fulcher points out that these mass movements were the ideological counterpart of the idea of progress (see below). She quotes the utopian theorist Fourier, who considered music to be a most valuable means to integrate the proletariat into society.[22] By 1880 these choral societies were superseded by brass bands and harmony bands, especially in the industrialized north of France.[23]

German workers' choirs, on the other hand, emerged as an alternative to the bourgeois *Liedertafel*. They were established much later than the French *Orphéons*—i.e., ca. 1860—and survived longer. A large number of them were suppressed by the so-called anti-socialist law (*Sozialistengesetz*) of 1878. Ten years later, when the law was repealed, workers' choirs became very popular again. In 1898 the "Liedergemeinschaft der Arbeiter-Sänger-Vereinigungen Deutschlands" represented 713 choral societies with 29,000 members.[24] In German mines and mills, brass bands and harmony bands could rely on a well-established tradition of *Bergkapellen* (miners' bands). Let us not forget that Friedrich Blühmel, who shared the invention of the valves with Stölzel, was a *Berghautboist* in Silesia (see above). As in Paris with Sax, the use of newly invented valve instruments and the changes in composition and repertoire of these bands were induced by the military.[25] Military band musicians as rule became the conductors of these bands.[26]

At the end of nineteenth century, relatively highly industrialized Belgium counted 1067 brass bands and 389 harmony bands of a total of approximately 2500 amateur societies.[27] The most progressive wind instruments makers, such as Adolphe Sax[28] in Paris and Mahillon[29] in Brussels, had their own fanfare or harmony bands. In the case of Mahillon, this band was made up of workers from his own factory, as frequently happened in other sectors of industry.

The search for progress

The "search for progress" is common to a large number of inventions made in the musical instrument industry in the nineteenth century, but not to all of them. Some patents did not bring any innovations, but were simply commercial tricks to attract attention at national or international exhibitions. Moreover, in most cases this "search for progress" is implicit. However, some manufacturers explicitly revealed their belief in the need for progress through innovative techniques. Three major wind instrument makers of the nineteenth century, Theobald Boehm (1797-1881), Adolphe Sax (1815-94), and Victor-Charles Mahillon (1842-1924), referred to the parabola as the most appropriate theoretical framework to solve the musical problem of a brighter and more brilliant tone with consistent tone quality throughout the entire range of the instrument. The parabola was considered to be the theoretical paradigm for progressive wind instrument makers.

Theobald Boehm

There are several sources[30] in which Boehm elucidated his vision of the parabola, which he used in his flute *nach einem wissenschaftlich begründetem System* of 1847. I quote the British patent of 1847:

> For greater facility of fingering and improvement of tone, the body of the flute is made "cylindrical, instead of a long cone, as has therefore been done; but the head joint or mouthpiece of the instrument, instead of being cylindrical as hitherto, I make conical, or rather in the form of the parabola."[31]

In the second edition of his translation of Boehm's *Die Flöte und das Flötenspiel*, Dayton Miller explains the parabolic form of the head joint of a flute very clearly (see Figure 4):

> The "parabolic" contraction in the head-joint of an excellent specimen of Boehm & Mendler flute is shown in Fig. 8. At the right is the section of the tube, drawn in full size. The length of the tapered portion is 134 millimeters. Starting at the cork, where the diameter of the bore is 17.1 millimeters, the

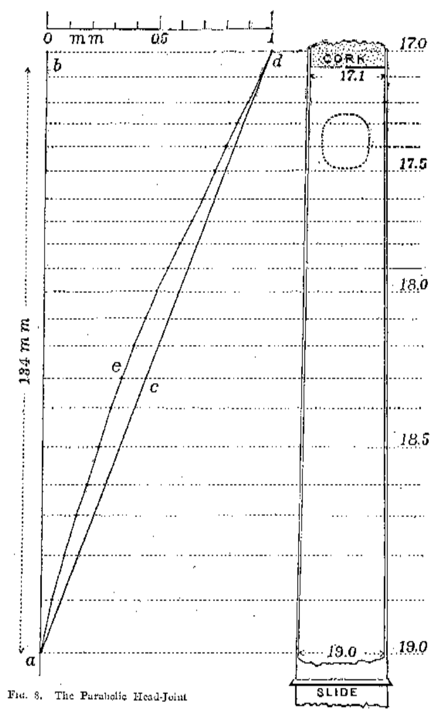


Figure 4

"Parabolic Head-Joint," from Theobald Boehm, *The Flute and Flute Playing in Acoustical, Technical and Artistic Aspects* [2nd English edn., revised and enlarged, transl. and annotated by Dayton C. Miller] (Cleveland: Dayton C. Miller; London: Rudall, Rose, and Carte, 1922), 18.

> horizontal dotted lines indicate the sections increasing in diameter, successively, by 0.1 millimeter, up to 19.0 millimeters, near the tuning slide. The figures on the dotted lines are the diameter of the tube at various sections. At the left is an exaggerated diagram of the actual contraction in this specimen of the flute; the horizontal scale for this part of the figure is 50 times the vertical scale. If the bore of the tube were cylindrical, one side of it would be represented by the line ab; if it contracted by a straight taper, the line acd would represent the inner surface of the tube; the parabolic curve actually existing is shown by the curved line aed.[32]

Measurements taken by Karl Ventzke in the 1960s on the head joints of flutes No. 5 (1848), No. 77 (1854), and a flute without number (ca. 1860) from the workshop of Theobald Boehm confirm the presence of a parabolic curve.[33]

Adolphe Sax

On several occasions Sax promoted the parabola as the ideal musical form. There is, of course, the patent of the saxophone:

> More than any other instrument, the saxophone allows us to modify the sound [in brightness and tone color] over the complete scale: I made this instrument in brass and gave it the shape of a parabolic cone. [34]

It is not clear what Sax meant by this parabolic cone. Unlike Jaap Kool,[35] I believe that this parabolic cone is restricted to the main tube and the beginning of the bell section. I believe this because Sax had already patented a *réflecteur sonore* for his bass clarinet,[36] which later became the standard bell of his saxophone. In any case, Sax used the parabola for optimizing the reflection of sound.

Sax again used the parabola for reflection of sound in his patent for a concert hall of 1866 (see Figure 5). The acoustical properties of the parabola did not permit Sax to use the paradigm without restriction. Indeed, a parabola's maximum reflection is obtained in the focus, but it was of course impossible to place the audience there. Instead, Sax put the orchestra in the focus of the parabola and imagined an elliptical wall opposite the orchestra, creating an overall "egg" form:

> The parabola has an infinite main axis; the solid body which it generates by turning around its axis must be infinite too. In order to build a sonorous wall at the side of the audience, I join to this parabolic surface an elliptical one, which seems to me more appropriate to concentrate on the audience the sound rays reflected by it. This closely resembles the shape of an egg.[37]

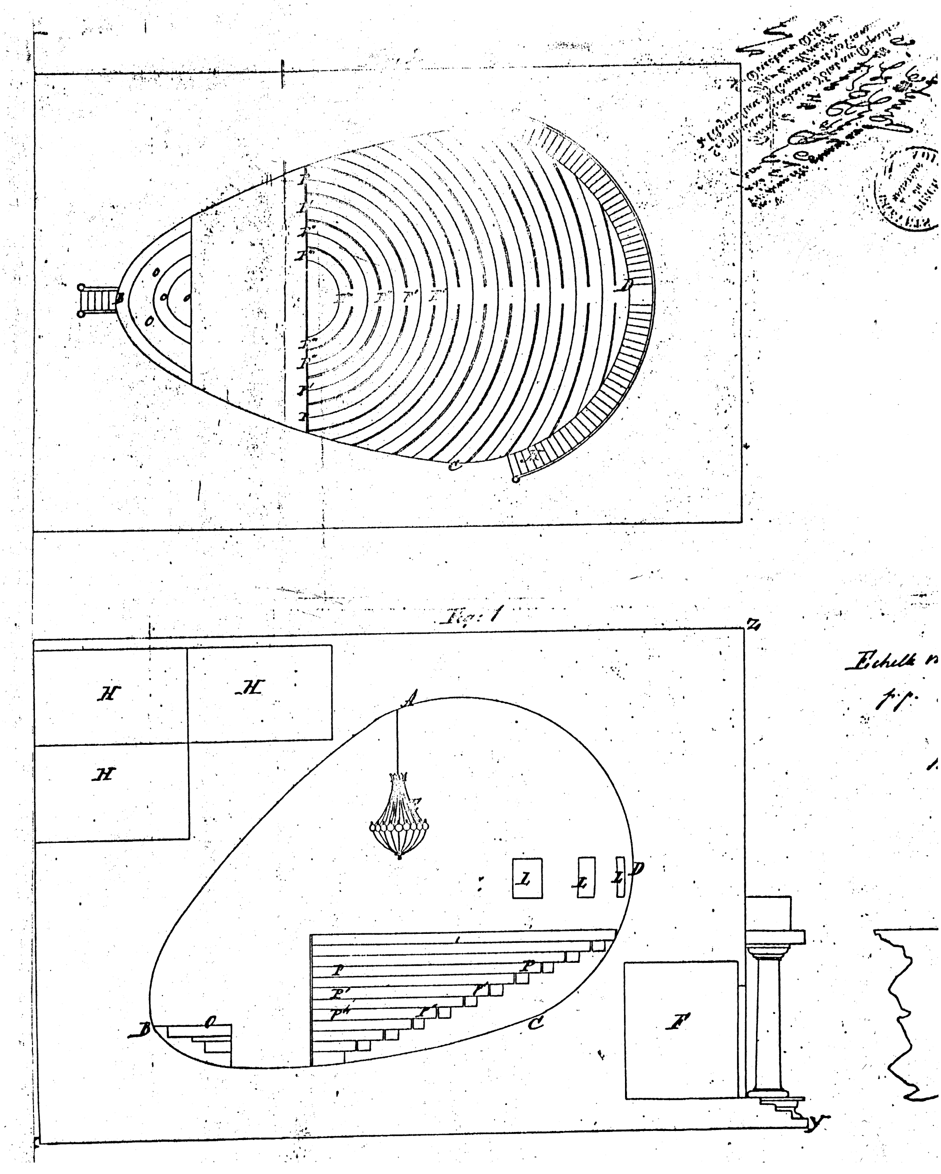


Figure 5
Drawing from French patent BF 72010, by Adolphe Sax, dated 18 June1866.

Victor Mahillon

Mahillon was more sympathetic to the hyperbola, the difference between the parabola and the hyperbola being one of practical application within a tube. A parabola is a conic section produced by the intersection of a right circular cone and a plane parallel to an element of the cone. A hyperbola is a conic section produced by the intersection of a circular cone and a plane that cuts across both layers of the cone. A parabola is therefore more suitable for a closed section—the head joint of a flute, for example—while the hyperbola is better suited to a tube (see Figure 6).

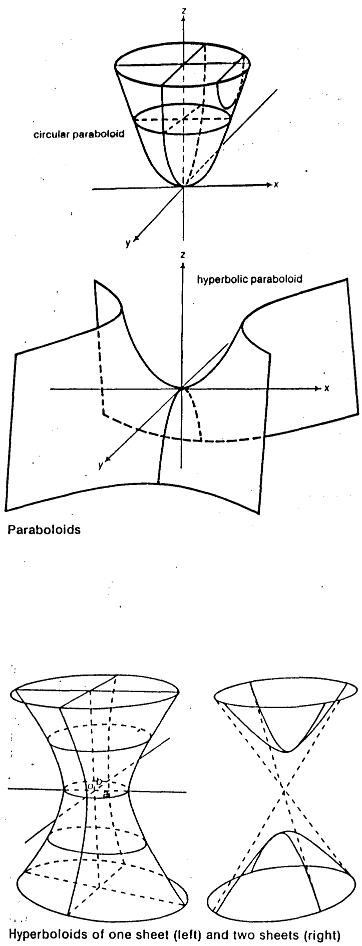


Figure 6
Parabola and hyperbola.

Mahillon writes in his *Eléments d'acoustique* (1874), "Nevertheless, we are convinced that these proportions follow the development of a geometrical curve, the form of which comes near to that of a hyperbola. We hope to publish the formula for it later on."[38] Forty years later, during the First World War, Mahillon reworked his *Eléments d'acoustique*, integrating the results of his experiments that he had published earlier in the *Catalogue* of the Brussels Museum of Musical Instruments.[39] Mahillon never issued a new edition of his *Eléments d'acoustique*, but on the basis of his annotations preserved in the family archives, Daniel Bariaux, former professor of acoustics at Brussels University, published a posthumous edition in 1984. In his own annotations to the *Eléments d'acoustique*, Mahillon was forced to admit that he had failed to create a formula for his hyperbola, but he stressed his firm belief in the relevance of the hyperbola for the sound quality of wind instruments:

> What is the formula that serves as a basis for the development [of a conical air column]? Nothing serious has been published on this matter: the only guides hitherto were trial and error and empirical methods. But now, after many attempts, we are convinced that a cone or a cone joined to a cylindrical part, in order to establish an air column, must follow a hyperbolic curve or a geometrical curve, depending on the tone color that is needed. The greater the curve of the hyperbola, the more brilliant and bright the tone.[40]

Proportions and calculus

This discussion of the parabola brings us quite naturally to the question of the use of proportions in instrument design, revealed by Herbert Heyde in numerous publications, and recently in his excellent article on "Methods of Organology and Proportions in Brass Wind Instrument Making" in the *Historic Brass Society Journal*.[41]

Proportions of the bore of a brass musical instrument

For the design of the tube of their brass instruments, Sax and Mahillon clearly attached great importance to proportions. Sax expressed his general belief in proportions on several occasions, and notably in his defense before court:

> The enormous differences in sound quality, tone color, and sound volume of these three instruments (trumpet, horn, and flugelhorn), which are comparable from the point of view of the making of their tubes, depend only on the proportions and the differences in bore width of their tubes.[42]

Moreover, at that time Sax made six brass instruments of different shapes to display this: a B♭ trumpet, a B♭ trombone, a high B♭ horn, a baritone saxotromba, a B♭ bass saxhorn, and a B♭ ophicleide. They were sold together with his musical instrument collection in 1877. In the auction catalogue, the auctioneer goes into detail on Sax' "law" of proportions:

> These six instruments, with the same form, straight and of the same length, and therefore having all their harmonic partials at the same degrees of the harmonic scale, differ only in the sections or proportions of their tube. They were made by M. Sax in 1846 to serve in different trials and to prove the following law invented by him: "The tone color of wind instruments does not depend on the material of which they have been made, nor on the shape of the tube, but only on the interior proportions of these tubes at different points."[43]

The proportions of a conical bore are explicitly mentioned in Sax' patent for the saxotromba (see Figure 7).[44] Sax clearly indicates the section of the bore at certain points:

- at the mouthpiece: 11mm
- the tube at the exit from the valves: 12mm
- after the first bend of the tube: 16mm
- before and after the last bend of the tube: respectively 20mm and 24mm
- halfway between this point and the final flare section of the bell pipe: 34mm
- at the final flare section of the bell: 70mm.

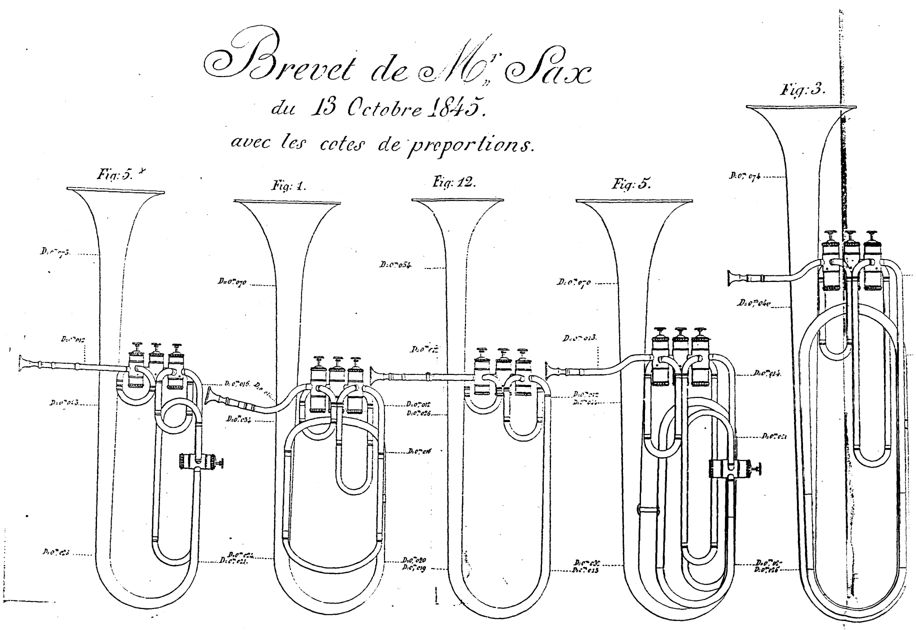


Figure 7
Drawings of the saxotromba, patent BF 2306, by Adolphe Sax, dated 13 October 1845.

These reference points allowed the expert designated by the court, engineer Surville, to answer the question as to whether the differences in proportions of Sax' instruments were relevant, as compared to those of the many variants of his rivals, i.e., bugle horns, clavicors, neocors, and ophicleides. The answer was clearly positive,[45] and argued in favor of the definitive acceptance of the unique qualities of the saxhorns and saxotrombas before the Court of Justice (see Figure 8).

— 36 —

§ IV.

COMPARAISON DU SAXOTROMBA EN MI BEMOL AVEC LES INSTRUMENTS DU MÊME TON QUI ONT ÉTE SAISIS ET DÉPOSÉS AU GREFFE.

Voici le tableau des instruments en *mi* bémol saisis qui ont été mesurés contradictoirement avec les parties.

DIAMÈTRES.	PAVILLON.	1er	2e	3e	4e	5e	6e	7e
Saxotromba	Brevet.	70	34	24	20	16	12	11
Id. *mi* b....	Sax.	60	33	23.5	18.5	16	12	11
Altos *mi* b.........	Besson 1er	61	36	27	22	20.5	13	12
Id. Id..........	Id. 2e	61	36	27	21.5	20	13	12
Id. *fa* et *mi* b....	Id. 3e	61	34	25.5	20	18	13	12
Id....	Id. 4e	60	34	25	20	18	13	12
Id.........	Id. 5e	62	34	25	20.5	17.5	13	12
Id. *mi* b..........	Halary 6e	66.5	35.5	26	21	19	11.5	11
Id..........	Id. 7e	68	35.5	25.5	21	20	11.5	11
Id. *fa* et *mi* b....	Id. 8e	66.5	33	25	20	18	12	12
Id....	Id. 9e	66.5	33	23	19	18.5	11.5	11
Id. *mi* b..........	Buffet 10e	68	34	26	22	20.5	12	12
Id.......	Id. 11e	64	34	25.5	21	17.5	12	12

— 37 —

DIAMÈTRES.	PAVILLON.	1er	2e	3e	4e	5e	6e	7e
Altos *fa* et *mi* b...	Beaubeuf 10e	58.5	33	24.5	19	18	12	11.5
Id. *fa* haut et *mi* b.	Gautrot 13e	61	32	24	18	15	12.5	11 5
Id. *mi* b..........	Guignon 14e	60	33	24	18	16	13	11.5
Id. Id...	Noblet 15e	68.5	37.5	29	24.5	20.5	13	11.5.
Id. Id............	Muller 16e	79	42	32	26.5	22	13.5	12
Alto en 8 *mi* b....	Gautrot 17e	52	30.5	22	17.5	16	12.5	12
Clavicor..........	Besson 18e	48	39	19.5	16.5	14	12	11
Id......	Id. 19e	59	39	21	17	16	13	11
Id.............	Id. 20e	60	34	29	22.5	19.5	12	11
Id.............	Id. 21e	65	38	31	26	22	13.5	11
Ophicléide.........	Kretschmann 22e	72	42	30.5	24.5	20.5	13.5	12
Id............	Id. 23e	75	42	31	25	21	13	12
Néo-Alto..........	Guichard 24e	82	48	38	32	28	14	12

1° Considérons d'abord la première série composée de quatorze instruments qui forment la tête de ce tableau.

Il est à remarquer que non-seulement les dimensions des diamètres correspondants varient dans les instruments des différents facteurs, mais encore dans ceux d'un même facteur. **Ainsi dans les altos de M. Besson, dans ceux de M. Halary il existe, d'un instrument à l'autre, des différences dans les diamètres correspondants qui s'élèvent de 2 à 3 millimètres.**

Cela confirme ce que nous avions déjà dit de l'influence de la fabrication pour faire varier la grosseur des tubes, et aussi ce que nous avons fait observer que ces variations sont ordinairement assez peu considérables pour ne pas altérer d'une manière sensible le timbre des instruments, **puisque tous ceux-ci sont donnés comme bons pour remplir les parties intermédiaires des orchestres,** *ce qui fait supposer qu'ils ont tous la même voix.*

Nous ferons encore remarquer que les dimensions ne varient sensiblement dans ces instruments **qu'au premier diamètre, celui où le tube se raccorde**

Figure 8

Table taken from "Comparaison du saxotromba en mi bémol avec les instruments du même ton qui ont été saisis et déposés au greffe," in *Rapport de M. l'expert Surville, ingénieur, déposé le 18 février 1859 et dire et de M. Sax* (Paris: Imprimerie Centrale des Chemins de Fer, 1860), 36-37.

Mahillon also made a set of four brass instrument bores of the same pitch (B♭), in order to prove that the difference in tone color depends on a difference in proportions. To attain this goal, he produced tubes in the shape of a trumpet, a horn, a trombone, and a tuba, respectively. Victor and Joseph Mahillon gave these tubes to the Brussels Musical Instrument Museum in the late 1870s.[46] Mahillon goes further than Sax in explaining the acoustical properties of the different bore proportions. It is interesting to read what he says about them:

> With the help of these tubes, one can prove:
> A. That the tone color that distinguishes the different brass musical instruments depends only on the proportions of the tube;
> B. That the influence of these proportions on the length of the tube is very slight;
> C. That the longer and narrower the tube, the easier the production of the upper harmonic partials, and vice-versa;
> D. That the shorter and larger the tube, the easier the production of the fundamental, and of the lower harmonic partials[47]

In his writings Mahillon gives precise information only on the general proportion that should be used in wind instrument bores. In order to double the frequency of the fundamental of a given pipe with a conical bore, a ratio of 1:4 is needed:

> A pipe containing a conical section that presents the ratio 1:4 from one point to another of its diameter is able to double the frequency and to give all harmonic upper-partial tones when it is blown, either with the mouth, a reed, or an embouchure."[48]

Mahillon also defines the "critical" length of the conical part of a pipe necessary for a well-balanced sound with "adequately" produced upper partials. According to Mahillon this "critical" length should be approximately half the theoretical length of the pipe: "In order to produce the harmonic upper-partial tones adequately, it is necessary to start at approximately the halfway point of the overall length."[49]

The most explicit practical observations concerning bore dimensions are given by Auguste Besson in a supplement to his 1855 patent. Besson explains that he developed the conical part of the bore starting with the inner diameter of the edge of the mouthpiece and that he doubled the difference of two succeeding sections of the conical bore at each fifth of its length.[50] It is thus obvious that brass instrument makers like Sax, Mahillon, and Besson, who considered acoustical evidence, turned to proportions in order to establish the most appropriate bore for their brass instruments. However, they were not able to quantify tonal color, since this physical parameter could hardly be measured in the nineteenth century. Spectrographs were unknown, nor was spectral analysis in real time. The "manometric flame analyzer for the timbre of sounds,"[51] for instance, which Helmholtz used, could give only an approximate idea of the upper partials in relatively simple wave patterns. Moreover, the nomenclature of bore dimensions they used was reduced to general categories such as "trumpet-shape," "horn-shape," "rendering upper partials adequately," etc. In conclusion, they could not establish any relevant relationship between the parameters they had at their disposal for describing brass instrument bores and those used to define tonal spectrum—even if they had wanted to do so.

Calculus for the placement of tone holes

On the contrary, to define where to place the sound holes on a pipe, these progressive wind instrument makers successfully turned to calculus rather than proportions, even if the formulas used in calculus were derived from proportions. Indeed, Boehm, as well as Sax and Mahillon, no longer used proportions to define the placement of the sound holes in a pipe, but calculus. Boehm wrote:

> With these relative numbers it is a simple matter to calculate the absolute vibration frequencies corresponding to any desired pitch, since any given vibration bears to all the other intervals exactly the same proportion as the relative number corresponding to this tone bears to the relative number of these other intervals. [52]

Sax did not publish the results of his calculations, but it is obvious that he could not have launched challenge after challenge to his rivals between October 1842, the date of his arrival in Paris, and 21 March 1846, the date of the patent of the saxophone, if he were not sure that the calculus of the sound holes he had in mind could not have been imitated by his fellow makers.

Mahillon wrote,

> The following tables will be very useful. The first one gives the number of single vibrations for each of the degrees of the scale, calculated according to the official pitch, now being internationally adopted…, the wavelength of all single waves calculated at the average velocity of sound ... and finally the theoretical length of open and stopped pipes. The second table gives the number of vibrations of each of the degrees of a chromatic scale.[53]

Boehm and Mahillon calculated also the correction factor to be applied to wind instruments. Boehm describes the correction factors for a flute as follows:

> In the case of the flute the flattening influence of the cork, the mouth-hole, the tone-holes, and the dimensions of the bore is such that, altogether, it amounts to an air column of 51.5 millimeters in length, which in the calculation must be considered theoretically as existing, in order that the length of the air column shall exactly correspond to the length of the string of the monochord determined from the numbers and proportions of the table. [54]

Boehm and Mahillon of course made diagrams too, but it would be inappropriate to deduce from the existence of these diagrams that they were to be considered to be proportions (see Figure 9). Mahillon wrote, “The calculus presents some difficulties to those who are not familiar with it. We tried to find an easier way and we thought that we found it in a scheme [based on the figures used in this calculus].”[55]

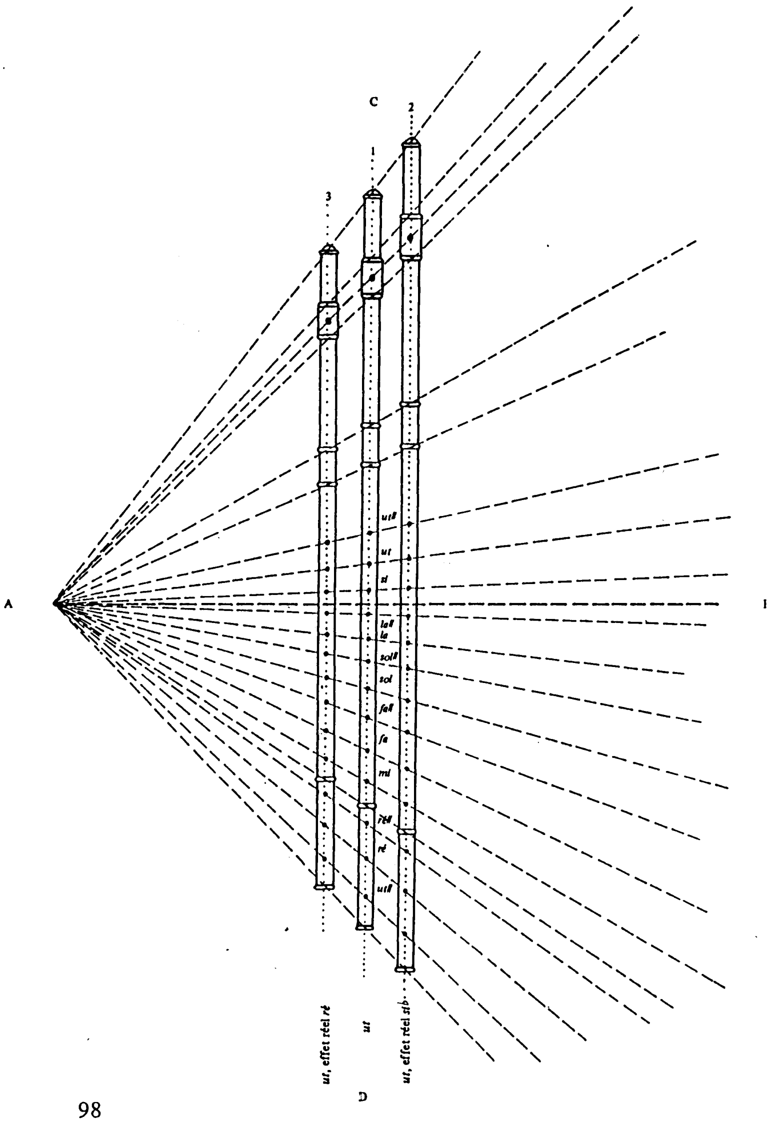


Figure 9
Diagram of a Boehm flute by Mahillon, from the posthumous edition of his *Eléments d'acoustique musicale et instrumentale* (Brussels: Les Amis de la musique, 1984), 98.

Boehm, Sax, and Mahillon worked with proportions and calculus in order to establish bore dimensions on the one hand, and the placement and dimensions of tone holes on the other. They no longer relied on tradition alone; they worked out new models and instrument types on the basis of research and scientific evidence, just like engineers solving industrial problems. That is why I call their approach, again, an industrial paradigm.

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APPENDIX

Excerpt from the *Certificat d'addition* dated 12 July 1856, supplement to French patent no. 22072 of 18 January 1855 for improvements to all types of brasswind instruments, by Auguste Besson (translation by IDK).

Guided by routine, I took the usual dimensions for mouthpieces without realizing that these had been determined without any form of calculation, but that they had been left to the mere whim of the individual worker. Thus, I gradually enlarged the conical section of the [brasswind] instrument, up to the flare of the bell. This is where the error was. My instrument had a constant irregularity that negated my calculations and research. Although I had made significant progress and considerable improvements, I was still dissatisfied. There was a construction defect that I was unable to find, notwithstanding my persistent efforts.

Today I admit that this defect was to be found at the starting point of the air column, which had a defective base. No one has, until today, explained why this or that mouthpiece stem had been manufactured at one particular thickness rather than any other. Furthermore, the conical section of the mouthpiece pipe did not correspond to the speaking part or sounding bore of the instrument, which produced truncated vibrations that destroyed the mathematical perfection of the sounding body.

Now I need to rebuild all mandrels with a new profile, no longer starting from the arbitrary diameter of the mouthpiece's bore. I shall start from the mouthpiece's edge, the mathematical point of invariability, since the already determined edge is proportional to each instrument and has been adapted by experience.

In order to build the bore of an instrument [i.e., brasswind instrument], I relied primarily on two invariable points, determined by experience: the diameter of the mouthpiece's edge and the diameter of the sounding body's base, up to the flare of the bell.

Furthermore, I know the length of the instrument, determined by the pitch it should have.

From the base's diameter I subtracted the diameter of the edge of the mouthpiece and calculated the remainder or the difference between them in tenths of a millimeter. The total sum of tenths of a millimeter, which should constitute the difference in the cone of the instrument, is divided according to the acoustical law that applies to the pitch of the instrument.

For example: In a B♭ bugle, five acoustical divisions are formed. One should thus proceed as follows: at the fifth of the length of the conical section, with the base as a starting point, I subtract half of the difference between the two diameters. Let's say that 410 tenths of a millimeter is the difference, then I reduce the fifth conical section by 205 tenths of a millimeter. The second fifth I reduce by the half of 205, which is $102^1/_2$ tenths of a millimeter. With the starting point still the basis assembled in the flare of the bell, I reduce the third fifth of the conical section by half of $102^1/_2$ tenths of a millimeter, which is $51^1/_4$ tenths of a millimeter. The fourth fifth I reduce by half of $51^1/_4$ tenths of a millimeter, which is $25^5/_8$ tenths of a millimeter. In the end the truncated height of the conical section that served as an invariable point will remain invariable.

On my working drawing I indicate the length of the cylindrical part that should match up with the valves. Starting from the diameter of this cylindrical part, I reduce the cone of the mouthpiece up to its edge, always according to the law of acoustical equations that no one before me had discovered or even imagined to have existed.

Once the ordinates and abscissae of my conical tube's profile were indicated on my working drawing, I needed only to draw the parabolic curve that constitutes the aforementioned acoustical profile.

For this I took a pliable ruler of spruce, sound and without gnarls, with small veins running perpendicular to the plane surface of the ruler. I calibrated perfectly the thickness of the ruler and by bending it in a convenient way, I drew a curve passing through all the points.

I cut the counter-proof of this curve in a well-prepared sheet [of brass]. This counter-proof was my template for fashioning the conical profile that was to become the prototype of the instrument's bore.

One can see that the turned and polished steel prototype, made according to this template, provided me with the bore of the sounding body, presenting the mathematical acoustical laws that I discovered with the greatest possible perfection and precision. This acoustical perfection is so real that it will produce the same sound with the same intensity, the same perfection in every tone, as if it were made of the purest brass of whatever thickness, independent of the material the instrument is made of, be it stucco, cardboard, rubber, leather, cloth, lead, zinc, etc.

Original French text

Extrait du *Certificat d'addition* du 12 juillet 1856 au brevet français n° 22072 du 18 janvier 1855 pour des perfectionnements aux instruments de musique de tous genres en cuivre, déposé par Auguste Besson. (Transcription: Géry Dumoulin)

[…] Je prenais, comme l'indique la rout[ine] la grosseur habituelle des embouchures, et je ne m'apercevais pas que cette grosseur avait été déterminée sans calcul et par un pur hasa[rd] laissé au caprice de l'ouvrier. Alors j'augmentais progressivement la partie conique de l'instrument jusqu'au tonnerre du pavillon; c'était là l'erreur; il y avait toujours dans mon instrument une irrégularité constante qui venait anéantir le résultat de mes calculs et de mes recherches; et malgré des résultats capitaux, des améliorations considérables, je n'étais jamais satisfait; il y avait constamment un vice de construction que je ne pouvais trouver, malgré la persistance de mes recherches.

Ce vice, je le reconnais aujourd'hui, consistait dans le point de départ de la colonne d'air qui avait une bâse défectueuse, puisque personne jusqu'à ce jour n'a dit pourquoi telle ou telle queue d'embouchure était maintenue à une grosseur plutôt qu'à telle autre; et puis, la partie conique de la queue de l'embouchure n'était pas en rapport de conicité avec le conduit vocal ou perce sonore de l'instrument, ce qui produisait des vibrations tronquées et des ressauts qui venaient détruire la perfection mathématique du corps sonore.

Je me trouve donc dans la nécessité de reconstruire tous mes mandrins et de les faire partir, par un nouveau profil, non plus du diamètre arbitraire de la perce de l'embouchure, mais bien d'un point mathématique invariable qui est le grain, proportionnel pour chaque instrument, de l'embouchure spéciale déterminée et adaptée par l'expérience.

Cela posé, pour construire la perce d'un instrument, j'ai d'abord deux points invariables indiqués par l'expérience, lesquels sont: le diamètre du grain de l'embouchure et le diamètre de la bâse du cône du corps sonore, jusqu'au tonnerre du pavillon.

J'ai ensuite la longueur de l'instrument donnée par le ton qu'il doit avoir.

Je soustrais du diamètre de la bâse le diamètre du grain de l'embouchure, et le reste ou différence est exprimé par moi en dixième de millimètre. La somme totale des dixièmes de millimètres qui doivent constituer la différence conique est divisée suivant la loi acoustique applicable au ton de l'instrument.

Par exemple, dans le bugle en si bémol, il se forme cinq divisions acoustiques, on doit donc procéder comme suit: à partir du cinquième de la longueur de la partie conique ayant la bâse pour point de départ, je diminue de suite la moitié de la différence des deux diamètres; soit, par exemple, 410 dixmillimètres pour la différence; je donnerai 205 dixmillimètres de rétrécissement au cinquième; ensuite, pour l'autre cinquième, la moitié de 205 ou 102 dixmillimètres $^1/_2$ de rétrécissement; puis au troisième cinquième, toujours en partant de la bâse qui s'assemble dans le tonnerre du pavillon, je donnerai pour rétrécissement la moitié de 102 dixmillimètres $^1/_2$ ou 51 dixmillimètres $^1/_4$; au quatrième cinquième je donne pour rétrécissement la moitié de 51 dixmillimètres $^1/_4$ ou 25 dixmillimètres $^5/_8$ de dixmillimètre; enfin le sommet tronqué de la partie conique qui m'a servi de point invariable reste toujours invariable.

Je porte sur mon épure la longueur de la partie cylindrique qui doit recevoir les pistons et à partir du diamètre de cette partie cylindrique je diminue mon cône d'embouchure jusqu'au grain de l'embouchure elle-même, toujours suivant la loi des équations acoustiques que jamais personne, avant moi, n'a trouvées, et dont personne, avant moi, n'avait pas même soupçonné l'existence.

Les ordonnées et les abscisses du profil de mon cône ayant été ainsi fixées sur mon épure, il ne me reste plus qu'à tracer la courbe parabolique qui constitue ledit profil acoustique.

A cet effet, je prends une règle pliante en sapin, à petites veines bien perpendiculaires au plan de la règle, d'un bois bien sain et exempt de nœuds; je calibre la règle parfaitement d'épaisseur, et en la pliant d'une manière convenable, je fais passer une courbe par tous les points.

Je découpe dans une tôle bien dressée la contre-épreuve de cette courbe; cette contre-épreuve me sert de calibre pour tourner un perçoir conique profilé qui sera le proto-type de la perce de l'instrument.

On conçoit que ce proto-type en acier tourné et rodé suivant le calibre, me donnera la perce d'un corps sonore ayant dans la perfection la plus grande et la plus minutieuse des principes mathématico-acoustiques découverts par moi; et cette perfection acoustique est si réelle que, quelle que soit la matière qui constituera l'instrument, plâtre, carton, caoutchouc, cuir, chiffon, plomb, zinc, etc, il rendra le même son avec la même intensité, la même perfection dans la note, que s'il était construit en laiton le plus parfaitement écroui, de quelque épaisseur qu'il soit. [...]

NOTES

1 See Malou Haine, *Les facteurs d'instruments de musique à Paris au 19e siècle: Des artisans face à l'industrialisation* (Brussels: Editions de l'Université, 1984), 114-21.

2 See ibid., passim. A breakdown by production numbers is not available since official statistics in France mention only the turnover of the different categories of factories. A breakdown by export numbers for brasswind instruments is available only for the period 1820-26. See ibid., 409.

3 See J. Gordon Parr, *Man, Metals and Modern Magic* (Cleveland: American Society for Metals/Ames, IA: The Iowa State College Press, 1958), 142-43.

4 See *Certificat d'addition* of 16 November 1857 and idem of 1 December 1857 to the original French patent no. 22072, dated 18 January 1855. I thank my colleague Géry Dumoulin for calling my attention to this patent.

5 "Enfin, dernier perfectionnement qui, je l'espère satisfera l'artiste le plus difficile pour la légèreté de l'instrument, c'est l'emploi de l'alluminium [*sic*] pour les pompes intérieures des pistons qui par ce moyen pèsent trois quarts de moins que celle qu'on a faites jusqu'à ce jour, de là une subtilité et une dextérité extraordinaires dans le mécanisme produites par le jeu de poids de ce métal ; or comme l'alluminium n'a pas encore été employé dans la facture des instruments de cuivre, j'en réclame la priorité non seulement pour son application aux pompes des pistons mais encore pour tout ce qui regarde les instruments à vent." See *Certificat d'addition au brevet d'invention ... pour perfectionnements aux instruments de musique de tous genre en cuivre*, Addendum of 16 November 1857 to patent no.

22072 of 18 January 1855, p. 17.
[6] See Haine, *Les facteurs,* 116.
[7] "Der grösste Vorzug der Metallschnäbel besteht aber darin, dass sie den Ton gleichsam veredeln." See Sch…t., "Eine Clarinette mit Metallmundstück," *Zeitschrift für Instrumentenbau* 1 no. 10 (15 February 1881): 125.
[8] See A. Hervé, *Manuels-Roret: Nouveau manuel complet des alliages métalliques contenant la préparation de ces alliages; leurs principales propriétés; leur emploi; leur existence dans la nature; leur analyse, etc.* (Paris: Librairie Encyclopédique de Roret, 1839), 356-58, 396, and 421.
[9] BP No 7994, 6 March 1839.
[10] BF No 70025, dated 9 January 1866 for "modifications dans la fabrication des instruments de musique."
[11] "La partie supérieure du basson, celle où s'adapte le bocal de l'instrument et à laquelle … on donne le nom d'aile, exige à cause de sa contexture compliquée, un mode de creusement extérieure tout spécial…. On place sur un tour, parallèlement, en regard, la pièce de bois et un modèle en fer ayant exactement les contours voulus, du moins quant aux lignes principales. Au dessus du bois se trouve une fraise rotative (lamelle d'acier, tranchante) emboîtée dans un porte-foret ou un porte-lame. Le modèle est surmonté d'une tige métallique. La machine mue par des poulis et une pédale imprime à la pièce de bois et au modèle un mouvement semblable de translation longitudinale de droite à gauche et vice-versa. La fraise et la tige qui lui servira de guide, sont attachées à la partie supérieure du mécanisme; elles ont également un mouvement commun, vertical. La tige suit la bosselure de modèle qui passe sous elle. La fraise rotative imitant fidèlement son guide creuse sa route sur la pièce de bois qu ne tarde pas à prendre une forme identique à celle du modèle." See Ch. B. [Charles Bosselet], "Les ateliers de la Maison Mahillon," in *L'écho musical* 11 (28 May 1885): 122.
[12] The first steam engine used in a Prussian piano factory was installed in 1853 by C.J. Gebauhr in Königsberg. In 1875 the Prussian musical instrument factories counted seventeen steam engines; in Germany as a whole, forty-three musical instrument factories used steam engines. See Herbert Heyde, *Musikinstrumentenbau in Preußen* (Tutzing: Hans Schneider, 1994), 449.
[13] See Haine, *Les facteurs*, 393.
[14] "Dans l'atelier du facteur d'instruments à vent, la machine à vapeur ne vient en aide que pour remplacer la force brutale. C'est du fini de la main-d'oeuvre intelligente que dépend, pour la plus grande part, la valeur de l'instrument." This text presumably was written by Charles Mahillon, since he was the only wind instrument maker on the jury of the National Exhibition of 1880. See "Classe VIII. Instruments de musique: C. Instruments [à vent:] Notice," in *Exposition nationale de 1880. Catalogue officiel. Première section: Enseignement, arts industriels et décoratifs,* 2nd edn. (Brussels: Adolphe Mertens, [1880]), 93-95.
[15] See Carl Alfred André, "Beschreibung des Präparations-Verfahrens für Hölzer," *Zeitschrift für Musikinstrumentenbau* 1 no. 17 (1 June 1881): 233-34.
[16] "Das überraschende an Blühmels Drehventil sind die drei Wechseldurchgänge. Die Spiralfeder befindet sich außen. Durch Nachziehen kann sie leicht straffer gespannt werden, im umgekehrten Sinne lässt sie sich entspannen. Die konische Form des Wechsels, durch die sich auch die technischen Ventile der schlesischen Hochöfen auszeichneten, besitzen auch die späteren Drehventile." See Herbert Heyde, *Das Ventilblasinstrument: sein Entwicklung im deutschsprachigen Raum von den Anfängen bis zur Gegenwart* (Wiesbaden: Breitkopf & Härtel, 1987), 29.
[17] See Karl Ventzke and Dietrich Hilkenbach, *Boehm-Instrumente / Boehm Woodwinds. Ein Handbuch über Theobald Boehm und über Kleppenblasinstrumente seines Systems / A Factbook on Theobald Boehm and Woodwinds of his System.* Teil I/Part I: *Theobald Boehm 1794-1881. Hofmusiker—Flötenbauer—Eisenhüttentechniker in München / Court Musician—Flutemaker—Ironworks Technician in Munich*

(Frankfurt am Main: Das Musikinstrument, 1982), 51-56.

[18] In the period 1850-70, several larger factories emerged, such as Lecomte (150 workers in 1867), Gautrot (700 workers in 1862 in both his plants, at Paris and Château-Tierry). In 1881 Lecomte employed 115 workers, Thibouville-Lamy 80, Besson 60, and Millereau 58. See Haine, *Les facteurs*, passim. See the articles on Besson, Gautrot ainé, Lecomte, and Tibouville-Lamy in William Waterhouse, *The New Langwill Index: A Dictionary of Musical Wind-Instrument Makers and Inventors* (London, Tony Bingham, 1993), passim.

[19] See "Séance du 20.VII.1897," 11 (non-inventoried protocol from the archives of the *Chambre syndicale des facteurs belges d'instruments de musique* [Brussels Musical Instrument Museum, Fonds Hautrive]).

[20] See Patricia Van Den Eeckhout, *Lonen van Brusselse arbeiders in openbare instellingen (1809-1934): bouwvakken, ziekenhuis- en stadspersoneel* (Brussels: V.U.B., 1979), passim.

[21] See Haine, *Les facteurs,* 378.

[22] See Jane Fulcher, "The Orphéon Societies: 'Music for the Workers' in Second-Empire France," *International Review of the Aesthetics and Sociology of Music*, 10 no. 1 (June 1979): 47-56. The same belief reigned in Britain as well. See Trevor Herbert, "Nineteenth-Century Bands: Making a Movement," in *The British Brass Band: A Musical and Social History,* ed. Trevor Herbert (Oxford: Oxford University Press, 2002), 32.

[23] See Philippe Gumplowicz, *Les travaux d'Orphée. 150 ans de vie musicale amateur en France: harmonies-chorales-fanfares* (s.l.: Aubier, 1987), 68, 75-76. British brass bands also stood in close relationship with working-class culture, but not exclusively, since volunteers played an important role as well. See Herbert, "Nineteenth-Century Bands," 36-43.

[24] See Josef Eckhardt, "Arbeiterchöre und der 'Deutsche Sängerbund'," in *Musik und Industrie: Beiträge zur Entwicklung der Werkchöre und Werkorchester* (Regensburg: Bosse, 1978), 46-48.

[25] Adolphe Sax' move from Brussels to Paris in 1842 is an obvious case of "brain drain" to fulfill the desire of the French military establishment to have modern wind bands comparable to those of the German and Austrian armies. General de Rumingny not only pushed Adolphe Sax to go to Paris, but protected him as long as the political situation allowed him to do so. Saxophones, saxhorns, and saxotrombas were thus designed for the military. On the other hand, the link between Sax and Distin being established on historical evidence, one could say that the use of saxhorns in British brass bands is "dialectic": they had been designed to serve military power, which they never fully did, but instead became the symbol of British workers, for whom they had not been intended.

[26] See, for example, the curriculum of bandmasters in the *Bergkapellen* in Saarland, quoted in Christoph-Hellmuth Mahling, "Werkschöre und Werkskapelle des Hütten und anderer Saarländischer Industriebetriebe," Anhang V, in *Musik und Industrie*, 192-95.

[27] See Jules Dufrane, *Annuaire officiel de la musique en Belgique: 4^{e} année* (Frameries-Mons: Dufrane-Friart, 1899), passim.

[28] See Malou Haine, *Adolphe Sax: Sa vie, son œuvre, ses instruments de musique* (Brussels: Université Libre de Bruxelles, 1980): 108-09. This harmony band was called "Société de la Grande Harmonie"; it was composed of members of the *banda* of the Paris Opéra and was conducted by Mohr.

[29] The fanfare of the Mahillon factory was called "Le cercle musical" and was conducted by Victor Mahillon himself. See a communication in *L'écho du parlement* quoted in "Nouvelles," *L'écho musical* (15 April 1871): [1].

[30] See Theobald Boehm, *The Flute and Flute Playing in Acoustical, Technical and Artistic Aspects,* transl. and annotated by Dayton C. Miller (Cleveland: Dayton C. Miller, 1908), 7; and Boehm's booklet, *Die Flöte und das Flötenspiel in akustischer, technischer und artisanaler Beziehung,* quoted in Karl Ventzke, *Die Boehmflöte: Werdegang eines Musikinstruments* (Frankfurt am Main: Das Musikinstrument,

1996), 65-66.
[31] See BP No 11,853, dated 6 September 1847. The full text of this quotation is a "communication from abroad"; Boehm's original remarks are enclosed in quotation marks.
[32] See Theobald Boehm, *The Flute and Flute Playing In Acoustical, Technical and Artistic Aspects,* 2nd English edn., revised and enlarged, transl., and annotated by Dayton C. Miller (Cleveland: Dayton C. Miller/London: Rudall, Rose, and Carte, 1922), 17-19.
[33] See Ventzke, *Die Boehmflöte*, 55-57.
[34] "Mieux qu'aucun autre, le saxophone est susceptible de modifier des sons afin de leur donner les qualités qui viennent d'être mentionnées et de leur conserver une égalité parfaite dans toute leur étendue: je l'ai fait de cuivre et de forme de cône parabolique." BF No 3226 of 21 March 1846.
[35] See Jaap Kool, *Das Saxophon* (Leipzig: J.J. Weber, 1931), 58-65. Kool sees parabolic sections at the sound holes for E/E♭, A/G♯, C/B. These deviations in bore are very slight, and are presumably caused by dilatation of the material.
[36] BB N° 145/.1051/3739 by Adolphe Sax, dated 21 June 1838.
[37] "La parabole ayant un axe principal infini, le solide qu'elle engendre en tournant sur cet axe ne puisse qu'être infini. Pour former du côté de l'auditoire l'enceinte sonore que je propose, je raccorde à la surface parabolique une surface ellipsoïdale, surface qui me paraît la plus propre à concentrer sur l'auditoire les rayons sonores réfléchis par elle. C'est à peu près la forme d'un oeuf." BF N° 72.010 by Adolphe Sax, dated 16 June 1866.
[38] "Cependant, nous avons la conviction que ces proportions suivent le développement d'une courbe géométrique dont la forme se rapproche de l'hyperbole et dont nous espérons un jour publier la formule." See V.C. Mahillon, *Eléments d'acoustique musicale et instrumentale comprenant l'examen de la construction de tous les instruments de musique en usage dans l'orchestration moderne* (Brussels: Manufacture générale d'instrument de musique C. Mahillon, 1874), 94.
[39] These results were put into a coherent system of thirty acoustical laws by Friedrich August Drechsel in 1927, who published them under the title *Zur Akustik der Blasinstrumente*. A new edition with actualized figures by Otto Steinkopf has been published as *Kompendium zur Akustik der Blasinstrumente nach Victor-Charles Mahillon* (Celle: Herman Moeck, 1979).
[40] "Quelle est la formule qui sert de base à ce développement [conique de la colonne d'air]. Rien de sérieux n'a été publié à cet égard: le tâtonnement, l'empirisme ont été jusqu'à présent les seuls guides. Mais nous sommes persuadés aujourd'hui après de multiples essais, que le cône employé seul à l'établissement d'une colonne d'air où le cône associé à une partie cylindrique doit se développer en suivant une courbe hyperbolique ou une courbe géométrique d'après les timbre à produire. L'incurvation de la courbe hyperbolique étant la plus prononcée produira le timbre le plus brillant et le plus éclatant." See Victor-Charles Mahillon, *Eléments d'acoustique musicale et instrumentale comprenant l'examen de la construction de tous les instruments de musique en usage dans l'orchestration moderne remaniés et complétés par l'auteur,* posthumous edn. (Brussels: Les Amis de la musique, 1984), 147.
[41] Herbert Heyde, "Methods of Organology and Proportions in Brass Wind Instrument Making," *Historic Brass Society Journal* 13 (2001): 1-51.
[42] "L'énorme différence dans la qualité, le timbre et la puissance des sons de ce trois instruments (trompette, cor, bugle) qui sont dans les mêmes conditions comme contours de tubes n'est absolument due qu'aux proportions et à la différence de largeur des tubes." See Adolphe Sax, *Note pour messieurs les conseillers* (Paris, [1850]), 9-10.
[43] "Ces six instruments, de la même forme, en ligne droite, de même longueur, ayant par conséquent tous leurs harmoniques placés au même degré de l'échelle chromatique ne différant entre eux que par les diamètres ou les proportions de leurs tubes, ont été construits par M. Sax en 1846, pour servir dans

ses divers procès et prouver la découverte faite par lui de la loi suivante: 'Le timbre des instruments à vent ne dépend pas de la matière dont ils sont composés ni des contours que l'on peut donner aux tubes, mais bien de leurs proportions intérieures sur les différents points de ces mêmes tubes'. " See [footnote] (1) at nos. 224 to 229 in Gustave Carré (Commissaire-Priseur), *Catalogue du Musée Instrumental de M. Adolphe Sax: Collection unique d'instruments de musique de tous temps et de tous pays* (Paris: V[es] Renou, Maulde et Cock, 1877), 17.

[44] See BF 2306 dated 13 October 1845. I prefer to use the publication of the Tribunal Correctionnel de la Seine, 6me Chambre, *Nullité de brevet: Instruments et brevets Sax: Affaire Rivet contre Sax* (Paris: Vve Dondey-Dupré, 1865).

[45] See "Comparaison du saxotromba en mi bémol avec les instruments du même ton qui ont été saisis et déposés au greffe," in *Rapport de M. l'expert Surville, ingénieur, déposé le 18 février 1859 et dire et de M. Sax* (Paris: Imprimerie Centrale des Chemins de Fer, 1860), 36-37.

[46] They are listed as nos. 566, 567, 568, and 569.

[47] "A l'aide de ces tuyaux, on démontre: A. Que le timbre qui distingue entre eux les instruments de cuivre est dû aux proportions du tuyau; B. Que l'influence de ces proportions sur la longueur de tuyau est très faible; C. Que la production des harmoniques élevés est d'autant plus facile que le tuyau est plus long et plus étroit et vice-versa; D. Que la production du son fondamental et des harmoniques graves est d'autant plus facile que le tuyau est plus court et plus large." See Victor-Charles Mahillon, *Catalogue descriptif et analytique du Musée instrumental du Conservatoire royal de musique de Bruxelles*, 2nd edn. (Ghent: Ad. Hoste, 1893), 1:487-88.

[48] "Dès l'instant qu'un tuyau se développe en cône pour atteindre la proportion de 1:4 à ses deux extrémités, la bouche, l'anche ou l'embouchure étant appliquée à la troncature, ce tuyau octavie et fait entendre tous les sons pairs et impairs de la résonance harmonique." See Mahillon, *Eléments d'acoustique*, posthumous edn., 145.

[49] "Pour que le rapport entre tous les sons de la résonance harmonique soit exact, il est nécessaire que le développement conique du tuyau prenne naissance vers le milieu de sa longueur totale." See ibid., 146.

[50] The relevant text of the *Certificat d'addition* dated 12 July 1856, an addendum to the French patent BF No. 22072 from 18 January 1855, is published in the Appendix to this article. I thank Géry Dumoulin for transcribing it. Note that Besson also considers the parabola to be the definitive form of the acoustical profile of a bugle, even though his description of it is not entirely clear.

[51] See *Catalogue des appareils d'acoustique construits par Rudolph Koenig* (Paris: [Koenig], 1889), 86.

[52] See Theobald Boehm, *The Flute and the Flute Playing* (1908), 16-17. It is worth noting that Schafhäutl too, writing under the pseudonym C.E. Pelisov, published an acoustical work on air columns in pipes, *Theorie gedackter cylindrischer und konischer Pfeifen und Querflöten* (Halle: Anton, 1883).

[53] "Les tableaux qui suivent nous seront très utiles. Le premier nous donne pour chacun des degrés de l'échelle des sons le nombre de vibrations simples calculé sur l'étalon officiel, devenu international…, la longueur de chacune des ondes simples calculée à la vitesse moyenne de su son…, et enfin la longueur théorique des tuyaux ouverts et fermés. Le second tableau donne le nombre de vibrations de chacun des degrés d'une gamme chromatique." See Mahillon, *Eléments d'acoustique*, posthumous edn., 77.

[54] See Theobald Boehm, *The Flute and the Flute Playing* (1908), 18.

[55] "Le calcul offre parfois certaines difficultés à ceux qui n'y sont pas habitués. Nous avons donc cherché un moyen plus commode et nous pensons l'avoir trouvé par le système de projection." See Mahillon, *Eléments d'acoustique*, posthumous edn., 98-90.