METHODS OF ORGANOLOGY AND PROPORTIONS IN BRASS WIND INSTRUMENT MAKING

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1. Introduction: Sources and critique of methodology

Any brass instrument maker's dream is a beautiful-sounding instrument that speaks easily, with accurate intonation and excellent playing qualities. If a new model with a new bore is to be developed, the maker faces a long process, beginning with a rough concept and ending with a fully developed and tested product. This process involves shaping and refining the dimensional structure of the air column so that the resulting sound corresponds to the envisioned concept, and the sound has aesthetic appeal if not beauty. Instrument building is at its core an empirical craft, but developing new models today usually requires the assistance of musicians, and perhaps acousticians as well.

Acoustical science, in both its theoretical and practical aspects, has had a revolutionary influence on professional instrument making since the beginning of the nineteenth century. The historical context suggests that prior to the rise of acoustical science, makers used proportions and geometrical procedures[1] as an aid in determining the major factors that influence the tonal quality of an instrument. Not a few organologists dismiss this idea for two reasons: first, there are no sources—or at least, very few sources—that testify to their use; second, there are logical reservations against them. The principal argument is that these means do not have the required physical properties to improve the musical qualities of an instrument; they may have a bearing on external appearance, but not on sound.

When the present author included proportional analyses of brass instruments in his publications of 1980, 1982, 1986, and 1989,[2] he relied largely on historical context in default of direct evidence. The contextual evidence seemed persuasive enough to suggest the use of proportions. Critical response, however, tended to regard the analyses as speculative and contrived. Unfortunately, the critics paid little attention to the historical context, laid out in the 1986 publication, but kept demanding direct evidence. A short while later the author found nineteenth- and twentieth-century sources that confirm his assumption. The most important of these sources are described in the following paragraphs.

In his pamphlet *Note pour Messieurs les Conseillers* [of the court of Rouen] (1850), Adolphe Sax (1814-94) wrote,

> Proportions are the governing laws and constitute the nature of the instrument; indeed, it is not the form that gives them their voice, their sound quality: it is only the proportions. These proportions are, therefore, different for each species of instrument; ... And my enemies dare to repeat at the Court [in Rouen] what they told the experts, [namely] that they know that

> they [i.e., the proportions] are far from being a fundamental law, they are without importance; and that they need to be modified according to the demands of the artists! [3]

This quotation makes it clear that Adolphe Sax believed in proportions. His words refer to a heated controversy about their value and justification. At that time there were apparently two camps of brass instrument makers in Paris, one in favor of proportions, the other condemning them. The composer and music theorist Adrien de la Fage, in his report about the Paris industrial exhibition of 1855, even pointed out that Parisian makers of his time, including Besson, used proportions extensively and applied the following two principles:

> First, a firm rule for the proportion and development of each instrument's tube; second, a means that is sure and universally applicable in order to follow this rule. M. Besson attained the first by a series of sleepless nights, endless calculations, and numerous trials.[4]

Sax and Gustave Besson were not oddball makers, out of step with their time, but manufacturers of international renown. Moreover, Victor-Charles Mahillon,[5] descendant of a distinguished brass instrument manufacturer in Brussels and himself a noted acoustician, also defended proportions. He refers to them in his book *Éléments d'acoustique* (1874),[6] which we will encounter again in section 6 of this article. In this context we should also mention Wilhelm Wieprecht in Berlin, who in his patent application for the *Basstuba* (1835), demonstrated how he designed the new instrument with the assistance of the monochord. He used its divisions to lay out the valves for the two "mother-tones," F and C, and to determine the length of the bell.[7]

A design principle, cognate to proportions, uses graded diameters of the tube.[8] The most important version is the *Teleskopmensur*, which Gustav Gnädig in Berlin developed in 1908.[9] The *Teleskopmensur* replaces the conical section of an instrument with a sequence of cylindrical tube sections, the diameters of which increase at a rate equal to the double wall thickness, resulting in a quasi-conical tube (see Figure 1).[10] Several manufacturers employed and modified the *Teleskopmensur,* for example, C.F. Schmidt in Berlin, Gustav Eschenbach in Berlin, Herfeld & Comp. in Neuenrade (Westphalia), and A.K. Hüttl in Graslitz (Kraslice).[11] Improving the *Teleskopmensur,* Hüttl took out patents concerning the lengths of the telescopic and bell section. He suggested a few variants, among others, $^3/_4$ telescopic section + $^1/_4$ bell (German *Reichspatent* 364650 of 22 November 1921). Paul Suchy, a chemist and builder of brass instruments, combined the telescopic design principle with acoustical notions. He suggested that the telescopic increment of the diameter should follow an exponential course of a particular kind. For trumpets he specifically suggested a ratio of 1:4 for those diameters, which coincide with the first and last node of the eighth harmonic. In a B♭ trumpet these nodes are located approximately 8cm from the beginning of the tube and 8cm from the end of its acoustical length. As optimal lengths of the telescopic section and the bell, he proposed the configuration of 2/3 + 1/3 (German *Reichspatent* 525246 of 1 January 1930).

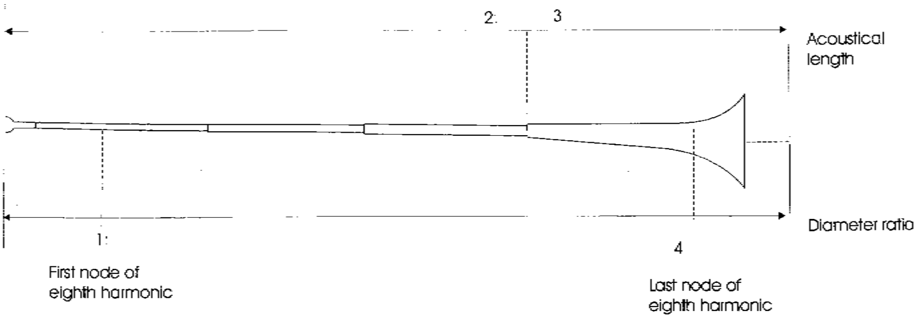

Figure 1

Proportional system of a brass instrument after Paul Suchy. German *Reichspatent,* 1930. *Proposition 1*: The first two-thirds of the acoustical length (total length with mouthpiece and end correction) follows the principle of the *Teleskopmensur,* i.e., the diameter increment from one cylindrical tube section to the next equals the double wall thickness of the previous section. The number of sections depends on the type of instrument. *Proposition 2*: The diameter increment between the first and last mode of the eighth harmonic follows the ratio 1:4.

The position of those makers who fought against proportions in Sax' time grew increasingly stronger, and finally won the day. Proportions eventually disappeared as an operative concept in brass instrument manufacture around the time of World War II. But two important questions remain unanswered: first, what was the situation concerning brass instruments prior to the nineteenth century—a period from which we have no written evidence concerning proportions? Second, how did makers of the nineteenth century and earlier use proportions? The sources cited above confirm that some instrument makers did use proportions. They also make it clear that contextual evidence, which provided a point of departure for the present author in his attempts to demonstrate the use of proportions, obviously can be taken seriously. Moreover, they encourage us to question organology's demand for direct evidence exclusively as a precondition for establishing historical truth about the structure of instruments.

In traditional organology the general methodology concerning design works in this way: one collects written and iconographic sources, translates, interprets, and summarizes them. Likewise, one collects and compares observational data and measurements of instruments and draws conclusions from them. Such a methodology allows a fact-oriented description and comparison of the instruments of various periods. The borders of knowledge are established largely by means of direct sources. Only if such sources are available can we make secure statements; otherwise we enter the realm of speculation. This method, however, does not yield adequate answers to questions as to why or how something evolved historically; for example: Did instrument makers use proportions? And if so, why and how? Our lack of knowledge on this matter results from the fact that the researcher looks backward with the eyes and arguments of our period. To answer historical questions such as this we must return to the time when the instruments were built. Only by observing from this vantage point can we properly assess why and how things occurred. An approach of this kind requires an expanded methodology as well as the inclusion of sources relating to the broader historical context. In the following sections of this article I shall outline and develop this methodological approach, using proportions by way of example.

2. The dual nature of musical instruments

Musical instruments, by virtue of their nature, have two different aspects—one cultural-artistic, the other physical. Instruments were built for cultural (musical) purposes and reflect the cultural situation of their period and the creative capabilities of the inventor and maker. They are cultural objects in the first place, while their physical side is the necessary complement. This circumstance dictates that musical instruments comprise an extremely wide range of associations, reaching from one end of our intellectual capacity to the other. This makes organology a very complex discipline.

To elaborate on this dual nature and the primacy of the cultural side, we will first address sound. While stone and wood, which the sculptor uses for his works of art, are products of nature, musical sound is molded by culture. Apart from its physical aspect, musical sound has an artistic and individual aspect and may be a bearer of meaning. The cultural side is the active part, but the physical side is more than just its reflex. At the same time any technological realization impresses its mark on the sounding result. No matter how comprehensive and deep the cultural associations of the instruments, the physical characteristics of air columns or strings remain basic to the sound.

Organology, as we understand it, sees as its goal the understanding of both sides of reality, the cultural-aesthetic and the physical. Though the two sides are closely related, the physical side cannot explain the cultural-aesthetic side. Physical methods can describe only the physical phenomena that correlate with subjective, artistic, and cultural phenomena. These methods can describe, measure, and compare the structure and the applied technology of instruments, but only in the vaguest sense can they infer artistic quality, the cultural environment in which the instruments evolved, or the ideas behind their design. One can measure and analyze a Bronze Age *lur* and appreciate its casting technology, but this does little to help us understand the ideas that created its form and design, how the instrument was used, or for what purpose.

As soon as ideas and concepts of design have assumed shape in the structure of an instrument, they are no longer recognizable as such but are translated into structure. Clues from and comparisons with other instruments are needed in order to interpret physical characteristics as they relate to the original ideas. Such knowledge can come only from sources about *lurs* and information about their cultural context. As there are no such sources, we cannot reach any conclusions concerning these cultural matters from an examination of physical characteristics. In contrast to *lurs,* however, a different situation obtains as regards brass instruments of the fifteenth through the nineteenth centuries. There is a host of contextual sources, which, if properly interpreted, may help us to understand the design of extant instruments. Specific sources from the cultural side are needed in order to understand the relationship of an instrument's physical structure to its cultural and artistic context.

In a painting the primacy of the cultural and artistic side is obvious; canvas, paint, and frame as elements of the physical side are easily recognizable simply as supporting constituents. In a musical instrument, however, the technological and physical side is more prominent; thus paintings naturally tend more toward the artistic side of the continuum, while musical instruments tend more toward the physical and technological side. This situation bears on the character of both art history and organology. The "material" prominence often tempts researchers to study an instrument exclusively from its physical side. Indeed, organology often adopts this approach, taking the physical examination of the instrument for the whole and explaining the musical properties on an acoustical and technological basis. This leads necessarily to underestimation of the instrument's cultural and artistic aspects, and to one-sidedness. It may even lead to an epistemological cul-de-sac, in which some organologists and acousticians conclude that acoustics is the basis for understanding the cultural and aesthetic aspects of the instrument. Shifting research to the physical side is methodologically safe and simple, but one-sided and, given the broad cultural scope of musical instruments, ultimately highly unsatisfactory. Organology must seek to balance the cultural-artistic and physical aspects.

It is important to understand yet another facet of an instrument's dual nature—that the creative impulses involved in instrument making do not come from an autonomous, self-contained brain. They are intertwined with the cultural situation, intellectual and artistic currents, and social conditions. They are also intertwined with the understanding of the laws of nature of the respective period as well as contemporary technological standards. Designers and makers use information associated with both sides of the musical instrument, the cultural-artistic and the physical. Technological progress exercises an incentive for application in instrument making and holds a reservoir available for possible uses. It can open up entirely new possibilities for structure and sound. For example, the invention of metal processing and the discovery of electricity provided the basis for the development of entirely new types of instruments—large and looped horns, long and folded trumpets, and the new world of electronic instruments. The physical complexity of technological systems usually has undesired "side effects": the introduction of valves on brass instruments brought certain intonation problems and the new electronic instruments came with some undesired "electronic timbres." Sometimes makers assumed solutions that were suggested by favorable physical functioning. In the case of the Boehm flute this was a factor in the historical change from the more delicate and colorful timbre of the conical flute toward the greater dynamic range and nimbler playing technique of the cylindrical flute.[12]

In instrument making, evolution works in such a way that those properties that appear important to musicians, manufacturers, and listeners prevail, while less desired properties are minimized. So we see that the primacy of the cultural side of the musical instrument is to some extent compromised by physical and technological necessities and suggestions. The mediating agent between both sides, the cultural and the physical, is human creativity. Thus any instrument bears the marks of the individuals who were directly involved in its development.

3. Two approaches of historical organology and the principle of historicity

Musical instruments have evolved over a long period of time in a multiplicity of forms and structures. Two aspects of evolution, variation and temporal sequence, provide the basis for the two major branches of organology,[13] which I call systematic and historical, respectively. Systematic organology, as its name indicates, pertains to the systematic aspects of a musical instrument—that is, its physical structure, dimensions, taxonomic placement, acoustical workings, material, applied technology, musical and sound properties, and its musical application. It is the study of the instrument without its historical aspect. Systematic organology uses the methods of the empirical sciences, which include description, documentation, taking measurements, structural analysis, and identification of material. Acoustics is a branch of physics, but in its immediate relationship to musical instruments it also forms a part of systematic organology.

Historical organology, on the other hand, deals with an instrument's history, both in its entirety and in relation to individual aspects that figure in systematic organology. I distinguish two approaches of historical organology, the descriptive and the interpretive.

The descriptive branch has in view the instrument's change over time and its association with place of manufacture, maker, or "school." It builds on systematic organology and describes changes in an instrument's structure, sound qualities, or musical applications, as they occur over time and relate to a place, country, or artisan. It connects the observational data to the historical coordinates of time, place, and individuality of the maker. One documents and comments on direct sources (instruments, written and iconographic sources, etc.), compiles, documents, and represents them as information about a particular time, culture, place, and instrument maker. The vantage point is in the present, and the researcher looks backward along the line of direct sources and extant instruments.

This approach to instrument history has its benefits as well as its limitations. Its strength is factual documentation. It fails, however, if we want to understand the reasons and motives for historical changes, why and how masters and designers proceeded in the specific ways that we encounter in their extant instruments. Answering "why-and-how" questions requires a different approach. Here interpretive organology comes into its own. It aspires to an understanding of the instrument in the context of the time in which it was built.

Here artistic and intellectual currents and countercurrents, ways of thinking, the social environment of the period, and information about other building trades are important. I consider this context as the matrix from which instruments emerge. Sources that elucidate that context do not directly refer to musical instruments, and therefore we call them "indirect" or "contextual." Interpretive organology thus draws its statements and conclusions from three types of sources: direct sources, indirect sources, and the instruments themselves. Interpretive organology attempts to understand and describe the process of emergence and change of musical instruments as determined by the entire cultural context. This context includes modes of thinking and the use of proportions. The latter is a very controversial issue. A bone of contention is the question whether, why, and how instrument makers used proportions. In the discussion that follows I shall delineate both sides of the controversy.

Opinions that reject proportional schemes

After the author originally published his views on the use of proportions,[14] he was confronted with many opposing points of view, which can be summarized as follows:

a) *History can be written only on the basis of sources.* This is a true statement, but the question is what one understands by "sources." It is a deeply ingrained convention that only those documents that refer directly to musical instruments can pass for sources. However, they do not represent the full range of sources. A distinguished German organologist succinctly told the author after the appearance of *Musikinstrumentenbau*, "Show us the sources, then we will believe you"—having only the direct sources in mind. In fact, there are few direct sources that demonstrate that proportions were used. And one could argue that these sources might be the whims of eccentrics, or isolated instances that cannot be applied to instrument making on a broad scale. Given this source situation, descriptive organology has reached the boundaries of secure knowledge. It argues that if we analyze instruments, we can only speculate as to how early instrument makers proceeded.[15] However, interpretive organology offers a different approach through the inclusion of historical context.

b) *Instrument makers in all periods have faced the same problems in dealing with wood and metal, and thus have confronted the same laws of nature. Therefore it is appropriate to use present experience to assess not only historical instruments but also early methods of construction.* There is no doubt that the laws of nature are universal and timeless, but we find that man's understanding of how nature works has changed considerably over time (see sections 4-6, below). Though a seventeenth-century maker faced the same objective laws of nature as we do today, his ideas about how nature works were different. This difference is essential to historical research, and it is a matter of considerable consequence for interpretive organology. Changing viewpoints and growing critical thinking have transformed opinions as to how proportions work. The more recent understanding, based on practical experience, tends to believe that proportions neither affect the quality of sound nor enhance its beauty. The advocates of this point of view refer to the fact that a proportional configuration is a geometric rather than a physical attribute. Sound is a complex acoustical event, so they point out, that is determined by several physical parameters and not merely a single geometrical attribute. Given these unassailable facts, some organologists have assured the author that the old makers had enough experience to determine that proportions had no effect, and that is why they did not use them. However, the historical context makes it clear that proportions were not used in the sense of physical causality; rather, they were artistic tools that functioned on a psychological basis.

Tracing the evolution of our knowledge in reverse, beginning with the concepts of our scientific age, we soon encounter metaphysical and speculative ideas. In human history, cognition and knowledge initially have grown slowly, reflecting cognition first in animistic and mythological forms, later in metaphysical forms. Among earlier understandings that relate to instrument making is the notion that musical sound is not only a physical process but also ratio and is connected with ideas of *musica universalis* and *musica humana* (see section 4, below). Another metaphysical concept was the understanding of proportions as part of a universal world image. In this context, proportions had spatial, visual, and aural connotations. These perceptions are speculative in our modern scientific understanding and therefore excluded from physical consideration. But one must remember that when it comes to aesthetics, an acoustically correct opinion does not necessarily make more sense than an acoustically speculative opinion. An understanding of history begins with respecting historical facts, no matter how wrong they may appear to the modern mind. Extrapolating on the basis of modern convictions instead will necessarily violate the principle of historicity.

c) Proportions may have a bearing on the visual side of an instrument but not on its sound. Musical instruments are sound-producing instruments in the first place. Thus it is logical that they were developed on the basis of notions related to sound, acoustics, and music, and not according to visual criteria. During the nineteenth and twentieth centuries musical instruments were mostly developed on the basis of free design and acoustical reasoning. According to common understanding, proportions, including the golden section, had a bearing only on an instrument's visual appearance. However, in the period prior to the eighteenth century we encounter some cultural facets that point to a closer association and correspondence between visual and aural aspects: ratio-related understanding of sound, the foundation of architectural design on music theory, and the philosophy of a united world image. These relationships evolved in a cultural context in which thinking was less abstract and critical than today and was oriented more toward "wholeness." These facts, which have a psychological basis in synesthesia, provide the historical basis for an understanding of proportions, in their visual as well as their aural aspects.

d) *Proportions are derived from mathematics and philosophy; they therefore have nothing to do with instrument building.* According to this notion, instrument making was an empirical craft without any connection to philosophy; hence to detect proportions in historical instruments is artificial. Some organologists say that the use of proportions was likely brought forward by modern "office workers" or Renaissance philosophers who were not familiar with the practice of instrument making.[16] Contrary to this opinion, historical evidence shows that collaboration between instrument makers, musicians, and theorists was common practice from the fifteenth century and even earlier (see section 4, below), and still is today. Unlike earlier makers, modern builders of historical reproductions customarily work alone, because they are released from design work, which was done a long time ago. History teaches us that in the fifteenth through seventeenth centuries, philosophy stood in a different relationship to the crafts than in the last two centuries. The sciences that form the quadrivium provided the theoretical basis for the mechanical arts. They had a speculative basis and were closely linked with philosophy and theology. In the course of the Enlightenment this hierarchical system of knowledge and cognition disintegrated. Organologists who claim that instrument making has nothing to do with philosophy are correct as concerns our own period, but not as regards the fifteenth through seventeenth centuries.

e) *Proportions found in historical instruments may be accidental, or may result from the maker's subjectively free discretion.* Some—perhaps many—organologists who deny the use of theoretical proportions allow for free pondering of the right measure when designing and building an instrument. If proportions should be found in some historical instruments, then they probably result from those creative procedures—so they argue—rather from mathematical calculation. There is no doubt that weighing and balancing are basic tools of all artistic activity and are embedded in human nature. When designing a structure or working on an instrument, "proportional feeling" is always involved as a guide. Human beings apparently have a natural predisposition for symmetry, balance, and the golden section in any area of creative activity.[17] From a historical point of view, however, this is not the whole story. Contextual evidence shows that in some periods, particularly in the Renaissance and Baroque eras, these inborn propensities interacted with philosophical ideas and came to be reflected in proportional building theory. It resulted in the use of mathematically defined proportions in architecture as well as instrument making. These proportions—including particular partitions such as the diagonal of a square, monochordic divisions, and the Fibonacci series—have a clear historical basis. Designers used them to form proportional systems, or schemata. If the basic dimensions of an instrument's design correspond convincingly with a local unit of measurement, such a match may corroborate the interpretation of the schema.

The opinions presented under a) through e) reject the use of mathematical proportions in instrument making on the basis of a way of thinking that is in keeping with the craft tradition of the nineteenth and the twentieth centuries and the methods of the empirical sciences. The empirical method in the sciences as an outcome of the Enlightenment found its rigorous expression in positivism, which in its philosophical generalization was delineated by Auguste Comte (1798-1857). Its basic concepts are: (1) there are no causes apart from physical facts; thus the question of final causes is excluded and left to philosophy and religion; therefore, metaphysics, philosophy, and religion are barred from scientific discourse; (2) all relationships in a physical system are subject to causality; and (3) all inferences are made on the basis of inductive reasoning.[18]

This epistemological disposition has proved to be an adequate basis for the sciences to date. Adjusted to the humanities, the scientific code requires that any conclusion has to be made on the basis of sources, i.e., of direct evidence, while indirect evidence is regarded as vague and inconclusive. In default of direct sources in organology, the physical side of musical instruments has tempted some organologists to develop opinions about the past on the basis of current craft experience, common sense, and logical reasoning. These procedures have their cognitive basis in modern times and are extrapolated to the past. This manner of creating historical inferences violates the principle of historicity, which says that change in history is constant. Modern workshop experience and common sense may appear to be timeless, but in fact they are not. In other words, this way of reaching historical conclusions does not consider that the use of proportions is not a subject of systematic organology but a historical issue. Our own time has its specific ideas, which of course embody infinitely more truth and scientific information about the material world than those at any period of the past. Extrapolating from modern reasoning means to foist modern ideas—even though they are logically adjusted to a more elementary condition—upon the past. Proportions in their historical perspective are a multifaceted notion that must be approached, not only from the physical side, but also from the side of art and metaphysics. Here lies the border region where positivist scientific methodology, by virtue of its definition, is not applicable to history.

Interpretive organology aims at understanding such notions as proportions and sound from the perspective of their respective historical periods. Adhering to the principle of historicity, we claim that statements about history require full historical evidence, not merely the fractional information provided by direct sources. Conclusions that fail to take into account contextual and metaphysical aspects of the past violate the principle of empirical positivism in its broadest sense—namely, to base any conclusion on evidence. They embody an approach that denies that early instrument makers thought in different ways and that there once flourished a different approach to design that was capable of creating instruments of high quality.

In order to understand the methodological situation in organology we must realize that instrument makers and acousticians had and have a significant role in shaping this discipline. It is understandable that these people remained committed to patterns of thinking consistent with their training and occupations when they turned to organological research as an avocation. One of their most firmly held opinions is that early instrument makers based their work on empiricism, taste, and acoustical science, which is understood as physical acoustics.[19] This opinion appears largely to be a projection of the recent way of thinking and not the outcome of historical research. There is no doubt that the empirical approach is primary in instrument making as in any craft, but empiricism never operates entirely in isolation. It is always connected with some sort of "theory," which may include educated taste, concepts of what is right/wrong, proportions, or acoustical reasoning. These "theoretical" positions and arguments help to guide empirical decisions. Acousticians tend to understand historical instruments as acoustical devices and their makers as working on the same basis as today's makers, with the difference that they did not yet have the modern sophisticated command of acoustical theory.[20] So they accomplished their work empirically, guided by taste, as many makers of the nineteenth and twentieth centuries did. However, this concept of subjective empiricism did not emerge before the middle of the eighteenth century (see section 5, below).

Historical understanding requires measuring the various historical periods by their own standards. Looking back at the previous five centuries, we see that the basic empirical approach has always constituted the core of instrument making. The theoretical underpinning changed constantly and was nourished to an ever-increasing extent by physical understanding. Thus attention shifted ever more to the side of acoustical theory. When organology evolved in the nineteenth century, it logically adopted the methods of the empirical sciences. Small wonder that the past came to be seen through the eyeglasses of this period, and intellectual one-sidedness began to gain ground.

Acceptance of proportions and the methods of interpretive organology

Interpretive organology considers all available source material, including the contextual. The research goal is a comprehensive understanding of the musical instrument, developed in light of our knowledge of the past. We attempt to understand its design from the conditions of the period in which it was developed. Total reconstruction of the modes of thought of a particular period, however, is neither possible nor necessary.

If we consider the historical record and exclude all preconceptions from nineteenth- and twentieth-century patterns of thinking, we find that instrument making prior to the mid-1700s largely stood on a different basis from that of the last two centuries. The basis has shifted in relation to intellectual and artistic currents, command of the laws of nature, and the socio-economic system. From the fifteenth century through the eighteenth, physical acoustics was in its infancy, while monochord theory and the concept of resonance served as sources for the application of proportions to instrument making. Nevertheless, instrument makers developed a high level of workshop experience and exercised marvelous craft skills. The sound and musical qualities of their instruments are not inferior to those of the nineteenth and twentieth centuries. Although proportions and physical acoustics rest on entirely different approaches, both were and are merely supporting aids for the maker, who works empirically in the first place.

In this context we should remember that art does not follow the concept of "progress" that is familiar to the sciences, which strive toward an increasingly higher level of truth and information about the workings of material objects. Art instead changes its character only according to cultural conditions, rather than proceeding to a higher evolutionary level. Art has always been connected with the modes of expression common to the culture that created it, which often included mythology and metaphysics, particularly before the rise of science. Great art can be created by means of concepts of reality that are scientifically incorrect. The point is that these "scientifically incorrect" ideas form "bridges" to trigger and channel artistic processes. As I will demonstrate in the sections that follow, the use of proportions in musical instruments worked in the same fashion—as a "bridge" or trigger.

To answer questions about instrument design in a genuinely historical sense we must return in our research to the period in which the instruments were made. In so doing we proceed in three preparatory steps and one analytical step. The preparatory steps lay out the foundations of knowledge as prerequisites to the analytical step. In the *first preparatory step* we must study the intellectual and artistic currents of the various historical periods in question, the driving historical forces, the situation in neighboring arts and crafts, professional standards and design principles of the crafts, and the artisan's way of thinking. Most of this knowledge comes from indirect sources.

The *second preparatory step* is to study direct sources concerning the design and structure of the different kinds of musical instruments. This second body of sources includes treatises on proportional design such as that of Arnaut de Zwolle (fifteenth century), Pablo Nassare's *Escuela Musica segun la practiga moderna* (1724), treatises on organ pipe scaling (tenth through nineteenth centuries), and "conservative" sources of the nineteenth century that persist from older traditions (see sections 1 and 6 of this article). It also includes sources on instrument construction and temperament, both written and iconographic.

The indirect and direct sources of the first and second body of knowledge are diverse. Before we can integrate information obtained from them, we must be certain that they are consistent with each other and with the contextual sources. This requires seeking answers to such questions as: Can we apply sources concerning architecture to musical instruments? Sources on string instruments to wind instruments? Arnaut de Zwolle's drawings (fifteenth century) to instruments of the seventeenth century? The answers cannot be given from the viewpoint of the modern situation in architecture and instrument making but only from the viewpoint of the specific historical conditions. Consistency presupposes that design sources from different professional branches have essentially the same intellectual and artistic basis. It does not mean that instrument makers and architects used the same design procedures, but it means that the procedures have a common denominator. This is in principle the case if they are derived from the same intellectual and artistic currents and traditions, and arise from equivalent socio-economic contexts. If the different sources derive from those crafts that are related to architecture as a common mother trade, and are thus members of the group of *artes mechanicae,* another supporting criterion of consistency has been met. For example, cabinets built for Renaissance patricians by professional carpenters have in principle the same basis in craft theory as musical instruments built for the same social strata by professional makers (see section 4, below). The border of consistency is reached at the transition to folk culture. Folk instrument making of the same time and place, having a different artistic, intellectual, and social basis, would not meet the criteria of consistency. Its standards of proficiency are different. So far as we know neither mathematical proportions nor acoustical science were used in the design of folk instruments. There is a gray area between professional instrument making and folk instrument making, which may include rural violin making and amateur trumpet making. However, precise knowledge of the respective instruments is required in order to class them in these categories.

Once we are convinced of the consistency of the various sources, their information can be extrapolated to broader—and at the same time, more specific—knowledge. In this way we can assemble from different sources a mosaic of knowledge about design practice in the "higher crafts," including instrument making. Again, this refers not to the literal transferal of design procedures of carpenters or architects to instrument making but to a more general approach, which is common to all of them.

In the *third preparatory step* we learn about historical workshop practice, historical technology, the manufacturing process, and trade law. Further, we learn about measuring techniques and historical units of measurement, tolerances, the shrinkage of wood, and the assessment of errors perpetrated by both makers and researchers.

After we have reached a command of these preparatory steps we can begin to analyze the design of surviving instruments. This decisive step presupposes the knowledge that systematic and descriptive organology has provided about the respective instruments. It also presupposes an assessment of the physical condition of the instrument to be analyzed, and the certainty that its dimensions represent the original sizes. Measurements procured for systematic and descriptive research are usually inappropriate or insufficient in kind and accuracy for the analytical task required here. If one uses the measurements of descriptive organology and condenses them, they hardly ever yield proportions. This is another reason why some organologists dismiss the use of proportions. They expect that proportions should be revealed by means of simple statistical compounding. What is required is to learn the dimensions the maker used and to compare them in a proper way. Design analysis is not like solving an algebraic equation, but a subtle approach to the exploration of a maze. In order to avoid anachronism, we must avoid the intrusion of preconceived ideas and modern trains of thought. In this context, what a typical modern maker or acoustician says about the instruments he or she analyzes is of no interest. Ideally, it matters only what makers thought and how they reasoned at the time the instruments were built.

Researching instruments of the sixteenth through the eighteenth centuries according to the historical context outlined above may or may not lead to a proportional schema as the assumed original plan. While proportional design is suggested by the historical context, we must allow for the possibility that not all instrument makers adhered to professional standards, others modified the proportional scheme, while still others copied previously altered models. And of course the physical conditions of an envisioned instrument may thwart the establishment of proportional schemata. If we arrive at a proportional schema for a particular instrument, such an interpretation would constitute, epistemologically speaking, a hypothesis. Should we succeed in finding consistent schemata in other instruments, the initial hypothesis can be upheld; if not, it cannot be upheld. The more consistent the interpretations, the greater the support for the hypothesis. A well-supported hypothesis may become a theory. In the end, a hypothesis is the basic form of conclusion in the humanities. Cognition usually advances from a weaker hypothesis to a stronger hypothesis, from less reliable to more reliable statements and conclusions. Organology is no exception.

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Summarizing our concept of historical organology, there are two different approaches, which we call the descriptive and the interpretive. The former describes, documents, and compares, while the latter deals with "why and how" questions, offers explanations, and places those explanations within a historical context. The former measures a horn or a lute in the conventional way, with lengths and diameters in modern terms, whereas the latter attempts to return—if possible—to the original design, which includes the original measurements and concepts. The former measurements are "objective," the latter, interpretive. We can compare the two approaches in the following way: both view history from different angles. The descriptive approach of historic organology looks backward from the present time; one assembles the observational data, compares, and condenses it. The interpretive approach looks at the instrument from the period of its manufacture. These complementary approaches have their strong points as well as their limitations. Both are useful and necessary, because both contribute different facets of reality to our knowledge of the musical instrument.

The author would not wish to replace the first approach with the second, but he pleads for the acceptance of the interpretive approach to historical organology, which is, in a cognitive sense, an objectively existing research possibility. Its acceptance would lead not only to an enrichment of organology, but also to a broader and deeper understanding of the musical instrument in culture and history. Benefits can also be anticipated for building historical reproductions of instruments. Instead of copying on the basis of physical understanding alone, it should be possible to recreate instruments from their historical basis in all its aspects—intellectual, artistic, and spiritual. Perhaps we could then reach the level of artistry of the old makers, with its attendant leeway for individual expression.

Linked with the culture of thinking in traditional organology, which is understandably opposed to the concept of interpretive organology, there is another inauspicious factor. It is the fact that organology is splintered into tiny factions or specialties. It is all too common for a viol researcher to care nothing about harpsichords, or a trumpet specialist, nothing about violins. This situation, which is often regarded as specialization, results from the fact that organologists often develop from musicians or instrument makers, who have an interest only in "their" instrument. Not a few conduct organology only as an avocation, while pursuing instrument making or musical performance as a career. Focusing on a special field to the exclusion of other fields is admittedly convenient, but it nourishes a myopic outlook that precludes potential benefits from neighboring fields. It foregoes the "compound" effect.

4. The professional craft of instrument making—sound and proportions

In this and the following sections of this article I shall outline the historical and intellectual context in which the use of proportions evolved and demonstrate how makers proceeded in principle. A fitting period with which to start our survey is the fifteenth century, when the Renaissance emerged and polyphonic instrumental music arose. It was a time when instruments such as the clavichord, harpsichord, slide trumpet, trombone, and viola da gamba came into use. The new instruments had to conform not only to the standards of *ars musica,* but also to the social conditions of the middle and upper classes—that is, the social bearers of the new music. The adjustment included not only the enhancement of workmanship and technical capacities, but also the sound's attunement to the ethos of *ars musica.* Instrumental sound was thought to emanate from *harmonia universalis* and *harmonia humana.*[21] Organ building and bell foundry had already ascended to the new professional standards at a much earlier time. In all these instruments we find that a different situation pertains to instruments that served traditional improvised folk and minstrel music. Changes in instrument construction did not occur abruptly but gradually, as did the transition from traditional improvised instrumental music to polyphonic instrumental music.[22]

According to medieval and Renaissance tradition, architecture comprised not only the art of building churches and other edifices, but also the higher technical arts such as carpentry, organ building, bell foundry, turnery, brazing, and clock making. With specialization and diversification of the crafts—including the divergence of clavichord making from carpentry, and trumpet making from the trades of the braziers and coppersmiths—the old tradition of architecture as a mother trade disintegrated. Nevertheless, architecture kept its mother-role for some time, setting standards for workmanship and design. Within the hierarchy of professions and occupations, architecture and all its scions were classified as *artes mechanicae.* This group of the arts ranked below the sciences, which were united in the quadrivium and comprised arithmetic, geometry, astronomy, and music theory. Aside from their own pursuits these studies functioned as basic sciences for the mechanical arts. Unlike their modern descendants, the sciences of the quadrivium were branches of natural philosophy. Along with philosophy, they ranked just below theology, which was "the queen of the sciences." Following scholastic-Aristotelian understanding, their goal was not to make new discoveries but to demonstrate and to learn by observation how nature works as God's creation.

The founder of Renaissance architectural theory, Leon Battista Alberti, in his seminal *De re aedificatoria* (1450/51), based architectural design specifically on music theory, not on geometry or arithmetic.[23] In his *I dieci libri dell'architettura di M. Vitruvio* (Venice, 1556), Daniele Barbaro made the musically based architectural theories of Vitruvius (first century B.C.E.) available to a wider audience.[24] Music theory was considered to be the basis of harmony, but Renaissance architects also cited educational reasons for founding architecture on music.[25] Following the Pythagoreans, Plato, and Boethius, music aided man's struggle for his ennoblement and sublimity, which was also the goal of architecture. In the decades around 1500 practicing architects tried to establish links between music and architecture. For example, Francesco Colonna (ca. 1453-1517), Cesare Cesariano (ca.

1477-1543), and Donato Bramante (ca. 1444-1514) argued that the orders of Classical columns (Doric, Corinthian, etc.) affected the viewer's soul in a manner similar to that of the musical modes (Dorian, Phrygian, etc.); a related line of thought linked the spacing of a colonnade to the mensural structure of music.[26] Just how seriously architects took this dependency on music is revealed by the fact that the music theorist Franchino Gaffurio was invited to serve as a musical consultant to Bramante when he designed the *tiburio* of Milan Cathedral. Later, in 1518, Gaffurio published *De harmonia musicorum instrumentorum*, which, however, does not address the design of musical instruments. It treats only music theory, which he considered to be the intellectual basis and incentive for all aspiring learned designers and makers.

In the fifteenth century, unlike today, the word "harmony" had meanings reaching far beyond that we now understand as musical harmony: it had a universal connotation and extended to the realm of spatial partition. Harmony was closely connected if not identical to the idea of beauty, and was also closely related to the concept of rightness and ethos. All these notions—harmony, beauty, regularity, rightness, and ethos—had their philosophical basis in a worldview in which numbers, ratios, and elemental geometric structures were the constituents of the universal whole. According to ancient and Renaissance thought, numbers appeared in arithmetic in their own right, in geometry as spatial relationships, in astronomy as the distances between the planets, and in music as intervals. The Pythagoreans considered the world to be perfect, harmonious, and beautiful, and Plato (ca. 427-347 B.C.E.) in his *Timaeus* had expanded this worldview to a high level of sophistication. He distinguished between the inner "proportional" beauty and the outer beauty that appeals to the senses and is bound to physical immediacy. He also inaugurated the seminal idea that the goal of the arts ought to be the imitation of Nature, i.e., reality. The appropriate way for an artisan and artist to imitate reality was to proceed on a small scale, as the Creator did on a large scale. Thus the artisan was obliged to use proportions to establish the "inner" form if he wanted to be "professional" and wanted to become a respected practitioner of his craft. According to this philosophy, proportions guaranteed both beauty and rightness of the product. Though of ancient origin, these ideas were brought to new life and expanded during the fifteenth and sixteenth centuries. Antiquity was regarded as the Golden Age, which thereafter deteriorated toward the present. We know that this assumption was a fallacy, but nevertheless it was a powerful driving force in Western civilization.

Returning to Alberti, we can now understand why he as well as architects before and after him based architectural design on music theory: it is the epitome of harmony and conveys the concept of a united world with its movement from one area of reality to another. Its transits include bridges between music, sound, proportions, and space, which lead—when building an instrument—from the artistic aspect to the physical. Regarding the numerical basis of visual and auditory forms, Alberti wrote,

> I affirm again with Pythagoras: it is absolutely certain that Nature is wholly consistent. That is how things stand.

> The very same numbers that cause sounds to have that *concinnitas*, pleasing to the ears, can also fill the eyes and mind with wondrous delight. From musicians therefore who have already examined such numbers thoroughly, or from those objects in which Nature has displayed some evident and noble quality, the whole method of outlining is derived. But I shall dwell on this topic no longer than is relevant to the business of the architect.[27]

Alberti refers to number-based harmony, which creates the sensation of beauty in the ears as well as the eyes. The term *concinnitas* comprises, in addition to harmony, propriety, rightness, and ethos in the sense of the Greek *kaloskagathos*. [28] In this philosophy and mindset we recognize the theoretical basis also for the use of proportions in instrument making. Alberti was a seminal, "mainstream" figure in his field who influenced virtually all later Italian architects—Filarete, Francesco Colonna, Bramante, Serlio, Andrea Palladio, and others. North of the Alps we find somewhat older but similar design theories—for example, in Lorenz Lechler's Gothic design booklet of 1516.[29] When the Italian Renaissance expanded north of the Alps, its theories of design followed. Though the decorative and formal style changed from Renaissance to Baroque, and later to classical idioms, architects and cabinetmakers continued to use these underlying proportional schemes. They were still using them extensively in the seventeenth and eighteenth centuries, if not later. They appear, for example, even in the "masterpiece drawings" of the cabinetmakers' guild of Mainz from the end of the eighteenth century. Such drawings were the first part of the *Meister* (master) exam, their practical renderings as furniture pieces the second. In Regensburg the cabinetmakers' masterpiece regulation decreed building a desk "according to proportion, T-square, compasses and quadrants."[30] In addition to architecture and its scions,[31] other art forms similarly derived their foundation from musical proportions: dance,[32] poetry, and painting.[33] And as for music, Pietro Aaron summarized succinctly, "The power of number has precedence over music...."[34] It goes without saying that proportions were used only to establish the basic frame, while all details were free renderings within the context of contemporary conventions and trends.

After reviewing the context and the situation in related arts and crafts, we can assume that instrument making fits the same model. In addition, there is the cultural context of sound and its specific understanding that suggests the use of proportions. Sound is the most critical artistic quality of an instrument. It is a quintessential expression of many cultural factors; it reflects thinking and feeling of a period, the musical trends, and the maker's imagination. We can summarize these cultural and psychological factors of sound in the following four points:

1. It was universally accepted that music was a reflex of the harmony of the universe, which usually was connected with the idea of the consonances. This concept encapsulated a rational and a spiritual element; both were archetypical reference points of music. The rational element of sound is a potential source for the use of proportions in music and instrument making.

2. Sound was assumed to have a dual nature; it was understood as both *ratio* and physical event. Emphasis lay on the notion of ratio.[35] Summarizing the assumptions then current, Gioseffo Zarlino in *Istitutioni harmoniche* (1573) argued that the *numero* was *sonoro*, and thus the acting sonorous agent.[36] Sound qualities were encapsulated in ratios, which were drawn from the observation that each interval has its own sounding quality. Shortly thereafter, Vincenzo Galilei criticized and rejected this assumption (see below). The understanding of sound as a ratio corresponds with this condition: In a proportionally organized physical structure, the sound can find the adequate condition for its unfolding, just as an identically tuned instrument responds in resonance. This correspondence between the rational concept of sound and its physical analogue, the structure of the instrument that produces the sound, is a harmonious relationship, which suggests the potential of creating a beautiful sound.
3. Sound was connected with different fields of reality by way of correspondences. Correspondences are supposed links between various aspects of reality, which have at least one factor in common. Within ancient and Renaissance thinking they were common means of making reality understood.[37] They included the cited associations between architectural types of columns and musical modes, the association between trumpets and the Gospels, the correspondence between macrocosm and microcosm, sun and gold, etc. In a wider sense correspondences also comprised attributes, which are related by causality, such as the monochordic relationship between string length and pitch. There are also correspondences between timbre and dimensions of the air column, which cannot be expressed by simple numerical relations. However, the Pythaogoreans, who extrapolated extensively from the monochord system, connecting astronomy, arithmetic, geometry, and music by means of number, universalized the causal relationship between string length and pitch. It was not until the scientific revolution and the Enlightenment that these correspondences were approached critically, distinguishing "speculative" from causal relationships.

Even though some of the correspondences may be considered speculative, such as the association between visual and aural conditions, they have a rational basis in *synesthesia*. Today's cognitive psychology defines *synesthesia* as "experience in which stimulation of one sensory modality also arouses sensations in another."[38] Synesthetic experiences are manifest, for example, in expressions such as "bright sound," "deep sound," "mellow color," in which the modifiers belong to different sensory fields from the nouns. In this innate form of relating different sensual areas we find the psychological basis for many correspondences, including the association between sound and visual/spatial conditions. While sound qualities are not directly measurable, visual conditions are; therefore visual equivalents can be used to plan analogous sound qualities in instruments. In addition to this synesthetic relationship, extrapolation from the monochord comes into play. Renaissance scholars and learned instrument makers did not argue on the basis of synesthesia, but used the concept according to which the human soul is composed of the perfect consonances.[39] Whether one perceives a visual or an aural message, the soul will respond in the same way. This is the very argument that Alberti cited. It goes without saying that a harmonious sensation will occur only if the visual or spatial structure is proportionally arranged. Here we arrive at the opinion of Plato and Aristotle as to the task of the artist: he must proceed basically in the same way as the Creator, namely by building his work on numerical ratios and elemental geometrical units. Irrational visual proportions such as the golden section have sounding correspondences as well.[40] This explains why we find the golden section in historic instrument making on a regular basis. In addition to the mathematical attributes of the golden section, the Venetian mathematician Luca Pacioli's *De divina proportione* (1509)[41] lists a series of religious and ethical associations and praises its spiritual depth.

4. The input of contemporary musical trends. While the previous three factors suggest the use of proportions in one way or another, historically more recent impulses do not support their use. Aside from the renewal of ancient ideas in the Renaissance, there were also trends that reflected various aspects of the contemporary tendency toward a more realistic relationship with nature. They included correspondences between sound and space: the range of spatial experience as high and low—Heaven and Earth—became associated with tonal range. Here we probably find the root for the increasing bright-dull gradient that exists between treble and bass instruments. This gradient increased constantly over the centuries and found its most telling expression in the wider bore of bass wind instruments. A reference closer to reality came to be reflected in the "rhetorical" imitation of the voice in instrumental playing. This trend demanded instruments more responsive to the intentions of the player. It led, for example, to a more differentiated treatment of the thickness of the top and bottom plates of string instruments. Realism corresponded also with clarity and distinction in tonal and musical expression, with a sonorous and resonant sound quality.

Taking all four factors together, they form a complex system of ideas and correspondences that may constitute a concept of sound as precondition for the development of a new model, or a new instrument. When realized, these factors endow the physical sound with meaning. The first three factors, which have their origins in ancient thought, suggest the use of proportions in instrument making. The notion on which the suggestion is based is the principle of analogy. Accordingly, proportions are suggested not by physical causation but by reasoning similar to the phenomenon of resonance. The fourth factor, as the most recent one and which grew in strength after the Renaissance, bears on empirical refinement of the instrument's structure.

Even though the use of proportions is suggested on the grounds of a way of thinking characteristic of the Renaissance, the question remains as to whether proportions are effectual as acting agents to generate a conceived sound. Those who reject proportions (see section 3, above) usually make their case with physical arguments: A proportion is merely a geometrical attribute, while the creation of a special sound quality requires the combination of several physical parameters—thickness of the material, elasticity module, etc. Any violin maker knows how profoundly the thickness of the plates can affect the sound, while changing the width-length ratio from 1:2 to, for example, 1:1.9 makes little difference. As early as the 1580s, Vincenzo Galilei demonstrated in his *Discorso particolare intorno diversata delle forme del diapente* that a particular ratio, such as 1:2, applies to string length only under the conditions of equal tension and thickness. For example, when retaining equal string length and thickness, a fourfold increase in tension is required in order to obtain an octave.[42] Once other parameters are involved the acoustical event becomes complex, a situation not taken into account in the proportional structure of instrument design. In the case of vibrating air columns, sound qualities are determined by geometrical configurations, which hardly produce satisfactory results in tonal quality and intonation. Adjustments must be made, and as was said before, there is no persuasive evidence that a configuration of 1:2 yields better results than 1:1.9.

These arguments represent "modern" knowledge, which evolved since the scientific revolution and during the scientific age. Extrapolating this knowledge to an era that thought in other terms violates the principle of historicity. Neither philosophers/scientists nor instrument makers of the Renaissance were yet aware of complex physical conditions, as they were addressed by Vincenzo Galilei, then by Galileo Galilei and Marin Mersenne, and subsequently by physicists. Renaissance scholars and makers thought in terms that, as regards the materialization of a sound concept, did not employ the notion of physical causation, as we will show. Scholars approached reality subjectively, rather than taking an objective position, looking at nature from the outside as we do. Following ancient teachings they understood reality as a system of phenomena, which they demonstrated, compared, and explained by correspondences.[43] It is an approach to reality that in today's scientific perspective is more comparable to that of an artist than a scientist. According to modern physical standards, which regard causation as the agent to determine the factual relation between phenomena, the principle of analogy passes for speculation. However, instrument making as we have described it functioned as an art rather than as an empirical craft aided by acoustical science. It is therefore a misconception to apply the notions of modern science as a means of judging early instrument making. The principle of analogy works via artistic channels and, of course, uses speculative concepts. Any art is speculative at its heart and may follow physical terms only as an admixture.

Developing a new model from scratch, instrument makers would proceed in a series of sequential steps in which the sound concept was gradually realized along the principle of analogy. We can summarize this path of developing and building an instrument in two major steps, each divided into two sub-steps:

1a. Initial step. At the beginning there may be a rough concept, developed on an empirical basis. It may be executed as a preliminary drawing. If there are similar models already in existence, these may offer guidance.

1b. Design phase (*lineamento*). The rough concept is adjusted to a proportional scheme in order to predispose a proper and beautiful sound. In the ideal case this scheme is realized in the form of a technical drawing.

2a. Building phase (*prattica*). The *lineamento* is realized in the form of a finished instrument. The maker transforms the envisaged and predisposed sound into physical reality, using two creative approaches: empirical method (feedback, trial and error) and imaginative rendering. The concept of sound as the maker imagines it, encapsulated in the *lineamento,* may serve as a guide for constructing the instrument.

2b. Artistic phase. This phase exists only if the maker has artistic talents, and only in conjunction with 2a. If the maker has such talents he is capable of imparting particular and outstanding qualities to the instrument. Although any artistic and creative work eludes analysis, we know from the widely differing qualities of instruments that this phase existed.

The aesthetic experience we have when listening to music and musical instruments of the Renaissance period confirms that the analogy principle worked successfully. Who would argue that the sound of those instruments is accidental and does not reflect the artistic and intellectual self-understanding of the Renaissance? On the contrary, the music and sound of those instruments convey the spirit of that period in an intimate and appropriate way.

The two- (four-) step procedure that we outlined was still in use during the Baroque period, but with some important differences. Expressive tone qualities came ever more in demand and required greater empirical input on the part of the maker. In the eighteenth century, when subjectivity of expression and standardization of instruments expanded, subjective empiricism supplanted the old proportional methods. In the following paragraphs we will elaborate on the more practical aspects makers employed to impart their sound concepts to the instruments.

As outlined above, Renaissance makers proceeded in two steps when developing and constructing an instrument. Italian architects from the fifteenth century on called the first step of planning and laying out *lineamento*[44]; German architects called it *Visierung, or Riß.*[45] Apart from establishing the basic plan, its principal objective was to guarantee propriety and "inner" beauty of the structure (in Plato's sense). Instrument making apparently proceeded in principle in the same way as architecture and the other branches of the mechanical arts, apart from the specific musical aspects. Therefore we can call instrument making of the Renaissance, with some justification, "sounding architecture." Arnaut de Zwolle's drawings (fifteenth century) are just such *lineamenti,* and Pablo Nassare's description of the vihuela (1724) is in a sense a verbal *lineamento.* A properly prepared *lineamento* predisposed a beautiful and "right" sound, giving the appropriate shape to the layout of a viola or the air column of a trumpet.

The proportions used in instrument making were diverse and included related geometrical procedures. Drawing on experience with string and wind instruments, designs usually incorporated the ratios of the consonances, 1:2:3:4:5, the diagonal of the square (1:1.414), and the golden section (1:1.618). Moreover, designers used other ratios and geometric methods.[46]

Architects called the second and far more extensive step *prattica,* which referred to the fleshing out of the skeleton of the *lineamento.* Makers are generally empiricists by orientation, and the diversity of sixteenth- and seventeenth-century instruments in type and execution demonstrate makers' attempts to try different solutions. In the ideal case, a detailed practical plan was laid out before the maker began the process of construction. The goal was a durable instrument that worked and sounded well. Starting from the lineaments, the instrument builder had to make decisions about such aspects as the thickness of the walls, types of joints and buttressing, materials, and decoration. Craft experience, manual skills, technology, and experience in all questions of sound and its relation to structure came into play.

Imparting a beautiful sound to an instrument requires activating and internalizing the envisioned sound concept, which in a proportionally designed instrument is encapsulated in its most subtle form in the proportions. Conversely, in a freely designed instrument the sound concept remains in the imagination. The maker would approach the internalization of the sound concept on the broad front of his entire competence. On the lowest level he would engage his experience, employing trial and error in the form of feedback between the envisioned sound concept and the sounding result. This procedure steers the transient sounding results ever closer toward the intended concept, eventually making them analogous. On a more advanced level, creative channels come into play, which will subconciously or even unconsciously assist the maker in realizing that to which he aspires. If the maker has artistic talents, he will be able to translate the original sound concept into a beautiful sound quality. Carving out a violin plate or hammering a trombone bell may proceed intuitively to some extent and may entail a refinement that eludes measurement and documentation. A maker without creative talents is capable only of manufacturing an instrument, using his craft experience. When in 1719 a customer from Rudolstadt asked who among the eight masters in Nuremberg would make the best trumpets, the answer was J.W. Haas.[47] It was he who on the basis of his inborn talents and experience was able to create that refinement that is reflected in the high quality of his instruments. What ultimately determines the artistic and market value of an instrument is the maker's creative talents and not its reliance on proportions or acoustical calculations.

The various attributes of the sound concept—clarity, restraint, spirituality, expressiveness, etc., are translated, ideally, into physical sound. Listening to it elicits corresponding feelings on the part of the listener. If this correspondence occurs, the sound concept has been successfully realized. The proportional design of the instrument is part of the analogy because the sound concept itself is derived in part from the analogue rationality associated with the sound. This correspondence in instrument making equals the analogy among *musica mundana, musica humana,* and *musica instrumentalis.*

Apart from materializing the intended sound concept—not to mention other aspects of building and technology—the maker might be required to modify proportions. In particular, such modifications may be necessary in wind instruments, where good intonation dictates a slight adjustment of strictly cylindrical or conical bores of the *lineamento.* Makers developed these modifications on a purely empirical basis, generating precious craft experience, which they handed down from generation to generation without committing them to paper. Adjusting rigorous geometrical configurations does not nullify the use of proportion as a design principle. According to my observations in woodwind instruments, makers modified particularly the diameters between the proportional end points. However, adjustments may affect the corner dimensions of the proportions, thereby leading to their distortion. Thus it may at times be difficult today to distinguish the two levels of work and to identify the proportions of the lineaments on an empirical basis. It challenges us to develop precise measuring tools and examination procedures in order to determine as precisely as possible how the maker proceeded. Modern acoustical aids, for example, may help us decide what observations induced the old masters to modify a bore. Flutes, oboes, trumpets, etc., were not the only instruments subjected to proportional modification. Concerning the construction of organ pipes, the organ builder Johann Philipp Bendeler said in 1690,

> Lest you think that I would suggest that you could not or should not deviate somewhat from the musical proportions, I am going to tell you how to proceed if you decide to deviate somewhat from the musical proportions, in such a way that the equality is not noticeably obstructed, and therefore you can be assured as to the height and depth of the tone.[48]

The two (or four) steps involved in developing and building an instrument, outlined above, are a simplified means of describing a complex process. In practice, things blend and flow into each other. It also should be mentioned that the dichotomy between *lineamento* and *prattica* existed in more or less pronounced form also in other arts and crafts. In musical composition, for example, *lineamento* included determining *metrum, tempus,* and the *cantus prius factus*; *prattica* the fleshing out of the *lineamento* in harmony. In the age of thoroughbass the *lineamento* consisted of the bass and treble lines and figures, while *prattica* meant their execution in harmony, including the selection of number and kind of instruments.

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Apparently more than a few organologists who deny the use of proportions regard early instrument makers merely as skilled but empirically working craftsmen. If we examine history more closely, we find that the Renaissance was a period of learning. Any cabinetmaker, plumber, clock or instrument maker who wanted to meet the standards and challenges of the time had to learn more than just the basic skills of his craft.[49] We see mathematics beginning to penetrate the economic system and the crafts; it entered the design of fortresses, cannon foundry, and cabinet making. Collaboration between craftsmen and learned people was a requirement of the time. The authors of the anonymous clavichord treatises of the fifteenth century, Arnaut de Zwolle's treatise, and most of the numerous authors who calculated the fret positions for lutes and viols[50] were learned musicians or scholars who obviously worked with or for instrument makers. Personal contacts were probably the most important channels through which the knowledge of learned people trickled into the design practice of the makers. And those who were not capable of or willing to develop lineaments could purchase them.[51] Some of these learned people became makers themselves. Among them was "Maestro Laurentio de Papia organorum fabrecatori" in Venice, who appears in the records as *musicus* and had a command of Latin. Around 1500 he made viols, harpsichords, clavichords, and organs, and on 11 August 1508 he attended a lecture by Luca Pacioli concerning Euclid's *Elementa* in the church San Bartolomeo di Rialto in Venice. A "Magistro Antoni che fa i liuti" appears in the records of Cremona in 1556. *Magistro* was an academic title given to teachers; it must not be confused with *maestro,* referring to a "master" of a craft. Jacobo della Corna in Brescia is variously identified as *magistro a leuttis* (1524), *leutario et mercatore* (1524), and *magistro lirii* (1529/30).[52] We also find the roles of teacher, maker, and dealer combined in records concerning Girolamo Virchi (1523-after 1574), Gasparo Bertolotti (1540-1609) in Brescia, and Hans Frei and Hans Gerle in Nuremberg. These individuals were Renaissance men; they came into existence because they were needed in their time. Perhaps we can add to this list the Nuremberg town trumpeters and coppersmiths Hans Neuschel (II) and Georg Neuschel (died 1557), who received imperial privileges for trumpet and trombone making. In 1547 Johann Neudörffer praised Hans Neuschel and Sigmund Schnitzer for their skill in tuning entire sets of instruments, which they shipped to Italy, France, and various cities in Germany.[53] Although we do not have any information about their educational background or their possible collaboration with learned people, the historical context suggests that brass makers who were originally trained as braziers or coppersmiths somehow acquired music-related theoretical knowledge.

During the nineteenth and the twentieth centuries we also find collaboration between instrument makers, musicians, and learned people, the latter now mostly experts in acoustical science. We can even say, for example, that most of the important inventions and improvements in the field of brass instruments, flutes, and reed instruments were made by musicians rather than by instrument makers. Since the beginning of the nineteenth century, acoustical knowledge has become increasingly important to instrument makers. It has gradually become available in courses in acoustics in trade schools, in acoustical introductions to instruction manuals, and via personal contacts with acousticians. Since the 1930s scientific expertise has become obtainable to manufacturers also through acoustical research laboratories. In all centuries since the Renaissance, theoretical knowledge of the state of the art found its way into workshops, adjusted and probably for the most part reduced to the basics. In periods of revolutionary changes in craft and design theory—in the fifteenth century and in the first half of the nineteenth—it took a couple of generations for the new tenets to gain ground. Thus not only did proportional theory enter the workshop, but in a later era acoustical science did so as well—neither one however in its most profound expression but in a workshop-relevant form.

Given this situation, instrument making should be understood as a collective and applied craft. Its intellectual base is provided largely by music, philosophy (including the sciences of the quadrivium), and later, acoustical science. Theory is required particularly in the phase of an instrument's development. As the maker holds the sole responsibility for the product and marks it with his name, the theoretical input usually becomes obscure; only in written sources are theoretical contributors and inventors occasionally mentioned. As organology evolved in the last two centuries, it relied largely on the names of the makers (or dealers and businessmen) found on the instruments. But the scant information that is usually available about these names prevents us from gaining deeper insights into workshop practice. From a few cases we have learned that it was not always the same person who designed, built, and marked an instrument.

Instrument makers came from different backgrounds, and those who built instruments in the fifteenth and sixteenth centuries did so primarily as a sideline. This historical context suggests not only many different patterns as to workmanship, technology, and style, but also different approaches in design and the use of design methods. Clavichords built by trained organ builders were probably somehow different from those built by carpenters, lute makers, or former builders of folk instruments.

Surviving instruments show different standards of workmanship and musical qualities. Some of the makers were ambitious, innovative, and adhered to highly professional standards, while others resorted to mediocrity and copying. Proficiency included treating models as the term implies: using them for orientation. The execution of individual instruments may deviate from the model, as dictated by practice needs. We should also acknowledge that there were bunglers who were not properly trained, not licensed, or unfit for the job. Johann Heinrich Zedler's *Universal-Lexikon aller Wissenschaften und Künste* (1741) defines them in this way: "In all mechanical arts ... there are two kinds of bunglers. The one lacks knowledge and command of the spiritual and theoretical principles of the craft [art], the other the practical and manual skills."[54] Nor should we forget those makers in the tradition of folk musical instruments, who tried to bridge the gap between their craft—which usually followed purely empirical principles—and that of the professional makers. Our heritage of surviving instruments mirrors the complete array of professional levels. The first problem the researcher faces when examining an instrument is to ascertain its place in the continua of quality, workmanship, and proficiency.

5. Scientific revolution—Baroque—Enlightenment

The scientific revolution of the seventeenth century heralded a new era. The new age set out with an entirely new concept of how things work in nature—the mechanical philosophy.[55] It replaced scholastic-Aristotelianism, which studied nature as God's creation, with a more realistic approach to the understanding of reality. The controversy between Gioseffo Zarlino and Vincenzo Galilei in the 1580s about the nature of sound (see previous section) was one of the early touchstones of this new approach. From about this time on, scholars assumed a critical position toward the statements of the ancient authorities and began to take an objective stand toward the subjects of their study. Empirical method and the introduction of the experiment were important novelties in the sciences. Experience and observation gradually became the major source of knowledge, and causality was recognized as the fundamental relationship between physical properties. Mechanical configurations were explored and implied everywhere, even in the human soul. Some thinkers went as far as to regard man as a machine. Such interpretations were dealt as trumps in science's struggle for independence from religion and philosophy. Step by step, the sciences endeavored to shield any aspect beyond the realm of physical causality from scrutiny, and attained this goal in the nineteenth century. As a result of the new trends, instrument makers paid increasing attention to the causal relations between vibrating material and sound while excluding the metaphysical aspects of sound. After Galileo Galilei and Marin Mersenne laid the foundation of physical acoustics, research progressed slowly but steadily during the seventeenth and eighteenth centuries.

In tandem with the progress of both the scientific revolution and the Enlightenment, we observe a retarding current on all cultural levels. Here we can observe that historical changes do not effect a sudden eclipse of disparaged older traditions and beliefs. For example, when Nicolaus Copernicus proposed his heliocentric world image in 1543, over the ensuing generations only a few insiders believed him. The first step in its wider acceptance was Galilei's observation of the moons of Jupiter with the aid of the telescope in 1609-11, while the second was Pierre Gassendi's observation of Mercury's transit in 1631, followed by the transits of Venus in 1671 and 1679. Only after Johannes Kepler discovered the laws of the planetary orbits (1609) and Isaac Newton placed the system on the gravitational law (1687) did the heliocentric world image become generally acknowledged. But there were still unbelievers in the eighteenth century, and even in the year 2000 a "Flat Earth Society" existed in the U.S.A. While the use of proportions in instrument making is not comparable to a scientific discovery such as the heliocentric planetary system, in instrument-making methods too we notice an evolving bifurcation. On the one side we have a progressive current that embraced the more aesthetic and physical understanding of the sound, while on the other side is a conservative current that adhered to the rational and Pythagorean perception of sound. Those makers who favored the first current gradually began to abandon proportional methods. Of these modernists the organ builder Johann Philipp Bendeler wrote in his *Organopoeia* (1690) regarding the proportional layout of organ pipes,

> And some fell on the idea that the foundation of mensuration must be sought in stereometry and not in musical proportions; and therefore they did not hesitate to stigmatize musical proportions as antiquated and deceptive fictions of Pythagoras.[56]

Bendeler's statement shows that the trend of breaking away from proportions was tangible as early as in the seventeenth century, and the trend accelerated during the eighteenth century.

The Baroque style in the arts and the Enlightenment in intellectual life evolved in roughly parallel fashion with the scientific revolution and empiricism in the sciences. Both of the former currents promoted human awareness toward a higher self-confidence and subjective expression in the arts. A turning point was reached in the middle of the eighteenth century, when educated taste became the principal agent in the formation of an instrument's ideal sound. Sound was losing, if it had not already lost, its rational nonmusical correspondences and became an aesthetic quality associated with subjective sensations and taste-related assessment. Educated taste was elevated to a position of prominence from which it could render aesthetic judgments. Proportions were likely seen as restricting subjective expression, and hence were gradually abandoned. A building method evolved—we will call it "subjective empiricism" or "free design"—based on the subject's taste and discretion. The lack of rational aspects sets up a sound that suggests free design with no proportional arrangement. Not only the sound but also the form, and the relationship between the two, were included in the taste-governed consideration of the design. While the maker works freely in creating the outline or the bore of an instrument, he is expected to achieve a balance so that the form or bore will yield the sound he has envisaged. Thus the maker was expected to develop a fine taste also for a harmonious form that was the frame for a cognate sound. Otherwise he might earn scorn, as did those violin makers of whom Giovanni Antonio Marchi in 1786 sarcastically said,

> There have been violin makers who have outlined their violins as if they were outlining a shoe. It is true that one should be endowed with good discernment and a refined taste to outline a violin, and the same applies to the neck.[57]

Makers now began to assess instruments on the basis of their harmonious design, looking at them with the eyes of connoisseurs. If proportions were used, the relationship between sound and structure was determined quantitatively by means of proportions. In order to prove their existence, these proportions would have to be measurable. Free design is not so easy as it appears to be, because establishing the correspondence in a way that produces a musically satisfying result is left to the free proportional pondering and discretion of the maker. The difficulty of creating a free design was probably one reason why some makers adhered to proportions; proportions formally guaranteed harmony, visual correctness, and symmetry. The correspondence between sound concept and form in free design is realized by empirical and artistic methods, as is the materialization of the sound concept when building the instrument. These methods continue to work largely on the basis of the principle of analogy, as they have always done. They include the use of experience, trial and error, and creative-artistic work. Instead of using a *lineamento,* the designer of a new model would establish an empirically developed drawing. In general he would modify the structure of an instrument until the preconceived sound was achieved.

The aesthetic taste of the Enlightenment espoused the ideas of the natural, the balanced, and the measured; reason and experience were enshrined as the supreme intellectual authorities. This is the point at which aesthetics and empiricism began to form an alliance with acoustical science. The insights of science were seen as capable of supporting empirical methods. In this way physical causality became an aid to empirical methods in establishing a new model and building it. Aesthetics and subjective empiricism are on the cultural side of the instrument, acoustical science on the physical side. The more acoustical science penetrated instrument making during the nineteenth century the more the understanding of the musical instrument shifted toward acoustical device.

Subjective empiricism evolved along with aesthetic strivings for tonal homogeneity of the entire tessitura and free chromaticism. Subdued and weak tones as well as tonal imbalances were seen as inconsistent with reason and "the natural," and regarded as outdated. It was practitioners—musicians and instrument makers—who targeted practical problems of instrument design, such as the shadowed tones resulting from cross fingering in woodwind instruments and the subdued tones in horns as a product of hand stopping. The Enlightenment embraced the idea of progress and believed in the improvement of human culture. This attitude cast a shadow on the past, which began to be seen as inferior. And it cast a shadow on proportional methods in instrument making, which were likely to be seen as rigid and ineffective, if not totally wrong. However, several decades were to pass before the acoustical aspirations of the Enlightenment were realized, during the period of industrialization soon after 1800.

6. The rise of physical acoustics and Romanticism; the demise of proportions

Since about 1800/10 the most devastating blows against proportions have been dealt by physical acoustics and Romanticism. Distinguished acoustical novelties were Ernst Chladni's discovery of sound figures (1802), which show how violin plates actually vibrate,[58] Félix Savart's research on the *eigenmodes* of the violin (1819),[59] and Gottfried Weber's practical acoustics of wind instruments (1816).[60] Weber argued that the traditional position of the finger holes of wind instruments, including serpents, was acoustically incorrect. Positioned to accommodate the player's hand rather than following acoustical principles, these finger holes were too small in diameter and too closely spaced, resulting in a "small" sound. If finger holes could be arranged according to acoustical law, so was the understanding, a louder, more open, and thus more natural sound would result. From that time on, particularly after about 1830, the new principles of practical and theoretical acoustics penetrated the entire craft of instrument making. The impact was so fundamental and seminal that we can speak of an acoustical revolution in instrument making. Makers were aware of the new orientation in the craft and pilloried traditional instruments and their methods of construction. At the same time they saw in modern acoustics the solution for all problems of instrument making. For example, the Munich piano makers Friedrich Danchell and Friedrich Greiner wrote in a patent application in 1834,

> We realized that the main flaws of earlier string instruments consist in this: 1st, that instrument making to date does not rest on a firm and proven principle with respect to acoustics, which is why the execution of each single instrument and its quality is purely accidental....[61]

Thanks to acoustical science, so they argued, only "modern" instrument makers would be in a position to overcome the imperfections of traditional instruments. Félix Savart was even convinced that his discovery of the *eigenmode* of 512 Hz in Stradivari's violins would make possible the manufacture of instruments of equivalent tone quality.[62] One needed only to tune the belly to 512 Hz. The belief that acoustical science would be the key to further improvement of the instruments took hold also in musical and aesthetic terms.

Nevertheless, while most makers adopted the modern empirical and acoustical approach, a few still advocated proportional methods. This fact stands out even in the source literature. Speaking only of the latter group, the literature on organ building includes Georg Andreas Sorge's *Die geheim gehaltene Kunst von Mensuration von Orgelpfeiffen* (1764),[63] François Bedos de Celles' *L'Art du facteur d'orgues* (1766-1778),[64] and Johann Gottlob Töpfer's *Orgelbaukunst* (1833) and *Lehrbuch der Orgelbaukunst* (1855/56),[65] all of which present organ pipe scaling according to proportional methods.[66] In piano making we encounter in addition to the 1:2 ratio[67] a smaller "tempered" 1:2 ratio, which allows its retention through a larger section of the compass than in the case of the precise 1:2 ratio. In 1811 the firm of Joseph Wachtl & Bleyer in Vienna was apparently the first to advocate such a smaller octave ratio, namely of 1:1.946, which was later adopted by Carl Kützing[68] and Johann Gottlob Töpfer as well. Later, in 1896, Wilhelm Fischer in Berlin even suggested a ratio 1:1.88.[69] A different kind of proportionally based string scaling was described by Heinrich Welcker von Gontershausen in 1853.[70] In violin making there were, for example, Wilhelm Theodor Gutermann (1828-1900) in Vienna, who built violins on a proportional basis following the number theory of the physician Franz Liharžik (d. 1866), and the Berlin violin maker Carl Schulze, who designed a monochordic-proportional violin in 1901. As for brass instrument making, we have already listed the principal relevant documents in the initial section of this article.

Adolphe Sax' statement of 1850 (see section 1, above) indicates that the struggle for and against proportions was painful. On the surface, it was about special building problems, but on a deeper level it touched upon basic beliefs concerning how things work in general. Unfortunately, then and now the battles were and are settled on the premise of right or wrong, yes or no. It would be more correct to say that the problem was and is one of talking at cross-purposes. Given the general scientific orientation in the nineteenth/twentieth-century western mind, it is logical that the acoustical current eventually prevailed. Nevertheless, if we evaluate the entire range of instruments of the sixteenth through the twentieth centuries in artistic terms, the later instruments are not superior to the earlier ones; they do not have superior sound, musical, and structural qualities. They are only different, more or less. It can also be said with certainty, for example, that the Boehm flute's prevalence over the simple-system flutes was not the result of its acoustically based design but rather mostly because of the practical advantages of its key system, as well as its greater dynamic range and loudness. We see that the role of science in instrument making, which is in the end an empirical art and craft, is relative. We also see that not only do proportionally designed bores require adjustments, but also acoustically designed bores. The physicist Emil Carl von Schafhäutl, who made the calculations for Boehm's cylindrical flute, wrote in 1882,

> I very often brought Boehm results of long calculations, but as soon as he had constructed his flute according to them, there always were a few cycles too few or too many [i.e., the pitch was slightly too high or too low].... Theory alone would not have been able to generate the new flute. It required secondly the ingenious musical mechanical artist Boehm, ...The third reason ... was that Boehm himself was a virtuoso. As a virtuoso and artist he alone was in a position to assess what can be executed, by whatever means theory and practice have created, in order to meet the highest requirements of the art....
> If theory, which replaces creative thought, is capable by means of measuring and calculating to penetrate the inner nature of the phenomena of sound waves and, for example, to elucidate the laws of sounding vibrations, so it is likely that only the ingenious mechanic and virtuoso, building further on the practical consequences of theory, can create a true—i.e., practical—musical instrument. Lacking the attributes of such a virtuoso, centuries would certainly have been required for its accomplishment. [71]

Sax' adversaries criticized the need for adjustments and used this as an argument to disregard proportions. In their view, proportions were worthless because they needed to be "modified according to the demands of the artists."[72] There can be no doubt that acoustical science has made tremendous strides over time, but as a science it is incapable of creating aesthetic improvements from the cultural roots of the art. After Savart's efforts fell short of producing violins of Stradivari's quality, acousticians found a second *eigenmode*, and ultimately, in 1926, a third one, which also failed to yield a solution to the problem.[73] More recently, in the 1950s acousticians recognized the borders of acoustical science and relinquished the claim of improving musical instruments in an aesthetic sense.[74] Sound qualities are determined by cultural-aesthetic factors in the first place and realized on the basis of the principle of analogy. Since the second half of the eighteenth century, subjective empiricism and free design have increasingly expanded as the main methods of designing and building instruments.[75] Building an instrument engages various empirical methods, ranging from basic craft experience, trial and error, and more refined empirical methods such as weighing and balancing, to specific artistic procedures. Acoustical science, which works on the basis of physical causation, adds another facet to this spectrum of methods. Even though acoustical science has limited creative possibilities, it has successfully developed and continues to develop its potential, particularly regarding quantitative, pitch-, and intonation-related aspects. These are factors of considerable importance in our modern period of increased standardization. They help to realize those often minute nuances in intonation, response, and tone quality that have become so essential in the electronic age. While acoustical science acts on the sound from the physical side of the sound, proportions have influenced sound from the cultural-psychological side. They were instrumental in realizing the sound concepts of Western civilization in earlier eras. What we appreciate today in the music and the sound of the Renaissance and Baroque eras was in part accomplished by means of proportions, in one way or another.

The increasing emphasis on the acoustical side of sound parallels larger cultural shifts. The nineteenth century adopted the Enlightenment's belief in reason and experience as supreme values, and material benefits from the rapidly developing industrial sector confirmed the "truth" of this tenet. Science became the prime intellectual authority and expanded its competency into cultural fields wherever possible. In the wake of this trend, instrument makers tended to follow acousticians regarding musical instruments as acoustical devices. This transformation goes hand in hand with a movement from a more idealistic to a more materialistic world view. Proportions are associated with idealism and metaphysics, acoustical science with materialism. During the nineteenth century both acoustical and proportional building theory sought support from scientific research. Unquestionably most research supported the non-proportional side. But there also were scientific discoveries that supported proportional design, including the following:

- Jean Baptist Joseph Fourier (1768-1830) discovered that overtones relate to each other as integers. Thus a single tone encapsulates a monochord system, in a sense.
- In 1865 and 1876 Gustav Theodor Fechner's research into psychological perception demonstrated that humans, if asked to choose among objects with different ratios of width to length, prefer forms that follow the golden section, are symmetrical, or have simple numerical ratios. Recent psychological research largely confirms the inborn nature of these preferences.[76]
- Empirical research has shown that natural forms as found, for example, in minerals, snowflakes, conch shells, cranial structures, and the growth patterns of plants often show geometrical regularities. For example, the ratio of the width of an oak leaf to its length corresponds to the golden section.[77]

These findings support the older, waning belief that nature's fundamental laws are based on regularity, simplicity, and harmony. This perception lived on in philosophical currents of neo-Platonic and neo-Pythagorean bent, and focused on the phenomenological side of nature. It increasingly lost ground and almost disappeared from the purview of science. However, a thin layer of it has survived to the present day,[78] and has enjoyed greater attention in the last few decades as the global aspects of climatic change and the discussion of intelligent design in astronomy and biology have begun to haunt the modern mind. It is also noteworthy that such distinguished scientists as Henri Poincaré, Albert Einstein, and Werner Heisenberg have repeatedly maintained that nature works on the basis of simplicity, coherence, and harmony.[79] Unlike the ancient authorities, who arrived at the same conclusions by way of philosophical speculation, these modern scientists drew their conclusions on the basis of empirical inquiries in the fields of physics and astronomy.

Nonetheless, tradition-minded natural philosophy increasingly became sidelined as did the use of proportions. Romanticism embraced subjectivism to a degree never seen before. At the same time critical thinking stripped off what remained of the former wealth of correspondences and exposed sound to the light of sober abstraction. If we find proportions in musical instruments of the second half of the nineteenth century and later, the reason is most likely one of the following:

- The maker followed tradition, or a philosophical or Pythagorean current, regarding proportions as a universal law. Proportions are considered a mark of professional work.
- Proportions suggest order and meaning, rightness and harmony. In this context geometrical methods may have been connected with physical acoustics.
- The maker used proportions to support the visual correctness of the instrument and to create a harmonious form or bore. These characteristics were intended to influence the quality of the sound in a positive way.
- Inspired by revival currents and a growing interest in history, the maker speculated that the old masters might have used proportions. He therefore used proportions in the belief that they would enhance the musical quality of the instrument.

Adolphe Sax was one of those who referred to the proportions as "governing laws" and used them to build frames for the bores of his instruments. Otherwise he was well versed in practical acoustics and an extraordinarily inventive empiricist. We do not know (so far) how he understood proportions specifically—whether he relied on the significance of proportions in music, the role of the harmonics as the backbone of acoustics, whether he thought in philosophical terms, or pondered the phenomenological side of nature. Violin designers such as Liharžik relied on Pythagorean natural philosophy, Alfred Stelzner and Anton Schneider, more on geometric-monochordic precepts, and Max Möckel on a historistic basis. In this context we must remember that, contrary to repeated claims, the use of proportion does not improve the artistic quality of the instruments, but it can contribute to shaping the character of the sound.

In the second half of the nineteenth century and the first half of the twentieth, some researchers tried to bridge the gap between proportions and physical acoustics, taking as their point of departure the fact that harmonics relate to each other as integers. There might be a way, so they thought, to coordinate the system of the harmonics with the structure of the air column. Among these researchers was Victor-Charles Mahillon, who wrote in his book *Éléments d'acoustique* (1874),

> The proportions of the air column are of extreme significance; not only do they determine what we call differences in timbre among the instruments, but also their regularity and their exactness, which contribute to their development, depending on the accuracy of the harmonics. A brass instrument is false if the regularity of the proportions is interrupted. Exact proportions

> are necessary; all makers know that, but how to define them? What is the formula that serves as the basis for their development? Nothing serious has been published in this respect; the procedure, the empirical laws are the only guides one can use at present. Yet we have the conviction that the proportions follow the course of a geometrical curve, the form of which approaches that of a hyperbola, about which we hope to publish one day its formula.[80]

Mahillon considered a geometrically defined curve of the bore as precondition for a beautiful sound. He claimed that correctness of the harmonics and proper formant configuration, as determinants of the timbre, depend on a proportionally well-designed tube. Apparently Mahillon did not succeed in developing such a geometrical formula for an ideal bore. He might have come under the influence of Hermann von Helmholtz' *Lehre von den Tonempfindungen* (1863), which significantly expanded the knowledge of physical acoustics. Helmholtz explored how sound qualities depend on the intrinsic system of vibration, overtone structure, formants, and the attack and decay of the tone. This new approach deflected the point of view from the shape of the air column to the inner system of vibration. Helmholtz taught us to understand that the position of internodes within the air column is important, as is the physical condition of the tube at the positions of the nodes. This has a bearing on where the tube sections are connected and on the irregularities of the diameter, for example, which may result from several different causes. These are aspects that bear on more minute facets of the vibrating process that transcend the scope of a rational proportionality. In 1930 Paul Suchy went a step further than Mahillon as he attempted to coordinate internodes with the diameter progression of the air column (see Figure 1). He redirected the focus on proportionality from the technical length of the tube (with or without mouthpiece) to the length of the vibrating air column including the end correction.

Looking back at the nineteenth century we find bifurcation not only in the sciences, in philosophy, and instrument making, but also in the arts. This indicates that the parallel application of physical and proportional methods in instrument making was part of a more general cultural pattern. On the one hand we notice form-emphasizing traditionalism that lived on particularly in conservative art academies, while on the other we observe a trend toward free design. In music, this bifurcation was recognized and addressed as early as 1854 by Eduard Hanslick in his *Vom Musikalisch-Schönen.* One current, represented by Schumann and Brahms, espoused a more formal and structured approach, following the model established by Beethoven. The other current favored free-flowing forms and subjective expression of free emotionality, as exemplified in the music of Wagner and Liszt.

Against this background we can understand that the struggle between proportions and acoustical science is also part of the bifurcation in Western thought. Proportions inhabit the form-oriented, idealistic, and traditional side, while subjective empiricism, free design, and acoustical aids are on the other, more modern one. The former side understands sound in a spiritual and mind-oriented way, the latter, as a means of subjective, sensually oriented expression.

With the rise of atonal music and Expressionism in the arts, a new period had arrived. The era of formal structure in the arts was not over by any means; it merely assumed different forms. We encounter complex quantitative structures in Cubism, Synchromism, Dodecaphony, and Dada. Can we add the *Teleskopmensur* in brass instrument making, contrived in 1908? Perhaps so, but more research into the deeper intellectual layers of that period is needed in order to understand the common basis for all these artistic currents and methods. In other words, we first must determine whether there is a common intellectual denominator for those forms of artistic expression as well as the *Teleskopmensur.* Speaking of the nineteenth century, we can certainly connect the form-centered currents with tradition; but the same cannot be said of the twentieth century. In the arts the more constructive and ratio-related forms of articulation can be found in avant-garde currents.

So far we have seen the demise of the use of proportions during the nineteenth century in the context of the historical changes: the rise of the sciences and of philosophical materialism, the intensified subjective expression in the frame of musical Romanticism. Two factors, which we have addressed above only perfunctorily, were of great significance in helping to undermine the use of proportions more from the outside. Both of these factors were misconceptions as well as ideologies. The first factor concerns a specific understanding of proportions that wrongly attributed physical properties and causality to them. This misconception may have begun during the eighteenth century with the rise of subjective empiricism, and as the traditional, artistic understanding of proportions became increasingly blurred. In the wake of this comprehension, during the nineteenth and twentieth centuries various stories have surfaced, claiming that Stradivari discovered exactly the right proportions, which imparted outstanding musical qualities to his violins. It was wrongly believed that proportions by virtue of their own power would generate a beautiful sound. What was once an artistic method came to be regarded as a physical concept, used to create beauty. In the nineteenth and twentieth centuries this vulgar-materialistic view provided ammunition for all kinds of adversaries of proportions, who could easily show that proportions do not have the physical properties necessary to create a beautiful sound. It brought discredit upon proportions and gave them a bad name. It is the concept that still prevails today.

The second of the factors that precipitated the demise of proportions was the ideology of progress.[81] This ideology emerged with the Industrial Revolution and the triumph of positivist science. The wealth generated by material production, technology, and command of the laws of nature was unprecedented. It gave rise to the perception that mankind had reached its apogee in Western civilization. Surely this is true for those three material aspects, taken per se. However, it promulgated the illusion that Western civilization was also ahead in areas that do not progress to a higher level, but only change their character, such as the arts, religion, law, value systems, and ethical standards. This extrapolation from the material to the cultural side easily led to a superiority complex with regard to other civilizations and earlier historical periods. At its worst, it blended with imperialism and racism.

Art is a matter of a particular talent; it can be seen as early as the Cro-Magnon period. Art cannot be evaluated with the measuring stick of scientific and technological progress.

The dual nature of musical instruments made them vulnerable to the ideology of progress. As scientific and technological progress fertilized the physical side of instrument making, the scientific worldview insidiously shaped mental eyeglasses through which some people saw and continue to see predominantly this aspect of musical instruments. They came to be regarded primarily as acoustical devices, and thus older, non-scientific methods and concepts related to their manufacture were looked upon as simplistic and outdated. The empirical approach with the aid of acoustical reasoning prevailed; it is a setup analogous to the methodological approach of the sciences: both work on the basis of empiricism and causality. While science systematically infers causal relations from observational data, instrument building makes use of this knowledge in a general way, testing results through experimentation and demonstration. Accordingly, physical acoustics became the appropriate method for this empirical approach. As the discipline of acoustics advanced it became ever more useful as an aid to empirical design in a historical situation in which sound qualities are very much standardized.

In addition to the triumph of the empirical sciences in the nineteenth century, there was another powerful, albeit differently oriented, current that derived from the Enlightenment. This current featured curiosity about history. It included interest in the wealth of timbres and forms of sound-producing instruments. Collecting musical instruments, appreciating them, and exploring the aesthetic values of the sound qualities of historical and non-Western cultures evolved into organology and ultimately into the early music movement. Only the latter movement fought successfully against the ideology of progress.

Although the scientifically and historically minded currents appear to be quite different, they have the same roots and are closely related. The historical current as it is practiced in musicology and organology assumed largely the methods of the empirical sciences, resorting to description, interpretation, and comparison of direct sources. Thus much information about the past was consigned to oblivion. It is up to our generation to take a critical stand concerning those methods, and assess to what degree they should be employed to generate a faithful picture of the past.

7. About proportional analysis

The steadily advancing state of research makes it necessary for me to review the proportional analyses that I published in the 1980s and comment critically on them.[82] These analyses were developed at a time when my knowledge of the historical context was still limited. Thus my earlier findings have many shortcomings, which may be summarized for brass wind instruments as follows:

(1) I did not always distinguish between the maker's assumed design and my own description of it. This is particularly true of the diameter D_3, which I always determined for the sake of comparison and rounded to the nearest common fraction—for example, $3\,^3/_4$, $4\,^1/_2$. This does not necessarily mean that the maker proceeded in this way. This inconsistency was due to the arrangement of the catalogues in question, which followed

the empirical method. I made the instruments comparable by using quotients for the observational points. My goal was to catalogue as many collections as possible in the same manner, which would provide raw material for data processing in order to show how the instruments have changed over time, as well as how they reflect the geographic area of their origin and the makers' individual styles. The consistent measuring points were D (bell diameter), d (minimal bore diameter), d at 2/3 of the tube length, D_3, D_2, and D_1 (= diameter in the distance of 1 D, $^1/_2$ D and $^1/_4$ D from the end).

(2) The diagrams of the bells also do not consistently distinguish between the maker's assumed design and my own description of it. In addition, many of the measuring points I chose were too close together. So my readings may have blended with the margin of error.

(3) The tolerances of manufacturing and measurement were sometimes underestimated, thus my interpretations and measurement analyses are not always secure.

(4) Some numerical ratios (for example, 2:15, or 7:10) and scales (with 15 equal marks, for example) for laying out the lengths of instruments were scarcely used by the makers; I have used them, however, in a descriptive way.

The proportional analyses of brass instruments that I demonstrated in 1986[83] represent my best efforts to date in this area, and I still largely stand by them. In practice, proportional schemata often needed modification in order to give the instruments their required pitch and to achieve good intonation and response. Musical qualities had priority and proportions were merely aids in establishing the frame for a proper sound. Proportional "character-types" are particularly obvious in standardized instruments—for example, in the natural trumpet. Its common type as it was built, for example, by the Nuremberg makers has a length of $^5/_7$ cylindrical tube + $^2/_7$ bell. Making the tube somewhat shorter or longer for the sake of adjustment to a particular pitch, which results in distortions of the schema, was routine. One customer wanted a somewhat higher pitch, another a somewhat lower pitch. Few makers would have adjusted the lengths of all the components in order to retain precise proportions. Therefore, a natural trumpet with heavily distorted proportions is no argument against the hypothesis that this type of instrument was initially laid out according to a proportional scheme, and is meant in this way. It is an open question when the conscious use of the scheme $^5/_7$+ $^2/_7$ vanished and was replaced by simple empirical adjustment. The earlier a type becomes standardized the earlier this will occur.

There are other types of ratios in folded trumpets, for example $^3/_4$ cylindrical tube + $^1/_4$ bell (trumpet by Marcian Guitbert, Limoges, 1441),[84] or $^2/_3$ cylindrical tube + $^1/_3$ bell. The common type with $^5/_7$ cylindrical tube + $^2/_7$ bell seems to be of French origin because of two important clues: there is a historical source pointing to France,[85] and there is a match between the proportional scheme and the Parisian *pied*. According to this unit of measurement the original design would have a length of 7 Paris *pieds* (= 2274 mm), yielding a pitch that supposedly was also used as a tuning standard (later known as *Chorton*).[86] The cylindrical section was subdivided into 2 x 2 feet for the long yards and 2 x $^1/_2$ foot for the bows. One may argue that the proportional schema of the natural trumpet resulted from its empirical setup and the schema was merely implied. Certainly most instrument types and models had their approximate conceptual origin in the various needs and challenges of musical practice. Then the rough concepts were adjusted to proportions in order to meet professional standards, and subsequently the theoretically correct type could be subject to empirical modification for the sake of proper pitch and good intonation. This detour from an empirical basis via theoretical adjustments to empirical modifications was an important step toward aesthetic refinement of the instrument's sound. In a time before the advent of the tuning fork, the congruency between simple units of length (2 feet, $^1/_2$ foot) was probably also a practical means of dealing with pitch.

Reconstructing the original proportional concept for the bore of an instrument is more difficult than that for length because the margin of error per unit of measurement is higher. Makers may have revised the bore empirically, thereby possibly rendering its originally proportional structure unrecognizable.

8. Analyses of instruments by Adolphe Sax

While Adolphe Sax' statement of 1850 indicates that he used proportions, he never revealed how he applied them.[87] Following the approach outlined in this essay and judging from a small number of instruments, we find that Sax employed a traditional proportional frame consisting of at least five or six numerical ratios for the bore diameter, which he associated with numerical ratios of the tube length. The following instruments from Sax' factory will illustrate his approach according to my hypothesis.

Example. 1: Nouveau Saxhorn contrebasse, E♭, 6 valves, serial # 32296, built ca. 1867. New York, Metropolitan Museum of Art, no. 89.4.2703.

Length (L)	*Bore diameter [mm]*	*Theoretical value [mm]*	*Ratio*
beginning of tube	15 [d min]	15	
at $^1/_2$ L	17.1-17.4	17.5	1
at $^2/_3$ L	33.5-35	35	2
at $^5/_6$ L	66-78	70	4
at L - D = beginning of turn-bell*	139.5	140	8
end of bell (D)	277-280	280	16

* "Turn-bell" refers to *pavillon tournant,* a term Sax used to refer to the short and bent end of the bell that forms an independent building unit. In a *Nouveaux Saxhorn* the turn-bell can be turned around its axis in order to project the sound in different directions.

The table indicates that the bore diameter doubles at points that correspond to simple ratios of the length of the tube.[88] The mouthpiece is not included. The governing principle is the ratio 1:2, associated with the ratios displayed in the left-hand column. Deviations

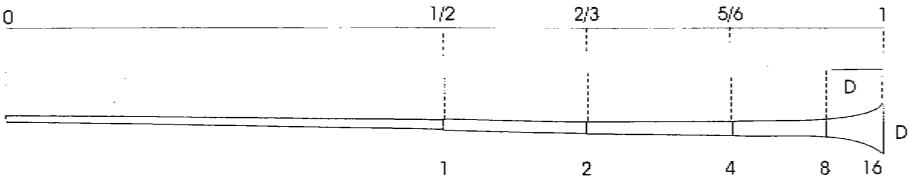

Figure 2
Proportional system of Nouveau Saxhorn, serial# 32296 (ca. 1867).
New York, Metropolitan Museum of Art, no. 89.4.2703

from the ideal values in column 2 (listed in column 3) appear to be a mixture of measuring errors, tolerances, and empirical adjustments to improve intonation, response, and timbre.[89] In *Rapport de M. l'expert Surville*, printed in 1860,[90] Sax admits that the developing and manufacturing processes may involve modifications and deviations from the theoretical figures. It would be worthwhile to investigate the deviations at $^2/_3$ L, which do not seem to be accidental. Here, BIAS[91] appears to be the currently appropriate system to scrutinize what happens acoustically at that point in the bore. What would happen if the diameters were theoretically correct, and why was Sax, or his developers, forced to modify the diameter? In the quotation from Sax in section 1 above, the developers are referred to as "artists." We see in them the musicians who tested the instruments in the factory, the foremen, and Sax himself, who thereupon changed the bore according to their experience. The model was tested and corrected again and again until the results appeared sufficient and Sax decided to begin regular production.

Example 2: Nouveau Saxhorn bass in B♭, 6 valves, serial # 35795, probably 1868/69. New York, Metropolitan Museum of Art, no. 1993.164.

Length (L)	*Measurements [mm]*	*Theoretical value [mm]*	*Ratio referred to d min*	*Ratio referred to bell diameter D*
beginning of tube	12 [d min]	12	3	
at $^1/_2$ L	16,0, 16.3	16	4	
at $^2/_3$ L	31.5	32	8	
at $^5/_5$ L	51-54.5	52	13	1
at L - D (= beginning of turn-bell)	105.5-106	105		2
end of bell (D)	210	210		4

In the case of this instrument, proportional fractions of the bell diameter determine the last one-sixth of the tube length. Thus the proportions follow two references, the minimum and maximum diameter of the bore.

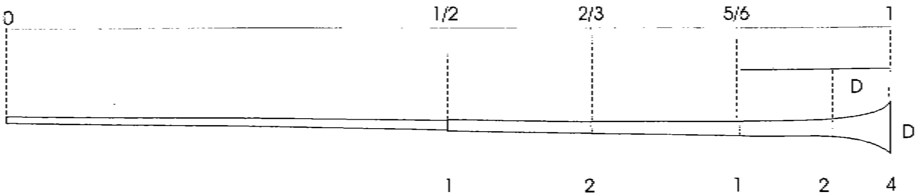

Figure 3
Proportional system of Nouveau Saxhorn, serial# 35795 (ca. 1868/69).
New York, Metropolitan Museum of Art, no. 1993.164

Example 3: Nouveau Saxhorn alto in E♭, 6 valves, serial # 26497, built in ca. 1863. Brussels, Musée des instruments de musique, no. 2469.[92]

Length (L)	*Measurements [mm]*	*Theoretical value [mm]*	*Ratio referred to d min*	*Ratio referred to bell diameter D*
beginning of tube	11 [d min]	11	1	
at $^1/_2$ L	12.5	12.5		
at $^2/_3$ L	ext.*16	16.5	$1^1/_2$	
beginning of bow (25 mm lower)	16.7-17			
at $^4/_5$ L = beginning of bell	ext. 22.5-23.5	22	2	
at L - D (= beginning of turn-bell)	ext. 55-57	55	5	2
end of bell (D)	135-138	137.5	$12^1/_2$	5

* ext. = outside measurement; otherwise the dimensions refer to the inner diameters.

Although the three six-valve saxhorns analyzed above are taxonomically members of the same family, they display different proportional schemes. This is in accordance with what Sax meant in his *Note* of 1850, quoted above: "These proportions are, therefore, different for each species of instrument." The difference from size to size results from the shift of the timbre from dark/mellow to bright. This shift characterizes any set of instruments from bass to soprano, each in its own specific way. The next diagram shows the proportions of a regular saxhorn with four valves:

Example 4: Saxhorn basse in B♭, 4 valves, serial # 35795, probably 1868/69. Vermillion, SD, America's Shrine to Music Museum, no. 3183.

Length (L)	*Measurements [mm]*	*Theoretical value [mm]*	*Ratio referred to d min*	*Ratio referred to bell diameter D*
beginning	12 (d min)	12	1	
at $^{1}/_{2}$ L	24.5, 25	24	2	
at $^{2}/_{3}$ L	35.5	36	3	
at $^{5}/_{6}$ L	60	60	5	
at L - D	81	81.8		3
at L- 1/2 D	108	108	9	4
end of bell (D)	217-218	216	18	8

Here again, we find the proportions arranged from both ends of the tube, the beginning and the bell-end.

Example 5: Fluegelhorn in B♭, serial# 40693, built ca. 1880-85. Brussels, Musée des instruments de musique, no. IT 180.

Length (L)	*Measurements [mm]*	*Theoretical value [mm]*	*Ratio referred to d min*
beginning	10 (d min)	10	1
at $^{1}/_{2}$ L	ext. 15.5/16	15	1 $^{1}/_{2}$
at $^{2}/_{3}$ L	ext. 21	20	2
at $^{5}/_{6}$ L	ext. 33.5-33.9	33.3 (30 ?)	3 $^{1}/_{3}$ (3 ?)
at L - D	ext. 40.3/41.7	40	4
end of bell (D)	147,5	150 ?	15 ?

As in many keyed bugles, half-moons, and fluegelhorns, the tube of the previous instrument consists of two sections of equal length: 50% narrow conical tube (with cylindrical screw slide and valves) + 50% bell.[93] It is often not clear to what extent deviations are attributable to intentional modifications, accident, or to manufacturing and/or measuring errors. Here too it would be worthwhile to investigate further, using acoustical methods in order to understand what occurs physically in the tube at the locations in question. In this way we might be able to understand the maker's experiences, skills, and methods, which he employed in order to optimize the musical qualities of the instrument.

In our experience, other instruments by Sax sometimes display strong deviations and thus thwart the identification of proportions. Such cases invite even more acoustical inquiry in order to understand the manufacturer's methods and the problems he faced in developing the final dimensions of the bore.

Exactly how Sax proceeded in the areas between proportional points—that is, particularly toward the open end of the bell—remains an open question. In some cases it seems that he used additional proportional figures in between, while in others he apparently proceeded freely, using templates and eye measure to fill in the gaps.

Analyses of as many as possible of Adolphe Sax's approximately 165 surviving brass instruments would be necessary in order to obtain a broader overview and a firmer basis for assessing the validity of these hypotheses.

9. Conclusion

Traditional organology works in a mode that is both descriptive and comparative, using observational data, measurements, written and iconographic sources. This is the basis not only for the systematic inquiry of musical instruments, but also for the exploration of their history. Writing history, organology uses the sources' and instruments' place and time of origin, as well as the individuality of the author or maker, as historical parameters. This method has obvious advantages in terms of historical documentation, but it does not adequately address questions as to why and how instruments evolved in a specific way and with a particular sound. Nevertheless, the "why-and-how" questions are not only basic questions of human curiosity, but also genuinely historical questions. Realizing the significance of these questions, many organologists, instrument makers, and acousticians have attempted to answer them, using both common sense and modern workshop experience. However, these modes of investigation violate the principle of historicity and are unscientific.

In previous sections of this essay, I attempted to demonstrate that if we want to determine why and how early instrument builders proceeded and how they used proportions, we must begin from the perspective of the period during which the instruments were built. Such an approach requires us to go beyond the direct sources and examine the historical context. Only then will the logical consistency between question and method—i.e., the epistemological precondition to answer a question properly—be satisfied.

Musical instruments have a physical as well as a cultural-aesthetic side and are developed for cultural purposes. Some organologists see musical instruments largely as acoustical devices and tend to underplay their cultural aspects. If we want to transcend mere description of a historical instrument's design as well as simple technical understanding of its operation, we must begin with the cultural and artistic side. This side cannot be understood by means of physical methods. The acoustical study of a modern or historical instrument can describe and explain how the instrument works as a physical device and demonstrate changes over time, but it is incapable of explaining the musical instrument as the result of historical change and artistic creativity. Making sense of physical data requires interpretation; that is, the data must be associated with artistic and historical notions. Organology is in its very nature a humanistic discipline, while the appropriate function of physical acoustics is to serve as a tool for understanding the physical workings of musical instruments.

No musical instrument was ever designed and developed by a totally self-sufficient individual. Musical, aesthetic, cultural, technological, and scientific ideas have always been closely intertwined with the process of designing an instrument. These ideas lay embedded in the intellectual and artistic culture of the respective period. They corresponded to and were associated with the period's command of the laws of nature, technology, and material living conditions. Moreover, any design bears the marks of the individuals who were directly involved in its development. The maker's concept of the sound is one of the principal factors influencing the design. The nature of the sound-ideal is complex, and may reflect religious, philosophical, and scientific concepts as well as folkore. It includes spiritual, aesthetic, and physical aspects, all of which may have a bearing on shaping the sound and structure of an instrument.

If we want to understand how a new model was conceived and constructed in its time, we must begin with original methods and modes of thought. Such an approach presupposes extensive historical research into the intellectual and artistic context to offset the lack of direct sources—and to understand the means and methods of early instrument makers. Modern science and experiences in modern instrument making are inappropriate bases for such research. Evidence must be sought from the full range of historical sources, not just the direct sources. If an instrument was designed with the aid of proportions, we must apply appropriate proportional methods in order to understand it and/or reproduce it. By the same token, if it was developed in an acoustical laboratory in the 1930s, we would have to replicate those methods, no matter how inadequate they might be, compared to modern knowledge and modern acoustical equipment. Instrument makers at any time had to struggle with the physical phenomena of wood and metal, but the perceptions of the relevant physical principles were always different and changed constantly.

The design methods using either proportions or acoustical science are associated with the fundamental beliefs and insights of their period. Both approaches helped to articulate and realize the aspirations of their period. Until well into the period of the Enlightenment, rational and proportional ideas were at the root of understanding sound and found their way into the design by way of correspondences and analogy. Proportions worked on the cultural-artistic side of the instrument and were an important means of articulating the ethical and aesthetic trends of the Renaissance and Baroque periods. Working according to the principle of analogy, they helped to establish the foundations of the specific sound character and musical standards of instruments such as the violin, viola da gamba, trombone, and bassoon.

Acoustical science works on the physical side of the instrument and operates according to the principle of cause and effect. The greatest benefit it can provide is as an aid to the empirical method, in particular as a means of realizing quantitative, pitch-, and intonation-related aspects, which may bear on response, attack, and decay of the sound. It is a method that can aid subjective empiricism. Acoustical methods are welcome in historical organology as a means of understanding the structural conditions of instruments and as an aid in the development of historically determined design methods.

The move away from proportions was caused by several factors, in particular the evanescence of the united world image, the rise of critical and scientific thinking, and the increasing role of subjective expression in music. Loosening its rational associations, sound became an ever more qualitative entity, closely connected with subjective sensation and aesthetic evaluation. The middle of the eighteenth century marks a turning point in that subjective empiricism and free design gradually began to compete with—if not override—the use of proportions. It was a time when the classical orchestra formed and most types of instruments proceeded toward standardization. In this context aesthetic aspirations aimed at the natural, at balance and refinement. This was chance and challenge for a new kind of rationality in the form of acoustical science, which helped to achieve a sound that was intended ideally to be natural—i.e., homogeneous, open, and balanced. In the first half of the nineteenth century acoustical science penetrated instrument making in a revolutionary way. Proportional methods fell into disuse. Adolphe Sax was one of the brass instrument makers who adhered to tradition in terms of designing the bore, while in terms of technology and inventiveness he was one of the most innovative and prolific makers of the nineteenth century. At the time when the empirical sciences instituted their positivist methodology, instrument makers began to regard instruments as acoustical devices. This was the intellectual basis on which, some time later, organology evolved.

I express my thanks to Stewart Carter and Laurence Libin for their advice in the preparation of this article.

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NOTES

[1] In this article, the term "proportion" is used in its informal and broad meaning: a ratio (i.e., a relation consisting of two terms, for example, a:b), a combination of two ratios, or a particular geometrical partition. The more rigorous usage of the term "proportion" restricts it to a combination of two ratios, such as a:b:c, or a:b = c:d. Subsumed under the term proportion are also geometrical

procedures used in instrument making which, however, can usually be associated in one or the other way with rational or irrational proportions.

[2] Herbert Heyde, *Trompeten, Posaunen, Tuben. Katalog des Musikinstrumenten Museums der Karl-Marx-Universität Leipzig*, vol. 3 (Leipzig: VEB Deutscher Verlag für Musik, 1980); in the same series: vol. 5: *Zinken und Hörner* (1982); idem, *Musikinstrumentenbau. Kunst—Handwerk—Entwurf* (Leipzig: VEB Deutscher Verlag für Musik, 1986); idem, *Historische Musikinstrumente der Staatlichen Reka-Sammlung am Bezirksmuseum Viadrina Frankfurt (Oder)* (Leipzig: VEB Deutscher Verlag für Musik, 1989).

[3] Quoted after François-Joseph Fétis, *Biographie universelle des musiciens et bibliographie générale de la musique*, 2nd ed., (Paris, 1878), vol. 7, p. 416: "Les proportions sont les lois régissent et constituent la nature des instruments; ce n'est pas, en effet, leur forme qui leur donne leur voix, leur qualité de timbre: ce sont les seules proportions. Ces proportions sont donc différentes pour chaque espèce d'instrument.… Et mes adversaires osent répéter à la Cour ce qu'ils disaient aux experts, à savoir que, loin d'être une loi fondamentale, les sont sans importance, et qu'ils sont appelés à les modifier, suivant les exigences des artistes!" Fétis quoted this paragraph freely from *Notes pour les Messieurs les Conseillers*, 1850. An original copy of the *Notes* survives in Musée des instruments de musique in Brussels.

[4] Adrien de la Fage, "Vistes à l'Exposition universelle," *Revue et gazette musicale de Paris* 22, no. 44 (4 November 1855): 343: "1° une règle fixe pour la proportion et le développement des tubes dans chaque instrument; 2° un moyen certain et universellement applicable pour l'observation de cette règle. M. Besson a obtenu la première à la suite de bien des veilles, de calcules sans nombre et d'une multitude d'essais."

[5] For a comprehensive study of Mahillon, see Ignace de Keyser, *De geschiedenis van de Brusselse muziekinstrumentenbouwers Mahillon en de rol van Victor-Charles Mahillon in het ontwikkelen van het historisch en organologisch discours omtrent het muziekinstrument* (Ph.D. diss., Universiteit Gent, 1996).

[6] Victor-Charles Mahillon, *Éléments d'acoustique musicale & instrumentale; comprenant l'examen de la construction théorique de tous les instruments de musique en usage dans l'orchestration moderne* (Brussels: Manufacture générale d'instruments de musique C. Mahillon, 1874; 2nd ed., Brussels: Les Amis de la Musique, 1984).

[7] Herbert Heyde, *Das Ventilblasinstrument. Seine Entwicklung im deutschsprachigen Raum von den Anfängen bis zur Gegenwart* (Leipzig: VEB Deutscher Verlag für Musik, 1987), pp. 127-229.

[8] Ibid., p. 87.

[9] German *Reichspatent,* no. 209711 of 10 January 1908. Ibid., p. 87.

[10] If the internal diameter of the first cylindrical section is 10 mm across and the wall thickness .5 mm, the following tube sections have internal diameters of 11, 12, and 13 mm.

[11] The Hüttl firm was a major producer of brass instruments in central Europe between 1910 and 1940.

[12] In 1847 Theobald Boehm replaced the conical bore of the ring key flute with a cylindrical bore. According to his own statement Boehm decided on the cylindrical bore on the basis of his finding that in a cylindrical bore with a diameter of 1/30 of the length of the instrument, the formation of sound waves and nodes occur more easily and offer the best sound-producing qualities for the player. See Theobald Boehm, *Die Flöte und das Flötenspiel in akustischer, technischer und artistischer Beziehung* (Munich: Aibl, 1871), p. 3.

[13] For a general introduction to organology, see Renato Meucci, "Organologia: definizione e contenuti di una recente disciplina," *Il museo degli strumenti musicali del conservatorio "Luigi Cherubini,"* ed. Mirella Branca, Galleria dell'Accademia. Il luogo del David 2 (Livorno: Sillabe, 1999), pp. 108-19. See also by the same author, "On 'Organology': A Position Paper," *Historic Brass Society Journal* 11

(1999), pp. viii-x. An outline of current organology can be found in *Die Musik in Geschichte und Gegenwart*, 2nd edition, ed. Ludwig Finscher (Kassel: Bärenreiter, 1996), s.v. "Instrumentenkunde," by John Henry van der Meer.
[14] See n. 2.
[15] For example, John Koster, *Keyboard Musical Instruments in the Museum of Fine Arts, Boston* (Boston: Museum of Fine Arts, 1994). On p. 15 he advances these arguments against measurement and structural (proportional) analysis: "The complexities of musical instruments are such, that among the dozens of dimensions that one may measure, there will always be some related by simple ratios to each other or to some ancient unit of measurement. Further, even if those ratios were consciously applied by the maker, his reason might be unknown to us."
[16] Denzil Wraight, "The Identification and Authentication of Italian String Keyboard Instruments," in Howard Schott (ed.), *The Historical Harpsichord*, vol. 3 (Stuyvesant, NY: Pendragon, 1992), p.72: "It is, I feel, expecting too much of most practical men with a limited education to suppose that they habitually incorporated such abstruse ideas in practical instruments, although it is possible that some instrument makers with a theoretical bent would have designed instruments in this way." By "abstruse ideas," Wraight means proportions, which he thinks modern "office workers" have read into old instruments. He thinks that "the skills were passed on through an apprenticeship, for which it was expected that payment would be given to the master. A market for office workers seeking creative hobbies after hours and requiring technical information on instrument making did not exist before the industrial revolution. Thus, whenever treatises do occur, one should regard them with some suspicion: why were they written? How could the writer have gained any first-hand knowledge of the subject?" (pp. 68-69).
[17] Gustav Theodor Fechner (1801-87), the founder of experimental psychology, laid the empirical foundation for the hypothesis that preferences for the golden section and other geometrical configurations exist objectively. Later psychologists resumed this issue, using different methods. They hardly argued against the existence of preference as such; however, controversy arose in the context of the nature-nurture debate, centering on whether these preferences are congenital, or learned from the intellectual environment. For an overview of this issue, see Daniel Ellis Berlyne, *Aesthetics and Psychobiology* (New York: Appleton-Century-Crofts, Meredith Corporation, 1971). Most objections against the universality of the golden section have cited the fact that the source material originated almost exclusively from the Mediterranean area. Therefore those preferences might be a learned faculty rather than biologically founded. After all, in the 1960s and 1970s several psychological studies were conducted with Asian and African subjects who clearly supported the universality and biological nature of those preferences. In 1974, Berlyne/ Robbins/ Thompson summarized their findings from a study with Canadian and African subjects as follows, "All in all, this study has revealed more similarities than differences between the reactions of Ugandan and Canadian Ss [subjects] faced with the same stimulus material and the same tasks.... There clearly are differences among individuals and among ethnic groups, as some of our findings illustrate. But there are also impressive similarities in the ways in which people with markedly different cultural backgrounds respond to the same visual material. And when there are differences, it seems not too much to say that they are generally differences in degree. Apart from anything else, our findings confirm what a study of artifacts from a variety of periods and civilizations will demonstrate, namely that aesthetic reactions all over the world depend on common variables, notably the collative or informational variables that the patterns used in our experiments were designed to sample, even if the preferred values of these variables fluctuate." D.E. Berlyne, M. C. Robbins, and R. Thomson, "A Cross Cultural Study of Explanatory and Verbal Responses to Visual Patterns Varying in Complexity," in D.E. Berlyne ed., *Studies in the New Experimental Aesthetics. Steps toward an Objective Psychology of Aesthetic Appreciation* (Washington:

Hemisphere Publishing Corporation, 1974), p. 277.

[18] Induction is the inference to a generalization from incidences such as observational data, measurements, or facts.

[19] For example, the physicist and violin maker Carleen M. Hutchins wrote, "The violin was developed and brought to its height of excellence along with the beginnings and flowering of the Scientific Revolution in Europe and the creative expansions of the arts, music, and literature of the Baroque era." Carleen M. Hutchins and Virginia Benade, eds.: *Research Papers in Violin Acoustics, 1975-1993*: *350 Years of Violin Research* (published by the Acoustical Society of America through the American Institute of Physics, 1997), Introduction, p. 5. It must be said that the evolution of the violin was completed by ca. 1550, a significant length of time prior to the onset of the scientific revolution. The acoustical side of the scientific revolution is connected with the physical nature of the sound and the vibration of strings, etc., explored by Vincenzo and Galileo Galilei and Marin Mersenne. This research did not begin before the 1580s. Another example: Karl Fuhr (*Die akustischen Rätsel der Geige*, p.171, see n. 73) claims that the development of the violin was based on good taste, refined aesthetic sense, acoustical considerations, and practical function. These criteria fit the mind-set of subjective empiricism, which evolved in the eighteenth through the twentieth centuries.

[20] There are, of course, also physicists who understand that each historical period has to be measured and understood by its own standards, for example, Walther Krüger, "Die Entwicklung der Konstrucktionsprinzipien von Holz- und Metallblasinstrumenten seit 1700," *Qualitätsaspekte bei Musikinstrumenten*, ed. Jürgen Meyer, Edition Moeck no. 4044 (Celle: Moeck, 1988), pp. 35-50.

[21] The concept of music's origin in the universe (macrocosm) and in the human soul as its image (microcosm) was well established in antiquity. Music treatises of the Middle Ages through the seventeenth and sometimes eighteenth century rarely omit this topic. See *Die Musik in Geschichte und Gegenwart* (1st ed., vol. 5, 1956), s. v. "Harmonie," by Heinrich Hüschen. The notion of emanation, the gradual increase of "density" from a spiritual to a physical condition, was a basic concept in mythological, religious, and early philosophical thinking.

[22] Part of this transitional area is the music for the *alta capella* of the fourteenth and the fifteenth centuries. See Keith Polk, *German Instrumental Music of the late Middle Ages: Players, Patrons, and Performance Practice* (Cambridge / New York: Cambridge University Press, 1992).

[23] Rudolf Wittkower, *Architectural Principles in the Age of Humanism* (New York: Random House, 1965).

[24] Since the beginning of the fifteenth century, Vitruvius' *De re architectura* enjoyed increasing attention, and the musical aspect of architecture was well understood. Music theorists also understood this well, among them Gioseffo Zarlino and Pietro Aaron. In 1523 Aaron said, "Let us add that, according to Vitruvius, architecture will not be perfect without music." See Pietro Aaron, *Toscanello in Musica* (Venice 1523; rev. ed. with supplements of 1529, transl. and ed. Peter Bergquist, Colorado Springs: Colorado College Music Press, 1970.), book 1, chapter 1.

[25] Daniele Barbaro, *I dieci libri dell'architettura di M. Vitruvio tradutti et commentati* (Venice, 1556), chapter 5.4. See Ann E. Moyer, *Musica Scientia. Musical Scholarship in the Italian Renaissance* (Ithaca/ London: Cornell University Press, 1992), pp. 184-93.

[26] John Onians, *Bearers of Meaning: The Classical Orders in Antiquity, the Middle Ages, and the Renaissance* (Princeton, NJ: Princeton University Press, 1988), pp. 208-35.

[27] L.B. Alberti, *De re aedificatoria* (1450/51), book IX, chapter 5. Transl. Joseph Rykwert, Neil Leach, and Robert Tavernor as Leon Battista Alberti, *On the Art of Building in Ten Books* (Cambridge, MA: MIT Press, 1988), p. 305.

[28] In IX, 5 Alberti called *concinnita*s the "source of her [a building's] dignity, charm, authority and worth." See ibid., p. 302.

[29] L.R. Shelby and R. Mark, "Late Gothic Structural Design in the 'Instructions' of Lorenz Lechler," *Architectura* [Munich] 9 (1979): 113-31.
[30] Christoph Weigel, *Abbildung und Beschreibung der Gemein-Nützlichen Haupt-Stände* (Regensburg: Christoph Weigel, 1698; facs. ed., Nördlingen: Verlag Dr. Alfons Uhl, 1987), p. 433: "alles nach Proportion / Winckel-Maß / Circkel und Quadranten."
[31] Pietro Aaron said about the use of music theory in engineering in 1523, "According to Hierophilus it is especially effective in the tempering of ballistae, catapults, scorpions, and hydraulic machines." *Toscanello in Musica*, transl. Bergquist, book 1, chapter 1 (see n. 24).
[32] Guglielmo Ebreo da Pesaro, *De pratica seu arte tripudii = On the Practice or Art of Dancing*, edition and translation by Barbara Sparti (Oxford/ New York: Clarendon Press, 1993).
[33] With the invention of geometrical perspective in painting around 1430, a stricter usage of proportional scheming began. Though many painters withdrew from strict geometrical lineaments of laying out of scenes and figures as early as in the sixteenth century, some painters adhered to it much longer. Among them was Nicholas Poussin (1594-1665). See Naomi Joy Barker, "'Diverse Passions': Mode, Interval and Affect in Poussin's Paintings," *Music in Art* 26/1-2 (2000): 5-24. In architecture we encounter a different situation. There, proportional methods continued to be used as late as in the eighteenth and even nineteenth century.
[34] Pietro Aaron, *Toscanello in Musica* (see n. 24), chapter XXXII.
[35] Moyer, *Musica Scientia,* pp. 199-282.
[36] Gioseffo Zarlino, *Le Istitutioni harmoniche*, vol. 1 (Venice, 1573; ed. and transl. Michael Fend, Frankfurt (Main)/New York: P. Lang, 1989), chapter 1.15.
[37] E.M.W. Tillyard, *The Elizabethan World Picture* (London: Chatto & Windus, 1943).
[38] Raymond J. Corsini, *The Dictionary = of Psychology* (Philadelphia: Brunner/ Mazel, 1999), s.v. "synesthesia." Such cross-modality experiences occur, for example, if the color blue is felt as cool, red as warm. The dictionary also mentions that "Musical notes may yield specific colors. Or numbers are experienced as sounds." Synesthesia between pitches and colors had found application, for example, in color pianos. Synesthesia is a common but faint and often subconscious experience or sensation. Only a few individuals have vivid cross-modality experiences.
[39] This teaching fell on fertile ground and was perpetuated over the centuries. I mention only one reference, Pietro Aaron's *Toscanello in Musica* of 1523 (see n. 24): "Plato affirms in the Timaeus that our soul is composed of musical numbers. The Pythagoreans also affirm that the world is composed of musical reason, of which man is the image, and from this comes the so-called microcosm, which in our common language means little universe."
[40] In a general sense the golden section equals the proportion A: B = B: (A+ B). Thus, a shorter length A relates to a longer length B as the longer to the sum of the first two lengths. It is a continuous proportion; the arithmetic ratio of each terms equals 1: 1.618. Man's aesthetic sense "naturally" seeks out balance and symmetry (in its general sense), which often takes on a ratio ranging around the golden section (see n. 17).
[41] Ed. with German transl. by C. Winterberg (Vienna, 1889).
[42] V. Galilei's trials were discussed, among others, by Daniel Pickering Walker, *Studies in Musical Science in the Late Renaissance*, Studies of the Warburg Institute, vol. 37 (London: Warburg Institute, 1978), pp. 23-26.
[43] Peter Dear, *Revolutionizing the Sciences: European Knowledge and Its Ambitions, 1500-1700* (Princeton, NJ: Princeton University Press, 2001).
[44] The term is spelled *liniamento* in early sources relating to architecture, such as Alberti's *De re aedificatoria* (see n. 27). The modern spelling, *lineamento,* is used in this article.
[45] The closest English equivalents are schematic outlines, definition, lineament, and measured ground-

plan. See transl. of Alberti's *De re aedificatoria* by Rykwert et al (n. 27).

[46] A sequel to the author's *Musikinstrumentenbau* (1986, see n. 2) is in preparation.

[47] Herbert Heyde, "A Business Correspondence from Johann Wilhelm Haas in the Year 1719," *Historic Brass Society Journal* 4 (1992), pp. 45-56.

[48] "Damit man aber nicht gedencke / als hielte ich dafür / man könte und dürffte gar im geringsten nicht von denen Musicalischen Proportionen abschreiten; So will ich auch zeigen / wie man procediren müsse / wenn man von denen Musicalischen Proportionen etwas abweichen wolle / und zwar doch also / daß es der Æqualität nicht mercklich hindere / und man auch wegen der Höhe und Tieffe des Soni gewiß könne versichert seyn." Johann Philipp Bendeler, *Organopoeia* (Frankfurt/Leipzig, 1690; reprint ed. by Rudolf Bruhin, Amsterdam: F. Knuf, 1972), p. 13.

[49] Paolo Galuzzi, *Mechanical Marvels: Invention in the Age of Leonardo* (Florence: Giunti, 1997).

[50] See Mark Lindley, *Lutes, Viols and Temperaments* (Cambridge / New York: Cambridge University Press 1984).

[51] Arnaut de Zwolle (ca. 1400-66) was an astronomer and physician at the courts of Burgundy and France. Nothing is known about his involvement in instrument making except for his lineaments for various musical instruments. Drawings could be purchased, as we know, for example, from litigation that took place in Augsburg in 1564. The carpenter Peter Heyß, who had bought drawings for his use, testified, "So it has always been customary, and it still is not prohibited to any craftsman or artisan, to have lineaments made [by draftsmen] of his handiwork according to his liking, as to date our work is embellished by painters, sculptures, turners, locksmiths, engravers and gilders." ("So es doch jederzeit gebräuchig, und noch einem jeden Handwerksmann oder Künstler unverboten ist, ihm die Visierung zu seiner Handarbeit seines Gefallens reißen zu lassen, wie denn auch noch auff diese Stund unsere Arbeit mit Malern, Bildhauern, Drexlern, Schlossern, Etzern und Verguldern gezieret wird.") Augsburg, Stadtarchiv, K.A. I. 107; citation after Fritz Hellwag, *Die Geschichte des deutschen Tischlerhandwerks vom 12. bis zum Beginn des 20. Jahrhunderts* (Berlin: Deutscher Holzarbeiter Verband, 1924), p. 470.

[52] These and the following citations after Flavio Dassenno and Ugo Ravasio, eds., *Gasparo da Salò e la liuteria bresciana tra rinascimento e barocco: 450º Anniversario della nascita di Gasparo da Salò* (Brescia: Fondazione Civiltà Bresciana, 1990), and Ugo Ravasio, "Vecchio e nuovo nella ricerca documentaria su Gasparo da Salò e la liuteria bresciana," *Liuteria e musica strumentale a Brescia tra cinque e seicento.* Atti del convegno. Annali, vol. 1, Sessione organologica, Salò, 5-6 ottobre 1990 (Brescia: Fonzaione Civiltà Besciana, 1992), pp. 25-43.

[53] Johann Neudörfer, "Nachrichten von Künstlern und Werkleuten ... aus dem Jahre 1547," *Quellenschriften für Kunstgeschichte und Kunsttechnik des Mittelalters und der Renaissance*, vol. 10, ed. G.W.K. Lochner (Wien: W. Braumüller, 1875).

[54] Johann Heinrich Zedler, *Großes vollständiges Universal-Lexikon aller Wissenschaften und Künste*, vol. 27 (Leipzig/ Halle, 1741), s.v. "Pfuscher." The complete text: "Zu allen Künsten wird theils eine wohlgeübte Wissenschaft der Natur der Sache; theils eine daher flüssende gründliche Geschicklichkeit, mit solchen Sachen nützlich umzugehen, erfordert, daher in allen Künsten zweierley Arten ungeschickter Leute sind. Den einen fehlt es an theoretischen Kenntnissen und an Beherrschung der geistigen und theoretischen Prinzipien des Handwerks, den andern an praktischen, manuellen Fertigkeiten."

[55] For an introduction see John Henry, *The Scientific Revolution and the Origins of Modern Science*, series Studies in European History (London/New York: Macmillan Press, 1997).

[56] "Und dieweil einige auf diese Gedancken kommen / als müsse das Fundament der Mensuration in der Stereometria und nicht in denen Musicalischen Proportionen gesucht werden; auch sich dahero wohl nicht gescheuet / die Proportiones Musicas als alte und betriegliche Figmenta des Pythagorae

anzustechen." (Johann Philipp Bendeler, *Organopoeia*; see n. 48), p. 6.

57 Giovanni Antonio Marchi, *Il manoscritto liutario di G.A. Marchi* (Bologna, 1786), ed. Roberto Regazzi; English transl. by Nicoletta Sbarra and John Guthrie (Sala Bolognese: A Forni, 1986), p. 128.

58 Ernst Florens Friedrich Chladni, *Die Akustik* (Leipzig: Breitkopf & Härtel, 1802).

59 Félix Savart, *Mémoire sur la construction des instruments à chordes et à archet* (Paris: Deterville, 1819; reprint ed., Geneva: Minkoff, 1972).

60 Gottfried Weber, "Versuch einer praktischen Akustik der Blasinstrumente," *Allgemeine Musikalische Zeitung* 48 (Leipzig, 1816): 33, 49, 65, 87; and 49 (Leipzig, 1817), pp. 809, 825.

61 Berlin, Geheimes Preußisches Staatsarchiv, Rep 120 D XIV, Fach 2, no. 3, vol.2, p. 7. Patent application for a crowned sound board, dated 7 February 1834, addressed to the Prussian Ministery of the Interior in Berlin: "Wir nahmen nemlich wahr, daß die hauptsächlichen Mängel der bisherigen Saiteninstrumente darin bestehen: 1. daß der Instrumentenbau, bisjetzt auf keinem festen durchgeführten Principe in akustischer Hinsicht beruht, weßhalb die Ausführung jedes einzelnen Instruments und dessen allenfallsige Güte nur ein zufälliges Ergebniß ist."

62 See n. 59.

63 Reprint and English transl. by Carl O. Bleyle as Georg Andreas Sorge, *The Secretly Kept Art of the Scaling of Organ Pipes*, Bibliotheca organologica, vol. 33 (Buren: Frits Knuf, 1978).

64 English transl. by Charles Ferguson as François Bedos de Celles, *The Organ-Builder* (Raleigh, NC: The Sunbury Press, 1977).

65 Johann Gottlob Töpfer, *Lehrbuch der Orgelbaukunst*, 3rd ed. by Paul Smets, 3 vols. (Mainz: Rheingold, 1936-1939); 2nd ed. by Max Allihn as *Die Theorie und Praxis des Orgelbaues*, in series Neuer Schauplatz der Künste und Handwerke, vol. 208 (Weimar: B. F. Voigt, 1888).

66 Christhard Mahrenholz, *The Calculation of Organ Pipe Scales from the Middle Ages to the Mid-Nineteenth Century* (Oxford: Positif Press, 1975).

67 Carl Kützing, *Beiträge zur praktischen Akustik als Nachtrag zur Fortepiano- und Orgelbaukunst* (Bern, Chur: J.F.J. Dalp, 1838), p. 24. The ratio 1:2 refers to the four octaves between f^4 and *f*.

68 Carl Kützing, *Das Wissenschaftliche der Fortepiano-Baukunst* (Bern und Chur: J.F.J. Dalp, 1844), pp. 43-45.

69 For an overview see Hubert Henkel, "Mensurberechnungen von Hammerklavieren im 19. Jahrhundert," *Das Musikinstrument* 40/9 (September 1991): 28-31.

70 Heinrich Welcker von Gontershausen, *Der Flügel oder die Beschaffenheit des Piano's in allen Formen*, (Frankfurt am Main: Heinrich Ludwig Bronner, 1853), pp. 59-60.

71 Carl Emil von Schafhäutl, "Theobald Böhm. Ein merkwürdiges Künstlerleben," *Allgemeine Musikalische Zeitung* 17, no. 34 (1882): 537-38: "Ich brachte Böhm sehr oft Resultate langer Rechnungen; allein sobald er seine Flöte darnach construiert hatte, waren immer ein paar Schwingungen zu wenig oder zuviel.... Die Theorie allein hätte also die neue Flöte nicht hervorgerufen. Es gehörte zweitens dazu der geniale musikalische Mechaniker Böhm, ... Der dritte Grund... war, dass Böhm selbst ein Virtuose war. Er als Virtuose und Künstler war allein im Stande, zu beurtheilen, durch welche Mittel das, was Theorie und Praxis geschaffen, den höchsten Anforderungen der Kunst entsprechend ausgeführt werden könne.... Wenn die Theorie, der schaffende Gedanke im Stande ist, messend und rechnend in das innere Wesen der Bewegungserscheinungen einzudringen und zum Beispiel die Gesetze der tönenden Schwingungen dem Geiste klar zu machen, so wird es nur dem genialen Mechaniker und Virtuosen allein möglich, auf den Ergebnissen der Theorie weiter bauend ein wirkliches, d.i. ein praktisches musikalisches Instrument zu schaffen, zu dessen Vollendung ohne diese Eigenschaften des Virtuosen Jahrhunderte nothwendig gewesen sein müssten."

72 For the complete quotation see section 1 of this article.

[73] Karl Fuhr, *Die akustischen Rätsel der Geige: Die endgültige Lösung des Geigenproblems* (Leipzig: Carl Merseburger, 1926), p. 34.
[74] Emile Leipp, *Le violon. Histoire, esthétique, facture et acoustique* (Paris: Hermann, 1965): "All attempts to perfect the violin have failed." Lothar Cremer, *The Physics of the Violin* (English edition, Cambridge, Mass/ London: The MIT Press, 1984), p. 1: "The quality of both performance and instruments has been achieved through empirical methods; consequently, our application of the "exact" methods of the natural sciences will not result in any fundamental improvement.—Nonetheless, natural scientists ... have again and again undertaken research into string instruments."
[75] See the previous section of this article.
[76] See n. 17.
[77] Otto Hagenmaier, *Der Goldene Schnitt. Ein Harmoniegesetz und seine Anwendung* (Heidelberg: H. Moos 1963), p. 22.
[78] Among these attempts is the "Harmonik" by Hans Kayser (1891-1964), which researches the proportional structure of plants, skeletons, minerals, etc.
[79] Trinh Xuan Thuan, *Chaos and Harmony: Perspectives on Scientific Revolutions of the Twentieth Century* (New York: Oxford University Press, 2001).
[80] Mahillon, *Éléments d'acoustique*, p. 94, n. 6: "Les proportions de la colonne d'air ont une importance extrême; non-seulement elles detérminent, comme nous venons de la dire, la différence de timbre entre les instruments, mais c'est à leur régularité, à l'exactitude apportée dans leur développement, qu'est due la justesse des harmoniques. Un instrument de cuivre est faux lorsque la régularité des proportions est interrompue. Les proportions exactes sont nécessaires, tous les facteurs le savent, mais comment les défenir? Quelle est la formule qui sert de base à leur développement? Rien de bien sérieux n'a été publié à cet égard; le tâtonnement, les lois empiriques sont les seules guides dont on se soit servi jusqu' à présent. Cependant, nous avons la conviction que ces proportions suivent le développement d'une courbe géometrique dont la forme se rapproche de l'hyperbole et dont nous espérons publier un jour la formule."
[81] About the ideology of progress in general, see: Laurence Libin, "Progress, Adaptation and Evolution of Musical Instruments," *Journal of the American Musical Instrument Society* 26 (2000): 187-213.
[82] See n. 2.
[83] Ibid.
[84] According to a drawing provided by Graham Nicholson, to whom I express my thanks; see Pierre-Yves Madeuf, Jean-François Madeuf, and Graham Nicholson, "The Guitbert Trumpet: A Remarkable Discovery," *Historic Brass Society Journal* 11 (1999): 181-86. One may argue that the configuration of 3/4 + 1/4 may be accidental in this early trumpet. So far we have no other evidence for such a proportion from the fifteenth and sixteenth centuries.
[85] *Vollständige theoretische und praktische Geschichte der Erfindungen* (anonymous), 4 vols. (Basel, 1789-1795), vol. 1 (1789), p. 218: Speaking of the history of the trumpet, this reference work states, "Ein gewisser Moriz, unter der Regierung Ludwigs des Zwölften, gab ir die heutige Gestalt." ("A certain Moriz gave it its current shape during the reign of Louis XII.") Louis XII lived from 1462 to 1515, and "Moriz" is probably the phonetic form for "Maurice." As I know, this source has been overlooked in previous research on the history of the trumpet.
[86] The putative correlation between length and pitch in brass instrument making needs further examination. In organ building, the relationship between pitch and length standards was addressed as early as the nineteenth century. See Bruce Haynes, *Pitch Standards in the Baroque and Classical periods* (Ph.D. diss., Université de Montréal, 1995), 1: 39-43.
[87] There is only one document, Sax's application for the patent of the Saxotromba, filed in 1845, in which he adds some diameters. However, the figures seem only to be easily recognizable measuring

points, chosen to facilitate comparison of different instruments. Thus engineer Surville, who in 1859 served as an expert in one of Sax' lawsuits, used the figures in this sense and did not refer to them as proportions. See *Rapport de M. l'expert Surville Ingenieur déposé le 18 février 1859 et Dire de M. Sax* (Paris, 1860).

[88] The bore of the first half of the tube is slightly conical or quasi-cylindrical and extends to the end of the valve section. However, its length, 2793 mm, equals only forty-eight percent of the overall length of 5872 mm. In the following example 2, the slightly conical section covers fifty-one percent of the tube length, suggesting that fifty percent is the theoretical length for the basses and contrebasses of the Nouveaux Saxhorns. The six-valve altos (Example 3)follow a different layout with the tuning slide after the valves. If the diameters of the bore were not accessible to direct measurement, they were measured externally and .5 mm were substracted from the wall thickness.

[89] The strong deviation at $^{5}/_{6}$ L occurs in the lower bow, which is heavily dented.

[90] See *Rapport de M. l'expert Surville.* p. 22.

[91] Werner Winkler and Gregor Widholm, "BIAS Blas Instrumenten Analyse System," *15 Jahre Institut für Wiener Klangstil. Hochschule für Musik und Darstellende Kunst in Wien*, ed. Eduard Melkus (Vienna: Institut für Wiener Klangstil, 1996), pp. 95-106.

[92] I am very grateful to the Musée des instrument de musique in Brussels, in particular Ignace de Keyser, for making various instruments accessible for examination.

93 The precise half of 1320 has its place within the 27mm-wide ferrule, and therefore cannot be measured directly.