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## Shaping and understanding sound : Violin makers, musicians and scientists from Renaissance to Romanticism

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The training of instrument-makers in Renaissance Italy is linked to a rediscovery of theoretical works on physics and sound as well as to some new tools and skills. Then, the development of physics in the seventeenth and eighteenth century lead the establishment of acoustic as a modern science, with the distinction of partials from harmonics. The "western world" has given explanations on vibrations, modes and then elasticity theories, some of which have been included into general knowledge. By times, links between scientists and makers have developed and have participated to the development of musical instruments. Traditional violin makers are craftspeople, and they construct instruments by choosing step by step between many possibilities from the drawing of the model and the choice of materials, to the cutting out of the shapes to create air volumes and vibrating facings. Their parameters are the dimensions, shapes, weight, elasticity, quality and duration of sounds and notes. The test for judging the results is the playing of the instrument by a very competent musician. We will explore, with a point of view of the historian of techniques how the meeting of different cultures and knowledge have transformed the instruments from the Renaissance to the beginning of the 19th century.

## 1 Introduction

In the first part of our talk, we will see how the designs of the violin family evolved from the monochord proportions to the *Divina Proportion*. The further work of Da Vinci on arch influenced arched belly on instruments.

Then we will see the step of ruling out the consonance as a result of the universal harmony of whole numbers, and the rediscovery of Achimedes work on gravity, as well as experimental work from Gallileo on strings.

Last, we will show the influence of Chladni on Savart and Vuillaume.

## 2 First shapes in violins

### 2.1 Proportional compasses in Italian Renaissance

Proportional designs, as applied to stringed musical instruments is directly derived from the divisions of the monochord, which was an instrument of mathematics as well as music pedagogy during the Middle Ages.

The musical context in which the violin family appears is that of polyphony, first written for choirs by composers such as Ockeghem and Josquin des Prés. Woodwind instruments are the firsts to play as ensembles this "music without words", and Isabella d'Este seems to be one of the initiators who played bowed instruments as families. [1] What is remarkable at that time is the circulations of knowledgeable people converging to Italy from many different places : musicians from Spain with the new Aragonese pope in 1492, the same year Jews were expelled from Spain and found refuge elsewhere. [2]

The wealthy activity of editors in Venice, favours the presence of many German woodcarvers working for the printing industry [3].

Experienced German lute makers immigrate to northern Italy from Füssen, where lute making has been a speciality since the crusades [4]. (workshops of Maler and Frei in Bologna; of Venere, member of the Tieffenbrücker family, in Padua) [5].

We can see a vihuela shaped instrument in a marqueterie of Urbino dated 1474, with a flat body made out of cut out planks, without arches, sound holes in a C shape facing each other, and flat bridge. If it is bowed, the strings are not played independently. The pegs are inserted from the front into a rounded peg box.

An instrument painted by Bellini thirty years later (Virgin, Venice, San Zaccharia, 1505), a lira da braccio with five strings and two bourdons, played in chords to accompany the voice. Four corners are now distinct in the outline. The table is also flat, as is the bridge, which is moved a little more towards the tailpiece. The lira da braccio was very fashionable at the time, especially by painters in Florence. Leonardo da Vinci and Bramante played it. [6]

Bellini shows here another position of the bridge, lower down, proportionally increasing the vibrating string in relation to the body length of the resonant box.

The violins in the sixteenth and seventeenth century have a variety of designs that are still made with techniques of proportional drawings, but rely on different ratios, depending on the different schools. Kevin Coates [7] shows that the golden section, the square root of 2 and other root proportional obtained by rule and compass, were differently used by makers, thus producing quite different looking instruments. Remy Gug completes the argument in showing how the underlying thought of the makers in the 16<sup>th</sup> century is that of whole numbers [8].

At that time of wars and conflicts that affect essentially the political relations between towns and States, French armies try to gain territories in Italy, and alliances change from year to year between Venice and France. Mathematics and practical arts meet then in an urge of knowledge. In 1496, Leonardo starts friendship with mathematician Luca Pacioli, and both men work towards the publication of *de divina proportione* by in 1509. Leonardo writes theoretical notes on the nature of arches and on the resistance of beams. In 1500 Scipione Del Ferro solves the cubic equation, Leonardo paints a portrait of Isabella d'Este in Mantova, and a violin maker named Carcanius, is registered in Cremona. Dürer learns Italian drawing techniques in 1494 and 1505-1506, and we can see it in his *Underweysung der Messung* in Nuremberg (1525). The use of compasses for proportional drawings, as described in his treaties, is used by craftsmen in northern Italy

## 2.1 Arches, curved walls and parabolic mirrors

The next step of the new making techniques can be seen in a painting by Carpaccio : *Presentation of Jesus at the Temple*, where the arching of the belly is clearly visible, with a fluting all around the edge and C holes lying on level lines. The analogy between light and sound may have been used to evolve from flat plates to carved out inside volumes, while works on the vaults in architecture showed the better resistance to pressure of certain types of arches.

In 1513 Leonardo works on parabolic mirrors. Concerning the reflection of sound on curved walls, architects of the time were rediscovering the works of Vitruvius. In *De architectura* Book 5, Vitruvius discusses acoustics. Sarton writes [9]:- *Vitruvius explains sound as a displacement of air in waves which he compares with the waves that can be observed on the water's surface when a stone is thrown into a pond. What is more remarkable was Vitruvius' application of the wave theory to architectural acoustics. The wave theory of sound was Greek, its application to the acoustics of a hall typically Roman. ... Vitruvius analyzes the acoustics of a theatre and the phenomena that may spoil it, which we call interference, reverberation, echo.* In Book 10 Vitruvius describes water organs, stringing and tuning of catapults ...

It is worth noting that, although today we see Vitruvius more as a practical man rather than as a scholar, Cardan (**Gerolamo Cardano** (Pavie, 1501 - Rome, 1576)) included him in his list of the twelve leading thinkers of all time. Tartaglia (1499-1587), a mathematician born in Brescia, translated the *Elements* by Euclid and *De insidentibus aqvae* by Archimedes. He is known to have earned a living in teaching mathematics and geometry to craftsmen, making it accessible to instrument makers in a town renowned for its musical instrument maker in the 16<sup>th</sup> century such as Girolamo Da Virchis and Gasparo da Salo.

## 3 Science and music in the 16th and 17<sup>th</sup> century

### 3.1 Consonance and dissonance : from the harmony of whole numbers to cultural taste

The physicist Giambattista Benedetti (1530-1590) introduces a new way of studying sounds, which is not a mathematical deduction, but by physical experiment. He introduces the idea that consonances and dissonances are not separate qualities of sound, but must be taken as continuous series. This is a very important change, because, up to then, the way music and mathematics were linked was with a coincidence of whole numbers. Vincenzo's Galilei's father has the same opinion, and for him there is no interval that is more "natural" than another. For them, consonances have nothing to do with the aesthetics of simple proportions. It is the first time that a theorician thinks that what sounds nice does not depend on a numerical system,

but by the judging of the ear. For musicians, it is time to reconsider the modes and natural scales and their consonances, and to switch to equal temperament, as was promoted by Giosefo Zarlino in his *Istitutioni Harmoniche*. The cistre by Gerolamo Da Virchis show placements of fixed frets that experiment with new temperament. The interval of a third, which becomes then musically acceptable, does not meet the preceding theories on the harmonies of numbers [10].

### 3.2 Centre of gravity

In the year 1582-83 Ostilio Ricci, who was the mathematician of the Tuscan Court and a former pupil of Tartaglia, taught a course on Euclid's *Elements* at the University of Pisa which Galileo attended to study the works of Euclid and Archimedes from the Italian translations which Tartaglia had made. The treatise *on plane equilibriums* sets out the fundamental principles of mechanics, using the methods of geometry. Archimedes had discovered fundamental theorems concerning the centre of gravity of plane figures and these are given in this work. In particular he finds, in book 1, the centre of gravity of a parallelogram, a triangle, and a trapezium. Book two is devoted entirely to finding the centre of gravity of a segment of a parabola. In the *Quadrature of the parabola* Archimedes finds the area of a segment of a parabola cut off by any chord. [11] It seems that the balancing point of violin plates have deliberately being placed at the position of the bridge by the most informed makers that can be achieved by a proportional drawing of the outline, taking into account the position of the geometrical centre of the table. It means that the bridge is proportionally distant from the rib structure in relation to the mass of wood it has to put in vibration to exercise forces on the rib structure.

## 4 The birth of modern acoustics: a new science for understanding sound

### 4.1 Stradivari, concertos and concert halls

The science of Acoustic has been named as such by Joseph Sauveur (1653-1716) a member of the "Académie des sciences" in Paris, as was Mersenne. He had studied the high harmonics of a vibrating string and gave the names to the nodes ("noeuds") and antinodes ("ventres"). [11]. Pigott and Noble had worked independently on the same subject in England and their work was presented by Wallis in 1677. Sauveur wished to organise the science of sounds and make it into a branch of physics. In 1715, Brook Taylor, developing results obtained by Mersenne, gives the frequency of the fundamental of a vibrating string in function of its length, linear density and tension.

But at the time of Vivaldi and Stradivari, the improvement in violin making is essentially turned towards the satisfaction of concerto playing. That is still visible today is the change in the shape of the arching. In Nicolo's Amati's

instruments, and in the early Stradivari's, the arches are high, and slightly "pinched". A large channel scoops the plates around the tables, and the turning point of the arch is quite far from the outline of the plate. [12] The front is very thin, frequently around 2 or 2.5 mm at the thinnest.

Stainers archings have like a flat on the top and a sudden drop towards the scooped channel. Both Amati and Stainer arch models are high and quite stiff. The kind of sound that is referred to at the time for a violin is a fluted tone.

But progressively, Antonio works his models until having a lower arch, fuller around the outline, and more flexible. This gives more power and a good response.

The virtuosity of the instrumentalists of the time increased notably, and the size of the halls where they are played increases to accept the first public concerts. A good carrying power is necessary. Stradivari becomes the most appreciated makers for violin, and his models (outlines and arching) are copied. If they become the standard in the next century, as does the work of Giuseppe Guarneri Del Gesu, is probably due to the capacity of the plates of their instruments to enhance the sound of the violin to satisfy solo playing, and to adapt to the classical and romantic bows and bowing techniques.

"The mathematical theory of sound propagation began with Isaac Newton (1642-1727), whose *Principia* (1686) included a mechanical interpretation of sound as being "pressure" pulses transmitted through neighbouring fluid particles. Accompanying diagrams illustrated the diverging of wave fronts after passage through a slit. The mathematical analysis was limited to waves of constant frequency, employed a number of circuitous devices and approximations, and suffered from an incomplete definition of terminology and concepts.(...) Substantial progress toward the development of a viable theory of sound propagation resting on firmer mathematical and physical concepts was made during the eighteenth century by Euler (1707-1783), Lagrange (1736-1813), and d'Alembert (1717-1783). During this era, continuum physics, or field theory, began to receive a definite mathematical structure. The wave equation emerged in a number of contexts, including the propagation of sound in air. " [11]

Practically, in the domain of music performance, the increase of the size of concert halls with the development of public concerts is starting; it corresponds to this understanding of sound propagation. Multiplication of the number of musicians in orchestras is one of the consequences, and it is for two centuries a change in the social use of music which will lead to symphonic orchestra music and compositions techniques. These preoccupations are common for people at the time, but makers and physicists seem to work independently for the same aim.

## 4.2 Science for Progress: Chladni, Savart and Vuillaume

The work of Chladni marks a new step in the correspondences between physicists and violin makers [13, 14]. Published in 1798 and 1802, after those of Thomas Young who established the vibrating nature of light. In 1794 the École Centrale des Travaux Publics was founded by and was directed by Carnot and Monge. It was renamed the École Polytechnique in 1795 and de Prony was certainly one of the main lectures by this time. It seems that with

Laplace and Lagrange, he had as students at Polytechnic Poisson, Savart and Chanut., studied there when it was open in 1798, as well as Sophie Germain who, being a woman, was reading the teachings of the prestigious school at home by herself. These have all seen Chladni's demonstrations on the modes of vibrating plates. Napoleon assisted to one in 1808, and was so pleased with it that he to commissioned the further study of the mathematical principles of vibrating plates which then encouraged a plethora of research in waves and acoustics [26]. Germain, as an unknown and unrecognisable mathematician, then devoted herself to respond to the concours challenge: *formulate a mathematical theory of elastic surfaces and indicate just how it agrees with empirical evidence*. In 1815, she obtained finally the price, but didn't present herself to receive it. Before her death, she completed papers on number theory and on the curvature of surfaces "*Recherche sur la théorie des surfaces élastiques*" (1821) et "*Mémoire sur la courbure des surfaces*" (1830).

Meanwhile, Savart constructed the flat rectangular violin, while Chanut, a student who came from Mirecourt and was from a violin makers family, showed to the Academie a cornerless arched violin, made by a young maker: Jean-Baptiste Vuillaume.

The violin maker Jean-Baptiste Vuillaume came to Paris from Mirecourt to make the experimental violin designed by Francis Chanut while he was put aside by the army after Napoleon's defeat. He was only eighteen, when he arrived from Mirecourt to work for Chanut in Lété's workshop, but this time influenced all of his carrer. He kept relations with Savart, and counted the musicologist Fétis in his acquaintances. Vuillaume published Fétis book on the origin and transformation of violin [15], and was the inspirer of most of its content, even though Fétis was the right man to write, study and correct the subjects that evidently interested Vuillaume. Fétis mentions experiments with pieces of wood certainly cut out by Vuillaume from old Cremonese instruments. It seems that Vuillaume has used the Chladni patterns with the help of Savart. He also most probably tuned his plates. One table of an instrument by Vuillaume has been tested by John Dillworth [16] for the three modes 1, 2 and 5, and they were found an octave apart.

## 5 Conclusion

The violin family appears around 1500 in northern Italy at the same time as the viol family and takes its modern shape in a few decades. Is there any influence of scholars and mathematicians in its designs? Are there any links between the theoretical works of the time and the design of the instruments?

It is a common thought amongst scholars to believe that techniques have derived from scientific discoveries. However, the study of artifacts, ideas, makers and scientists show that very good experimental craftsmanship, can produce extremely well designed instruments without the help of theoretical work. But we have shown that crystallization of knowledge between scientific experimenters and craftspeople have had an definite influence on instrument making.

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