

**CAPIROLA'S LUTE STRINGS, including a reply to articles to FoMRHI Comm 2151 and articles in *Lute News***

About 14 years ago I wrote Comm 1810 (Ref 1) which contained an analysis of Capirola's description of tapered lute strings. Vincenzo Capirola, 1474 to 1548, was an early lute composer, and his pieces and some instructions were compiled by a pupil, Vidal (Ref 2). I hope this brief note will be sufficient enlightenment for any readers of two recent articles from Mimmo Peruffo (Ref 3), in a long delayed reaction to Ref 1.

My initial interest was certain highly puzzling aspects of stretch sharpening in strings, and the survival of old lutes with angled bridges and necks. During this work the mechanics of a string with long-range variations of mass arose, and then I recalled Capirola's 'tapered' strings. This is an important distinction from years of speculation hoping for any written primary evidence, or prolonged attempts to explain some document. Other current notions seemed entangled in etymological problems such as catlines, or lack of written evidence for loading strings with dense materials. In contrast, there was an ancient source on 'taper', and well worth some study.

My initial analysis of taper (Ref 1) included a substantial list of several interesting practical effects, and Capirola's 'The Secret of Stringing the Lute' provided several tuning effects for individual strings described as 'one end thicker than the other', with the basis of a stringing scheme for the courses on a lute. General musical translators may have sensed some technical relevance, but perhaps not the serendipity experienced by a researcher in several areas of physics and biology, with some academic history. A present reader will need to study closely both Ref 1 and Capirola, but attempting some summary here would rapidly spread into details. However, as an illustration of the richness and subtlety of the ancient account there is a string type that only sharpens whichever end is tied to the bridge. Ref 1 noted that while this may seem to indicate a uniform string its strict meaning could be a taper no more than is needed to cancel its own stretch sharpening.

We can now address some statements made in Ref 3. This will concern the more prominent points only, and will not stray into inconclusive areas.

An early criticism in Ref 3 is that Capirola has limited use as only a single source - but clearly one more than loading with dense materials, which Ref 3 might consider worth the weight of Capirola's book in gold particles. Later in Ref 3 it is concluded, after many minor and incorrect points, that tapered strings never existed and Capirola is misled and wrong. This appears to forget or ignore that Capirola demonstrated the existence of taper by continual references to turning a string round on the lute, which is effectively a detector and measurer of taper, as shown in Ref 1, and also the whole descriptive thrust. Dismissal of vital, credible, written evidence is unacceptable in any subject.

This treatment of Capirola in Ref 3 is also received by several other notable early writers. The introductions cite Bermudo, Vincenzo Galilei, both important theorists, and the composers John Dowland and Le Roy. Such a roll call often aims to attract kudos to the writing, but here they receive advanced chastisement for not assisting the author's aim. It is unsought praise to be included in such a group.

A reader also needs to be aware that there are several topics in Ref 3 which had appeared earlier in my further work in Refs 4 to 8, but they are not cited in Ref 3 and a reader should be able to see them. These included remarks on the tapered structures of guts as a natural material and how ancient large scale production would have led to a wide range of tapered strings, among which a uniform string would have been a rare statistical oddity. There is also a conspicuous absence of any term such as 'uniform' in Capirola. Some earlier readers had the impression I advocated the making of exact tapers or conical shapes. However, taper would not have been a smooth perfect ramp, but rather a long-range effect like a rocky slope, as described in Ref 1. Also the general ancient procedure would have been making best use of a great variety of strings resulting from large scale hand production, and cleverly realizing that certain arrangements of tapers allowed acceptable

tuning. They certainly would not have discarded most of their strings, while searching for some uniform rarity.

Ref 3 also addresses the matter of tapered strings, firstly by describing the shape of inflated guts, which is interesting and has some bearing on a final string. Their uniformity was stressed in line with some modern expectations, arising mainly from extruded polymer strings and overspun strings. Other makers also show these tests, but are not too concerned with uniformity. In contrast, my interest was the many small departures, and also splitting or cutting into strips that can affect the final strings. Further highly interesting effects in the manufacture processes of winding and finishing strings will be discussed below.

Readers may notice that Ref 3 appears to be based on a preconceived belief that Capirola's strings and all other early strings were uniform, but rather than trying to understand the early written evidence and later analyses, the technique is a simple scan for any little phrase that can be queried. This is not a generally recognized procedure for technical research, and it also leads to a series of confused propositions and non sequiturs. A typical example is a sentence in Capirola where the subject may seem a little unclear, but refers to the topic of the previous sentence, whereas Ref 3 looks around for another noun which produces some minor disagreement. A related lapse of logic seems to believe that simply making a single slight query in the scheme for taper immediately proves complete uniformity. As if someone fails to recognize a local feature in their city, and immediately concludes they are permanently transferred to some small distant village.

Ref 3 also shows some tests on just two gut strings, which we must remember are obviously modern. String 1 appears to be a gut string suitable for a top or second course, but there are no further details of the material. Its diameter was measured with a micrometer, valid for a modern test, at unspecified points along its length of 7.2 metres. The diameters are said to 'oscillate' between 0.52 and 0.54 mm, but with the ends at 0.52 and 0.53mm. However, there is no measure of a 'wavelength', or any other account of the distribution of diameters over lengths of about 1 metre as used on a lute. Qualitative descriptions of variations in diameter in Ref 3 are 'not very noticeable, rather imperceptible' etc. The most one can deduce are differences of 0.01 and 0.02 mm. A lowest taper could be 0.01mm over 7m perhaps with some other local variation of 0.01mm, a moderate taper might be 0.02mm over about 3½m for at least one cycle of an 'oscillation', and the highest taper could be 0.02mm over maybe 1m or even less.

Presumably by coincidence, my earlier Ref 1 had used this last taper of 2% to illustrate a tuning effect in the region of practical interest for stretch sharpening. Larger effects from greater tapers would be useful for angled bridges with shorter bass strings, whereas elastic effects were not a possible mechanism (see Refs 4 to 8). Ref 3 may have had a taper in the predicted region of interest, rather than a refutation of the effect.

However, this is just one test and the variations are close to the micrometer's smallest division. Above all, there is simply not enough data for defining a profile, and one cannot truly discriminate three possibilities of near uniformity, a degree of taper, or more localized defects. One can also see the considerable problems of measuring dimensions for building a profile, even for an improved design of test.

In contrast, Refs 1 and 8 showed that the acoustic test could give a far better and quicker measure of any average taper. This used to be known as an 'operational method', provided by the underlying physical relations, where very small tapers are predicted to have significant acoustic effects that can be measured with reference to the frets. Only three equations were required, but Ref 3 does not seem to be conversant with this form of expression, which is vitally necessary for a quantitative understanding in the modern absence of a good supply of tapered strings for demonstrating the ancient methods.

Incidentally, this 2% taper, from 0.02/1 over 1 m, is a far more practical scientific measure than an engineering gradient of 0.02/1000 or 0.00002 or  $2 \times 10^{-5}$ .

String 2 is a great contrast, and is made from a single lamb gut, and also a possible top string. The range of measured diameters is given as 0.33 to 0.44mm, but no length is given. This variation is

relatively huge, 0.11/0.33 or 33%, even if referenced to a 7 meter length, giving a 5% variation for 1m. This is described as 'substantially constant in diameter' by Ref 3. Possible reasons for the large difference between the two strings should have been addressed.

Ref 3 considered these strings uniform, but Capirola's uniform reference would lie between a fourth and fifth course, with about twice the diameter. However, Ref 1 had also used a uniform top course for illustrating Dowland's much later lute, and this may also be helpful for understanding tapered schemes.

A crucial point in all reporting of scientific tests is a necessary inclusion of relevant details for samples. The present cases would include the initial components, production methods, and importantly any finishing after drying.

So far, these measurements have been treated at face value as objective valid tests, but a closer look at the samples and results suggests a serious problem. The internet shows that the bulk of Aquila gut strings are a variety of types above 0.5mm in diameter and all are described as 'half-rectified', eg HR demi-rectified, HU unsplit lamb gut, HV varnished and beef. The dimensions of all these types are given by reference to the example of a 0.66mm mean diameter, within a strict 'window' of 0.65 to 0.67mm. This differs from a usual random tolerance of 0.01mm, since the upper measure has been limited by a mechanical process. The original unrectified object would have had a greater diameter of around 0.69mm with a more irregular profile. It is also worth adding that these tight tolerances, related to the micrometer division of 0.01mm, may give a good relative guide to the rectification process, but they are unlikely to be generally appropriate for a variable heterogeneous material, sensitive to humidity and temperature.

String 1 had the identical pattern of three measurements: 0.52, 0.53, 0.54mm. A reader would have expected the sample to be an original unrectified string, with a diameter of at least 0.56mm. This could also explain the lack of definite taper and more variable local imperfections in Ref 3, and maybe also the curious 'oscillations'. Clearly, using a modern string that had been made almost uniform for a demonstration to support a belief that early strings had been uniform would be unhelpful, and completely unacceptable. At the same time, the limited presentation of small variations did not exclude some taper and imperfection in the initial objective analysis.

String 2 below 0.5mm diameter would have escaped this process, and indeed showed considerable variation of diameter and likely taper. Some further measurements and photos of the string and micrometer readings, similar to string 1, could have been highly interesting.

A reader may well consider there is now no need to continue pressing ahead with this reply but several aspects require attention, including the historical context of rectification. Regarding types of gut, alluded to above, Ref 3 was unwise to dismiss the relevant matter of ancient sheep anatomy, especially by references to nuclear catastrophes.

Hopefully, readers are keeping up, but there are two further features of string making that require attention. The first is a constant effect arising from the winding process itself, where twisting is naturally concentrated at the winding end, which consequently has a smaller diameter. In providing analyses for various degrees of taper in Ref 1 it seemed unnecessary to include this further complication explicitly among all the other sources of taper, but string makers would have been aware of it. This effect could lead to a general taper in any string, unless there were elaborate compensations such as an exactly opposite taper in the thickness of the initial guts. As a reminder, other contributions to a final taper would include natural taper in a gut diameter, flares, wall thickness, and also splitting or cutting into strips. Further details that might compensate, such as diameter and wall thickness, or various reversals of tapers within a string, would still be expected to leave some residual degree of imperfection leading to slightly tapered strings, especially with the added effect of end winding. My references also noted that strings with many component guts could be more easily controlled than those with only a few. These are reasonable conjectures of a practical scientist. In view of all these effects, Ref 3 should have been more concerned with explaining how uniform strings could ever have been the general ancient result.

The second matter concerns the finishing of a dried string, which may change its surface and also its profile, including a loss of taper. The ancient process was an oily rub with horsehair pads, and maybe some pumice. This would clean up minor defects, but have little effect on the profile of a string, whether tapered, uniform or with local irregularities. However, in the early 19<sup>th</sup> century a stronger method known as 'rectification' was begun, to remove imperfections that were perceived to produce poor tone, primarily on thin violin strings. Complaints from notable figures such as Louis Spohr in his 1831 'Violin School', and earlier by Mozart, led to partially effective 'sanding boards', and then much later around 1950 to grinding wheels capable of removing controlled amounts of material, while still aiming to minimize damage to the complex fibrous structure. A large gap would remove just the highest peaks, and a smaller gap could produce a perfectly cylindrical, or uniform, string. Ironically, with the introduction of a steel top string the original need disappeared, but the process spread over time to all other gut strings, ensuring economically a repeatable saleable modern product. However, the lute had declined completely, well before rectification started, so this process cannot have been present in any original lute strings. This explanation is also necessary for the following historical understanding of 'falseness' and 'taper'.

The early notion of falseness relates to testing an 'outstretched' string, also mentioned later by Le Roy and others. This stems from large scale local irregularities. In contrast, a slowly varying slight taper is not revealed by this test, but produces slight inharmonicity of overtones. This was a chief concern of rectification, and the important distinction between large defects and gradual taper was probably established only by this process. Ref 1 analysed some simple cases of both effects.

Ref 3 appears to suggest that Capirola mistook falseness for taper. This may seem an unnecessary concern after both were claimed to be small for string 1, but would provide a further distraction from taper. More decisively, as already stressed, taper would have been revealed by the all-important turning around of ends on a lute. The ancients would therefore have seen mainly taper, with and without significant falseness, but only a very few uniform strings, also with and without falseness. They would have been concerned with making the best use of taper and also some falseness.

Modern players might find a little inharmonicity annoying but it appears to have been an unavoidable and acceptable compromise for the ancients. In brief, there would be compromises between inharmonicity and all the tuning advantages for stretch sharpening, and for angled bridges or necks. There would be a limit on the maximum tolerable taper, and similarly the limiting case of no taper would be a rare possibility. However, this was not mentioned by Capirola, who as an aristocratic amateur could well have afforded any perceived ultimate refinement. The tapered strings themselves may now seem even more fascinating than the initial tuning problems in Ref 1.

An astonishing misconception of practicality in Ref 3 is an apparently serious belief that ancient production of tapered strings would have required exact measurements in a modern form, such as mm or inches. This is elaborated in detail, and even used to argue that tapered strings could never have existed. Modern makers might need this, but my discussions have shown the ancient procedures were different.

For example, string thickness or diameter, with its difficulty of measurement, was not a familiar concept. The modern understanding of the relative string diameters across six courses, such as a factor of 2 for each octave, was not explicitly known, but there may have been an approximate practical notion. Accumulated experience and large bundles of standard nominal types and weight are probable early methods. Very helpfully, Capirola advises setting the three lowest courses and preserving these durable strings as a guide for replacing the fragile upper courses. A remarkable aspect is that the ancients appear to have had a greater grasp of the second order effect of taper than the first order nominal thicknesses, the opposite of the modern situation. Selection of tapered strings and their reversing would not be more onerous than making and adjusting reeds for wind players. Strings in boxes and envelopes with a numbering code or precise dimensions came much later. All this was covered in Ref 1.

There is a related concern with precise dimensions in Ref 3, misconstruing my suggestions that the ancients might prefer certain tapers. However, my writing explained that the main method would be

selection from large variable stocks, and perhaps by noticing certain trends in using various types and arrangements of guts etc. Detailed measurements and substantial sanding would not have been used for the original lute strings, but it is not impossible that a particularly obvious defect could be removed, similar to adjusting reeds. My single reference to experimental sanding was for a nylon string as a check on the fundamental relations between taper and tuning, which was confirmed as would be anticipated for a purely geometric effect.

Taken together, all the above considerations indicate that slightly tapered gut strings were the main reality, and not only for Capirola and his time. Amazingly to us in 2021, this would have continued up to the 19<sup>th</sup> and even 20<sup>th</sup> century, since it is unlikely that elaborate non-abrasive compensations were used systematically on all strings.

After seeing the constant preoccupation with uniform strings in Ref 3 readers might wonder about the reason and purpose. Maybe there was no desire to engage with understanding complications of taper and its acoustic effects, and simply install the easier modern notion of uniformity. This would also provide a useful claim that all his modern strings - monofilament, loaded, gut - were following ancient practice. Any of these reasons seems a small gain for dismissing valuable ancient sources, and potentially distorting the history and legacy of an ancient craft. The approach seems like breaking up a valuable and unique old clock in working order, just to find some spare parts for a modern clock.

There have been similar concerns with loaded strings for many years, where it would be helpful if someone would simply test for residues on old bridges and pegs, rather than continually speculating on small holes and coloured strings. The quest in Ref 3 for uniform early strings should be seen as a similar line of speculation, but separate from the remarkable evidence of Capirola and sound modern analysis. Perhaps many lute players would be most interested in the manufacture of synthetic polymer strings with a range of elasticities suitable for many courses.

Even though there are many problems with the material of Ref 3, the writing of it must have taken considerable time and effort. Its entire purpose was to promote a notion of uniform thickness, and the use of two sizeable articles indicates some desperation. However, it is important to understand that the venture was not based on a full use of reliable evidence and objective analysis. A final paragraph in Ref 3 becomes confused, perhaps stretching the automatic translator's power. The author appears a little apologetic and seems to admit the subject is too difficult for him, and might even like my help.

Reflecting on this strongly technical response to Ref 3, there may be some explanation for clashes of views. This depends on the stage in someone's interests when they are confronted by a particular unexpected ancient practice, and there are three examples in this piece. Firstly, the mistaken view that Ref 1 had suggested the ancients made special tapers to correct angled bridges arose after a keen amateur had made a mistake in gluing on a bridge. Secondly, there is a far more serious case in Ref 3, making and selling uniform strings for decades, then seeing my analysis of taper and Capirola, and feeling seriously disturbed. Thirdly, I had limited experience and just a general interest in strings before beginning to study their detailed mechanics, realizing the possible use of taper, recalling Capirola, and analysing the ingenious ancient effects. For tuning temperaments, a continually surprising challenge has been understanding how these could have been conceived and described with the available ancient concepts. This same mentality has been a useful approach for strings and lutes themselves, and requires science and history rather than modern product engineering.

Any future tests would benefit from an unbiased approach. A string maker would be needed but the wide range of natural tapers for a full demonstration is unlikely in modern business. A partial study where perhaps three synthetic strings are sanded, emulating the selection of tapers, could be interesting. This may be a suitable place to record my 'intellectual property' concerning a revived use of tapered lute strings described in Capirola's lute book.

Many modern players and makers may take a relaxed pragmatic view of all this. However, the topic needed some brief reply before specialists and more general readers are misled. Since there are many other pressing concerns these days I shall not be spending much time on the subject, and further queries may already have been addressed in Refs 1, 2 and 4 to 8.

#### References

1. C. J. Coakley. FoMRHI Comm 1810.
2. Vincenzo Capirola's Lute Book. 1517. The Lute. Vol 23 Part 2, 23-8.
3. M. Peruffo. FoMRHI Comm 2151 .and Lute News Number 137.
4. to 8. C. J. Coakley. FoMRHI Comms 1809, 1814, 1986, 1987, 2036.