Quarterly No. 140, March 2018

FoMRHI Quarterly

BULLETIN 140   Christopher Goodwin   2

COMMUNICATIONS

The next issue, Quarterly 141, will appear in May. Please send in Comms and announcements to the address below, to arrive by 1st May

Fellowship of Makers and Researchers of Historical Instruments

A couple of months later than intended this is the last issue of the nominal 2017 subscription year (numbers 137-140). You will find a subscription form herewith if you have not yet paid for 2018; a number of people have already paid in advance. Many thanks once again to contributors to this issue, who include leading authorities in their respective fields. Mimmo Peruffo's paper on historic mandolin stringing originated in a joint meeting of the Lute Society and the British Banjo, Mandolin and Guitar Federations. We are delighted also to receive another instalment of Peter Forrester's long-awaited work on cittern building. A further chapter of this is in hand, with the promise of drawings too. As the spring springs we look forward to further excellent Comms.

Further to the report of November's AGM in the last issue, the committee subsequently approved the draft accounts, and approved an increase of £1 in the subscription, to a still-reasonable £19 per annum, and we have negotiated a slightly lower handling fee for use of the Lute Society's Paypal facilities.

Welcome to new members

We welcome new members this quarter: Nicolas Bouils, and Malcolm Prior.

Cambridge Woodwind Makers

This announcement from the Cambridge Woodwind Makers:

We are pleased to announce that we now have new premises! The new workshop will be in the nearby village of Linton and we are thrilled to announce that we will be sharing the space with Cambridge Art Makers which is the new name for the organisation that will run classes in mixed media, jewellery making, glass art, textiles, print making and more.

This is an exciting new prospect for us as we can now continue to develop our offerings for the world of woodwind making within a dynamic and supportive space.

We have yet to devise the full schedule of courses but are delighted to already have Oboe Reed Making in March and the much-anticipated Trumpet Making already set for 2018. We will continue with Repair & Care courses that, for now, will stay running from the repair department of Wood, Wind & Reed specialist music shop in Cambridge. Our first Repair & Care for 2018 is for Flutes on Sunday 4th February so please pass details of that on. Links to book all the currently scheduled courses can be found below.

As we enter this new phase we will also be shifting over to a new website and we will share news of this, further courses, and Cambridge Art Makers in due course.

For now we thank you for your continued enthusiasm and hope you can join us for some Repair & Care courses while we get ourselves set up.

<div align="right">
With best wishes,
Daniel & Rosemary
Cambridge Woodwind Makers
</div>

Forthcoming courses:-

Oboe Reed Making with Adam Shapiro | Saturday 24th March | Sunday 25th March | £100

Long Trumpet Making with Robert Barclay, Richard Seraphinoff & Michael Münkwitz | Monday 11th - Friday 15th June | £940

Repair & Care courses with Cambridge Woodwind Makers at Wood, Wind & Reed specialist music shop:-

All the below courses are on a Sunday unless otherwise stated

Flutes | February 4th | July 1st
Clarinets | March 4th | August 5th
Saxophones | April 10th TUESDAY (this will be held at the NEW premises in Linton) | September 2nd
Oboes & Bassoons | May 6th | October 7th

www.cambridgewoodwindmakers.org

STANDING CALL FOR PAPERS

The Fellowship of Makers and Researchers of Historical Instruments welcomes papers on all aspects of the history and making of historical musical instruments. Communications or 'Comms' as they are called, appeared unedited (please don't be libellous or insulting to other contributors!), so please send them EXACTLY as you wish them to appear – in 12 point type, on A4 paper with a 25mm or 1 inch border all round, or to put it another way, if you are using non-European paper sizes, then the text area must be 160 x 246 mm (or at least no wider or longer than this). Our printers make a good job of scanning photos.

   In naming your Communication, remember that people will search for it online using keywords. So if you are discussing, say, a Ruckers harpsichord in Paris, call it 'Observations on a Ruckers harpsichord in Paris', rather than 'Observations on a curious old instrument.'

   You can send contributions EITHER on paper, OR as a Word-compatible or PDF attachment. If you *really* do not have access to a word processor of any kind, we may be able to retype typed or handwritten submissions; send it to our cover address.

   The email address for Comms sent as attachments (and other email correspondence) is Lutesoc@aol.com or secretary@fomrhi.org Non-members will be given a year's free subscription if they send in a Communication to the Quarterly.

    If your interests have changed, and you don't now want to be a member of FoMRHI, please let us know, to save postage costs.

How I Build a Cittern, part 2 - the Back and Sides.

The first job is to rough-turn more pegs than will be needed. Because metal strings react to tightening and slackening several times quicker than gut or nylon, their pegs need to be as perfect as possible. If they are partly ready and hung in a warmish area of the workshop, hopefully any movements that the wood wants to make will occur before they are finished and fitted.
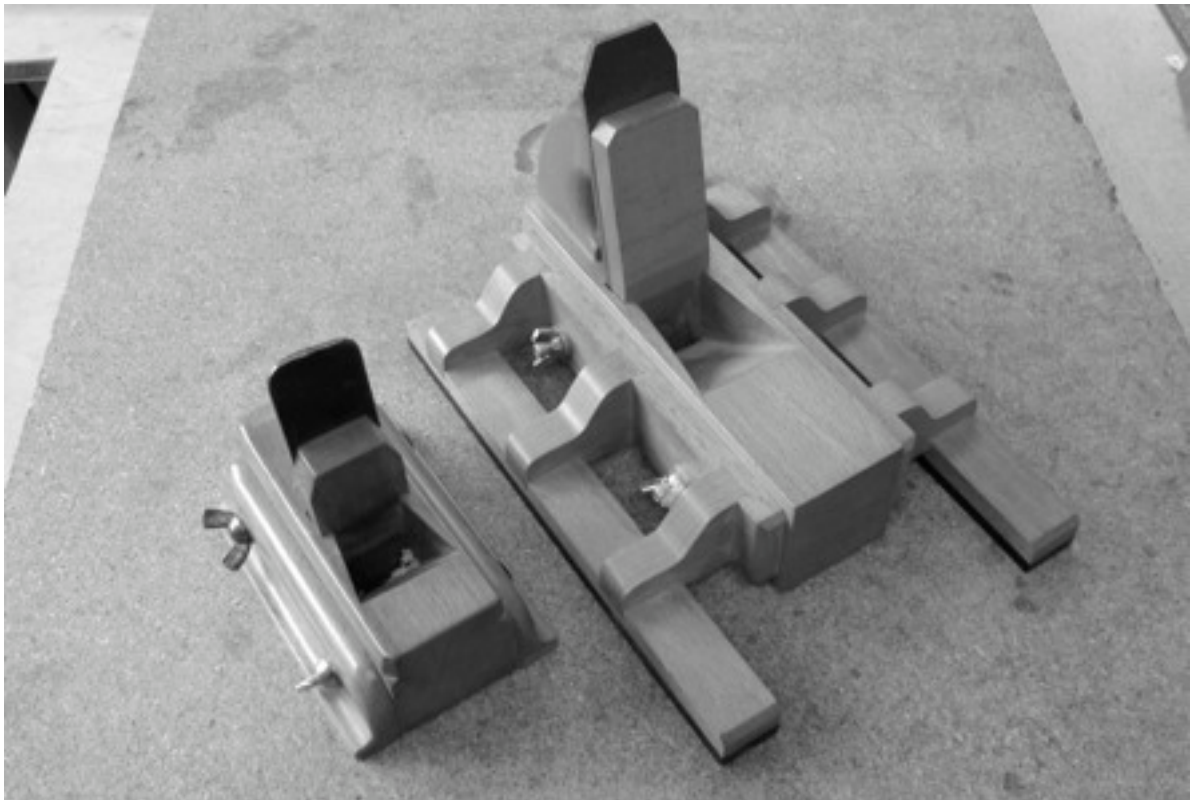

The staves or strakes for the back, and the sides are thicknessed using the smaller of the planes above. The other is merely a larger version used for bandora sides, etc. The blades are toothed. Their rationale and use are described in Fomrhi comm. 1469, July 1996. After writing the article I found a very similar plane, although without the toothed blade, a 'reglet' plane described by Holtzapffel, and used in type making. In use, the 'best' side of the work is prepared using a scraper. It is then reversed and the thickness reduced from the back, using the plane and a scraper alternately. It is especially useful on figured wood, and can be accurate to around .05 mm. Best used with the work sideways to the light. I thickness most backs to 3 mm or slightly less, and sides to 1.5 mm or very slightly more, depending on the wood.

The back has a more subtle curve than bowl-shaped instruments. It is distressingly easy to produce irregularity and I have sometimes been dissatisfied, although the sound is not affected, and the unevenness can be disguised though not eradicated. The simplest means of making the joints between staves is, after bending, to start with straight edges for the central strake and use a simple (school?) compass to mark the slightly convex curve on the adjacent strakes. These in turn will have their outside edge as a straight line to which the next pair will be fitted. Obtaining a good joint

probably needs an inverted large plane used as in lute-making, which I supplement with metal sanding plates. These measure 6 x 22.5 cm and were made by Sandvik in three grades, but may no longer be obtainable. A sanding board would be a useful


substitute. A bendable straight-edge - a metal rule or strip of formica - will be necessary. How accurate the joint will be can be judged by holding the strakes up to a strip-light or a window. The thickness of the back means that ornamental lines, if
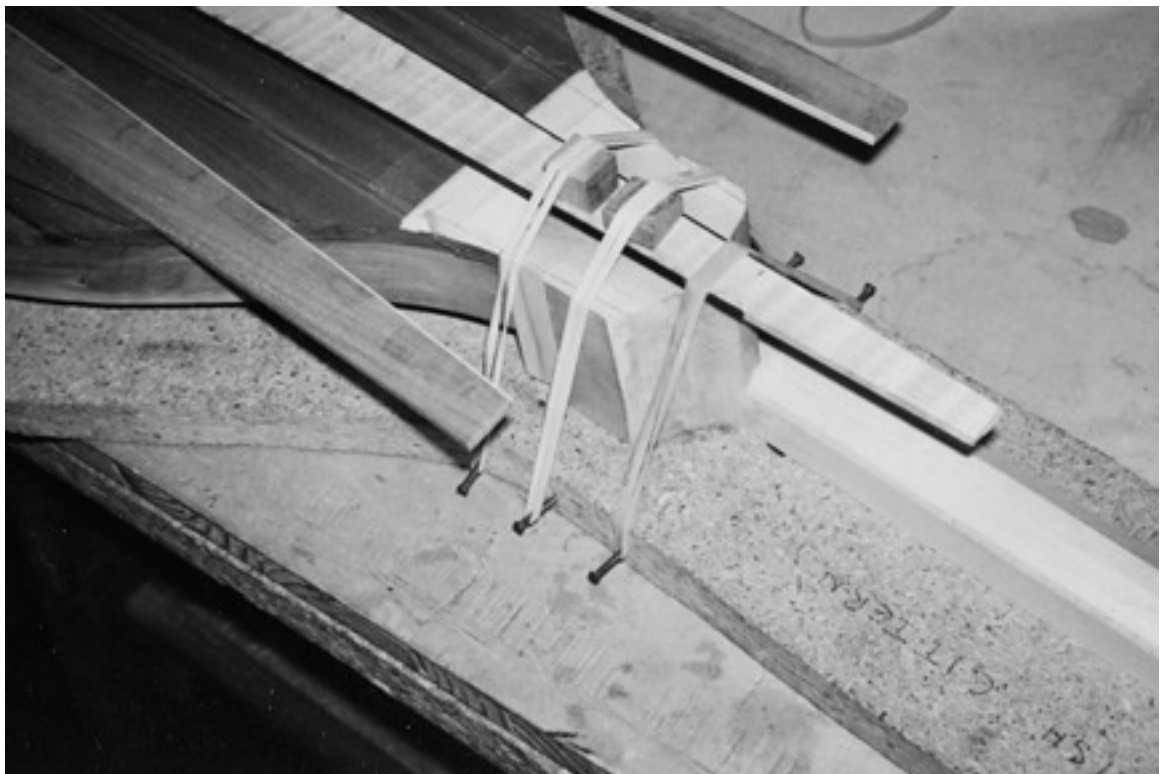
used, need to be cut from sheet veneer and glued to each strake before the latter are glued to the neck-block. After checking that these lines have not altered the fit between strakes, the central strake is glued to the block. The photo above shows a simple clamping method which is quicker and easier than G-cramps. If there is more

excess than can be conveniently planed off the next two strakes, allowing for any 'inlay', the simple jig above will enable a previously bent strake to be safely passed through the bandsaw. (It can also be used later for the outline of the back on the sides.) Subsequent strakes are glued to the first, or previous one, 'in the air' - off the mould - using sellotape. My method is to initially attach the tape loosely and use a small electric fire, perhaps with a brush-load of water, to remelt the glue whilst checking against my strip-lighting that no light is showing between the strakes, then re-tightening the tapes and replacing the assembly on the mould for the glue to set. When all the strakes of the back are glued up, it is sensible to do other work - the belly, the rose, carve a head? - to allow the glue to shrink before cutting the outline of the back down to the mould. Although individually thin, the possibly thirty or so glue lines add up. The back will be best kept clamped and/or weighted in contact with the mould.
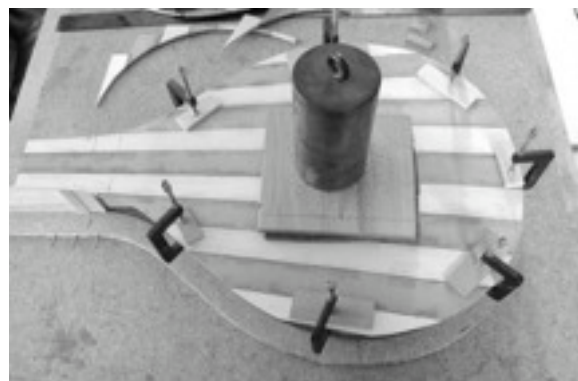
When ready to continue, the back is cleaned up with a scraper and perhaps thinned towards the sides. It then needs trimming as close as possible to the outline of the mould. The grosser excess can be removed on the bandsaw, and a block plane can ride on the backboard to ensure that the outline remains vertical around the convex part. A curved plane, or sanding with a curved surface will be necessary for the concave areas near the neck. It is essential not to allow it

to become too small, which could happen because there will inevitably be a very small 'give' in the attachment between the neck and the mould. The ideal would be a paper-thin excess, and certainly no more than 0.5 mm. There needs to be a continuous curve between the back and the rebates in the neck block. The smaller photograph shows that a small gap is left in these rebates when the side is fitted. Ideally of course this would not exist, but because the side needs to be pulled around the back and glue squeezed out, it is impossible to judge the exact length required. Worse would be to have too much when it is being glued. The gap will be covered by the ornamental balusters later.

The side is tested for fit and length and lightly fastened in place so that the shape of the back can be outlined upon it, and its exact position marked. The pressure of the tapes during gluing causes the back to rise in the end-block area and perhaps at the sides, so the excess wood is cut away, leaving around 2 mm to be trimmed later. This will help, but a clamp or taping to the backboard may be necessary. End-grain areas are sized with dilute glue, dried and smoothed. The mould is lightly wax polished. Assembly commences at the end-block position after glue has been applied to all the areas to be glued on both the side, and the back and rebates. It may need refreshing

as work progresses. The glue will need remelting with a domestic iron and a wet brush. The aim of the taping is is to squeeze the glue-line, so some of its direction when commencing is at an angle, pulling the side towards the neck as well as against the back. Short sections are worked on alternate sides. As well as much tape to pull the side to the back, a cramping arrangement will be needed at the rebates, and support for the straighter part of the sides between the convex and concave curves. The photograph above will give a good idea of what may be necessary. (The photographs in these articles will be of several instruments, of different sizes, and purposes.)

After trimming the side to the back, strips of tape are stretched laterally across the back against the possibility of glue being weakened when fitting the lining and bars. As the thin cittern sides surround the thicker back a stronger joint is obtained than if the reverse was used, especially helpful to strengthen the shallow cittern body against the bowing strain of the strings. No linings between the back and sides are used, although some citterns, and my own, add fabric patches.

I usually, though not always, fit the end or bottom block first, usually using lime or sycamore. Then the bars, followed by paper linings on the back and fabric on the back/side joint - not as in the photo! Using the compasses as a measuring gauge, mark and cut the outline of the block which will contact the 'side'. Next place it in place inside the cittern and mark and cut the outline against the back. Lastly use an adjustable square to measure the angle between back and side at the centre of the end-block position, and plane the end-block to match it. This operation should be straightforward if taken one step at a time. Two problems may occur. There may be a small amount of glue fillet between the back and 'side' which is best avoided by a


small chamfer on the edge of the block. Be sure that the block is sufficiently deep on its inside surface. Gluing and cramping up should be straightforward. Cramp to the side first, then to the back.
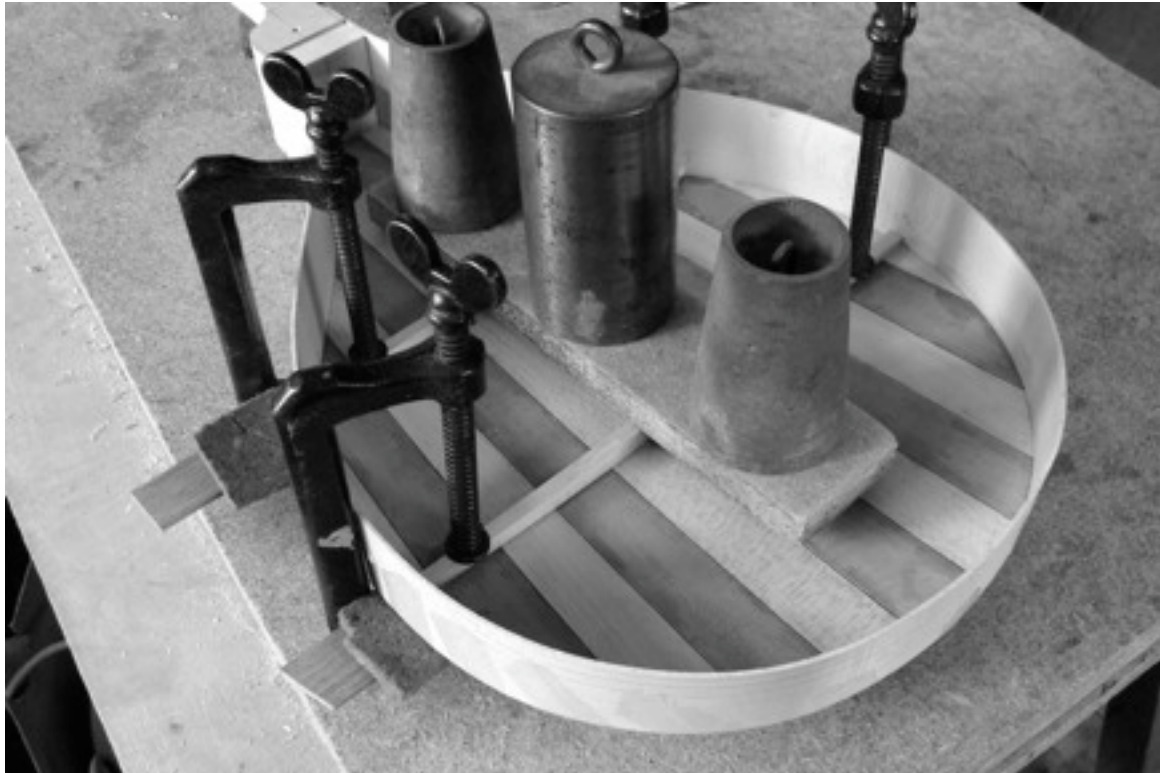
The bars are planed to width, 5 - 6 mm, and cut to length. Using the compasses again, mark and form the curved and flatted shape that fits to the back. It may be easiest to do this on the outside rather than the interior. Reduce each to the depth required. Gluing will be fiddly. Something like the photo will be necessary. The outside cramping uses foam padding and flexible strips of plywood. This will be insufficient for the centre of the bars so they are weighted from the inside whilst still contacting the bench surface. An alternative would be an outside template and joy-bars as used for belly-barring. Or rebates in the mould to take the bars as the back staves are assembled. I find it necessary to remelt the glue with a small electric soldering-iron.

The back is lined with a strong but not too thick paper. I use a watercolour paper which uses cotton or linen fibres in its construction. Quite expensive, but one sheet will be enough for a lot of instruments. Cotton tape will accept animal glue best for the back/side joint.
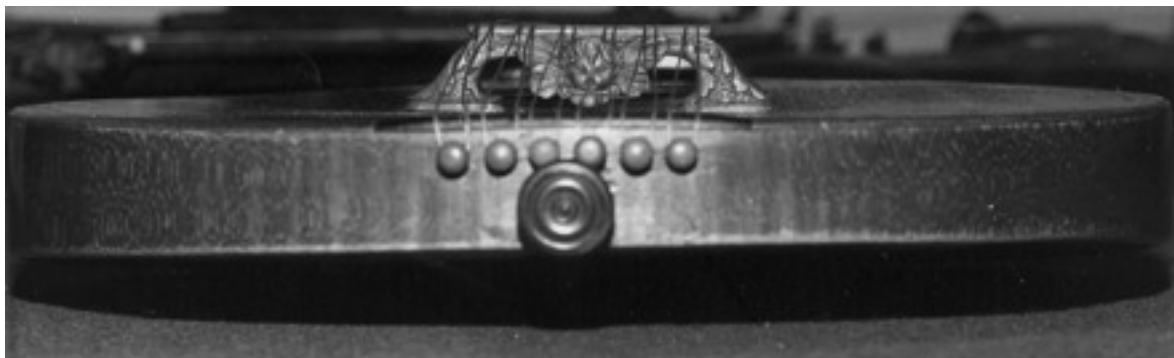
The belly/side shape cannot be cut until the belly has been prepared. Nor the reinforcements on the sides supporting the bars. One task which is most easily done now is to drill pilot holes for an end pin if required, and the hitch-pins, while the body can still be conveniently clamped to the bench.

This detail of a Virchi cittern in Paris will give an idea of the problem, in this case for six double courses. The hitch-pins are dangerously close to the surface of the block,
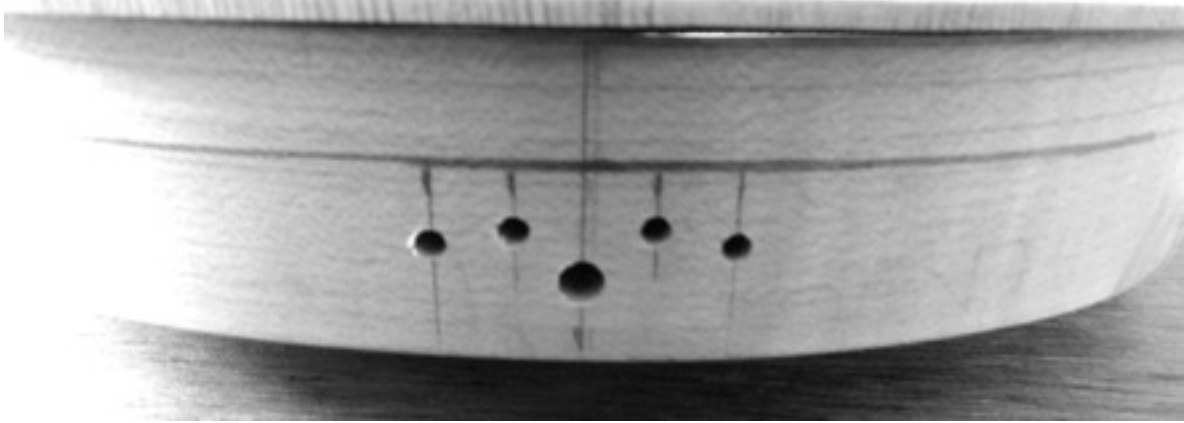
and a crack has started to form, whilst the end-pin over-hangs the edge of the back. Four courses are easier and the following photo shows my own, inauthentic, solution. The dark pencil line is of course the projected edge to which the belly will be glued. Although neat little brassed pins are available commercially, it will be best if the hitch-pins are quite thick so that a sharp bend does not cause string breakage here. Bone pins are ideal provided they are clean and dry - any trace of fat will become fatally acidic.

The interior of the back ready for closure when the belly is completed.

part 3 - the belly.

I have no information on the wood used for cittern bellies originally. My preference is for sitka spruce as it is reasonably loud, and sustain is provided by the wire stringing. Bellies can be made of two pieces in the usual way, but the shape and size of a cittern's belly also allows for producing it in three pieces - a central panel and two 'wings' - from one half of a pair intended for lute or guitar. Providing of course that the grain is suitable, and the 'wings' can be arranged with any 'run-out' matching the central section. Or a four piece front. Both of these occur on extant citterns. There are several ways of jointing and gluing bellies. I use wedges to apply pressure when gluing and check the joints befo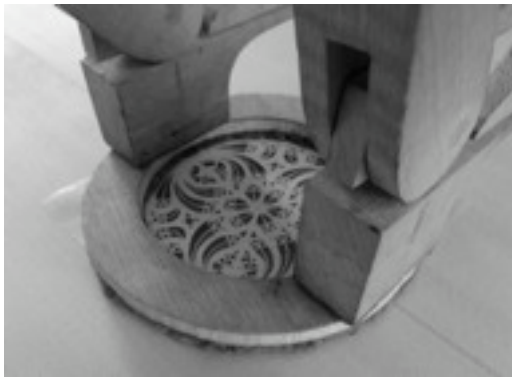rehand by holding them against a window pane. The belly is then planed and finished to 2.8 mm or slightly less all over - for the present. It should match or be slightly thicker than its rebate in the neck block. It can be cut down to near its final size and the rose and bar positions marked.
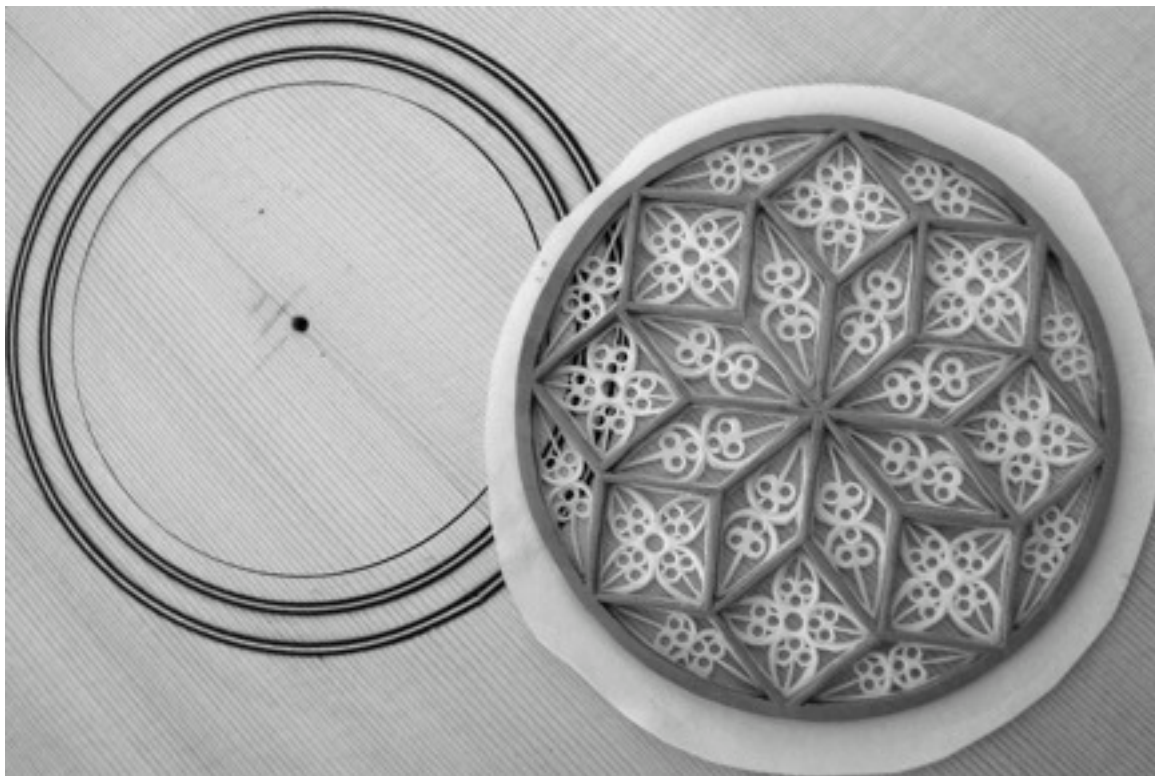
I cheat when making roses. Three sheets of pear-wood veneer are glued together to make a plywood. The photocopied design is glued in place and cut out using fine blades in a jeweller's fretsaw. Note that photocopiers sometimes stretch or shrink prints in one direction resulting in distorted circular shapes. Cow Gum used to be excellent for attaching the design, and rubbed off easily when required. It has been discontinued and more recent versions are less successful and need experimenting with. The wooden pattern is then glued to parchment, with an excess of perhaps 1 cm. This layer will give strength to the wood layer, and can have fine detail added to the design. I have used superglue in the past (the wood will need a sizing coat of perhaps varnish for the superglue to adhere to) but now use animal glue previously painted onto both surfaces, allowed to almost dry, and remelted with the domestic iron. Care is needed, and the parchment may need roughing with light sandpapering, and sizing on both sides whilst stretched flat. This parchment will be glued to the inner surface

of the belly, but I usually add a further parchment layer to the central pattern for elaboration. The hole in the belly for the rose is marked, but not cut out until the surrounding rings are purfled and finished. The wooden layer of the rose will measure 1.7 - 1.8 mm in thickness, so the rose will be recessed about 1 mm. Animal glue is used on both the wooden junction of rose and belly, and the parchment surround. Cramping pressure must be only on the parchment, and the glue is remelted using the iron after about one hour. When solid, I insert a contrasting ring to cover the slightly untidy fit. Many cittern roses are not recessed at all, which may be slightly better for sound projection? This particularly applies to the traditional carved citterns with their thicker soundboards. That in the Museo Bardini, Florence, in fact constructed to look carved, has its rose in a rebate in the soundboard. (Notice the soundboard '**wings**') Not infrequently the inner circle of purfling has been used to fill the junction between rose and belly.

Alexander Batov's website gives much information on original roses, including citterns. www.vihuelademano.com/rosesinvihuelas.htm

I always use a barring pattern shown in the Gasparo da Salo cittern in the Ashmolean museum, Oxford. This seems the most common although others exist. (*See below*.)
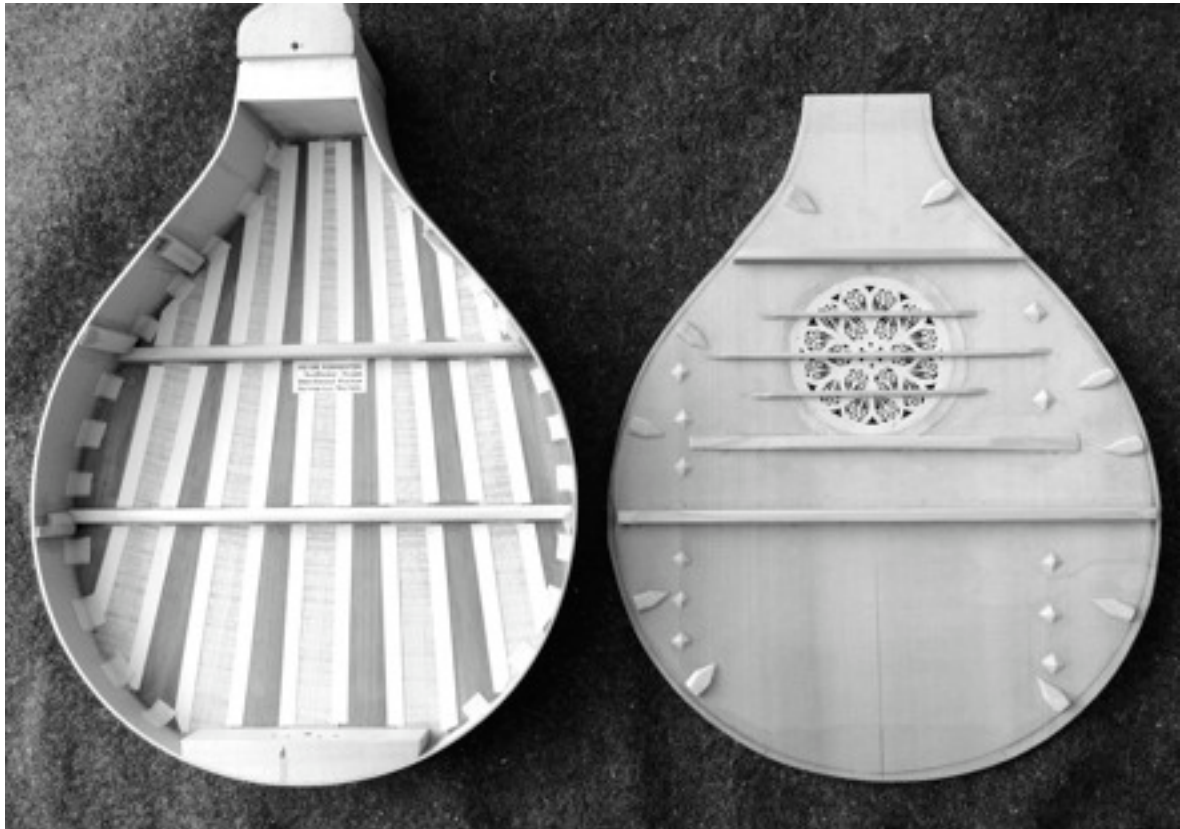
The two back bars are at the widest part of the body and below the centre of the rose. The main belly bar is above the back bar and is prevented from collapsing by small reinforcing supports which connect these bars. Further reinforcements are associated with the other back bar and with the belly bar above the rose. Their purpose is to strengthen the flattish areas of the sides against the downward pressure of the strings. The short bar between the main bar and the rose holds the belly down against this pressure around the fulcrum of the main bar. Some positioning blocks seem usual and useful. I also reinforce belly joints - a three part belly in this case.

The belly needs a rise of around 6 mm in the centre. This is achieved by removing 1 mm from the exterior later and adding 5 mm to the centre of the main bar. The photo shows a method of marking this curve using a 2 foot rule and four G-cramps for the main bar and copying the curve to the others. Like the back bars, these for the belly need gluing in place with flexible strips and extra cramps for the centres. Finishing the bars is left until the outline of the belly/side joint has been made. They will need finishing to a rounded or chamfered surface, and tuned like lute bars although less easily. It is probably sufficient to get a good 'ring' when tapping the belly surface. But firstly, the belly is used to find the shape and

amount of the side(s) which needs to be removed.

Parallel lines drawn around the body with a marking gauge and perhaps 5 mm apart will show whether both sides of the body are similar. The main belly bar should fit temporarily, but happily, in place opposite the main back bar. Now the angle of the belly has to be fixed so that its distance from the neck rebate is equal to that between the belly and the finished height of the end-block. Some packing will be necessary and a minimum of adhesive tape. Some small wood blocks and 1 mm card offcuts will be useful. Using the compasses as a gauge, the required shape is drawn on the side(s). The earlier parallel lines will now be invaluable. Some of the waste might be removed
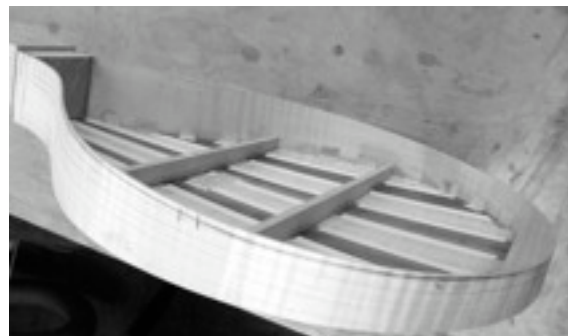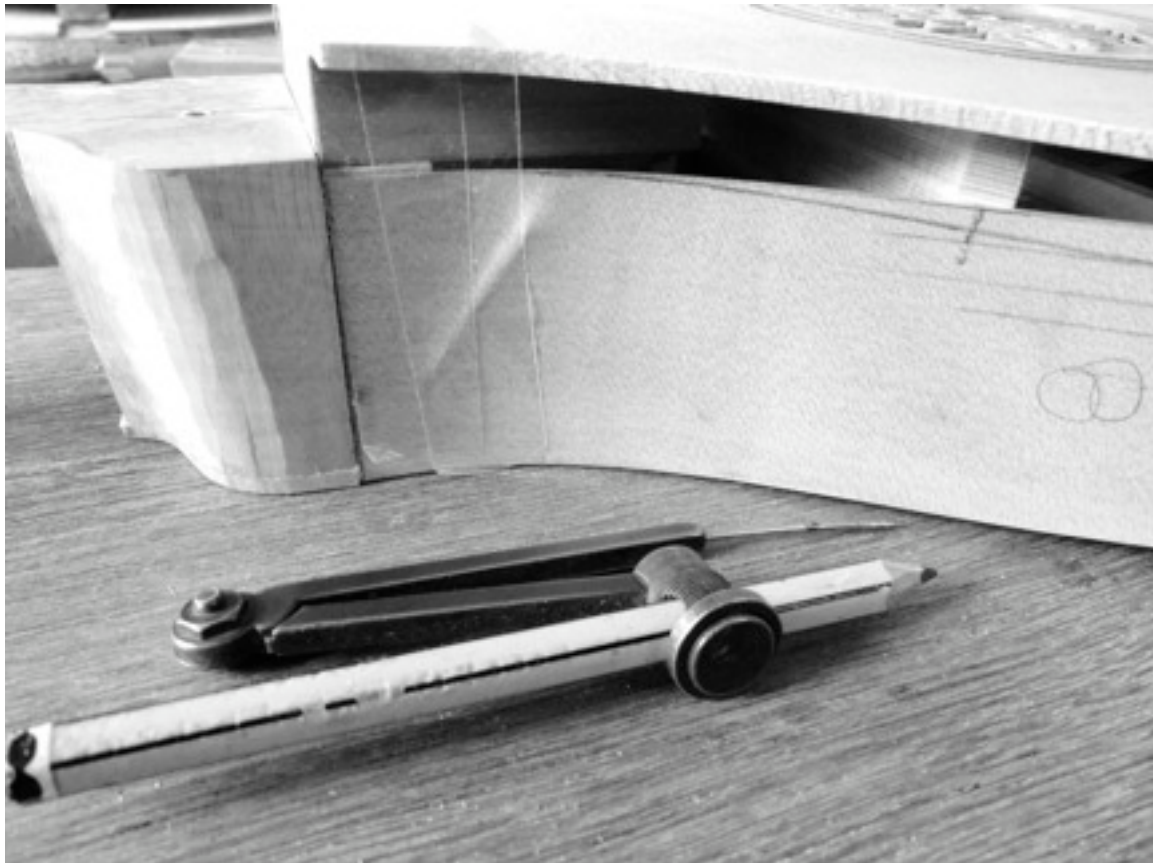
with a saw, but a plane is probably safer, and a sanding block will preserve the angle of the belly. The downward pressure of the bridge does have a damping effect on the sound. My experience has been that a certain amount of tension built into the belly balances this out, and makes the response between the pluck and the emergence of the sound quicker. At any rate, some of my customers think so. If some of the side is left and not cut away, as in the

photo, the belly will have to be pulled down the last 4 or 5 mm at the end-block to gain this. Something like pressing on a spring. Be careful that a smooth curve is preserved and no other gaps caused.

When this is satisfactory, the side reinforcements can be added. Some originals can be as simple as halved cylinders. After finishing the belly bars, the belly is glued in

place and trimmed to the body outline.
The belly is thinned to around 1.8 mm at its circumference and faired and levelled to the surface of the neck. An imagined cross-section would show a steady taper rather than abrupt steps. Some further thinning can be done later with the cittern finished and strung, before varnishing, if the sound seems too tight. Purfling is fitted as far as the joint with the neck.

Provisional Addenda.

1. When making instruments, solitary, with little contact with other builders, one learns how to make parts, what to do with them, and how they add up to a whole. It is not necessary to name them. The backs of my citterns are made up of strips of wood which I have called, I realise, staves or strakes. They could equally have been merely planks, or possibly following lute nomenclature, ribs. One piece of wood joins the back and the belly of a cittern. Should we refer to it as the side? the sides? And when it nears the end-pin? Perhaps Fomrhi should lay down some rules? International of course! Meanwhile I hope my intentions have been reasonably clear.

2. Observed alternative barring patterns, some of which may have been altered, include:
Virchi cittern, Paris. Back bars as above. Belly bars - two above the rose, one immediately below the rose, one between the bridge and end block. This weak barring

in the bridge area must account for the flattening of the belly observable in the photo above.

Diatonic cittern KM 1524, Brussels.
Marks of removed bars on the back below the rose and greatest width. Belly bars in the usual positions, but none reach as far as the sides. Several, rather arbitrarily placed, side supports approximately 10 mm wide and shaped as sections of a cylinder.

Cittern by Abraham Tilman, 1602, Berlin.
This has back bars at the greatest width and below the rose centre, with side supports connecting these bars to belly bars. There are in addition bars immediately above and below the rose, both of which finish well before reaching the sides. Two more small bars across the rose. There are no other side supports, but the sides are constructed of a sandwich involving a full lining with ebony strips and mother-of-pearl plates on the exterior, and a probably later wood lining between the sides and back.

3. The grain direction of the neck. Traditional carved citterns are made as though from a split trunk or branch with the belly adjacent to the split. This means that subsequent shrinkage will be least across the belly, and will tend to increase its curvature rather than the reverse. Constructed cittern necks seem to follow the same orientation. It is often not easy to see, but fingerboards seem to be similar or occasionally cut on the quarter.

4. Citterns seem almost always to have had carved heads attached separately, some quite crude, others well carved. The only exceptions are the scrolls on traditional citterns from Urbino(?), and a very few other scrolls in simpler images. The easiest way to produce a head is to use modelling clay, and copy it in wood. Alternatively it could be cast in resin and painted, although this would be heavier. It should be fun to do! Enjoy it.

5. Since Comm. 2073 on cittern bellies was published, I learn that the belly of the Vermillion treble cittern NMM13500 has been dendro-dated. The latest visible tree ring matches a date of 1610, suggesting that the instrument was built post around 1620, rather than the 1579 date previously claimed. The dendrochronologist was Peter Ratcliff who has worked on many important instruments. His half-hour video on dating Stradivari's 'Messiah' violin is viewable on YouTube.

THE SET-UP OF 4- AND 6- COURSE XVIII CENTURY MANDOLINS: A FEW CONSIDERATIONS, BY MIMMO PERUFFO

When faced with the problem of what kind of strings were used on 18th century mandolins of six and four courses, the first thing that stands out is the great heterogeneity of their set up—if we follow the two surviving instructions, by Fouchetti and Corrette, discussed here. What is especially hard to understand is the stringing of the 4-course Neapolitan mandolin: here we find together gut strings, single and twisted metal wires, and wound strings on gut/silk. To complete the already heterogeneous picture, for the fourth course there are also two choices between unison and octave stringing.

Here is the first question: why was a gut first course used, and not a metal wire like the other courses, already available in the first half of the 19th century? This question is logical: the average breaking load stress (breaking point) of the gut is 'only' 34 kg/mm2, much lower than the average of iron and bronze of the time, which easily exceeded 100 kg/mm2.

To understand the reason, we must first start from the mechanical and acoustic behaviour of the string. In this way we will be able to try to figure out what the guiding criteria were used to determine the vibrating lengths of plucked and bowed instruments, including mandolins.

Strings and their characteristics

Musical strings follow the rules that are summarised in the string equations of Taylor-Mersenne or indeed Hook's Law (although the first to mention it was Vincenzo Galilei around 1580), which relates frequency, vibrating string length, diameter and density of the string.

However, when the gauge of a string increases, another consideration is not included in this equation: with increasing string diameter comes also a progressive loss of its acoustic properties until reaching the point where, over a certain gauge, the string has clearly lost most of its musical performance. This is caused by the progressive increase in the stiffness of the string. This phenomenon is called inharmonicity: before the appearance of the wound strings (in the second half of the 17th century) it was the main problem which all the makers of plucked, bowed and keyboard instruments had to deal with.[1]

Inharmonicity clearly determines a limit to the total number of bass strings that an instrument can have, i.e. the open range. There is a second problem: poor elasticity, i.e. a high elastic modulus, this also produces an unwanted sharpening of the note when pushed down onto the frets; this phenomenon is particularly noticeable on short vibrating length instruments ('pitch distortion').

The best solutions, in order to keep the inharmonicity within limits and the string still 'sounding good', is to limit the diameter increase by some means (or, alternatively, keeping a thicker gauge but increasing the elasticity of the string to reduce the stiffness). Our main interest is represented by these relationships:

—Diameter and vibrating length are inversely proportional.
—Diameter and tension are inversely proportional.
—Diameter and density are inversely proportional.

The solutions that, at the same frequency, can contribute to reduce the diameter are the following:

1) Reduction of working tension
2) Increase in the vibrating string length

However, there are other implementable actions:

3) Increasing the elasticity of the string (without reducing the diameter)
4) Increase the density of the string (and reducing the diameter)

Point 1 is exclusively a decision of the player: according to the ancients the right string tension (which I argue is better called the right feel of tension) is when the strings are not too stiff, nor too slack under the fingers. There is, however, a lower tension limit, otherwise not only do you lose finger control on the string, but also its acoustic power, its 'fire', along with the increase of what is commonly called 'pitch distortion' due to the fact that the strings are too slack and so out of the control of the performer.

Point 2 depends only by the luthier. This solution was adopted from ancient times on the harp, but later also for keyboards, theorboes/archlutes etc, where the vibrating string length increases, step by step, towards the bottom strings making them, step by step, thinner than they would otherwise have to be; proceeding in this way, the inharmonicity is under control.

Points 3 and 4 depend on the string maker: the appearance of the wound strings in the middle of the 17th century can be considered a good example of point 4; a roped gut string/a very high twist string is an example of point 3.

At the end of the day, the only point on which the luthier can act is point 2, where vibrating length and diameter are inversely proportional (assuming that the performer has already done his or her job in the choice of the right feel of tension).

In the 16th, 17th and (maybe) the first half of the 18th century, the problem of string inharmonicity was well-known to luthiers: it can be seen, for example, from the surviving bowed and plucked instruments, whose vibrating string lengths are all related to the frequency of the note on the highest string and the hypothetical standard pitch: in practice we are speaking of the well-known rule of those times to tune the first string as high as possible, until just before it broke.

In order to optimise the sound performance of a musical instrument luthiers therefore followed the rule of using the maximum vibrating length possible for a given treble note indicated by the customers (depending on the region and its local pitch standard); only in that way could all the strings have the minimum gauge at the right feel of tension for the benefit of the overall acoustic performance.

However, the vibrating length cannot be increased as desired because of the limit imposed by the breaking load of the first string: there is a limit that we call upper limit. At the same time, it is not possible to increase the number of bass strings (i.e. increasing the open range) because there is another boundary called the lower limit. In other words, the full open range of a musical instrument is enclosed within these two borders.

The so-called lower limit, however, using pure gut strings, begins to heavily manifest itself when the frequency range between the first string and the last reaches more or less two octaves. Only the 6-course mandolin has this range; the 4-course instrument does not. Generally speaking, the problem was, however, partially solved after the middle of the 16th century by the introduction of a kind of very elastic and/or denser bass gut strings, and then totally solved by the introduction of wound bass strings in the second half of the 17th century. In the second half of the 18th century, the wound strings were probably in universal use.

The upper limit

When a string of any material is progressively stretched between two fixed points (its vibrating string length) it will at some point reach a frequency where it will instantly break (breaking point). In the case of a modern gut string, the average value of this frequency for a vibrating length of one metre is about 260 Hz (actually, after several tests, I have found a range of 250-280 Hz), which is a slightly low C.

The value of such a frequency limit, known as the 'breaking frequency', is completely independent—as strange as it may seem—of the diameter and this can easily be verified both by mathematics (applying the general formula for strings) and empirically. By changing the diameters, the only changing parameter is the tension value, always corresponding to the breaking point (i.e. the breaking frequency). The breaking frequency is inversely proportional to the vibrating length at which the string is stretched. So, if the string length is cut down to a half the frequency doubles and vice versa.

This means that the product of the vibrating length (in m) and the breaking frequency (in Hz) is a constant defined as the 'breaking index', or more simply FL product (i.e. vibrating length x breaking frequency).

By introducing the breaking index into the string formula, considering a unit section of 1 mm^2 (that is equal to 1.18 mm in diameter) at 1.0 m of vibrating string length, at the corresponding breaking frequency value in Hz we obtain (of course) the breaking load stress value of 34 kg/mm^2. In other words, a string of 1.18 mm gauge, 1.3 of density, 1.0m, length, under 34 kg of breaking tension will reach a music pitch limit of 260 Hz. In short: the breaking point of a modern gut string, according to our practical tests, ranges from 33 to 38 Kg mm^2, which is equivalent to a breaking index of 250-280 Hz/m (mean value: 260 Hz/m).[2]

Breaking vibrating length

Going back to our main topic, a luthier thinks the other way round from what has been just explained; it is the frequency of the first string which is the first parameter to be fixed when designing a musical instrument such as a mandolin, lute, etc. By dividing the breaking index for the desired first string frequency, you will obtain the theoretical vibrating length limit where the string will break when reaching the desired note (breaking point):

This is a simple proportion: 260: 1 metre = 1st string's frequency: X (were X is the vibrating length to be attributed in metres). In the case of a 6-course mandolin whose first string is a G: 698.5 Hz (at 18th-century French pitch of 392 Hz)[3] we obtain a result of 260/698.5 = 0.37 m. This is therefore the vibrating limit length where we know that the string will break reaching the note G (here we are referring to the ancient French pitch standard of 392 Hz).

The choice of vibrating 'working' length should therefore consider a prudential shortening of this limiting length. But how much? The more they are shortened, the thicker the strings are with the risk of losing acoustic performance.

Prudential shortening or working index

Examining the vibrating string lengths of the plucked and bowed instruments of the tables of Michael Praetorius (*Syntagma Musicum*, 1619) makes it possible to calculate their working index and put them in correlation to the gut breaking index. This allows us to understand the security margin adopted in those times.[4,5]

However, in the various calculations, unfortunately the scholar Ephraim Segerman has taken as a reference the average breaking load value—or breaking point—of a modern gut string found in the literature: 32 kg mm^2 (which is equivalent to a breaking index of 240 Hz/m) that is actually lower than the reality.

So, this value can be placed on a 'lower quadrant' of the range of breaking loads that we have found in today's commercial strings during our experiments (we will here suggest the average value of a breaking point of 34 kg/mm^2, equal to 260 Hz/m of breaking index).

However, comparing the breaking index of 240 Hz/m with all the other working indexes, he found that the choice of the vibrating working length of the lute family and some gambas (viola bastarda for example) was about 2-3 semitones below the breaking index (and hence also of the theoretical vibrating length that we calculated before).

Considering our example, therefore, shortening of the strings by two / three semitones would represent the real vibrating length to be adopted (corresponding to a G of 392 Hz): 32.9 / 31.1 cm, values that are actually found in the 6-course mandolins of the time.

To give concrete evidence of what has been said so far, we have subjected a gut string to a progressively increasing tension (stress) and measured the related stretching (strain).
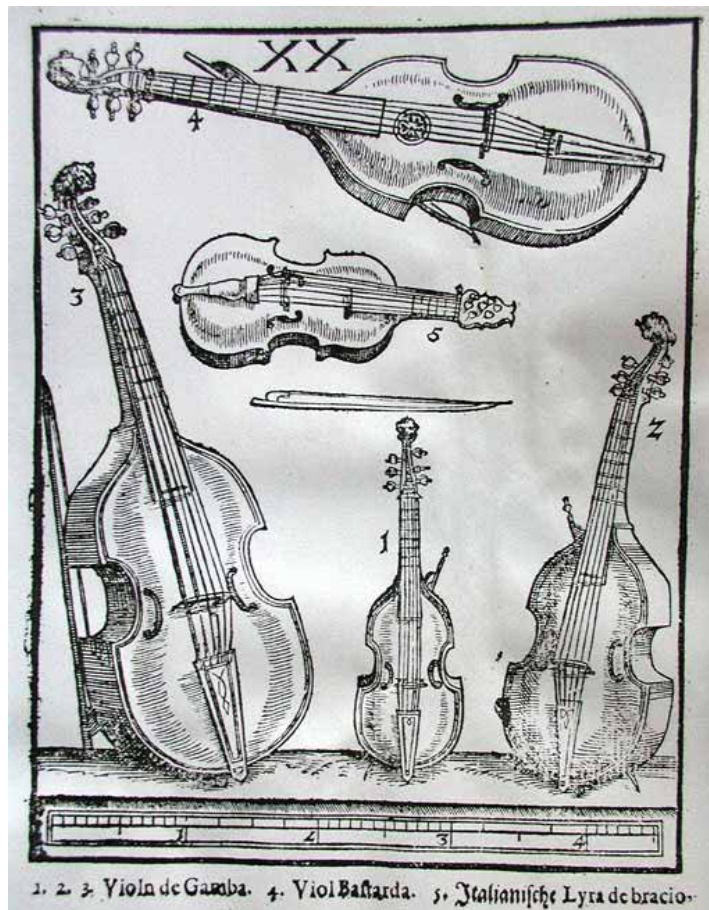
Drawing from *Syntagma Musicum*, Michael Praetorius (1619)

Examining the resultant stress/strain diagram, the initial proportional variation that emerges follows the Hook's Law (also called Tyler / Mersenne). At a certain point, the proportional variation stops and you reach a condition where the stretching (and therefore the corresponding tension) suddenly rises for very small further peg turns imposed on the string:
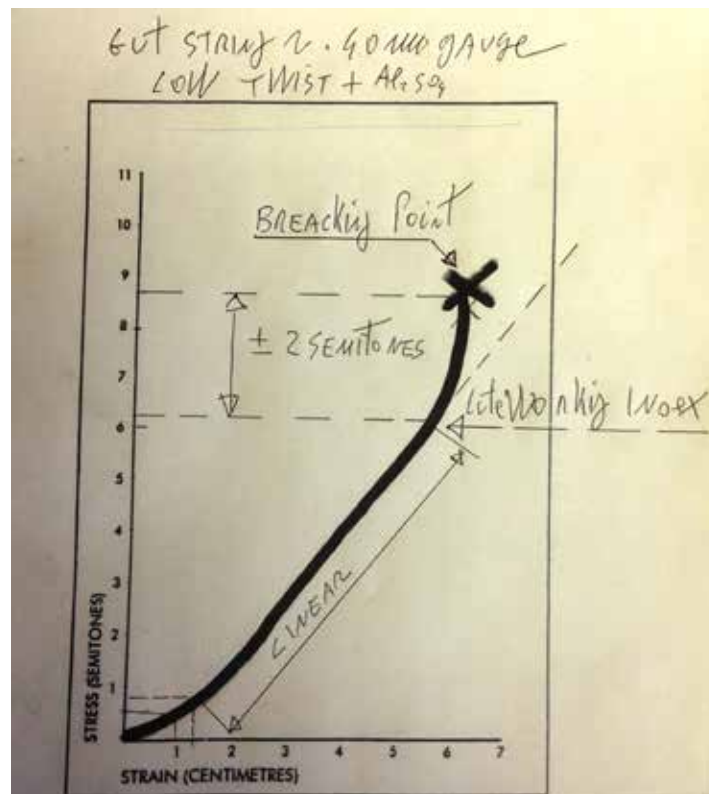
The string therefore maintains its linear stretching behaviour until about 2-3 semitones from the breaking point; beyond this value, it enters the critical phase. This is different from the typical behaviour of metals and nylon/nylgut/fluorocarbon strings. From this point gut almost completely loses its ability to stretch itself reaching rapidly its breaking point.

It is therefore concluded that the use of the maximum vibrating length can only work in the upper point of the linearity just before that the line on the chart starts to bend up to reach final breakage. The maximum acoustic performance (given by the maximum reduction of the diameter of all strings = maximum control on the inharmonicity) is determined by the fact that the instrument is working on the upper limit of where it is still stretching proportionally, just before it changes, and this is exactly two to three semitones from the final exitus, as shown on the graph. This behaviour of the gut string was well known even to the ancients and was therefore applied as one of the basic rules in the design and construction of musical instruments.

For Example, Marin Mersenne was aware of the right proportions that a musical instrument must have (*Harmonie Universelle*, 1636, Livre Troisième, Proposition X, 129) :

ment par la cognoiſſance des premieres tenſions que l'on a experimentées aux chordes, ſi quant & quant l'on ne ſçait de combien l'extenſion de chaque chorde doit eſtre plus grande à la 2, 3, ou 5 fois, qu'à la premiere : c'eſt pourquoy il ſuffit icy de remarquer combien chaque chorde s'eſtend depuis ſon ton plus graue iuſques à ſon plus aigu, auant qu'elle rompe, afin que l'on puiſſe conclure par la diuiſion de l'extenſion en eſgales parties, combien chaque ton ou demy-ton fait plus, ou moins eſtendre la chorde : toutes-fois les extenſions ne ſont pas touſiours eſgales, encore que l'on y adiouſte des forces eſgales, car les dernieres ſont quaſi touſiours plus grandes que les premieres. L'experience fait voir que les chordes de Luth s'eſtendent pour le moins d'vne vingtieſme partie, auant qu'elles rompent, car la chanterelle qui a cinq pieds de long, & que l'on tend auec vne demie liure, s'eſtend de trois poulces ou enuiron, depuis l'extenſion qu'elle reçoit de cette demie liure iuſques à ce qu'elle rompe par la force de trois liures & demie. Et apres qu'elle eſt tenduë par vne demie liure, la ſeconde demie liure que l'on y adiouſte la faict alonger d'vn demy poulce, & la troiſieſme la fait encore alonger d'vn autre demy poulce, & ainſi conſequemment iuſques à ce qu'elle ſe rompe, n'y ayant point d'autre difference, ſinon que les derniers alongemens ſont vn peu plus grands que les premiers.

And here is what Bartoli wrote at the end of 17th century:[6] 'Una corda strapparsi allora che non può più allungarsi . . .' (a string breaks when it cannot stretch any further).

Hor venendo alla propoſitione poſta di ſopra, Vna corda ſtrapparſi allora che non puo piu allungarſi : ella contien due parti, l' vna delle quali mi pare hauer ſicura : cioè, Che finche puo allungarſi, non puo ſtrapparſi : e mi par tanto vera, quanto è, Il non venirſi nelle operation naturali e neceſſarie, all' eſtremo, che prima non ſi ſien paſſati tutti i mezzi, e vinte le lor reſiſtenze, che ſi truouano ſempre minori. Ma lo ſtrapparſi, è l' eſtremo dello ſtiramento, adunque non ſi viene ad eſſo, mentre la corda, coll' allungarſi puo non iſtrapparſi . Che poi ſi habbia a ſtrappare quando non ſi puo piu allungare, mel perſuade il diſcorrer coſì . Poniamo, che la grauezza del peſo ſia creſciuta a tal miſura che per eſſa la corda ſi truoui

Daniello Bartoli: *Del suono, de' tremori armonici e dell'udito* (1679).

Meanwhile, the rule of those times of tuning the lute and even some bowed instruments beginning at the highest open note and stop immediately before the breaking of the first string is well known: this is the ultimate proof of what we have already showed graphically.

The example of the lute

The vibrating lengths that were chosen for some of the old, surviving lutes impart valuable information. The main problem is that in order to make an evaluation we have to find and use instruments in their initial state, not modified to later tastes, and instruments whose standard pitches can be determined with a relative certainty. This is the case of with at least some unmodified renaissance Venetian lutes, German D-minor baroque lutes, and French baroque guitars.

Starting from hypothetical standard pitches (for their times and places of origin) and from what has emerged from the study of their vibrating string lengths, the research on the various 5-course French guitars (at the 17th century French pitch standard close to 390 Hz) as well as the German 13-course D-minor lutes tuned at s Kammerton pitch of 410-420 Hz (see Baron 1727: his Kammerton F note for the first course) and finally including even some surviving renaissance Venetian lutes whose scale lengths of 56-58 cm probably related related to Venetian standard *mezzo punto* pitch of 460 Hz more or less, researches have allowed us to establish a working index between 225 and 235 Hz/m with an average of 230 Hz/m: this can be considered the lute working index of past times (theorboes generally speaking worked with a bit more safety; some Magno Graill or Buechenberg large theorboes have vibrating string lengths around 95 cm; at the Roman pitch standard of 390 Hz/m, the related working index range is 210-220 Hz/m). We are very close to what we calculated for example from Segerman: 210 Hz/m.

If we consider true that the working index of these examined original instruments presents a safety margin of two or three semitones from the breaking point (as we have seen on our stress/strain graph), it is even therefore possible to estimate the average breaking point in kg of lute first strings of those centuries. This can be obtained by increasing the working index that we have deduced of two or three semitones.

From this simple reverse calculation, it is possible to determine that the average breaking load of the gut chanterelles of the 16th, 17th and 18th centuries would be between 33.7 and 35.1 kg/mm^2 (corresponding to a breaking index range of 256-268 Hz/m) in the case of two semitones of safety margin and 35.7-37.3 kg/mm^2 (breaking index 273-285 Hz/m) if the safety margin was instead of three semitones.

As we can see, the range of all these values is perfectly in line with that of the current treble lute gut strings of 0.36-0.46 mm gauge (34-38 kg / mm^2).

Going back to the 6-course mandolin with a first string at G, a prudential shortening of two semitones in the average value of the breaking index of 260 Hz/m determines a vibrating length of 32.9 cm; it will be 31.1 cm if we are considering three semitones as a safety margin: these are the typical vibrating lengths found in the surviving instruments.

The range of working index (the product of the frequency of the first string, times vibrating length in metres) is as follows:

G/Sol (at the standard pitch 392 Hz); 32.9 cm   31.1 cm
                                       230 Hz/m   217 Hz/m

G/Sol (at the standard pitch of 415 Hz); 32.9 cm   31.1 cm
                                          244 Hz/m   230 Hz/m

As can be seen, a 6-courses mandolin exceeds the typical working index of the surviving lutes and 5-course guitars only if the safety margin is two semitones, with a pitch standard of 415 Hz.

In the case of the 4-course Neapolitan mandolin with a vibrating length of 33 cm (a string length typical of the violin) the following figure is obtained:

E / Mi (at 392 Hz reference pitch); 33.0 cm
194 Hz/m

E / Mi (at 415 Hz reference pitch); 33.0 cm
205 Hz/m

The conclusion is that both these working indices are within the breaking index of a gut treble. The 6-course mandolin in particular works exactly like a lute while the 4-course Neapolitan mandolin has a lower tension on the first string, just like a violin. A plausible explanation would be that while on the 6-course mandolin the range between the open first and the last strings is two octaves (24 semitones), on the 4-course instrument this range is reduced to 18 semitones, so it is not strictly necessary for the strings to be working at their highest possible acoustic performance, i.e. close to their breaking point, as is the case on those instruments with open range of two full octaves like the lute, in order to preserve the acoustic performance of the bottom strings.

However, our initial question is still unanswered: why not use a metal treble whose sound would be much brighter and quicker speaking, would have had less wear and tear and even a higher breaking load than gut?[7]

The breaking load stress of 17th century iron wire for the harpsichord can reach up to 100 Kg / mm^2. For old brass this value is lower but always much higher than the average breaking load stress of gut. The explanation is that the highest note is certainly directly proportional to the breaking load but also inversely proportional to the specific weight of the material, which is very high in metals: 7.0 g / cm^3 for iron, 8.5 g / cm^3 for brass; but only 1.3g / cm^3 for gut.

From simple calculations, taking into account the ancient pieces of wire for keyboard instruments discussed in some essays of those times, we can list a series of breaking indices. According to Mersenne:[8]

Silver: 155 Hz/m
Iron: 160 Hz/m
Brass: 150 Hz/m

The typical high density of metals affects quite strongly the limit of the breaking index: an 'ancient' steel string with a breaking load of 100 kg/mm^2 for example (which is one of the higher values found among the absolute values of old keyboard strings), however, has a breaking index of just 178 Hz/m.

This clearly explains why the battente guitar, fitted with robust metal strings can have a vibrating string length limited to just 55–58 cm, while those with less strong gut strings can reach 68–73 cm (at the same historic pitch standard).[9]

A lot has been discovered concerning metal strings' breaking load stress in the past.[10] Here are some breaking indices found for old metal strings on spinets or harpsichords:

'Old' harpsicord iron: 158–188 Hz/m; mean 173 Hz/m.[11]
'Old' spinet and harpsichord iron: 164-187 Hz/m; mean 175 Hz/m.[12]
Old' spinet iron from the second half of the 17th century: 159–195 Hz/m; mean 177 Hz/m.[13]

Other metals:

'Old' copper alloys: 112–138 Hz/m; mean 125 Hz/m.[14]
'Old' brass: 101–155 Hz/m; mean 128 Hz/m.[15]
'Old' brass: 148–153 Hz/m; mean 150 Hz/m.[16]

It can be easily seen that the difference between Mersenne's data and the average measured values is not particularly relevant.

The reason why mandolins used gut for the highest string is therefore clear: they did not have pure metals and/or metal alloys that could reach a breaking index similar to that of gut (260-280 Hz/m). Considering iron (the metal with the highest breaking index), this would correspond to a breaking load of 145-160 kg / mm².

The evidence of the use of gut trebles on the mandolin is a clear demonstration that strong metal strings were not available in the 18th century and even the first decades of the 19th. A metal wire with these values would have been employed immediately, as actually happened for a time at the turn of the 16th and 17th centuries and after 1830.[17] The mandolin was therefore inevitably forced to use gut string for the first course due to lack of any alternatives.

Historical sources

There are few historical sources from the 18th century containing information regarding the string set-ups of 4- or 6-course mandolins; these few are, at the end of the day, only Fouchetti and Corrette.[18, 19] Let's see what they wrote and what can be deduced.

Fouchetti

What Fouchetti wrote about the 4-courses Neapolitan mandolin set-up, generally speaking, is considered unreliable, if not fanciful. A set of strings like those he described appears to be the most bizarre and heterogeneous among those of all the plucked and bowed instruments of his time: different materials on a set of just four courses: gut string, brass wires, twisted brass wires, and wound gut/silk strings. This degree of heterogeneity is absolutely amazing. By looking more closely and by making some calculations, we realise that this set-up gives about the highest perfection possible for that time both from a mechanical point of view and from the acoustic point of view, and indeed with very few other alternatives, if we consider what was available in those times to make strings—keeping in mind that the most desired feature in this instrument was brightness and prompt speaking, as it had to imitate the harpsichord:[20]
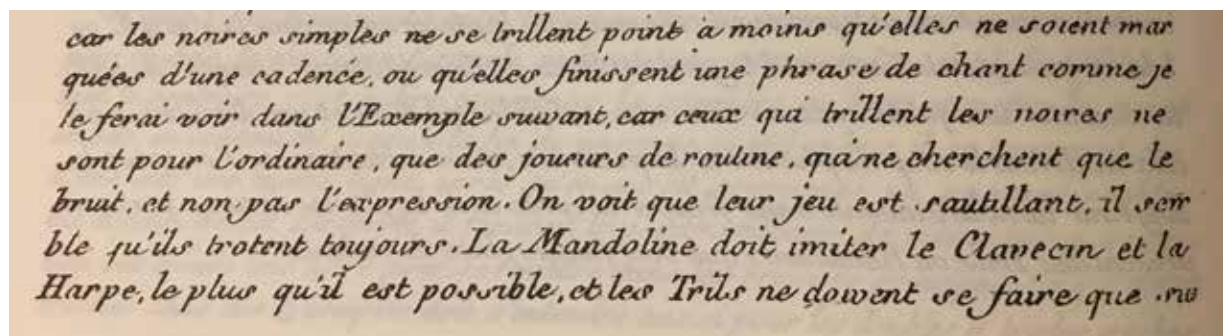
As far as vibrating lengths are concerned the sizes used conforms with clear evidence, especially on the 6-course mandolins, that we are considering an instrument that, like the lute, had the maximum vibrating length possible in order to ensure the best acoustic performance.

Here is the set for the Neapolitan 4-course mandolin (Fouchetti says nothing about the 6-course mandolin):

1. a pardessus gut treble
2. a harpsichord gauge 5 yellow brass
3. two harpsichord gauges 6 yellow brass twisted together
4. a light G violin wound fourth. The core can also be silk. As an octave pair you can use 5-gauge yellow brass as on the second course. Sometimes the fourth courses are strung in unison.

J'ai parlé de la Mandoline à quatre cordes, c'est-à-dire à quatre cordes doubles, car elles sont accordées de deux en deux à l'unisson, c'est-à-dire, du même son, excepté la grosse corde, ou Sol, à laquelle on met une octave. On se sert pour cela d'une corde semblable à celle de La, que l'on accorde à l'Octave au dessus de la grosse corde Sol. Quelque fois l'on met deux bourdons ensemble, alors on les accorde à l'unisson comme les trois autres cordes.

A l'egard des cordes elles doivent être de laiton. L'on prend pour les La, des cordes de Clavecin du numéro 5. Les Re sont du numéro 6, mais l'on en met deux tordues ensemble pour chaque Ré. A l'égard des Mi, l'on se sert de cordes de boyau l'on prend des chanterelles de Pardessus de Viole. Les bourdons, ou Sol, sont aussi des cordes de Boyeau, mais filées; l'on prend des bourdons de Violon, mais plus petits. On fait quelque fois filler des cordes de soye, pour servir de bourdons; elles sonnent très bien.

First string: considering the range of the working index that we determined, the first string must be of gut due to the lack of possible alternatives: Fouchetti suggests a first pardessus string. According to the data provided by De Lalande,[21] and other sources, we know that the treble for pardessus and also mandolin was made up of two whole lamb guts, and the violin first string of three. There are numerous researches,[22, 23, 23] that associate three whole lamb-guts with a gauge of .68 to .73 mm. By simple proportions, the mandolin/pardesssus first string had a diameter of .56-.59 mm.

Second string: Fouchetti says you should use a yellow brass wire of gauge 5. The second course's working index is around 129 Hz/m so the brass wire available (for harpsichord) was not going to break. The use of a brass string and not of a more robust iron has only one explanation, of an exclusively acoustic nature: brass, due to its specific weight higher than iron, is brighter: this fits quite well with the criteria of those time were mandolin should imitate the sound of the harpsichord. According to the Cryseul gauge scale,[25] the gauge 5 corresponds to a diameter of about 0.30 mm.[26] The yellow brass had a specific weight around 8.5 g /cm³ (red brass was around 8.7 g /cm³).
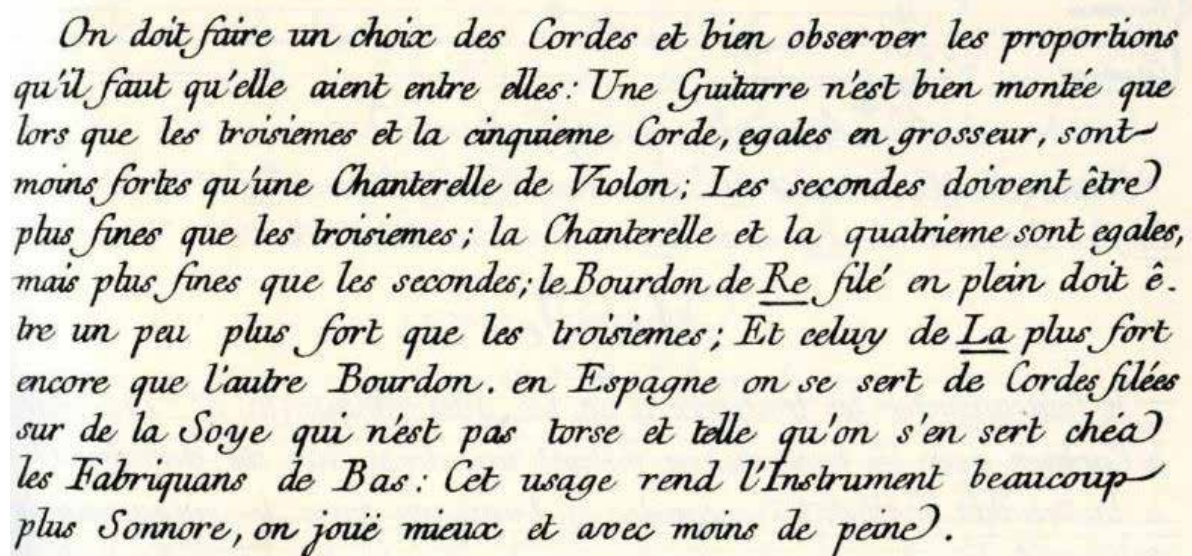
Third string: Fouchetti says to take two yellow brass harpsichord of gauge 6 twisted together. The purpose is clear: the strings twisted together become more elastic than a single strand of the same gauge, so they minimise the 'pitch distortion' effect on the frets which with a simple single wire would be very evident even for small pressure variations and / or lateral displacements on the string. With a single metal wire, there would also be a considerable difficulty in tuning and keeping it stable over time because even an imperceptible rotation of the tuning peg would produce significant variations. By twisting two wires together, the abovementioned problems are solved; the use of the brass still guarantees the best acoustic performance in terms of tonal brightness and projection even though it is still a little less 'round' than a single wire. Gauge 6, again according to the Cryseul scale, corresponds to .29-.30 mm in diameter. The problem here is to determine the strings' degree of twist and the behaviour of the yellow brass, as Fouchetti says nothing about it.

   We can find a solution by realising different types of twisting and checking the mechanical strength, sound, and especially the resulting working index, and compare it to the working indices of the other courses. Thus by experiment we have found that two .30 mm brass strings twisted together with a low twist produced a string of .39 mm diameter (1.30 times the diameter of the starting wire) or .46 mm (1.54 times the diameter of the starting line) if the twisting ratio is very high. In this second case, however, we found the sound was far better: the working tension, tuned to D of 262 Hz (Parisian pitch standard of 392 Hz) is around 3.4 kg.

Fourth string: For the fourth string a violin G wound string was used, but a bit thinner than normal (in those times they were made using a medium second violin string as the core: we have employed a thin second string) Considering a gut-core wound string, it is evident that you lose the characteristic brightness of the three top strings.

This problem is greatly mitigated by the fact that a yellow brass octave (and not a gut) string is added, whose obvious purpose was to add brightness to obtain an acoustic alignment with the higher ones. This course was also sometimes strung in unison but Fouchetti tells us that this was seldom done.

The author suggests, alternatively, the use of silk as the core of the fourth, thus anticipating what would then become the standard for the bass of six-course guitars in the 19th century. With the use of a silk core the sound became even a little brighter. Indeed, the use of silk core basses for five-courses guitar had already been described by Juan Guerrero in 1760.[27]

On doit faire un choix des Cordes et bien observer les proportions qu'il faut qu'elle aient entre elles: Une Guitarre n'est bien montée que lors que les troisiemes et la cinquieme Corde, egales en grosseur, sont moins fortes qu'une Chanterelle de Violon; Les secondes doivent être plus fines que les troisiemes; la Chanterelle et la quatrieme sont egales, mais plus fines que les secondes; le Bourdon de _Re_ filé en plein doit ê-tre un peu plus fort que les troisiemes; Et celuy de _La_ plus fort encore que l'autre Bourdon. en Espagne on se sert de Cordes filées sur de la Soye qui n'est pas torse et telle qu'on s'en sert chéa les Fabriquans de Bas: Cet usage rend l'Instrument beaucoup plus Sonnore, on jouë mieux et avec moins de peine).

Tablature)

But how was a wound violin G string made in those times? Some sources wrote that a second string of the same instrument was taken for the core and then covered with a thin silver wire or silver copper wire (see Francesco Galeazzi, 1792). The equivalent gut string to ensure a balanced set-up (with scaled tension) for this instrument ranged from 1.70 to 1.90 mm. Fouchetti writes, however, that this string has to be a bit thinner than normal, but by how much? We must calculate its equivalent gut from the mandolin scale length, the presumed pitch standard and the gauges of all the other strings (and so, by calculation, the related working tensions).

Thus, with a vibrating string of length 33 cm, the diameters and the density of the materials, it is possible to obtain the working indices values of all the strings at the supposed Parisian pitch standard of 392 Hz with the following results.

First course: 5.44 kg (average tension value between .56 and.59 mm; diameter = .575 mm)
Second: 5.3 kg (gauge 5 = .34 mm)
Third: 3.4 Kg (two gauge 6 low twist wires = .30 mm)
Fourth, octave: 4.46 Kg (.34 mm)
Fourth, wound bass: the tension should be the same as the paired octave string: 4.46 Kg

Some remarks

1) at 'Parisian' 392 Hz pitch standard, the working index of the yellow brass wire for the octave of the fourth string is about 115 Hz/m (122 Hz/m at 415 Hz): a yellow brass wire can therefore be safely used.

2) The set-up presents a scaled tension profile which would probably lead to a situation of equal tactile feel if were it not for the third course where we have abnormally low tension. In reality, it is possible to balance the situation if we consider a thinner gauge for the first string, always made, however, from two guts.

3) Then, in order to have the same working tension as its paired octave, the equivalent gut of the fourth string should be 1.75-1.80 mm: in fact, we have a fourth violin string which tends to be at the lighter end of the tension range.

Fouchetti's stringing: conclusion

The set-up described by Fouchetti presents almost perfect coherence in tension values between the various strings and on the acoustic side; due to the careful choice of materials and string types, it achieves the highest performance, that results in powerful projection and brightness.

It should be noted, however, that there were not many alternatives available at the time: the first string had to be gut, while the fourth had to be a wound gut/silk-core string. Most likely, on the second and third courses, iron wires for harpsichord could be used but this would be at the expense of brightness (though wires of this material providing the same working tension as gauge 5 and 6 yellow brass would probably not be available) as there was no intermediate gauge between n ° 5 and n ° 6.

The octave of the fourth course could be unisons, adding another violin G wound string instead of a brass wire, but here too, there would have been a loss of brightness, a factor which is emphasised by Fouchetti, who points out, as already said, that the mandolin must imitate the harpsichord and harp.

Corrette

Examining the method of Corrette, the first noticeable thing is that he does not propose any novelties as described by Fouchetti for the 4-course mandolin tuned in fifths. In fact, looking at his diagram printed below, there are substantial differences and, in my opinion, several errors.

First course, called F: this must be a 5-course guitar first string
Second course called G: this must be a harpsichord gauge 5
Third course called H and R: R must be a demi file, nothing is said about H
Fourth course in octaves, called K and I: I is a wound string, nothing is said about K

The first gut string is not a pardessus treble as Fouchetti says, but a 5-course guitar first string: what diameter could it be? We need to know if there are direct references to the number of strands, or to guitar strings or at least an indirect reference to another musical instrument. Unfortunately to date we have no direct reference; instead, there are several references to a well-studied instrument: the violin.

In the Stradivarius Museum there is a drawing on cardboard (drawing no. 375) which shows the description of the necessary strings for the five orders of the *chitarra attiorbata*, which is basically a normal 5-course guitar with 5 single diapasons ('bordone') added on an extended neck.
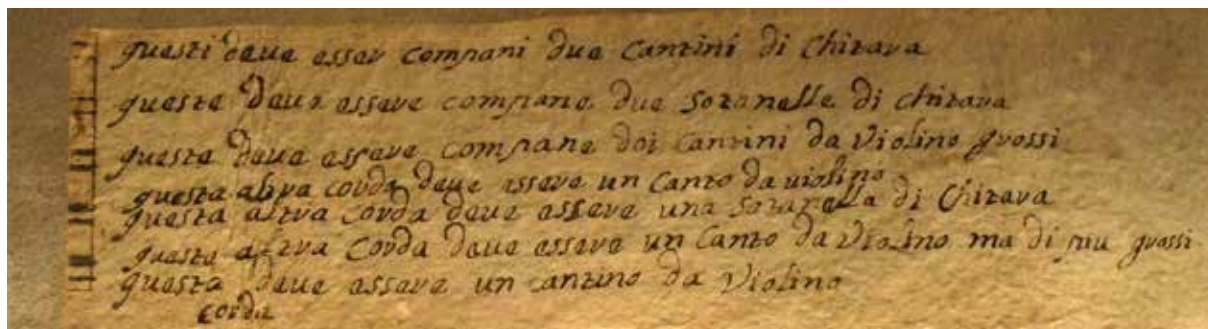
The instructions are as follows.

• First and second string (first course): 'Questi deve essere compani due cantini di chitara'. (These must be a pair of guitar top strings)
• Third and fourth strings (second course): 'Queste deve essere compane due sotanelle di chitara'. (These must be two guitar second strings)
• Fifth and sixth string (third course): 'Queste deve essere compane doi cantini da violino grossi'. (These must be a couple of thick violin top strings.)

And so on.[28] To solve this problem then we need to know what the average violin string diameter of those times and what could be called a 'thick' treble.

Count Riccati (who was, in addition to being a great physicist, aa amateur violinist friend of Tartini) around 1740/50 made some interesting measurements of the strings of his violin: from his calculations we get the size of the treble on his violin: about .70 mm.[29]

This estimate is indirectly confirmed by the data provided by the French traveller and astronomer De Lalande around 1760,[30] concerning the gut used to make mandolin, violin and double bass strings by the famous stringmaker of Abruzzo (though working in Naples), Domenico Antonio Angelucci; these proportions remained strictly constant until the end of the following century, in Italy and in France.[31] As for the 'thick' trebles, let's consider as reference the thicker E and A gauges made from the same number of guts as George Hart suggested in 1881.[32] Considering the standardisation in the manufacturing process of violin strings it is then possible to assume that a 'thick' three-strand gut string could be around .73-.74 mm.

Since the third course of this guitar used a violin gut string (made with three guts or 'fili') using simple proportions—maintaining a constant tension—the second course had to consist of two-strands (like the treble of the mandolin and the pardessus, according to De Lalande) and the first of one gut only, just like the treble of the lute.[33] In theoretical calculations, the ratio between the diameters is equal to the square root of the ratio of the number of strands used; but then we have to deal with the tactile feel of tension that must be homogeneous: two gut strands therefore produce a diameter between .57 and .59 mm.

Since with three-gut string we obtained an average diameter around 0.70 mm (here we refer expressly to a 'big' treble, for example .73 mm, which is considered 'thick' by George Hart), considering a set up with the same feel as the guitar (which, however, leads to scaled or graduated tension measured in kg, conditioning the choice of its gauges), this is what we obtain:

First course: .44-46 mm (made from a single whole gut).
Second course: .57-59 mm (made from two pieces of gut).
Third course: .73 mm ('a thick violin treble': made of three strands of gut), etc.

Corrette writes that:

> La guitarre se mont en cinq rangs de cordes, le 1er n'en a qu'un qui se nomme chantarelle, et les quatre autres rangs en ont chacun deux . . . Il faut observer que les deux cordes du 3me rang et la petite corde a l'octave du 5me rang soient égales en grosseur pas si forte que la chantarelle de violon. . . [34]

Corrette thus himself confirms what is written in our document of Stradivarius. Now that we have a more precise idea of 5-course guitar gauges, we can go back to the 4-course mandolin described by Corrette and try to provide the diameters:

a) First string: Corrette talks about the guitar first string. The reference starting point to find out the guitar gut gauges is the third course, which has a gauge equal to a (thick) violin treble: in order to preserve an even feel of tension between the strings, the first then, according to what the author wrote, has to be of about .44 to .46 mm gauge.

b) Second string: a harpsichord gauge 5 wire is used. Corrette, however, does not specify the type of metal; however, the analogy with Fouchetti is consistent and hence we may consider that he is talking about yellow brass. [In the diagram above Corrette does use the word 'jaune'—*Ed.*]

c) Third string: Corrette oddly seems to consider each as single string even though on his stave diagram we can see that they are in unison. A futrher oddity, already noted, is that he provides no explanation for some of the letters on his own diagram: of 'H', nothing is said, while 'R', is a demifilé, but with no further details given; unfortunately, from this statement it is not possible to get anything concrete; we do not know if the strings were both demi filé and there is no further specification.

d) Fourth string: Corrette says nothing about the octave string 'K'. Of the bass string 'C' we are just told that it is a wound string. However, we do not know which core to use—silk or gut. But anyway thanks to Fouchetti we know that both materials were suitable therefore we might guess that, again, it is a violin G string.

Considerations

The information given by Corrette concerning the 4-course mandolin is, in the view of the present writer, totally unreliable.

First course: with a gauge of around .44-.46 mm it would have a working tension of only 3.0-3.2 kg per string.

Second course: presumably a yellow brass gauge 5, but nothing is specified—here the tension rises to at least 5.3 kg per string. The gap between this and the tension on the first course is remarkable. To have a working tension comparable to the second course, the first course should use the guitar second-course strings (two strands of gut = mandolin first course = pardessus first course according to De Lalande) in accordance with Fouchetti.

Third and fourth courses: nothing useful can be learned from Corrette; if it were not for Fouchetti (which gives a useful comparison) the data provided by Corrette would be completely meaningless.

Six-course mandolin

After the problems already encountered on the 4-string mandolin tuned in fifths, we inevitably expect issues. In fact, other indications in Corrette's diagram are unfortunately incorrect: some reasoning is needed. Only at after reviewing the evidence can we arrive at a workable solution for the 6-course mandolin.

a) First and second courses: Corrette writes that courses 'L' and 'M' must be guitar trebles: what does he mean? That he used the guitar treble for the second course of the mandolin as well as the first? This cannot be right; there cannot be trebles installed on the second course: there would be a total misalignment in the working tension. I therefore feel that Corrette is referring to the first and second courses of the guitar.

b) The third course 'N': Corrette says to use a harpsichord gauge 5 wire but omits to specify the type of metal: however, I think it is the usual yellow brass, used for harpsichord.

c) Fourth course 'S': Corrette says that this is a demi filé string but does not add further detail, such as to whether it is a silk or gut core.

d) Fifth course 'P': this is a full wound string but we have no other information: the octave string is not mentioned at all.

e) Sixth course 'Q': This is a full wound string but we have no other information: again the octave string is not mentioned at all

Considerations

From the data provided by Corrette, no one today (or indeed in his time!) would be able to work out the string set up; however, it is possible to introduce some reasoning that eventually might solve the enigma.

Let us start from the only certain data available: the third course A which is a harpsichord gauge 5, presumably of yellow brass (.34 mm). Using a typical 6-course mandolin average vibrating length of 31.5 cm, and a presumed Parisian/Roman pitch of 392 Hz, we obtain a working tension of 4.8 kg.

The first and second courses of the instrument must therefore somehow relate to this value: by putting on these two courses the first and second strings of a guitar (of which we have a more accurate idea thanks to Stradivari's violin information) the following working tensions are obtained: 3.9-4.3 kg for the first course and 3.8-3.9 kg for the second. Compared to the tension value of the third course, it is not really in balance, yet will still be functional.

Things are much simpler with the sixth course: as it is a G we can suppose that it may be a violin fourth string as per Fouchetti, with the octave the same as the gut second (the third on the guitar): considering this hypothesis as valid the tension of the bass and its paired octave is about 3.9 kg. The paired octave may be the same yellow brass gauge 5 already used for the third course: a gut string would be about .90 mm in gauge.

Having deduced the working tension of the first, second, third and sixth courses it is logical to think that the working tension of the fourth and fifth must necessarily be between 4.8 kg (third course) and 3.9 kg (fourth course): How can this condition be achieved while fitting in the technological and acoustic correct range?

Fourth course: as we have seen, Corrette says to use a demi filé string. It is necessary here to consider a working tension range slightly lower than that of the third course but in any case, higher than the theoretically associated range in the fourth course. The range has to preserve the linearity of the values

calculated so far. If we assume that the range is 4.4-4.7 kg, the following diameters are obtained: 1.10-1.14 mm. These diameters correspond exactly to a third Violin string that was then made in France usually as a demi filé.[35, 36]

Violins with an open wound or demi filé third string (France, mid-18th century)

Its octave should have a diameter between .55 and .57 mm: the first string of a 4-course mandolin or second course of a guitar.

Fifth course: Corrette states that this is a unison and a full wound string. From simple calculations, considering a tension range slightly above that of the fourth course in order to preserve the linearity of the values calculated so far (assuming that the range is 4.1-4.3 Kg) for the note B we obtain an equivalent gut of 1.42-1.47 mm in diameter.

The data should be reliable: its octave, at the same tension, varies between .71 and .73 mm in diameter; the guitar third string (i.e. a violin first string).

The problem is to realise this stringing, especially if you use a gut core. In those times, according to our research, metal wires with a diameter of less than about .13- .15 mm[37, 38, 39, 40] were not produced because they did not have technology to draw thinner metal wires.

In other words, the half-wound string described by the writer was not at all a transition string between a gut string and a wound string but a technological way out, in view of the non-availability of thinner metal wires; in fact, we can find proof in the metallicity index characteristic of these particular strings, which is similar to that of full-wound strings, and not less.

If the core is instead of silk, which, according to Fouchetti, was used on the mandolin and then also in the fourth and fifth courses of 5-course guitars and on 19th and early 20th century guitars, with silk cores, rather than gut, the relationship between the core and the metal can be unbalanced in favour of the metal, so that a full-wound string can have a brilliant acoustic output (higher metallicity index).

It is interesting to note that the equivalent gut and the way of making the close wound strings on silk for the fifth and sixth courses of the 6-course mandolin would then be used respectively for the fourth and fifth strings of the 6-single string guitar, which in ten or fifteen years was to appear on the music scene.

To sum up, even for this kind of mandolin Corrette does not allow us to come to certain and plausible conclusions. However, we have made a number of arguments that lead to the following proposed set-up, based on the few information from Corrette (the only really positive piece of information is the indication that the third course uses gauge 5 wire, from which we can deduce the values of the tensions: at this point; the highest course must have a higher tension while the bass side tensions decline according to a Fouchetti's similar mandolin profile) and with the support of Fouchetti:

1G: the first string of a 5-course guitar = .44-.46 mm in diameter; average tension: 4.1 kg per string.

2D: the second string of a 5-course guitar = .57-.59 mm in diameter; average tension: 3.9 kg per string.

3A: gauge 5 yellow brass for harpsichord = .34 mm diameter; average tension: 4.8 kg per string

4E: demi filé string (third violin according to French use) = 1.10-1.14 mm equivalent gut; average tension: 4.0 to 4.5 kg
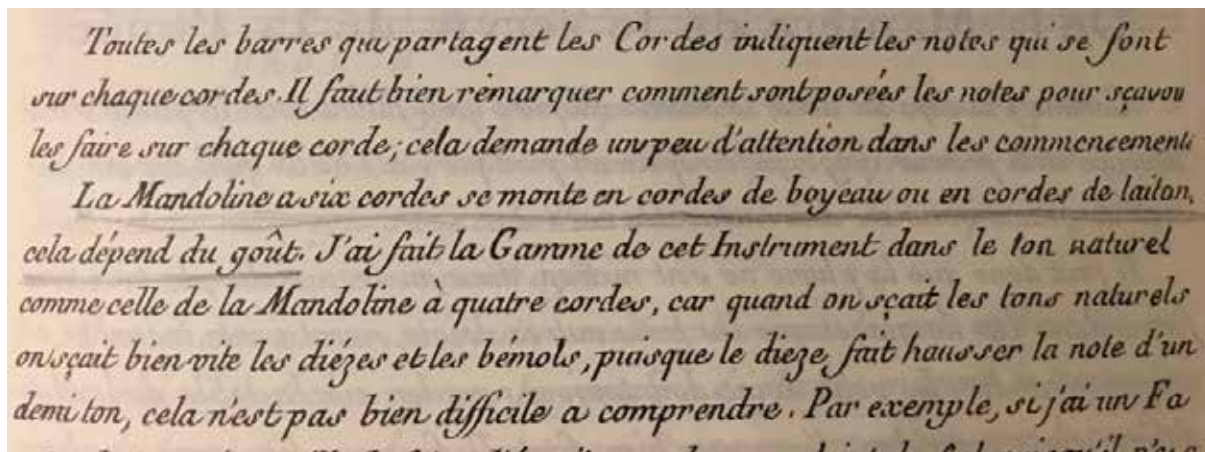
5B octave: third strings of a five-course guitar = .70-.73 mm in diameter; average tension: 4.2 kg

5B: bass: full wound string on a silk core with gut equivalent = 1.42-1.47 mm diameter; average tension: 4.2 Kg

6G octave: another gauge 5 yellow brass harpsichord wire = .34 mm diameter; average tension: 3.9 kg (or a gut string of .88-.91 mm: in practice the same as the fourth course of the guitar).

6G bass: full wound on silk core (it is difficult to think they would have used a gut core or indeed a violin fourth string)= 1.8 mm diameter gut equivalent; average tension 3.9 kg.

The uncertainty over using octave strings in gut or yellow brass gauge 5 is a matter of relative importance: Fouchetti points out that the use of metal wires or gut strings was a matter of personal taste:

Toutes les barres qui partagent les Cordes indiquent les notes qui se font sur chaque cordes. Il faut bien remarquer comment sont posées les notes pour sçavoir les faire sur chaque corde; cela demande un peu d'attention dans les commencements. La Mandoline a six cordes se monte en cordes de boyeau ou en cordes de laiton, cela dépend du goût. J'ai fait la Gamme de cet Instrument dans le ton naturel comme celle de la Mandoline à quatre cordes, car quand on sçait les tons naturels on sçait bien vite les diezes et les bémols, puisque le dieze fait hausser la note d'un demi ton, cela n'est pas bien difficile a comprendre. Par exemple, si j'ai un Fa

Practical evidence

Four-course mandolin: the Fouchetti set-up

First course: .56 mm gut gauge string: no mechanical or acoustic problems were found.

Second course: yellow commercial brass wire for harpsichord diameter .35 mm. The main problem turns out to be how to tie it on. Being a very hard harpsichord brass wire the problem is its fragility when bent. In our case, we solved the problem by making a very long loop so that, when put in tension, it will 'lock' itself, eliminating any string breakage problem at the pegs due to the presence of sharp angles.

Third course: we used .30 mm yellow commercial harpsichord hard brass wire. It is not possible to twist together directly the two wires, the brass being very hard as it tends to break during twisting, resisting the operation, finally coming to different degrees of twist along the string. The solution to this problem was to soften the two wires just a bit (not totally) by heating them to 350 degrees (in this regard we did a number of tests whose final result indicated that the wire has to be heated between 330 and 370 degrees Celsius) for one minute. The wire thus obtains an intermediate degree of hardness, allowing it to be bent and still retaining a residual degree of hardness counteracting the yielding of the wire under tension.

The degree of twisting of the string is a crucial aspect: if it is very high (high twist) the sound is very bright but it also reduces the tensile strength. With less twist (low twist) the sound is less metallic; you have less sustain but you have a higher tensile stress. In other words, depending on the degree of twisting, you can modulate the desired tonal output until you find an acoustic balance between the second and the fourth course.

Fourth course: following the historical instructions we obtained a violin wound G whose equivalent gut is 1.80 mm (a slightly lighter violin second string covered with silver wire): for the octave a second yellow brass wire is used, the same as those of the second course.

Conclusions: The overall acoustic balance of the set was homogeneous and thus also the feel of tension among the strings (at a pitch standard of 392 Hz).

Six-course mandolin according to our interpretation of Corrette interpretation (and playing with a cherry bark pick)

First course: .46 mm gut: no acoustic or mechanical problems found

Second course: .56 mm gut: no acoustic or mechanical problems found

Third course: .35 mm yellow brass wire: the tension feels a little higher than the upper strings; it sounds more brilliant than the second and third course. Working tension: for a better balance the diameter should be reduced to .33-.34 mm. There is no solution for the brilliant acoustic output. Alternative: .88 mm gut string: no mechanical problem; acoustically aligned with the first two top courses and with the fourth course

Fourth course: two violin third demi filé strings are used: equivalent to gut of about 1.15 mm. There were no mechanical problems. The sound was a bit duller compared to that of the third course, when the latter is yellow brass instead gut.

Fifth course: the bass consists of an average 19th century guitar fourth D string wound with silvered copper wire on silk core whose equivalent gut is about 1.40 mm. The octave string is a gut third string of a 5-course guitar of .73 mm (see the Stradivari information above, re: the thick violin top string).

Sixth course: the bass consists of an average 19th century guitar fifth A string wound with a silvered copper wire on silk whose equivalent gut would be about 1.80 mm. The octave string is a .88 mm gut equivalent to a fourth string of a 5-course guitar.

In the view of the present writer this experimental set-up is completely satisfactory. There are no mechanical problems; acoustic and dynamic balance are good including with regards to the fifth course. We tested a yellow brass wire as an octave for the sixth course but this resulted in a tonal disequilibrium with the other higher courses.

Critical points revolve around the use of brass wire on the third course, due to the tonal difference with the other gut courses. Likewise, the use of a yellow brass wire as an octave on the sixth course is unlikely to be successful due to the tonal disequilibrium that occurs. The best balancing set-up therefore is the one that uses gut strings for the first three courses and for all the octaves; close wound silk core for the fifth and sixth course and a demifilè wound gut string for the fourth course: however, for this course one could experiment with a silk-type string on silk core, which, however, so far has not been found in the records of the 18th century.

Conclusions

Although some 18th century mandolin methods have survived, when it comes to understanding what kind of strings to use, we have only two available sources: Fouchetti and Corrette.

The data provided by Fouchetti for 4-course double-strung mandolins are technically and acoustically consistent: they give a set-up whose tension value is within a range of acceptability and homogeneity between the various strings. The strings of the four courses are from the technological and acoustic vision point, close to perfection considering what was available at that time. Unfortunately, Fouchetti says nothing about the 6-course mandolin.

The description provided by Corrette, however, is incomplete and sometimes confusing: it is not possible to directly extract anything usable unless you go through a critical re-elaboration of the data provided as we have done here. If we see how much he wrote in comparison with Fouchetti (in some ways there are interesting overlaps), it is always necessary to take in account what could or could not be done at the time (in short the technical limits and materials available), then it is possible to formulate a concrete proposal even for the 6-course mandolin.

For the 4-course mandolin Fouchetti's data is validated only partially by Corrette (in respect of the the gauge 5 wire for the second course, for example).

For the 6-course mandolin, as we have seen, we can refer only to Corrette: I believe that our process of reasoning and evaluation is interesting not only from the acoustic point of view but also from the point of view of the times available materials.

However, we have a last consideration: Corrette does not clarify whether the 6-course mandolin should be played with the plectrum or with fingers, like the lute. One would point out that from the tension values we calculated you could have considerable difficulty playing a 6-course mandolin directly with the fingers. As an example, the tension range currently accepted on the lute today (which is a much larger instrument) is between 2.7 to 3.3 kg.

The rules of the time are clear and repeated several times in historical documents: big lutes have fatter strings, small lutes have thinner strings (i.e. with reduced tensions): a mandolin played with fingers and not with a plectrum with a vibrating length of only 31.5 cm giving a tactile feel of tension similar to the lute should therefore have in proportion a fairly low tension, say around 2.0 Kg. This would involve, however, a gut string for the first course of .31-.33 mm gauge only: this is not physically possible. In fact, the thinnest, unpolished gauge that comes out from a single lamb gut of a few months old—as indicated by ancient sources—is about .40-.46 mm in diameter and produces a higher working tension than those of 2.0 Kg before indicated.

One possible solution (the only that can work out, in my opinion) is that the 6-course mandolin with glued bridge may have been played exclusively with nails. Such a solution would have enabled it to work easily without the plectrum (the nail itself can acts close to a plectrum), with clear and crystal sound and even under considerable working tensions (like in use on the modern classical/flamenco guitars that cannot be used without nails), otherwise objectively it is difficult to play only with the fingertips. It is historically known that among the 18th-century mandolinists there are also many theorbo and archlute players who used the nails of their right hand, such as Filippo da Casa. Hard to cut them off just to play the mandolin while they are, at the same time, playing also the theorbo.

I pass that question on to all the similar mandolin players: nevertheless these are the calculations and the results that emerged.

Vivi felice!

NOTES

1. Djilda Abbott, Ephraim Segerman: 'Strings in the 16th and 17th centuries', *The Galpin Society journal*, XXVII (1974), pp. 48-73.

2. The values obtained in this example are the ones specifically made using the manufacturer technology for trebles, which is used to obtain the maximum tensile strength (and all 'surface abrasion'), as we will see better later on. In other words, in their manufacturing process elasticity is not consider (factor that can be overlooked for these thin strings), factor that is on the contrary consider for all the other kind of that are not used on the first spot: for these strings we only want to achieve the maximum elasticity possible. Elasticity and tensile strength are inversely proportional.

3. To make things easier we decide to use a standard frequency value. The French reference pitch according to the existing studies was included between 385 and 400 Hz. See: Alexander J. Ellis in *Studies in the History of Music Pitch: Monographs by Alexander J. Ellis and Arthur Mendel* (Amsterdam: Frits Knuf, 1968; New York: Da Capo Press); Arthur Mendel: 'Pitch in western music since 1500: a re-examination' *Acta musicologica*- L (1978), pp. 1-93; Ephraim Segerman: 'On German Italian and French pitch standards in the 17th and 18th centuries', *FOMRHI quarterly* no. 30, (January 1983), comm.442.

4. Ephraim Segerman: comm 1545 in *FOMRHI Quarterly* 89, (October 1997).

5. Ephraim Segerman: comm 1593 in *FOMRHI Quarterly* 92, (July 1998).

6. Daniello Bartoli: '*Del suono, de' tremori armonici e dell'udito', a spese di Nicolò Angelo Tinassi,* (Roma 1679), p. 263.

7. Metal strings worked near to their breaking point; see: William R. Thomas and J. J. K. Rhodes: 'The string scales of Italian keyboard instruments', *The Galpin Society Journal* XX (1967), p.48; Michael Spencer: 'Harpsicord physics', *The Galpin Society Journal*, XXXIV, (March 1981), pp. 3-7, Ephraim Segerman: 'Bulletin Supplement', *FOMRHI quarterly* no. 39, April 1985, p.11; 1768—Adlung's statement: 'When a harpsicord is strung so that the pitch can be safely raised a semitone, one can be secure . . .'.

8. Marin Mersenne: *Harmonie Universelle* (1636, Livre Troisiesme), Proposition XII e Proposition XIII, see note no.7 p. 58.

9. Ephraim Segerman: 'New Grove DOMI: ES Mo 4: Ca to Ci entries'. *FOMRHI quarterly* no. 43, (April 1986), comm. 698. Also Harvey Hope: 'Ref J. M. S. remarks on the New Grove Chitarra battente', *FOMRHI quarterly* no.43, (April 1986), Comm. 709; Peter S. Forrester: 'Citterns and chitarras battente: re. Comm. 698, Grove Review'. *FOMRHI quarterly* no. 44, July 1986, comm. 740; Ephraim Segerman: 'Response to Comms 739 and 740', *FOMRHI quarterly* no.44, July 1986, comm. 742; Peter S. Forrester: '17th c. Guitar woodwork'. *FOMRHI quarterly* no. 48, July 1986, comm. 825; James Tyler: *The Early Guitar—A History and Handbook*; Early Music series: 4, (Oxford University Press, London, 1980). Quoted by Ciro Caliendo: *La Chitarra battente.*

Uomini, storia e costruzione di uno strumento barocco e popolare (Edizioni Aspasia, Aprile 1998), pp. 24–25.

10. Cary Karp: 'Strings, twisted and Mersenne', *FOMRHI quarterly* no. 12, (July 1978), comm.137; Ephraim Segerman & Djilda Abott: 'On twisted metal strings and Mersenne's string data', *FOMRHI quarterly* no.13 (October 1978), comm. 164. See further Cary Karp: 'On Mersenne's twisted data and metal strings', *FOMRHI quarterly* no. 14, (January 1979), comm. 183; Ephraim Segerman: 'Mersenne untwisted-a counter-Carp to comm.183', *FOMRHI quarterly* no.15 (April 1979), comm. 199.

11. Cary Karp: *The pitches of 18th Century strung Keyboard Instruments, with Particular Reference to swedish Material*, SMS-Musikmuseet Technical Report no. 1 (SMS-Musikmuseet, Box 16326, 103 26 Stockholm, Sweden, 1984), 129 pp. See also: 'On wire-comms and wire-comm comments', *FOMRHI quarterly* no. 11 (April 1978), comm. 134; Karp wrote that 'In as much as the lower portion of this range was generated by piano wire . . .'.

12. Remy Gug: 'About old music wire'. *FOMRHI quarterly* no. 10, (January 1978), comm.105. Gug wrote that 'Let us first specify that the concerned strings have been taken from instruments used in the XVIIth and XVIIIth centuries: harpsicords, spinets, clavichords, dulcimers'.

13. Marco Tiella: *Problemi connessi con il restauro degli strumenti musicali*, pp. 22-23.

14. See note no. 10.

15. Ephraim Segerman: 'Neapolitans mandolins, wire strengths and violin stringing in late 18th c. France', *FOMRHI quarterly* no.43, April 1986, comm. 713, the first modern paper on the subject, as far as Segerman himself knew.

16. Gianni Podda: 'Prove di trazione e determinazione della tensione di rottura per corde antiche e moderne', pp. 36-38, *Atti del seminario per la didattica del restauro liutaio* (estate musicale 1981; Premeno).

17. Remy Gug: 'Jobst Meuler or the secret of a Nuremberg wire drawer', *FOMRHI quarterly* no.51, (April 1988), Comm. 866, p. 29. Editor's note: strong metal strings allowed the brief flowering of the metal-strung orpharion.

18. Giovanni Fouchetti: *Méthode pour apprendre facilement á jouer de la mandoline á 4 et á 6 cordes* (Paris 1771, reprint: Minkoff, Genève, 1983), p. 5.

19. Michel Corrette: *Nouvelle Méthode pour apprendre à jouer en très peu de temps la Mandoline par Mr. Corrette* (Paris, 1772).

20. Op. cit. 17.

21. Francois de Lalande, *Voyage en Italie […] fait dans les annés 1765 & 1766, 2a edizione,* vol IX, (Desaint, Paris, 1786), pp. 514-9, Chapire XXII 'Du travail des Cordes à boyaux . . .' : '. . . on ne met que deux boyaux ensemble pour les petites cordes de mandolines, trois pour la premiere corde de violon . . .'.

22. Mimmo Peruffo: 'Italian violin strings in the eighteenth and nineteenth centuries: typologies,

manufacturing techniques and principles of stringing', *Recercare*, IX, (1997) pp. 155-203. See also Antoine Germain Labarraque: *L'art du boyaudier* (Imprimerie de Madame Huzard, Paris 1812), pp. 31-2.

23. Patrizio Barbieri: 'Giordano Riccati on the diameters of strings and pipers', *The Galpin Society Journal*, XXXVIII, 1985, pp. 20–34: 'Colle bilancette dell'oro pesai tre porzioni egualmente lunghe piedi 1 _ Veneziani delle tre corde del Violino, che si chiamano il tenore, il canto e il cantino. Tralasciai d'indagare il peso della corda più grave; perchè questa non è come l'altre di sola minugia, ma suole circondarsi con un sottil filo di rame.'.

24. Ephraim Segerman: 'Strings through the ages', *The Strad*, part 1, (January 1988), pp. 20–34, pp. 52–5, part 2 ('Highly strung'), March 1988, pp. 195-201, part 3; 'Deep tensions', (April 1988), pp. 295-9.

25 Cryseul, Géoffrion: *Moyen De Diviser Les Touches Des Instruments à Cordes, Le Plus Correctement Possible . . . On y Voit La Manière Dont Les Artistes Doivent Considérer Les Loix Qu'Impose Le Tempérment . . . Et L'on Imagine Un Moyen D'Accorder Les Clavessins* (Paris: Rodez, 1780).

26. http://harps.braybaroque.ie/Taskin_stringing3.htm. On this website you can find interesting comparisons between the Cryseul gauges scale and its relative mm gauges based on numeours scholars' opinions.

27. Don Juan Guerrero: *Methode pour Aprendre a Jouer de la Guitarre* (Paris 1760).

28. Patrizia Frisoli, 'The Museo Stradivariano in Cremona', *The Galpin Society Journal*, XXIV, (July 1971) p. 40.

29. Patrizio Barbieri, op. cit. 21.

30. De Lalande: op. cit. 19.

31. Philippe Savaresse: 'Cordes pour tous les instruments de musique', in Charles P.-L.aboulaye: *Dictionnaire des arts et manufactures*, vol. I, (3rd edn., Lacroix, Paris, 1865).

32. George Hart, *The violin and its music* (Dulau and Schott, London 1881), pp. 46-7. Michel Corrette, *Les Dons d'Apollon*, (Paris, 1763), p. 22, Capitolo XVI.

33. Attanasius Kircher, *Musurgia Universalis sive Ars Magna Consoni et Dissoni in X. Libros Digesta,* (Roma, 1650), Caput II, p. 476: '. . . ita hic Romae gravissimam tesdudinis chordam ex 9 intestinis consiciunt, secundam ex 8, & sic usque ad ultimam, & minimam, quae ex uon intestino constat.'.

34. Michel Corrette, *Les Dons d'Apollon*, ibid.

35. Sebastien de Brossard: [*Fragments d'une méthode de violon*], manuscript, *c.*1712, Paris, Bibliothèque Nationale, Rés. Vm8 c.i, f. 12ʳ, cited in Barbieri: 'Giordano Riccati', p. 34.

36. Jean-Benjamin de Laborde, *Essai sur la musique ancienne et moderne*, (Eugène Onfroy, Paris 1780), livre second, 'Des instruments', pp. 358-9: 'Violon [. . .] Ordinairement la troisième et la quatrième sont filées; quelque fois la troisième ne l'est pas' (Violon [. . .])

37. The thinnest Creyseul gauges scale is no. 12, equal to almost 0.15 mm.

38. James Grassimeau, *A musical Dictionary*, (London 1740). In this dictionary it is clearly written that with the current metallurgical technology only gold, silver, brass and iron wires can be made, including gauges between 1/100 inch: 0,50-0,25 mm. This book is a translation of the Sébastien de Brossard 1703 dictionary.

39. Marco Tiella, personal communication, the thinnest diameter found by him in some spinets were around gauge 0.15 mm

40. The clothes of those times could represent an unexplored field of study in metal wire technology: round section metal wires were widely used to make complex mediaeval and renaissance clothing decoration. From first examinations of round and flat wire sections it turned out that the thinnest gold gauges (the more malleable metal) of those times clothes were around 1/100 to 1/120 inch maximum. This means .12 mm after stretching an intact wire can reach easily .14-.15 mm gauge.

FoMRHI Comm. 2084   **John Downing**

From Monofilament Silk Lines to Acribelle Violin Strings.

"Strong silk-threads with the appearance of violin-strings are known in commerce by the name *tengusu*; English, *silkworm-gut*; French *fil de Florence.* In China they are made directly from the spinning glands of full grown silkworms, and have for the same time been used with us for surgical sewing thread, and also in large quantity for fishing-lines (see also *Caligula Japonica,* Butl.)" – Johannes Justus Rein, 1884 (Note 1)

Silkworm gut is a monofilament silk strand made by manually drawing out the contents of the silk sacs of mature silkworm caterpillars. Before synthetic plastic lines became generally available in the 1950's, silkworm gut strands were used by fishermen as transparent leaders to which their fish hooks are tied. Silkworm gut was first advertised for sale to anglers in 1722. (Note 5) Prepared silkworm gut was also used by the medical profession as surgical sutures. The primary source of a superior silkworm gut destined for rod and line fishing came from Murcia, one of the silk producing regions of Spain but other countries with an established sericulture industry such as Italy also marketed similar products that were, however, considered to be less satisfactory by the angling fraternity.

Spanish Silkworm Gut
A detailed account of the preparation of Spanish silkworm gut is provided by A.M.C. Humphries (Note 2). He notes that the sac of a caterpillar (Bombyx Mori) can only be drawn to a certain length by the operator dependent upon the judgement of the operator who otherwise has no control over the size and length of the silkworm gut. The drawn gut is sorted into lengths ranging from 7 to 18.5 inches and 9 diameters ranging from 0.009 inch (0.23 mm) to 0.02 inch (0.51 mm). Each gut length tapers from centre to end so is subject to further processing if smaller diameter, perfectly uniform cylindrical gut lengths are required (as for surgical suture applications). This is achieved by passing the gut through holes in a metal draw plate to shave the gut down to the required diameter.
Silkworm gut, prepared the Spanish way for the angling market was, therefore, limited in length. Longer lengths required knotting together shorter lengths. Also the gut was brittle and required soaking in water to soften it before a knot could be tied. The softening procedure did not affect the tensile strength of the gut.
The result of attempting to tie a knot in a sample of dry Spanish silkworm gut (of unknown vintage) can be seen in Fig.1 – the gut cracked when bent and then split longitudinally.

Chinese Silkworm Gut
Chinese silkworm gut was made from the caterpillars of a species of giant wild Saturniidae moth such as *Caligula Japonica,* native to regions of China and Japan and the Far East. Due to the commercial value of Spanish silkworm gut, the Chinese product attracted the attention of the Europeans as a possible lucrative market alternative. The following summary of late 19th C British Foreign Office correspondence provides more information about the gut and its preparation (Note 3).

- The caterpillars do not descend from the tree until they are ready to spin. They are then caught and broken and the silk-gut immediately extracted, steeped in vinegar, washed and drawn out. The operation must be executed without delay – if the worms are kept the gut is useless. Each gut if properly managed will draw out to 20 or 30 feet. The gut is then dried in a shady place then rolled up and considered ready for use. (Swinhoe report to Foreign Office, 1867)
- The silkworm gut drawn from the caterpillar is the sole use to which the creature is applied. For the purpose it is not reared but captured on its descending from the tree to spin its cocoon. The mature worms are steeped in vinegar for a day and then drawn out into gut which is used for fishing lines and for various economical and ornamental purposes. (British Consulate, Amoy, 1867)
- The cocoons of the caterpillar (they are not Bombyx Mori) are worked by the worm into the bark of the tree and are so coarse and thin as to yield silk of coarse texture and in small amount so is unlikely to be of interest to Western cultivators. In this district the Chinese use the worm only for the purpose of making silkworm gut. The true silkworm is only reared here in small non commercial quantities. (British Consul, Amoy, 1867)
- The silk was made from a species of caterpillar that thrives on the 'feng' tree (Liquidambar formosana, Hance) – prepared by throwing the mature caterpillar into boiling vinegar and drawing the silk glands apart to form a thread say, 5 feet long and strong enough to make a line with which to catch small fish. (Kiungechow, 1891)
- In Canton the silk is called 'fish silk' or 'fish head silk'. In Hoihow it is called 'insect silk'. The best silk comes from Hainan in the mountains of the Ling-mên neighbourhood. The male caterpillar produces a single thread of better quality than the double thread of the female. (Kiungechow 1892)
- The gut in China is in considerable demand for making fish lines and seems so strong and serviceable that there should be a commercial use for it in England. Charles Farlow and Co., Fishing Tackle manufacturers, London stated that the Chinese gut tested was very similar to the Spanish gut that was once avaialble years ago but perhaps not quite so brittle. In their judgement it could not be used for fishing purposes and otherwise did not know for what purpose it could be used. (letter to Kew, 1892)
- Exports to Europe from Kiungehow of Chinese silkworm gut for making leaders for fishing lines sometimes amounted to 16,800 pounds. (1892)

So it can be assumed from these reports that the Chinese silkworm gut differed from the Spanish gut in that it was drawn to much greater lengths, was less brittle and was derived from a larger moth of the giant Saturniiaed species. The Chinese silkworm gut was also called 'marvello hair'.

Japanese Silkworm Gut
'The moth species – originally from Hainan Island in Southern China – is the giant silkworm (Saturnia Pyretorum Westwood) also known as the Fish-line Silkworm. Indigenous to India, Vietnam and Southern China with a domesticated breeding history dating back as early as the 9th C. The species was introduced to Taiwan (then Formosa) during the Japanese occupation in the first half of the 20th C for commercial production of silk fishing lines for export. The farms were shut down in 1950 (as Nylon lines became generally available) after which the moths spread into the wilderness and are now naturalised' (Digital Taiwan – on line source)

Curiously the Japanese silkworm gut exported for sale internationally immediately post WW2 was not like the drawn monofilament Chinese (or Spanish) gut but was made from multifilament silk thread soaked in a binder to form a smooth and transparent line very similar in appearance to genuine monofilament silkworm gut. According to Humphries (Note 2) the binder was a boiling preparation of animal glue and extract of seaweed (Agar?). In the process the silk reduces to an almost semi-liquid state so that it becomes saturated with the boiling liquid. On drawing off the saturated line is very sticky so is quickly chemically hardened. The most satisfactory proportions of silk filament to glue are 85% to 15%. It is not known when the Japanese invented this type of string.

A sample of Japanese 'silkworm gut' was tested for viability as a lute string – first course, 60 cm vibrating string length pitch f' 350 Hz, 0.36 mm diameter. The string was flexible enough to tie into a knot when dry and sounded promising while being tuned up to pitch. However the string broke about a tone lower than full pitch – equivalent to a string tension of about 2.3 Kg. The break occurred between the tuning peg and nut – the region of highest tension when the string is being brought up to pitch. The breaking load was then separately determined on a test rig as 2.6 Kg equivalent to an Ultimate Tensile Stress (UTS) of about 0.24 Gpa .This value is lower than advertised on the string package (10 lb or 4.2 Kg). Assuming the manufacturer provided a reasonable safety factor for the breaking load (20%?) then the string under test failed at around 50% of the specified UTS. Silk filament is quickly degraded in strength by direct exposure to ultraviolet radiation (sunlight) so this may be the reason for the premature failure of the test string – being stored in a clear packet for around 60 years or so (Note 4). Had the string retained its original strength it likely would have performed satisfactorily as a lute treble string.

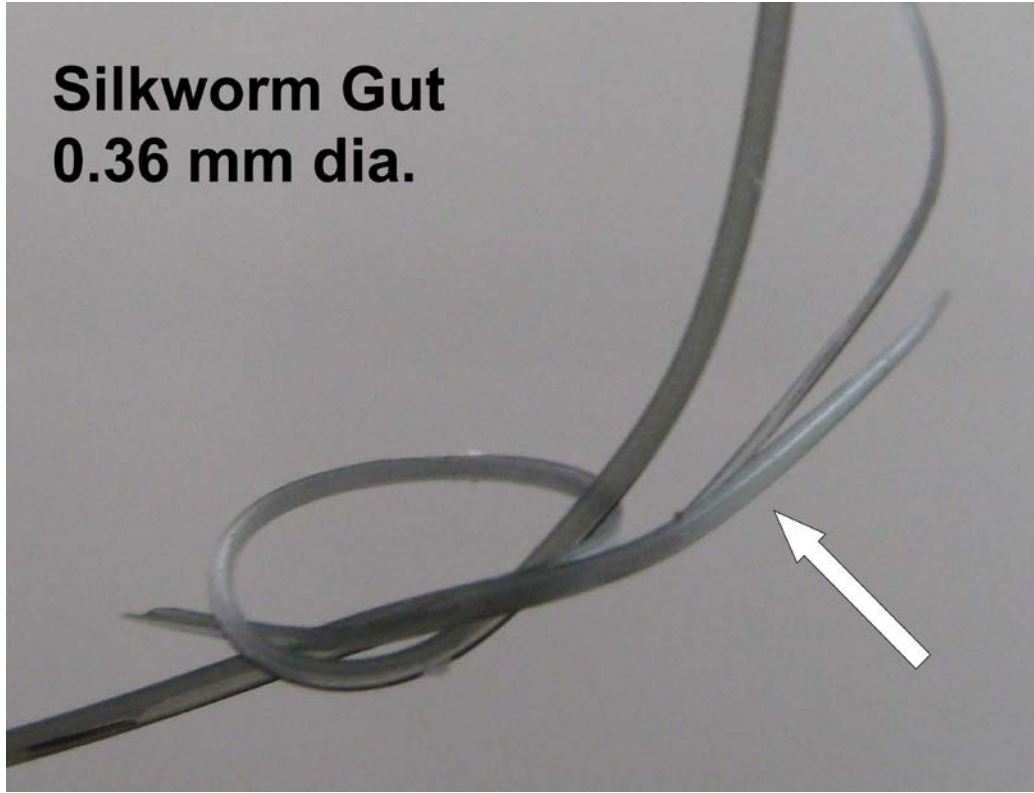The binder on this sample was soluble in boiling water.

Japanese Silk Gut
Fishing Leader - 0.63 mm dia.

Japanese Silk Gut Leader
Glue Binder Removed

Fig 1 – Spanish Gut Brittle Failure

Acribelle Silk Violin Strings

Although considered by some to be inferior in tone and durability to gut strings made from animal intestines, Acribelle silk violin E and A strings enjoyed popularity in the West for more than three decades from the late 19th C until the 1920's. This type of string was manufactured from silk filament made homogeneous – like the Japanese 'silkworm gut' - with some kind of flexible binder. Advertised as 'Acribelle'- presumably a generic term for similar strings made by a number of different manaufacturers?

According to Franz Jahnel ' Die Guitarre und ihr Bau', 1963 these strings were manufactured in Vogtland and Schönbach, Bohemia using processes that dissolved the outer surfaces of the layers of silk filaments to obtain a smooth and shining lustre. However, other manufacturing procedures were also used to make smooth transparent strings of this type – unknown processes because they were never patented.

Notes
 1) 'The Industries of Japan: together with an account of its Agriculture', 1889 footnote 2, page 196. (free Google ebook). J.J. Rein was a German geographer, professor of geography at the Universities of Marburg (1876) and Bonn (1883

2)"The Story of Silk and Silkworm Gut", the post graduate medical journal, 1949. (free Google search)

3) As reported in the 'Bulletin or Miscellaneous Information' published by the Royal (Botanical) Gardens Kew, London, 1892, pages 222 to 227.

4) Both nylon and silk filament are subject to degradation on direct exposure to sun light. For example the severity of degradation for a nylon parachute canopy exposed to summer sun is a loss in breaking strength of 52% after 1 week, 71% after 2 weeks and 94% after 3 weeks. The strength loss for the older silk canopies is even greater. For this reason parachutes used by the armed forces are given a service life or limited to a certain number of jumps. The service life for silk canopies was 7 years. Tests on 15 year old silk canopies that were not exposed to sunlight showed that their strength had fallen to below 30% of the original specified value.

5) See Comms 1751 and 1795. Note a typo in the latter Comm ' The silk apparatus of the caterpillar consists of two 15 inch (38cm) long glands …' should read … two 1.5 (3.8 cm) long glands … Some caterpillar!

The specification of stringed instrument string configurations

During my research into bowed stringed instrument history I have developed a method of describing the number and configuration of the strings. This string configuration specification is in a compact human readable form, that may be readily understood and can be queried programmatically if stored in a database. Over the last three years I have used this specification to classify and analyse iconography. It has proven useful during discussions with makers when commissioning instruments, and with other players and researchers, particularly when discussing the vielle tunings of Jerome of Moravia.

Any specification of string configuration relies on the instrument being appropriately orientated to ensure consistency of meaning. A configuration is made up of one or more specifiers, and each specifier describes a string or set of strings. Specifiers are ordered to describe the strings from left to right when viewing the front of the instrument with the neck vertically upwards and the bridge/saddle towards the floor.

Specifier	Meaning
n	Multiple strings forming a course. n is the number of strings. All strings in the course are considered to be stopped **and sounded** together. Where a course consists of a single string "1s" should be used instead.
nb	A bourdon/drone; actively played but generally not stopped. n is the number of strings.
n*	Special case. Multiple strings forming a course. n is the number of strings. n must be > 1. All strings in the course are considered to be stopped together **but sounded** separately.
ns	Single string courses individually stopped. n is the number of single strings there are.
+	Separation between courses.
/nv	Sympathetic vibration strings. Not actively played. n is the number of strings.
nx	Multiple courses. This is a shorthand to reduce the size of the specification. It is particularly useful with instruments with significant numbers of courses such as lutes. This should only be used to replace more than 2 repetitions of a specifier.

The shortest, most compact description should be used with + notation preferred to x notation. For instance

    4s rather than 4x1s
    2+2 rather than 2x2
    3x2 rather than 2+2+2

The specification allows for grouping of sympathetic strings. To show that the twelve sympathetic strings are placed in two groups of six one would use the specifier /6v+6v.

Here are some example specifications along with suggestions of the typical instruments that the string configuration may be found on:

1s	A monochord such as early tromba marina, some early vielles.
3s	Rebec.
4s	Violin family with four strings, ukulele, tenor guitar.
5s	Vielle with 5 strings over the fingerboard, 5 string violin, early cello/bass violin, 5 string bass guitar.
6s	6 string guitar, viola da gamba.
7s	7 string guitar.
1b+4s	Vielle with a bourdon and 4 separate strings on the fingerboard.
2b+5s	Lira da braccio.
2b+11s	Lirone.
1b+2+2	Early vielle with a bourdon and 2 courses of each with a pair of strings.
2b+3+2b	Hurdy gurdy.
1s/24v	18th century tromba marina.
4s/4v	Hardanger fiddle.
1b+3s/12v	Nyckelharpa (modern chromatic)
6x2	12 string guitar.
7x2+1s	8 course Renaissance lute.
11x2+2s	13 course Baroque lute.
1b+3s/24v+6v+5v	Sarangi.
2*	Huqin

I hope this will be particularly useful for those involved with renaissance and medieval instruments where several string configurations may be found.

MUSICK

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