# Not Only Cones Make It… and Cylinders Almost.

*by F. A. Jaén*

In the time since Tim Olsen's article "Cylinders Don't Make It" [1] the main ideas there have been accepted, developed and, finally, simplified and distorted. Many, including myself, remembered it more like "Only Cones Make It." The first impression that something in my ideas was wrong was when I made a CAD model of a fretboard some time ago. I wanted it to have a constant curvature radius of 300 mm (around 12"). There are many customers that still want that, in spite of offering well-designed conical-shaped fingerboards. My first thought was to draw two circles, 12" diameter, one directly above the other, at the distance from nut to end. After that, I would trace two diverging straight lines connecting both circles and defining both the edges of the fretboard and the widths at its ends. The surface could then be generated by moving one of the edge lines towards the other, using the end circles as rail curves (what is known as a "Sweep" command in many CAD packages). I stared looking at the drawing. It looked good, but it was strange. The edges were straight as arrows – if there were strings above them, they would lie flat on the fingerboard. But that wasn't a cone, as both ends had the same curvature radius, 12". In spite of the identical circles at both ends, it clearly wasn't a cylindrical fretboard either, as the edges were not parallel, and all the lines contained in a cylinder must be parallel. Figure 1 shows, exaggerated, that same construction, so that everything is clearer:

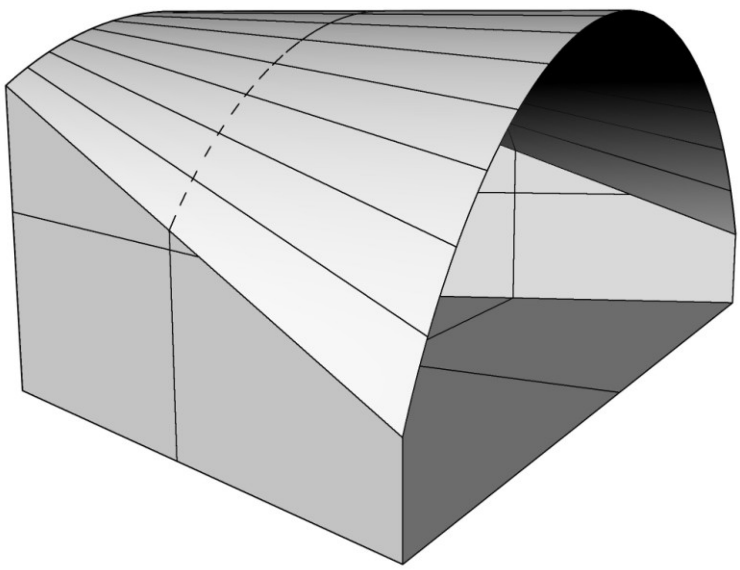

Figure 1

A true cylinder is a different thing:

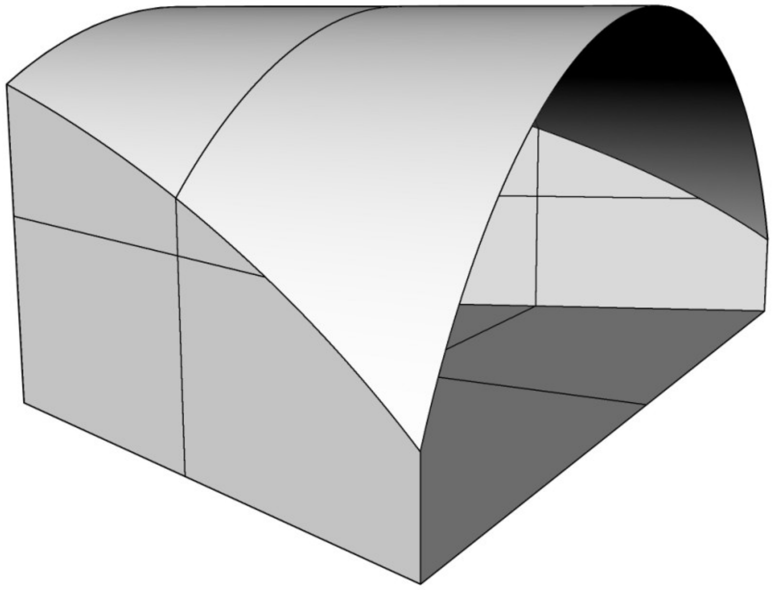

Figure 2

Notice that a real cylinder like this has a “hump” around the middle of its length, more noticeable the further we are from the center line, which is the only place where a string could lie flat. The edges of the fretboard show this hump in all its magnificence – compare it to the straight edges in Figure 1.

Clearly the surface in Figure 1 is not a cone or a cylinder or anything common; it is in fact what is known as a “complex surface”; in this case, I would like to call it a “complex cylinder.” As we saw above, building it with CAD tools is easy, as most packages have commands that work very well for this. However, you may want to build the surface having greater control, because many complex CAD commands perform algorithms that are not exactly what you expect them to be. In this case, think of this surface as generated by a “sliding ruler” that leans on both circles at the ends. The ruler moves at a constant speed, but faster on the wider end. The rate at which it moves faster is given by the ratio of the length of the wider arc to the length of the narrower arc. The method that I use for material (real) fretboards is equivalent, and easy as this: “leave the first and last fret untouched while filing along the string lies.” More on this later.

Clearly, this method produces fretboards whose end sections have the same radius and still the strings lie flat on them. This is a surprising result because, for some reason, most of us have come to think that only cones do it. Not R.M. Mottola, who contemplated the possibility of optimal complex surfaces, different from cones [2].

I had begun to doubt my intuition on this matter, so I decided to rethink every single concept. The ubiquitous cones were the logical next step. They are great if you want to be able to bend the strings in the upper frets with a very low action, not getting the usual buzz, but they are not necessary at all if you just want to play with the lowest action not bending notes. But, as Mr. Olsen stated in [1], string bends are part of the basic vocabulary of the electric guitar, and an instrument that cannot accommodate them is not fully functional.

This is my construction for an optimal cone:

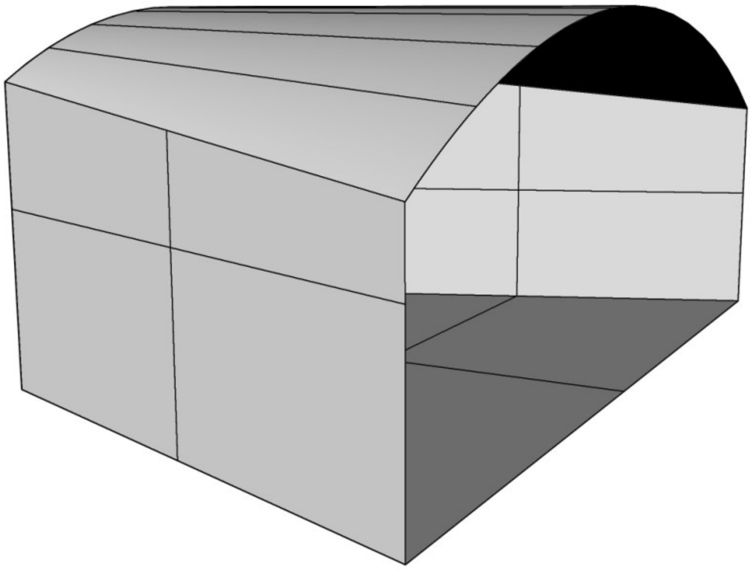

Figure 3

It is one among the infinite number of optimal cones. It shares the curvature radius at the nut with the other surfaces that we have seen until now; the curvature radius at the other end has been calculated so that the strings lie flat on it. Interestingly, we could have chosen to share the curvature radius at the other end, or perhaps midway between them. I am sure that this last possibility would have reduced the differences between both.

Apart from that, there is another indetermination. Most guitar makers read the curvature radius with a radius gauge, placing it perpendicular to the surface. Also, the planes defined by the curved frets are perpendicular to the surface.  These conventions do not work for right cones, only for the oblique ones that we have used for the surface in Figure 3, which was obtained as shown in Figure 4:

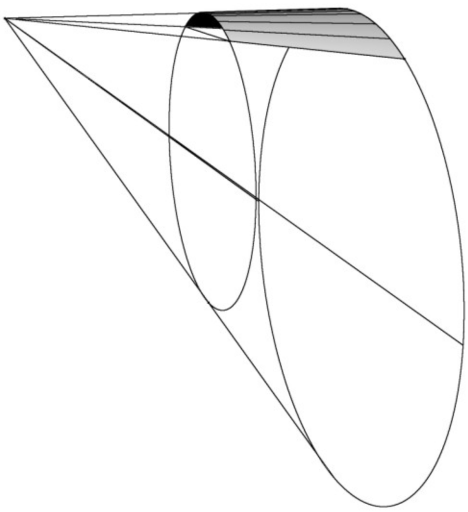

Figure 4

The sections that are seen as ellipses in the figure are in fact circles distorted by the perspective.

Oblique cones are not as commonly well understood as right cones; however, these are the surfaces that we should be thinking of when talking *conical fretboards* (aside from that, when designing conical fretboards within a CAD program, they are easier to handle). What I would like to emphasize here is that we could use a right cone and have another, different, optimal surface. Logically, from what have been said, it is not fair to compare a true cylinder (well determined geometry) with an optimal cone (two indeterminations).

Tim Earls gave the principles for designing optimal conical fretboards in his article *In Search of the Perfect Cone* (American Lutherie #30), but he also noticed that commercially available units didn't suit his theory, otherwise correct. By now you will understand that there are optimal surfaces that look like cones but that are not really conical, so it is not enough to measure the curvature radii at both ends of the fretboard. The principle is the same that we saw above for complex cylinders, and the resulting complex surface could be called a "complex cone." Complex cones don't need to have the usual shape of true cones, with a more curved nut end. Take a look at this "complex reverse cone", which has a larger curvature radius at the nut than at the other end:

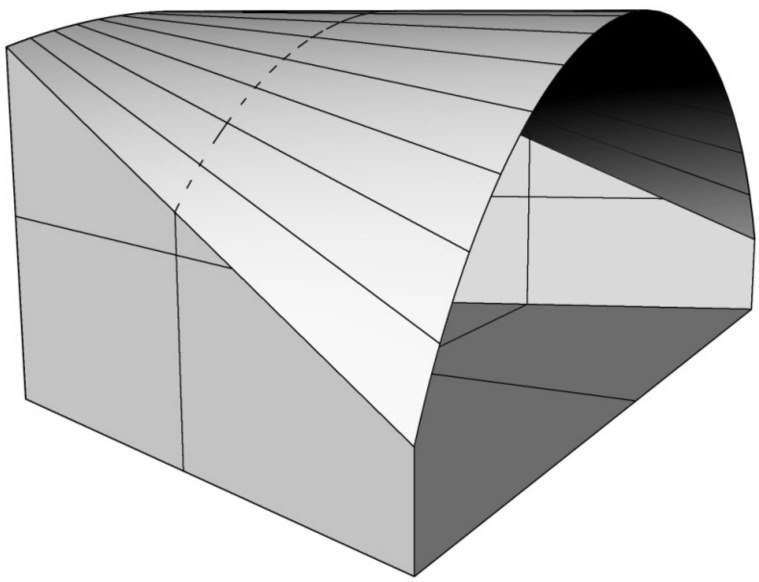

Figure 5

This surface is built using the same method explained for the complex cylinder. The only difference is the end curves. Still, the strings have the usual taper and will lie flat on its surface. Regarding string-bending capabilities, this design works better than the usual cone *when the strings are bent towards the edges of the fingerboard*. That is not the most common technique, but it makes me think that there might be some complex surfaces with useful properties waiting to be discovered.

This last construction explains perhaps the biggest anomaly in the table at the end of the aforementioned article by Mr. Mottola [2]. He was surprised to find a reverse conical section in a Gibson “that played just fine.” We have just seen that such a thing is feasible indeed.

The more I tried different things, the more I was convinced that almost anything would do it, even some unusual surfaces:

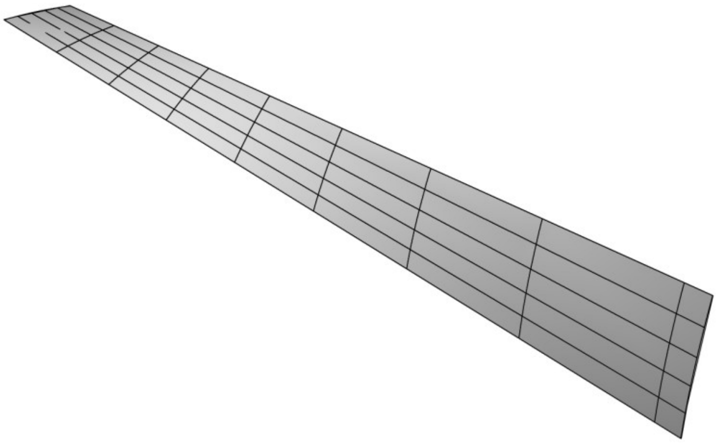

Figure 6

This is a twisted fretboard, built with a “Sweep2” command from the Rhinoceros 4.0 software. To check whether the surface was correct or not, I traced the strings and found their intersection with the surface. They were completely in it for all their length, so this is a feasible fretboard. In fact, that concept has been used. See Leo Burrell’s article, *At the Outer Limits of Solid geometry: The Twisted Neck Guitar* in American Lutherie #12.

Getting back to optimal cones, they have been used to call our attention on the imperfection of cylinders. We have seen that it is not obvious which cone we should use for the comparison but, anyway, that has been done once and again. This may be the main reason why we think of cylinders as undesirable creatures, but I will try to show you that in fact they make extremely good fretboards. I believe that true cylinders should be compared to complex cylinders instead, for two reasons: 1) because complex cylinders are already optimal and 2) because they are almost identical to true cylinders when the curvature radii at the ends are the same. I have put them together (combining Figures 1 and 2) in this drawing:

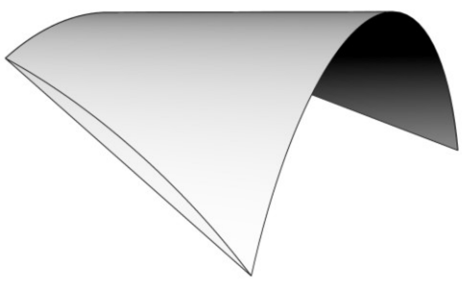

Figure 7

Notice that both surfaces differ the most, more or less, midway between the nut and the other end. I have detailed calculations that quantify this very precisely. They are available at www.guitarrasjaen.com/galArticle/complexRadius.htm, together with some utilities to check these surfaces and some examples. A cylindrical fretboard , 1.625” wide at the nut and 2.207” at the other end and curvature radius of 10”, has a maximum height above the optimal complex cylinder of 0.001”, independent of the scale length. These dimensions have been taken from [2], where they were used to show the difference between a true cylinder and an optimal cone, which was found to be .028”, 28 times bigger.

The conclusion is obvious: *true cylinders make great fretboard surfaces, so close to being optimal that it can be said that they already are*. Note that this does not take into account the fact that cones may be better for bending strings in the upper frets; a thorough study of this is not simple and would need more research.

Some may want to judge true cylinders using a different test procedure. Imagine setting a straight edge at the nut, following the path of the edge and being tangent to it, like this:

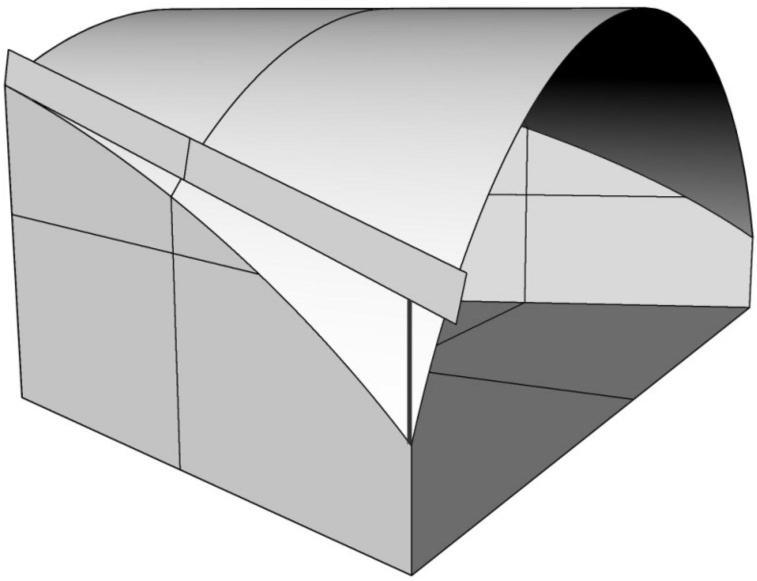

Figure 8

This can be justified because the string in fact would ideally follow the path of the straight edge. Notice that this will result in a much amplified difference (the thick line in Figure 8).

There are good reasons to rebut the validity of this procedure, but we won’t mention them because, in fact, the length of that line is still quite small. I have included a calculator for this in the web page mentioned above; applying it to the figures that we have been using in this article (1.625” wide at the nut, 2.207” at the other end and curvature radius of 10”) the result is 0.0043”, still well below construction tolerances and distortions.

I have checked my calculations many times and, even knowing that they are correct, the tiny figures that justify the main conclusion here, i.e., that true cylinders make great, almost perfect fretboards, still surprise me. If you have leveled the frets in many guitars you will know that you always have to file, whichever the fretboard profile. There are distortions in the wood of the neck and fretboard caused by changing humidity, the frets work like small wedges, they are not perfectly seated, etc.  But I believe there is also a psychological process causing a bias. Conical fretboards suffer the same distortions, but the guitar maker will remember that they are perfect, as it has been shown so many times. So, he thinks, it must be the neck that must be distorted. Cylinders, on the other side, have been repeatedly found to be so imperfect compared to cones that, under the same circumstances, he will put the blame on them.

Finally (not everything will be theory), I will explain how I make guitars with optimal complex cylindrical fretboards:

- Make a constant radius fretboard. These are also available from many suppliers.
- Glue the fretboard to the neck, hammer the frets in and glue the neck to the soundbox.
- Tighten the truss rod a little. This allows to correct some small degree of backbow (an odd possibility, though, but I usually do it because I still use one-way truss rods).
- File the frets, trying to leave untouched the first and the last. Follow the lies of the strings, checking the straightness with a thin ruler.

That's it. Since long ago, I have been following the last step of that procedure without thinking about all this in depth, so perhaps it is not new for you, either. Anyway, if you want to use a radiused sanding block for that step, creating a true cylinder, by all means do it: nobody will be able to tell the difference.

***References***

[1] Olsen, Tim.
*Cylinders Don't make It*
American Lutherie #8, 1986.

[2] Mottola, R.M.
*Optimizing Playing Surface Geometry*
American Lutherie #89, 2007.