How flutes are made

In the first article of a series, we see how flute bodies are produced

By Jim Phelan

I am writing this series of articles on flutemaking from the perspective of a non-fluteplaying flutemaker. I am, in fact, a horn player. However, I financed my degree at the New England Conservatory by repairing all brass and woodwind instruments, including flutes.

Why is this interesting or even important? Because I am a bit detached from the rest of the flutemaking community. I repaired many flutes, modern and historic, before being hired by the great Boston flutemakers Powell in 1976. It was Bickford Brannen who hired me (he was general manager there at the time, before he set up his own business). Fenwick Smith, a flute maker who was also a member of the Boston Symphony Orchestra, had recently introduced Albert Cooper's scale to Powell and Albert himself had made a visit. I padded Edward Almeida's flutes when they came into the shop. Dana Sheridan and John Lunn worked on either side of me. And, of course, Lillian Burkart, who became my wife, was a few rows away. They, except for the clarinet-playing Brannen, are all flute players. Yet, I would go home at night, put on my tux and go play the horn, leaving the flute world behind.

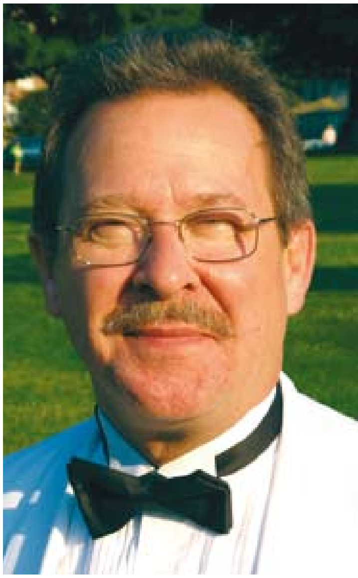
Being detached has allowed me to look at flutemaking through, I think, particularly clear lenses. I love this job, but it is a job. And in these articles I will try to convey the view of flutemaking that I have gained in these thirty-odd years.

I have asked to write four separate articles: on making the body, the keys, the headjoint, and on finishing or padding. I asked to do this for a very specific reason. That is, each job requires different skills and, in my way of thinking, different personalities.

Of course, there are individuals who possess the skills to build an entire flute themselves. I've built two flutes, start to finish, myself. Dana and Lillian have built many as has John Lunn. Yet, if you asked these people which jobs they prefer and which they do not, I daresay each would have their favourite. I, personally, prefer finishing or padding. Dana might prefer making headjoints or keys, though we need to get over a brew or two to sort that out. Without a doubt, Lillian prefers making headjoints.

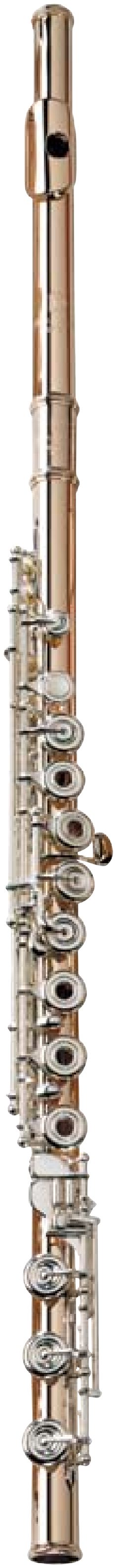
In the ensuing articles, I hope to convey a sense of what the jobs entail and why certain people are drawn to one or another. We'll start with making the body.

Jim Phelan started making flutes in 1976 for a venerable Boston firm. He published the first edition of *The Complete Guide to the Flute* in 1980. That book is now in its second edition and sixth printing. He left the flutemaking world in 1989 and spent six years working in high-tech and the medical instrument industry as a mechanical engineer. In 1996 he joined his wife, Lillian Burkart, to make the Burkart flute. Even so, they are still happily married.



Making flute bodies

There is a little parlour trick where one takes a flute headjoint, forms a paper tube around the end and makes a flute out of it. Doing so, one makes a flute which can be tuned with a pair of scissors. Then, one can produce one tone higher than the



other simply by snipping the paper tube shorter. It's brilliant! All the toneholes do is make the tube shorter!

So, let's take a look at what goes into making a flute body. Fundamentally, it is a tube. It could be a square tube, as is sometimes the case with organ pipes, but more commonly it is round. How about its diameter? If you have a US penny available and a collection of flutes, you will find that the penny fits snugly into each of the tubes. The US penny is meant to have a diameter of 3/4 of an inch, or 0.750". However, they end up being a hair (about 0.002") smaller. This is also exactly 19mm, the diameter Theobald Boehm decided on for his flutes and what the vast majority of flutemakers use today for flutes.

The next most important dimension is the tube's length. This is determined by what the lowest note we want is, let's say middle C on the piano. The wavelength for this note is related to its frequency, about 523 Hz., by the equation just below. Then, the physical length is just slightly shorter than that wavelength. If we do the mathematics, we find that the length we need, measured from the middle of the embouchure hole to the end of the tube, is about 0.65650mmm or about 25 3/4 inches. If you measure your flute, you will find that this agrees pretty closely with reality. So, the speed of sound, c, is related to the frequency of a particular note and its wavelength by the following equation. In a flute

$$\text{Wavelength} = \frac{c}{\text{frequency}}$$

With this, we can do two things. We can (1) determine the pitch of our flute by finding the distance from the embouchure hole (which we'll discuss in another article) and the A tonehole and (2) the distance from the embouchure hole to each of the other toneholes, completing our scale.

We mentioned above that the physical length is slightly shorter than the wavelength. You might wonder why. The reason is that the wave does not terminate abruptly at the tube end. It extends a bit past the end of the tube before being reflected back. This is referred to as the 'end correction'.

There are other features of the flute that can affect the wavelength relative to the flute's physical length. Hence, physicists often refer to the acoustical length of the tube to distinguish it from the physical length. An example might be 'adding toneholes contributes to the acoustical length of the flute'.

(By the way, the A tonehole is the one underneath the G key. Remember that the pitch is determined by the last *open* tonehole. Hence, when you are depressing the A key, it is the tonehole under the G key, the next open tonehole, that determines that pitch.)

If we wish our flute to be able to play more than a couple of notes, we have to have toneholes. Sometimes referred to as chimneys, these are the small sections of tubing either drawn from the tubing material or applied by soldering. Their position, the scale, is far too great a subject to be part of this discussion, but suffice to say, they are positioned carefully using many years of experience.

Drawn toneholes, as I mentioned, are extruded from the body material. Some flute players fear that this operation puts stress into the material surrounding the tonehole. This is not true. I have drawn toneholes, cut a cross-sectional (across the axis) sample, had it tested in a materials laboratory, and found that the material only becomes harder where the deformation takes place: in the tonehole wall. Even here, the difference in hardness is quite small. The greatest differences are at the point where the tonehole emerges from the body and at the top of the tonehole where it is rolled.

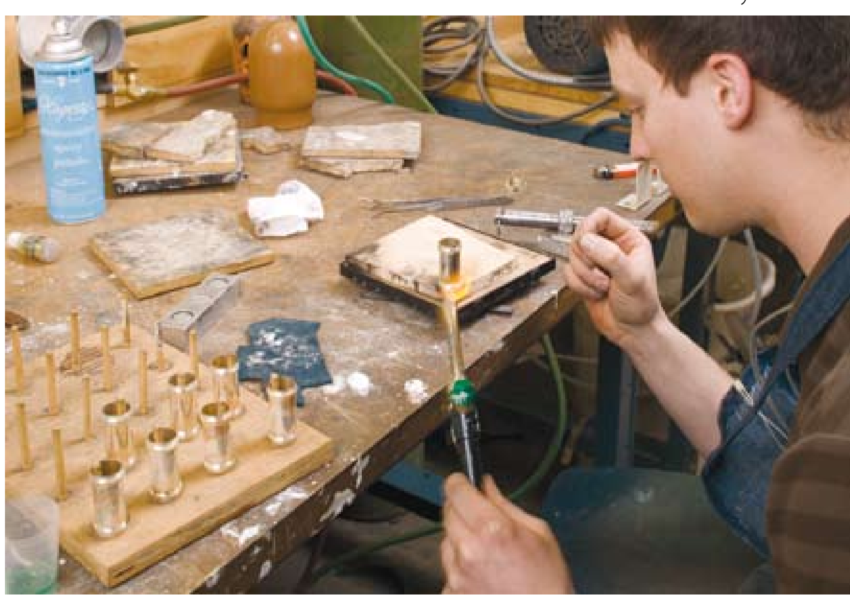
Preparing a tonehole for soldering onto a flute body.

Soldered toneholes are, as their name implies, soldered to the flute body. They are typically machined from thicker-walled tubing with a radius matching that of the tube's outside wall. This is trickier than it sounds. Creating a radius on the end of a tube requires a milling machine, something like a drill press but beefier. Cutting a tube perpendicular to its axis requires a lathe. So, flutemakers are often in the unenviable position of marrying some reluctant old lathe to a resigned milling machine, damning them forever to a life together making toneholes.

The solder used to attach the toneholes to the flute was, until the 1980s, always an alloy of tin and lead. Soft, easy to solder at low temperature, thus seemed to be an ideal material. However, this alloy, with time, becomes harder and more brittle, a phenomenon we will revisit. Over the life of a flute, it is assembled and disassembled many times.

This and the vibration from playing the flute was found to cause some of these solder joints to fail, leading to leakage. So, over the past twenty-five years or so, flutemakers have looked for soft-soldering alloys that do not age-harden. Unfortunately, all of these newer solders require higher soldering temperatures which approach or equal the annealing temperature of silver (the temperature at which the silver becomes softer). While the hardness of the tube has long been held to be an important characteristic of good flutes, conscientious flutemakers have had to find ways to put this hardness back in either through heat-treatment or mechanical means or both.

Soldering ferrules to a socket before soldering the socket to the flute body.



So, what are the differences between drawn and soldered toneholes besides their manufacturing methods? The most profound difference is in their respective wall thicknesses. The drawn tonehole is made from the wall of the tube. The drawing process thins the material by a factor of about a quarter. Hence, the tonehole of a flute with

Checking the alignment of the pillars.

0.4mm walls will have a wall thickness of about 0.3mm. That is why flutemakers roll over the top of the drawn tonehole, lending it additional thickness and strength.

Soldered toneholes are made from tubing with a wall thickness of approximately 1mm. This is more than three times thicker than the wall of a drawn tonehole. If one multiplies this by the sixteen or more toneholes on a typical flute, a significant amount of mass, hence weight, is added. Weight is another material characteristic that is considered important in a flute's performance characteristics.

There is one other important difference between drawn and soldered toneholes. That is in terms of repair. If a flute body with drawn toneholes is damaged, the tonehole is often beyond repair, must be removed and replaced with a soldered tonehole. This is not an easy job. In the case of a flute with soldered toneholes being damaged, the tonehole nearest the damage often pops off and can be soldered back on.

Our final discussion on flute bodies focuses on the ribs and posts (usually called straps and pillars in Britain). These are the components that support the key mechanism. As such, their most important contribution to a well-made flute is being geometrically orthogonal. That is, the ribs should be in line with the central axis of the flute body (or at right angles in the case of the thumb rib), the posts should be at right angles to the ribs, and the holes in the posts should be in line with each other and parallel with the central axis. As we step into the realm of key making, the facings on the posts, that is, the flat surfaces that mate with the key hinge tubing, should be flat and perpendicular to the hole axis running through the post.

The posts are silver-soldered (see sidebar) to the ribs for strength and the ribs are soft-soldered with the tin-lead alloy to the body to keep from further softening the tube.

Now that our flute body is assembled, it has to be made beautiful. This is done with polishing wheels and a variety of fine abrasives. The skill of the polisher is in removing the stain from the tin-lead solder and bringing the surface to a high polish while keeping the sharp edges sharp. Not a mean feat.

Now, all of this is assuming we are making a flute with a metal body. If we are making a wooden flute, most of what we have just said holds true, but there are some distinct differences acoustically and in technique.

Wooden flutes start as a billet of wood. Several species of wood are used but they all share a few characteristics. They are fine-grained hardwoods that do not make dusty chips like mahogany and, therefore, can have fine screw threads machined in them. They do not contain resins that cause allergic reactions and their sawdust is not poisonous. With the exception of boxwood, they largely come from the rosewood family. Without a doubt the most common wood used in musical instruments is Grenadilla, also known as African Blackwood. In Africa, it is known as Mpingo. Grenadilla is a fascinating tree, but I'll let the reader learn more about it independently of this article.

Before a billet of wood can be used to make a flute or piccolo, it must be at equilibrium moisture content, or EMC. This is the state at which the wood will gain or lose small amounts of water as ambient conditions change. In the case of Grenadilla, the EMC is about 7%. To accelerate this, the flutemaker usually bores a hole axially through the billet. That allows the inner fibres of the wood to release their water. That hole becomes the bore of the instrument.

Once EMC is achieved, the machining process can begin. The outside diameter is machined concentric with the bore. Rings are machined and pressed onto the ends of the body to increase strength and to reduce the chance of cracking.

The next step is the one that, in my opinion, marks the greatest difference between metal and wooden flutes. To make the toneholes, drills and specially-shaped cutters are used to form the toneholes in the wall of the wooden body. The important point to understand here is that the tonehole's height, an important parameter in the instrument's acoustic, is machined into the body. Hence, the wall thickness plays a very important role in how the flute will play; more so than in the case of a metal flute.

Rather than being soldered on, the ribs are screwed onto the wooden body. The design and manufacture of the screws and screw holes are critically important because it is here that the expansion and contraction of the wood, which are far greater than those of the metal, must be accounted for. Improperly done, over time the screws can loosen or, worse, provide sites for cracks to initiate. From here, the wooden body follows the same path as the metal.

Our flute body is finished and we are ready to begin making the keys.