Let's say we're working on ro. Adding to the halfway point in the bore will sharpen the pitch of ro. Removing will flatten it.

Below is the fine tuning section of my pdf: Ken

A pitch usually goes flat if material is removed at the 1/2 way point and sharpens if removed from under the hole or utaguchi. The differences are noticed more on *Jiari* flutes that are more pitch specific. Sometimes doing additions or removals on Jinashi flutes do very little to the pitch. If a pitch is more than 30 cents off on a *Jinashi* flute, it would be better to plug and move the finger hole.

Ro and ro kan octave tuning problems are often the result of 1/2 the bore length having too much or too little volume (space). If you slide a chopstick or two into the top half of the bore, ro kan should sharpen considerably. If it balances the two pitches, you can fill in the upper half or remove in the bottom half.

A few other options would be to spot fill at the 1/4 and 3/4 points in the bore or remove at the 1/2 point.

Opening from the choke point to the end of the flute will most likely sharpen both ro and ro kan. Also, you might want to doublecheck that you are blowing ro kan with enough power. It can be easy to play this note flat.

Some possible fixes for ro are looking at the choke point, opening up the bottom end, adjusting the top end opening, adjusting in the middle of the bore. However, it's always better to look at all the problems of the flute at once as well as the strong points, figure out all the possible fixes of multiple problems without messing up the strengths, then try to do things in the most efficient way.

If you still have a problem, note that a flat kan means that the area of the bore ~1/2 the distance between the last open tone hole and the top of the utaguchi is too large. In your case this would mean the point just slightly beyond the midpoint of the flute. Of course this also means that the area above must also be filled proportionately so that the taper of the bore is more or less even. Bamboo culms grow differently and have different proportions, and it is not always possible to have a purely jinashi flute in tune. Alternately, you can spend a huge amount of time opening up the whole bottom of the bore, but if the bore is too wide the tone and response of the flute will suffer, even if it is in tune.

Depending on where the additions are in the bore and the overall bore profile, there are often times when an action will influence pitch and not tone or even tone and not pitch. Or, maybe disproportionate amounts of each. Also, it's not always easy to exactly mimic the influence of a bead with ji. It's more of an approximation.

Perry and Toby make good points about temperature and overall bore profile. Using spot tuning to correct 30-40 cent octave differences can cause problems in other areas. That much difference usually suggests that half the bore is disproportionately larger or smaller than the other half. So, it's likely best to get the bore profile dimensions closer to an established average. That should take care of the major problems before starting on spot tuning.

The extra "compliance" (as the scientists say) added by the fingerholes is relatively minor, especially on the shakuhachi with its small holes (as compared to sax or flute, for instance). What effect it does have is manifested as a slight lowering of pitch when compared to an identical bore without such fingerholes, but the effect is global, and does not change between the octaves. There is a further effect called the "tonehole lattice effect", in which a series of open holes acts as a kind of high-pass filter. Smaller holes have a low cutoff frequency and so give a mellower tone, while larger holes have the opposite effect. I think this is what you are referring to.

The sounding frequency of any hole in the bore is determined by two quantities: the position and the size. As a rough guide, variations of 10% in the hole diameter, or 1% in distance to the acoustical top of the instrument cause variations in tuning of about 10 cents.

True octaves depend on having the paritals line up correctly, and this is a function of the bore profile, not the fingerholes. Because a certain amount of what is called "mode locking" exists, bore profiles can vary somewhat and still have at least some of the partials at the correct frequencies, but this can break down as you go higher, giving a lot of trouble (for us) in the dai-kan. And in fact up there moving or changing the postion and/or size of the fingerholes can have a large effect, but not so in the otsu or kan. Trouble with any note in the otsu or kan almost always can be traced to a bore problem at a displacement antinode of the fundamental of the problem note, or of one of its significant partials.

It should also be realized that there is no "ideal" bore, just as there is no ideal animal or ideal child. Each bore is a compromise, with strengths and weaknesses. For instance a thinner bore tends to make the high notes easier to sound and the response lively, but at the cost of thinness of tone and poorer response in the lows. A wide bore gives a strong low register, but the sound is often rather dull and lacking focus, with slower response and a difficult top end. I believe that what we wish to achieve is "balance".

One further note: I have been studying the acoustic effects of sharp fingerhole edges in the bore. These always lead to significant acoustic losses, especially with small holes such as on the shakuhachi, and especially at louder playing volumes. It is acoustically *very advantageous* to undercut all your fingerholes, or at the very least to round the inner edges. Rounding the edges on the outside is also highly recommended.

That all being said, you do have to get within certain limits in order to have a decent bore, and this is where the published bore profiles are extremely valuable. Those will at least get you in the right neighborhood, and from there it is the "art" that Perry speaks of that can create a truly outstanding, balanced instrument as opposed to a merely adequate one. But if you are outside that "sweet spot" no amount of fiddling is ever going to solve all the various problems of response and intonation that you will encounter.

There is a reason that dedicated shakuhachi makers study and apprentice themselves for years: it is to give them a solid foundation in the basics and a feel for and control of the effects of fine adjustments to those basics.

There are only two "mathematically correct" woodwind bores: a cylinder and a cone. Theoretically, only these pure shapes produce partials at perfect harmonic intervals. I'll come back to that in a minute...

Essentially what is happening is that a standing wave is set up between the utaguchi and the first open tone hole (although that is super-oversimplified). That determines the fundamental frequency. However along with that frequency, the air column vibrates in smaller segments, which (for musical purposes) should be exactly 1/2, 1/3, 1/4, 1/5...1/n the wavelength of the fundamental. These sound as contributing pitches and add richness to the fundamental: 1/2 is the octave, 1/3 the twelfth, 1/4 the second octave, etc.

If the bore is not of the correct shape, you get something like 1/1(fundamental), 1/2.1, 1/3.2, 1/4.4...or perhaps 1/1.9, 1/2.8, 1/3.7--the ratios are incorrect and the partials inharmonic in respect to the fundamental.

This works OK in the otsu, where the fundamental predominates. Mistuned partials can even be desirable, giving a complex, "hollow" "woody" tone. Many jinashi flutes have this characteristic to some extent or another.

The problem begins in the kan. When you overblow to the kan, what you are doing is creating a condition where the fundamental is inhibited and the first partial (1/2: the octave) predominates. If the bore creates non-harmonic partials, your kan register will not be in tune with the otsu.

The dai-kan gets even nastier, as it uses a shorter air jet and faster airstream to inhibit the fundamental, first and second partials and so jumps to sounding the third partial (1/4: second octave). Since this partial is weaker than the lower partials, and harder to maintain in a bore optimized for a decent fundamental, it must be close to harmonic to sound at all. If it is not, and is missing in the otsu and kan, that is not a huge problem; its absence will only make the sound a bit less edgy, as the fundamental or first partial predominates. But if you blow so as to inhibit the fundamental and first and second partials and there is no decent third partial, you won't get the note in the dai-kan, no matter how good your embouchure.

There is also a thing called "mode-locking", in which partials that should sound slightly out-of-tune will be pulled into a harmonic relationship with other strong frequencies present. It's a bit like "snap to grid" in a graphics app: if its close, it will jump into place, but after a certain point it will not do so. So there is some "forgiveness" for a bore which normally would create inharmonic partials, but only up to a point.

Now, let's back up a minute. The bore of the shakuhachi is basically a reverse cone, which is certainly not a cylinder, so what gives with that? Essentially, this acts mathematically like a cylinder, however with a modified impedance curve which tends to increase pitch stability with blowing pressure. It stretches the partials somewhat, which helps to offset an acoustic phenomenon whereby blowing harder raises the pitch, making it possible to blow the lower notes harder and upper notes softer and stay in tune. Piccolos are made in two styles: cylindrical and reverse conical, with the former used in bands where volume is needed, and the latter used in orchestras where more control is desirable. Recorders and pre-Boehm simple system flutes also have reverse-conical bores.

So generally, as long as the reverse cone is constant (possibly with a widening at the end to bring the partials of the lowest notes into tune (let's not go into it)), it will act mathematically almost like a cylinder (and actually help compensate some defects of a cylinder under real-world playing conditions), but not if the angle of conicity changes in the main part of the bore. That will create inharmonic partials.

Of course there are small local changes to the cone angle in the bore of all reverse-conical (and conical and even cylindrical instruments), which makers have come up with after long empirical trial-and-error experimenting, and which are necessary to compensate for many factors in actual instruments, such as the extra compliances introduced by side holes, some characteristics of the way the air jet works (in flutes), etc.

There is another factor to consider, apart from generally incorrect bore profiles. There are two important points for any standing wave: 1) a pressure node, where the air molecules do not move, but alternately get compressed and rarefied, and 2) a displacement antinode, where the air molecules move back and forth, but where the pressure does not change. If you constrict the bore at a node, it raises the pitch, but if you constrict it at an antinode, it lowers the pitch. If you widen (instead of constrict) the bore at those points it has the opposite effect.

So perhaps you have a constriction at a certain point that is a node for note A in the kan, but an antinode for kan note B. What happens? Even if your otsu A and B notes are in tune because you have put the fingerholes in the right places, (and that point of perturbation does not lie in a critical point for those otsu notes), the kan note A will be sharp and the kan note B will be flat :-/

So you are dealing with a whole bunch of interactive factors: the overall bore profile, local variations in the bore, and the size and position of the fingerholes, any one of which changes tuning of a given note to some extent, but which affects the partials differently. The main point of the game is to correctly align all factors so that the flute has decent intonation in all three registers, and further has balanced response and timbre as well.

Shakuhachi makers, after a few hundred years of trial and error, have come up with some reasonable bores which behave decently and allow for instruments with adequate intonation and response across the compass of the instrument. There is some wiggle room due to mode locking and other factors--a bit of range in which we can adjust flutes: "fine tune" them, or create our own characteristic response or timbre. Generally, though, the bore profile remains pretty much the same, or the profile is altered across the range--keeping the general cone angle--without large local variations.

The intonation of jiari flutes depends in large part on the correct bore profile no matter what the hole position (at least in terms of correct intonation of the octaves and harmonics and response up higher, which is related), but the overall diameter has a great effect on the timbre. This can be adjusted while keeping the geometry correct for intonation (by enlarging or reducing the whole bore while keeping the same shape). In addition there is much that can be done in this direction in the upper part of the bore, which corresponds to the headjoint on a concert flute. A great deal of the global character of the sound originates there, and adjustments can be made to it (to some extent) which change the timbre without overly affecting the intonation, although response in the third octave especially can be tricky.

My sensei told me that the area from around 6-8 cm down from the top should be slightly widened before starting the contraction, and adjustments to this area can be quite critical to the tone and overall response

---

Fine tuning the bore is the main challenge in constructing a quality shakuhachi. It is a combination of mathematics, luck, educated guess, intuition, patience and perseverance.

This process is, essentially, adding and/or preferably removing space along various areas of the bore until all the tones play well. The actual space along the bore that will need to be removed or added will most likely be minute, but nonetheless, critical to the potential sound quality of the instrument.

Each note has corresponding 'critical points' along the bore which can be adjusted to affect tone and tuning. For the low octave notes, these points are found at the 1/2 point between the blowing edge and the open hole of the note being played (1/4 & 3/4 points for second octave), as well as directly under the open hole. If a particular note is not playing well or out of tune, it can be corrected by adding or removing space at one or more of these areas. To check if space needs to be added, fold up a small piece of wet newspaper (approximately 1 1/2" by 1/2") and apply it to the 1/2 point in the bore. Play the flute to check for tone improvement. (A long split bamboo stick with foam rubber tied to the end works well to slide the newspaper to the desired spots.) If it improves the note, the newspaper can be removed and the area can be built up with a dab of glue and sawdust, ji paste, or paste resin. If there is no improvement, try adding newspaper to the other critical points. Then try adding in different combinations, then at every centimeter along the bore. You can also experiment with smaller or larger pieces. If there is no improvement after exhausting all the possibilities, you will need to remove space at one or more of the critical points. Various tools will work to remove space. You can wrap a thin strip of coarse sandpaper around the end of a dowel or weld a 1/2" section of a bastard file to a metal rod. A dremel sanding drum bit on the end of a long rod also works well. If the tone improves after grinding one or more critical areas, stop and move on to the next note that needs improvement. If there is still no improvement or the tone sounds worse, the areas will need to be refilled. It is also possible that a combination of adding and removing will be needed. This is where experience helps. A good rule of thumb is to exhaust every possible simple solution before attempting the complicated combinations. Altering the critical points for one tone can also affect the other notes as well so it is important to work slowly to get a feel of what is happening to the flute on a whole.

It takes patience and experience to develop a mental map of the shakuhachi bore using this fine tuning method. It may be helpful to work a little every day or two to slowly get to know the peculiarities of each flute. Each is unique, requiring an approach which is beyond pure mechanics. The shakuhachi is much more than physics. Listen to the bamboo.
