

Constructing a PVC Flute

EQUIPMENT

- PVC pipe The instructions are for 3/4" diameter PVC 480 PSI or 200 PSI. The thickness of the PVC depends on the PSI rating.
- Corks or dowels that fits into the end of the PVC pipe (#9 corks for 3/4" ID pipe 480 PSI, 1/2" dowel for 1/2" ID pipe). Note 200 PSI PVC requires #10 corks or Diam II Wine Corks 23.5mm diameter which I picked up at a home brewing place)
- Rulers, in cm
- Tools: power hand-drills, drill bits, hacksaws, round and flat files, hammers, center punches, matt knives
- Dremel tools
- Mini vices
- Protective eyewear
- Tuners for measuring frequency
- Plumber's goop for sealing the ends. Or wood filler. Or glue-guns.
- Sandpaper
- Mirrors, antiseptic mouthwash
- Copy of Hopkin's book out to read.
- PVC cutters (we have one)

Note: two figures in this chapter are from Bart Hopkin's book "Musical Instrument design."

Materials: Every student should make their own flute.

Warnings: If you share your flute or borrow somebody else's **sanitize it first!** Use the disinfecting mouthwash or wash the flute in a bathroom sink before you blow into it!

Use protective eyewear when you are near operating drills. When you are drilling make sure that everybody watching the drill is also wearing protective eyewear.

INTRODUCTION

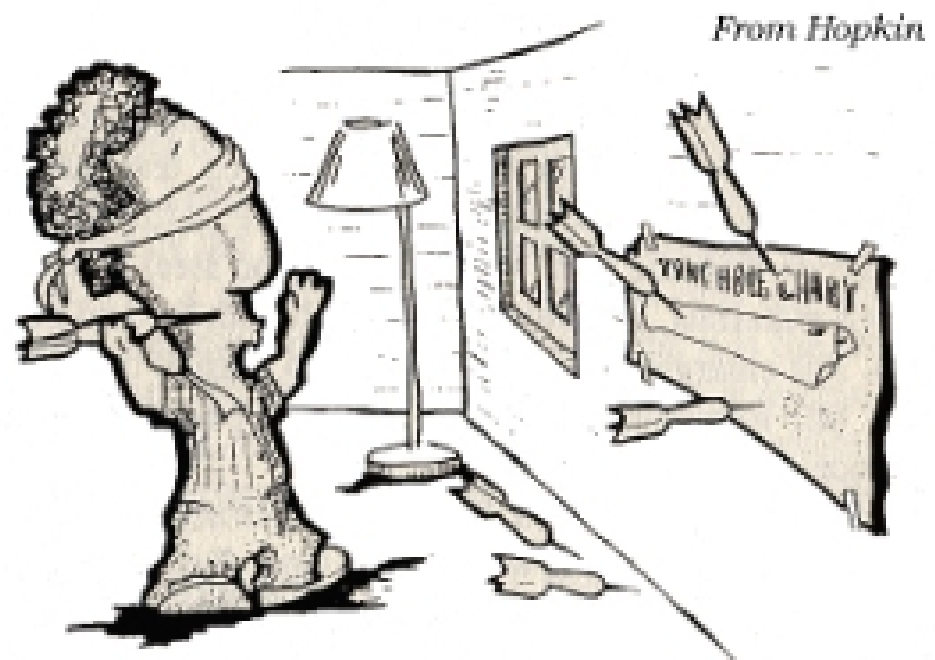
Here we will build our own PVC pipe flute. PVC looks nasty but I have found that the tone of the flute has a lovely soft bamboo like sound. It is possible to make a beautiful instrument with PVC. You can improve its appearance by sanding away the lettering and decorating it. The challenge is to make the flute playable, and in pitch.

A flute when blown can be considered a vibrating resonant column of air with two open ends. When constructing your flute, you will need to decide where to put finger holes. The following equation approximately describes a relation between length and frequency of the fundamental tone

$$f_1 L_1 = f_0 L_0 \quad (\text{Equation 1})$$

where f_0 and f_1 are frequencies corresponding to the fundamental tones for pipes of lengths L_0 and L_1 , respectively. Lengths are measured between the mouth-hole and the first open finger hole.

The above equation is consistent with



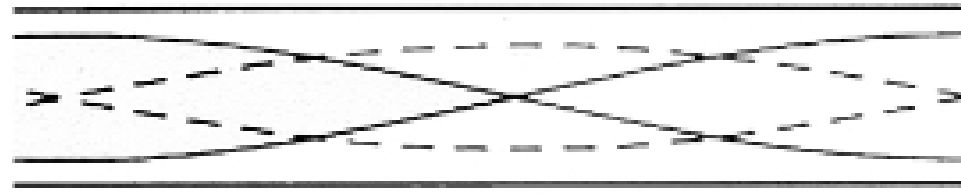
The Scientific Approach to Tonehole Placement.

It is difficult to predict the notes of a flute. Good flutes have been redesigned many times to achieve accuracy in pitches.

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$$f_0 = \frac{v}{2L_0} \quad \text{(Equation 2)}$$

predicted for the fundamental mode of a narrow pipe with two open ends where v is the speed of sound.



However a real flute is not exactly a narrow cylindrical pipe with two open ends. Consequently Equations 1 and 2 are not accurate predictors of tones blown by the flute.

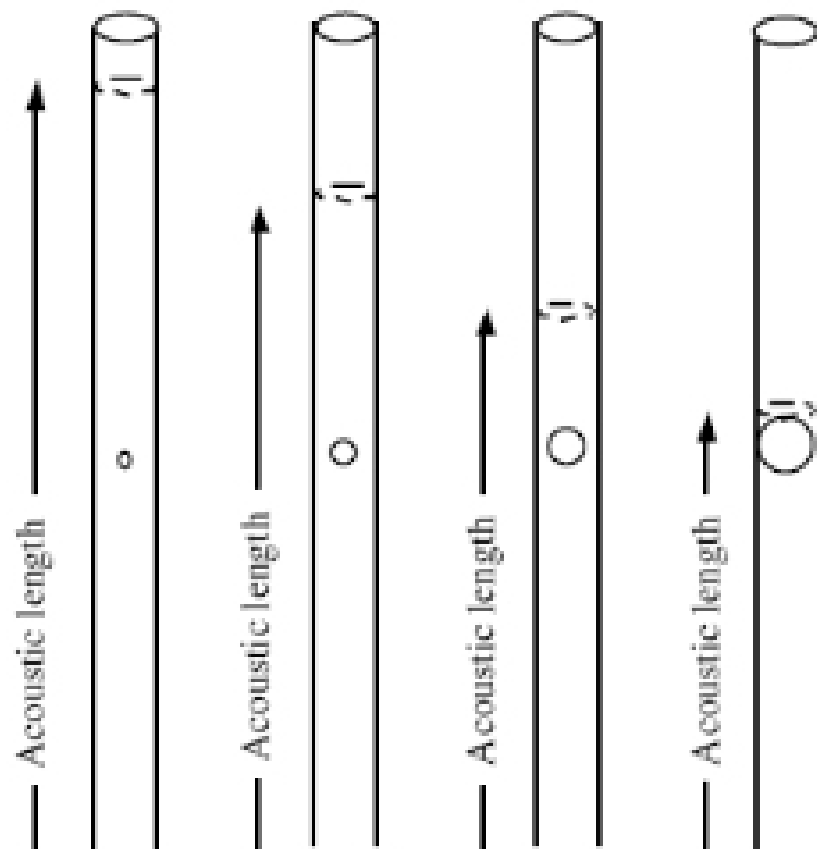
The end correction: An end of a cylindrical tube behaves as if it were slightly longer than its length. A better approximation to the actual fundamental frequencies of a tube with two open ends can be made with the following formula.

$$f_0 = \frac{v}{2L_e} \quad \text{(Equation 3)}$$

where v is the speed of sound. L_e is the "effective length of the tube. For each end the pipe is effectively about $0.6R$ longer where R is the radius or $0.3D$ longer where D is the diameter. For a pipe with two open ends,

$$L_e = L + 1.2 R \quad \text{(Equation 4)}$$

The above two equations (while an improvement from equation 2) still won't predict exactly the frequencies of a tube with multiple holes in it.



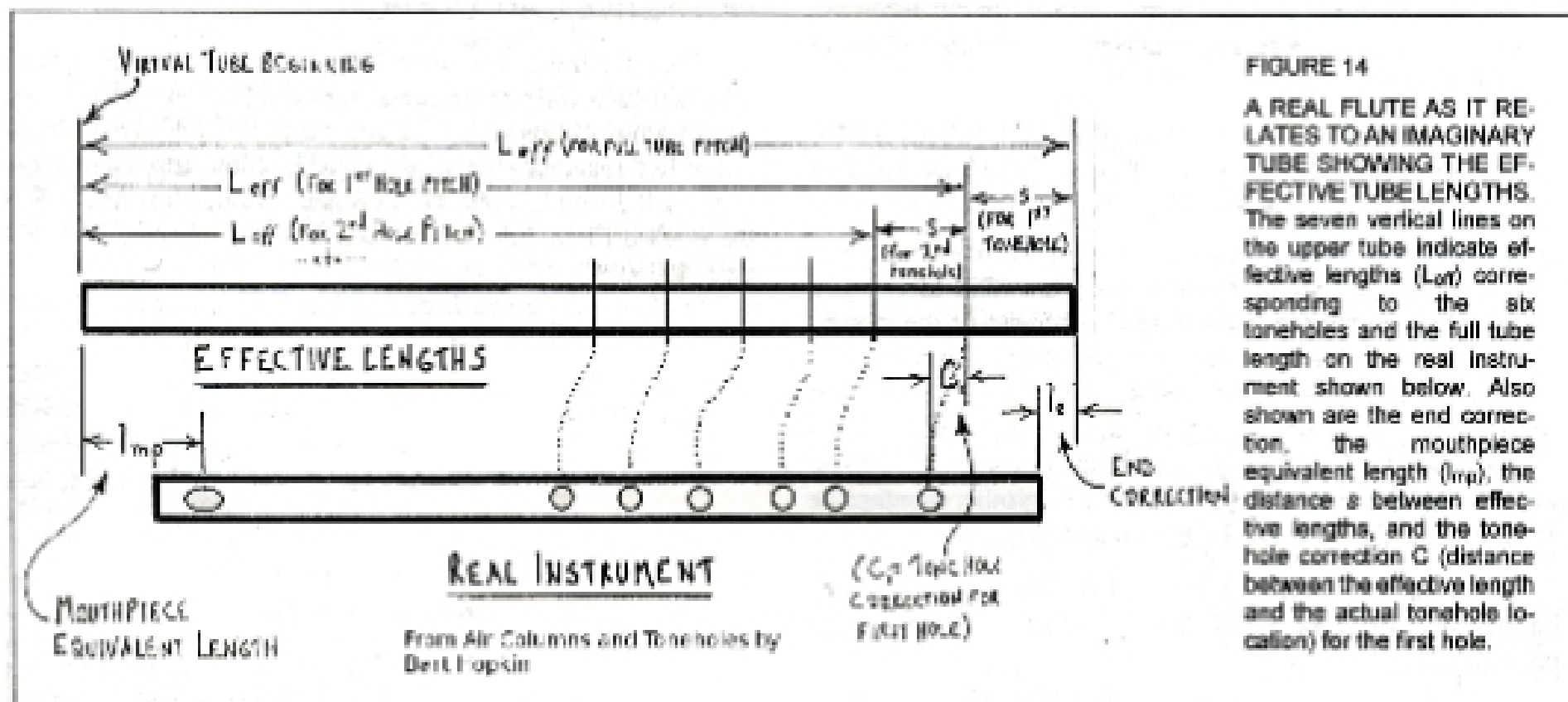
A hole drilled on the side of a pipe changes the effective acoustic length of the pipe. The larger the hole, the closer the acoustic length will be to the hole position. Figure from www.tufts.edu/as/wright_center/physics_2003_wkshp/book/

A number of things affect the sounding pitch of a note played on a flute.

- The closer to the mouth piece the first open hole is, the higher the pitch. See equation 1 or 2.
- The larger the first open hole, the higher the pitch. See the above figure.
- A larger hole in a thicker barrel is similar to a smaller hole in a thinner barrel. The depth of the hole affects the pitch.
- Additional open holes below the first open tonehole will raise the pitch. The smaller the first open tonehole is, the more it will be affected by the open holes below it.
- Closed holes above the first open tonehole can affect the pitch played, however they can either raise or lower the pitch.

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The flute can be modeled in terms of a virtual flute with effective lengths for the entire thing and corrections for the end, the mouth piece and each hole. This is explained in Bart Hopkin's book 'Air Columns and Toneholes' (that should be in the lab) and refers to J. W. Coltman's paper 'Acoustical Analysis of the Boehm Flute', J. Acoust. Soc., 1979, 65, 499-506 (but see the Figure below for the idea).



Pitch measurement: Pitches are commonly measured with respect to the frequencies of the tempered scale with a concert A of 440Hz. These frequencies are listed in the table below. Tuners usually give the nearest note on the tempered scale and the difference between this note and the one you played. This difference is given in cents. Cents are defined in the following way: There are 100 cents in each half tone, and twelve half tones in an octave. So there are 1200 cents in an octave. An octave corresponds to a frequency change of a factor of two. In other words a second note that is an octave above a first note has

twice the frequency of the first. Consequently 1 cent corresponds to a factor of $2^{\frac{1}{1200}}$. If you are sharp by

+21 cents you multiply the frequency of the nearest tempered scale note by $2^{\frac{+21}{1200}}$ to calculate the actual frequency of your note. If you are flat by 18 cents you would multiply the nearest tempered scale note by a

factor of $2^{\frac{-18}{1200}}$.

PURPOSE

The purpose of this lab is to explore how tone holes affect pitch in a flute. It is quite difficult to make a flute that is easy to play and that can play notes that are in tune. In this lab you may discover that the simple numerical estimates for pitch (that given by the above equations) are not exact. By creating this instrument we can perhaps gain respect and admiration for the design and redesign effort that goes into many musical instruments.

On making accurate and clean holes in PVC: It is good to start by drilling a small hole. You only want to drill through one side of the PVC tube. Don't push the drill in too deeply as you don't want to drill through the opposite side of the PVC tube! After you have made a small hole, you need to widen it. Widen it using a somewhat larger drill bit. When drilling larger holes it is best to **drill slowly into the PVC!** Slowly widen the hole progressively using larger and larger drill bits, never skipping more than a few sizes. The PVC will be less likely to jump or vibrate as you drill and your hole edge is less likely to become chipped when you drill slowly and enlarge the hole drill size by drill size. Afterwards de-burr the edges of the hole with a matt knife or sand paper or Dremel tool.

Everyone should make his or her own flute! PVC is cheap. If you don't like your flute, throw it out and try again!