

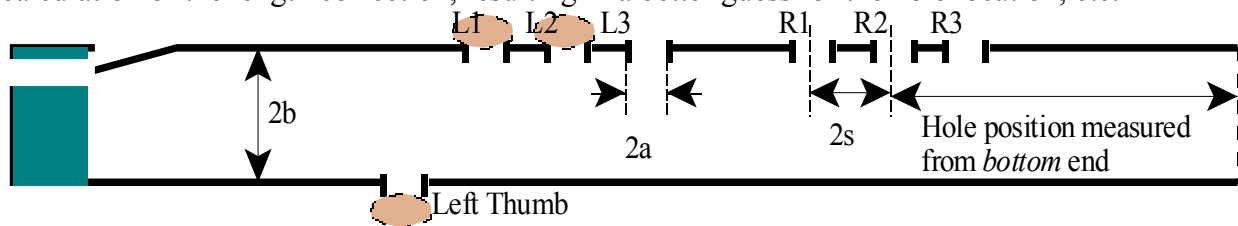
Lab 6M - Flute Design Worksheet

Goals: To find useable finger hole locations for a flute; to learn more about the length corrections for tone holes.	
Relevance: the roles of length and aperture size on resonance frequencies; designing by balancing constraints	
<i>Music</i> - wind instrument resonance frequencies	<i>Communication</i> - vocal tract resonance frequencies
Materials Needed: FLUTE.XLS spreadsheet, computer and spreadsheet program	

A wind instrument plays different notes by effectively changing the length of its *air column*. A trombone has a slide that directly lengthens its tube; other brass instruments have valves that connect to extra tubing. A woodwind instrument usually has *tone holes* that can be covered by fingers to progressively lengthen or shorten the tube.

To begin an instrument design, one first must decide what notes need to be played. To each note there is a frequency (the 1st harmonic), and there is an ideal tube length that corresponds to this frequency. The hole in the side of the tube is meant to shorten the tube to this new length. However, a hole is not as effective at shortening the tube acoustically as if the tube is chopped off cleanly, and a small hole is even less effective. Therefore, the hole needs to be placed further *up* the tube [we'll use *up* to mean closer to the mouth, making a shorter tube, and *down* to mean further away, a longer tube] relative to the ideal tube length. This distance is called the *length correction* for the hole.

The hole of importance is always the first hole (counting from the top end) that is open. The major factors that affect the length correction include the size of the hole, the size of the tube bore, the height of the hole's *chimney* (the very short length of the hole, if viewed as a short tube), the distance to the next opening in the tube, and that opening's size. After including as much information as possible about these, the length correction can be estimated by calculation, and then this correction is *subtracted* from the ideal length to arrive at a good guess for the best location of the hole. This guess gives us better information that we can use to improve the calculation of the length correction, resulting in a better guess for the hole location, etc.



1. The spreadsheet **P:\Physics\phoekje\phy101\supplies\flute.xls** has been set up to automatically calculate the length corrections for woodwind tone holes. Open Excel, choose File|Open and find this file, and then choose File|SaveAs to save it in an appropriate folder on your H: drive. In general, the information that you provide or need to review is shown in **boldface**. You will find that a scale of note names and their corresponding frequencies have already been entered in the cells A8..A15 and B8..B15. The bore diameter (*2a*) of a standard plastic plumbing pipe (called CPVC pipe in 3/4" Copper Tubing Size) has been entered for each hole in C8..C15. Actually, note that row 15 is actually for the open bottom end of the pipe. **All dimensions are given in centimeters (cm).**

	A	B	C	D
8		Desired Playing Frequency	Bore Diameter	Hole Diameter
9	Desired Note Names	f (Hz)	2a (cm)	2b (cm)
10	F5 - But really want 0XX XXXX	697.70	1.78	0.32
11	E5	654.10	1.78	0.48
12	D5	586.10	1.78	0.48
13	C5 - Only one hand left to go	523.30	1.78	0.48
14	Bb4	465.20	1.78	0.48
15	A4	436.10	1.78	0.64
16	G4 - One hole open	390.70	1.78	0.48
17	F4 - All holes closed	348.90	1.78	

You may choose to use the notes and frequencies given, or design your own scale. In this class we'll all use the same tube size, but if you want to reuse this outside of class, you are free to use any tube size you want, and you can change column C.

2. A first guess for hole diameters (2b) has been entered in cells D8-D14. You should note that this is only a guess; in fact, it turns out that the hole

B	C	D	E	F	G	H	I	J	K
Desired Playing Frequency	Bore Diameter	Hole Diameter	Effective Chimney Height	Nominal Lengths	Hole Spacing	Local Cutoff Freq.	Open Hole Correction	Closed Hole Correction	New Hole Positions
f (Hz)	2a (cm)	2b (cm)	Te (cm)	L (cm)	2s (cm)	fc (Hz)	Co, Cs	Cc (cm)	L-Co-Cc
697.70	1.78	0.32	0.47	24.72	1.65	1127.62	4.11	0.00	20.61
654.10	1.78	0.48	0.59	26.37	3.06	1106.73	3.66	0.01	22.70
586.10	1.78	0.48	0.58	29.43	3.53	1024.12	3.88	0.01	25.54

sizes are all **too small**, for a reason we'll discover eventually. Cells E8-E14 calculate the effective acoustical length (Te) of the hole, which is longer than its physical height. **In F8-F15 are the ideal tube lengths (L)**, based on the desired frequencies and the speed of sound. From this is calculated the spacing ($2s$) between holes, which we need for the length correction calculation, and eventually, in I8-I15, are calculated the open hole length corrections. Clearly these are significant, being a few centimeters (a couple inches). There are also some minor corrections in column L due to the holes closed above the current hole, and finally a new estimate of the hole positions is calculated in K8-K15.

Because the new hole positions have different separations $2s$ than the ideal lengths, we need to repeat (*iterate*) this process a few times until things stop changing. You'll find these iterations further down the spreadsheet, and the hole position results from the last iteration are copied to B19-B26. Actually, these numbers have been translated to measure from the bottom end of the instrument, for definiteness.

19	RESULTS		
20	Desired note names	Distance from bottom end (cm)	
21	F5 - But really want 0XX XXXX	29.59	0.32
22	E5	26.15	0.48
23	D5	23.02	0.48
24	C5 - Only one hand left to go	20.20	0.48
25	Bb4	15.53	0.48
26	A4	12.25	0.64
27	G4 - One hole open	9.01	0.48
28	F4 - All holes closed	0.00	

3. Use a ruler to lay out the hole positions on a piece of paper, and see how they feel to your fingers. Try changing the hole size for A4 (cell D13) to be the same as the others (0.48 cm). Notice that the spreadsheet can't find a position for the Bb4 hole (cell B23) that can make this work! Restore the hole size for A4, and now make the hole for G4 bigger (0.64).

- Q1. When a hole is enlarged, in which direction should it be moved? Explain?
- Q2. When a hole is enlarged, does it affect the best position for the hole above it? How?
- Q3. Explain in your own words what you think is happening physically in Q2.
- Q4. When a hole is enlarged, does it affect the best position of the hole below it? Why?

Adjust the hole sizes in column D until you have a finger layout that you like. You are advised to make the holes a little larger than they are now. Keep to hole sizes that correspond to fractions of an inch, so we can use standard drills (0.32 cm = 1/8", 0.48 cm = 3/16", 0.64 cm = 1/4", 0.80 cm = 5/16", 0.96 cm = 3/8"). Avoid using holes that are too big. Try to get a relatively even spacing of the holes for each hand. Meanwhile, watch the numbers for the *cutoff frequency* in column H; they should be relatively uniform, and should be about twice the frequency in cells B8 and B9.

Q5. Print out a copy of your spreadsheet, using File|Print. BRING THIS WITH YOU TO LAB NEXT WEEK!