SCI220 – Foundations of Musical Acoustics
Cogswell Polytechnical College
Fall 2008

Week 14 – Class Notes

Woodwinds (HSH[1])

Reeds and Mouthpieces

There are two classes of reed systems: single reeds (clarinets, saxophones) and double reeds (oboes, bassoons, and bagpipes).

For a single reed instrument, blowing with proper lip tension bends the reed slightly toward the flat upper surface of the mouthpiece in such a way as to partially close the mouthpiece aperture. The air rushing in through this aperture tends to close it still more, with only the peaks of the pressure fluctuations caused by the air vibrating in the bore push the reed open momentarily in each cycle. In order to have sustained oscillations, the frequency of vibration when the reed is blown without a bore must be higher than that of the note desired from the assembled instrument.

Just as in brass instruments, the vibrational recipe or shape of the puffs of air entering the bore given by the opening and closing of the reed against the mouthpiece determine the tone of the instrument. The mouthpiece cavity too takes part in the tone of the instrument by affecting the higher vibrational mode frequencies. In double reed instruments, the vibrational shape of the two reeds as well as the volume found in the cavity in between the reeds determine, in a similar fashion as single reeds, the tone color, pitch, and loudness.

Woodwinds vs. Brasses

The first difference we can make from woodwinds and brass winds is the excitation mechanism. Brass winds use the player's lips as the reed-valve mechanism, while woodwinds rely on small slivers of cane shape in particular ways called reeds.

Secondly, the vibrating lips of a brass player strongly influence the behavior of the bore and as a result the ability to play “privileged” notes. For woodwinds, the bore has almost total domination over the action of the reed. Meaning that the frequencies close to those of the vibrational modes of the bore are the only ones that can be excited, and change between them is difficult by lip pressure alone. Thus, only the first two or three modes are usable and one has to rely on the side holes to be able to transition between them.

As a result, we can not make a woodwind instrument in the fashion of a brass (use of slides) because of 1) the bore shape (if conical) and 2) because they can not be built in tune, it would result impossible to play musical passages with large intervals.

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1 Horns, Strings, and Harmony. A.H.Benade. 1992. Dover Edition.

Finger Holes

In order to achieve different horn lengths, we must resort to drilling side holes to the side of the pipe. The frequency of vibration of the lowest mode increases as the bore is shortened, so by drilling a hole large enough will function as effectively shortening the bore by the length in which we have placed to hole. We can summarize be stating that the extent in which the pipe is thus effectively shortened depends on the relation of the area of the hole to the cross-sectional area of the bore at that point, and it depends as well on the thickness of the wall through which the hole is drilled.

However, a pipe with a side hole does not have the same set of vibrational mode frequencies as does its “equivalent” shortened pipe. The side hole creates a “new shape”, but as long as the hole is close to the pipe's open end or there are many open holes in between it and the open end, we can say that this system has a nearly similar shape as the undrilled bore.

Getting a Scale

For a straight and uniform cylindrical pipe attached at one end with a mouthpiece and a properly sized reed, the lowest mode is produced by blowing on the reed. If we proceed to drill a series of eighteen properly placed holes along the pipe, we can play a rising chromatic scale until we reach a note exactly a semitone lower than the pitch of the second vibrational mode of the whole pipe. We can continue along if we close all of the holes and overblow in order to achieve the second mode. Now we have a new set of pitches at a new octave.

Useful Bore Shapes

The Bessel horn family proves to be useful in the bore shape of woodwinds. However, only two member prove to be musically adequate: the cylindrical pipe, the simple cone. These familiar shapes are the only ones having frequencies with integer ratios.

While the real shape of a conical instrument is that of a truncated cone, the missing volume of the cone is made up by the inner volume of the mouthpiece. As such, the truncated cone and mouthpiece behaves like a ideal complete cone.

Cylindrical-bore instruments are not as sensitive to the size and shape of the mouthpiece cavity as the conical-bore ones.

More about the Side Holes

The unused tone holes in a bore affect the bore shape by creating a “lumpy” cavity that has different vibrational frequencies from those of a smooth bore. However, if the diameter of the closed holes are properly related in their spacing, it is possible to make the lumpy bore have the same vibrational frequencies as a smooth one. The side holes get progressively smaller as we go up the bore toward the reed in order to keep the bore and its holes behaving as a proper cone or cylinder.

The spacing of side holes as we go up the bore decreases by 6% for every semitone up in the scale. Also, the size and spacing of holes that are more than two or three away from the highest open hole do not appreciably affect the pitch of the played note.

Changing Registers

A flute, for example, behaves as a pipe open on both sides that has vibrational modes at integer ratios from the frequency of the lowest mode. The flute can shift modes easily by changing the velocity and angle of the blown air, as well as using the finger holes to help them in the change. In order to achieve a note at a higher register, the player can resort to using the different modes that have the same frequency as the desired note. For example, in achieving the F above the staff, it is possible to finger F and overblow the 4^{th} mode or finger Bb and overblow the 3^{rd} harmonic. In reality, the player does both at the same time. The fingers are set for the first possibility, while the highest open hole of the second is opened. In summary, finger the note of the same name in the low register, and open the fifth hole above the highest open hole of this fingering.

For other woodwinds like oboes, "speaker holes" are provided in order to shift modes easily.

What is the Bell for?

As opposed to brass winds which radiate all of the vibrations through the bell, woodwinds radiate through the side holes when some of them are open and only through the bell when all the side holes are closed.

Tone hole sound radiation effectiveness depend on the diameter and spacing of the side holes. Larger holes radiate sound more effectively that small diameter ones.

The lowest note on all woodwinds is played with no open holes on a normal instrument. The bell is put on the lower portion of the bore because it acts as a substitute for the missing holes. A bell can is an efficient radiator and prevents the projection of unwanted noise associated with an abruptly ended bore.

Vibration Recipes and Woodwind Tone Color

By now we know that conical bores have whole-number multiples of the playing frequency, while cylindrical bores have odd-numbered multiples of the fundamental frequency.

For an oboe, the low register recipe is characterized by stronger harmonics and a weaker fundamental. A saxophone has an irregular spectra with some weaker harmonics. Finally, the clarinet has weak contributions from even-numbered harmonics and stronger odd-numbered harmonics.