THE HORN: Stopped, Muted, and Open

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1. Why Another Article on Stopping?

Many articles and even books which discuss stopping of the horn have stressed the fact that a stopped note can be derived smoothly from above, by gradually closing the hand. While true, this has led many authors to what I believe to be an incorrect explanation of the effects. Examples are the book by John Backus (2) and the article (8) by B. Lee Roberts in the May 1976 Horn Call. The latter references the Schrodinger equation to awe the uninitiated, but it rests essentially on the one basic piece of evidence.

Other evidence appears in the article (1) by Dr. Aebi in the same issue of the Horn Call. His graphs of the actual standing waves clearly show what happens, if interpreted correctly. Dr. Aebi does mention the derivation from above, but correctly numbers the harmonics to show that this method changes the harmonic. Another piece of evidence is that a stopped note can also be derived smoothly from below, using a procedure described by Birchard Coar (5) The whole bell is covered by a pad at the rim (which doesn't change the pitch), then the pad is gradually moved in to the full stopped position. The farther in the pad is moved, the higher the pitch goes.

The smoothness of derivation, then, doesn't get us very far. It can be used to show that stopping lowers the pitch, or that it raises it. Clearly, though, the final form of the standing wave must be the same no matter which route one takes to get there. Any complete explanation must show how both derivations work, and how they lead to the same final result. The correct explanation, as I will show, is that stopping makes the horn function as a pipe closed at the bell end (also), and shortens it, as many authors have claimed.

I hope the reader will forgive one more article on stopping. The discussion is beginning to take on something of an angels-on-the-point-of-a-pin flavor. However, there is some danger that players will be misled into trying to use inappropriate fingerings for stopped notes, especially the higher ones, based on a misconception of the physics. Moreover, a correct explanation may conceivably help improve techniques of both open and stopped horn playing. I admit also that search for the correct explanation interests me in itself. Anyway, an issue of the Horn Call wouldn't be complete without at least one article on stopping. Let's keep at it until we get it right!

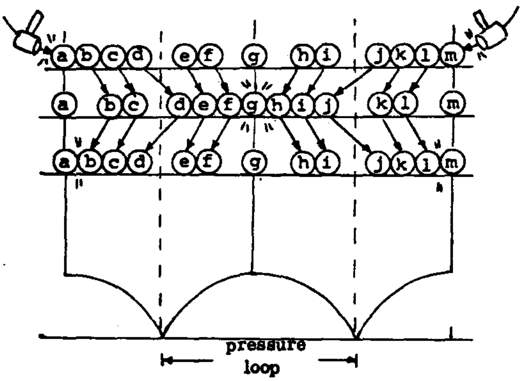
2. The Basic Physics

It seems best to start with a brief review of the basic physics of sound waves and standing waves. A sound wave travels through the air (or other medium) by longitudinal propagation. The crest is a region of compressed air, in which the molecules are moving chiefly in a certain direction. They bump into the molecules in front, stopping their own motion, but conveying the forward motion to the adjacent molecules. This is rather like a rear end collison. The compressed region moves forward, as the moving molecules are pushed into those further forward. The wave action is not a wind—only the wave moves, while the molecules move only back and forth. (The blowing of a horn serves only to make the lips vibrate; the blown stream of air moves much slower than the sound wave, and has nothing directly to do with it). As the compressed region moves forward, the momentum of the molecules creates a rarefied region behind it—the wave trough.

A standing wave, as in a pipe or horn, results from sound waves moving simultaneously in both directions. When two crests collide, they bounce off each other, each giving its energy to the other, so the wave motion goes further in each direction. This works much like the toy with balls hanging next to each other on threads. If one raises, say, two balls at each end, then lets them go simultaneously, each pair will hit the balls in the center and will knock back the two balls at the opposite end. In a standing wave, the crests of opposing waves always meet at the same points, called *nodes*. At a node, the displacement of the air molecules is zero, just as for the balls in the center of the toy, but the pressure change—called the *sound pressure*—is at a maximum. The air pressure is highest when the two crests meet; as they recede, it drops to a minimum as the two troughs meet. The energy in the two waves need not be the same, just as, in the toy, releasing two balls on one end and three on the other will drive out three and two balls, respectively, on opposite ends.

Between any two adjacent nodes, there is an *anti-node*. Here the crest of one wave always meets the trough of the wave going the other way. At an anti-node, the air pressure changes the least, but the displacement of the air molecules is greatest. They rush first in one direction, then the other (the total displacement is very small, however). The sound pressure at an anti-node, while at a minimum, is zero only if the opposing waves have equal energy. The area between two adjacent nodes is called a *pressure loop*.

The principles of a standing wave can be illustrated by balls rolling on a track. One full cycle looks like:



Nodes are shown by solid vertical lines, anti-nodes by dotted lines. The graph at the bottom shows the density (pressure) *change* at each point. At the start of the cycle, enough force is applied at each end to drive loose 3 balls—b, c, d, and j, k, l. Each group of three hits the next stationary group, driving three balls out the other end. For example, b, c, and d hit e and f, driving d, e, and f on and leaving b and c behind. When d, e, f and h, i, j hit g from opposite directions, each group transmits its energy to the other, driving it back again. This presumably rattles g's eyeteeth a bit, but it doesn't move. The other half of the cycle is just the same in reverse; when b, c, d and j, k, l hit a and m respectively, the cycle will repeat if a and m are anchored in place or if the outside force is again applied at each end.

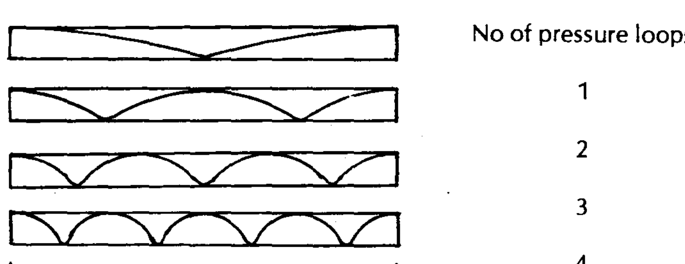
Observe that the balls at the nodes (a, g, and m) don't move. Those in the vicinity of the anti-nodes (d and j) move farther than any others. When the crests are meeting at a node, the two troughs are always just meeting at the adjacent nodes on both sides, and two crests again at the nodes adjacent to those (if there are that many nodes).

3. Open and Closed Pipes

Normally a standing wave arises when a wave is reflected back in some way. For example, in a pipe with closed ends, each wave crest bounces off the end, and is reflected back as a crest. If the wave length is just right for the length of the pipe, reflection occurs at both ends, setting up the standing wave, or in other words, causing the air column in the pipe to resonate. The reflection points are at nodes of the standing wave.

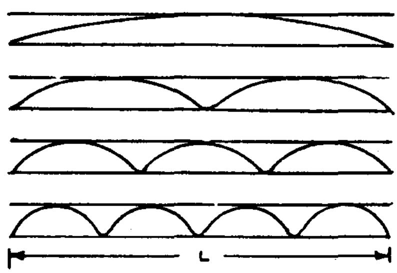
The open end of a pipe can also reflect back a wave, but differently. At this point, the pressure of a wave trough is normally below atmospheric pressure, so as the trough reaches the end, air molecules from outside are pushed by atmospheric pressure back into the rarefied region. A trough reflects back as a crest and vice versa. The pressure does not change, but air molecules rush rapidly in and out. The reflection occurs at an anti-node of the standing wave. A reflection from an open end has less energy than the outgoing wave. Energy not reflected back is radiated into the atmosphere, creating an audible sound wave. If the standing wave is to be maintained, the lost energy must be replaced by pulses at the proper times. In a brass instrument, the vibrating lips do this.

A standing wave can have multiple pressure loops, so that there is more than one mode of resonance in a pipe. The modes for a pipe closed at both ends are:

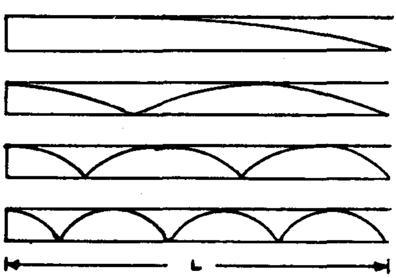


and so on. (As will be seen, it is not a coincidence that this resembles Dr. Aebi's Fig. 1 for muted or stopped horn). The pipe contains 1, 2, 3, 4, etc. pressure loops. Most readers are probably aware that this gives natural resonance frequencies, or harmonics, of 1, 2, 3, 4, etc. times the fundamental frequency. A little algebra pins it down: For a cylindrical pipe, the length of one pressure loop is the length of the pipe divided by the number of loops: p equals L/n. The wave length is twice the length of one pressure loop, because the crest must traverse the loop in both directions for a full cycle: W equals 2p, or substituting, W equals c/W, or again substituting and rewriting, f equals n (c/2L). Hence the harmonic frequencies for a cylindrical pipe closed at both ends are (c/2L), 2(c/2L), 3(c/2L), 4(c/2L), etc.

A pipe open at both ends has the same harmonics, but the pressure loops are offset by half a loop. The ends are at anti-nodes:



The resonance modes for a cylindrical pipe closed at one end and open at the other are:



$f = n(c/2L)$

$f_1 = \frac{1}{2}(c/2L) = c/4L$

$f_2 = 1\frac{1}{2}(c/2L) = 3c/4L$

$f_3 = 2\frac{1}{2}(c/2L) = 5c/4L$

$f_4 = 3\frac{1}{2}(c/2L) = 7c/4L$

and so. (Again, note that this looks rather like Dr. Aebi's Fig. 1 for open horn). Here the pipe contains ½, 1½, 2½, 3½, etc. pressure loops, giving harmonics which are 1, 3, 5, 7 times the fundamental. The algebra is shown above. Because this kind of pipe contains only half a pressure loop for the fundamental, its fundamental is an octave lower than that of a pipe of the same length closed at both ends or open at both ends.

4. More Complicated Reflections

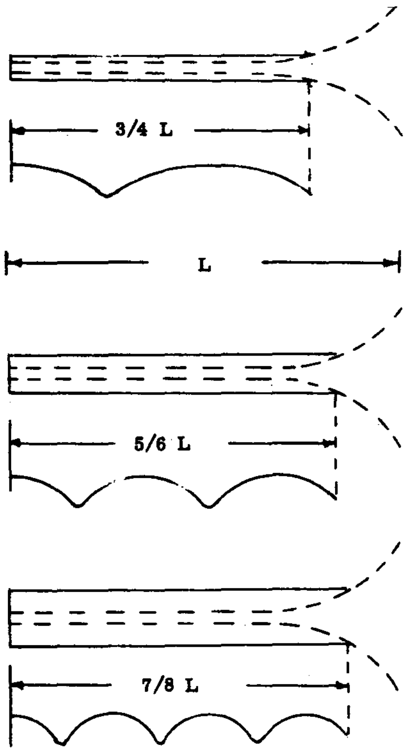
The horn is basically a pipe closed at the mouthpiece end by the player's lips and open at the other (if not muted or stopped). How then does it produce harmonics at multiples of approximately 2, 3, 4, etc. times the pedal tone frequency, rather than 3, 5, 7, etc.? The answer is the shape: for a tapered pipe, there are additional ways in which reflection can occur.

A wave crest is not a single thin sheet of compressed air. In a cylindrical pipe, the pressure gradually rises from trough to crest and drops off again until the next trough—the crest can be thought of as an entire region, half a wave length long, with pressure gradually mounting, then falling again within it.

Now consider a cone, complete to the point. As a wave crest approaches the point, its pressure must rise because of the decrease in the size of the pipe. As the forward part of the crest squeezes into the point, its pressure rises more rapidly than that of the crest peak, which is also being squeezed, but is always in a larger section of the pipe. By the time the peak of the crest is half a pressure loop away from the point, the pressure all the way forward to the point is the same. The crest therefore, bounces off itself, as it were, at what amounts to a closed end—closed by the pressure of the forward part of the crest. The point of effective closure is at different places for different frequencies. As it works out, the harmonic frequencies and the positions of the standing wave nodes are the same as those of a cylindrical pipe of the same length open at both ends. The point of the cone doesn't act like an open end, but it does in effect close the pipe off at different points for different frequencies.

For a pipe which flares rapidly enough at the open end, like a horn, a similar but inverted effect occurs as a crest approaches the open end. At an open end, a crest normally "runs interference" for the following trough. The atmospheric pressure outside cannot rush in to fill in the trough (creating a reflection) until the crest, which is at higher pressure, leaves the pipe. However, as a wave moves into the flare, the pressure drops as it expands to fill the extra space. If the flare is rapid enough, the pressure of the crest drops so much that it can no longer protect the following trough. The atmospheric pressure rushes in to fill the trough while the trough is still well inside the pipe, and the standing wave reflection starts back from that point. The rest of the pipe has no effect on that particular standing wave (although it does affect any overtones). Just as for the small end of a cone, the effective end of the pipe occurs at different points for different frequencies—farther in for lower ones. Essentially, the governing factor is the growth in the size of the pipe between the trough and the preceding crest. In a steadily flaring pipe, this growth is greater over a longer distance—that is, for longer wave lengths.

If the bell flares at the correct rate, the harmonic frequencies and the positions of the standing wave anti-nodes are very close to those of a cylinder of the same length closed at both ends. For the bell, though, the last node is missing; the last anti-node determines the effective end of the pipe. The amount of energy radiated into the atmosphere depends on the size of the radiating area, and so is less for lower frequency notes, because they radiate from well inside the horn. The effective end of the pipe for the 2nd, 3rd, 4th, etc. harmonics is approximately 3/4, 5/6, 7/8, etc. of the way down the horn. In other words, one could chop off approximately the last quarter of the horn and still play the 2nd harmonic at the same pitch! The horn behaves very much like a sequence of cylindrical pipes of different lengths and different bell areas for different frequencies:



$$f_2 = 1\tfrac{1}{2}\,\frac{c}{2\,(3/4\ L)} = 2c/2L$$

$$f_3 = 2\tfrac{1}{2}\,\frac{c}{2\,(5/6\ L)} = 3c/2L$$

$$f_4 = 3\tfrac{1}{2}\,\frac{c}{2\,(7/8\ L)} = 4c/2L$$

This is somewhat oversimplified. Rapid growth in the bore size in any part of the horn also increases the wave length and the speed of sound in that region. The effect is minor, however. The most important effect of the bell flare is that it gives close to the proper harmonic series, except for the fundamental. (The flare starts after the halfway point, so the fundamental is quite low, as others have noted. There exists a usable pedal tone at the desired frequency, because of the resonance of the overtones).

5. The Muted Horn

Muting the horn closes the end. There is some leakage around the mute (otherwise no sound would be heard), but the waves of all frequencies now travel all the way to the end of the mute, whence they are reflected back *at a node*. The open and muted horns produce the same frequencies, but in a different manner. This is no accident—the shape of the bell flare is designed to give the open horn the same harmonics as a pipe closed at both ends. Insertion of the mute simply adds on half a pressure loop in the region that was effectively cut off by the bell flare, changing the shape of the air column only at the very end. The harmonic number does not change—for a given harmonic number, a closed pipe always has half a pressure loop more than a pipe open at the end, as the earlier illustrations showed. Because the mute reduces the rate of expansion and the area of radiation, the wave crests can now successfully protect the following troughs all the way to the end even for the lower frequencies.

Most of this is clearly shown by Dr. Aebi's diagrams, except for the last anti-node reflection point for the open horn. The sound pressure continues to drop all the way to the end of the horn; the last part is apparently due to overtones. Note that whatever the differences in wave lengths inside the horn, the time between wave crests is the same at every point. Hence it doesn't matter that with a non-transposing mute, the radiation into the room occurs before the final reflection point. The wave crests are like punctual trolley cars; they come every so often whether one is at the end of the line or not.

This also explains why higher notes are more secure muted than open. The area of radiation is much smaller with the mute in, so more of the energy reflects back to reinforce the vibration of the lips.

Even with the horn open, proper placement of the hand makes higher notes more secure by reducing the radiation and increasing the reflection. This is not to say that the wave bounces off the hand when the horn is open, only that the area of radiation is reduced. Closing the hand more gives a darker and finally a muffled sound because it cuts down the radiation of higher frequency overtones. The lower ones are still radiated from well inside the horn, until the hand is closed quite far.

6. The Stopped Horn

This brings us finally back to hand stopping. The physics of the derivation from below should now be clear. A pad over the end of the bell has the same effect as a non-transposing mute: the horn is now closed at both ends, but the pitch doesn't change. As the pad is gradually moved in, the horn is shortened, raising the pitch.

The derivation from above is more complex because the harmonic changes. For a low note, partial closure of the hand reduces the area of radiation, making the horn more like a cylinder. The last (anti-node) reflection point moves out to the heel of the hand, lowering the pitch. Once the reflection point is at the heel of the hand, for any note, further closure increases the rate of expansion just at that point, slowing down the wave. That is, the wave takes longer to pass in and out because of the increase in acoustic mass. It can't go as far between pulses, so the last half of the last pressure loop gets shorter and the last node moves farther out, lengthening the inner pressure loops and lowering the pitch (the speed inside the horn doesn't change). Finally the last node moves so far out it reaches the hand. At that instant, the horn begins to behave like a closed pipe for that frequency and all higher ones—the reflection is now from the hand at a node, not the atmosphere at an anti-node. The relative harmonic of the stopped note changes, because the last half of the pressure loop has been pinched off. The n-1st harmonic of a closed pipe always has ½ pressure loop less than the nth harmonic of an open-ended pipe. Once this happens, the pitch goes down no farther; the node reflection point remains right at the hand, no matter how much farther it is closed. This is why the flattening stops at about ½ step above the next lower harmonic—a fact not explained by the pure lowering theory. One is in fact *playing* the next lower harmonic, a half-step higher because the hand shortens the horn.

The hand actually shortens the horn by only 5 or 6 inches, as compared with the non-transposing mute. The second valve for an F horn, though, adds more than 8 inches of pipe. The difference is apparently due to the fact that stopping cuts off more volume and therefore, more acoustic mass from the air column; the volume is more pertinent than the length.

This can all be checked by experiment, and the pinching off of half a pressure loop is very clearly shown by Dr. Aebi's diagrams. Apparently no one has noticed that the harmonics are brought into closed mode one by one, starting at the top—perhaps because for the middle and high notes, it happens while the hand is still somewhat open, before the sound takes on a real stopped quality. For instance, when starting with the 6^{th} harmonic (middle C, concert) there comes a point when the played frequency is still in a ratio of 6/5 with the next lower harmonic, but 5/6 with the next upper one! (It is harder to check harmonic ratios going upward, but it can be done by counting how many it takes to make a fifth, for example). The note is functioning as the 6^{th} harmonic with respect to the still open ones below, but as the 5^{th} harmonic in the closed series above. This explains why low notes are so hard to stop—the last node has to be pulled out one heck of a long way before it reaches the hand; to start with, even the last anti-node is well inside the horn. It takes a lot of closing to stop a low note.

This explanation also shows what would happen to the fundamental if it could be played and stopped—the pure lowering theory would seem to require that it be lowered to zero Hertz, or perhaps a half step above that (?!) In fact, both the first and second harmonics would end up at the same pitch—a half step higher than the pedal tone (a major seventh below the original second harmonic). The original fundamental has no pressure node to be pulled out, so the closure of the hand must create a new one. The second harmonic does have a pressure node which is pulled out as far as the hand. This should make it crystal clear that reaching the stopped mode from above changes the harmonic for all except the fundamental—the 1st and 2nd harmonics end up the same. I have tried this on a very short horn I have, closing it off at the very end, and the effect is as described—the first harmonic doesn't move (on this particular horn, the flare starts quite early, so the first harmonic is true), but the second is lowered an octave to join the first.

7. Some of the Math

Some of the above effects are described quantitatively by the so-called Webster horn equation, actually first derived in the 18^{th} century by Daniel Bernoulli, Euler, and Lagrange. I have explained as much as I could without using the equation, to make the effects clear to the non-mathematical reader, and to avoid traps of reasoning. Functions do not reflect waves—the atmosphere, hands, and mutes do. Moreover, the Webster equation does not describe the physics exactly [7], and the simplified form I will use here assumes an increasing radius throughout the horn. I will use the Schrodinger form as presented by Benade [3,4] ; a similar form was derived at least as early as 1945 by Salmon (7). The equation gives the wave length as a function of the horn profile:

$$\lambda = \frac{c}{\sqrt{f^2 - U \quad (c/2 \quad)^2}}$$

Where: λ is the wave length

c is the velocity of sound at that point (it varies somewhat throughout the horn)

f is the frequency

U is the so-called *horn function*, defined as

U = r''/r, Where

r is the radius of the tube at that point

r'' is the second derivative of r with respect to length; it is the acceleration in the change in size of r. Benade points out that r'' is approximately equal to 1/R, where R is the external radius of the bell flare at the given point.

As the value of U increases, the wave length becomes larger, and the speed of sound increases for a given frequency. If U becomes large enough relative to the frequency, the wave length becomes imaginary—that is, $c/\sqrt{-k}$.

Physically, this means that the wave becomes attenuated—that the standing wave cannot be maintained past the point where U gets larger than $(2\pi f/c)^2$. For the open horn, this is the chief effect of the bell flare; U does increase as the bell gets larger until just before the end (where the *rate* of change decreases). Thus a low frequency standing wave must end well before the end of the horn, as discussed earlier. Note that the cutoff occurs only if the bell actually flares; for a cone, U is zero throughout. For the cutoff point to vary with the frequency, the flare must be more rapid than exponential.

According to Pyle (7), the profile of a medium bore horn bell is quite closely described by the function:

$$r = 88.6894/(x + 5.8157)$$

where x is the distance in from the end of the bell (the bell opens to the left on the graph). All dimensions are in centimeters. With these particular constants and a bell length of 142 cm, the bell rim diameter is 30.5cm and the diameter at the start of the bell is 1.2 cm. Differentiation gives the horn function (r''/r) for this profile:

$$U = 2/(x + 5.8157)^2$$

(With this particular profile, U increases all the way to the bell rim. With an actual bell, it normally peaks just before the end. This affects only the highest frequencies, and only slightly). For each frequency, there is a value of x at which the denominator of the horn equation becomes imaginary. The total length of the horn minus this value is the effective length of the horn for that frequency. Assuming a speed of sound (c) of 34400 cm per second, and an actual horn length (L) of 374.7 cm (from Dr. Aebi's article), the horn equation and the horn function for this bell go together to give the effective length (EL) for each frequency (f):

$$EL = L - (c/\sqrt{2}\pi f - 5.8157)$$

$$= 374.7 - (7742.72/f - 5.8157)$$

Based on this, the following table gives the effective lengths for some of the harmonics of an F horn with this bell. The table also gives the amount effectively cut off by the flare of the bell, the effective muted horn length, and the effective frequency. The last two assume the horn behaves like a closed cylinder with the given effective length. The muted horn length is obtained by adding on half a pressure loop to the effective open length; that is, by multiplying the latter by 2n/ (2n-1), for the nth harmonic:

Harmonic	*Frequency*	*Amount Cut Off*	*Effective Open Horn Length*	*Effective Muted Horn Length*	*Effective Frequency*
1 (F)	44	142*	232.7	465.4	36.96
2 (F)	88	82.17	292.53	390.04	88.19
3 (C)	132	52.84	321.86	386.23	133.60
4 (F)	176	38.18	336.52	384.60	178.89
5 (A)	220	29.38	345.32	383.69	224.14
6 (C)	264	23.51	351.19	383.11	269.37
7 (E♭)	308	19.32	355.38	382.71	314.60
8 (F)	352	16.18	358.52	382.42	359.82
16 (F)	704	5.18	369.52	381.44	721.42

**Bell Length*

The table does not show the effects of the hand, the mouthpiece and lead pipe, and the small changes in wave length within the horn. These would all conspire to bring the effective frequencies to just what they should be. The bell alone brings them quite close.

Interestingly enough, if an "ideal" bell could be designed for the F horn, in terms of intonation, it would also be "ideal" in this sense for the B♭ horn (assuming all intonation correction is made by the bell flare). The following table shows the behavior of our same bell for the B♭ horn, assuming an actual horn length of 281 cm (¾ the F horn length):

Harmonic	Frequency	*Amount Cut Off*	*Effective Open Horn Length*	*Effective Muted Horn Length*	*Effective Frequency*
1 (B♭)	58⅔	126.16	154.84	309.68	55.54
2 (B♭)	117⅓	60.17	220.83	294.44	116.83
3 (F)	176	38.18	242.82	291.39	177.08
4 (B♭)	234⅔	27.18	253.82	290.08	237.18
5 (D)	293⅓	20.58	260.42	289.36	297.21
6 (F)	352	16.18	264.82	288.89	357.23
7 A♭)	410⅓	13.04	267.96	288.57	417.23
8 (B♭)	469⅓	10.68	270.32	288.34	477.21
12 (F)	704	5.18	275.82	287.81	717.13

For the B♭ horn, the bell comprises more than half the horn, and the fundamental is only about a half step flat. For the F horn, it was a minor third low.

As noted, the form of the horn equation given here is not necessarily pertinent for pipes which flare, then shrink again—for example, the muted or stopped horn. The horn function does have a very large negative peak at any point where the radius suddenly starts to become smaller (this fact was missed by Mr. Roberts). This would give a wave length of zero at such a point, using the horn equation. In any case, it is clear that the standing wave reflection comes back at a node from such a point. Immediate or full closure is not necessary; for example, the stopping mute creates an effective closed end just where it starts to decrease in size.

8. Summary

The surprising thing about the horn is not its behavior when muted or stopped, but the way it works when open. Most players believe it acts like a cone of the same length, giving it the proper harmonic series. In fact, it behaves quite differently. In a cone, the small end acts to create a sort of wall of air which reflects back the sound wave at a node of the standing wave. The air wall acts like a closed end, which is farther from the point for lower frequencies. A flaring bell, though, effectively brings the *open* end into the horn—farther in for lower frequencies. The full length of the horn is used only for *high* notes, not low ones!

With a properly designed bell, the harmonic frequencies and the positions of the anti-nodes are very close to those obtained by closing the bell at the rim. Such closure adds on half a pressure loop, and since for a given harmonic, a pipe closed at both ends always has half a loop more than a pipe open at one end, the harmonic doesn't change. The profile of the bell flare is crucial for in-tune harmonics—the series by no means springs with Pythagorean exactness from the simple length of the pipe, as it does for a cylinder or a cone.

Muting or stopping, then, makes the horn function as a pipe closed at both ends. The sound leaks out through the cracks, but this has no essential effect on the standing wave. Clearly a shorter closed pipe has higher resonance frequencies than a longer one, so stopping *does* raise the pitch as long as the harmonic remains the same. The further in the stopper is put, the higher is the pitch, as one would expect.

Smooth derivation of a stopped note from above is possible, but the physics of the process is not so simple. (Actually, for me it's not even simple to keep the derivation smooth, for the lower notes). What happens is that as the hand is partly closed, the wave crest must expand and contract more rapidly, so it can't go as far in a given time. The last node must move further out, to allow the reflection to get back in time—this in turn lengthens all the pressure loops inside the horn, lowering the pitch. (This much is apparently generally accepted). The last half of the last pressure loop gets shorter and shorter, until finally the node itself reaches the heel of the hand. At that point, the horn starts behaving like a pipe closed at the bell end, and the wave reflection is from the hand at a node. Dr. Aebi's diagrams show this clearly. The closed pipe has ¼ a pressure loop less than the open pipe did, but for the same harmonic it should have ¼ a pressure loop more. Therefore, the harmonic number is one less than it was, except for the fundamental. The smoothness of the change should not be surprising—as I pointed out in my letter to the Autumn 1973 Horn Call, smooth changes from one harmonic to a different one occur in many different circumstances in horn playing.

I see no reason why it is better to practice deriving stopped notes from above rather than below, although there is nothing wrong with such practice. Personally, I find it easier to hear the intonation and to get a good stopped hand position by starting from below, and closing the hand fairly rapidly.

It does seem that the importance of a proper hand position for the *open* horn may not be stressed enough. The hand is an essential part of the instrument for notes in the highest octave, and is not put into the bell just out of tradition or only to control tone quality. Without the hand, instrument makers would have to keep the bell throat narrower longer. Pyle (7) reports that, using laboratory equipment to create sound waves in a good horn without the hand in the bell, there were essentially no resonance peaks above the high E*b* (concert pitch); Benade has also noted that resonance peaks in the last octave are quite weak. The relative treacherousness of the horn in the highest octave is due not only to the closeness of harmonics, but also to the weakness of the reflected wave. Use of the B*b* horn helps the first, but it takes a different bell shape to help the second. The hand does reshape the bell, and helps the lips maintain the desired frequency. This also explains why it is harder to play softly in the high register—most of the energy radiates into the atmosphere.

REFERENCES

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