Why It Was Time to Rethink the Contrabassoon

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This year marks the fifteenth anniversary of the introduction of the Fast System contrabassoon into the woodwind section of the New York Philharmonic. Now is an appropriate time to look back at its beginnings. The following is an adaptation of an article I wrote before the end of December 1996, eight months into my employment with the New York Philharmonic, when I began contemplating the improvements to the instrument I felt I needed. At the time I titled the article "Is it Time to Rethink the Contrabassoon?" The answer was so obviously YES *that I never finished the article, and quickly moved into the design process and the realities of convincing a manufacturer to build the new instrument. The article languished until I read it again this past year and realized that it contained the history behind the development of the Fast System contrabassoon built by Fox Products Corporation in Indiana. Now that we are twenty years beyond the first investigations chronicled below, it seems appropriate to look at how this came about, and what has been accomplished.*

One of the essential components of good woodwind playing is clean, articulate playing. With it, music sparkles, good phrasing comes alive and we get drawn in to listen more closely. Without it, the sound has a dirty quality that tarnishes even the most beautifully shaped phrase. My quest to play with as much clarity and precision, good intonation, and even tone color on the contrabassoon as on the bassoon led me to examine both instruments to try to discover what it is about the bassoon that allows precisely these qualities, and what it was about the traditional contrabassoon that made those goals so nearly impossible to achieve. Let's admit it: the contrabassoon had long been the "dirty dog" of the woodwinds. When I joined the New York Philharmonic I was acutely aware of the struggles I went through to play upper register notes with the clarity I wanted, and I heard in recordings that other contra players obviously faced the same challenges that I did with cracked notes in the middle and upper registers. In addition, there were many notes on the instrument that had other problems, which I and other contrabassoonists did our best to disguise.

My frustrations and resulting investigations focused on the notes of the contrabassoon's second octave and some of the notes of the third, and why they had the problems they did: cracked notes, unreliable attacks, unstable notes, pitch problems, thin and uneven tone from note to note, lower partials sounding with the note, and complicated fingerings. The bassoon was my reference point for understanding how these problems might be resolved on the contrabassoon. While both of these instruments are acoustically complex in different ways, I believed there were some fundamental principles at work on the bassoon that might help me understand the contrabassoon. Could we find some ways to make it a better instrument, allowing us to play it with the same beauty and precision that we were used to hearing on other woodwind instruments?

Let's look at the fingering and keywork systems on these instruments. On conical bore woodwinds (which includes all orchestral double reed instruments), the notes of the primary octave are played by opening one finger hole after another along the bore until all fingers are up. On the bassoon and contra this is the F scale, and when we reach open F (F3),[1] we have no more tone holes to open to get us to higher notes. In order to continue playing up the scale, we begin to repeat the lower octave fingerings while using some method of assisting the production of the higher notes. On the bassoon, we use a half-hole for the first three notes of the second octave (F♯3, G3 and G♯3), and small vent holes further up the bore on the wing joint and the bocal to assist the attack of the notes from A3 to D4. These notes, from A3 to D4,[2] are produced by repeating primary octave fingerings and using the appropriate octave venting. At D♯4 and above, the notes are produced by exploiting the third or fourth (or higher) harmonics of notes in the fundamental octave. The fingerings become more complex as a result.

Every note above the primary octave on the bassoon results from a long sound wave being divided into shorter segments, producing a note in a higher register, or mode.[3] There must be an appropriate amount of venting in order for the higher-mode note to respond cleanly and reliably. The exact choice of which vent to use on a particular primary octave note will affect the response, intonation, and tone of the upper register—or higher mode—note. On the bassoon there are a variety of ways these vents work, by themselves and in combination with each other, and by exploiting these principles, we are able to play with clarity of articulation for almost another two octaves above open F3 without special reeds or equipment. While there are many compromises built into the system of vent holes we have on the modern bassoon, they work well enough to allow us to play all the notes of the instrument cleanly, in tune, and with an even tone color, note to note.

In order to understand how these vent holes work, I undertook a systematic study of the vent holes on the bassoon. As part of my study, I drilled three more vent holes into an old bocal above the whisper key vent. Two of these extra holes were intended to allow me to study octave speaker vents for the notes E4 and F4. The third was a very small hole even farther up the bocal, and was an attempt to duplicate on the bassoon some of the characteristics that the contrabassoon exhibited in the second and third registers. Some of the results of this study will be described later.

At the time, I hypothesized that the contrabassoon should be as capable as the bassoon of producing notes with clean attacks in all dynamics, good pitch and stability, and even tone color throughout its second and third octaves. I had faith that the laws of physics did not suddenly change when I picked up the contrabassoon, and so I began to consider the instrument, note by note, in comparison to the bassoon.

The first notes as I went up the scale in the second octave of the contrabassoon were F♯3, G3 and G♯3. Now, on the bassoon we use a half-hole for these notes, widening the opening for F♯, and closing down the opening for G♯ to accommodate the fact that these two notes (F♯ and G♯) actually need vents in slightly different locations for ideal response. The contrabassoon, on the other hand, has one fixed-size hole with an automatic half-hole mechanism. This mechanism opens the same octave key vent for all three notes. No variation of hole size is possible on the contra because our first finger operates a lever instead of covering a hole. For F♯3, even with this hole open, the note sometimes balks or cracks if the embouchure isn't set just right. Why is this? Is it because the hole is too small, or because it is misplaced? Increasing the amount of venting solves that problem. You can prove it by propping open the vent key on the tuning slide and then playing F♯3 with the normal fingering. Now this note can be attacked with confidence at any dynamic, even though one will protest that its tone and stability are compromised. All we have done is increase the amount of venting. Even though this additional venting is many inches away from the half-hole vent on the wing joint, it provides response we can rely on. However, the two negatives of poor stability and tone outweigh the benefit of the improved attack.

The note G3 on the contra (half-hole G) is even more prone to cracking than F♯3. With our bassoon mentality we might assume that the vent hole under the automatic half-hole key must be optimally sized and placed to produce a reliable note. After all, this G is the middle of the three half-hole notes, and the automatic half-hole should be most perfectly suited for it. But I had to ask the question: If this was the case, why did many players have problems with this note and devise various solutions for it? And why was it that when I did experiments, I could obtain 100% reliability of attack on this note by propping open the water key on the tuning slide? Yes, the water key (colloquially called the spit valve). You can prove this to yourself: prop open the water key on your contrabassoon and you will get a clean attack on the written note G3 every time, whether you have the half-hole open or closed. On my instrument the pitch is higher by at least 20 cents, but the attack is clean. While playing G3 this way, opening and closing the half-hole makes almost no difference in pitch. My tuner needle moves a couple cents, a barely noticeable movement.

Next in the scale was the note G♯3. The Heckel[4] as well as Seltmann-Angerhöfer[5] fingering charts that I had in 1996 showed that this note should be played with the half-hole open but with no left thumb register key. However, this note was notorious for unreliable attacks when played with this fingering. It was my impression that in order to provide a reliable attack, one also had to depress the lower of the two left thumb vent keys. This is what I did. My burning question was: where does the unreliability of attack come from? Does it come from inappropriate vent hole size, incorrect vent location, or both?

Let's think back to half-hole usage on the bassoon. We close down the half-hole vent a little to get a G♯3 with a clean note beginning. But bassoonists all know that this is an imperfect solution because G♯ is a touchy note, prone to cracking or squawking if the half-hole isn't quite right. On the contra, the half-hole is a fixed size and there is no ability to finesse it to get a predictable note with a clean attack. Let's look at the next available hole higher up the bore, which again happens to be the water key. A clue can be obtained by propping it open and playing G♯. Now that note speaks reliably and cleanly every time. You can achieve a similar result (reliable


Photo by Steve Malarskey, Malarskey Woodwinds

Illustration 1: The right thumb keys of my Fox contrabassoon photographed in 1997, showing a piece of cane wired to the lower vent key allowing me to open the vent on the tuning slide independently with my thumb.

note with no cracking) by propping open the next hole up on the bore: the vent on the tuning slide. When I discovered this, I actually wired a piece of cane cut from the tube of a formed-up reed onto the mechanism of the tuning slide vent so that I could reach over and lift it up manually with my right thumb, opening that vent *(see Illustration 1).*

This gave me reliable clean attacks on G3 and G♯3 when they occurred as isolated notes. As I mentioned earlier, contra players usually learn early on that to get a reliable attack on this G♯, one has to add the lower of the two left thumb vent keys. One of the two G♯3 fingerings shown in the fingering chart from Fox[6] as well as the one fingering shown for this note in the Piard *Enseignement du Contrebasson*[7] indicate this. But when we play G♯3 with the lower vent key in the fingering, we create a situation in which there are three vent holes open, spread out over about a 13" region of the instrument, solely to achieve a clean attack on an octave note. On the face of it, this seemed absurd. Why was this needed? It was needed because the automatic half-hole was located too far down the bore to be an effective octave hole for this note and was unable by itself to produce reliable attacks. The next hole up the bore that could be used to help out for the attack on G♯3 was on the tuning slide, but it could only be opened from the lower vent key system, in which two vents were opened simultaneously. The upper of these two vents was the one that was about thirteen inches up the bore from the automatic half-hole, and it was certainly much too high on the bore to be appropriate as an octave key for G♯3. These two vents (which opened simultaneously) were about 4-1/2" apart, depending on where the tuning slide was set, and while they improved the response of the G♯, that note still had a tendency to warble or flutter at soft dynamics.

There was another serious issue that seemed to be related to the lower vent system: both G3 and G♯3 tended to be unstable during crescendos and decrescendos when I used the lower vent key in the fingering to ensure a clean attack. This instability issue led me to investigate the mechanism on the contrabassoon that linked the low E key to the lower vent system. After some experiments, I discovered that G3 and G♯3 were *not* destabilized if the low E pad was open while playing those notes. I could get a clean response as well as the stability I needed in crescendos and decrescendos if I depressed the lower octave vent only part way (opening the octave vent holes, but not closing the low E key all the way). This was a great solution but a dangerous way to live.

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Further experiments with the effect of the low E pad (whether open or closed) for the next four notes going up the scale (A3, B♭3, B3, and C4) revealed that the linkage from the lower vent key to the low E key was important for evenness of tone color on *those* notes. This was the reason I did not simply disengage the linkage between the lower vent mechanism and the low E key. I would lose more than I could gain by doing this. As a result, I began to study clutch mechanisms that would open the low E key on G3 and G♯3.[8]

Returning to my discussion of the half-hole notes, the question that came to mind was whether it could be physically possible to vent all three of these notes from one optimally placed half-hole and have all three notes respond reliably, cleanly, with good intonation and tone color. If not, what would the solution be, and what would need to be done in terms of keywork and placement of vent holes to achieve this?

For the next notes A3, B♭3, B3, and C4, their response is guaranteed on the bassoon by use of the left thumb speaker keys. Two articles published in *The Double Reed* in 1995 by **Robert Williams**[9] and **Norman Herzberg**[10] describe this technique. I used the speaker keys on the bassoon as described in these articles and took for granted the good results.[11] But my complaint about the contrabassoon was that I was using the speaker keys it had, and those notes *still* cracked. Why was this? Was it a problem with my reeds, or with the instrument?

I first experimented with reeds and discovered that clarity of articulation on these notes was somewhat affected by the shape and scrape of the contrabassoon reed used. I experimented with different shapers and I also hand-modified the blade shapes in an attempt to solve the problem of dirty attacks. I also experimented with how the reed was balanced. However, the modifications that got me closer to clean attacks presented severe penalties in quality of tone at loud dynamics (to put it nicely), or had other limitations I wasn't willing to live with. It made me ask two questions: Why should we be locked into using a particular shape of reed or into balancing our reeds in a certain way to disguise the bad attacks on the contrabassoon? And shouldn't clean attacks be provided by the system of register holes on the instrument? These questions drove me to keep investigating the contrabassoon and comparing its design to the bassoon. I wanted to know why the instrument didn't provide a clean attack on those notes with the octave holes provided.

I started comparing the sizes of the vent holes on my Fox contrabassoon (#225) with those on my 12000 series Heckel bassoon. I soon came to believe that the speaker holes on my contrabassoon were too small. On my Fox contra even the largest vent hole on the metal pipe was smaller than the smallest octave vent on the wing joint of my bassoon. This made about as much sense to me as installing a motorcycle transmission on a 2-ton truck! Now, I had to consider that the lower vent holes on the contrabassoon were also used in the third octave, on G♯4 and above, and enlarging them would also have implications up there. Because of these complexities, I came to believe that research needed to be done to find out what would correct the problem of inadequate venting for the notes A3 to C4. There were some special considerations for contrabassoon speaker keys on these notes:

1) The tuning slide was near this vicinity where we might locate better-functioning holes.
2) Since the tuning slide was located between most of the vent holes and the wooden parts of the instrument with the tone holes that produce the fundamental scale, any time we moved the tuning slide we would also change the location of the octave vents in relation to the tone holes, and that might be problematic.
3) The fact that the lower vent key was also used to play many of the high notes of the contrabassoon in the third octave from G♯4 on up had to be taken into account. Some compromises were inevitable to keep the keywork simple enough that we could get around the instrument technically.

The bassoon has many compromises in these respects, and it seemed possible that understanding them might help lead us to some solutions on the contra. For example, on the bassoon, the A speaker key vent is a larger size than it would need to be if its only function were to be an octave vent for A3. This key is the high-note vent for the notes A4 and B♭4 in the third octave, and they wouldn't speak properly or have a full tone if that hole were smaller. If we were only concerned with making the second octave notes of the bassoon speak optimally, we could make the A vent smaller and thus also have a perfect octave vent for G♯3. As it is, we compromise on the bassoon and live with a G♯3 in the second octave that needs a relatively precise half-hole, or we truly have to flick this note since holding down the A key in the G♯3 fingering produces a note with bad intonation and tone color.

For some reason I did not write about my data results on the note C♯4 in 1996. I will, however, mention one unforgettable problem I experienced on the contrabassoon with this note. There was a tendency, when I attacked the note very softly, for a G♯4 to speak rather than the C♯4 I wanted. This happened even though I was using the fingering that provided the most reliable attack. In February of 1997 we performed and recorded[12] the Benjamin Britten *War Requiem* with Kurt Masur. In a rehearsal of the fourth movement (the *Sanctus*) *(see Illustration 2)*, I was mortified when a very delicate *pianissimo* entrance on C♯4 produced an unintended G♯4.

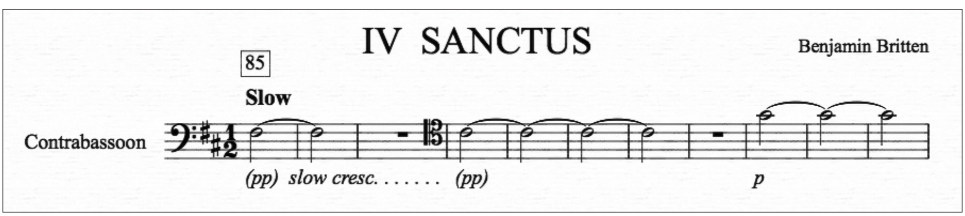


Illustration 2: The Benjamin Britten *War Requiem* excerpt with the problematic C♯4.

An analysis of the lower vent system showed that the lower of the two pads this key opens (this is the one on the tuning slide) was so low on the bore for the note C♯4 that it was probably what caused the twelfth to sound rather than the octave. In the short term I had to figure out what to do to ensure that I really would get a

C♯ in performance, and this was a strong motivating force for me to somehow find a *real* solution to this problem.

Now for the note D4: I considered this to be the crux of the problem of the contrabassoon as we knew it. This was a note that we creatively had to find our way around because the seemingly obvious fingering (upper vent, 1 2) recommended by Heckel, Seltmann-Angerhöfer, Piard, and Fox, was a complete nightmare. With this fingering, D4 commonly had one or more of the following problems: the note cracked or it could even contain a lower octave partial as a component of the tone; it was too sharp, and/or it was unstable. Why was this such a problem? I knew that the bassoon had its octave vent for the note D4 (the whisper key) on the bocal. How could I calculate where the octave key should be for that note on the contrabassoon?

I walked across the street to The Juilliard School bookstore and picked up a copy of Arthur Benade's *Fundamentals of Musical Acoustics*. Within twenty minutes I had located his statement (thanks to a very large graphic drawing that was hard to miss) that the correct position of a register hole serving as an octave hole is "exactly at the midpoint between the apex of the cone and its effective open end."[13] But two pages later he also states, "Because misplaced [vent] holes have almost no practical implication for oboes, and need have very little for saxophones and bassoons (whose many register holes have various degrees of appropriateness), we shall devote most of our attention to the clarinet, where the problem is particularly serious."[14]

Excuse me. The problem is very serious on the bassoon and even more dire on the contrabassoon! I was astounded, enraged, and inspired all at once. While I had no idea how to calculate for the apex of the cone beyond the end of the reed or the effective open end beyond the tone hole, I set to work measuring my bassoon, completely ignoring any end-calculations.[15] Measuring the location of the C speaker vent for the note B3 on my bassoon, the vent was 54.3% of the distance between the tone hole and the tip of the reed, measuring from the tone hole. For the note C4, if we take a wild guess that its tone hole would ideally be located in the middle of the tenon between the wing and the boot joint, that relationship was just about 50% of the distance. This put some numbers to the register key system on the bassoon that I knew worked well, and suggested that 50 to 54.3% was a workable range for the location of a vent hole (as measured from the tone hole). Both B3 and C4 on the bassoon have excellent response, intonation, and tone when one uses the high C key as an octave key. Extrapolated to the contra, this 50 to 54.3% ratio put an octave vent for the note D4 on my Fox contra somewhere between 11-3/4" and 14-5/8" down from the top of the metal pipe. This meant that the ideal location for an octave vent for this note (D4) was most likely about a foot away from the octave vent I was trying to use! No wonder we had to devise a variety of other fingerings to achieve a usable D4. Two common fingerings are (upper vent, 1 2 - / - 2 3 F), and (C♯, 1 2 3 / 1 2 3). The first of these is very similar to the fingering you use if you want to play this D4 on the bassoon with the whisper-key lock on. You must add some fingers in the right hand (2, 3 and F are the most successful for me). The second contrabassoon fingering mentioned above is based on the fundamental octave note G2, with the

C♯ key acting as the vent that produces a third-harmonic note (third mode note), a twelfth above the fundamental. However, this fingering guarantees a dirty attack.

I firmly believed that a properly located and sized vent hole on the metal pipe of the contra would give us a totally reliable, stable, in-tune D4. I knew that in all likelihood, the potential was there that this vent hole could produce more than one good note, and the neighboring C♯4 and D♯4 were also begging for improvements to their response, intonation, and tone, as well as for simplified and more logical fingerings. I started eyeing my sets of drill bits.

The next note on the contra, E4,[16] played with the basic fingering (upper vent, LH1), was one that had a better attack than the D just discussed, but it was characteristically a weak and unstable note, particularly on Fox and Heckel contras. Many players (including me) use the C♯ key in combination with the upper vent to stabilize this note. Many contrabassoons are made with some version of keywork for the left thumb that allows the C♯ key to be pressed along with the upper vent key. There are three basic variations of this. Many contrabassoons have one of these three, but some (a surprising number of them) have none.

At this point in the scale an interesting thing occurs on the bassoon. At the note D4, we are using the whisper key hole on the bocal as an octave vent, and it is the highest vent hole provided on the bassoon. Notice that we are not at the top of the second octave yet. But we have run out of vent holes to continue our upward scale based on repeating fingerings from the octave below. Here at D♯4, we begin using third-harmonic (or third-mode) fingerings, where one or another left hand finger is up, acting as a register hole in the fingering. On the contrabassoon, however, there is a different acoustic layout: its normal E4 is based on the primary octave fingering, though it does need the helper C♯ key. As we go up through this part of the scale, high E and above, our notes once again improve in terms of quality of attack, pitch, and stability. The note F4 also needs the added C♯ key, but it can be played with the simple fingering (upper vent, C♯ key).

Now I was at the top of the second octave of the contrabassoon, but when I got to the notes F♯4 and G4 in the third octave, I was finally in the part of the scale for which the position of the upper vent key seemed to be the least problematic. I wanted more clarity on those notes, though.

In **Lyndesay Langwill**'s book *The Bassoon and Contrabassoon* he writes about the A and C speaker keys on the wing joint of the bassoon and the crook hole, saying, "a better term for these holes is 'harmonic-holes' as they assist in the production of twelfths, etc., as well as octaves."[17] This helped to confirm to me that our fingerings for the bassoon notes D♯4, E4 and F4 were really third mode notes. And similarly, F♯4 and G4 on the contrabassoon were also third mode notes. This is no surprise for these notes on the contrabassoon since F4 is the top of the second octave and you must use third mode (or higher) notes to play higher. The similarity between these five notes on the two instruments is that they are all double vented.[18] For the three notes on the bassoon, this involves either the left hand third finger (for D♯4) or the second finger (for E and F4), plus the open-standing whisper key. For F♯4 and G4 on the contrabassoon, the two vents involved are the automatic half-hole and the upper vent. These notes on the contra can be sustained easily enough using only the automatic half-hole, but in order to get anything approaching a clean attack, one must include the upper vent key in those fingerings.

I got curious and did some comparative measurements of my bassoon and contrabassoon. On my bassoon there was a 9.8” (24.9 cm) distance between the entrance of the open F tone hole into the bore of the wing joint and the hole in the crook. On my contrabassoon there was a 32” (81.28 cm) distance between the hole in the top vent and the entrance in the bore of the automatic half-hole, which is really part of the open F tone hole. This distance increased to 35.25” (89.5 cm) if measured to the F tone hole itself. This means the contrabassoon has more than three times the length of pipe above the tone holes where register holes can be located, compared with the bassoon. One would expect twice the length since the contrabassoon plays one octave lower.

The implications of all this were astounding. I had a woodwind instrument that I should be able to play with clean attacks completely through its second octave on its primary octave fingerings plus the appropriate register key. In fact, the first two notes of the third octave (F♯4 and G4) would be provided by the top register hole on the contra itself. What was needed was a system of properly placed vent holes, all of which would easily lie between the present top vent and the point where the metal pipe enters the wing joint. The big question to me was, how many vent holes would we need (or rather, how few could we really get by with) for a second octave with good attacks at all dynamics, good intonation and tone, and how could we configure the keywork to facilitate good technique? Here was where a thorough understanding of how to locate an entirely new system of register holes would become necessary.

I imagine some readers are already reacting to my suggestions of putting more speaker vents into the metal pipe of a contra by suspecting it might negatively affect the acoustics of the instrument. Fortunately, this worry is completely without grounds. No bassoon or any other woodwind instrument was ever ruined or harmed by adding more speaker vents. On the contrary, an adequate number of properly placed vents on the bassoon and oboe are what have really allowed these instruments to be played at the high levels of artistry that we can hear today.

In late November and early December of 1996 I carried out an exhaustive study on the bassoon to quantify the behavior of each of the fundamental octave notes when different register holes were used, *one at a time* (I only studied the register holes, not the high E key or the F♯ trill key). I quantified the following characteristics:

1. Which note was being tested? Which register hole was used?
2. What was the note that came out? What was its pitch?
3. Description of the stability of the note. Did it become unstable during changes of dynamics? Description of any other characteristics.
4. Did the note have clean articulation?
5. Was the note predictable? Did any other note want to speak?
6. Description of the tone.

This study took three weeks to complete, but it revealed all of the symptoms that occur when a register hole is too high or low on the bore, and when it is too large or too small. Some of the things it revealed were:

1. As successively higher vents are used above the octave nodal point for a note (or as a vent is moved up the bore), the pitch of the note produced goes up. The pitch rises a certain amount, *in relation to the size of the hole*, and if there are holes far enough up the bore, the next harmonic (a twelfth above the fundamental) wants to sound.
2. As successively lower vents are tested, or to put it another way, as a vent is moved down the bore below the nodal point, the tone progressively deteriorates, becoming diffuse, weak and unstable, and then the next harmonic will want to sound (again, a twelfth above the fundamental). The attack of the note may suffer. It may have a hesitation, or in a very soft attack, the note may start too low and "scoop up" to pitch with a little glissando. **Chip Owen** of Fox Products and I ran into this last symptom when we were testing for the proper location of the register holes on the contrabassoon at the Fox factory some years later. I mention it here because it was so distinctive.
3. When a vent is located at the correct octave nodal point for a certain note, its size can be changed with almost no effect on intonation. The hole may be made smaller or larger, and while the tone color will change, the pitch will not. It is worth noting that the A vent on the bassoon is nearly four times the diameter, fully fifteen times the area, and twenty-two and a half times the volume of the whisper key vent (calculating it from the size of the hole and the length of the vent key insert), and yet both of them provide good usable intonation for their respective octave notes. Articulation, on the other hand, will suffer when the vent is made too small. The note will likely crack, especially at loud dynamics. Going to a smaller size yet, the second octave note will contain a lower octave partial in the tone that never resolves out. These last symptoms were precisely what I sometimes encountered on the contrabassoon's note D4 with the simple fingering.
4. When a vent hole is made small, it will provide good intonation for many notes. But clarity of attack may be provided on only one or two notes.
5. When a vent hole is made large, it will provide clarity of attack for many notes. However, it may provide good intonation for only one or maybe two notes, depending on *how* large it is in relation to the size of the bore.
6. If you want to install a moderate-sized octave key vent hole on the bassoon that provides clarity of attack at all dynamics and also musically usable intonation for only one note, you can locate it anywhere within a 3" window and it will function just fine. The implication of this for the contrabassoon, since it is double the length of the bassoon, is that there is a 6" window.[19] This seemed remarkable.
7. If you want to install a moderate-sized octave key vent hole that provides clarity of attack at all dynamics and also musically usable intonation for

> more than one note, you face significant limitations. You quickly become confined to a much narrower location on the bore of the instrument, and the vent hole must be a certain size.

There were many more details about how vents function, both individually as well as in combination, that were revealed in the study. However, the central question boiled down to this: for how many notes can one expect good response, intonation, and tone from each octave vent? The answer, derived from the results of my study on the bassoon, was three *(see Illustration 3)*. This had to be tested and proven when applied to the contrabassoon, but in the end, five holes were necessary to solve for fourteen notes, F♯3 to G4. Remember, the top vent of the contrabassoon is used for F♯4 and G4, the first two notes of the third octave. The response of these notes needed to be improved, too.

Many years later, I did the math to calculate the theoretical octave nodal points of the notes of the primary octave of the bassoon (based on the speed of sound at 1,125 ft/sec), and it showed that the nodal point for providing the note B♭3 was 3.168" away from the nodal point for C4. This confirmed my conclusions drawn from the 1996 vent hole study (which were done on a purely aural basis), that there is at least a 3" window where one can locate a register hole for a single note. I came to call this 3" window the nodal region,[20] and it is the overlap of nodal regions of adjacent notes in the chromatic scale that allows one vent hole to be used for three notes.

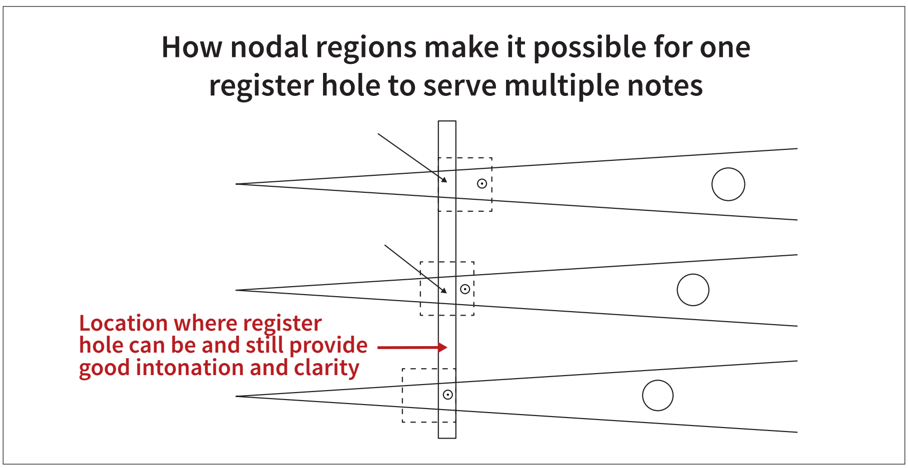


Illustration 3: Illustration of the Concept of Nodal Regions.

The three horizontal cones represent a conical bore with a tone hole and a register hole. Tone holes for three successive notes are shown by the large holes in successively higher locations (top to bottom) on the bore. The small holes locate the theoretical nodal points for each note. Each note's nodal region is shown by the dotted-line boxes. The tall vertical rectangle illustrates that the upper two cones can use the register hole location (indicated by the black arrows) of the lowest cone because of the overlap of the nodal regions. Although the hole for the upper two cones would not be in the theoretically correct location, it would function just fine for all three notes because it would be within the nodal region of all three. (Illustration by Arlen Fast)

In January of 1997 I plotted the midpoint between the end of my reed and the D3 tone hole on my contrabassoon to provide an octave vent for the note D4. I drilled a hole at the X marked at that midpoint, and with the simple fingering 1, 2 from the octave below, there was that note D4 with a clean attack! Then all I needed was a key. Three months later I went to **Steve Malarskey**, a trusted woodwind craftsman. Together we located, and he built, a speaker key for the note D4 *(see Illustration 4).*

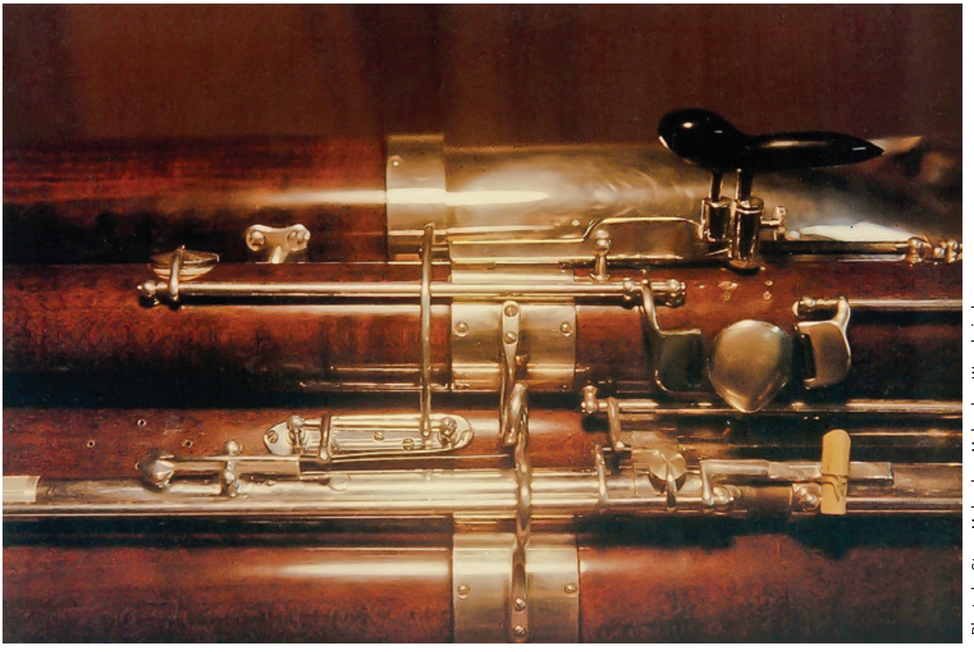


Photo by Steve Malarskey, Malarskey Woodwinds

Illustration 4: The original D vent key built by Steve Malarskey in April 1997. The new vent hole and pad cup are on the metal pipe in the lower left of the picture. The right hand crutch was put on a pivot and a linkage opened the vent key when the crutch was pushed down.

This was a revelation. Suddenly I had a pure attack with security, excellent intonation and a stronger tone for that note, as well as the neighboring C♯4 and C4, all with simple fingerings. I immediately wanted the next new key and began drilling more holes to discover locations for other speaker vents.[21] But I knew that we had picked the low-hanging fruit and the next keys would be exponentially more complex. I started thinking about applying the new paradigm of larger register holes to the entire second octave of the contrabassoon rather than putting more band-aids on a completely inadequate system.

The Modern Heckel Contrabassoon After 1879

In 1879 Heckel patented and introduced the contrabassoon in essentially the form we know today. The instrument had a lowest note of written C2 and it only had one register key, but this design is the platform upon which the modern instrument evolved. By 1896 the range was extended down to B♭1, and in 1901 a new model was introduced that contained a second register key. This second register key is documented in a 1901 *Nachtrag* (translation: *Supplement*) added to the book *Der Fagott*, which Wilhelm Hermann Heckel first published in 1899. One translation of the description of the register key system reads: "Two octave–keys in the metal tube made it possible to finger the notes above upper [D4] as the same notes are fingered in the middle register, and also made the high notes easy to execute in quick passages."[22] The original German version of this in the 1901 *Nachtrag*[23] was very specific about the notes that their new octave key improved: from "oberen C" (C4) to "hohen F" (F4). This description confirms that the new octave key was placed very high on the pipe (otherwise it couldn't provide an F4). This key, in conjunction with the lower vent key, meant that all the notes to the top of the second octave would have one register key or another for aiding production of the notes.

Illustration 5: Pictures of a new model Heckel bassoon (left), and contrabassoon (right) in 1901. The bassoon does not have a whisper key. But the contrabassoon already has its newly-developed upper vent key.

In the same 1901 *Nachtrag*, Heckel shows a new bassoon that has two wing joint keys: the A and C keys, but it has no whisper key. It, too, is a new model, but its improvements lie elsewhere on the instrument. The A and the C keys had made their appearance on the wing joints of some bassoons about one hundred years earlier; many instruments in the 1850s already had a crook hole, and some had one version of a crook key mechanism or another. The one illustrated in the *Nachtrag* did not have a crook key.

It is tempting to look at the Heckel bassoon and contrabassoon in that 1901 *Nachtrag* and think of the two register keys that each of them had as being equivalent *(see Illustration 5)*. Shown there are a bassoon and a contrabassoon from the same manufacturer in the same year, both having two register keys. But in fact, as we have already seen, the register keys were very different. Their origins and primary functions were different, their upper vents were positioned in different areas of the bore, and the instruments were in completely different stages of development. A brief look at the history of the bassoon might be useful here.

Through the late 1800s many manufacturers built bassoons with crook holes, and some of them built key mechanisms to close a pad on the crook hole. This was a response to the fact that from Mozart, Haydn, and especially Beethoven[24] onward, composers frequently scored for the bassoon in the upper part of the second octave and the lower part of the third octave. What bassoonist has not heard the term "the Beethoven register"? I would define this (approximately) as A3 to A4. This register was weak on the baroque bassoon, which had no wing joint vent keys or crook key. By 1800, the year in which Beethoven completed his first symphony, speaker keys (A and C keys) had begun to appear on the wing joints of bassoons.[25] By 1824, Almenräder documented how these keys could be used to provide clarity of attacks on A3 to C4[26] as well as the high notes A4 to C5. But the notes from D4 to G4 in 1800 were still weak. The development that made those notes stronger, more certain, and more stable over the decades was the gradual change of those fingerings (especially E4 and F4) to third-mode notes. The crook hole was part of this development. In the fingering charts before 1800, third-mode fingerings for these notes are not found. Between 1800 and 1900 they become increasingly common, and by 1900 the simple overblown octave fingerings disappear from the bassoon fingering charts.

The bassoon went through a tremendous series of developments by various manufacturers during this time, and part of what drove those developments was that its upper middle register voice became an essential part of the woodwind sound in the orchestral and opera repertoire. Langwill refers to an 1820 article by **Carl Bärmann**, first bassoon in the Royal Prussian Orchestra, saying: "As the bassoon plays a tenor part in music, all study must accordingly aim at imitating a fine tenor voice and at contesting for rank with a talented tenor singer. Noble impressiveness, *cantabile* and *sostenuto*, is admittedly very difficult to produce but this lies in the nature of the bassoon and is its true and most beautiful characteristic."[27] The fine tenor voice Bärmann describes was made possible by the development of the third-mode fingerings of the upper second octave notes in the 1800s. The crook hole was essential to this because it is what enabled those notes to speak cleanly. Yet no one had developed a satisfactory mechanism for it.

The solution came in 1905, only four years after the new bassoon shown in the 1901 *Nachtrag* mentioned earlier. Heckel patented and introduced this further improvement: the whisper key with the linkage to the low E key on the boot joint.[28] This mechanism enabled one to close the crook key with the left thumb, or with the low E key. This provided security of response for all the low notes on the instrument, and it also allowed the whisper key to stand open for all the upper second octave notes played with third-mode fingerings (D♯4 to F4), providing clean attacks for them. Today we take this mechanism for granted, but it really was revolutionary in how many issues it solved. We can summarize this peek into the bassoon's history by saying that in 1901 the bassoon, firmly established in the orchestra for over 130 years, and having gone through constant improvement through this time, was poised to evolve into the modern instrument we know today with the development of the whisper key.

Meanwhile, the Heckel contrabassoon in 1901 had just gotten a new second register key. It was installed near the bocal socket at the top of the metal pipe, and according to Heckel's description, this made it possible "to finger the notes above upper [D4] as the same notes are fingered in the middle register."[29] Prior to this, Heckel contrabassoons had no upper register key, and players had to tailor their reeds to be able to play their upper second octave notes in either the first or second modes readily, just as bassoon players had done for second-octave notes on their instruments over a century before. The implication is that the contrabassoonist of 1900 was playing an instrument that was nearly a century behind the bassoon in its second octave response characteristics. It is easy to understand how it must have been troublesome enough that a new register key was deemed necessary.

One more digression here may help shed light on the situation of the contrabassoon in 1901. By that time, it already had had a long history in the orchestra, but its repertoire was not very extensive compared to the bassoon. Beethoven did write for it in his Fifth and Ninth Symphonies as well as the *Missa Solemnis*, but the contrabassoons of Grenser, Tauber, Horak, Schollnast, and others used during the late Classical and early Romantic eras must have been unsatisfactory instruments. The reason I say this is that between 1842, when Glinka wrote his *Russlan and Ludmilla Overture,* and 1867 when Verdi scored for it in *Don Carlo*, there is no orchestral repertoire that includes a dedicated contrabassoon part.[30] This is a remarkable twenty-five year gap.[31] Brahms included it in his *German Requiem* in 1868, but even that is an "ad lib" part. The *Variations on a Theme by Haydn* (1873) and *Symphony No. 1* (1876) of Brahms are the next commonly known works in the orchestral repertoire that include the contrabassoon. Heckel's revision of the Stritter[32] instrument in 1879 was monumental, and it was from here forward that the contra gained a firm footing with composers. Mahler started writing for it in 1880 and Richard Strauss in 1881. The result of this is that the contrabassoon in 1900 had a relatively small amount of repertoire in the orchestra, and its register key design was just about to be taken forward from the Classical era instrument of one hundred years earlier.

By 1907, the lower octave vent of the contrabassoon was made into two holes in the same vicinity.[33] The lower vent key opened both of those pads at once, so together they became the lower vent system. A tuning slide was added in 1907,[34] but the register key system from that time remained the standard on all contrabassoons up until 2001. This is the register key system that had made only one step out of the Classical era.

Now let's consider what kinds of music were being played before 1900. Stravinsky, Bartok, Prokofiev, Ravel, Bloch, and Shostakovich, not to mention Berg, Webern, and Schoenberg all had yet to make their mark on the musical world. Bassoon and contrabassoon players lived with the instruments they had, of course, and much of the music of the Romantic era focused on the long musical line and the relationship of phrases. Thus, it did not constantly demand the kind of short, concise, staccato notes that reveal so clearly any flaws in articulations. But already in the early 1900s more music was being written that required such playing, and I would suggest that the appearance of Heckel's whisper key for the bassoon in 1905 must have made it feel revolutionary to suddenly be able to articulate the notes D♯4, E4, F4 and F♯4 on the bassoon cleanly without complex compensatory fingerings. If you have any doubts about this, lock down your whisper key and play through the orchestral excerpts from the above-named composers and listen to what comes out of your bassoon.

The contrabassoon, having benefitted from one big change in 1901 and another small revision by 1907 (the tandem lower vent system), had just seen some improvements. However, the holes of the two register keys on the metal pipe of this improved contrabassoon[35] were made extremely small in order to serve the entire second octave plus the first two notes of the third. Clarity of attack was sacrificed in favor of intonation, but even that principle[36] was pushed to the extreme. The range of notes each hole served was so great that it required the player to use reeds more reminiscent of baroque instruments than modern. Even the best of these reeds could not fully overcome the inadequacies of the vent system. Thus, they too were full of compromises. Meanwhile, the modern orchestra continually pushed forward, demanding clarity of articulation, a fuller, more robust sound, and more agile and accurate technical ability in the upper registers. On top of everything else, these demands begged for a more simple and logical fingering system.

Why did the register key system remain unchanged from the very early 1900s until after the turn of the *next* century? This is a question I can't fully answer. But we can look at several things that might have contributed to this situation. One is that the contrabassoon's solo voice, so distinctive, was its lowest octave.[37] The instrument was not pushed into its higher registers by composers like the bassoon had been a century earlier. Thus there was never a reason to re-configure the tone holes and bore of the contra to favor the tenor range. Another possible explanation was that not enough players demanded a highly developed upper register. Orchestration teachers as well as the authors who wrote the orchestration books commonly made statements like: "There is seldom reason to use [the contrabassoon] in its upper register since bassoons or bass clarinet are better equipped to play those notes."[38] This is ridiculous. Imagine the opening of *Rite of Spring* played by the oboe instead of bassoon, since the oboe is better equipped to play those notes! Sadly, I believe that the reality of the contrabassoon was that because it was such a difficult instrument to play well through its second and third octaves, composers remained convinced that their orchestration books were right.

Finally, let's also look at who bought and owned contrabassoons, and who might have had enough interest to invest the time and money to do the research to make real changes. Through the 1950s and probably also the 1960s the majority of purchasers of contrabassoons were institutions—orchestras and music schools large enough to need one. Many bassoonists who played those instruments probably did just enough practicing to survive the particular pieces they had to play. I am fully aware there were notable exceptions, but the reputation of the contra was that of a difficult and quirky instrument that is formidable to master (something I can verify from personal experience). So the frustrations of the players were isolated from the manufacturers because it was the institutions that bought and owned the instruments. Up until 2001, the attitude of many (though by no means all) bassoon players toward the contrabassoon was some combination of fear, disdain, and avoidance. Is this any surprise, considering how little the contrabassoon had changed for an entire century?

The development of certain key systems have allowed revolutionary changes in technical facility on woodwind instruments. Two examples of this are the Boehm system for the flute[39] and the automatic octave key system, patented and applied to the saxophone by Arsène Lecomte in 1888. Stephen Cottrell declares that the automatic octave key system was "[t]he innovation that had the most profound impact on saxophone performance…"[40] Similarly, the development of the Fast System[41] contrabassoon with its five vents on the metal pipe and two automatic octave key mechanisms has made the most profound impact on contrabassoon performance in a century. The two automatic octave key systems allowed the paradigm change to the larger register hole sizes that was necessary in order to provide clarity of articulations for the upper register notes.

Illustration 6 *(see following page)* shows how the five holes of the Fast System on the metal pipe correspond with the notes that each hole provides. The three vertical columns contain the upper register notes for the contrabassoon in each successively higher octave. Starting with the four notes G3 to B♭3 in the lower left box, you ascend through the second octave using successively higher vent holes. Hole number one (at the top) provides the first two notes in the second octave (F♯4 and G4). Then in order to continue up the scale in the third octave (starting with G♯4), you return to the bottom hole (number five) in the system. Now you follow the sequence of notes in the center column, where each successively higher vent on the pipe provides the next set of higher notes in the scale. The note F5 is the highest note that can be provided in this sequence, and it comes from hole number two. In order to continue up the scale, we must go back down to the lowest hole (number five), where we start yet again to move up through the sequence of holes. Now the corresponding notes are in the right column. At this point in the scale, the fingerings get more complicated, but this is typical of all woodwinds in their extreme upper register.

The middle vent hole, hole number three (the D vent), activated by a side key under the right hand first finger knuckle, serves to provide relief for the left thumb and enables whole and half-step trills which otherwise would be difficult or impossible on an instrument with two distinct register keys. The five vent system is also rich with possibilities of how to produce upper register notes, and provides good choices for optimal fingering sequences for particular passages.

Now that I can look back on the beginnings of the new register key system and the other improvements that came along with it such as the divorced low E mechanism, it is clear that many things led to where we are now. First, it was a necessity for me to have an instrument with clean articulations. The New York Philharmonic deserved it and I needed it for my own musical satisfaction in my career. Each book on woodwind acoustics that I read contained some little clue about how things worked, although not one of them contained the complete set of answers I needed to solve the problems of the old contrabassoon's dirty attacks. My exhaustive study of the bassoon's vent holes was critical in order to answer these questions, and it

The Fox Fast System Contrabassoon Metal Pipe Holes
and their Corresponding Notes

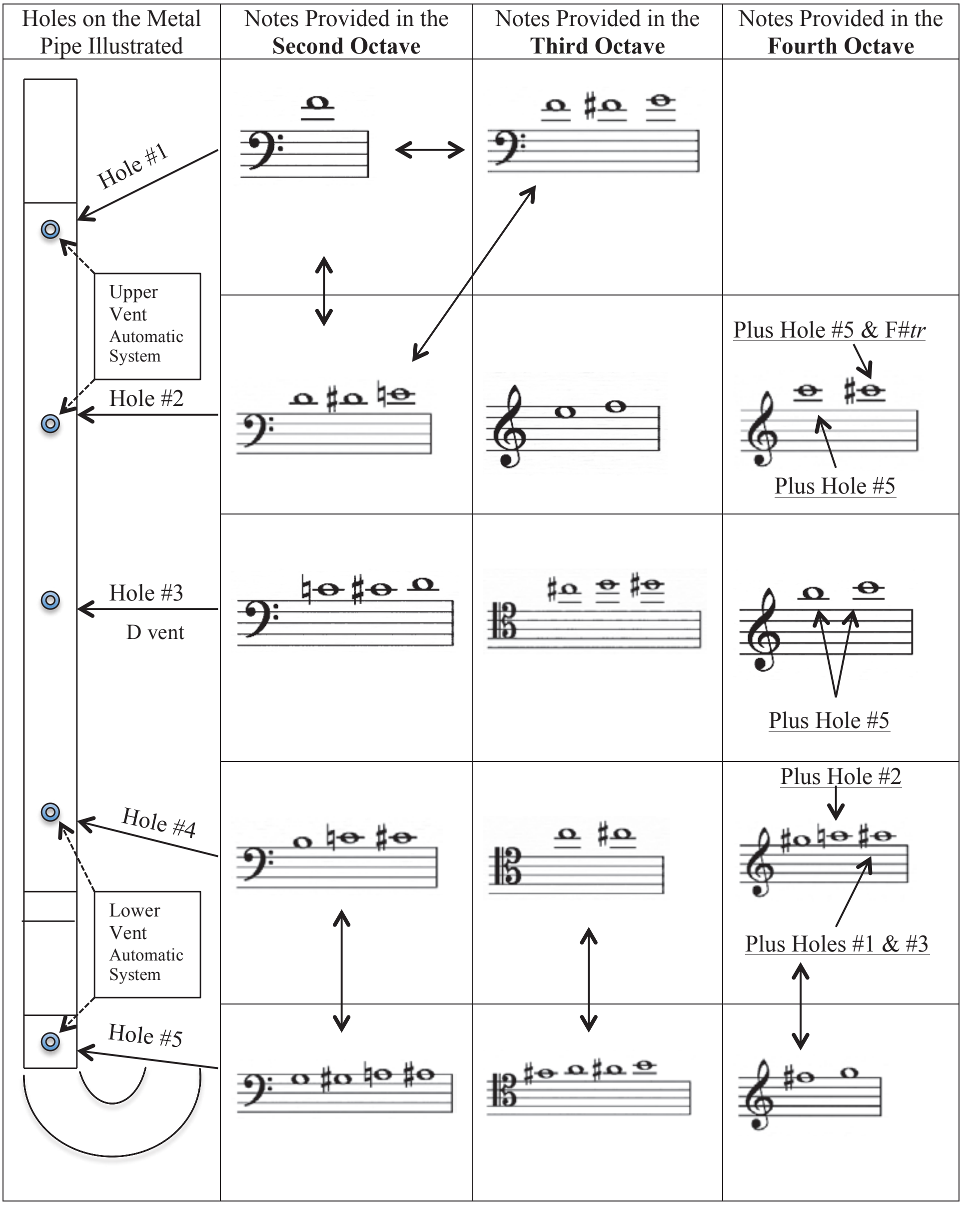


Illustration 6: A diagram of the metal pipe of the Fox Fast system contrabassoon showing the five vent holes. The chart shows the notes corresponding to each hole in the three upper octaves. Note: Holes and their positions are shown for illustration purposes only and are not to scale. (Illustration by Arlen Fast)

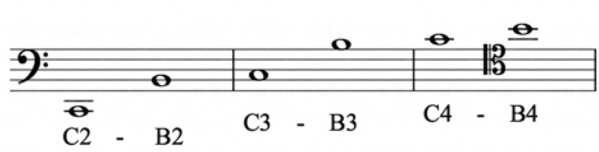
provided the diagnostic tools for locating a new set of register holes. Steve Malarskey had the skills and patience required to create a brand new register key with the new paradigm, and he was the perfect collaborator. Chip Owen at Fox was willing, capable, and dedicated to building the key mechanisms that made the entirely new register key system possible. **Alan Fox** supported and encouraged this project through the research, development, and production processes. I received valuable feedback on the prototype instrument from many contrabassoon players in other major orchestras in the USA and Europe. **Burl Lane** of the Chicago Symphony deserves special credit for his intuitive insights. And the high standards that this instrument had to meet to succeed were driven by the excellence of the New York Philharmonic.

Now we have a transformed instrument with a new world of capabilities whose design easily allows the complete range of musical expression. A one-hundred-year leap forward has been made.

*I would like to thank **Nora Post** for her insightful comments on this article. It was her encouragement that inspired me to revisit and complete the work I had started twenty years ago. Thanks are also due to **Anne Ediger** for her support and **James Kopp** for his knowledge of the history of the bassoon.*

Endnotes

1 In this article, notes of the scale will be referred to by their Acoustical Society of America designations. All notes for the contrabassoon will be described by their written pitch, although they sound an octave lower.



2 The note C♯4 is a little more complicated in that it has several common fingerings. One *is* a repeat of the lower octave with the whisper key open, but there are two other “long” fingerings with right hand fingers added to strengthen the note.

3 Conical bore instruments such as oboes and bassoons have certain patterns of vibration. They overblow the even-, as well as the odd-numbered harmonics. A higher mode note is one that is produced by dividing the sound wave of a fundamental octave note into shorter segments. On conical bore instruments, second mode means dividing the wave into two parts, producing a note one octave up. Third mode means dividing the wave into three parts, and the resulting note is an octave and a fifth higher. Fourth mode provides a note two octaves up. A fifth mode note is two octaves and a major third higher than the fundamental octave

note. This sequence continues to follow the pattern of the overtone series. For further reading on the topic of conical bores, see: https://newt.phys.unsw.edu.au/jw/woodwind.html

4 Richard Plaster, "Contrabassoon? Let's Get to the Bottom of This" *The Journal of the International Double Reed Society* 3 (June, 1975): 40-43. The Heckel fingering chart is on page 40. It is available at: http://www.idrs.org/publications/controlled/Journal/JNL3/contrabassoon.html

5 Werner Seltmann and Günter Angerhöfer, *Fagott-Schule: Das Kontrafagott* 6 (Mainz: Schott, 1984): 130-146.

6 The Fox standard system contrabassoon fingering chart is available at: http://www.foxproducts.com/602089faa8_sites/www.foxproducts.com/files/CBsnFingeringChart.pdf

7 Maurice Piard, *Enseignement Du Contrebasson* (Paris: Alphonse Leduc, 1952). The fingering chart is a separate insert.

8 I designed a clutch mechanism that opened the low E key for the notes G3 and G♯3. This mechanism was built on the first production Fast System contrabassoon. On subsequent Fast System instruments, Chip Owen replaced this mechanism with the divorced low E key, achieving the same results with a simple, more elegant mechanism.

9 Robert Williams, "Bassoon Basics for the Flicking Bassoonist!" *The Double Reed* 18, no. 2 (Fall, 1995): 41-47.

10 Norman Herzberg, "Years of Innocence, Ignorance, Neglect and Denial: The Importance of Speaker Key Use on the Bassoon," *The Double Reed* 18, no. 3 (Winter, 1995): 53-63.

11 Anthony Baines, in his book *Woodwind Instruments and Their History* (New York: Dover Publications, 1991): 160-162, describes this quite accurately:
Use of the left thumb on the tenor notes:
This forms the most difficult part of the fingering. The crook hole is smaller than on the French bassoon and less efficient as an octave vent. It is too small to give adequate help to the notes from [C4] down to [A3], and if it is made larger, these notes only become unsteady and windy. The result is that when they are attacked, they are apt to sound for a split second in the low register before settling in the upper, making an audible grunt or croak which has to be avoided at all cost. It is avoided as follows. For [C4 and B3] the high C key is opened, and for [A3], the high A key; for [B♭3], whichever gives the note best in tune. This is normal technique on the German bassoon, cumbersome though it is.

12 Benjamin Britten, *War Requiem*. Kurt Masur; New York Philharmonic. Recorded Feb. 5-8, 1997. Teldec 0630 17115-2. Note: re-released in 2012 by the Apex label, Catalog # 2564659416.

13 Arthur Benade, *Fundamentals of Musical Acoustics* (New York: Dover Publications, 1990): 457.

14 Ibid., 459.

15 End-calculation is a term used to quantify the difference between a) either the reed tip at one end or the tone hole at the other end and b) the theoretical turnaround

point of the sound wave. The reed at one end turns the sound wave around with the timing that imitates the cone of the conical bore taken to its apex. At the tone hole, the sound wave turns around a little bit beyond the actual hole, according to the size of the hole.

16 In 1996 I had not written anything about the results of my investigations on the note E♭4.

17 Lyndesay Langwill, *The Bassoon and Contrabassoon* (London: Ernest Benn Ltd., 1975): 147. Note: just to be clear, Langwill uses the terminology *a' and c" octave keys* which refer to the high register notes A4 and C5.

18 In this double venting situation, each vent is acting on a different nodal point of the third-mode note.

19 There is a parallel between conical bore woodwind register holes and string instrument harmonics. When a string player presses the string all the way to the fingerboard, the note produced is strong. The pitch will change immediately if the finger is moved while keeping the string pressed, *but the tone will remain strong.* This is analogous to using a tone hole on a woodwind instrument to produce a note, then having the ability to move it very slightly. When a string player touches the string to produce a harmonic, the string can be touched in approximately the right area, and the harmonic note will be in tune. If the finger is slid away (in either direction) from the ideal point for the harmonic, the pitch will change very little, but the tone will suffer, becoming weaker and more diffuse. This is analogous to what happens with register holes. The hole may be moved within a certain range with very little change of pitch. However, since the holes on woodwind instruments are fixed, we need to think of this in a different way: one register hole will provide clean articulation and good intonation for three notes on the bassoon and contrabassoon (for two of the three notes, the hole will be slightly misplaced, but because of this principle, those notes will still play in tune and have good articulation).

20 I use the term *nodal region* to describe the location on the bore where one may install an octave vent for a particular note and obtain good response (clean at all dynamics) and intonation (within six cents above or below the prescribed frequency in an equal-tempered scale) for that note.

21 Since these holes were drilled into the long metal pipe, it was simple to cover them with Scotch strapping tape to keep them sealed off during normal practicing, rehearsals and performances.

22 Wilhelm Heckel, *The Bassoon (Der Fagott)* (Chicago: University of Chicago Press, 1950). Note: there are no page numbers in this booklet, but the text in question appears in the section titled "The Contra Bassoon" near the bottom of the page.

23 Wilhelm Hermann Heckel, *Der Fagott, Kurzgefasste Abhandlung über seine historische Entwicklung, seinen Bau und seine Spielweise* (Biebrich am Rhein: Heckel publication, 1899 with a 1901 *Nachtrag*). Note: there were a number of printings of this publication. The WorldCat system shows several: http://www.worldcat.org/title/fagott-kurzgefasste-abhandlung-uber-seine-historische-entwicklung-seinen-bau-und-seine-spielweise/oclc/1936568/editions?referer=di&editionsView=true

24 Beethoven's symphonies were composed between 1800 and 1824. The piano concertos were composed between 1797 and 1811, and the violin concerto was premiered in 1806.

25 Lyndesay Langwill, *The Bassoon and Contrabassoon* (London: Ernest Benn Ltd., 1975): 48; Eric Halfpenny, "The Evolution of the Bassoon in England, 1750-1800," *The Galpin Society Journal* 10 (1957): 30-39; Etienne Ozi, *Nouvelle Methode de Basson* (Paris, 1803; reprint, Geneva: Minkoff Reprints, 1974). Fingering Chart in a foldout page at beginning of the book.

26 Carl Almenräder, *Abhandlung über die Verbesserung des Fagotts* (Mainz: B. Schott Söhne, 1824): 7, 8.

27 Carl Bärmann, "Concerning the Nature and Peculiarities of the Bassoon and its Use as a Solo and Orchestral Instrument," *Allgemeine Musikalische Zeitung* 36 (September 6, 1820), as cited in Lyndesay Langwill, *The Bassoon and Contrabassoon* (London: Ernest Benn Ltd., 1975): 39.

28 Edith Reiter, *Wilhelm Heckel, Six Generations Dedicated To Music* (Wiesbaden: Waldemar Kramer Verlag, 2015), drawing on page 113.

29 The German text reads: "Der Heckel-Contrafagott ist durch Anbringung einer neuen Oktavmechanik ausserordentlich rein geworden. Besonders ist das "A" in der Oktave kein summender Ton mehr. Die Töne vom oberen "C" bis zum "hohen F" können genau wie in der Mittellage gegriffen werden, nur dass noch die oberste Oktavklappe geöffnet werden muss. Hierdurch wird ermöglicht, dass selbst die schwierigsten Figuren äusserst leicht ausgeführt werden können. Auch diese Erfindung ist durch Gebrauchsmuster geschützt. Der Heckel-Contrafagott hat bekanntlich genau dieselbe Griffweise wie der allgemein übliche Heckel-Fagott, wird aber auch mit der oben erwähnten französisch-englischen Griffweise gefertigt.

30 There is one exception to this twenty-five year gap that I know of in the opera literature. Verdi's opera *Macbeth* (1847) contains a contrabassoon part in a small offstage ensemble of eleven wind instruments.

31 During this twenty-five year gap, some manufacturers were busy developing a satisfactory new double reed contrabass instrument. Others built quite highly developed versions of the Classical era contrabassoon. One of the most beautiful is by Bradka and is displayed in the historic instrument collection of the Kunsthistorisches Museum in Vienna.

32 Friedrich Stritter was an employee at the Heckel firm between 1870 and 1900. He obtained a patent in 1877 for a contrabassoon redesigned with three large wooden tubes instead of two, like the Hasenier contrabassophon. Edith Reiter shows documentation in her book *Six Generations Dedicated To Music* (Wiesbaden: Waldemar Kramer Verlag, 2015): 70-71, that this idea actually came from her great-grandfather Wilhelm Heckel. This design shortened the instrument, making it more manageable, but it put the right hand on top, making it unfamiliar to bassoon players. Two years later in 1879 Wilhelm Heckel made a significant further revision, moving the wing joint to the upper part of the instrument, allowing the left hand to be on top like the bassoon. The drawings of the Stritter

system instrument on page 73 of her book and of a later Heckel contra on page 75 (probably between 1901 and 1907, as evidenced by the register key system) illustrate these instruments quite clearly.

33 Edith Reiter, *Wilhelm Heckel, Six Generations Dedicated To Music* (Wiesbaden: Waldemar Kramer Verlag, 2015): upper photo on page 155.

34 James Kopp, *The Bassoon* (New Haven: Yale University Press, 2012): 204.

35 The two vent holes of the lower vent system function as one key.

36 The principle at work is that if a register hole is small, it can provide usable intonation for many notes. See items 4 and 5 in the summary of the results of my study of the bassoon's vent holes in this article.

37 Contrabassoon solos in Beethoven's *Fidelio* (1814), Verdi's *Don Carlo* (1867), Ravel's *Mother Goose Suite* (1911), and his *Concerto for the Left Hand* (1930) are a few examples.

38 Kent Kennan, *The Technique of Orchestration* (Englewood Cliffs: Prentice-Hall, 1970): 98.

39 Theobald Boehm, *The Flute and Flute Playing, in Acoustical, Technical, and Artistic Aspects* (New York: Dover Publications, 1964): 90-93.

40 Stephen Cottrell, *The Saxophone* (New Haven: Yale University Press, 2012): 74. Cottrell explains this innovation: "Lecomte made one particularly significant contribution to the development of the instrument by combining the two previously independent octave keys into a single automatic key operating two vents according to context; the correct octave vent would automatically be opened depending on the note required, rather than the vent having manually to be opened by the player's left thumb choosing between two separate keys, as on Sax's system."

41 US Patent #6765138: Fox Products Corporation, patent holder. Fast, A. & Owen, T., co-inventors. See:
http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=4&f=G&l=50&co1=AND&d=PTXT&s1=Contrabassoon&s2=%22Register+key%22&OS=Contrabassoon+AND+%22Register+key%22&RS=Contrabassoon+AND+%22Register+key%22