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# Using Flute Physics to Tune Multiphonics

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**Abstract:** The horizon of multiphonic flute playing has not been fully explored, due to well-established perceptions of the technique's limitations. These perceptions are not fully accurate, although they came about with good reason. Sustaining, tuning and balancing multiphonics all present significant challenges. However, this article questions the perceived and widely-accepted limits of the technique, and presents a tool kit of strategies for overcoming the challenges the technique presents.

***Keywords**:* flute; multiphonics; extended techniques; practice; tuning

## The perceived limits of multiphonic flute-playing

The horizon of multiphonic flute playing has not been fully explored, due to well-established perceptions of the technique's limitations. These perceptions are not fully accurate, but they came about with good reason; multiphonics are very difficult to sustain, and the western flute's design often naturally nurtures multiphonic intervals which do not fit neatly into the traditional mod-12 atonal or diatonic systems that constrain much of music composition. Further, one pitch of a multiphonic is often more easily stabilized than the other(s), which means that without an appropriate intervention, one pitch will often dynamically overpower the other. This presents a challenge for smoothly connecting inner voices in a chord progression. An alto or tenor line sung by a sole alto or tenor achieves a continuity of timbre and dynamic that multiphonic flute does not easily achieve. This is because, in multiphonic flute playing, pitches that are reiterated are often produced by a different fingering. Different fingerings impart drastically different tendencies of timbre, dynamic, articulation potential, and intonation. For the same reason, pitches that move stepwise are difficult to balance into a smooth, intentionally-shaped line.

As an illustration of the problem, Figure 1 presents a series of multiphonics that can produce the typical diatonic chord progression I—IV—V$^{7}$– I$^{4—3}$. To produce this chord progression the flutist must not only tune the major 6th from D to B (measure 2), but must also tune that major 6th to the second sonority, a minor 6th {E, C}. The second sonority is one diatonic step up for each of D and B (measure 3), and these steps must sound like a whole step and a half step, respectively. The chord progression then requires three C's (measures 3, 4 and 5) in close proximity to one another, which use three drastically different fingerings. Matching the frequency and timbre of all three Cs without losing the integrity of any of the vertical sounds (the sixth between E and C, the diminished fifth between F# and C, and the perfect fourth between G and C) presents various layers of challenges. Additionally, the scalar climb in the lower voice, from D through E and F# to G (lower voice, measures 2, 3, 4 and 5) must be tuned like a diatonic scale—the timbre and dynamic of its steps balanced and matched such that a smooth, well-controlled scalar motion upward is perceived. This passage would be very easy to play on piano, and relatively easy on violin, simply because there are multiple strings on those instruments. Since the flute is a singular air tube, the method of producing two pitches at once is to choose a fingering which affords the tube two different wavelengths,

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and discover (with much work and finesse) what type of air stream efficiently supports both sounds.

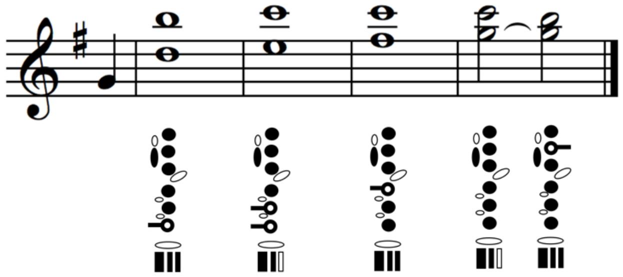

*Figure 1* A chord progression that can be played on flute, but which presents a number of problems to be solved

The most common accusations that are railed at multiphonics are that they are always soft, and that they are out of tune. Indeed, some composers value multiphonics for these very qualities, and beautiful works of art have been created by sensitive composers who are willing to work inside the space of these limits. Unfortunately, however, the challenges of balance and intonation are widely accepted to be absolute limitations of multiphonic flute technique. In fact, throughout many of the manuals dealing with multiphonics, authors provide subjective assessments of the various sounds' idiosyncrasies. For example, Thomas Howell frequently describes fingerings as "breathy".[2] This practice has been enormously helpful for composers who do not play flute but would like to exploit the idiosyncrasies of a given fingering; composers seek out sounds that are labelled "breathy", etc. on purpose. It is an advantage because flutists can spend their time pursuing the timbre and dynamic that the flute most naturally produces. On the other hand, it has also served to constrain the usage of the various fingerings, which in turn reinforces the idiosyncrasy.

Another practice that has been beneficial yet also serves to reinforce idiosyncrasies is that of masking the difficulties of multiphonics through compositional techniques. One can find three important strategies that have been employed in the classic repertoire. The first strategy, which is employed in Berio's *Sequenza* and Carter's *Scrivo in Vento*, is to place multiphonics in isolation. This strategy accomplishes two goals: it gives the player optimal room to prepare for the multiphonic, and it masks any timbre or intonation discontiguities among multiphonics or between regular tone and multiphonic tone. A second strategy has been to keep the fingers in a constant flurry, moving between different multiphonics in a tremolo fashion. This strategy, employed often by Robert Dick and Salvatore Sciarrino, for example, creates a fluttery musical texture that masks instabilities and inequalities. A third strategy that is evident in the flute literature is to not mask, but simply embrace intonation patterns that result from the standard fingering system, and integrate multiphonics into sound worlds that are mod-24 or otherwise employ quarter-tones or smaller distances; this embracement is evident in the music of John Eaton and Toru Takemitsu, among others.

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[2] Howell (1974)

These strategies have been successful in that despite the difficulty of multiphonics, the sounds have come to be accepted in flute-playing as a standard extended technique and composers have come to regard them as a useful and expressive set of timbres. Moreover, the variety of ways that composers approach the challenges of multiphonics might be regarded as contributing to a stylistic richness within the repertoire. Indeed, the creativity that is evident in the early multiphonic repertoire is breathtaking.

However, the strategies have also helped to carve multiphonic technique into a niche that is largely considered “special effects”; multiphonics have been used skillfully and artistically by composers as a device of timbre, but are not often used to project harmony or voice-leading.

In abandoning strategies that avoid, mask or embrace the difficulties—in asking ourselves to learn to hold a vulnerable multiphonic still, for example, or to move transparently through two harmonically connected sounds, we stand to risk going outside the realm of the practical. However, in doing so, we also stand to open a space where we might push the boundaries of what is possible, and explore the edges of an artistic technique that has the unique power to evoke humility, intimacy, strength, and utter clarity, among other human states. Pablo Picasso once asserted that “the chief enemy of creativity is ‘good’ sense.” This publication aims to challenge some of the generalizations that have grown in and around a good sense of practicality and subsequently limited the repertoire, by asserting that players need not accept *all* the idiosyncrasies that a given multiphonic presents as final or absolute. With work, many multiphonics that are naturally very soft can be made surprisingly more penetrating. It is also possible to widen and/or narrow intervals that are produced such that they can be tuned in mod-12 spaces. One can learn to blow such that a weak component of a multiphonic is strengthened and a balance can be achieved. Finally, strategies can be employed such that complexes can be tuned to one another with a greater precision than the design of the flute naturally allows. Namely, for composers who use pitch systems (tonality or set classes, for example) as an expressive device, multiphonics can be employed more deeply toward projecting pitch-based meaning than is generally believed.

Section 2 of this article presents two examples of works that use multiphonics to project pitch meaning by creating smooth, well-balanced voice leading motions between chords or sonorities, in both a tonal and a non-tonal musical environment. In Section 3 and Section 4, the challenges that arise in this type of repertoire are illuminated upon, and solutions based upon the physics of the instrument are proposed to empower performers to push the boundaries and further the development of repertoire for multiphonic flute. Section 5 then presents a toolkit of adjustments that flutists will find helpful in expanding the limits of tuning and balancing multiphonics.

Meeting the demands of multiphonic-playing is a difficult negotiation which requires the flutist to explore non-traditional techniques of blowing and fingering, and this exploration can often be frustrating. Indeed, one might rightfully ask whether the journey is worth the reward. An analogous question that might be posed, however, is whether or not young artistic voices should be nurtured in an era where technology has already preserved the work of established artists? We simply do not know what the limits are. At the moment, multiphonics provide a set of unique, beautiful and interesting sounds, whose fragile timbres span the expressive gamut from the delicate to the raucous. Their limits in terms of projecting pitch structures successfully within the constraints of classical aesthetics (with smooth voice-leading, good intonation, careful and intentional dynamics and phrase shape, etc.) are not yet known, despite the air of certainty that dominates many discussions of the challenges they pose.

## An introduction to multiphonic flute-playing and its challenges

A multiphonic is any instance where a wind player (flutist, clarinetist, saxophonist, etc.) produces more than one pitch at a time. Early formal usages of flute multiphonics include the *Sequenza* by Luciano Berio (1958) and *Proporzioni* by Franco Evangelisti (1958). Over two centuries ago, in 1810, Georg Bayr made a sensation playing what he termed "Doppeltöne." He published a manual called *Practische Flöten-Schule* (1823) with fingerings for various intervals. The technique was (and continues to be) revolutionized through the work of American flutist-composer Robert Dick, while modern resources include Bartollozzi (1967), Thomas Howell (1974), Dick (1975), and Pierre-Yves Artaud (1980).

Multiphonics are often produced by accident, when a player aims their air such that two notes are produced simultaneously. This is one type of a group of mistakes that are popularly known in wind-playing as 'cracks'. With extreme precision, these would-be mistakes can be sustained, stabilized, and even tuned. Surprisingly, when they are well-controlled, multiphonics can sound like sonorities, and even function harmonically in the way that a violinist's double stops do.

Demonstrations 1 and 2 below present two musical works which ask the performer to use multiphonics toward a smooth voice-leading among clearly-audible harmonies. Both works are by the same composer and use the same multiphonic fingerings, but in two different harmonic contexts. The first piece*, Parallel Transformations*, is tonal, and uses 18th and early 19th century harmonic techniques. The second piece, *Transforming Parallels*, uses a more modern harmonic style; the music uses set classes. In both works, the soloist must work to master the sonorities in themselves, as well as the connections between sonorities. The classical aesthetics of clear intonation, smooth phrasing in inner voices, and a good, intentional control of dynamic levels are vital to the works.

**Demonstration 1.** *Parallel Transformations* (2015), a work that uses 18th/early 19th century harmonic techniques.
*https://www.youtube.com/watch?v=n1wiCDOIEkY*

**Demonstration 2.** *Transforming Parallels* (2017), a work that uses set classes.
*https://www.youtube.com/watch?v=y0XLhT69FC0*

Reliably producing and sustaining a multiphonic that is well-balanced and in tune presents distinct challenges that need to be overcome. It is a particularly complex endeavor because any adjustment to the tube-length or air stream that is made in order to improve one of the notes of the multi-pitch sonority is likely to impact the other pitches as well, and not always in an amelioratory way. For example, see Demonstration 3 below. In the video, the performer is attempting to tune a fingering which can produce either B4 or G#5. When the two pitches are combined into a multiphonic, some severe issues regarding intonation emerge. The B is sharp, and the G# is extremely flat. The performer first rolls in to alleviate the sharpness of B, which unfortunately also (further) flattens the G#. The next strategy used is called finger venting. The performer opens the left hand ring finger hole a minimal amount, while keeping the ring closed. This solves the problem of the flat G#, but it also further sharpens the B, then causes the B to disappear/be unstable, and introduces a new low note to the dyad that is not wanted.

**Demonstration 3.** Adjustments that improve one of the notes often negatively impact the other. https://archive.org/details/Demonstration3

In many cases, these difficulties can be surmounted by being aware of the physics of the instrument and using multiple means of adjustment in tandem, such that an adjustment that improves one of the pitches but negatively impacts the other is countered with another adjustment that remediates the new problem that was created. In short, having a large toolbox of potential adjustments with which to experiment is key to achieving this goal. Such a toolbox is presented in Section 5, as Figure 3.

In preparation for presenting this figure, some of the principles behind stabilizing and tuning multiphonics will be illuminated. Two major questions will be briefed regarding the mechanics of flute-playing:

- How does a flute transform an airstream into flute sound?
- Why does changing the fingering change the pitch?

These questions are addressed in Section 3 and 4. Some information regarding the process wherein air is transformed into flute sound, as well as some heuristics and animations for visualizing the impacts of blowing and fingering choices are presented. For those musicians who find it useful to visualize and/or understand the physical processes that impact their tone and intonation, and for those who simply appreciate envisioning some of the magic behind physical phenomena such as multiphonics, these sections will be a valuable resource. It is not possible in such a short article (if at all) to codify and document a mechanistic prescription of exactly how to generate the confluence of blowing and fingering and flute that creates a beautiful multiphonic for *all* multiphonics of the universe.[3] However, some ability to imagine the processes at work can go a long way toward a productive exploration. The science is discussed in this spirit; that the limitations of multiphonics that have long been accepted might be challenged by thoughtful work that is directed by logic and sound feedback.

## A brief survey of aspects of the physics of the flute: creating wavelengths through fingering

One way of conceptualizing the production of a multiphonic is that the flutist supports an extremely rapid vacillation among two different wavelengths that are potentiated by a

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[3] Some resources that move in this direction include the Virtual Flute, developed by Andrew Botros, and Flouble, developed by Gergely Ittzés. Hanns Wurz' *Querflötenkunde* and Werner Richter's *Bewusste Flötentechnik* are manuals for flute playing that include tables that move in this direction as well.

fingering; these wavelengths produce the two pitches of the multiphonic.[4] The alternation of wavelengths must occur rapidly enough that the illusion of simultaneity is achieved, and neither of the pitches comes to predominate in the listener's perception. If one of two pitches in a multi-pitch sonority gets more "airtime" so to speak, it will appear to over-balance the other pitch; it will be perceived as louder.

Therefore, the activity of producing a multiphonic is really a game of timing, in increments of time that are almost inconceivable. Flutists conquer the same game as regards single-note playing, so the thought shouldn't intimidate the reader. In traditional, single-note flute-playing, the flutist uses their ear to gauge sound feedback and master pressure alterations, such that they can hold a single pitch consistently and move smoothly between the different pitches of a moving line. At the highest levels of playing, flutists learn to manipulate the alterations so that interesting timbres, vibrato and fine nuance can be created within a window of not losing control of the pressure alteration pattern/not producing a "crack" or allowing the pitch to sag/rise. The difference is that for single-note playing, the activity concerns a single fundamental wavelength, while for multiphonic-playing, two fundamental wavelengths are involved.

Both fingering and blowing come into play when achieving either goal of creating a beautiful single tone/series of single-tones, or creating a well-timed vacillation among two well-tuned wavelengths. This section deals primarily with fingering; Section 4 deals primarily with blowing.

When a flutist blows wind across the open hole of a flute mouthpiece, a complex of wind speeds and directions strikes the wall of the mouthpiece's chimney that is opposite their lips. Striking the wall further upsets the air stream-complex that is provided by the flutist; not only does the stream split into two (inside the chimney/outside the chimney), but friction near the inner and outer walls pulls parts of the stream back, while more remote parts continue at more powerful speeds. The dichotomy of frictions results in the formation of tiny tornado-like swirls of current, called *eddies.* Multiphonics require a great finesse of these eddy systems. They are illustrated in greater detail in Section 4.

As long as a flutist continues blowing, air molecules that lie within the complex of eddies find themselves to be amidst a complex and high pressure system. The pressure seeks a release, and will attempt to migrate in all directions toward that release. Currents that migrate to the *outside* of the flute tube achieve this: they dissipate into the open air. Some of the currents that migrate to the more *inner* parts of the mouthpiece soon find themselves to be trapped in the space between the chimney and the crown. This is a critical component of

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[4] Other theories have been asserted regarding the nature of the wave activity that produces a multiphonic. The conceptualization that a multiphonic is a result of rapid vacillation among wavelengths has been found to be very useful toward balancing the various pitches within a multiphonic, since it offers us a tangible way of understanding balance. The assertion is based on the supposition that a given air molecule cannot be in two locations at once, and therefore cannot vibrate at two different frequencies during a given moment. Rather, a given molecule vibrates in a way which represents a sum-over-time of the amplitude of the forces that are acting upon it. In blowing a flute, the sum pattern travels through the air, sets the eardrum in motion in synchrony. It is the basilar membrane that separates the sum pattern into discrete pitches, by virtue of its properties of resonance in different locations. (This is in fact how we process timbre, which is rarely a pure sine wave, but is rather a complex sum over time.) The continuity we experience then is an artefact of the physical systems (membranes, neurons, etc.) that transmit and transduce air pressure changes into sound.

how the flute transforms the flutist's air stream into a flute sound. For some moments, a turbulent system grows uniquely in this small space, largely cut off from the rest of the flute by the flutist's continued blowing. However, once the trapped pressure reaches a critical level, the highly compressed air escapes, bouncing fiercely down the tube.

A trail of low pressure follows this high pressure bubble as it moves down the tube. When the high pressure bubble reaches either a substantially opened hole or the open far end of the flute's footjoint, some of the pressure dissipates into the open space, but its high pressure remnants bounce back into the tube, toward the low pressure bubble that was in its trail. Demonstration 4 illustrates this process, for a variety of flute fingerings. It can be observed that if all the keys are closed, a long wavelength is afforded by the flute; the air tube essentially ends at the end of the metal tube, with a small end correction just past the end of the foot joint. This will produce a low B on a B-foot flute, or a low C on a C-foot flute. If, however, fewer keys are closed, the air tube is shorter, and a shorter wavelength is afforded by the flute. This will produce a note that is higher than that of the long tube.

***Demonstration 4*.** The relationship between fingering and wavelength.

https://archive.org/details/Demonstration4

If the flutist continues to blow once the high pressure bubble returns to the chimney, it bounces again—reinvigorated by the newly-accrued pressure (due to continued blowing). The process repeats itself as long as the flutist continues to blow against the wall of the chimney, because this action continues to produce the complex eddy system that causes pressure to be trapped; its entrapment continues to magnify to the critical level wherein it escapes, sending another high pressure bubble down the tube.

The pressure alternations within the space of the flute tube cause a wave of pressure changes to radiate *out* of the flute. The wave complex that radiates out of the flute—in turn—shakes our eardrum in a pattern over time that is synchronous with the pressure alternations. The tiny bones of the inner ear follow, moving the oval window, and the perilymph of the inner ear shakes our basilar membrane—also in synchrony—, causing ion channels to open and neurons to fire. These firings are our physical mechanism for perceiving the pressure alternations that radiate out of the flute, which we call *sound*. It is the pressure alternations that are generated by the flutist's eddy system and escape from the trapped space between the chimney and the crown that begin this very long chain reaction and cause us to hear the sound of a flute.

This process occurs extremely rapidly. For example, A-440 has a fundamental frequency of 440 rotations per second. This frequency is directly contingent upon the length of the air tube, or the fingering that the flutist uses. A long tube takes longer for a rotation, so we call this a long wavelength. It has a low frequency—because farther distance means fewer rotations per second—, so it shakes our eardrum fewer times per second.

A short tube, on the other hand, takes a short time for a rotation. There are more rotations per second, hence the term *high frequency.* A higher frequency of pressure alternations shakes the eardrum more rapidly than a lower frequency. This is perceived as a higher pitch.

The finger holes are usually drilled in locations such that the wavelength increases systematically. On modern western flutes, the pitch lowers according to the chromatic scale. Each hole (not necessarily each finger, due to levers on the Boehm flute) lowers the pitch by a semitone. Within any given fingering, a number of actions can be taken which multiply the possibilities for heard pitches. These are well-known to flute pedagogy, so they will only be briefly reviewed here:

1. Blowing harder and/or closing the aperture through which the flutist blows has the impact of increasing the pressure, resulting in a pitch that is twice the frequency, or one octave higher. This can also be accomplished at 3/2 the frequency (an octave plus a perfect fifth), 4/3 the frequency (two octaves), 5/4 (two octaves plus a major third), 6/5 (two octaves plus a perfect fifth), so on so forth. (This is called the *harmonic overtone series.*)
2. The doubled or three-halved pressure can also be obtained by rolling in, which has two impacts: it decreases the distance between the source of power (the lips) and the edge of the wall it strikes, thus allowing less force to dissipate before reaching the chimney, and it changes the angle at which the air stream strikes the wall. However, this particular method has the added disadvantage of increasing the width of the end correction zone, whose size is directly dependent upon the size of the blowing hole. In rolling the headjoint in toward the lips, part of the blowing hole is eliminated, and the end correction zone is increased. This in effect lengthens the air tube, flattening the pitch a number of increments.
3. The aperture can also be moved closer to the edge of the wall by changing the jaw position or the shape of the front of the lips.[5]
4. Opening a tone hole at a strategic location in between the end of the air tube and the mouth suppresses the fundamental frequency and promotes an overtone to full-fledged pitch status. The flute's high register fingerings reflect this strategy. For example, opening a tone hole that lies near the halfway point in an air tube promotes the first overtone: E6 is produced by fingering an E4 and opening the tone hole that is roughly at the mid-point of the air tube, causing the note that is two octaves above E4 to sound. Opening a tone hole that is 2/3 of the distance of the air tube promotes the second overtone, a note that is one octave and one perfect fifth above the fundamental: D6 is produced by fingering a G4 and opening a key that is 2/3 of the distance down the air tube.

In multiphonic playing, two wavelength distances are supported within the same metal tube. The pressure alternations escaping the space between the chimney and the crown vacillate rapidly among these two (or more) fundamental wavelengths. For example, the fingering that produces an F5 and C5 dyad is shown in Figure 2 below.

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[5] Some pedagogues warn that excessive jaw motion on a horizontal axis can contribute to a set of medical conditions related to the tempo-mandibular joint.

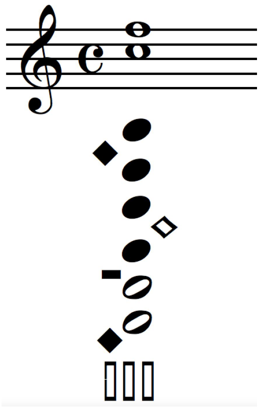

*Figure 2* This fingering can produce F5 and C5

The aspect of the fingering that supports the wavelength for F5 is that all of the keys are closed up to the flutist's right middle finger. The distance that a trapped pressure bubble moves following escape is such that our eardrum shakes enough times per unit time that F5 is perceived.

The aspect of the fingering that supports the wavelength for C5 is the open trill key. If a flutist opens thibullets trill key without closing any of the keys associated with the F5, the pitch that is produced is a slightly-sharp D5. Adding the closed keys that are associated with the F5 has the impact of lengthening the air tube, thus flattening this sharp D5 into a C5.

Meanwhile, the open trill key—since it is located near the halfway point of the wavelength for the F5 fingering—only impacts the F in the sense that it suppresses the fundamental (F4), promoting the first overtone (F5) to full-fledged pitch status as described in number 4 above. This serendipitous relationship allows this fingering to produce the dyad C5/F5 as shown in Figure 2, as long as the flutist modulates the pressure systems in the space between chimney and crown in such a way that those wavelengths vacillate in a good balance.[6]

Since this task begins with the creation of an eddy system near the chimney wall, eddy systems will play a starring role in the discussion of Section 4. The discussion begins, however with a strategy called finger-venting.

The most immediate way of modulating the pitch or balance of a multiphonic is to vent a key hole that is closed. That is, to close the ring of the key but move the finger off of the hole at the center of the key to some degree. This can be done in increments varying from fully vented (the entire hole is open) to barely vented (the shape of a crescent moon is open). Finger-venting decreases the length of the air tube in a miniscule but audible way: a closed but vented key produces a note that is sharper than that of a fully-closed key.

This strategy is illustrated in Demonstration 5. The performer demonstrates a fingering that can either produce a G5/E6 dyad or a G#5/E6 dyad. The difference between the dyads is the size of the crescent-shaped openings on the left hand's middle and ring finger keys.

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[6] See Botros et al (2002) for a useful diagram of the standing wave patterns that can be created using this fingering.

***Demonstration 5**.* Finger venting.

https://archive.org/details/Demonstration5

### A brief survey of aspects of the physics of the flute: creating an eddy system that supports a set of wavelengths

Finger-venting is the single most immediate method of tuning. It can even be done to fingerings that are traditionally fully-closed/use no vented rings. For example, one might slightly vent the left hand ring finger to sharpen a single-note *ppp* D6, which is a notoriously flat note on many flute models. However, finger-venting has its limits; this was evidenced in Demonstration 3, where the performer attempted to sharpen the G# of a B4/G#5 dyad by venting the left hand ring finger, an adjustment which caused the B to become unstable and even introduced a third, unwanted tone to the sonority.

In a case where finger venting is ineffective or not effective enough, all of the traditional means of tuning can be used in tandem: rolling in/out, blowing more/less, and changing the size and/or location of the aperture. In addition, the tongue, which is a very flexible structure, can be shaped into a tremendous variety of shapes, both symmetrical and asymmetrical. To begin understanding how each of these adjustments work, it is useful to look in greater detail at the phenomenon of the eddy. After all, the first task of creating either a multiphonic or a single-note flute tone is to generate an eddy complex, by blowing across the wall of the chimney, and it is the success of the flutist's eddy complex that determines whether the flute successfully supports the wavelengths that are demanded by a given fingering, and whether those wavelengths are supported in a good balance.

For some flutists, it will be helpful to have a visual representation of what is going on physically during the moments between the onset of blowing and the moment when trapped pressure escapes the space between the chimney and the crown. This visual representation can be useful when deciding how to experiment. I therefore invite the reader to imagine, as an heuristic, the familiar process wherein ocean waves meet their shore: in particular, the type of ocean wave called the *plunging breaker*. As a plunging breaker approaches shore, the ground beneath it becomes higher and higher—eventually approaching the level where land rises above the sea. As a wave approaches this point, the water that is caught in the wave cannot climb indefinitely against gravity. The sand's gradient and gravity work in tandem to compress the space where the wave might fill. The water molecules that are closest to the sand beneath the wave are forced to slow down; the sand "captures" some of the force and this is called *shoaling.* In the meantime, the force at higher locations in the wave continues to smoulder forward.

The difference in momentum between the top and bottom portions of the wave becomes paramount, as it is in tension with the force of gravity pulling the wave down, and the bonds which attract water molecules to one another. These forces act on the water simultaneously, causing a plunging breaker to achieve its characteristic concave shape—its top racing ahead of its bottom while it crashes in on itself.

The key element in the heuristic is the curling impetus due to the competition of forces that act on the water molecules as the wave achieves its climax. In flute-playing, the same curling phenomenon occurs when the air stream strikes the chimney wall, because of a dichotomy of frictions between parts of the air stream that are close to the chimney wall and parts that are farther from the chimney wall. Demonstration 6 provides two heuristics for visualizing this.

The video begins with an heuristic of a basin, filled with water. Sprinkled into the water is cinnamon, which doesn't dissolve in water. The will enable us to see the currents that arise when a force is applied to the water. It can be seen that when a utensil is moved along a trajectory through the cinnamon water, water is temporarily displaced. But it is not simply displaced in the direction of the disrupting utensil. Tiny swirls arise in the trail of the utensil. These swirls— eddies—arise because efforts to fill the empty space that is left in the path of the utensil interact with efforts to maintain an intact (though liquid) structure and—for the molecules closest to the utensil—, attractions between the water molecules and the utensil itself. The interaction of these forces results in a dichotomy of friction strengths at various locations in the water. The forces counter one another, and the molecules' motion reflects a type of sum-over-time of the forces. Points of high displacement, in interaction with points of lower displacement cause the water to curl into the circular motion that can be observed. This is an eddy.

The video's (second) heuristic is perhaps more illustrative for the flutist, since it represents a current which meets a barrier, just as the flutist's air stream meets a barrier in the walls of the flute's chimney. The video shows a gentle current entering an inlet of sand. The foam in the video makes the currents apparent: when the current meets the opposing sand barrier, the sand absorbs some force, and levels of friction interact, causing eddies.

***Demonstration 6.*** Visualizing eddies. https://archive.org/details/Demonstration6

The purpose of these heuristics is to help the flutist to visualize an invisible air stream, and understand how changes in blowing angle, pressure and location in relation to the walls of the chimney impact the pressure system they are supporting. The multiphonic flutist needs to open a tremendous flexibility in terms of how and where they aim air for each of the various fingerings. Of particular use for multiphonics will be a flexibility in the shape and location of the tongue. The tongue is highly flexible and is capable of producing many shapes, both symmetrical and asymmetrical. Thinking of the tongue as a bed of sand which shapes an eddy system much like the sand in an inlet shapes the currents entering it can guide experimentation and open the potential for stabilizing and balancing multiphonics that otherwise are unstable or out of tune.

Many variables shape a system of eddies. Gradients along three dimensions come into play. At what angle does the current strike the various barriers? The general rate of change in gradient (the lumpiness of a sand bed, or in flute-playing, the lumpiness of the tongue) modulates the force and decay of an eddy. Eddies can interact with one another in a reinforcing way or a destructive way, and peaks of interaction among eddies can be located in different places by changing the location, angle, force, and shape of the initial air stream. Keeping in mind that the goal is (for holding a single note) to produce a trapped pressure bubble that will move with just enough energy to get to the far end of the air tube, and (for holding a multiphonic) to produce a *series of* trapped pressure bubbles such that they will escape in confluence with the fingering—a good experimentation can begin. The goal is to build an eddy system that is optimally compatible with a vacillation among the wavelengths afforded by a fingering.

## A toolkit for balancing and tuning multiphonics

Often an efficient way to begin working is to choose a set of pitches to pursue, and find a fingering that is likely to produce those pitches. One can work ad hoc, discovering fingerings by using the standard fingerings as a guide, but there are several powerful software tools available that predict fingerings based on impedance minima. Virtual Flute and Flouble are two programmes that do so.[7] One might also choose a multiphonic flute piece that suggests fingerings, or one of the many method books that were cited above as a starting point. These programmes and publications make good predictions but they are not absolute, as they were created using individual flute players (with all their unique blowing properties, dental structures, headjoints, etc.) as initial data. Therefore, it is best to choose one fingering and work with it for a while, using various strategies, and be prepared to abandon that fingering if it has truly been exhausted and still doesn't meet intonation, dynamic, and timbre goals.

The flutist can begin their practice by simply blowing a fingering, and allowing the flute to reveal its strongest propensities for that fingering: which pitch is loudest, how wide/narrow is the interval, etc. Adjustment can then begin by allowing a more prominent note to sound for a moment and gradually inviting a second pitch in. Key to this process is to sustain the prominent note, but allow the second wavelength to vibrate as well. Another method would be to produce the naturally-weaker pitch, and gradually invite the naturally-stronger pitch in, correcting in a more refined way each time the stronger pitch overwhelms the weaker one. Gradually the pitches will even out for the patient and flexible practicer. The flutist might find themselves blowing out of unexplored areas of the aperture; they may feel the aperture taking on strange or asymmetrical shapes, or reaching forward into a tunnel-like shape. The tongue might raise to different heights, higher or thicker on one side than on the other. These oddities are what will allow the eddy complex to support a vacillation among wavelengths. The flute will reveal what it needs if the flutist provides it with a wide variety of adjustments and listens carefully to its response. The work will be slow at first, and rough: the muscles will need time to discover what the multiphonic requires.

The table 1 makes a handy summary of strategies that can be employed toward achieving a clear pitch, a salient timbre/balance, or a desired dynamic level for a given fingering. The chart is necessarily ad hoc, for four reasons:

1. There is a range for each of the adjustments. For example, blowing harder makes a pitch louder to a point, but after that point, it makes it quieter, since the force causes the air stream to overshoot the target area of the chimney wall.
2. Combining adjustments has a synergistic effect. Aiming higher on the chimney might provide something a fingering needs, but when combined with blowing to the right of the chimney, that benefit may be lost.

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[7] Virtual Flute can be found at http://flute.fingerings.info/. Flouble can be found at http://flouble.com/.

3. Adjustments affect different fingerings differently. The flute is not a fixed instrument: we change its shape every time we change our fingering. The energy that is used to support these wavelengths needs to vary accordingly.
4. Different dynamics on a given fingering will require different adjustments.

The multiphonic flutist needs to embrace and continuously develop a highly detailed blowing palate. This toolkit is intended to provide useful guidance toward building that palate.

*Table 1* A toolkit for balancing and tuning multiphonics

| ***Strategy*** | ***Physical Impact*** | ***Result*** |
|---|---|---|
| **Things to do with the fingers/hands** | | |
| Finger venting somewhere near the last closed key or last few closed keys | Shortens the air tube. | Raises the pitch to a point, after which the integrity of the desired wavelength might be lost; in this case a new set of wavelengths established/can be discovered. |
| Finger venting near the middle of the air tube | Will create an impedance that causes a node in the wavelength, suppressing a fundamental, and potentially creating a new wavelength. | Causes some pitches of a multiphonic to disappear, as the fundamental tone is suppressed. Might introduce new pitches if a new wavelength is afforded due to the vent. |
| Trying a different fingering (closing/opening a different set of holes or vents) | Will change which wavelengths are afforded, and will change whether the various wavelengths will compete well with one another for the energy the flutist provides. | Changes the pitches which are possible. |
| Rolling in | Decreases the distance between the chimney wall and the aperture; also increases the end correction (lengthening the air tube). | Lowers the pitch, after a point higher partials sound easily. |
| Rolling out | Increases the distance between the chimney wall and the aperture; also decreases the end correction (shortening the tube). | Raises the pitch, after a point substance of the tone is lost. |
| **Things to do with blowing** | | |
| Blowing harder | Adds force. | Will raise the pitch and louden the volume, to a point, after which higher partials are supported. Blowing much harder without opening a wider aperture results in a rapid vacillation among partials. |
| Blowing less | Provides less force. | Will lower the pitch and quiet the volume, to a point. At a point, higher partials cease to be possible. |
| **Things to do with the tongue** | | |
| Curling the tongue | The tongue acts like a luge track; it directs the air. Frictions develop at the periphery of the | Affects different fingerings differently; generally, can promote a more penetrating sound to a point. This can |

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| | stream which result in complex interactions among eddies. | be an effective way of strengthening a weakly-potential pitch within a multiphonic. |
| Raising the tongue | Compresses the space inside the mouth. | Affects different fingerings differently; generally the higher potential sounds will become more prominent/easy to stabilize. |
| Using an asymmetrical tongue shape | Directs the air on one side in a way different from the other side, resulting in different forces as the stream exits the aperture. This changes the locations of frictions that are borne as air travels over a lumpy structure. | Affects different fingerings differently; is very effective at stabilizing combinations of pitches that are naturally unbalanced. |
| Forming a concave shape with the tongue/angling the tongue on a diagonal such that its tip is lower than its middle/back. | The tongue acts like a luge track; it directs the air. A concave shape results in distinct friction patterns due to differences in momentum at points that are not in the direct path of the air stream's force. | Can be effective at supporting multiphonics with a wide range and/or three or more pitches. |
| **Things to do with the lips** | | |
| Using a smaller aperture | Increases the pressure of the air stream (given the same volume) and is likely to change the angle of the stream (see "aim lower/higher on the chimney wall"). | Concentrates tone to a point, after which higher pitches become more prominent. |
| Using a larger aperture | Decreases the pressure of the air stream (given the same volume) and is likely to change the angle of the stream (see "aim lower/higher on the chimney wall"). | Makes the tone airier. At a point, lower pitches sound, eventually the air stream loses its ability to support a standing wave. |
| Aiming higher on the chimney wall | Locates the primary stream of force at the initial eddy complex that is borne at the chimney wall. | Affects different fingerings differently; generally will raise the pitch of part or all of a multiphonic. Often some pitches will raise to a higher degree than others, even within the same fingering. Some pitches might disappear or be introduced. |
| Aiming lower on the chimney wall | Locates the primary stream of force deeper within the chimney. | Affects different fingerings differently; generally will lower the pitch of all or part of a multiphonic. Often some pitches will drop more than others, even within the same fingering. Some pitches might disappear or be introduced. |
| Aiming toward the right or to the left on the chimney wall | Locates the primary stream of force on one side of the chimney. | Affects different fingerings differently, and different components of a fingering differently. Aiming part of the air to one side and part of the air toward the |

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|---|---|---|
| | | middle is often an effective way to strengthen a weak pitch and balance a multiphonic. |
| Moving the bottom lip forward in relation to the top lip | Will change the angle of the stream as it strikes the wall (resulting in different interactions in the eddy system); will change the distance between aperture and chimney wall (promoting or disallowing a dissipation of force before striking the wall). | Raises the pitch, after a point substance of the tone is lost. This is an effective way to strengthen higher components of a multiphonic. |
| Moving the bottom lip back in relation to the top lip | Will change the angle of the stream as it strikes the wall (resulting in different interactions in the eddy system); will change the distance between aperture and chimney wall (promoting or disallowing a dissipation of force before striking the wall). | Lowers the pitch, after a point substance of the tone is lost. This is an effective way to strengthen lower components of a multiphonic. However, it often must be accompanied by a small aperture, or some other means of maintaining higher components. |
| Using a wide, short aperture (a short oval as opposed to a circle) | Affects the locations of frictions that are borne when the air crosses the tissue of the lips. | Affects different fingerings differently. Changing this variable at the moment of connecting two different multiphonics (when done well) results in a cleaner or purer approach to the new multiphonic/connection between multiphonics. |
| Using a a narrow, tall aperture (a tall oval as opposed to a circle) | Affects the locations of frictions that are borne when the air crosses the tissue of the lips. | Affects different fingerings differently. Changing this variable at the moment of connecting two different multiphonics (when done well) results in a cleaner or purer approach to the new multiphonic/connection between multiphonics. |
| Making a very long, tunnel-like aperture | Allows more force to reach the chimney wall. | This is an effective way to strengthen weak components of a multiphonic. |
| Using an asymmetrical aperture | Will change the force of the current at various locations within the air stream, which results in more powerful eddy systems in some locations and less powerful/complex eddy systems in other locations. | Affects different fingerings differently. This is an effective way of strengthening a weak component of a multiphonic/balancing a multiphonic. It is also a very effective way to widen or narrow intervals within a multiphonic. One pitch can be lowered or raised more than the other. |

Ultimately, the variables of headjoint cut, individual flutists' conceptions of what constitutes more/less/large/small/where one should keep their tongue, etc., and even things that are largely out of our control, such as the weather, make the pursuit of good multiphonics a very individual pursuit. Flutists should use their ears as their primary device of feedback *("If it sounds good, then it is good").* The sound we hear is our interface—our feedback, and our only way to communicate with this otherwise invisible phenomenon, save for having fancy lab equipment that can measure and model the phenomenon in another way which enables us to manipulate it. Having said that, a keen awareness of the potential variables that are within reach can spark the imagination of the creative experimenter. Additionally, in many cases visualizing the impact of our blowing choices on a close level can expedite work, since it offers us a tangible means of documenting what we have tried, and what we have not yet tried. This can take some of the frustration out of work that can often feel directionless for a student. Most importantly, the toolkit enables a flutist to believe more definitely in the possibility that some felicitous combination of elements lies in their future, which will be the key to achieving a balance or intonation goal.

## Toward the development of repertoire for multiphonic flute

Often, multiphonics are defended on the basis that they are pedagogically useful. As an example, Robert Dick assesses that this type of work "develops the strength, flexibility and sensitivity of the embouchure and breath support, increasing the player's range of color, dynamics, and projection. The ear is strengthened, too: one must hear the desired pitch clearly before playing it when familiar fingerings are not used, and quarter-tone and smaller microtones sharpen the sense of pitch as well".[8] This is all true. However, this article acknowledges a relevance for multiphonics that doesn't appeal to how their practice can serve a player's traditional playing, or playing-in-general. Rather, it asserts that multiphonics can be a source of harmony and project voice-leading in tonal and non-tonal mod-12 environments, and that challenging the accepted limits of the technique untraps a formidable artistic potential. After all, multiphonics are an interesting timbre. Even outside the element of the mystical that is evoked by the thought of a single flute producing two pitches at the same time, the timbre holds interest that is not the same as that that can be found in a duo of flutes holding a dyad: there is a beauty that is born in fragility. Many composers and flutists already knew this; it is evidenced by the prominent timbral role that multiphonics play in much music of the later 20th and early 21st centuries. The question is whether this unique voice might be used more extensively if the sounds that flutists make 1) projected pitch meaning more successfully, 2) were more audible as discreet pitches, and 3) sacrificed less in terms of balancing and controlling dynamics and timbre. The music presented in Demonstrations 1 and 2 represent beginning steps into such an exploration.

## References

Artaud, P., & Geay, G. (c. 1980). *Flutes au present: Traite des techniques contemporaines sur les flutes traversieres a l'usage des compositeurs et des flutists.* Paris and Bryn Mawr, PA: Editions Jobert and Editions musicales transatlantiques.

Bartollozzi, B. (1967). *New Sounds for Woodwind*, trans. Reginald Smith. London: Oxford University Press.

Bayr, G. (1823). *Practische Flöten-Schule*. Vienna: Tranquillo molo.

Benade, A. (1976). *Fundamentals of Musical Acoustics.* London: Oxford University Press.

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[8] Dick (1986), p. 7.

Botros, A. (2001). *Virtual Flute.* Retrieved from http://flute.fingerings.info/.

Botros, A., Smith, J., & Wolfe, J. (2002). "The virtual Boehm flute—A web service that predicts multiphonics, microtones and alternative fingerings," *Acoustics Australia*, 30/2.

Dick, R. (1975). *The Other Flute.* London and New York: Oxford University Press.

------ (1986). *Tone Development through Extended Techniques*. St. Louis: LKM Publishing.

------ (2012). Acoustics: Real Life, Real Time—Why the Flutist and Flute Had to Evolve. *Leonardo Music Journal, 22*, 15-16.

Howell, T. (1974). *The Avante Garde Flute.* Oakland: The University of California Press.

Ittzés, G. (2012). Flouble [Computer software]. http://flouble.com/.

Pickles, J. (1988). *An Introduction to the Physiology of Hearing.* Cambridge: Academic Press.

Richter, W. (1986). *Bewusste Flötentechnik: Die Spieltechnik der Querflöte abgeleitet und erklärt aus exakten Grundlagen.* Darmstadt: May & Co.

Wurz, H. (1988). *Querflötenkunde.* Baden-Baden: Klaus Piepenstock.