Lecture to Indiana University bassoon students/ November 2014

Brains and Membranes; a Fresh Look at Reedmaking

As aspiring bassoonists, success with reeds is the absolutely essential ingredient in your recipe for happiness. When you find a good reed, you nurture it and hope that it remains faithful. When University life gets busy, you can avoid the reed room and coast for a few days, but everyone in this room knows in their gut that they need to get back to their tools and to their cane. Next week's lesson, next month's orchestra concert, tomorrow night's wind quintet – all looming ahead. And every time you put the reed on the bocal you wonder if you are going to be able to make some music or simply suffer.

Those of us who make a living at this, and those of us who want to, have a hard time explaining to our families and our audiences just how problematic and time consuming this reed making business is. I often tell non musicians that had I spent the same number of hours studying physics that I spent at the reed desk, I'd probably have a nice job studying the Higgs Boson at the CERN labs.

When you think about the aspiring physicist, you realize that he or she went about learning about Quantum Theory in a very different way then the one we take as reed makers. They begin by learning basic rules, starting with Newton and ending with Hawking. There is lots of creative thinking, and a lot of beauty inherent in expanding our understanding of the world through physics. But they read and they speak in a language based on equations and established theories. I would venture to say that very few physicists consider their work to be an artform. When they build particle accelerators, they are not exercising a craft. Any advance in science is only meaningful if is reproducible.

When you think about the aspiring bassoonist, you realize that he or she goes about learning reed making in a very different way. We are taught the craft of reed making by our teachers. We are given a set of instructions designed to replicate the concepts of our teachers by using specific dimensions and a series of steps that we hope will lead to the occasional good reed. We don't have any equivalent of Newton's laws of thermodynamics, no basic structures of knowledge upon which to build our success. It is an empirical wisdom that we seek, a skill set built on trial and error. And unlike laws of physics, which are universally true, our reed making skills seem to resist consistent reproduction of successful reeds.

42 years ago, in one of my first lessons with my teacher Sol Schoenbach, I asked him how sound was produced on the bassoon. He took my reed and pointed to the tip. "The open F is produced here, the E just behind it, and so on until you get to the back where the low Bb comes from."

Does that make sense to you? No, it didn't to me either. But then Schoenbach told me about his path as a reedmaker. He had gone to Germany after the war to study reed making with the legendary reed maker Mechler. On the first day, Sol cut his thumb with his reed knife and decided that this was not how he wanted to spend his life. So, like many bassoon artists of his time, he had his reeds made for him for the next few decades.

So, there I was, the same age as most of you. I was in a pickle, like most of you, because I had this enormous respect for my teacher – who was an absolutely brilliant and thoughtful man – but he it was clear he didn't know much about how reeds work, or was simply not interested in telling me.

During my first year of study with Schoenbach, it must have been clear to him that I had absolute no talent for reed making, so he sent me to up to New England to a little fishing village on the Maine coast to spend my first week with the legendary reed maker and pedagogue, Louis Skinner. Skinner, who was the most loving and gentle man you could imagine, soon got me organized. He showed me how to improve my small motor skills, gave me some great ideas about designs and measurements and imparted what he perceived to be some basic rules about reed acoustics. During subsequent visits to Skinner, by techniques improved and my reed outcomes improved, but I can't say in all honesty that my understanding of how reeds worked really developed. I will tell you why, and this will lead me to the main ideas I want to convey to you today.

Skinner was very clear that he associated the basic peeping sound of the reed with its dimensions; longer reeds had a lower basic frequency and shorter reeds had a higher basic sound. For his approach, a reed that measured 28 mm from first wire to tip should sound a D, a reed that measured 27 mm should sound an Eb, and so on. Of course, this was just a guide, and it turns out that for many players a 28 mm reed producing a D natural is way too flat. In later visits, Skinner completely agreed with me that the pitches were somewhat arbitrary and dependent on many variables. But at the heart of his thinking was this: you build a reed to produce vibrations that make your bassoon play in tune. In fact, in our very first conversation about the principles of reed making, he said, "We define the bassoon reed as a tuned oscillating device." Further to this, his insistence on a particular peeping frequency supported his rationale that bassoon reeds are fixed pitch oscillators. This suggest that a specific fundamental frequency and its associated harmonics enter the bocal and comes out at the other end as the Jolivet Concerto.

So, early in my life as a bassoonist, I was caught up in this way of thinking. I thought of reeds in a very uni-directional way, that is, they send vibrations into the bassoon which are modified and amplified to produce the sound we love, or the sound we hate as it is so often the case.

I ended up winning a first bassoon chair when I was 22. I was thrilled and I was miserable. Honestly, I wasn't ready, I had no confidence and my reed making was sitting at about a 5% success rate. My first concert included Haffner symphony – can you imagine trying to negotiate the final movement double tonguing with crappy reeds? Of course you can, it is a universal experience. I had nightmares about being able to earn my tenure and I spent 4 or 5 hours a day at the reed bench, even more than I had done when I was a student.

Somehow, my older colleagues took pity on me and decided that I would eventually improve, so I did get past probation and got more and more determined to do things that involved leaving my reed desk. Sol Schoenbach's instruction to me in my first year of study that the open F was produced at the tip seemed so completely absurd that I started to think it was time to learn something about the bassoon. So, I bought Arthur Benade's books on Musical Acoustics, and then those of John Backus, then the indecipherable Cornelis Nederveen, and so on.

If you have ever seen cane growing, you will feel a certain magic connection with this plant and the realities of your tedious lives as reed makers. Did nature produce this giant grass so you could play Sacre? Not exactly. So, why is it that a small segment of dried arundo donax folded into a reed should have the innate capacity to play from low Bb to high F in every dynamic?

"Can you explain how a bassoon reed works?"

This is the first question I ask of a student reed maker. After a few moments of helpless uncertainty, the tentative answer might be:

- "Is it what produces the sound?"
- "Doesn't it vibrate?"
- "Well, it makes a crow so I guess the bassoon amplifies that to get the tone."
- "I think it's a kind of tuned oscillator, but I'm not really sure what that means."

From the very first day we hold a bassoon in our hands, we experience the reed as the primary connection between body and bassoon. We feel its vibration and its structure with our lips - we can even taste it!

As we try to master the basics of the instrument, we are painfully confounded by the fact that reeds seem to control response, intonation, articulation, sound quality – and, most especially, our emotional state! We develop a largely subjective vocabulary about reeds: resistant, unresponsive, hard, bright, dark, buzzy, muffled, tubby, flat, harsh, sharp and just plain bad. Considering how much time we devote to reed making, it's alarming how little we understand about them.

It's logical to conclude that because the reed is the source of so much grief it must be the *actual source* of the sound itself. Bassoonists tend to think of their reeds as *independent sound generators* that are adjustable in all sorts of subtle ways to give us a decent or horrible tone, good or bad intonation and flexible or inflexible response. We nurture a *unidirectional view* - where sound comes *out* of the reed *into* the bassoon - a one way flow of energy. The reed makes noise and the bassoon produces tone.

But, it's a faulty model.

To find a better model, it helps to consider sound production in other instruments.

The sound of a violin comes from the vibration of the string amplified by the body. Vibration occurs when the string is displaced from its resting position. The energy of this motion is transferred to the violin body, amplifying complex modes of vibration that excite the air molecules both inside and outside the violin. This excitation occurs in very organized and repetitive ways, causing compression waves to move outward and eventually engage our eardrums.

Nature gives a stretched string a natural tendency to move back and forth at frequencies dependent on it's tensile strength, elasticity and length.
The most basic motion is a simple displacement from end to end. Strings also exhibit more complicated *modes* of displacement; while the string moves back and forth in its whole length, it also experiences motion in smaller segments. These modes occur in a very predictable way, with the string dividing into halves, thirds, quarters, etc. Each of these vibrations happens at different speeds - frequencies - that exhibit a simple mathematical ratio. We call them *harmonics.* It's an extraordinary fact of nature that the string produces these multiple modes of displacement *simultaneously.*

The simple way to get a string to vibrate is to pluck it. Pizzicato is a great musical tool, but because it involves a single input of energy (one finger plucking) it can't produce a sustained tone. Guitars, with their very large bodies, extend the duration of their plucking significantly, but violinists need a better way of *sustaining* the sound. By pulling stretched horsehairs across the string, the movement of the bow continually excites the natural frequencies of the string and we achieve a sustained tone.

Violinists will pay a great deal of money for a good bow - and are meticulous about the condition and tension of the bow hairs - but they don't think of the horsehair itself as the *source* of sound. Rather, they understand a violin achieves a singing sound through the *interaction* of bow hair and string. Notwithstanding the fact that well designed bows offer significant performance improvements, a violinist is not so likely to say that "this bow sounds better", but rather "this bow gives me a more intimate and responsive interaction with the violin." Violinists implicitly understand that the basic tonal character comes from the violin; the bow is the means of supplying energy to those very expensive boxes.

Here is the big picture: the food that the violinist eats for breakfast is converted to stored potential energy in the body; the movement of the bow arm transfers this energy into the mechanical interaction of bow to violin, producing the acoustical energy we call tone.

A bassoon without a reed is like a violin without a bow. Just as a bow serves as the energy conduit from bow arm to instrument, the reed converts the blowing energy of the bassoonist into the sustained acoustical energy within the bore of the bassoon. In a violin, the tension of the four strings and the placement of the fingers determine the pitch. In a bassoon, the length of the air column determines the note you play.

Sound in the bassoon is produced by the back and forth motion of compression waves within the conical bore of the instrument. Sound, being nothing more than the human perception of air compression, is achieved when pressure waves are emitted from the open tone holes of the bassoon. Sound pressure waves in a wind instrument act longitudinally. If we to line you up in a row, all facing one direction, and push the person at the back of the line forward, she would bump into the guy in front of her, who would push into the guy ahead of him, and the initial energy would transfer from one end to the other. This is how compression waves travel in an instrument, each molecule being pushed and itself pushing, until the initial input of energy comes out at the end of the bore.

Imagine a compression wave moving from the tip of the bocal to the end of the instrument; what happens when that energy meets the open air?

Fortunately, a great deal of the energy is reflected back into the bore. Thank goodness. Imagine that you are all lined up as before, but this time the guy at the front of the line is standing at the edge of the Grand Canyon. When the girl behind him pushes, he is going to yell really loud and try not to fall; he is going to try and resist the transition that occurs from the contained line of compressed people into the vast open space ahead of him.

Sound waves in bassoons act in kind of the same way. Only a portion of the transferred compression energy escapes the first open tone holes. If wind instrument bores gave up all their energy to those first available openings, we wouldn't have wind instruments. When it meets the Grand Canyon of the air around you, most of that initial compression wave reverses direction and heads back to the reed, where the process will begin again. Compression waves (followed by *rarefaction waves*) travel back and forth in the instrument at the speed of sound, so the reversal of direction happens many times a second. Violin strings have natural frequencies (pitches) determined by their diameter, tension and length. Bassoons have natural frequencies determined by the length, internal diameter and taper of the bore. As bassoonists, we have control over the length of the bore according to the number of fingers and keys we close. Longer bores produce long wavelengths and lower pitches. Shortening the bore produces shorter wavelengths and higher pitches. And just as a violin string operates with simultaneous modes of division, so too does the bassoon bore operate with simultaneously overlapping frequencies of harmonics.

The next two minutes will get a bit tricky.

If you ask a physicist to describe the basic mechanism of sound production on a bassoon, you might get the following:

Let's examine what happens when you blow into a reed with a good forte tongue attack.

1. The reed sits in your mouth in its resting state of equilibrium. As you consider the note you are about to play, you control the aperture with your embouchure.

2. Then you simultaneously increase pressure in your mouth and release the tongue - air starts flowing through the partly open reed.

3. The accelerating movement of air through the reed causes the interior pressure to drop, closing the reed, reducing and eventually stopping the air flow momentarily. After the air flow stops, the elasticity of the reed causes it to re-open and its resulting "outward" momentum causes it to overshoot its equilibrium state--thereby opening more widely than at its resting position. In all, this motion gets the reed oscillating at all its natural frequencies---generally all much higher than any note you can finger on the bassoon.

4. At the same time, the abruptness of the beginning air flow causes a pulse of air to start traveling down the bassoon. When it reaches the first open hole - the Grand Canyon in my metaphor - it encounters a change of impedance which induces a partial reflection of the pulse back up the bassoon towards the reed end.

I'm guessing that last sentence did not make too much sense to you, especially using the term impedance. Unless you have studied physics or electric currents, impedance is a difficult concept. Simply put, acoustical impedance is the ratio of the sound pressure in air to the velocity of the air particles. Measuring the acoustic impedances of a bassoon bore is a way of determining the natural resonating frequencies for a bore. Let's just kick the impedance word out of the conversation, and accept that when a pressure pulse travelling down the bassoon bore meets some open tone holes, it doesn't all drain out into the room, but reverses direction and heads back home.

Anyway…

5. Before this pulse reaches the reed, that reed is vibrating at essentially ALL frequencies. An impulse got it vibrating with a very broad sent of frequencies (not at all-equal amplitudes, however). When the reflected pulse reaches this vibrating reed, the pulse's higher air pressure tries to open the reed. This completely stops

the reed vibration at many of its natural frequencies---in particular, those frequencies for which the reed is trying to close when the pulse arrives) In contrast, the reflected pulse reinforces the reed motion for many other frequencies---those for which the reed is in the process of opening when the pulse arrives.

6. In this manner, this first reflected pulse constrains the reed's vibrations and encourages them to be consistent with the natural frequency and harmonics of the bassoon tube. Bassoon makers have expended huge efforts of the last 150 years to make these natural frequencies and harmonics be pleasantly related and in tune with each other and properly pitched. These natural frequencies are immensely complicated functions of (1) the tube length to the first open hole, (2) lengths to closed holes below that first open one, (3) all the details of the bore diameter, including cross-sectional-area "bumps" in the bore caused by closed holes, (4) the volume of the bore, (5) the tendency of the bore towards being either cylindrical or conical, etc. etc.

7. As more and more pulses travel up/down the bore, they even out and set up a standing wave in the bore for the fundamental and each of its harmonics. This equilibrium is reached quite quickly, because the pulse velocity in the bore is essentially very fast (some 1 foot per millisecond).

By the way, when you take a finished bassoon reed and play it alone, you are not hearing the reed's natural frequencies. Instead, you are hearing the standing wave set up inside the reed tube and caused by impedance-discontinuity reflection at the lower, open end of the reed tube. The reeds natural frequencies are much higher and are very "broadband" because of the graininess in the reed wood.

So, that's the physicist's viewpoint. Let's get back to the bassoonist's viewpoint.

If you're fingering a middle C [256 Hz], no matter what you do with your blowing pressure and embouchure, you're not going to produce a D. [The most you can do is play the C flatter or sharper - unless you build a reed that's four inches long or the size of a toothpick.)

It stands to reason that something about the behavior of the reed is determined by how many keys you have open or closed. But if the reed is an independent sound generator, *why* must it be so restricted by the choice of fingering and the length of the air column? If you finger C, the reed vibrates at 261 Hz? Why not 277 hz? Why not 246 Hz?

The obvious answer is that the bassoon itself is exercising significant control over the behavior of the reed. The delivery of acoustical energy turns out to be a two-way street. You can even go so far as to describe it as a master/servant relationship.

The reed is the servant. And perhaps the best way to describe it is – a pressure controlled, variable frequency valve.

I'm asking for you to make a big shift in how you imagine and visualize your reeds. Some of you will have followed what I've said, but many of you might need some reinforcement. So, I'm going to go back and expand on some of the ideas you've just heard, and repeat them in some different language.

Let's think for a few minutes about different ways of making producing sound.

Every possible fingering on the bassoon has natural resonating frequencies. There are certain fundamental frequencies that want to establish themselves for any given length of bore.

Everywhere in nature, we see a strong inclination for objects - or the spaces in which they inhabit - to vibrate at certain frequencies. Musical instruments take this physical principle to the highest level.

It is a defining feature of all successful musical instruments that specific frequencies are efficiently achieved and maintained. Tuning forks like to vibrate at frequencies determined by their size and mass. Bells ring at the frequencies determined by their size and shape. Drums tend to ring at pitches relative to their size and the tension on their heads. Even the table you're sitting at might have a resonating frequency that you can hear by whacking it. You can knock out the William Tell Overture on your head by modulating the size of your mouth!!

Blowing on a pop bottle is a great way to demonstrate the natural resonating frequencies [input impedances] for the airspace inside the pop bottle. Just as hitting a tuning fork causes the mechanical energy of that impact to set up a specific and long lasting tone, so blowing across the open end of the pop bottle both excites and reacts to the natural resonating frequency of that particular airspace.

If you had the most fantastic lips, you might be able to get a pop bottle sound on the bassoon by fingering a low Bb and blowing across the open end of the bell. [You'll need long arms, too.] In actual fact, the diameter of the open bassoon bell discourages this being a useful way of playing the bassoon, but you can imagine the process. A simpler way to test the natural resonating frequency of your bassoon is to finger low Bb, blow into the bocal and slap your tongue against the open bocal tip. Acoustically, this is pretty much like playing the violin pizzicato - it's a single, unidirectional energy input and the bassoon resonance only lasts briefly. It works from both ends, too. You can slap the palm of your hand at the top of the bell and hear a natural resonance, the frequency of which will depend on how many keys you have closed.

The point is, there are different ways to excite vibrations in the bassoon bore, including the single impact, unidirectional slapping at one end or the other and the imaginary method of playing at the bell end like a pop bottle or flute. However, just as a violin needs the continual energy input of the bow on the string, the bassoon works best with an efficient interface between resonating chamber and the blowing energy of the player.

The hair of the violin bow interacts mechanically with the violin string, catching and releasing in a complex way that continually excites the natural resonances of the string.

In most wind instruments [excluding the flute but including all the other brass and woodwinds] the interaction between player and bore resonances is achieved by means of a pressure controlled valve.

You use a pressure valve when you control the flow of water from a tap, releasing the pressure from your city water system and allowing the stream of water to flow freely. The lips of a trumpet player or the reed on the bassoon perform a similar function, in that they release the air pressure built up in your lungs. But unlike the faucet, which controls unidirectional water flow into the average atmospheric pressure in your kitchen, these musical instrument valves are bidirectional mechanisms that are able to respond to pressure variations in the bores of the instruments and allow the mechanisms to operate at variable frequencies. Pressure control valves like bassoon reeds convert the potential energy within your compressed lungs into acoustical energy. By emitting pressure pulses into the bassoon they sustain the tone in somewhat the same way that a bow sustains the legato of the violin.

The catch and release process of the bow hair on the string has to happen at the same frequency as the primary resonance frequencies of the string. If the violinist is playing a middle C, the friction of the bow hair interacts with the string 261 times per second. That frequency is not determined by the pressure of the bow or speed of the stroke but by the natural frequency for that particular string at that particular length.

Similarly, the bassoon reed must convert steady blowing pressure into 'pressure pulses' at the frequency of the natural bore resonances of the bassoon. If we finger a middle C, the reed will be supplying pulses of air pressure 261 times per second, regardless of how loud we are playing. Pressure controlled valves like bassoon reeds have a feedback mechanism that controls the frequency of their energy conversion.

Before investigating that process, let's step back and try to picture this interaction of bassoon bore and the reed valve we stick on the end of the bocal.

Bassoon bores have a natural tendency to set up resonances at specific frequencies. Long bore notes have slower fundamental frequencies; short bore notes have higher frequencies. These resonances take the form of compression waves travelling back and forth from one end of the bassoon to the other. Between compression waves there are areas of molecular rarefaction. Higher than average pressure/Lower than average pressure. At certain points of the bore, including the bocal tip, we have a continuous alternation of pressure. Those changes in pressure happen at frequencies determined by the natural bore resonances of the bassoon. In order for these natural resonating frequencies to be sustained, energy has to be constantly supplied – and mostly at the specific frequency of those natural bore resonances. So, if the bore resonance is A 220 Hz, the pressure inside the small end of the bore varies between compression and rarefaction 220 times a second, and the input energy has to be supplied 220 times a second.

Imagine the reed sitting at the front end of this process. It has to convert steady blowing pressure into 'pulses' and those pulses have to be delivered at the rate of the fundamental resonance frequency of the note being fingered.

Let's sidestep for a few moments and look at the basic physics of airflow.

Bernoulli's Principle

Stop and consider your physical relationship to the bassoon. It involves your lungs blowing through the two blades of the double reed and your lips controlling the inherent tension of cane.

What happens when you blow air into the aperture? Does the reed close or open?

You would think the introduction of blowing pressure would force the blades apart. In fact, the opposite occurs; the flow of air pressure draws the two blades together. The bassoon reed is a type of valve that closes when we first introduce air flow. This is due to the odd fact that while pushing air thru a restricted passage increases its velocity, it simultaneously reduces the pressure inside, between the two blades.

That seems a bit counterintuitive, doesn't it? But you can easily get a picture of this process by holding two pieces of paper, bent to simulate the aperture of a bassoon reed. Try blowing air thru this opening. You might be surprised to find that the two pieces of paper come together, despite the fact that you seem to be delivering a lot of air pressure. You're not blowing AT a surface, you're blowing BETWEEN two surfaces. In 1738 the physicist Daniel Bernoulli observed this fact and came up with this important principle of fluid dynamics:

$$P + 1/2pv2 + pgh = \text{constant}$$

It states that for a non-viscous flow, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure in the fluid's potential energy.

Relax. You don't need to understand the math. You just need to accept that when airflow increases in velocity, the measurable pressure on the inside surfaces are reduced. With the paper test the net result is that atmospheric pressure closes the paper aperture due to a decrease of pressure on the interior surfaces of the two pieces of paper.

Consider the miracle of flight. Much of the lift from an airplane wing comes from this same process. The shape of a wing will always include a more curved upper surface and because air has to travel further on the upper surface of the wing then the lower surface, it must travel faster. Bernoulli's Principle tells us that the measurable pressure on the upper surface of the wing will therefore be reduced, leading to a good deal of lift.

Blowing into the bassoon reed accelerates the flow of air, reduces the internal pressure and causes the blades to be 'sucked' together. This is the first step in the interactive process of converting stored air pressure into the living acoustical energy of the sustained bassoon tone. Just as Bernoulli's Principle helps us understand how an airplane gets off the ground, it also explains the fundamental process by which the reed pressure valve engages the bassoon. You could say that the reduction of internal pressure, bringing the blades of the reed together, gives a constant 'lift' to the system and keeps the tone in flight.

Visualizing the valve closing in response to air flow leads us to see that the reed is able to sustain the tone by the constant delivery of air pressure pulses. How are these pulses organized?

Look Both Ways

Bassoon reeds are a special class of acoustical valves; they close in response to input flow and open in response to output pressure. Bernoulli's Principle shows us that the blades come together when we blow. Once closed there is no longer a flow of air and the natural resiliency of the cane and the structure of the reed cause the blades to open. Once open, the air flow is readmitted, the air velocity increases, the internal pressure drops and the blades are drawn closed. This process happens over and over and, Lo and Behold!, we have sustained tone.

The frequency at which this constant reengagement of the air stream occurs is determined by the change of internal pressure inside the reed. Remember: the reed sits at the apex of the conical bore of the bassoon, and its interior experiences constant variations in internal pressure as the sound waves within the bore oscillate back and forth. The blades of the reed will be forced open when the internal pressure begins to increase, allowing airflow to resume and reinitialize the process. The shift of internal pressure from minimal to maximal pressure occurs as the sound waves change direction, a process occurring at the frequency of the fundamental resonances of the bore. If the player has chosen to play a low A, 110 times a second the pressure waves in the bore shift direction; 110 times a second the pressure at the apex of the bore [where the reed sits] alternates between rarefaction and compression.

That shift from low pressure to high pressure controls the timing of the reed valve opening. So, a fundamental resonating frequency of 110 Hz signals the reed to open 110 times a second and each time it opens the higher pressure coming from the player causes the valves to close and emit another pulse of acoustic energy.

Over and over, at the rate of the fundamental frequency of the note being played, the reed reengages the acoustical activity in the bore *and is at the same time controlled by it.* As a pressure controlled valve, its own operating frequencies are determined by the natural resonating frequencies for any given length of bassoon bore.

It is a two way street, a bidirectional process, and a complex interaction wherein the bassoon reed serves the acoustical needs of the bassoon.

And now, the most overused and misunderstood word in the craft of reed making.

Response…the word we use to describe the behavior of the reed in the context of musical demands. A reed is 'responsive' if…the sound begins with a predictable and comfortable input of air…if it allows changes in dynamic and color with a reasonable amount of embouchure effort and lung pressure…if it will play the pianissimo low E for the Tchaikovsky 6 or a predictable attack for the opening of Le Sacre. But with our new definition of the reed as a 'pressure controlled valve', we can start by defining 'response' in a more objective way.

On one hand, 'response' refers to the reaction of the reed to the flow of air from our lungs. However, response also refers to the reaction of the reed to the complex pressure changes going on in the bassoon bore. As I explained before the break, it's a two way process: the success of your reeds depends both on their functional reaction to the air you put into them AND to the their complex compliance with the acoustical 'information' coming to them from the bore.

I like to describe these two viewpoints of as '*input*' and '*output*' response. They're the Yin and Yang of reed making.

This famous symbol reveals the interconnectedness and interdependence of polar opposites, and we can use the concept to construct a holistic way of thinking about trimming bassoon reeds. As we start to flesh out the meaning of input and output response we will keep in mind that, while we can indeed analyze reed making processes as either '*input*' or '*output*', everything we do ends up affecting the reed's whole behavior.
The *mechanical* reaction of the reed to the input flow of air is the traditional way of characterizing 'response'. Let's examine the *mechanics* of air input.

Before I continue, I want to introduce a new term to your reed making: membranes. A membrane is a pliable sheet or layer especially of animal or plant origin. It comes from the Latin *membrane,* which means skin. I like to thing of the blades of my reeds as the stretched membranes that contain the air and the internal vibrations, while being compliant and responsive to what's happening inside. It's a nice organic word. You can think of tympani heads as being stretched membranes – they were originally made from calfskin, and they vibrate according to their tuned tension and the size of the kettle they're attached to. When I use the word membrane in place of blade, it helps me think of the behavior of the reed in more holistic terms. I wasted a lot years thinking about how individual parts of the reed operate independently – like Sol Schoenbach's assertion that different notes came from different parts of the reed. After 45 years of reed making, I'm at last able to think of the behavior of each blade as interconnected flexibility, a single membrane stretching, contorting and vibrating in a totally interconnected way.

Where was I… Oh, yes, the mechanics of air input.

When we consider the reed as a pressure valve we must think about its ability to modulate air flow by closing and opening. So, the first reaction we are concerned with is how the two membranes respond to the motion of air from our lungs. In my earlier discussion, I described Bernoulli's Principle, which explains how interior pressure *decreases* as airflow accelerates inside the reed. Bassoon reeds are shaped in a manner that encourages acceleration of air; without the arrow shape we would have a very inefficient valve. [We would also not have the necessary transitional from the *horizontal* lips to the *round* tube of the bore.]

A pressure valve works by opening and closing. Do you remember which comes first?

The bassoon reed-valve operates by *closing and then opening.* Not all musical instrument valves work in this way [brass players' lip-valves open before they close.] This idea of first *blowing the reed closed* is critically important to understanding why we profile as we do. For the membranes to bend inwards they require the flexibility achieved through profile thickness.

That Bernoulli effect is strongest where the membranes are close together. Since the membranes are closer together at the tip than at the collar, and the sides are closer together than the midline, so we capitalize on the Bernoulli effect by making the blades more flexible where that effect is more pronounced. Therefore, we [almost universally] make our tips thinner than our backs and our sides thinner than our centers.

In traditional language, we would say that we can't make an attack if the tip is too thick. There is an immediate functional connection between thin tips and input response: the valve must close efficiently to begin the interactivity between air flow and air column excitation.

The Bernoulli induced closing of the membranes is followed by an immediate springing open – those membranes have a lot of internal resiliency. Remember - the timing of this re-opening is determined by the oscillation in internal bore pressure. As soon as the membranes re-open they are once again subject to airflow, followed by internal pressure reduction, followed by Bernoulli induced collapse and the cycle repeats. This closing and opening happens extremely quickly – at the rate of the fundamental frequency of whatever note you are playing. In a very real sense, the 'attack' is not just at the beginning of your tone but at the beginning of EVERY closing and opening.

So, in my language, 'Input response' is a way of describing the efficiency with which the two blades of the reed come together to initiate vibration. And this interaction *is not just at the beginning of each note, but ongoing throughout its full duration.*

The mechanics of input response deal with the relative tensions of the membranes - from side to center and front to back. All connected at a cellular level. The combination of profile and internal structure determines how efficiently the reed responds to the Bernoulli force, both initiating and maintaining the sound.

We can all look at our reeds and observe the shape of the *resting aperture*. The idea of the *functional aperture* – what happens to the aperture while constrained and vibrating – is the more profound concept. If you view the behavior of the two membranes as the outer skin of a mechanical process, it makes sense to control the balance and symmetry of membrane tensions.

All bassoonists employ some degree of dampening pressure with our embouchures. Even those who make the lightest of reeds recognize that the lips do more than simply prevent air leakage. You can't play the bassoon like a recorder. If you want to play high and low, loud and soft, you have to build in enough membrane tension to cope with flexibility of register and dynamics. Then the role of the embouchure is to dampen out the stuff we don't need at any given time.

Building bassoon reeds always reminds me of Goldilocks and the Three Bears. Papa Bear reeds are flat enough to be vibrant in the bottom register; Mama Bear reeds are a bit sharper and comfortable enough for sustained tones in the middle register; Baby Bear reeds are firmer and sharp enough to handle the Ravel Concert high E.

For modern orchestral bassoon playing, one size does not fit all. The trick is to meet Papa Bear's needs with only minimal embouchure pressure, but trim it so you can achieve Mama and Baby's middle and upper register requirements with a comfortable application of embouchure dampening. When we think about Papa Bear's preference, we think of a more open aperture. Most of us will tend to open up our reeds before playing the solo from Peter and the Wolf or articulating the low solos in the Stravinsky Violin Concerto. When we think about Baby Bear's preference, we think of a reed that is sharper and more closed. I wouldn't think of choosing an open, flat reed to play the Ravel Piano Concerto. And in the middle, Mama Bear reeds serve that whole tenor range where all the lyrical orchestral solos reside.

Part of what defines what size 'bear' you're imitating is how your embouchure pressure affects the functional aperture. To understand this concept we need to explore the idea of *dampening.*

In the complex interaction between reed and bassoon, the reed needs a tremendous amount of acoustical compliance; it needs to be able to vibrate in complex, multimodal ways. The membranes must have enough inherent resilience and springiness that they will interact and support a broad band of potential frequencies and amplitudes. Every note we play has a fundamental frequency and a related, complex series of harmonics, all of which need sustaining with variable degrees of loudness. It is rarely sufficient to design a reed that meets only the minimal requirements for a particular range and dynamic. Rather, we need reeds that have the capability to respond to air and embouchure changes to give pianissimo or fortissimo in all registers. We have to make reeds capable of versatility. As bassoonists, our responsibility is to control the whole mess.

We do this primarily by dampening excess vibration in the reed. By combining subtle changes in embouchure pressure and shape with varying amounts of blowing pressure, we can tame the bassoon/reed system to allow softer dynamics, diminuendos or changes in color. Most importantly, we use dampening for *tuning.*

The primary mechanism for dampening is the use of embouchure pressure to change the general openness of the reed. Because of its arrowhead shape, squeezing the embouchure at about halfway back on the blades [where our lips are typically placed] results in a change in the shape of the aperture. Membrane tension – the inherent capacity of the thin wafer of arundo donax to maintain a fixed position – varies according to the width of the cane. Inward embouchure pressure applied around the half way point, translates into more pronounced closing at the tip then if applied in the back half. Typically, embouchure pressure increases concave collapsing of the membrane in the wings.

If we think about the topological changes in the reed from the viewpoint of input response, we recognize that a more closed tip with more concave wings will enhance the Bernoulli effect. This is because bringing the blades together will cause accelerated airspeed and reduced internal pressure. While most of us can identify with the idea that a more closed reed is more responsive to attack, the opposite effect often predominates: if you squeeze the aperture too closed, you *reduce* the efficiency of the attack.

Why the paradox? While embouchure pressure brings the blades closer together it also *dampens* the vibration of the cane and stiffens the membrane. If you hold a tuning fork by its handle, it will ring when struck; if you touch the vibrating portion it will quickly dampen. Sustained acoustical systems like bassoons have several dampening processes. Molecular friction in the bore is undoubtedly the primary dampening culprit, as are little problems like leaky pads or open seams in the bocal. We recognize these are largely detrimental. But the selective embouchure dampening of the vibrating reed is a positive and necessary part of system. Without embouchure control we would have no ability to control pitch and sonority.

Trimming a reed so that it has more natural side to center collapse gives us a head start. We primarily achieve this by thinning the wings, which allows the membrane to relax toward the corners. But, we must balance the advantages of an initially collapsed wing with the disadvantages associated with sides that are too weak. I use the term *functional dampening* to describe the constant interaction of embouchure pressure and membrane tension.

Aperture shape influences not only the overall response of the valve; it allows us to selectively alter response according to the register in which we are playing or to alter the sound spectrum to either enhance or reduce the relative volume of fundamental and overtones.

Whether you trim reeds with very pronounced hearts and very thin tip edges, or prefer a more elongated and heartless trim, the fact remains that the front third of the reed is critical for the relationship between airflow and valve function. One way or another, we utilize the tip area to engage the airflow. When the tip is quick to respond to the Bernoulli effect, the reed gains 'lift'.

The airplane wing is a potent example of the Bernoulli principle at work. Because the top of the wing is curved, air passing over the wing must move faster than air passing beneath the wing. The result is a reduction in air pressure on the top surface, which results in lift. Now, airplane wings have to lift loads and there must be a workable balance between the efficiency of the airfoil, the power of the engine and the amount of cargo on board.

The analogy with a bassoon reed works like this: the reed airfoil is measured by the efficiency with which the front portion of the reed responds to blowing pressure; that very blowing effort is analogous to the engine; and the inertia of the reed, especially in the back half, behaves like cargo.

Carrying this analogy a bit further, we might observe that some players prefer reeds to behave like Cessnas, some like F18 fighters and others prefer an Airbus 320.

Being sensitive to the immediate connection of airflow and vibration is a critical skill for the bassoonist. Much depends on the average amount of air you are willing to use. One of the illuminating experiences for young reed makers is their first opportunity to play on reeds that might be considerably heavier than they have started with. Like the Airbus, it takes a lot of initial blowing pressure to achieve liftoff. But – and this is very important – the fact that a reed may require more air to engage the blades does not mean that the reed will be unable to perform pianissimo or to allow notes to taper. The Airbus can still land gently!! It just takes more work.

In the summer of 1975, Milan Turkovic and I were the two bassoonists at the Marlboro Festival. At our first rehearsal together, I asked to try his reed – I could not make a sound on it. He was used to a lot more basic effort, a kind of an Airbus reed. I eventually moved in the same direction, as I developed a more robust sound for a large symphony hall.

The analogy of the wing providing the right amount of lift for the engines and the cargo fits nicely into this new vision of reeds. If the blowing pressure represents the horsepower in the airplane engine, what is corollary to the 'cargo'? Really, it's just the stiffness of the membranes as a whole. If the cane wasn't inherently stiff, the cane plant would fall over. You have to remove enough material so that the lift from the tip can 'drive' enough motion in the whole valve to satisfy the acoustical needs of the bassoon.

So, it's time to focus on the idea of *output response.*

Our unavoidable focus on the bassoon reed can give us the misleading idea that the reed is *creating the sound* and the bassoon is just an amplifier. But the reed is more like a servant to the natural resonating frequencies of the bassoon bore. Great reed making is about making the reed *compliantly* serve these acoustical needs. My term '*Output response'* is a way of describing this *compliance.* It's the 'willingness' of the membranes to cooperatively flex in reaction to the complex variations in pressure going at the apex of the conical bassoon bore.

Successful sound depends on the interaction of bassoon, reed, embouchure and oral cavity. Without the physical attachment to the bassoonist, a rich and beautiful tone can't be achieved. Skillful players use lip dampening to adjust membrane tension and select the richest harmonic spectrum.

Because the conical bore of the bassoon is truncated at the small end [permitting the presence of a reed valve], the natural resonating frequencies for the bore are somewhat compromised. The problem has to do with the tuning of the 2nd, 3rd and 4th modes of vibration. When you play F#3 [in the staff] you make a first finger half-hole. This is in effect a *leak* which eliminates the possibility of the fundamental F#2 from sounding. From this note up through D4, we play the bassoon in its 2nd mode. From Eb4, we begin to play in the 3rd mode; Eb is actually the 2nd overtone of the fundamental low G, creating by making a leak in the bore at the left hand 3rd finger. But wait! The second overtone should be a perfect 12th higher. So, why is this an Eb instead of a D? It has to do with the stretching of the overtones due to that truncated bocal. 3rd and 4th mode notes, i.e. everything from Eb4 up, are increasingly sharp. It is only with patient attention to embouchure and oral cavity shaping, and some judicious fingering adjustments, that we can play the upper register of the bassoon in tune.

If you were a brave little acoustical physicist sitting inside a bassoon reed, you'd be in a position to observe the remarkable complexity of air pressure variations that constitute the ongoing tone.

Of course, you would feel a general breeze flowing from the mouth towards to the bassoon; without that flow we would not have the mechanism for the constant input of energy. The sound of the bassoon does not come from that flow of air, but from the rapid back and forth pressure waves induced by the pressure controlled oscillations of the reedvalve.

Further imagine that you could slow the passage of time…

Surrounded by this large shell, you watch the closing and opening of the thin membranes of the blades, contorting into various shapes as they interact with both the air flow from the player [via input Bernoulli force] and the complex multi modal pressure variations associated with every pitch on the bassoon. With increased blowing pressure [crescendo], you would see an increase in the size of the membrane displacements and some changes in the symmetry of the whole process. You are fascinated to observe that while dynamic changes affect the amplitude of motion, the essential frequency of this activity remains the same. As a mezzo forte is attained, you are surprised to see the blades stay closed for a longer period within each cycle. You are dimly aware that the bassoonist is making changes in how he *dampens* all this vibration. You notice he is increasing the embouchure tension when the overall frequency seems too slow, or relaxes when the frequency is too fast. Above all, you are amazed to see that the blades seem to be closing and opening in a totally nonlinear way, asymmetric in both shape and time. You think to yourself that the bassoonist – who embouchure is valiantly dampening this complex activity– could just as well be riding a bucking bronco…

The bassoon reed valve needs to have tremendous flexibility in order to accommodate the countless frequencies produced throughout the full range of the instrument. Just as a violin string needs to move simultaneously in both its whole length and in many divisions, the reed must be able to move in wide, slow modes of closing/opening and narrow, fast modes. Viewing this action from inside the reed in our hypothetical slowed-down time, we are able to observe lower frequency full side to center closures of the tip aperture and at the same time witness higher frequency displacements along the longitudinal midline of the reed. We can witness how the multimodal closing and opening of the valve supplies the necessary energy to sustain the multiple frequencies and varying amplitudes of pressure waves oscillating in the bore.

From this vantage point, we can also watch the changes the bassoonist makes to help optimize the reeds interaction with this bore output. The most obvious change is the effect of embouchure pressure on the overall opening of the reed. The bottom blade and the top blade are brought closer together - or allowed to remain apart – according to range and dynamic.

If the bassoonist is trying to play Prokofiev's Grandfather he will allow the blades to remain as far apart as possible. This allows the internal cavity of the reed to be slightly larger and for the cane itself to move a bit more freely.

I describe the design and tuning of the reed with a little formula. If you think about it, the conical bore never actually reaches and apex, or a point. Instead, it is cut to allow a reed and the input of energy. There is a certain theoretical volume to that missing bore - that truncated cone. The size and the flexibility of the reed has to substitute for the missing conical ape. If your missing conical apex was a larger volume, the instrument would play flatter; if your missing conical apex was a smaller volume, the instrument would be sharper. The two factors that describe how the reed substitutes for that missing volume are physical size and flexibility.

Here is my formula, which my students grow to love or hate, depending on their success with reeds.

Reed Volume modified by Compliance equals the theoretical Missing Conical Apex.

Rv X C = MCA

You could also say, the length and width of the reed, tempered by how flexible it is, produces a predictable tuning outcome.

Playing the Grandfather requires us have a Papa Bear reed because the bottom range of the instrument responds best to a bigger, flatter reed with more compliance; in other words, the MCA needs to be effectively longer. Papa Bear reeds are achieved through increased reed cavity volume and more flexible membranes. A large, free blowing reed makes the Grandfather easier to play. By relaxing the embouchure and allowing the blades to sit slightly farther apart, the bassoonist allows the reed to operate with that necessary increased internal volume; that same relaxation takes some of the dampening tension away from the material, decreasing inertia and increasing the reed's compliance to the lower register frequencies.

If the bassoonist is trying to play the Bolero solo she will close down the aperture with embouchure pressure. This makes the internal cavity of the reed slightly smaller and increases the membrane tension, in other words, decreasing the compliance of the cane. That's the Baby Bear reed. The high register of the bassoon operates best with a smaller effective MCA.

Getting back inside the slow motion reed, and observing the complex aperture shapes from within, we also notice a very important change in the overall shaping as we move from low register to high register. There is a reduction in the amount of motion out in the wings, a weakening of the relative strength of vibration at the wider portions of the reed. This collapse of the wings occurs because the blade membranes become concave with increased embouchure pressure. Concavity in the wings reduces the potential amplitude of motion in the wider, slower modes of vibration. In other words, when we squeeze the lips we reduce membrane motion in the corners.

The widest modes of vibration support the lowest frequencies for any given note. Embouchure dampening therefore reduces the amount of energy in the fundamental frequency of any note on the bassoon. It turns out that the ability to selectively dampen the lowest available vibrational mode is absolutely essential to playing the bassoon in its upper modes. As we begin to play in the 2nd mode from half-hole F# up, and in the 3rd mode from Eb above the staff up, and in the 4th mode in the altissimo, more than half the range of the bassoon requires dampening and elimination of the fundamental and later the 2nd and 3rd harmonics.

You can prove this to yourself with all but the most extremely light reeds. Play the reed with your lips over the 1st wire and observe what happens as you ascend chromatically. The bassoon may continue to operate for a few notes past F# but you will almost certainly find the bassoon reverting to its lower modes, and sounding like a dying porpoise.

Repeating the experiment with lips on the reed but with only enough embouchure to seal the air will take you a little bit further – or much further if your reeds are quite light. Instinctively, we tend to dampen the embouchure and increase air support as we ascend.

Back inside the time dilated reed, we can see the player frequently dampening or relaxing the reed as he moves from note to note. Reducing reed cavity volume through dampening raises the pitch of the flat notes; increasing the volume through relaxation lowers the sharp ones. Increased embouchure pressure increases the tension of the membranes, raising their operating frequencies.

From your perch inside the reed, you observe how increased dampening facilitates a diminuendo, whereas embouchure relaxation facilitates the crescendo. Dampening the reed reduces the overall *amplitude* of its vibrations. Relaxation allows greater airflow, increasing amplitude and loudness.

We all know that when we press a violin string to the fingerboard and shorten the vibrating length, the pitch will rise. But what happens when we only slightly touch the string? The initial effect will be to *deaden* the vibration making the string more resistant. We're effectively choking the string's vibrational modes so the bow must work a harder to overcome the increased resistance. We see the same effect in reeds - embouchure dampening necessitates increased air input.

Our intuitive use of the embouchure to alter the size of the reed and the shape of the aperture has a direct effect on both the input response and the output response of our reeds.

Much of the skill of reed making hinges on this fact. In this new model of reed acoustics, decisions about the best place to trim involve choosing which aspect of response is most pertinent to a given situation. We might begin with "Is the reed failing to respond to the Bernoulli function because of inflexibility in the front?" or "Is the problem due to its lack of compliant response to the tuning of the overall system?" The next question might be "Am I dampening the embouchure in order to bring the blades closer together to enhance the Bernoulli function", followed by "Is my closed embouchure compromising output response by making the system too sharp?" "Is the system too sharp because the embouchure dampening is making it smaller or because the greater tension on the cane is raising the pitch of the system?"

As you can see, these questions start to get more and more involved, because we're back at the intersection of Yin and Yang. Trimming for input response has a critical effect on the factors defining output response and vice-versa. The art is in learning how to balance these two interacting behaviors for the best results.

So, what are you going to do with this information? Does it have relevance to the next time you pull out your reed tools? Is there a concrete model, a set of dimensions, a certain pitch, a certain crow that you should now pursue.

Probably not. I don't advocate the one size fits all approach to reedmaking. Your teachers and great artists and experienced reedmakers, and they have painstakingly learned their craft and formed their opinions for very good reasons.

But let me give you a brief list of some concrete things to thing about when you next profile a stick of cane, build a blank and then start trimming it.

If you accept this proposed model, then you are going to be committed to viewing your reeds as well designed valve mechanisms. So you had better take care of the details. Whether you prefer wide reeds, narrow reeds, thin tips, channels/no channels, thick backs, thin backs…there is no right solution. Have some humility: you cannot micro manage how the bassoon controls the profoundly complex, non linear vibrations of your reeds. The best you can do is to commit to bassoon reeds that are built with highly symmetrical structures. That means blades that are balanced, even and that sit in opposition to each other like mirror images. Everything you can do to make your reeds look beautiful will translate into rapidly improved outcomes.

The motion of these reedvalves is so incredibly complex and so nonlinear, they're not going to function better if you make them inherently uneven. The asymmetry of the coupled system will be achieved more successfully with increased symmetry of the valve itself. For this reason, I strongly advocate one overall design rule, and that is to make profile transitions smooth. Those of you who like abrupt changes in thickness at various points in your reeds will be averse to this. So let's compromise, if you must trim your reeds with the hills and valleys of American oboe reeds, at least try and make the bumps symmetrical in all four quadrants.

Next, if you are using your Indiana University profilers to do the work for you, and by that I mean most of the profile work, you are probably doing your self a disservice. This is a harsh viewpoint, but from my experience if you can't take a popsicle stick heavy blank and trim it successfully you will always be constrained as a reedmaker. Furthermore, I cannot recommend to you highly enough the tremendous gains you can make by hand profiling. Yes, you heard me. I guarantee that if you don't touch a profiler for the next six months and do everything by hand you will be a much better reed maker at the end of those six months. Why? Because it forces you to imagine the contours you want and requires your hands to do better work. And, most importantly, instead of profiling within a fraction of an inch to your desired outcome, and suffering the painful loss of reeds built from cane that is too soft, you should learn to be like Michelangelo. Michelangelo looked a block of marble and saw the David hiding inside. He just had to remove the extra stone.

So, to conclude this very long lecture, I invite you to start using your brains, think of membranes and think like Michelangelo.

Thank you.

Postscript…

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In the preceding essay, you will have seen a couple of references to "MCA"

This refers to a formula we use to think about how size and stiffness affect the outcome of reed design:

The formula is - Rv x C = MCA

*What the *%$#???*

Those of you who are new to my studio and language about reedmaking will need to understand this equation. You are going to hear this quite frequently. This little equation is a very simplistic way to talk about tuning and the relationship between reed size, reed behavior and the effective pitch of bassoon/reed systems.

"Rv" stands for reed internal volume, which is a result of the length, width and height of the reed. A big honker of a reed will be have a large "Rv" value. A tiny little reed will have a small Rv value.

"C" stands for compliance. Compliance is a great word to use about reed behavior and it means pretty much the same thing as the word "compliance" does in human behavior. If you are flexible and giving in your relationships, you are being compliant. In acoustical terms, compliance means flexibility and ease of motion, a willingness to vibrate and flex in response to acoustical forces.

MCA sounds like the name of a grunge band. At NU we use the acronym to mean "Missing Conical Apex"**.** This is easier than it sounds. Your bassoon has a conical bore, which means it gets smaller the closer you get to the energy conversion source [THE REED !!!!]. In geometry, cones have an apex, where the taper comes to a point. You could make a bocal that came to a point, but it would be a bit impractical. [There would be no place to put the reed and you would have to make all the sound from the other end….] We truncate the cone to create an opening for the reed. The missing part of the cone is the "Missing Conical Apex"**.** The longer the missing conical apex would have been, the greater the internal volume of the bore as a whole. The bassoon reed takes the place of that MCA, so it is a convenient way to think about how reed dimensions impact pitch.

The key thing to remember about the MCA is this: if it is theoretically longer, the resulting acoustical system will be larger and flatter in pitch. If it is theoretically shorter, the system will be sharper.

You can start plugging specific values into this Magic Equation and pretty soon some commonsense results will be evident.

Here are some examples:

If the reed is long and wide, the Rv value will be larger. If "C" was a constant, then logic tells us that the resulting MCA value will be larger as well. The simple conclusion is that increasing a reed's length or width, without necessarily altering its compliance, will produce the same effect as playing on a longer bocal. The result is a flatter system.

Works the other way, too…

If the reed is short and narrow, the Rv value will be smaller and the resulting MCA value will be smaller. This is like playing on a shorter bocal and produces a sharper system.

On the other hand, we can leave the Rv value as a constant and change the "C" compliance value.

A more flexible reed has a larger compliance value and therefore an increase in the resulting MCA. Conclusion? A more flexible reed produces a larger MCA value, just as increasing the length of the missing bocal would. The result is a lower pitched system.

A less flexible reed has reduced compliance and therefore a decrease in the resulting MCA. This produces the same effect as a shorter missing conical apex and results in a sharper system.

All the normal variables in your reed making fit easily into this equation and your experience as a reed maker will fit the predictions of this model.

Many changes to reed design have a simultaneous effect on both volume and compliance. What do you do with a collapsing E? Cutting a reed shorter prevents the drop – by reducing its volume and decreasing its compliance the overall effect is to raise the pitch of the system. Sharp low register? Drop the pitch of the whole system; removing cane generally increases a reed's compliance and produces an increased MCA value. A larger MCA = more flexible reed, lower pitch system = Pathetique Symphony! Ravel G major? High E's like higher pitched systems = smaller MCA value = stiffer, or smaller reed.

Here are some factors effecting compliance…..

- Profile thickness
- Profile distribution
- Cane hardness/softness
- Cane stiffness/resilience
- Tube structure
- Age of cane
- First wire tension/openness
- Cane gouge
- Gouge eccentricity

Here is another way of expressing the Rv x C = MCA relationship:

<u>The size of the reed combined with its willingness to vibrate defines the effective pitch of the system.</u>