Sumui acoustics: An introduction to how a Sumui works

Joyanta Sarkar[*], Anil Rai[**]

[*] Research Scholar, Department of Humanities and Social Science, Birla Institute of Technology and Science, Pilani
[**] Assistant Professor, Department of Humanities and Social Science, Birla Institute of Technology and Science, Pilani

Abstract- Music is important to the Tripuri people of North-East India and Bangladesh since it is directly intertwined with their socio-social existence. The Tripuri clans' instruments and music claim their wealth and profundity of imaginations related with the entrance of the primary note. They often try to retain rhythm and tempo while travelling by hitting a drum. Tripuri's folk music is known as Tipra Bharat. The clan's music is as ancient as the clan itself, and it has continually served as a convention. Tripuri people tunes, like all other people melodies from other zones, are commonly shared among the general population. These tunes were composed by people whose personalities were unknown and overlooked during the start of their lives. Old customs, ideas, wishes, love, the evolution of jhum collecting, festivities, convictions, superstitions, and so on all influence people's music. The musical theme has remained unchanged over time, and society tunes are still performed by people surprisingly and excitedly in their original form or with minor variations. Individuals from Tripuri undertake a variety of traditional rituals. As a result, after some time, the next generation no longer uses many of these technologies, and they are being phased out of the world. Many people in Tripuri are currently unaware of the names of such instruments or their presence. These instruments are not perceived by a substantial section of the younger generation. Some instruments are specifically designed to cause individuals to change their behaviour. In this paper we are presenting the physics of Sumui.

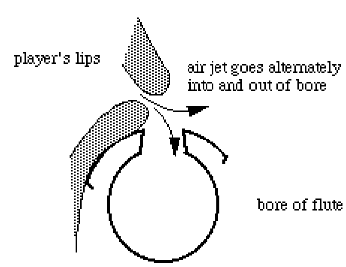
Index Terms- Lipping, Upstream Space, Ultra High Resonance, Viscothermal, Pinschofon

I. INTRODUCTION

A fast jet of air is blown through the embouchure opening by the sumuist. The pressure within the player's mouth is greater than the ambient pressure (typically a few tens of kPa: enough to support a few tens of cm height difference in a water manometer). The power input to the instrument comes from the labour done to accelerate the air in this jet. The player continually supplies power: in a practical comparison, it is analogous to DC electrical power. Sound, on the other hand, needs an oscillating motion or air movement (like AC electricity). In the sumui, an oscillating component of the flow is produced by the air jet in collaboration with the resonances in the air in the instrument. When the air in the sumui begins to vibrate, part of the energy is transmitted as sound via the end and any open holes.Much more energy is wasted as a result of friction (viscous loss) with the wall. This energy is replaced by the player's energy in a sustained note. The air column in the sumui vibrates significantly more easily at certain frequencies than at others (i.e. it resonates at certain frequencies). These resonances greatly influence the playing frequency and consequently the pitch, and the player selects the appropriate group of resonances by selecting a proper key combination. In this article, we will look at each of these impacts individually.

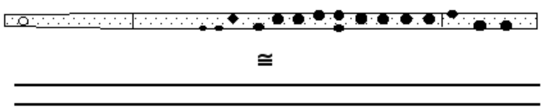
II. THE JET OF AIR TREMBLES

The embouchure hole's sharp outer edge is struck by the air jet the player's lips produces as it crosses over the hole's aperture. This type of jet can blow into or out of the embouchure hole when it is disturbed because of a displacement that moves along it and deflects it like a wave. The airspeed of the jet, which is typically in the range of 20 to 60 metres per second, depends on the air pressure in the player's mouth, is about equal to the speed of this displacement wave on the jet.The jet disturbance is caused by the sound vibration in the sumui tube, which causes air to flow into and out of the embouchure hole. If the jet speed is exactly tuned to the note being played, the sumui will generate a sustained tone. To amplify the sound, the jet will enter and exit the embouchure hole at the further edge at exactly the proper phase.In order to generate high notes, the travel time of waves on the jet must be shortened to meet the higher frequency. This is done by increasing blowing pressure, which accelerates the jet, and pulling the lips forward to reduce the distance along the jet to the tip of the embouchure hole.We ultimately learn to make these adjustments on our own when playing the sumui. Flautists are often taught to narrow their lip aperture when playing high notes. The jet is alternately directed up and down, out of and into the bore in the picture to the right of the sumui at the embouchure.

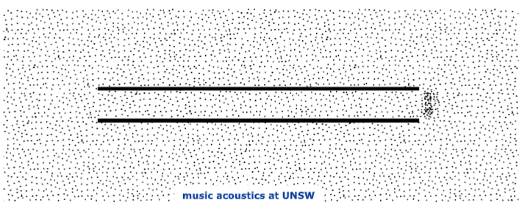


III. THE SUMUI IS AN OPEN PIPE

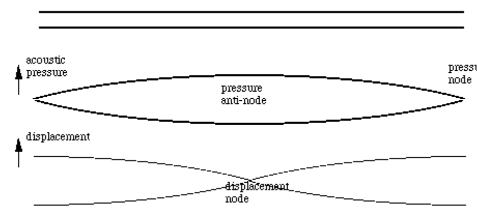
Both ends of the sumui have apertures. It is obvious that the other end is open. Even though the player's lower lip partially covers the embouchure hole, a sumui player maintains a considerable amount of the hole that is visible to the surroundings, as seen in the illustration above. To begin, let's consider a pipe that is simpler than a sumui. First, we'll suppose that it's a simple cylindrical pipe, which implies assuming that the head is cylindrical and that all holes are closed (at least to a certain point). The side-mounted embouchure hole will also be replaced with a hole at the end. Actually, it sounds more like a shakuhachi and less like a sumui. Despite being a poor approximation, it retains a lot of the basic mechanics and is easier to discuss.



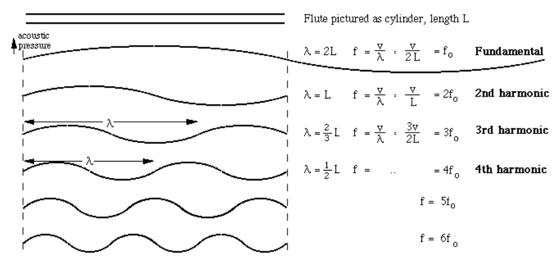
A more detailed explanation is given in the animation that follows, which is from Sumuis vs. clarinets: Open vs. Closed Pipes. It exhibits the reflection of a high pressure pulse in a pipe having air holes on both ends. Remember that one entire cycle of vibration is equal to the time it takes the pulse to travel twice as far as the sumui (once in each direction). Because the pulse moves at the speed of sound, or v, as we shall discover later, the cycle would repeat at a frequency of v/2L.



Resonances are what cause the air in the sumui to naturally vibrate. The fundamental or lowest resonance of the sumui is demonstrated by the air pulse that reflects in the animation. The standing waves page contains further information about resonances. What resonances or standing waves are conceivable in an open cylindrical tube? We will now provide a solution to this query using sine waves and harmonics. Since the ends of the pipe are exposed to the atmosphere, the total pressure there must be close to atmospheric pressure, which indicates that the acoustic pressure—the fluctuation in pressure brought on by sound waves—is zero. These spots are known as pressure nodes, and they actually extend just a little bit past the tube's end (about 0.6 times the radius, as shown: this distance is called the end correction). It is not necessary for the pressure within the tube to be atmospheric; in fact, during the initial resonance, the centre of the tube has the greatest pressure fluctuation (the pressure anti-node). Below is a drawing of a standing wave. The difference in pressure is shown by the bold line, and the difference in the displacement of the air molecules is shown by the fine line. The latter curve features anti-nodes at the ends, where air molecules can freely enter and exit. (Take note that a node for air motion and a node for pressure are not the same thing; in fact, pressure nodes sometimes overlap with anti-nodes for motion and vice versa. Examine pipes and resonances. In Open vs. Closed Pipes (Sumuis vs. Clarinets), which contrasts them using wave diagrams, air motion animations, frequency analyses, or other flow animations, the differences between closed and open pipes are described.)



The wave shown above is the longest standing wave that can satisfy this condition of zero pressure at either end. In the figure below, we see that it has a wavelength twice as long as the sumui. The frequency f equals the wave speed v divided by the wavelength l, so this longest wave corresponds to the lowest note on the instrument: C4 on a C foot instrument. (Sumuists please note: this page uses the standard note names, not the names sometimes used by sumuists.) We might want to measure the length L of our sumui, take the speed of sound as v = 350 metres per second for sound in warm, moist air, and calculate the expected frequency. Then check the answer in the note table. (We will find that the answer is only approximate, because of end corrections.)We can play C4 on the sumui with this fingering, but we can also play other notes by blowing harder, or by narrowing the lip aperture (either gives a faster jet). These other notes correspond to the shorter wavelength standing waves that are possible, subject to the condition that the sound pressure be zero at both ends. The first several of these are shown in the diagram below.



The series of notes with frequency f_o, $2f_o$, $3f_o$ etc is called the harmonic series, and notes with these frequencies have the pitches shown below. With all the tone holes closed, the first ten or so resonances of the sumui are approximately in this ratio, so we can play the first seven or eight of the series by closing all the tone holes and blowing successively harder (or by narrowing the lip aperture). Note the half sharp on the seventh harmonic - it falls roughly midway between A6 and A#6. (We might be interested to compare this with the analogous diagram and sound files for the clarinet, which has only the odd harmonics present. There is also a more detailed discussion of the harmonic series of open and closed pipes. Also see a warning about the words 'fundamental' and 'harmonic'.)

Each of the standing waves in the sketch above corresponds to a sine wave. The sound of the sumui is a little like a sine wave (a very pure vibration) when played softly, but successively less like it as it is played louder. To make a repeated or periodic wave that is not a simple sine wave, one can add sine waves from the harmonic series. So C4 on the sumui contains some vibration at C4 (let's call its frequency f_o), some at C5 ($2f_o$), some at G5 ($3f_o$), some at C6 ($4f_o$), etc. The 'recipe' of the sound in terms of its component frequencies is called its spectrum. (See sound spectrum for an explanation.) Looking at real sound spectra for played C4 (Open a new window for C4) we will see that, at *pianissimo*, the first harmonic (fundamental) and the frequency of the note C4 dominates, and that the higher harmonics become more important as the note is played more loudly, and as the sumui develops a richer tone and sounds less and less like a sine wave. (For a detailed explanation, see Loudness and timbre.)

IV. HOW THE AIR JET AND PIPE WORK TOGETHER

To sum up the preceding sections: the bore of the sumui has several resonances, which are approximately in the ratios of the harmonics, 1:2:3:4 etc, but successively more approximate with increasing frequency--we'll see why below under frequency response. The air jet has its own natural frequency that depends on the speed and length of the jet. To oversimplify somewhat, the sumui normally plays at the strongest bore resonance that is near the natural frequency of the jet. (We shall see below how register holes are used to weaken the lower resonance or resonances and thus make one of the higher resonances the strongest.). When the sumui is playing, the jet is oscillating at one particular frequency. But, especially if the vibration is large, as it is when playing loudly, it generates harmonics (see what is a sound spectrum?). For low notes, the first several harmonics are supported by standing waves. However for high notes, the resonances of the sumui are no longer harmonic, so only a small number of harmonics---only one in the third and fourth octave are supported by resonances of the bore. Played loudly however, harmonics of the vibration are present in the spectra, as we can see by looking at the spectra for any note.

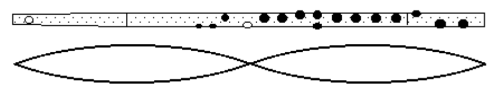
V. OPENING TONE HOLES

If we open the tone holes, starting from the far end, we make the pressure node move closer up the pipe - it's rather like making the pipe shorter. On the Boehm sumui, each opened tone hole raises the pitch by a semitone. After we open 4 holes on a C foot sumui, as shown below, we have the fingering for E4, which is shown below. (Open a new window for E4).

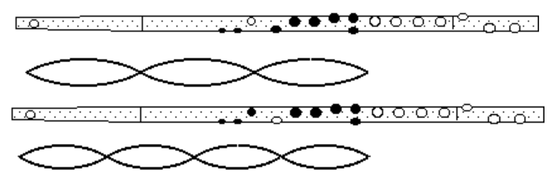
For the moment, we can say an open tone hole is almost like a 'short circuit' to the outside air, so the first open tone hole acts approximately as though the sumui were 'sawn off' near the location of the tone hole. We shall return to qualify these assumptions below when we discuss register holes and cross fingerings. (For the technically minded, we could continue the electrical analogy by saying that the open tone hole is actually more like a low value inductance, and so it behaves more like a short circuit at low frequencies than at high. We return to this point when discussing cut-off frequencies below.)

VI. REGISTER HOLES

Holes can also serve as register holes. For instance, if we play C4 and then lift our left thumb, we are opening a hole halfway down the instrument. This makes the fundamental and the odd harmonics impossible, but hardly affects the even harmonics, which have a node there. So the sumui 'jumps up' to C5 ($2f_1$), and will also play C6, G6 etc. Here the register hole makes the played note (at least) one octave higher, because it is halfway along the working length of the sumui and so permits the second harmonic of the fundamental C4. The example shown is not a standard fingering, but a register hole at half the length is used for the standard fingerings for D5 and others.



When the desired wavelength is short (i.e. for high notes) one can open a register hole at a different fraction of the length. For example, the fingering for D6 uses a register hole at approximately one third of the working length for G4, and so facilitates the third harmonic of G4 (and thus produces a note a twelfth higher than G4). The fingering for G6 also uses the working length for G4, but has a register hole about one quarter of the way along, and so facilitates the fourth harmonic.



One of the alternative fingerings for D#6 uses the working length for D#4 but has two register holes, at one quarter and one half the wavelength. Notes in the third octaves of all sumuis rely heavily on using tone holes as register holes. Specific examples are explained on the pages for these notes. (See Sumui Acoustics and choose a note above D#6.)

VII. ACOUSTIC IMPEDANCE OF THE SUMUI

The way in which the jet flows into and out of the sumui depends upon the acoustic impedance at the embouchure hole, which is why we measure this quantity. The acoustic impedance is the ratio of the sound pressure to the oscillating air flow. (See Acoustic impedance for more detail.) If the impedance is low, air flows in and out readily and a loud sound can be produced. In fact, the resonances, which are the frequencies for which the acoustic impedance is very small, are so important that they 'capture' the behavior of the air jet, and so the sumui will play only at a frequency very close to a resonance. We discuss the acoustic impedance below, under Frequency response of the sumui. There is further explanation on what is acoustic impedance and why is it important? and also a discussion of the impedance for C4.

VIII. CROSS FINGERING

On the modern or Boehm sumui, successive semitones are played by opening a tone hole dedicated to that purpose. There are twelve semitones in an octave, so that one needs to open twelve keys in a chromatic scale before going from say D4 in the first register to D5 in the second register. (Because of the use of register holes for D5 and D#5, the fingerings do not repeat exactly over an entire octave, but only between E4/5 and C#5/6.) Twelve holes exceeds the number of fingers on standard players, particularly when the right thumb is employed to support the instrument. Boehm's key system employs clutches so that one finger can close more than one hole.

Sumuis in the baroque and early classical periods had few keys. (See The anatomy and evolution of the sumui.) They had six open holes covered by the three large fingers on each hand. Opening these holes in sequence gave the 'natural' scale of the instrument, which was D major. Writing X for closed hole and O for open, the fingering chart for such an instrument is approximately:

D4 : XXX XXX
E4 : XXX XXO
F#4: XXX XOO
G4 : XXX OOO
A4 : XXO OOO
B4 : XOO OOO
C#5: OOO OOO
D5 : OXX XXX

with E5 to B5 using the same fingerings as E4 to B5. (Much more detail on fingerings and how they work is given on the pages for baroque and classical sumuis.)

On such instruments, cross fingerings are used to produce some of the intervening notes. In a cross fingering, further holes are closed downstream from the first open hole. For example, the fingering for F4/5 on the baroque sumui is:

F4/5 : XXX XOX

Compare this with the fingering for F#4/5, which is XXX XOO. For F#, the standing wave extends down the bore of the instrument past the first open hole. The extended wave is stronger in the baroque or classical instruments than in the modern sumui because the holes are smaller and so the acoustic impedance between the bore and the outside field is smaller. (In the modern sumui, the open hole acts more like an acoustical short circuit, so the sumui behaves almost as though it were 'sawn off' at a point not far below the first open hole. So the modern sumui has relatively small end corrections.) Closing the downstream hole extends the standing wave even further and so increases the effective length of the instrument for that fingering, which makes the resonant frequencies lower and the pitch flatter.

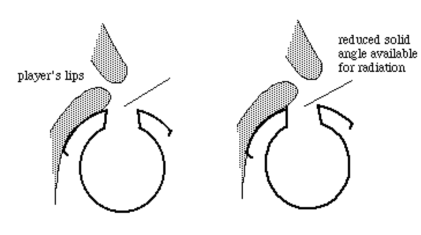
The effect of cross fingerings is frequency dependent. The extent of the standing wave beyond an open hole increases with the frequency, especially for small holes. This has the effect of making the effective length of the sumui increase with increasing frequency. As a result, the impedance minima at higher frequencies tend to become flatter than strict harmonic ratios. One effect of this is that some cross fingerings cannot be used in both first and second register: the cross fingering used for G# in the first register will be too flat in the second register, or may not even play a note near G# at all. (See for example the fingerings for G#4 and G#5 on the baroque sumui.)

A further effect of the disturbed harmonic ratios of the minima in impedance is that the harmonics that sound when a low note is played will not 'receive much help' from resonances in the instrument. (Technically, the bore does not provide feedback for the jet at that frequency, and nor does it provide impedance matching, so less of the high harmonics are present in the jet and they are also less efficiently radiated as sound.) As a result, the sound spectra for notes such as F4 and G#4 on the baroque sumui have weaker higher harmonics, and so these notes are less loud and have darker or more mellow timbre than do the notes on either side.

We noted previously that the 'natural' scale of these instruments is D major: in D and in B minor they use no cross fingerings, so their timbre is bright. In Eb major or C minor, their timbre is dark and they play more quietly. These observations are also true of the baroque oboes, baroque (and modern) recorders, and approximately true of the baroque bassoon. I suspect that this has contributed to the different qualities associated with different keys: keys with a couple of sharps are associated with bright and relatively loud winds, whereas keys with a few flats are associated with dark and quiet winds. For more information on the acoustics of cross fingerings, download a scientific paper on the topic.

IX. 'LIPPING' UP AND DOWN

The design of a sumui involves compromises and many notes require slight pitch adjustment by the player. (See Tuning woodwinds.) Players lower the pitch mainly by a combination of drawing the chin back or pushing it forward, rolling the sumui's embouchure hole towards them or away and changing the jet geometry. These actions do several things: (i) they increase the fraction of the embouchure hole that is covered by the lower lip, thereby decreasing the size of the hole opening to the atmosphere, (ii) they decrease the solid angle available into which the sound wave can radiate (informally: they 'get in the way of' the radiation), and (iii) they decrease the length and change the angle of the jet .

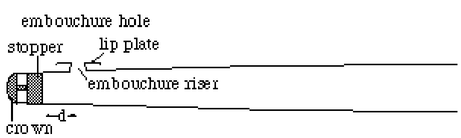


Effects (i) and (ii) increase the effective length of the sumui and so make the resonant frequencies lower and the note flatter.

Rolling the embouchure away and/or extending the lower jaw have the reverse effects, and so raise the pitch. Technically, these actions work because they change the radiation impedance at the embouchure: when a note is 'lipped down', the embouchure hole is "less open" (both the hole and angle are smaller so there is more impedance to radiation from the bore to the external field). The effects of the jet itself are more complicated.We have measured these effects explicitly by installing our impedance measuring equipment in a sumui head and measuring the impedance at the embouchure hole. (This is the impedance of the radiation field, 'looking out' from inside the blowhole, which is partially blocked by the lower lip. The flutist's lip and face also provide a baffle that reduces the angle for radiation. These results are reported in a recent conference paper - see our research papers site.) The interval that can be lipped depends on the details of the impedance spectrum and on some properties of the jet. It is easier to adjust the pitch of notes using a short length of tube, whose impedance spectra have fewer and shallower harmonic minima than do those of long tube fingerings. The analogous effects are much bigger on the shakuhachi, and are described on that site.

X. THE CORK AND THE 'UPSTREAM SPACE'

Between the point where the embouchure riser meets the main bore of the sumui and cork in the closed end of the instrument is a small volume of air. The cork is normally positioned to be about 17 mm from the centre of the embouchure hole (the exact value varies from player to player - see tuning wind instruments). Any very substantial variation seriously upsets the internal tuning of the sumui. So how does this work?

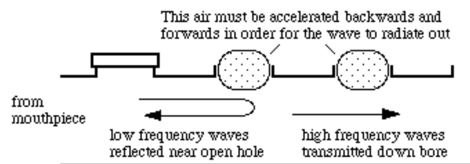


This 'upstream air' acts like a spring - when we compress it, the pressure rises. The air in the embouchure riser tube can be considered as a mass. Together they can resonate like a mass bouncing on a spring (ie they form a Helmholtz resonator).This has a resonance over a broad range of frequencies, but centred at about 5 kHz. At much lower frequencies, which is to say over the playing range of the sumui, it acts as an impedance in parallel with the main part of the bore, but an impedance whose magnitude decreases with frequency. The primary effect of this is good: with the cork correctly placed, it compensates for the frequency dependent end effects at the other end of the sumui and so keeps the registers in tune with each other. On the other hand, it does reduce the variation in impedance with frequency when the frequency approaches the Helmholtz resonance, and so is one of the effects that limits the upper range of the instrument. If we push the cork in, as Charanga style players do, we can go further up into the fourth octave, but at the expense of having an instrument whose octaves are badly out of tune. If we want to know more about this effect, download our technical paper about it. To scale the highest reaches of the sumui's range, search for 'high playability' fingerings on the virtual sumui and the report on F#7 and G7

The important message for sumuists, however, is this. Among the orchestral winds, the sumuis have the simplest method of adjusting their internal intonation. If our octaves are narrow, try pushing the cork in a little. If they are wide, pull it out. We will of course have to move the tuning slide as well. See also tuning wind instruments.

XI. CUT-OFF FREQUENCIES

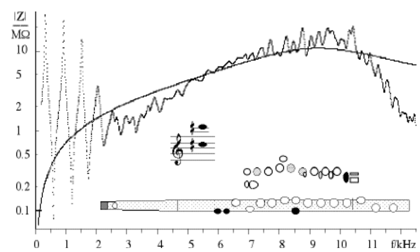
When tone holes were initially considered, we claimed that they lowered the tube's effective length because they expose the bore to outside air. This is true at low frequencies because the hole creates a low impedance'short circuit' to the outside air, which causes the wave to reflect at or around this location. However, it becomes more challenging at high frequencies. The air around the tone hole and inside it is dense. A sound wave must accelerate this mass in order to travel through the tone hole, and (all other things being equal), the needed acceleration rises with the square of the frequency, leaving little time for a high frequency wave to start moving after half a cycle.



The air in the tone hole therefore acts as a barrier to high frequency waves since it doesn't 'appear so open' to them as it does to low frequency waves. High frequency waves travel longer (which can enable cross-fingers), while sufficiently high frequency waves pass down the tube past the open holes. Low frequency waves are reflected at the first open tone hole. As a result, a series of open tone holes serves as a high pass filter, allowing high frequencies to pass while rejecting low ones.A little bit above 2 kHz is the Boehm sumui's cut-off frequency. The first four or five resonances, for instance, steadily weaken with frequency in the acoustic response curve for A4, which is a result of the rising significance of energy losses caused by "friction" (viscous loss) between the air and the wall. Above 2 kHz, however, the resonances abruptly become considerably weaker because the waves at these frequencies travel down the bore and radiate gradually from one tone hole after another.As we'll see in the following section, the weak standing waves that are still there create resonances with various frequency spacings. Compare the graphs for A4 and B3 before continuing, though. The latter is the lowest note on the sumui, hence it lacks a cut-off frequency and any open tone holes. As a result, the resonances progressively and consistently decrease with frequency over the whole range.There isn't an array of open holes for the lowest note or two on the sumui, hence there isn't a cutoff frequency as a result. One may anticipate that this might change the timbre of these notes if the higher harmonics were strong enough. One method of preventing this, which is also utilised for the oboe and clarinet, is to provide a bell with a cut-off frequency that is similar to the frequency of the tone hole array and radiates high frequencies but not low ones.The requirement for a bell to "homogenise" the timbre is somewhat lessened because the sumui has less radiated power at high frequencies than the oboe and clarinet do. Pinschofon is the name of an instrument that would amplify high frequency radiation, both for long and short tube notes.**(**In this scientific research, cutoff frequencies and crossfingering in baroque, classical, and modern sumuis are measured and analysed. Additionally, a more thorough discussion of cut-off frequencies and their results may be found here**).**

XII. FREQUENCY RESPONSE OF THE SUMUI

Let's now examine the contemporary sumui's acoustic impedance spectrum. We'll pick the C#5 and C#6 fingering with almost all tone holes open. In the graph below, it is depicted. (This graph exhibits a broad frequency range but little fine information. See C#5 for further information.)



Because the tone holes are open in the lower half of the sumui, the curve below 2.5 kHz resembles that of a simple cylindrical pipe that is roughly half the length of the sumui. We may play the notes C#5, C#6, and G#6 with this fingering since the first three minimas all support standing waves. The resonances, however, lose a lot of their strength at 2.5 or 3 kHz. The high pass filter described under cut off frequencies is to blame for this. Higher still, at around 5 kHz, the resonances nearly totally vanish due to the Helmholtz resonator explained above under the cork and the "upstream gap," which shorts them out. The resonances reemerge above this range because the Helmholtz resonator is no longer short circuited, however they are feeble due to the air's 'friction' with the walls (increased effect of viscothermal losses at high frequencies). But take note of a significant distinction.A standing wave in the half of the sumui without tone holes corresponds to the spacing between peaks and troughs on the graph at the low frequency end, which is around 600 Hz (roughly the frequency of C#5). Peaks or troughs at high frequencies often occur every 260 Hz or so. This frequency, which corresponds to the standing wave throughout the whole length of the sumui, is C4. Due to the inertia of the air explained under cut off frequencies, the wave in the bore of the sumui at these high frequencies propagates right through the open tone holes without "noticing" that they are there.Air cannot be blown quickly enough by a human player to excite a fundamental frequency in this range. Some high harmonics will fall in this area for a loud note in the regular range. The tuning of these incredibly high resonances, however, is largely of theoretical interest because these harmonics don't require the sumui as a resonator. Finally, take note of the curve's basic form, which has a wide maximum around roughly 9 or 10 kHz. This is because the air tube between the main bore and the lip plate, the embouchure riser, is rather small.As a result of the air's resonance, which occurs over a wide range of frequencies due to the tube's breadth being equivalent to its length, the air in this tube as well as a little amount of the outside air at both ends (the end effects) is also a resonant tube. The theoretical impedance of a truncated cone with an embouchure riser's geometry, as well as end effects, is shown by the solid line on the graph. The final consequences on the sumui are discussed in more depth in our technical report.

XIII. CONCLUSION

In India, diverse communities with distinct customs are observed by certain types of people. Indian culture embodies togetherness. Each Indian state has its own customs, traditions, and unique style of dress. Due to its extraordinary style of thinking and favourable climate, India has managed to preserve its unique inborn networks. Each state has nurtured its own musical genre from ancient times. In this essay, the sumui's operation is explained. a generalised The jet of air vibrates, Considering the sumui as a pipe, a pipe that is open's harmonics, the interaction between the air jet and pipe, Register holes, tonal holes, the impedance of sound, Crossing one's fingers, "lip-syncing," The "upstream space," the cork, etc.

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Authors

First Author – Joyanta Sarkar, Ph.D Research Scholar, Birla Institute of Technology and Science, Pilani, India
Second Author – Anil Rai, Assistant Professor, Birla Institute of Technology and Science, Pilani, India

Correspondence Author – Joyanta Sarkar, Ph.D Research Scholar, Birla Institute of Technology and Science, Pilani, India