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The Contemporary Transverse Flute and the Shakuhachi: Convergences
An Acoustic Analysis of Performance Techniques

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Translated from the French by Catherine Dale

Introduction

Performance on the transverse flute has been enriched for some thirty years by new techniques of playing which incorporate aspects of flute sound previously rejected and disparaged as continually present or sudden, explosive sounds produced by the breath. At the same time musicians have become increasingly sensitive to the sonorities of traditional music and are beginning to discover that these "novel" sounds have existed for thousands of years in the musical practice of other types of flute, in particular of the Japanese shakuhachi.

Can musical acoustics throw any light on the reasons for the conciliation of and dialogue between two instruments which appear so different in construction? The visual acoustic representations which are available to us today and which provide a sort of exhaustive musical score, demonstrate that the convergence of the types of sounds produced by these two flutes is becoming increasingly clear.

1. An Acoustic Analysis of Flute Sound

1.1 *Analysis of flute music*

On hearing a piece of music played on a flute, one may make all kinds of remarks concerning the sound quality of the instrument, its dynamic possibilities, or the musician's style of playing. When one visualizes an analysis of the sound demonstrating the temporal evolution of its Fourier spectrum, a correspondence between the characteristics perceived on hearing the sound and the data afforded by the analysis may easily be established. In many respects, a visual representation of this nature provides a complete musical score of the sound phenomenon picked up by the microphone.

As in a musical score, the analysis indicates the evolution of the pitches on a vertical axis plotted against time which is represented on the horizontal axis; the intensity of the sound is expressed by the depth of shading and the thickness of the lines. Moreover, all the qualities of the sound are apparent: its harmonic richness, mode of attack and vibrato, together with any extraneous noises. These analyses thus permit the apprehension of the spectral structure of the material and the manner in which this evolves through time.

Figure 1 shows two fragments of music by J. Haydn and J. S. Bach played on the transverse flute. In Figure 2, two extracts of traditional music played on the shakuhachi may be seen.

It is apparent that the sound of the flute in the first two examples, in which it is constituted principally of harmonics, reveals a remarkable homogeneity. The musical phrase is articulated by changes in pitch (shown by the distance between the lines) and duration. The two examples played on the shakuhachi indicate, on the other hand, a wide diversity of sound spectra. Sounds characterized by a high degree of extraneous noise run counter to very "pure" ones as at the begining of

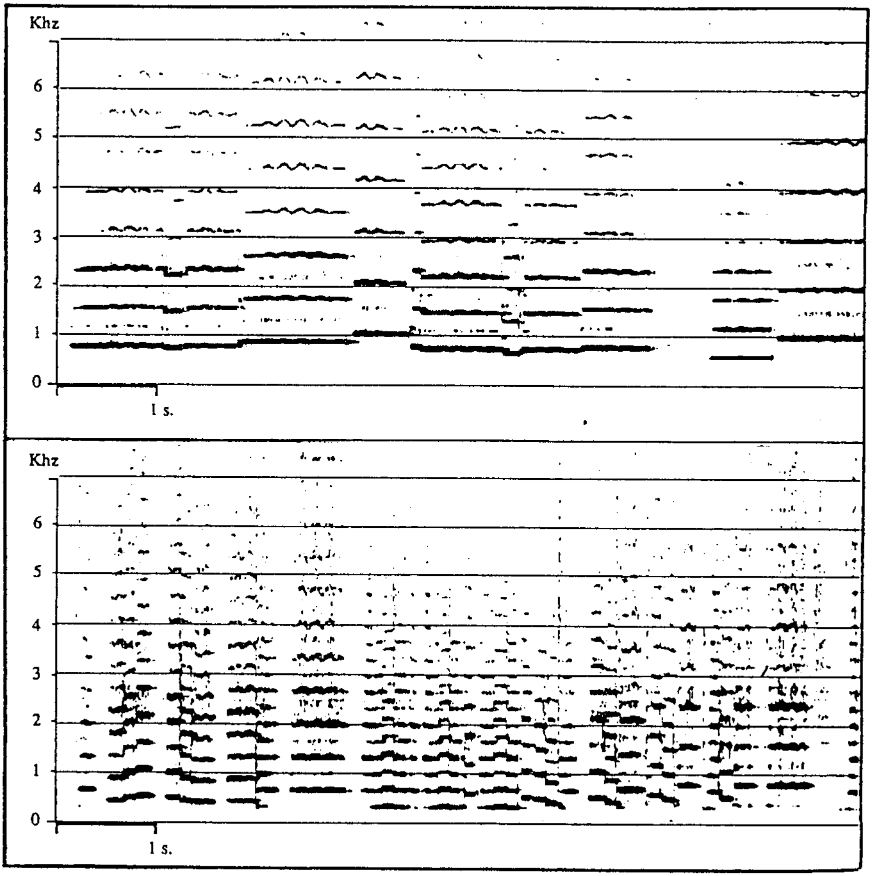

Figure 1 Transverse flute. Sonagraph analysis of two extracts of classical music. Above: J. Haydn, London Trio. Below: J. S. Bach, Bourrée from Suite in B minor.

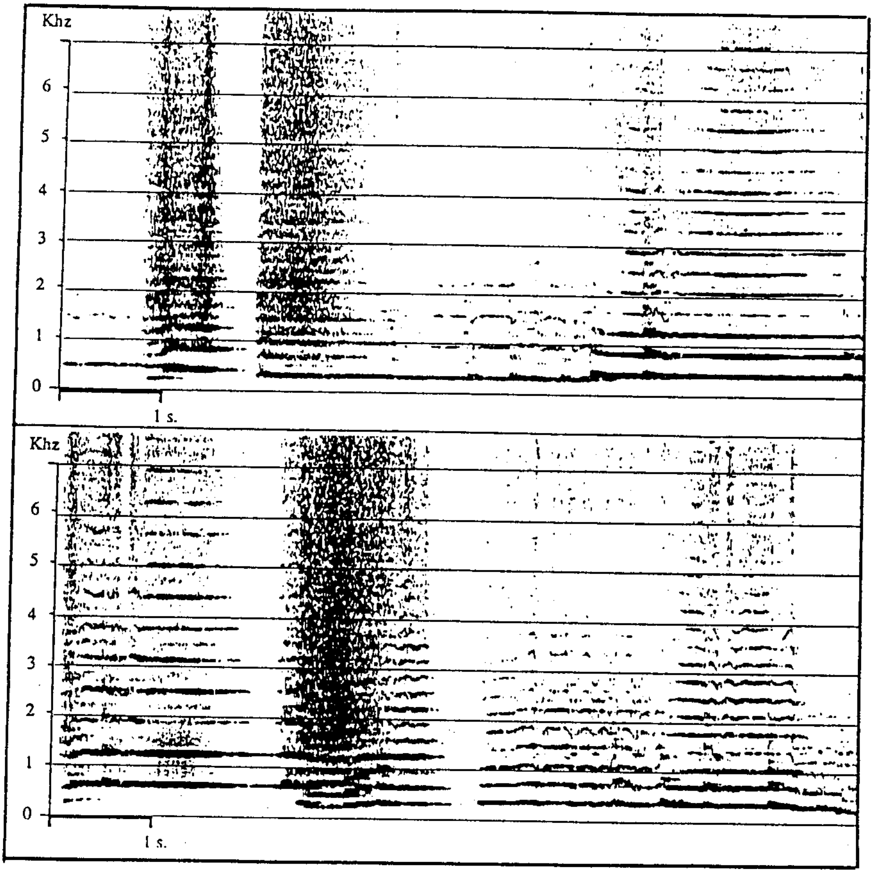

Figure 2 Shakuhachi. Sonagraph analysis of two extracts of traditional music performed by Iwamoto.

the first phrase, or, alternatively, to ones which are very rich in harmonics (as at the end of this same phrase). The articulation of the sonorities forms an integral part of the musical structure.

In both cases the question is clearly one of flute technique. For the reader who may conclude rather too hastily that the differences observed in Figure 1 and Figure 2 are due essentially to the differences in construction between a transverse flute and a shakuhachi, we present in Figure 3 two extracts from contemporary works (Ferneyhough and Lévinas) played on the same transverse flute as was used in Figure 1. This time the degree of convergence with the sound of the shakuhachi is obvious! What, then, has occurred? The music has certainly changed, but, most importantly, so has the way in which the sound of the flute is deployed.

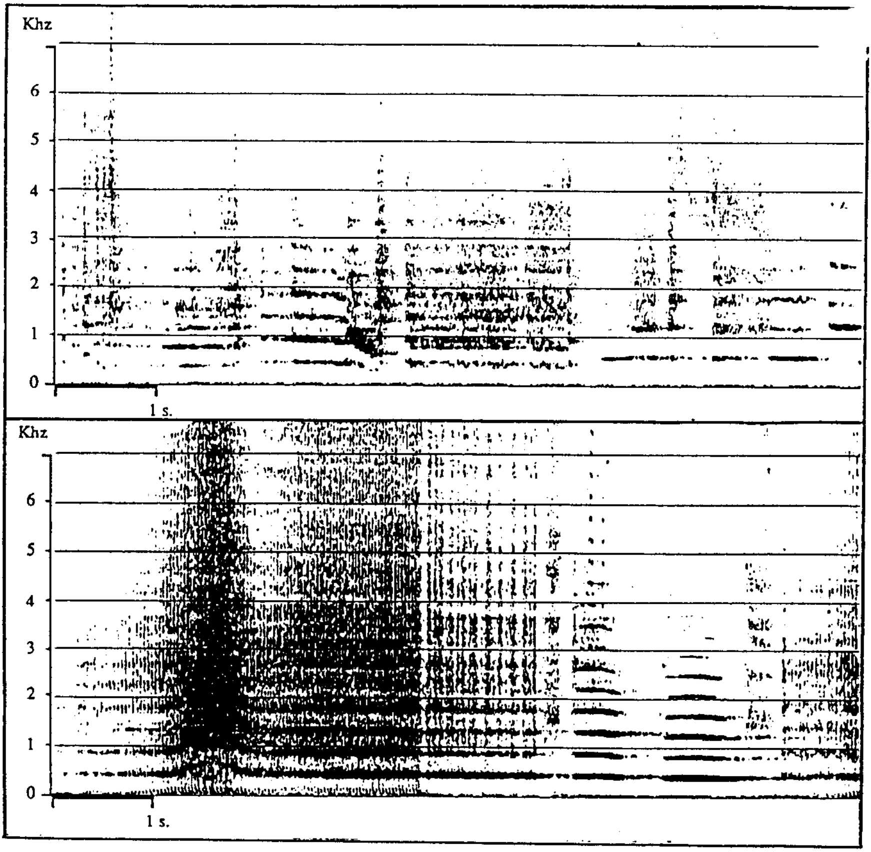

Figure 3 Transverse flute. Sonograph analysis of two extracts of contemporary music performed by Pierre-Yves Artaud. Above: B. Ferneyhough, *Unity Capsule*. Below: M. Lévinas, *Froissements d'ailes*.

If the method of sound production is common to all flutes throughout the world and may be described in general acoustical terms, the actual realization of this sound implies a certain number of choices. Just as a new-born child, potentially endowed at birth with all the muscular capabilities to utter the sounds and articulations of every imaginable language, soon reduces this range of movements to those which correspond to the language of his immediate circle, a student flautist traditionally exploits a series of muscular "gestures" in order to produce the sounds that the teacher requires, and thus excludes other possible ones.

1.2 *Sound production*

Any observer may note that particular conditions are required in order to bring about the oscillation of an air column: firstly, a jet of air must be emitted and this must then be directed carefully across the edge of the tube, while remaining an appropriate distance from this edge.

As far as the emission of the sound is concerned, flutes may be divided into two broad categories.

In the first category, all the elements which are essential to the creation and oscillation of the jet form an integral part of the instrument itself and are governed by its construction: this category comprises the fipple flutes and organ pipes. In these instruments the musician's role is limited to the control of the air pressure, which facilitates performance but at the same time reduces the possibilities of the instrument.

The second category consists of transverse flutes, notched flutes – of which the shakuhachi is an example – and oblique flutes such as the nāy, that is, all those instruments in which the musician controls the production of the sound. The performer may thus recreate "the ideal flute sound" he has in mind, shape it at each moment, adapt it according to context, and even destroy it. The instruments in this category are far better able to adapt to changes in sound aesthetic and may even initiate such changes, as the transverse flute did in Europe in the 1940s.

Playing the flute involves setting the air enclosed in a tube or cavity into alternative motion by means of the breath alone. The tube or cavity has a certain number of privileged frequencies, the resonances, and the mere act of blowing across the edge of a hole excites these and produces a noise of fairly well-defined musical pitch. But the name "flute" is customarily reserved for a particular type of treatment which has remained a mystery for some time since the vibration of air cannot be seen. It is now known that the excitatory element which lies at the origin of the sound is the oscillation of a jet of air produced across the embouchure.

1.3 *The respective contributions of the embouchure and the tube*

The sound that we hear is caused by the vibration of the air in the *tube*. It reaches our ears through the various "escape" holes in the tube, that is, the side holes, the embouchure and the foot-joint opening.

The geometrical dimensions of the tube: length, variations in internal diameter, and the position and dimensions of the side holes, determine the modes of vibration and therefore the possible frequencies of the musical scale as well as the potential harmonic content. But it is at the *embouchure* that the choice of the vibratory mode of the tube, the types of attack, the relative proportions of breath sound to harmonics, and the possibility of modifying independently of one another the intensity, pitch and harmonic richness of the sound is made.

1.4 *The resonator (the tube)*

The resonator is passive: it does not produce, but absorbs energy. The resonator of the flute is provided by the tube: the air contained in the tube may vibrate (displacement by reciprocating motion along the axis of the tube) creating zones of compression (a surplus of air) and zones of depression (a shortage of air). These vibrations can only be produced at certain frequencies. The values and specifications of the possible frequencies are determined by the internal geometry of the tube. Each fingering gives rise to a series of possible frequencies, each of which is linked to a particular method of operation of the tube and is termed a mode or partial of the tube. These correspond to the different notes that may be obtained from a given fingering.

If these frequencies lie close to multiples of that of the lowest mode, the partials correspond to the harmonic series (the octave, twelfth, fifteenth, seventeenth, etc. . . .). In this case, the tube will produce a sound which is rich in harmonics. On the other hand, when the frequencies of the partials do not lie close to multiples of that of the lowest partial, the tube produces a sound which contains few harmonics.

If the frequencies of the lowest modes of a transverse flute and a shakuhachi are compared (see the articles by Coltman and Ando), it may be observed that those of a transverse flute are far richer in harmonics than those of a shakuhachi for the majority of fingerings used by the two instruments.

There are two reasons for this:

(i) the ratio of length over internal diameter of the tube is smaller in the shakuhachi, and the larger this ratio is, the more harmonic are the partials;

(ii) the ratio of the diameter of the holes over internal diameter of the tube is smaller in the shakuhachi. As in the previous case, the larger the ratio is, the more harmonic are the partials.

For these reasons, the lowest note of the shakuhachi is the one which gives the most harmonic pattern (the acoustic length of the tube is at its maximum and the first opening is the hole at the foot of the instrument: its diameter is that of the tube).

The differences of harmonicity between a transverse flute and a shakuhachi illustrate the way in which the construction of the instrument has been adapted to the type of music for which it is intended: the classical repertoire played on the transverse flute calls for a sound which is rich in harmonics favourable to the precise perception of pitch. The homogeneity of sound across the entire range of the instrument and the precise intonation of the different registers are qualities which are valued most highly. The repertoire of traditional music played on the shakuhachi seeks other qualities from the sound of the instrument, such as possibilities for ornamentation and breath effects as well as important differences in timbre.

The player may influence the geometry of the tube, and therefore the partials, considerably by covering the embouchure hole to a greater or lesser extent with his lips. But he has a still more far-reaching control over the method of excitation which sets the air in the tube into vibration: the air jet.

1.5 *The sound source (the air jet)*

The jet which is formed between the lips of the player is the source of energy which maintains the oscillation. By adjusting the parameters of the jet: its speed (this depends on the pressure in the player's mouth), the distance travelled by the jet between the lips and the blowing edge (the musician may modify this by drawing his lips over the embouchure) and the dimensions of the jet (its width and thickness are conditioned by the shape of the aperture between the lips), the performer has tremendous possibility for modifying the sound.

How does the air jet function? Let us consider first of all a jet which is directed towards an edge without any tube or resonator. Suppose that, for one reason or another, this jet is deflected slightly and blows out from one side of the edge. A surplus of air is created on this side of the edge which tends to cause the jet to pass to the other side. The same procedure will occur on this side and so on and so forth. Finally, the jet will oscillate on both sides of the edge at a frequency determined by the velocity of the jet and the distance between the aperture and the edge. This type of behaviour is known as an "edge tone". If a resonator is placed close to the jet and the edge, the jet will be influenced by the vibrations of the air in the tube and will oscillate at the frequency determined by the tube as shown in Figure 4. In this case, the jet serves as the "motor", the active component in the functioning of the instrument. This second type of behaviour is termed a "tube sound". The jet may also create a noise which is comparable to that of a balloon being deflated. This sound has no definite pitch or frequency, but is "coloured" by the partials of the tube in the same way that an extraneous sound heard escaping from the embouchure hole is. The coloration has the effect of endowing the sound with definite pitch, and it is this procedure which is exploited by the transverse flute in the production of "Aeolian" tones. The coloration of the noise explains why a faint, indistinct sound may be perceived at the frequency of the first partial when a higher partial is played.

These three types of jet behaviour are all controlled by the player: the first control is that of the partial the performer selects from among all the possible frequencies of the tube. This is effected by adjusting the distance between the aperture and the edge, and the speed of the jet. The player may also modify the harmonic content of the sound by controlling the thickness and velocity of the jet. He may regulate the relative importance of extraneous noise and edge tone in the sound produced.

These controls are identical in the case of both the flute and the shakuhachi since they depend solely upon the player.

1.6 *The birth of the sound: the starting transient*

The starting transient, the moment in which the sound is born, is fundamental for it defines the acoustic character of the sound of the flute. If the succession of events which occur during the initial milliseconds of a sound attack are analysed one finds first of all a very shrill, unstable sound with a greater or lesser degree of extraneous noise. This is the *edge tone* produced by the oscillation of the jet as if it were detached from the tube. The relationship between the oscillation of the jet and the vibration of the air in the tube is then established, and the various harmonics begin to appear progressively. These diverse phenomena are shown in Figure 5 on the shakuhachi as well as on the transverse flute.

The treatment of the edge tone in a particular way permits the production of "whistle tones".

Sometimes the edge tone is not eliminated when the harmonics are established; it combines with these, producing hissing and crackling sounds which are generally perceived as defects.

When a sound which begins *ppp* and becomes progressively louder is emitted, the edge tone is inaudible at first, but becomes apparent with the crescendo. In

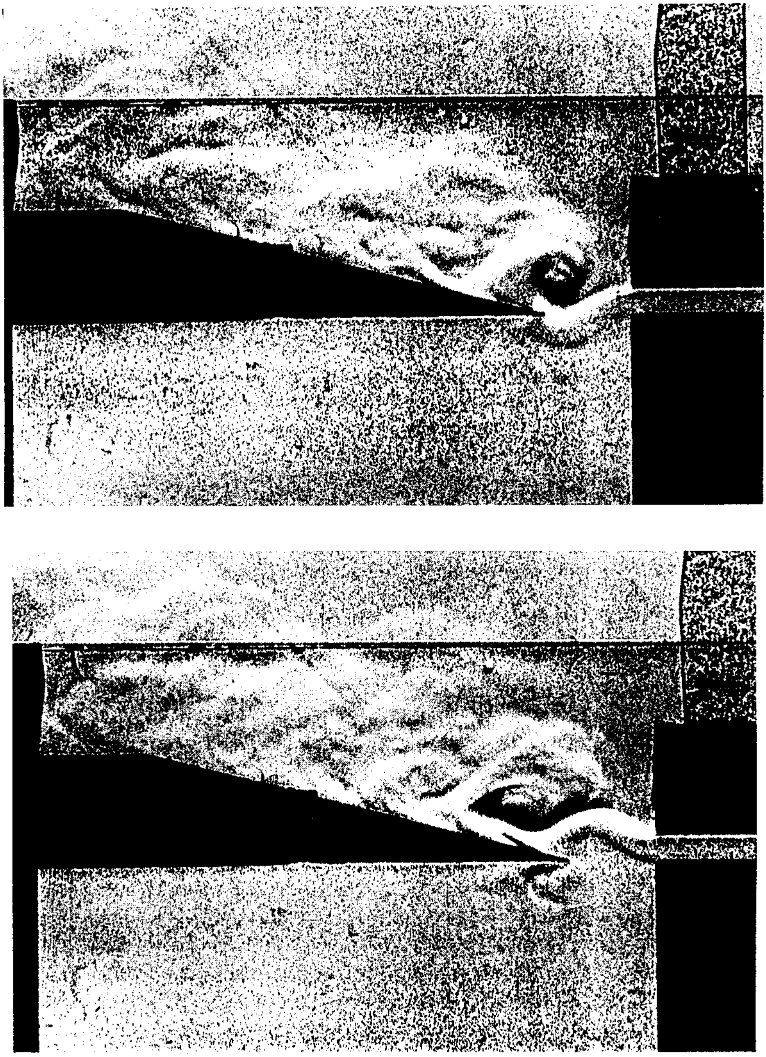

Figure 4 Jet oscillation at the mouth of a small organ pipe: the jet flows successively inside and outside the pipe during the sound period. Photography by Wijnands, Hirschberg, Fabre, Technical University, Eindhoven, the Netherlands.

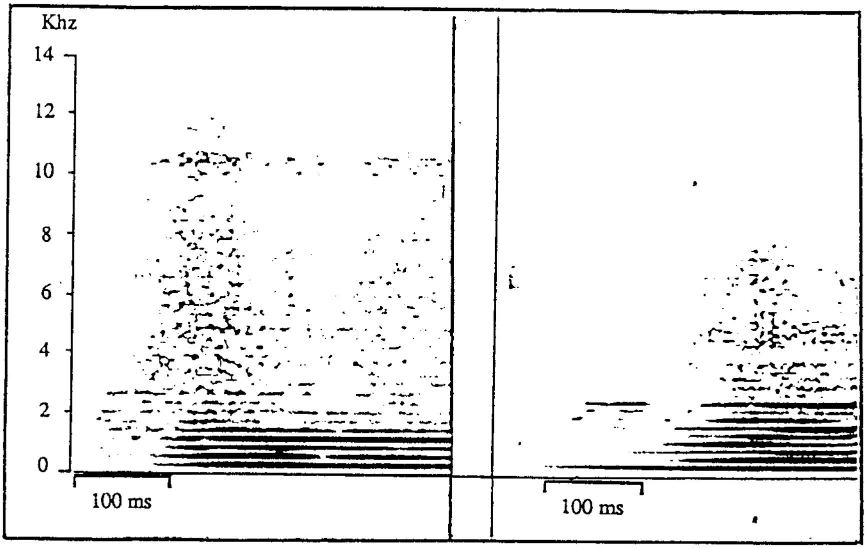

Figure 5 Comparison of the starting transient of two notes. Left: shakuhachi. Right: transverse flute. The sound of the breath is represented by an agglomeration of dots and the harmonics are shown by parallel lines.

staccato playing the flute tone is preceded by a percussive sound which corresponds to the little impulse of breath at the moment of attack of the tongue.

There appears to be a close relationship between the duration of the attack and the presence of extraneous noises. Within the European classical aesthetic of "pure" sound, the transverse flute is the instrument which takes the longest time by far to speak: up to one-tenth of a second in the lower register. As soon as the performer accepts, or seeks to create, the noise of the attack, the sound becomes established more rapidly and may even assume a percussive character as in the case of the shakuhachi. But in all types of flute the length of the attack is necessarily greater for notes in the lower register in which the tongue attack cannot be too rapid for fear of overblowing. Figure 6 shows the staccato attack of two low notes then two high notes played on the transverse flute.

1.7 Sound and blowing noise

The various examples analysed above illustrate the importance of the sound of the jet noise in the constitution of flute tone; this may include the noises and hissing of the edge tone, the sound of the tongue attack, and the constant diffuse breath which underlies the sound. Two attitudes are clearly possible with regard to performance on this instrument. Either the musician may consider the noise of the breath to be as much a constituent part of flute tone as the periodic sound and may develop an embouchure technique which enables him to control this noise musically, or he may prefer the periodic sound and consider the various other

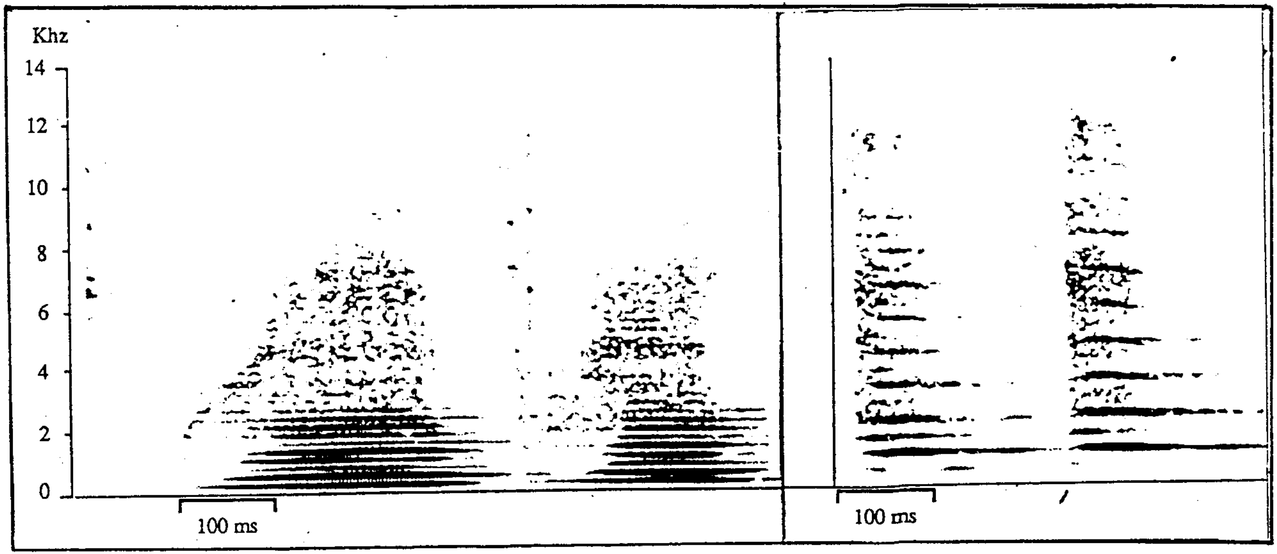

Figure 6 Analysis of the starting transient of two notes on the transverse flute. Left: low register (C^4 and C sharp^4). Right: upper register (C^6, C sharp^6). The duration of the starting transient is much shorter in the upper register (15ms) than in the lower one (100ms).

inevitable noises as parasites. This second attitude has prevailed in the case of the classical transverse flute in which the sound required by composers should not admit extraneous noise but should be "clear, crystalline, translucent, fluid, pure". When it is considered undesirable, this noise is sought out from the earliest student days and is reduced so that the listener, for whom it is alien to music, will not hear it at all! In recording the sound, moreover, the sound engineer will endeavour to find a microphone position which will minimize it.

Let us now consider the ways in which the acoustic analyses increase our understanding of the sound of the shakuhachi and the contemporary transverse flute.

2. Notable Characteristics of Performance Techniques on the Shakuhachi

2.1 *The blowing noise*

Hearing a piece of traditional music played on the shakuhachi reveals immediately the importance of the noise as part of the sound material, and Figure 7 demonstrates this clearly. The breath remains permanently present in the sonority of the instrument and frequently passes into the foreground. When the performer has succeeded in mastering the embouchure he may alternate at will between the production of breath across the whole spectrum of sound, which may be coloured to a greater or lesser degree by the resonances of the tube, and a harmonic sound which is almost but never completely devoid of noise. Figures 7a and 7b show analyses of two sounds produced by the shakuhachi; the first, a "normal" sound, contains a high proportion of extraneous noise at the high frequencies, and the second, a "pure" sound, reveals a trace of edge tone between 9 and 12 Khz.

Sometimes the blowing noise appears suddenly at the end of the sound, like an ornament: this is known as muraiki (Figure 7c).

Most often it is at the moment of attack that the musician employs the noise.

2.2 *The attacks*

The different types of attack that we have been able to study with Iwamoto are complex ornamental processes of relatively long duration – up to a second – which combine the breath with the simultaneous production of grace notes before the main note. By modulating the intensity and the speed of these elements the musician may produce a great variety of sounds, six examples of which are illustrated in Figure 8.

The strongest attack, which is also the shortest, is perceived as a percussive sound, but even in this case the full range of harmonics is not established until one-eighth of a second later! Only sound (b), designated "without attack", grows progressively out of silence. The attack labelled "normal" is preceded by a slight impulse of breath.

2.3 *Control of the harmonics*

The changes in sonority that may be detected through long notes provide another source of amazement for the listener hearing the shakuhachi for the first time. We

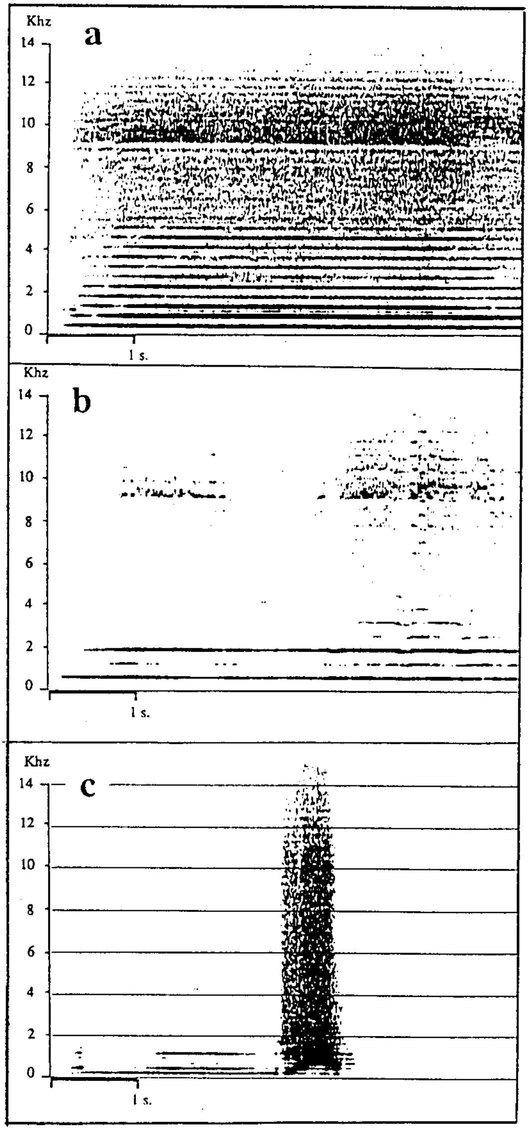

Figure 7 The presence of extraneous noise in a sound produced by the shakuhachi. Above: "breathy sound". Centre: "pure sound". Below: the ornament "muraiki".

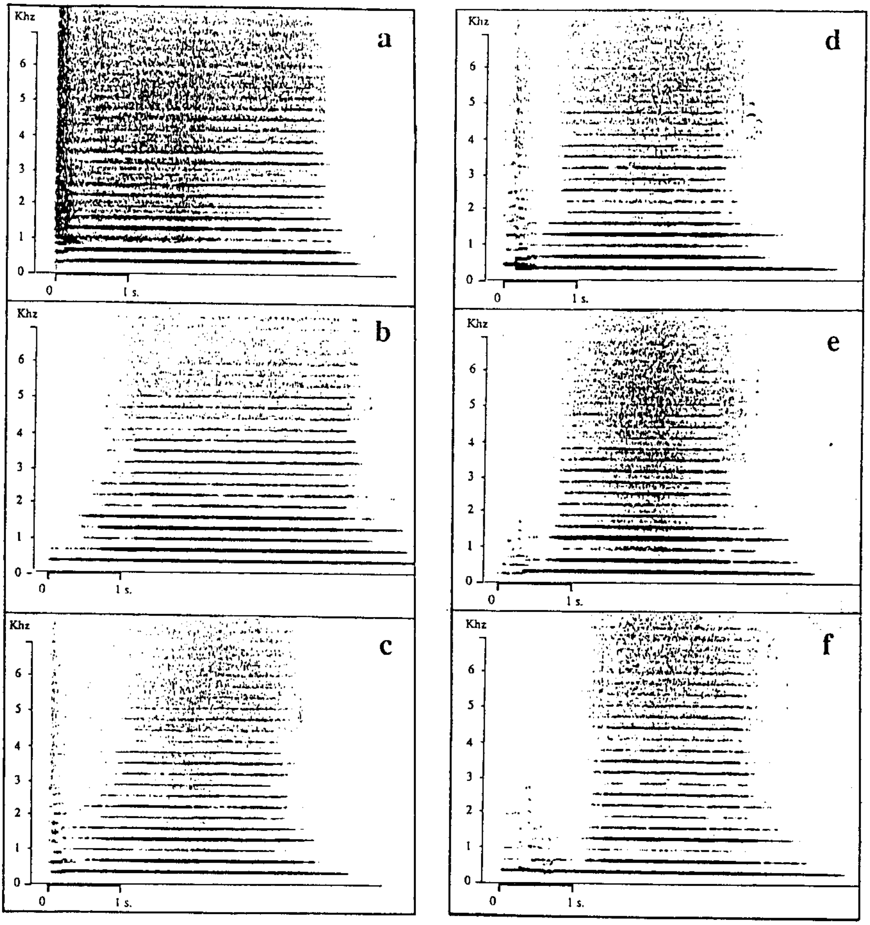

Figure 8 Shakuhachi. Sonograph analysis of several types of attack of a single sound. (a) Harsh attack; (b) without attack; (c) normal attack; (d), (e), (f) three types of attack with traditional ornaments.

know now that the flautist may effect these changes by modifying the incidence of the jet on the edge together with the lip aperture shape. Figure 9 shows an excellent example of this. During the ten seconds for which the sound is sustained, the number of harmonics increases from one to twenty!

2.4 *Modulation of the sound, vibrato, flatterzunge*

Vibrato is normally produced on the transverse flute by a regular modulation of the air flow, the speed of which lies between five and seven cycles per second. At this speed the ear fuses the variations and perceives a "mean" pitch embellished

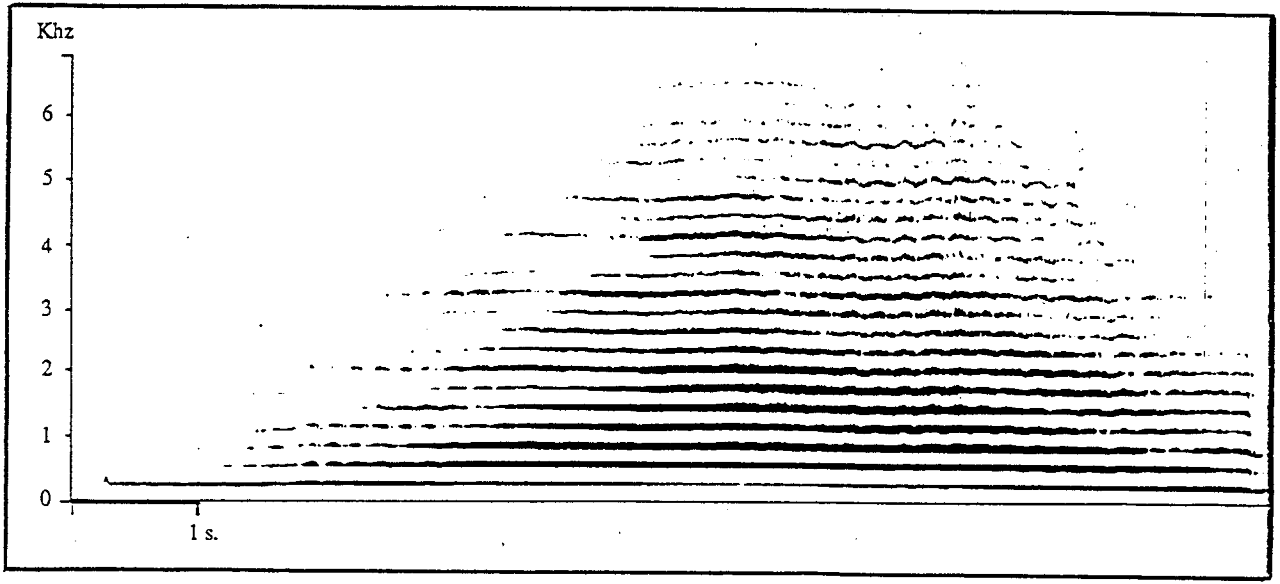

Figure 9 A sustained note played on the shakuhachi. Throughout the ten seconds' duration of the sound, the musician modifies the spectrum considerably, from one harmonic at the beginning to twenty harmonics around the fifth second!

by certain tone qualities. There is some disagreement among flautists as to whether the modulation of the breath acts as a variation in frequency or in intensity. In the light of the analyses, we can reconcile these differing views straight away by affirming that the two are always combined in proportions which vary according to the register, nuance and technique employed. We have been able to study three methods of producing vibrato with Pierre-Yves Artaud. By comparison with normal diaphragm vibrato, throat vibrato is wider and favours the variation in intensity. On the other hand, the vibrato produced by the lips tends towards the variation in frequency; it is also much slower: 4.5 cycles/s as opposed to 6.5.

The shakuhachi player is clearly able to produce these types of vibrato also, but in the traditional style of playing he approaches them in a completely different way. The modulation of the sound is obtained by the oscillation of the player's head in relation to the flute either in a lateral (left to right) or a vertical (up and down) direction. By moving his head in these ways the player modifies the direction of the jet and the extent to which the blowing hole is covered. The result is extremely complex and cannot strictly be called vibrato since it does not aim to produce temporal regularity – quite the opposite.

The first example of modulation (Figure 10) obtained by the vertical movement of the head shows brief falls in frequency of around a semitone which begin slowly (one per second) then become progressively more rapid. A particular type of ornamentation concludes the sequence.

The second example results from the lateral oscillation of the head and illustrates a surprising modulation in timbre produced by complex exchanges in intensity between the harmonics, a procedure which differs considerably from the synchronic modulation which may be observed (Figure 10).

Flatterzunge, a rapid (24/s), regular interruption of the breath produced either in the throat or by the tongue, is common to both types of flute (Figure 11).

The interruption is shorter and the sound is of better tone quality in the throat technique.

2.5 *Timbre ornaments*

Obtained either by striking a hole with the finger – karakara – or by the rapid alternation between the opening and closing of two holes simultaneously – korokoro – these traditional ornaments embellish the timbre in a way analogous to the "battements" of baroque flute technique but in the upper register. The startling effect of these ornaments is due to the abruptness and complexity of the acoustic changes which separate the two notes of the trill (Figure 12). This effect may only be obtained on certain notes for which the opening of the hole creates an abrupt change in the vibratory regime of the tube. In addition to the variations in pitch and timbre, the short, quick interruption of the sound (12 to 14/s) makes an astounding impression on the ear.

3. Performance Techniques used by the Contemporary Transverse Flute

The present-day flautist incorporates into his technique the methods of sound production which we have described in connection with the traditional style of

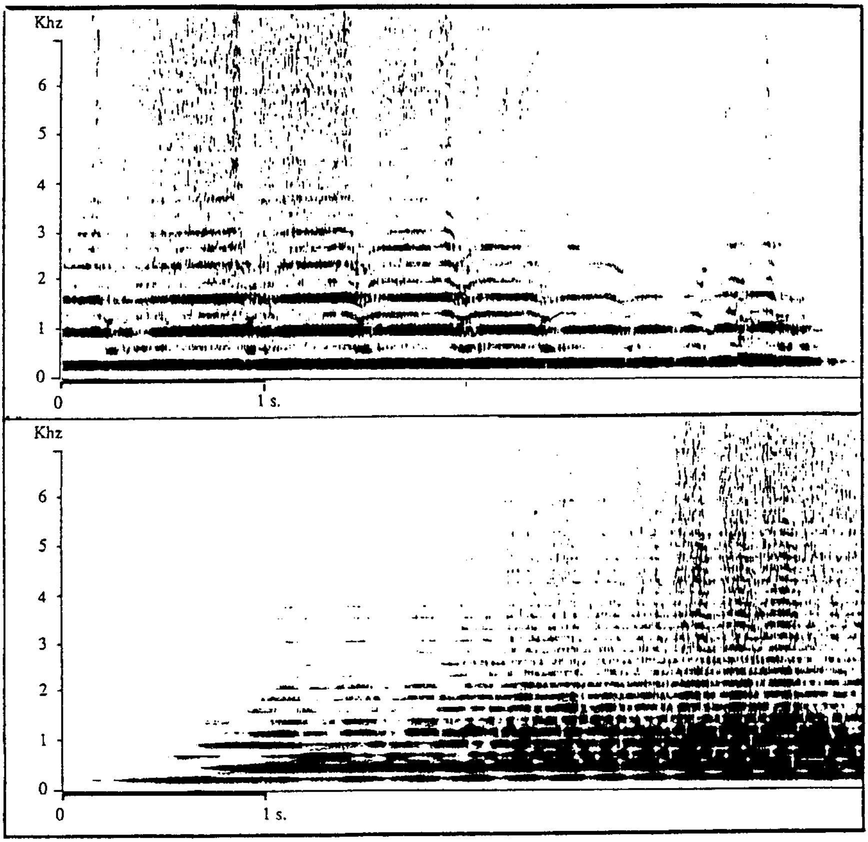

Figure 10 Shakuhachi. Above: modulation of the sound by the vertical oscillation of the head, producing brief falls in frequency. Below: modulation of the sound by the lateral oscillation of the head; the variations, which are much more rapid, are essentially fluctuations in intensity.

performance on the shakuhachi. A number of other techniques are employed in addition to these.

3.1 Multiphonic sounds

This method of flute playing does not differ fundamentally from the ordinary one other than that the air jet must ensure the simultaneous maintenance of two or three modes of vibration in the tube which need not be related harmonically. The maintenance of these modes is often difficult to stabilize on a Boehm flute. It requires a lip position and a flow of air which differ from those required by normal flute playing in the same register.

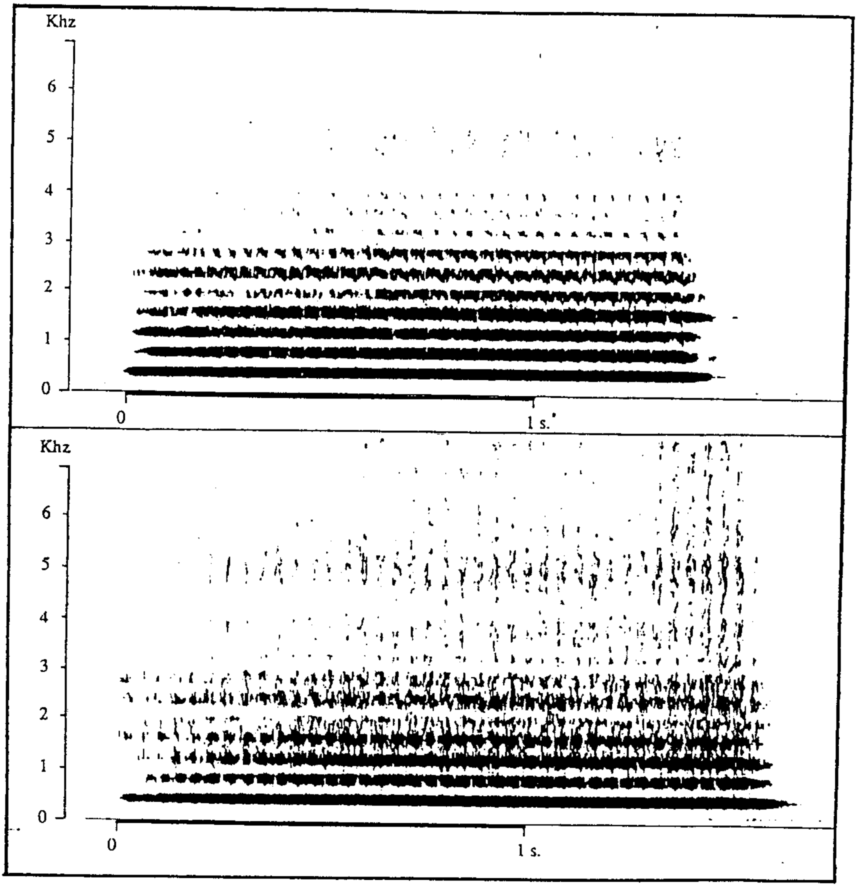

Figure 11 Transverse flute. Analysis of the two methods of flatterzunge. Above: flatterzunge produced by the throat. Below: flatterzunge produced by the tongue.

From an acoustic point of view, multiphonic sounds are very complicated phenomena. In cases in which the frequencies of the modes are able to adapt themselves and settle on a common denominator, the sound may be assimilated into a periodic sound of which only certain harmonics may be heard. In other cases the modes which occur in turn appear to conflict with one another, and in these cases the sound is animated by fast or slow rattling and grating noises.

3.2 *Flute and voice*

By singing at the same time as playing the flute two musical notes are produced simultaneously, one with the vocal cords, the other with the flute. But since both

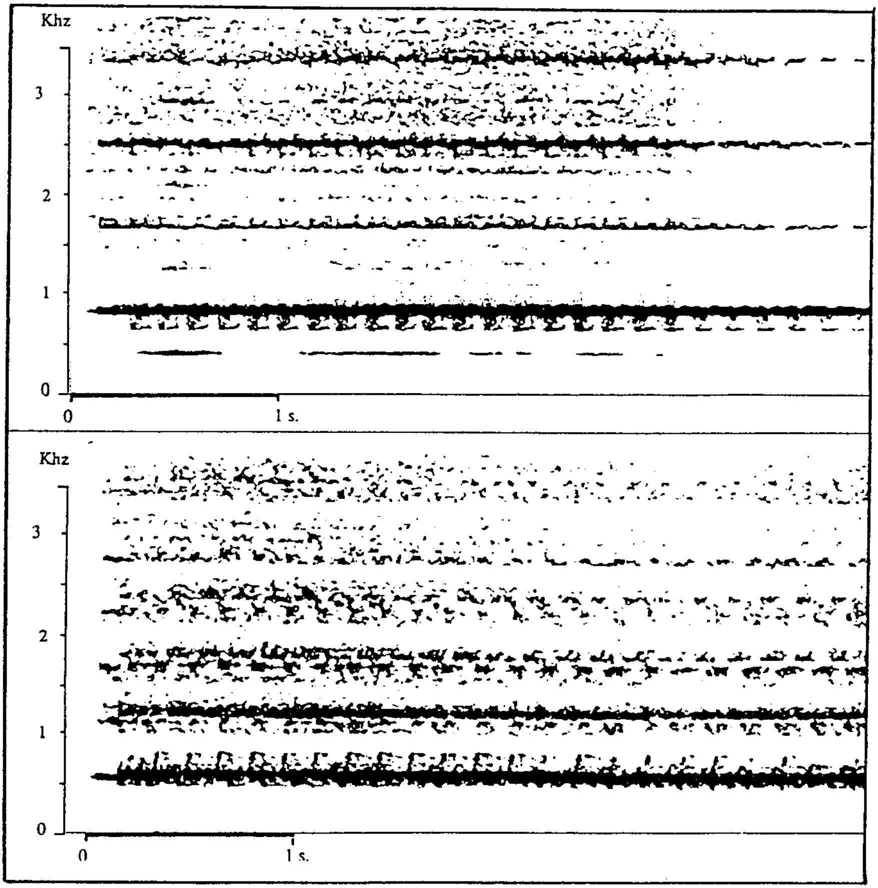

Figure 12 Shakuhachi. Two traditional ornaments. Above: karakara. Below: korokoro.

sounds are generated by a single breath, that of the musician, they are closely combined: the sound of the flute is modulated by that of the voice which may be very rich in harmonics. The overall sound effect depends essentially on two factors:

(i) the pitch of the vocal note (higher or lower) in relation to that of the flute;
(ii) the degree of consonance between the two sounds.

As it is extremely difficult to produce a stable vocal note, the musical result is actually very complex. One hears beats of variable speeds, and the resulting sounds fluctuate according to the extent to which the instrumentalist chooses to modulate the intensity and richness of his voice.

3.3 *Edge tones or whistle tones*

The performance of edge tones gives tremendous pleasure to the flautist, but these tones may only reach the listener by means of amplification. The sounds, which are especially beautiful, are very difficult to stabilize on account of the weakness of the pressure used for this type of emission. The frequency that we hear in this method of playing is that of the air jet. As the frequency of the oscillating air jet is directly dependent upon the speed of the air, it is subject to very rapid changes (Figure 13). It becomes more stable in the tube as it passes over a neighbouring resonance, then jumps more or less rapidly to others according to the stability of the breath. Edge tones may be produced on an organ when, having first pulled out the flute stops, the air supply is cut. If some of the keys in the first octave are depressed when the air supply is almost expended, an abundance of soft, high-pitched sounds jumping rapidly from one note to another may be heard.

3.4 *The flute as a percussion instrument*

Several techniques of playing employed in contemporary music depart resolutely from the usual method by which the air jet maintains the vibratory mode of the tube. Whether these involve key clicks, tongue pizzicati or tongue rams, the air cavity enclosed in the tube, set in motion by a single impulse, produces a short noise of more or less well defined pitch. In the case of the tongue ram, the note produced is slightly less than an octave below the fundamental of the instrument. The intensity of key clicks, which is often weak, may be improved by amplification. Figure 14 indicates clearly the originality of these "flute" sounds which are characterized by an initial vertical line typical of percussion sounds.

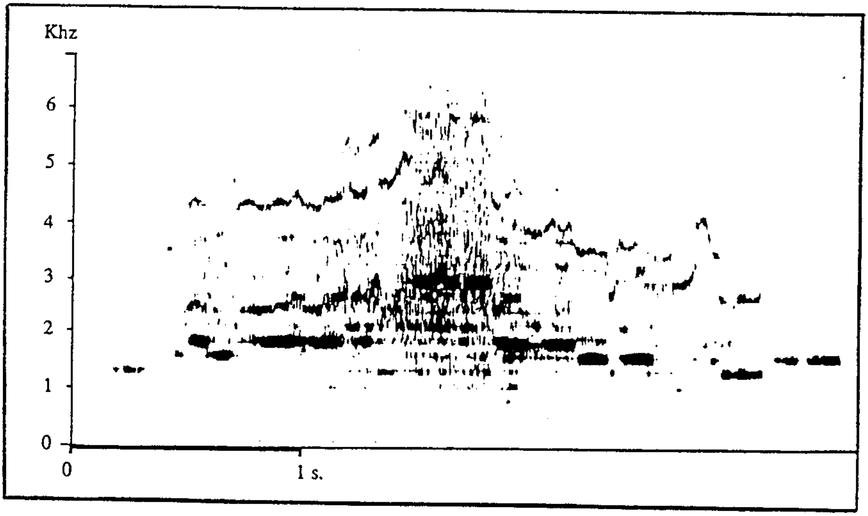

Figure 13 Transverse flute: performance of edge tones or "whistle tones".

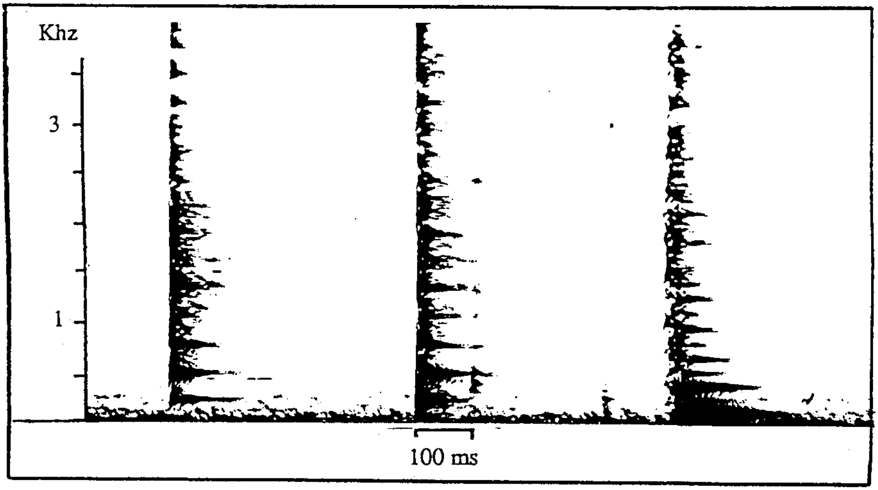

Figure 14 Transverse flute. Left to right: key click, pizzicato and tongue ram.

Conclusions

This study is deliberately limited to a few examples of playing techniques. Certain effects employed on the transverse flute in contemporary music are paralleled in traditional music for the shakuhachi (particularly with regard to the use of the blowing noise), while others (multiphonics, tongue rams etc.) are more difficult to reconcile with methods of shakuhachi playing. Conversely, a number of techniques peculiar to the shakuhachi are not exploited by the contemporary flautist even though these might enrich still further the range of both performer and composer.

For if the differences in construction between a transverse flute and a shakuhachi are obvious, the method of sound production – the jet of air formed between the lips of the musician – is common to both instruments. For this reason, there are no fundamental acoustic differences between the transverse flute and the shakuhachi; both instruments offer the musician a wide range of potential sounds from which each instrumentalist must choose according to his musical culture, aural curiosity and personal tastes etc. Over and above the instrument held in the musician's hands, it is the image of the "ideal sound" that he seeks to reproduce which determines the final sound. Ultimately, the attention of the listener may be directed towards aspects of flute sound which he had previously tried to disregard, however little the musical writing and the performer may emphasize these.

If a certain convergence between contemporary performance techniques on the transverse flute and those found in traditional music for the shakuhachi may be observed today, we lay wager that interaction with other forms of traditional music might further enrich the approach of both performer and composer to the transverse flute.

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