2.3 Kamp P., Castellengo M. and Štěpánek J. : Acoustic Criteria for the Characterization of the Attack Transients of Two Flue Stops and How These Criteria Evolve Over the Entire Compass.

Critères acoustiques pour la caractérisation des transitoires d'attaque de deux jeux de tuyaux à bouche et évolution de ces critères au long de la tessiture.
Les analyses de transitoires de tuyaux à bouche ne se rapportent souvent qu'à un petit nombre de tuyaux ([2], [3], [4]). De plus, ces analyses prennent rarement en compte le contenu harmonique du son de biseau. Notre étude se concentre sur l'analyse de tous les tuyaux de deux jeux : un principal (tuyaux ouverts) et un bourdon (tuyau bouché). Pour caractériser l'attaque, on propose deux critères acoustiques qui peuvent être interprétés sur le plan perceptif. On analyse ensuite la variation de ces critères pour chaque tuyau des deux jeux et particulièrement la courbe de variation du critère 'temps de montée'.

Acoustic criteria for the characterization of the attack transients of two flue stops and how these criteria evolve over the entire compass

Ph. KAMP*, M. CASTELLENGO*, J. ŠTĚPÁNEK**

* *Laboratoire d'Acoustique Musicale, Université de Paris VI/CNRS/Ministère de la culture, 4 place Jussieu, 75252 Paris cedex 05, France*

** *VUZORT a.s., Plzeňská 66, 151 24 Praha 5, Czech Republic*

Abstract: The analyses of flue pipes attack transients concern usually a small number of pipes ([2],[3],[4]). Futhermore these analyses take rarely account of harmonic components of the mouth-tone. The study focuses on the analysis of all pipes of two stops : a principal (open pipe) and a bourdon (stopped pipe). To characterize the attack, two acoustic criteria are proposed which are interpretable at the perceptive level. Then one analyses the variation of these criteria for each pipe of the two stops and particularly the variation curve of the criteria : "buildup duration".

1. INTRODUCTION

This paper should be seen in the context of the study of the sonority of musical sounds. The sonority is the property which allows to judge the sound quality once its source is identified [1]. The timbre allows the identification of the source [1].

One distinguishes usually three parts in a musical sound : the attack transient, the steady-state and the decay transient. However one should keep in mind that this temporal structure of the sound is based on an **acoustic** point of view. Most probably, the ear does not perceive this structure as such but rather as a global pattern. The attack transient is of foremost importance in the musical context and particularly in the performance practice of baroque music. It is one of the means used by the musician to deliver the musical oration. At the organ, the musician controls the attack by the speed at which the key is depressed (organ with mechanical action).

We are interested, here, in the sonority of the attack transient for two typical organ stops : the principal (open pipe) and the bourdon (stopped pipe). These stops are recorded on their entire compass with an approximately identical depressing speed to ensure a good reproductibility of the attack. Acoustic signals are picked up by one microphone placed inside the organ case and are acquired by DAT and PC.

The few investigations about the sonority of the organ are often limited to some notes of one or more stops ([2],[3],[4]). But, it is of utmost importance to analyse a stop on its complete compass. Fabre [5] has, in fact, showed that the spectrum varies significantly from one pipe to the other in the same stop. This irregularity is delibarately pursued by the organ builder. Fabre emphasizes the fact that computation of an average spectrum to get rid of this irregularity is not realistic from a perception point of view.

2. DESCRIPTION OF THE CHARACTERISTIC PHENOMENA OF THE ATTACK TRANSIENT

Most frequently, the phenomena occuring during the attack transient are presented and interpreted in terms of a physical model. This quantitative approach is, however, less convenient for the acoustic and perceptive characterization of the produced sound. A model imposes hypotheses and thus does not completely capture the reality. A qualitative approach, based on a experimental procedure puts itself in real listening conditions. On the basis of Castellengo's contribution [6] concerning this approach, we describe below briefly the main phenomena.

Chapter 2 : Pipe instruments

First, the *mouth-tone* appears, and then the different harmonics of the future steady-state start growing. The *mouth-tone* consists of inharmonic components and noise bands. These inharmonic components consist in the pipe partials (resonance frequencies) and combination sounds with the fundamental when the latter appears. Some of these components can persist during the steady-state. Castellengo showed that the edge-tone components are present in the mouth-tone. The edge-tone is the sound produced by the jet-edge system alone i.e. when the resonator is disabled. A spectrogram of an edge-tone and a mouth-tone is showed in Fig.1.

The mouth-tone depends on the parameters proper to the pipe such as : mouth height, mouth width, edge position... It's also influenced by several components of the wind supply of the pipe : moving speed of the pallet valve, chest and wind supply where oscillations may take place.

3. INVESTIGATIONS OF THE ACOUSTIC CRITERIA

3.1. Methodology

The investigations of acoustic criteria is carried out following two approaches : listening and acoustic analysis. On the basis of listening, remarkable notes are selected and grouped together according to their common characteristic features : fast attack, slow attack...The acoustic analysis is implemented first at a global level (spectrograph) and next at a detailed level ("fine" short-term Fourier transform).

By a spectrographic analysis of these notes, one extracts the phenomena which lead to the same grouping as obtained by listening. Finally, one carries out a "filtering" by a short-term Fourier transform in the region of the spectrum where these phenemena take place. One chooses, finally, the acoustics criteria which best express these phenomena.

Some remarks about this procedure are essential. First of all we draw the attention to the fact that the only purpose of listening is here to guide the determination of acoustic criteria. The aim is not to establish some correlation between perceptive and acoustic criteria, which would require a set of psycho-acoustic tests followed by a multidimensional analysis.

We consider listening as an analysis mean in its own right integrated with standard signal processing tools. An acoustic study should not make us forget that a musical signal is first of all made to be listened at.

The spectrograph is used for its ability to give a global qualitative image of the signal. One can therefore, better apprehend its global structure and links it to perception. Moreover, it allows to guide the type of quantitative analysis applied at a detailed level as well as the choice of spectrum regions to examine more in detail.

3.2. Investigation proper

From listening sessions we select the following descriptors : *clear-soft, fast-slow*.

As expected, we observe the presence of several partials in the spectrograms and among them an especially marked one called dominant partial in the sequel. For the bourdon this is the partial 5 (≅third + 2 octaves) being a typical characteristic of this stop. The principal has a dominant partial 3 (≅fifth + 1 octave) which is unusual but can be explained by the fact it is not a baroque principal. Principal of this latter type exhibit generally an important partial 5 as well as high frequencies bands which incidently are also missing in our case.

Comparing the spectra of the clear and soft notes, it seems that the clearness is related to the dominant partial. Two extreme situations are given in Fig.3 and Fig.4 for a note perceived as very clear, the dominant is very marked, whereas in a very soft note, the dominant partial is nearly missing.

For the descriptor fast-slow, the spectrographic analysis directs us towards the buildup duration of the steady-state.

Next, we investigate at a more detailed level the dominant partial and the attack duration by an harmonic analysis using a short-term Fourier transform. In fact, it is not an harmonic analysis in the strict sense. What we want to obtain is the amplitude in the frequency band around harmonic, including the possible partial of the same rank. Both are indeed very close each other. In order to avoid confusion we will therefore use the term band instead of harmonic. Thus what we call dominant band is the frequency band including the dominant partial and the harmonic of the same rank as this partial. The band 5 (harmonic 5 and partial 5) is the dominant band for the bourdon. For the principal it is the band 3 (partial 3 and harmonic 3). We extract also the frequency band around thre fundamental and call it fundamental band.

This analysis suggests us to choose the following **acoustic criteria :**
(1) time required for the amplitude of the dominant band to reach its maximum during the transient
(2) buildup duration of the steady-state (= duration of the attack transient)

We choose the classical definition of the buildup duration of the steady-state : the time necessary for the fundamental to reach 90% of its final value.

The two extreme situations for clearness mentioned above, showed for criterion (1), that the amplitude reaches its maximum very quickly in the case of clear note, whereas the opposite holds for a soft note.

4. EVOLUTION OF THESE CRITERIA ON THE WHOLE COMPASS

Criterion (1) has a great number of irregularities for the principal and the bourdon. This corroborates the heterogeneousness of the attack of theses stops already detected at the time of listening. This irregularity is less marked for the criterion (2). The evolution of the latter criterion is not linear as can be observed in Fig.2 for the bourdon. This nonlinear evolution agrees with the results obtained by Luce [7] for the transverse flute. One would at first glance assume it would behave linearly since the builup time of the stationary wave is at least the time required for the wave to travel two times up and down (stopped pipe) i.e. the period of the fundamental.

This nonlinearity could be explained by the diameter progression of the stop. Castellengo [6] showed experimental evidence that a pipe of same height but with a larger diameter has a shorter buildup duration of the steady-state. For shorter pipes, the ratio D/L (D:diameter, L:length) increases and therefore the buildup time decreases. The nonlinear evolution of D/L is reflected in the buildup duration.

The explanation given here is exclusively related to the resonator of the pipe. The parameters of the excitator (geometry of the mouth, pressure at the foot...) probably also share some responsability in this nonlinearity.

5. CONCLUSION

We have obtained two acoustic criteria likely to be relevant at a perceptive level i.e.:
(1) time required for the amplitude of the dominant band to reach its maximum during the transient
(2) buildup duration of the steady-state

The choice of these criteria was guided by listening sessions of two organ stops studied here : a bourdon and a principal. Two characteristics were selected: the clearness of the the attack and its quickness. They suggested respectively criterion (1) and (2).

The important irregularity of criterion (1) caused by the heterogenousness of the attack, does not allow a meaningful interpretation of its evolution along the compass. Criterion (2) on the other hand, varies in nonlinear fashion. This can be explained by the fact that the buildup duration depends on the ratio D/L (D:diameter, L:length) which follows a nonlinear law.

In future, it would be advisable to undertake a detailed acoustic and perceptive study about the attack transients. In a first step synthetised organ sounds would be used to establish precisely some correlations between perception and various parameters of the transient. Next, these correlations would be validated on vast corpus of bourdon and principal sounds of baroque organs of different styles and which could be modified by a signal editor.

It would also be interesting to examine the sonority of transients for different depressing speeds of the key in a realistic range of values. This would require the speed to be measured in a real performance situation. This would provide good opportunity to look more closely at the role of this parameter in the musical context.■

REFERENCES

[1] Castellengo M., "Les sources acoustiques", in *Le livre des techniques du son*, Mercier (ed.). Eyrolles, 1987, pp. 45-70.

[2] Lottermoser W., Meyer J., *Orgelakustik in Einzeldarstellungen*, Teil I, Das Musikinstrument, 1966.

[3] Keeler J.S., *Picewise-periodic analysis of almost periodic sounds and musical transients*, IEEE Transaction On Audio and Electroacoustics vol. AU-20, n° 5, 1972, pp. 338-344.

[4] Pollard H.F., *Feature analysis and musical timbre*, Journal of the Catgut Acustical Society vol 1, n° 1 (series II), 1988, pp. 232-244.

[5] Fabre B., *Caractérisation d'un jeu d'orgue*, Mémoire de DEA en acoustique appliquée, Université du Maine, 1988.

[6] Castellengo M., *Contribution à l'étude expérimentale des tuyaux à bouches*, Thèse de l'université Pierre et Marie Curie (Paris VI), 1976.

[7] Luce D. et Melville Clarck J.R., *Durations of attack transients of non percussive "orchestral instruments"*, Journal of the Audio Engineering Society vol. 13, n° 3, 1965, pp. 194-299.

[8] Štěpánek J. et Otčenášek Z., *Acoustic documentation of 12 pipe organs and analysis of their plena*, in Colloque C5, supplément au Journal de Physique III, vol. 4, 1994, pp. C5-645 to C5-648.

[9] Kamp Ph., *Caractérisation de la sonorité du transitoire d'attaque de jeux d'orgue à bouche*, Mémoire de DEA en acoustique appliquée, Université du Maine, 1994.

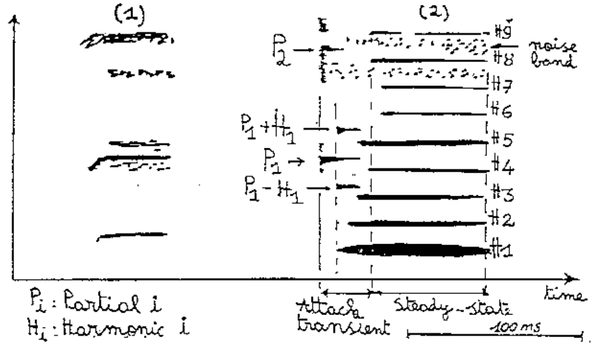


Fig.1 [6] : (1) pipe with resonator disabled : *edge-tone*
(2) normal pipe : *mouth-tone* (partials and noise bands) and harmonics

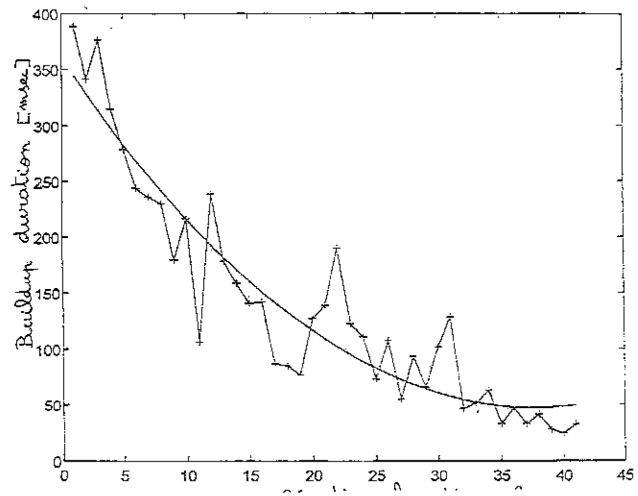
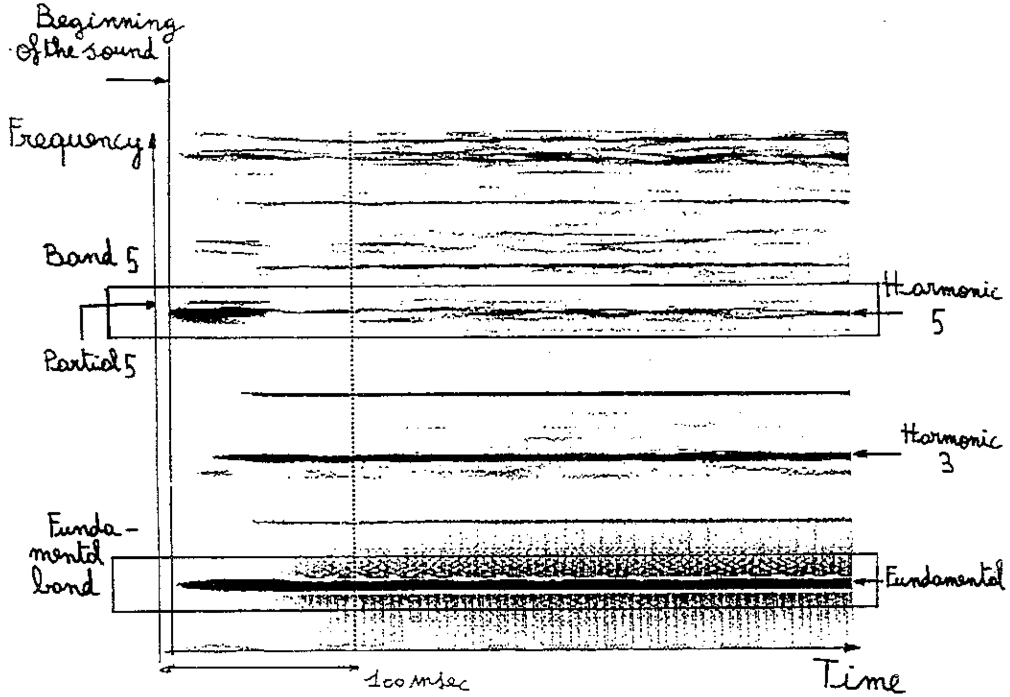
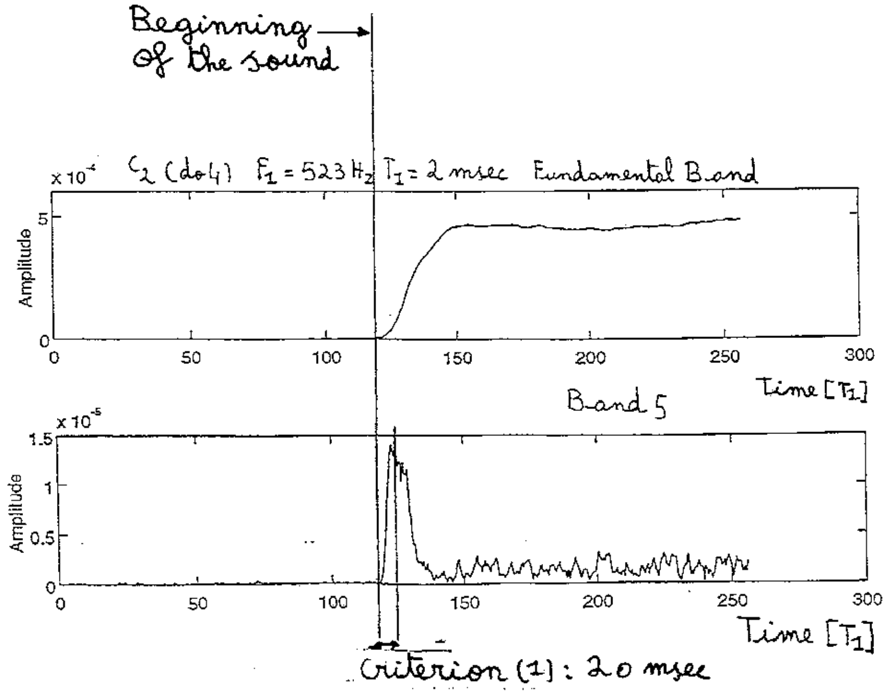
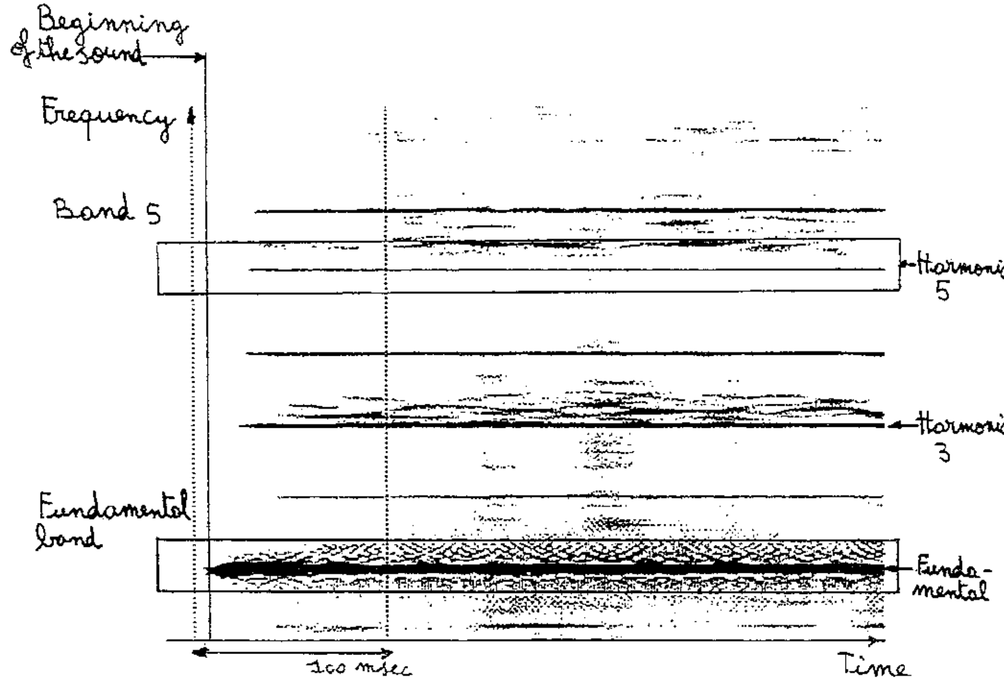


Fig.2 [9] : buildup duration of the steady state for the bourdon and its polynomial fitting





Chapter 2 : Pipe instruments



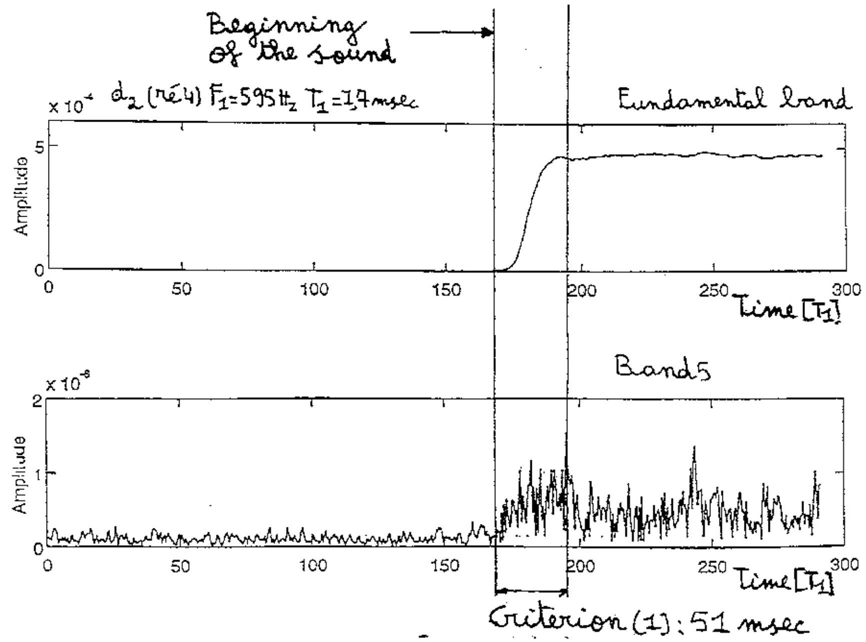


Fig.4 : soft attack for a bourdon d2 (ré4) note