SATURATION MECHANISM IN REED INSTRUMENTS

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Dalmont Jean-Pierre[1], Ducasse Eric[2], Ollivier Sébastien[1]

1. Laboratoire d'Acoustique de l'Université du Maine, UMR CNRS 6613
   Avenue Olivier Messiaen
   72085 Le Mans Cedex 9, France
   Tel: (33)2 43 83 32 77 and (33)2 43 83 36 12
   Fax: (33)2 43 83 35 20
   E-mail: jean-pierre.dalmont@univ-lemans.fr and sebastien.ollivier@univ-lemans.fr

2. Ecole Nationale Supérieure d'Arts et Métiers
   Esplanade des Arts et Métiers
   33405 Talence Cedex, France
   Tel: 05 56 84 53 40
   Fax: 05 56 84 53 97
   E-mail: eric.ducasse@bordeaux.ensam.fr

ABSTRACT

When blowing a wind instrument, the sound level is limited by the fact that when the blowing pressure increases the level also increases until a maximum beyond which the reed closes suddenly. Time domain simulations and experiments using an artificial blowing machine are used to demonstrate that losses are responsible for this phenomenon. Due to losses the pressure in the mouthpiece becomes too low to ensure the reopening of the reed. It is shown that, in the case of conical instruments, the same mechanism is responsible for the bifurcation to unusual modes such as the inverted Helmholtz motion.

INTRODUCTION

When a beginner starts studying the clarinet, he needs to learn to control is breath so that the pressure is sufficient to maintain an oscillations but not to high which leads to the closing of the reed channel. In other words the player may deliver a pressure in between the threshold of oscillation and the saturation threshold. To our knowledge this saturation threshold have not been studied. Moreover, lossless models do not emphasise such a threshold. Introducing losses may explain the phenomenon but experiments show that the saturation threshold is much lower than expected with a model with standard losses parameters. In the case of conical woodwinds, the saturation threshold for the fundamental standard regime also exists but does not lead directly to the closing of the reed. The oscillation bifurcates to another regime in principle unstable when the standard regime is stable. This regime can be either the octave of the standard regime or a regime at the same frequency such as the inverted Helmholtz motion.

1. CYLINDRICAL CASE (CLARINET)

1.1 Lossless model

A lossless model in which losses and reed inertia are neglected and in which the clarinet is considered as a perfect cylinder have been exhaustively studied by Maganza and others [1-3]. In this model the reed is closed when the pressure drop between the mouth and the mouthpiece is larger than a pressure P_M characteristic of the embouchure. Up to the beating threshold, the standard regime alternates two states. For the first state, the reed is open and the pressure in the mouthpiece P is equal to the pressure P_m in the mouth. The pressure drop between the mouth and the mouthpiece $\Delta p = P_m - P$ is equal to zero. For the second state, the reed is closed $P = -P_m$ and the pressure drop is $\Delta p = P_m - P = 2P_m$ (see figure 1). This regime of oscillation is called “Helmholtz motion” because of the analogy with the bowed string [3, 4]. Nothing in the model points out a saturation threshold which is rejected to infinity.

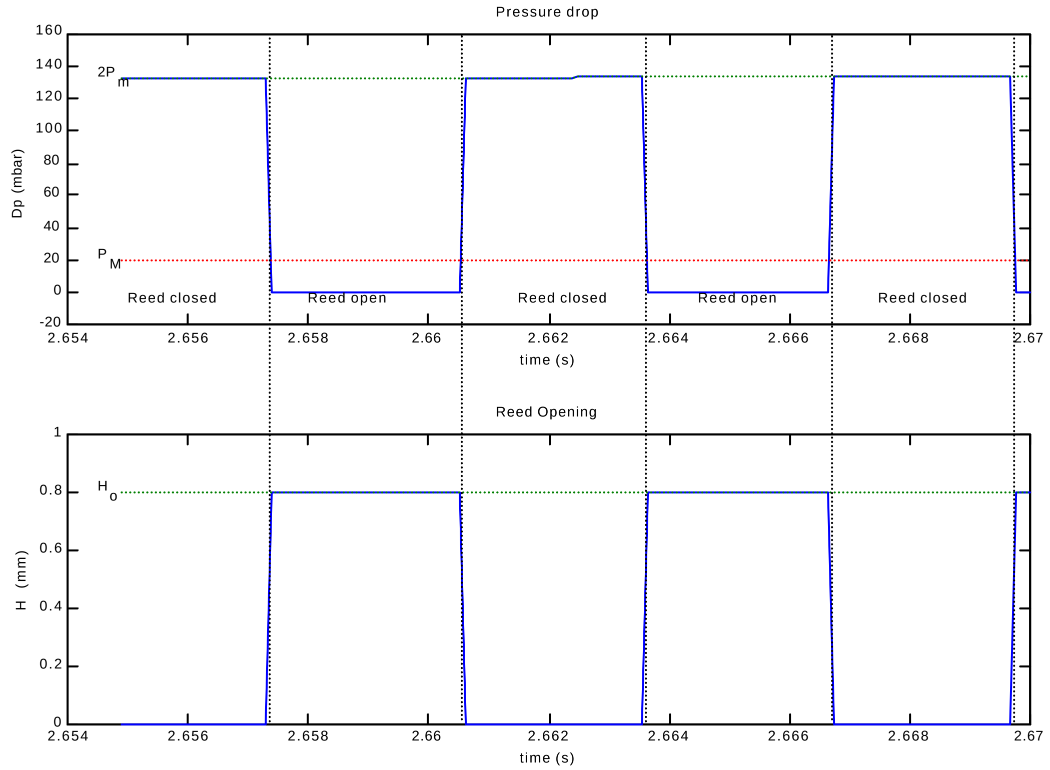

Figure 1 : Pressure drop and reed opening signals as a function of time in the case of lossless model.

1.2. Model with losses

Losses can be easily introduced in the model [5]. In our simulation standard visco-thermal losses are not sufficient to produce a saturation at a realistic pressure. Therefore the reflection coefficient at the open end of the tube has been decreased to R=0.98. This shall not be considered as shocking, as it has been demonstrated [6, 7] that the non-linear phenomena at the end of a tube may increase losses considerably. The difference with the lossless model lies in the fact that the pressure signal is not a square signal. It appears that when mouthpressure increases beyond the pressure P_M, the pressure drop is lower than P_M for a time lower than a half period (see figure 2). Consequently the reed opens for a decreasing duration when the mouthpressure increases. When this duration becomes too small the oscillation stop suddenly. We notice a small out of phasing between the opening episode and the time during which the pressure drop is lower than P_M. This, as well as the fact that the reed opening can be larger than its rest position, is due to the taking into account of the reed inertia.

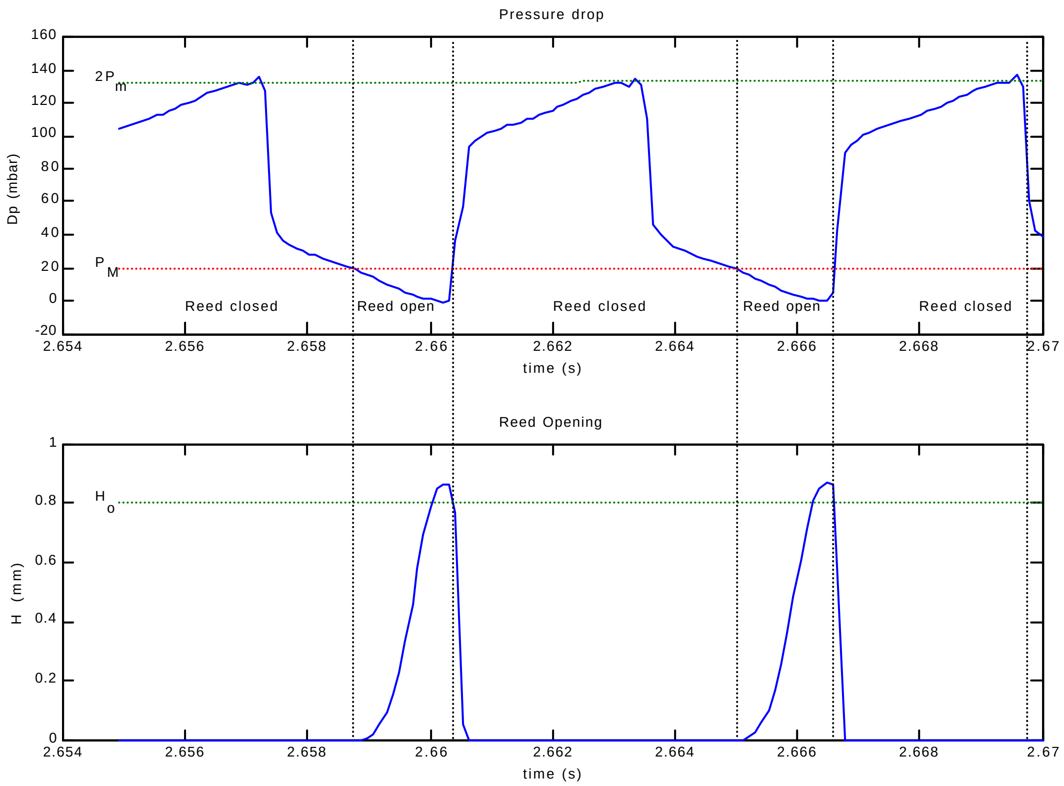

Figure 2 : Pressure drop and reed opening signals as a function of time near the saturation (simulation including losses and reed inertia).

1.3 <u>Experiment</u>

Experiments have been carried out with a blowing machine [8]. The pressure drop have been measured with a high sensitivity pressure transducer (ENTRAN EPE-541-M). The reed opening have been

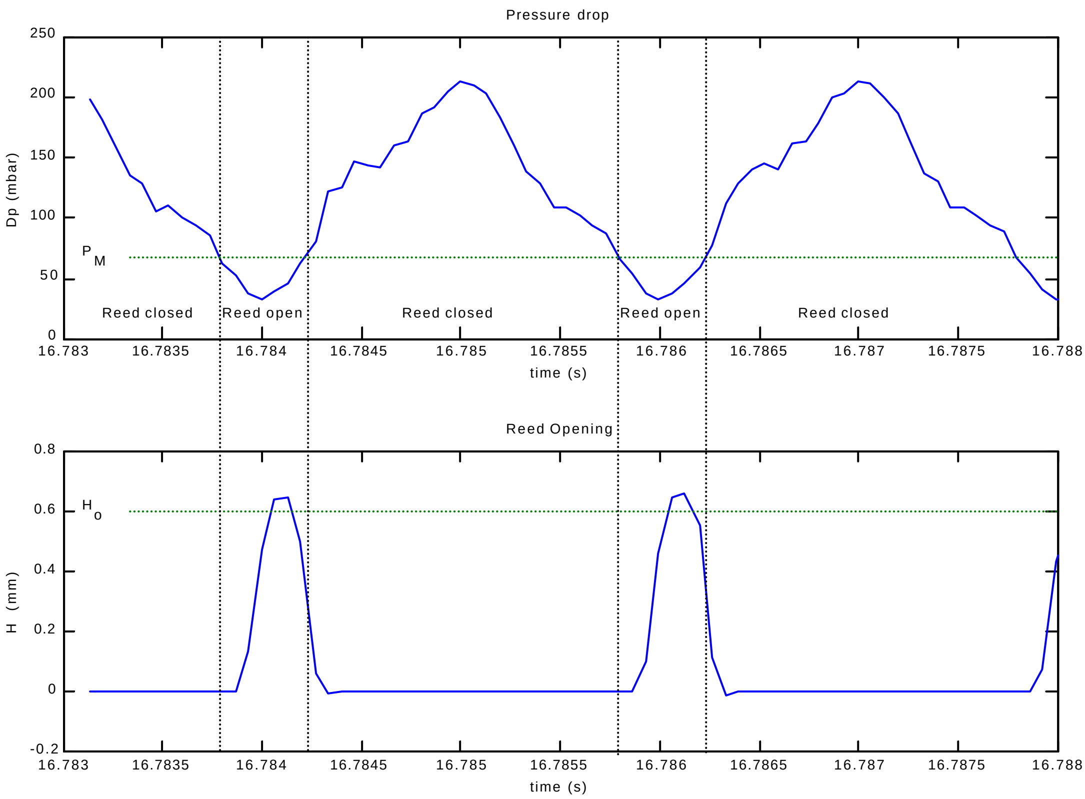

Figure 3 : Pressure drop and reed opening signals as a function of time near the saturation (experiment).

measured with a LASER and a photo diode [9]. It appears that when the mouthpressure increases the pressure drop when the reed is open increases. When this pressure drop is larger than P_M, the reed do not reopen and the oscillations stop. The behaviour is similar to what is obtained with the model with losses but the saturation appear more suddenly and for a mouthpressure lower than in our simulation (see figure 3). The explanation is probably due to the fact that, due to the non linear losses [7], the reflection coefficient at the end of the tube is probably much lower than 0.98.

2. CONICAL CASE (SAXOPHONE)

2.1 Lossless model

We consider a model without losses in which the resonator is a succession of N cylinder of same length and such that $S_i=i(i+1)S_1/2$ where S_i is the cross section of the i^{th} cylinder. Such resonator are known to behave like a saxophone [3, 4, 10]. With such a model, as for the clarinet, up to the beating threshold, the standard regime alternates two states. First state, the reed is open and the pressure in the mouthpiece P is equal to the pressure P_m in the mouth. The pressure drop $\Delta p=P_m-P$ is equal to zero. Second state, the reed is closed $P=-NP_m$ and the pressure drop is $Dp=P_m-P=(N+1)P_m$ (see figure 4 for N=2). This regime of oscillation is called “Standard Helmholtz motion” because of the analogy with the bowed string and because another solution, the “Inverted Helmholtz motion”, may also exists [3, 4]. For the standard Helmholtz motion the reed is open the main part of the period i.e. N/(N+1) times the period (see figure 4 for N=2).

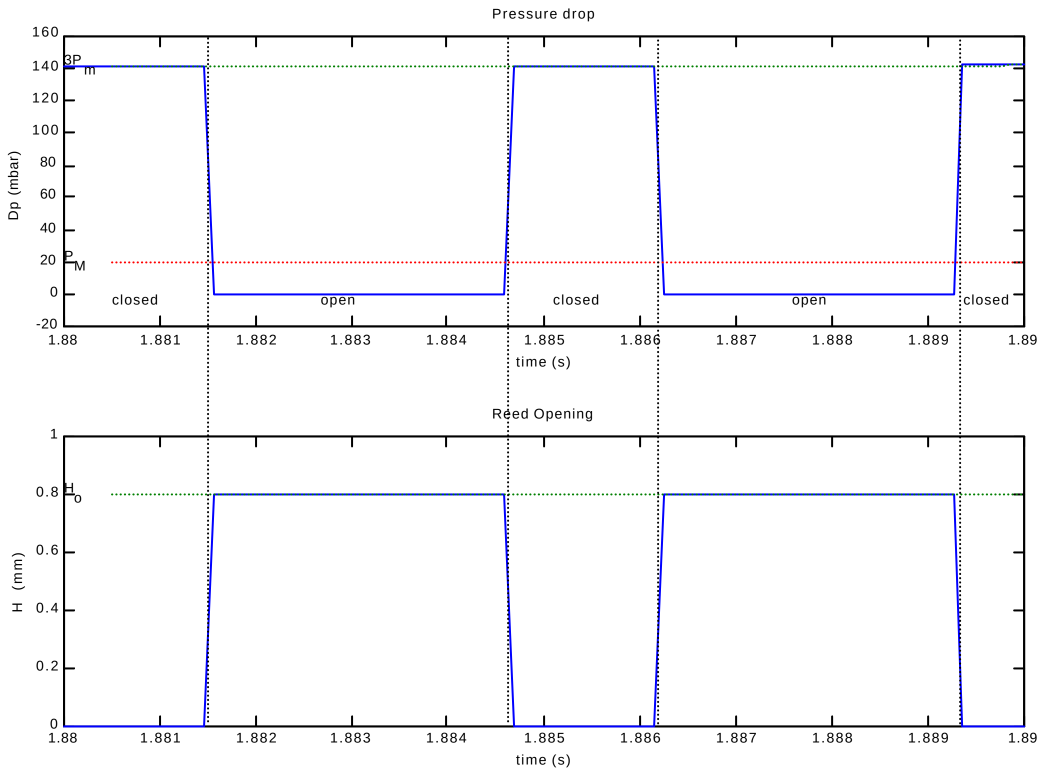

Figure 4 : Pressure drop and reed opening signals as a function of time in the case of a lossless model for a resonator made with two cylinders (N=2).

2.2. Model with losses

When losses are introduced, the same phenomenon as with the clarinet appears. The opening duration which should be 2/3 of the period for a “standard Helmholtz motion” for N=2 diminishes when the mouthpressure increases until it reaches 1/3 of the period. Then, the oscillations bifurcate to a “three step motion” (see figure 5). For this regime the duration of the opening is a third of the period and the pressure drop takes ideally three values 0, P_M, $2P_M$. When the mouthpressure keep increasing the opening duration keep diminishing until the oscillation vanishes.

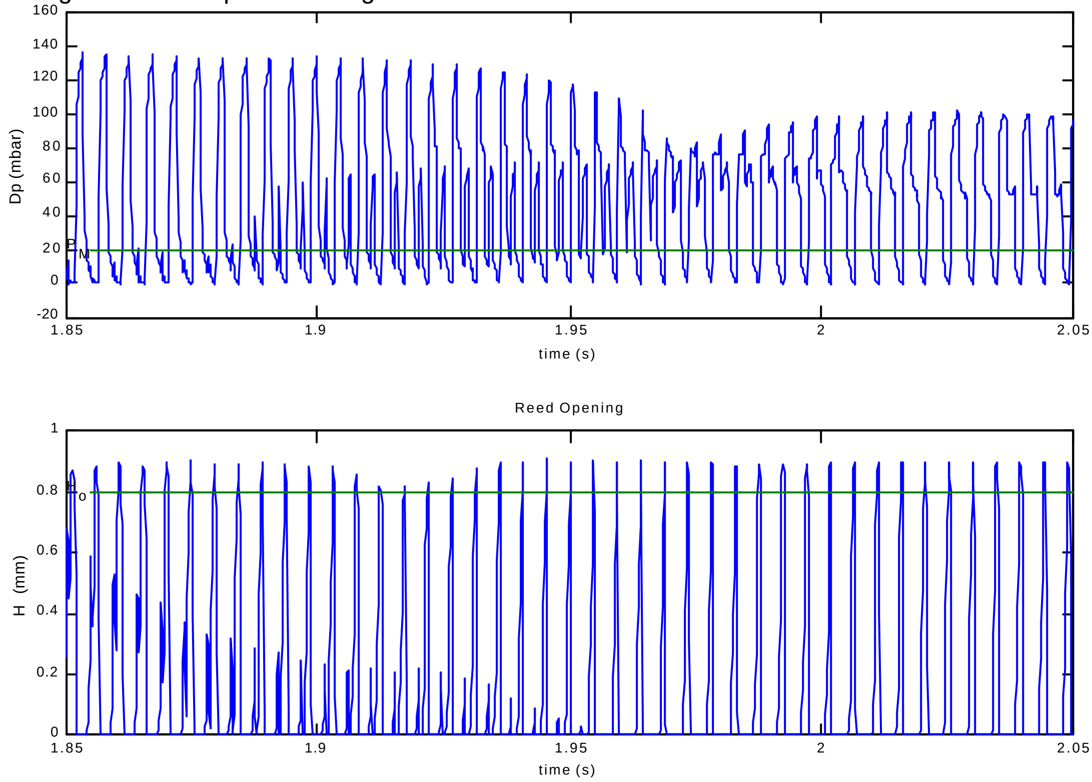

Figure 5 : Bifurcation from the standard Helmholtz motion to a “three step motion” (simulation including losses and reed inertia for a resonator made with two cylinders (N=2))

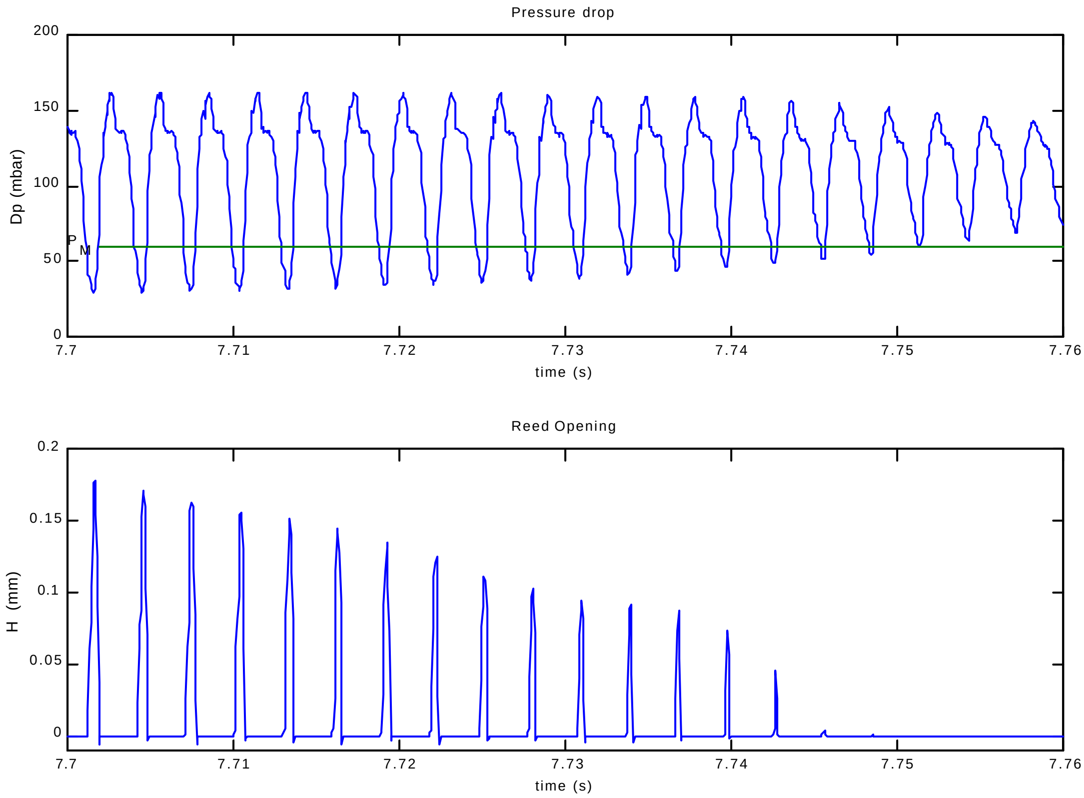

Figure 6 : Extinction of the oscillation (experiment with a resonator made with two cylinders (N=2))

2.3 Experiment

Experiments have been carried out with a saxophone made with two cylinders. Experiments show that when the opening time diminishes the shape of the pressure signal is modified and tends to a signal which can be more or less interpreted as an "inverted Helmholtz motion" (figure 6). As observed with the simulation, when the measured mouthpressure keep increasing the opening duration keep diminishing until the oscillation vanishes (figure 6).

CONCLUSION

The mechanism which leads to the saturation is due the finite value of the pressure drop between the mouth and the mouthpiece when the reed is open. When this pressure drop reachs the closing pressure P_M, the mouthpiece pressure is no more sufficient to ensure the reopening of the reed and the oscillation stops. Simulations shows that this phenomenon can be observed only if important losses, such as non linear losses on a side hole, are taken into account in the model. The saturation mechanism is also the cause of the bifurcation to non standard regimes such as the "inverted Helmholtz motion"

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REFERENCES

1. C. Maganza, R. Caussé, F. Laloë "Bifurcations,period doubling and chaos in clarinet-like systems", Europhysics Letters, 1, 295-302 (1986).
2. J. Kergomard "Elementary considerations on reed-instruments oscillations" in Mechanics of musical instruments, Lectures notes CISM, Springer (1995).
3. J.-P. Dalmont, J. Gilbert, J. Kergomard "Reed instruments, from small to large amplitude periodic oscillations and the Helmholtz motion analogy", ACUSTICA-acta acustica, **86**(4) 671-684 (2000).
4. S. Ollivier, J.-P. Dalmont, J. Kergomard "Idealised models of reed woodwinds. Part I: Analogy with the bowed string", submitted to ACUSTICA-acta acustica (2002).
5. E. Ducasse "Modélisation et simulation dans le domaine temporel d'instruments à vent à anche simple en situation de jeu : méthodes et modèles", Thèse de doctorat de l'Université du Maine (Le Mans (2001).
6. J-P. Dalmont, C.J. Nederveen, V. Dubos, S. Ollivier, V. Meserette, E. te Sligte : "Experimental determination of the equivalent circuit of a side hole: linear and non linear behaviour", to be published in ACUSTICA-acta acustica.
7. J.-P.Dalmont, S. Ollivier, E. Ducasse "Practicle consequences of tone holes non linear behaviour", International Symposium of Musical Acoustics, Perugia (Septembre 2001).
8. J.-P. Dalmont, B. Gazengel, J. Gilbert et J. Kergomard "Some aspects of tuning and clean intonation in woodwinds", Applied Acoustics **46**, 19-60 (1995).
9. J.-S. Cullen, J. Gilbert, D.M. Campbell "Brass instruments : Linear stability and experiments with an artificial mouth", ACUSTICA-acta acustica, **86**(4) 704-724 (2000).
10. J.-P. Dalmont et J. Kergomard "Lattices of sound tubes with harmonically related eigenfrequencies", Acta Acustica, **2**, 421-430 (1994).