# MECHANICAL BEHAVIOUR OF ARTIFICIAL LIPS

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**Abstract**

This system aims at reproducing the behaviour of a musician's lips in a stable and controlled way.

Firstly, the study focuses on the characterisation of this determining element (i.e. artificial lips) in order to improve their performance. Secondly, artificial mouth settings are studied to identify their correlation with the tonal response of the system.

A minimal configuration has been chosen for this study : a plexiglass mouth cavity connected to an air supply and water-filled lips. It is possible to control the lip stiffness and the cavity air pressure by adjusting the water volume in the lips, the air flow in the cavity, and the distance between the lips and the mouthpiece.

The first study pointed out the complexity of the mechanical system composed with the two lips, their high sensibility to the settings, as well as the results dispersion due to initial state of stress and damage. This sensitivity to external factors was confirmed during the second step thanks to the use of an audio descriptor set applied to recordings carried ou during the experiments.

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## ARTIFICIAL MOUTH GOALS

The mastery of the technique of playing for an acoustic instrument (i.e. its control) is a difficult and lifelong pursuit. The quality and reproducibility of a musical performance depends on the level of the technique attained; this technique could well be described in terms of various system parameters (still not well understood), and of course, the interaction between the player and the instrument. One general goal of the Consonnes project [Projet CONSONNES], in which the following study is conducted, is to solidify the understanding of the breakdown of the instrument model into its constituent parts (in particular the resonator), and to characterize the different modes of operation of the instrument in terms of control parameters supplied by the player.

Using an artificial mouth, the main parameters of control of a trumpet player are adjustable in a controlable and objective way as opposed to a musician who will adjust many parameters inconsciently from sensitive and audio feedbacks [Gilbert *et al.*, 1998], [Cullen *et al.*, 2000], [Neal *et al.*, 2001].

## LIPS CHARACTERIZATION [Freour, 2006]

### Experimental Setup and Procedure

The experimental measurements are carried out using an artificial mouth composed with a mouth cavity of 1,5.10$^6$ $mm^3$ in plexiglas. The lips are created with two latex cylinders filled with water. Water volume is controled in each lip with a precision of 0,01ml, air flow in the mouth cavity is controled thanks to a leak and the distance between lips and the mouthpiece of the trumpet (stress exerted by the trumpet on the lips) is controled with a precision of 0.01 mm. A loudspeaker is set on the mouth cavity in order to solicit the lips with an acoustic signal during the mechanical response measurements. In the mouth cavity, a borehole allows the setting of a microphone to control the loudspeaker signal. This microphone is placed just behind the lips to get a signal as close as possible to the acoustic sollicitation around them. When the artificial mouth is working, a stopper made of nylon is used to replace the microphone. The trumpet used for this study is the following : B flat Blessing Scholastic Elkhart with a Vincent Bach 1 1/2 C mouthpiece. Sound recording is carried out with a Brüel & Kjaer Type: 2669 microphone and a Brüel & Kjaer Type: 2690 OS preamplifier. Signal acquisition ans treatment is done with Matlab and a National Instrument card.

In order to maintain the stress of the mouthpiece when the trumpet is removed, a mouthpiece support is mounted on the bench. Therefore the mouthpiece is fixed and the trumpet removable without changing the stress condition between the lips and the mouthpiece ring.

Mechanical measurements are carried out with a laser velocimeter which expands through the backbore of the mouthpiece up to the lips.

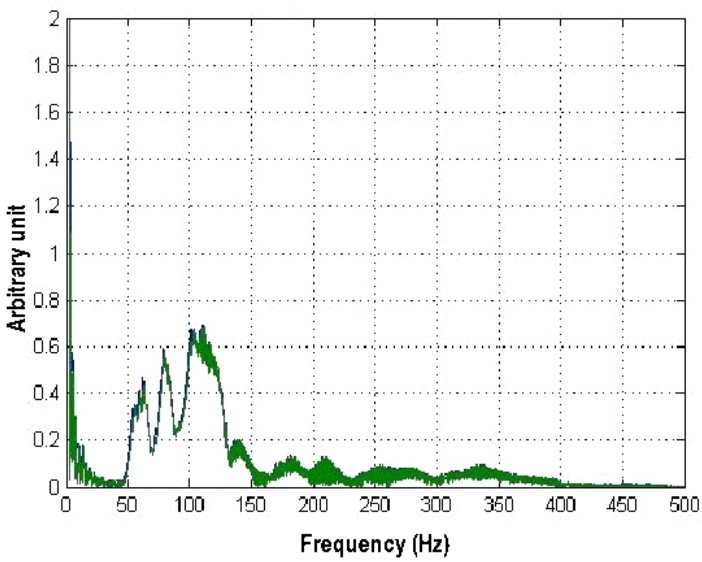


*Figure 1:* Mechanical response of the lips (magnitude of the displacement in arbitrary units).

An experiment consists in adjusting the artificial mouth parameters in order to get a note which fits with a sound obtained by a trumpet player. The sound is recorded and the playing frequency is deducted from the sound spectrum. Then the air flow is turned off and the nylon stopper replaced by the microphone. A sweep in frequency is generated with the loudspeaker in the mouth cavity from 0 to 500Hz. The amplitude of the sweep is modulated to get a constant level. While the acoustical pressure solicits the lips, mechanical measurements are carried out with the laser velocimeter which gives access to the velocity response of the lips in the axis of the laser beam. The mechanical response of the lips in displacement is calculated from this velocity acquisition by integration.

Thanks to this procedure we can characterize artificial lips as function of the time taking into account their ageing and deterioration, and as function of the different lips used (variation of the thickness).

## Results

Figure 1 shows an acquisition of the mechanical response of the lips. We can see three peaks of resonance in this figure corresponding to three resonance modes. For each experiment, we generally observed between one and three main peaks. Figure 2 represents the playing frequency as a function of the average resonance frequency of the lips for each experiment.

At first, we observe a logical raise of peak frequencies with the playing frequency (successively Bb2, F3, Bb3 and D3). This observation points out the increase of the global rigidity of lips with the playing frequency. Secondly, we observe a huge dispersion of the results due to deterioration of the latex by water (for each pitch, we find resonance peaks on a large range of frequencies). This last observation shows the necessity to focus on the mechanical behaviour of the lips with more precision, trying to get more information about the response with the laser beam.

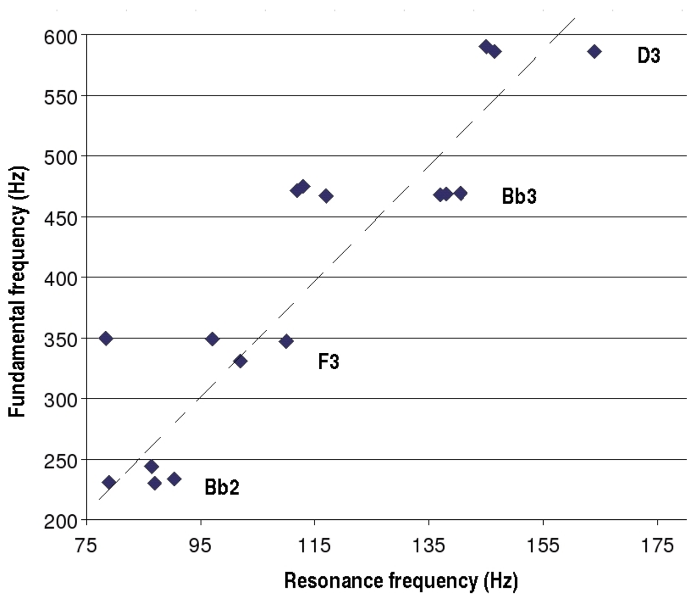


*Figure 2:* Playing frequency as function of resonance frequency.

A second experiment consisted in modifying the direction of the laser beam to change its incidence (beam focus on the right side, center, left side of both lips and on the contact area of the lips). It is very difficult to describe the laser beam incidence with precision with this bench. As a matter of fact, the mouthpiece hides the vibrating area of the lips. Figure 3 shows the amplitude of the main resonance peaks observed during an experiment as a function of the incidence of the laser beam. We can see that the amplitude of each peak moves according to the incidence. This results leads to two main hypothesis:

1. The lips do not have the same mechanical behaviour. Each one influences the mechanical response of the other because of the contact interactions.

2. Each measure makes resonances modes appear in the same direction as the beam. Modifying the incidence of the laser beam, we point out the mechanical resonance modes in the new laser direction.

These hypothesis have to lead a new experimental procedure making possible to control the incidence with precision. In keeping with this conditions and to improve the accuracy of the measurements, a new bench has been developed using guidance rails (Figure 4) and a new mouthpiece with a removable cup was developped.

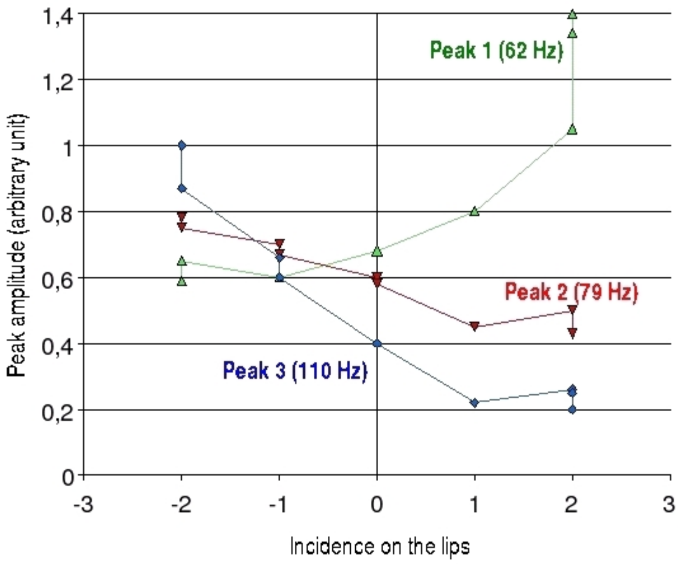


*Figure 3:* Peak amplitudes as a function of the incidence of the laser beam (-3: edge of the left lip, 0: contact area of the two lips, 3: edge of the right lip).

## SOUND CHARACTERIZATION: INFLUENCE OF SETTING PARAMETERS [Kurijn, 2007]

### Experimental Setup and Procedure

In this part, the study focuses on the tonal response of the system using a set of audio descriptors [Peeters, 2004]. The experiment aims at indentifying correlations between the sounding response and artificial mouth settings (water volume in

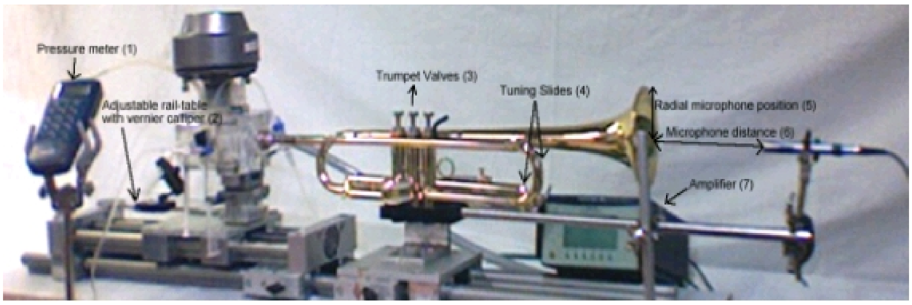


*Figure 4:* Artificial mouth bench developed using guidance rails.

lips, distance between lips and mouthpiece, air pressure in the mouth cavity). All experiments are conducted with the new bench allowing more accurate adjustments.

Experiment procedures consist of adjusting the artificial mouth settings in order to obtain a sound. Once a recording is done, one setting parameter value is modified around its initial position keeping other parameters constant. For each recording, a set of audio descriptors is used to quantify some functioning and quality features like the *fundamental frequency, the pitch, the roughness or the intensity (sound level).*

## Results

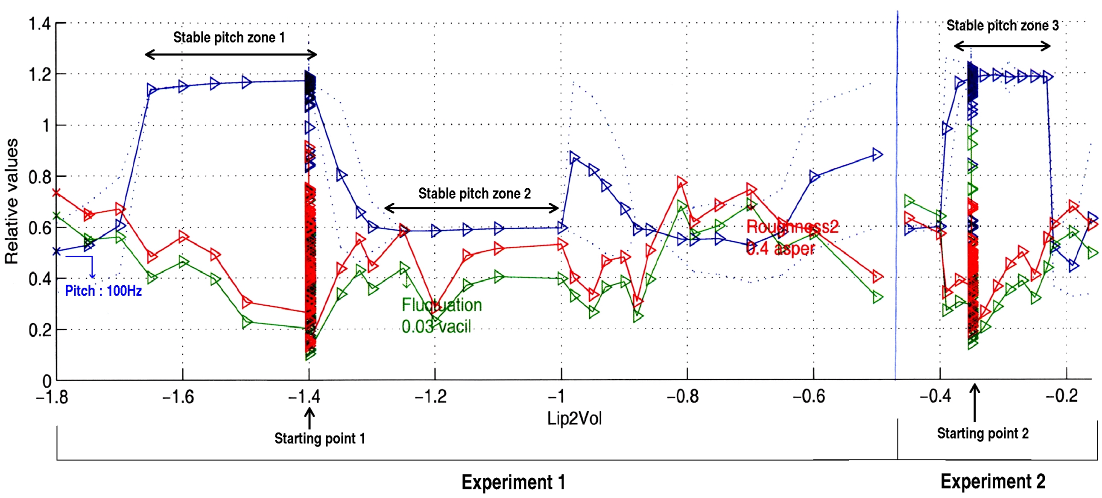


*Figure 5: Pitch, Roughness* and *Fluctuation* as function of Lip2Vol (graduation relative to the water volume in the lip2).

Figure 5 presents an example of results: *fundamental frequency, roughness and fluctuation* of the sound as function of the water volume in one of the two lips. Two experiments (from two starting points), proceeded at different times, are shown on this figure. For the first experiment, the starting point is such as Lip2Vol = -1,4 and for the second one such as Lip2Vol = -0,35 (arbitrary unit). In the same way, other parameters have differents value at each starting point.

In the two experiments, we observe a zone of stable pitch (between -1,65 and -1,4 for experiment 1 and between -0,35 and -0,25 for experiment 2). For both zones, the fundamental frequency is very close to the theoric second resonance frequency of the trumpet. These zones have different sizes acording to the experiment, what point out two strategies of setting to obtain a same note.

Secondly, we see that *roughness* and *fluctuation* have the same behaviour within this zone in both experiments (curved shape). In the case of experiment 1, the minimum of *roughness* and *fluctuation* fits with the perceptual clearest sound within the stable pitch zone (Lip2Vol = -1,4 for experiment 1). This observation is confirmed by the spectral analysis. A second stable pitch zone is observed in the experiment 1 (between -1,3 and -1). We see that *roughness* and *fluctuation* have almost the same value for the points Lip2Vol = -1,2 and Lip2Vol = -1,4 of experiment 1. In spite of this observation, sound perception differs: we perceive the same pitch in spite of the octave variation calculated by the pitch descriptors. We also hear a double sound, what is confirmed by the spectral analysis witch reveals the presence of sub-harmonics.

## CONCLUSIONS

These two studies - one on the mechanical response of the lips and the other on sound characterization - demonstrate the different steps that must be carried out before arriving at the creation of a reliable artificial mouth system that makes it possible to obtain a desired sound.

The first one concerns the reproductibility of the system's response. In both studies, we noted primarily a problem on un-reproductibility: using the same setting, the sound differs from one session of the experiment to another. This flaw is due mainly to the deterioration of the latex and to other parasitic factors related to the mechanical assemblage. The perfecting of the manufacturing process by IRCAM's machineshop lab makes it possible today to develop new lips using silicone, a material whose properties remain intact when it comes into contact with water. The automation of the artificial lips, carried out simultaneously as a part of the BARMstrong [BARMstrong] project, should let us improve the mechanical mounting and the settings, especially for the two lips. These improvements can lead to a new mechanical characterisation, this automation giving the precision required to describe the complex behaviour of the lips.

The second step concerns the use of sound descriptors to characterize the sounds made by the artificial mouth. During this study, we noticed that for certain sounds a simple reading of the descriptor's values could lead to mistakes (e.g. a mistake on an octave, or a mistake of the pitch detected for multiphonic sounds). We now need to perfect these techniques and find combinations of descriptors that will avoid these wrong interpretations.

## ACKNOWLEDGMENTS

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