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MUSICAL ACOUSTICS AS LEARNING SUPPORT FOR ENGINEERS: EXAMPLES OF STUDENT ACHIEVEMENTS AT MECHANICAL ENGINEERING DEPARTMENT - INSA LYON

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ABSTRACT

Since 2016 and the merger of two old departments, a new project is proposed to INSA Lyon students in first year of the mechanical engineering program (L3 in LMD system or Bachelor degree). It consists on a scientific and technical project of around 40 hours on classroom plus an equivalent time duration of personal work at home; it is supervised by a pair of teachers. The idea is to insist on the abilities of thinking, analysing, well-defining, and resolving a given scientific problem. To this end, we propose each year to six pairs of students to work on musical acoustics projects. The principle is that the subject must be theorised and defined by the students without the help of the teacher, related to any field of musical acoustics, on experimental, theoretical or numerical skills. A long duration of the beginning of the project is dedicated to the definition of the scientific problem and objective, and to the clear exposure of a scenario to answer to them. One constraint concerns the budget of eventual experimental campaigns: we privilege the use of a simple smartphone (and the sensors existing in it) to do the measurements. Some examples of recent results on studied projects will be given and discussed. Examples of some of them would be: design and conception of metallic xylophone bars for given harmonic series helmholtz resonance of a classical guitar, modeling and measuring a Cajon, experimental and analytical study of the wolf note of a cello...

1. INTRODUCTION

The mechanical engineering department of INSA-Lyon (Génie Mécanique GM) has been created in 2016 after the merger of two old departments (Génie Mécanique Conception and Génie Mécanique Développement). On this occasion, the educational provision was deeply reviewed and updated. Teachers together with department pedagogical direction were invited to think and create new teachings and projects that will insist in the interaction between scientific domains and skills. To this end, a new scientific and technical project in the first year of the mechanical engineering program (L3 in LMD system or Bachelor degree) called "Projet Scientifique et Technique, GM-3-PST" has been built. PST consists on a scientific and technical

project, in pairs, of around 40 hours on classroom plus an equivalent time duration of personal work at home; it is supervised by a pair of teachers. The idea is to insist on the abilities of thinking, analysing, well-defining, and resolving a given scientific problem.

The PST subject depends very much on the professors in charge of a group, depending on their personal background and/or researcher profile. A not exhaustive list of subject examples proposed in the past years at INSA could be: numerical simulations of dexterity games (billiard, bowling, boules...), modelling of a Jacquard textile (lace) machine, material choice for a given engineering problem, design and production of golf ball launcher, development of a moon landing mission... In our group we see musical acoustics as a perfect theme for multidisciplinary approaches, that offers a good variability of projects from year to year, and also a good way to give motivation to our students. Moreover it allows to find projects that fit their background at this time of their education (L3, Bachelor). In fact during the first year of "Génie Mécanique" they follow several classes: linear mechanics of continuous media (solid mechanics, vibrations, acoustics, fluid mechanics, thermal mechanics, etc.), signal processing (Fourier transform...) and computational methods (finite elements, programming languages as matlab, python, etc.). Musical instruments are a really good field to apply this knowledge.

2. PROPOSED TEACHING APPROACH

2.1 How to formulate a musical acoustics problematic and a scenario to answer to it?

In the group we are in charge of, we propose each year to six pairs of students to work on musical acoustics projects. The general frame given to the students is: pick an instrument of their choosing, and build questions that could be answered with the help of experimental, numerical or theoretical work. The first sessions at the beginning of the project are dedicated to the definition of scientific problems and objectives, and to the clear exposure of a scenario to answer to them. Each year the six students duo lead to six different projects. A small budget is dedicated to students for specific purchases if needed, but we also encourage them to use experimental setups in our labs, and to

make an optimal use of personal sensors hidden in smartphones.

The first reactions of students, when they are asked to build "musical acoustics scientific problematic", can be very different depending on their musical education or curiosity. Most of them usually don't have any idea of the physics behind musical instruments (even if they currently take a class on it). However, after one or two working session of two hours, all students are enthusiastic on a given instrument found in their environment (family/friends), and start to imagine experimental measurements or numerical simulations. Obviously they need small help from us to simplify the problematic they chose and to fit into the project time and their abilities. But this project is a good opportunity for them to build the problematic on their own: that's why we insist regularly on making them verbalise. Clarification of the problem can last until the 5th or 6th session of two hours but greatly benefit them (in overall, there are twelve session of "work" on the project plus four last hours of oral presentation).

Few tips are also given to students in the beginning. It can be an initial help for the definition of the problematic, doing for example a focus on how are made energetic transfers in a given instruments, but also some first references to initiate their bibliographical work. To give an idea here, the main document we advise as an entry for the "science and music" field is the book of Antoine Chaigne and Jean Kergomard "Acoustics of musical instruments" [1], also available in french [2]. A second entry is a nice website developed at UNSW by the team of Joe Wolfe [3] with well-made animation/sounds/video explaining easily and simply some complicated mechanical phenomena but always remaining scientifically very precise and accurate. Physical classifications of instruments through typical mind mapping tools such as [4] are also nice way for students at the beginning of the project to understand and separate (in terms of mechanics involved behind) the different musical instrument families.

2.2 How to present results of a musical acoustics project in a scientific report and an oral presentation

PST project is also a good opportunity to focus on the writing of technical reports. Students assessment includes a part on general layout, quality of figures and charts. A template (*TeX* and *.doc*) quite similar to the one used here (double column) is provided, following the model of scientific journals, and full size of manuscript if limited to 5 pages in order to make them focus on main results. The projects ends with a final oral presentation of 10 minutes (plus 5 minutes of questions), here again quite similar to a conference format. The overall assessment of the students for the whole PST project work is divided in three equally weighted marks: team working during the project, technical report, and final oral presentation.

3. EXAMPLES OF STUDIES

Examples of studies and results of recent projects are given here below. We will develop and go deeper into details of these studies during the oral presentation.

3.1 String instruments

The figure 1 taken from [5] shows an example of numerical video analysis tool (Latis-Pro) students used to visualise and follow the movement of the plectrum (or the finger/nail...) during the string excitation of a classical guitar. The purpose of the study was precisely to measure and un-



Figure 1: Video analysis of a guitar string excitation with a plectrum, from [5].

derstand the differences in terms of produced sound and subjective perceptions when a plectrum is used or not for classical guitar.

Another selected study of string instrument concerned the influence of the soundhole on the vibroacoustical response of a classical guitar. In the figure 2 taken from [6],

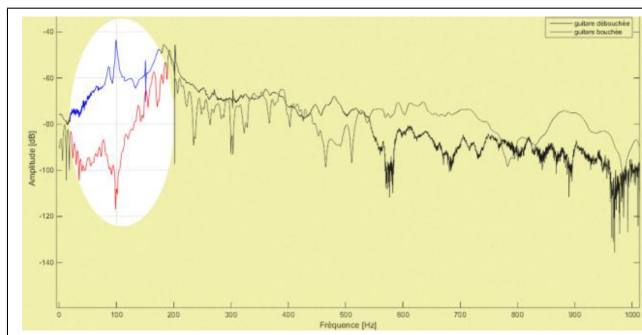


Figure 2: Transfer function of a typical classical guitar (radiated sound amplitude) from [6]. Blue curve: guitar with an open soundhole. Red curve: guitar with a closed soundhole.

students measured experimentally the radiated sound of a guitar before and after having closed the soundhole with cardboard showing nicely the strong influence of the Helmholtz resonance for the low frequency domain loudness of the instrument.

3.2 Percussion instruments

Some students chose to dimension and design musical instruments; the study presented figure 3 done on metallophone bars is a perfect example [7]. Shape optimisation of

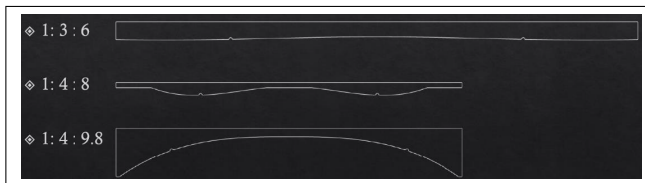


Figure 3: Optimised shape of metallophone bars for given modal resonance series, from [7].

metallic bars for given (arbitrary) modal resonance series after numerical calculations (Newton-Raphson method) is presented. The bars were designed in aluminum using waterjet cutter following the different optimised shapes, and then measured (first flexural modes of the beam) using a hammer and a microphone to compare with predictions.

The physics of other percussion instruments were also studied during the PST projects. A group was for example interested to model and measure the vibroacoustic transfer function of a Cajon [8]. In figure 4 one can see a ca-

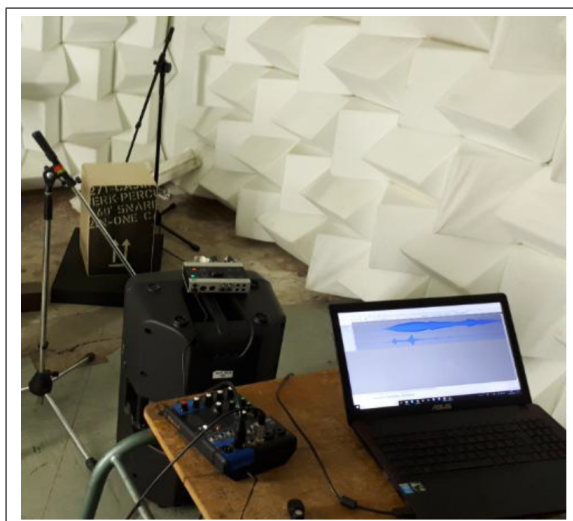


Figure 4: Transfer function measurement of a Cajon, from [8].

jon excited by a loudspeaker in a semi-anechoic room of the LVA (Laboratoire Vibrations Acoustique, INSA Lyon). Students came with their own material (computer using Audacity software for recording, a soundcard, and two microphones) and measured the transfer function between the microphone of "reference" near the loudspeaker and the second microphone at the rear of the cajon.

3.3 Keyboard instruments

Kinematic modeling of a grand piano key action mechanism with Adams software is presented on figure 5, from [9]. One note that the softwares used by students are not imposed at all. We made the choice to give the liberty

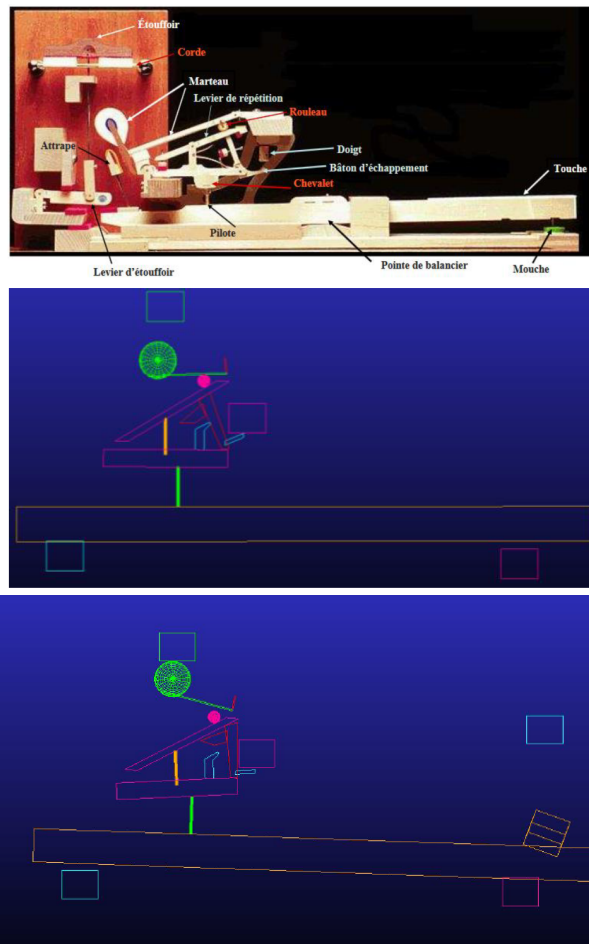


Figure 5: Numerical kinematic model of a grand piano mechanism, from [9]. First photo from the PhD of José Lozada [10].

to students to use tools and softwares they want, for which they are formed and feel at ease.

3.4 Woodwind instruments

Spectral comparisons (spectrogram) of clarinet sound are presented in fig 6, from [11]. This PST group wanted to study experimentally and analytically the influence of playing parameters on the sound of a clarinet. Here the influence of the level of excitation on the sound tone (spectral enrichment) is experimentally shown.

Other studies concerned more uncommon musical instrument. Ansys numerical study of airflow propagations in a simplified Ocarina is given on fig 7 from [12]. During this PST project, students investigated numerically the relation between airflow amplitude and resonant frequency of the equivalent Helmholtz resonator.

A last example concerns here again the Helmholtz resonator phenomenon. The figure 8 is a typical slide of the final defence of a PST group summarising the experimental protocol chosen by students: here registering 96 radiated sound signal sample for different empty bottles of different geometries and for different playing parameters (level of airflow, angle...) [13].

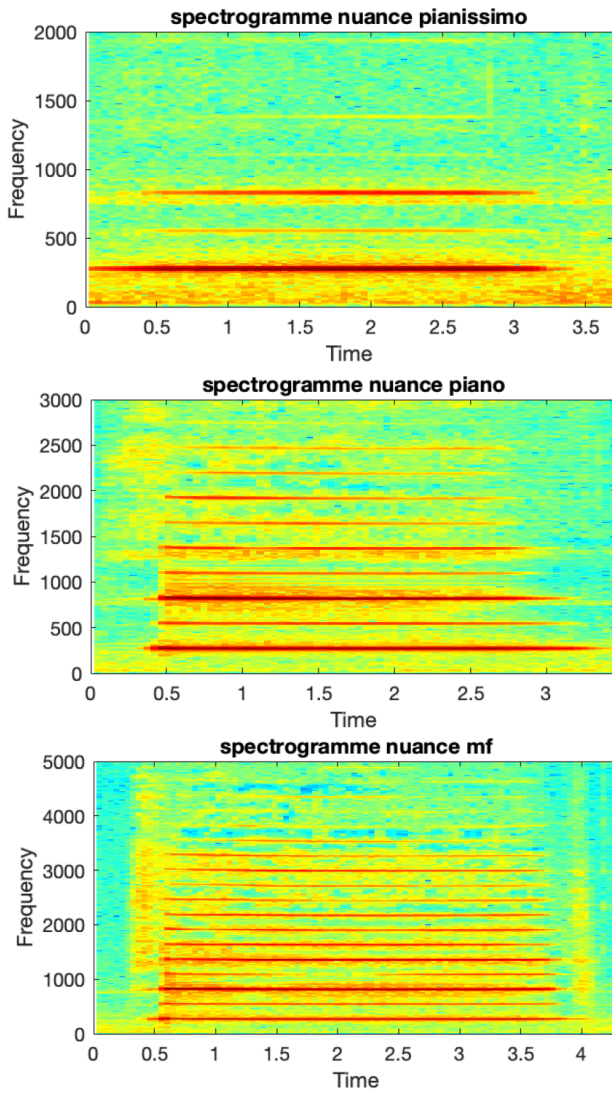


Figure 6: Spectral comparison of clarinet sound recorded for three different level of excitation, from [11]

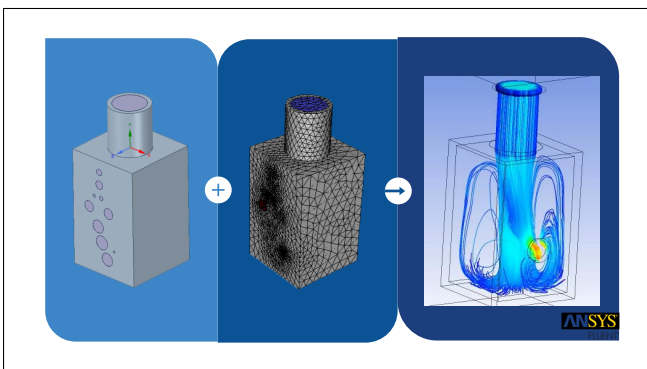


Figure 7: Numerical study of air propagation in a simplified Ocarina, from [12].

4. CONCLUSION

This short communication gives an overview of the scientific and technical projects of the GM department of INSA Lyon, during which musical acoustics subjects are proposed to group of students. The mechanics of musi-

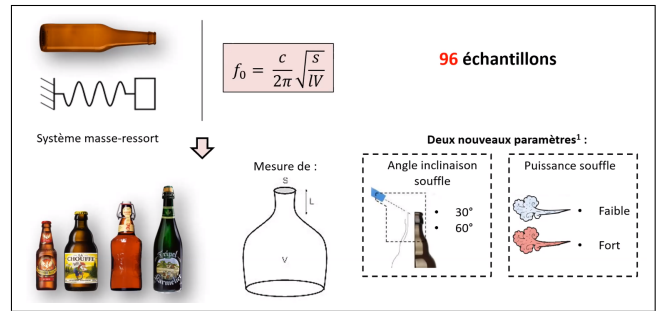


Figure 8: Example of a final defence slide (in french) of a PST project (study of the Helmholtz resonance of an empty bottle), from [13].

cal instrument covers the whole physics and the number of scientific questions that can be formalised are endless. Such teaching is a nice opportunity to interest students and develop their curiosity on musical acoustics aspects. The proposed teaching approach is explained in this proceeding and some examples of past studies are mentioned; more details and results will be shown during the oral presentation.

5. ACKNOWLEDGMENTS

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