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SOUND AND VIBRATION IN AN INTERDISCIPLINARY CONTEXT; SOME EXAMPLES FROM THE LAB

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ABSTRACT

The Norwegian University of Science and Technology (NTNU) has for years encouraged researchers and professors to engage in interdisciplinary co-operations. This paper presents three examples of classical sound and vibration problems with astonishing contributions, discussions and explanations based on musical knowledge and experience. The examples are “Singing riser”, Hagetrø violin top plate and the building construction of a music hall stage floor. An enhanced understanding of the structural physics behavior and the musical experience are discussed.

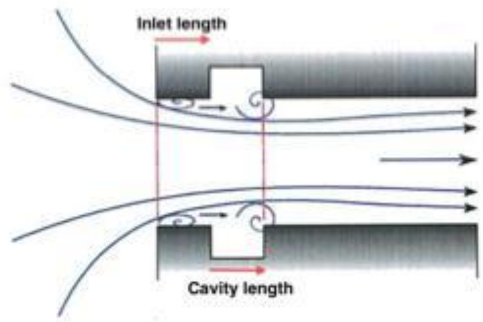
Keywords: Musical vibro-acoustics, aero acoustics interaction, applications and case studies in structural acoustics and vibration, violin top plate analyses, subjective perceptual analyses.

INTRODUCTION

We have chosen to discuss three different but typical sound and vibration problems in an interdisciplinary context; The singing riser, Hagetrø violin top plate and Building acoustics stage floor. This is about integrity and reliability but no failure.

The interdisciplinary aspect here has so far been an important approach to bring acoustical problems in front of both engineers and musicians, into a multi-disciplinary discussion, measuring quantitatively and listening analytically to sounds.

The singing riser.



Figur 1: Circular flow pipe with cavity. [1]

A class of vibration problems involving no vibrating surfaces are the so-called aero acoustic interaction problems.

An unstable flow interacts with a rigid geometry to create powerful tones. We have recently experimented with a simple system consisting of a short circular flow pipe having a small axis-symmetric cavity close to its inflow end.

This set-up involves two oscillatory systems: the acoustics of the pipe, and the oscillations in the shear layer created where the flow separates at the sharp inflow corner. The flow and acoustic systems are coupled in such a way that high acoustic levels are generated. The flow oscillations in the shear layer will curl up into vortices which are convected downstream into the cavity region where they generate acoustic power.

A feedback system exists where the acoustics of the system triggers the formation of new vortices at the right moment for creating acoustic energy. For a given geometry, and increasing flow velocity, the whistling heard will jump to the next, higher, resonant frequency once a certain velocity is reached. Each resonance normally represents a stable flow acoustic situation. (See [2] for further reading).

Invited into the lab to experience this singing tube we rapidly discovered change in pitch of the tone when we disturbed the inflow by moving the hand in front of the tube. The hand as an obstacle in front of the tube changed the air flow and subsequently generated a higher pitch, the 3rd harmonic, duodecim in musical terminology referring to the original pitch.

Figur 2: Singing resonance down.

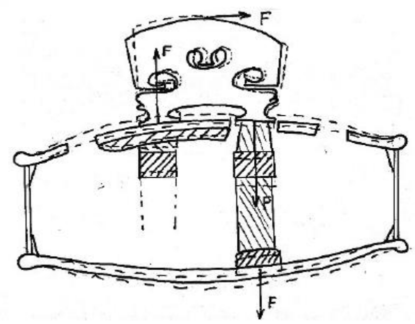
How will a musician react to this magic change in pitch? Of course, try to force the pitch down again, by singing in the end of the tube. As a voice tenor I intended to sing/produce the fundamental frequency into the tube but ended up with the 2nd harmonic, an octave above the fundamental, and the magic happened again.

The resonance frequency jumped down to its original fundamental pitch. This possible downward jump forced from outside may have not been discovered without our interdisciplinary physical and musical approach.

Find the short video clip on YouTube at

www.youtube.com/watch?v=ukPTpv66tw0

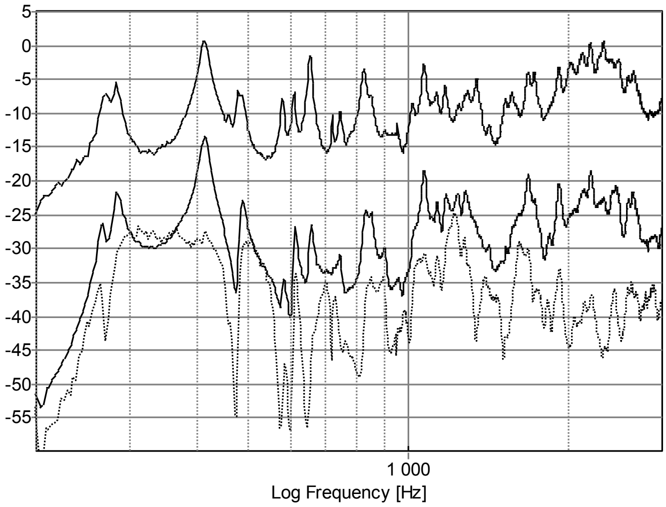
The Hagetrø violin is a new special constructed violin instrument with an extraordinary pressure absorption mechanism inside. The top and bottom plates are built in preformed plywood to minimize structural tension, to increase strength and decrease weight. The plate thickness is conform close to 2 mm.



Figur 3: Breathing mode [3].

The sound post is directly in contact with the right foot of the bridge through a hole in the top plate in order to enhance the "breeding modes" of the violin and consequently have the instrument to act more like a pulsating sphere. See Fig. 3.

Evaluating the traditional violin as a sound radiator it is not constructional optimized for the lower and middle tone register (200-1000 Hz) as the sound source is substantially smaller compared to the radiated sound waves. The instrument radiation is heavily connected to and dependent of the body resonances where the instrument acts most efficiently. The «breathing mode» is this kind of an effective radiation mode.



Figur 4: The curves show, from top, the total normalized power (Re[Y]), the normalized radiated power, and the radiation efficiency (dotted line) for the Hagetrø violin. (From [4])

Morset (ref. 4) has described a method for measuring radiation and internal mechanical losses of violins. The method is based on the assumption that the real part of the input mobility gives the total normalized power transferred to the violin. This equals the sum of the radiated power and the mechanical loss.
In addition we have to measure the radiated free field power normalized with respect to the force added to the bridge parallel to the top plate, simulating the bow movement.
Radiation efficiency is then defined as the fraction between the normalized radiated power and the input mobility.
The Hagetrø violin had a slightly lower radiation efficiency compared to a Stradivari copy. However, since the radiation efficiency normally is quite small (between 1 and 2 %, typically) the discussion about violin quality has to incorporate other factors as well, as the radiation efficiency depends largely on frequency (fig. 4).

The mathematical and physical understanding of this kind of structural analysis of musical instruments need a certain background from engineering cources. One of our courses in basic

Figur 5: Left: Stradivari-copy top plate with node lines at 570 Hz. Right: Hagetrø preformed plywood top plate with similar node lines at 740 Hz. (From [5])

instrumental acoustics for non-engineers includes a lab assignment in violin top plate vibrations, mainly producing Chladni patterns. This has been the very first introduction to sound and vibration for some of our musicians and sound artists. This lab has been designed mainly to encourage the search for better understanding of instrumental acoustics, whether you are a musician, a sound producer or an engineer.
To fulfil the work and analyses of the Hagetrø violin we invited the violinist Elena Denisova

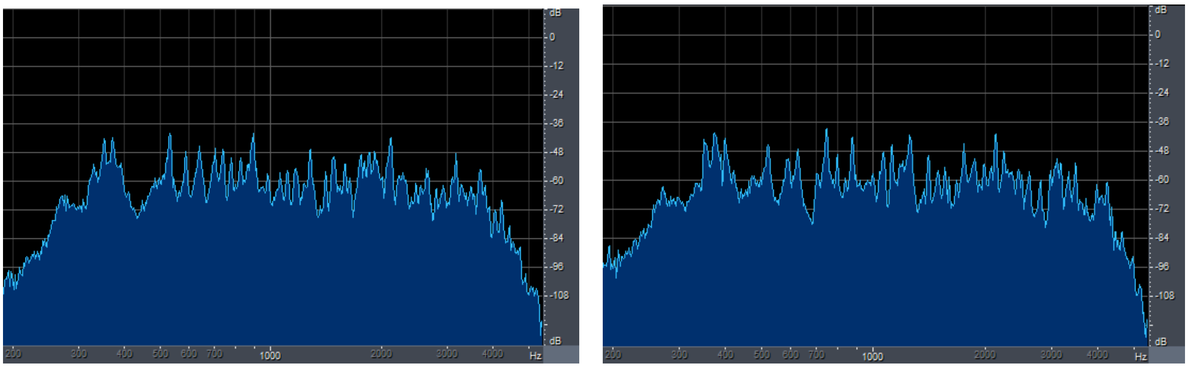
Figur 6: Elena Denisova performing in the ARC anechoic chamber.

(http://www.elena-denisova.com/en/welcome.html) to compare the Hagetrø violin with her own old Italian masterpiece. We made anechoic recordings with the same piece of music played on different instruments. The musician described quite specifically how she tried to make a personal artistic sound whatever instrument she played.

From this anechoic recording session we compared three different violins, only two described here, i.e. her own high quality Italian violin and the Hagetrø plywood violin.

Even if the instruments are sounding quite differently and are very different to play, the overall long time average spectrum analyses (LTAS) of a short musical passage are quite similar. This may be due to this specific performer's skill to force different instruments to sound with the optimal quality.

Sound examples will be presented at the IRF conference.



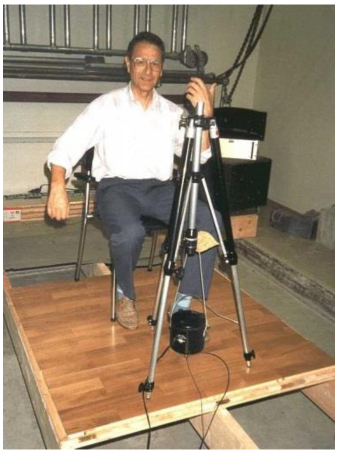
Figur 7: Comparison of long time average spectrum (LTAS) for the Italian (left) and the Hagetrø (right) violin.

The long time average spectrum (LTAS) analyses are shown in fig. 7. The analysed musical phrase is a rapid arpeggio sounding around the open d-string with fundamental frequency of 294 Hz. A pronounced difference between these instruments is the uniformity of resonance peaks in the frequency band 500 to 1000 Hz for the Italian violin, with level fluctuations of less than 24 dB while the Hagetrø violin has a much larger fluctuation span in the same frequency band, up to 38 dB. There may be perceivable differences above 1 kHz as well.

The Dokkhuset stage, (http://www.dokkhuset.no/) a small concert hall specifically designed for chamber music, has developed to be a multi-music genre presentation scene. The original stage was well defined acoustically by the acoustics consultant, referring to an old Sintef research report signed by the corresponding author.

The report was based on a comprehensive room and building acoustic study on vibration and transmission in different stage floor (podium) designs. Criteria included a subjective test of preference among cello and double bass musicians (instruments with an instrumental foot on the floor). As a double bass player the author know the need for a floor response during the performance.

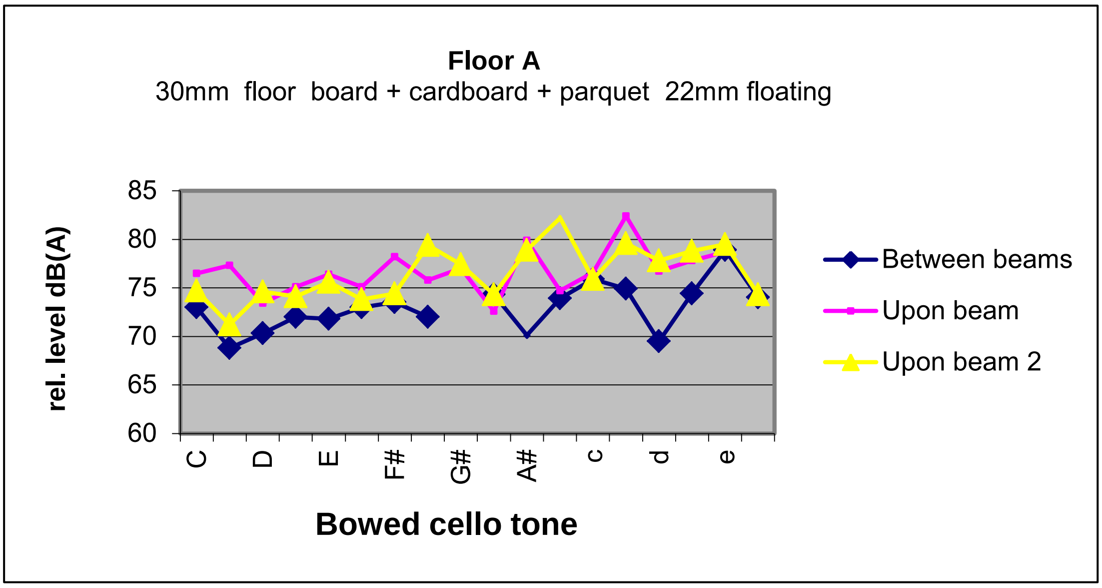
Several different floors were built in the lab, tested for vibrational properties and tested by a cello and double bass performer playing single scale tones. The picture Fig. 8 is from another similar project; with 60 cm equal distant 2"x6 floor beams.



Figur 8: Professor Emeritus Vigran with his "air cello".

The Dokkhuset podium was built with standard beams, 30 mm floor board, cardboard and 22 mm floating mounted parquet as this was the subjectively preferred construction.
The podium floor construction is, as mentioned, of vital importance for the performing musician due to the feedback response influencing the instrument control and the sound radiation. In addition we need to control floor absorption, reflection and vibration transmission.

Fig. 9 is an example of floor transmission from a bow exited cello playing 18 single chromatic tones, from C with a fundamental frequency of ≈130 Hz (chromatic increasing frequency steps of 5.95 %) up to the tone f with a fundamental frequency of ≈349 Hz. The vibration reference position was meters away from the instrument foot.



Figur 9: 18 cello tones performed between and upon beams, (From [6])

With a musical approach the analyses showed some remarkable results.
We expected a pronounced vibration transmission when the instrument foot was directly above the beam, as shown in the resulting graph, yellow and pink markers. Two measurement series with the cello foot placed upon a beam where analyzed.
In addition the measurements included one series with the cello foot placed in the middle between two beams, the blue markers. The two upon-beam data series show significantly higher vibration levels compared to between-beam data as expected. The level variation from tone to tone is however unexpected large and documents a low degree of uniformity even with semi-pro musicians. In addition these data show partly low reproducibility with differences larger than 5 dB when we compare the yellow and the pink graph (upon-beam data, tones C sharp and B).

RESULTS AND CONCLUSIONS

The paper describes three different vibration analyses projects, the singing riser, the Hagetrø violin top plate vibration and position dependence of stage floor vibration transmission. The discussion about these physical phenomena includes some important musical aspects which are not always stated in the traditional description of physical vibration analyses.

ACKNOWLEDGMENTS

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