Sound pressure measurement of orchestral instruments in the concert hall of a public school

A. Ruggiero, M. C. De Simone, D. Russo, and D. Guida

Abstract— The aim of this work is the acoustical characterization of some orchestral instruments (flute, trumpet, bass tuba, drums, violin, horn, piano and tenor sax) in the concert hall of the Liceo Statale "Alfano I" in Salerno, Italy. The variations in respect of time and frequency of main acoustical parameters of all orchestral instruments used, relative to the C major diatonic scale - one octave ascending and one descending-, are reported. In particular, for the temporal variations of pressure levels measured there is a comparison between the average signal unweighted (LZeq average), signal A weighted (LAeq) and unweighted signal in FAST mode (LZF). In this paper the notes played in an acoustically correct room are measured using a class A phonometer. The results provide a useful *data base* both for designers who deal with predictive analysis for acoustic design of concert halls and those who digitally simulate sounds produced by orchestral instruments.

Keywords— Acoustical Measurements, Diatonic Major Scale, Musical Instruments, Spectra Analysis, Time History.

I. Introduction

MUSIC signals, like many other non-stationary signals we encounter in practice, such as speech, seismic activity, machine vibrations, and biological signals exhibit time variable or non stationary characteristics [1]. Therefore it is useful to apply to such signals time and frequency analysis, providing a characterization of signals in terms of time and frequency content to study their changing spectral properties. Music content analysis in general has many practical applications, including structured coding, database retrieval systems, automatic musical signal annotation [2]. The analysis of orchestral instruments is a very important problem of old standing. It has been addressed on various occasions both by physicists and psychologists, dating back to the days of Helmholtz's work with his resonators [3]. This paper presents an acoustical characterization of several orchestral instruments obtained by a measurement session in the concert hall of the Liceo Statale "Alfano I" in Salerno, Italy. In carrying this out, it has been thought useful to measure individual instruments playing short pieces of music together as an orchestra, rather than single notes to measure them in such a way as to obtain an average of distribution of amplitudes in terms of magnitude and frequency. A wide set of features covering both spectral and temporal properties of sounds was presented and the most important data relating to performances of each instrument were processed in order to provide a useful *data base* both for designers who deal with predictive analysis for the acoustic design of concert halls and those who digitally simulate sounds produced by orchestral instruments. In particular, in the software used by designers for acoustic predictive analysis it is very important, in order to achieve actual and not estimated results, making use real data from the sound sources in the room. In this case it was considered particularly useful to determine in an acoustically correct room the sound pressure levels of the named instruments. With regard to each instrument graphs are shown relating to the performance of the sound pressure levels in the time and frequency domain.

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II. Measurement Session

At first, in order to verify the correctness of the acoustics in the Concert Hall of the Public School "Liceo Statale Alfano I" in Salerno, where are conveniently located on the walls and ceiling some acoustic panels in low-density polyethylene foam with calibrated closed cell structure (Stratocell® Whisper®), the average reverberation time was measured at various frequencies using Integrated Impulse Response, in accordance with the international standard ISO 3382- "Measurement of the reverberation time of rooms with reference to other acoustical parameters" .

Fig. 1 Picture of the concert hall

Only professional musicians were employed for the tests. In each case the musician was instructed to play (except for the drums) a C major diatonic scale - one octave ascending and one descending. Using a class A phonometer Larson Davis model 831, placing the microphone at 1 meter from the acoustical source and a height of 1,5 m, sound pressure levels were measured.

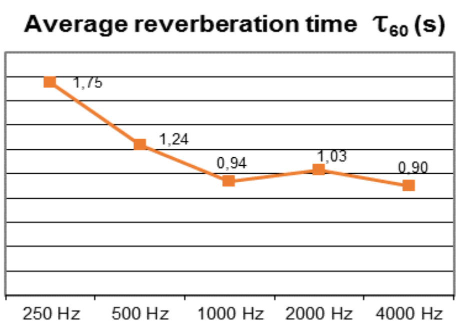

Fig. 2 Frequency trends for average reverberation time

Figure 2 shows that the reverberation time at the frequency of 500 Hz falls in the range indicated in the literature for a room of this volume and type and its variation in frequency in the range of 250-4000 Hz is also similar to that in the literature.
The orchestral instruments played in the concert hall were:

- Transverse Flute Yamaha 517: closed holes, offset G, E-mechanism, silver headjoint, headjoint type AM, with C-feet, silver plated.
- Trumpet Bach Professional Stradivarius Model 37: 459" Medium-large bore, standard weight body, standard weight yellow brass one-piece hand-hammered #37 bell, standard construction #25 mouthpipe, monel pistons, silver-plate finish.
- Bass Tuba Yamaha Established in 1887: 4-valve compensating system, Bore size: 0.689–0.728" (17.5–18.5mm), Bell diameter: 19" (480mm),Four sprung water keys, Wooden shell case with wheels.
- Drums Sonor Smart Force Series, Color: Brushed Copper (Chrome Shell Hardware), Set containing 22"x17,5" Bass Drum thomann (with Bracket), 12"x09" - 13"x10" Tom Toms, 16"x16" Floor Tom, 14"x5,5" Snare Drum, DTH Doubletomholder, 4-pcs doublebraced Hardwarepack containing Hi-Hat Stand (HH174), Snare Stand (SS177), straight Cymbalstand (CS171), Bass Drum Pedal (SP273), 9-layer 7,2mm thickness Poplar Wood Shells, Sonor Designs Tune Safe thomann Tuning Lugs, Ball Clamp Doubletomholder.
- Violin A. Pivetta pupil of S. Scarampella, Mantovana School, end of 800: length of back 358 mm.
- Horn Paxman 50 m: F / Bb, Yellow brass, Bell unscrewed, Mechanics fixed, Without lacquering.
- Piano Libermann GP 170: Extruded aluminum, Beams Walnut, Bridges Vertically laminated with maple cap, Fallboard Slow fall, Hammers T-stapled 22 lbs premium felt, Key bed material Butcher-Block-Spruce, Pinblock 19 cross ply maple, Tuning pins Nickel plated steel, cut-thread, Length 5' 7", Weight: 820 pounds (Boxed, including bench).
- Tenor sax Selmer : Body Material Yellow Brass, Body Construction One-Piece Body, Ribbed Body Construction, Handmade in France, Range Low Bb - High F#, Pads Pisoni Pro, Mouthpiece Selmer S80-C*, Deluxe Case.

Fig. 3 Violin

Fig. 4 Tuba

III. Results

If In this section time and frequency characteristics of all orchestral instrument used are reported: for the temporal variations of pressure levels measured for each instrument there is a comparison between the average signal unweighted (LZeq average), signal-A weighted (LAeq) and unweighted signal in FAST mode (LZF) .

LZeq average is a measure of the average sound pressure level equivalent during a period of time T in dB without any correction (Z is for Zero frequency weighting, which implies no frequency weighting. In reality the range is 10 Hz to 20 KHz ±1.5 dB):

$$LZ_{eq} = 10Log\frac{1}{T}\int_T \left[\frac{p(t)}{p_{rif}}\right]^2 dt \tag{1}$$

LAeq is sound pressure level equivalent measured in A-weighting in dB (adding the A-weighting corrections to the measured levels), equivalent to the total sound energy over a given period of time T:

$$LA_{eq} = 10Log\frac{1}{T}\int_T \left[\frac{p_A(t)}{p_{rif}}\right]^2 dt \tag{2}$$

LZF is sound pressure level with Zero Frequency weighting and Fast Time weighting (time constant of 125 ms):

$$LZF = 20Log\left[\frac{\frac{1}{0{,}125}\int_{-\infty}^{t} p^2(\xi)e^{\frac{-(t-\xi)}{0{,}125}}d\xi}{p_{rif}}\right] \tag{3}$$

where

- ξ is a dummy variable of time integration from some time in the past, as indicated by – ∞ for the lower limit of the integral, to the time of observation t,
- $p(\xi)$ is the Zero frequency-weighted instantaneous sound pressure,
- p_{rif} is the reference sound pressure, equal to 20µPa.

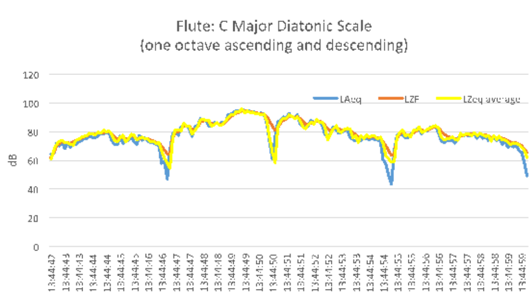

Fig. 5 LAeq, LZF and LZeq average time history

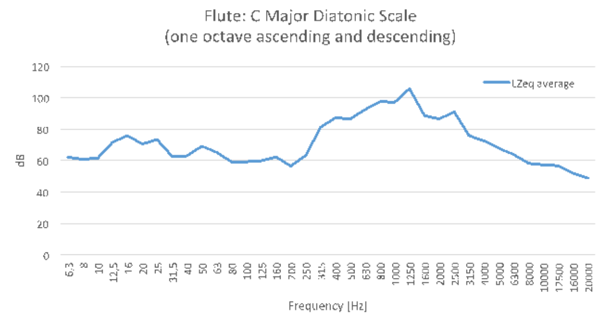

Fig. 6 Spectrum

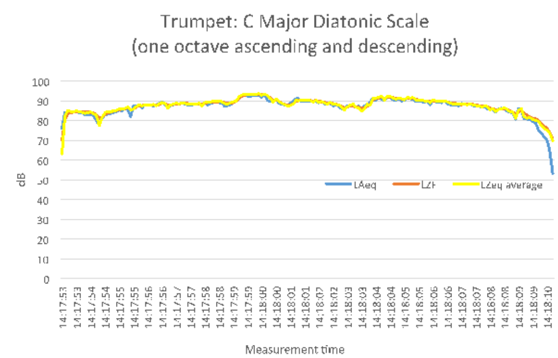

Fig. 7 LAeq, LZF and LZeq average time history

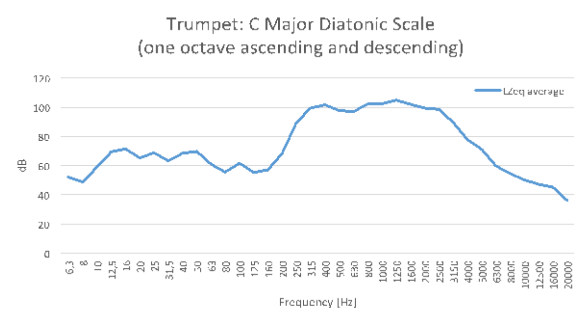

Fig. 8 Spectrum

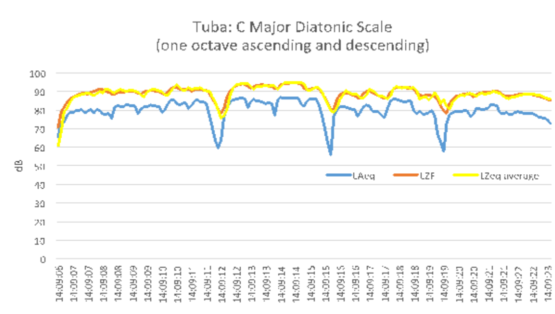

Fig. 9 LAeq, LZF and LZeq average time history

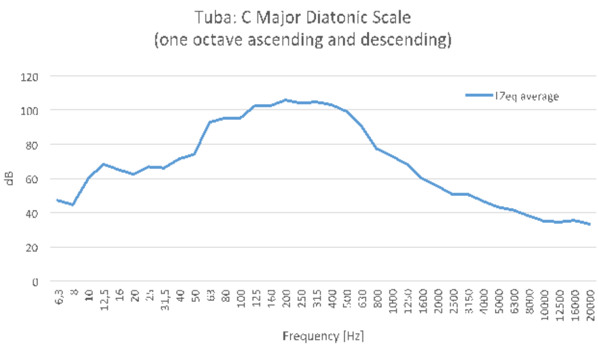

Fig. 10 Spectrum

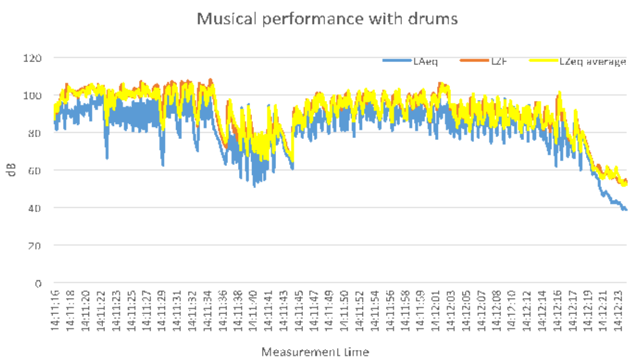

Figure 11 - LAeq, LZF and LZeq average time history

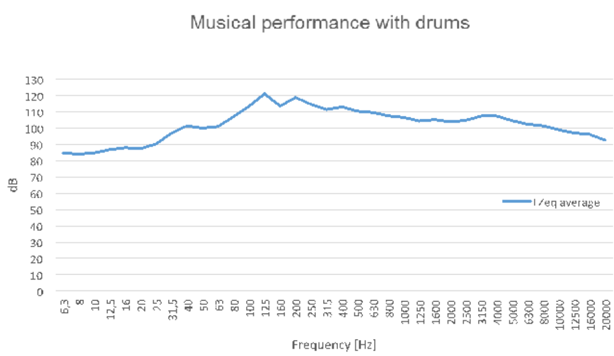

Fig. 12 Spectrum

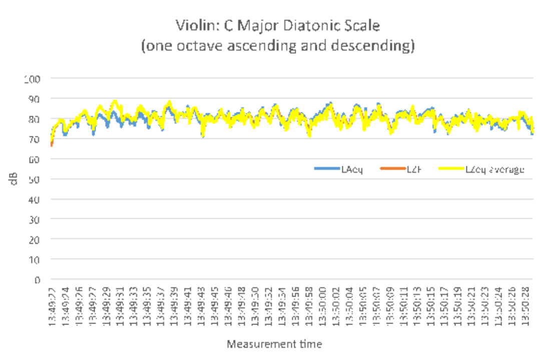

Fig. 13 LAeq, LZF and LZeq average time history

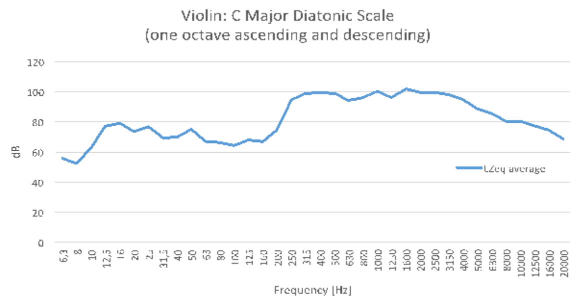

Figure 14 - Spectrum

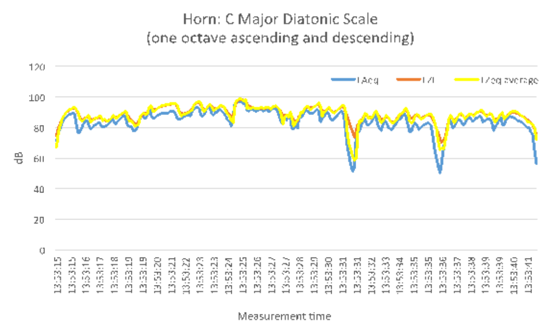

Fig. 15 LAeq, LZF and LZeq average time history

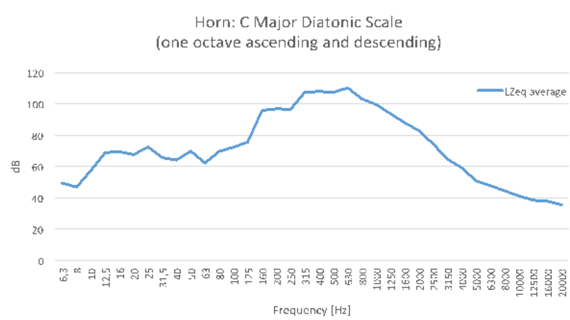

Fig. 16 Spectrum

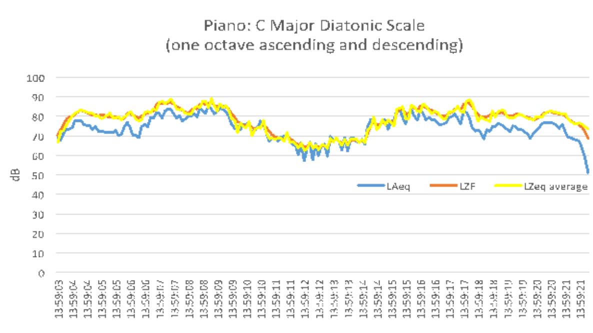

Fig. 17 LAeq, LZF and LZeq average time history

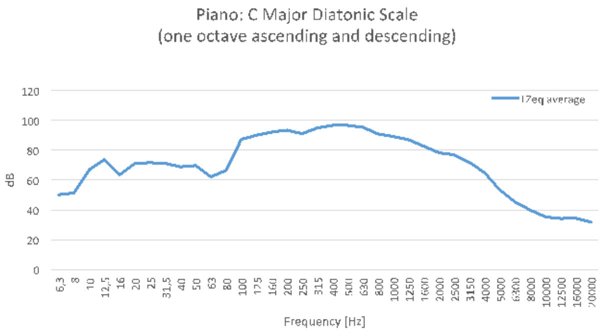

Fig.18 Spectrum

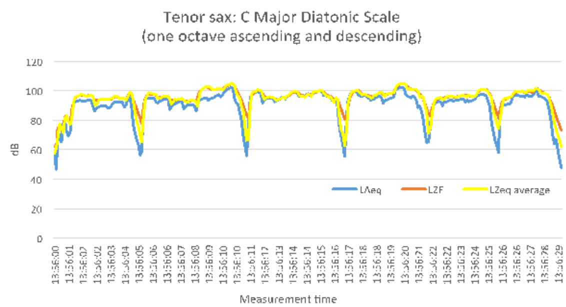

Fig. 19 LAeq, LZF and LZeq average time history

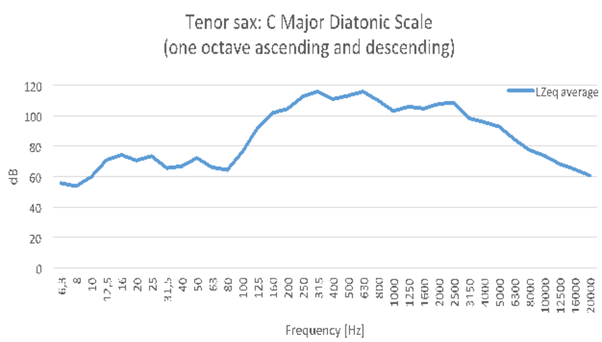

Fig. 20 Spectrum

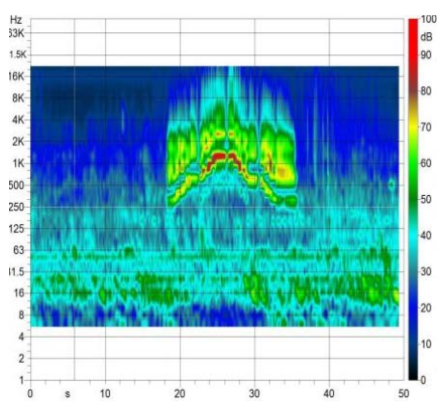

Fig. 21 Flute: Waterfall

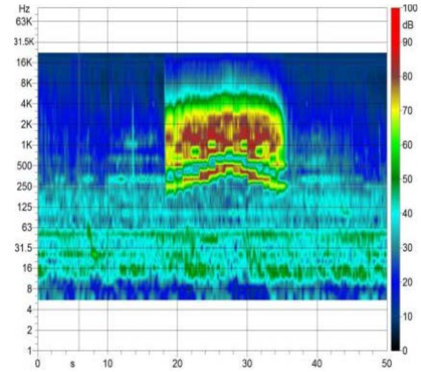

Figure 22 – Trumpet: Waterfall

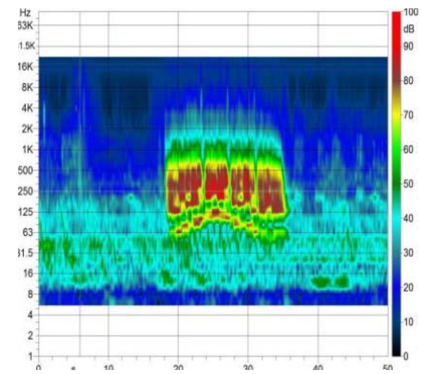

Fig. 23 Tuba: Waterfall

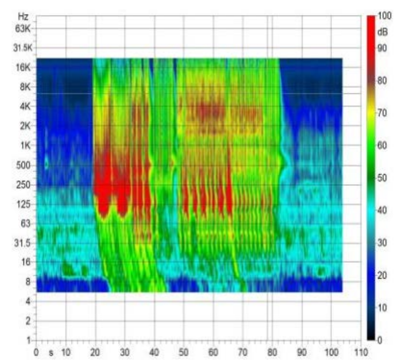

Fig. 24 Drums: Waterfall

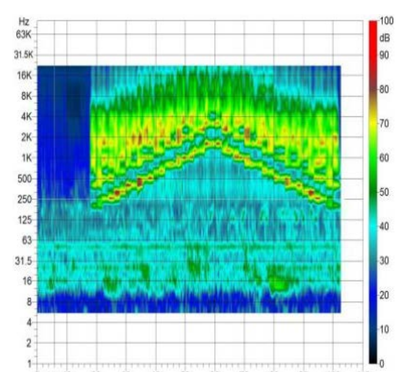

Fig. 25 Violin: Waterfall

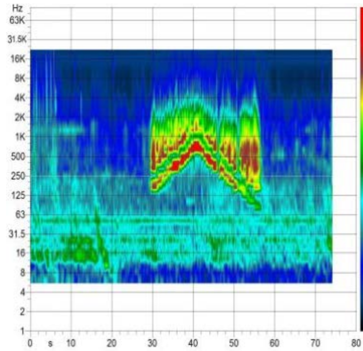

Fig. 26 Horn: Waterfall

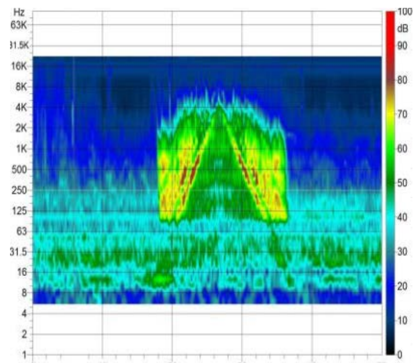

Fig. 27 Piano: Waterfall

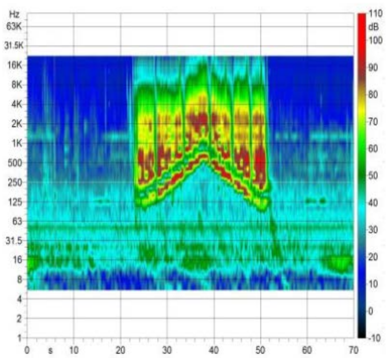

Fig. 28 Tenor sax: Waterfall

IV. Conclusion

This paper presents an acoustical characterization of several orchestral instruments (flute, trumpet, bass tuba, drums, violin, horn, piano and tenor sax) obtained by a measurement session in the acoustically correct room concert hall of the Liceo Statale “Alfano I” in Salerno, Italy.

For each musical instrument used the variations in respect of time and the frequency of main acoustical parameters relative to the C major diatonic scale - one octave ascending and one descending- are illustrated.

The most important data relating to performances of each instrument were processed in order to provide a useful *data base* both for designers who deal with predictive analysis for the acoustic design of concert halls and those who digitally simulate sounds produced by orchestral instruments.

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