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Variations on acoustical measurement procedures and their influence on acoustical parameters

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PACS: 43.55.Gx Studies of existing auditoria and enclosures.

ABSTRACT

During the year 2009, the room acoustics group of the LAM (Équipe Lutheries-Acoustique-Musique, Institut Jean Le Rond d'Alembert, Université Pierre et Marie Curie, Paris) performed a series of acoustical measurements in music halls in Paris. Variations on acoustical configurations, sound source directivities, pre-filtering signals and presence or not of public are studied. Two of the measured halls are equipped with variable acoustics, by means of sliding panels which allow modulation of the absorption surface. Measurements were made for different absorbing configurations. Besides, we used a directivity controlled sound source in some halls, which allowed changing from a directive to an omnidirectional pattern of radiation. The effects of a pre-filtering sweep signal were studied. The halls were also measured in the presence of the public. Acoustical parameters according to ISO 3382 international standard were calculated for all these variations. The results and some conclusions will be presented.

INTRODUCTION

During the year 2009, the room acoustics group at LAM (Équipe Lutheries-Acoustique-Musique, Institut Jean Le Rond d'Alembert, Université Pierre et Marie Curie, Paris) performed a series of acoustical measurements in music halls and theatres in Paris. The halls and theatres were selected for their historical, architectural, or acoustic interest.

A large-scale protocol for checking room-acoustical measurement procedures was set up. We tested various measurement scenarios by varying parts of the procedure. These variations included source directivity, acoustics configuration (for rooms with variable acoustics), use of pre-equalized excitation signals, and presence of public.

The results made it possible to evaluate the impact of these variations on acoustical indices measured according to ISO Standard 3382 [1].

PROCEDURE VARIATIONS

Source directivity

Standard ISO 3382 stipulates the use of omnidirectional sources to measure the acoustics of a room. However, the directional behaviour of any source depends on its construction, and omnidirectionality only holds in a restricted range of frequencies, usually the low frequency range.

We could verify this last characteristic while testing the dodecahedral source used in our series of measurements. The directional response of the source was measured in the large anechoic chamber of the French National Laboratory for Metrology and Tests (LNE), located in Trappes, France. Here are a few measurement results:

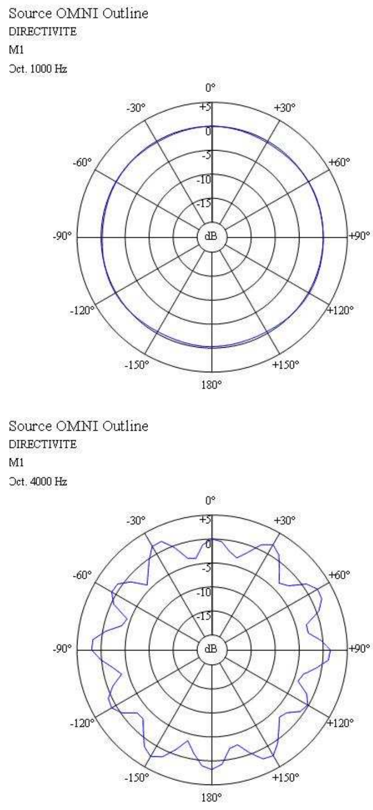

Figure 1. Directional responses of the source at 1kHz and 4kHz in omnidirectional mode.

Below 1kHz, the source truly is omnidirectional; but from 4kHz upwards, the directional behaviour displays perturbations.

However, our dodecahedral source presents an interesting technical characteristic: its loudspeakers can be independently controlled by groups of three, thus making it radiate towards four distinct directions.

We systematically set up the source in its frontal directional mode to compare indices thus measured with those measured in the omnidirectional mode. All comparisons are presented in Section "Results".

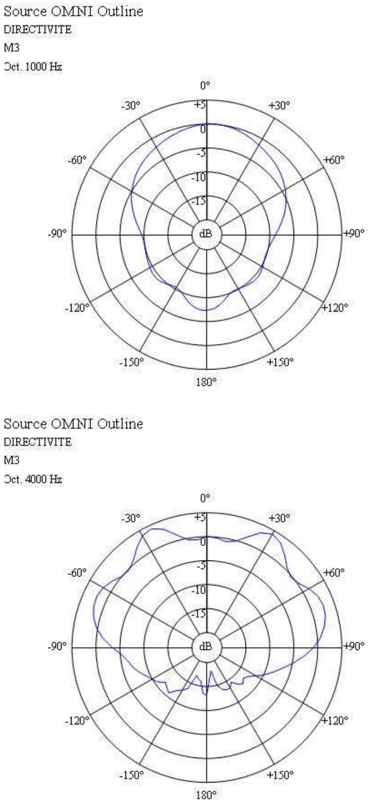

Figure 2. Directional responses of the source at 1kHz and 4kHz in frontal mode.

Pre-equalising excitation signal

The technique used for obtaining the impulse responses was is the deconvolution of the signal recorded in the room by the original signal. An exponential sweep-sine signal was used as original signal, because it allows *a posteriori* elimination of harmonic distortions from the sound source, as well as efficient signal-to-noise ratio [2], [3].

Because of its versatility and efficiency, the data-processing toolbox selected for recording and signal processing was the Aurora plug-ins, developed by Angelo Farina from Parma University.

The sweep sine signal is generated 20 Hz up to 20 kHz in 30 seconds. A relatively long duration was selected because the signal-to-noise ratio is proportional to the sweep time. Increasing this ratio is desirable especially when measuring in occupied rooms, where the signal has to be played at a lower level than in an empty room in order not to strain the hearing of the attendance.

After choosing the positions of the source and the microphone, the signal was played and recorded on 4 channels (1 omnidirectional channel, and 3 bidirectional channels displayed along the 3 spatial axes). Thus 4 impulse responses are obtained for each recording position.

The recordings were made with a B-format Ambisonics microphone, because the research project includes 3D-auralisation of the recorded sound fields in a room equipped with twelve loudspeakers regularly displayed around the listening position.

The calibration of the source system consisted in recording the impulse responses of the source system at different levels in the anechoic chamber of the LNE. Then we calculated the inverse filters of these impulse responses, which reduce the influence of the source on the final results.

For each source/microphone position, the sweep-sine was played in the rooms and recorded. The recorded signals were convolved with the inverse sweep-sine signals, which is equivalent to a deconvolution operation of the recorded signal. The result of this first deconvolution is an impulse response of the room which includes the influence of the source system. After a second deconvolution, this time by the inverse filters calculated from the impulse responses measured in the anechoic chamber, we obtain the impulse response of the room alone, and we can calculate the indices according to ISO Standard 3382.

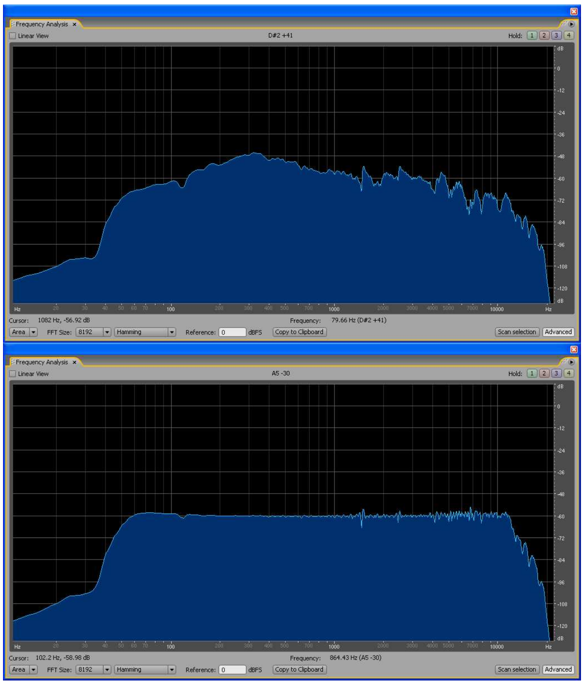

Figure 3. Frequency response of the source system before (top) and after (bottom) filtering.

In one hall (Japanese Culture Centre), we made measurements with the non-equalized signal and then with the equalized signal, while preserving all the other variables. This makes it possible to evaluate the influence of pre-equalization. In the others halls, we used equalized signals only.

Absorption configurations

The halls retained for studying the variations due to absorption configurations are the Auditorium of Orsay Museum and the Japanese Culture Centre in Paris. The Auditorium of Orsay Museum, located in the Orsay Museum, is an intimate room of 347 seats, whereas the Japanese Culture Centre is a larger room, even if the difference in seat numbers is not very large (400 places for the Japanese Culture Centre). Both halls are multifunctional. Indeed, both halls have mobile panels which make it possible to adjust acoustical absorption. In the Auditorium of Orsay Museum, these panels are located on the sides only, whereas in the Japanese Culture Centre they are located, on the sides as well as behind and principally in front of the public. This difference of disposition causes a huge difference in the variations of index LF between the two halls when one changes the configuration of the panels. In the Auditorium of Orsay Museum where the panels are located on the sides only, lateral energy decreases in comparison with the energy coming from all other directions when the absorbing configuration is set up: obviously the index LF will be reduced, and this is indeed the case. On the other hand, in the Japanese Culture Centre, not only lateral energy but also omnidirectional energy (principally on the stage where there is a relatively large amount of panels) will decrease when the absorbing configuration is set up. In this case, we observe an increase of index LF.

Two acoustical configurations, the most reflective and the most absorbing, are considered for these two rooms. Between the two configurations, the amount of added absorption (ΔA) is $74\,m^2$ in the Auditorium of Orsay Museum, and is $91\,m^2$ in the Japanese Culture Centre.

Presence of public

Acoustics measurements in occupied rooms are relatively rare due to many kinds of difficulties. A particular protocol was developed for our measurements in the occupied halls [4].

After long negotiations with hall managements, the protocol was defined. Since measurements were made in real concert situations and could not last more than 4 minutes, we retained only two positions of microphone and one position of source for each hall.

The signal level was kept below 80 dB, measured in the first rank of the public, in order to ensure a sufficient signal-to-noise ratio without disturbing the public. The relatively long duration of the sweeping signal (30 seconds) helped to achieve this goal.

Measurements in empty and occupied halls were made with an interval of a few hours in-between, thus preserving the same conditions, except obviously for the presence of the public.

THE HALLS

Beside Auditorium of Orsay Museum and Japanese Culture Centre (rectangular rooms), the halls involved with this study are Abbesses Theatre (auditorium with balconies), Salle Cortot (rectangular with the stage in the middle of the *long* side), the major hall of Cité de la Musique, and Salle Pleyel (both rectangular).

These are major halls in the Parisian musical scene and their architectural characteristics are rather different.

The table 1 gives some information on each hall, 'occupation' referring to the number of people present during measurements in the occupied hall.

Table 1. Information on the measured halls.

	Volume (m3)	**Seats**	**Occupation**
Orsay	1700	347	310
Cortot	2580	400	205
Abbesses	4500	396	350
Japanese Centre	6300	400	170
Cité de la Musique	13400	1200	950
Pleyel	17800	1900	1100

RESULTS

We selected a representative number of microphone positions for each hall. For each position, we computed indices averaged over the 4 octave bands of centre frequencies 250 Hz to 2kHz. For each procedure variation, we calculated the differences measured for the same recording position, then the averages of these differences over all recording positions. The procedure variations were: omnidirectional vs. directional source, pre-equalized vs. non-equalized signal, reflective vs. absorbing configuration, empty vs. occupied hall; they are respectively represented by DIR, E, RA, and P in the tables below. The standard reference to which the variations are compared is [omnidirectional, equalized, reflexive and empty]. Index variations are given in dB for C80 and expressed as percentage for the other indices. For instance, the value (-10) for T30 with respect to P means that the presence of the public reduces T30 by 10%.

Table 2. Variations of index values due to variations of acoustical measurement procedures.

Orsay	DIR	P	RA
T30 (%)	0.04	-15.7	-17.7
EDT (%)	-7.39	-10.6	-14.4
Ts (%)	-17.78	-13.4	-16.8
LF (%)	-6.76	35.7	-26.8
C80 (dB)	1.42	1.01	1.4

Japanese C.	E	P	RA
T30 (%)	-0.43	-13.37	-12.48
EDT (%)	-0.42	-18.2	-11.56
Ts (%)	1.45	-14.61	-12.64
LF (%)	-12.7	-5.1	76.2
C80 (dB)	0.17	0.99	0.83

Abbesses	DIR	P
T30 (%)	0.31	-22.89
EDT (%)	-4.38	-23.50
Ts (%)	-19.16	-22.81
LF (%)	-17.70	-10.23
C80 (dB)	1.51	2.04

Cite	DIR	P
T30 (%)	0.18	-6.7
EDT (%)	-6.07	-5.4
Ts (%)	-20.7	-2.53
LF (%)	-13.15	-9.06
C80 (dB)	1.93	0.01

Pleyel	DIR	P
T30 (%)	-0.36	-19.9
EDT (%)	5.04	-3.81
Ts (%)	-27.3	-12.2
LF (%)	-47.1	3.42
C80 (dB)	1.2	1.1

Cortot	DIR	P
T30 (%)	-2.5	-5.9
EDT (%)	-4.5	-6.1
Ts (%)	-21.4	-18.2
LF (%)	22.1	-45.3
C80 (dB)	1.7	1.9

Averages over all measured halls are given in the next table.

Table 3. Mean index variation

Mean variation	DIR	P	RA	E
T30 (%)	-0.47	-14.08	-15.09	0.43
EDT (%)	-3.46	-11.27	-12.98	0.42
Ts (%)	-21.27	-13.96	-14.72	-1.45
LF (%)	-12.52	-5.09	24.7	12.7
C80 (dB)	1.55	1.18	1.12	-0.17

CONCLUSIONS

The first observation is the rather small variation of index T30 with directivity variation of the source. Changing from omnidirectional to frontal directional mode produces a difference of -0.47% on this index. Therefore, it is not necessary to use a dodecahedral source for measuring T30 only, and a simpler source gives basically the same values. This conclusion supports our previous work [5].

In a similar way, using pre-equalisation plays a negligible influence on all indices, except LF. Thus, using a filter, the calculation of which can be lengthy, is not necessary if the goal is only to measure indices. However, this is not always so and depends on the shape of the source spectrum [6]. On the other hand, if auralisations are considered, the use of pre-equalisation, as well as post-filtering, is imperative.

Regarding index LF, we observe huge variations between halls. This variations cast doubt on the significance of a single mean variation across halls.

One also observes that T30 variations due to the presence of public have no direct relationship with the volume of the hall. For example, this variation is -17.7% for Auditorium of Orsay and -19.9% for Salle Pleyel: similar T30 differences, although the difference in volume is rather large. The same observation can be made for Salle Cortot and Cité de la Musique Room. This only means that surface materials, especially those on the seats, play the major rôle in T30 variation. As for the others indices, their variations strongly depend on the characteristics of the halls.

The last observation concerns variations with absorption configuration (RA) and presence of public (P). One notices that T30, Ts and C80 variations are rather similar. In other words, when one changes the equivalent absorption by a similar amount as attested by T30 variations, be it by means of panel configuration or presence of public, the two other indices change in the same way. Therefore, in the two present halls, manipulating acoustical panels could be used to simulate the presence of public when measuring these acoustical indices. This coincidence needs validation in a larger number of halls before generalization.

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