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PRACTICAL ASPECTS OF ROOM ACOUSTIC MEASUREMENTS ON ORCHESTRA PLATFORMS

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About ten years ago room acoustic parameters for analysis of the performers' room acoustic conditions were developed at the Acoustics Laboratory, Technical University of Denmark [1]. Since then their use in research and consulting have given valuable experience regarding their advantages and limitations, which will be discussed in the following.

THE PARAMETERS AND THEIR PRACTICAL MEASUREMENT

The mathematical definitions of the parameters as presently used by us are shown in Table 1. Apart from Early Decay Time (EDT), the list contain three 'Support'-parameters, which are all measured at a fixed distance of only one metre from the omni directional source. (Both transducers are also placed one metre above the floor.) Thus they all three measure some portion of the sound energy reflected back to the performer from the room relative to the emitted direct sound energy.

Room acoustic par.	Symbol	Mathematical definition	Unit
Early Support	ST_{early}	$10*\log \frac{E(20,100ms)}{E(0,10ms)}$	dB
Total Support	ST_{total}	$10*\log \frac{E(20,1000ms)}{E(0,10ms)}$	dB
Late Support	ST_{late}	$10*\log \frac{E(100,1000ms)}{E(0,10ms)}$	dB

Table 1: *Mathematical definitions of ST-parameters.*

Some of the names and definitions have changed since [2], in which our general layout of measurement positions and some field experiences were described:

ST_{early} used for measurement of ensemble conditions is the new name for ST1 in order to avoid confusion with STI, (Speech Transmission Index). It is striking, that this parameter measured with this short transducer distance has had success as a descriptor of the ease of hearing other orchestra members, whereas our parameter originally intended for this purpose (EEL) failed in this respect when applied in actual halls [2]. The reason probably is, that the calibration of ST_{early} is much more stable than that of EEL (compared to the small measurement interval of relevance - see later), and that when position averaged, ST_{early} describes adequately well the average density of early reflection energy on the platform, which - considering the lack of control with other factors such as local scattering within the orchestra and the complex positioning and directivity patterns of the individual instruments - is all that one can hope to test with present day techniques. Only in cases where relatively small reflectors have been specifically oriented so as to direct "ensemble" reflections from one end of the platform to another, is it obvious that placing the source and microphone close together as prescribed for ST_{early} measurements may yield wrong results. However, normally the effect of such reflectors can still be measured by selecting the positions carefully.

ST_{total} describing support from the room of the sound from the musicians' own instrument replaces the formerly used ST2, in which "2" stands for an upper integration limit of 200 ms. Although the majority of the reflection energy will have arrived within the first 200 ms, this change allows the total build up of reflected energy to be considered by the measurement.

ST_{late} replaces CS (=Clarity measured one metre from the source) for describing the impression of reverberance, and - as one would have hoped - the ratio between ST_{late} and ST_{early} seems to be useful for describing the degree of masking of ensemble information by loud reverberation (as described later).

During measurements of the ST-measures on orchestra platforms, these should be equipped with chairs and music stands in order to:

1) provide some absorption and scattering as a rough substitute for the absent musicians, and

2) to avoid too large and unrealistic reflections from eventual risers.

However, the furnishing should be removed within a two metre distance from the transducers, whereby only the direct sound and the (almost hall-independent) floor reflection components will fall within the 10 ms window in the denominator of the ST formulae. (In the lowest octave of interest, 250 Hz, these two components will be smeared out over the whole 10 ms interval.) Likewise, with proper concern about the orientation of music stands and chairs, the scattering from these obstacles will be fairly weak after 20 msec, where the integration in the numerator starts. Thus the ST-parameters will mainly measure the influence of major surfaces around the orchestra platform - as intended. On the other hand, the 20 ms limit implies, that the transducers should be placed at least 4 metres from any wall, ceiling or reflector of interest. Therefore, if one wishes to apply these parameters in smaller rooms (i.e. rooms which do not accomodate a full symphony orchestra), the 20 ms limit must be reduced - and the furniture removed.

EDT like ST_{late}, is intended for measurement of reverberance; but it has an additional role as a more precise measure of timbre, since the 1/1 octave band values of EDT are probably less influenced by statistic random fluctuations than the ST values.

The ST-parameter values are normally measured in and averaged over the four 1/1 octaves from 250 to 2000 Hz. After further averaging over positions (both done arithmetrically), the random variations become very small as seen later.

CALIBRATION

In all three ST-definitions, the reflection energy is measured relative to the emitted direct sound. Therefore, calibration is only needed in those octave bands where the loudspeaker might not be adequately omnidirectional. In these octave bands it is necessary to establish the ratio between the power response and the pressure response of the loudspeaker in a microphone position fixed relative to the loudspeaker directivity pattern and at one metre distance from the center. If for instance the emitted power is found to be lower than that corresponding to the value obtained by multiplying the intensity (derived from the pressure measurement) with the area of the measurement sphere = 4 * Õ * 1 m^2, then this difference should be added as a positive correction to the ST-value. (The fixed microphone position should be chosen in front of a gently varying maximum of the directivity pattern rather than near one of the sharper and more position-sensitive notches.)

MEASUREMENT ACCURACY AND REPRODUCIBILITY

Like most other energy-fraction measures, the ST-parameters show large random variations compared with the variance of interest: between halls or positions. In order to estimate this random variance a special measurement session was carried out in a regular shoe box hall with a 130 m^2 orchestra platform. Around each of the three normal measurement points, four additional points were chosen 30 cm left/right and forwards/backwards of the "exact" positions (as was also done in a similar investigation by Bradley and Halliwell [3]). This 30 cm distance corresponds well with the average accuracy of positioning the transducers in pre-selected measurement points.

On average, the standard deviation (STD) found from the 30 cm displacements were very close to 1 dB for all three ST-parameters and all four octave bands. Using this figure as an external estimate, the STD after averaging over the four octaves becomes: 1/sqrt(4) = 0,5 dB, and after further averaging over three positions: 1/sqrt(4*3) = 0,3 dB.

This accuracy may also be illustrated by our experience after having repeated measurements in the same hall (in all cases with a period of more than five years between the two tests). The same test signals and transducers were used for all measurements; but most of the electronics hardware was changed in 1989. The results regarding ST_{early} can be compared in Table 2 below:

Frequency averaged values of STearly [dB]					
Hall	Year	Pos 1	Pos 2	Pos 3	Aver.
DR	1982	-15.8	-14.5	-13.2	-14.5
	1987	-15.7	-13.1	-14.0	-14.3
MA	1983	-14.1	-13.7	-12.1	-13.3
	1990	-14.5	-14.2	-11.4	-13.4
HG	1983	-10.2	-9.9	-9.3	-9.8
	1991	-10.5	-9.9	-9.0	-9.8

Table 2: *Comparisons of repeated measurements in three halls.*

While differences in the order of 1 dB sometimes occur in individual positions, it is seen that the reproducibility of the position and frequency averaged values is within 0.2 dB in all three cases.

An error as small as this is also necessary keeping in mind the relevance of small variations. Thus; an architecturally (and probably also subjectively) dramatic 20 % reduction e.g. in the height of the ceiling or in the distance between the side walls will result in ST_{early} increasing only about 1 dB. (Such expected changes can be found from the empirical prediction formulae listed in [4], which were developed by statistical analysis of acoustic and geometrical data from over 35 halls.) Correspondingly, the interval for optimal values of ST_{early} for symphony orchestras is also rather narrow: from about -13 to -11 dB.

A CONSULTING EXPERIENCE

Recently, we had the opportunity to apply these platform measurement techniques in an interesting consulting job. One of the regional symphony orchestras in Denmark asked to have the acoustics of their rather small rehearsal hall (in the following denoted "Reh.") changed towards the conditions as found in the larger hall used for their regular concert performances ("Per.").

In order to analyse this problem and the feasibility of fulfilling this wish, objective measurements as described above were carried out in five positions in both halls and compared with subjective opinions obtained from interviews with musicians representing each of the main sections in the orchestra.

Hall code	Hall Volume m3	Platform Volume m3	Platform Area m2	Ceiling Height m	Sidewall Angle degrees
Reh.	5.000	1.800	260	7	0
Per.	14.100	2.200	245	8	33

Table 3: *Basic geometric data for two halls.*

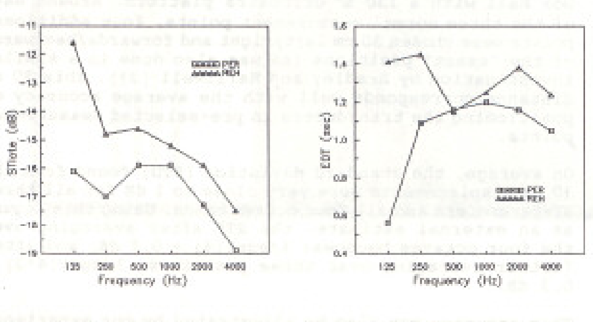

Fig. 1: *EDT and ST_{late} data from two halls (see text).*

The main geometric data for the two halls are listed in Table 3. Regarding acoustic differences, neither ST_{early} nor RT revealed any clear picture. Actually, their frequency averaged values were equal in both cases (-12.7 dB and 1.4 sec. respectively). However, large differences - especially towards low frequencies - are clearly seen from the curves of EDT and ST_{late} versus frequency shown in Fig. 1.

The subjective judgements were also very clear:

Ensemble is difficult to achieve in Reh. due to an excessively loud and muddy sound, while the only problem in this respect in Per. is, that the deep instruments are difficult to hear.

There is almost too much support for ones own instrument in Reh., while especially the deep strings lack this support in Per.

There is too much Reverberance in Reh., while there is too little ("non existent" at low frequencies) in Per. In view of their functions, it would have been more advantageous if that situation had been reversed!

Timbre is good in Reh., while in Per. there is no warmth and attack noise from instruments is highly exposed.

An ST_{early} value of -12.7 dB should not cause any difficulties in ensemble. Therefore, as also indicated by the musicians' statements, the cause of the problem in Reh. may rather be found in the ST_{late}-curve as too much late sound - particularly at low frequencies - masking the otherwise useful ensemble information.

With the average RT-values being similar in both halls, it is also seen, that the differences regarding the "amount" of reverberance between these halls is judged from the difference in reverberant level (as measured by ST_{late}) caused by the different volumes rather than in a different slope of the decay curve. However, an attempt to match the level of reverberation in Reh. to that in Per. would require RT in Reh. to be reduced to about 1 sec., whereby at least final chords would clearly be judged as even dryer here than in Per. This illustrates why a large and a small space can never be made to sound alike. With RT Per. actually being less than optimal particularly at low frequencies, it was anyway not recommended to reduce RT in Reh. that far.

As a result of this investigation we recommended absorbing panels (membrane and perforated panel types) to be installed in Reh. in order to reduce RT to about 1.2 sec. at all frequencies. however, the point is to place this absorption mainly on surfaces situated far from the orchestra whereby only ST_{late} and not ST_{early} will be changed. Regarding the lack of bass in Per., we have suggested adding thickness and mass to the thin plywood panels, of which the orchestra shell is made.

The renovation of the rehearsal hall is taking place while these lines are written, while no decissions about changes in Per. have yet been made.

CONCLUDING REMARKS

It is hoped, that it has been demonstrated how refined measurement techniques, and knowledge of their limitations opens up for more precise consulting regarding acoustic design and renovation of orchestra platforms.

Two of our students: Claus Lynge Christensen and Flemming Højskov Andersen did the 1991-series of measurements in HG including the tests on random variance.

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