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COMPARSIONS BETWEEN RAY-TRACING AND REALITY

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SUMMARY

During the past 10 years we have been developing and using a ray-tracing computer program for room acoustical design. In this paper we have compiled totally 67 comparisons between predicted and measured echograms in 8 different halls. The parameter used are D, C, LF, Ts, EDT and G.

The calculation input data were not modified using the measurement results. Consequently, the results are not only a pure test of the program but also a test of the skill of the operator. The results presented are therefore not directly comparable to other tests where input data has been optimized based on measurements in the real hall.

The results show that the ray-tracing technique in most cases is a reliable design tool. Most of the room acoustical parameters reveal very good agreement. The mean absolute difference between the calculated values (obtained during the design phase) and the measured values are less than the subjective difference limen for the parameters D, Ts and G. For the parameters C and LF the mean differences are slightly more than the subjective difference limen. Furthermore, EDT and LF are mostly somewhat overestimated.

INTRODUCTION

In the litterature there are very few validation tests of room acoustical computer programs. An exception is a round robin test of 14 different programs which was recently performed [1].

The parameters used in this test are D, C, LF, Ts, EDT and G defined according to ISO/DIS 3382. The halls are presented in Table 1 together with some data concerning the ray-tracing calculations.

RAY-TRACING CALCULATIONS

The first version of our ray-tracing program was written around 10 years ago. Since then the program has been continously used. During this period many improvements and usable features have been added. At present some of the features are: arbitrary source directivity, unlimited number of sources with individual delays, plane and spherical receivers, eight different surface properties - absorption (also with transparence), random diffusion, cylindrical diffusion, convex calotte, convex and concave cylinder, false normal (reorientation of the normal), radar (the reflected angle same as the incoming angle). The amount of each surface characteristic is given i % and many of them can be combined on the same surface. There are several ways of presenting the results.

MEASUREMENTS

Most of the measurements of the impulse response were performed with the MLSSA system [2] which uses a pseudo-noise sequence of the maximum length type (MLS). The sound source was a dodecahedron loudspeaker with 12 four inch elements. This source is essentially omnidirectional up to the 2kHz octave band (f<2kHz: omnidirecional, 2kHz octave band: level variation < appr. ±1.5dB, 4kHz octave band: level variation < appr. ±4dB). The acoustical parameters were calculated in octave bands (125Hz to 4kHz) and in a three octaves broad

	No. of seats	No. of planes	No. of rays	Spherical receivers. Radius	Plane receivers. Area	Comments
Västervik Folkets Hus	356	253	203.712	1 m (half)	-	Multi-purpose hall. One source position on stage, five receiver positions in the seating area. Two setups - with and without stage velvet textiles and back wall textile. In the damped condition there were also two receiver positions on the stage.
PTB auditorium	274	122	814.896	0.4 m	-	Lecture hall. Two source position on the podium, five receiver positions in the seating area. This hall was used as the test hall of an international round robin test. The measured data used here were the mean values of 7 independent measurements [1].
Malcussalen in Halmstad	300	53	458.344	1.5 m (half)	-	Lecture hall. One source position on the podium, five receiver positions in the seating area.
Romanhallen in Kalmar	850	201	164.952	-	2x2 = 4 m^2	Multi-purpose hall set for orchestra concerts. One source position on the podium, eight receiver positions in the seating area.
Tonhallen in Sundsvall	860	156	73.368	-	2x2 = 4 m^2	Multi-purpose hall. One source position on the podium, five receiver positions in the seating area.
Växjö Konserthus	800	275	61.648	-	2x2 = 4 m^2	Multi-purpose hall set for orchestra concerts. One source position on the podium, eight receiver positions in the seating area.
Borgen in Visby	321	159	203.712	1 m (half)	-	Hall used for theater, reinforced music and film. One source position on stage, three receiver posiotions in the seating area and one on the stage.
GöteborgsOperan	1300	450	114.616	1.5 m (half)	-	The new Gothenburg opera house, opened in autumn 1994. Three source positions, two on the stage and one in the pit. Five receiver positions three in the stalls, one on the first balcony and one on the third balcony. The stage was set for the first scene of Madama Butterfly. In the pit there were music stands and chairs. The stage was rather simply modelled in the ray-trace calculations.

Table 1. The halls used in this study.

band centered at 1kHz (354Hz - 2828Hz). The measurements used in the comparisons with the ray-tracing results were the three octaves broad BP-filtered values. Observe that in some cases the parameter values may differ considerably for the octave bands 500Hz, 1kHz and 2kHz.

Two of the halls, Romanhallen in Kalmar and Tonhallen in Sundsvall, were measured using a simpler system based on sampling a puls emitted by a small 4 inch loudspeaker. These measurements were BP-filtered with two octaves bandwith (500Hz and 1kHz octave bands). The loudspeaker had a diffractor in front of the cone to improve the spread. The level variation around the loudspeaker was ±1.5dB in the 500Hz octave band and ±3dB in the 1kHz octave band.

The measurement data for the PTB lecture hall were the mean values of 7 measurements performed by 7 independent groups [1]. All groups used PC-based MLS measuring technique. The parameters were calculated in the 1kHz octave band.

RESULTS

The values of the estimated room acoustical parameters using ray-tracing and the corresponding measured data are plotted in scatter diagrams in Fig. 1. A measure of the agreement is given in Table 2 as the mean af the absolute differences between calculations and measurements. The spread around this mean value is indicated by the standard deviation of the differences. These values shall be compared with the subjective difference limen [3]of the parameters (which naturally also show inter- and intra-individual spread). The results show that the mean difference between the calculated values (obtained during the design phase) and the measured values are less than the subjective difference limen for the parameters D, Ts and G. For the parameters C and LF the mean differences are slightly larger than the subjective difference limen. Furthermore, the Early Decay Time (EDT) is mostly somewhat overestimated, especially for the lower values measuring around 1s. The correlation coefficients given in Table 2 indicates the degree of linear dependence. However, high correlation is not sufficient for good agreement. On the other hand low correlation does not necessarily imply useless values. This is illustrated by the parameter LF which has a fairly low correlation coefficient of 0.65 but the mean absolute difference is only 0.06 (subjective difference limen around 0.05).

	D	C	LF	Ts	EDT	G
Number of comparisons	67	67	50	67	54	25
Correlation coefficient	0.912	0.928	0.651	0.959	0.906	0.995
Mean absolute difference	0.047	0.74 dB	0.06	6.7 ms	22.1 %	0.55 dB
Std dev of the differences	0.040	0.66 dB	0.05	6.1 ms	14.5 %	0.46 dB
Subjective difference limen [3]	0.05	0.5 dB	0.05	10 ms	5 %	1 dB

Table 2. Results of the comparisons and order of magnitude of subjective difference limens.

DISCUSSION

The best agreement is for the parameter Ts. This parameter is less sensitive than D and C to the exact arrival time of reflections. This is probably the reason for the somewhat greater discrepancy for these two parameters.

As indicated by the correlation the LF scatter diagram show the largest spread. It is also a tendency to slightly overestimate the values. Possible explanations can be the simple modelling of

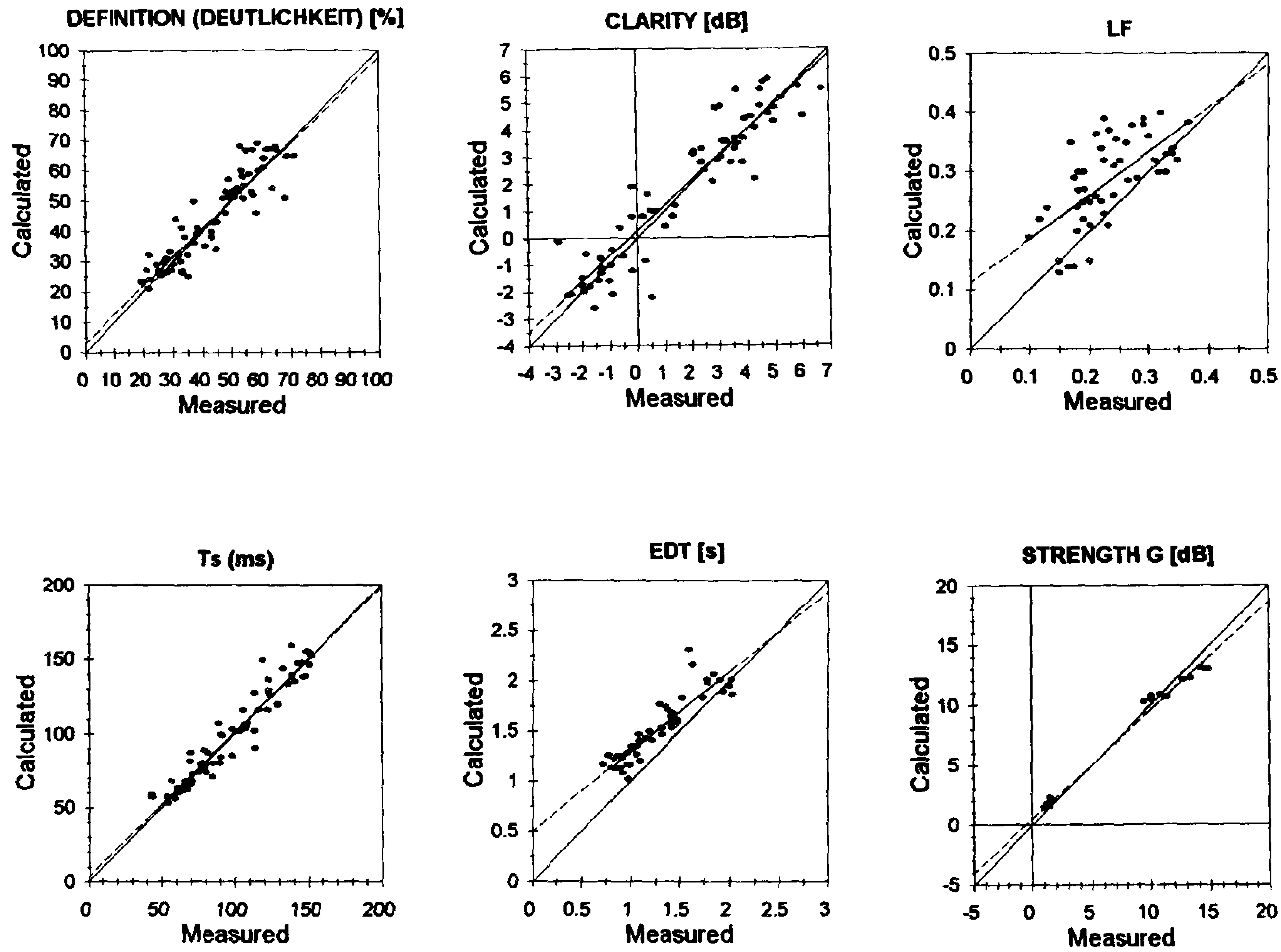

Fig. 1. Scatter diagrams of the room acoustical parameters. The unbroken line represents perfect agreement. The dashed line indicates the least squares fit to the data points (linear regression).

the seating area, wave phenomena near the receivers (diffraction of sets etc) and that many of the receiver spheres extend too high above the seating plane. Of course, LF is also the parameter hardest to measure.

There is a tendency to overestimate the EDT, especially for lower values. One probable reason may be too low ray density, i.e. too low dynamic. With too few rays the end of the echogram shows a broken curve with a "noisy" tail which is irrelevant. This tail consists of occasional impacts. Backwards integration of such a echogram will of course give too long EDT. This error does not influence the other parameters in the same extent since they are not based on the backwards integrated curve.

REFERENCES

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