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INTERNATIONAL ROUND ROBIN ON ROOM ACOUSTICAL COMPUTER SIMULATIONS

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SUMMARY

14 different programs for room acoustical computer simulations were compared regarding the results of 8 acoustical criteria (T, EDT, D, C, TS, G, LF and LFC) in a speech auditorium. 2 source positions and 5 receiver positions were chosen and the criteria were calculated for the 1 kHz octave band. The simulations were carried out by 16 participants independently, most of them the developers of the software. Measurements were performed correspondingly by 7 participants. The project was run in two steps: first without information on the measurement results, the room geometry and the material data being provided on the basis of construction plans and material descriptions in words. Secondly, the simulations were repeated using the same absorption coefficients throughout the hall.

The results of the first phase showed a surprisingly large scatter with a strong tendency to underestimate the absorption coefficients and thus to overestimate the reverberation time. Some results were totally wrong due to a false interpretation of the parameter definitions. In the second phase the agreement was, of course, better but even with harmonized input data some results varied considerably from others. Only three programs can be assumed to give unquestionably reliable results. The results of these programs differ from the measurement results by an order of magnitude of the standard deviation of the average measurement result. This order of magnitude is also approximately the same as for the subjective difference limens of the acoustical parameters. Some of the other programs have produced differences of up to 5 - 6 times the subjective limens.

There are indications that some systematic shifts in the results may be caused by neglecting wave effects, namely of the attenuation of sound at grazing incidence over the audience or seating. It also seems to be necessary to include diffuse reflections in the algorithms, at least from the 2nd to 4th order, since the results from purely "specular approaches" were more outlying than algorithms with some kind of random reflections or statistical reverberation tails.

INTRODUCTION

More than 25 years have passed since the famous paper on computer simulations in room acoustics by Krokstad, Strøm and Sørsdal [1] was published. Many programs have been developed based on various algorithms. They are in use today for the purpose of research, training and consulting. Several simulation algorithms also form the basis for auralization of room acoustics - a technique which is ready to be established as an efficient tool for consultants, thus replacing the scale model measuring technique. It is therefore time to slow down research and development for a while and to perform validity checks on a number of programs used.

However, before discussing problems concerning auralization, the "simple" task of predicting some well-known room acoustical criteria should first be investigated.

This paper deals with a comparison of results from simulations and measurements in a speech auditorium in one octave band (1 kHz). The auditorium is located on the premises of the PTB in Braunschweig. The hall has a seating capacity of 274, a volume of about 1800 m^3, an approximately rectangular ground area of 22 x 14 m^2 and a seating area inclined by 12°. The average reverberation time is about 1,1 to 1,2 s (approximate geometry see Fig. 1). Two source positions on the stage and five receivers were chosen, thus making ten combinations possible.

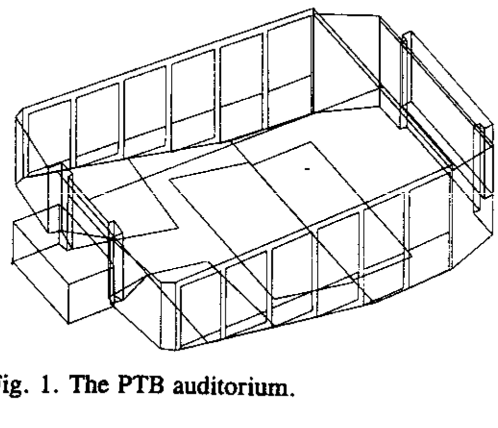


Fig. 1. The PTB auditorium.

PARTICIPANTS

The idea of performing this intercomparison was born in the Technical Commitee for Building and Room Acoustics of the German Acoustics Society, DEGA, but it soon turned out that there was also great interest in such a project in other countries. In the event, active participation came from Sweden (4), Germany (4), Belgium (3), Switzerland (2), France (1), Denmark (1) and Italy (1). The names and addresses of the participants can be distributed on request by the author. It was agreed, however, that the results be treated anonymously. Some of the programs used were commercial: CATT, dBRay, EPIDAURE, RAMSETE, RAY, RAYNOISE, RAYPID, ODEON and others were research developments without trade names. As far as possible, the developers of the software themselves participated. Some participants used more than one program and some programs were used by more than one participant.

PROJECT ORGANIZATION

From the ground plan and side view of the auditorium and the additional material information (for instance "plastered brick wall", "3 mm carpet", "wooden lining" etc.) received by each participant, the parameters and input data of the programs were chosen. The geometries used were therefore similar but not identical.

The parameters listed in Table I were determined for the 1 kHz octave band in three steps:
Simulations I: based on information on the geometry data and descriptions of materials in words (January - April 94),
Measurements according to ISO/DIS 3382:1995 [2] (July - August 94) and
Simulations II: based on the same geometry as in phase I but on prescribed absorption data (August - October 94).

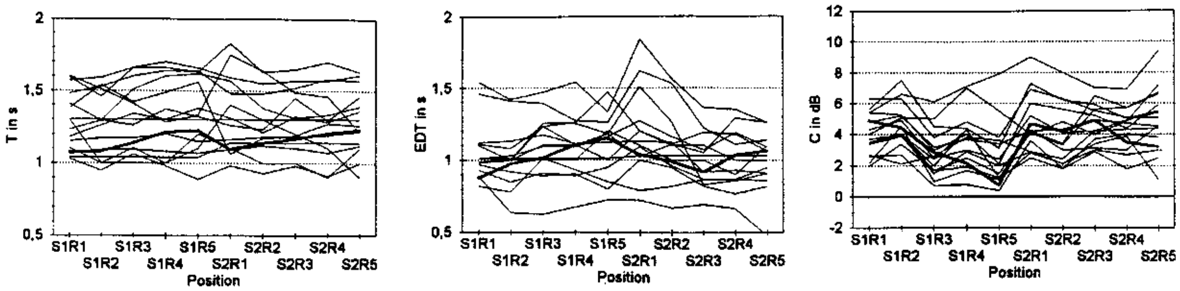
Table I. Room acoustical criteria determined in the intercomparison (according to ISO/DIS 3382) and order of magnitude of subjective difference limens (roughly rounded from the data of [4]).

Parameter	Definition	Subj. limen
T_{30} / s	Reverberation time, derived from -5 to -35 dB of the decay curve	5 %
EDT / s	Early decay time, derived from 0 to -10 dB of the decay curve	5 %
D / %	Deutlichkeit (definition), early (0 - 50 ms) to total energy ratio	5 %
C / dB	Clarity, early (0 - 80 ms) to late (80 ms - ∞) energy ratio	0,5 dB
TS / ms	Centre time, time of 1. moment of the energy impulse response	10 ms
G / dB	Sound level related to omnidirectional free-field radiation in 10 m distance	1 dB
LF / %	Early lateral (5 - 80 ms) energy ratio, $\cos^2$(lateral angle)	5 %
LFC / %	Early lateral (5 - 80 ms) energy ratio, cos(lateral angle)	5 %

The programs can be divided into two groups using different general approaches:
a) one group of (at least a partly) deterministic nature (image source, cone-, beam- or pyramid-tracing or the so-called "hybrid" models) with or without the inclusion of a statistical reverberation tail, b) the other group containing the purely statistical methods (conventional ray tracing). The main difference between the methods is that in case a) the distance law of sound radiation into free space (spherical waves) is calculated explicitly from the $1/r^2$ law - at least for the early reflections, whereas in case b) the distance law is fulfilled implicitly in the number of rays (or "sound particles") counted when they hit volume or cross-section receivers. Usually, in case a) the time resolution of the impulse responses calculated can be infinitely high and sound scattering during reflections can only be treated if statistical properties (for instance "reverberation tails") are added. In case b) the time resolution is limited and diffusion can very easily be treated. In both variants the accuracy of the results depends on the number of rays. The following list contains some features of the programs with numbers denoting case a) and letters case b). The symbols **6**, **11**, **12** and **A** are omitted because there was no participation in phase II.

	Algorithm (reflection order/number of rays)	No.of Surfaces	Calculation time	Hardware
1	Image sources (5/-) + random tail	75	35 min	PC 486DX2/66
2	Hybrid model (10/5.000) + random tail	109	5 min	PC 486DX2/66
3	Hybrid model (40/40.000) + random tail	44	3 h	PC 486/33
4	Hybrid model (-/50.000)	1833	12 h	HP 9000/735
5	Image sources (6/-) + tail	40	3 h	PC 486/SX
7	Hybrid model (-/46.056)	150	25 h	PC 486/50
8	Hybrid model (?/?) + random tail	154	4 h	PC 386/25
9	Hybrid model (-/150.000)	289	3 h	PC 486/33
10	Hybrid model (15/10.000) + random tail	233	32 min	PC 486DX33
B	Ray tracing (-/814.896)	122	10 h	PC 486/33
C	Ray tracing (-/10.000)	109	12 h	PC 486DX2/66
D	Ray tracing (-/160.000)	44	26 h	PC 386/20
E	Ray tracing (-/100.000)	46	20 min	PC 486/66
F	Ray tracing (-/200.000)	74	140 min	PC 486DX/33
G	Ray tracing (-/6617)	184	40 min	PC 486DX2/66
H	Ray tracing (-/46.000)	120	16 h	PC 486/50

RESULTS OF PHASE I (individual absorption data)
It was very surprising how large the scatter between the results was after allowing free choice of absorption coefficients. Apparently, there is a strong tendency to underestimate absorption (see examples in Fig. 2). There were striking variations in the way the geometry was modelled (see Table II), even the simplest feature of the auditorium, its volume, derived in some cases from the mean free path, differing markedly (± 6 %).



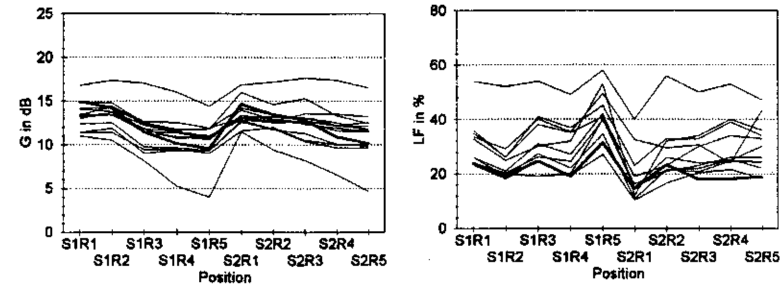


Fig. 2. Individual results of phase I (thin lines) for parameters T, EDT, C, G and LF. The thick line marks the average measurement result. As the results shown here are only intended to indicate the large differences, the curves are not marked by symbols.

RESULTS OF PHASE II (general absorption data)
After completion of the measurements, which were performed by 7 independent groups from Germany, Sweden, Norway and Italy [3] (all used PC-based MLS measuring technique), absorption and diffusion coefficients were estimated and distributed among the participants for the repetition of the simulations. The intercomparison is now focused on the algorithms without any influence of the operator. The input data were harmonized as far as possible. The results (Fig. 3) are now compared to see how far they deviate from the average measurement result and the corresponding $\pm 2\sigma$ deviation (thick lines). The differences are much smaller than those reported in phase I. They are, however, still large compared with the standard deviation of the measurement results and with the subjective difference limens for the parameters (see Table I and below).

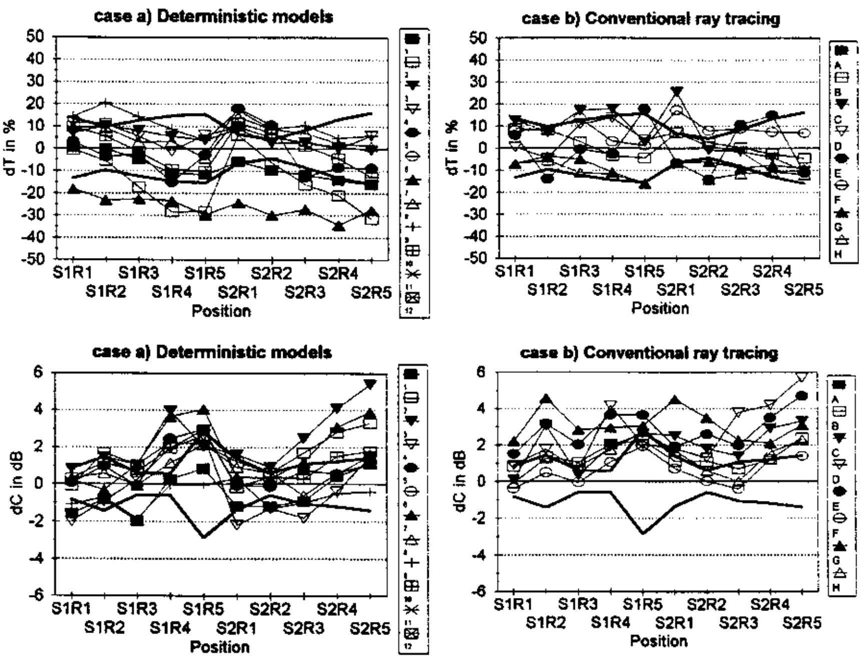


Fig. 3. Examples of results of phase II.

ACCURACY RATING
The overall accuracy of the computer simulations can be estimated by a single number rating. This quantity is derived from the absolute difference between the result from the simulation and the measurement on each of the ten source and receiver combinations. The average of these location-dependent differences is then related to the subjective difference limens for the acoustical criteria (see Table I). The resulting relative error for each acoustical parameter is shown in Fig. 4. Note that a value of 1 indicates the order of magnitude of the subjective limen (for instance 5% for T and EDT, 0.5 dB for C or 10 ms for TS).

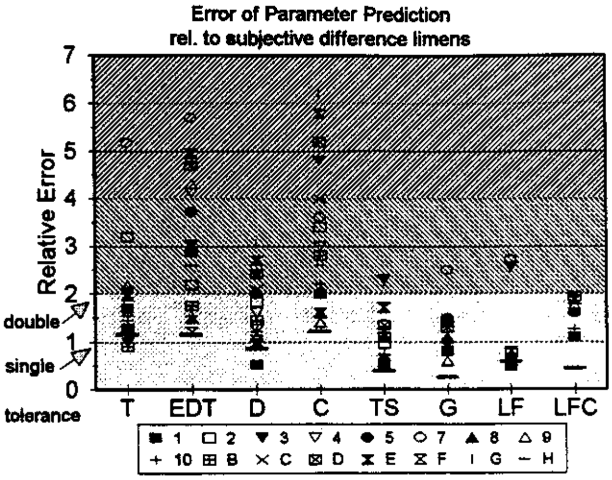


Fig. 4. Individual symbols and thick lines for standard deviation of average measurement result.

Not every program is intended to be used for the calculation of all parameters, so some symbols are missing in Fig. 4. It is most interesting that some parameters (T, TS and G) can be calculated or measured more easily than others (EDT and particularly C !). If the area between 0 and 1 is referred to as a single tolerance interval and the area between 0 and 2 as a double interval, the programs can be rated according to the number of results which fall into the interval (a kind of "point system", see Table III). The double interval was introduced because the result of a prediction or a measurement of acoustical parameters is not totally useless if the accuracy is less than the subjective limen. More than the double interval, however, would indeed be very uncertain.

Table III. Percentage of results within tolerance intervals and overall accuracy rating. A "100" means that this program produced 100% of the parameters provided (at most 8) within the tolerance interval. Finally, the overall rating in the right-hand column is the average of the numbers in double and single tolerance.

Program	% in double tolerance	% in single tolerance	Rating 0..100
1	88	50	69
2	67	17	42
3	29	14	22
4	67	17	42
5	88	25	57
7	29	0	15
8	100	43	72
9	75	25	50
10	86	29	58
B	75	25	50
C	50	0	25
D	50	0	25
E	57	29	43
F	100	50	75
G	33	0	17
H	25	0	13
σ(meas.)	100	67	83

CONCLUSIONS

Although the accuracy rating is somewhat arbitrary and should not be over-interpreted, it seems to be reasonable because all numbers are well removed from the "100" due to familiar problems in the measurement and simulation of some parameters. The standard deviation of the measurements has a slightly higher number than the best programs. But irrespective of the overall rating or single or double tolerance numbers, there are only three programs that are unquestionably reliable in the prediction of room acoustical parameters: F, 8 and 1. Note that unlike the others, these three programs require neither extremly high calculation times nor extremely detailed room geometries (see Table I). It should also be noted that all three algorithms include diffuse reflections, which could be an indication of problems involved in "specular models". A detailed error investigation can now be carried out. Based on the results of this intercomparison, the participants can check the validity of their software regarding details of the algorithms (transition order and level matching the early and late part of the impulse response, or consistency within the results, such as too high T corresponding to too high G and too low D, etc.). Of course, other room shapes and volumes should then be taken into account. Another interesting point for further investigation is the significantly increasing difference between results from simulations and measurements at increasing source-receiver distances. The reason could be that in none of the programs is the attenuation of sound waves at grazing incidence over seat rows or the audience taken into account. This particularly affects the direct sound and the first reflections. For instance, the predicted results of D and C would be too high and the EDT would be too low (as indeed is the case, see Fig. 3).

ACKNOWLEDGEMENT

The author is grateful for the ready cooperation of all participants. He hopes that the results of this intercomparison lead to progress in simulation techniques and to better comparability.

REFERENCES

[1] Krokstad, A., Strøm, S., Sørsdal, S., J. Sound Vib. 8 [1968], 118, [2] ISO/DIS 3382:1995, [3] Lundeby, A., Vigran, T.E., Bietz, H., Vorländer, M., Acustica 81(4) [1995], [4] Cox, T.J., Davies, W.J., Lam, Y.W., Acustica 79(1) [1993], 27.