A ROUND-ROBIN TEST PROGRAM ON WAVE-BASED COMPUTATIONAL METHODS FOR ROOM-ACOUSTIC ANALYSIS

PACS: 43.20.Rz, 43.55.Ka

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ABSTRACT

A round-robin test program for wave-based computational methods is being planned on the WWW, aiming at providing a public opportunity to mutually compare the computational performance. In this program, several kinds of benchmark problems regarding room acoustics are settled in three categories of external, internal and structural-acoustic problems, each of which consists of basic and practical problems. A trial calculation is carried out with several methods (FEM, BEM, FDM etc.) at four institutions. Comparison between the results is done with respect to accuracy and efficiency of computation, which clarified some points to be considered in the program.

1. INTRODUCTION

In recent years, the application of numerical methods, such as FEM, BEM, FDM and so on, to acoustical problems has widely spread, and furthermore, various kinds of new related techniques are also being developed. However, practical software users are sometimes confused with choosing an appropriate method among them, because clear indications about the choice can hardly be found. On the other hand, in general, one researcher has implemented one new method, and has to spend much time to get comparable results with other methods, or cannot make a sufficient comparison. One of the reasons for this situation is that there have been few collaborative opportunities to mutually compare the computational performance, although such activities on ray-based room-acoustic simulations have been done [1, 2].

Aiming at providing such a public opportunity to activate research and development in the field of Computational Acoustics, a round-robin test program for wave-based computational methods is being planned on the WWW, where a suite of benchmark problems is arranged, especially regarding room acoustics. The web site of this program is open to the public, linked with the page of Technical Committee of Computational Acoustics in the EAA site (http://www.european-acoustics.org/). This paper presents the contents of the round-robin test program at this stage, and also demonstrates some results of a trial calculation with several methods offered by four institutions.

2. FRAME OF ROUND-ROBIN TEST PROGRAM

2.1. General Policy

This round-robin test program provides benchmark problems for wave-based computational methods, specific submission forms, and bulletin boards for contributions on the WWW, which enable all participants to mutually compare computational accuracy and efficiency of various methods. Those who have carried out the tests are requested to submit their results to be opened on the boards, provided that the burden of the proof is on the contributors.

2.2. Benchmark Problems

Considering typical applications of wave-based methods, benchmark problems are settled in the three categories of external, internal and structural-acoustic problems. Each category has two types of problems in the frequency and/or time domain: a basic type having rigid surface of simple shape, and a practical type having surface of complicated shape and with damping. Table 1 shows the list of the benchmark problems now proposed, including candidates, which is possible to be extended with careful selection.

Category A for exterior problems has basic ones concerning radiation, scattering and diffraction, some of which give analytical solution, and practical ones with a loudspeaker box, a diffusing surface, and a barrier. Category B for interior problems has basic one with a cubic cavity, which gives analytical solution with mode superposition, and practical one with an actual auditorium. Category C for structural-acoustic problems has basic one concerning insulation of a baffled plate,

Table 1. List of the benchmark problems.

category	type	index	domain	object	phenomenon
A. exterior	0. basic	A0-1F	freq	vibrating cube	radiation
		A0-2F/T	freq/time	cube	radiation
		A0-3F/T	freq/time	sphere	scattering
		A0-4F/T	freq/time	square panel	diffraction
	1. practical	A1-1F/T	freq/time	loudspeaker	radiation
		A1-2F/T	freq/time	diffuser	scattering
		A1-3F	freq	barrier on the ground	diffraction
B. interior	0. basic	B0-1F/T	freq/time	cubic cavity	scattering
	1. practical	B1-1F/T	freq/time	auditorium	scattering
C. structural-acoustical	0. basic	C0-1F	freq	plate in baffle	insulation
	1. practical	C1-1F	freq	plate in room	radiation
		C1-2F	freq	plate between rooms	insulation

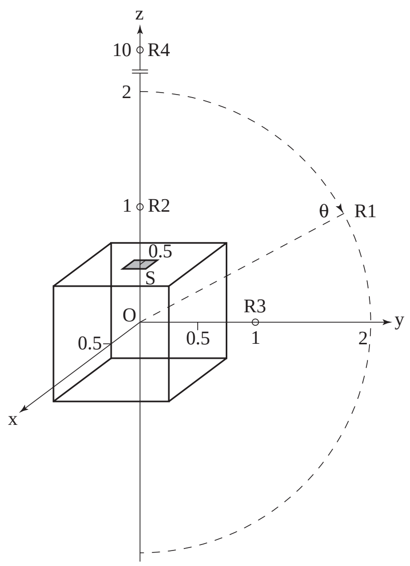

Fig. 1. Geometry of Problem A0-2F/T, with a piston (S) and receiving points (R1-R4). Unit: [m].

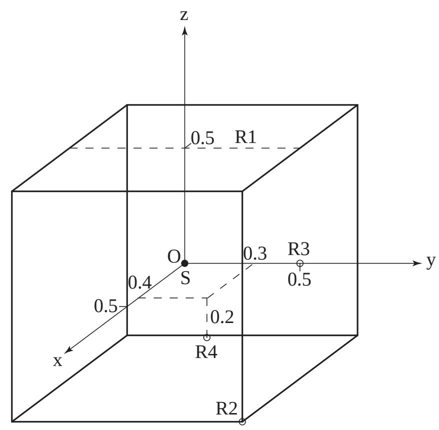

Fig. 2. Geometry of Problem B0-1F/T, with a point source (S) and receiving points (R1-R4). Unit: [m].

and practical ones coupling sound field in a room and vibration of its wall. For example, Figures 1 and 2 show the geometries of basic Problems A0-2F/T and B0-1F/T, respectively, both of which has the surface of 1 m^3 cube.

2.3. Tasks of Calculation

Generally, as output data, the frequency-domain tests require spatial distributions at specific frequencies and frequency responses at specific points, and the time-domain tests require impulse responses or the similars with a filtered pulse at specific points. Besides, some special acoustical values are required for practical problems. Furthermore, each test requires to measure computing performance, such as processing time and used memory, with dividing the computation into a few processes, however, taking no account of the process for mesh generation.

2.4. Regulations for Calculation

In the frequency-domain tests, a stationary state with each specific frequency is considered. The frequencies for calculation are specified for each problem, and the highest frequency is fixed at 4 kHz for all problems, however, permitting calculation in the possible frequency range. In the time-domain tests, the sampling frequency is fixed at 8 kHz for all problems. Each discrete-time sampled value corresponds to the integrated value ±0.5 time samples of the continuous-time signal. If a filtered pulse is used for the source, the source signal must be supplied as complementary information.

2.5. Arrangements for Contribution

To make clear comparison among contributed results, a prescribed submission form is arranged for each problem in an electronic file (MS Excel format), which are downloadable on the web site. This form includes three entry pages for information on face items (method, programming, subsidiary software, machine specifications, comment, references, contributor, etc.), computed results and computing performance results. Supplementary information can be also included in free space, which will be helpful in detailed discussion.

3. TRIAL CALCULATION

3.1. Outline

A trial calculation with a basic interior problem (Problem B0-1F/T, see Figure 2) was done with six methods at four institutions. Table 2 shows the data on the main face items for the trial. All codes are self-programmed, and the programming languages, machine specifications and precision of mesh are diverse in the same way as the actual state of the round robin test. In the frequency-domain test, FEM, BEM and a new technique fast multipole BEM [3] were tested comparing with analytical solution by way of modal summation. In the time-domain test, FDTD [4] was tested comparing with analytical solution given by image sources.

Table 2. Main face items for the trial calculation.

method	domain	language	machine	notes
Modal Summation (MS)	freq	Matlab 4.2	iMac, PowerPC G3 500MHz, 640MB	analytical solution approx. 9.4 million modes
FEM	freq	C	SunBLADE-1000 2xUltraSPARC III Cu 900MHz, 2.5GB	2nd-order tetrahedron elements edge length: approx.5.6 cm sparse matrix storage: CSR interative solver: CG
BEM	freq	C	Dell Precision WS 610 2xPentium III Xeon 550MHz , 2GB	constant rectangular elements, approx. 1/8 wave length interval iterative solver: BiCGSTAB
Fast Multipole BEM (FMBEM)	freq	C	ditto.	ditto. using fast multipole algorithm
Image Source Method (ISM)	time	Matlab 4.2	iMac, PowerPC G3 500MHz, 640MB	analytical solution approx. 1.3 million image sources
FDTD	time	Fortran Power Station 32	Dell Dimension XPSB Pentium III 1GHz 256MB	staggered grid, 0.625cm interval leapfrog scheme time step: 0.01ms

3.2. Frequency-Domain Test

Figure 3 shows some results of the first task to calculate the sound pressure distribution on the line R1. Good agreement is seen among the four methods below 1 kHz, although the result with FEM is remarkably different from others at 2 kHz due to using coarse mesh. Figure 4 shows results of the second task to calculate the frequency response at R2, where good agreement is also seen. Table 3 shows the computing performance results for the first task. The processing time with BEM

Table 3. Computing performance results for a task of Problem B0-1F.

		processing time [s]				used memory [MB]			
	f [Hz]	MS	FEM	BEM	BEM	MS	FEM	BEM	FMBEM
per frequency	31.5	131	20	30	N.A.	-	-	2	N.A.
	63	131	18	32	N.A.	-	-	2	N.A.
	125	131	19	32	N.A.	-	-	2	N.A.
	250	131	29	32	N.A.	-	-	2	N.A.
	500	131	52	459	N.A.	-	-	38	N.A.
	1000	131	184	7221	1154	-	-	605	97
	2000	131	1298	N.A.	11153	-	-	N.A.	386
	4000	131	N.A.	N.A.	N.A.	-	N.A.	N.A.	N.A.
common		2470	5	-	-	230	91	-	-

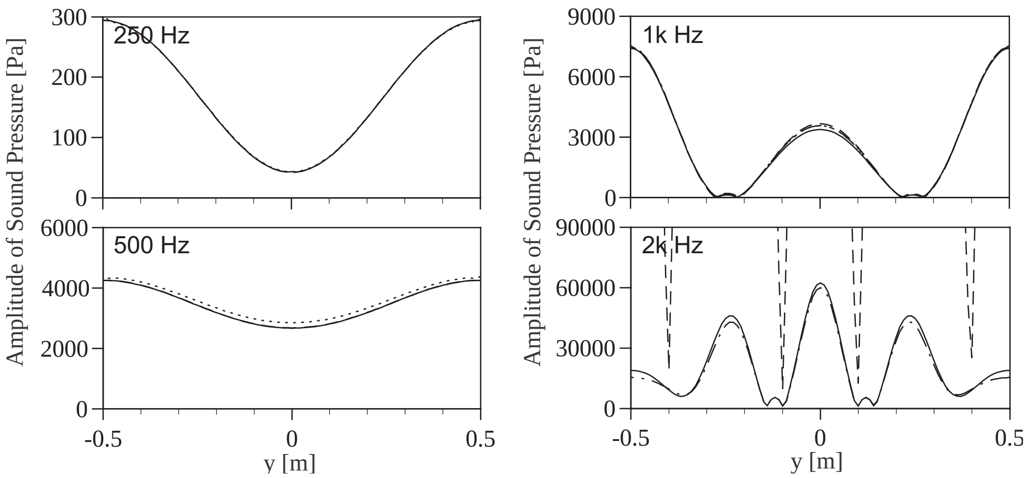

Fig. 3. Distributions of sound pressure amplitude on R1 from 250 to 2kHz, with MS (thick lines), FEM (dash lines), BEM (dot lines, below 1kHz) and FMBEM (dash-dot lines, above 1kHz).

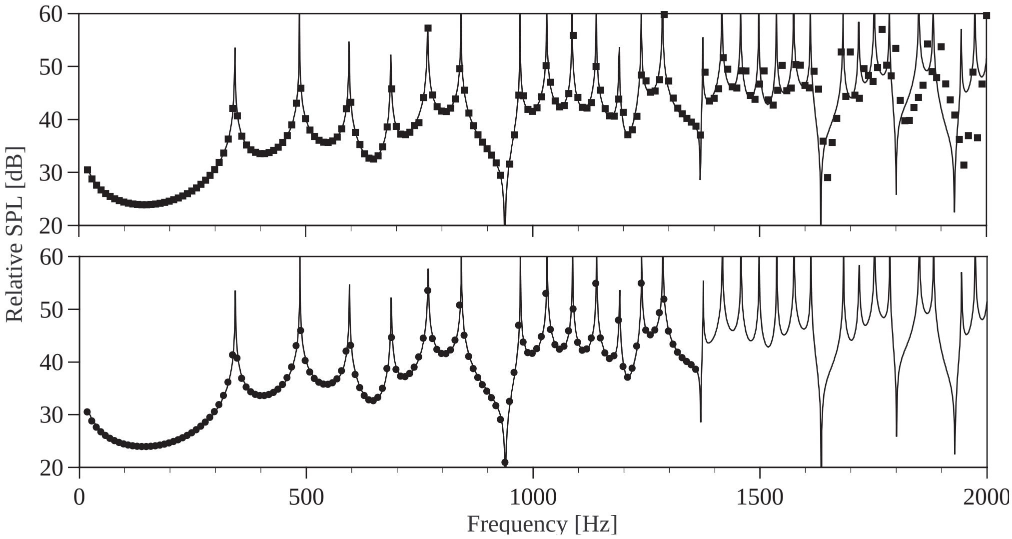

Fig. 4. Frequency responses at R2, with MS (thick line), FEM (square marks in the upper) and BEM (disk marks in the lower).

remarkably increases as the frequency rises, due to changing the mesh with the frequency. On the other hand, the FEM calculation used fixed mesh, which caused the moderate increase. For further discussion on computing performance, some information on mesh precision, such as an average node interval, and on CPU performance, such as SPECfp, need to be considered.

3.3. Time-Domain Test

Figures 5 and 6 show results of the task to calculate the pulse response at R2, where as a source signal, the derivative of Dirac function is given with the image source method, and one sine wave in the spatial domain is given with FDTD. Good agreement is seen between the two responses in general appearance, and also in the arriving time of pulses. For the calculation up to 0.2 s, the image source method required 69 s of processing time and 500 MB memory, and FDTD required 36808 s and154 MB. To make clear discussion on computational accuracy, the used source signal must be specified in a comparable form.

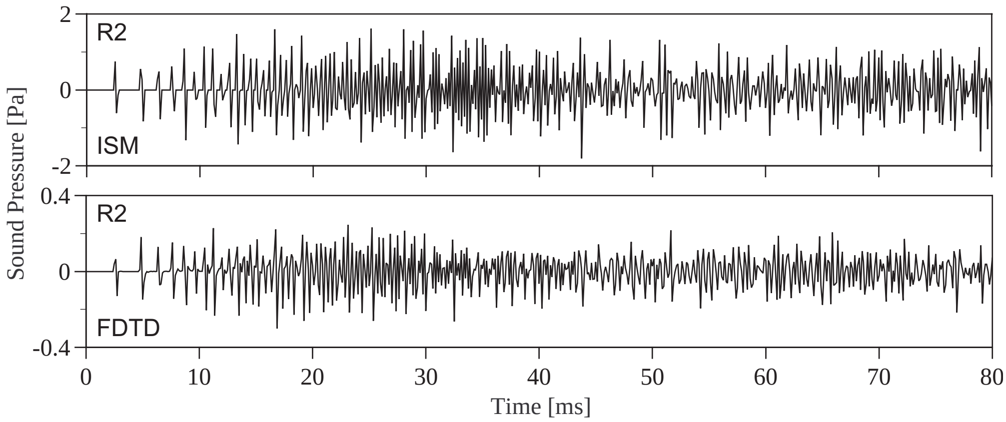

Fig. 5. Time-domain responses at R2, with ISM (upper) and FDTD (lower). Different source signals are used for the two calculations.

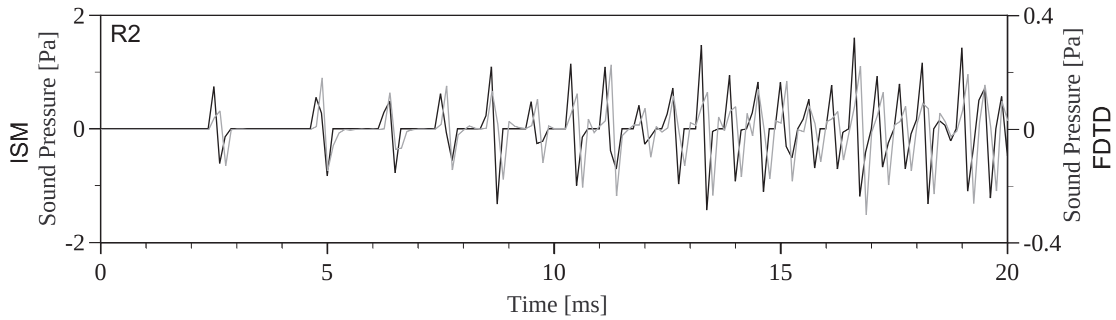

Fig. 6. Close-up of the time-domain responses at R2, with ISM (think line) and FDTD (pale line).

4. CONCLUDING REMARK

A frame of the round-robin test program was presented with some results of a trial calculation. To make the program widely useful, indications, rules and forms on the tests must be provided as clearly as possible, and furthermore, practical benchmark problems need to be enriched with precise geometrical information and reliable measured results. This program will be progressed in cooperation with all participants who offer computed and measured results, benchmark problems, ideas for comparison, utilization and so on.

ACKNOWLEDGEMENT

The authors wish to thank Yasuda, Y. (Inst. Environ. Studies, Univ. of Tokyo) and Strauch, O. (Inst. Tech. Acoust., Tech. Univ. of Aachen) for providing some numerical results.

BIBLIOGRAPHICAL REFERENCES

[1] Vorländer, M., International round robin on room acoustical computer simulations, Proc. 15th ICA (Trondheim), 689-692, 1995.

[2] Bork, I., A comparison of room simulation software - the 2nd round-robin on room acoustical computer simulation, Acustica-acta acustica 86, 943-956, 2000.

[3] Sakuma, T. and Yasuda, Y., Fast multipole boundary element method for large-scale steady-state sound field analysis, part I: setup and validation, Acustica-acta acustica (in press).

[4] Sakamoto, S., Seimiya, T. and Tachibana, H., Visualization of sound reflection and diffraction using finite difference time domain method, Acoust. Sci. Tech. 23, 35-39, 2002.