Austin RCS Benchmark Suite Developments

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***Abstract*—Recent developments in, and additions to, the Austin RCS Benchmark Suite are described and presented. The benchmark suite has been expanded to include new measurement data to validate simulations for problem set III-A "PEC almonds." It has also been expanded along the material dimension to problem sets I-B "semiconductor spheres" and I-C "water spheres."**

I. Introduction

The Austin RCS Benchmark Suite [1] is being developed to quantify the performance (i.e., the error-cost tradeoff [2], [3]) of modern radar cross section (RCS) simulations and enable meaningful comparisons of ever more diverse computational methods on increasingly heterogeneous computing platforms. The suite, which aims to exercise features of simulation methods relevant to aerospace applications, has been organized along six dimensions of increasingly demanding simulations [1]: (D1) geometrical fidelity, (D2) material fidelity/diversity, (D3) lengths, (D4) frequency, (D5) solution accuracy, and (D6) simulation cost.

In the last year, three initial sets of problems aligned along the D1/D2 dimensions have been defined: perfect electrically conducting (PEC) spheres (problem set I-A), zero-thickness PEC plates (II-A), and PEC almonds (III-A) [4]. A range of lengths and frequencies of interest was identified for each set, and the D3/D4 problem space was spanned by sampling this range logarithmically [1]. In D5/D6 dimensions, each problem is expected to be solved at multiple error levels and each solution's wall-clock time, memory requirement, and parallel efficiency is to be observed. While the suite can be used to identify extreme cases in D3-D6 dimensions—and test alternative formulations, algorithms, software implementations, or hardware at these extremes—using the suite to perform error-vs.-cost, cost-vs.-frequency, and cost-vs.-size sweeps by sub-sampling the problem space [1] is particularly informative. Recommended sweeps have been identified for each problem set in [5].

This article presents several recent developments in the benchmark suite: the addition of new reference results, the specification of performance measures, and the expansion in the D2 dimension by including non-PEC scattering problems.

II. Reference Results

Accurate reference data are necessary to validate RCS simulation results as well as to quantify errors and uncertainty in these simulations. Analytical solutions are used as reference in the Austin RCS Benchmark Suite whenever possible. Because there are a very limited number of such solutions [6], and because analytical solutions can involve simplifications of the problems of interest or approximations to the solution of the problem, alternative references are also needed. These include higher-accuracy simulation results [3]. To ensure that all physical phenomena [7] are captured in the simulations, "meaningful and accurate" measurement results [8] should also be used as references. It is worth noting that all three types of references (analytical, numerical, measurement) have limitations and are beset by various sources of uncertainty and error [9]. Indeed, as capabilities of RCS simulations have improved over time, measurement data in publications such as [4] have become less adequate as references, and the need for precisely instrumented, carefully documented, and publicly available RCS measurement data with detailed uncertainty accounting has arisen**.**

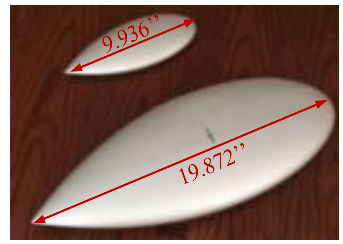

Fig. 1: An ~10in. almond and ~20in. almond used in the measurement campaign.

We conducted a campaign to obtain improved measurement data compared to [4] and over a wider range of frequencies, for the problem III-A in the suite [10]. The measured RCS results at multiple frequencies for two almonds additively manufactured according to the mathematical definition in [4] of length 9.936 in. and 19.872 in. (Fig. 1) were added to the suite [5].

III. Performance Measures

A. Error Measure

To facilitate error-cost tradeoff studies, it is useful to have a single number to quantify error. In the suite, the following definition for error is used:

$$\overline{err}^{TH}_{uu,\mathrm{dB}} = \frac{1}{\Omega_s \Omega_i} \oiint_{\Omega_i} \left[\oiint_{\Omega_s} \left| err^{TH}_{uu,\mathrm{dB}} \right| d\Omega_s \right] d\Omega_i \ (\mathrm{dB}) \qquad (1)$$

This averages over an appropriate (problem-set dependent) sector of scattered and incident solid angles the point-wise difference between the numerical result and the reference RCS after thresholding, which is given by

$$err^{TH}_{uu,\mathrm{dB}} = \max(\sigma_{uu,\mathrm{dB}}, TH_{\mathrm{dB}}) - \max(\sigma^{\mathrm{ref}}_{uu,\mathrm{dB}}, TH_{\mathrm{dB}}) \ (\mathrm{dB}) \qquad (2)$$

Here, TH_{dB} is a threshold value below which the differences in RCS values are considered negligible and $uu \in \{\theta\theta, \phi\phi\}$ is the polarization. For each problem set in the benchmark suite, the RCS sector and the threshold level of interest are specified.

B. Cost Measure

The simulation costs are quantified using the observed wall-clock time t^{wall} and the peak-memory requirement per core

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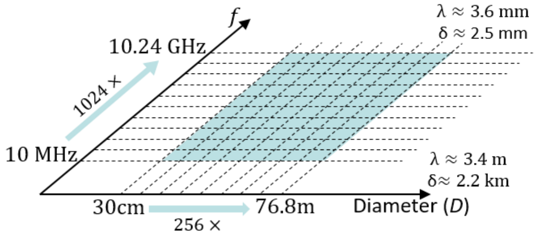

Fig. 2: The frequency and length scales for the 99 cases in Problem I-C of the benchmark suite; the lengths shown correspond to water at the specified frequencies.

$mem^{maxcore}$, as well as the "serialized" CPU time t^{total}, and the total memory requirement mem^{max}:

$$\begin{aligned} t^{total} &= N_{proc} \times t^{wall} \text{ (s)} \\ \text{mem}^{max} &= N_{proc} \times \text{mem}^{maxcore} \text{ (bytes)} \end{aligned} \quad (3)$$

where N_{proc} is the number of cores used for the simulation.

IV. Materials

Increasing the material fidelity/diversity increases, often drastically, the overall difficulty of RCS simulations, potentially giving rise to type 2 multi-scale problems [11]. Such simulations can reveal strengths and weaknesses of different methods. The initial material configurations in the benchmark suite are homogeneous, isotropic, and lossy dielectrics: problem set I-B consists of "semiconductor spheres" and I-C "water spheres". Progressively more complicated material configurations are expected to be developed for the Austin RCS Benchmark Suite.

Problem sets I-B and I-C correspond to the simplest problems in D1 geometry dimension in the benchmark suite. The problems cover a physical length scale of 256x and frequency range of 1024x in D3 and D4 dimensions that are logarithmically sampled just as for problem set I-A (PEC spheres) [1] (Fig. 2). For these problems, unlike for PEC spheres, doubling the frequency and halving the diameter does not result in identical problems and the 99 possible problems cannot be reduced to 19 unique ones. While the semiconductor spheres' parameters are frequency independent, the water sphere is assigned frequency-dependent properties corresponding to distilled water at 25 °C [12]. The parameters give rise to internal wavelengths and penetration depths that are significantly different than the free-space wavelength (Fig. 3); e.g., the wavelength in water spheres is about nine times smaller than that of the free-space exterior region, while the penetration depth varies from tens of wavelengths at the lower frequencies to about half a wavelength at the highest frequency of interest. This increases the complexity of the problem and the requirements from the solution methods.

V. Conclusion

We continue to develop the Austin RCS Benchmark suite to include new reference results, performance metrics and data for various solvers, and new problems. Performance data for various simulations for problems I-B and I-C will be presented at the conference to show how their inclusion in the suite increase its suitability to evaluate computational systems.

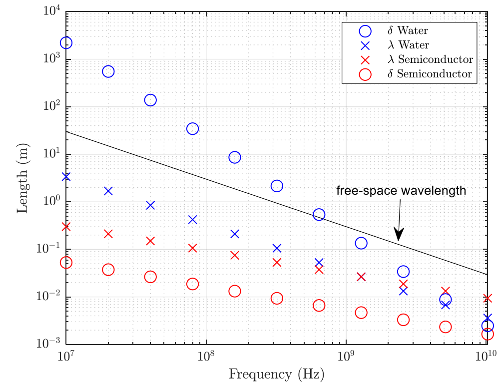

Fig. 3: Wavelength and penetration depth for the distilled water and the semiconductor material at the benchmark frequencies.

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