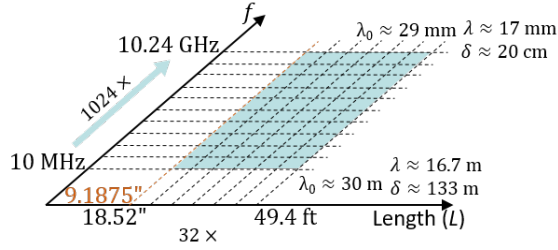


Description of Scattering Object

A homogeneous complex aircraft model made out of a low-loss dielectric material.

Length Scale and Frequency Range



The problems of interest cover a range of $\sim 64\times$ in physical length scale and $1024\times$ in frequency; the ranges are logarithmically sampled to yield 99 scattering problems. In these problems, the model sizes are in the range $0.007 \leq L/\lambda_0 \leq 514$ and $1.8 \times 10^{-3} \leq L/\delta \leq 76$, where λ_0 is the free-space wavelength and δ is the penetration depth in the resin.

Interesting Features

1. The logarithmic sampling is distorted along the size axis for the smallest model: the smallest EXPEDITE-RCS aircraft has $L=9.1875''$ (instead of $L\approx 9.261''$). The sampling is also distorted along the frequency axis: scattering from the smallest aircraft at frequencies $f \in \{10, 20, 40, 80, 160, 320, 640, 1280, 2580, 5120, 7000, 10250\}$ MHz are included in the problem set. These distortions are because of publicly available measurement data [1] and add 12 unique scattering problems to the set.
2. The model cannot be described sufficiently with a few equations, drawings, or pictures [1]; it presents modeling, meshing, and reproducibility challenges.
3. The low-loss dielectric material introduces extra uncertainties and sensitivities to RCS measurements and simulations [2].

Quantities of Interest

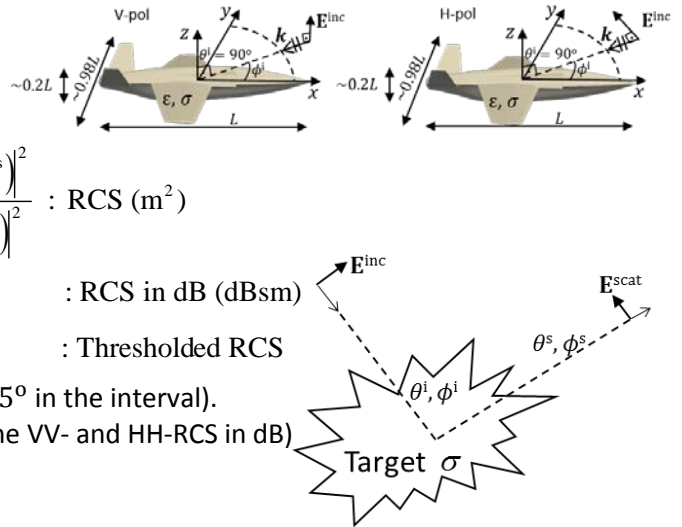
Radar cross section (RCS) definition

$$\sigma_{vu}(\theta^s, \phi^s, \theta^i, \phi^i) = \lim_{R \rightarrow \infty} 4\pi R^2 \frac{|\hat{v}(\theta^s, \phi^s) \cdot \mathbf{E}^{\text{scat}}(\theta^s, \phi^s)|^2}{|\hat{u}(\theta^i, \phi^i) \cdot \mathbf{E}^{\text{inc}}(\theta^i, \phi^i)|^2} : \text{RCS (m}^2\text{)}$$

$$\sigma_{vu,\text{dB}}(\theta^s, \phi^s, \theta^i, \phi^i) = 10 \log_{10} \sigma_{vu} : \text{RCS in dB (dBsm)}$$

$$\sigma_{vu,\text{dB}}^{TH}(\theta^s, \phi^s, \theta^i, \phi^i) = \max(\sigma_{vu,\text{dB}}, TH_{vu,\text{dB}}) - TH_{vu,\text{dB}} : \text{Thresholded RCS}$$

1. Set $\theta^i = 90^\circ$. Vary $0^\circ \leq \phi^i \leq 180^\circ$ (every 0.5° in the interval).
2. Compute back-scattered $\sigma_{\theta\theta,\text{dB}}$ and $\sigma_{\phi\phi,\text{dB}}$ (the VV- and HH-RCS in dB) at $N_\phi = 361$ scattering directions.



Material Properties

The permeability of the resin is the same as that of free space. A Debye model expressed as $\epsilon(f) = \epsilon_0 \epsilon_r(f)$, where

$$\epsilon_r(f) = \epsilon'_r(f) - j\epsilon''_r(f) = 2.85 - j0.0687 + \frac{0.365 - j0.0602}{1 - jf(-0.1135 + j0.899)}$$

was used to calculate the complex permittivity of resin at the frequencies of interest. The reference simulation results were computed using precisely the permittivity values (i.e., to machine precision) shown in the below table. The above Debye model for the resin is slightly different than that in [2]. This is because a second set of measurements were performed following the submission of [2] that yielded slightly different values for the dielectric properties [3]. The average of the two measurements are used to fit the above Debye model as described in [3].

Frequency f (MHz)	ϵ'	ϵ''	Frequency f (MHz)	ϵ'	ϵ''
10	3.21	1.29×10^{-1}	2560	2.96	9.64×10^{-2}
20	3.21	1.29×10^{-1}	2580	2.96	9.63×10^{-2}
40	3.20	1.28×10^{-1}	5120	2.91	8.60×10^{-2}
80	3.19	1.28×10^{-1}	5125	2.91	8.60×10^{-2}
160	3.17	1.26×10^{-1}	7000	2.90	8.22×10^{-2}
320	3.13	1.23×10^{-1}	10 240	2.88	7.85×10^{-2}
640	3.08	1.18×10^{-1}	10 250	2.88	7.85×10^{-2}
1280	3.02	1.08×10^{-1}			

Performance Measures

Error Measure: Simulation errors shall be quantified using

$$avg. err_{uu, dB}^{TH} = \frac{1}{2\pi} \int_0^{2\pi} \left| \sigma_{uu, dB}^{TH}(\phi^s) - \sigma_{uu, dB}^{ref, TH}(\phi^s) \right| d\phi^s \approx \frac{1}{N_\phi} \sum_{n=1}^{N_\phi} \left| \sigma_{uu, dB}^{TH}(\phi^s) - \sigma_{uu, dB}^{ref, TH}(\phi^s) \right| \quad (\text{dB}) \quad \text{for } u \in \{\theta, \phi\}$$

where

$$TH_{uu, dB} = \max_{\phi^s} \sigma_{uu, dB}^{ref} - 80 \quad (\text{dB})$$

This error measure discounts errors in RCS values below TH .

Cost Measure: Simulation costs shall be quantified using observed wall-clock time and peak memory/core

$$t_{main}^{wall} \text{ (s) and } mem_{main}^{maxcore} \text{ (bytes)}$$

as well as the “serialized” CPU time and total memory requirement

$$t_{main}^{total} = N_{proc} \times t_{main}^{wall} \text{ (s) and } mem_{main}^{max} = N_{proc} \times mem_{main}^{maxcore} \text{ (bytes)}$$

Here, N_{proc} denotes the number of processes used in a parallel simulation. It is expected that results will be reported for at least 2 runs: “Efficient” (small N_{proc}) and “Fast” (large N_{proc}).

Study 1: Error vs. Cost Sweep

Fix frequency and fix aircraft dimensions. Simulate many error levels (proxy: mesh densities) for 4 cases:

Case 1: $f=10$ MHz, $L=9.1875$ in

Case 2: $f=7$ GHz, $L=9.1875$ in

Case 3: $f=10$ MHz, $L \approx 49.4$ ft (592.763 in)

Case 4: $f=320$ MHz, $L \approx 49.4$ ft (592.763 in)

It's recommended to simulate as many error levels (mesh densities) as possible. 3-5 error levels is typical.

A typical error-vs.-cost study will consist of $4 \times 3 = 12$ -20 simulations.

Study 2: Frequency Sweep

Fix aircraft dimensions and error level (proxy: mesh density). Simulate many frequencies for 4 cases:

Case 1: $L \approx 18.52$ in, error level 1 (coarsest mesh)

Case 2: $L \approx 49.4$ ft, error level 1 (coarsest mesh)

Case 3: $L \approx 18.52$ in, error level 2 (finer mesh)

Case 4: $L \approx 49.4$ ft, error level 2 (finer mesh)

Frequencies shall be chosen as $f \in \{10, 20, 40, \dots, 5120, 10240\}$ MHz. It's recommended to simulate as many frequencies as possible. A full frequency-sweep study will consist of $4 \times 11 = 44$ simulations.

Study 3: Size Sweep

Fix frequency and error level (proxy: mesh density). Simulate many sizes for 4 cases:

Case 1: $f=10$ MHz, error level 1 (coarsest mesh)

Case 2: $f=320$ MHz, error level 1 (coarsest mesh)

Case 3: $f=10$ MHz, error level 2 (finer mesh)

Case 4: $f=320$ MHz, error level 2 (finer mesh)

Dimensions shall be chosen as $L \in \{9.1875, 18.524, 37.04, \dots, 296.3815, 592.763\}$ in. It's recommended to simulate as many sizes as possible. A full size-sweep study will consist of $4 \times 7 = 28$ simulations.

Reference Quantities of Interest

The following RCS data are made available in the benchmark to enable participants to calibrate their simulators:

4 RCS measurement results corresponding to the smallest aircraft ($L=9.1875$ in) at frequencies $f \in \{2580, 5120, 7000, 10250\}$ MHz. These measurements were made using an aircraft scale model of size $L=9.1875$ in. These data are provided for ϕ^i sampled every 0.25° .

4 RCS simulation results for the smallest aircraft at the above 4 frequencies found by using the ARCHIE- AIM code, a frequency-domain FFT-accelerated integral-equation solver developed at UT Austin [4]-[6].

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- [5] F. Wei and A. E. Yilmaz, "A more scalable and efficient parallelization of the adaptive integral method part I: algorithm," *IEEE Trans. Antennas Propag.*, vol. 62, no.2, pp. 714-726, Feb. 2014.
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