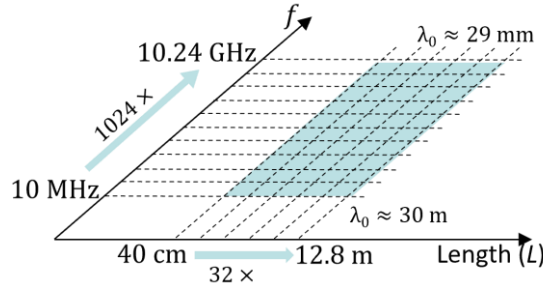


### Description of Scattering Object

A perfect electrically conducting (PEC) hexagonal prism with a circle-cylinder shaped duct. A fan-blade assembly is inserted into the duct.

### Length Scale and Frequency Range



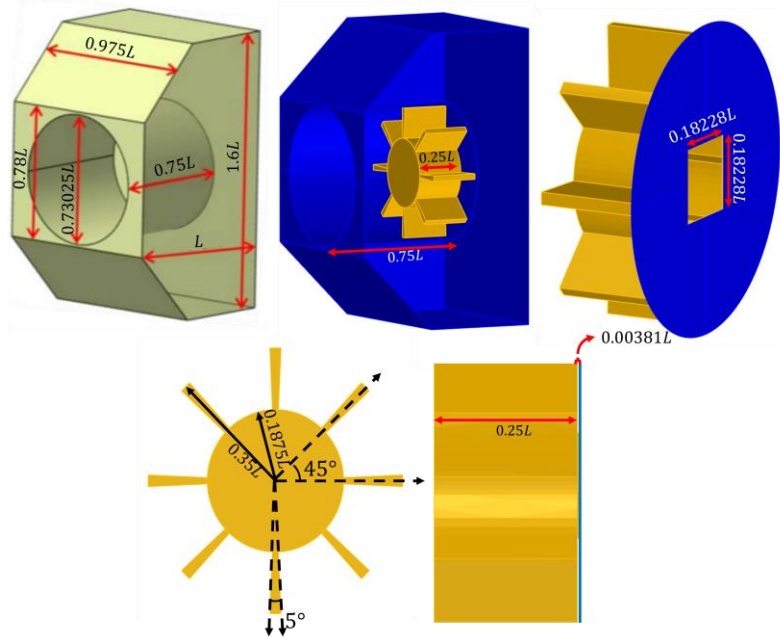
The problems of interest cover a range of 32x in physical length scale and 1024x in frequency; the ranges are logarithmically sampled to yield 66 scattering problems. Because the camera boxes are PEC, there are only 16+1 unique scattering problems in Problem Set IIISD. In these problems, the model sizes are in the range  $0.013 \leq L/\lambda_0 \leq 438$ , where  $\lambda_0$  is the free-space wavelength.

### Interesting Features

1. The camera box is designed as a host structure to enable reproducible RCS measurements of ducts. The flat-plate geometrical features of the housing promote strong backscattering in certain directions that are minimally affected by the scattering characteristics of any voids in the box [1],[2]. The camera box host structure used for Problem Sets IIISA and IIISB was modified in the following manner: its dimensions were scaled by 3x in the y-dimension and 2x in the z-dimension compared to that in [2] (see diagram for exact dimensions).

2. The diagram shows the dimensions of the straight-blade fan-loaded camera box. For the smallest problem in the problem set, a 2.88 in.  $\times$  2.88 in.  $\times$  0.06 in. metal plate connects the fan-blade assembly to the back-wall of the duct [1]; as a result, there is a 0.06-in. gap between the blades and the back wall of the duct. The sampling of the frequency range is distorted for this problem: scattering from the smallest camera box at frequencies  $f \in \{10, 20, 40, 80, 160, 320, 640, 1280, 2560, 5120, 7000, 10240\}$  MHz are included in the problem set. This distortion is because of publicly available measurement data [1] and adds 1 unique scattering problem to the set.

3. The VV-polarized RCS pattern at 2.56 GHz for the smallest problem in the problem set was found to exhibit unusually high sensitivity to computational errors and simulation parameters in the  $15^\circ \leq \phi^i \leq 30^\circ$  range [3]. Methods and parameters that typically yield sufficiently accurate results may yield results that agree poorly with the reference simulation and measurement data for this part of the pattern.



## Quantities of Interest

Radar cross section (RCS) definition

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

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

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

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

## Performance Measures

*Error Measure:* Simulation errors shall be quantified using

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

where

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

This error measure discounts errors in RCS values smaller than  $TH$ .

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

$$t^{\text{wall}}(\text{s}) \text{ and } mem^{\text{maxproc}}(\text{bytes})$$

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

$$t^{\text{total}} = N_{\text{proc}} \times t^{\text{wall}}(\text{s}) \text{ and } mem^{\text{max}} = N_{\text{proc}} \times mem^{\text{maxproc}}(\text{bytes})$$

Here,  $N_{\text{proc}}$  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  $N_{\text{proc}}$ ) and “Fast” (large  $N_{\text{proc}}$ ).

## Study 1: Error vs. Cost Sweep

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

Case 1:  $f=10$  MHz,  $L=40$  cm

Case 2:  $f=7$  GHz,  $L=40$  cm

Case 3:  $f=10$  MHz,  $L=6.4$  m

Case 4:  $f=320$  MHz,  $L=6.4$  m

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  $4 \times 3 \times 5 = 12$ -20 simulations.

## Study 2: Frequency Sweep

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

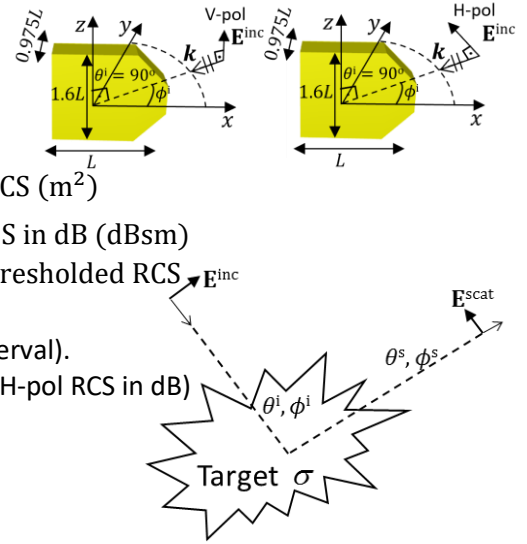
Case 1:  $L=40$  cm, error level 1 (coarsest mesh)

Case 2:  $L=6.4$  m, error level 1 (coarsest mesh)

Case 3:  $L=40$  cm, error level 2 (finer mesh)

Case 4:  $L=6.4$  m, 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  $L \in \{40, 80, 120, \dots, 640, 1280\}$  cm. 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:

8 RCS measurement results corresponding to the smallest straight-blade fan-loaded camera box ( $L=40$  cm) at frequencies  $f \in \{2560, 5120, 7000, 10240\}$  MHz. These data are provided for  $\phi^i$  sampled every  $0.5^\circ$ .

4 RCS simulation results for the smallest straight-blade fan-loaded camera box 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].

**References**

- [1] J. T. Kelley *et al.*, "Reproducible measurements of "fan blades in a pipe" CEM benchmark," in *Proc. Antenna Meas. Techn. Assoc. Symp.*, Oct. 2023.
- [2] A. E. Yilmaz *et al.*, "Camera boxes: a set of complex scattering problems to test EM simulations and measurements," in *Proc. IEEE Antennas Propag. Soc. Int. Symp.*, July 2022.
- [3] A. Maicke, J. T. Kelley, and A. E. Yilmaz, "MFIE-induced RCS errors in CFIE simulations of a fan-loaded camera box," in *Proc. ACES Symp.*, May 2024.
- [4] M. F. Wu, G. Kaur, and A. E. Yilmaz, "A multiple-grid adaptive integral method for multi-region problems," *IEEE Trans. Antennas Propag.*, vol. 58, no. 5, pp. 1601-1613, May 2010.
- [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.
- [6] J. W. Massey, V. Subramanian, C. Liu, and A. E. Yilmaz, "Analyzing UHF band antennas near humans with a fast integral-equation method," in *Proc. EUCAP*, Apr. 2016.