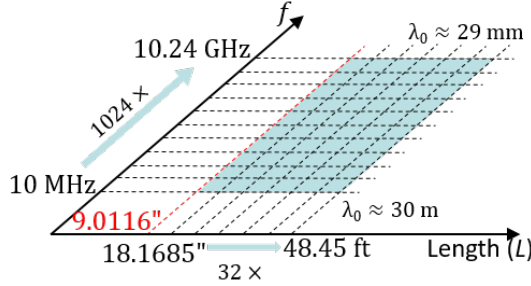## Description of Scattering Object

A perfect electrically conducting (PEC) complex aircraft model with open inlet and exhaust ducts.

Length Scale and Frequency Range

The problems of interest cover a range of ~64x in physical length scale and 1024x in frequency; the ranges are logarithmically sampled to yield 99 scattering problems. Because the aircrafts are PEC, there are only 17 + 13 unique scattering problems in Problem Set IVC. In these problems, the model sizes are in the range $0.007 \leq L/\lambda_0 \leq 510$, where λ_0 is the free-space wavelength.

Interesting Features

1. The logarithmic sampling is distorted along the size axis for the smallest model: the smallest Open-Duct PRIME aircraft has L=9.0116'' (instead of $L \approx 9.0843$''). The sampling is also distorted along the frequency axis: scattering from the smallest aircraft at frequencies $f \in \{10, 20, 40, 80, 160, 320, 640, 1280, 2560, 2580, 5120, 7000, 10240\}$ MHz are included in the problem set. These distortions are because of publicly available measurement data [1] and add 13 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. This model is similar to that in problem set IV-A (PEC Closed-Duct PRIME aircraft model) [2], except that the engine intake and exhaust entrances are opened and curved ducts introduced.
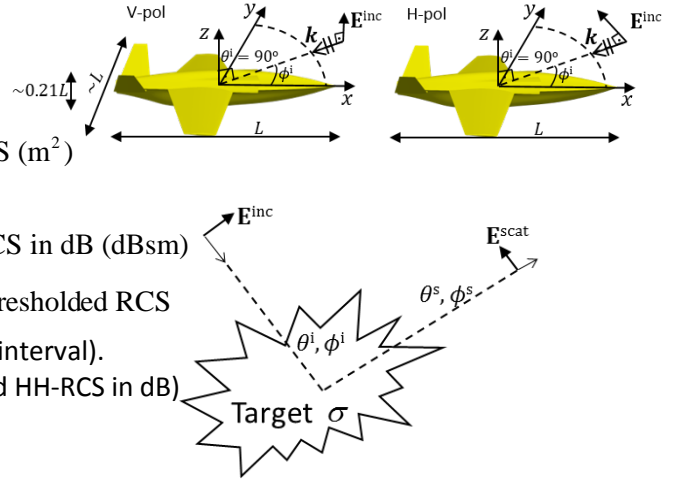
Quantities of Interest

Radar cross section (RCS) definition

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

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

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

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.

Performance Measures

Error Measure: Simulation errors shall be quantified using

$$avg.err_{uu,\text{dB}}^{TH}=\frac{1}{2\pi}\int_{0}^{2\pi}\left|\sigma_{uu,\text{dB}}^{TH}\left(\phi^{s}\right)-\sigma_{uu,\text{dB}}^{\text{ref},TH}\left(\phi^{s}\right)\right|d\phi^{s}\approx\frac{1}{N_{\phi}}\sum_{n=1}^{N_{\phi}}\left|\sigma_{uu,\text{dB}}^{TH}\left(\phi^{s}\right)-\sigma_{uu,\text{dB}}^{\text{ref},TH}\left(\phi^{s}\right)\right| \quad \text{(dB)} \text{ for } u\in\{\theta,\phi\}$$

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

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

as well as the "serialized" CPU time and total memory requirement

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

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=9.0116 in   Case 2: f=7 GHz, L=9.0116 in
Case 3: f=10 MHz, L≈48.45 ft (581.3927 in)   Case 4: f=320 MHz, L≈48.45 ft (581.3927 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 4x3-5=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≈18.52 in, error level 1 (coarsest mesh)   Case 2: L≈48.45 ft, error level 1 (coarsest mesh)
Case 3: L≈18.52 in, error level 2 (finer mesh)   Case 4: L≈48.45 ft, error level 2 (finer mesh)
Frequencies shall be chosen as $f \in$ {10, 20, 40, … , 5120, 10240} MHz. It's recommended to simulate as many frequencies as possible. A full frequency-sweep study will consist of 4x11=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 $L \in$ {9.0116, 18.1685, 36.3370, …, 290.6963, 581.3927} in. It's recommended to simulate as many sizes as possible. A full size-sweep study will consist of 4x7=28 simulations.

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

7 RCS measurement results corresponding to the smallest aircraft (L=9.0116 in) at frequencies $f \in$ {2560, 2580, 5120, 7000, 10240} MHz. These measurements were made using three aircraft scale models [1]: one was of size L=9.0116 in and the other two were scaled up 2x and 4x in all dimensions. These data are provided for ϕ^{i} sampled every 0.25^{o}.

5 RCS simulation results for the smallest aircraft at the above 5 frequencies found by using the ARCHIE-AIM code, a frequency-domain FFT-accelerated integral-equation solver developed at UT Austin [3]-[5].

References
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[2] J. T. Kelley, A. Maicke, D. A. Chamulak, C. C. Courtney, and A. E. Yılmaz, "Adding a reproducible airplane model to the Austin RCS Benchmark Suite," in *Proc. Applied Comp. Electromagnetics Society (ACES) Symp.*, July 2020.
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[4] F. Wei and A. E. Yılmaz, "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.
[5] J. W. Massey, V. Subramanian, C. Liu, and A. E. Yılmaz, "Analyzing UHF band antennas near humans with a fast integral-equation method," in *Proc. EUCAP*, Apr. 2016.