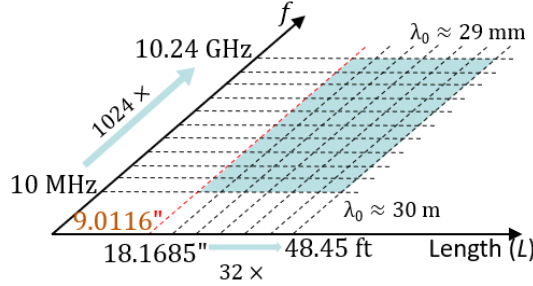**Description of Scattering Object**
A perfect electrically conducting (PEC) complex aircraft model with open inlet and exhaust ducts.

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 77 scattering problems. Because the aircrafts are PEC, there are only 16 + 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 are introduced.

Quantities of Interest
Radar cross section (RCS) definition

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

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

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

1. Set $\theta^i = 90°$. Vary $0° \leq \phi^i \leq 180°$ (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-pol RCS in dB) at $N_\phi = 361$ scattering directions.

Performance Measures
Error Measure: Simulation errors shall be quantified using

$$avg.\,err_{uu,\text{dB}}^{TH} = \frac{1}{2\pi} \int_0^{2\pi} |\sigma_{uu,\text{dB}}^{TH}(\phi^s) - \sigma_{uu,\text{dB}}^{\text{ref},TH}(\phi^s)| d\phi^s \approx \frac{1}{N_\phi} \sum_{n=1}^{N_\phi} |\sigma_{uu,\text{dB}}^{TH}(\phi_n^s) - \sigma_{uu,\text{dB}}^{\text{ref},TH}(\phi_n^s)| \;\; (\text{dB}) \;\; \text{for } u \in \{\theta, \phi\}$$
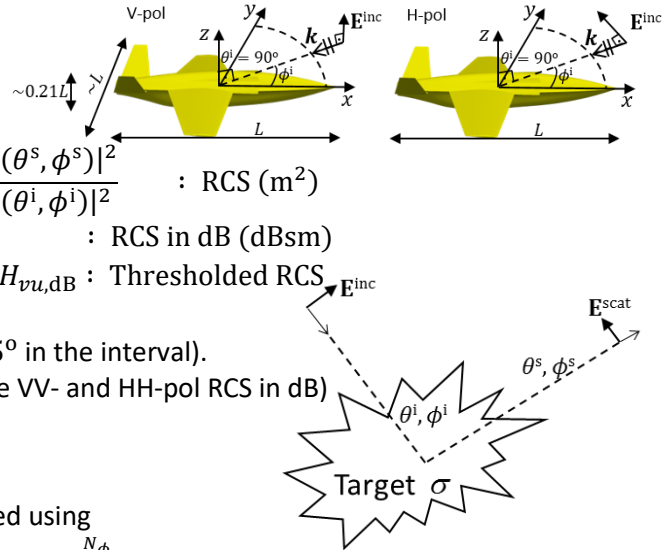
where $TH_{uu,\text{dB}} = \max_{\phi^s} \sigma_{uu,\text{dB}}^{\text{ref}} - 80 \; (\text{dB})$. This error measure discounts errors in RCS values smaller than TH.

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

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

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

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

1

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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[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.