Adding a Reproducible Airplane Model to the Austin RCS Benchmark Suite

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Abstract—**A full-size airplane model (the EXPEDITE-RCS model) was developed as part of a benchmark suite for evaluating radar-cross-section (RCS) prediction methods. To generate accurate reference data for the benchmark problems formulated using the model, scale-model targets were additively manufactured, their material properties and RCS were measured, and the measurements were validated with a surface-integral-equation solver. To enable benchmarking of as many computational methods as possible, the following data are made available in a version-controlled online repository: (1) Exterior surface (outer mold line) of the CAD model in two standard file formats. (2) Triangular surface meshes. (3) Measured and predicted monostatic RCS data.**

I. Introduction

The radar cross section (RCS) of realistic airplane models—complex models that cannot be described sufficiently with a few equations, drawings, or pictures—is used frequently to motivate advances in computational electromagnetics as well as to demonstrate capabilities of new methods (e.g., see [1]-[5]). Unfortunately, the published RCS data for such airplane models found by numerically solving the scattering problem—even if the computed results correlate well with independent physical measurements as in [1]-[3]—are generally impossible to replicate or corroborate [6]. It is also generally impossible to use the published data for such models to objectively compare the performance of a new algorithm, software, or hardware for predicting RCS to existing or future alternatives [7]. This is in part because complex models are almost never available to anyone but the authors of the study that used them—even the authors can lose access to the models and the ability to reproduce their published data over time. This article introduces a high-fidelity airplane model to the Austin RCS Benchmark Suite [7]-[11], a publicly available suite that is being developed to verify, validate, and benchmark modern and future computational methods for predicting RCS. It also describes various difficulties encountered when developing such models and the steps the authors followed to increase the likelihood that the model and its RCS patterns can be reproduced precisely and used independently to judge different RCS prediction methods.

II. Development of the EXPEDITE-RCS Model

The benchmark airplane model is based on a test platform created by Lockheed Martin Aeronautics and collaborators as part of the ongoing expanded multidisciplinary analysis and design optimization for effectiveness based design technologies (EXPEDITE) program [12]. The major elements of the EXPEDITE program are structured to be as open as possible with a minimal amount of proprietary information [12], thus enabling public release of precise CAD models derived from the test platform. Thanks to this exceptionally favorable setup for collaboration, an airplane model could be rapidly developed for RCS benchmarking.

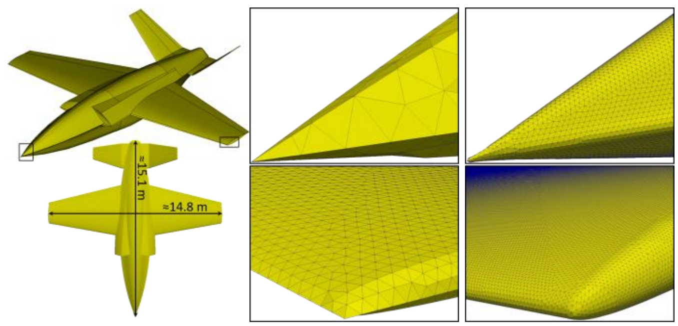

Fig. 1. The surface of the EXPEDITE-RCS model visualized from the defeatured IGS file (left) and triangular meshes of the model's nose and wingtip using an average edge length of ~2 in (middle) and ~0.25 in (right).

Because of a lack of precedents for sharing geometrically-complex targets, the authors faced numerous major choices during the development of the benchmark model. While aiming to maximize the model's utility, the authors also had to manage the uncertainty in the RCS computations and measurements, in the amount/type/format of data to be shared, and in the process of releasing the model and building benchmark problem sets. This led to four major decisions: (i) While the EXPEDITE program's test platform is architected as a fully parameterized geometry that enables multidisciplinary trade-off studies, a particular realization—referred to as the EXPEDITE-RCS model—was selected rather than an ensemble of potential designs (Fig. 1). (ii) The engine intake and exhaust cavities of the selected model would be closed at first (but can be opened in the future). (iii) Simple materials would be used at first. (iv) Scale-model targets would be additively manufactured and their RCS patterns would be measured carefully. Following these decisions, the model was developed in five steps.

Step 1: Initial evaluation. The surface of the EXPEDITE-RCS model was meshed in the same CAD software used to design the test platform [12]. The model's RCS was computed assuming it was perfectly electrically conducting (PEC). The simulations were used to verify that the model was closed, its surface could be meshed properly, its RCS patterns were symmetric, and the results converged as the mesh was refined.

Step 2: Preparation for manufacturing. The suitability of the original model for additive manufacturing was evaluated by specialists. Various geometrical features (e.g., sharp wing tips)

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of the scaled model were deemed too small for accurate printing and the design was modified accordingly to respect the minimum feature sizes and tolerances of the 3D printing process, e.g., the airfoils' trailing edges were thickened and the surface joints were blended. The modified design's computed RCS patterns were also tested for symmetry and convergence.

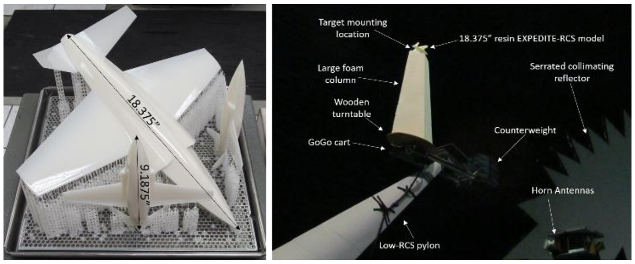

Fig. 2. Left: The additively manufactured scale models before their support structures were removed and they were sanded and metallized. Right: The measurement of the ~18.4-in long model in the compact chamber.

Step 3: Manufacture and measurement of scale models. Proportionally scaled resin targets of length ~18.4-in and ~9.2-in were printed and their RCS were measured (Fig. 2) using the facilities and methodology detailed in [10],[11]. The targets were then coated with a highly conductive silver paint and their RCS were measured again. The measured data were post-processed and validated with simulations just as in [11]. A sample result is shown in Fig. 3; additional data and accompanying simulations, for both the metallized and resin targets at 2.58 GHz, 5.12 GHz, 7 GHz, and 10.25 GHz are available as part of the problem sets IV-A and IV-B in [9].

Step 4: Preparation for public release. To facilitate replicability of the model, its surface description was exported in STL and IGS file formats. The STL file was the one used in 3D printing of the scale models. The IGS file was imported to a second more widely available meshing software to test the relative ease of independent mesh development. This revealed that there were 220 surfaces in the IGS file; many were artifacts from the test platform, including minute surfaces with edges that are smaller than 1 in. These could be merged easily with neighbors while ensuring tangential (C^1) continuity with the help of a CAD tool. Other surfaces had to be first split into smaller sub-surfaces using iso-curves along edges shared with a neighbor; this also helped align edges of neighboring surfaces, resulting in a model composed of 108 surfaces that can be relatively easily meshed. While this defeaturing process led to minute differences between the old and new model surfaces, computations using the two models converged to visually identical RCS patterns. In addition to the STL and IGS files, a series of increasingly finer triangular surface meshes (coarsest-finest: $\sim 2 \times 10^3 - \sim 5 \times 10^7$ elements) are also shared in [9].

Step 5: Publication and presentation. The model was first described in this article, shown at the conference, and made available in [9] at the time of the conference presentation.

III. CONCLUSION

A realistic airplane model was developed to serve as a publicly available reproducible RCS benchmark target. To increase the utility of the model, metallized and non-metallic scale-model targets were additively manufactured, RCS measurements supported by simulations were performed and documented, and model files, meshes, measured RCS data, and computed RCS data were shared on an online repository [9].

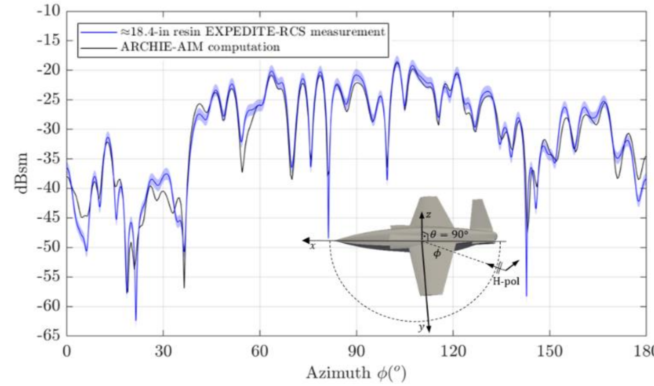

Fig. 3. Measured and computed HH-polarized monostatic RCS at 7 GHz for the ~18.4-in long uncoated-resin model. The measured data are shown with a ±1 dB uncertainty band [10]. The computed data were generated using the resin material properties in [11].

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