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Numerical Computation of the Radar Cross Section of the ZSU-23-4

Ronald Chase, H. Bruce Wallace, and Thomas Blalock

ARL-MR-430 April 1999

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Numerical Computation of the Radar Cross Section of the ZSU-23-4

Ronald Chase, H. Bruce Wallace

Sensors and Electron Devices Directorate, ARL

Thomas Blalock

Defense Intelligence Agency Missile and Space Intelligence Center

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Abstract

A computer geometry model of the ZSU-23-4 (a quad 23-mm self-propelled antiaircraft gun) was obtained in Ballistic Research Laboratory-Computer Aided Design (BRL-CAD), a combinatorial solid geometry-based modeling system. The BRL-CAD file served as input to a software package (ECLECTIC) that generated a flat, triangular, all-metal facet representation of the ZSU exterior structure, containing approximately 78,000 facets. The facet model served as input to Xpatch, a high-frequency signature prediction code based on the shooting and bouncing ray (SBR) technique. Xpatch was run at the Defense Intelligence Agency, High Performance Computing Center with several Silicon Graphics, Inc. (SGI), Origin, Onyx, and Challenge machines that used 426 CPUs and 60 Gflops of computing power. The configuration parameters for the ZSU model, both with and without a perfect metal ground plane, included two depression angles (12° and 30°), both polarizations, 256 frequencies (about each center frequency), and azimuth steps of 0.05° (for *X*-band) and 0.015° (for K_a-band). The configuration parameters were selected based on measurement data taken on a ZSU vehicle at the U.S. Army Research Laboratory Aberdeen Proving Ground test facility. The model predictions will include radar cross-section data as a function of polarization and angle and synthetic aperture radar images. This report details the preliminary results from the computer modeling.

1. Introduction

The U.S. Army Research Laboratory (ARL) is participating in a North Atlantic Treaty Organization (NATO) research study group (RSG20) with a focus on the military applications of millimeter-wave (MMW) imaging. RSG20 conducted an experiment at Swynnerton, UK, that involved the use of airborne synthetic aperture radar (SAR) systems to collect imagery of a military location. The experiment assessed the applicability of MMW imaging for locating and engaging ground vehicles and other fixed targets. One of the ground vehicles used in this test was a ZSU-23-4, a quad 23-mm self-propelled antiaircraft weapon system (see fig. 1). ARL conducted a series of measurements at the outdoor signature research facility at Aberdeen Proving Ground (APG), MD, in August 1996 to characterize the MMW signature of this vehicle for comparison to similar measurements obtained at Swynnerton. As an adjunct to the original intent of comparing measurements, the participants agreed to perform radar cross-section (RCS) predictive modeling using this target as a baseline. The United States agreed to provide a flat, triangular facet representation of the exterior structure of the ZSU that would be suitable for RCS calculations. The parameters used in the modeling would be the same as those used in the measurements at ARL. The aim was to allow direct comparison of model results with a standard set of signature visualization tools.

The fully polarimetric instrumentation radars at the ARL signature research facility were used to collect data on the ZSU vehicle at both *X*-band and K_a-band. Table 1 summarizes the main characteristics of the measurement instrumentation in figure 2.

A full description of the operation of the radar and data acquisition system can be found in Stratton et al.* Measurements made with this system are taken with the radar mounted on an elevator on a 125-ft-high tower. The radar is pointed at an in-ground turntable 153 ft away. The test

Figure 1. ZSU-23-4 vehicle at APG measurement facility.

*Suzanne R. Stratton, H. Bruce Wallace, Robert L. Bender, and Ann E. M. Brodeen, *A Comparison of Radar Cross-Section (RCS) Measurements of 11 T72M1 Tanks at 35 GHz*, U.S. Army Research Laboratory, ARL-TR-1421 (July 1997).

vehicle sits on this turntable. Figure 1 shows the ZSU vehicle at the APG facility. Target rotation is always counterclockwise; thus, 90° is always on the left side of the vehicle when looking at it head-on. A complete rotation for frequency measurements at 34 GHz takes about 10 min. A fully calibrated RCS plot can be ready 10 min after the measurement is completed. A series of inverse synthetic aperture radar (ISAR) images displayed on a CRT as a movie is available 25 min after the measurements are completed. Table 2 displays the measurement conditions that were replicated in the ZSU modeling work.

Table 1. *X*-, K_a-, and *W*-band polarimetric ISAR instrumentation data.

Parameter	*X*-band	K_a-band	*W*-band
Center frequency (GHz)	9.25	34.25	94.25
RF bandwidth (MHz)	1511.64	1511.64	1511.64
Frequency step (MHz)	5.928	5.928	5.928
Peak transmit power (dBm)	+27	+20	+13
Pulsewidth (ns)	100	100	100
PRF (MHz)	1.0	1.0	1.0
3 dB beam-width (°)	8.5	8.5	8.5
Polarization isolation (dB)	30	35	35
System noise figure (dB SSB)	7	9	11
Minimum detectable signal	–80	–80	–80

Transmitted polarization: vertical and horizontal
Received polarization: vertical and horizontal

Figure 2. *X*-, K_a-, and *W*-band polarimetric ISAR.

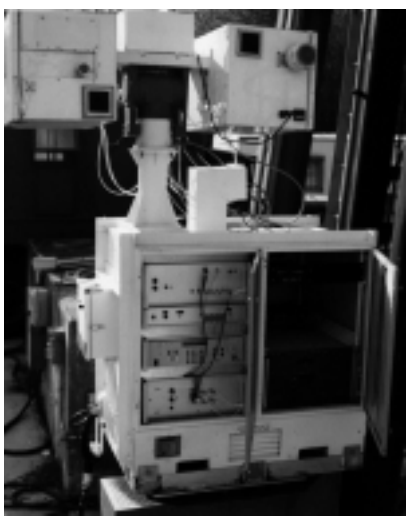


Table 2. ZSU measurement parameters.

Parameter	*X*-band	K_a-band
Nominal center frequency (GHz)	9	34
Start frequency (GHz)	8.00000	33.48836
Stop frequency (GHz)	9.51164	35.00000
Step frequency (MHz)	5.928	5.928
Number of frequencies	256	256
Depression angles (°)	12 and 30	12 and 30
Angle sampling interval (°)	0.05	0.015

Measured polarizations: vertical/vertical, vertical/horizontal, horizontal/vertical, horizontal/horizontal

2. Development of the Facet Model

The computer modeling of the ZSU-23-4 began with the development of a geometric representation of the exterior of the vehicle in some suitable format. An existing geometry model of the ZSU was found at ARL-APG. This geometry model was created with the Ballistic Research Laboratory-Computer Aided Design (BRL-CAD) software package. These BRL-CAD models were originally developed to analyze various physical properties (such as center of mass, moments of inertia) and vulnerability, but in recent years they have been used for optical, radar, and infrared (IR) signatures.

BRL-CAD software development started in 1979 as a task to provide an interactive graphics editor for the BRL vehicle description database. The software package includes a solid geometric editor; the ray-tracing library; different lighting models; and many image handling, data comparison, and other supporting utilities. This software package now totals more than 500,000 lines of C source code and undergoes continuous development (the current version is 4.4). It runs under UNIX and is supported by more than a dozen product lines from Sun Microsystems workstations to Silicon Graphics, Inc. (SGI), supercomputers. BRL-CAD supports a variety of geometric representations, including an extensive set of traditional combinatorial solid geometry (CSG) primitive solids such as blocks, cones, and tori; solids made from closed collections of uniform B-spline surfaces as well as nonuniform rational B-spline (NURBS) surfaces; purely faceted geometry; and n-manifold geometry (NMG). All these geometric objects may be combined using Boolean set theory operations such as union, intersection, and subtraction. All the geometric entities provide different material representations. The software is an unpublished work that is only available through the terms of a limited-distribution agreement. BRL-CAD is licensed at nearly 800 sites worldwide.

The BRL-CAD representation of the ZSU vehicle contains both interior and exterior feature details. This representation is not suitable as input to the software selected to perform the RCS calculations, Xpatch. Xpatch requires either a triangular facet representation or an international graphics exchange specification (IGES) representation of the exterior structure of the vehicle. Several geometry format conversion packages are available that will accept a BRL-CAD input file and produce facet and/or IGES formats. In addition, Xpatch software includes a utility for this process. A facet representation of the model was generated, since Xpatch can compute the required RCS data about four times faster for a facet input file than for an equivalent IGES input file. The speed difference is related to the ray-tracing algorithm in the software.

Initially, a utility in Xpatch called Cifer was applied to convert the BRL-CAD file into a facet representation. This attempt failed because the ZSU CAD representation was too large to process in a single step. It would have been necessary to edit the CAD model (with a BRL-CAD editor) to divide the original model into three or four segments, facetize each

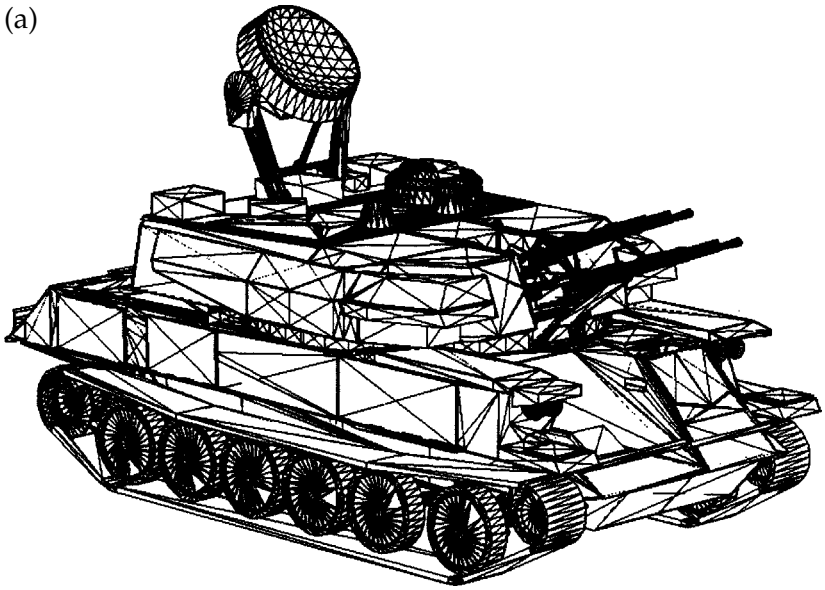
segment, and recombine the faceted segments. The next attempt employed a software converter—a pre-release version of ECLECTIC—that was developed by the Army Tank and Automotive Command (TACOM). ECLECTIC is an extension of an earlier converter called Facet Region Editor (FRED) that was also developed at TACOM to generate flat, triangular facet representations from BRL-CAD models to support IR signature analysis on computers. ECLECTIC generates facet models in several stages by identifying and facetizing geometry primitives, separately handling intersections of primitives (edges), and determining interior and exterior elements of the model. Several levels of facet size refinement are available in the code, from coarse to relatively fine (designated 1 to 10). Plans were made to examine the ZSU model at several different facet sizes to compare the resulting representations for quality (facet skewness), uniformity, and number of facets. However, the need for an unexpected early release of the model to the NATO participants forced the use of the facet representation existing at that time. The model facet size used in this program was four, slightly higher than the default value in the software. We believe that it is appropriate to comment here that even if the facet level in the software were set to the highest level (i.e., 10) the facet model would still consist of the same order of magnitude of individual facets. The conversion software discussed here cannot produce a "high resolution" facet model of the ZSU like the one discussed later in this report. The facet size level relates more to the capability of the software to handle geometry intersections and small features in the model. The facet model generated by this software contains listings of the nodes, their interconnections, the normal vector for each facet, and extensive listings of the facets by regions and elements directly referenced to the BRL-CAD file.

Another software package used by our organization—ACAD, developed by the Lockheed Fort Worth Company—can also be employed to read in and convert BRL-CAD representations into facet representations. ACAD, which is supported by the Electromagnetic Code Consortium (EMCC), includes a stand-alone CAD development capability that is an alternative to BRL-CAD for electromagnetic (EM) model development. EMCC is a group of individuals from government, academia, and industry who have been very active in shaping the development of EM analysis software used in high-performance supercomputers over the last decade. Two of the authors are active members of this organization. It is interesting to note that the BRL-CAD converters employed by Xpatch and ACAD are slightly different versions of the TACOM software FRED. The version of FRED included in the Xpatch utility (Cifer) is a formula translator (FORTRAN) programming language implementation with hard-coded limits on array sizes. Cifer could not produce a facet representation of the ZSU model because the number of nodes in the model exceeded the array size limit. However, ECLECTIC, which uses the same basic algorithms as FRED to generate the facet representation as Cifer, was able to convert the entire ZSU model. ECLECTIC is coded in C language and employs dynamic memory allocation for arrays, so the hard-coded limits associated with older FORTRAN versions were avoided.

The ZSU facet model used in this work consists of a flat, triangular facet representation of the exterior structure of the vehicle. The model contains 40,037 nodes and 77,955 facets, with each facet representing metal material. Because of the number of facets and their inconsistent size and uniformity, the model is categorized as a coarse representation. Figures 3(a) through 3(d) show the ZSU facet model as it would appear sighted along the boresight axis of the APG radar. Figures 3(a) and 3(b) depict a depression angle for the radar measurements of 12°, with azimuth angles of 45° and 225°, respectively. Figures 3(c) and 3(d) depict a depression angle of 30°, with azimuth angles of 30° and 260°, respectively. The use of flat, triangular facets to represent curved features on the ZSU model will always result in some "discretization" error. Small facets minimize this error to a large degree, considering the additional approximations inherent in the modeling software. The inconsistent size and uniformity of the facets in the model introduced modeling errors associated with Xpatch software and numerical machine precision, and these are discussed in section 3.

Figure 3. ZSU facet model as it appears to APG radar measurement facility looking down boresight of radar. Configuration shows a 12° depression angle and (a) 45° and (b) 225° azimuth angle.

(a)



(b)

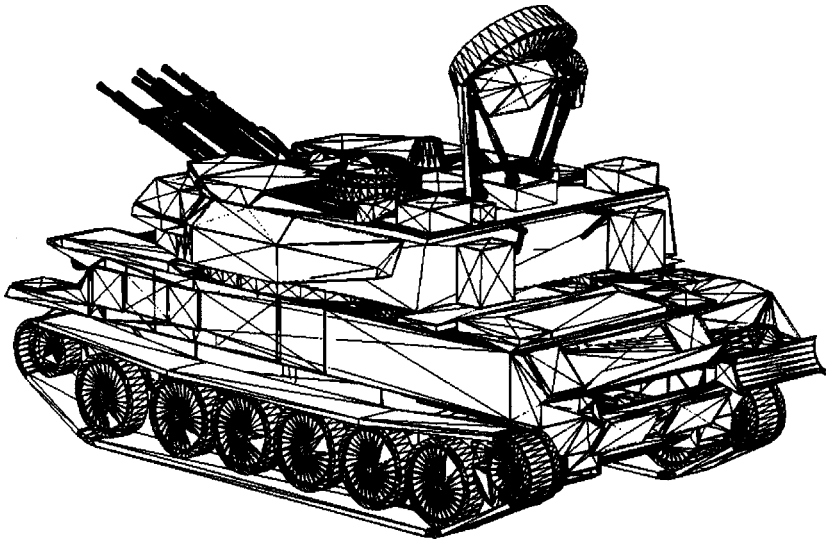
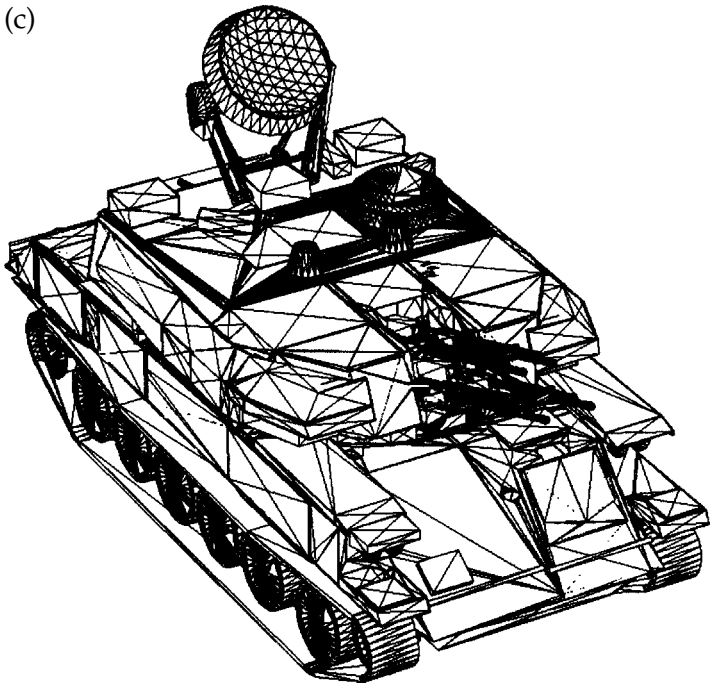
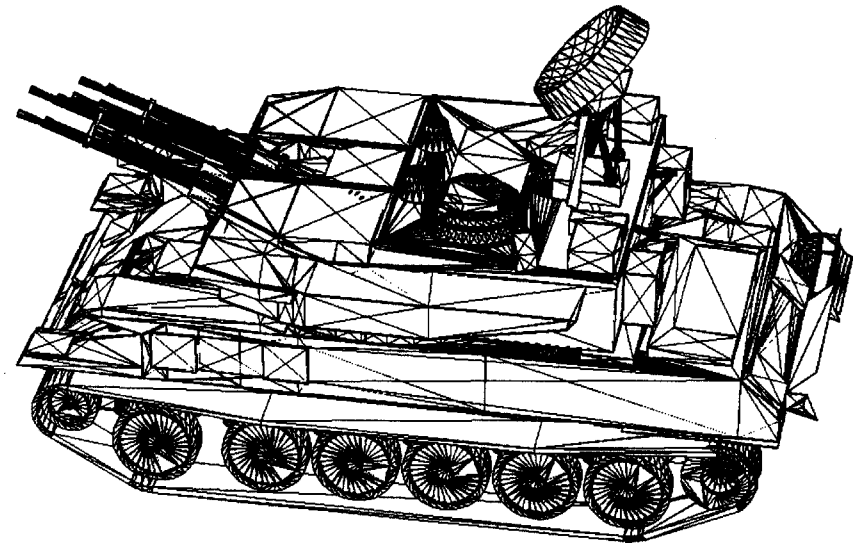


Figure 3 (cont'd). ZSU facet model as it appears to APG radar measurement facility looking down boresight of radar. Configuration shows a 30° depression angle and (c) 30° and (d) 260° azimuth angle.

(c)



(d)



3. Xpatch Software

The first version of Xpatch was developed in 1988 at the University of Illinois in Urbana-Champaign. The code remained largely unused for several years. In late 1991, the code was adopted as a signature computation tool by the Air Force. Xpatch currently enjoys Department of Defense (DoD) support for feature enhancement and distribution under the software development activity that is included in the Defense High Performance Computer Modernization Program. One goal of this activity is the porting of Xpatch software to all parallel computer architectures supported in the program. DEMACO, Inc., and the Center for Computational Electromagnetics at the University of Illinois are responsible for current development of the software. The latest version of the software (version 2.4d, released March 1997) is supported on most SGI and SUN computer platforms.

Xpatch is a high-frequency radar signature prediction code based on the shooting and bouncing ray (SBR) technique. With the SBR technique, a dense grid of rays is shot from the radar toward the target. Rays are traced according to geometrical optics theory as they bounce around within the target. The tracing includes the effects of polarization, ray divergence, and layered material transmission and/or reflection. At the point where the ray exits the target, a physical optics integration is performed to calculate the scattered far field from the target. All single and multiple bounce contributions are included in the geometrical or physical optics (PO) theory. Current versions of Xpatch allow for first-order edge diffraction to be included in the computations. This software consists of three parts: (a) electromagnetics: XpatchF and XpatchT for frequency domain and time domain calculations, (b) CAD and visualization tools, and (c) a graphical user interface (GUI). The code is written in FORTRAN, C, and C++ languages. The EM portion and the ray tracer consist of approximately 0.6 million lines of code, and the tools and GUI account for 0.8 million lines of code. Table 3 describes some of the differences between the two EM domain computations in Xpatch.

The distribution of the Xpatch computer code and its documentation is subject to export control laws. Xpatch is generally available to U.S. government agencies and contractors performing work for the government.

Table 3. Comparison of XpatchF and XpatchT.

Capabilities	XpatchF	XpatchT
Computation domain	Frequency	Time
Target geometry	Facet/IGES/CSG	Facet/IGES/CSG
Coatings/materials	Yes	Approximate
First-bounce	PO/z-buffer/SBR	z-buffer/SBR
Higher-bounce	SBR	SBR
Edge diffraction	Metal	Metal
Best for	RCS/range-profile	SAR/range-profile

The accuracy of Xpatch for RCS calculations depends on many factors; one is the facetization representation of the model. Extremely narrow facets can generate numerical instabilities in the Xpatch ray tracer. The actual criterion used to disqualify a facet is a complex expression in geometrical terms. Facets with very small interior angles (less than 0.002°) and side ratios in excess of 10 to 1 have a good chance of being rejected by the code. A utility in Cifer checks and reports "bad" facets in the facet model. There were three bad facets identified in the current ZSU model. These facets are simply ignored by the code. Any rays that intersect these facets disappear into the interior of the model and are not accounted for in the far-field determinations. The size and locations of the bad facets were such that they were judged to be insignificant for the accuracy of the calculations performed in this work. Other issues related to facetization—such as verification of a closed, connected, continuous outer surface (except for the three bad facets)—were checked with other Cifer utilities.

There are significant concerns about Xpatch software when considerations of verification arise for cases in the higher frequency ranges of 35 and 95 GHz. Xpatch was originally designed for the *X*-band frequency range; hence its name. Although the software is increasingly being used at the higher frequency ranges, a significant body of verified data does not exist to warrant a high confidence level in the results.

The current versions of Xpatch have known limitations that can cause measurable errors if they are not considered in the interpretation of the computer results. For instance, the existence of cavities and large seams in the modeled object cannot be treated in the present versions of the code. Therefore, little confidence can be placed in results at very low depression angles where the wheels/tracks of the vehicle are illuminated and would form a set of large cavities. In addition, there is no present capability to consider the effects of surface roughness on the vehicle. Finally, while there is a provision to incorporate material properties in Xpatch as part of the model, layered materials and uncertainty in material properties require experience in the interpretation of Xpatch data.

4. Computer Resources

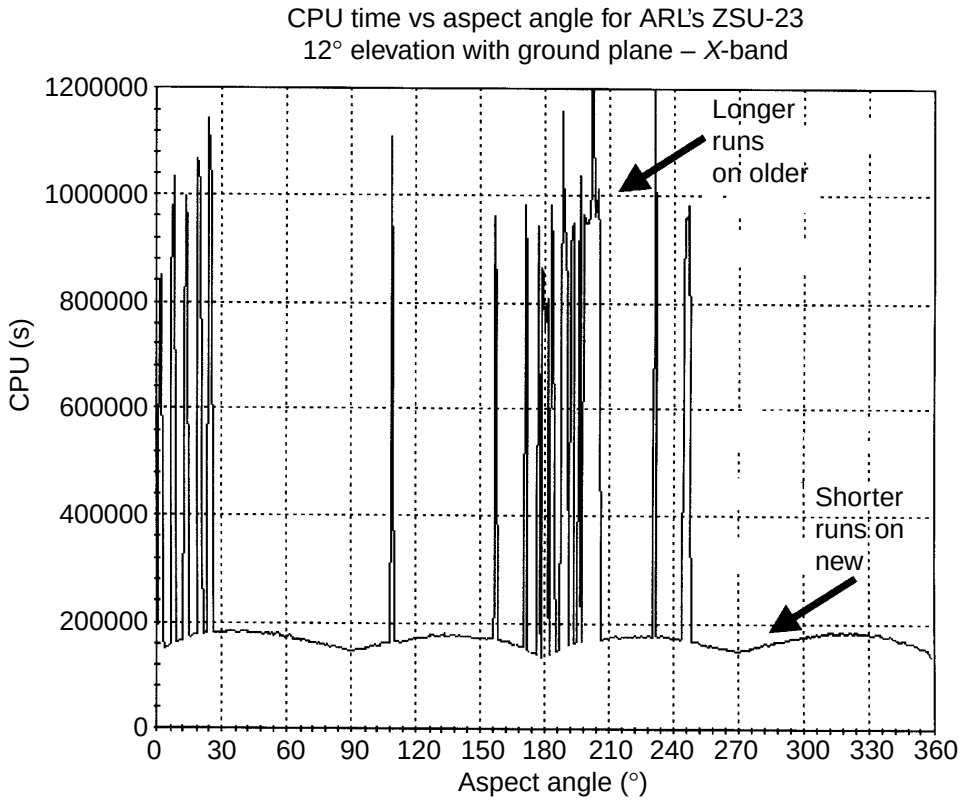
The Xpatch computations using the ZSU model were performed on the high-performance computers at the Missile and Space Intelligence Center (MSIC) of the Defense Intelligence Agency (DIA) at Redstone Arsenal in Alabama. MSIC has the mission for the intelligence community of computing, storing, cataloging, and disseminating radar signature data on foreign assets. It has an extensive database of RCS measurements and validation data obtained with state-of-the-art RCS calculation software. MSIC is the leader in the development of high-fidelity CAD model representations of assets, employing proprietary digital three-dimensional (3-D) laser scanning tools to generate CAD models of targets. MSIC's high-performance computer system is the largest computer system in the intelligence community. The system has logged more than 115 years of central processing unit (CPU) hours for radar signatures. The CPU hours needed to perform the ZSU computations that were completed are presented in table 4.

The amount of time is determined in large part by the type of computer system on which the model runs. On the networked computers at MSIC, any particular computation shown in table 4 would have been distributed to different platforms depending on the current machine loads. Figure 4 shows an example of the variation in the computational times involved on the different platforms for a 12° depression angle, with ground plane, run at *X*-band. The computation at K_a-band, with a 30° depression angle including the ground plane had not begun to run at the time that these data were generated. It is estimated, based on the previous runs, that this computation will take about 84 days to complete and use more than double the CPU hours required for the similar computation with the 12° depression angle.

Table 4. CPU hours for ZSU computations.

Condition	Without ground plane	With ground plane
12° depression angle		
X-band	296	1,339
K_a-band	5,737	25,046
30° depression angle		
X-band	233	2,620
K_a-band	6,661	(Not completed)
Totals	12,927	29,005

Figure 4. Example of variation in run times for one type of computation at MSIC.



5. Data Format and Analysis

The computed data (monostatic RCS as a function of frequency and angle) were received from MSIC on 4-mm digital audio tapes separated according to each computation that was completed. The computer runs were divided into eight groups corresponding to frequency range (*X*-band and K_a-band), depression angle (12° and 30°), and whether or not a ground plane was present. Each group was divided into 360 files, with each file containing the data for one azimuth angle. All the data were in compressed ASCII format. Each *X*-band group contained 84 MB in compressed format, which expanded to 920 MB when uncompressed. Each K_a-band group contained 280 MB in compressed format, which expanded to 3.1 GB when uncompressed. Seven of the eight groups were completed and delivered to ARL. As mentioned above, the K_a-band computations at 30° depression angle including the ground plane had not begun to run at the time that the rest of these data were provided to ARL.

All the computed Xpatch data were converted into the data format of the ARL-APG radar measurement system (raw) data. This would allow the calculated data to be processed in precisely the same manner as the measured data. This also would provide for a direct one-to-one comparison between measured and computed results. This direct comparison will extend to the format of the data output plots and ISAR image presentations/movies since the signal/data processing software will be the same for both measured and computed data. This common processing software includes the data analysis tools developed and verified over the years at a production radar measurement facility. Further, all the standard statistical parameters used to characterize the measurement data are automatically available in the software and can be applied to the computed data. At APG, a standard format is used for all RCS polar plots, allowing the computed ZSU data to be directly compared against data from other vehicles measured at the APG facility.

While the benefits to this data conversion were evident, there were still challenges to implementing it. The least of these involved the actual data conversion. The ARL-APG radar data set consists of an ASCII header portion that describes the specifics of the measurement conditions. An ASCII data block follows with specifics on the data format. Finally, arrays of 2-byte integers containing the real and imaginary parts (I, Q values) of the calculated fields as a function of frequency and angle for each measurement channel complete the data set. The only interesting feature that occurred here involved the requirement to write the 2-byte integer values in the reverse of the “normal” byte order on most systems.

Modern radars include a complex signal-processing pipeline that acts on the raw data to account for many factors (including channel imbalance, image rejection, clutter elimination, etc). This signal-processing pipeline at APG uses a set of five reference/calibration files that “correct” the raw data based on reference measurements and calibration factors. The converted, computer-generated Xpatch data must flow down this signal-processing pipeline when they are processed by the APG radar

software. Xpatch data are "perfect" since all the above corrections to the APG measurement data are not necessary, with the exception of scaling the computer data to the final magnitude. The challenge was to generate five reference/calibration files that approximate a perfect radar system by not altering the computer data (scaling the exception). Fortunately, with expertise from H. Bruce Wallace (one of the authors, as well as the system designer and software developer), the needed reference/calibration files were developed. At present, there is still a slight discrepancy (a factor of the square root of two—too small) in the magnitude of the cross polarization channels that was not corrected by the reference/calibration files. This discrepancy does not substantially affect the data comparisons presented in section 6.

6. Data Comparisons

To present an introduction to comparisons of the measured and computed data, we decided to focus on an interesting feature that was noticed in the computer-generated data but that was missing from the corresponding measured data, yet that appeared in related measured data at a different frequency. We will also present a comparison of the data obtainable from a high-fidelity, high-resolution facet model of the ZSU (developed for another program) to indicate why such models are of great utility for RCS calculations.

Figures 5 through 7 show comparisons between Xpatch data and the corresponding APG measured data. The data presented in these figures are the average over the frequency of the RCS values (in dBsm) plotted at every 0.5° in azimuth. The data were generated by software used at APG, with the same processing conditions applied for the computed and measured data values. While the details in any individual figure could change slightly if all (or a different part of) the azimuth values in the data set were used, the comparison is still quite good since both the measurement data and computer data are processed in exactly the same manner.

Figure 5 presents the comparisons of measured and computed data at *X*-band for a 30° depression angle, representing the cross-polarized component of electric field and the vertical transmit and horizontal receive conditions. Notice the peak in the Xpatch data at about 290° in azimuth and the absence of a corresponding peak in the APG data. The comparison between the two data plots is poor—mainly because the Xpatch results were taken from the calculations of the ZSU **without** a ground plane (i.e., as if the vehicle were floating in free space).

Consider figure 6, which shows the same conditions as above, but where the Xpatch data were computed **with** the vehicle on a metal ground plane. There is a significantly better agreement of the computed data with the measurement data. Thus, we can infer that the earth response is a very important contribution to the RCS for ground vehicles. It is also interesting that the comparison is so good, considering that the measurements include the response from an "earth" ground, while the computed data involve a metal plane. In addition, the cross-polarization Xpatch data are slightly lower in amplitude for all azimuth angles because our data analysis approach is not finalized. For reference, the size of the ground plane used by Xpatch is approximately 10 times greater than the size of the largest dimension of the modeled object (a general "rule of thumb" requirement).

Figure 7 shows measurement conditions identical to the previous two figures with the exception that the center frequency of interest here is at K_a-band. We note that the APG measurement data show a peak response near 290° azimuth that did not appear at *X*-band. The Xpatch data in figure 7 are for the case **without** a ground plane, which again accounts for the poor agreement between the two plots. Unfortunately, the computation with the ground plane and at this depression angle had not yet been run.

Figure 5. Comparison of Xpatch and APG RCS data for ZSU measurement at *X*-band, 30° depression angle, cross-polarized field components (vertical transmit, horizontal receive). Xpatch results are for a vehicle without a ground plane.

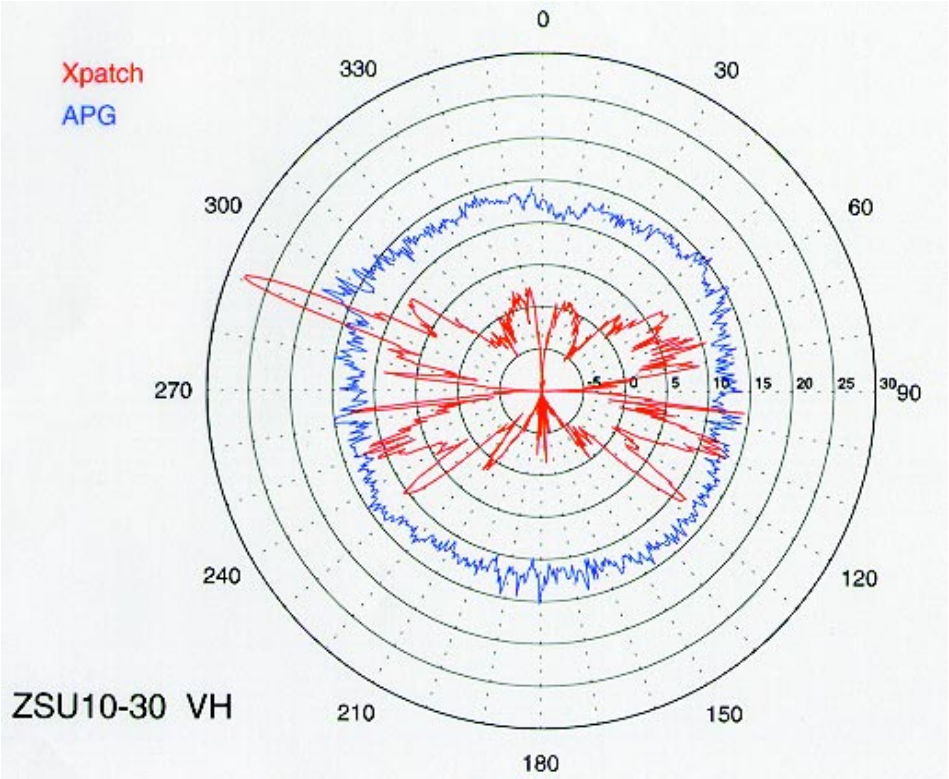
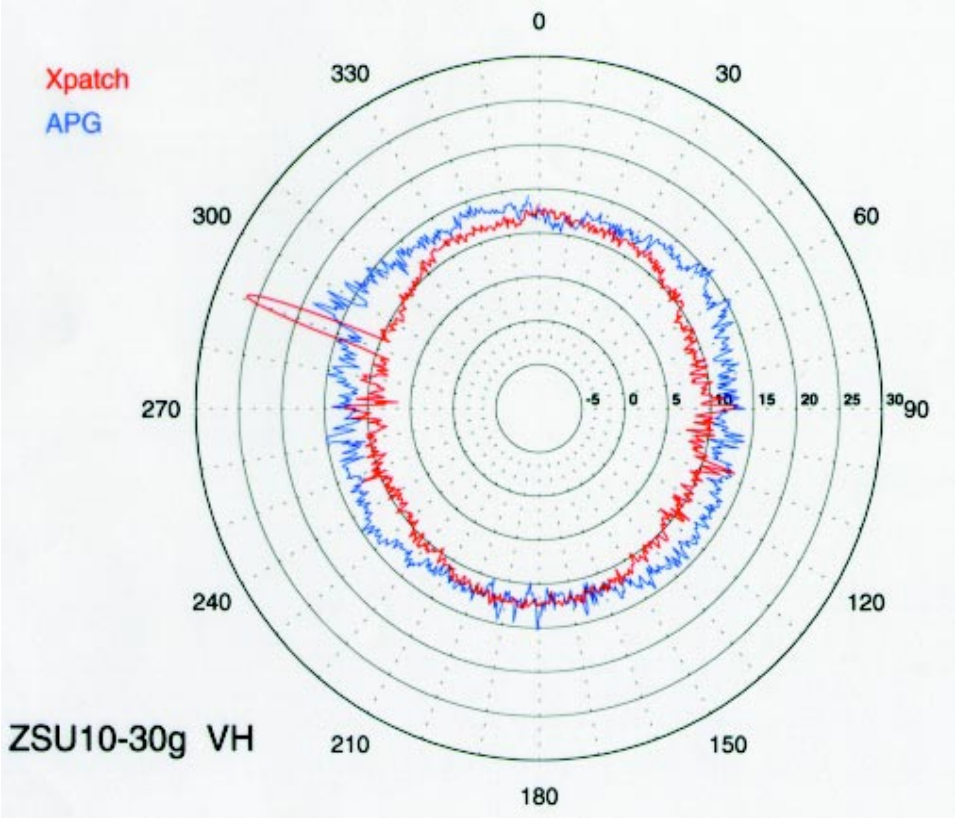


Figure 6. Comparison of Xpatch and APG RCS data for ZSU measurement at *X*-band, 30° depression angle, cross-polarized field components (vertical transmit, horizontal receive). Xpatch results are for a vehicle with a ground plane.



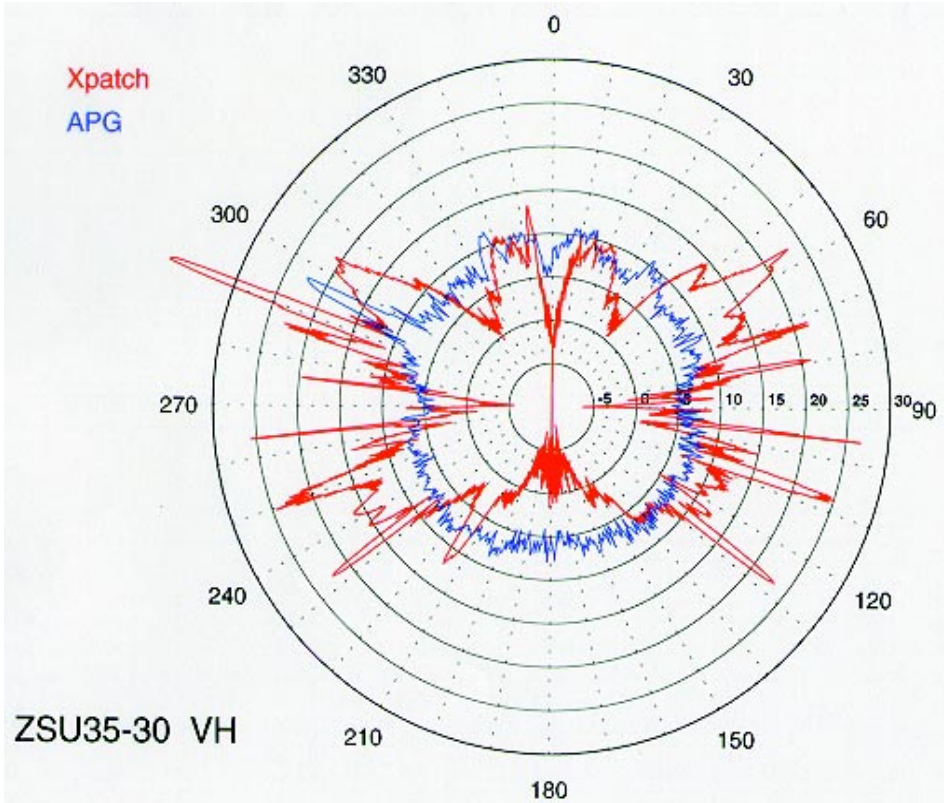
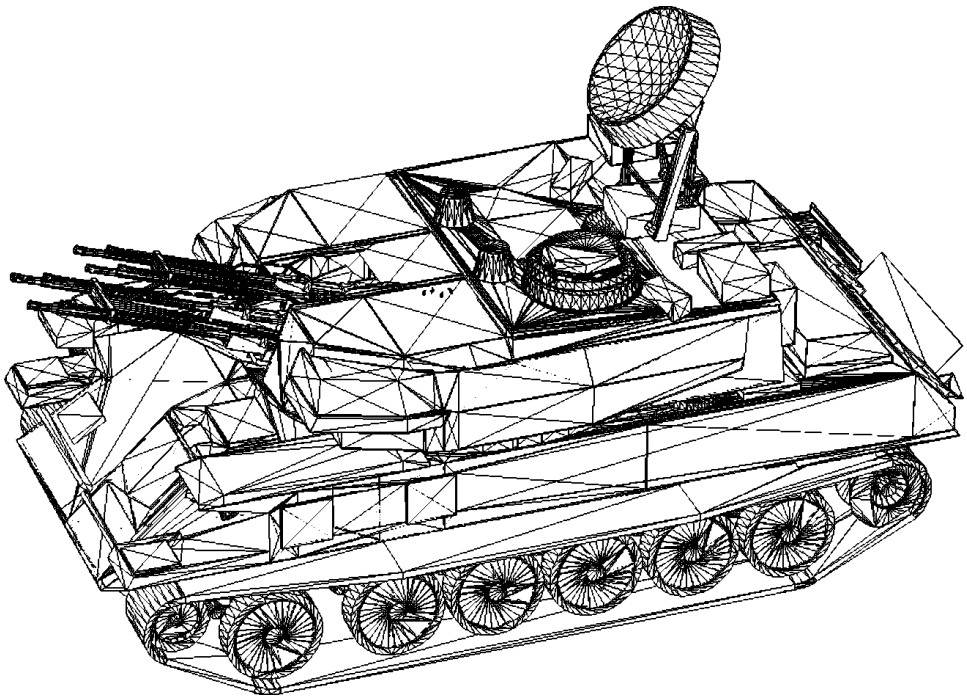


Figure 7. Comparison of Xpatch and APG RCS data for ZSU measurement at K_a-band, 30° depression angle, cross-polarized field components (vertical transmit, horizontal receive). Xpatch results are for a vehicle without a ground plane.

The actual feature on the vehicle that is responsible for the prominent peak value in the RCS data appears to be related to the indentation on the front left side of the vehicle (see fig. 8). To confirm this suspicion, one could look at the ISAR image data for this case (near 290° azimuth angle), or look further at the RCS polar plot data under circular polarization conditions. This type of analysis is planned for our more complete future report on the ZSU computed versus measured data comparisons.

The previous data were generated from a facet model with approximately 80,000 facets. For a vehicle of the size and complexity of the ZSU, this facet model is considered coarse. The visual representation of the model shows many abutting planes, poor representation of curved surfaces, and absence of "small" details. At *X*-band, coarse models have been considered adequate based on comparisons with measurements and code limitations. At K_a-band, or especially at *W*-band, the predictions from coarse resolution facet models become more suspect. Theory indicates that the lack of sufficient details in the model at these higher frequencies will affect the predictive results. The degree of error at these higher frequencies is strongly model-dependent (or geometry-dependent) and also related to code limitations (such as edge diffraction) that play a role even at *X*-band. High-fidelity CAD models, with a factor of 10 or more greater numbers of facets than the ZSU model, are becoming more common for RCS prediction. The geometric representation of detail is much greater, bad facets are absent, and the model appears much more visually realistic (see fig. 9). Experience with high-fidelity models shows that they can yield significantly better results not only at high frequencies where

Figure 8. Facet model of the ZSU at 30° depression angle and 290° in azimuth angle.

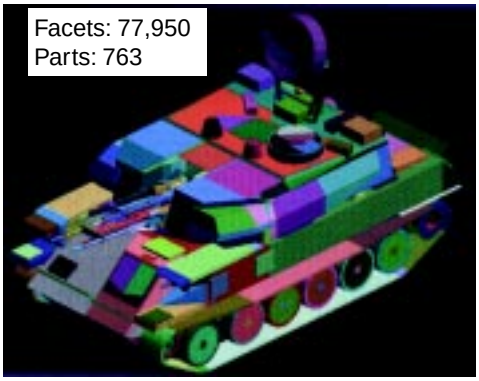


sufficient detail is needed, but also at *X*-band. Consider the SAR image comparison presented in figure 10 for the ZSU model used in the NATO research study group versus the high-fidelity model of the ZSU generated for another program. The SAR image from the high-fidelity model provides a better representation. Another measure of model performance that better highlights the results from a comparison of the two levels of model resolution is shown in figure 11. This figure indicates that the high-fidelity model provides a greater feature recognition capability from RCS radar data, to the degree that it becomes possible to separate and distinguish between different vehicles from Xpatch data sets. In the current model, the ZSU could be distinguished from similar vehicles using Xpatch data at only one azimuth angle (0°) over the 360° range. Using the high-fidelity model, the ZSU could be distinguished from other similar vehicles at over 25 different azimuth angles.

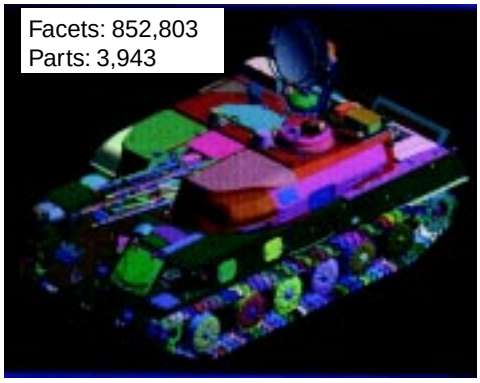
High-fidelity models do produce better results, but these come at a price. The development of these models from CAD packages takes longer and requires significantly greater resources than for low-fidelity models. The high-fidelity facet model of the ZSU took over 3 months to develop starting from the same CAD description as the coarse model. In addition, the computational resources and the time required to run these models are greatly extended (quantitative data on the ZSU high-fidelity model are not yet available). The modeler must decide when the information required from the model warrants the additional investment of time and resources to pursue the high-fidelity approach.

Figure 9. Comparison of (a) current ZSU facet model with (b) high-fidelity facet model.

ZSU-23 virtual target models



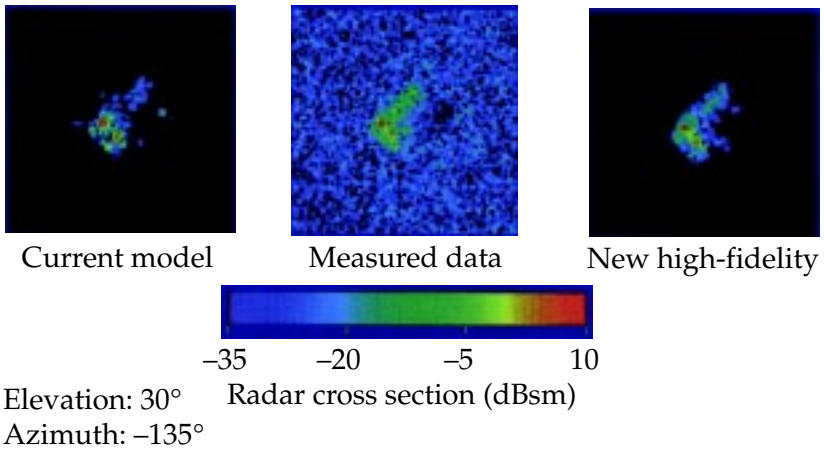
Current model



New geometrically exploited high-fidelity model

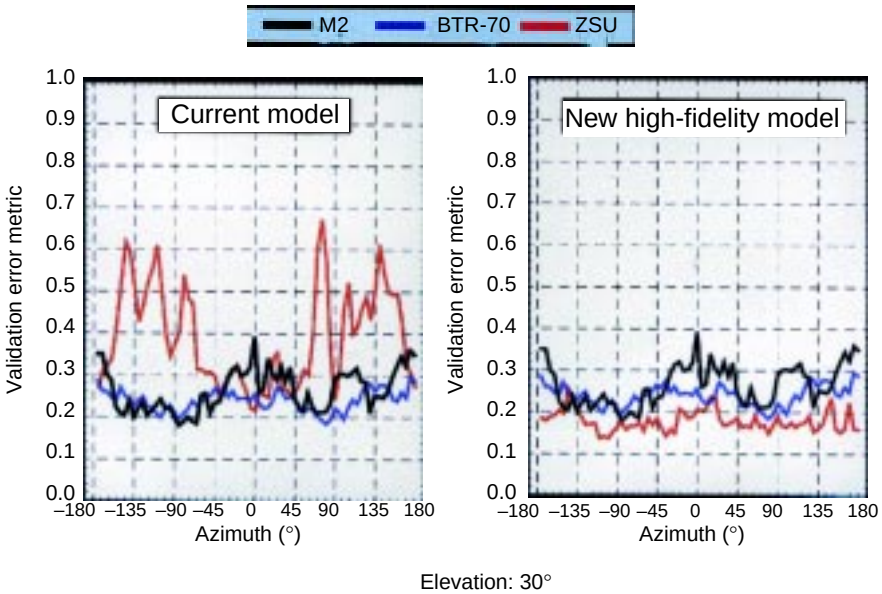
Source: Missile and Space Intelligence Center.

Figure 10. ISAR data comparisons between coarse resolution ZSU model and high-fidelity ZSU model.



Source: Missile and Space Intelligence Center.

Figure 11. Value of using high-fidelity models, even at *X*-band.



Source: Missile and Space Intelligence Center.

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U.S. Army Research Laboratory
Attn: AMSRL-SE-RE email: rchase@arl.mil
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13. ABSTRACT *(Maximum 200 words)*

A computer geometry model of the ZSU-23-4 (a quad 23-mm self-propelled antiaircraft gun) was obtained in Ballistic Research Laboratory-Computer Aided Design (BRL-CAD), a combinatorial solid geometry-based modeling system. The BRL-CAD file served as input to a software package (ECLECTIC) that generated a flat, triangular, all-metal facet representation of the ZSU exterior structure, containing approximately 78,000 facets. The facet model served as input to Xpatch, a high-frequency signature prediction code based on the shooting and bouncing ray (SBR) technique. Xpatch was run at the Defense Intelligence Agency, High Performance Computing Center with several Silicon Graphics, Inc. (SGI), Origin, Onyx, and Challenge machines that used 426 CPUs and 60 Gflops of computing power. The configuration parameters for the ZSU model, both with and without a perfect metal ground plane, included two depression angles (12° and 30°), both polarizations, 256 frequencies (about each center frequency), and azimuth steps of 0.05° (for *X*-band) and 0.015° (for K_a-band). The configuration parameters were selected based on measurement data taken on a ZSU vehicle at the U.S. Army Research Laboratory Aberdeen Proving Ground test facility. The model predictions will include radar cross-section data as a function of polarization and angle and synthetic aperture radar images. This report details the preliminary results from the computer modeling.

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