A summary of the development and verifications of a computer code, RECOTA (return from complex target), developed at Boeing Aerospace for calculating the radar cross section of complex targets is presented. The code utilizes a computer-aided design package for modeling target geometry in terms of facets and wedges. It is based on physical optics, physical theory of diffraction, ray tracing, and semiempirical formulations, and it accounts for shadowing, multiple scattering, and discontinuities for monostatic calculations.

I. INTRODUCTION

The calculation of a radar cross section (RCS) for complex targets involves the following:

1) Target modeling where the geometry of the target's exterior surfaces, ducts, wedges, apertures, discontinuities, and so on, is described in terms of mathematical models.

2) The computation of scattered electromagnetic fields which arise from different mechanisms, such as specular reflection, diffraction, and multiple scattering. For the same target, the contribution of each of these mechanisms varies greatly with the scattering configuration, frequency, polarization, and so on. The RCS designer should be aware of these scattering mechanisms and their sources and should know how to estimate and control their effects accurately.

The objective of this paper is not to present a literature review [1], [2, pp. 539–670], [3], nor to report well-known mathematical formulations, but rather to show how the current available formulations may be utilized to provide an effective computational tool to aid in the analysis and design of complex targets from the RCS point of view. For illustration purposes, we limit our presentation to the monostatic case for perfectly conducting bodies. The publication of dielectric surfaces, various second-order scattering effects, and bistatic calculation will follow in a future paper upon completion of the ongoing verification effort.

II. TARGET MODELING

A variety of hand-generated geometry techniques have been used for modeling the geometry of complex targets. Although these techniques may vary in their degree of complexity and modeling time, all share the common limitation of geometric approximation. As an illustration, consider the following two techniques:

1) Body of revolution technique. This technique is limited to simply shaped targets whose surfaces are made up of, or approximated as, bodies of revolution. Thus when using this technique for RCS analysis one is faced with a serious limitation in model application, and, if more generally applied, the calculated RCS does not necessarily represent the true target.

2) Method of components technique using primitives. This technique is, generally speaking, time consuming and applicable to electrically large bodies, that is, \( kL \gg 1.0 \), where \( k = 2\pi/\lambda \) is the wavenumber and \( L \) the maximum dimension of the body. In this technique the designer can break the complex target into a set of components. The shape of each component is then approximated to match the geometry of one of the primitives, such as cone, cylinder, or flat plate, that is allowed by the designer RCS code, and the target's RCS is calculated accordingly. Obviously this technique provides more flexibility than the body of revolution technique. It still produces only a coarse estimate of the RCS. This is due to the inherent approximations in modeling target components and their phase relations, and to the neglect (or very limited capability) of shadowing, multiple scattering, and so on.

To overcome the aforementioned difficulties, a computer-aided design (CAD) package [4], [5] was used for modeling target geometry. In this case the target is described in terms of facets and wedges, where a collection of these form a surface and a collection of surfaces form an object. We refer to this technique as method of components technique using facets and wedges. Depending on the designer objectives, the object may represent the target itself, or one of its components or subcomponents. It provides the following capabilities:

1) No limitation on target geometry
2) No limitation on the shape of its components
3) Flexibility in changing the shape of a target
4) Better account for phase calculations since phases are considered at the facet level rather than at the component level
5) Detailed multiple scattering can be performed
6) Straightforward approach in accounting for shadowing
7) Dielectric materials may be applied to any surface of the target
8) Discontinuities may be assigned at any location on the target surface.

One should recognize, however, the potential limitation of the faceting approach where a large number of facets might be required which may exceed declared array sizes or which can lead to longer computer run times. This should not detract from using the code, but it may limit its use in some complex targets to the study of its components separately. This is not a significant limitation in preliminary design trade studies, but it does force the user to plan the analysis carefully.

As an illustration of these geometry modeling techniques, let us consider the nose section of a missile, as shown in Fig. 1(a). Its geometry is approximated as shown in Fig. 1(b) and (c), when body of revolution and method of components (using primitives) techniques are used, and is almost exactly duplicated by facets and wedges as shown in Fig. 1(d) when a CAD technique is used. The impact of these geometric approximations on the RCS calculations is illustrated in Fig. 2.

![Fig. 1. Example of target modeling approximation by different codes. (a) Original drawing. (b) Axisymmetric code. (c) Method of components code (primitive components). (d) RECOTA code, method of components (facets and wedges).](image)

III. SCATTERING CALCULATIONS

Selecting an appropriate scattering method depends on the main objective behind the scattering calculations, the computing equipment, the geometry of the target, its electrical length, and its conductivity. This paper deals with RCS analysis where it is implicitly assumed that the radar frequency is high enough such that the corresponding wavelength is small compared to the physical dimensions of the scattering body. Therefore we use the term complex body to imply also a body with large electric dimensions. Thus the scattering calculations are in the high-frequency region. Due to the difficulties associated with geometrical optics for flat plates and singly curved surfaces (recall that the straightforward application of geometrical optics leads to an infinite RCS for a flat plate) and due to the poor rate of convergence of the moment method when applied to electrically large bodies (in addition to its requirement for a large computer), it is only logical to use the physical optics method. On the other hand, the accuracy of physical optics calculations for a flat plate disintegrates as the scattering direction moves away from the specular direction (recall that the straightforward application of geometrical optics leads to an infinite RCS for a flat plate) and due to the poor rate of convergence of the moment method when applied to electrically large bodies (in addition to its requirement for a large computer), it is only logical to use the physical optics method. On the other hand, the accuracy of physical optics calculations for a flat plate disintegrates as the scattering direction moves away from the specular direction [2, p. 513], [6], [7]. Ulmstev [8] stated that the physical optics prediction for a flat plate is improved by adding nonuniform current, due to a flat plate’s edges, to the uniform current produced by its surface. This is regarded as the basis for the physical theory of diffraction. We included this correction in our calculations by accounting for the currents that are induced on facet’s free edges and on wedges that are formed between neighboring facets. Thus, the first-order term for the overall scattered field from a complex body may be written as

\[
\text{total scattered field} = \text{scattered fields from facets} + \text{scattered fields from wedges}.
\]

When calculating these fields one may proceed by using magnetic or electric field integral equation formulations. The following calculations are presented in terms of electric field formulations, where the time-dependent term \( e^{-i\omega t} \) has been suppressed for simplicity.

A. Facet Scattering

The scattered electric field from an arbitrary facet is based on the following form for the electric field integral equation [9, pp. 464–470]:

\[
\vec{E}(x, y, z) = \frac{1}{4\pi} \int_{s_1} \left[ \mu_0 \mu_r \left( \vec{A} \times \vec{H} \right) \phi + \left( \vec{n} \times \vec{E} \right) \times \nabla \phi \right] \cdot \vec{n} \, da' \tag{1}
\]

where \( \vec{E}(x, y, z) \) is the total electric field at an interior point in a source-free region (i.e., no charge or current within its interior) bounded by a closed surface \( s \) which may extend to infinity, \( \vec{E} \) and \( \vec{H} \) are the fields that are just inside the surface \( s \), and \( \vec{n} \) is the inward surface unit normal. Also,

\[
\Phi = e^{i\vec{r}' \cdot \vec{r} / \vec{r}' \cdot \vec{r}} \tag{2}
\]

is the free-space Green’s function. Here \( \vec{r} \) and \( \vec{r}' \) represent the position vectors for the observation point and the incremental area \( da' \), respectively.

By interchanging the source-free region and the outer region, the direction of \( \vec{n} \) is reversed and thus represents the outward unit normal for the surface \( s \).

If the surface \( s \) is assumed to be composed of two surfaces \( s_1 \) and \( s_2 \) separated by a closed contour \( C \) such that \( s_2 \) surrounds \( s_1 \), and both surfaces have the same electric...
properties, then the integration in Eq. (1) may be carried out over both surfaces without any additional terms. If, however, surface $s_1$ is assumed to represent a conducting surface of a facet, while surface $s_2$ represents free space, then an additional term ought to be added to Eq. (1) in order to correct for the discontinuity in the tangent components of $\vec{E}$ and $\vec{H}$ when passing across $C$ from $s_2$ to $s_1$. (This term has been introduced by Kottler [10] and represents a line distribution of current about the closed contour $C$.) Therefore, by applying the proper boundary conditions at both surfaces, applying physical optics approximations $(\vec{n} \times \vec{H}_{\text{total}} = 2 \vec{n} \times \vec{H}_{\text{incident}})$ over $s_1$, and applying the far-field approximation, that is, the observation point is located far enough from the scattering object such that $|\vec{r} - \vec{r}'| \gg D$, $D$ being the maximum dimension of the illuminated region, Eq. (1) is reduced to the following expression for the received scattered field:

$$
\vec{\rho}_s \cdot \vec{E}_s = \left( \frac{ik}{4\pi} \right) \sum_{n=1}^{N} \left[ \vec{P}_e \cdot [\vec{n} \times \vec{h}_i] + (\vec{n} \times \vec{e}_i) \times \vec{k}_i \right] \cdot \left\{ \int_{\sigma} e^{ik\vec{n} \cdot \vec{r}} \cdot e^{-ik\vec{k}_i \cdot \vec{r}} \, d\sigma \right\} e^{ik\vec{n} \cdot \vec{r}} \tag{3}
$$

where $\vec{E}_s$, $\vec{H}_i$, and $\phi$ were replaced by

$$
\vec{E}_s = [\vec{E}_s | \vec{E}_s | e^{ik\vec{n} \cdot \vec{r}}] \tag{4}
$$

$$
\vec{H}_i = [\vec{H}_i | \vec{h}_i | e^{ik\vec{k}_i \cdot \vec{r}}] \tag{5}
$$

$$
\lim_{r \to \infty} \phi = \frac{e^{ik\vec{n} \cdot \vec{r}}}{r} e^{-ik\vec{k}_i \cdot \vec{r}} \tag{6}
$$

and we also used the following notation:

- $\vec{E}_s$ = scattered field due to the facet's surface
- $\vec{P}_e$ = polarization unit vector for receiver electric field
- $k = 2\pi$/wavelength of incident radiation
- $\vec{n}$ = outward unit normal to the facet's surface
- $\vec{h}_i$, $\vec{k}_i$ = polarization unit vectors for incident electric and magnetic fields
- $\vec{k}_i$, $\vec{k}_i$ = incident and scattered propagation unit vectors.

Also $e^{ik\vec{n} \cdot \vec{r}}$ is a phase term that has been introduced into the equation in order to account for the facet location with respect to the global coordinate system. Here $\vec{R}$ is the position vector for the facet's reference vertex with respect to the global coordinate system.

The integral in Eq. (3) is calculated following Gordon's method [11]. Equation (3) is then calculated for every illuminated facet, and the RCS due to scattering from $N$ illuminated facets is thus

$$
\sigma = 4\pi \lim_{r \to \infty} \sum_{n=1}^{N} \left[ \vec{P}_e \cdot [\vec{n} \times \vec{h}_i] \right]^2 \left| \vec{E}_s \right|^2. \tag{7}
$$

### B. Wedge Scattering

Upon examining a faceted model for a solid object one should distinguish between two types of wedges, 1) real, that is, wedges that are intentionally modeled in accordance with a blueprint specification, and 2) artificial, that is, those that are generated as a result of faceting the solid object. Inner angles for the artificial wedges depend on the radius of curvature in a plane normal to the axes of these wedges and on the faceting resolution. Therefore, the same solid object might have different sets of artificial wedges depending on the selected degree of resolution. This variation in inner angles of those wedges is somewhat compensated by the corresponding variation in the direction of the unit normals of associated facets. The RCS contribution from these wedges is added to the contributions from the facets. This is because of the applied technique in using both physical optics for calculating the scattered field from the facets (due to the uniform current) and the physical theory of diffraction for calculating the scattered fields from the wedges (due to the nonuniform current). Therefore, inclusion of returns from these wedges in the overall return is an important process, and one should be aware of their magnitude. Thus whether the wedges are real or artificial, their contribution is calculated using the physical theory of diffraction and the equivalent edge currents concept. This approach has been investigated by many authors. Detailed accounts of their work is beyond the scope of this paper. However, the main formulations are presented. For detailed derivations, the interested reader may refer to [12]-[16], for example. The underlying assumption for this calculation is that electromagnetic scattering from a wedge is expressed as the sum of two terms; 1) scattering from the wedge's surfaces which have been calculated in the previous section, and 2) scattering from the wedge's apex which is calculated by assuming that the wedge's apex may be replaced by filamentary electric and magnetic line source currents, which are defined in [16] for the monostatic case as

$$
\vec{I}_e = -\frac{2\pi i (\vec{r} - \vec{r}')}{2kZ} \tag{8}
$$

$$
\vec{I}_m = -\frac{2\pi i (\vec{r} - \vec{r}')}{2kZ} \tag{9}
$$

where $\vec{e}$, $\vec{h}$, are defined by (4) and (5), $\vec{l}$ is a unit tangent along the wedge's apex, and

$$
\beta = \cos^{-1} (\vec{k}_i \cdot \vec{l}). \tag{10}
$$

$Z$ and $Y$ are the free-space impedance and admittance, respectively, and $f'$ and $g'$ are the diffraction coefficients for monostatic scattering. They are defined as follows.

**Bottom face is illuminated, $\pi \leq \gamma \leq \pi$:**

$$
\begin{align*}
f' &= x - y - \frac{1}{2} \tan (\gamma - \delta) \\
g' &= x + y + \frac{1}{2} \tan (\gamma - \delta)
\end{align*} \tag{10a}
$$

**Top face is illuminated, $0 \leq \delta \leq \gamma - \pi$:**

$$
\begin{align*}
f' &= x - y - \frac{1}{2} \tan \delta \\
g' &= x + y + \frac{1}{2} \tan \delta
\end{align*} \tag{10b}
$$

Both faces are illuminated, $\gamma - \pi \leq \delta \leq \pi$:  

$$
\begin{align*}
f' &= x - y - \frac{1}{2} \tan [\delta + \tan (\gamma - \delta)] \\
g' &= x + y + \frac{1}{2} \tan [\delta + \tan (\gamma - \delta)]
\end{align*} \tag{10c}
$$
where

\[ x = \frac{1}{n} \sin \left( \frac{\pi}{n} \right) \cos \left( \frac{\pi}{n} - 1 \right) \]

\[ y = \frac{1}{n} \sin \left( \frac{\pi}{n} \right) \cos \left( \frac{\pi}{n} - \cos \left( \frac{20}{n} \right) \right) \]

\[ \delta \] is the angle between \( \hat{k} \), and the wedge's top surface and is measured in a plane normal to the wedge length, \( \gamma \) is the wedge's exterior angle, and \( n = \gamma / \pi \).

The scattered field is thus expressed in terms of the corresponding Hertzian electric and magnetic vector potentials \( \mathbf{\Xi}_e \) and \( \mathbf{\Xi}_m \) [9, p. 394]

\[ \mathbf{\Xi}_e = \nabla \times \nabla \times \mathbf{\Xi}_e + jkZ \nabla \times \mathbf{\Xi}_m \]

\[ \mathbf{\Xi}_m = \frac{1}{jk} \int \mathbf{\Phi} \, dl' \]

where \( \mathbf{\Phi} \) being the free-space Green's function.

Now let us consider a straight-line wedge with length \( L \). For an incident plane wave, Eqs. (4) and (5), one may assume no phase variation over the entire length of the wedge, and \( \mathbf{\Xi}_e \) and \( \mathbf{\Xi}_m \) are constant over the wedge length. Hence by ignoring end effects, the contour integrations in (12) and (13) may be replaced by linear integrations over \( L \). Substituting (12) and (13) into (11) and applying the far-field approximation leads to the following expression for the received scattered field:

\[ \mathbf{\rho}_e \cdot \mathbf{\Xi}_m = \frac{L}{2\pi} e^{j\lambda r} |\mathbf{\Xi}_e| \sin^2 \beta \]

\[ \cdot \sin (kL \cos \beta) e^{j\lambda r} \]

\[ kL \cos \beta \]

where \( \mathbf{\Xi}_m \) is the wedge scattered field, \( \mathbf{\rho}_e \) and \( \mathbf{\rho}_m \) are the polarization unit vectors for the scattered electric and magnetic fields, \( \mathbf{\rho}_e = \mathbf{\rho}_m \) and \( \mathbf{R} \) is the position vector from the origin of the global coordinate system to the center of the wedge.

RCS for \( M \) illuminated wedges is defined in the same way as in Eq. (7). Therefore, the overall RCS for the complex body, assuming only first-order terms, is

\[ \sigma = \frac{4\pi \lim_{r \to \infty} \left| \sum_{n=1}^{N} (\mathbf{\rho}_e \cdot \mathbf{\Xi}_n) + \sum_{m=1}^{M} (\mathbf{\rho}_m \cdot \mathbf{\Xi}_m) \right|^2}{|\mathbf{\Xi}_e|^2} \]

C. Shadow Region Calculation

The shadow region calculation is composed of two parts, the self-shadowing of each object and the shadowing of one component by another. The term "object" as used here may refer to a component or to the target itself. The self-shadowing calculation identifies facets and wedges of an object which are shadowed by other facets of the same object. The component/component shadow calculation identifies facets or wedges of one component that are shadowed by facets of all other components.

The computational procedure for either case starts by assigning an illumination flag to each facet of the object if the unit normal to that facet satisfies the condition \( \hat{n} \cdot \hat{k} < 0.0 \), where \( \hat{n} \) is the facet outward unit normal (i.e., it is pointing to the outside of the scattering object) and \( \hat{k} \) is the radar incident line of sight. Next, each illuminated facet is projected onto a plane which is determined by the radar line of sight. Thus the complex geometry of the object is replaced by two-dimensional regions over the projection plane, where zones of intersections among those regions are identified, and the order of their overlapping is determined. Finally, the illumination flag for each facet or wedge whose center of mass is within any of these zones and which are covered by at least one zone is turned off, thus eliminating the contributions of these facets or wedges to the total scattered field. The resolution of the shadow region calculation increases as the number of facets increases and as the aspect ratio for each facet decreases. The mathematical formulation for this shadowing calculation is based on geometric optics, hence the partial illumination of facets that lie in the transition regions (regions due to diffractions around curved surfaces) is not accounted for.

D. Multiple Scattering

Calculating the contributions of multiple scattering to the RCS of a complex body is a formidable task. However, describing the complexity in terms of facets and wedges significantly reduces the problem. The multiple scattering contribution is primarily expressed in terms of facet-facet, wedge-wedge, and facet-wedge interactions. To simplify and speed up the calculations, we have limited the calculation to facet-facet interactions. The algorithm for this case is composed of three major steps.

First, facet pairs that might contribute to multiple scattering are sorted according to certain criteria which are independent of the radar line of sight. For example, facet pairs may illuminate each other [Fig. 3(a)],

\[ n_1 \cdot n_2 > 0.0 \]

The intersecting point for the normals of facet pairs is in the illuminated region between the two facets, that is, one facet may not obscure the other [Fig. 3(b)],

\[ \mathbf{c}_1 \cdot n_1 < 0.0 \]

\[ \mathbf{c}_2 \cdot n_2 < 0.0 \]

or, equivalently,

\[ \mathbf{c}_1 \cdot n_1 > 0.0 \] and \( \mathbf{c}_2 \cdot n_2 < 0.0 \)

\[ \mathbf{c}_1 \cdot n_1 < 0.0 \] and \( \mathbf{c}_2 \cdot n_2 > 0.0 \)

Second, further screening is applied according to criteria that are line-of-sight dependent. For example, the incident propagation vector has a nonvanishing component in the plane formed by the unit normals of the facet pair,

\[ \{ \hat{k} - (\hat{k} \cdot \hat{n}_1) \hat{n}_1 \} \neq 0.0 \]

and so on.
Finally, a ray tracing technique is applied to each selected pair to compute the phase delay due to multiple bounce between the facets of the pair, and also to calculate the effective illuminated area of each facet of the pair due to the presence of the other facet. The multiple scattering contribution for each selected pair is then computed by using a generalized form of Knott's calculations for an obtuse rectangular dihedral corner reflector [17]. His calculations were extended to account for the general case, in which the shape of the facet of the pair is quadrilateral or triangular, and the pair forms an obtuse or acute dihedral with unattached sides. Computed contributions are then added to the overall fields in Eq. (15).

E. Discontinuity

Various discontinuity types such as empty slots or screws are integrated into the code. They are modeled as straight-line segments, and their locations are assigned to the target's surfaces by using the CAD system. The scattering calculations are based on semiempirical formulations [18]. Results of these calculations are presented in the verification section.

IV. Run-Time Statistics

RECOTA (return from complex target) execution time for the same geometry varies considerably from one job to the other depending on the analyst's requirements, such as whether or not contributions due to discontinuities, shadowing, multiple scattering, and so on, are required. The CPU time for different jobs requiring computation for facets, wedges, shadowing, and multiple scattering has been recorded. The CPU time has been normalized, and the CPU time/facet/angle for a single frequency and one polarization has been selected as the representative parameter for evaluating required run time. The average value for this runtime parameter was found to be 0.0115 second on the VAX 11/785 using the VMS 4.5 operating system.

V. Verification

Experimental and theoretical verifications for RECOTA were conducted. To ensure correlation with computations, special attention was given to the accuracy of model construction. Dimensions of each model were measured before testing and the corresponding CAD models were made accordingly. Also, model alignments were conducted whenever possible for each frequency band before recording measured data. Illustrations of the verification work are presented in the following sections.

A. Airfoils

Scattering of electromagnetic waves from an airfoil presents an interesting problem from the RCS analyst's point of view. It provides the analyst with the opportunity to examine the accuracy of his or her predictions for first-order scattering terms, namely, specular reflections from its surfaces and leading edge, and diffraction from its trailing edge. It also provides the opportunity to assess the impact of second-order scattering terms, that is, creeping waves around the leading edge, traveling waves from the trailing edge, or tip-tip interactions on the overall RCS predictions. The purpose of this test was twofold, to evaluate the accuracy of RCS prediction for an airfoil counting only first-order terms, and to examine the accuracy of RECOTA predictions as the airfoil's leading edge radius of curvature is varied.

Various types of NACA four-digit series airfoils (description of this class of subsonic airfoils is presented in [19]) were tested in the indoor RCS range in the frequency range of 4–18 GHz for both parallel and perpendicular polarization, that is, the electric field is parallel or perpendicular to the blade's length. Shapes and dimensions for these airfoils are shown in Fig. 4. These airfoils have the same lengths and chords but differ in the radius of curvature at the leading edge and in the inner wedge angles. As an illustration for this work, measured and predicted RCS values for NACA 3317 at 16 GHz are shown in Figs. 5 and 6.

For roll 0°, Fig. 5 indicates the RECOTA predictions are in good agreement with measured data for horizontal polarization, and within about 1–2 dBsm for vertical polarization. In this test case, the blade's end caps are treated, so it reduces the effect of the interaction pattern around the main lobes.

For roll 90°, Fig. 6 indicates that RECOTA predictions are in excellent agreement with the predictions of a moment method code [20] when $\vec{E}$ is parallel to the blade length (Fig. 6a) and are within 1–2 dBsm when $\vec{E}$ is perpendicular to the blade length (Fig. 6b). These differences are due to the contribution of higher order terms, such as traveling and creeping waves to the leading and trailing edges' returns, respectively.

A condensed summary of results for airfoils is presented in Fig. 7. It illustrates RECOTA predictions for the RCS variations with the radius of curvature of the airfoil's leading edge. For horizontal polarization the quality of agreement

Fig. 3. Illustration of some sorting criteria.
Fig. 4. Airfoils used in RECOTA verification.

Fig. 5. RCS for NACA 3317. Roll 0°, frequency 16 GHz, pitch 0°. (a) RECOTA, horizontal polarization. (b) Range, horizontal polarization. (c) RECOTA, vertical polarization. (d) Range, vertical polarization.
between calculated and measured data is excellent. For vertical polarization the agreement is poor for small $ka$: it improves, however, as $ka$ increases, where the difference decreases from 3 dBsm at $ka = 1$ to about 1 dBsm at $ka = 4$. This is expected for physical optics codes.

B. Shadowing and Multiple Scattering

Fig. 8 shows computed and measured results for a conducting sphere in front of a perfectly conducting plate for 10-GHz and horizontal polarization. The agreement is excellent.
Fig. 8. (a) RECOTA predictions and (b) measured RCS for sphere and vertical flat plate. Frequency 10 GHz, vertical polarization, $\theta = 0^\circ$.

Fig. 9 shows excellent agreement between computed and measured RCS values for an unconnected right-angle corner reflector. It gives a high degree of confidence in the quality of multiple scattering prediction for complex bodies in terms of facet pairs.

Fig. 10 shows predictions and measurements for a $50^\circ$ corner reflector where multiple scattering and multiple shadowing take place simultaneously. It shows step-by-step progression in the calculations, from the inclusion of only the first-order scattering term to the full inclusion of both
Fig. 9. Multiple scattering for unconnected facets. Roll 0°, frequency 10 GHz, horizontal polarization, pitch 0°.

Fig. 10. Measured RCS and RECOTA predictions for rectangular corner reflector.
Fig. 11. RECOTA predictions for empty channel slots. Frequency 18 GHz, horizontal polarization.
shadowing and multiple scattering terms, as compared to measured data. The agreement is very good.

C. Discontinuity

Fig. 11 indicates the excellent agreement of RECOTA predictions for a set of empty channel slots compared to range measurements as well as a moment method code [20]. (Note: This version of RECOTA does not accommodate traveling wave effects; however, these effects had been suppressed in the model by the application of R-card treatments at the edges of the ogive plate.)

D. Complex Geometry

Various complex bodies have been used for RECOTA verifications. The following presents an illustration for a generic missile model (Fig. 12). Background calibrations for its RCS measurements indicated that flashes due to the supporting tower were about −15.0 dBsm and were located at the azimuth angles of −70° and −110°. Fig. 12 shows predicted and measured RCS values for the missile at zero pitch and zero roll configuration for vertical polarization at 12 GHz. Keeping in mind the interferences of the tower flashes with the missile's return, the overall agreement is very good, except for the displacement of the null around −130°. This was found due to the incomplete agreement between the CAD model and the shop model for the vertical stabilizer. Similarly, Fig. 13 presents predicted and measured data for the same missile, but at −10.5° for the pitch angle. The agreement is excellent.

VI. CONCLUSIONS

The application of physical optics, physical theory of diffraction, and ray tracing together with a computer-aided design for modeling a complex target in terms of facets and wedges provides an accurate and powerful approach for calculating its RCS, including shadowing effects, returns
from discontinuities, and multiple scattering. Publication for dielectric surfaces, various "second-order" scattering effects, and the bistatic calculations will follow in a future publication upon the completion of the ongoing verification effort. The overall predictions of RECOTA are in good agreement with range measurements as well as with moment method predictions.

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