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PREDICTIVE SIGNATURE MODELING VIA SOLID GEOMETRY AT THE BRL

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FEBRUARY 1988

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For almost two decades the BRL has generated solid geometric models for use in vulnerability and neutron transport calculations. In the past four years, the Laboratory has embarked on a two-phase program to 1) improve its ability to generate, display and modify geometry and 2) couple geometry and related attribute data to a diverse set of analysis codes. Over the past year substantial attention has been given to the development of a predictive signature capability. This report reviews current progress in solid geometric modeling to include examples of color-shaded renderings of weapons systems currently under analysis. In addition, new results of signature models and supporting codes will be discussed and illustrated.

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I. INTRODUCTION

The Ballistic Research Laboratory is the Army's lead laboratory for the assessment of vulnerability of tactical systems to conventional weapons. For more than thirty years, system assessments of survivability have been made for bullet, high-energy laser, and neutron transport threats.

At the outset, it was realized that geometry is pervasive in these assessments. Some 18 years ago the BRL contracted for support in generating the first techniques capable of automating the interrogation of system geometry. For almost two decades the BRL has generated solid geometric models for use in vulnerability and neutron transport calculations. In the past few years the Laboratory has embarked on a two-phase program to 1] improve its ability to generate, display and modify geometry and 2] couple geometry and related attribute data to a diverse set of analysis codes. Objective 1] has been substantially impacted by the development of an interactive graphics editor called GED (Graphics Editor) and described in detail previously.[1] As the ability to generate and modify geometry has improved, new avenues of applications have opened. Another paper[2] has described some of the applications of solid geometric modeling. At the Fifth KRC Symposium,[3] the initial efforts in support of signature calculations with solid geometry were reported.

Over the past year substantial attention has been given to the development of predictive signature capabilities. This report reviews current progress in solid geometric modeling to include examples of color-shaded renderings of weapons systems currently under analysis. In addition, the results of some signature models will be discussed and illustrated.

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[1] P. H. Deitz, "Solid Geometric Modeling at the US Army Ballistic Research Laboratory," Proceedings of the Third Annual Conference and Exposition of the National Computer Graphics Association, Inc., held 13-16 June, 1982, Vol. II, pp.

[2] P. H. Deitz, "Solid Geometric Modeling - the Key to Improved Materiel Acquisition from Concept to Deployment," in the Proceedings of the XXII Annual Meeting of the Army Operations Research Symposium, 3-5 October 1983, Ft Lee, VA, pp. 4-243 to 4-269. Also in the Proceedings of Defense Computer-Graphics International Conference and Exposition, Washington, DC, 1[illegible]-14 October 1983.

[3] P. H. Deitz, "Predictive Vehicle Signatures Through Solid Modeling," Proceedings of the Fifth KRC Symposium on Ground Vehicle Signatures, August 2[illegible]-24 1983, Houghton, MI., p. 107.

II. GENERATION OF GEOMETRY

Methods of structuring geometry have been described previously.[2] They include:

A. Constructive Solid Modeling

B. Boundary File Representation

1. Explicit
2. Implicit

In approach A., various geometric shapes are combined with logic operations and attribute definitions. In approach B.1., the surfaces of objects are explicitly modeled as flat, polygonal elements. In approach B.2., the surfaces of objects are implicitly modeled through mathematical representations. Surface information is computed to various levels of approximation depending on the application. Changes in the surface topology are accomplished by changing the underlying mathematical representation.

The BRL uses the constructive solid modeling method. As noted above, this process has been greatly enhanced through the use of an interactive editor, GED.[4]

Figures 1 and 2 illustrate some current examples of GED modeling. These images have been calculated using a high-density ray casting program and rendered using a framebuffer display. Internal views are generated by directing the ray casting program to ignore particular classes of components (in this case, exterior armor).

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[4] M. J. Muuss, K. A. Applin, J. R. Suckling, C. A. Stanley, G. S. Moss and E. P. Weaver, "GED; An Interactive Solid Modeling System for Vulnerability Assessments," BRL Technical Report, ARBRL-TR-02480, March 1983 (UNCLASSIFIED).

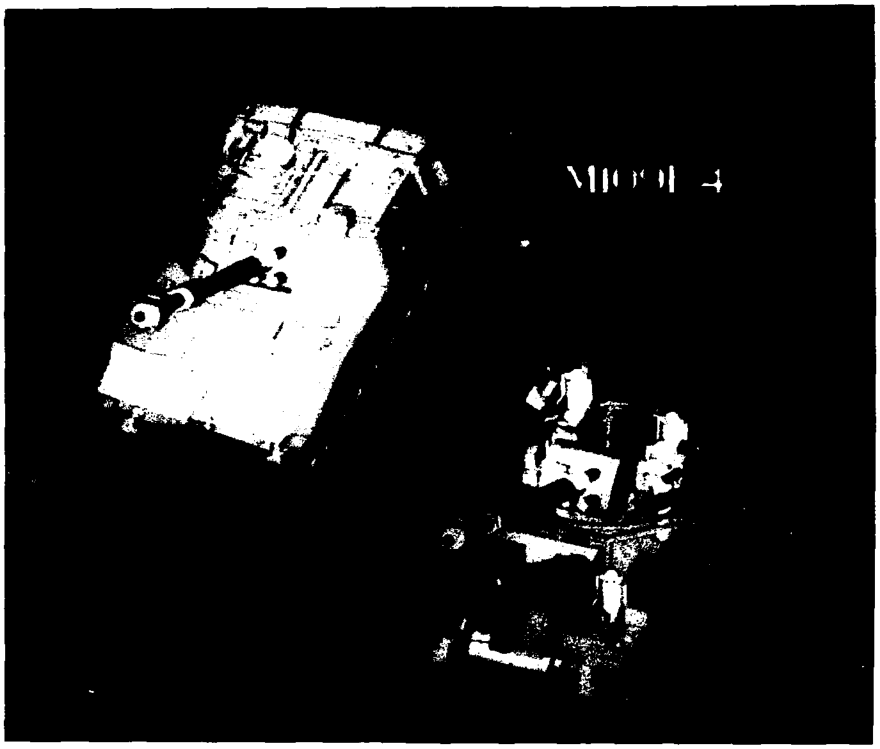

Figure 1. Color-shaded image of the M109 Howitzer. On the left is image derived from first-surface intersection of rays; on right, interior detail.

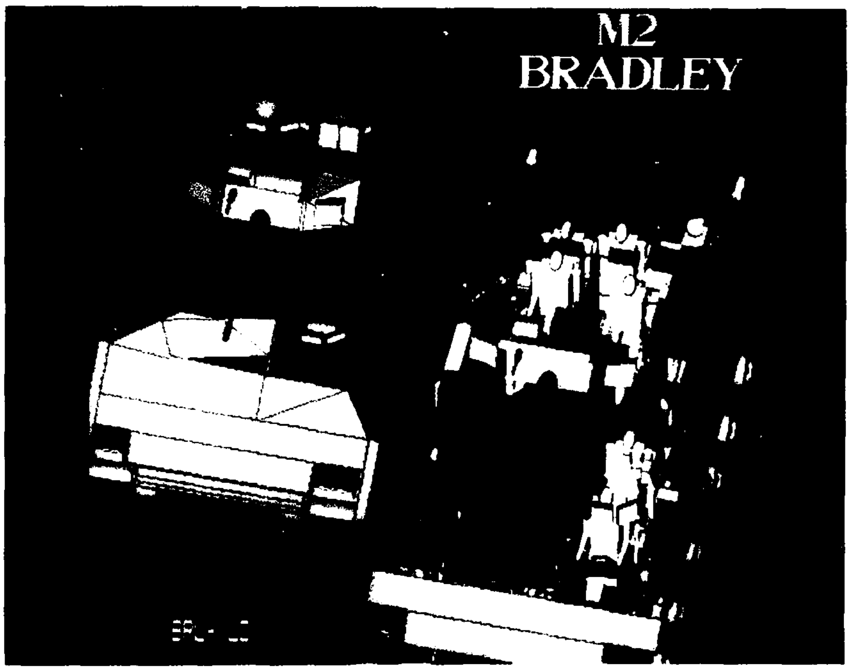

Figure 2. Color-shaded image of M2 Bradley Fighting Vehicle. On left is exterior geometry; on right, interior detail.

Note that no shadows are generated in these images. The rendering technique used here computes a single set of rays which is directed from the viewer's vantage point to the mathematical description. The first surface intersection by each ray is calculated, including its location in space, its surface normal, and object identification. All of that information is used to calculate the intensity and coloring of the image pixels. A more advanced lighting model, capable of computing shadows, will be described in Section IV.

Figure 3 shows a composite image of a tank which has been modeled using an Implicit Boundary Representation scheme (method B.2.). The surface of the tank has been described using discrete bicubic splines. The analytic smoothness of this technique together with the ability to introduce high geometric fidelity make it particularly attractive as a basis for signature modeling.

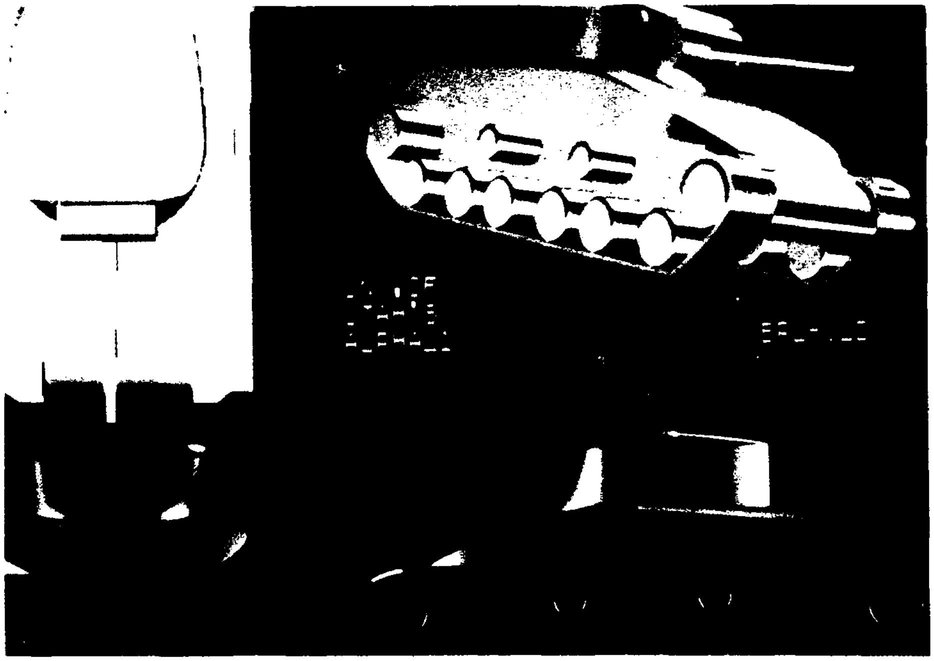

Figure 3. Four views of a Sherman tank constructed using discrete, bicubic splines. Object assembled using a geometric modeling system called Alpha_1. (Courtesy of the University of Utah.)

III. GEOMETRIC INTERFACES

Although solid geometry is often the point-of-departure for high-resolution, weapons-system analyses, the predictive performance models (including signature applications) normally do not utilize the geometry directly. Rather, the geometric information, which is coupled to specific attribute data (density, hardness, specific heat, emissivity, etc.), is passed first through a processing program. This process is illustrated in Figure 4.

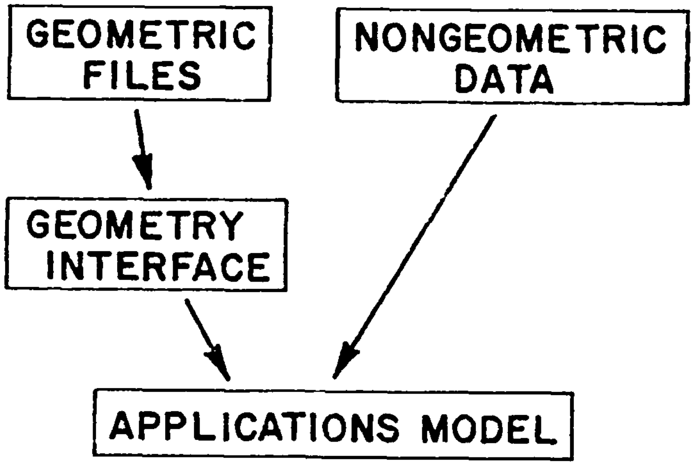

Figure 4. Geometric data is processed through an interface where it is combined with other (nongeometric) information for use in an applications model.

There are at least four ways in which geometry is passed to predictive models. They are:

1) Ray casting
2) 3-D Surface Mesh Generation
3) 3-D Volume Mesh Generation
4) Analytic Representation.

In method 1), geometric rays are intersected with the geometry file to find points of intersections and angles of orientation. Ray casting was used to calculate the images shown in Figures 1 and 2. It was also used to compute a slice through an M48 target description illustrated in Figure 5. These rays are calculated for one-inch intervals across a horizontal plane, 15 inches below the turret ring. The various colors indicate different system components.

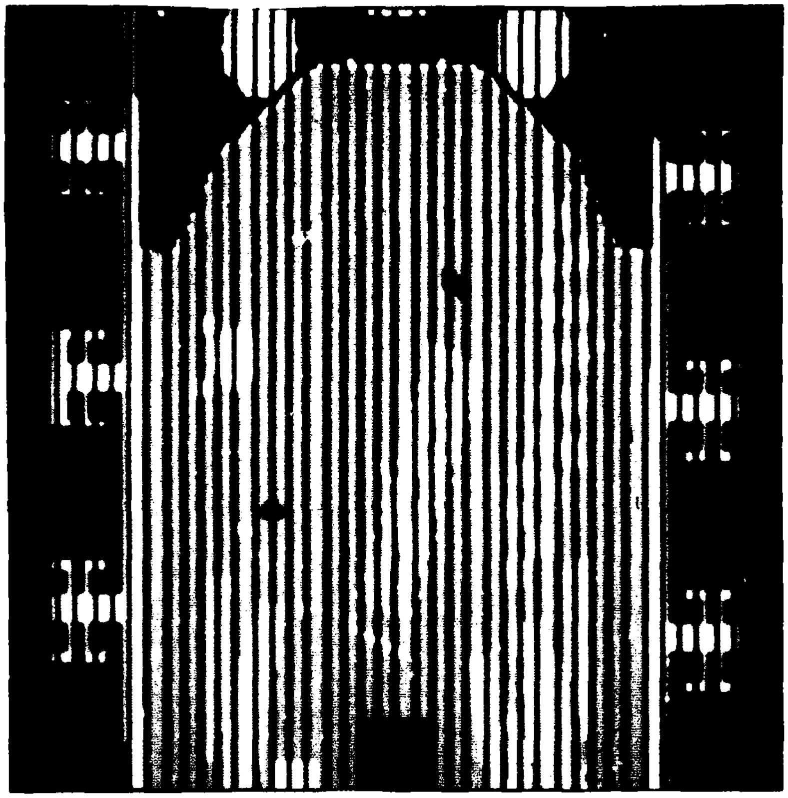

Figure 5. A horizontal slice of high-density ray information (1-inch between rays). Slice is taken 13 inches below the turret ring on an M48 tank. Various colors indicate different system components (e.g., white is armor and suspension, yellow is ammunition, red is personnel, etc.).

An entirely different form of geometric characterization is described by 3-D surface and volume mesh data. By these methods, geometry is posed as a series of lines connected at nodes over the surface of an object (Method 2) or throughout the volume of an object (Method 3). Meshes are used as the basis for many mechanical and heat-flow analyses.

In order to exploit analysis methods which require mesh generation, a commercial finite-element mesh pre- and post-processing program called PATRAN-G* has been purchased. Although PATRAN has its own geometric modeler, in order to avoid the high-overhead task of regenerating existing geometry in yet another format, a translation program has been written** to transfer GED files into the PATRAN format. Figure 6 illustrates those interfaces. GED

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*PATRAN-G is a product of PDA Engineering, Santa Ana, CA.

**Private Communication with G. S. Moss.

files are passed through a translator (GEDPAT). In effect, each geometric shape (or primitive) is reformatted by GEDPAT and then passed to the PATRAN code itself.

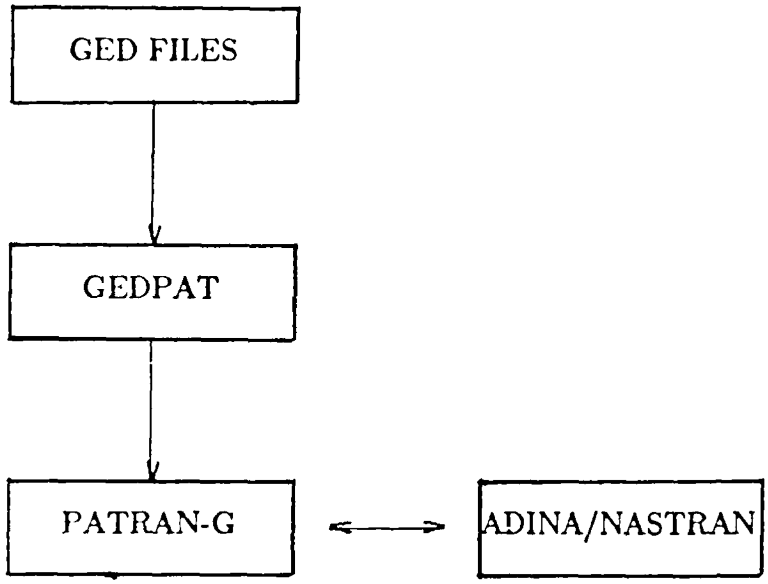

Figure 6. GED files are converted through an interface program, GEDPAT, into a PATRAN-G format. Once posed in the form of PATRAN geometry, objects can be converted into 3-D surface <u>or</u> volume meshes. These results can then be passed to ADINA or NASTRAN structural analysis programs for processing and then back for interpretation.

Figure 7 shows a simple construction consisting of a cube intersected by two cylinders. For this object, the cylinders are subtracted from the block. Figure 8 shows the result of the subtractive operation followed by the volume mesh generation. The mesh density is user selected for the application and computer resources. The mesh is then ready for processing by such codes as NASTRAN or ADINA. PATRAN-G is also used to interpret the results of the calculations.

Figure 7. An example of three simple primitives (two cylinders and a box) which were passed to PATRAN-G from GED.

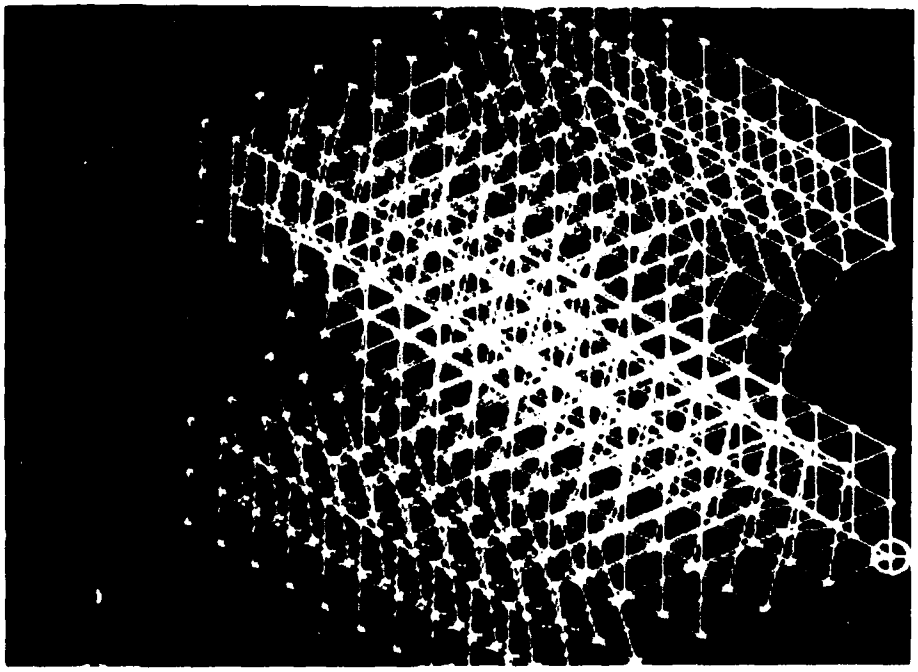

Figure 8. A three-dimensional mesh generated by PATRAN-G calculated from the three primitive shapes illustrated in Figure 7.

Although analytic representation is not used in most computer-aided schemes, its use will probably grow. In this approach, signature properties, for example, are computed using closed-form solutions and analytic geometry. A solution is computed over an entire geometric representation instead of piecewise approximations. This approach is similar to the classic electromagnetic calculations for free-field scattering from discs and spheres. With the rise of computer-based geometry, solutions to scattering problems have reverted to massive ray casting methods to derive necessary data. However, with the development of geometric methods based on implicit boundary file representations and analytic mathematical forms, there may be an opportunity to develop a new approach to signature modeling.

IV. SIGNATURE APPLICATIONS

A. IR Imagery

In the design of smart munitions it is important to know the nature of vehicle signatures over a range of detection bands and a variety of signal-processing schemes. To estimate the infrared performance of a smart system called STAFF,[5] a series of measurements in the 8-12 micron band were made for a Soviet T62 tank under various operating conditions. For each set of conditions, a complete thermal signature was gathered over the vehicle surface. The measured temperatures were then associated with the corresponding exterior regions of the GED description. Such an approach, although not predictive, ensures that the effect of sensor aspect angle is accurately accounted for in the subsequent simulation.

Figure 9 shows a (GED-generated) color-shaded image of a T62 Soviet tank together with a thermogram of the tank from the same aspect angle (90,45). The false-color image illustrates the signal strength in the 8-12 micron band; this data was taken during clear night-time operating conditions, and the color scale represents a range of about 18 to 35 Degrees C. Although this is not an example of predictive modeling, the solid model serves an invaluable role in achieving proper image perspective in the sensor simulation.

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[5] J. R. Rapp, "A Computer Model for Estimating Infrared Sensor Response to Target and Background Thermal Emission Signatures," BRL Memorandum Report ARBRL-MR-03292, August 1983.

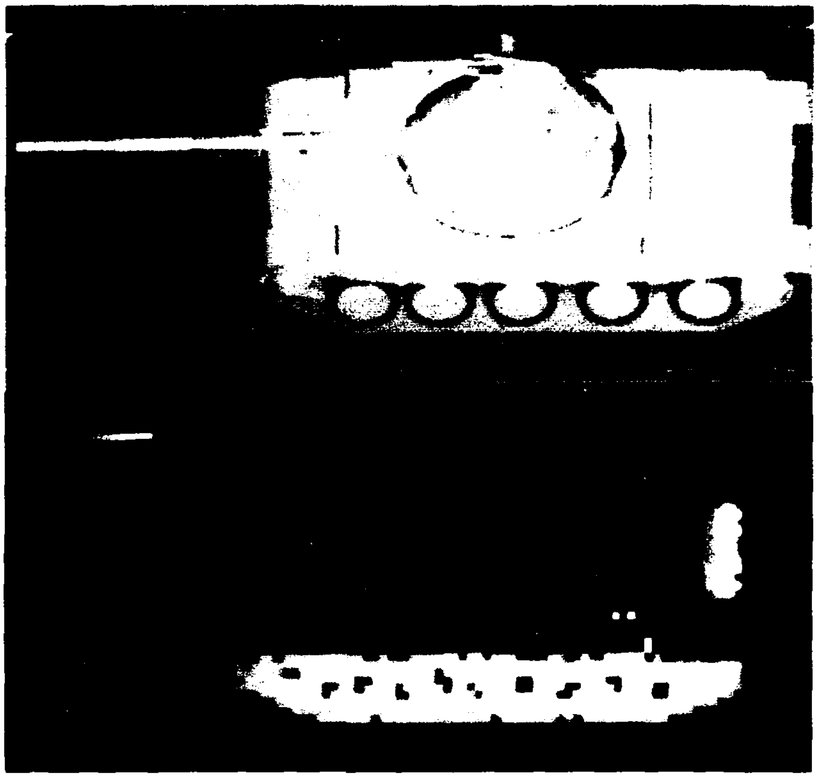

Figure 9. Infrared (IR) image (lower) and standard optical image (upper) of T62 vehicle. Measured target temperatures were used with BRL solid model to derive thermal image.

Actual predictive IR modeling is possible based on solid modeling but it is considerably more difficult. To make detailed predictions it is necessary to calculate a complete heat budget throughout the vehicle accounting for all sources and sinks of heat among all components including the rates of heat flow as well. Generally thermal models are developed around a Finite Element Mesh (FEM) structure. Heat flow is calculated from node to node with mesh links characterized by coupling coefficients. Clearly solid geometric models represent a critical element that must be exploited to achieve a true predictive IR modeling capability.

B. <u>Bistatic Lighting</u>

In the color-shaded pictures shown in Figures 1 and 2, a single high-density ray file was calculated for each image. By that process the effective light source is located at the viewers eye. As such, no shadows are generated.

In order to see the effect of optical sources not co-located at the viewers eye, it is necessary to enhance the ray casting process with a secondary calculation.* As each ray hits the first surface of vehicle geometry, a secondary ray is sent to the light source. If intervening geometry is

*Private communication with G. S. Moss and G. G. Kuehl.

encountered, then that particular vehicle element (pixel) is in a shadow. The depth of shadowing can be modified by modulating the illumination level for all pixels to set effectively a background lighting level.

In addition, because all of the geometry associated with incident and reflected rays is known, the proportion of specular and diffuse scattering can be accurately simulated. By the choice of those characteristics, the effective surface roughness of the target is simulated.

Figure 10 shows an image of an M48 tank calculated by the bistatic lighting model. Shadows of the gun barrel and turret are clearly evident. In this particular image, a range-dependent intensity factor has been introduced so that portions of the vehicle closer to the observer appear brighter and _vice versa_.

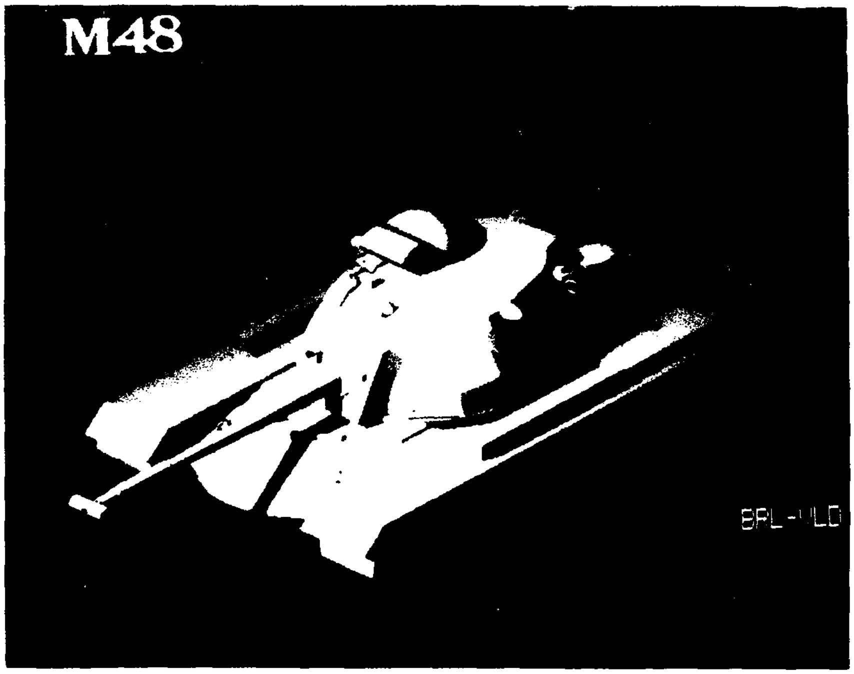

Figure 10. Color-shaded image of an M48 tank. A bistatic lighting model is used (illumination and viewing aspect angles are different) to compute the shadows. Surface reflection properties can be simulated by controlling the relative amounts of spear and diffuse contributions.

An important application of this bistatic lighting model is shown in Figure 11. Here an M48 target model has been rendered for four lighting conditions. In the upper left, an optical source uniformly illuminates the target at an angle 60 degrees to the left of the viewer's line of site. In order to make the specular versus diffuse scattering clearly evident, those portions of the vehicle exhibiting specular scattering are rendered in yellow. Diffuse scattering is shown in blue.

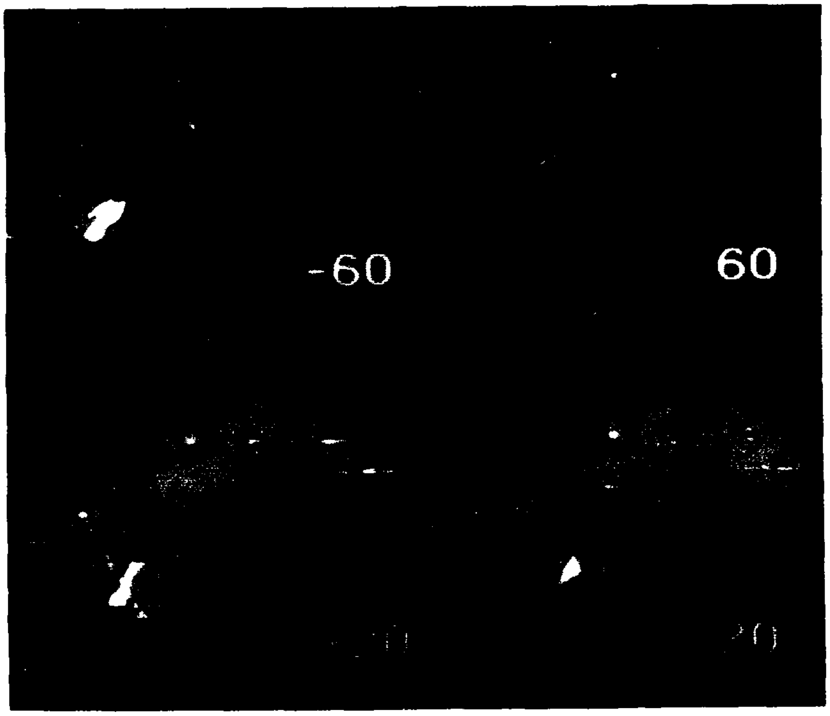

Figure 11. Four bistatic optical images similar to the image of Figure 10. Source illumination angles of -60, -20, 20, and 60 (relative to the viewing plane) are illustrated. Portions of the images exhibiting specular scattering are shown in yellow. Diffuse scattering is shown in blue.

The image in the lower left corner shows the result for a source illumination 20 degrees to the left of the viewer. The lower-right and upper-right images correspond to 20 and 60 degrees to the right, respectively. As noted above, the surface roughness properties can be easily simulated through the choice of the specular and diffuse scattering functions. Such a capability lends itself to a number of imaging applications included semi-active guidance analyses.

A final application of bistatic lighting is shown in Figure 12. Here an LVTP7 (a Marine landing craft) is shown from a high elevation for four different angles of solar illumination. A ground plane has been placed beneath the vehicle so that ground shadows can be calculated. Such predictive imaging might be used to calculated the performance of a top-attack optical sensor which uses edge-discrimination techniques.

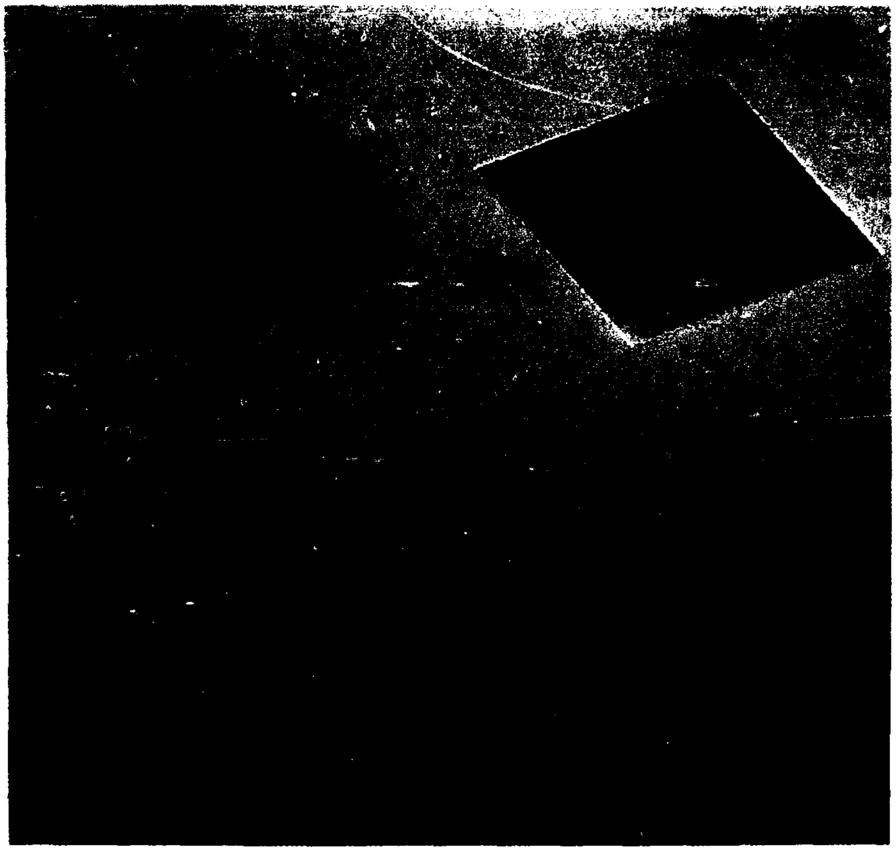

Figure 12. Four views of an LVTP7 Vehicle with a ground plane. Each view simulates a particular sun illumination angle that a top attack optical sensor might see.

C. Vehicle Topology

For certain classes of target signatures the mathematical characteristics of a vehicle shape play a key role. An obvious example involves the scatter of radio waves. It is well established that dihedral and trihedral metal elements act as particularly efficient reflectors for radar. A millimeter wave (MMW) signature model has been developed at the BRL[6] which models ground vehicle geometry as a collection of dihedral elements of various sizes and orientations. Although such a collection of elements can be generated by hand, a processing scheme has been developed* which uses GED files as input to compute orthogonal surface elements.

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[6] J. Lacetera, "Deterministic Modeling of Tank Targets for MMW Radar Systems", elsewhere in the Proceedings.

*Private Communication with G. S. Moss.

Figure 13 illustrates this process for an M48 tank. First a viewing orientation is chosen and ray intersections are calculated at the vehicle first surface. Next the surface normal is calculated for every ray intersection. Then a search algorithm is applied so that effectively every surface normal is compared with its neighbors to check for orthogonality. Such a process yields three classes of orthogonal relations: concave, convex, and disjoint. Concave elements are formed of those target pixels which are orthogonal to each other and open towards the viewer. The convex elements are open away from the viewer. Disjoint elements are orthogonal to each other, are adjacent to each other when projected into screen space, but are actually disconnected along the line of sight.

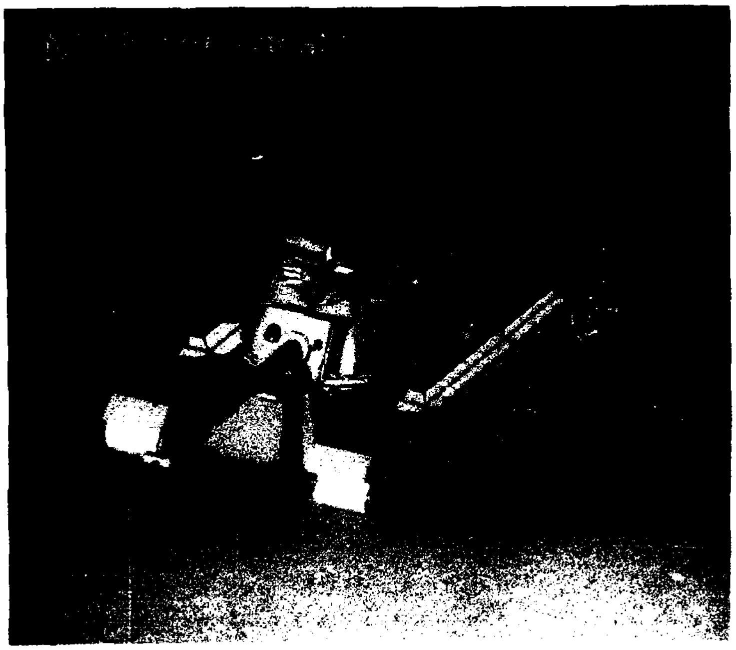

Figure 13. The surface topology of an M48 tank has been processed in order to find adjacent orthogonal (i.e., dihedral) elements. Green lines indicate open dihedrals (concave), red lines indicate closed dihedrals (convex), yellow lines indicate orthogonal target elements adjacent in the viewing space, but actually disconnected along the line-of-sight (disjoint). Tan areas show an approximation to the extent of concave dihedral elements.

For the radar problem, the concave class of elements is important. The search algorithm has been designed so as to search the extent of the concave dihedral surfaces and render them in a tan color. The final step in the preparation of input for the radar model is to merge the dihedrals computed from four or so views so that essentially all of the contributing vehicle geometry is represented.

In addition to the direct support of the deterministic radar model, this processing method has utility for system design. As we shall see in the next section, there indeed is a high correlation between dihedral vehicle surface topology and the magnitude of radar scattering. As such, this method represents and important tool for analyzing and reducing vehicle signatures in the design stage.

D. SAR Imagery

Synthetic Aperture Radar (SAR) is a technique by which multiple radar[7] samples in space can be used to infer image information about a target. In contrast to standard radars in which only total target backscatter and range are computed, SAR methods can resolve distinct scattering regions of a target.

The ability to predict the nature of SAR imagery is also a useful tool for the design of fighting ground vehicles. For various aspect angles, polarization schemes, and wavelengths, it is important to analyze the scattering efficiency of particular vehicle regions. Such knowledge impacts how, for example, an active MMW seeker would detect and guide to a target. The integrated contributions of all the target scatterers relate to the radar cross section (RCS); thus a byproduct of the calculation, the RCS, represents a figure-of-merit which relates to the ranges at which battlefield targets can be detected. In terms of vehicle design, such analyses make it possible to examine the effect of surface shape (i.e. topology) and surface material (for signature suppression) on radar performance.

During the past year the BRL has implemented a predictive SAR model called SRIM (for Simulated Radar Image Modeling) which was written by personnel at ERIM.* The complete logic flow required for the SAR results mirrors the process illustrated in Figure 14. After a solid geometric model has been chosen (or generated), a ray casting utility is used to interrogate the model. The current BRL ray casting program, GIFT,[8] was modified** in order to accommodate multiple ray reflections that occur over the surface of the vehicle. A given ray can reflect up to some preset number of times or until it leaves the vicinity of the target. The choice of the ray density is based on the frequency of the radar being simulated and, perforce, the cross-range resolution of the process.

Figure 14 illustrates the spatial relationships of the SAR process using color shaded optical images. In the upper right-hand portion of the figure is an M48 tank viewed from an aspect of (60,12). This is the orientation of the SAR radar with respect to the tank. In addition, the radar is moving in a horizontal direction. Thus the radar resolves the target horizontally and in

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[7] J. C. Toomay, Radar Principals for the Non-Specialist, Lifetime Learning Publications, London, 1982.

*Private communication with I. J. La Haie, Environmental Research Institute of Michigan (ERIM).

[8] G. G. Kuehl, L. W. Bain, Jr., M. J. Resisinger, "The GIFT Code User Manual; Volume II, The Output Options (U)," USA ARRADCOM Report No. 02189, Sep 79, AD# A078364. GIFT stands for Geometric Information for Targets.

**Private communication with G. G. Kuehl.

range (because of time resolution of the pulse detection), but not at all vertically. When the SAR information is processed and plotted in the form of azimuthal vs. range data, the appearance is similar to the view shown in the lower righthand portion of the figure. You will note that the view orientation is orthogonal (-120, 78) to the radar aspect angle. This bistatic lighting view only suggests the SAR result. In the visual model, whether viewed from the top or the bottom, only first-surface information can be seen. In the true SAR image all radar scatter for a given range/azimuth is projected into a given point in range/azimuth space. However the shadow generation and general image orientation is similar.

Figure 14. Two high-density images of an M48 tank which illustrate the Synthetic Aperture Radar (SAR) process. In the upper-right, the target is viewed by the SAR system from a (60,12) aspect angle. The SAR is modeled as moving in azimuthal direction (elevation and range constant). Left-hand image shows the complimentary view (-120,78) which is suggestive of the SAR image when cross-range (azimuthal variation) is plotted against range. This is actually a bistatic optical image in which the indirect lighting (from the viewer direction) has been set to zero.

Figure 15 shows the actual results of the SAR calculation against an M48 vehicle at a (60/12) aspect angle. The labels VV and VH represent two combinations of transmit/receive polarization states. In addition, these calculations have been made in a high-resolution mode (about two-inch resolution) and are not constrained by practical frequency or coherence considerations of <u>realizable</u> radar systems. In each of these images, the radar signal is propagating from left to right.

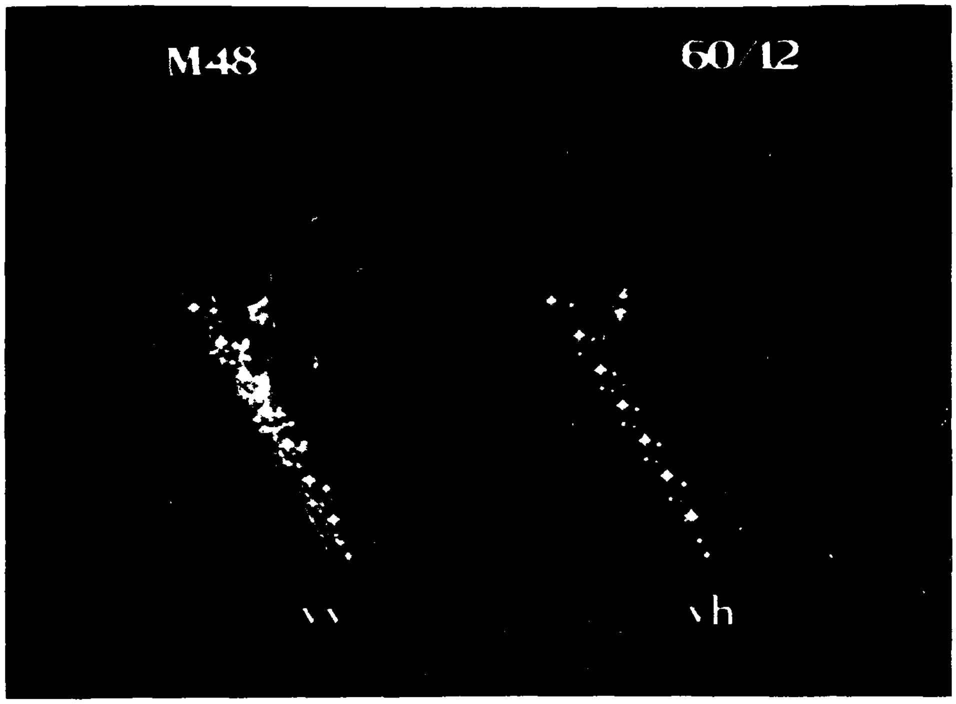

Figure 15. High-resolution SAR images of an M48 vehicle. In both images, cross range is plotted against range. On the left, the vertical/vertical (vv) polarization components are shown; on the right, the vertical/horizontal (vh). These images indicate the resolution of the modeling process; actual constraints of source-detector stability, noise, and other factors have not been introduced into the simulation.

Figure 16 shows yet another option of this processing scheme. In the left example (ABS Turret), the turret material has been changed from conducting to absorbing in order to see the effect on signature reduction. The voids caused by reduction in signal return are clearly evident. In the right-hand example, (ABS Wheels), the wheels have been made absorbing, resulting in a similar decrease in backscatter from the suspension system.

Figure 16. High-resolution SAR images of an M48 showing the effect of radar-suppression material.

V. SUMMARY

In this report we have reviewed briefly the way in which solid geometry can be used to support high-resolution, weapons-system engineering, in particular, predictive signature calculations.

Specific examples have been shown for applications in the IR, optical, and radio-wave regimes. Such calculations have broad utility for many applications including smart munitions analyses, vehicle survivability assessments, and vulnerability reduction efforts.

It is important to appreciate that even with modern interactive computer techniques, the generation of solid geometry files of vehicles is still an expensive and demanding task. Depending on the task, the level of geometric detail may differ from one application to the next. Nevertheless, the philosophy taken here is to develop a broad set of analyses which are supported from the same geometric file structure. This makes it possible to recycle the same (or incrementally enhanced) geometry in support of many eclectic analyses to produce high-detail, system perspectives on vehicle design.

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