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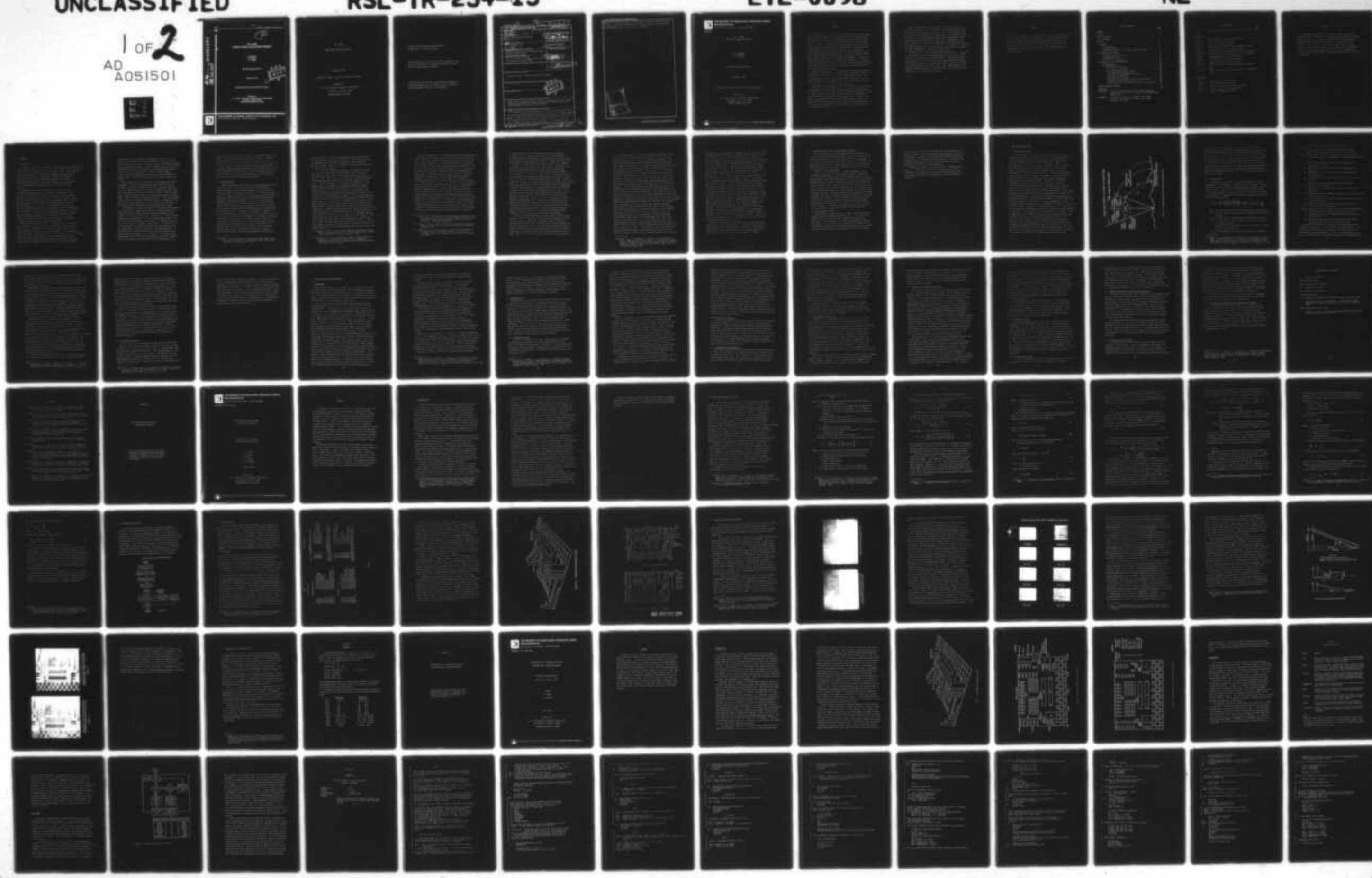

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ETL-0098
RADAR IMAGE SIMULATION PROJECT

J. C. Holtzman
V. H. Kaupp
J. L. Abbott

RSL Technical Report 234-15

September, 1976

Approved for public release; distribution unlimited

Prepared for:
U. S. ARMY ENGINEER TOPOGRAPHIC LABORATORIES
Fort Belvoir, Virginia 22060
CONTRACT DAAK02-73-C-0106

THE UNIVERSITY OF KANSAS CENTER FOR RESEARCH, INC.
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This document summarizes the results of a radar image simulation study performed at the Remote Sensing Laboratory, the University of Kansas, Lawrence Kansas. The work was sponsored by the Engineering Topographic Laboratories, The United States Army, Fort Belvoir, Virginia. The goal of this study was to develop radar image simulation techniques. The purpose of this

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CRES
REMOTE SENSING LABORATORY

SUMMARY

This document reports the results of a study performed by the Remote Sensing Laboratory (RSL) at the University of Kansas, Lawrence, Kansas. The purpose of this study was to develop radar image simulation techniques. This work is a natural focus of over 10 years of prior research at RSL. It is built upon the experience developed in a host of studies. These studies include among others, determination of theoretical models of radar backscatter from realistic terrain and vegetation models, acquisition of a large empirical data base of radar backscatter measurements, and development and verification of the utility of IDECS (Image Discrimination, Enhancement, Combination, and Sampling) for image data extraction and enhancement. The purpose of this document is to summarize those investigations, to identify significant accomplishments, and to make recommendations concerning future research needs and potential applications of the results of this work.

What has been developed is the capability to create radar image simulations for the general case. The basic problems have been identified and solved. The next step is to develop specific applications. With each application will come unique, new problems which must be solved. These applications and the problems they bring are the areas where the research efforts must be concentrated in the future.

The general model developed in this study for radar image simulation can be used in a variety of applications. It can be used to simulate the image products of different radars and can accept a variety of sources of input ground truth data. Both SLAR (Side-Looking Airborne Radar) and PPI (Plan-Position Indicator) radar images can be simulated. The model can handle equally well scenes of terrain having little or no relief and terrain having significant relief. Potential applications run the gamut from guiding remotely-piloted vehicles to photo interpreter (or pre-mission) training.

A very important milestone achieved in this study was the use of empirical backscatter data for the ground truth target reflectance information required by the model. The results of this study demonstrate the great value of using empirical backscatter data in the simulation model. This concept removes some of the previous limitations placed on simulation and greatly expands potential applications. Although the use of empirical data was a significant accomplishment, the limited amount of these data available requires theoretical backscatter models to extend and extrapolate the data for cases not available. Even with this limitation the model developed has a wide range of applications.

The objectives of the investigation have been fulfilled. The concept of radar image simulation has been developed and shown to be a viable tool for a multitude of potential applications. Many areas have been identified as a result of this study which require additional research in order that the promise offered by radar image simulation be realized. With significant progress in these areas, radar image simulation can be exploited to the fullest extent possible to aid the United States Army in attaining its goals and mission objectives.

PREFACE

The engineering results summarized in this report reflect the cooperation and contributions of many individuals. The work was sponsored by the Engineering Topographic Laboratories, The United States Army, Fort Belvoir, Virginia, and was performed at the Remote Sensing Laboratory, The University of Kansas, Lawrence, Kansas. Many people at these organizations should be recognized for their specific contributions to the work reported.

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ABSTRACT

This document summarizes the results of a radar image simulation study performed at the Remote Sensing Laboratory, The University of Kansas, Lawrence, Kansas. The work was sponsored by the Engineering Topographic Laboratories, The United States Army, Fort Belvoir, Virginia. The goal of this study was to develop radar image simulation techniques. The purpose of this document is to summarize those investigations, to identify significant accomplishments, and to make recommendations concerning future research needs and potential applications of the results of this work.

1.0 SUMMARY

1.1 Introduction

For the past 3 years a study has been conducted at the Remote Sensing Laboratory (RSL), The University of Kansas, to develop radar image simulation and feature extraction techniques for terrain imaging radars. This study was conducted under contract to the Engineering Topographic Laboratories (ETL), United States Army, Fort Belvoir, Virginia. The purpose of this document is to summarize those investigations, to identify significant accomplishments, and to make recommendations concerning future research needs and potential applications of the results of this work.

We normally take the expression "image" to mean some visual representation of an object (or scene) which is produced by lenses, mirrors, or other optical elements. We are familiar with such images when they are formed at wavelengths in the visible (to the human eye) portion of the electromagnetic spectrum - approximately 4000 to 7000 Å. These wavelengths are the region of the electromagnetic spectrum to which the human eye is sensitive. It is possible to form images of objects with electromagnetic waves of much longer length. In particular, if these images are formed with wavelengths in the microwave portion of the electromagnetic spectrum, they are called radar images. Although images and imaging systems taken by or operating in the microwave and optical region of the spectrum have many features and properties in common, they will display significant differences.

Modern imaging radars designed to operate in complex environments are too expensive to build just to see if they will perform as desired. Even if a radar is available, the cost of operating it makes its use unjustifiable for ordinary or trivial applications. This is especially true for airborne or spaceborne radars. These and other factors to be discussed account for the increasing demand for the simulation of radar images. Simulation of radar images means that knowledge of the radar system and ground scene to be imaged are converted by suitable techniques into an image which represents what the radar would have "seen" if it were actually flown. Radar simulations are produced, typically, either by optical techniques (an optical computer is used) or by digital techniques (a high-speed digital computer is used). Depending upon the application for which a particular radar image is to be simulated, the simulation effort can be relatively simple or it can be amazingly complex requiring very detailed knowledge of the terrain and vast amounts of computer time. In general, the radar image simulation problem is not simple.

Radar imagery possesses several distinct advantages over optical photography. The two prime advantages of radar are the facts that microwave frequencies are affected less by meteorological conditions, and, since radar provides its own source of illumination, radar images can be made equally well during either day or night. Cloud cover and light precipitation do not prevent the successful operation of imaging radars - hence the name, all-weather surveillance. These two advantages, alone, reinforce the value of imaging radars and, by implication, they establish the potential applications for imaging radars and, hence, the projected value and applications for simulated radar imagery.

The capability to create simulated radar images has great potential value in many areas. Among these areas are such applications as the guidance of remotely-piloted vehicles, navigation progress checks, analysis aid to the image interpreter, and training. A flight guidance computer could be developed to use the simulated radar imagery to fly (or guide) the vehicle along a specific path or a navigator could use the simulated imagery for flight progress checks. The capability to create simulated radar images can be seen also to provide an active and viable analysis and assessment aid to the image interpreter. It would enable the interpreter to create for training purposes (or to baseline damage assessment - civil or military - in the event prior reconnaisance imagery had not been obtained) virtually any simulated image at any frequency and polarization for which knowledge of the terrain (ground truth data) was available. As valuable as the interpreter is, it is highly unlikely that each interpreter is familiar with the image products of every radar for every possible scene. Radar image simulation will provide the interpreter with the capability to make comparisons outside the realm of his experience and will, therefore, expand his experience base thereby increasing his efficiency value. Other potential applications for simulated radar imagery run the gamut from tactical terrain reconnaisance to agricultural crop health, maturity, and moisture content evaluations.

1.2 Project Summary

Several approaches to the radar image simulation problem have been investigated at RSL. The first investigation was conducted to analyze the nature of the simulation problem. The results of this effort were reported by Parashar[1]. This initial effort was partially successful. Much was learned in this investigation and much insight was gained into the nature and priority of the simulation problems and parameters. The approach reported in this first investigation was to model the test site as a flat agricultural area. Existing radar imagery covering the kinds of agricultural crops present in the test site were used to define the data base from which the simulated image was to be constructed. In an image, the parameter of importance is the relative variation of lightness (or darkness) from point to point. If we call the relative value of lightness of a particular image point the greytone of that point, then the total range of variation in an image would be the greyscale. This first RSL radar image simulation work obtained the greyscale data for each microwave reflectivity category (formerly called agricultural crop) to be simulated from existing radar imagery. The attempt undertaken was to obtain as much statistical data as possible about homogeneous regions of each

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1 Parashar, S. K. and A. K. Fung, "Simulation of Radar Image: Garden City Test Site, Kansas," TR 234-5, Remote Sensing Laboratory, The University of Kansas, May, 1974.

category and then use existing electromagnetic backscatter theories to interpolate and extend these limited data. This was not a successful approach for the solution of the general simulation problem. But it did produce a wealth of information and indicated directions to be taken for future research.

The second investigation was conducted to demonstrate the applicability of the radar image simulation model to a relatively flat agricultural area and to solve some of the problems identified in the first study. The results of this study were reported by Parashar[2]. The simulated image was compared to a real radar image of the same scene. A number of points of dissimilarity were identified in this comparison but, on the whole, the simulation looked like a radar image. Some of the points of dissimilarity were due first to the relative coarseness of the digital data base which represented the ground truth information (geometrical and backscatter characteristics) from which the simulated image was produced. The difference between this and the first study is the model used to extrapolate the empirical backscatter data. The area for which a simulated radar image was to be produced was almost exclusively agricultural, thus it was decided to use Clapp's model[3] to extend and interpolate the backscatter data which were obtained in the same way as in the first study. While for some applications Clapp's model may be a reasonable approximation for the angular variation of backscatter data, it is too simplistic for the radar image simulation problem and this caused a second error to be introduced. On the whole though, this work showed that the simulation of a radar image for a medium resolution radar could be achieved (at least for a relatively flat, agricultural area) and identified more problems that needed to be handled before the simulation model could be applied to more complex areas.

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2 Parashar, S. K, A. K. Fung, and R. K. Moore, "Simulation of a Radar Image for Garden City Test Site." TR 234-8, Remote Sensing Laboratory, The University of Kansas, February, 1975.

3 Cosgriff, R. L., W. H. Peake, and R. C. Taylor, "Terrain Scattering Properties for Sensor System Design (Terrain Handbook)," Engineering Experiment Station Bulletin, The Ohio State University, vol. XXIX, no. 3, pp. 10-12.

The next investigation was conducted to demonstrate the application of the radar image simulation model to a surface which has significant relief. Also, the microwave reflectivity data used to calculate the image greytones present in the simulations produced for the selected test site area were taken from applicable scattering theories[4,5]. The results of this study were reported by Parashar[6]. The limiting factor that prevented more precise comparisons between simulated and real radar imagery of the same site was the specification of ground truth information. The data base of ground truth information that was prepared for this test site was made by hand and, consequently, it was a rough approximation to that area. The quality of the simulation effort at this time was superior to the data base. A clear conclusion to be drawn from this study is that we need to define the minimum amount of information to be included in the ground truth data base. A way to approach this problem is to analyze the sensitivity of the various parameters which together make up the simulation problem and establish for a given application of radar image simulation the minimum required level of information. This information can then become the guideline for building ground truth data bases. While on the subject it should be pointed out that the most expensive part of radar image simulation is the building of ground truth data bases. The recommendation that a sensitivity analysis be performed to establish minima

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4 Hevenor, R. A., "Backscattering of Electromagnetic Waves from a Surface Composed of Two Types of Surface Roughness," TR ETL-TR-71-4, Engineering Topographic Laboratories, The United States Army, Fort Belvoir, Virginia, October, 1971.

5 Fung, A. K., and H. L. Chan, "Backscattering of Waves by Composite Rough Surfaces," IEEE Transactions on Antennas and Propagation, September, 1969.

6 Parashar, S. K., A. K. Fung, and R. K. Moore, "Digital Simulation of a Radar Image of Pisgah Crater Test Site California," TR 234-10, Remote Sensing Laboratory, The University of Kansas, July, 1975.

for ground truth data bases should be very seriously considered. To be able to simulate a good quality radar with a high resolution, a very detailed and exact knowledge of the ground truth (microwave reflectivity properties and geometry of the site) is needed. The magnitude of the problem is best illustrated by the fact that if it is desired to simulate the image products of a radar having a resolution of only 100 feet, the ground truth data base must contain at least 2800 points per square mile of terrain (50 feet would require 11,100; 25 feet, 44,600; etc). A simulated scene can easily exceed 100 square miles and at 25 foot resolution the data base would have to contain in excess of 4 million points. The problem rapidly gets out of hand. Several other lessons were learned in this investigation that are worth pointing out here. First, more experimental (empirical) microwave reflectivity data needs to be collected and theoretical scattering models need to be developed to support directly the mission objectives of the U.S. Army. It is strongly beleived that radar image simulation will play a very important role in the future for the U.S. Army (in fact, for the entire Department of Defense). If this is true, it will become increasingly important to obtain these data. Second, it is necessary to define objective image quality measurement criteria. As the tool of radar image simulation begins to be used in more applications it will become increasingly important to be able to measure in a quantitative and objective manner the quality of radar image simulations and their suitability to fulfill the task for which they were produced.

The final investigation conducted on this contract had the widest scope of all the investigations. This study was conducted to investigate the problems raised in the first three studies; it explored new directions for the simulation problem and it completely generalized the simulation problem (that is the radar image simulation problem was viewed as having general, broad-range applications, and the simulation model should be designed to handle any of them instead of just one of them). The results of this investigation were reported by Holtzman, et al.[7]. The general model for radar image simulation developed in this study can be used to simulate the image products of different radars and can accept a variety of sources of input ground truth data. Both SLAR (Side-Looking Airborne Radar) and PPI (Plan Position Indicator) radar images can be simulated. The model can handle equally well terrain having little or no relief and terrain having significant relief. A very important milestone achieved in this study was the use of empirical backscatter data for the microwave reflectivity data used in the simulation. This study represents the first time at RSL that empirical backscatter data bases were used in the simulated radar image greytone calculation. Previously, the.backscatter data had been taken by suitable statistical techniques from a real radar image of the scene to be simulated. In this study, the backscatter data were taken from an extensive empirical calibrated data bank which is being developed at the RSL on a contract sponsored by another agency. The results of this study demonstrate the great value of using empirical backscatter data bases as the input microwave data for the radar image simulation problem and, further, demonstrates the potential requirement for a similar effort to be conducted on behalf of the goals and mission objectives of the Army. No new data bases were constructed in this study and the simulation model was vastly superior to the available ground truth data. A very good data base needs to be developed so that the true fidelity of the simulation model can be appraised. All of the first-order effects (e.g. the most important effects) were incorporated in the simulation model. These include shadow, layover, near-range compression, fading, etc. Not all of the effects were shown in the sample radar image simulations presented in this last report bacause the data base was unsuitable; it was flat terrain. But the problems were solved and applications will be shown in this report. An alternative to the static simulation model was explored in which a human being (photo analyst, etc.) was placed in the decision process of the computer software in an interactive,

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7 Holtzman, J. C., V. H. Kaupp, R. L. Martin, E. E. Komp, and V. S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interactive Simulation Model, and Sample Results," TR 234-13, Remote Sensing Laboratory, The University of Kansas, February, 1976.

real-time (e.g., as the program ran) operational mode. This interactive simulation technique was shown to be highly flexible and to be a significant improvement over conventional techniques which require adherence to inflexible formats with hard-coding of the simulation instructions prior to production, and thus the simulation parameters and scene categorizations are difficult or impossible to alter easily and rapidly. It is felt that the value of interaction between computer and analyst has been shown in this study. By including the human in the decision process,a whole greater than the sum of its parts is created. The computer is a very useful tool but its decision-making capabilities are very limited. By using the computer to maximize its strengths (e.g. rapid manipulation of vast amounts of data) and using the trained human to make decisions, tremendous improvements can be achieved in the radar image simulation problem. By extrapolating this capability to other areas it seems natural to infer that the interactive mode is the obvious method of choice for preparation of data bases. Much of the problem of data base construction is centered around the drudge of data manipulation; the computer is very good at this task. On the other hand, many decisions must be made regarding the nature of the terrain from which a data base is to be constructed; humans are very good at this task but computers are not. The optimum method for data base construction would combine the strengths of both computer and human; the computer for data manipulation, image enhancement techniques, statistical image classification and pattern recognition techniques, and the human for his own special expertise: applying his years of training and practice to make important decisions regarding the intrinsic properties of the terrain.

What has been developed is the capability to create radar image simulations for a host of applications. The basic problems have been identified and solved. What remains is to develop the applications. With each application will come unique, new, problems which must be solved. This is the area where much work remains to be done.

1.3 Potential Applications of Radar Image Simulation

The radar image simulation model developed on this contract is a rigorous mathematical model which treats the radar, scene, and image medium as a closed system. The variables which comprise the model of this closed system can be specified as precisely as is desired. The application for which the simulated radar image is to be created will dictate the degree of detail that is required for each of the simulation parameters and the data base.

Since this simulation model is a rigorous mathematical model, its potential applications are practically limitless. Rather than list and discuss the applications which immediately come to mind when thinking about radar image simulation (e.g., navigation, terrain analysis, damage assessment, guidance, image interpretation, feature extraction, mission planning, terrain classification, training, etc.) we wish to discuss a few less obvious potential applications. For instance, radar image simulation could become an invaluable tool in future radar system development programs. Simulation could be used to determine the optimum frequency, polarization, antenna, transmitter characteristics, receiver characteristics, and etc., for discrimination of the desired targets. In other words, simulation could be used to determine the minumum specifications and tolerances for the various (or just the critical) sensor parameters. It could also be used to evaluate the testing criteria themselves to determine the ability of the tests to measure the desired effects.

Once candidate radar systems are designed, simulation could be used to evaluate and compare competing designs. Their applicability to specific program goals and their capabilities to meet those objectives could be evaluated. Simulation could be used to compare the capabilities of existing radars and measure their applicability to the goals and objectives of a particular program and, thus, could be used to help make the decisions of whether to build a new system or to use an existing system. Simulation could be used to evaluate the parameter tradeoffs and to help determine the radar specifications for a new program. Simulation could also be used to define and evaluate scientific as well as engineering testing criteria. It could be used to produce sample data for evaluating the testing criteria, data handling systems, and for training personnel.

In other words, precisely because this model is mathematically rigorous it is extremely flexible. This flexibility and utility should not be lost but should, instead, be exploited to the fullest extent possible to help the U.S. Army attain its goals and mission objectives.

2.0 RADAR SIMULATION MODEL

2.1 Simulation Introduction

An analytical approach to the problem of the simulation of radar imagery was developed. This approach resulted in a unique description of the radar image simulation problem by considering the image product, radar system and ground scene to be a closed system. Figure 1 is a conceptual model for this closed system. Reference to this figure will show the relationships between the three basic parts of the closed system: image medium, radar system, and ground scene. A simplistic explanation of this system would be as follows. A transmitter generates short bursts (or pulses) of energy (at microwave frequencies) which are blocks of energy traveling at the velocity of light propagated into space by means of a directional antenna. The energy is confined to illuminate the surface of the earth in a narrow path. At any one instant, the area of the earth's surface illuminated by the transmitted pulse is limited in the direction of the pulse's propagation (range direction) by the physical length of the transmitted pulse and in the orthogonal direction (azimuth direction) by the beamwidth, real or synthetic, of the directional antenna. Objects which are reflective to the energy at a particular frequency or wavelength will re-radiate a fraction of the transmitted energy back to the antenna (this is called backscatter and the percentage of energy re-radiated back in a specific direction per unit area by a particular object is called its scattering coefficient - σ°). This energy will be received by the antenna and will be converted by the radar receiver to a video signal. The magnitude of this video signal at any instant in time is determined by the scattering properties of the objects having the same round-trip delay time from transmitter to ground to receiver. That is, for each pulse of energy, the receiver processes the received energy according to the time elapsed from the time the energy was transmitted; the energy re-radiated from objects which are closer to the radar will be received and processed before the energy from objects which are farther away. This video signal can be processed in a number of ways. The object is to convert the signal into an image and many ways are available.

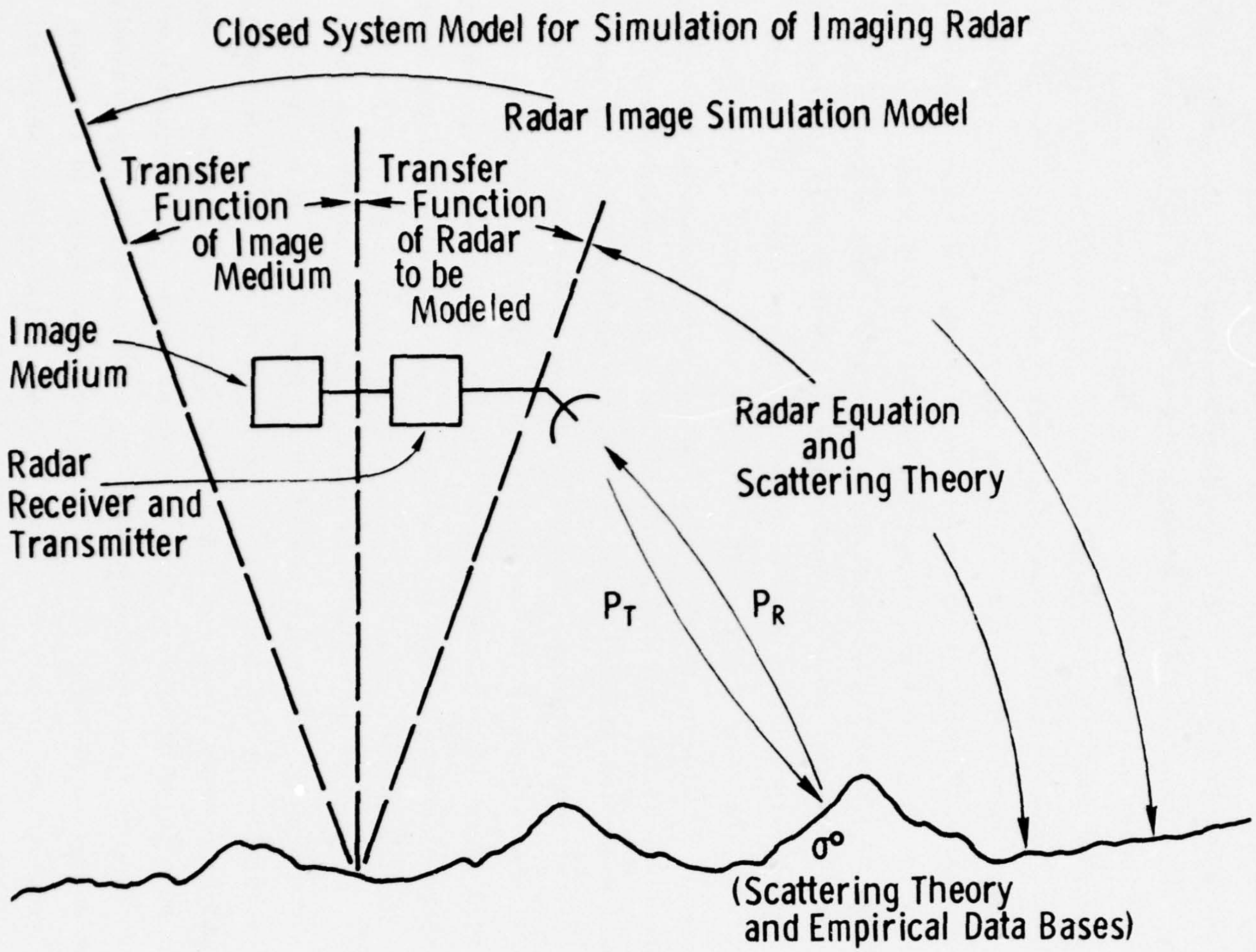

Figure 1. Closed System Model for Simulation of Imaging Radar

For example, it can be recorded directly on signal film; it can be converted to digital data and stored on magnetic tape; it can be displayed by intensity modulating the electron beam of a CRT (Cathode Ray Tube), and photographed; or it can be processed by other, more elaborate methods. The final image (the visual record of the radar return signal) depends on variations in the relative strengths of the signal returned from the different parts of the area imaged to produce contrasts, edges, and the range of brightness in the image. The two primary factors determining the strength of the signal observed on the final image produced, and consequently the brightness of an image point, are geometric and dielectric properties of the target.

2.2 Simulation Model

The development of the radar image simulation model will not be repeated here. The development is reported by Holtzman, et al.[7] and the results are summarized. Recalling that the relative brightness between white and black of a point in an image is called the greytone of that point, then the parameter we wish to calculate for each point in an image is the greytone. The greytone for each point in an image can be computed from the following equation:

$$G_{R_{c_2}} = G_{R_{a_1}} + \frac{255}{x}\left\{\gamma \log_{10}\left[\frac{P_{T_2}\sigma^\circ_{c_2}(\theta_{\ell_2})\Delta A_2 G_2^2(\theta_2)\lambda_2^2 R_1^4}{P_{T_1}\sigma^\circ_{a_1}(\theta_{\ell_1})\Delta A_1 G_1^2(\theta_1)\lambda_1^2 R_2^4}\right] + \log_{10}\left(\frac{k_2}{k_1}\right) + \gamma \log_{10}\left(\frac{M_2}{M_1}\right) + \log_{10}\left(1 + \frac{RN}{\sqrt{N}}\right)\right\} \tag{1}$$

$G_{R_{c_2}}$ = The instantaneous greytone, including fading, to be calculated for each discrete point for scatterers belonging to backscatter category 'c';

$G_{R_{a_1}}$ = The greytone value added to the value computed for each point to calibrate the range of brightness in an image according to a known reference;

γ = A property of the image medium (in this case, film, i.e. image medium transfer function);

P_{T_2} = The transmitter output power of the radar to be simulated;

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[7] Holtzman, J. C., V. H. Kaupp, R. L. Martin, E. E. Komp, and V. S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interactive Simulation Model, and Sample Results," TR 234-13, Remote Sensing Laboratory, The University of Kansas, Feb., 1976.

P_{T_1} = The transmitter output power of the calibrator;

$\sigma^o_{c_1}(\theta_{\ell_2})$ = The scattering coefficient per unit area for each ground point; corresponding to the local angle of incidence θ_{ℓ_2};

$\sigma^o_{a_1}(\theta_{\ell_1})$ = The scattering coefficient per unit area for the reference backscatter category; corresponding to the local angle of incidence θ_{ℓ_1};

ΔA_2 = Area of the ground spot resolution cell illuminated by the radar to be simulated;

ΔA_1 = Area of the ground spot resolution cell illuminated by the calibrator;

G_2 = One-way gain of the antenna of the radar to be simulated (in direction of ΔA_2);

G_1 = One-way gain of the antenna of the calibrator (in direction of ΔA_1);

λ_2 = Wavelength of the electromagnetic energy transmitted by the radar to be simulated;

λ_1 = Wavelength of the electromagnetic energy transmitted by the calibrator;

R_2 = The distance from the antenna of the radar to be simulated to each ground resolution cell;

R_1 = The distance from the antenna of the calibration system to the reference ground spot;

k_2, k_1 = Constants which depend upon the exposure time and on the film processing and development;

M_2, M_1 = Constants of proportionality relating the return electromagnetic power received by the antenna to intensity on the film;

N = The number of independent samples contained in uncorrelated resolution cells;

RN = A Rayleigh distributed random number between zero and one having zero mean value and variance equal to one.

Not explicitly shown in this equation (1) are the methods by which the various properties of the imaging problem have been satisfied. For instance, since the earth is not smooth and flat, when calculating the angle between a line perpendicular to the surface of the earth at a point and a line from that point to the antenna of the radar, the components of the slope (or tilt) of the surface in a particular coordinate system must be found. Shadow, layover, and range compression must all be treated. All of these effects, and more, are implicit in the greytone equation and are properly accounted for in the simulation model and are treated in detail in the referenced report.

Since that report was published, additional progress has been made toward the radar image simulation goal. A data base which contains significant elevation relief has been developed which can be used to show the effects, shadow, layover, etc., not demonstrated by the flat, agricultural data base used in the earlier work. The results[8] of this work are shown in Appendix A. The results presented in Appendix A are for a specific application of the general radar image products of a SLAR (Side-Looking Airborne Radar). Within the limitations imposed by modeling a SLAR, complete generality was retained. The computer program which was developed and is reported in Appendix A is easily altered to change radar, or other, parameters (so long as the modeled radar is a SLAR) and, therefore, is most useful for a variety of radar image simulation studies.

The expression for the image greytones, Equation (1), when it includes the necessary parameters for a particular radar flying at a specified altitude over a desired ground track, and when it includes the parameters of the mechanism by which the visual record is to be produced, and when it includes the backscatter and geometric properties of the terrain in the scene to be formed, becomes the mathematical model for the simulation of a specific radar system. The number of variables which interact in this model is relatively large. The level of detail required for specification of these parameters is dependent upon the intended application for which the final image product is to be used. If ten foot (or better) resolution with critical geometric and greytone fidelity is not necessary for the intended application, then it is very inefficient and costly to set up the simulation model and ground truth data base with this level of detail.

Since this radar image simulation model is mathematically rigorous, it is unnecessary to keep it in a particular configuration for fear

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[8] Martin, R. L., J. L. Abbott, M. McNeil, V. H. Kaupp and J. C. Holtzman, "Digital Model for Radar Image Simulation and Results," TR 319-8, Remote Sensing Laboratory, The University of Kansas, August, 1976.

that the model will be invalid in another configuration. The model is completely general and rigorous. The model should be simplified according to the specific requirements of each application. Only by doing this will the true value of the model be realized. Unfortunately, it is not known to what level of detail it is necessary to specify the ground truth data for any particular application. Since this represents the major cost in radar image simulation (ground truth data bases) the problem needs to be studied and the minimum degree-of-specification of the ground truth data bases for specific applications needs to be established. Only after this is accomplished can the true simplicity and value of the radar image simulation model developed here be realized.

This model has been tested against a data base consisting of geometric solids. The data base of geometric solids is a test data base that was constructed to evaluate the output responses of the simulation model. The geometric data base has been reported[9] and is included as Appendix B to this report. The geometric data base has been an invaluable testing tool because it provides us with the capability to measure objectively the response produced by our simulation model; the input data are completely known and the output response is completely predictable. Precisely because the output response is calculable can this test tool be used to measure the validity of our simulation model. Sample results of the application of our simulation model to the geometric data base are included in Appendix A.

2.3 Simulation Conclusions

At this stage in the development, the radar image simulation model is superior to the available data bases (at RSL) of real scenes for which we can test it. The next step will be to compare a simulated radar image and a real radar image of the same site. A very good data base is in the process of being built to serve this purpose. Upon completion of that data base, the next stage of refinement required to make this simulation model applicable to the various potential uses for simulated radar imagery will be determined. It should be said that by further refinement

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[9] Komp, E. D., V. H. Kaupp, and J. C. Holtzman, "Construction of a Geometric Data Base for Radar Image Simulation Studies," TR 319-1, Remote Sensing Laboratory, The University of Kansas, July, 1976.

is not necessarily meant additional complexity. In fact, simplification of the simulation model data requirements is sought. Of the three components of the closed system (image product, radar system, and ground scene) which are included in this model, the area in which simplification would have the greatest impact is in the ground scene data base. Ground scene data bases are terribly expensive to make and any reduction which can be made in the minimum level of detail required in the specification of the terrain data translates into dollars saved. A study needs to be conducted to establish these criteria for each of the potential applications for radar image simulations.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

What has been developed is the capability to create radar image simulations for a wide variety of applications. The basic geometrical problems have been identified and solved. What remains is to develop the applications. With each application will come unique, new problems which must be solved. These applications and the problems they bring are the areas where research effort must be concentrated in the future.

The study was conducted to investigate the applicability of radar image simulation to assist the U.S. Army in attaining several specific mission objectives. Each phase of the study explored new directions and broadened the general applicability of the concept (radar image simulation) to more areas. As the investigations continued, it became apparent that radar image simulation would in the future become an increasingly important tool. Radar image simulation has not lived up to its potential in the past because of several very real limitations. These limitations are being overcome with the use of high-speed digital computers, with the development of empirical microwave backscatter data banks, with more automated ways to develop the ground truth data bases. By the conclusion of this study the basic theoretical model had been developed. The basic technical problems had been defined. A rigorous mathematical model had been constructed. Remaining were the difficult problems associated with applying the model to particular radar systems for specific uses. Many radar phenomena are implicitly included in the model developed but depend upon implementation of the model for explicit representation. These phenomena together with the problems associated with constructing ground truth data bases almost invariably depend upon the parameters of the radar system being modeled and the intended use of the resultant simulated imagery. Even though a rigorous mathematical model has been developed which is practical to use, much future research effort is still required. To maximize the value of this simulated capability this research effort must be concentrated on the problems associated with specific applications of the simulation, ground truth data base construction, empirical data acquisition and theoretical modling, large image handling problems, and cultural scene simulation. These are the prime areas where immediate research is needed.

The general model developed in this study for radar image simulation can be used in a variety of applications. It can be used to simulate the image products of different radars and can accept a variety of sources of input ground truth data. Both SLAR (Side-Looking Airborne Radar), real and medium resolution synthetic aperture, and PPI (Plan-Position Indicator) radar images can be simulated. The model can handle equally well scenes of terrain having little or no relief and terrain having significant relief. The model is developed by Holtzman, et al.[7] Potential applications run the gamut from guiding remotely-piloted vehicles to photo interpreter (or pre-mission) training.

A very important milestone achieved in this study was the use of empirical backscatter data for the ground truth target reflectance information. The results of this study demonstrate the great value of using empirical backscatter data in the simulation model. This concept removes some of the previous limitations placed on simulation. Although the use of empirical data was a significant accomplishment, the limited amount of these data available requires theoretical backscatter models to extend and extrapolate the data for cases not available. Even with this limitation the model developed has a wide range of applications.

Most terrain can be modeled as collections of a number of homogeneous regions. These homogeneous regions are typically much larger than the resolution element of the radar system being modeled so they are normally called distributed targets. The model for radar image simulation developed here handles distributed targets exceptionally well. Cultural targets (hard targets) are not handled so well by this method because of the extreme complexity of adequately specifying the geometric and dielectric properties of this class of target. Another model involving optical techniques

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[7] Holtzman, J. C., V. H. Kaupp, R. L. Martin, E. E. Komp, and V. S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interactive Simulation Model, and Sample Results," TR-234-13, Remote Sensing Laboratory, The University of Kansas, Feb., 1976.

reported by Frost[10], et al., is the choice for simulation of cultural targets. The optimum method for simulating a scene consisting of both distributed and cultural targets would combine the strengths of both techniques; digital simulation techniques for distributed targets and optical techniques for cultural targets. Given this method for the simulation model, the capability to produce high-quality simulated radar images far exceeds the capabilities to produce high-quality data bases.

3.2 Recommendations

The objectives of the investigation have been fulfilled. The concept of radar image simulation has been developed and shown to be a viable tool for a multitude of potential applications. Many areas have been identified as a result of this study which require additional research in order that the promise offered by radar image simulation be realized. With significant progress in these areas, radar image simulation can be exploited to the fullest extent possible to aid the U.S. Army in attaining its goals and mission objectives. Without significant progress, radar image simulation will continue to be an expensive tool with only limited applications. The following discussion treats a partial list of the most obvious areas which need work. The discussions are based upon the problems and achievements encountered during the performance of this study. Importance has been assigned to these problem areas according to their significance as they appeared to the investigators.

3.2.1 Feature Extraction

The utility and versatility of radar image simulation is dependent upon automating the problems of ground truth data base definition. Clearly, the biggest single problem to be handled is that of identifying the geometric and electromagnetic properties of the scene which are to be transferred into the data base. The term most often applied to this task is feature extraction.

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[10] Frost, V. S, J. L. Abbott, V. H. Kaupp, and J. C. Holtzman, "A Mathematical Model for Terrain-Imaging Radar and Its Potential Application to Radar Image Simulation," TR 319-6, Remote Sensing Laboratory, The University of Kansas, November, 1976.

Classical techniques for feature extraction are primarily manual. Typically, a photo interpreter scans the intelligence data and draws upon his interpretation experience to decide what information to transfer manually to the data base under construction. These decisions are made with as few digital computer image enhancement techniques as possible. This reticence to use available enhancement routines is caused, in part, by the very nature of the automatic routines. They are not generally applicable to any but specific, well-structured, test cases. In addition, use of these techniques requires that the interpreter also be a computer expert. Moreover, the interpreter loses control and visibility of what he is trying to accomplish when he enters the computer world of automatic land-use classification, or pattern recognition, or region definition, or ad infinitum. These reasons have serious ramifications for feature extraction and, consequently, data base construction; they cost money. They cost money in the sense that it takes a much longer time to extract the features for a data base than might otherwise be necessary; data are manipulated by hand and the best information may not have been obtained.

Clearly, a tremendous improvement of the product developed, resources expended, and time required could be obtained if a workable marriage between computer and interpreter could be arranged. The computer is very good at manipulating vast amounts of data in short periods of time; the human is not. The human is beyond comparision when it comes to drawing upon learning experience to make decisions. The computer excels at clearly defined repetitive tasks, at statistical analyses, at image enhancements. A cooperative approach in which the human is used to make decisions and guide the processing directionof the software, and the computer is used to manipulate the data rapidly and easily and to remove the drudge from the human would be optimal in the sense of maximizing the return for resources expended and minimizing the time and effort. This cooperative approach is called interactive feature extraction, or automated feature extraction (not automatic feature extraction since this is impossible with the state of the art available today).

The concept of interactive feature extraction uses the human for his specific strengths and the computer for its specific strengths. In interactive feature extraction, the computer is used to display, enhance, manipulate, and otherwise aid the human interpreter as he performs his function. Viewed another way, the human is used to make decisions and to guide the computer in real-time as the programs run. Interaction can be accomplished by giving the interpreter a few basic tools with which to communicate his decisions to the computer; a keyboard for commands and joystick for direct specification are probably the minimum to be provided. Given these capabilities, the data base can be built directly as the feature information is processed and decisions are made. Boundaries separating different regions can be specified directly by the interpreter and, while the human is analyzing the next problem area, the computer can build the symbolic data base immediately and display the results. Depending upon the level of sophistication of the interactive software and the computer and display complex, tremendous savings of resources and improvements in efficiency and quality of the finished product are visualized. Given an interactive feature extraction system, special emphasis could be built in to maximize the use of the intelligence data normally available from which to define the geometry, dielectric properties, and elevation data which are required by radar image simulation.

3.2.2 Sensitivity Analysis

The utility and versatility of radar image simulation can be improved and the cost reduced if the minimum level of detail required to be in the data base for specific applications of radar image simulation can be determined. As previously noted, the most expensive part of the radar image simulation process is the building of the digital data base. If it can be determined, for a specific application, that the level of detail in the data base can be reduced, this translates directly into savings of time and money. It is recommended that such an analysis be conducted for the applications of radar image simulation most often used by the U.S. Army to attain its mission objectives.

3.2.3 Data Compression Techniques

Vast amounts of data must be processed for all but trivial applications of radar image simulation. As presently structured, data bases consist of a point in a matrix, at least, for each pixel (picture element) in the final simulated radar image. This means that most data bases for operational systems are exceptionally large and even the most trivial image handling is inordinately complex. Simple things such as rotations of data bases to alter the look direction (flight line) are tremendously time consuming and expensive. It is recommended that both techniques for data compression and alternate methods for information storage and retrieval be investigated. Since data bases used in radar image simulation have several unique features and since there are several critical limitations on them, techniques of data handling and compression for more general image processing are not necessarily optimal and may not be applicable. On the other hand, procedures rejected for more general image data bases may be well suited when aimed at radar simulation data bases for a specific application. Thus, investigation of data compression techniques which might be viable for data bases for radar image simulations should be coupled with sensitivity analyses.

Alternate methods for information storage and retrieval probably will require the assembly of a special purpose computer and memory device designed strictly for image processing applications. The great potential value of radar image simulation as a useful tool seems to argue that this investigation needs to be conducted.

3.2.4 Image Quality Measurements

The quality of a simulated radar image or, for that matter, a real radar image to suit its intended purpose must presently be assessed by a human being. This determination of quality is very subjective and relies on the judgements of different people who have different bases of experience from which to judge. As the number of applications increases for both simulated and real radar images.so also increases the necessity to use more objective image quality measurements. Presumably, these objective image quality measurements would use a digital computer to relate the data of the visual record (recorded in the image) to application. Certain statistical properties of the image should be used to predict the usefulness of an image to satisfy specific objectives. Such a set of measurement criteria do not presently exist. It is recommended that an investigation be conducted to define such a set of image quality measurement parameters.

This set of image quality criteria would be invaluable to the recommended sensitivity study. In fact, a limited study of the type recommended here will be required for success in the sensitivity study. Moreover, as use of radar image simulation increases, necessity will decree that these criteria be identified, application by application. The opportunity exists to consolidate these individual efforts and to define the criteria in advance of specific need. Success here will make it easy to relate the value of radar image simulation to each new application and will allow different agencies, or labs, or people, to understand how a particular image may satisfy their needs.

3.2.5 Empirical Data Measurement Program

The concept of radar image simulation has been shown to be a valuable tool for a multitude of potential applications. A major obstacle must be overcome before the promise offered by radar image simulation can be realized. In fact, that same obstacle is a main reason why radar imagery is not used to the fullest extent possible. So little is presently known about the backscatter properties of most objects in the terrestrial envelope that the visual record of this parameter, present in images as the greytone variation, is not properly utilized for the information it contains. With more certain knowledge of the backscatter properties of objects in a scene would come a significant increase in intelligence gathered from each image. That obstacle is the necessity to have backscatter data available for as much of the terrestrial envelope at as many microwave frequencies and polarizations as required to attain the mission objectives of the U.S. Army. If radar image simulation is going to be used increasingly by the U.S. Army (or Department of Defense), reliance on existing small programs and the mission objectives of other agencies to collect these data is ill-founded. It will require many years and good luck for this need for backscatter data to be fulfilled in this way.

We recommend that a five-pronged study be implemented to gather these required data. First, the major projected applications for radar image simulation should be identified. After this is done, the specific microwave reflectivity categories, frequencies, and polarizations can be identified for which backscatter data will be required. Second, a data collection system should be developed which will gather these data. Whether this system is a synthesis of existing hardware, or designed and built specifically for this requirement, or both, is immaterial. Very probably there already exists hardware in the defense inventory which could be used. If so, this good fortune would reduce the cost of this phase of the program by a substantial amount. Third, a program should be designed and implemented to collect the required data. The data should be collected for as many seasonal variations of each category as decreed by the intended applications. Next, a program must be designed to process the data. This program will have to organize, catalogue, and file these data in addition to processing the raw data. Last, theoretical electromagnetic scattering studies need to be initiated for certain specific requirements. It is not reasonable to expect to measure backscatter data for all permutations of the variables. There are too many combinations. This is where theoretical studies show their value. Theories can be developed to extend and extrapolate the measured data for the cases which are not measured.

This program, or some other realization of it, is required if the U.S. Army (or Defense Department) is to have an active and viable radar image simulation program. It is not the specific steps of the program outlined that is important, it is the collection of these data. Without these data, neither can the concept of radar image simulation nor can radar data itself be exploited to the fullest extent possible to help the Army attain its goals and mission objectives.

3.2.6 Theoretical Models

The increasing applications for radar image simulation as well as interpretation of radar imagery require an even larger store of backscatter data. All radar image simulations must use some model for the reflectivity properties (backscatter) of the objects in the scene. These data are required by the simulation model to produce the greyscale data in the simulated image. It is not reasonable to expect to measure and record the backscatter data for all possible permutations and combinations of the variables: Frequency, polarization, categories, seasonal changes, and etc. Theoretical models must be developed to extend and extrapolate the measured data to cases which have not been or cannot be measured. This is a real need, not a whimsical musing. These theoretical models will form an integral part of radar image simulation as applied to the various applications.

3.2.7 Other Sensor Systems

As it is believed that the trend in intelligence gathering systems is to use electro-optical systems which are an aggregate of a number of different sensors, it is recommended that the concept of simulation be extended to these other sensors. Radar is just one sensor of this aggregate. Another sensor, for example, which seems to have great potential value is the FLIR(Forward-Looking Infra-Red). Other sensors also exist. These sensors need to be modeled and the underlying phenomena investigated. It would appear that transfer functions analogous to the famous radar equation relating the various aspects of sensor, scene, and medium can be obtained. Since applications for these sensors are expected to increase, it is recommended that these investigations be conducted.

3.2.8 Develop Applications for Radar Image Simulation

The general concept of radar image simulation has been developed. What remains is to extend the general concept to specific applications. With development of each application will come unique, new, problems which must be solved. These problems will run the gamut from feature extraction for building data bases to image handling problems. Some of the more important problems that need to be tackled are those related to making operational or nearly operational systems and research more cost effective. The studies required to attain this goal will carry over into the research area and will open the door to increasing the number of applications for radar image simulation.

It is recommended that the general concept be developed for several specific applications, the problems identified and solved, the value determined. Doing this will document the value of radar image simulation and will increase the demand for solution of the problems presented in this section. In this way the use of radar image simulation can be accelerated and exploited to the fullest extent possible to help the Army attain its objectives.

3.2.9 Cultural Scene Simulation

The simulation of the radar return from cultural objects by digital techniques is very difficult. Extensive knowledge of the geometric and dielectric properties of the objects is required. Also, it takes a lot of computer time to use these data. Alternate techniques for the simulation of the radar return from cultural objects need to be investigated.

A promising potential candidate is offered by an optical filtering technique[10]. This optical filtering model needs to be investigated to determine its range of applicability together with alternate processing techniques to realize the model. For instance, the model might be realized on the digital computer instead of the optics bench by digital bandpass filtering techniques. Techniques need to be devised to combine the optical radar simulation with the digital simulation. The resulting hybrid radar image simulation model would combine the optical simulation for cultural objects with the digital simulation for distributed objects. Great potential savings in time and resources are offered by this hybrid.

In addition, other techniques need to be investigated. Development of a number of techniques for simulation of a particular class of object would simplify the simulation process and reduce costs.

3.2.10 Validation of the General Radar Image Simulation Model

It is recommended that a study be conducted to produce simulated imagery of a specific area for comparison with real imagery of the same area. The area selected should consist of as many of the variables encountered in radar imagery as is possible. A good data base should be produced for this area. This data base should be used as input to the simulation model and the output simulated radar imagery should be compared to the real imagery. The results of this study would establish the true potential value of radar image simulation. This, then, is a way in which the model can be validated and will establish a baseline of quality for radar image simulation.

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[10] Frost, V. S., J. L. Abbott, V. H. Kaupp, and J. C. Holtzman, "A Mathematical Model for Terrain-Imaging Radar and Its Potential Application to Radar Image Simulation," TR319-6, Remote Sensing Laboratory, The University of Kansas, November, 1976.

ABBREVIATIONS AND ACRONYMS

Å Angstroms (10^{-10} meters)

CRT Cathode Ray Tube

FLIR Forward-Looking Infra-Red

PI Principal Investigator

PPI Plan-Position Indicator

Pixel Picture Element

RSL Remote Sensing Laboratory, University of Kansas, Lawrence, Kansas

σ^o Scattering Coefficient (Backscatter). The percentage of energy reradiated in a specific direction per unit area by a particular object.

SLAR Side-Looking Airborne Radar

θ Angle of Incidence. Angle between antenna electrical boresight and a local vertical from the antenna.

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APPENDIX A

DIGITAL MODEL FOR RADAR IMAGE SIMULATION AND RESULTS

The following technical report (TR 319-8) prepared by the Remote Sensing Laboratory, The Center for Research, Inc., University of Kansas, is included in this report to provide the rationale for the discussion of Section 2.

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DIGITAL MODEL FOR RADAR IMAGE SIMULATION AND RESULTS

Remote Sensing Laboratory
RSL Technical Report 319-8

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ABSTRACT

The theory and implementation of a digital closed-system, radar image simulation model are reported. Visual results of several SLAR (Side-Looking Airborne Radar) simulations with a slant range mode are presented. The model and computer software, which were developed at Remote Sensing Laboratory, have the capability of producing SLAR or PPI (Plan-Position Indicator) imagery. A test of the integrity of the model and software implementation was conducted with a data base consisting of computer-generated geometric objects. This allowed the calculable shadow and layover response to be employed for validation of the operation of the SLAR model. Though the shapes of objects for the test site were artificially generated, the dielectric properties encompassed in the scene were derived from empirical backscatter data. This input reflectivity information originated from the agricultural/soil moisture data bank available at the Remote Sensing Laboratory.

Pictorial examples reveal that the simulated imagery realistically models radar effects seen in real imagery; for example, layover, shadow and fading. Examination of layover and shadow on the imagery produced for various flight tracks reveals that the simulation package is performing well. As an example of the application of radar image simulation to "real world" problems, a simple study of the visual effects caused by changing frequency or polarization or both is included. The frequency-polarization tests indicate the applicability of simulation for optimum discrimination studies, feature enhancement tasks, and general radar system design.

1.0 INTRODUCTION

A theoretical model has been developed at the Remote Sensing Laboratory in an effort to simulate radar imagery. The result is a closed-system model; that is, a mathematical formulation which encompasses the phenomena that affect the known, transmitted, pulsed energy and subsequently the final image product of a radar system. The implementation of the model with suitable input data and software routines for a digital computer has been accomplished. SLAR and PPI formatted imagery have since been successfully simulated. A description of the radar image simulation theory (in particular for the SLAR model), applications of the model, and experimental results are included in this document in addition to a copy of the digital simulation program and a brief outline of the necessary input data.

Radar image simulation (RIS) techniques have been applied to military tasks, for example, interpretation training, navigational aids and guidance systems for unmanned airborne vehicles[1]. The suitability of RIS for technologically advanced electronic guidance has been recognized in light of recent testing of tactical and strategic SLCM's (Sea-Launched Cruise Missiles) and ALCM's (Air-Launched Cruise Missiles) in the United States. The resources exist at RSL to develop simulation models for potential hybrid guidance schemes employing, for instance, multi-spectral sensors. The capability to predict sensor (and successful mission) performance must have an impact on the design of such future systems as well as, of course, use in providing the reference information.

RIS also has importance as an instrument for research in the areas of electromagnetics and scattering theory and it provides a method of predicting and optimizing system performance when information concerning the microwave response of terrestrial scenes is available. Although volume scattering theories and backscatter data for vegetation have existed for

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[1] For a more comprehensive discussion of applications of radar simulation see, "Military-Oriented Applications of Radar Image Simulation," (authors - J. C. Holtzman, V. H. Kaupp, and J. L. Abbott), Remote Sensing Laboratory, University of Kansas, TR 319-10. See also Scientific American, February, 1977, "Cruise Missiles," (author - Tsipis).

several years, it is doubtful that this knowledge has been previously assembled (that is, to visually predict a radar response) in the manner presented in this report. For example it would be very difficult for one to postulate or mentally envision the differences in radar images (for a particular complex ground scene in which the frequency of the radar was changed) without the aid of simulation of the imagery. Thus, the point of the frequency/polarization study is that the microwave response of a terrestrial scene varies rapidly with frequency and that optimum performance of a discrimination radar can be sought. Another valuable application of RIS is estimation of seasonal variations on the radar imagery, particularly for radar guidance systems in which the resolution and dynamic range of greytones (image density) are fixed. For example, it would be important to know before flight whether the presence of a heavy snow fall over a target area would mask the otherwise dominant characteristics of the scene.

This work is organized into three subtopics, (1) SLAR model theory, (2) the mechanics of producing radar image simulations, and (3) results which include simulated imagery from several experimental flight situations. The ground scene for this work is an artificial data base, in that the elevation data was assigned by a computer to describe three dimensional objects on a plane. The purpose of employing a deterministic scene was to allow the researchers to calculate known shadow and layover response to a SLAR at a known altitude and distance from the near range of the data base for verification of accuracy of the SLAR simulation program. Since radar return also depends on the backscatter characteristics of the ground, empirical sigma zero data were associated with specific areas within the scene. The significance of this may not be clear until it is realized that the simulated imagery will accurately represent the dynamic range of image density on the film that a real radar would produce from the same scene. What has been attempted here has been to provide a fine resolution data base which doubles as a test mechanism for SLAR simulation. Some of the results may be surprising to those persons not familiar with multi-frequency/polarization imagery; nevertheless, the imagery included reinforces the idea that radar image simulation or similar modeling techniques may have many interesting applications.

Before proceeding to the description of the mechanics of simulating SLAR images, the theory which is the basis of the closed system model will be presented to illustrate the determination of greytones (image density).

2.0 RADAR IMAGE SIMULATION THEORY

In an imaging SLAR, a short pulse of microwave energy is transmitted into space from an antenna whose boresight is orthogonal to the flight track. This energy, confined within the antenna beam solid angle (and sidelobes) strikes the ground. A portion is reradiated in the direction of the antenna (amount governed by backscatter characteristics and geometry of the scene) and is detected by the receiver. The video signal can be processed in various ways. For example, it can be recorded directly on signal film, it can be converted to digital data and stored on magnetic tape, it can be displayed by intensity modulating the beam of a CRT (Cathode Ray Tube) and photographed, or processed by other, more elaborate methods. The final image (the visual record of the radar return signal) depends on variations in the relative strengths of the signal returned from different parts of the area imaged to produce contrasts, edges, and the range of image brightness (greytones). The two primary factors determining the strength of the signal observed on the final image produced, and consequently the brightness of an image point, are geometry and dielectric properties.

Simulation of radar images may be accomplished by mathematical operations on the known parameters of the radar to be modeled and site to be imaged to form a visual display. The general technique utilized in this document is reported by Holtzman, et. al.[2] In this method the radar equation is used to relate target empirical backscatter coefficients to relative image greytones. A general form of the greytone expression is developed in this section. Also included in the simulation model are (1) the effects of relief and tilting of resolution cells, (2) layover and shadow, and (3) radar fading.[2]

The general model for mean power received is based upon the radar equation which may be expressed as[3]

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2 Holtzman, J. C., V. H. Kaupp, R. L. Martin, E. E. Komp, and V. S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interactive Simulation Model, and Sample Results," TR 234-13, Remote Sensing Laboratory, The University of Kansas, Feb., 1976.

3 Moore, R. K., Remote Sensing Manual, (Editor - Reeves), Chapter 9, American Society of Photogrammetry, 1975.

$$\overline{P}_r = \frac{P_T \cdot \sigma^\circ(\theta_\ell) \cdot \Delta A \cdot G^2(\theta) \cdot \lambda^2}{(4\pi)^3 R^4} \tag{1}$$

where $\overline{P}_r$ = Average return power received at the antenna terminals;

P_T = Average transmitted power;

$\sigma^\circ(\theta_\ell)$ = Scattering coefficient of the ground spot resolution cell (function of local angle of incidence, θ_ℓ, the incident wavelength (λ), transmit/receive polarization, and surface parameters);

θ = Radar incidence angle to surface;

$G(\theta)$ = Antenna gain in the direction of ΔA (function of the radar system modeled and assumed to be identical in the return direction);

λ = Wavelength of the incident wave;

R = Distance to the ground spot resolution cell (A function of altitude and look angle);

ΔA = Area of the ground spot resolution cell.

The area ΔA of a resolution cell for a pulsed radar can be modeled as[2]

$$\Delta A = w\ell = \left| \frac{h'\phi}{\cos\theta \cos\theta_A} \right| \cdot \left| \frac{c\tau'}{2\sin(\theta - \theta_c)} \right| \tag{2}$$

where: w = Size of resolution cell in the along-track direction;

ℓ = Size of resolution cell in the cross-track direction;

h' = Height difference between the cell and the radar;

ϕ = Antenna beam width;

θ = Radar incidence angle;

τ' = Signal pulse width;

θ_A = Local slope of resolution cell in the along-track;

θ_c = Local slope of resolution cell in the across-track.

---

[2] Holtzman, J. C., V. H. Kaupp, R. L. Martin, E. E. Komp, and V. S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interactive Simulation Model, and Sample Results," TR 234-13, Remote Sensing Laboratory, The University of Kansas, February, 1976.

If the average return power $\overline{P}_{r_{c_1}}$ from a particular category of scatterer (C) at a particular angle of incidence (θ_1) for a calibration system is known, then equation (1) can be rewritten:

$$\overline{P}_{r_{c_1}} = \frac{P_{T_1}\sigma^{\circ}_{c}(\theta_{\ell_1}) \cdot \Delta A_1 \cdot G_1{}^2(\theta_1)\lambda_1{}^2}{(4\pi)^3 \cdot R_1{}^4} \quad (3)$$

Equation (1) can be used to define the average return power $\overline{P}_{r_{c_2}}$ from the same category of scatterer (C) at a different angle of incidence (θ_2) for the radar system being modeled.

$$\overline{P}_{r_{c_2}} = \frac{P_{T_2}\sigma^{\circ}{}_{c}(\theta_{\ell_2}) \cdot \Delta A_2 \cdot G_2{}^2(\theta_2)\lambda_2{}^2}{(4\pi)^3 R_2{}^4} \quad (4)$$

Dividing Equation (4) by Equation (3) gives:

$$\overline{P}_{r_{c_2}} = \overline{P}_{r_{c_1}} \left[\frac{P_{T_2}\sigma^{\circ}{}_{c}(\theta_{\ell_2})\Delta A_2 G_2{}^2(\theta_2)\lambda_2{}^2 R_1{}^4}{P_{T_1}\sigma^{\circ}{}_{c}(\theta_{\ell_1})\Delta A_1 G_1{}^2(\theta_1)\lambda_1{}^2 R_2{}^4} \right] \quad (5)$$

Thus the average return power for each point in an image (for any particular category of scatterer) can be found if the average return power for one point belonging to a category is known (σ°_c absolute) in addition to backscattering coefficients and angles of incidence for both points.

The visual presentation medium modeled was photographic film. An image density which is related to the average return power is displayed on real SLAR images. This image density is often called a greytone, which is a relative measure, that is, it was produced with respect to some calibration reference. In a digitized image, the greytone represents a specific image density level within the possible dynamic range on the image. The return power (related to video intensity), properties of the film and photographic processing methods determine the photographic density (D) on the film by[4]

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[4] Goodman, J. W., Introduction to Fourier Optics, Chapter 7, McGraw-Hill, 1968.

$$D = \gamma \log_{10} I + \log_{10} k \qquad (6)$$

where: γ = Gamma of the film;

k = A positive constant which depends upon the exposure time and on the film processing and development;

I = Image intensity;

D = Photographic density.

This relationship holds true in the linear portion of the film dynamic range. If a linear radar receiver is assumed, the the intensity (I) is directly related to the average return power ($\overline{P}_r$).

$$I = M \cdot \overline{P}_r \qquad (7)$$

where: M = A proportionality constant.

Rewriting (6) to incorporate (7) gives

$$D = \gamma \log_{10} \overline{P}_r + \log_{10} k + \gamma \log_{10} M \qquad (8)$$

This result will be used for the final greytone expression.

The photographic density (D) is defined by[4]

$$D = \log_{10}\left(\frac{1}{\tau}\right) \qquad (9)$$

where the film transmittance τ is given by[4]

$$\tau = \frac{I_t}{I_o} \qquad (10)$$

with: I_t = Transmitted intensity;

I_o = Incident intensity.

Rewriting Equation (9) produces

$$D = \log_{10}\left(\frac{I_o}{I_t}\right) \qquad (11)$$

---

[4] Goodman, J. W., Introduction to Fourier Optics, Chapter 7, McGraw-Hill, 1968.

The normalized value of the density (D) is the greytone level. The image simulations were digitized into 8-bit binary words for display, allowing 256 distinct greytones. If the optical density used in a simulation is in the range from 0 to X, the linear portion of the film dynamic range is required to be of sufficient size that

$$I_{t_{min}} = 10^{-X} I_o \tag{12}$$

In the simulated imagery produced at RSL, a greytone of 255 was associated with white and zero with black. This is the expression for a positive. This signal is then used to intensity modulate a CRT (a positive image). This image is then photographed (a negative). The negative is then used to produce a photo (a positive) which is the final product. The greytone level G_r corresponding to a density D was given by

$$G_r = \frac{255}{x} \cdot D \tag{13}$$

The general relationship between the average return power and greytone level for each resolution cell in the simulated image is obtained by rewriting Equation (8), incorporating Equations (5) and (13):

$$G_{r_{c_2}} = G_{r_{c_1}} + \frac{255}{x} \left[\gamma \log_{10} \left\{ \frac{P_{T_2} \sigma^{\circ}_{c_2}(\theta_{\ell_2}) \Delta A_2 G_2^{\,2}(\theta_2) \lambda_2^{\,2} R_1^{\,4}}{P_{T_1} \sigma^{\circ}_{c_1}(\theta_{\ell_1}) \Delta A_1 G_1^{\,2}(\theta_1) \lambda_1^{\,2} R_2^{\,4}} \right\} + \log_{10}\left[\frac{k_2}{k_1}\right] + \gamma \log_{10}\left[\frac{M_2}{M_1}\right] \right] \tag{14}$$

This equation states that the relative greytone values for each point in an image corresponding to any angle of incidence of a category of scatterers can be obtained if the greytone and angle of incidence is known for one discrete point in any category. This equation is the general result which establishes the relationship between the average return power and relative greytone levels for a simulated radar image. It should be pointed out that on a radar image and, thereby, on a simulated radar image, the important parameter is the relative greytone level between points on the image and not the absolute values of the greytone. Since this is true, Equation (14) can be used to establish the relative greytone levels between all categories of scatterers included in an image provided that the absolute values of the scattering coefficient, σ°, and the appropriate angles of incidence for all points are known and provided that, in addition, the greytone of one point in the image is known. The more general result is, then:

$$G_{r_{c_2}} = G_{r_{a_1}} + \frac{255}{x}\left[\gamma \log_{10}\left(\frac{P_{T_2}\,\sigma^\circ_{c_2}(\theta_{\ell_2})\Delta A_2 G_2^2(\theta_2)\lambda_2^2 R_1^4}{P_{T_1}\,\sigma^\circ_{a_1}(\theta_{\ell_1})\Delta A_1 G_1^2(\theta_1)\lambda_1^2 R_2^4}\right) + \log_{10}\left(\frac{k_2}{k_1}\right) + \gamma \log_{10}\left(\frac{M_2}{M_1}\right)\right] \qquad (15)$$

where: $G_{R_{c_2}}$ = Greytone level of some point belonging to category 'c' and having the scattering coefficient, $\sigma_{c2}^\circ(\theta_{\ell 2})$, measured at the appropriate angle of incidence, $\theta_{\ell 2}$, by a radar system;

$G_{R_{a_1}}$ = Known greytone level for a particular point belonging to category 'a' and having the scattering coefficient, $\sigma_{a1}^\circ(\theta_{\ell 1})$, measured at the appropriate angle of incidence $\theta_{\ell 1}$, by a calibrated system.

Equation (15) is the general theoretical result which has been implemented in a computer simulation package. Implicit in this equation are the effects of geometry which cause the phenomena of shadow, layover and reflection of microwave energy (in accordance with local tilt of resolution cells). Reference [2] contains a more complete treatment of these effects.

2.1 Fading

Equation (15) gives the impression that a deterministic process is occurring. The interaction between the radar and a surface is a random process to some extent, and the mean value of the greytone level for a given set of parameters is described by Equation (15).

If one assumes that the process can be modelled as additive, i.e. signal = mean + noise, a model for the true statistical properties of the phenomena can be derived. The return power from a single scatterer has a noise-like characteristic that follows a Rayleigh distribution[5]. This

[5] Moore, R. K., Radar for Geoscience Instrumentation, Chapter 5.6. Geoscience Instrumentation, (E.A. Wolfes, Editor), John Wiley and Sons.

distribution is characterized by equal mean and standard deviation. The probability for N' such scatterers follows a chi-squared distribution with 2N' degrees of freedom. The mean and variance of chi-squared distribution are given by:

mean = degrees of freedom = $2N' = \mu$

variance = 2 (mean) = $4N'$

standard deviation = $\frac{\text{mean}}{\sqrt{N'}}$

For radar, the number of independent samples in a given resolution cell is given by[5]:

$$N = \frac{2w}{L} = \frac{2h'\phi^2}{\lambda \cos\theta} \tag{16}$$

where: θ = Radar incidence angle;

w = Azimuth resolution;

L = Horizontal aperture length of antenna ($L \approx \frac{\lambda}{\phi}$);

h' = Effective altitude;

ϕ = Antenna beamwidth;

λ = Wavelength of microwave energy.

Therefore, the standard deviation due to fading can be represented by:

$$\frac{\text{mean}}{\sqrt{N}} = \overline{S}_x = \frac{\mu}{\sqrt{N}} \tag{17}$$

For a particular cell, the return power (P_r) can be represented as:

$$P_r = \mu + \overline{S}_x \cdot RN \tag{18}$$

where: RN is a random variable which has the desired characteristics (chi-square distribution with mean and variance described above).

For computational purposes the random variable (RN) can be normalized to zero mean and variance of one leading to:

$$P_r = \mu + \frac{\mu}{\sqrt{N}} \times RN = \mu\left(1 + \frac{RN}{\sqrt{N}}\right) \tag{19}$$

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[5] Moore, R. K., Radar for Geoscience Instrumentation, Chapter 5.6, Geoscience Instrumentation, (E. A. Wolfes, Editor), John Wiley and Sons.

This can be shown in terms of greytones[2] as

$$G_r = G_{r_{c_2}} \left(1 + \frac{RN}{\sqrt{N}}\right) \tag{20}$$

where: $G_{r_{c_2}}$ = Equation (15)

The term, due to fading, is described by:

$$G_{r_{FAD}} = \frac{255}{x} \gamma \log_{10} \left(1 + \frac{RN}{\sqrt{N}}\right) \tag{21}$$

where x is the theoretical dynamic range of the film.

This equation used in conjunction with Equation (15) defines the image intensity a specified SLAR would produce corresponding to a particular target area. Geometrical effects that enter the determination of target area (resolution cell size and local orientation) are treated rigorously in the digital simulation model and are thoroughly covered in Reference [2]. The SLAR simulation programs are able to treat both the case of little or no and of significant relief. Second-order effects such as multipath which may occur due to local geometry have not yet been implemented in the SLAR program.

The succeeding sections discuss the macro-flow chart of the SLAR programs, the input data which may be adjusted by the user according to the application, and the data base that has been an experimental tool for validation of the closed system model for digital simulation of radar images. A copy of the SLAR programs is included as Appendix I.

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[2] Holtzman, J. C., V. H. Kaupp, R. L. Martin, E. E. Komp, and V. S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model, and Sample Results," TR 234-13, Remote Sensing Laboratory, The University of Kansas, February, 1976.

3.0 SLAR SIMULATION PROCESS

The SLAR simulation package (a copy is included as Appendix I) consists of four separate programs and associated subroutines as given in Figure 1. They can be run separately so that (1) the failure of one module does not affect successful completion of the previous programs, and (2) experimentation can be conducted in one program for a particular radar being modeled, thus avoiding the cost of rerunning the entire package. For example, it might be desired to change a reference greytone or the dynamic range in the simulated image. This sturcture for the software would allow SLAR Geometry, SLAR Slope, and SLAR Shadow (the first three programs) to be run once, and the output tape to be used for several successive experimentations of SLAR Greytone (the fourth program).

MACRO-FLOW CHART OF SLAR SIMULATION PROCESS

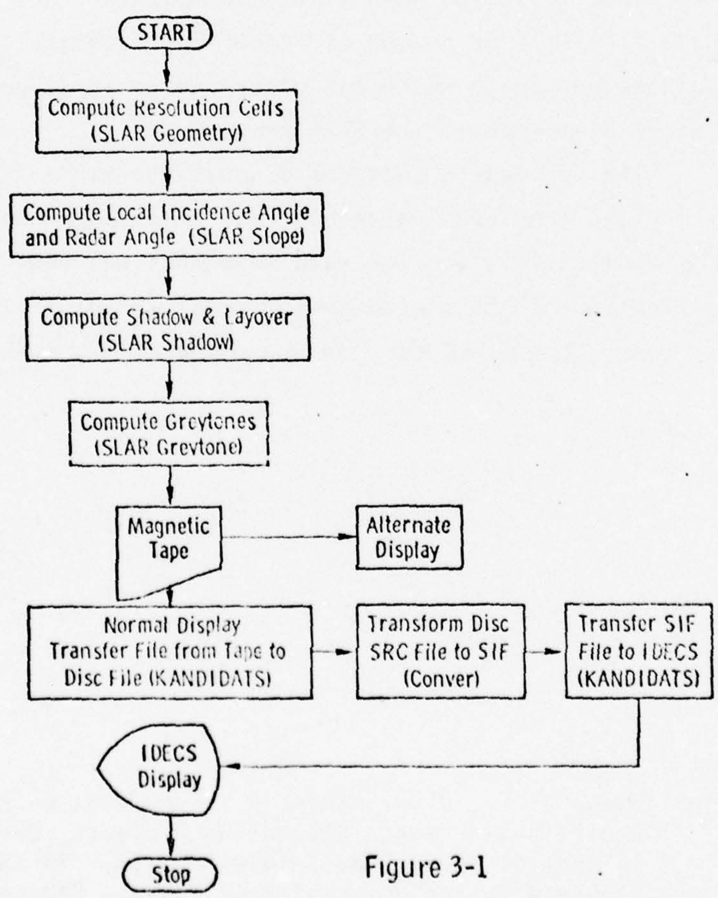

Figure 3-1

3.1 Input Parameters

Four arrays, RADAR, GROUND, REFER and PROCES contain locations for data which vary with the desired application of the SLAR simulation and may be adjusted by the user. Descriptions of the arrays are contained in Figure 2 which is a summary of all parameters (summarized from program listing in Appendix I) which are changeable. The asterisks denote exceptions as explained at the conclusion of the listing. The user must have a minimal knowledge of the interdependence of the radar and ground parameters before attempting to alter the values in these matrices. For example, a change in the parameter RADAR(6) may necessitate compensation in GROUND (1), (2), (5), (10) and RADAR (7), (8), and (9) parameters.

3.2 Data Base

An artificial data base (scene consisting of geometrical solid shapes) was used to test the operation of both the simulation model and the software. A data base of geometrical shapes was used for these purposes because of the known input/output response characteristics of such a data base. The input was known exactly and the output was deterministic and calculable. The artificial data base described by Komp[6] is a composite of three dimensional objects. The matrix of elevation and category data (stored in a computer word for each position) which forms the data base is 700 by 1000 points in extent, representing 20 by 20 foot resolution. Thus, the data base appears to be 14,000 by 20,000 feet. Known empirical backscatter characteristics, in the form of sigma zero versus angle of incidence, for ten separate vegetation categories, have been assigned to the ground scene. The value of such a data base with completely specified dielectric and geometric properties is that it provides us with a means to validate the SLAR simulation. The calculable response (eg., extent of shadow and layover due to each object) of the geometric solids to various flight tracks, frequency/polarization combinations, near and far range depression angles, etc., allows the final image product to be judged objectively. Naturally, a high resolution (or large matrix) data base can be generated by a computer; however, the number of data points used will be limited by the specific application and computer resources.

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[6] Komp, E. D., V. H. Kaupp, and J. C. Holtzman, "Construction of a Geometric Data Base for Radar Image Simulation Studies," TR 319-1, Remote Sensing Laboratory, The University of Kansas, July, 1976.

TABLE I

SIMULATION PARAMETERS

SIMULATED RADAR PARAMETERS

**RADAR (1)	ORIENTATION (# OF DEGREES)
**RADAR (2)	LATITUDE OF START (DEGREES)
**RADAR (3)	LONG. OF START OF FLIGHT TRACK
**RADAR (4)	LATIT. OF END OF FLIGHT TRACK
**RADAR (5)	LONG. OF END OF FLIGHT TRACK
RADAR (6)	SWEEP DELAY TIMES (SECONDS)
RADAR (7)	SWEEP LENGTH TIME (SECONDS)
RADAR (8)	PULSEWIDTH (SECONDS)
RADAR (9)	AZIMUTH BEAMWIDTH (RADIANS)
**RADAR (10)	PRF (HERTZ)
**RADAR (11)	AIRSPEED (FT/SEC)
RADAR (12)	ALTITUDE (MSD. IN FT.)
RADAR (13)	FREQUENCY (GHz)
RADAR (14)	POLARIZATION (1,HH;],VV;3,HV;4,VH)
*RADAR (15)	NEAR RANGE DIST. (FT) (COMPLETED)
RADAR (16)	POWER TRANSMITTER (WATTS)
RADAR (17)	# OF INDEPENDENT SAMPLES (REFERENCE 2)
RADAR L18-20)	NOT PRESENTLY USED

GROUND TRUTH PARAMETERS

GROUND (1)	DISTANCE FROM FLIGHT TRACK
GROUND (2)	DATAPT SIZE (ALONG TRACK)
GROUND (3)	DATAPT SIZE (ACROSS TRACK)
GROUND (4)	IS FLAT EARTH REASONABLE (1=YES)
GROUND (5)	SIZE OF MATRIX (ALONG TRACK,#DATA PTS)
GROUND (6)	SIZE OF MATRIX (ACROSS TRACK,#DATA PTS)
GROUND (7)	AVERAGE HEIGHT OF GROUND-IF FLAT EARTH
GROUND (8)	NO CATEGORIES PRESENT (1=TRUE)
*GROUND (9)	RESOLUTION SIZE IN CROSS-TRACK (COMP)
*GROUND (10)	RESOLUTION SIZE IN ALONG-TRACK(COMP)
*GROUND (11)	# OF DATAPT IN ALONG DIRECTION (COMP)
*GROUND (12)	# OF CELLS ALONG IN GEO. MATRIX (COMP)
*GROUND (13)	# OF CELLS ACROSS IN GEO. MATRIX (COMP)
GROUND (14-20)	PRESENTLY NOT USED

TABLE I (CONTINUED)

***REFERENCE CELL PARAMETERS

REFER HOLDS INFORMATION ABOUT THE REFERENCE CELL AS FOLLOWS

REFER (1)	REFERENCE GREYTONE
REFER (2)	PT. POWER TRANSMITTED
REFER (3)	SIGMA °-(FUNCT., ANG.) REFER = [dB/10]
REFER (4)	AREA OF CELL
REFER (5)	ANTENNA GAIN - F(THETA), REFER = $GAIN_2$
REFER (6)	REFERENCE RADAR WAVELENGTH, REFER = R^2
REFER (7)	RANGE TO CELL SQUARED
REFER (8-10)	PRESENTLY NOT USED

PROCESSING PARAMETERS

PROCES HOLDS INFORMATION PERTAINING TO THE PROCESSINF OF THE MATRIX. PROCES (5) THRU PROCES (13) HOLD SWITCHES WHICH TELL THE PROGRAM TO EXCLUDE (SW 0) OR INCLUDE SW=0), THE TERM SPECIFIED IN THE GREYTONE FORMULA.

PROCES (1)	X, OPTICAL DENSITY RANGE
PROCES (2)	GAMMA, A PHOTOGRAPHIC CONSTANT
PROCES (3)	KR, PHOTO CONSTANT OF REFERENCE RADAR
PROCES (4)	AR, PHOTO CONSTANT OF REFERENCE RADAR
PROCES (5)	SW - K TERM
PROCES (6)	SW - M TERM
PROCES (7)	SW - PT TERM
PROCES (8)	SW - WAVELENGTH TERM
PROCES (9)	SW - ANTENNA GAIN TERM
PROCES (10)	SW - BACKSCATTER TERM
PROCES (11)	SW - AREA TERM
PROCES (12)	SW - RANGE TERM
PROCES (13)	SW - FADING TERM
PROCES (14)	K, PHOTO CONSTANT OF TEST RADAR
PROCES (15)	M, PHOTO CONSTANT OF TEST RADAR

*THESE PARAMETERS ARE COMPUTED BY THE PROGRAM - INPUT A ZERO

**THESE PARAMETERS ARE PRESENTLY NOT USED - INPUT A ZERO

***IF NOT INCLUDING A PARAMETER AS INDICATED IN THE PROCESS ARRAY - INPUT A ZERO

Figure 2

The data base of geometric solids is shown in Figure 3. The flat checkerboard conceptually represents areas of several vegetation types. The objects consist of hemispheres, cylinders, pyramids and rectangular parallelopipeds, with heights and dimensions drawn to scale. The variety of shapes present many different local tilts to the radar and will cause greytone changes at the sides of objects. By making the data base large and with resolution much finer than the simulated radar image, it was possible to study many properties of the simulation software (e.g., the formation of resolution cells by the SLAR package and the layover effects).

Figure 4 shows the relative position and elevation of the many objects on the data base. The maximum variation of relief is 2000 feet, therefore, a wide range in the amounts of shadow and layover are expected to be evident in simulated imagery of this scene.

Figure 5 illustrates the microwave reflectivity category assignments for the objects. Comparing Figures 4 and 5, it is seen that the same vegetation covers several objects of differing height. The value of empirical backscatter data for simulation is readily apparent, for if it were not available, complicated analytical expressions derived from volume scattering theories would have been necessary as input data. Backscatter data at increments of one degree between zero and ninety degrees (incidence angle) were stored (for each vegetation type) on input file tapes.

The SLAR simulation produces two types of output: (1) a "shadow map" (hard-copy output of the SLAR package) and (2) a magnetic tape compatible with a digital computer controlling a display medium. The shadow map consists of a large matrix of characters, zeroes representing shadow areas, nines indicating no data, and all other numbers the sum of the data points falling within a resolution cell bin. Both types of output are illustrated in the following sections for a radar system operating at 8.6 GHz with HH polarization (with the exception of the frequency/polarization study results). Thus, the shadow map indicates the shadow as well as layover, and sums the number of transposed cells.

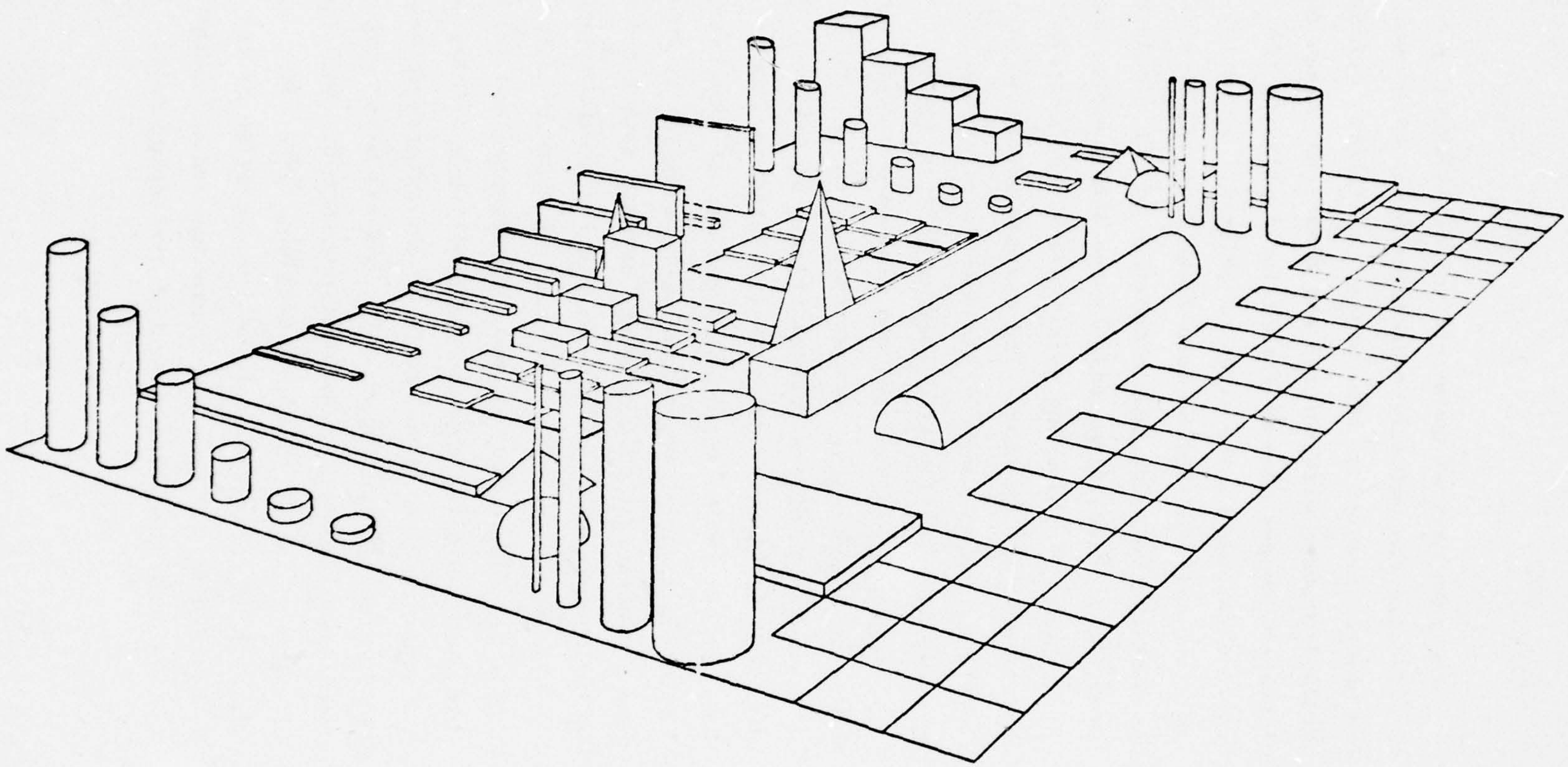
Figure 3-2 Data Base of Geometric Solids

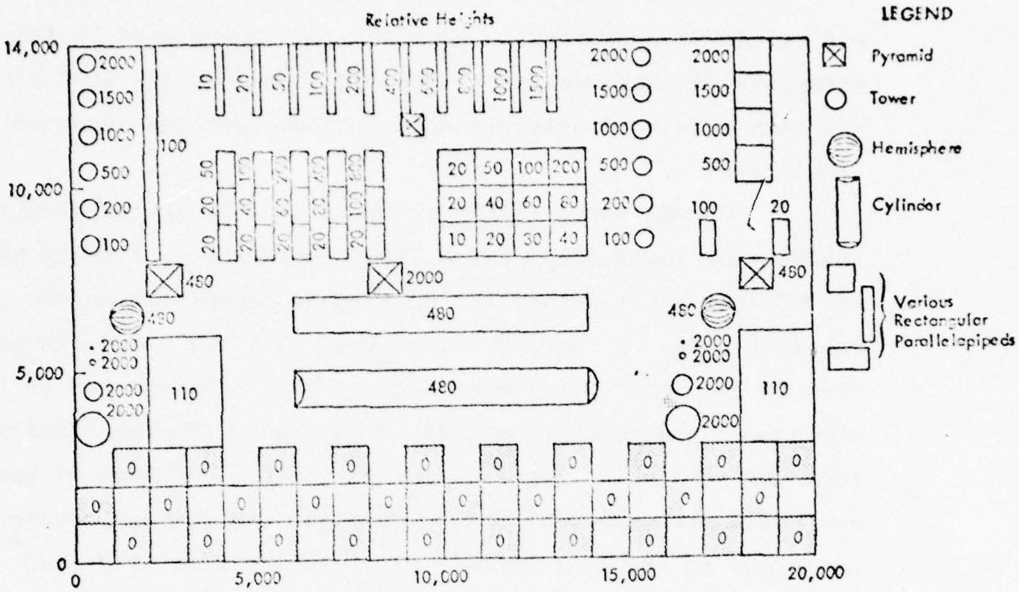

Figure 3-3 Relative Position and Elevation

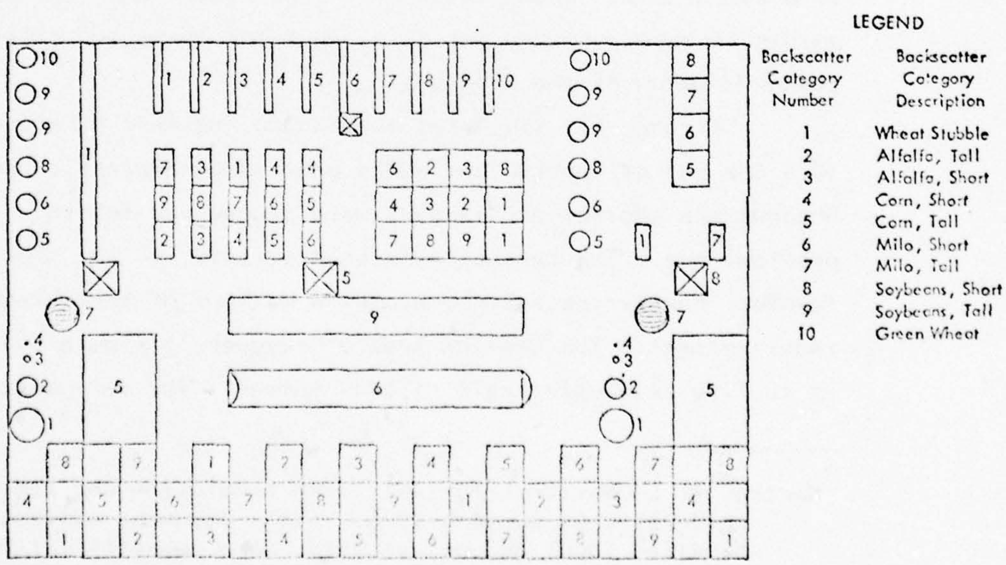

Figure 3-4 Microwave Reflectivity Category Assignments

4.0 DIGITAL SLAR SIMULATION RESULTS

The data base information (data point location in the array, height, and category) contained on magnetic tape[7] generated by the method of Reference [6] was used as the ground scene for the SLAR simulation programs. Two sets of visual displays were produced, shadow maps and radar image simulations.

The map shown in Figure 6a illustrates the effects of layover and shadow that would occur for a SLAR operating at 8.6 GHz HH flown at a 40,000 foot altitude and 20° near range depression angle. Comparing this map to Figures 3 and 4 it is seen that the level checkerboard pattern lies in the upper portion of Figure 6a. The symbols on the map indicate the sum of the resolution cells whose radar returns simultaneously reach the SLAR receiver. Zeroes represent shadow, or lack of appreciable return, and nines are employed to show no data. Shadow and layover effects do not occur on the flat terrain, just as would be predicted. Careful study of Figures 3, 4, and 6a reveal that the SLAR package is accurate in handling radar geometrical phenomena. This particular version of the simulation limited the number of resolution cells laying over into one bin to a sum of six. Examination of the map shows that the maximum number of points to enter one bin was five, thus the above restriction did not limit the performance of the programs.

Figure 6b simulates the shadow and layover effects for a SLAR (8.6 GHz HH) at 40,000 feet and a near range depression angle of 40°. Shadows are shorter and layover more pronounced for this case than for the previous one. The centrally located pyramid in 6b shows a larger area of layover. However each bin contains a maximum of three resolution cell radar returns. The smaller area of layover in Figure 6a has bins with up to five resolution cell returns summed. The more distinct outlines of

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[7] Martin, R. L. Martin's Thesis, "SLAR Simulation and Applications," University of Kansas, 1976. (This document addresses problems of handling input and output data, tape compatibilities of machines, and system routines.)

[6] Komp, E. D., V. H. Kaupp, and J. C. Holtzman, "Construction of a Geometric Data Base for Radar Image Simulation Studies," TR 319-2, Remote Sensing Laboratory, The University of Kansas, July, 1976.

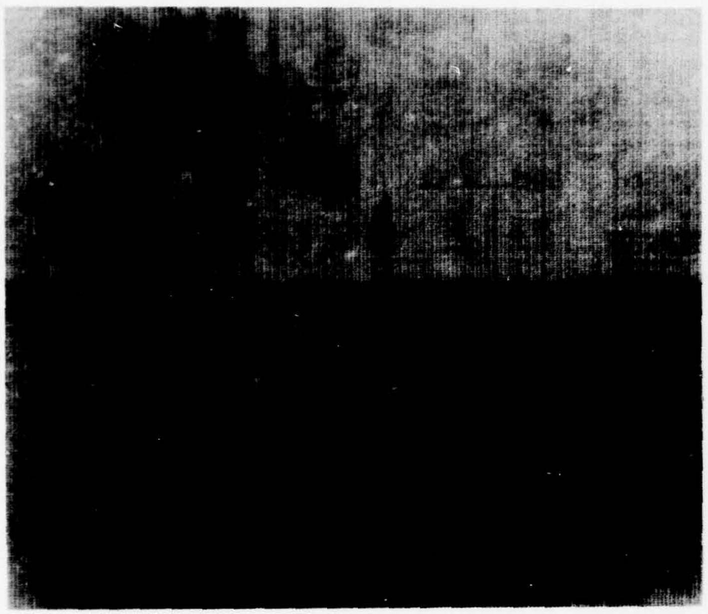


FIGURE 6a. 20° DEPRESSION ANGLE, 40,000 FT. ALTITUDE
9's INDICATE NO DATA, 1's-NO LAYOVER, 0's-NO SHADOW

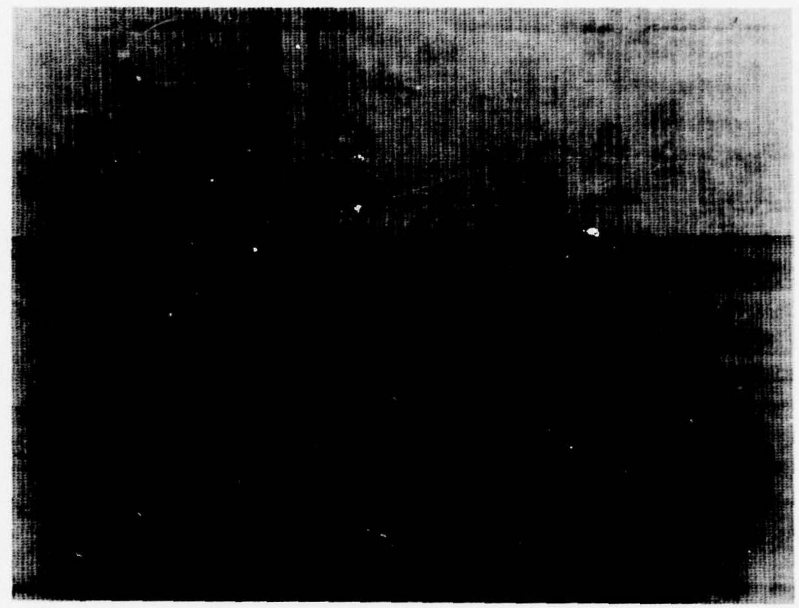


FIGURE 6b. 40° DEPRESSION ANGLE, 40,000 FT. ALTITUDE

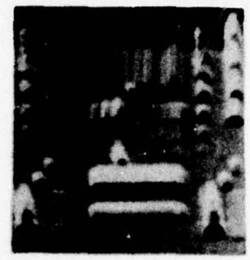
6b allow each object to be identified in conjunction with Figures 3 and 4.

It can be seen that radar interpretation for military personnel could be facilitated by the use of shadow-layover maps similar to those presented. The shadow map allows one to understand differences in image formation between radar and conventional photographic processes. The distinctions arise because the radar emits pulsed energy such that the return energy can be plotted versus time, the lack of return power causing shadow, and the propagation time determining the placement of relative greytones due to return signals. However, in the case of optical photographic imaging, the source of illumination (the sun) emits energy continuously, the reflected energy giving rise to a video signal which cannot be charted versus time without considerable ambiguity as to the time origin of the transmitted signal. Thus the continuous superposition of reflected energy masks shadow formation (in the sense of lack of return signal) when the photographic imaging platform is in the path between the illuminator and the object to be sensed. The handicap imposed by familiarity solely with photographic images is difficult to overcome, and this can only be accomplished through practice. Experience with shadow and layover for various flight situations simulated with the aid of an artificial data base could be extremely useful for overcoming the urge to think in terms of photographic phenomena. The shadow map, by the very fact that it contains a limited amount of quantified information about the processes occurring in radar terrain imaging, provides the necessary elements for understanding shadow and layover. Despite the fact that the geometrical data base is not representative of common landscapes, the corresponding maps generated by simulation are valuable.

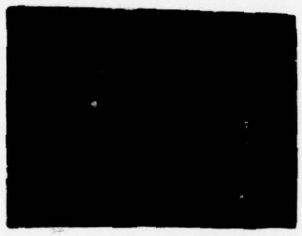
Simulated radar images for a SLAR altitude of 4000 feet and a near range depression angle of 40 degrees (far range ten degree depression angle) were produced for a frequency/polarization study. The accentuation of shadow and layover was caused by the presence of objects on the data base up to 2000 feet high and the extremely low flight altitude. The results are shown in Figure 7 for six different frequency/polarization combinations. Several interesting radar effects can be spotted by an untrained eye: (1)

RADAR SIMULATION STUDY OF GEOMETRIC DATA BASE

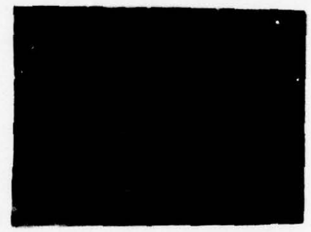
Original



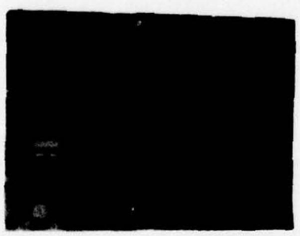
Orginal 3-D



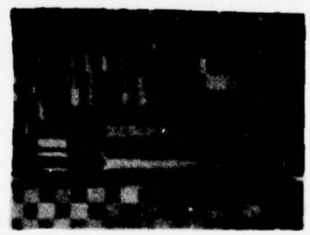
8.6 HH



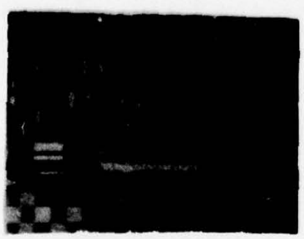
8.6 VV



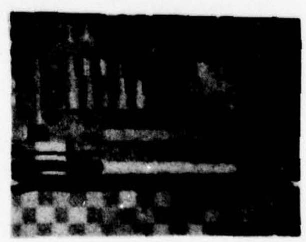
13.8 HH



13.8 VV



16.2 HH



16.2 VV

near-range compression; (2) backscatter category discrimination and variability; (3) same-category blocks of the checkerboard changing greytone across the map because of changes in sigma zero data with progressing angle of incidence, theta; (4) selective brightening of objects with polarization adjustment; (5) obviously, layover and shadow; and (6) loss of signal due to local tilt of resolution cell on sides of cylinders.

It is possible that a fine resolution radar (and correspondingly finer data base resolution) would indicate the presence of hard targets on the geometrical data base due to some of the corners and edges of the shapes involved, although the categories strictly represent vegetation. However, this would not be likely if the real SLAR produced 60 foot resolution as simulated, for the random averaging processes across a resolution cell would somewhat mask the effects of return power from the hard targets (eg., top edges of cylinders and parallelepipeds). Treatment of this data base (with computer generated resolution as fine as desired) as a composite of distributed targets is accurate as long as coarse (eg., 60 x 60 foot) resolution is employed in the simulated imagery.

Assume that the flight mission of a real SLAR was to produce category information over flat terrain and that a low altitude constrained the near and far range depression angles such that only the middle third of the images in Figure 7 were sensed. Such a mission would be fruitful if the particular radar system was operating at 8.6 GHz with HH polarization. With any other combination of frequency/polarization shown, the information gathered would not justify the expense. Radar parameters have already been studied in this manner for the Earth Resources Shuttle Imaging Radar to predetermine discrimination ability[8]. Whether the imaging system is a SAR or SLAR, waste and inefficiency in related missions can be avoided by forethought; a helpful aid would be the simulation of radar images from data base with relief and category (hopefully, empirical backscatter) information, be it a real site or the construct of a geographer's imagination.

Rather than simulating flight at 4000 feet in the midst of terrain varying in height from 0-2000 feet, an altitude of 40,000 feet might be more reasonable for a SLAR. Experiments have been conducted with two

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[8] Bush, T. F., "Cropland Inventories Using a Satellite Altitude Imaging Radar," Ph.D. Dissertation to be published (Spring 1977), University of Kansas.

flight geometries as shown in Figure 8. The extent of shadow and layover will differ in the cases of 20 and 24 degree near range depression angles. Figure 9 illustrates that shadows will be longer in the 20° example, and that data points layover greater distances toward the flight track in the 24° depression angle case, especially in the near range (this assumes ground range presentation). However, more brightening will occur in the layover areas of the 20° case due to the greater density of cells entering bins on the near range side of tall objects.

The resulting simulated radar images are shown in Figures 10 and 11. Close examination of lengths of shadows and layover are aided by employing the checkerboard as a distance marker. Allowing for the distortion in photographs of the IDECS* visual display, the shadows are longer in Figure 10 and data points lay over greater distances toward the flight track in Figure 11. Near range compression due to the slant range presentation partially masks the difference in layover between the two images. Unfortunately, the scan lines in the IDECS display interfere with the study of the two simulations, so they must be viewed at a distance. However, differences can still be distinguished in the category discrimination ability, fading, object brightening, shadow and layover. The center pyramid in the Figure 10 has many cells located in bins along a line parallel to the flight track, whereas Figure 11 has a larger area of brightening (lower intensity) constituting a triangular section.

In conclusion, it has been shown that the SLAR simulations correctly represent layover and shadow. The use of the artificial data base makes possible the quantification of these radar phenomena for validation of the SLAR model. Empirical backscatter data at the frequencies and polarizations of Figure 7 lends credence to the idea that the SLAR simulation is very valuable for system optimization tests, especially

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* IDECS - Acronym for Image Discrimination, Enhancement, Combination and Sampling, (an image processing station), Remote Sensing Laboratory.

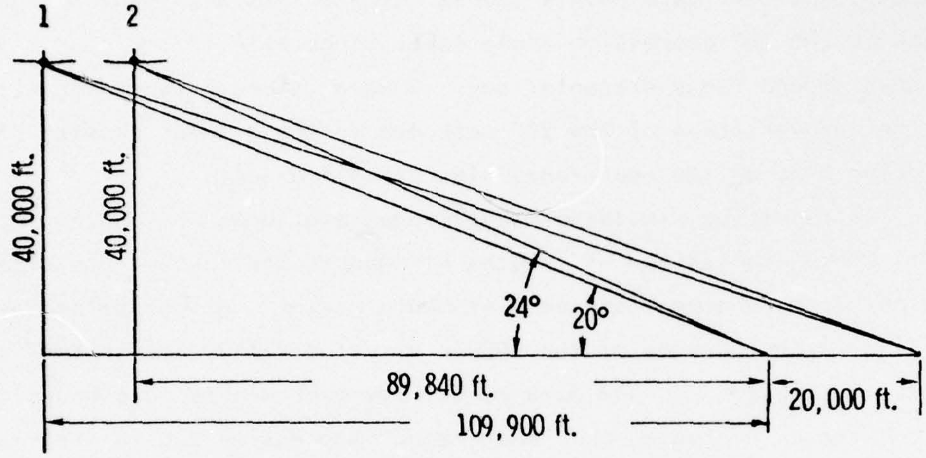


Figure 4-3

Flight Geometries for Equal Altitude Test
Appendix A contains Ground and Radar matrix values.

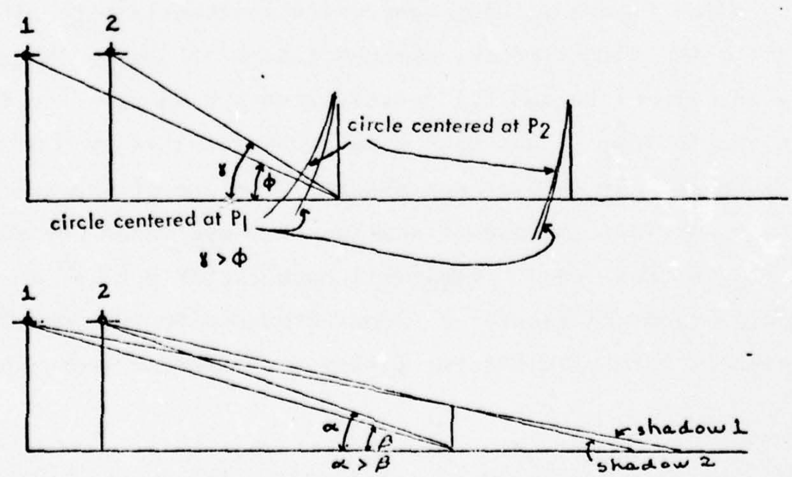
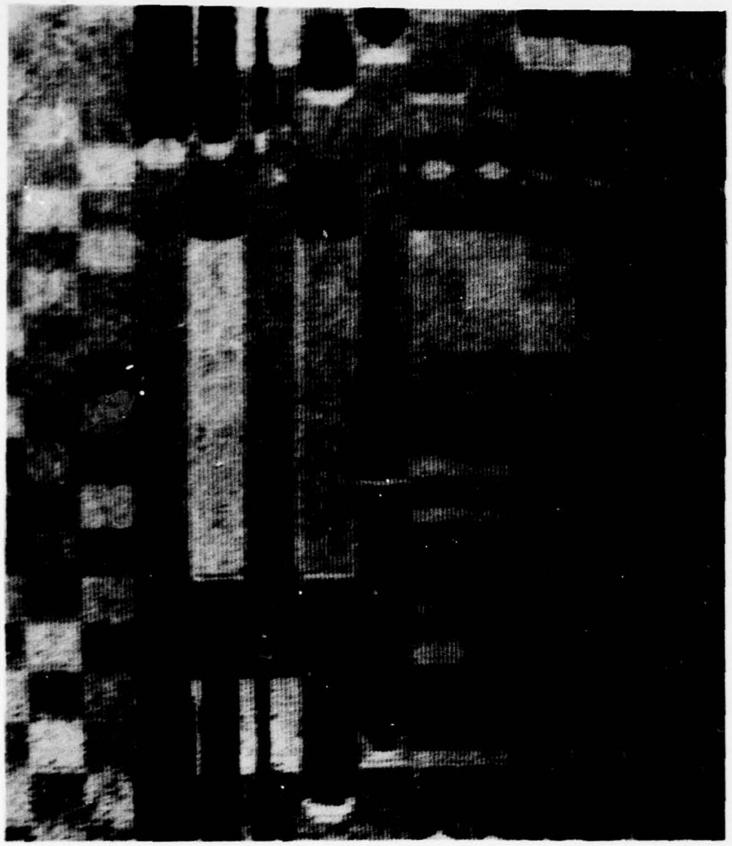
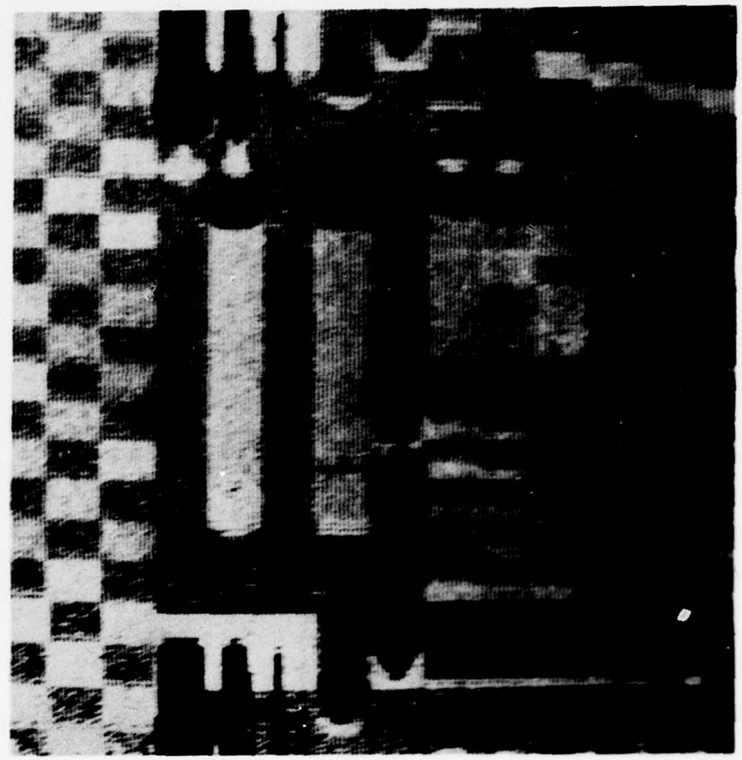


Figure 4-4 Shadow and Layover Difference



RADAR SIMULATION OF ARTIFICIAL DATA BASE
20° DEPRESSION ANGLE 40,000 FT. SLAR ALTITUDE

FIGURE 10



RADAR SIMULATION OF ARTIFICIAL DATA BASE
24° DEPRESSION ANGLE 40,000 FT. SLAR ALTITUDE

FIGURE 11

in the area of backscatter category discrimination. It is not possible to make statements about the overall adequacy of the closed system model for it is not yet possible to objectively measure the quality of the simulated images and their suitability for specific applications. Future studies are being aimed toward the goal of defining image quality factors for very specific applications, but until these factors can be quantified, the value and quality of the simulation is left to the subjective opinion of engineers and radar interpreters. It should be noted, however, that simulations of real scenes produced at RSL have consistently been mistaken for real imagery by staff radar interpreters.

5. Conclusions and Recommendations

The calculable response of an artificial data base has been used to explore the accuracy of the SLAR simulation programs which embody the theory briefly described in this document. The closed-system model which has been developed to imitate ground-radar interactions has been shown to have considerable flexibility by the application results presented. The simulated images shown herein illustrate effects such as (1) layover; (2) shadow; (3) frequency/polarization; (4) near range compression; and (5) category discrimination. The value of image simulation for pre-evaluation of future radar systems has been stressed because recent developments since the publishing of Reference [2] have shown the utility of a geometrical data base (with empirical backscatter characteristics and computer generated shapes) in conjunction with the SLAR simulation programs of the Remote Sensing Laboratory.

The lack of a large catalogue of empirical backscatter data (VV, VH, HH, HV, circular direct and cross polarizations) and computer resources, have hampered the simulation efforts to some degree. The apparent advantages of accurately predicting system performance prior to construction as well as use in guidance systems would seem to be incentive to apply what has been learned about radar-ground interactions through use of this particular closed-system model.

The radar image simulation methods developed will next be applied to a real data base (Pickwick, test site) to measure its performance and to validate the model by comparison of simulations with real imagery of the same site. Subsequently, experiments will be performed at the Engineering Topographic Laboratories to determine the suitability of the simulated imagery for missile navigation systems in the developmental stage.

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2 Holtzman, J.C., V.H. Kaupp, R.L. Martin, E.E. Komp, and V.S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interaction Simulation Model, and Sample Results," TR 234-13, Remote Sensing Laboratory, The University of Kansas, February 1976.

APPENDIX I

The SLAR simulation program is contained in this section. The data which must be supplied to the program were previously listed in Table 1. Due to interdependence of some of the Radar and Ground matrix values, the following formulas are useful:

$*Gr(9) = R(8) \cdot \frac{c}{2}$

$*Gr(10) = R(6) \cdot \frac{c}{2} \cdot R(9)$

$*Gr(11) = Gr(10)/Gr(2) + .5 \qquad 1 \leq Gr(11) \leq 5$

$*Gr(12) = G(5)/Gr(11)$

$*Gr(13) = R(7)/R(8)$

$*R(15) = R(16) \cdot \frac{c}{2}$

The asterisked quantities are computed within the body of the program. When changing R(6), for example, R(9) must be altered to compensate such that Gr(10) has the desired value.

Parameters for Figures 4-5 and 4-6 are given below for a more complete description of the radar systems being simulated by the SLAR programs.

	Figure 4-5	Figure 4-6
Gr(1)	109,900	89,840 feet
Gr(2)	20	20 feet
Gr(3)	20	20 feet
Gr(5)	700	700 feet
Gr(6)	1000	1000 feet
Gr(10)	80	80 feet
R(6)	2.38×10^{-4}	2.00×10^{-4} seconds
R(7)	3.93×10^{-5}	3.77×10^{-5} seconds
R(8)	1.63×10^{-7}	1.63×10^{-7} seconds
R(9)	6.80×10^{-4}	8.10×10^{-4} radians
R(12)	40,000	40,000 feet

APPENDIX B

CONSTRUCTION OF A GEOMETRIC DATA BASE FOR RADAR IMAGE SIMULATION STUDIES

The following technical report (TR 319-1), prepared by the Center for Research, Inc., University of Kansas, is included in this report to provide the rationale for the discussion of Section 2.

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CONSTRUCTION OF A GEOMETRIC DATA BASE FOR RADAR IMAGE SIMULATION STUDIES

Remote Sensing Laboratory

RSL Technical Report 319-1

E. Komp

V. Kaupp

J. Holtzman

July, 1976

Supported by:

U. S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

CONTRACT DAAK-02-73-C-0106

ABSTRACT

A computer program to produce a digital ground truth data base of a controlled scene of geometric solids has been developed for radar image simulation studies. The data bases which can be made by this program have well-defined geometric properties and have well-defined boundaries separating different microwave reflectivity categories. Since the geometric properties of the features in a scene are of paramount importance to radar, a test data base with known geometry is crucial in radar image simulation work. Also important to radar image simulation work is the capability to easily change the reflectivity categories of the various regions contained in a scene. All of these features are available in the data bases which can be produced by this program. These data bases are ideally suited, therefore, to radar image simulation studies; they have a known input to the simulation program and produce a calculable response.

INTRODUCTION

A software package to produce a digital ground truth data base of a controlled scene of geometric shapes and solids has been developed for radar image simulation studies. The data base produced by this computer program provides to the simulation program a known input with well-defined interactions and relationships between the various features contained in the scene. The uncertainties in the geometry and dielectric properties of the features in a scene inherent in digital data bases of real terrain are removed. Thus the data bases which can be developed from this program are ideally suited to provide a known calibrated input to radar image simulation studies of an investigative nature; they have a calculable response, and hence can be thought of as a standard scene.

The most difficult aspects of the radar image simulation problem are to obtain the geometry of the ground features and knowledge of the microwave reflectivity properties of the ground scene. Some of the more common sources of these data are high resolution aerial photography, maps, and other radar imagery at, perhaps, a different wavelength and polarization. Independent of the ground scene data source, it is necessary to extract the desired information and convert these raw data into a suitable digital data base (ground truth data base) for input into a digital computer. Typically, the scene for which it is desired to simulate the imagery of a specific radar will require the generation of a large number of points in the ground truth data base. For example, if the radar system to be modelled for the production of simulated imagery is only capable of resolving features (objects) which are separated by 100 feet or more, a 10 mile by 10 mile scene would contain approximately 279,000 independent elements. (50 foot resolution would require more than a million elements.) Production of simulated images of scenes of a reasonable size can require the development of a very large ground truth data base.

In a broad sense, there are two classes of radar image simulations that can be produced: the first is the class of simulations where the simulated radar imagery is the goal, and the second is the class where the imagery is not the goal. The simulations of the first class are produced, typically, to reproduce faithfully the radar imagery characteristics of a particular scene based on the real properties of that scene. For this class of simulations it is necessary to generate the appropriate ground truth data base for each scene. The applications of the simulated imagery produced in the second class are unrelated to the scene itself. Some examples of simulation where the radar image is not the goal are found in troubleshooting software, in sensitivity studies, in parameter optimization studies, etc. A standard calibrated data base with known input characteristics would be ideal for this class of simulation. Typically, however, an existing data base produced for some other application is used. This approach has the problem that it is difficult (if not impossible) to determine the origin of the results produced in the simulation (e.g. anomalies might be caused either by the data base or the study). In fact, experience has shown that using existing data bases to troubleshoot new software, to determine thresholds of sensitivity for various simulation parameters, to evaluate discrimination capabilities, or for other similar studies is inefficient, can mask results, and can lead to incorrect interpretations of results. A controlled data base of known geometry, dielectric categories and features, and having a calculable response is required for studies of this kind.

Several geometric data bases have been produced by the program described here. A specific example is shown in Figures 1, 2, and 3. Figure 1 shows an isometric line drawing of this data base. This figure illustrates the relative orientation of the various geometric shapes included. Figure 2 is a plan view of the same data base showing the relative heights and positions of the various solids. Figure 3 is also a plan view of this data base, but this figure illustrates the microwave reflectivity category assignments made for this one data base. This data base has been used to troubleshoot the image simulation software and to verify that layover, shadow, range compression, local angle of incidence, and fading were all

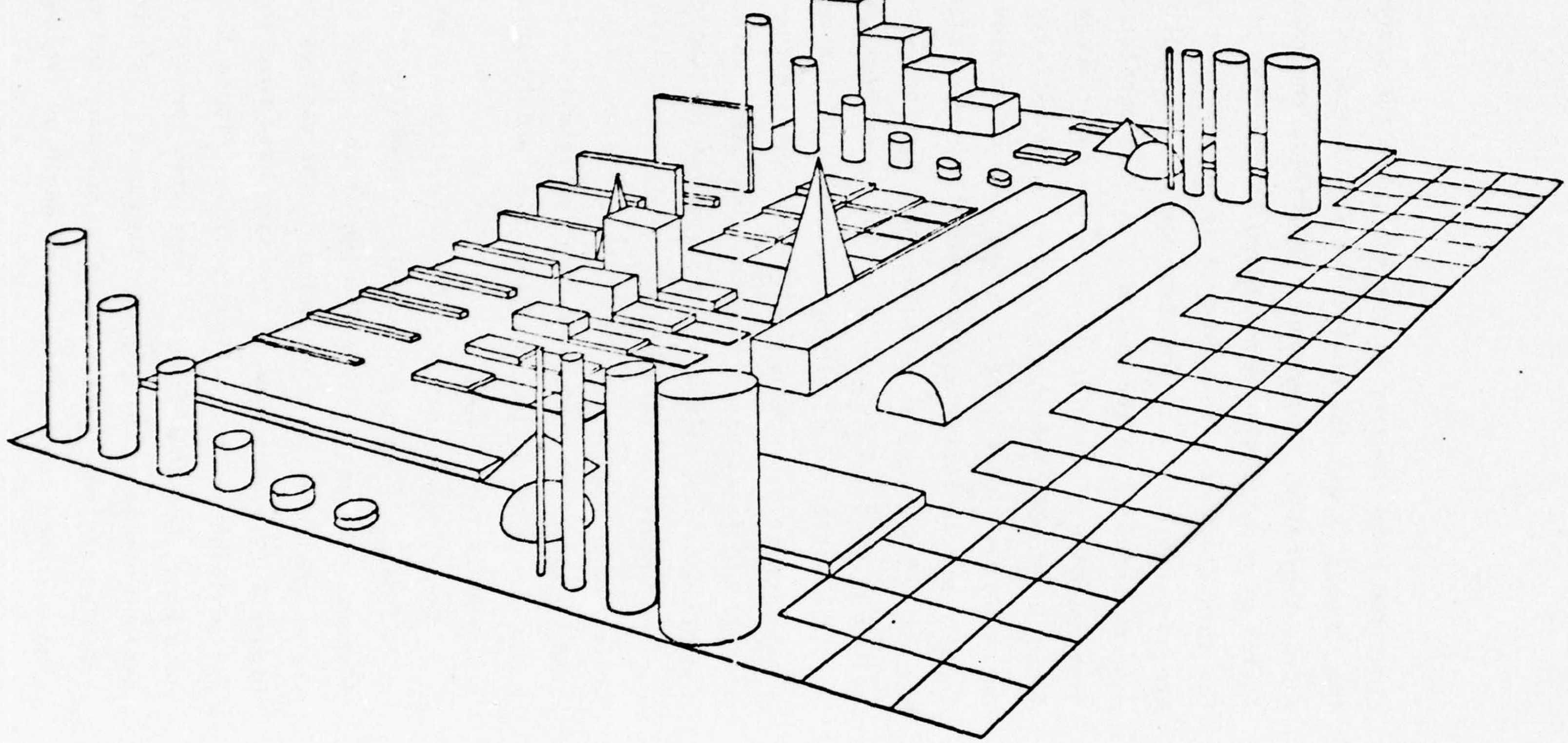


Figure 1. Data Base of Geometric Solids.

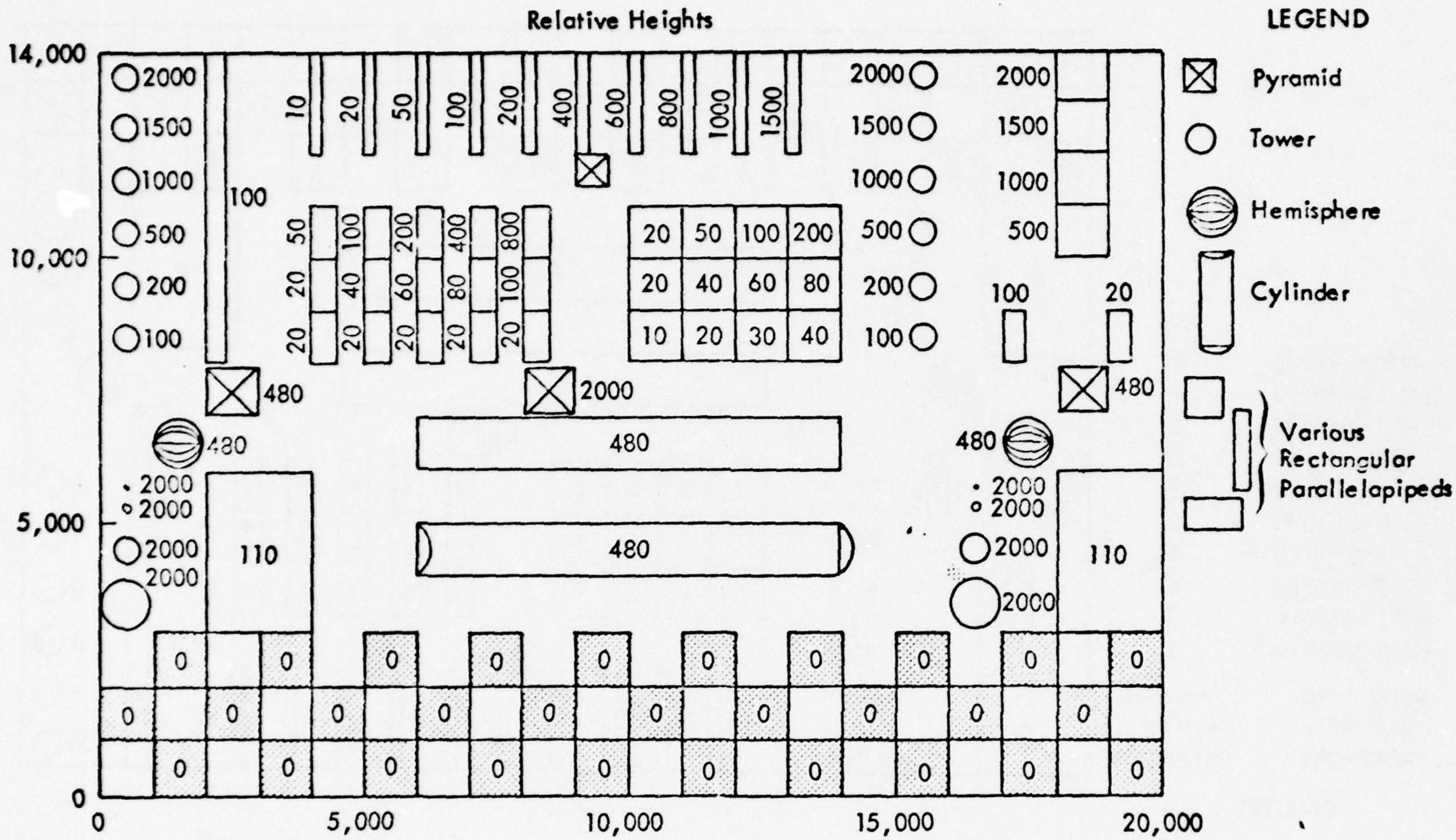
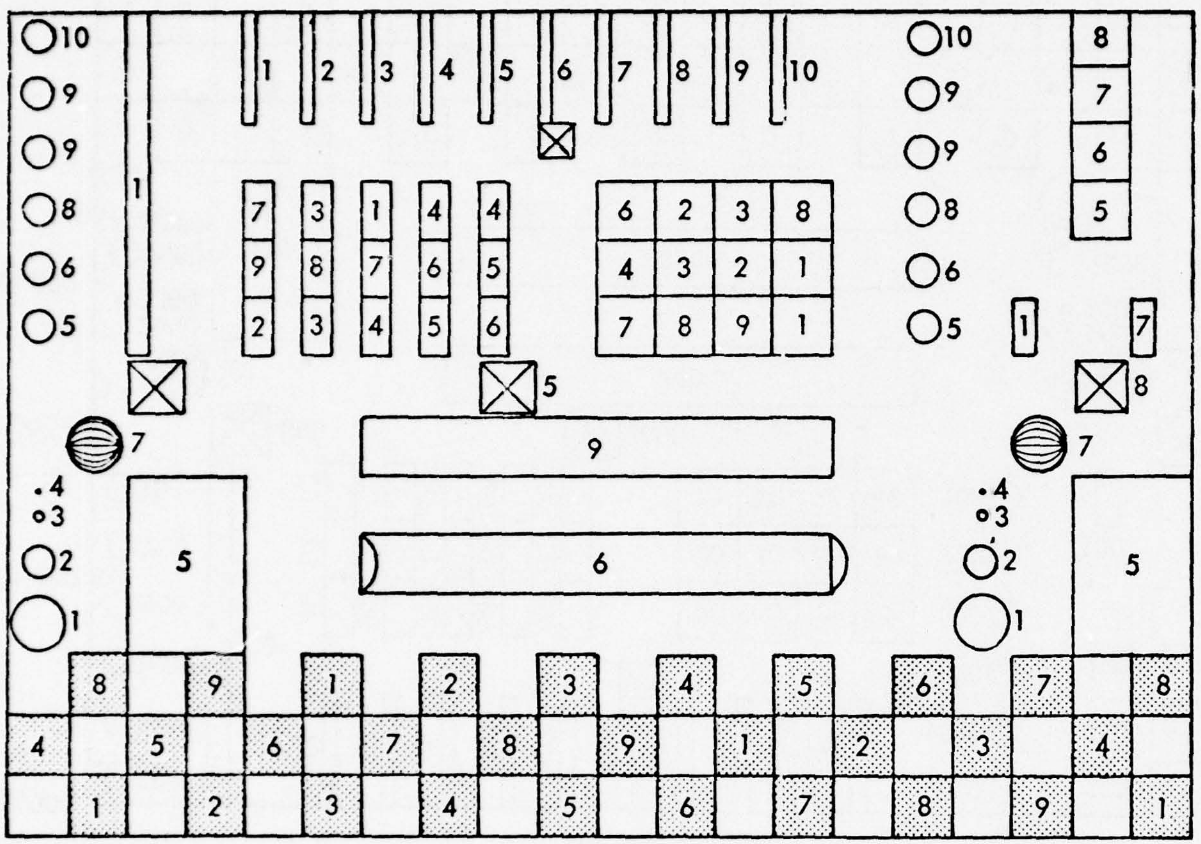


Figure 2. Relative Position and Elevation.



LEGEND

Backscatter Category Number	Backscatter Category Description
1	Wheat Stubble
2	Alfalfa, Tall
3	Alfalfa, Short
4	Corn, Short
5	Corn, Tall
6	Milo, Short
7	Milo, Tall
8	Soybeans, Short
9	Soybeans, Tall
10	Green Wheat

Figure 3. Microwave Reflectivity Category Assignments

properly simulated. It has also been used to demonstrate visually the effects of changing carrier frequency and polarization for a well-defined scene. It is expected that this data base will be invaluable in future studies.

METHODOLOGY

The software design for the construction of the various geometric solids was made as simple as possible. The various geometric solids which can be selected for inclusion in a data base to be constructed by this program are available as subroutines. The objects available as subroutines and the options for user specification are listed in Table 1. This program creates a grid matrix of an arbitrary size. (Present operation creates 1000 x 1000.) Cell size is user-specified, but must be square.

Within this grid matrix, 3-dimensional representations of regular surfaces are constructed by user specifications (details of available structures to follow). In addition, a specific microwave reflectivity category may be assigned to each object. The elevation and category assignment (i.e. reflectivity category) for each cell is packed into one word; the rightmost six bits are reserved for category number (giving possible range of values 0 → 63), and the remaining upper bits are reserved for the elevation. Those cells where no object is defined are implicitly defined with Ø elevation and Ø category.

This computer program will produce data bases as large (or as small) as is desired. To prevent problems caused by computer core limitations, the data base is constructed in horizontal strips. In the first pass, all the columns of the first N rows of the grid matrix are constructed and stored on an external device; pass 2 produces the next N rows; pass 3 the next N rows, etc., until the matrix is complete. N is chosen by the user so that (N ROWS * M COLUMNS) is a "reasonable" amount of core requirements. For the specific data base herein described (Figures 1, 2,

TABLE I

Geometric Solids

Solid	Options
Cube	User supplies start row and start column, length and width of base, the angle of rotation in degrees, and a microwave reflectivity category number assignment.
Wedge	User specifies start row and start column, length of wedge, maximum height of the wedge, slope of the front face, width of the flat top, slope of the back face, angle of rotation, and a microwave reflectivity category number assignment.
Pyramid	Produces a pyramid of arbitrary height with a square base. User specifies start row and column, length of base, angle of rotation, and microwave reflectivity category number. (Slope of the sides is implicitly determined by the height and length of the side.)
Hemisphere	User specifies row and column of center, radius, and microwave reflectivity category number.
Tower	Produces a cylinder standing on end. User specifies start row and column of center, radius, length, and microwave reflectivity category number.
Cylinder	Produces half of a cylinder lying on its side. User specifies start row and column of center line, radius, length, and microwave reflectivity category number.
Patch	Assigns to a given number of matrix cells the desired microwave reflectivity category number with no elevation.
Checkerboard	Assigns to a series of matrix cells each of the different microwave reflectivity categories consecutively with no elevation.

Note:

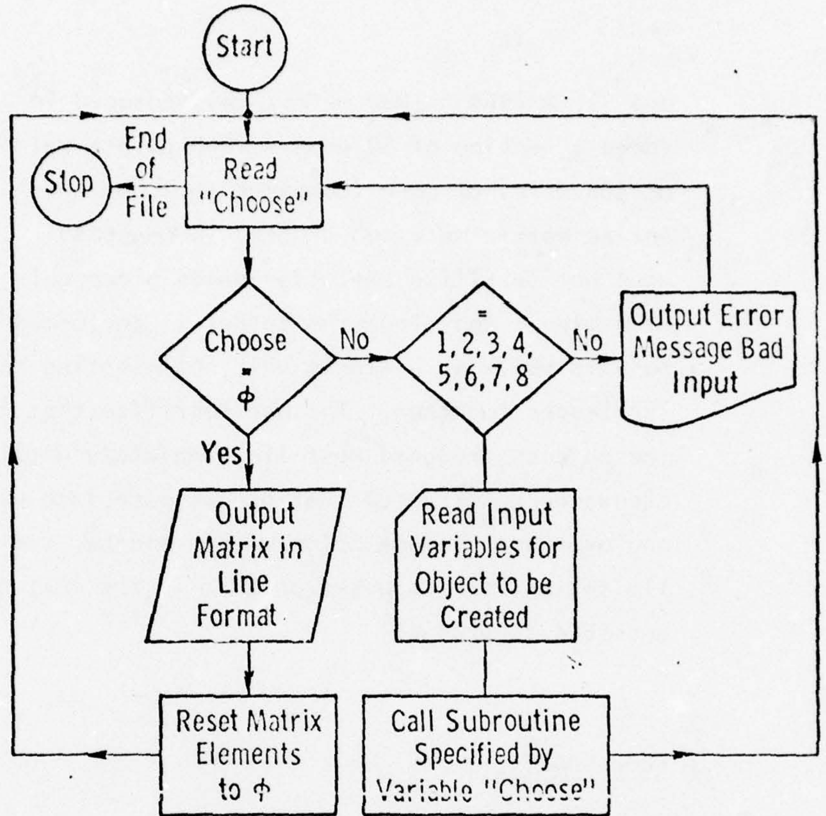
Patch and checkerboard are available to compare changes in the return strength of the various categories at different incident angles. Patch may provide a reference greytone next to an object to analyze the effect of changing the local incident angle.

and 3), a 1000 x 1000 matrix was produced in 20 passes. Each pass produced a section of 50 rows x 1000 points which required a single block of 50K words of core (compared to 1000K which would be required if the entire matrix were constructed in one pass). The multiple pass concept does not sacrifice execution speed since only one object can be constructed at a time. And since the output is performed on entire lines, the data base is built as a single unit, eliminating the complexities of mosaicking sub-images together. The one sacrifice that is made, however, is that the objects produced must lie completely within a single strip; an object cannot be constructed that begins someplace within one horizontal strip and overlaps to some point within another strip. Aside from this minor limitation, the computer program is the most general in design it was possible to produce.

FLOW CHART

The computer program (geometric data base construction) has been designed to be as versatile as possible. The size of the data base and the size, location, orientation, and shape of the various geometric solids are easily controlled. Figure 4 presents the basic operations, in flow chart form, of this computer program. Digital data bases of geometric solids are constructed according to the user's design and specification. Also shown is a listing of the eight geometric shapes available as subroutines in this program. A copy of the program is included in Appendix I of this work.

To use this program, it is necessary first to design the desired data base. The size, location, orientation, and shape of each geometric shape must be specified. The computer program, as listed in Appendix I, will produce a digital data base matrix constructed of 1000 elements by 50 rows at a time for as many repetitions as are desired. (A matrix of 1000 x 1000 data values would require 20 repetitions.) If it is desired to construct a data base of a different size, the dimension statements



Geometric Solid	Variable Choose	Software Name
Patch	1.	Patch
Cube	2.	Cube
Wedge	3.	Wedge
Pyramid	4.	Pyramid
Hemisphere	5.	Hmisp
Cylinder	6.	Cyl
Tower	7.	Tower
Checkerboard	8.	Chkrbd

Figure 4. Geometric Data Base Flow Chart.

must be changed from the values specified (specified in the program listed in Appendix I) to the desired values. The only real constraints on data base size are imposed by the core size of the computer used to construct the data base. After the data base size has been defined and the dimension statements of the program have been specified correctly, the data base can be constructed. Reference to the flow chart shown in Figure 4 will make clearer the following discussion. For each geometric shape to be included in each horizontal strip, two data cards are required to be input to the program. The first card is a number between Ø and 9 that specifies the surface to be constructed, and the second card specifies the required construction data. (These requirements are listed both in Table 1 and in the various subroutine listings in Appendix I.) Two cards are required for the program for each shape desired in a strip. A data card of Ø signifies that no more geometric solids are desired for a given strip and that construction is to begin for the next strip. In this way, the data base is constructed strip by strip until the data base is completed.

The data bases which can be constructed from this program are not likely to be encountered in actual radar use. But they can be very useful for testing radar simulation programs and problems since all aspects--height, local slope, category assignment--are precisely known. Furthermore, any or all of these parameters can be changed by the user in a very controlled manner to study the relative effects and importance of each, as well as to evaluate the simulation techniques. These changes can be accomplished either by constructing a new data base for each arrangement or by incorporating this program in the simulation model to produce the desired effect. One can also study the importance of the size of the data base cells by changing the appropriate parameter during the production of a data base. There are many more potential uses for a data base like this, and to increase the value of this program by making the output more generally applicable, facilities to rotate the data base to run radar simulations with different flight paths have been included.

APPENDIX I

Listing of Computer Program to Construct Geometric Data Bases

PROGRAM TITLE:	FAKE
AUTHOR:	E. Komp
IMPLEMENTED ON:	Honeywell 635
PURPOSE:	

Creates a grid matrix of elevation, geometry, and reflectivity for input to a radar image simulation program.

```
C                         FAKE
C
C
C  THIS PROGRAM CREATES AN ARTIFICIAL DATA BASE CONSISTING
C  OF REGULAR 3-DIMENSIONAL GEOMETRICAL SHAPES AS SPECIFIED
C  BY THE USER
C
C  THE DATA BASE IS CONSTRUCTED IN RECTANGULAR FORMAT.
C  EACH CELL REPRESENTS A FIXED SQUARE AREA, THE LENGTH OF
C  THE SIDE OF EACH CELL IS DETERMINED BY THE VARIABLE --
C  CELSIZ
C  EACH CELL IS CHARACTERIZED BY AN ELEVATION AND A CATEGORY
C  THIS INFORMATION IS PACKED INTO ONE WORD.
C  THE LOW ORDER 6 BITS ARE RESERVED FOR THE CATEGORY,
C  THE HIGH ORDER BITS FOR THE ELEVATION
C
C  TO USE THIS PROGRAM THE USER SPECIFIES THE OBJECTS DESIRED
C  ALONG WITH THE NECESSARY DESCRIPTIVE PARAMETERS AND THE
C  COORDINATES OF THE LOWER LEFT CORNER FOR PLACEMENT IN THE
C  DATA BASE ( OR THE CENTER FOR CYLINDRICAL AND SPHERICAL
C  OBJECTS) PLUS THE DESIRED CATEGORY
C
C  ALL UNSPECIFIED CELLS HAVE IMPLICIT ELEVATION AND CATEGORY 0
C
C  TO MINIMIZE CORE REQUIREMENTS THE DATA BASE IS CONSTRUCTED
C  IN STRIPS 50 CELLS WIDE (THIS NUMBER MAY BE VARIED BY
C  ALTERING THE DIMENSION STMT).  THE FIRST FIFTY ROWS ARE
C  CONSTRUCTED AND PUT ON TAPE WHEN COMPLETE.  THEN THE NEXT
C  FIFTY ROWS ARE CONSTRUCTED AND PUT ON TAPE, AND SO ON
C  THE USER SPECIFIES THE COMPLETION OF A STRIP ON INPUT
C  BY INPUTTING 0 FOR CHOOSE
C  THEREFORE AN ARBITRARY NUMBER OF ROWS MAY BE
C  CONSTRUCTED.  THE NUMBER OF COLUMNS IS LIMITED BY THE
C  DIMENSIONS OF THE ARRAY MATRIX (IN THIS CASE 1000)
C
C  OBJECTS MAY NOT CROSS OVER THE BOUNDARIES OF STRIPS
C  EACH OBJECT SPECIFIED MUST FIT COMPLETELY INSIDE THE
C  STRIP
C
C
      IMPLICIT INTEGER (A-W)
C
C  THE FOLLOWING VARIABLES ARE REQUIRED BY MOST OR ALL OF
C  THE SUBROUTINES AND SO ARE PLACED IN BLANK COMMON AND SO
C  DO NOT HAVE TO BE PASSED AS FORMAL PARAMETERS
C
C  BUF - SMALL I/O BUFFER FOR DEBUG WRITE STMT IN VARIOUS
C        SUBROUTINES
C  MATRIX - THAT PORTION OF THE DATA BASE BEING CONSTRUCTED
C        THAT IS PHYSICALLY IN CORE
C  CELSIZ - SIZE OF EACH CELL IN DATA BASE (IN FEET)
C  STROW,STCOL - STARTING ROW AND COLUMN OF THE SURFACE TO BE
```

```
C          CONSTRUCTED (FOR RECTANGULAR OBJECTS THIS IS LOWER LEFT
C          CORNER; FOR CYLINDRICAL OBJECTS THE CENTER)
C          ***NOTE*** STROW MUST BE GIVEN MODULO 50 (SINCE ONLY A
C          50 ROW STRIP OF THE ENTIRE DATA BASE IS IN CORE
C          AT ANY ONE TIME)
C   CAT - CATEGORY ASSIGNMENT FOR THE SURFACE
C   ANG = ANGLE OF ROTATION (APPLICABLE ONLY TO RECTANGULAR SHAPES)
C          THE OBJECT WILL BE ROTATED COUNTER-CLOCKWISE ABOUT ITS
C          LOWER LEFT CORNER THE SPECIFIED NUMBER OF DEGREES
C
C
      COMMON BUF(20), MATRIX(1000,50),CELSIZ,STCOL,STROW,CAT,ANG
      DIMENSION LINE(500)
C
      CELSIZ =20
      HALFCEL = CELSIZ/2
C
      DO 620 I=1,70
      DO 620 J=1,500
 620  MATRIX(J,I)=10
C
C
C   CONSTRUCTION OF EACH SHAPE REQUIRES TWO DATA CARDS
C   FIRST CARD IS A NUMBER BETWEEN 0 AND 9 (I2 FORMAT)
C   THAT SPECIFIES THE SURFACE TO BE CONSTRUCTED
C   0 - BEGIN NEW STRIP OF DATA BASE
C   1 - PATCH
C   2 - CUBE
C   3 - WEDGE
C   4 - PRYAMID
C   5 - HEMISPHERE
C   6 - CYLINDER
C   7 - TOWER
C 8 8 - CHECKERBOARD
C
C   SECOND CARD NECESSARY DESCRIPTIVE PARAMETERS FOR THAT
C   OBJECT  -- SEE SPECIFIC ROUTINE FOR DETAILS
C
C   ***NOTE***    STROW AND STCOL ARE TO BE SPECIFIES IN TERMS
C                 OF MATRIX CELLS (ROW,COL) - ROW MODULO 50 -
C   FOR EASY PLACEMENT OF OBJECTS RELATIVE TO ONE ANOTHER
C      ALL OTHER PARAMETERS (LENGTH,WIDTH, HEIGHT) ARE TO
C   BE GIVEN IN FEET SO THE USER CAN EASILY DESCRIBE THE
C   PHYSICAL SIZE DESIRED
C
C
  1   READ(05,05,END=900) CHOOSE
  5   FORMAT(I2)
C
      IF(CHOOSE .EQ. 0) GO TO 500
      GO TO (10,20,30,40,50,60,70,80), CHOOSE
C
```

```
C   BAD INPUT  OUTPUT ERROR MESSAGE AND READ NEXT CARD
C
      WRITE(6,810) CHOOSE
 810  FORMAT(//,' ***WARNING***',I5,' IMPROPER VALUE TO
     1 SPECIFY NEW OBJECT.  IT HAS BEEN IGNORED'//)
C
C   SKIP CARD WITH PARAMETERS FOR BAD OBJECT
C
      READ(05,05,END=900) CHOOSE
      GOTO 1
C
C
C                   PATCH
C
C   PATCH - SQUARE AREA OF DATA BASE ASSIGNED SPECIFIED CATEGORY
C          NO ELEVATION IS ASSIGNED
C
C   SIZE - DESIRED LENGTH OF SIDE FOR THE SQUARE AREA
C
C
  10  READ(05,11) STROW,STCOL,SIZE,CAT
  11  FORMAT(10I5)
      CALL PATCH(SIZE)
      CONTINUE
      GO TO 1
C
C                    CUBE
C
C   CUBE - RECTANGULAR SHAPE OF ARBTRAY CONSTANT ELEVATION
C
C   LEN - LENGTH IN X DIRECTION (ACROSS)
C   WID - WIDTH IN Y DIRECTION (VERTICAL)
C   HGT - HEIGHT CONSTANT ELEVATION TO BE ASSIGNED EACH CELL
C
C
  20  READ(05,11) STROW,STCOL,ANG,LEN,WID,HGT,CAT
      CALL CUBE(LEN,WID,HGT)
      CONTINUE
      GO TO 1
C
C                   WEDGE
C
C   WEDGE - OBJECT WITH SLOPING FRONT FACE, A FLAT TOP
C           OF CONSTANT ELEVATION AND ARBITRARY WIDTH AND A SLOPING BACK
C           FACE
C
C   LEN - LENGTH OF WEDGE IN X DIRECTION (ACROSS)
C   SLOPE - SLOPE OF FRONT FACE
C   HGT - MAXIMUM ELEVATION OF WEDGE
C   TOP - WIDTH OF FLAT TOP
C   BSLOPE - SLOPE OF BACK FACE
C
```

```
C
   30    READ(05,11) STROW,STCOL,ANG,LEN,SLOPE,HGT,TOP,BSLOPE,CAT
         CALL WEDGE(LEN,SLOPE,HGT,TOP,BSLOPE)
         CONTINUE
         GO TO 1
C
C                         PYRAMID
C
C  PRYAMID - REGULAR FOUR SIDED PYRAMID
C
C  LEN - SIZE OF BASE OF PYRAMID (WILL HAVE SQUARE BASE)
C  HGT - HEIGHT OF PYRAMID
C
C
   40    READ(05,11) STROW,STCOL,ANG,LEN,HGT,CAT
         CALL PRYAMID(LEN,HGT)
         CONTINUE
         GO TO 1
C
C                         HEMISPHERE
C
C  HEMISPHERE - HEMISPHERE WITH CENTER AT (STROW,STCOL)
C
C  RAD - RADIUS
C
C
   50    READ(05,11)STROW,STCOL,RAD,CAT
         CALL HEMISP(RAD)
         CONTINUE
         GO TO 1
C
C                          CYLINDER
C
C  CYLINDER - CYLINDER LYING ON ITS SIDE
C
C  RAD - RADIUS OF CYLINDER
C  LEN - LENGTH OF CYLINDER (IN X DIRECTION)
C
C
   60    READ(05,11) STROW,STCOL,RAD,LEN,CAT
         CALL CYL(RAD,LEN)
         CONTINUE
         GO TO 1
C
C                   TOWER
C
C  TOWER - CYLINDER STANDING ON END
C
C  RAD - RADIUS OF CYLINDER
C  HGT - HEIGHT OF CYLINDER
C
C
```

```
C
 70     READ(05,11) STROW,STCOL,RAD,HGT,CAT
        CALL TOWER(RAD,HGT)
        CONTINUE
        GO TO 1
C
C                    CHECKERBOARD
C
C   CHECKERBOARD - ROW AND COLUMN OF PATCHES REPRESENTING THE
C          VARIOUS CATEGORIES (FOR COMPARISON OF RELATIVE
C          GREYTONES FOR THE CATEGORIES)
C
C
C
  80    READ(05,11) STROW,STCOL
        CALL CHKRBD
        CONTINUE
        GO TO 1
C
C
C   OUTPUT COMPLETED STRIP OF DATA BASE TO TAPE
C   IN BINARY UNFORMATTED FORM
C
 500    DO 600 I=1,50
        WRITE(01) (MATRIX(J,I),J=1,1000)
 600    CONTINUE
C
C   RESET ALL MATRIX CELLS TO 0 BEFORE BEGINNING NEXT
C   STRIP OF DATA BASE
C
        DO 610 I=1,50
        DO 610 J=1,1000
 610    MATRIX(J,I)  = 0
        GO TO 1
 900    STOP
        END
C       SUBROUTINE PATCH(SIZE)
        SUBROUTINE PATCH(SIZE)
C
        IMPLICIT INTEGER (A-W)
        COMMON BUF(20), ARRAY(500,70),CELSIZ,STCOL,STROW,CAT,ANG
C
C
C   SIZE DIMENSION CONVERTED TO NUMBER OF MATRIX CELLS
C
        SIZE = SIZE/CELSIZ
C
        DO 100 II=1,SIZE
        I = II-1
        DO 100 JJ=1,SIZE
        J =JJ-1
C
```

```
C   APPROPRIATE CELLS ARE ASSIGNED THE DESIGNATED CATEGORY
C
 100    ARRAY(STCOL+I,STROW+J) = CAT
        RETURN
        END
C       SUBROUTINE CUBE(LEN,WID,HGT)
        SUBROUTINE CUBE(LEN,WID,HGT)
C
        IMPLICIT INTEGER (A-W)
        COMMON BUF(20), ARRAY(500,70),CELSIZ,STCOL,STROW,CAT,ANG
        DATA LC,BC,LR,BR/500,0,500,0/
C
C
        I=-1
C
        HALFCEL = CELSIZ/2
C
C   ANGLE OF ROTATION OF BASE OF CUBE
C
        ZANG = FLOAT(ANG)/57.295
C   SINE OF ANGLE OF ROTATION
        ZSIN = SIN(ZANG)
C   COSINE OF ANGLE OF ROTATION
        ZCOS = COS(ZANG)
C
C
C
C   THESE DO LOOPS CALCULATE THE CELLS THAT WOULD BE INCLUDED
C   IN THE CUBE IF THERE WERE NO ROTATION
C   IF THE OBJECT IS TO BE ROTATED (ANG =/ 0)
C   A ROTATION OF AXES IS EFFECTED BY THE TRANSFORMATION
C       XNEW = X * COS(ANG) - Y * SIN(ANG)
C       YNEW = X * SIN(ANG) + Y * COS(ANG)
C
C   THEN THE CELLS REPRESENTED BY XNEW AND YNEW ARE ASSIGNED
C   THE APPROPRIATE VALUES
C   NOTE IF ANG = 0 NO CHANGE IS MADE
C
C   THIS SAME TECHNIQUE IS USED FOR ROTATION OF ALL OBJECTS
C
        DO 100 IY = HALFCEL,WID,CELSIZ
        Y = IY
        YSIN = ZSIN * Y
        YCOS = ZCOS * Y
        DO 100 IX = HALFCEL,LEN,CELSIZ
        X = IX
        COL = ZCOS * X - YSIN
        ROW = ZSIN * X + YCOS
        COL = COL/CELSIZ + STCOL
        ROW = ROW/CELSIZ + STROW
C
C   LR, LC - LEAST ROW AND LEAST COLUMN INCLUDED IN THIS OBJECT
```

```
C   BR, BC - BIGGEST ROW AND COLUMN INCLUDED
C          THESE PARAMETERS REQUIRED FOR THE SUBROUTINE FILLIN
C
          IF(COL .LT. LC) LC = COL
          IF(COL .GT. BC) BC = COL
          IF(ROW .LT. LR) LR = ROW
          IF(ROW .GT. BR) BR = ROW
C
C                   DEBUG WRITE STATEMENT
C
           GO TO 90
          I=I+2
          BUF(I)= COL
          BUF(I+1)= ROW
          IF(I .LT. 15) GO TO 90
          WRITE(6,60) (BUF(M), M=1,16)
 60       FORMAT(8(5X,2I5))
          I=-1
 90       FLD(18,12,ARRAY(COL,ROW)) = FLD(24,12,HGT)
C
C   PROPER ELEVATION AND CATEGORY IS ASSIGNED TO EACH OF THESE
C   CELLS
C
 100      FLD(30,6,ARRAY(COL,ROW)) = FLD(30,6,CAT)
C         WRITE(6,60) (BUF(M),M=1,16)
          DO 10 I=1,16
 10       BUF(I)=0
          CATEG = CAT
C
C
C   SINCE ROTATION WAS DONE ON DISCRETE POINTS IT IS POSSIBLE
C   THAT THERE ARE SOME HOLES (CELLS INTO WHICH NO ROTATED
C   POINT WAS PLACED) IN THIS OBJECT
C
C   SUBROUTINE FILLIN CHECKS OBJECTS FOR SUCH 'HOLES'
C   AND FILLS THEM IN WITH THE APPROPRIATE ELEVATION AND
C   CATEGORY
C
          CALL FILLIN(LC,BC,LR,BR,CATEG)
          CONTINUE
          RETURN
          END
C         SUBROUTINE WEDGE(LEN,SLOPE,HGT,TOP,BSLOPE)
          SUBROUTINE WEDGE(LEN,SLOPE,HGT,TOP,BSLOPE)
C
          IMPLICIT INTEGER (A-W)
          COMMON BUF(20), ARRAY(500,70),CELSIZ,STCOL,STROW,CAT,ANG
          DATA LC,BC,LR,BR/500,0,500,0/
C
          WRITE(6,65) STCOL,STROW
 65       FORMAT(/,30X,'WEDGE',5X,2I6,//)
C
```

```
C
      PT =-2
      HALFCEL = CELSIZ/2
C
C  ANGLE OF ROTATION -  SEE CUBE FOR DETAILS OF ROTATION
C
      ZANG = FLOAT(ANG)/57.295
      ZSIN = SIN(ZANG)
      ZCOS = COS(ZANG)
C
      ZZTOP = FLOAT(SLOPE)/57.295
C
C  TANGENT OF SOP FOR FRON FACE OF WEDGE
      ZTAN = SIN(ZZTOP)/COS(ZZTOP)
      CNT =C
C
C  ELEVATION INITIALIZED TO ZERO
      ELEV =0
C
C  WIDTH OF TOP IN NUMBER OF CELLS
      TOP = TOP/CELSIZ
      INCR =0
      IY = HALFCEL-CELSIZ
 100  ELEV = ELEV+INCR
      IF(ELEV .LT.0) GO TO 200
      IY = IY+ CELSIZ
      Y = IY
      YSIN = ZSIN * Y
      YCOS = ZCOS * Y
C
      DO 110 IX =HALFCEL,LEN,CELSIZ
      X = IX
      COL = ZCOS * X - YSIN
      ROW = ZSIN * X + YCOS
      COL = COL/CELSIZ + STCOL
      ROW = ROW/CELSIZ + STROW
C
C  PARAMETERS FOR FILLIN AS DESCRIBED IN CUBE
C
      IF(COL .LT. LC) LC = COL
      IF(COL .GT. BC) BC = COL
      IF(ROW .LT. LR) LR = ROW
      IF(ROW .GT. BR) BR = ROW
      GO TO 90
      PT =PT+3
C
C  DEBUG PRINT STATEMENT
C
      BUF(PT)=COL
      BUF(PT+1)=ROW
      BUF(PT+2)=ELEV
      IF(PT .LT. 13) GO TO 90
```

```
      WRITE(6,60) (BUF(M), M=1,15)
 60   FORMAT(5(5X,2I5,2X,I5))
      FT =-2
 90   FLD(18,12,ARRAY(COL,ROW)) = FLD(24,12,ELEV)
      FLD(30,6,ARRAY(COL,ROW)) = FLD(30,6,CAT)
 110  CONTINUE
C
C
C  CHECK FOR REACHING TOP OF WEDGE
C
      IF (ELEV .GE. HGT) GO TO 150
C
C  HAVE NOT REACHED TOP SO INCREMENT ELEVATION FOR NEXT ROW
C  PROCEED TO NEXT ROW
C
C
      INCR = ZTAN * FLOAT(CELSIZ)
      GO TO 100
C
 150  CNT = CNT +1
C  HAS FLAT TOP OF WEDGE BEEN COMPLETED?
C
      IF(CNT .GT. TOP) GO TO 160
C
C  NO, SO NO CHANGE IN ELEVATION FOR NEXT ROW
C
      INCR =0
      GO TO 100
 160  IF(BSLOPE .GE.90) GO TO 200
      Z3 = FLOAT(BSLOPE)/57.295
C
C  BEGIN DESCENDING ALONG BACK FACE OF WEDGE
C  MODIFY SLOPE FACTOR
C  NOTE IT IS NEGATIVE SO THAT ELEVATION WILL BE
C  DECREMENTED
C
      ZTAN = -SIN(Z3)/COS(Z3)
      INCR = ZTAN * CELSIZ
      GO TO 100
 200  CONTINUE
C200  WRITE(6,60) (BUF(M),M=1,15)
      DO 11 I=1,15
 11   BUF(I)=0
      CATEG = CAT
      CALL FILLIN (LC,BC,LR,BR,CATEG)
      CONTINUE
      RETURN
      END
C     SUBROUTINE PRYAMID(LEN,HGT)
      SUBROUTINE PRYAMID(LEN,HGT)
C
      IMPLICIT INTEGER (A-W)
```

```
      COMMON BUF(20), ARRAY(500,70),CELSIZ,STCOL,STROW,CAT,ANG
      DATA LC,BC,LR,BR/500,0,500,0/
C
C  ANGLE OF ROTATION IF ANY (SEE CUBE FOR DETAILS)
C
      ZANG = FLOAT(ANG)/57.295
      ZSIN = SIN(ZANG)
      ZCOS = COS(ZANG)
C
      HALFCEL = CELSIZ/2
C
C  HALF THE LENGTH OF THE FINISHED PRYAMID
C
      HFLEN = LEN/2 + HALFCEL
C
C  TANGENT OF SLOP OF PRYAMID FACE
C
      ZTAN = FLOAT(HGT)/FLOAT(HFLEN)
C
C
C  DO LOOP FOR ROWS OF PRYAMID
C  BECAUSE OF SYMMETRY FOR EACH POINT BELOW THE CENTERLINE
C  THERE IS A CORRESSPONDING POINT EQUAL DISTANCE ABOVE IT
C  Y - IS Y VALUE FOR LOWER CELL
C  Y2 - CORRESSPONDING CELL ABOVE
C
      DO 100 IY=HALFCEL,HFLEN,CELSIZ
      Y = IY
      YSIN = ZSIN * Y
      YCOS = ZCOS * Y
      Y2 = LEN - IY
      Y2SIN = ZSIN * Y2
      Y2COS = ZCOS * Y2
C
C
C  X VALUE FROM LEFT TO RIGHT
C
      DO 150 IX = HALFCEL,LEN,CELSIZ
      X = IX
      COL = ZCOS * X - YSIN
      ROW = ZSIN * X + YCOS
      COL = COL/CELSIZ +STCOL
      ROW = ROW/CELSIZ + STROW
C
      COL2 = ZCOS * X - Y2SIN
      ROW2 = ZSIN * X + Y2COS
      COL2 = COL2/CELSIZ +STCOL
      ROW2= ROW2/CELSIZ + STROW
C
C  PARAMETERS FOR FILLIN
C
      IF(COL .LT.LC) LC=COL
```

AD-A051 501 KANSAS UNIV/CENTER FOR RESEARCH INC LAWRENCE REMOTE --ETC F/G 17/9
RADAR IMAGE SIMULATION PROJECT.(U)
SEP 76 J C HOLTZMAN, V H KAUPP, J L ABBOTT DAAK02-73-C-0106
UNCLASSIFIED RSL-TR-234-15 ETL-0098 NL

2 OF 2
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```
      IF(COL2 .LT. LC) LC=COL2
      IF(COL .GT. BC) BC = COL
      IF(COL2 .GT. BC) BC = COL2
      IF(ROW .LT. LR) LR = ROW
      IF(ROW2 .LT. LR) LR = ROW2
      IF(ROW .GT. BR) BR = ROW
      IF(ROW2 .GT. BR) BR =ROW2
C
C  IF X < Y THEN ELEVATION AT THAT CELL = XDIS*SLOPE OF FACE
C  (REPRESENTS LEFT FACE OF PYRAMID)
      ELEV = ZTAN * X
      IF (IY .GE. IX) GO TO 70
C
C  IF X>Y AND Y< LENGTH-XDIS THEN ELEVATION = YDIS*SLOPE
C  (FRONT FACE)
C
      ELEV = ZTAN * Y
      IF(IY .GE. (LEN+CELSIZ-IX)) ELEV = ZTAN*(LEN+CELSIZ-IX)
C
C  ASSIGN THE TWO SYMMETRICAL POINTS THE APPROPRIATE
C  ELEVATION AS JUST CALCULATED
C
  70  FLD(18,12,ARRAY(COL,ROW))=  FLD(24,12,ELEV)
      FLD(18,12,ARRAY(COL2,ROW2)) = FLD(24,12,ELEV)
      FLD(30,6,ARRAY(COL,ROW)) = FLD(30,6,CAT)
      FLD(30,6,ARRAY(COL2,ROW2)) = FLD(30,6,CAT)
 150  CONTINUE
 100  CONTINUE
      CATEG = CAT
      CALL FILLIN(LC,BC,LR,BR,CATEG)
      CONTINUE
      RETURN
      END
C     SUBROUTINE HEMISP(RAD)
      SUBROUTINE HEMISP(RAD)
C
      IMPLICIT INTEGER (A-W)
      COMMON BUF(20), ARRAY(500,70),CELSIZ,STCOL,STROW,CAT,ANG
      HALFCEL = CELSIZ/2
      PRAD = RAD
C
C  RADIUS IN NUMBER OF MATRIX CELLS
C
      NCELL = FLOAT(PRAD)/FLOAT(CELSIZ) +.5
      ZRAD2= RAD**2
C
C  CENTER POINT
C
      ARRAY(STCOL,STROW) = RAD
C
C  UTILIZE SYMMETRY OF HEMISPHERE
C  CALCULATE THE ELEVATION FOR EACH CELL IN ONE QUADRANT
```

```
C   AND THE SAME VALUE CAN BE ASSIGNED TO THE CORRES-
C   SPONDING CELLS IN THE OTHER THREE QUADRANTS
C
          DO 100 I =1, (NCELL+1)
          ROW = (I-1) * CELSIZ
          ZR2 = ROW**2
          NCOL = SQRT(ZRAD2-ZR2) /FLOAT(CELSIZ)+1.
C
C
          DO 100 CL=1,NCOL
          COL=CL-1
          ZHYP2=(COL*CELSIZ)**2 + ZR2
C
C   CALCULATE ELEVATION AT CELL USING RIGHT TRIANGLES
C
          ELEV =SQRT(ZRAD2 - ZHYP2)
C
C   ALGORITHM TO PLACE VALUE IN CORRESSPONDING CELLS
C   OF ALL FOUR QUADRANTS
C
          S = -1
   70     S2= -1
   71     C = S*COL + STCOL
          R = S2*(I-1) + STROW
          FLD(18,12,ARRAY(C,R)) = FLD(24,12,ELEV)
          FLD(30,6,ARRAY(C,R)) = FLD(30,6,CAT)
          IF (S .EQ. 1) GO TO 80
          S =1
          GO TO 71
   80     IF(S2 .EQ. S) GO TO 100
          T = S2
          S2 = S
          S = T
          GO TO 71
  100     CONTINUE
          RETURN
          END
C         SUBROUTINE CYL(RAD,LEN)
          SUBROUTINE CYL(RAD,LEN)
          IMPLICIT INTEGER (A-W)
          COMMON BUF(20), ARRAY(500,70),CELSIZ,STCOL,STROW,CAT,ANG
C
C
          HALFCEL = CELSIZ/2
          ZRAD2= RAD**2
          NCOL = LEN/CELSIZ
          NROW = RAD/CELSIZ
C
C
          DO 100 II=1,(NROW+1)
          I= II-1
          ROW = I*CELSIZ
```

```
      ELEV = SQRT(ZRAD2-ROW**2)
      DO 100 J =1,NCOL
      JJ = J-1
C
C  PLACE APPROPRIATE ELEVATION IN CELLS EQUIDISTANT ABOVE
C  AND BELOW THE CENTERLINE
C
      FLD(18,12,ARRAY(STCOL+JJ,STROW+I)) = FLD(24,12,ELEV)
      FLD(18,12,ARRAY(STCOL+JJ,STROW-I)) = FLD(24,12,ELEV)
      FLD(30, 6,ARRAY(STCOL+JJ,STROW-I)) = FLD(30,6,CAT)
      FLD(30, 6,ARRAY(STCOL+JJ,STROW+I)) = FLD(30,6,CAT)
 100  CONTINUE
      RETURN
      END
C     SUBROUTINE TOWER(RAD,ELEV)
      SUBROUTINE TOWER(RAD,ELEV)
      IMPLICIT INTEGER (A-W)
      COMMON BUF(20), ARRAY(500,70),CELSIZ,STCOL,STROW,CAT,ANG
C
C  THE SAME ALGORITHM AS USED FOR HEMISPHERE EXCEPT
C  THAT THE ELEVATION NEED NOT BE CALCULATED - IT IS
C  CONSTANT VALUE
C
      HALFCEL = CELSIZ/2
      NCELL = FLOAT (RAD)/FLOAT(CELSIZ) +.5
      ZRAD2= RAD**2
      ARRAY(STCOL,STROW) = ELEV
C
C
      DO 100 I =1, (NCELL+1)
      ROW = (I-1) * CELSIZ
      ZR2 = ROW**2
      NCOL = SQRT(ZRAD2-ZR2) /FLOAT(CELSIZ)+1.
C
C
      DO 100 CL=1,NCOL
      COL = CL-1
C
C
      S = -1
  70  S2= -1
  71  C = S*COL + STCOL
      R = S2*(I-1) + STROW
      FLD(18,12,ARRAY(C,R)) = FLD(24,12,ELEV)
      FLD(30,6,ARRAY(C,R)) = FLD(30,6,CAT)
      IF (S .EQ. 1) GO TO 80
      S =1
      GO TO 71
  80  IF(S2 .EQ. S) GO TO 100
      T = S2
      S2 = S
      S = T
```

```
      GO TO 71
 100  CONTINUE
      RETURN
      END
C     SUBROUTINE CHKRBD
      SUBROUTINE CHKRBD
      IMPLICIT INTEGER (A-W)
      COMMON BUF(20),ARRAY(500,70),CELSIZ,STCOL,STROW
      DO 100 I=1,20,4
      CATEG = I/4+1
      DO 100 J=1,4
      DO 100 K=1,4
      ROW =J + STROW
      COL = I+K+STCOL
      ROW2 = I+K+STROW
      COL2 = J+STCOL
      ARRAY(COL,ROW)=CATEG
 100  ARRAY(COL2,ROW2)=CATEG
      RETURN
      END
C     SUBROUTINE FILLIN(LC,BC,LR,BR,CATEG)
      SUBROUTINE FILLIN(LC,BC,LR,BR,CATEG)
C
C  THIS SUBROUTINE CHECKS ROTATED SURFACES FOR 'HOLES
C  AND FILLS THEM IN WITH APPROPRIATE ELEVATION AND
C  CATEGORY IF IT FINDS ANY
C
      IMPLICIT INTEGER(A-W)
      COMMON BUF(20),ARRAY(500,70)
      DATA HUN/0100/
C
C
C
C  BEGIN AT LEAST ROW AND COLUMN AND PROCEED TO BIGGEST
C  ROW AND COLUMN TO CHECK FOR HOLES
C
C
      DO 100 I=LR,BR
      DO 100 J = LC,BC
C
C  IF THE CELL IS NONZERO IT HAS BEEN ASSIGNED A VALUE
C  AND IS OK.  PROCEED
C
      IF (ARRAY(J+1,I) .NE. 0) GO TO 100
C
C  THIS CELL IS ZERO.  IF BOTH OF ITS NEIGHBORS (TO LEFT AND
C  RIGHT) ARE NON ZERO, THEN WE HAVE FOUND A HOLE
C  OTHERWISE THIS CELL IS NOT PART OF THE OBJECT
C  AND CAN BE IGNORED
C
      IF(ARRAY(J,I) .EQ.0 .OR. ARRAY(J+2,I) .EQ. 0) GO TO 100
C
```

```
C   FILL IN HOLE WITH AVERAGE OF ITS TWO NEIGHBORS
C
        ARRAY(J+1,I) = ((ARRAY(J,I)+ ARRAY(J+2,I))/HUN * HUN /2) +CATEG
 100    CONTINUE
        RETURN
        END
```

CRINC LABORATORIES

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Remote Sensing Laboratory

Flight Research Laboratory

Chemical Engineering Heat Transfer Laboratory

Nuclear Engineering Laboratory

Environmental Health Engineering Laboratory

Information Processing Laboratory

Water Resources Institute

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