PROJECT 1183 AN EVALUATION OF DIGITAL RADAR LANDMASS SIMULATION

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Part I ● The Requirement

In order to provide a capability to satisfy the problems of existing light optical and new Digital Radar Landmass Simulator Systems, USAF Project 1183 was initiated. The purpose of Project 1183 is to evaluate the improved training effectiveness which is possible using a truly high resolution digital radar landmass simulation system. Concurrently, the Defense Mapping Agency (DMA) is developing a new digital data base to be used by the simulator. The Project 1183 data base will cover a limited area, 57,000 square nautical miles, with features encoded at various levels of resolution depending on their relative importance. The data base is structured so that it is capable of supporting all future radar landmass simulations. Features (individual buildings, groups of buildings, etc. in place of general city outlines) included in the DMA data base are described by their material type, percent roof cover, percent foliage, height, location, orientation, size, etc. At the conclusion of Project 1183 the fidelity of simulation required to train radar operators will be known as well as the cost to produce the simulation. Similarly, the cost and resources required to produce a data base at specified resolutions will be known. This data will be used in responding to future needs of Using Commands.

Project 1183 is an engineering development program under the auspices of the USAF Aeronautical Systems Division at Wright Patterson AFB. The Using Commands will conduct an evaluation phase after delivery of the hardware. The digital radar landmass simulator will be installed in an F-111 Mission Simulator in 1975 by replacing the present transparency system. This will be done to insure the system can be installed with a full mission simulator and also to determine the true training capability that can be accomplished using data with increased elevation accuracy for terrain following and terrain avoidance radar training. Figure 1 pictures the system.

OBJECTIVES OF PROJECT 1183 & METHODS OF EVALUATING ITS IMPROVED SIMULATION CAPABILITY

Evolution of Project 1183

Radar simulation systems produced in the last 14 years have generally used a tri-color or black and white transparency to represent landmass data. Information is read from the transparency by a flying spot scanner in the form of an analog signal. This signal is processed to simulate radar effects and is then fed to the radar display. This type of radar simulation system was initially developed to provide a high altitude radar training capability and has generally been satisfactory for this purpose.

Present Deficiencies

Current weapon systems such as the F-111 include high resolution ground mapping radars. Their mission profiles include high altitude navigation, target identification and terrain following/terrain avoidance capabilities. The transparency radar simulation systems presently employed are inadequate for providing all radar training capabilities required for newer weapon systems. Examples from the F-111 training program are the inability to properly teach correct aircrew coordination of Attack Radar (AR) and Terrain Following Radar (TFR) procedures during night and adverse weather TFR flights and the inability to properly teach specific target identification and radar bombing. Further

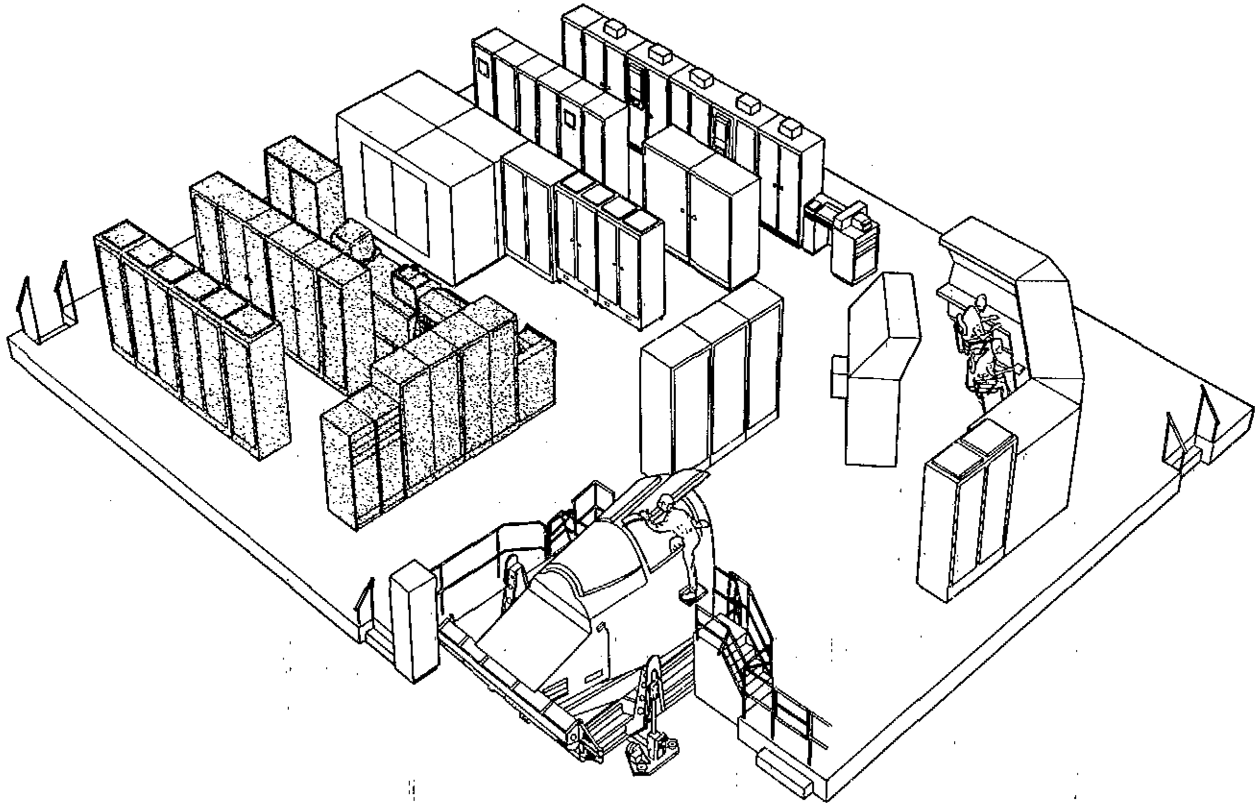


Figure 1. Artist's Conception of F-111A Simulator, Incorporating Project 1183 Digital Radar Landmass System

development of the transparency approach is considered inappropriate because of limitations of flying spot scanner and transparency technologies. The improvement in airborne radar capabilities coupled with the advent of additional mission profiles (primarily low level) necessitates corresponding improvement in simulation capabilities.

Limitations of the present day transparency radar simulation systems used in F-111 trainers include:

a. Inadequate breakup of cultural features

b. Lack of height data for cultural features

c. Costly and lengthy process to make even minor updates to the transparency and data base

d. Unusable display on the attack radar on the short range scales

e. Unrealistic simulation of the terrain following radar system

f. Maintenance problems due to complex analog servomechanisms and analog signal processing

g. Inability to consistently reset the simulation to precise geographic positions and obtain precise repetition of the simulation over a previously flown ground track

h. Point features are aligned in the cardinal directions instead of their true orientation.

First Generation DRLMS

Because of these limitations other fields of technology were investigated with a view to their applicability to radar simulation. The result is the digital radar landmass simulator (DRLMS) concept which uses all-digital storage and processing. DRLMS systems are a combination of mass memory, general purpose computers, and special purpose processors. The radar propagation equation is solved in special purpose electronics because general purpose computers are too slow. First generation DRLMS systems are expected to rectify many of the problems cited above.

Project 1183 Objectives

Because of technological problems in developing a DRLMS that universally duplicates all radar system capabilities and because it is not known what degree of fidelity or realism is required for various levels of training, Project 1183 has been established as an engineering development program with the following objectives:

a. To evaluate the improved low level radar training capability offered by digitally generated radar landmass images.

b. To demonstrate the technical and operational feasibility of modifying an F-111 simulator with a DRLMS capability.

c. To collect data upon which to base decisions regarding the retrofit of other F-111 and FB-111 simulators.

d. To establish a basis for future radar simulation.

e. To demonstrate and evaluate selected characteristics of B-1 and C-130E radars.

f. To develop techniques and capabilities to produce a DRLMS digital data base.

Aeronautical Systems Division (ASD) has procurement and overall management responsibilities for Project 1183. TAC has responsibility for developing the Initial Operational Test and Evaluation (IOT&E) Plan and executing it. SAC is to participate in the IOT&E. The Defense Mapping Agency (DMA) is responsible for data base development. The Singer Company, Simulation Products Division, is the prime contractor for the DRLMS system. These organizations have formed a cohesive working group to accomplish the above objectives.

System Definition

At the time Project 1183 was established the feasibility of the DRLMS concept had already been demonstrated in a laboratory environment and by other DRLMS programs under development, e.g., F-4F, E-2C and UNTS. To provide radar simulation which satisfies the F-111 training requirements of the using commands, both data base and processing system problem areas had to be attacked.

Data Base Concept

One goal of Project 1183 is to develop a data base that can support all radar simulation. DMA has undertaken the task of developing a digital data base that describes ground truth in terms independent of any specific radar.

To provide breakup of cultural complexes the data base must individually identify significant cultural features. This level of breakup is contrasted to the general area type of return on transparencies where only gross city outlines are portrayed with heavy industrial complexes sometimes depicted. As is done on the transparencies, small point features are included in the data base; however, Project 1183 will include many more of these features as well as their orientation.

Because of the greater expense of producing this new type of data base a multi-resolution concept has been adopted whereby only significant areas are in the Off-Line digital data base (DDB) at the highest resolutions, e.g., 50 or 100 feet. This is consistent with training requirements since the using commands train students to identify and react to only selected significant features on the radar scope. For example, the Weapons System Officer (WSO) or Radar Navigator (RN) does not require a detailed breakup of cultural features except for areas of interest, e.g., target areas, aiming points, turning points, etc. The WSO concentrates on these localized areas of the radar display and is usually oblivious to surrounding detail.

Radar Simulation Requirements

Off-Line DDB features are described using a geocentric coordinate system and the On-Line DDB is similarly referenced. This allows gaming areas to be described world-wide using a single coordinate system. Gaming areas can also be defined with any shape within the Off-Line DDB. This is in marked contrast to the transparency system using Lambert Conformal Conic (LCC) Projections of predefined geographic areas. Because the standard parallels vary for different transparencies the distortion also varies within each gaming area. It will be far simpler to change gaming areas and to correct unwanted distortions in the Project 1183 data base.

To reduce processing speed first generation DRLMS systems sometimes use PRF calculation rates lower than the actual radar PRF at least for radar systems having high PRF modes, e.g., 2022 PPS. This can result in significant features in the data base being missed by successive line sweeps. For example, an object 200 feet wide can be missed at 30 nautical miles since the distance between line sweeps at that range with one-half true PRF calculation rate is about 232 feet. To assure that all significant features are retained for processing they might be forced to a line sweep (using suitable logical processing) but this displaces features from their true position (up to 232 feet in the above example). To evaluate "missed data" effects in a training environment caused by reduced PRF calculation rates, Project 1183 will calculate line sweeps at true PRF, one-half of true PRF and two-thirds of true PRF.

Another potential problem in DRLMS systems is quantizing errors which result in unwanted "range rings" on the display. To insure that this does not occur Project 1183 requires the LSB of calculated power to be no greater than one-half decibel.

Because of the need to provide better low level training, Project 1183 includes capability to experiment with low level effects. The data base contains more features which are normally significant only at low level, e.g., power pole pylons. Adjustable variables in the DRLMS for Project 1183 include the altitude below which low level returns become visible (1000 feet to 5000 feet AGL) and the altitude at which the returns reach maximum intensity (500 feet to 2500 feet AGL).

Project 1183 requires both attack and terrain following radar systems to be completely and independently simulated. Current problems with the F-111 TFR simulation which will be overcome by the DRLMS system include erroneous fly-up commands caused by noise spikes which derive from transparency imperfections. Improved TFR simulation is essential for realistic low level training since it requires aircrew coordination. Low level training in the simulator is obviously much safer than in the aircraft.

The F-111 is the most complex mission simulator in the field. Successful integration of the DRLMS will be a significant achievement. Because of the intricate tie-in of the radar systems with other subsystems this integration task cannot be taken lightly. It is required that the DRLMS completely replace the existing transparency system. The integration includes tie-in with unmodified radar indicators, the Radar Homing and Warning System (RHAWS), radar altimeter, navigation systems, flight control system and other simulator-unique equipment.

Project 1183 will be the first program to completely integrate a very high resolution DRLMS capability into an existing simulator currently being used in a training environment. Retrofit decisions for other F-111 Simulators will be based on results of this effort.

Evaluation of Project 1183 Results

One purpose of Project 1183 is to determine the training effectiveness and operational suitability of a DRLMS system and establish the degree of realism necessary to provide various levels of training transfer. The need to do this becomes obvious when costs for producing large area, high resolution data bases and complex high speed processing electronics are examined. To aid in these determinations the Government will collect data in Project 1183 upon which future DRLMS requirements will be based.

Determination of Training Effectiveness and Operational Suitability

The Project 1183 DRLMS will be integrated into one of three F-111A Mission Simulators at Nellis AFB. Assumptions and ground rules for the evaluation of training effectiveness and operational suitability include:

a. Following DRLMS integration all three F-111A simulators at Nellis AFB will be kept in the same configuration throughout the evaluation phase.

b. Once the evaluation commences no training program changes will be made that will affect the DRLMS evaluation.

c. The evaluation will be conducted using the current syllabus, although individual lesson plans may be changed to satisfy the DRLMS evaluation.

Several techniques will be used to determine the training effectiveness and operational suitability of the DRLMS. These basic techniques include:

a. Detailed analysis of DRLMS radar scope photography.

b. Comparison of DRLMS radar scope photography with airborne radar scope photography under similar conditions, i.e., same geographical area and radar scope control settings.

c. Comparison of DRLMS radar scope photography with existing light optical transparency simulation system radar scope photography.

d. Completion of questionnaires by new students, instructors and aircrew members regarding DRLMS features and capabilities.

e. Comparison of student performance using the Radar Bomb Scoring (RBS) System during F-111A evaluation flights.

f. Comparison of how rapidly stuents adapt to new situations, e.g., low level missions.

To collect statistical data incoming students will be divided into two groups. Each group will complete the same training course following the established syllabus except that one group will receive all simulator training in the DRLMS-modified F-111A Mission Simulator and the other group will receive all simulator training in one of the unmodified F-111A Mission Simulators. Additional comparisons will be made with students who had previously completed the same training course. The WSO training course at Nellis AFB is 18 weeks duration with new classes entering every 4 to 6 weeks. Evaluation of the DRLMS will continue for about eleven months.

During Project 1183 development, several assumptions were made which need to be validated. Of foremost importance is the multi-resolution data base concept. Besides determining whether the higher resolution of the DRLMS significantly improves training the Government will make other observations. For example, the Government will determine relative training value provided by 50 foot or 100 foot versus coarser resolution source data. It will also be determined whether negative effects are caused by such things as detailed breakup of only selected areas, i.e., whether increased breakup draws the student's attention to it on the display.

Because operation and maintenance (O&M)

costs can be significant for a simulator that is used 16-20 hours per day, data will be collected to appraise DRLMS reliability and maintainability. The using commands will also evaluate the ease with which the DRLMS can be used in an actual training environment. This will include data base change, data base update of points and areas of interest, and reinitialization so that specific portions of missions can be reflown.

Determination of Future DRLMS Requirements - Cost Effectiveness

Besides determining what system resolution is required for various types and levels of training the cost of providing that system capability must also be determined. Tradeoffs must be made in data base production costs and in on-line simulation processing complexities. High resolution data bases become significantly more expensive due to the extensive analysis and digitization requirements. Higher system resolution also requires more complex and costly simulator processing.

It is expected that future DRLMS data bases will have only two or three levels of resolution rather than the six levels used in Project 1183. Levels will be adopted based on resolution versus training effectiveness versus cost tradeoffs conducted subsequent to the evaluation phase. However, these tradeoffs will not obviate the need for each project to determine whether unique requirements exist for it. The resultant Off-Line DDB will retain sufficient flexibility to handle special resolution requirements for some programs.

Another tradeoff study to be conducted is with respect to the PRF calculation rate. If it is determined that reduced PRF calculation rates do not degrade training future DRLMS systems can use a time shared (AR and TFR) processing channel and thus save material cost and system complexity. A further benefit of reduced PRF is slower and less expensive electronics.

Of particular concern to DMA are source material versus information content tradeoffs in producing the various levels of the Off-Line DDB. These considerations range from the types of source materials required to produce a given level data base to the depth of analysis necessary to adequately describe radar significant features.

Further experiments will be defined during the coming year and some experiments will be refined during the evaluation phase based upon initial results. Some aspects of the evaluation will remain flexible while those having to do with comparisons of student performance must of necessity be fairly rigid once the evaluation has begun so that comparisons are made on a common basis.

Determination of DRLMS Capabilities/Limitations

Special experiments will determine areas requiring added study. However, these will be limited by the inherent capabilities of the system. As an example, it is not presently known whether seasonal effects should be implemented in the processing system, the data base, or a combination of both. The off-line DDB presently identifies landscape by its general characteristics, e.g., sand, gravel, rock, etc. and this information might be used during the data base transformation process to alter reflectance codes as a function of season. The data base also identifies at least two different kinds of foliage, coniferous and deciduous, which might be used during the data base transformation process to determine reflectance codes of the foliage based on seasonal retention of leaves. The geographic location of features, i.e., latitude and elevation might also be used in conjunction with foliage type to determine more refined reflectance codes. The power return of reflectance codes can be changed in the DRLMS system to alter the returned power of selected reflectance values. This type of change must be closely related to the transformation process.

Effects to be investigated will also include the significance (in a training environment) of apparent corner reflectors formed by the relative location and orientation of structures, e.g., highly reflective structures forming a tee intersection, hard surface parking lots butted against buildings, etc. These are representative of the effects to be investigated within the limitations of the presently defined DRLMS system.

Project 1183 will be formally completed at the end of its scheduled evaluation phase (approximately September 1976).

Subsequent to this date the Project 1183 DRLMS system will be used by TAC for F-111A training as well as continued verification of initial evaluation results and additional, refined experimentation.

Part II ● The DRLMS

With the evaluation phase being a central focus of Project 1183, the hardware/software system must fulfill project goals by providing a flexible means of synthesizing very high resolution real-time radar imagery. To achieve this, the DRLMS system is designed around characteristics of the AN/APQ-113 and AN/APQ-110 radar sets, in addition to requirements which extend the capability to experimental purposes.

System Hardware

The DRLMS system consists of a hierarchy of memories through which data passes on its way to the display. Each succeeding memory is smaller and faster than the previous one and describes smaller geographical areas. Special purpose computational hardware extracts data for radar sweep lines from the final memory and assigns an intensity to each resolvable element on the display. Two minicomputers are included in the system for control and data management tasks.

Data Flow

Figure 2 traces the paths of data from DMAAC to the radar display. The regional memory can accommodate a gaming area of up to 1.6 x 10^6 square nautical miles of radar intelligence by modular expansion of the initial 57,000 square nautical mile area. The district memory, which holds all data within radar range, provides storage for three elevation data bases and three cultural data bases. These multiple resolution data bases service short, medium, and long range settings. Sector memories are updated with the portion of district memory lying closest to the simulated antenna's azimuth. Retrieval subsystems form sweep lines of data from cultural and terrain elevation sector memories, which then pass to the radar equation subsystem and azimuth beamspread subsystem for computation and integration of discrete display elements.

Simulator Interface

In addition to satisfying the basic requirements for a high-fidelity radar picture, the Project 1183 DRLMS is required to replace an existing analog radar landmass system and to duplicate all the ancillary functions of that system. Some of these functions include target occulting, terrain following computer simulation, antenna stabilization, and simultaneous video for two different radars (attack radar and terrain following radar). Servicing these additional functions requires complex timing and control, a task greatly enhanced by the two general purpose minicomputers.

Display Characteristics

Project 1183 specifications demand unprecedented resolution and effects for a simulator. Among the requirements are: 50-foot resolution to 15 nautical miles range; separate computation of horizontal aspect attenuation; means of portraying low-level effects, zero-width objects, and radar reflectors; sixteen levels of radar reflectance; and vertical terrain accuracy of 50 feet. These display characteristics are produced by first insuring that the data contains all the necessary descriptors and then by providing a real-time geometric computational model that has all the required outputs.

a. Intensities. The intensity of each display element is influenced by geometric and electronic factors, but is most strongly influenced by the radar reflectance of the object portrayed. Physical descriptors provided in the off-line DDB by DMAAC are interpreted by the Digital Data Base Transformation Program (DDBTP) into one of sixteen reflectance code assignments. Each code has a modifiable db level assigned in the DRLMS system so that intensity levels can be adjusted in the simulator. Reflectance codes are processed through all the geometric influences appropriate to their placement in range and azimuth, processed through a receiver transfer characteristic model, and finally applied to the display to form an image.

b. Radar effects. Radar effects may be classed as geometric or electronic. Project 1183 requires a full range of simulated effects, from ac-

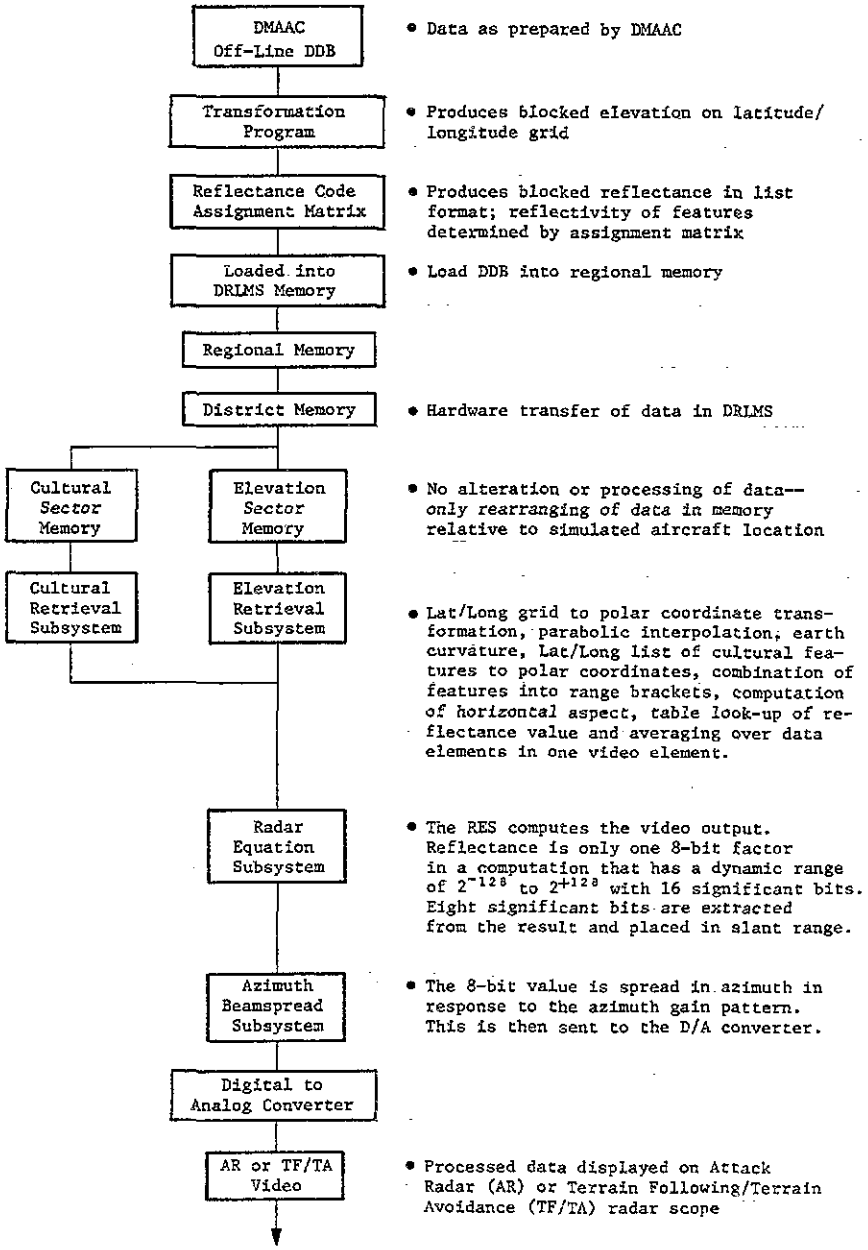


Figure 2. Data Path Flow Chart - DMAAC to the Radar Display

curate shadows and range attenuation to a faithful receiver model. Among the geometric effects, the requirement for a rigorous solution to the effect of horizontal aspect and the orientation of features has been the most influential on the form of the on-line data and the method of assembling sweep lines of data. A fully three-dimensional vector algebra solution for the angle between incident radar energy and the normal to the terrain or cultural surface is implemented in the system to produce a complete aspect effect.

Display Computation

Data which can contribute to the display is moved from regional memory to district memory in response to aircraft movement, and from district memory to sector memory in response to radar antenna movement. The data is divided into quadrangular blocks for convenience in assembling the district and sector geographic coverage. These data movements are controlled by the minicomputer complex. Once data is in sector memory, special purpose hardware extracts sweep lines of data - one sweep line of natural terrain elevation and a matching sweep line of cultural data to be superimposed on the terrain. The data passes through the radar equation subsystem where geometric and receiver effects are calculated, then through the azimuth beamspread subsystem for azimuth integration and convolution with the antenna azimuth gain pattern, then is converted to an analog signal which modulates the video input line of the radar indicator. Movement of data through the memory hierarchy is shown in Figure 3.

a. Data retrieval. The process of data retrieval consists of collecting data elements from sector memory along a sweep line and range ordering them for further processing.

The retrieval process for terrain elevation data is quite different from that for cultural data because the data structure is different. Elevation data is arranged in a grid structure in latitude and longitude. There are three subsets of elevation data having 3 second, 6 second, and 12 second grid pitch, respectively. The three data subsets are present everywhere in the gaming area and are used to support short, medium, and long radar range settings, respectively. To assemble a sweep line of elevation data, which is essentially a profile of the terrain along a sweep line, sector memory data along the sweep line's ground track is read directly from sector memory. Sweep line elements that fall between the data grid points are interpolated from a 4 x 4 matrix of elevation grid values. This process proceeds in range order from nadir to end of range for every sweep line. Since the sweep line's ground track lies on a great circle, and the data is on a geocentric grid, the sweep heading must be corrected at intervals to stay on track. This correction is accomplished automatically as the calculations proceed. At the output of the elevation retrieval process, earth curvature correction is added to the terrain profile. Finally, comparisons of sequential sweeps yield solutions to the horizontal and vertical components of the normal vector to the terrain, used later to determine the net aspect angle.

The cultural retrieval process does not proceed in range order because the data is directly addressable only by quadrangular blocks, not by data elements. Within each block cultural data is listed in terms of areal perimeter points for each feature along with reflectance and cultural elevation descriptors. The processor must analyze all the data in each candidate block to determine placement of data elements in range and azimuth, and then must reject elements which do not intersect the sweep line of interest. Range-azimuth solutions for points stored in latitude-longitude coordinates require the solution of a spherical triangle having as vertices one pole, the aircraft, and the data point. The equations for this solution are implemented in a high-speed processor which produces a solution every 200 nanoseconds. Subsequent processors sort the data by range and azimuth and fill in the voids between data intercepts so that the final range ordered cultural data sweep lines contain a reflectance, cultural elevation, and aspect description for each sweep line element. As many as five data samples may be averaged to form one sweep line element.

b. Radar equation. The radar equation subsystem (RES) calculates the geometric and electronic effects which act on the data provided by the re-

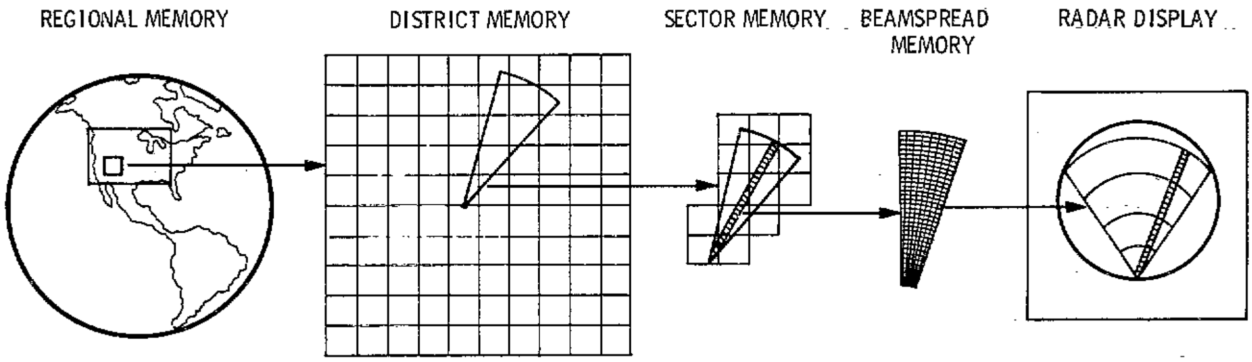


Figure 3. Memory Hierarchy of the Digital Radar Landmass Simulator

trieval subsystems. Each data element is assigned a slant range (R) and a depression angle (ϕ) by trigonometric computation from the data element ground range and elevation. Then the following equation is executed to compute display intensity for each data element:

$$P = K \text{ lin-log} \left\{ \rho \cdot \frac{1}{R^4} \cdot f_1(\Delta R) \cdot f_2(K_1 \tan\phi + K_2)\cos\phi \cdot \left[K_{IF} + K_{STC}(1-e^{-K_3 R})\right] \cdot e^{-K_4 R} \cdot G^2(\phi-\alpha) \cdot G^2_{RD} \right\}$$

Where

P = power at the receiver output

K = proportionality and video gain term

lin-log = receiver transfer characteristic

ρ = reflectance

$f_1(\Delta R)$ = pulse averaging term

R = slant range

K_1 = cosine of the vertical angle between the normal to the element and the normal to the sweep ground track

K_2 = cosine of the horizontal angle between the normal to the element and the sweep ground track

ϕ = depression angle

$f_2(K_1\tan\phi+K_2)\cos\phi$ = a table which provides for adjustment of aspect effects

K_{IF} = term proportional to IF gain setting

K_{STC} = term proportional to STC gain setting

$(1-e^{-K_3 R})$ = the STC attenuation where K_3 is proportional to STC slope

K_4 = atmospheric attenuation constant

$G^2(\phi-\alpha)$ = antenna gain, where α is antenna tilt

G^2_{RD} = radome gain

Receiver noise, shadowing, low altitude effects, and far shore brightening are not shown in the equation but are present in the hardware.

In the final processing of four-bit reflectance codes in the culture retrieval system, multiple elements are averaged together to form an eight bit number for processing by the radar equation subsystem. The eight-bit number is $\log_{20}$ with a five-bit characteristic and three-bit mantissa. The range of the number represented by the eight bits is $2^0 - 2^{-32}$, which yields a dynamic reflectance range of 0 to -96 db.

Any of the 16 reflectance codes, represented by a four-bit number in the data base can be assigned one of 256 values between 2^0 and 2^{-32} (to the nearest 3/8 db) by means of tables located in the cultural retrieval subsystem. These same tables perform the averaging function so any number in the specified range can emerge from the averaging process.

The logarithmic reflectance thus produced enters the radar equation subsystem where it is summed with other logarithmic geometric attenuation factors such as aspect angle, range attenuation, etc. When a return is attenuated below Minimum Discernible Signal (MDS), it does not drive the display, and when a return saturates the receiver, it drives the display at full brightness.

Digital computation with logarithmic algorithms yields exceptional dynamic range. The numbers carried in the RES could accommodate a radar set having a transmitter peak power of 10^{35} watts (10 followed by 34 zeros) and a receiver MDS of -384 dbm. The AN/APQ-113 has transmitter peak power of around 30,000 watts and a receiver MDS of -80 dbm - well inside the computational envelope. The dynamic range of the RES in the Project 1183 DRLMS will simulate any known radar set.

To simulate the linear-log transfer characteristic of the receiver, the K_{IF} term shown in the radar equation is manipulated in response to IF gain setting. For maximum IF gain, K_{IF} is set to about +175 db, bringing the computed power into the range of 0 to +80 db. For minimum IF gain, K_{IF} is set to +115 db, effectively shifting the gain transfer function.

The video gain control also shifts the transfer function. At minimum video gain setting a signal 80 db over MDS saturates the display while at maximum video gain setting a signal 14 db over MDS saturates the display. The gain term K is manipulated as a function of video gain to produce this effect.

c. *Radar effect examples.* Some examples of radar effects are shown in Figures 4 and 5. In Figure 4 a highway bridge near Eglin AFB, Florida is shown from two different radar vantage points. The radar range setting is 10 nautical miles. Most of the change in appearance of the bridge can be attributed to the more vertical incidence of radar energy in position 2. The appearance of the bridge is narrowed and more return is evident from the inner area of the land. Some farshore brightening is seen along the northern shoreline of the land areas. These effects are combinations of shadowing, aspect angle, secondary reflections, and slant range phenomena which are all accounted for by the radar equation subsystem.

In Figure 5 several interesting effects can be seen. The chain link fence exhibits a very narrow return in range. This kind of effect in the DRLMS is accounted for by encodement of such structures as line features. The identity of the feature as a zero-width return is carried through system computation and when pulse stretching is applied, its total duration in range is made equal to the effective pulse width. The GCA site portrayal illustrates the effect of azimuth beamspreading. In the DRLMS, successive sweep lines emerging from the radar equation subsystem are integrated and convolved with a realistic azimuth antenna gain pattern to achieve this effect. On the upper right of Figure 5, examples of terrain shadowing can be seen. The radar equation subsystem computes shadows by successive comparisons of depression angles (ϕ) as the sweep proceeds from nadir to end of range. The vertical row of bright returns to the left of the GCA site are hangars and maintenance buildings along the runway at Nellis AFB. These returns run together due to pulse stretching, an effect accounted for in the radar equation subsystem during the ground-to-slant range conversion process.

Distinctive features, such as the ammunition storage and POL sites and the grove of trees just above the sewage plant, are encoded in the data base by storing their perimeter points, reflectances, and elevations above the terrain. Any effects attributable to

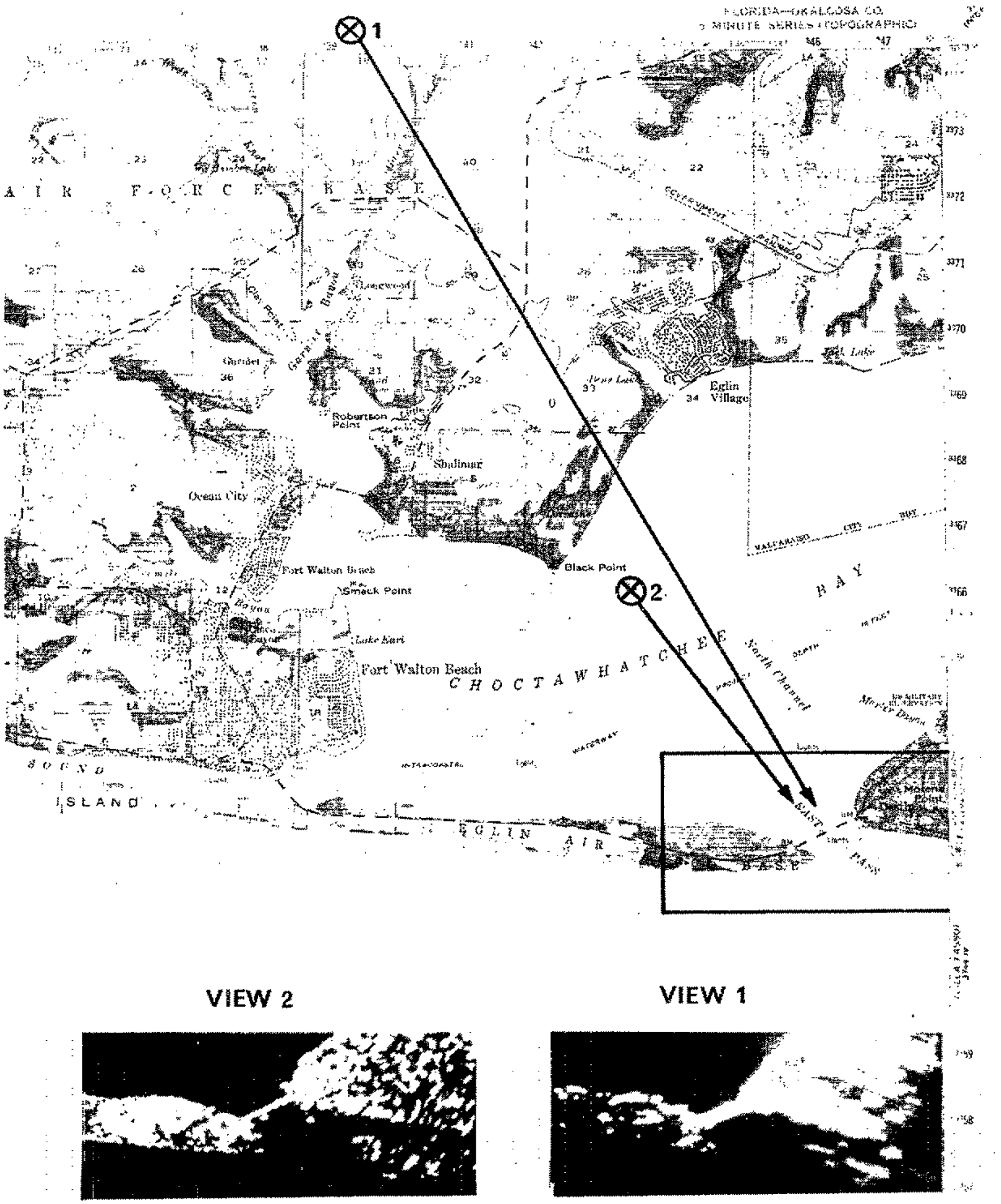


Figure 4. Example of Radar Effects - Eglin AFB

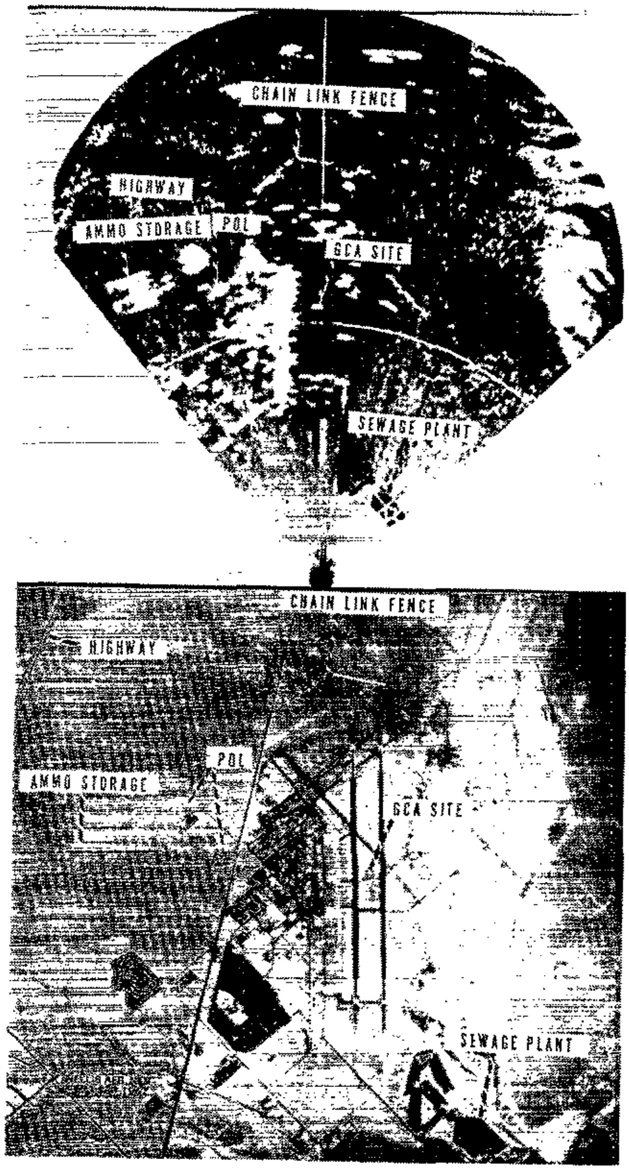


Figure 5. Example of Radar Effects - Nellis AFB

the nature of the feature itself or its surroundings (as in the case of far-shore brightening), such as low-level visibility or directionality are produced in addition to the normal effects of beamspreading, range attenuation, etc. by retaining the feature's identity up to the point in the processing where the effect is produced. For example, radar reflectors are retained up to the point in the retrieval process where their visibility can be determined. Low-level effects are retained until the radar equation subsystem can make a visibility determination from aircraft altitude.

d. Data base transformation. The DMAAC off-line DDB is an archival record of physical descriptors and does not readily lend itself to real-time simulation processing. A transformation of DMAAC data into DRLMS-loadable format is performed on the UNIVAC 1108 computer complex at St. Louis. A rescaling and re-formatting of positional descriptors occurs during this transformation as well as the deletion of qualitative descriptors in favor of a reflectance code. The latter process is accomplished by means of a matrix separately loaded at the time of transformation. This matrix correlates feature type, surface material, height, % tree cover, and % roof cover with one of sixteen reflectance code assignments. Each code represents a group of like returns whose absolute intensity can be adjusted in the DRLMS system.

The structure of the Digital Data Base Transformation Program (DDBTP), which converts the off-line DDB to an on-line simulation data base, permits compilation of partial gaming areas and selected levels of detail, thus allowing experimentation with data to define cost effective data base requirements.

Part III ● The Data Base

DIGITAL DATA BASE DEVELOPMENT CONCEPTS

As a result of the specific USAF requirement statement and the availability of resources, one of two procedures can be followed to produce a DDB (see Figure 6).

If photographic imagery is used as the basic source material, terrain (elevation) information is collected by an analytical stereoplotter, i.e., the AS-11 (see lower insert - Figure 6).

This instrument collects terrain location and elevation information (x,y,z) by means of an optical correlation process using as its information source stereo-pairs of photographic imagery.

If line maps are used as the basic source material, instruments represented by the DMA Lineal Input System (LIS - see upper insert Figure 6) are used to digitize the paper copy or an overlay keyed thereto. The LIS system consists of digitizing tables, plotters, computers and edit stations.

In both cases, collected information is sent to DMAAC's UNIVAC 1108 computer for additional processing to transform the digitized data into the DDB archival format. The data is then placed on a storage medium and becomes the "off-line" DDB.

The "off line" DDB is characterized as a multi-level data base. In broad terms it consists of descriptive data about points and areas including location, elevation and feature analysis information. DMA has adopted a concept for a multi-level DDB made up of three levels of data, i.e., Levels I, II & III.

The Production Specifications for digital data bases define three levels of cultural portrayal which are comparable to the detail visible in short, medium and long radar range settings. Although DMA has no requirement to relate its data files to reflectance or intensity, the specification (see Figure 7 for a capsule description) anticipates the scope intensity to be generally divided into 12 codes or surface material categories ranging in intensity from very bright to no-show. Each level has its own minimum size requirements and uses the 12 surface material categories listed in the specifications. Level I is the most generalized of the three and has larger minimum requirements to correspond with the less detailed long radar scope range. Level III on the other hand, is the most detailed and has smaller minimum sizes to simulate the detailed short radar scope ranges. Within a surface material category breakout, there may be another area of the same material that is "broken out" because of height alone. Each level has different mini-

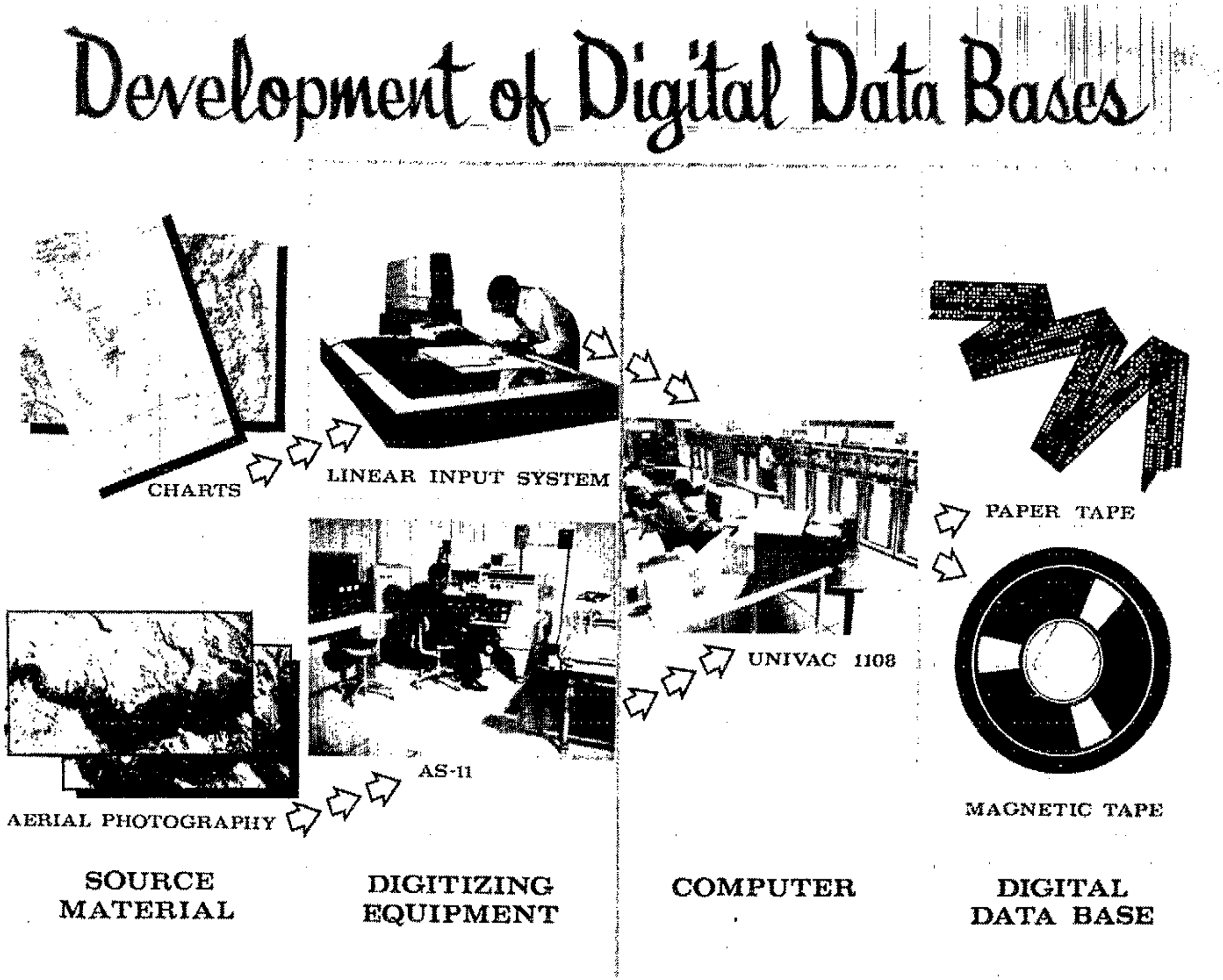


Figure 6. Development of Digital Data Bases - Two Procedures

RADAR CULTURAL PREDICTION SPECIFICATIONS

CODE NO.	INTENSITY	COMPOSITION	TYPE FEATURES
1	VERY BRIGHT	OVER 75% METAL	TRAILER COURTS, TRANSFORMER STATIONS, WATER TOWERS
2	BRIGHT	75% STONE, BRICK, 25-75% METAL	INDUSTRIAL BUILDINGS
3	HIGH MEDIUM	50-75% MASONRY 25-39% METAL	SCHOOLS, SHOPPING CENTERS
4	MEDIUM	75% WOOD 50% TAR, EARTH	SUBDIVISION, ORDNANCE STORAGE
5	WEAK	WOOD, SOD	WOODED AREA, GOLF COURSES
6	VERY WEAK	WATER AREAS	LAKES, DRY LAKES
7	RADAR INSIGNIFICANT	SAND, ROCK	DESERT
8-12	LITTLE OR NO SHOW	SOIL, MARSH, WOODS	DIRT, BOGS, BRUSH

Figure 7. Radar Cultural Prediction Specifications

mums for "breaking out" areas with a sufficient height difference over surrounding areas of the same surface materials. Special radar significant features, although belonging to one of the 12 surface material categories, can also be identified separately if such emphasis is desired. Examples of such features are listed in the specifications and include bridges, tanks, dams and airfields. All features, whether broken out at Level I, II, or III, are described in Feature Analysis Table sheets. Descriptions include predominant height, surface material category, number of structures per square nautical mile, percent of tree cover within a breakout, and percent of roof cover within a breakout, etc. Azimuth of features, when required, is also included to take into account specific aspect characteristics. (See Figure 8)

These specifications do not place resolvability limits on the detail that can be shown in the digital data base. Since the digital data base allows treatment of point features, targets and operationally significant radar objects may be included in the cultural digital data base as point targets with all of the relevant information developed as parametric header information. Such things as towers and other isolated constructions having physical dimensions down to the resolution limit of the radar system being simulated can be fully treated in the cultural digital data base as point targets. Thus, the dimensional specifications establish criteria for routine selection and encodement of complexes. The emphasis here is on the operational significance of features that are developed as point targets. The details mensurated, coded, and compiled in the cultural digital data base is based on physical characteristics. Since the digital data base development will undergo an evolutionary process, it is considered that the encodement in terms of physical characteristics and parameters will most effectively support the development of radar simulation and radar prediction algorithms.

Within the DMA, policy dictates that the off-line digital data base must be a master file to be made available and used as a source of digital data for the total DOD mapping, charting and geodesy community.

USAF Project 1183 (Nellis AFB Test)

a. Area outline. The area outline for the Project 1183 prototype digital data base covers some 57,000 square miles about a Tactical Air Command (TAC) training route at Nellis AFB, Nevada. Referring to Figure 9, the legend shows Levels I, II and III with certain amounts of real estate associated with each digitization level. Each circular area contains cultural and terrain breakout around specific points selected by TAC for test and evaluation.

The DDB development process consists of four major categories of effort, i.e., feature analysis, digitization, editing and data processing. The following paragraphs describe these processes.

b. DDB Production Procedures

1. Feature analysis. For the DRLMS project a considerable amount of production effort is required for coding of cultural data characteristics.

The analysis is performed to determine areas which will affect the simulator radar scope display portrayal. To perform the cartographic analysis the cartographer creates a mylar overlay upon which he plots and codes the point, linear and areal features to be incorporated into the data base. Associated with this overlay, descriptor data is recorded on a coding sheet by corresponding numbers for each feature. (See Figure 10)

Hypsography data is not a part of this analysis since radar reflection variations depend upon the slope and is taken into account by the transformation program when preparing the "online" data base.

The results of the cultural and selected feature analysis is keyed to a source map index. The mylar overlay (by level) then becomes the master graphic file referred to during subsequent updating procedures.

2. Digitization. To digitize, the cartographer affixes the source overlay, or terrain map, to the digitizer surface. A matte surface mylar sheet is taped over the source, so annotation can be made during digitization without cluttering the source graphic. The cartographer then initializes the digitizer, and sets the resolution and scale factors. Normally, however, source material is digitized with data recorded at the same scale.

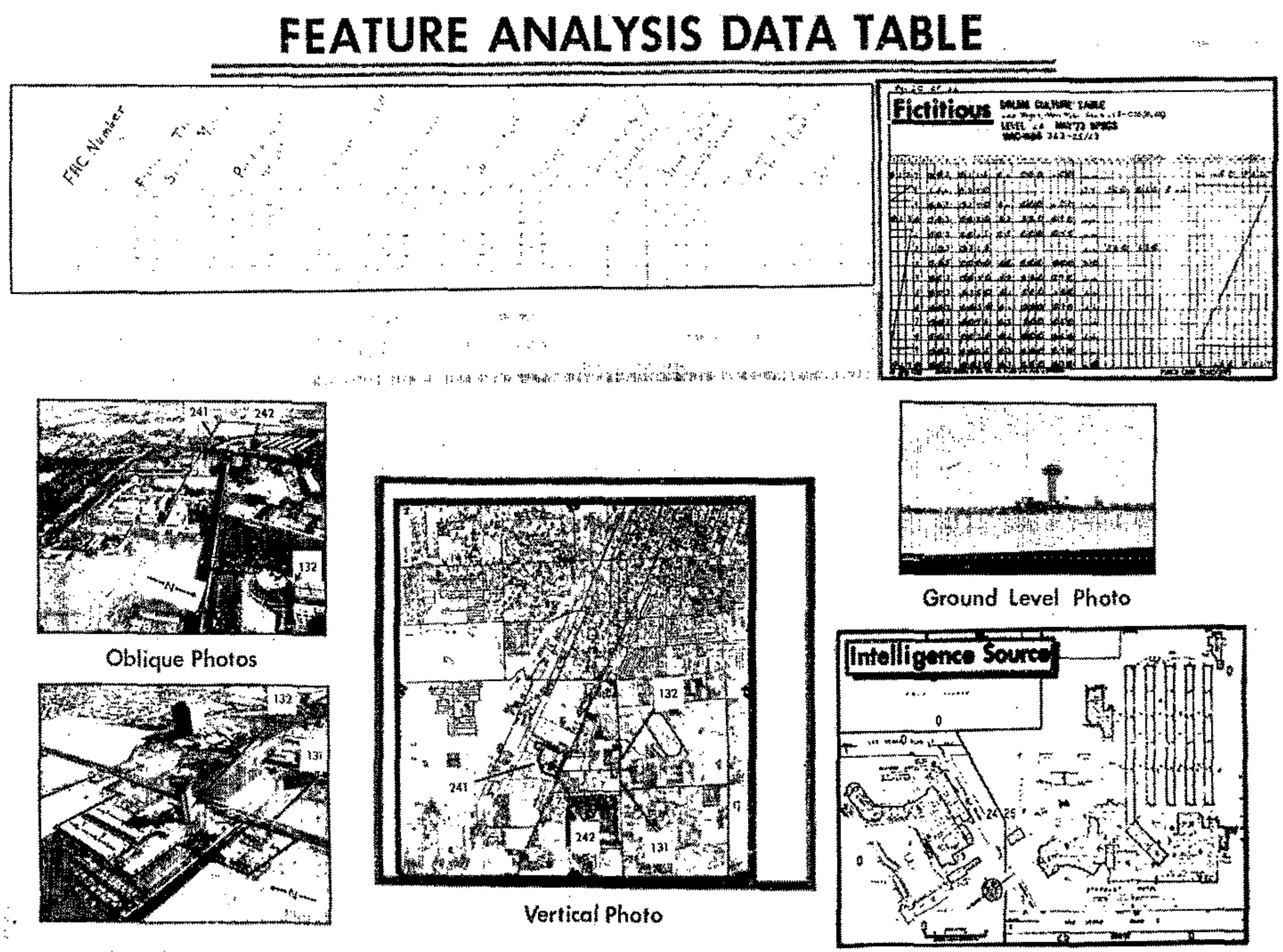


Figure 8. Feature Analysis Data Table

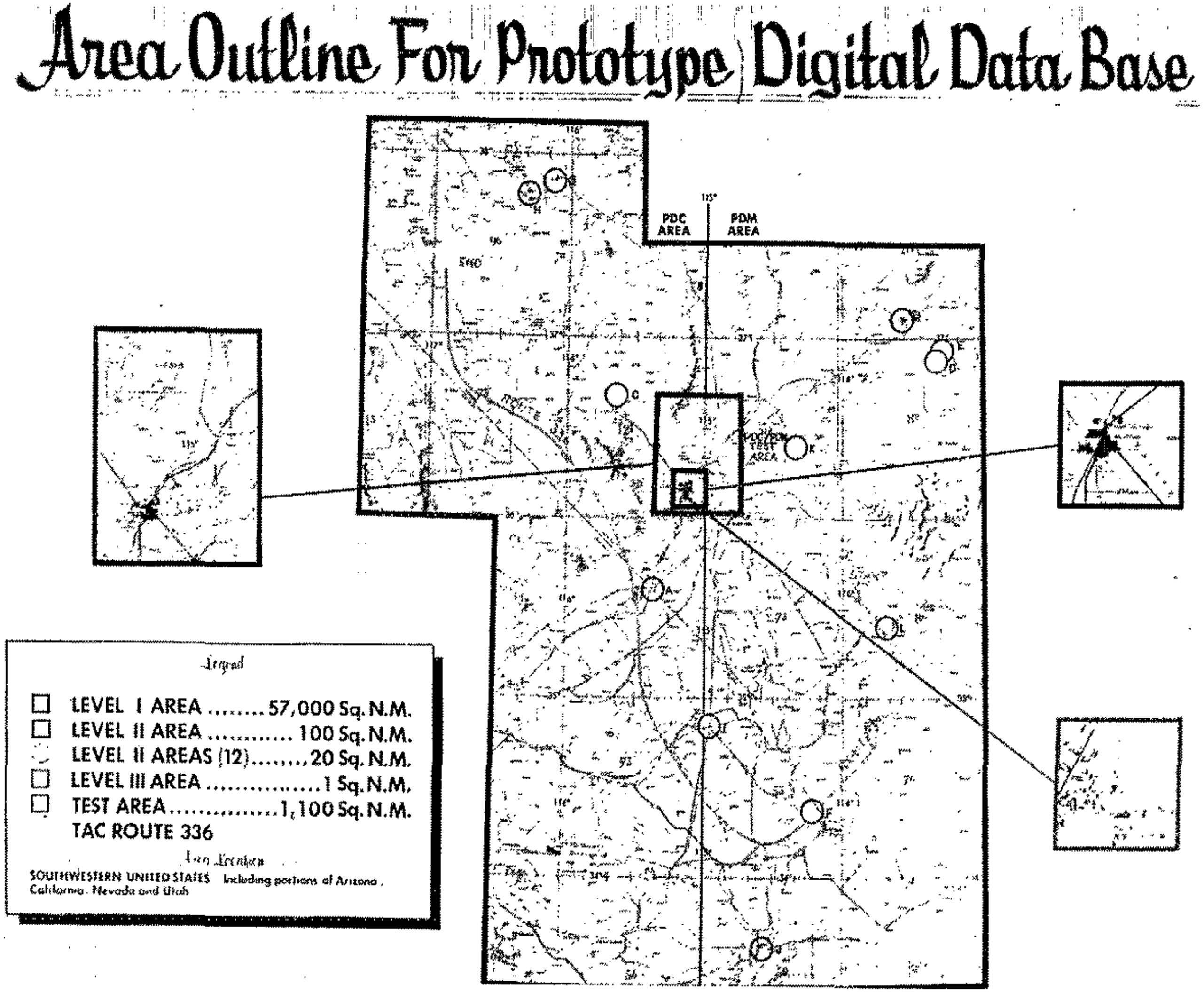
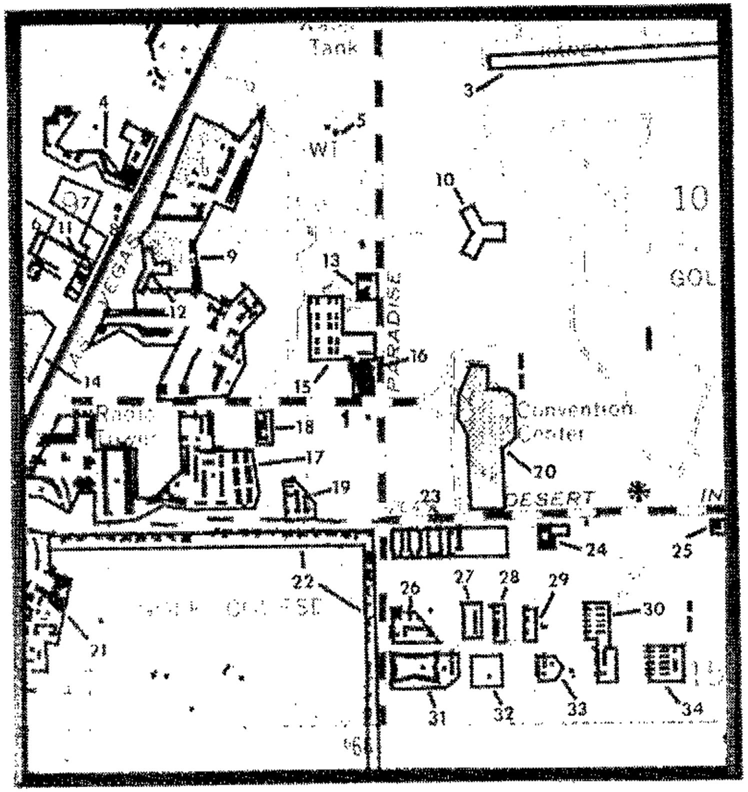


Figure 9. Area Outline for Prototype Digital Data Base

DIGITAL DATA BASE
LEVEL III CULTURE · LAS VEGAS AREA

SW LAS VEGAS



FEATURE ANALYSIS DATA
TABLE EXTRACT

FAC NR.	SURF. MATL.	HEIGHT	TREE COVER	ROOF COVER	ORIENTATION	FEATURE
5	A	15	00	100	360	WATER TANK
8	C	30	00	50	360	CIRCUS CASINO SIGN
12	C	90	00	100	-	RIVIERA HOTEL
16	C	340	00	100	360	LANDMARK
20	C	50	00	95	-	CONV. CENTER
22	D	15	00	50	-	COMM. BLDG.

Figure 10. Overlay - Digital Data Base

If the source is difficult to read or odd-sized, it may be photographically reduced or enlarged prior to placing it on the digitizer. The source is digitized at its original scale and retained in that scale until it is edited so a plot to source comparison may be made. Digitizing errors cannot be easily detected unless plot scale and source scales are consistent. Digital scale changes may be made for subsequent processing.

When the system has been initialized and the scale and resolution entered, the cartographer now starts recording data. The first entry is control. A header is entered and the digitizer stylus is positioned precisely over the first control point. A single data point is digitized for this position. This is repeated using the same header until all control points are digitized. In Project 1183 the four map sheet corners are digitized and identified with unique headers. These are permanently in the data file. The geographic values of these sheet corners are known and are used as the ground reference control when performing the registration process. These same control points are used for sheet reference.

Once the control and reference data has been digitized, the remaining entries are feature data. To digitize feature data, the stylus is moved to the start of a feature and the feature number (if contours the elevation) as the header, is entered. The digitizer is then put in the trace mode and the stylus moved very carefully along the feature. Digital data is collected along the traced line. When a feature is digitized, a mark is made on the overlay to indicate completion. A new header is then entered and the step repeated. When possible, regular features are digitized only at directional changes of straight line segments. This defines the feature and eliminates the many data points along the straight line.

The final product of the digitization process is a digital data file containing control, reference, terrain and/or feature data. The digital file is a duplication of the graphic overlay and may be verified by plotting.

3. Editing. Editing consists of the actions necessary to ensure that the digital file is free of errors and conforms to the specification.

The first step is to plot the data file for review. The review task is similar to that accomplished during normal chart production at DMAAC. Of considerable importance to the DRLMS is to ensure that terrain elevations are correct and properly assigned.

Presently, errors are corrected by redigitizing edited overlays and making the necessary correction to the data file. Features are accessed by FAC code on a particular sheet by the computer. Once the correct feature point is found the computer digitally splits the entire data file and either inserts or deletes data, depending on the change described.

The first computer run is for registration. The ground reference control points are used to register the digital file. An adjustment routine is entered to provide a least squares "best fit" for ground control. Remaining points have applied to them the control parameters. This places the data from separately digitized sheets into the same ground reference system with maximum relative accuracy. Since geographics are used in DRLMS, all data points are expressed in geographic values.

Figure 11 is a sample, from the Nellis test area, of a synthetic radar scene produced on a line plotter. Development efforts are just beginning that will allow the display of the culture file, and its consolidation with terrain. These synthetic scenes are a direct result of DMAAC's attempt to display the data base for editing purposes.

4. Data processing. The UNIVAC 1108 computer system is used to provide the digital file in the format required for Project 1183.

The editing of contours and features was a major bottleneck in the Project 1183 production pipeline. Improvement action by management led to the procurement of a very high speed proofing plotter, capable of plotting a 9 x 9 inch sheet in two seconds. Also acquired was an interactive cathode ray tube display allowing the cartographer to see and correct errors "on-line" and significantly reduce the editing time.

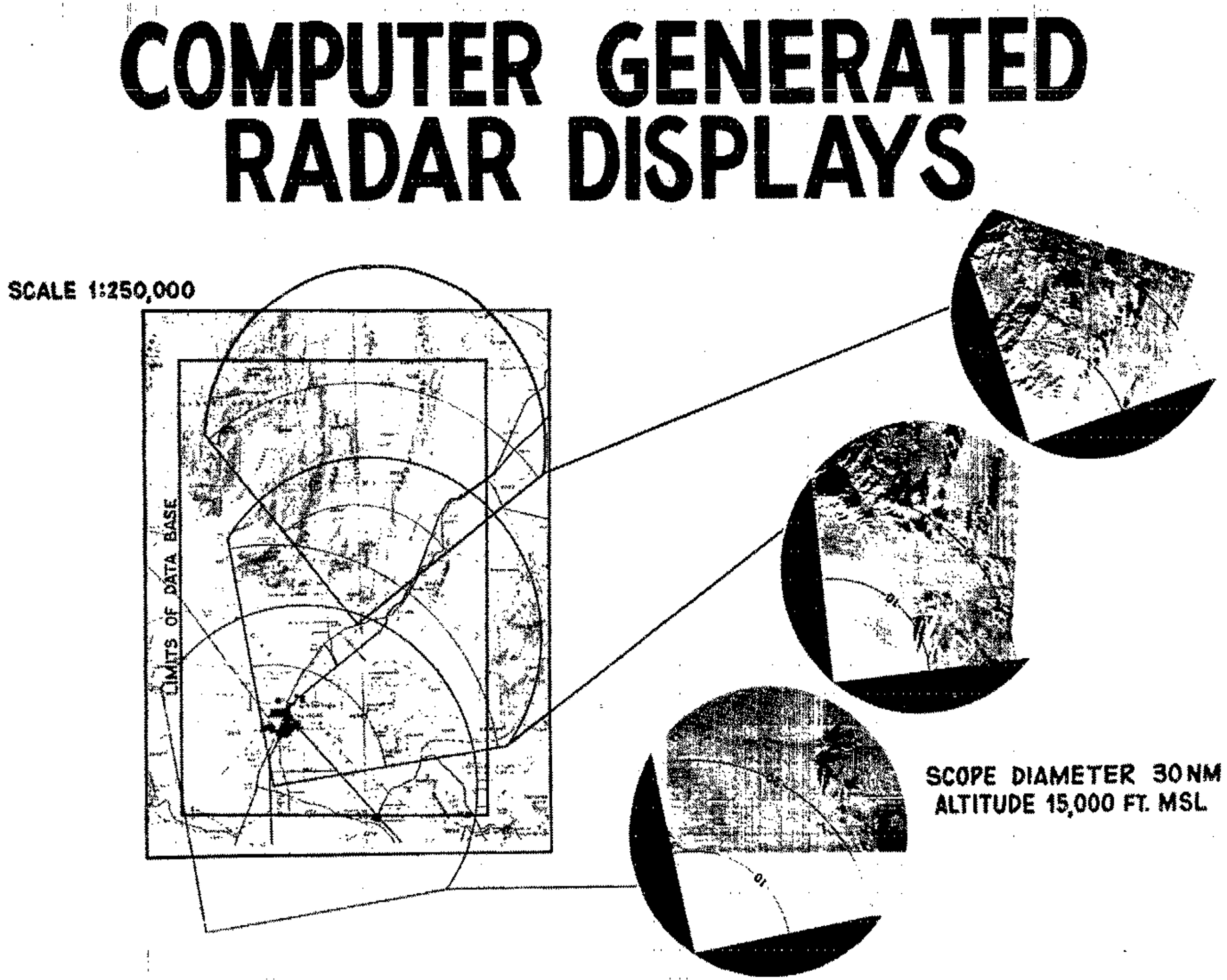


Figure 11. Computer Generated Radar Displays

Hypsography requires further processing for placement into a matrix array format. Since the data is collected linearly, additional processing is performed consisting of an interpolation of elevations on a digitally created scan line to the matrix interval desired.

The files (terrain and culture) constitute the off-line DDB and will be submitted to The Singer Company for processing to the on-line file for radar simulation purposes.

Major Challenges Facing the Cartographic Community

a. Reduction of unit cost--The cost per square mile to produce the DDB is at present very expensive. Level I costs appear reasonable, approximately 20 man-hours for 100 square miles of moderately dense real estate. However, the Level II & III costs are significantly higher and great care should be exercised in determining requirements for this level of data. For example, the user should keep in mind that Levels II & III are not intended to cover broad areas of the earth's surface.

The fewer highly dense cultural areas (large cities) that must be digitized, the lower the cost will be to the data producers for expanded coverage.

b. Consolidation of user requirements--Early knowledge of all user area and product requirements will allow identification of common needs. Planning can then progress to support many users with the same DDB on a priority basis. It is critical that this assessment be made as early as possible, before large scale production begins.

c. Technology development--with present DDB development technology it will be impossible to be responsive to the needs of classic mapping and charting in addition to providing the support of a myriad of different sensors.

The DMA recognizes this fact, and is devoting much of its R&D budget to improving its ability to produce digital data in a responsive cost-effective manner. Equipments are being developed and improved to digitize, edit, process and store digital information. Initial attempts to automate the feature analysis function have been initiated this FY.

The present technology with respect to digitization speeds is quite slow. Faster digitizing techniques appear close to becoming a reality. Graphic editing technology using interactive cathode ray tube displays is being implemented to speed up the production pipeline and reduce costs.

d. Standardization--Usually the thought of being involved with difficult standardization efforts causes everyone to run for cover. Nevertheless, the cartographic community has a standardization problem of considerable scope facing it. Premature standardization stifles creativity. Lack of timely standardization leads to duplication of effort and additional cost. With these happy thoughts in mind consider the following enumeration of areas ripe for the application of standardization efforts:

- Specification development--should a specification be developed that supports all functional users, e.g., radar simulation, production, other sensors, harbor entry training, correlation needs, classical mapping, etc.? Should specification development for each of these proceed with the objective of consolidation at a later date? The first approach seems an almost impossible task; yet the latter requires additional time, which is not available considering the operational need dates of many systems.

- Computer file structure--the specifics of record layout, header content and other design parameters are very important to efficient transfer of information and subsequent processing.

- Data base management--Standardization procedures for the digitization, dissemination, maintaining, storing and retrieval of digital data are required. Subjects such as standard scale size for feature analysis overlay maintenance need to be addressed.

Data base software for all involved processes is very expensive and should be developed to a common requirement against a common specification where possible. Users of the DDB will have to receive a detailed layout of the file structure to properly convert to their computer systems. Where joint production programs (inter and intra - DMA) are being considered common file structures and specifications will mitigate many problems associated with data base management.

SUMMARY

The completion of the Project 1183 evaluation phase will provide a digital radar landmass simulation benchmark to all agencies involved in radar training. The real training value of high-fidelity radar simulation will be established. Experience and data gathered during the project will define simulation parameters for future procurements.

The equipment developed to fulfill Project 1183 requirements and objectives will advance the state-of-the-art in digital radar landmass simulation, by using the most effective technology available or contemplated. The system architecture and computation techniques will provide global simulation capability for long-range missions, with new standards of image accuracy and fidelity.

Beyond equipment development is the following set of conclusions which, through Project 1183, forecasts a dynamic future:

- Future trends are to support advanced high-performance systems with cartographic information in digital form. Specifically, landmass simulation will be accomplished exclusively from digital files within the next decade.
- The costs associated with preparation of this data must be reduced and advanced technology holds the key to this cost reduction.
- The future of sensor simulation in the digital realm is international in scope.
- The potential cost savings to be accrued via improved simulation techniques are very large. Consequently, higher expenditures to create the digital data required to accomplish improved simulation are warranted.
- A significant effort to consolidate user requirements and evaluate standardization potential is necessary.
- With proper planning, the possibility exists to spread costs of DDB development over many end products.

ABOUT THE AUTHORS

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MR. ROGER C. DAHLBERG is Systems Engineer on Project 1183 at the Singer Company. Mr. Dahlberg is a graduate of San Jose State University with a Master's degree in Electrical Engineering. He received his B.S.E.E. from Illinois Institute of Technology. As systems engineer of Project 1183, Mr. Dahlberg directs the design and development activities of the Project 1183 digital radar landmass simulator system team. Prior to Project 1183, Mr. Dahlberg was the digital systems engineer

for the F-4F weapons system trainer digital radar landmass simulator. In this capacity, he directed both logical design and hardware development for storage and processing subsystems within the simulator system. In the F-4F program, Mr. Dahlberg also guided the development of an interactive data base update facility which permits additions, deletions and modifications to radar-significant objects and areas. Earlier experience at Singer's Simulation Products Division includes design and testing responsibility on drum memory electronics for the GP-4 simulation computer. Mr. Dahlberg also developed circuitry to permit video display and operator update of digital imagery representing manufacturing drawings. Mr. Dahlberg is the holder of a patent for a parallel/serial converter using phase locked loop techniques. He also has authored a paper entitled "An Interactive Facility for the Modification and Update of Digital Radar Landmass Simulation Data" for the Sixth Naval Training Equipment Center and Industry Conference, November 1973.

MR. ROGERS R. ROBINSON is Physical Scientist and Defense Mapping Agency Aerospace Center Program Manager on Project 1183. A DMAAC scientist for 20 years, Mr. Robinson holds a Bachelor's degree in Mathematics from Washington University, St. Louis, where he is currently preparing a thesis for a Master's degree in Computer Science. He has also completed graduate work in Astronomy at Yale University. Mr. Robinson is currently the DMAAC staff officer responsible for research and development activity directed toward improving production posture through the use of computer processing techniques. The Project 1183 off-line digital data base is a current example of this work. Mr. Robinson is a member of the original team responsible for the creation of the Defense Mapping Agency, and in earlier work has been involved with the cartographic production of aeronautical charts, geodetic/geophysical studies including trajectory analysis and ephemeris computation. He was involved with staff monitorship of the Intelligence Data Handling System Development at ACIC, and acted as an Air Staff representative responsible for acquiring two large scale computer systems for DMA.