A History Update of the

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Fort Belvoir, Virginia

1979-1983

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Preface

This brief history, covering the five years 1979-1983, relates the significant research and development activities at the U.S. Army Engineer Topographic Laboratories (USAETL) at Fort Belvoir, Va. It continues a tradition of periodic reports updating the histories of U.S. Army Corps of Engineers organizations. Previously, USAETL has published John T. Pennington's *History of U.S. Army Engineer Topographic Laboratories (1920-1970)*, ETL-SR-74-1 (1973), and Dr. Edward Ezell's *ETL History Update, 1968-1978* (1979). The authors of this report hope that, in addition to meeting official requirements, they have succeeded in recounting the accomplishments of USAETL in terms intelligible to the layman.

Applying the gains of the electronic and computer-based technological revolution to the ancient problems of mapping and surveying is a large part of what the men and women at USAETL do. In the last five years, USAETL has developed products which, when deployed, promise to provide major advances in the areas of topographic support to the Army's combat forces, intelligence analysis, weapon system guidance, weapon survey and map production. Where USAETL did not actively assist in a product's development, the laboratories often still played a role in the transfer of technology to new areas. Whether through research or dissemination, USAETL continued to provide the Army and other defense agencies with better systems to meet their needs for topographic maps and data, terrain information, surveying, digital image analysis, robotics and artificial intelligence techniques applied to topographic problems.

Much of what USAETL does is done in several technical vocabularies, none of them easily rendered in everday English. This historical update attempts to provide a window into the unclassified research and development programs at USAETL for the 1979-1983 period. The authors hope an understanding of USAETL's role will result from their effort.

Our own effort to understand USAETL would have been impossible without the generous cooperation of the scientists, engineers and administrators of that organization. Those who eased our task and patiently answered our questions are too numerous to mention in full, but our special thanks are owed to Col. Edward K. Wintz, USAETL's commander and director from 1981 to 1985, F Darlene Seyler, Sandra Cleva, Mark Ross, Barbara Jayne, Douglas Caldwell, Richard Clark, Lawrence Gambino, Frederick Gloeckler Jr., Dr. Kenneth Kothe, Bruce Opitz, Donald Skala, Dr. Robert Leighty, Anne Werkheiser, Daniel Edwards, Dr. Jack Rinker, Dr. John Viletto, George Simcox and Cedric Key. They opened the doors to us. Without their help, this historical summary would not have been possible.

Andrew Hamilton
Dr. Robert Hellman

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Introduction

Like having superior firepower, having better knowledge of your forces and the enemy's position can sometimes mean the difference between winning and losing a battle. Yet as John Keegan made clear in his popular study of the experience of war, *The Face of Battle*, men involved in close combat were often unaware of their position or the rapidly changing battlefield events going on around them. A past commander might have changed history with such knowledge; the present-day commander, who must cope with the faster and more lethal pace of modern battle, cannot afford not to have it.

Although the laboratories discussed in this history do many things at many levels of research and development, they are in a sense responding to the present-day need. In the broadest sense, the U.S. Army Engineer Topographic Laboratories is seeking ways to answer the questions, "What is our position? Where is the enemy? What is happening, or likely to happen, now?" From the creation of the Aerial Mapping Detachment at Wright Field, Dayton, Ohio, in 1920, through the Engineer Board of World War II, to the Geodesy, Intelligence and Mapping Research and Development Activity (GIMRADA) of the 1950s and 1960s, to the present-day organization located at Fort Belvoir, Va., that purpose has not changed.

Over the years, however, the methods used to meet the continuing need for the orientation of combat forces in the field have changed greatly. Just during the five years under study here, spanning 1979 to 1983, several major changes in focus took place. The creation of a Center for Artificial Intelligence within the Research Institute at USAETL, for example, pointed to a new area of research. Conversely, during this period, the study of geodesy underwent a steady de-emphasis. Similarly, work for the Army Space Program Office was on the ascent, while work for the Defense Mapping Agency declined. The largely mature technology of electromechanical mapping systems, which produces maps on paper, gave way during this period to the emerging technology of digital topography producing "maps" recorded on magnetic disks and tapes capable of being read by computers. USAETL found itself in a continual state of transition with respect to technology, customers and internal organization.

Such change is standard operating procedure at USAETL, the organization charged with research for and development of new systems for surveying, land navigation, terrain analysis, and the production of maps and related topographic products. As such, the laboratories have created high-precision positioning systems for artillery, targeting systems for tactical missiles, and improved systems for creating and reproducing the maps giving special military geographic information needed by the Army in the field. Together with continuing work on the automation of map production and digital image analysis, as well as wholly new work on autonomous land vehicles, it is easy to see that USAETL is an important part of the development of new technology for the future Army.

But throughout these changes, the goal remained finding new ways to get timely, high-quality topographic information, whether for a commander in the field or a "smart" missile. Accordingly, the USAETL record from 1979 to 1983 was one of continuing progress toward more demanding goals. Many ways were tried, and this is reflected in the variety and complexity of the material covered herein. There is, regrettably, no shortcut to understanding everything USAETL is doing (and indeed, a good portion of what the laboratories do is classified and thus not detailed here), but the authors have made every effort to make these technical subjects easily understood.

The Organization of USAETL

Since 1974, the laboratories which make up the organization presently known as the U.S. Army Engineer Topographic Laboratories, have been housed in the Cude Building and two small outposts, all located on Fort Belvoir's North Post, now the Humphreys Engineer Center. While the units comprising USAETL have changed over time—reflected in the organization charts attached to previous histories and to this volume—the basic structure during the 1979-1983 period consisted of the Topographic Developments Laboratory (TDL), the Geographic Sciences Laboratory (GSL), the Computer Sciences Laboratory (CSL), the Research Institute (RI), the Terrain Analysis Center (TAC) and staff offices.

Each component has a different focus, and tends to serve different customers. TDL, for example, encompasses development work in survey (largely for the Army in the field) and map production (largely for the Defense Mapping Agency). GSL aims its efforts at supporting the Army's requirements for field mapping and military geographic information. CSL largely serves the Army Space Program

Office and the intelligence community with its work in digital image analysis, but also provides computer support for the other laboratories and their customers.

The Department of Defense budget for research and development (R&D) distinguishes several different levels of development: exploratory, advanced and engineering. Research and exploratory development are largely concerned with inventing and proving the validity of new technologies; advanced and engineering development are concerned with creating militarily useful equipment incorporating these new technologies. The three laboratories are mostly concerned with the latter categories of work, advanced and engineering development, although they also do some exploratory work.

Research—the basic level of R&D work—is, at USAETL, primarily the province of RI, which was organized to support all of the laboratories. Thus, USAETL was designed as an integrated facility for topographic R&D.

But the organization also includes a small production activity, the Terrain Analysis Center, whose mission is to provide the Army with special studies containing military geographic information on selected areas around the world.

Finally, to guide and support the activities of the three laboratories, the Research Institute and the Terrain Analysis Center, USAETL contains administrative offices headed by a commander and director, a deputy commander and director, and a technical director. Organizational charts listing the various components of USAETL during the 1979-1983 period are provided at the end of this report, along with a listing of senior USAETL personnel.

The Organization of this Study

The changing nature of USAETL presented the authors with certain problems in organizing this work. The previous histories each used a different organization, one devoted to fields of scientific and engineering activity, the other to a listing of products for different customers. Neither approach seemed suitable for this effort. Nor, because of the frequent "cross-laboratory" efforts at USAETL, did a history organized exclusively around individual USAETL components recommend itself.

In the end, the authors settled on a functional division of the topic matter. Thus, Chapter I treats USAETL efforts in the realm of terrain analysis and field mapping, largely carried out in GSL. Chapter II treats a related activity, the Terrain Analysis Center, a production rather than an R&D organization. Chapter III is devoted to survey-related work, chiefly carried out in TDL and RI. Chapter IV turns to the complex field of mapping R&D, including digital image analysis, the main focus of TDL and CSL. Chapter V recounts two special projects, one each from TDL and CSL, which grew out of earlier USAETL work on automated mapping and digital imagery. The final section, Chapter VI, reviews the major activities of RI.

I. Terrain Information Research and Development

A. FEED: The Virtues of Digital Elevation Data

As has been observed, traditional maps are hard to use, seldom up-to-date and hardly ever contain the specificities required on the battlefield. Scientists at USAETL have long insisted that one key to the map problem is digital topographic data. Digital maps can theoretically be easy to use, up-to-date, and specifically tailored to a commander's immediate needs. It is, however, not always easy to show how something simpler to use can be created from the intimidating complexities of computer science. In some cases, USAETL was forced to do as much educating as it does inventing and evaluating. USAETL has sought to demonstrate to the military that the range of possible functions of digital topographic data is practically infinite. To do so, USAETL had to bring some laboratory technology to users on their own ground, by hitting the road in a truck full of working prototype equipment.[1]

The FEED road show

The best way to raise consciousness about the virtues of digital topographic data was discussed for some time at USAETL. Finally the decision was made to produce a demonstration program that provides a particular kind of information needed in the battlefield and show its new uses when supplied in digital form. Once chosen, the program would be taken out to the users. The decision was made to use digital terrain elevation data, readily available from the Defense Mapping Agency (DMA), and various display software developed by USAETL engineers, including contour, oblique and perspective plot views. All the equipment, with the exception of the disk drive, was to be standard militarized equipment, and even the data was standard DMA Level 1 Digital Terrain Elevation Data (DTED). A vehicle was needed to take the program on the road. A mobile home was chosen, camouflaged to suit military use and the Field Exploitation of Elevation Data

FEED's mobile home—the van used to demonstrate the system around the country.

(FEED) project was underway.

William Veigel, FEED project director, who was determined that FEED get a full viewing, dispatched the demonstrator to 14 sites during a 12-month period. In addition, there were Systems Program Reviews, a command post exercise (Golden Saber IV) and a U.S. Army Human Engineering Laboratory battalion artillery test (Helbat VIII). At the demonstrations, Capt. Mark Fornwalt handed out questionnaires on how participants could use FEED and other future fieldable automated terrain analysis systems.

Graphic demonstrations in the field

In a typical demonstration, small groups of uniformed and civilian personnel gathered in the van to watch the rugged military standard minicomputer perform. The system produced graphics on demand for the following:

- Line of Sight
- Terrain Masking (Field of Fire, Safe Areas, Acquisition Contours, Safe Area Below a Given Ceiling)
- Contour Plot
- Perspective View
- Oblique View

Fornwalt and Veigel also demonstrated how FEED allowed its operator to build a digital file of military features (units, symbols, boundaries, etc.) and overlay it on any of the available graphics.

Thinking digital topographic data

To the many officers and civilians exposed to the roving program, FEED was a revelation. Intelligence officers proved "highly interested in all capabilities that can be developed in the digital topographic data area."[2] Aviation personnel especially liked FEED's capability for providing perspective views of the terrain from various altitudes. They also were interested in radar acquisition plots and displays of safe areas—two types of computer graphics that give a pilot a real idea of which altitudes and lines of approach could be combined to shield his aircraft from enemy radar. Simple line-of-sight graphics, in turn, captured the interest of communication people. The FEED Road Show had succeeded, in the words of USAETL research and development coordinator Capt. David Gallay, in getting the Army "thinking digital topographic data."[3]

Had it remained at USAETL, the FEED demonstration would have been seen by a fraction of the people who were able to see the van at the 14 sites it visited. As it was, the mobile van gave tangible evidence that digital topographic data was moving out into the field.

The FEED system

As already noted, the FEED system was assembled from standard military hardware (except the disk drive). Its performance, taking "15 minutes to do what would normally take at least half a day," was doubly impressive in view of the humble components listed below.[4]

- Central Processing Unit—a Rolm 1602A AN/UYK-19 16-bit microcomputer
- Cathode Ray Tube—a TEKTRONIX RE 4012 with an 11-inch screen
- Hard Copy—VERSATEC Plotter map scale hard copy or transparency
- Magnetic Tape—MILTOPE AT 1161R 9-track tape
- Floppy Disk—MILTOPE DD400 M/S
- Disk—CO 9762 with 80 megabytes
- Disk Controller—AED 8000

Immediate uses

As basic as the above equipment appeared (to eyes of computer scientists), the real selling point for FEED was in the usefulness of its product. The people at Fort Benning, Ga. ("Home of the Infantry"), and Shaw Air Force Base (headquarters of the Tactical Air Command), for example, were handed on-the-spot graphics from the FEED system. Many graphics, such as line of sight, terrain-masking and contour plot were judged clearly of great and immediate use to the field commander who learned how to read them. Perspective and oblique graphics, in turn, brought home the added dimension of easy readability possible with FEED computer graphics. A look at a FEED oblique view illustrates what FEED was showcasing in its touring year.

INPUT:

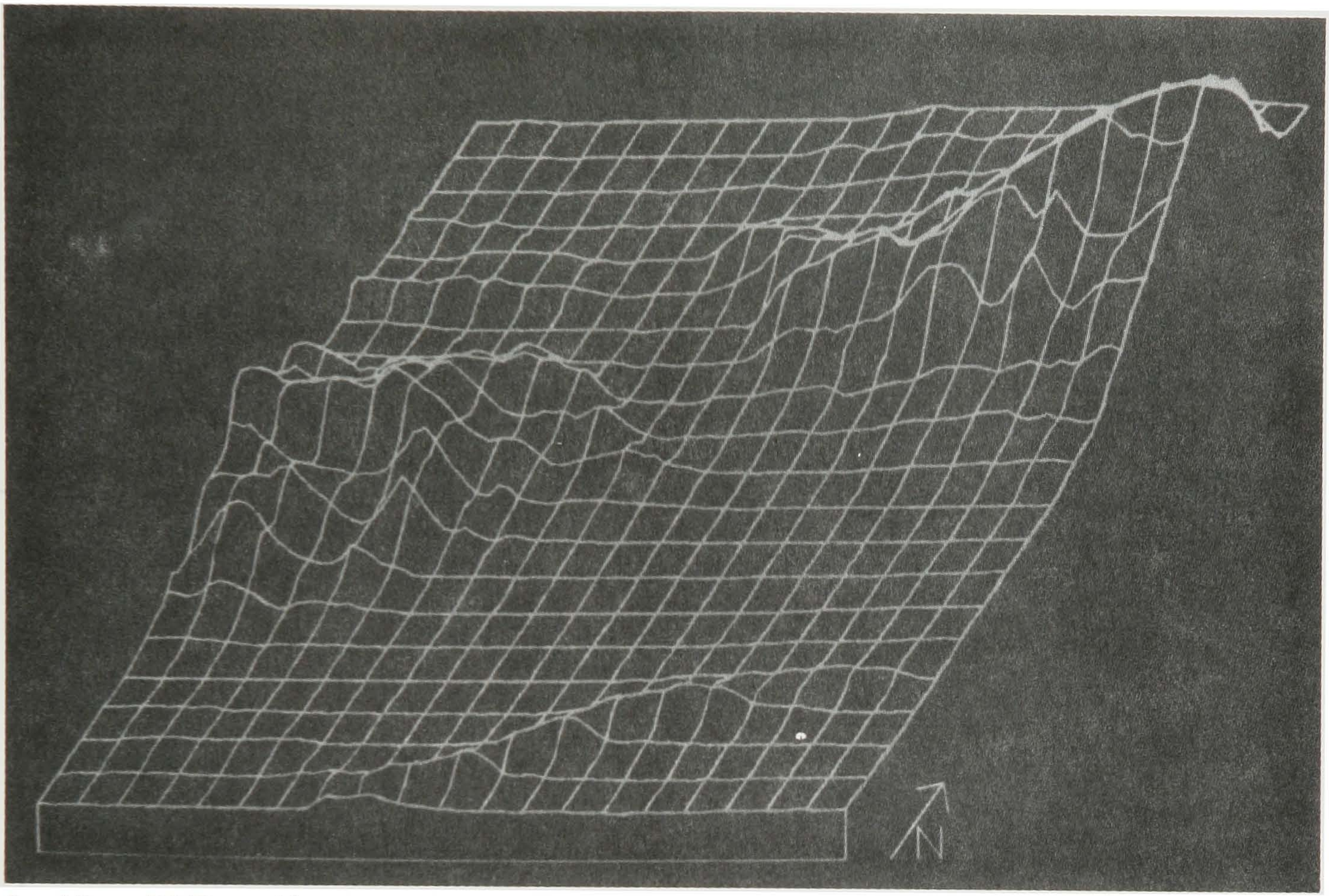
- Area boundaries
- Closest boundary (S,N,E,W)
- View origin (SW, S, SE, etc.)
- Vertical exaggeration
- Option for military features
- Type of view
  a. Grid
  b. Range lines
  c. Contour levels
  d. Range lines with grid
  e. Contour levels with grid

Typical Execution Time: 40 minutes for a 40 kilometer by
40 kilometer area.

Remarks: Grid spacing is selectable with options a, b and e.

Beyond maps

Though just one of FEED's capabilities, graphics like the oblique view gave evidence of the real possibilities of digital topographic data. Field commanders now saw that maps could not match such flexibility, nor could they be produced in such a short time. The 1982 Historical Summary of the Terrain Information Systems Group flatly stated that FEED's performance caused the "release of the Letter of Agreement for the DTSS."[5] The latter, the Digital Topographic Support System (DTSS), was to be the logical



An oblique FEED graphic.

extension/elaboration of what FEED so effectively demonstrated: the uses of digital topographic data in the field. DTSS, covered elsewhere in this history, would use FEED-type technology to supply a whole range of topographic information rather than mere elevation graphics. With FEED's tour, however, the point was made: there was more to topographic support than lugging around bulky maps.

The fate of FEED

Though envisioned as a demonstrator and a step toward DTSS, FEED's official termination in 1982 did not end its usefulness. The FEED van was dispatched to Fort Bragg, N.C., where users continued to funnel input back to research and development at USAETL. The Tactical Utilization of Digital Elevation Data (TUDED) work unit at USAETL was formed to support this continuing effort. The year 1983 started with a restructuring of application programs for FEED, which streamlined operation and the creation of views by 10 percent. This was done as part of the documentation contract.

In 1983, the unit was damaged while being set up in the field, prompting its return to USAETL. On 11 June 1983, the partly empty van caught fire and was destroyed. The Data General-based software was reconstructed and work was begun to convert it for continued use on the PDP-11/24 at Fort Bragg. The converted software and printer/plotter would permit a good look at a minicomputer exploiting digital elevation data, as compared with a large main frame (UNIVAC 1108) (following up on a 1979 contract with LNK Corporation) to look at the same general problem. Exercise Gallant Knight, slated for March 1984, was to test the minicomputer-based setup.

Summary

FEED was conceived as a demonstrator project to show how digital topographic data can be of use in the field. To that end, the van criss-crossed the country and showed the Army just that. The speed and flexibility of its graphics turned many heads, and it proved the first big step toward the DTSS. Plans and Requirements Branch Chief, Milt Goldin, summed it up as "an innovative experiment in bringing laboratory technology to users on their own grounds."[6]

Footnotes

1. FEED (Field Exploitation of Elevation Data) Prototype System. USAETL publication.

2. *Tech-Tran*, Vol. 6, No. 3 (Summer 1981), p. 2. A quarterly technology transfer newsletter published by USAETL, Fort Belvoir, Va.

3. Ibid.

4. Ibid.

5. Installation files, Geographic Sciences Laboratory, Terrain Information Systems Group (GSL-TISG), 1982, p. 1. Annual Historical Summaries are provided by each USAETL laboratory and retained in the "Installation Files" at USAETL. Much of the material is unpaginated.

6. *Tech-Tran*, Vol. 6, No. 1 (Fall 1981), p. 4.

B. The Army Digital Topographic Data Requirements Study

The Digital Topographic Data (DTD) Requirements Study was the result of the "quickly growing requirement throughout the Army for digital topographic data."[1] At the time of the study, however, only five DTD users had stated requirements in specific system and program documents or had been validated for support from the Defense Mapping Agency (DMA). These five included FIREFINDER, Pershing II, the All-Source Analysis System (ASAS), the Digital Topographic Support System (DTSS) and the Army Training Battle Simulation System (ARTBASS). There was a realization in the Army community that DTD had a lot of potential uses; and fielded systems such as Pershing II, as well as demonstration systems such as USAETL's FEED, were exploiting DTD advantages daily. Eventually USAETL was tasked with sorting out what was needed and what was available for Army use, present and future. The resulting DTD study spanned the years 1981-1984, and marked a major achievement of USAETL's Geographic Sciences Laboratory (GSL) during the period of this update.

Looking to digital needs

In the course of planning for the DTSS, the Army wanted to be sure that the digital data requirements of the system could be met by DMA. USAETL depended on DMA for digital topographic data. No matter how refined the DTSS or any collection of equipment might be, it could not fill a need in the field without an adequate DMA data base.

Accordingly, in 1981, an evaluation of two DMA prototype data bases for terrain analysis applications was begun by USAETL's Terrain Information Systems Group under the direction of Frank Capece. Planners within USAETL were aware that the DMA data base question reflected a larger problem: systems were being developed throughout the Army with differing data requirements. If USAETL's study showed that DMA could meet DTSS needs, that did not mean the unique requirements of other users could be met as well. In short order, USAETL's task "snowballed," according to Richard Herrmann, to a study of the digital topographic data requirements "not only for terrain analysis requirements, but for current and future uses Army-wide."[2] Finally, in addition to knowing what was required and what was needed now and in the future, USAETL was asked to help DMA evaluate two prototype data bases. USAETL, using much of the software developed for the Digital Terrain Analysis System, was looking for standard requirements for a data base. What began as a study for DTSS turned into an Army, Navy and Air Force evaluation of digital topographic data requirements with USAETL the Army's lead organization.

DTD demand: growing in all directions

The swiftness with which USAETL's task grew testified to the urgency of the study. Throughout the Army there was a "quickly growing requirement" for digital topographic data.[3] Such growth was in three basic areas: field Army terrain analysis; Army analysis community needs, such as simulation, modeling and training (e.g., war gaming); and tactical systems and programs (e.g., missile guidance). Such demands for DTD arose within the Army on a system-by-system basis, resulting in specific DTD requirements springing up suddenly from diverse users and developers. Duplication of effort was one concern, and DMA's support work load quickly became another. The Office of the Army's Assistant Chief of Staff for Intelligence (OACSI), responsible for current and emerging DTD requirements, recognized the problem. DTD demand was growing without direction.

In many cases this support capability (a compatible DTD data base) has been assumed by the proponent developer without consideration for the considerable amount of time and resources required to produce such a product. Such a situation could dangerously lead to fielded systems that could not be supported.[4]

Toward a standard digital terrain data set: DMA prototype testing

To address the data base problem, OACSI asked DMA to develop a prototype digital terrain data set which the Army could then evaluate against the background of its overall DTD needs. On 24 October 1980, an OACSI-sponsored conference resulted in the selection of Fort Lewis and Yakima Firing Center in Washington state as the test areas for DMA's production of two prototype data sets. These two sites offered DMA large variation in terrain with Fort Lewis resembling parts of Western Europe and Yakima resembling parts of the Middle East.

USAETL reentered the picture when DMA requested the Army develop a plan to evaluate the prototype data sets. The U.S. Army Materiel Development and Readiness Command, (now the Army Materiel Command) designated USAETL to act as its representative and lead agency in the evaluation. USAETL was also asked by the terms of DMA's request to identify all known and anticipated Army systems using DTD. Frank Capece, Richard Herrmann, Maj. Michael

Thompson and others at USAETL began a study that extended far beyond the requirement of the DTSS.

The Digital Topographic Data Requirements Study

USAETL was faced with three basic tasks: to evaluate DMA's two data sets, to articulate known and future DTD requirements and to provide a unified statement of Army needs, which was formulated as a specification for a digital topographic data base to support Army users. The Digital Topographic Data Requirements Study, carried out from 1981-1984, was USAETL's four volume, 700-page response to these three tasks.

DTD study: Phase I, Army evaluation plan

USAETL scientists assessed data sets in terms of data content completeness, absolute and relative accuracy (vertical and horizontal), resolution of the elevation and feature data, and the format or structure wherein the data were recorded (including the coordinate systems and referenced datums).

The Digital Terrain Analysis Station (DTAS), USAETL's in-house interactive graphics system, provided a means to do much of the above-mentioned evaluation. Software routines were developed to read and reformat the DMA data into the DTAS data base. Terrain analysis products were produced using both DMA data sets as DTAS input, and the results were compared with manually prepared products. The Terrain Analysis Center then conducted a visual analysis of the usefulness and acceptability of the prototype data element features and the automated terrain analysis products.

To further compare and quantify the differences between the digital and manual data features and products, USAETL also performed a statistical evaluation of both the DMA prototype features and products from each data set. USAETL also evaluated the elevation data using a second-order ground truth survey provided by the Air Force's Rome Air Development Center as a control.

Both the visual and statistical evaluation included data degradation analyses to fix the minimum acceptable resolution which could satisfy Army requirements. Again here, as elsewhere in the study, ground truth exercises were done by USAETL to verify digital data.

Finally, as in Phase II, USAETL conducted a review of the Army analysis community's data content requirements. The Army analysis needs, as well as terrain needs, were treated in both phases of the DTD study.

DTD study: Phase II, Army evaluation plan

Whereas Phase I, in dealing with prototype data bases and a data base standard requirement, involved a good deal of scientific evaluation, Phase II dealt with identifying and articulating Army DTD requirements, known and anticipated. Thus, concurrently with the DTAS work of Phase I, USAETL's Terrain Information Systems Group (TISG) set about canvassing the Army with questions about DTD needs in the near and long term. The equipment used in this case was not the computer and the trained eye, but rather the telephone and letter. In time, USAETL also developed a questionnaire to assist participating Army activities in identifying the DTD requirements of their systems. Personnel from TISG and Par Technology (a contractor) conducted on-site interviews with developers at more than 60 Army offices.[5]

The liaison established with potential users, and the interviews in particular, did more than throw light on developers' needs. For its part, USAETL got a better understanding of the system or program-specific DTD requirements. The developers, in turn, received an education in the use of DTD and ways to determine requirements for DTD in the future. The interviews and the 75 completed questionnaires received at USAETL provided a solid basis to identify and articulate Army DTD needs.

With questionnaires and interview records in hand, TISG scientists spent a good part of 1983-1984 working with Par Technology on individual summaries for each identified system/program, including the key findings on their individual DTD needs. Each summary also provided a description of the system/program, its status and applicable military function, and listed available documentation.[6] The summaries also provided details on both terrain elevation and feature data requirements as well as information relating to the on-site visits. All this information was then validated and verified by letter correspondence in which the summaries were sent back for review and correction.

Phase II final evaluation: 1983-1984

With verification and validation complete, TISG turned to putting DTD requirements into a workable format for the final evaluation. With users in mind, the summaries were divided into three categories: tactical; simulation, training, testing and development; and analysis community. DTD requirement matrices were then constructed for each of these three categories.

Once the three DTD matrices were in place, four main criteria were evaluated systematically: data content, data accuracy, data resolution and data format. An analysis was also performed of functions using DTD to pin down the types of applications that would use the data. Geographic coverage and data requirements were summarized throughout all systems/programs to get a general picture of data volumes and production requirements. The results of this, and the evaluation process, added up as follows:

1. A statement of Army DTD requirements was produced including the four data criteria mentioned above and incorporating the needs of the analysis community.

2. A comparative analysis was made between the DTD requirements emerging from Phase II and the DMA prototype capabilities evaluated in Phase I.
3. A simple Army DTD specification was defined by a merging of the Phase I evaluation and the Phase II requirements.

The DTD study: results, recommendations, conclusions

Much of the DTD study remained classified at the time of this writing. Some statements can be made, however, on the basis of interviews with TISG personnel and the unclassified "Executive Summary" of the report itself.

The DTD study identified 75 Army systems that "either require or anticipate a requirement for digital topographic data."[7] This count includes 31 tactical systems; 26 systems or programs for simulation, training, test and development; and 18 systems for the analysis community. Clearly, the Army had begun to appreciate the need for DTD.

On the other hand, the study revealed that most systems and programs required DTD having content, accuracy and resolution "exceeding the specifications for standard products currently produced by DMA."[8] If, in the words of Frank Capece, the availability of digital data had been an abiding "problem area," USAETL now identified a "quality" problem area as well.

The majority of applications, whether tactical or analytical, required data roughly equivalent to the 1:50,000 specification for standard topographic maps and terrain analysis products. Even more stringent were the emerging requirements of simulation, training, test and development users, with a 1:12,500 scale equivalent specification. Existing DMA products did not meet these specificities, and the two prototype data bases were evaluated with much higher demands in mind.

The DTD study concluded that the prototype data sets with modifications could meet the lesser requirement (1:50,000), but not the more stringent (1:12,500). For these reasons, Volume IV of the report states the Army's specification for DTD at two levels, mirroring the above requirements. Thus, standards for the near and long term have been set, and the users know what can be supported and what, for the time being, cannot.

Thus, the study pointed to problems with data quality at the same time it documented an increased need for DTD in general. While 75 users were lining up for DTD, only five were validated for support from DMA, and only three of those five were already getting that support, each to a specific system specification and format. The study underlined the present and future importance of getting developers a DTD standard that met their requirement and could be realistically handled by DMA.

Summary

The DTD study marked the "first time the total Army requirements for DTD were stated and approved by the Department of the Army."[9] It was also a landmark in the push for a standardized format, and in the move toward a close coordination between DMA and its developers and users. The study underlined USAETL's view that DTD can be a true force multiplier in support of the Army in the field if DTD development is pursued in an orderly, efficient and standardized way.

Footnotes

1. *Digital Topographic Data Requirements Study: Executive Summary*, p. vi, final document issued as *Army Digital Topographic Data Requirements* (ETL-GSL-4).
2. *Digital Terrain Analysis*, USAETL-R-00122, p. 2.
3. *Executive Summary*, p. vi.
4. Ibid., p. vi.
5. Interview, authors with Richard Herrmann, Fort Belvoir, Va., 14 January 1985.
6. *Executive Summary*, p. vi.
7. Ibid., p. v.
8. Interview, authors with Frank Capece, Fort Belvoir, Va., 14 October 1984.
9. Second interview, authors with Frank Capece, Fort Belvoir, Va., 26 January 1985.

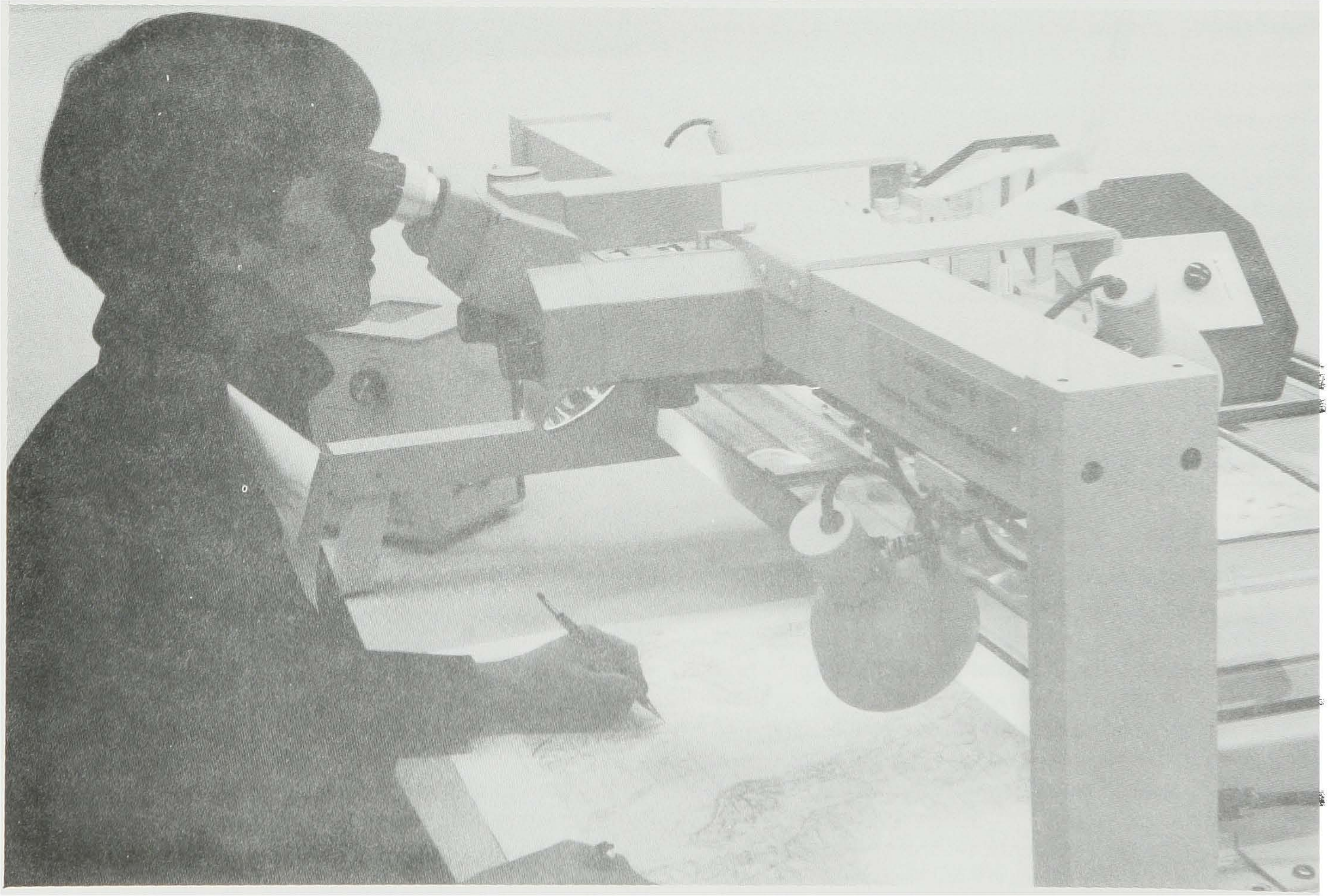
C. Needed: Better Topographic Support for the Army in the Field

The need for topographic support, to know more about the battlefield environment, was even apparent to the trench warriors planted for days on end in World War I. The soldiers of World War II, with their extensive use of the airplane, tank and motor vehicle, felt a more pressing need for precise, up-to-date maps. Indeed, the new Army had to have maps charting areas deep within enemy territory. Topographic support was forced to modernize in a hurry to meet World War II demands.

The Army today, needing yet a higher order of topographic support for much improved weaponry in a much more mobile mode, did not want to scramble once again to keep up. Two topographic requirement studies, entitled Geographic Intelligence and Topographic Support System, were made in the 1969-1971 time frame. The first study covered Army requirements for 1975 and the second study dealt with the period 1975 through 1985. These two studies were completed in 1971. The result was the approval of the Topographic Support System (TSS) Required Operational Capability document in January 1976. A fateful decision was made to proceed, not from a ground-up redesign of topographic equipment, but to use commercial non-developmental items. Thus, it was hoped, a system could be in the field by 1979 to replace the World War II equipment.

Off-the-shelf topographic support

The idea behind the Topographic Support System was to put together all the best non-developmenal equipment available (the best off-the-shelf components), make it all mobile, and put it in theater, corps and division areas. It



A Stereo Zoom Transfer Scope—one of the many pieces of equipment making up the TSS.

was hoped that Army commanders would then have all relevant topographic information, and have it quickly.[1] The new instrumentation was to enable engineer topographic battalions to revise and print maps, provide special-purpose graphics and other military geographic intelligence, and to establish survey control points under battlefield conditions.

Finding the actual items of equipment to carry out these functions proved a huge task. USAETL's Concept and Management Group spent many months from January 1976 to March 1979 evaluating the equipment to be included and coordinating its effect with the likely users of TSS through a series of meetings. The resulting concept of TSS differed somewhat from what topographic units were currently doing in the field. TSS included a military geographic information function that was only dabbled with by engineer terrain detachments. TSS did not, conversely, do original cartography, but only revision and enhancement of general-purpose maps. The results was tailored to the needs of the commander in the field as a special-purpose map.

TSS in concept: many functions

TSS was conceived to do many things, but its primary components were four data bases: the Thematic Graphic Data Base (including a general-purpose subset and a special-purpose subset), the Raw Military Geographic Data Base, the Point Positioning Data Base, and the Imager Data Base (i.e., up-to-date aerial photographs). As a combat support system, the TSS had seven functional subsystems, which were: command and control; storage, retrieval and distribution; reproduction; cartographic revision; survey; military geographic information; and image-based products.

The Command and Control Subsystem controlled the TSS, housing the engineer topographic staff as it planned production, assigned work, monitored project status and performed quality control. For example, the Storage and Retrieval Subsystem stored the data bases used by the TSS, maintaining the thematic graphic data base, photographic data base and distribution of all TSS products.

TSS in the field

The many topographic support functions undertaken by TSS meant that, from the beginning, the TSS was going to be a large collection of equipment. Indeed, the TSS required the use of 42 trailers to house it in the field. Each of the trailers, in turn, contained equipment that, while off the shelf technologically, still had to be evaluated, purchased and delivered. The possibilities for problems were many; and, since the TSS was to be designed and procured as a unit, the initial operational capability date would have to wait for its slowest components. Every component, in turn, had to meet military specifications to determine reliability, availability and maintainability. The project manager at the start of this history's time frame, Cornelius Manthe, faced that formidable task, knowing that the information he hurried to collect would still be required to meet an In-Process Review, scheduled for the first quarter of fiscal year 1979. The TSS could not meet its original timetable.

Review and rereview

Manthe recalled a primary, if not unfamiliar, TSS roadblock turning up in 1977:

> In January 1977 we were told that we would receive no money in fiscal years 1977 and 1978 for the Topographic Support System, but the Initial Operational Capacity date was still scheduled for the last quarter of fiscal year 1980.

The funding problem added to an already unmanageable situation. Commanders in the field wanted topographic equipment yesterday, but the decision to master the process by buying everything as is, yet as a whole, created disorder. Meeting with users to choose components produced a direction by committee climate where many people ruled on many matters concerning many things.

To MERADCOM and beyond

Following a design review in 1978 by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM) and U.S. Army Training and Doctrine Command (TRADOC), USAETL turned the TSS over to MERADCOM in 1979 for procurement. From then on, MERADCOM had full programmatic responsibility and USAETL was the technical adviser on the system. One of USAETL's functions in this role was to field inquiries, which included many complaints about parts, spares, etc.

Conclusion

USAETL—largely a developmental laboratory—was put to work on a non-developmental project: assembling components of a system that would be outdated upon completion. The magnitude of the task, the years without funding and the short time frame rendered the project unrealistic from the beginning.

USAETL scientists were not happy with TSS, but noted that with its unwieldy 42 vans and myriad "logistics train problems," it provided rich contrast for the merits of the Digital Topographic Support System—a ground-up developmental system worthy of the name.

USAETL wanted to provide more functionality to TSS than simple graphic arts operations, such as small computers to automate some tasks, e.g., coordinate conversion. USAETL was, however, strictly prohibited from doing this and thus had limited options for satisfying the TSS requirement. Finally, problems arose with a TSS contractor who proved "very good at bending metal, but very poor at managing logistics support."[3]

The intention to field a topographic system quickly was a good one, for the equipment in use was outdated by any standard. Similarly, the decision to replace and systemize things all at once had its merits on the surface. In both cases, however, the economy may have been a false one.

Footnotes

1. *Current Research and Development*, 1980, p. 43. USAETL in-house document scheduled for publication every two years.

2. Interview, authors with Chad Mullis, Fort Belvoir, Va., 7 January 1985.

3. Ibid.

D. Automating Terrain Information in the Field

1. ARTINS: A Developmental System

At the same time USAETL was struggling with the assembly of the Topographic Support System (TSS), another method of providing battlefield terrain information was being explored. The Army Terrain Information System (ARTINS) project was in early development by the Military Geographic Information Systems Group and other branches of the Geographic Sciences Laboratory. ARTINS, unlike TSS, was developmental, envisioning a highly automatic system that would satisfy the terrain intelligence needs of all Army elements. Where TSS only involved assembling the best off-the-shelf equipment, the scientists developing ARTINS were envisioning automated processing, production, storage, retrieval, dissemination and updating of terrain intelligence. From 1971, when ARTINS was approved by the Department of the Army, to 1978, when some software development was begun, limited funding was reflected in limited work on the system. The Army community was not sure where ARTINS fit into its plans, and USAETL had difficulties solving the system's computer storage problems with the available technology. The Department of the Army did not allocate money in 1979 to develop ARTINS. A modern system would have to wait a little longer.

A user in ASAS

Although the ARTINS project ended, the idea of a computer-based topographic system was not dead, but instead found some new friends at the end of the 1970s.[1] The Army community was moving toward computer battle management in the interest of efficiency and speed. The All-Source Analysis System (ASAS) was conceived to that end, and planners were looking for information that could be supplied in computer-readable digital form. Since terrain teams had recently proven their worth at the division level, the Army was looking for the same topographic help for ASAS in digital form.[2] USAETL was the obvious source, with its long experience in creating maps that "talk" to computers. A digital system for topographic support had a new potential user in ASAS.

The meeting at Huachuca

Army planners, assembled at Fort Huachuca, Ariz., in 1978, were putting together the Required Operational Capability of the ASAS. It was recognized that such a system needed position, time and terrain in digital form. Milt Goldin of USAETL convinced the ASAS planners that a Digital Topographic Support System (DTSS) could supply the required digital data, machine to machine. The inclusion of DTSS in the ASAS operational requirements was pivotal, and a Special In-Process Review was underway in 1981.[3] The ARTINS Letter of Agreement was revised and the system was retitled DTSS. On 30 September 1982, USAETL awarded a contract to Analytics Inc., for an ASAS/DTSS Interface Study.[4]

A turning point

That ASAS would embrace DTSS had an obvious logic in retrospect, but at the time it marked the turning point in USAETL efforts to show the Army that it needed automation to meet the demands of "the modern, fast-paced battlefield."[5] Many USAETL scientists agreed with Richard Clark of the Topographic Development Laboratory's Mapping Developments Division that field Army mapping was "still in the dark ages" and that part of USAETL's mission was to show how DMA-type automation could be brought into field operations. The Field Exploitation of Elevation Data (FEED) demonstrator, the West Point program (U.S. Military Academy Technology Transfer) and DEMONS (a Digital Image Analysis Laboratory—derived ASAS module demonstrator) must be seen in this context. The addition of DTSS to ASAS was as much a successful education as a continuing scientific effort.

Toward digital topographic support

The technique of making maps and graphics that "talk to" machines leads in so many directions today (from war gaming to missile guidance) that one easily forgets that most early research in this area was done to solve a production problem.[6] Mappers everywhere, but especially at DMA, were charged with producing accurate maps and graphics on short notice. Done manually, such work is slow, in addition to being labor and skill intensive. The sore-eyed and weary professionals who faced these chores continuously were difficult to keep on the payroll. If there was a way to streamline things, mapmakers would embrace it eagerly. Thus, not surprisingly, in the 1950s the map community was in the forefront of those looking at computers (e.g., the Army Map Service). Indeed, some automating concepts were "far in advance of reality."[7]

More uses for digital terrain data

At DMA—where mapping services extend to thousands

A USAETL scientist demonstrates a Digital Topographic Support System (DTSS) interactive work station, used to develop and evaluate automated terrain analysis software.

of customers in the U.S. Armed Forces, national security operations, the U.S. merchant marine fleet and to allied military forces—the need for automation was doubly urgent. DMA looked to USAETL for ways to speed the gathering, sifting and disseminating of map data. Then, as field applications of these evolving techniques arose, USAETL and DMA were no longer dealing with a mere production problem. The same digital mode explored for production reasons lent itself to many new military applications. Foremost among these (along with potential missile guidance use), digital map data lent itself to real-time use in the field. A commander might at long last have up-to-date knowledge of what was going on in the battlefield, by means of digital terrain data.

2. DTSS: A New Aid for the Commander

Coherent up-to-date maps and charts have an obvious place in Intelligence Preparation of the Battlefield. Getting such aids to the commander, however, has always been a problem.[8] DTSS, by providing terrain data in digital form, pointed to an entire new alternative for the commander.[7] Instead of using an unwieldy, hard-to-read, out-of-date map, the modern planner could turn to DTSS for computer graphics that portray the situation clearly and quickly. Anyone who has seen a good video game could appreciate the advantages of modern graphics over a maze of lines on an old topographic map. DTSS could provide such graphics and much more.

Planning an automated system

From the 1978 Huachuca meeting, throughout this period, USAETL's Terrain Information Systems Group was at work turning the DTSS idea into reality. DTSS was to pass through three phases: meeting the needs of ASAS and FIREFINDER (see page 33); producing digital data updates for fielded systems, topographic data for other Army elements and long-range weapons systems, in addition to topographic data and analysis for theater level planning; and developing a fully automated system merging the topographic elements of all echelons into an on-line system for data base maintenance and enhancement to support Army elements at all echelons. At this writing (1984), DTSS was to be fielded circa 1990.

At the same time DTSS was getting underway, the Terrain Information Systems Group was also at work on a digital topographic data (DTD) study that, among other things, was identifying potential users of DTD. Thus, long before the study was completed in 1984, scientists at work on the DTSS were uniquely aware that emerging systems, in addition to ASAS and FIREFINDER, would require DTSS support. Those at work on DTSS were, as Robert Thurber put it, "marching ahead, full steam."[9]

Designing and putting DTSS together created very different problems than the assembly logistics difficulties that had plagued the manual TSS. Where the TSS had 42 trailers, the DTSS would be housed in a single S-280 shelter mounted on a five-ton truck. The lone truck, however, would house a computer, a dual-screen work station, three disk drives, a large-format plotter, a map-size digitizer, a magnetic-tape unit, communications equipment and two to three terrain analysts. DTSS was to bring together the latest in hardware/software modularity with modern electronic data processing and computer graphics technology. To do so, however, meant many hours in the lab for USAETL scientists.

3. DTAS: A Laboratory for DTSS

Before DTSS could be sold to the Army in the field, it had to be demonstrated as a usable, automated tool in the laboratory. Such was the intention in developing the Digital Terrain Analysis Station (DTAS) at USAETL. Put together in the years 1979-1983, DTAS provided an interactive computer graphics system to develop and evaluate automated terrain analysis software. DTAS, in sum, was (along with TAWS) to supply the technology base for the DTSS, as an unruggedized, exploratory prototype DTSS.

In 1978, a step toward automated terrain analysis was taken when USAETL procured hardware to demonstrate the feasibility of such a system. For a time, limited data and lack of computer storage capability posed serious problems, causing the effort to flounder twice.[10] But by 1981, software included a contouring package, polygon processor and a raster-vector conversion package. Hardware included a black-and-white raster work station, a color work station and added alphanumeric cathode ray tube terminals. Work was underway on auto-slope map, path loss/line-of-sight, cover, concealment and cross-country mobility software.[11] Following the ASAS/DTSS Interface Study in 1981-1982 (by Analytics Inc.), and the 1981-1984 Digital Topographic Data evaluation study, DTAS as a project was on a "pretty fast track."[12]

DTAS capabilities

In general, DTAS had two initial capabilities—to provide intervisibility models and mobility models, though the system's powers were enhanced regularly as work went along. The intervisibility models showed what areas were visible, either optically or electronically, from a given site. Mobility models, as the name suggests, showed where one could go or establish lines of communication, portraying the potential effects of terrain upon friendly and enemy operations.

DTAS models: intervisibility

Using the DTAS gridded data base, USAETL scientists developed a number of capabilities potentially useful to the field commander. The interactive, graphic work station could include graphics with terrain profile, target acquisition, multiple-site target acquisition, composite target acquisition, masked area, perspective view and path loss/line of sight. DTAS demonstrated that all this information and more, in up-to-date and flexible form, could be at the finger tips of a commander supported by the DTSS.

DTAS models: mobility

Work on DTAS at USAETL produced new, immediate ways to allow a commander to weigh the potential effects of terrain on his plans and those of the enemy. Computer graphics capabilities allowed, for example, the creation of a cross-country movement model displaying off-road speed capabilities based not only on slope, vegetation and soil, but also on the characteristics of the vehicles in question. The cross-country movement model proved the "most comprehensive of all the models in terms of complexity and volume of graphic data that must be processed," yet the resulting "go, slow-go, no-go" would be intelligible to every commander.[13]

Initial DTAS work at USAETL produced many other mobility models, including slope, local relief, cover, concealment, key terrain and river crossing. In each case a model was created that offered up-to-date terrain information in a graphic form easy to interpret.

DTAS hardware and software configuration

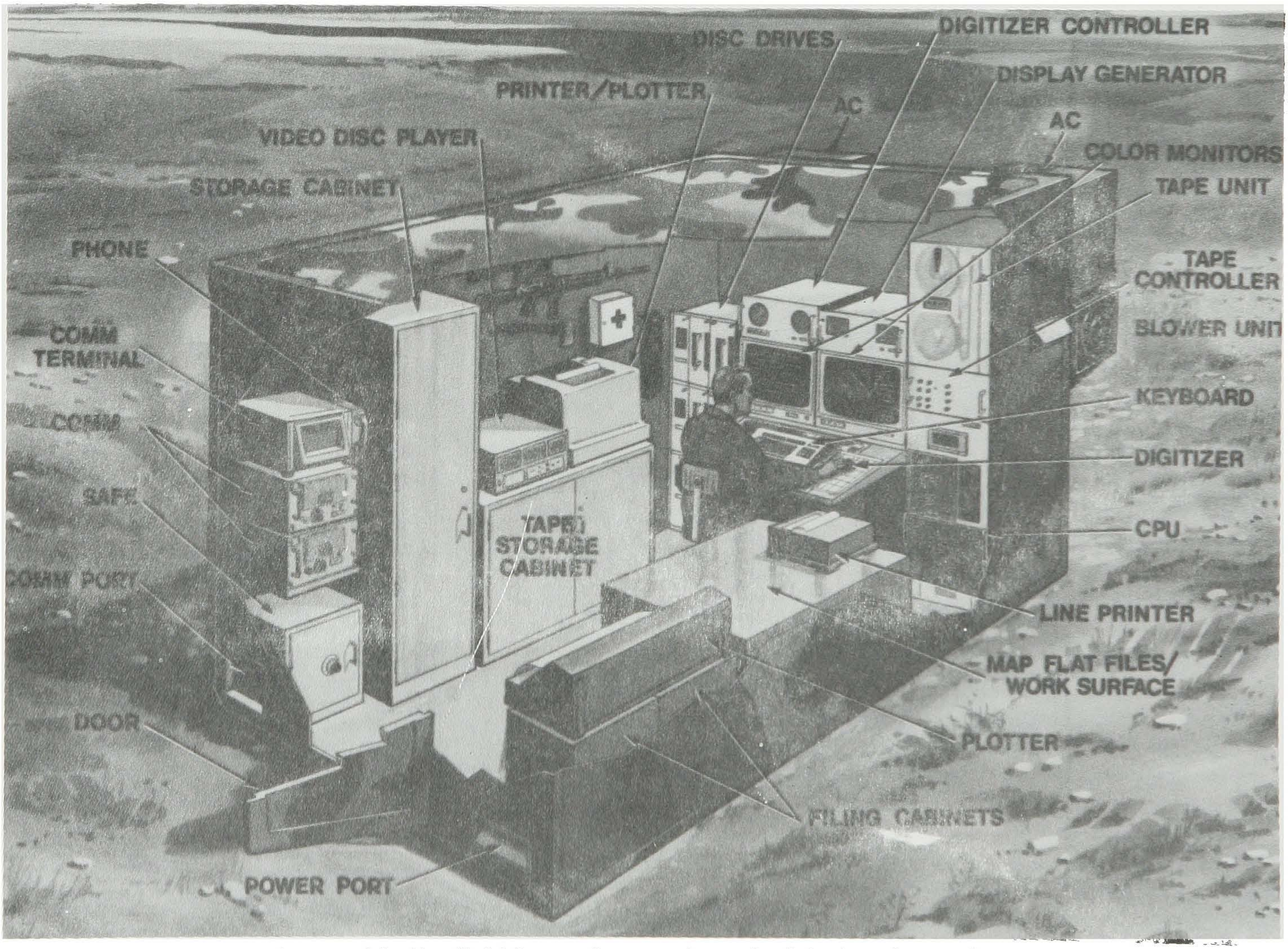
All these model capabilities, if done manually, would tax a whole army of terrain analysts. The DTAS planners needed to choose and integrate the devices necessary to automate many of the required activities. USAETL scientists developed the DTAS software to operate on a PDP-11/70 minicomputer under the RSX11M-Plus system with F0RTRAN IV-Plus the programming language. A turn-key interactive graphics design system supplied the graphics and data management capability. The operator of the graphics work station could use dual display screens, a digitizing table, a movable keyboard, a floating command menu, a multibutton cursor and a built-in microprocessor. This configuration was found best to meet design requirements which, in turn, had to meet the commanders' needs in terms of response time, flexibility and accuracy.

Having this integrated configuration of hardware and software, the DTAS user could compose original designs, encode existing drawings, modify designs, and store and retrieve designs. This work could be done directly at the work station or through an applications program.

The management of the data base, in turn, was closely integrated within DTAS to deal with both graphic data (largely used for the mobility models) and gridded data (suited to intervisibility models). In the case of graphic data, a polygon processor supporting three Boolean operations provided a key supporting capability of mobility models. All data base management, graphic or gridded, could be initiated through direct user interaction from a work station, through an alphanumeric terminal or through an applications program.

The importance of DTAS

USAETL personnel continually pointed DTAS work toward enhancing the eventual capabilities of the DTSS in the field. Models were added including air avenues of approach, drop zone/helicopter landing zone, barrier/denial, infiltration routes and lines of communication. The results were very promising, and USAETL maintained the feasibility of providing the terrain analyst a usable, automated tool had been demonstrated by DTAS.[14] This demonstration, the development of the many useful models, and support given the Army Digital Topographic Data Requirements Study were major contributions of DTAS. The on-going effort, however, was to build on the laboratory performances of DTAS, and use them to fashion a fieldable DTSS. That goal required definition of the digital topographic data base, integration of militarized computer hardware that could withstand field conditions and defining the interface requirements with other military systems. DTAS proved crucial to these projects and was a significant



The DTSS will one day be used in the field to produce and manipulate terrain products.

focus of effort for the Geographic Sciences Laboratory's Terrain Information Systems Group during the historical period.

4. TAWS: Building the Digital Data Base

While USAETL engineers and scientists put DTAS to work building the technology base for the DTSS, parallel efforts were underway to make sure the digital terrain data (DTD) would be there when the technology was ready to go. The Terrain Information Systems Group produced its study of DTD needs, present and future, and the Topographics Product Design and Development Group was charged with the production of terrain analysis procedural guides. A logical extension of compiling guides for manually derived source extraction, data base compilation, information analysis and product generation was to develop a computer-based system which could assist the terrain analyst in these labors. A group was formed within the Geographic Information Systems Division to build a work station that could create digital data in the field.

A Terrain Analyst Work Station

The planned station, known as the Terrain Analyst Work Station (TAWS), would differ from the DTAS in its ability to create and update digital data bases. The TAWS digital data bases would be extracted from hard-copy cartographic sources or generated from pictographic sources using techniques of analytical photogrammetry.

TAWS' ability to create and alter digital data in the field was not among the capabilities planned to be fielded with DTSS in 1990. Eventual plans called for the DTSS to incorporate the TAWS capabilities to create and modify digital terrain data. The work station, accordingly, must be seen historically as an important step in defining and developing requirements for the DTSS and introducing digital map technology to the field prior to DTSS deployment.

A commander needs much more than a large quantity of terrain information. The data also have to be up-to-date and in usable form. To fill this demand, Army planners were turning to digital data compiled in the field.

Unfortunately, digital data provided by DMA were not always sufficient to meet a particular commander's needs—accuracy, resolution and operational format were key parameters. Digital data from DMA could be out-of-date by months or years. In a battle, DMA data could be rendered out-dated by events taking place on the spot. TAWS, however, could create customized products, rather than the standardized products DMA distributed.

Extract, revise, intensify

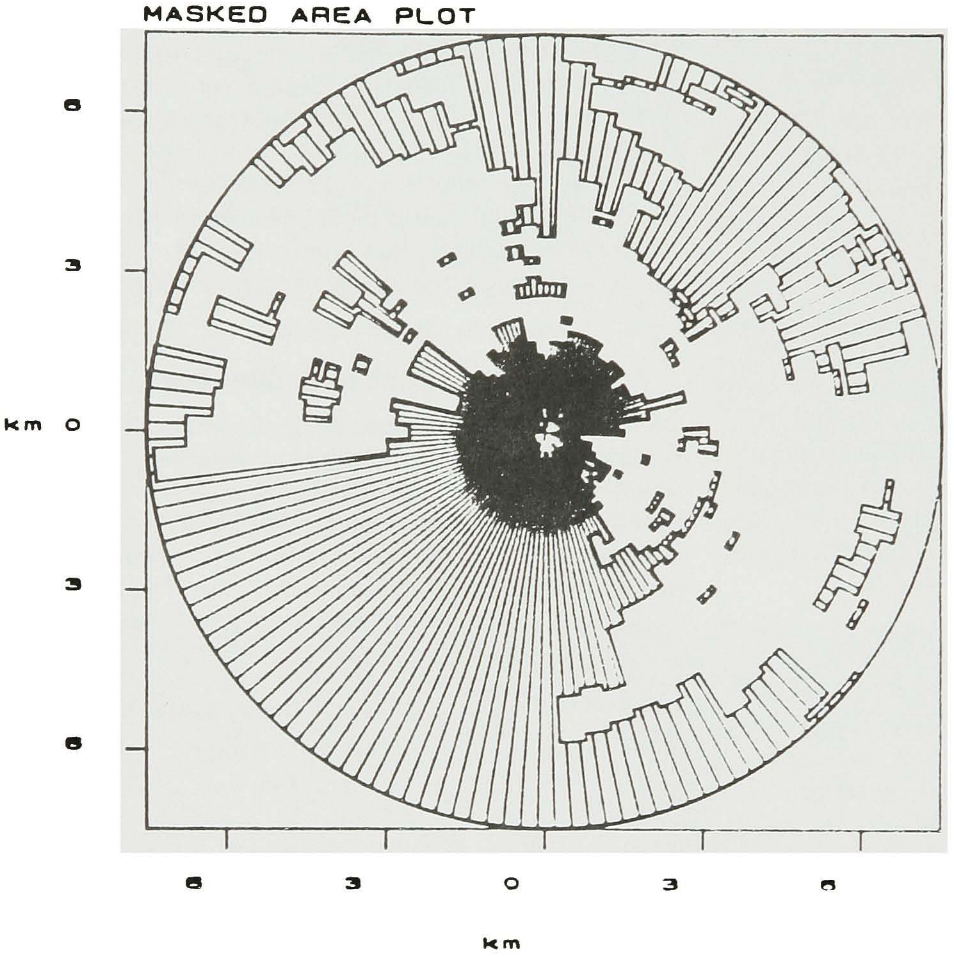
As work continued on the DTAS and new models were generated from available DMA digital data, USAETL scientists were taking steps to put together a work station that, in the absence of adequate data, could assist in creating the required data base in the field or revise what existed to meet requirements. In spring 1983, the lessons learned on civil works projects investigating the Analytical Photogrammetric Processing System were used to start the TAWS project in GSL's Terrain Analysis Group. The goal of Walter Boge (then GSL Director) and Laslo Greczy (first TAWS project engineer) was to build a Terrain Analyst Work Station that could build a digital data base. Such a station could extract digital data from a variety of hard-copy sources and revise or intensify already existing digital data.

A product improvement

In May 1983, the first contract package was prepared and the U.S. Army Corps of Engineers approved TAWS that summer. The initial delivery was scheduled for May 1984. There was, however, no plan to include TAWS capabilities in the initial DTSS. TAWS was, rather, a preplanned product improvement to the DTSS down the road. The idea, in 1st Lt. Eric Musser's words, was to have TAWS "up and running when DTSS hit the field."[15] Unlike the case of the Topographic Support System assembly, one system would not have to wait on another. While DTSS was under development, the TAWS effort would be advancing the state of the art in data extraction. Planned capabilities for generating hard- and soft-copy terrain and environmental products included some of the specialized DTSS mobility and intervisibility products.

The TAWS system

The TAWS prototype would use off-the-shelf hardware and adapt and enhance existing laboratory software to create a capability to input soft- and hard-copy source information, create, maintain and enhance geographic data bases, and generate hard- and soft-copy terrain and environmental products. The TAWS computer was a 32-bit microcomputer with 2.0 (later 4.5) megabytes of random access memory, 264 megabytes of Winchester disk storage and a nine-track, 1600-BPI tape drive. Peripherals included black-and-white and color graphics terminals, a color graphics plotter, a line printer with graphics capability, an X-Y digitizing table, and a light table digitizing and mensuration system. GSL planned to improve TAWS capabilities in 1986 by adding an analytical stereoplotter with dual-channel graphic super-position and profiling firmware. The TAWS computer could communicate with the Army-fielded MICROFIX computer system. In designing TAWS, the intent of the scientists and engineers was to take full advantage of advances in microcomputer technology, analytical photogrammetry, computer-assisted photo interpretation and geobased information processing.



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Site coordinate:
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Site elevation:
     624.4 meters
Site antenna height:
      10.0 meters
Radial storage file:
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Radial increment:
       5.0 degrees
Elevation extraction:
     125.0 meters
Elevation interpolation:
    4-point
Vegetation included? [Y/N]:
    N

Target altitude:
       2.0 meters agl
Minimum masked zone:
        .0 meters
Mode of surveillance:
    electronic
```

This masked area plot is a Terrain Analyst Work Station (TAWS) product.

TAWS software: adapting from CAPIR, DTAS and BEES

TAWS software evolved, in large part, from three USAETL systems.

1. The Computer Assisted Photo Interpretation Research System (CAPIR)—This geographic information system was designed to produce digital elevation models and to digitize feature information from hard-copy imagery and maps which are used to generate a variety of hard-copy and soft-copy cartographic products.
2. The Digital Terrain Analysis System (DTAS)—This product generation system was designed to create digital terrain products (cross-country mobility maps, concealment software, etc.) from prototype digital terrain data bases.
3. The Battlefield Environmental Effects Software (BEES)—This data base contained climatic and environmental information and associated applications routines used to support the terrain analysis and tactical decision process.

In order to guarantee that the software could be easily adapted to other systems without the normal modification costs, TAWS software was designed in modular form for easy updating; was made portable or exchangeable with other computer systems; was device-independent so that additional plotters or other peripherals could be added to a TAWS system without having to rewrite the software; and while complex and sophisticated, was user-friendly. These design criteria meant that existing research software had to be extensively rewritten, a process which slowed TAWS development at the front end, but promised to pay dividends down the road.

TAWS capabilities

Meeting all these criteria would enable TAWS to:

- Create topologically valid digital terrain data bases using monoscopic and stereoscopic, multi-sensor imagery, graphics, text and other military geographic information data sources;

- Edit, update, revise and intensify existing data bases;
- Merge data extracted from any of the data sources;
- Overlay features on digital elevation data;
- Manipulate, analyze and display, in 2-D and 3-D views, digital terrain data; and
- Generate and disseminate Army battlefield tactical decision aids.

Closing the data gap

TAWS sought to create digital data in recognition of a growing data gap. Since U.S. military commitments span the globe, it would be difficult (if not impossible) for DMA to provide the Army with all digital terrain information that may eventually be of strategic or tactical interest.[16] This data gap became doubly critical when viewed against the background of the many emerging uses of digital terrain data identified by the Terrain Information Systems Group in a study taking place in the same period as TAWS work. The existence of a digital data base was a given assumption in many future Army systems and programs, yet that data base often did not exist. It is then easy to understand why TAWS was such a "high-priority USAETL project."[17]

Fast and flexible

TAWS created the invaluable digital data base, but that job with time and effort could be done manually; indeed Laslo Greczy noted that working with grease pencil from imagery, an analyst could come within one hour of TAWS work, which might appear "not a big saving."[18] But a stronger selling point of TAWS was the potential spin-offs from its digital data product.[19] New products impossible in the manual mode were now possible, and updating and revising could be done at speed close to an order of magnitude faster.[20] Once the initial digitizing work was in place, TAWS proved fast and flexible.

Eventual reunion with DTSS

Though TAWS was on its own development track during the early to mid-1980s, it was gradually being pointed toward a juncture with DTSS in the early 1990s. In the interim, USAETL planned laboratory and van tests bringing TAWS closer to a fielded demonstration, with the likely site being Germany. On-going TAWS performance helped further define and develop requirements for the fieldable DTSS and for the Terrain Environmental Analysis System in support of the Army AirLand Battlefield Environment program. The work of the Terrain Analysis Group on TAWS was one of the Geographic Sciences Laboratory's highest priorities during this period.[21]

Footnotes

1. Interview, authors with Regis Orsinger, Fort Belvoir, Va., 24 October 1984.
2. Interview, authors with George Simcox, Fort Belvoir, Va., 16 October 1984.
3. Installation files, Geographic Sciences Laboratory, Terrain Information Systems Group (GSL-TISG), Historical Summary, 1982.
4. Simcox interview.
5. Ibid.
6. Interview, authors with Richard Clark, Fort Belvoir, Va., 14 September 1984.
7. Ibid.
8. Interview, authors with Frank Capece, Fort Belvoir, Va., 26 January 1985.
9. Installation files, GSL-TISG, Historical Summary, 1981.
10. Capece interview.
11. *Digital Terrain Analysis Station (DTAS)*, Capt. Michael Thompson, Robert Socher, p. 8. In-house document.
12. Ibid., p. 10.
13. Ibid.
14. Interview, authors with 1st. Lt. Eric Musser, Fort Belvoir, Va., 30 January 1985.
15. Ibid.
16. *Tech-Tran*, Vol. 8, No. 4 (Fall 1983), p. 3.
17. Ibid., p. 4.
18. Interview, authors with Laslo Greczy, Fort Belvoir, Va., 9 October 1984.
19. Ibid.
20. Ibid.
21. Ibid.

E. Military Geographic Information Procedural Guides

Every motorist is familiar with the experience of mistaking a county line for a road on a local map. All maps are not equally successful in depicting features, and the tourist is the loser. In military situations, where the loss may be in lives, not time, it is essential that maps be unambiguous. USAETL, with its mandate to develop terrain information systems, worked toward providing clear maps and graphics in a number of ways in 1979-1983. One of the most straightforward efforts toward clarity was USAETL's work to provide procedural guides to terrain analysts. The goal was to standardize the way in which terrain analysis and synthesis products were done.

Military geographic information for TSS

The Topographic Support System (TSS), the manual ancestor of the Digital Topographic Support System (DTSS), provided the initial rationale for military geographic information (MGI) procedural guides. MGI was required for topographic support, and it was essential that such information be provided in a uniform way. One analyst's depiction of a heavily wooded area might resemble his commander's notion of a marsh or something quite different. Conventions existed, but the wide variety of possible graphic needs made possible a wide variety of graphic misunderstandings.

Specific guidance

USAETL scientist Alexander Pearson convinced his colleagues that a detailed set of instructions was needed to support TSS.[1] However, the Engineer School, which was the Army's school for topography, did not move immediately to fill the MGI guidance need. USAETL, persuaded by Pearson's vast field experience in the topographic sciences, offered to assist the Engineer School in writing some instruction guides, but nothing came of it. Recognizing the pressing need for the timely completion of such guides, USAETL took the initiative itself in 1977.[2]

Procedural guides: 1977-1984

In the absence of suitable MGI procedural guides, USAETL specialists began the long labor of producing two series of guides designed to meet the needs of the military terrain analyst and the TSS operatives. The first, called the *Analysis Series*, sought to give guidelines for the extraction and reduction of data from maps, photographs, collateral sources and the generation of factor overlays (e.g., vegetation) with tables. The second, the *Synthesis Series*, addressed methods of using factor overlays and tables to predict terrain influences on military operations. Neither guide series attempted to develop or explain underlying theory, but simply showed the analyst how to analyze information sources or how to synthesize preformatted data.

Beginning in 1977 with the formation of the Procedural Guides Work Unit, USAETL specialists produced guides at a steady pace. The first guide, vegetation, took until March 1979 to finish, due to the fact that everything connected with the task was new.[3] Thereafter, however, the guides were produced every six months. Jeffrey Messmore and other specialists worked on Analysis and Synthesis Guides simultaneously. Eventually the analysis and synthesis work units were completed, and the procedural guides, as originally conceived, were completed.

Analysis guides: how to extract data

USAETL specialists worked to provide written, on-the-job assistance to the soldiers charged with producing military geographic information in the field. Step-by-step manual procedures were worked out to extract data, usually giving one or more ways to do it in each situation.[4] When needed, case studies were employed to illustrate the data extraction process. Working from maps, photographs and other sources, the soldier could then prepare simple, single-color overlays registered to a standard 1:50,000-scale topographic map. Each overlay—and there might be many needed—depicted a different terrain factor (vegetation, drainage, soils, slope, etc.) that required procedural guidance. Thus the completed analysis series included, in addition to the vegetation guide, guides to geology, roads and related structures, drainage and water resources, climate, soils, surface configuration, railroads, built-up areas and a collection of MGI source materials.

Synthesis guides: how to apply data

Guides showing how to extract data did only half the job. Synthesis Guides were also developed to help analysts use this data base to predict terrain effects and produce map-type terrain studies depicting, for example, possible cross-country movement conditions. USAETL specialists produced these guides to show soldiers how, with proper data, they could use programmable calculators and simplified analytical models to combine information. The synthesis guides also outlined manual procedures that relied on precalculated tables and graphs. Given an incomplete data base, analysts were provided guidance for insertion of subjective estimates and judgments.[5]

The synthesis series focused on data applied to a specific military situation. Guides included cross-country movement, obstacle siting, lines of communication, river crossings, and helicopter landing and drop zones.

Guides to the future

The procedural guides began in 1978 as an effort undertaken in support of TSS. The guides became, however, something else in the eyes of USAETL scientists planning the automated terrain analysis and synthesis of the future. While the TSS experienced delays, work was moving along on DTAS, TAWS and the eventual DTSS. The basic algorithms required to automate parts of the terrain analysis function needed to be worked out. These algorithms were available in the procedural guides, even though the latter dealt exclusively with manual operations.[6]

The analysis guides provided the basis for development of semiautomated MGI data-extraction techniques. To crack what Jeffrey Messmore called a "very tough nut"[7] required the use of imagery and image processing algorithms involving spatial, textural and pattern characteristics. A new work unit was formed in this connection to see what functions could be performed on the Analytical Photogrammetric Positioning System (APPS) at the Topographic Developments Laboratory. The *Analysis Guides*, however, already set the standards to be met.

Software routines from synthesis guides

Product synthesis techniques documented in the guides were incorporated into software routines by USAETL scientists in the early 1980s. For application on DTAS, the labs' interactive graphic system, specialists consulted draft guides on cross-country movement, river crossing, and helicopter landing and drop zones. In May 1983, for example, work on likely mine-field sites produced a computer-assisted routine to predict mine-field sites. Under Robert Falls, who had extensive mine experience, a work unit assembled a demonstrator that would produce a map of likely mine sites in a semiautomated mode. Though, strictly speaking, not born of a synthesis guide, this automation work was part of the same effort by the same people.[8] Similarly, work on digital/analog techniques to extract features persisted, resulting in an interim report in 1980 called *Interactive Digital Image Processing for Terrain Data Extraction* (ETL-0241). The procedural guide specialists were doing their part to help automate the terrain analysis process.

More than standardization

The procedural guides began as a support effort for TSS, seeking to standardize the extraction and application of terrain data. Step by step, the guides "complexed the polygon" until each of the 15 guides were complete in 1984. The result, however, was more than a mere guide or training device. The guides also provided the expert manual how-to information essential to any present and future effort to automate terrain analysis and synthesis. GSL and its Topographic Products Design and Development Group counted the guides among their major successes of 1979-1983.[9]

Footnotes

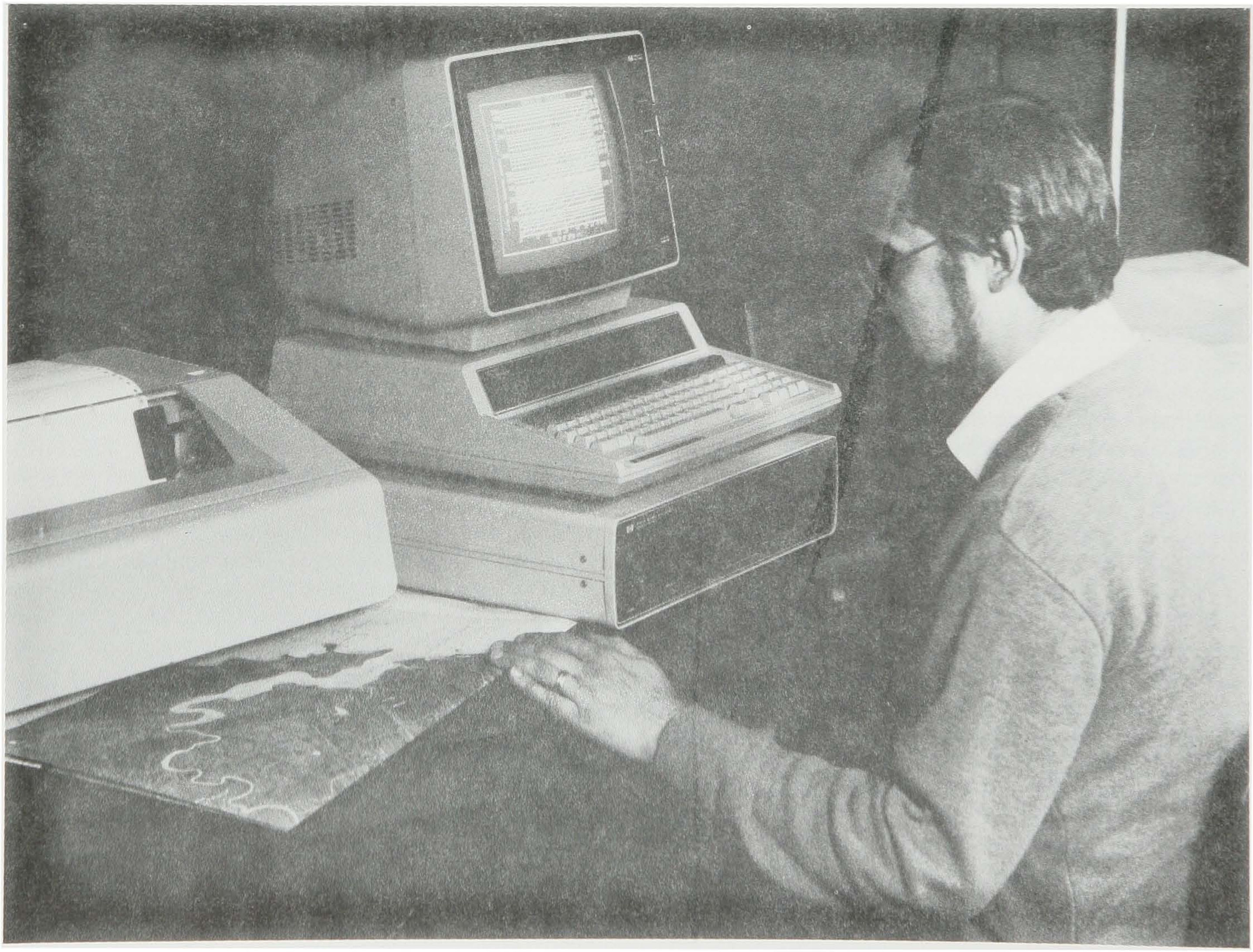
1. Interview, authors with Jeffrey Messmore, Fort Belvoir, Va., 3 October 1984.
2. Ibid.
3. Ibid.
4. Ibid.
5. Ibid.
6. Ibid.
7. Second interview, authors with Jeffrey Messmore, Fort Belvoir, Va., 11 March 1985.
8. Ibid.
9. Ibid.

F. BEES: Tracing the Effects of the Environment on the Battlefield

The Battlefield Environmental Effects Group (BEEG) of the Geographic Sciences Laboratory (GSL) was charged with identifying and publicizing the effects of environmental conditions on Army materiel. To that end, the group did both basic research into characteristics and distribution of terrestrial environments and applied research that related environmental knowledge to the design, test, storage, issue and use of materiel. One result of that research was the Battlefield Environmental Effects Software (BEES). BEES was designed for use on the Terrain Analyst Work Station (TAWS) and the eventual Digital Topographic Support System (DTSS). Such up-to-date information on environmental factors would give the commander a better grasp of the variables in his battle plan. BEES, TAWS and DTSS all were working toward making complete terrain information a vital element of the All-Source Analysis System (ASAS).

An interested bystander at USAETL

The winter-time motorist with a cracked engine block is painfully aware that environmental effects can be a factor in mobility. The modern, highly mobile Army could not afford to be unaware of environmental factors, and an Army entity had long existed to try to answer questions about possible environmental effects. Traditionally, the



A USAETL scientist works to develop the Battlefield Environmental Effects Software (BEES).

Environmental Effects Group researchers spent much of their time with miscellaneous requests for clothing requirements, temperature ranges at desert storage dumps and work on local climatic variations at arctic test sites. Such work, though useful, was still done as it had been 40 years ago, and even the group's researchers sometimes felt they did not fit in at USAETL among all the increasingly automated and sophisticated work groups.[1] Thus the group in 1978 felt itself an interested bystander as work at USAETL evolved dramatically toward automating and digitizing.[2] The wake-up call, however, was coming.

Waking up to computers

Paul Krause, a major figure in developing BEES, dated the change in the role of the Environmental Effects Group from a request by the Defense Mapping School in 1979. The school wanted weather effects slides and handouts for some courses, and the idea came to add some computer-depicted effects to the class menu. Thus, the idea was born to do the same at USAETL. Subsequently, Jim Beck, an official in the Office of the Army's Assistant Chief of Staff for Intelligence (OACSI), heard of USAETL's evolving, computerized environmental effects capability and got an OACSI briefing in 1981. Quite a few briefings followed, and at the Gallant Knight exercises in 1983, many others got a good look at what could be done with computers programmed to evaluate environmental effects.[3] The year 1983 also saw the purchase of new hardware, a 60 percent increase in software capability and conversion of part of the system to run on microcomputers for intelligence exploitation (thus tying into MICROFIX, an Army microcomputer for use by topographic units in the field). The former Environmental Effects Group of the Military Geographic Information Systems Division was now the increasingly computerized Battlefield Environmental Effects Group.

Focus of the Battlefield Environmental Effects Group

As the role of the environmental effects specialist grew, the new BEEG decided to focus their studies initially on five areas where military needs included a working knowledge of environmental effects. The five study areas of interface were spelled out in USAETL's *Current Research and Development* (1982):

1. The relationships between environmental factors and materiel design problems.
2. The frequency and distribution of natural battlefield obscurants.
3. Improving the technology base of information about environmental effects on materiel.
4. Developing a glossary of environmental engineering terms.
5. Research on climatic testing.[4]

The BEEG pursued these studies in the early 1980s, although some work evolved in new directions.

Environmental effects and materiel design

Army planners know that when equipment breaks down due to extreme climatic condition, the result may be disaster—witness the plight of the German Wehrmacht in the Russian winter. The Army cannot, however, afford to make every piece of equipment hold up in every extreme condition—it would be too expensive and often pointless (e.g., being "cold proof" when deployed in the tropics). Equipment needs to be designed only for the conditions it is likely to meet.

Defining what is likely

There was, however, "a lot of disagreement on extreme conditions" and the frequency of occurrence of such conditions.[5] Without some guidelines in this area, good design and cost cutting were unlikely. BEEG looked for ways to establish "more realistic extreme values."[6] The group worked to develop improved methods of presenting meteorological, climatological and geographic data. New techniques were developed to measure environmental stresses, and suitable methodologies were developed for existing data. BEEG scientists did a study of various ways to estimate heat exchanges and developed risk scenarios for certain combinations of climatic conditions. A design data base was being built.

An automated data base

A first thought, with BEEG now empowered by computers, was to build an automated data base of "100 'benchmark' meteorological stations" intended to be representative of all the Earth's climates.[7] In 1983, the project was redirected toward an automated data base built on extrapolation from available climatologies. BEEG researchers sought to establish the relationship of climate to terrain in a specific known case, and see if it could be spread to a parallel situation.[8] The effort was continued to find new ways to put climatology to work.

Battlefield obscurants

Battlefield commanders finding themselves quite literally in a fog could make use of the cover (e.g., for advance or retreat) far better if they were able to anticipate it. A work unit at BEEG under Ruth Wexler addressed this need as part of a larger effort to study the "world-wide distribution and frequency of atmospheric elements that reduce visibility and prevent optimum use of electro-optical systems on the battlefield."[9] Such study arose due to the Army's frustration because of a lack of information on environmental conditions (e.g., precipitation) that affect visibility, including those that degrade the performance of electro-optical systems on the battlefield. The BEEG work unit did a number of reports on fog, and freezing and thawing. Paul Krause asserted that work during this period did get a better handle on fog and yielded useful prediction algorithms.[10]

Improving the tech base

In addition to identifying environmental effects, BEEG was charged with publicizing them. The best data base was valueless if commanders and designers did not use or understand it. BEEG sought to ensure that a designer's environmental criteria reflected likely conditions, that the designers understood the rationale for the values given and how the values should be applied cost effectively. Toward that end, BEEG sat on Department of Defense committees and worked long hours on a version of Army Regulation 70-38 (Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions) which became effective in late 1979. BEEG and the Army recognized, however, that computers could get whatever had been found out to the Army in the field or the designers with far greater effect.

For the Army in the field: BEES

The Battlefield Environmental Effects Software (BEES) grew out of an effort to expand on the design regulations for extreme conditions. A handbook was projected for other than extreme conditions, bridging the gap between the Army environmental series publication on climatic criteria (e.g., MIL-STD-210) and the publication on environmental testing (MIL-STD-810).[11] BEES, in a sense, became that bridging handbook, but in computerized form.

Using new computer equipment procured by USAETL, the BEES work unit assembled an interactive, user-friendly, menu-driven environmental effects system using ever-growing environmental effects and climatological information. In 1983, BEES software was transferred to a minicomputer, thereby increasing storage, processing efficiency and user friendliness. Such improvements were necessitated by a "rapidly expanding BEES menu."[12] In 1983, software programs jumped from 10 to 16, adding surface wind climatology, density altitude climatology, atmospheric transmission, military engineering, psychometric calculations and units conversion factors. Much of the work on BEES involved converting existing data bases and equations to the computer language used by USAETL's desk-top computers.

BEES, with its continuing enhancements and growing subprograms was a pilot computer program pointed toward TAWS and the eventual DTSS. In addition, BEES programs were being reformatted by BEEG for use, where possible, by users of the MICROFIX system (13 programs and a large climatic data base were planned to be part of the MICROFIX 2.1 software release scheduled for the Spring of 1986). The battlefield commander of the modern, fast-moving Army would have environmental data fresh on hand as a possible force multiplier.[13] Staff and field commanders would at last be able to predict the environmental limitations on combat activities. A person with even "a little knowledge of computers could learn to operate BEES in a few minutes."[14]

For the designer: EDGE

An expanded and at-hand environmental effects data base was clearly of use in the field, but USAETL scientists foresaw related uses of equal importance. At the beginning of fiscal year 1983, BEEG personnel began to look at how their growing data base could, with software changes, be made useful to specification writers and designers. The resulting project came to be called the Environmental Design Guidance and Evaluation system, or EDGE.

Much as BEES sought to set the limits within which equipment should be used, EDGE looked for the limits within which it should be designed. In each case, the aim was to predict what would work and what would not in a specific environmental situation, but also what could be cut from costs without affecting performance. Both systems were developed as systems adding to the useful data base at hand, but also as cost-cutting projects.

The aim of EDGE, according to Paul Krause, was to "computerize what is done through telephone conversations with designers, developers and the writers of military specifications."[15] With the EDGE system, a computer could tell a designer what test method was best, what past results had been, how long a piece of equipment could be expected to be down—all in specific environmental situations. Maps of environmental effects could be produced and consulted, and past problems in such areas spelled out. All that had been detailed in the environmental testing literature (e.g., MIL-STD-810), and all that could be learned from phone calls to experts in all parts of world could be summoned forth in an instant by EDGE. The spec writer, taking advantage of the active on-line data base, could enter a description on his equipment and get back the appropriate climatological parameters.

At the end of 1983, BEEG was about to form a work unit for EDGE. The system itself, as a design and spec writer system, was not envisioned as a BEES-type fielded system. Rather it would use some of the same data bases to design dependable equipment for the Army regardless of environment. Thus, while not on a direct line to the DTSS, it looked to be a significant development of the same technology developed by the BEEG workers at USAETL.

Glossary of terms

Making sure computers spoke the same language was an abiding problem at USAETL as the laboratories became more automated, but language problems did not end there. Before a term could be entered, regardless of the computer language, there had to be agreement on its specific meaning. In the use of environmental engineering terms there was "little agreement."[16] Army scientists were disturbed that "seeability," for example, could mean what a sensor saw, visibility between points or prevailing visibility. The old *Glossary of Environmental Terms (Terrestrial)* (MIL-STD-1165) was not oriented toward environmental engineering. BEEG was asked to revise the glossary in accordance with the *Defense Materiel Specifications and Standards Office Program Plan* for the Environmental Requirements and Related Test Document area.

Beginning in 1979-80, BEEG personnel coordinated a draft glossary with Department of Defense personnel in the field. Many terms were taken from a glossary published by DARCOM (AMCP 706-119), but environmental engineers were widely consulted on what was needed in addition for the revision. Many new environmental terms were added through 1983, and completion was scheduled for late 1984.

An essential uniformity

Much as was the case with the Terrain Analysis Procedural Guides, USAETL knew that automation required a certain essential uniformity in what was being talked about and produced. In the case of environmental terms, the spec writer could approach his work with confidence only if the parameters of his design were expressed in a commonly accepted and specific language. The BEEG glossary was another step in this direction.

Improving climatic testing

In the early 1980s, USAETL environmental effects specialists became aware that "relatively little information" existed about the relationship between field tests and simulated (chamber) tests.[17] Without such information, selecting test procedures was more difficult. BEEG personnel began experiments to see if correlations could be found between the effects on materiel tested in an accelerated chamber and the same materiel exposed to natural conditions. Work was done to study materiel first exposed to nature and then put into a chamber. The aim was, in Krause's words, to "get realism into the environmental test arena."[18]

A summary of BEEG

The Battlefield Environmental Effects Group of the Geographic Sciences Laboratory ceased to be an interested bystander at USAETL during the 1979-1983 period. Through its various work units, it worked to develop the BEES capability for TAWS and the planned DTSS. EDGE was conceived, in turn, to put much of the same environmental effects data base to work for spec writers and designers. Testing procedure work continued as did BEEG reviewing of requirements documents for environmental effects adequacy. BEEG also provided continuing information services regarding environmental effects and climatic conditions throughout the world and consultant services on the use and interpretation of the published military environmental effects testing documents (e.g., AR 70-38, MIL-STD-810 and MIL-STD-210). The BEEG group fit in at USAETL in many new ways.

Footnotes

1. Interview, authors with Paul Krause, Fort Belvoir, Va., 5 February 1985; interview, authors with Regis Orsinger, Fort Belvoir, Va., 24 October 1984.
2. Installation files, Geographic Sciences Laboratory, Battlefield Environmental Effects Group (GSL-BEEG), Historical Summary, 1978, p. 2; Krause interview.
3. Krause interview.
4. *Current Research and Development*, 1982, p. 125. USAETL in-house document scheduled for publication every two years.
5. Krause interview.
6. Ibid.
7 *Current Research and Development*, 1982, p. 125.
8. Ibid.
9. Ibid.
10. Krause Interview.
11. *Current Research and Development*, 1982, p. 125.
12. *Tech-Tran*, Vol. 8, No. 2 (Spring 1983), p. 3.
13. *Tech-Tran*, Vol. 8, No. 4 (Fall 1983), p. 2.
14. Krause Interview.
15. Ibid.
16. Ibid.
17. *Current Research and Development*, 1982, p. 126.
18. Krause Interview.

G. The Quick Response Multicolor Printer: Faster Map Reproduction

One of the abiding goals at USAETL was that of providing better ways to get terrain information to the commander in the field. Such information is a force multiplier, making every bit of firepower count and minimizing losses for the new mobile Army. Thus, USAETL programs stressed the need for complete terrain information provided in an efficient and timely way. Among the more crucial efforts toward efficiency and timeliness was the replacing of old military map-printing procedures. A glance at the old method provides the obvious rationale for work done during 1979-1983 in the Geographic Sciences Laboratory at USAETL toward a Quick Response Multicolor Printer (QRMP).

30 years in the making

With so much emphasis on the "modern, fast-paced battlefield," a substitute for traditional battlefield mapmaking was a long time coming. By the old method, providing one multicolor map required 27 people a full eight hours, an unacceptable expenditure of time and manpower. These are two important variables in the emerging "shoot and scoot" tactics of the battlefield as demonstrated in the Middle East War of 1973. A commander had no use for maps arriving after the battle had been decided; he needed them on the spot, and in readable and up-to-date form.[1]

A xerographic solution

Printing presses could turn out huge volumes of maps, but they took too much time to set up, and were not suited to handle small runs of multicolor maps or other terrain products such as were often needed by a commander. In 1976, USAETL awarded a contract to Southwest Research Institute to survey the possibilities. USAETL tested the Xerox 6500 color copier, and concluded that xerography could be used for maps and graphics on the battlefield.

Accordingly, in September 1978, USAETL awarded a contract to Xerox for a QRMP feasibility study. The desired map measured 24 inches by 30 inches (as opposed to the standard 22.5 inches by 29.5 inches) to allow for annotation. Otherwise, the product was to be of equal quality with the products of the past, yet be quickly produced in small volumes. A 1980 report gave the preliminary design for a QRMP using xerographic techniques.

Instability in funding

Although the Army established the QRMP requirement by Letter of Agreement in August 1979, and August 1980 saw the contract awarded for a prototype, funding problems in 1981-1983 slowed things considerably. When funding appeared, if at all, it was often untimely, delaying testing and adding to the contractor's expenses.[2] It was not until the very end of 1983 that a completed prototype was operated. The QRMP development was delayed to the point where, in the interests of getting the QRMP going in time for eventual use with the Digital Topographic Support System (DTSS), testing was done in such a way as to assume ruggedizing could be done later.

The QRMP design

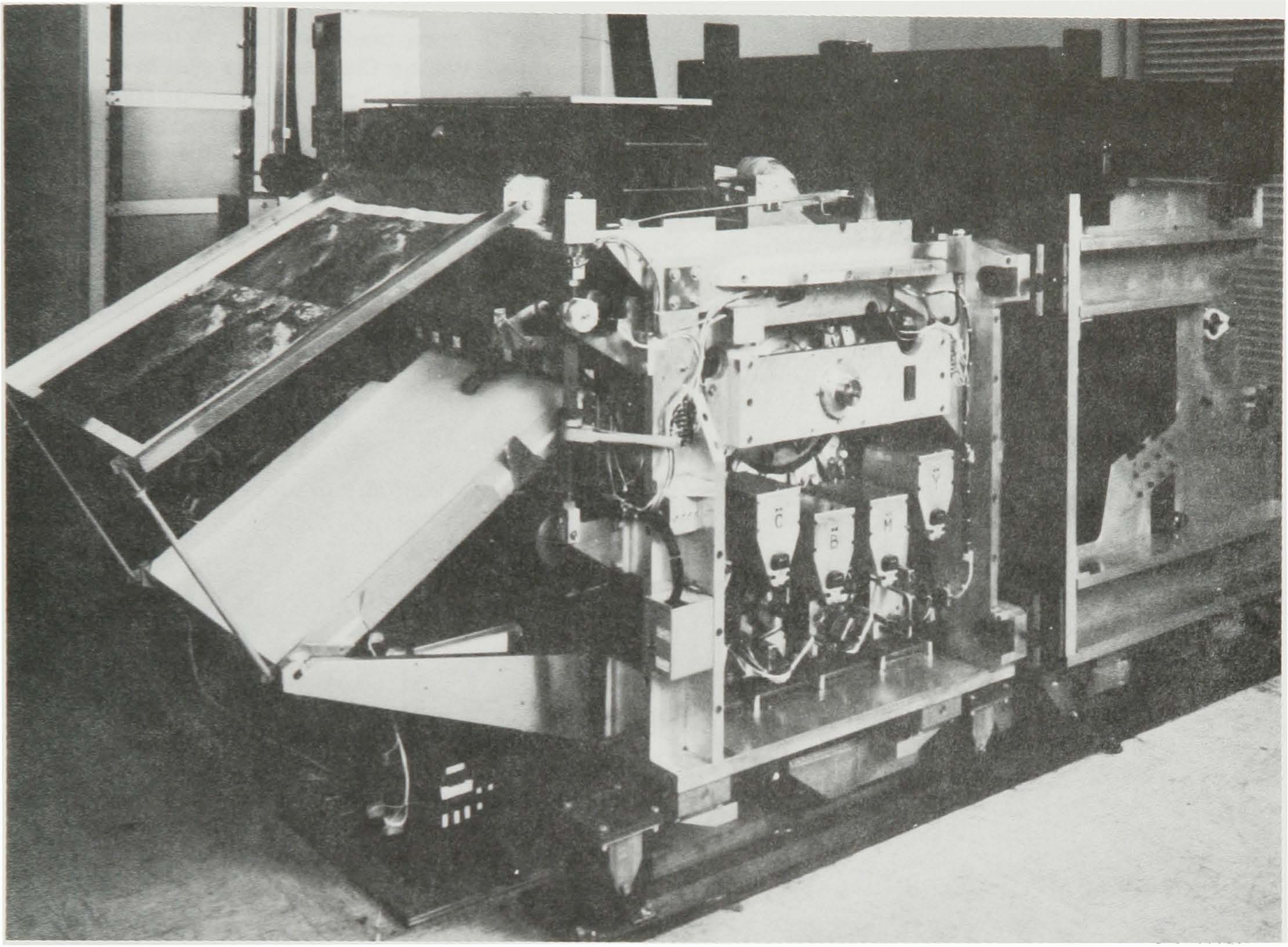
To date (1984), the QRMP plan had changed little. By 1980, most decisions had been made, though four separate processes would eventually become four on one drum. The basic idea remained to combine color xerographic techniques with laser technology in a dry-copying process that provided the very high resolution needed for map and graphic reproduction.

The first step in the QRMP process involved charging a selenium-coated drum with a blanket positive electrostatic charge and exposing the charged drum to a color map. A laser scanned the map and "wrote" the image information on the drum. One by one, four dry, negatively charged color toners were then applied to the drum. Each toner was attracted only to the charged image area corresponding to the color location on the original map; the toners were transferred to the paper by contact with the drum. After the toners had been applied, the composite image was fused and bonded to the paper. The process needed only to be repeated for the required number of copies once the initial reproduction had been made. The scanning and writing processes were almost simultaneous, and combining the toners reproduced any color hue.

Looking for a quick response

Given 30 minutes to warm up, the laboratory model QRMP produced a full-color, full-sized product in less than five minutes and added copies in less than a minute a piece. Although an offset press was faster once set up, USAETL scientists envisioned that for any runs under 500 the QRMP was far better, given the fact that a field press required eight hours to set up and produce one full-color map. The QRMP could turn out 75 copies per hour, while equaling the press' quality.

The QRMP was to be more than a fast way to copy single and full-color maps. The QRMP would also produce transparent overlays for existing maps and perform



The Quick Response Multicolor Printer (QRMP) prototype.

overprinting onto conventional maps. Thus, under combat conditions, field topographic units could produce graphics showing current enemy positions, damage to transportation routes and other battle area changes.

Size and manpower reduction

Field printing presses were not only slow and limited in capability, but bulky. The QRMP was smaller, lighter and more mobile. It could be housed in a 20-foot van and moved about without difficulty. The theoretical 27 people laboring by old methods to produce a single multicolor map were reduced to a lone soldier with a QRMP. Working alone, the soldier could run the printer and maintain it as well.

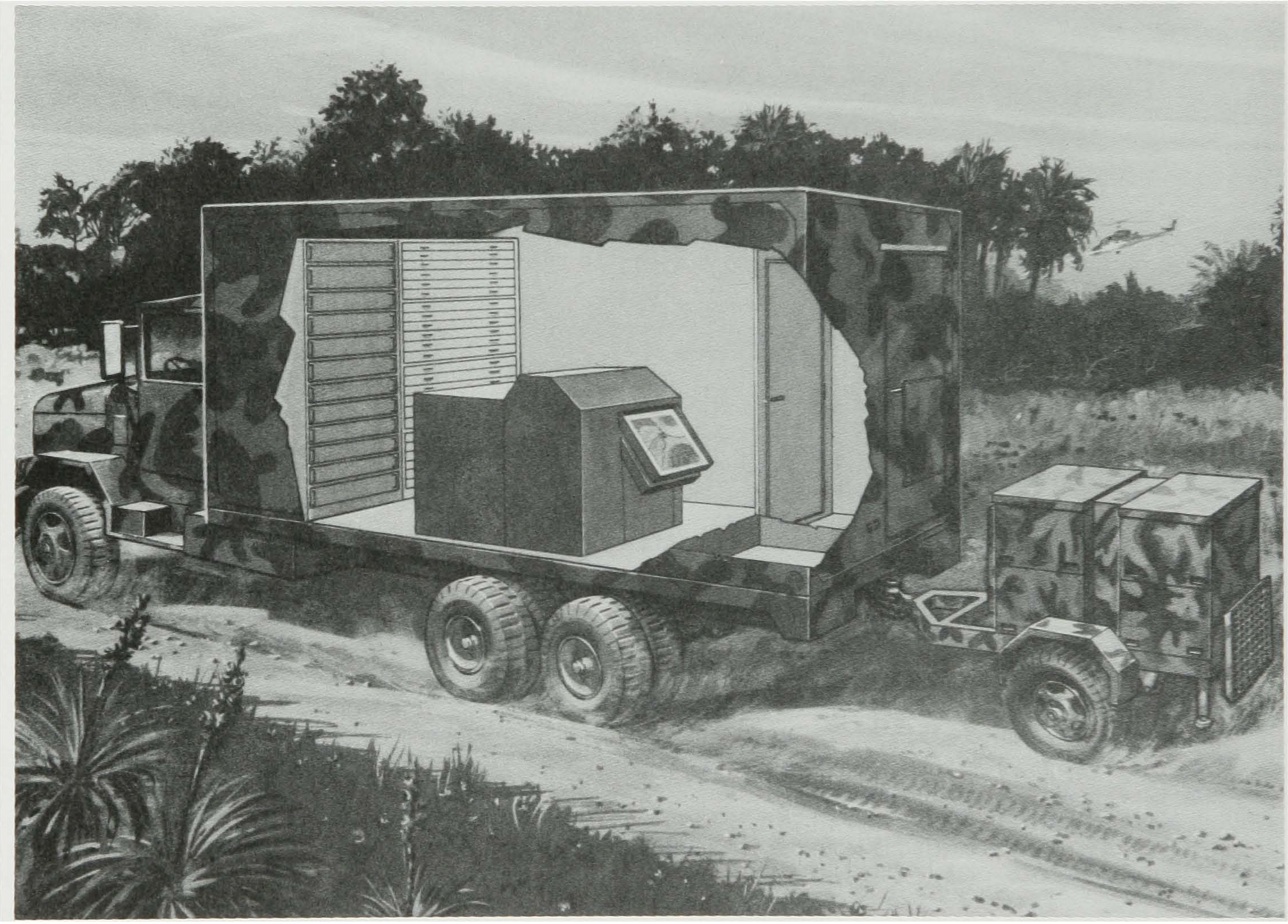
A digital dimension

In the course of developing the QRMP, USAETL scientists were aware of the system's potential use for digital topographic data. USAETL had pioneered work demonstrating the advantage of digital information in speed and flexibility. During this same period, USAETL had also done an exhaustive study of digital topographic data users and their requirements.

Digital printing improved the quality and expanded the capabilities of the QRMP. The soldier in the field could now combine sections of maps, emphasize selected features at the moment of printing, and allow scale and color changes. The digital interface let the printer edit map information and produce special products such as computer-generated overlays and photographs from satellite imagery. Digital capabilities significantly reduced the need to haul around huge inventories of hard-copy map originals to field locations, since it could receive digital files by radio transmission. Considering that the typical field Army consumed 2,700,000 maps weighing 162 tons and a daily replenishment of 120,000 sheets weighing 7.5 tons (World War II data), the equipment reduction was welcome. With its many digital uses, the QRMP became much more than "the first significant advance in combat map reproduction since World War II." Reproducing maps came to be seen as the least of QRMP's many capabilities.[3]

A whole family of uses

The QRMP would have, in Dr. Kenneth Kothe's words, "a whole family of uses." Its ability to produce low-volume, combat-oriented terrain intelligence in graphic form and produce it quickly had an obvious immediate user—the Army in the field. Dr. Kothe predicted that other users would soon be identified. William Clark saw the system cutting down both "effort and time," with cost savings coming a bit down the road.[4] In the interim, he suggested the QRMP will be "invaluable on the battlefield."[5] Envisioned as much more than a mere ruggedized color xerox machine, the QRMP program was a major effort of the Geographic Sciences Laboratory during the period of this history.



An artist's concept of the QRMP in the field.

Footnotes

1. Interview, authors with William Clark, Fort Belvoir, Va., 13 February 1985.
2. Ibid.
3. USAETL "QRMP," in-house information sheet, USAETL-40122.
4. Interview, authors with Dr. Kenneth Kothe, Fort Belvoir, Va., 11 October 1984; William Clark interview
5. Ibid.

II. The Terrain Analysis Center

The Terrain Analysis Center (TAC) is, in contrast to the research and development laboratories surrounding it, an operational element of the USAETL program. While some of the laboratories do work that may bear fruit only in the next century, TAC provides terrain analysis in the very short term. As a fast growing, high-priority element, however, TAC is a central part of the USAETL story in the years 1979-1983.

Eye-opener in the Middle East

The war between Egypt and Israel in 1973 stunned United States military planners with the swift and terrible losses suffered by both sides. General William DePuy (then commander of the U.S. Army Training and Doctrine Command) observed how in that war anything that could be seen was destroyed. DePuy, and others with him, came to espouse a doctrine whereby the terrain became an integral part of maneuvers. Shielded from observation by the terrain, the commander's forces were to make their final assault only when all available firepower was at hand. To do this, terrain analysts and terrain information were clearly needed. The call went out for trained scenarioists in various parts of the world where trouble was likely to occur.[1]

Answering a call for terrain analysis

Before a scenario area could be put together for Korea, the Middle East or anywhere, the Army needed terrain analyses. The Army Map Service, however, had turned the terrain analysis function over to the Defense Intelligence Agency (DIA) in the 1960s. The DIA had redirected its 600 terrain experts to other functions. There was no source ready to provide the kind of terrain information that was going to be needed.

The Defense Mapping Agency (DMA) and the DIA did not agree on who should be tasked with providing the terrain analysis function. The Chief of Engineers had some terrain teams, but even they lacked the assets of the Unified Commands.[2] A quick series of high-level meetings followed wherein the Army pushed hard to straighten things out.[3] As a direct result, an organization called the Engineer Agency for Resource Inventories was assigned to USAETL. In 1975, that organization became the Terrain Analysis Center. The message in the 1973 war was being heeded. TAC basically restarted the Terrain Analysis Program in 1975. Not until 1979 did the Defense Mapping Agency become the Department of Defense's (DOD) terrain analysis program manager, with TAC providing operational support.[4] Until then, the Army had a "very meager terrain analysis capability."[5] DMA did not have large-capacity terrain analysis capability until 1981.

The TAC mission

TAC, as an operational support arm at USAETL, was conceived to perform terrain analyses in response to worldwide requirements of a broad range of Army elements. Its colocation with the research laboratories of USAETL was designed to allow close interaction between TAC and the laboratories' developers. The Terrain Analysis Program was included in the Department of the Army Consolidated Topographic Program. The Army Assistant Chief of Staff for Intelligence validated and prioritized TAC efforts, with funding and capability provided through the Chief of Engineers. A memorandum from the Chief of Staff ("Army Departmental Terrain Analysis Requirement Processing," 24 February 1977), and Army Regulation 115-11 ("Army Topography," 1 December 1977) outlined the TAC mission:

- The Terrain Analysis Center had responsibility for Department of the Army terrain analysis production services that fill the gap between the broad-level support of DOD agencies (e.g., DMA) and the tactical support provided to field commanders by engineer terrain detachments. Responsibility included preparation of terrain studies and analyses specifically designed to support planning and operations, and the provision of quick-response data to meet emergency needs.

- TAC complemented the terrain analysis production efforts of field units by providing technical guidance and assistance as required.

- TAC maintained worldwide data management capability to support planning and operational requirements for military geographic information and terrain data.

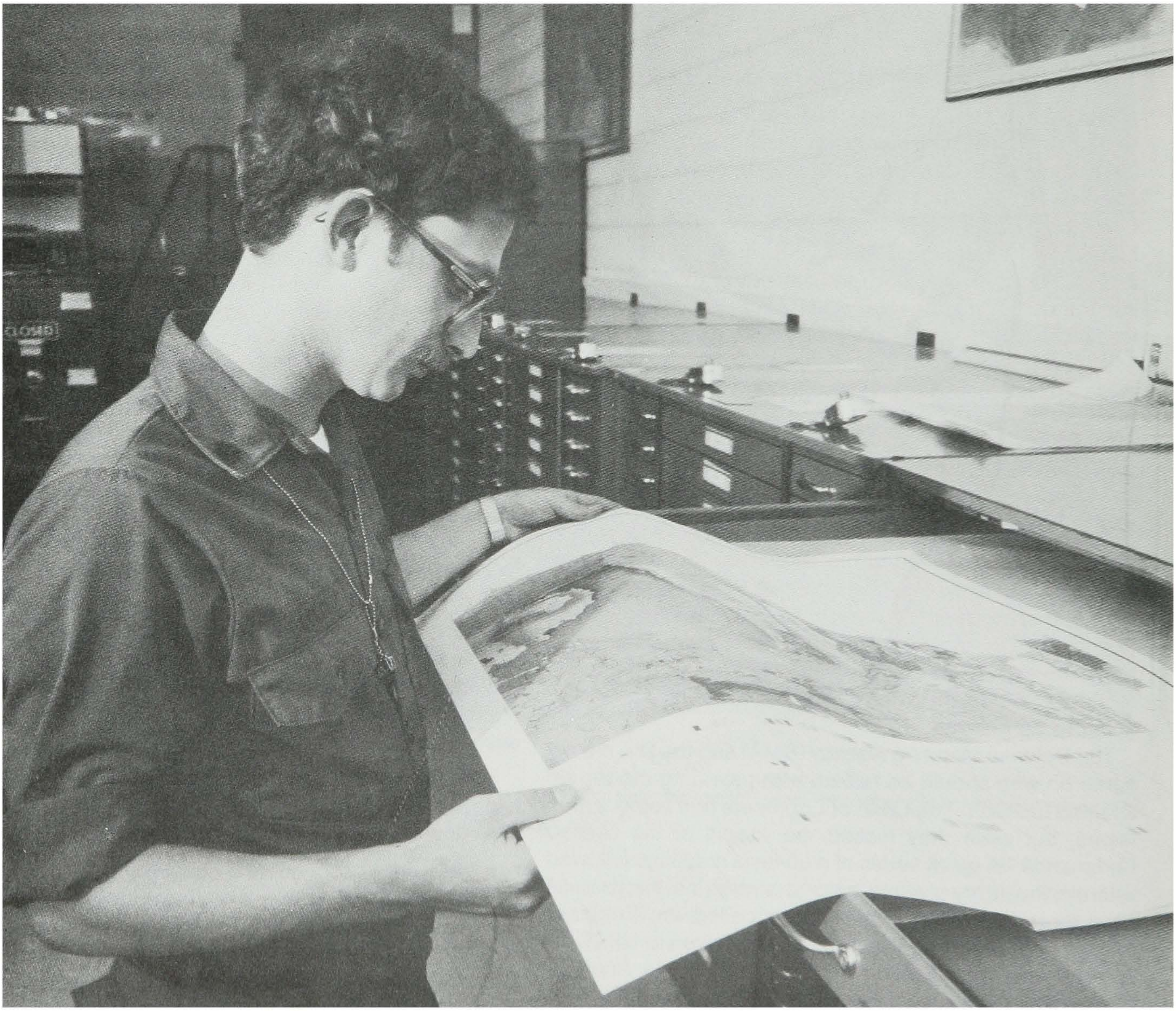
- TAC applied new methodologies, techniques and systems resulting from research and development and, conversely, identified, through its programs, operational requirements that should be addressed by the Research and Development (R&D) community.

TAC was active in the years 1979-1983 in all the above areas, and ranked only below Army Space Program Office work on USAETL's list of work unit priorities at the close of the period.[6]

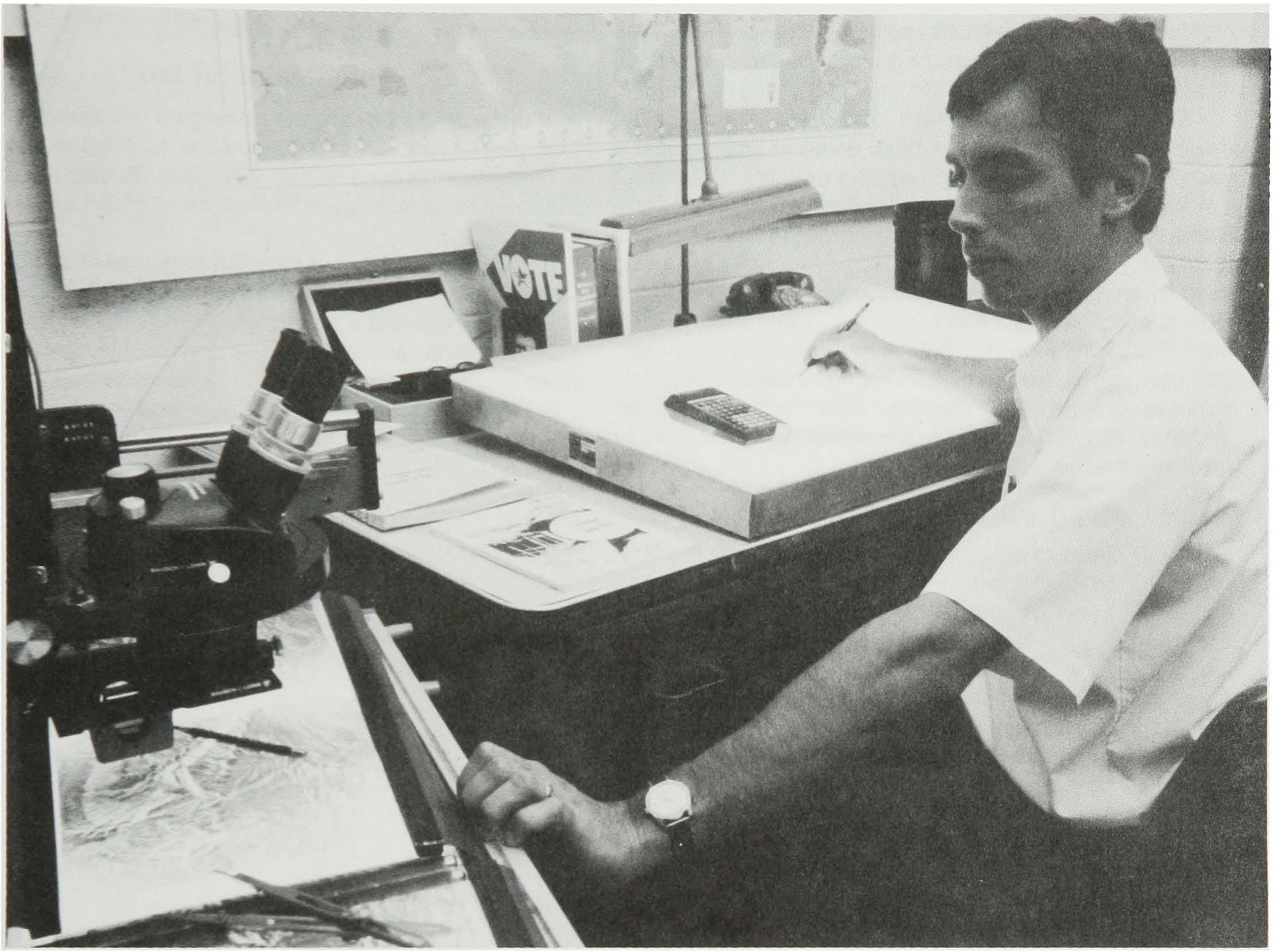
Terrain analysis at DMA and TAC

At the outset, TAC was alone in doing terrain analysis, but by 1981 DMA had a terrain analysis element in Louisville, Ky. DMA's products, however, were standard, applying to the broadest range of users. Local problems required changing or enhancing on the spot, making the DMA product less than ideal for the Army. Among the DMA terrain analysis users were the Unified Commands and the Air Force.

TAC, by contrast, began doing Army work (90 percent of its work from the start) and tailored its products to specific needs. TAC did a custom product and "always sought to do what was required, with no two jobs alike."[7] Whereas DMA did data base products at strategic and tactical specificities only (1:250,000 and 1:50,000 respectively), TAC might do a 1:25,000 or even 1:12,000 product for an urban area. Indeed, DMA itself tasked TAC with some 35 requests per year that could not be met. The Army, in turn, looked to TAC for what its terrain teams simply could not handle, such as long-term projects (e.g., projects with over 100 map sheets with 10 topics) each requiring an advanced degree of scientific knowledge (e.g., geology). The major TAC projects for the Army and DMA during 1979-1983 follow:



A soldier examines a geology map in the Terrain Analysis Center.



A USAETL scientist performs a terrain analysis interpretation using stereo imagery.

- **Corps/Division Terrain Analysis for XVIII Airborne Corps.** From 1979-1983 TAC did about three-quarters of a 172 map-sheet requirement for worldwide strategic planning at 1:250,000 scale. The first terrain analysis prototype map sheet was done in 1978, and the project was curtailed in 1984.
- **CONUS Base Terrain Analysis.** In 1976, TAC began continental U.S. (CONUS) base terrain studies to aid Army planners in troop restationing planning. Though the Corps/Division Study assumed higher priority, 22 base studies were done, with the last completed in 1982-83.
- **Ad Hoc Studies.** At a frequency averaging four to six times a year, TAC was tasked with emergency, special-study jobs. Some lasted over a month and others required terrain answers in two days. All studies were on special topics and very local. Some special analysis was done for the Pershing II project, for example, and work was completed for the Light Infantry Division Study as well.
- **V Corps in Germany.** From 1979 to 1983, TAC completed 26 map sheets of a 67-sheet requirement prepared specially for the U.S. Army Intelligence and Security Command.
- **Tactical Commander's Terrain Analysis (TACCTA).** From 1979 to 1980, TAC performed regional terrain analysis around specific regional (at 1:50,000) and urban (1:12,000) areas in graphic, pocket-size form for the Commander. DMA received studies for 11 areas in total. The last TACCTA study was completed in 1980.
- **Korea Terrain Analysis Studies.** From 1978 to 1980, TAC performed a multitopic terrain analysis of the area around Seoul, South Korea. Done at a scale of 1:25,000, the study included 31 map sheets with nine topics each.
- **Army Intelligence Survey.** In 1974, the Central Intelligence Agency-sponsored National Intelligence Survey came to an end. The survey, a kind of encyclopedia of the world's countries, grew more and more outdated in the years 1974-1981. In 1981, the U.S. Army Intelligence and Threat Analysis Center took up the project, envisioning

multivolume studies with six topics per country. TAC was tasked with doing the military geography volume (Vol. 2) in several country studies.

- **DMA Planning Terrain Analysis Data Base.** Beginning in 1983, TAC has been doing 35 map sheets a year for DMA as part of an ongoing project.
- **Water Resources Work: Overlays and Digital Data Base.** With water the key resource in many areas (especially Southwest Asia and North Africa),[8] TAC found itself charged with doing many overlays for the Rapid Deployment Joint Task Force (later U.S. Central Command) and others. Beginning in 1980, TAC produced 70-80 water resource overlays a year. Such products concentrated on surface, ground and existing water supply facilities information. TAC's water responsibility, however, was to grow even larger.

Managing worldwide water data base

A DOD directive dated 11 October 1983 made the U.S. Army the executive agent for water resources data in support of joint contingency operations. Military planners recognized there was "nothing more important" than water in a large number of the world's hot spots.[9] To be manageable, however, the planned data base clearly needed to be automated.

TAC, with the help of the U.S. Geological Survey, analyzed the various water data users' requirements. By 1984, TAC had visited the users and determined what data and what access would be required. TAC planners next turned to a review of potential hardware and software. A thesaurus and glossary of terms were completed in 1983 in the interest of standardizing terminology. TAC's water data people, taking advantage of the lab environment at Fort Belvoir, were able to use USAETL computers to pursue these ends. William Brierly, a TAC scientist, was pleased to say that TAC had "come quite a ways" by the end of the period covered by this report.[10]

Many tasks on tap

In the period following the retirement of James O'Neal, TAC proceeded, under Ted Howard, to refocus its effort to meet new responsibilities. TAC was divided into three divisions, reflecting three different areas of terrain analysis study.

1. The General Studies Division prepared terrain analysis studies and data bases for the Army and DOD in support of planning operations and training plans. The division also gave help to terrain teams in the field, and interacted with those in the related research and development community.
2. The Special Studies Division prepared quick response and special terrain analysis studies for Army and DOD planning, operations or emergency needs. It also helped terrain teams and kept contact with the R&D community.
3. The Product Support Division worked toward providing and maintaining all-source, worldwide military geographic intelligence/information to support the Terrain Analysis Program and other military requirements. The division also collected, processed and maintained worldwide land-based water resources information to support the DOD Water Resources Data Base. In addition, DMA's Terrain Analysis Program was supported through this division's overall responsibility for managing the military hydrology program. This same division also provided cartographic and reproduction services in support of the Terrain Analysis Program.

All the above divisions continued, in turn, to assist one another when required. The goal was a single one: having an Army Terrain Analysis Program to serve high-priority terrain intelligence requirements, major Army commands and joint commands.[11] The 1973 war had taught everyone that planning and operations could not proceed without combat-oriented terrain intelligence products and services.

Footnotes

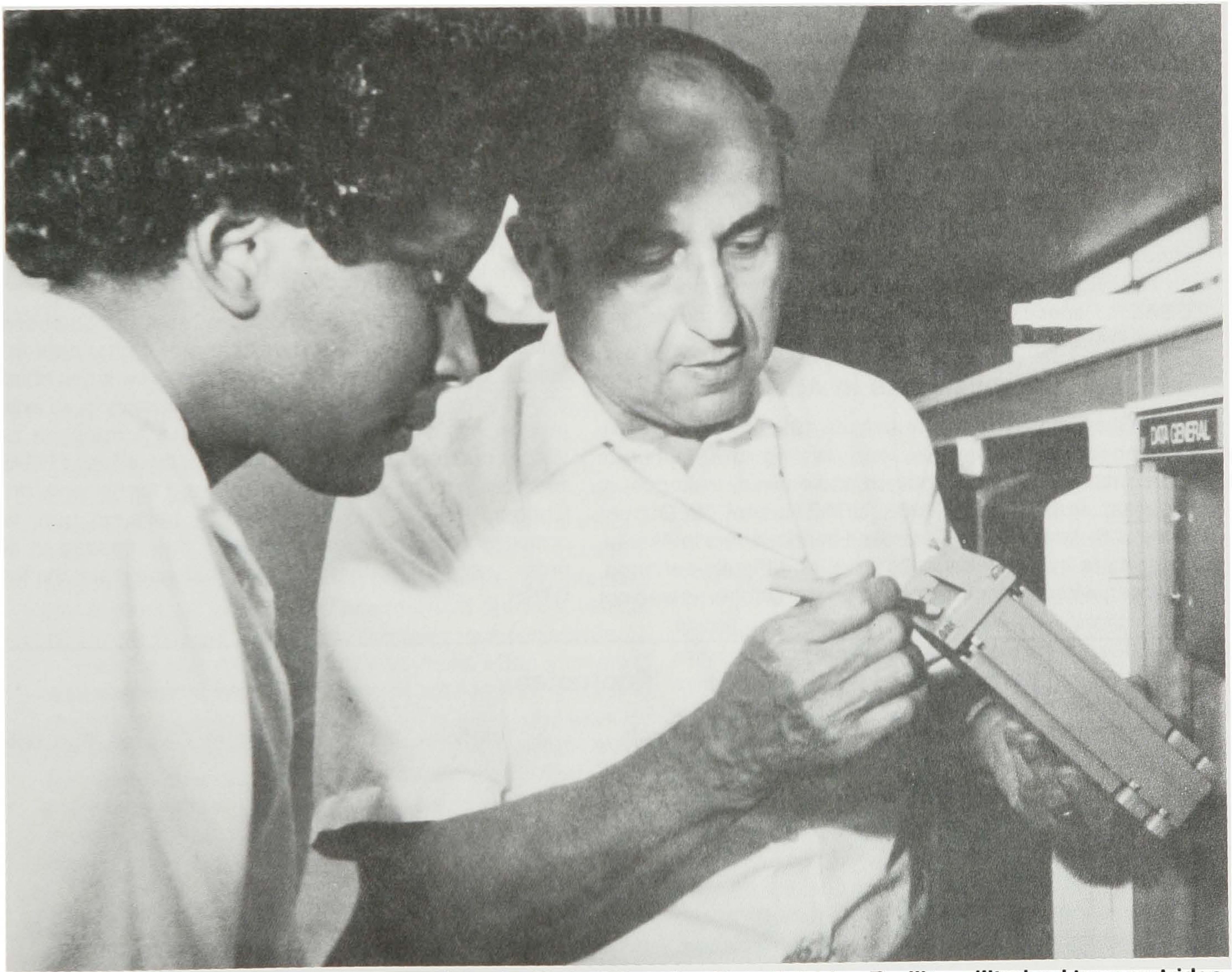
1. Interview, authors with Dr. Kenneth Kothe, Fort Belvoir, Va., 11 October 1984.
2. Ibid.
3. Ibid.
4. Interview, authors with Theodore W. Howard, Fort Belvoir, Va., 11 October 1984.
5. Kothe interview.
6. USAETL in-house list dated 14 October 1985, ranking USAETL units in order of priority.
7. Interview, authors with William B. Brierly Jr., Fort Belvoir, Va., 14 February 1985.
8. Ibid.
9. Ibid.
10. Ibid.
11. Ibid.

III. Survey-Related Research and Development

A. Dubber: An Improvement to FIREFINDER

Much of USAETL's work from 1979 to 1983 was to meet the requirements of AirLand Battle 2000, long-term research in support of the Army of tomorrow. USAETL was asked to work to solve the problems of already existing military systems. Such a case involved USAETL's 1981-1983 work on FIREFINDER, a system designed to locate the source of incoming mortar or artillery fire. In the very short term, USAETL was asked to provide a digital elevation data capability for two working Army tactical systems.

In 1979, the Army had in operation two tactical radar systems (AN/TPQ-36 and 37) that could backplot projectiles



A USAETL scientist demonstrates operation of a Digital Elevation Data Dubbing Facility-militarized tape cartridge.

from mortar and artillery. In both cases the systems, designed to provide information to the Tactical Fire Direction System (TACFIRE), left room for improvement in the speed with which they handled elevations. An automatic height correction was needed to allow timely response. Such an improvement, however, required digital elevation data technology not immediately at hand. Thus, in March 1981, the "march order" came from the U.S. Army Materiel Command to provide that technology as quickly as possible. Under the direction of Regis Orsinger and Larry Wright, the Terrain Information Systems Group (TISG) began work on the Digital Elevation Dubbing Facility, known as the Dubber.

Building an interim system quickly

The Digital Topographic Support System (DTSS), a major project underway at USAETL in these years, would have provided digital elevation data and much more. That system was, however, still some years away from completion. TISG specialists turned instead toward an interim system that could immediately satisfy the demands of the people in the field, yet be standardized enough so that the eventual DTSS could use it in providing digital elevation data.[1]

TISG members defined the "specs" of such a system, prepared a contract package and awarded a contract in June 1981 to the Command, Control and Communication Corporation of California to build a Dubber. The Dubber would provide digital elevation data support to FIREFINDER. It was to do so very soon, yet in a standardized form that could be used when DTSS came on line. It was to be a one-of-a-kind system, created at USAETL, specifically designed to bypass some normal steps in the interest of speedy completion.[2]

Improvements in Atlanta

TISG specialists spent much of 1982 monitoring the Dubber contractor's work and testing the Dubber's performance before acceptance and delivery in August of that year. In September 1982, USAETL sent the Dubber to the U.S. Army Forces Command headquarters in Atlanta, Ga., where it was to begin its work. A difficulty surfaced, however, with the controller used on the Dubber; it was not entirely compatible with that on FIREFINDER, and the two devices differed in how they wrote their records on tape. Larry Wright started working with FIREFINDER people from Fort Monmouth, N.J., and engineers from Hughes Aircraft and Raymond Engineering. By August 1983, the problem was ironed out and the dubbing facility was doing its job.

The Dubber: reformatting DMA data

The requirements of FIREFINDER dictated that, to assure effective counter-battery fire, faster and more accurate enemy gun location be supported by digital elevation data. Such data, as available from DMA on commercial 9-track tapes, needed to be reformatted, validated and stored on ruggedized cartridge cassettes before it suited FIREFINDER's uses. The Dubber was USAETL's quick answer to this need.

The Dubber went to work in 1983 continually reformatting DMA digital elevation data as it came in, ranked by FIREFINDER's commanders. As the 9-track tapes arrived, the Dubber facility verified their data, cataloged the tapes and maintained a master library. Each 100,000-meter grid zone was put on a master library tape, and the index to that zone was put on a system disk. The matrix of data was done by one-degree cells (1x1 degree cells of the Earth's surface 125 meters apart). The Dubber kept the data on the desired grid resolution, recorded on militarized magnetic tape cartridges, and stood ready to supply data in this form to FIREFINDER units.

An award winner

Frank Capece of USAETL noted that the Dubber was noteworthy as the "first application of digital data in the field."[3] More than that, the Dubber was a swift and effective effort by the laboratory to address a deficiency in an existing tactical system. Recognizing this, the Army gave Larry Wright its Research and Development Award, and USAETL awarded him the Commander's Award for his work on the Dubber project. The FIREFINDER units, in turn, were provided the digital elevation data they needed in short order, yet in a standardized form that would suit the future DTSS.

Footnotes

1. Interview, authors with Larry Wright, Fort Belvoir, Va., 25 March 1985.

2. Ibid.

3. Interview, authors with Frank Capece, Fort Belvoir, Va., 14 October 1984.

B. Inertial Survey Systems

1. The Story of "PADS"

Not all of USAETL's efforts lead to swift solutions. While in unusual cases, such as the development of the Dubber, things go from design to fielded product in 18 months, a much longer gestation period is more often the rule. Indeed, it can happen that filling an Army requirement can prove impractical or even impossible. In such cases the work of a research laboratory such as USAETL can lead to a dead end. When USAETL does have success, the usual recipe is years of hard work and refinement. The Position and Azimuth Determining System (PADS) is a good case of the latter. The development of PADS took years, but was worth it. With PADS, the field commander had a quick, new way to find out where his artillery should be.

Toward an inertial survey

In July 1979, Litton Guidance and Control Systems was awarded a $43 million production contract for 102 PADS systems. The contract, following upon PADS being approved as standard equipment in March of the same year, brought an end to a story beginning in 1958. In that year, the responsibility for the development of the Artillery Survey System was taken from the Ordnance Corps and transferred to the Corps of Engineers. The system was in dire need of better methods and equipment for survey. The existing methods were too slow, and improved weapons merely underlined survey deficiencies. The Corps quickly looked at various new techniques such as electronic hyperbolic systems, flare triangulation and simultaneous electronic ranging to an airborne station. A fourth approach, inertial technique, showed the most potential, but adapting the technology to the rough environment of a land vehicle would be difficult, and the technology was expensive.

The first step toward PADS was taken when a contract was awarded to General Electric in 1959 to do a study and preliminary design of an inertial system that would work for the artillery system. The resulting three-month study concluded that such a system, given the proper data-correction techniques, could be capable of doing the job. In January 1960, General Electric was given a contract to design and fabricate a prototype.

Changed designs with mixed results

In July 1960, however, the user requested that the system design be changed to permit data correction en route. This change (from traverse closure technique to open traverse survey) was one reason the prototype system was not ready for a system test until December 1962. Following such testing, the system was delivered to USAETL (then GIMRADA) on 16 April 1963. The results were mixed, and Robert T. Flowe's Engineering Design Test Report (October 1963) flatly stated that the equipment was not even suitable for engineering tests because the computer subsystem was unacceptably sensitive to banging around under field conditions.

With so many hurdles yet to overcome, USAETL (GIMRADA) was directed to abandon the inertial survey effort by 30 June 1963, pending the approval of a Qualitative Materiel Requirement by the Combat Developments Command. Neither the problems with the General Electric equipment nor the termination of the task in June made the prevailing need for such a system go away. Clarence W. Kitchens Sr., project engineer and the branch chief in charge of PADS development through much of the PADS story, stated his case:

> Classical surveying techniques cannot meet present-day artillery survey requirements because they lack flexibility and are too time-consuming. The modern field artillery requires a mobile survey system which can determine position, elevation and azimuth quickly and accurately as it moves across the field in tactical operation.[1]

The Army agreed, because its artillery was continually improving its mobility and its range, thereby aggravating the survey problem. Further inertial survey application studies were undertaken in 1965, and on 20 December, a contract was awarded to the Guidance and Control Division, Litton Systems Inc., as part of the development program for PADS. After studying the applications of inertial techniques of surveying, Litton declared that a pure inertial system could not meet all the goals, but a vehicle-mounted system could do the job with certain accessories such as a laser velocimeter and continuous Kalman filtering using high-grade inertial gyros and accelerometers.[2]

More studies

From December 1967 to June 1968, Litton made additional studies under contract, trying to make a better case for the land configuration of PADS. The final technical report (December 1968) cited inertial instrument testing, systems simulation, and laser velocimeter analysis and tests, which indicated such a system was practical. PADS would be self-contained, secure from detection, insensitive

Scientists record a survey position to give the Position and Azimuth Determining System a point of reference.

to electronic countermeasures and could be operated in all weather conditions. The military also liked the idea of PADS requiring fewer people to do the same survey job, yet doing it faster. As a result, the Army recommended that an experimental prototype model of the vehicle-mounted PADS be designed, built and tested. Litton was awarded the contract in 1971.

The PADS prototype

The PADS Advanced Development prototype permitted evaluation of odometer, laser velocimeter and zero-velocity updating of the inertial system. The latter was ultimately selected for production to minimize cost and complexity. In 1974, the Department of the Army approved a proposal for a required operational capability for PADS after a series of field tests and engineer design tests resulted in a number of improvements and design changes.

In June 1975, Litton was awarded a contract to produce five engineering development models which could withstand the full military environment and be operated by troops. Test equipment, manuals and training materials needed to support PADS in the field were also developed. The equipment was subjected to a full battery of engineering tests in Development Test II and arctic testing performed at the contractor's plant, Aberdeen Proving Grounds, Md., Navy Weapons Center, Calif., and Fort Greely, Alaska.

The Army Field Artillery Board tested the PADS hardware at Fort Sill, Okla., in mid-1977. The Board concluded that PADS was adequate for artillery purposes in speed, accuracy and operating characteristics. There were problems, however, with reliability and maintainability. Most of these problems were ironed out by early 1978, and an Operational Test IIA was carried out by the Field Artillery Board from March to July 1978. PADS was type-classified standard in March 1979. On 1 July 1979, Litton was awarded the first production contract, and PADS was at last a reality. A three-week mission at the Grafenwohr Training Area in Germany, and an Australian field trial, proved PADS' worth to other potential users. One observer in Germany was typical in urging that PADS be "fielded in Europe as soon as possible."[3] The persistent efforts of the Topographic Developments Laboratory at USAETL had taken time, but paid off.

How PADS works

PADS is made up of an inertial measuring unit (a modified aircraft inertial navigation system: CAINS AN/ASN-92), a control and display unit, a data processing unit and an independent power supply unit. All this is usually mounted on a jeep; but since it was designed to be mounted on a strap-down pallet, it can be put on nearly any wheeled or tracked vehicle, in addition to helicopters. An external theodolite, tripod and target set can be used to transfer azimuths out of the inertial platform. In the preferred method, PADS orients a line by determining the positions of both ends of the line and computes the azimuth. The control and display unit makes possible entering data pertaining to the initial survey control point. It also displays survey parameters for each succeeding survey control point, displays spheroid and Universal Transverse Mercator grid zones in use, and displays system status and unit malfunctions. With PADS, azimuth transfer can be done in less than 15 minutes, and position can be read out in UTM coordinates and elevation in meters in less than two minutes after the vehicle has stopped. Such speed, in the shoot and scoot world of the modern military, is crucial. PADS increases the speed of artillery survey by nearly an order of magnitude while dropping the manpower requirement to a third of the manual methods.

Quick and accurate

The operational requirements on the part of the operator are few. The jeep driver can proceed at any safe speed, over any terrain, day or night. His only constraint is to stop at intervals for zero-velocity updates (ZUPTS) to minimize system errors. This method, using Kalman filtering software, can maintain a position accuracy of 20 meters circular error probable, an elevation accuracy to 10 meters probable error and azimuth accuracy to one millimeter root mean square. Such automated surveying, which is both accurate and quick, eliminates the need for crews to halt missions at every turn for a line-of-sight measurement between two points.

It took time to develop PADS, but the system has proved its worth. Noncommissioned artillery officers from Fort Sill, Okla., who put PADS through brutal work in California's arid High Desert in 1981, sang the system's praises and declared its survivability proved beyond any reasonable doubt.[4] Its speed and accuracy were established earlier, but establishing the reliability and maintainability of PADS closed the circle. In subsequent and similar extreme applications, PADS proved as tough as it is fast and accurate. USAETL's Topographic Developments Laboratory's (TDL) Surveying Division counts PADS as a major success, perfected and fielded in the early part of the 1979-1983 time frame.

Building on PADS

Field teams reported amazing improvements in survey efficiency, and the reliability of the PADS package was very good. Not surprisingly, scientists were looking for ways to widen the application of PADS-type inertial surveying techniques. Many scientists had observed the slow but steady development of PADS and considered possible applications to civil works, airborne surveys, hydrographic surveys and, on the other side, mobile missiles.

2. The Inertial Positioning System

During the 1979-1983 period, DMA asked USAETL to undertake development of a PADS-related rapid method of getting horizontal positions and elevations for geodetic surveying. DMA wanted a quick way to supply accurate data when a higher order of accuracy was required than PADS could give. The new method was the Inertial Positioning System (IPS).

Added capability of IPS

TDL's Precise Survey Branch had Litton use inertial components and develop improved calibration and operation procedures to improve accuracy to one meter on closed traverses. The IPS was also equipped with a cassette tape recording deck to record gravity from a separate gravimeter and survey data for post-mission processing.

The result was a fast, cost-effective alternative to slow and labor-intensive manual methods. The measure of the system's worth is reflected in the quick development of a commercial version, the van-mounted Auto-Surveyor. In fact, the Corps of Engineers turned around and evaluated this commercial version for field surveying. The IPS was another step in inertial survey and opened doors in still other directions. The IPS was used almost continuously by DMA, and a commercial company is selling IPS use.

USAETL also sponsored the initial work with Honeywell's SPIN GEANS inertial platform which resulted in DMA's IPS-2 and a commercial spin-off. Other related work included the Rapid Geodetic Survey System (RGSS).

3. MAPS: Building Down from PADS

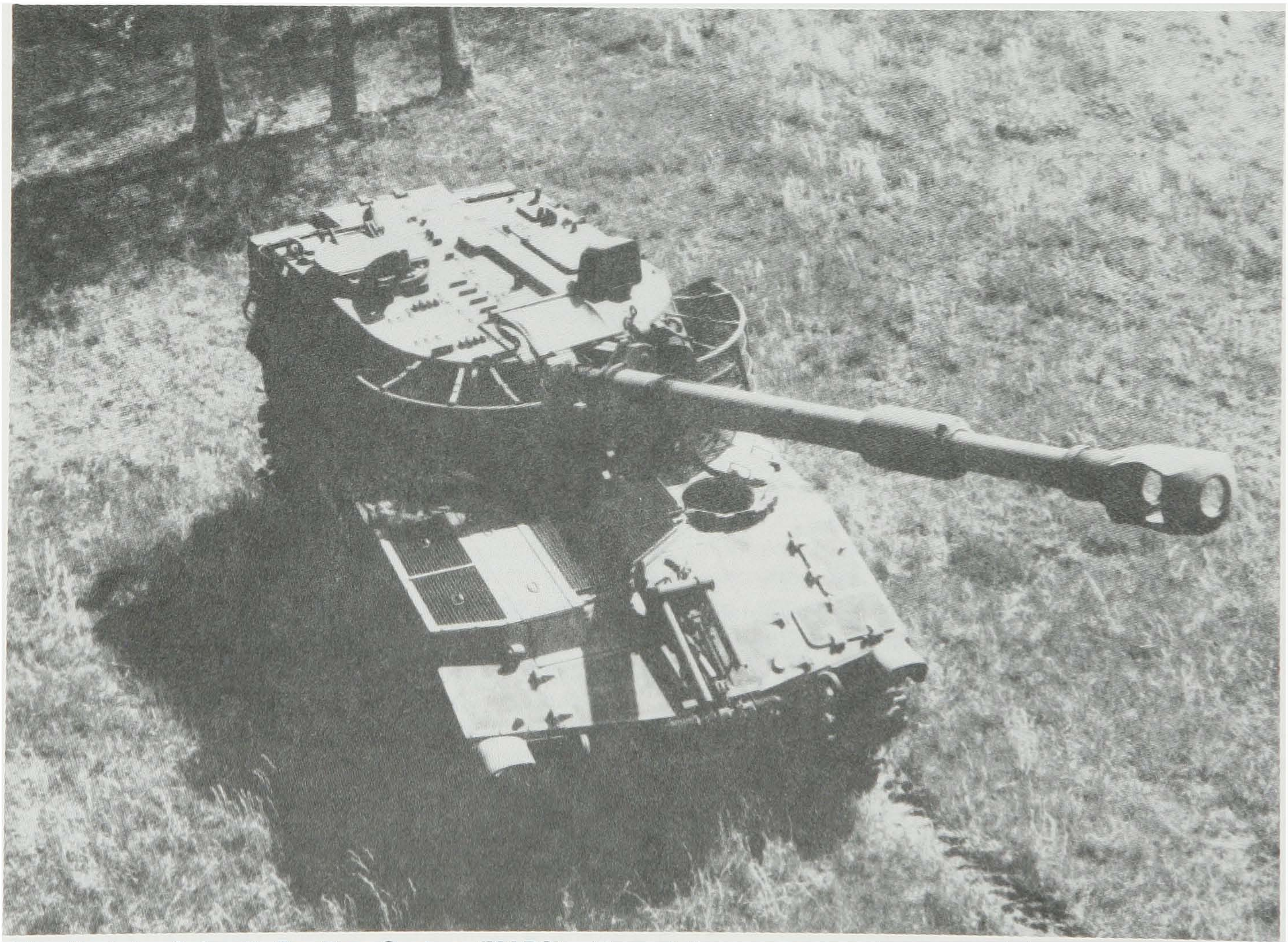
The inertial survey techniques championed by USAETL scientists John Armistead and Oscar Bowker bore fruit in PADS, IPS and RGSS. But there were problems still remaining. These techniques were very accurate, relatively inexpensive systems capable of replacing conventional survey. But for other uses, still another system was needed.

The Army was looking for something that could automatically point artillery weapons. Carl Friberg, Chief of USAETL's Surveying and Engineering Division, spoke in 1979 of an auxiliary system that might be developed and purchased at one-tenth the cost of PADS. Two land-navigation studies toward this end, called the Forward Area Survey Equipment (FASE) and the All-Gyro Heading System, reflected USAETL's growing interest in extending survey control to lower echelons, and helped to open the door for the later development of the Modular Azimuth Positioning System (MAPS). MAPS would prove to be a major USAETL effort to aid battlefield mobility for cannon artillery.

Learning what will work

In the FASE study, engineers in Friberg's Division drove a jeep-mounted prototype using Singer inertial navigation equipment over precisely surveyed dirt and paved test courses near Fort Belvoir, Va. Their purpose was to test the accuracy of a humbler system over a variety of terrain and environmental conditions. This exploratory development (6.2) project encountered problems in handling recoil shocks, but all and all, USAETL engineers felt that it had performed well. Although the managers of the Howitzer Improvement Enhanced Life Program did not select the USAETL FASE approach, they were made aware of the merits of inertial technology for land navigation. In this respect, USAETL's FASE report was considered an eye-opener.

A second effort along similar lines during this period was the All-Gyro Heading System, a 6.2 project for generating heading references in battle. Though such a system was not pursued further, its research work helped to identify the optimal size of a readout element. "Learning what will



The Modular Azimuth Position System (MAPS) will meet the survey requirements of this howitzer tank.

work," always a big part of a research and development laboratory's agenda, was engineer Jack Perrin's summation of the two projects.[5] The elements for MAPS were thus being assembled at USAETL. The impetus, however, was to come from outside USAETL.

A generic system

In the commercial marketplace, a successful invention, whether a compact disc player or an auto-focus camera, quickly breeds imitators, flooding the market with a choice of products—not all of them good. Similarly, the military market, observing that survey had been, in John Armistead's words, "revolutionized by PADS," faced the prospect of a host of inertial survey systems. All of them were expensive; not all of them were equally good. In the early 1980s, many Army developers were hard at work on individual survey devices specifically adapted to their own need. The possibilities for waste and logistical chaos were great.

In 1982, word came down from Army Undersecretary James R. Ambrose and the Army Materiel Command (AMC, formerly DARCOM) that a uniform device, compatible with all users needing a humbler PADS, must be developed. USAETL was tasked with furnishing the specifications, monitoring any contracts and drawing up the testing plans. Frederick Gloeckler Jr., and later, David Thacker, began work toward a 1987 fielding date.[6] Inertial survey was essential to the development of several new weapons systems in their roles in shoot and scoot battle strategy.

MAPS: A modular system

In exploring a variety of applications for PADS-type equipment, USAETL had developed improved survey techniques (e.g., with IPS and RGSS) for the mapping and civil works communities. In these cases, USAETL had added to or upgraded PADS components to achieve higher accuracies such as required for geodetic survey. With MAPS, things were a little different; the goal was to cut the costs of development, logistics and maintenance. As a weapons systems device, MAPS was for short-distance surveys requiring less, not more, accuracy than PADS. USAETL's engineers looked at improved microprocessor technology for ways to cut costs and meet the interchangeable modular goal.[7]

How MAPS works

The PADS system used a gimbal platform, mechanically leveling the system and keeping it pointing north. MAPS, looking to simplify things, would use strap-down (hard-mounted) gyros and accelerometers, and a computer to do mathematically what the gimbal platform did mechanically. Advances in microprocessor technology allowed MAPS to use less precise, less costly instruments to do much of the work. Thus there were two computers in MAPS, one doing PADS functions and one doing the work of the gimbal platform.

Though not as exact as PADS, MAPS would still meet the survey requirements of such diverse systems as the M-109/10 self-propelled howitzers, Patriot anti-aircraft missiles and FIREFINDER counter-mortar/counter-artillery radars. USAETL worked with the project manager of the Cannon Artillery Weapons System to assure that the standardized positioning/orientation device would work for a large number of different weapon and target acquisition systems.

Dynamic reference unit

The two-computer heart of MAPS was the Dynamic Reference Unit (DRU) system which provided an on-board inertial survey capability for mobile weapons and sensors. Indeed the DRU could be the only MAPS component a user required, provided he had his own power, interconnecting cable, etc. The howitzer, for example, would require only the DRU. The MAPS program was designed to furnish more capabilities but only whatever was required. It would furnish, in every case however, horizontal and vertical positions, attitudes (including measurements of grid azimuth, pitch and roll) and three-axis angular velocity. The detailed technical specifications for the DRU were completed in 1984. USAETL scientists were also at work on a Static Reference Unit (SRU) designed to provide just azimuth for weapons and sensors not needing the dynamic positioning provided by the DRU.[8] The extension of survey control to lower echelons first envisioned by Carl Friberg in 1979 continued.

At the close of the period included in this history, plans were being made to award three contracts to develop MAPS.[9] The plan was to achieve competition and further diminish the cost of the reliable, inertial survey package.

Footnotes

1. Dr. Edward C. Ezell, *ETL History Update 1968-1978*, (Fort Belvoir: USAETL document), p. 61.
2. "Application of Inertial Techniques to Surveying Final Report," Litton Systems Inc., Guidance and Control Division, November 1966.
3. *Tech-Tran*, Vol. 7, No. 2 (Spring 1982), p. 4. Quarterly technology transfer newsletter published by USAETL.
4. *Tech-Tran*, Vol. 6, No. 2 (Spring 1981), p. 5.
5. Interview, authors with Jack Perrin, Fort Belvoir, Va., 28 May 1986.
6. Interview, authors with Frederick M. Gloeckler Jr., Fort Belvoir, Va., 12 January 1985.
7. Ibid.
8. Ibid.
9. Ibid.

C. Circumpolar: Finding Azimuth at Night

The fast-moving battle conditions envisioned by the Army required equipment to be faster and adapted to night fighting. In developing such equipment some things remained constant, such as the requirements of aiming artillery. One must have an accurate determination of the direction to shoot, measured as an angle between true north and a point on the horizon. This angle, or azimuth, is needed in aiming all indirect-fire weapons with the degree of accuracy required increasing as the weapon's range and accuracy increase. The traditional method of obtaining accurate azimuths for artillery involved a time-consuming field survey.

Artillery pieces are large and must be carefully aimed, two conditions which require them to remain stationary while firing. But for stationary targets, life on the modern battlefield was expected to be short. To survive, artillery units could no longer enjoy the luxury of setting up and working from well-surveyed firing sites. Instead, they would have to shoot and scoot, often at night. Moreover, traditional survey methods for artillery tended to be more precise than needed. Practical limitations on accuracy were built into the design and ballistics of the weaponry. Accordingly, artillery officers were content with an azimuth error in finding true north of one millimeter or about three arc-minutes. What was needed was a "quick and dirty" night-time source of azimuth, making it possible to shoot and scoot. Two USAETL engineers invented such a method in the years 1979-1983 that was fast, rugged and—in contrast to a magnetic compass—accurate enough for the purpose.

The circumpolar method

In 1979, Donald Dere of USAETL's Precise Survey Branch (Topographic Developments Laboratory) was asked to evaluate a new method of finding azimuth, called the "Polaris II Method." Azimuth was sought by means of extensive modifications to a standard artillerist's device known as the M2 aiming circle. The Army Field Artillery School wanted to know if the idea would simplify finding azimuth in the field at night when outside control could not be brought in.

Taking advantage of the laboratory cross-fertilization possibilities at USAETL, Dere immediately brought the device to the attention of his colleague, Michael McDonnell, then of the Research Institute's Center for Coherent Optics. Together, they concluded that the proposed modifications to the M2 aiming circle would not be easy to use. Fortunately, the device served to stimulate a better idea.

A new method

Dere and McDonnell decided to fit the aiming circle with a special reticle upon which three circles were etched. In the northern hemisphere the North Star and two other circumpolar stars were then sighted and brought into the field of view of a telescope. Once the three stars were aligned on their respective circles, Dere and McDonnell had their aiming circle cross hairs on true north.

Experience not required

Though simplicity itself, the new device was an exciting breakthrough. Old methods of nighttime orientation required a high level of operator skill and the use of mathematical tables that have a way of getting lost in battle. Requiring only one-half hour for training, the new technique did away with timing systems, calculations and puzzling tables. Not surprisingly, the device was quickly tested in training exercises at Fort Sill, Okla., by the 82nd Airborne, and in the Bright Star rapid-deployment exercise in Egypt where it won high praise. The simplicity of the tool and its procedures were especially welcome in the shoot and scoot context.[1]

By 1983, the Dere-McDonnell reticle device was already in the Army's inventory. From a quick evaluation in 1979 to inventory in such a short time, the invention was a striking example of the benefits of cross-lab efforts. Civilian surveyors, private industry and many allied countries joined the military in putting this new method into quick use. For their timely invention, the two scientists received the Commander's Award at USAETL in 1982.[2]

Footnotes

1. Interview, authors with Donald Dere and Michael McDonnell, Fort Belvoir, Va., 12 October 1983.
2. Installation files, Topographic Developments Laboratory (TDL), *Historical Summary*, 1982.

D. Survey: Geodesy 1979-1983

As USAETL's commander Colonel Edward K. Wintz delicately admitted, much of the laboratories' work was so technical that even general officers of the Corps of Engineers had trouble understanding just what USAETL was doing. Nowhere was this more true than in the Center for Geodesy, where in the years 1979-1983, work continued on deflection of the vertical and related matters. Geodesy was "a dark and forbidding area of study to many people." It was also an important science for the deployment of intermediate and long-range rockets and missiles.[1]

Webster's dictionary says that geodesy is a "branch of applied mathematics" concerned with determining "the exact positions of points and the figures and areas of large portions of the Earth's surface or the shape and size of the Earth, and the variations of terrestrial gravity." As academic and ethereal as this sounds, it had a very concrete importance for the national defense.

Geodesy and weaponry

Geodesy does not come into play in the case of every weapon requiring survey. A tank commander, for example, navigating the desert using a map, might be satisfied with the orientation of a compass accurate to three degrees—he would have no use for geodetic survey information. Similarly, an artillery commander, though requiring an accuracy of one millimeter (50 times more precise than that of the tank), would have no need of geodesy. Locating and orienting an intercontinental ballistic missile, however, requires much more accurate positional information, including geodetic data, due to its very small room for error.

Reducing error through geodesy

Through its work in geodesy, USAETL played a major role in providing the technology designed to meet various levels of demand for accurate positional information in support of military operations. In the case of missile operations (with an error margin again 10 times smaller than artillery), USAETL's Center for Geodesy under Dr. Hans Baussus von Luetzow continued to work in-house on "optimal" and "quasi-optimal" methods (i.e., best and nearly best) ways to improve classical methods of geodetic measurement. Facing the fact that missiles must travel to the far reaches of the Earth, while relying on positioning equipment that would be far more accurate navigating around a perfect ball bearing, these scientists seek to factor-in the Earth's "imperfections" for guidance purposes. In the case of such distances, even small errors in the starting condition "can grow and magnify to completely prevent achievement of the intended purpose of the weapon."[2]

1. The Center for Geodesy

Work on geodetic problems began before the period covered in this update, but 1979, according to Dr. Baussus von Luetzow, saw a new, very strong concentration, on the ascending part of missile trajectories. "Superior hardware" was creating the need for a "superior theoretical model."[3] Whereas, in the past, geodesy was largely involved with the determinations of exact positions of points on the surface of the Earth for mapping or artillery control purposes, modern requirements for distance and direction required both the practical and scientific application of geodesy to furnish answers to missile guidance puzzles. Doctors Baussus von Luetzow, Angel Baldini and Eugene Margerum labored throughout this period on these puzzles.

A declining emphasis on theoretical geodesy

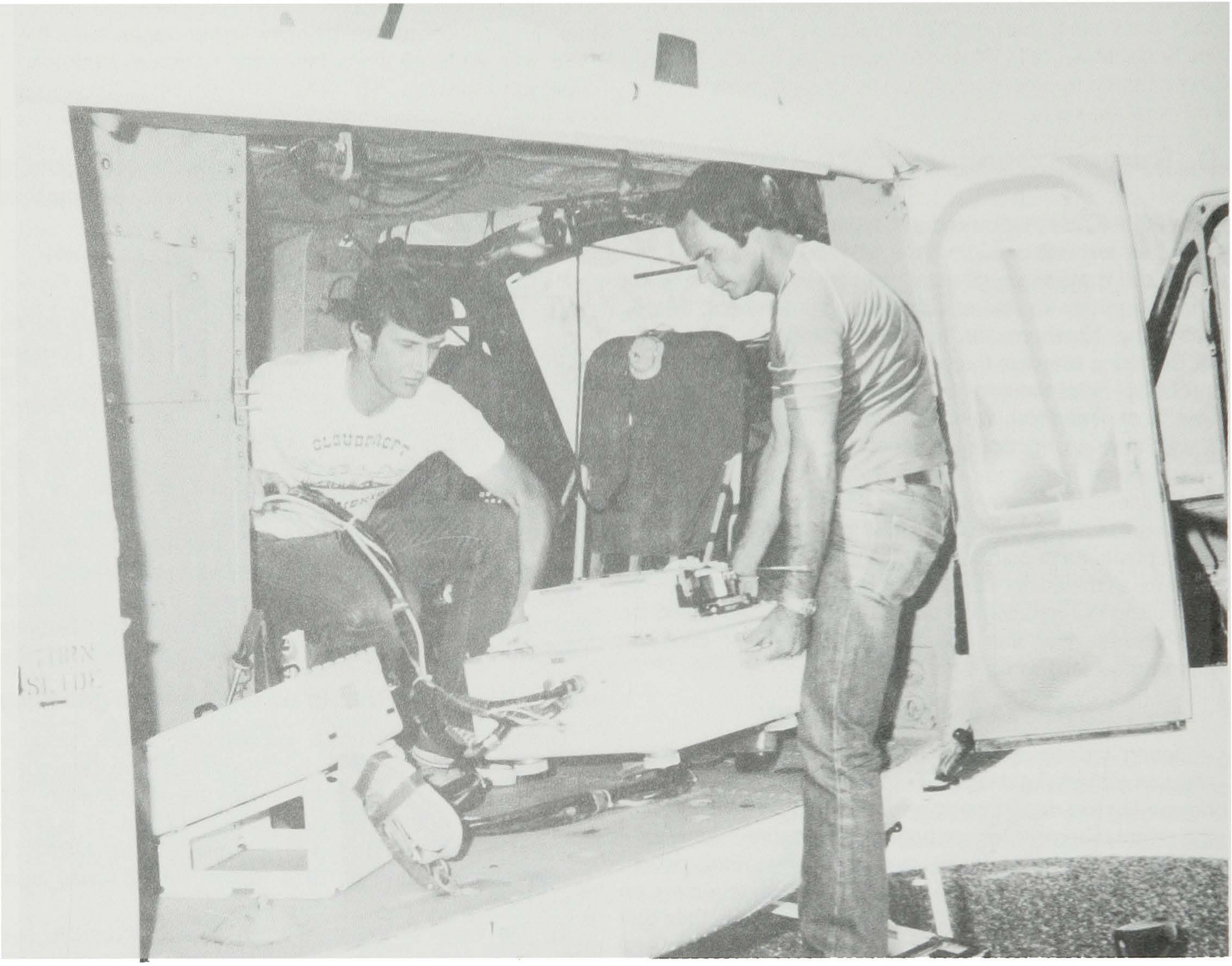
During the period under consideration here, work at USAETL underwent a steady "de-emphasis on theoretical geodesy."[4] Among the scientists of the organization, the view was generally held that "other parameters" were of greater concern. Indeed, following the USAETL organizational study in 1978, focus shifted away from geodesy in a major way.

By the close of the period 1979-1983, scientists had concluded that "looking further [into geodesy] would not satisfy the military's requirements."[5] The new focus became the physical limitations on the accuracy of positional measurements such as atmosphere and temperature, along with such exotic variables as solar wind. It was expected that theoretical geodesy would not warrant large expenditures "for the foreseeable future."[6]

2. Geodesy Applied: The Rapid Geodetic Survey System

The decline in emphasis on theoretical geodesy did not leave the science without a role at USAETL. Indeed, on the applied end, geodesy played a key role in developing a survey system derived from the hard work done on the Position and Azimuth Determining System (PADS), by the Surveying Division in the Topographic Developments Laboratory.

PADS, designed for artillery, had no application for missile site surveying. The order of accuracy required for an intercontinental ballistic missile, for example, required



These geodesists remove the Rapid Geodetic Survey System (RGSS) from a helicopter to record a position.

nearly a year of painstaking effort by manual survey methods to nail down 40 points on a complex site. PADS gave different information at a far lower order of accuracy. Nonetheless, work on enhanced PADS technology yielded a useful result for missile site survey.

Useful errors

In the course of operating the PADS and Inertial Positioning System (IPS, a PADS derived device giving horizontal positions and elevations for geodetic survey), USAETL scientists encountered repeated errors in their results, caused by gravity anomalies. The interlab contacts cultivated at USAETL assured that these errors would come to the attention of the Center for Geodesy.

In 1974-1975, Dr. Armando Mancini, then Director of the Center for Geodesy at USAETL's Research Institute, conferred with scientists at Litton about PADS errors. Could PADS survey errors attributable to gravity influences be turned to advantage as sources of gravity field information and measurement? If so, a quick PADS-type survey could be used for gravity survey too; for, with the proper geodetic parameters, tinkering with PADS software and components might provide a working Rapid Geodetic Survey System (RGSS).

Field work from 1978 to 1981 at White Sands Missile Range, N.M., and Gaithersburg, Md., provided the answer. The initial RGSS work was performed by modifying DMA's IPS. The original PADS Advanced Development prototype would be reconfigured and upgraded to become USAETL's own RGSS. With an improved accelerometer (for vertical gravity data) and IPS software upgrading (for the horizontal channel) RGSS could do the job. Traveling a much shorter time (1.5 minutes) than PADS (10 minutes) between zero velocity updates (ZUPTS), the Kalman filter on the RGSS allowed the computer to interpret the accelerometer error when stopped dead.

The resulting RGSS, rounding into final form in 1984, produced 60-centimeter accuracy in position and elevation (versus 5 meters with PADS) as well as deflection of the vertical with 0.25-0.3 arc-second errors. Determinations of equal accuracy by conventional methods would require three nights of star observation with a three-man team. Thus, in addition to not being weather-dependent, the RGSS was 30 to 40 times faster than manual methods.

Following the contract award to Litton in 1983, RGSS work was proceeding quickly at USAETL under Edward Roof. RGSS uses in guidance survey were many, and airborne survey and civil works applications were certain to follow. PADS-type survey, in RGSS too, widened its applications, as new techniques were tested, and hardware/software improvement continued at USAETL.

Footnotes

1. Capt. R.K. Burkard, *Geodesy for the Layman*, (St. Louis: Aeronautical Chart Information Center, 1968), p.1.
2. Ibid.
3. Interview, authors with Dr. Hans Baussus von Luetzow, Fort Belvoir, Va., 26 September 1986.
4. Interview, authors with Edward Roof, Fort Belvoir, Va., 14 March 1985.
5. Ibid.
6. Ibid.

E. GPS: A Global Positioning System

Much of USAETL's work, both theoretical and applied, has spin-off value for non-military uses. To that end, USAETL scientists and engineers appeared regularly at symposia and meetings to inform the public of work in progress during the years 1979-1983. As head of USAETL's civil works efforts, Kenneth Robertson was particularly active in demonstrating the wider applications of USAETL's work on dam monitoring and general survey. One of his favorite topics was the Global Positioning System (GPS), an example of USAETL technology transfer that would turn the Department of Defense's NAVSTAR Global Positioning System to non-military use.

Measuring from TRANSIT

Starting in 1958, the Navy developed its TRANSIT Satellite System for military use as a marine navigation aid. In the late 1960s, however, equipment was developed to use the system for surveying. On the navigation side, satellite position fixes were typically taken from a moving vessel in which each position fix was used independently to update the dead-reckoned position for navigation purposes. For survey use, the position of a fixed point was sought from multiple satellite passes at a single location. In such a case, appropriate data processing techniques had made it possible to get good survey results without conventional land traverse. After 25 satellite passes, a horizontal position repeatability of less than five meters was the norm. Thus, the second mode provided not very fast position for navigation, but quick position for survey.

The Navy's TRANSIT system was designed for ship's navigation, but had a number of survey uses: seismic line control, gravity surveys, control for off-shore positioning, mapping control and utility line control. Such uses were, however, for surveys not requiring great accuracy. Corps surveyors usually needed better than forty-hundredths of a meter for their work and would have liked to cut the time from the full day of observations required for the measurement of a single point. When the time came to supplant or update TRANSIT, the surveyors hoped for greater accuracy in less time, allowing more application to survey. USAETL scientists knew that very precise frequency and time from a known point in space would be an "invaluable source of information."[1]

The NAVSTAR Global Positioning System

The development of a new Global Positioning System had begun in the late 1960s when the Air Force's 621-B (the "eggbeater") and the Navy's "Timation" systems competed. The military wanted accurate position in near-real time. The system, as it evolved, was to do that and more, offering increased services to civil works users and surveyors. The system was, however, conceived as a tool for military sea, land and air navigation.

The NAVSTAR plan called for 18 satellites, with three allocated to each of six orbital planes. Completing an orbit at 20,000 kilometers each 12 hours, the satellites would enable the user to receive signals from at least four satellites at the same time (except at the extreme polar regions). "All 18 birds" were to be up by 1988, allowing the navigator to know his position at all times.[2]

Many modes of use

GPS was to be used in several modes, though some were to be encoded and not available to the civil surveyor. Direct access to the pseudorandom code in the high-accuracy (10 meter) navigation mode was to be restricted. In that mode, a cesium clock (within the satellite) controlled transmissions, allowing the user equipment to measure the time of the arrival of pulses by adjusting its internal code generator to phase match the code. Then, by knowing the arrival time of the signals from four satellites, position could be known in three dimensions plus an accurate time value.

USAETL and civil works modes

DOD planned to make a lower accuracy mode available to civil users. To USAETL personnel interested in civil works spin-offs, however, the mode of most interest was the differential mode, with a host of applications to civil works. The Corps of Engineers had a great number of projects to which survey control was critical. USAETL, as the Corps' expert survey element, had "long known what could be done" to make such a satellite system work to simplify and speed the Corps' many civil works tasks.[3]

Using a combination of commercially available GPS receivers and the GPS satellites, position determinations of high accuracy could be made in 30 minutes to two hours. Two or more GPS receivers would simultaneously receive signals from the same set of satellites, after which the observations would be processed to obtain the interstation difference in position. If one position were known, the three-dimensional position of the second receiver could be determined. The number of stations fixed simultaneously was limited only by the number of receivers.

Results of this method looked to be not only faster but more accurate. Accuracy projections ranged from between a "few millimeters for baselines of a few kilometers, to a few decimeters for baselines up to perhaps 5,000 kilometers.[4]

Civil works uses

The Corps of Engineers, faced with a shrinking number of in-house survey personnel and the need to contract out a greater proportion of its survey and mapping product needs, required help in a number of areas. Kenneth Robertson saw a number of civil works uses for the satellite system.

- Quality Control: The Corps' surveyor would be able to quickly check a contractor's conventional survey.
- Elevations Along the Mississippi: The Corps would be able to measure changes in elevation with full precision in a general area that may be sinking.
- Elevation Reference for Tidal Gauges: Elevation along coastlines and at offshore islands could be checked—as well as areas where conventional survey was difficult.
- Control in Remote Areas: GPS would bring first or second order control to remote areas without the usual ground traverse or triangulation net.
- Dam Monitoring: Relative, two-dimensional movements could be detected at a level of less than five millimeters.

Robertson's assessment was borne out by the excellent results achieved by Corps districts using the partially completed system under a lease arrangement.[5] Robertson asserted with confidence that the GPS would prove "an increasingly valuable tool" in the Corps civil works future.[6]

No more triangulation or traverse

By testing their interferometric or differential receivers, USAETL scientists planned to show that survey could significantly reduce its need for costly triangulation networks or running long traverses. With the full satellite configuration, the cost of geodetic control would come down.

Viewed in connection with RGSS, the GPS may be seen as a major step toward what USAETL's Peter Cervarich called the "geodesist's dream," a machine that gives accurate position, gravity and deflection of the vertical.[7] Thus, USAETL looked to play a role in the continuing evolution of the technology; including triangulation, electronic distance measuring, traversing and trilateration, and satellite survey.

Increasing use

Dr. Frederick Rhode of USAETL's Research Institute and Kenneth Robertson of the Topographic Developments Laboratory were confident about GPS applications to survey and civil works respectively. Indeed, the still-incomplete system, useful just four hours per day, was already being used by the National Geodetic Survey, the U.S. Bureau of Reclamation, Florida's Department of Natural Resources, Texas' Department of Highways and Public Transportation, and the Canadian Department of Energy, Mines and Resources. Demonstrations were planned in the Corps' St. Louis and New Orleans Engineer Districts for March 1984. Kenneth Robertson predicted that ultimately all survey would be "satellite-centered."[8]

Footnotes

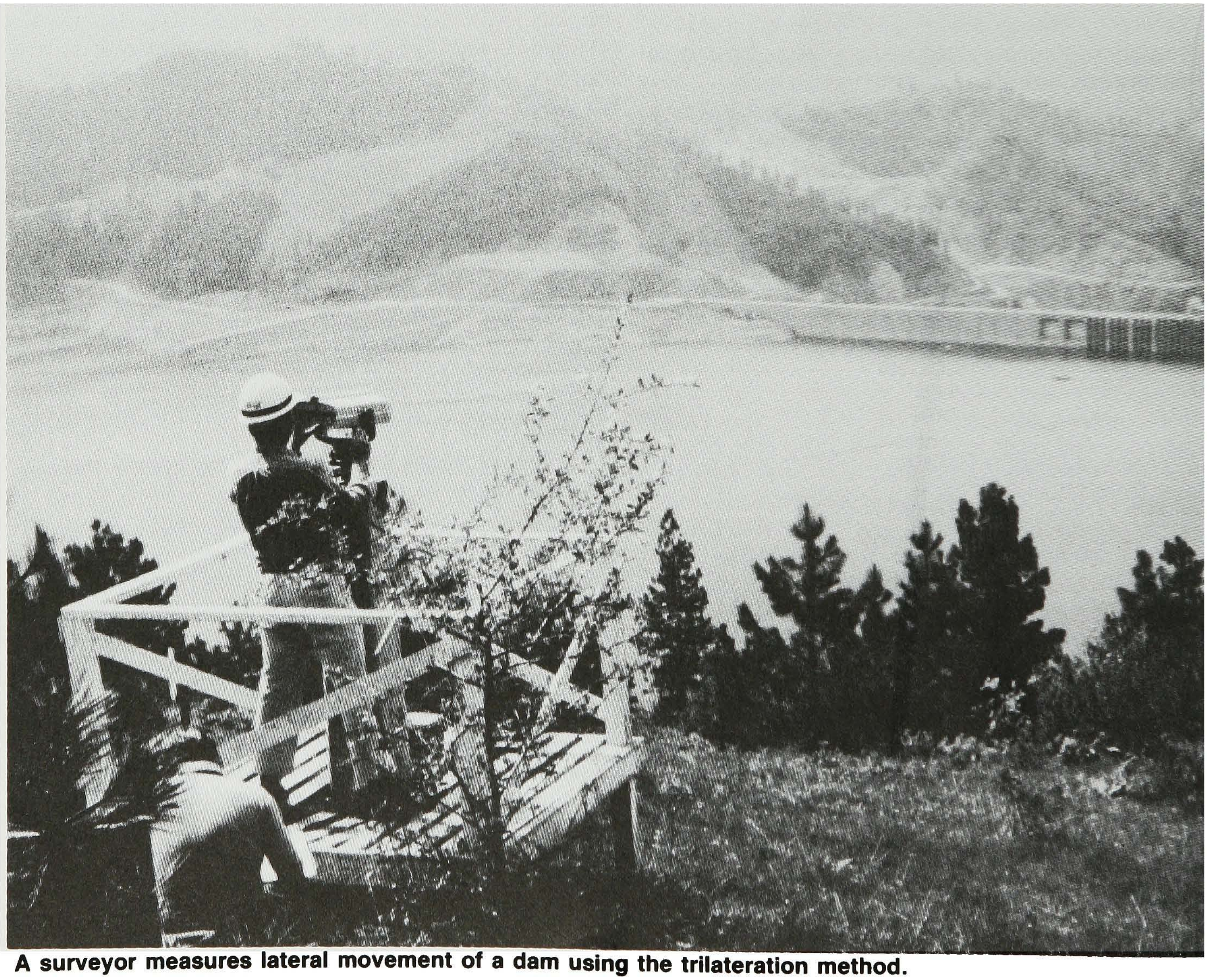
1. Interview, authors with Peter Cervarich, Fort Belvoir, Va., 5 March 1985.
2. Ibid.
3. Ibid.
4. Ibid.
5. Interview, authors with Kenneth Robertson, Fort Belvoir, Va., 3 October 1984.
6. Ibid.
7. Cervarich interview.
8. Robertson interview.

F. Survey: Civil Works Applications

Apart from its many efforts at technology transfer to the public, USAETL pursued an ongoing effort to transfer its evolving survey technology to Corps civil works. As John Armistead, head of the Topographic Development Laboratory's Surveying Division, pointed out, the Corps of Engineers had vast responsibilities throughout the country with only limited resources to oversee the quality control of civil works surveys.[1] Technological advances at USAETL helped the Corps meet these responsibilities during the years 1979-1983.

Technology borrowed from survey

The 1958 delivery of distance measuring equipment (DME) was employed by the Corps to aid in its many surveying tasks. Laboratory scientists knew that evolving DME survey techniques had wider applications to Corps civil works. Specifically, they knew that minute displacements of dams could be spotted quickly, and measured precisely by employing DME, calibration expertise and special techniques for reducing atmospheric uncertainties. A small program was initiated at the Surveying and Navigation Division to perfect and



A surveyor measures lateral movement of a dam using the trilateration method.

Using mirrors, a USAETL scientist measures the degree of tilt of a dam wall.

disseminate the new structural monitoring techniques. This effort, directed by Kenneth Robertson, drew upon USAETL studies of DME equipment done in the late 1960s and several years of field experiments resulting in techniques that reduced error.

Detecting displacement

USAETL studies had shown that the standard method of surveying, alignment by triangulation, was not precise enough to detect small movements in large structures—atmospheric conditions muddled such measurements. Accordingly, USAETL scientists devised a new method using standard distance measuring equipment and trilateration techniques.

Trilateration supplants triangulation

In the simplest case, with the trilateration method, surveyors measured the distance between two control points and a marker on a dam. Instead of calculating the angles of the triangle formed by the three points (i.e., triangulating), they determined the lengths of the sides of that figure. The ratio of these lengths was constant, unaffected by changes in temperature and air pressure. The old method, requiring 30-45 minutes of nighttime measurements (which minimized temperature fluctuations), could not guarantee accuracy. The new trilateration technique allowed daytime measurements accurate to within two to five millimeters. Surveyors could now measure lateral movement with speed and precision.

Detecting tilt

Corps surveyors wished to monitor all available indicators of structural instability, not just lateral movement. The degree to which a dam tilts or bends under load had traditionally been inferred from the use of plumb lines. Such lines were expensive, and had to be installed when the structure was built. USAETL developed instruments and techniques to do it better and cheaper.

USAETL's new tilt detection method, the brainchild of Kenneth Robertson, required mounting small mirrors on a structure. If the structure tilted, the mirrors moved with it. Surveyors used an automatic level fitted with an autocollimating eyepiece to detect small deflections of the mirrors and to measure the degree of tilt. The autocollimator projected a beam of light to the mirrors; the mirrors reflected the light back. The operator measured the difference in angle between the projected and reflected light. Aware that there had been no difference when they were initially mounted, the surveyor could make use of measurements of variations over time to track any change in the angular orientation of the mirrors and thus of the dam.

With this method, surveyors could measure tilt with an accuracy of two or three seconds of arc.[2] Whereas the plumb lines ran up to $50,000 each, the mirrors cost only $200 and the survey equipment roughly $4,000. In dam tilt, as in displacement, USAETL's research had led to a substantial savings. The technique itself was easily adapted to the monitoring of other large structures, such as lock walls during their fill and empty cycles.

Small but effective

Funded by the Corps' public works program, Robertson's civil works application of USAETL technology proved "a very small program but quite an effective one."[3] Every effort has been made to disseminate the new technologies. The tilt technique itself was developed in cooperation with the Corps' Wilmington District using Philpott Dam in Virginia as a test bed. Subsequently, the equipment was demonstrated in the Corps' Louisville and Mobile Districts and at a surveying symposium in Jacksonville in January 1982.[4] Earlier, on 18 September 1981, four officials from China's National Bureau of Surveying and Mapping visited USAETL and were briefed on the dam tilt technique by Kenneth Robertson. Such USAETL technology transfer efforts were successful, and 20 engineer districts were using the new method to monitor Corps structures by 1982.

Monitoring by satellite

Kenneth Robertson, Peter Cervarich and others were also busy during this period developing applications for the successor to the Navy's TRANSIT satellite navigation system. The new satellite navigation system, called the Global Positioning System (GPS), would have survey applications when used as an interferometer. A slightly different method, also using the interferometer technique, could monitor the movement of dams.[5] There were, accordingly, two levels of GPS thinking going on at USAETL—one dealing with survey, the other with the monitoring of dams and other large structures.

The GPS dams application, still in the thinking stage at the close of 1983, was envisioned as a number of antennae and a GPS receiver on the dam itself and a receiver on bedrock nearby. Using interferometer methods, accuracy comparable to USAETL's best displacement and tilt methods were thought possible.[6] Kenneth Robertson foresaw the day when receivers would be rented and tied to one another in some fashion. Indeed, he thought all surveying would be satellite-centered and dam monitoring just a part of it.[7] USAETL's Surveying and Navigation Division had played a major role in both improving the techniques of the past and providing the technology of the future.

Footnotes

1. Interview, authors with John Armistead, Fort Belvoir, Va., 2 October 1984.
2. "Structural Monitoring" (In-house document USAETL 4-07366), p. 2.
3. Interview, authors with Kenneth Robertson, Fort Belvoir, Va., 3 October 1984.
4. Interview, authors with Frederick Rohde, Fort Belvoir, Va., 17 September 1984.
5. Interview, authors with Peter Cervarich, Fort Belvoir, Va., 5 March 1985.
6. Ibid.
7. Robertson interview.

IV. Mapping-Related Research and Development

A. Overview: Stages of Mapping

The work of devising and developing new techniques for making maps (and the newer category of digital topographic products) at the Defense Mapping Agency (DMA) continued to command a large share of USAETL's resources during the period under consideration in this study. But it did so to a far lesser degree than it had in the 1960s and early 1970s. During the 1979-1983 period, mapping R&D at USAETL underwent a gradual but fundamental transition to a new technology—that of digital mapping—and developed a new institutional relationship with DMA.

This decline in the relative importance of mapping R&D at USAETL can be traced to two causes. First, as documented elsewhere in this history, the rising demand of the Army for equipment and weapons using digital topographic data and computer graphics caused USAETL's leadership to devote more of the laboratories' resources to satisfying Army customers. Second, USAETL's relationship with its principal customer for mapping R&D, DMA, underwent a major change. This change reflected DMA's determination to undertake more of its own R&D management as it pursued the creation of an all-digital topographic production process. The result was a reduction of the budget and manpower supporting mapping R&D at USAETL for DMA.

A time of transition

For the USAETL organizations engaged in mapping R&D, particularly the Mapping Developments Division (MDD) of the Topographic Developments Laboratory, the period between 1979 and 1983 was a time of transition in at least two ways. Not only was USAETL's role in mapping R&D redefined by the new relationship with DMA; but the focus of that research and development activity was also gradually redirected. USAETL's mapping engineers increasingly found themselves working on the promises and problems of digital mapping. This brought about a corresponding decline in projects supporting DMA's established production lines employing the relatively mature technology of optical, mechanical mapping equipment.

The change of emphasis in mapping R&D was perhaps most clearly symbolized by the reorganization of the Research Institute's Center for Coherent Optics into the new Center for Artificial Intelligence in 1980. The old center had developed, among other things, a research tool for analyzing the optical power spectrum of photographs. This research led to the development of the Optical Power Spectrum Analyzer, a machine capable of automatically scanning film and sorting out images which were too obscured (by clouds, haze or imperfect exposure) to be useful in mapping. The new center had the mission of applying techniques of computer decisionmaking to the automation of feature recognition, a major step toward the automation of the feature extraction phase of map production, as well as toward the creation of autonomous land vehicles.

USAETL's role redefined

DMA's decision in 1981 to develop an all-digital production process by the 1990s was followed by the creation of a DMA Special Projects Office to oversee the necessary research and eventual development. Prior to the creation of this new office, mapping R&D for DMA was performed on demand by the service technical organizations, like USAETL, that had previously supported the separate Army, Air Force and Navy mapping organizations which were merged into the Defense Mapping Agency in 1972. USAETL, for example, had primarily supported the Topographic Center at DMA. The Topographic Center, later the Hydrographic/Topographic Center (HTC), comprised elements which had formerly made up the Army Map Service.

The new DMA Special Projects Office became, in effect, a technical organization organic to the mapping agency, with management responsibilities for development and testing of digital map production equipment and procedures. The emergence of the new DMA technical organization and of new research and development priorities resulted in the cancellation of a number of ongoing USAETL projects for HTC, particularly those conducted by the MDD of the Topographic Developments Laboratory (TDL). Historically, MDD had been the main point of contact between USAETL and DMA on development work related to map production.

The emergence of the Special Projects Office did not completely sever USAETL's relationship with HTC. The realization of an all-digital production system was not expected to occur until the 1990s. DMA still needed R&D

to improve existing production lines, including those supported by equipment designed and developed under USAETL supervision in the previous 10 to 15 years. A number of USAETL projects during the 1979-1983 period were addressed to these needs. Nevertheless, the changed relationship had a dramatic impact on USAETL's work for DMA, which dropped by about a $1 million a year during the years after the formation of the new Special Projects Office. USAETL officials thought the eclipse of mapping R&D was likely to be only a temporary phase, and foresaw renewed DMA requirements for USAETL's help once its plans for the all-digital production system had progressed to the stage of actually developing new machines and computer programs.[1]

A by-product of success

Temporary or not, MDD's eclipse could be seen as an unexpected by-product of success. Some of the major accomplishments of USAETL during the 1960s and early 1970s were projects undertaken for the Army Map Service (AMS) which automated portions of the complex map-production process. Out of the relationship with AMS grew USAETL's pioneering work, in the 1960s, on the use of computers in map production. This work had two notable products: first, digitally driven automated plotting machines, for inscribing elevation contour lines and other graphic material on maps; and second, automated equipment for compiling elevations from stereoscopic photographic images. The UNAMACE automated compilation equipment developed by USAETL and its predecessor organization, GIMRADA, for AMS not only extracted elevation data automatically from stereo photos (with some limitations) but recorded the information in digital form so that it could be used by a computer to control an automated plotting machine.

Computers in mapping: promise and problems

Topographic data consists of longitude, latitude, elevation, azimuth and feature descriptions. Recording topographic data in digital form was first undertaken, as the plotter and UNAMACE examples show, as a step in automating aspects of the production of paper maps. The numerical data would be read by a computer to control equipment—the plotter—which in turn would draw graphic representations of terrain. But it soon became apparent that computers supplied with Digital Topographic Data could perform many other more useful tasks for the military. They could be used to create electronic simulations of targets to control radar-guided missiles, to provide swift computer-controlled aiming systems for artillery and to create computer graphic simulations of low-level flight. In 1983, a survey by USAETL of the demand for Digital Topographic Data for the Army found 75 systems which already used or planned to use this new tool. The major problem created by this burgeoning demand lay in the fact that even with the advances developed by USAETL and other mapping technologists in the 1960s and 1970s, the majority of the many steps of the map production process at DMA remained manual or mechanized, requiring high levels of skill. The production of a new map or a a digital topographic tape required months of mostly hand labor.

The production problem

During the 1970s, a need for mapping, charting and geodetic products for computer-based planning, training and weapons systems forced USAETL and DMA to "change from an analogue to a digital emphasis."[2] Moving to the 1980s, the digital mapmaking thrust continued to the point where half of DMA's efforts were "now directed to the production of digitized products."[3]

The demand for digital topographic products was expanding more rapidly than the supply. Digital products were increasingly needed for computer-based planning, training simulation and weapons support.[4] An old problem in a new form resurfaced in the "labor intensiveness of the present day digital-data-base production process."[5] However flexible and versatile the digital product was proving in use, it was even more time-consuming to produce than the old paper map. Furthermore, as one DMA researcher admitted, there was no quick fix on the horizon: "fully automated mapmaking using digital techniques is still in its infancy."[6]

USAETL's continuing role

For its part, USAETL had long been researching techniques to lighten the mapmaker's production chores. During the 1979-1983 period, the labs continued their efforts to streamline various aspects of mapmaking. Some of these were general, long-term and working toward full automation in an all-digital environment. Others were specific, short-term and working toward little improvements in the methods currently in use.

These efforts could be broadly grouped under headings more or less corresponding to stages of the map-production process, including the production of digital data bases. Consequently, the history of these efforts is organized under seven headings: Image Analysis, Other Compilation and Collection, Digital Topographic Data Processing, Cartography, Preparation for Press and Printing, and Distribution. Organizationally, most of the image analysis work was located in the Computer Sciences Laboratory, which concerned itself with digital photogrammetry and feature extraction. Most of the other work was the responsibility of the Mapping Developments Division and its two branches, Automated Compilation and Automated Cartography.

Footnotes

1. Interview, authors with Col. Edward K. Wintz, Fort Belvoir, Va., 15 March 1985.

2. Marshall B. Faintich, "Defense Mapping Undergoes a Digital Revolution," *Computer Graphics World*, June 1985, p. 10.

3. Ibid.

4. Ibid.

5. Ibid.

6. Ibid.

B. Image Analysis

Image analysis was a major focus of USAETL's mapping R&D efforts during the 1979-1983 period, with a particular focus on digital mapping requirements.

Image analysis is the identification and measurement of features found in a photograph or digital image. Its two major branches are feature extraction and photogrammetry. In feature extraction, skilled photo interpreters use clues from imagery, knowledge of the context of the image, and such research source material as gazetteers, old maps and geographies to identify natural and man-made features. These image-analysis skills are equally applicable in mapmaking, intelligence gathering, and target location and identification. Among some photo interpretation specialists, in fact, the term "targeting" is synonymous with feature extraction. Photogrammetry is the use of images as the basis for precise 3-D measurement.

A related field is terrain analysis, which addresses the detailed composition of terrain, including soil and vegetation type, space between tree trunks in a forest, slope, location of drinking water and construction material, and related facts. Terrain analysis provides military commanders with such information as the best cross-country routes, for example, or provides engineers with information on construction conditions. Much of the information required of terrain analysts could also be deduced from imagery with the aid of contextual knowledge. Admittedly, this definition does not incorporate the analysis of all remote sensing products, many of which might be useful in mapping, targeting and terrain analysis. During the period covered by this history, however, the science of non-imaged remote sensing had developed few practical applications for mapping.

Digital image analysis

Mapping often began with an aerial photograph on film. Information that went on a standard map sheet, such as terrain features, drainage patterns, roads, railroads and buildings, was extracted from the aerial photograph by trained analysts. Elevations were extracted from stereoscopic views formed by pairs of photographs. According to Lawrence Gambino, director of the Computer Sciences Laboratory since 1971, USAETL set up its computer research facility in 1969 to begin exploring how to perform all these image-analysis functions in a purely digital way on a computer.[1]

Initially, USAETL's digital image analysis research focused on digitized imagery made from photographs converted to digital form so that they could be manipulated on computers. Beginning in the mid-1970s, digital imagery began to be available from the Landsat Multispectral Scanner, and the Defense Mapping Agency (DMA) began to anticipate collecting mapping imagery in digital form from future satellite systems.

The digital imagery was recorded from the satellite by scanners sensitive to specified parts of the electromagnetic spectrum, including both visible and invisible wavelengths, then converted into a digital signal for transmission to Earth. Conversion of collection systems from cameras using film to digital image production was one of several factors which persuaded DMA to focus its development efforts in the 1980s on the creation of an all-digital production system.

1. Development of the Digital Imagery Analysis Laboratory

The principal tool used at USAETL for digital image analysis was a custom-made computer digital image manipulation system known as the Digital Image Analysis Laboratory (DIAL) together with software routines developed by engineers at the Computer Sciences Laboratory. Development of the original DIAL system began in 1975 and the system became operational in 1976.[2]

DIAL's components

In 1979, DIAL consisted of four interconnected hardware subsystems. These were: a Control Data Corporation 6400 mainframe computer with a 60-bit processor capable of performing several million instructions per second which acted as the overall system controller together with input-output devices such as tape decks and disk drives; the STARAN associative array processor, an experimental "supercomputer" used for specialized data processing problems associated with the very large data bases characteristic of large-scale digital images; a low-speed work station consisting of a PDP 11/50 minicomputer controlling two pairs of 512 by 512 picture element (pixel) COMTAL 8300 image displays (cathode ray tube (CRT) video monitors) and two terminals; and a high-speed work station consisting of a PDP 11/70 16-bit "supermini computer" controlling two high-density computer tape units and a COMTAL S-200 display system, consisting of two 512 by 512 color pixel CRTs and one 1024 by 1024 black-and-white monitor supported by a 4-megabyte data base memory.[3]

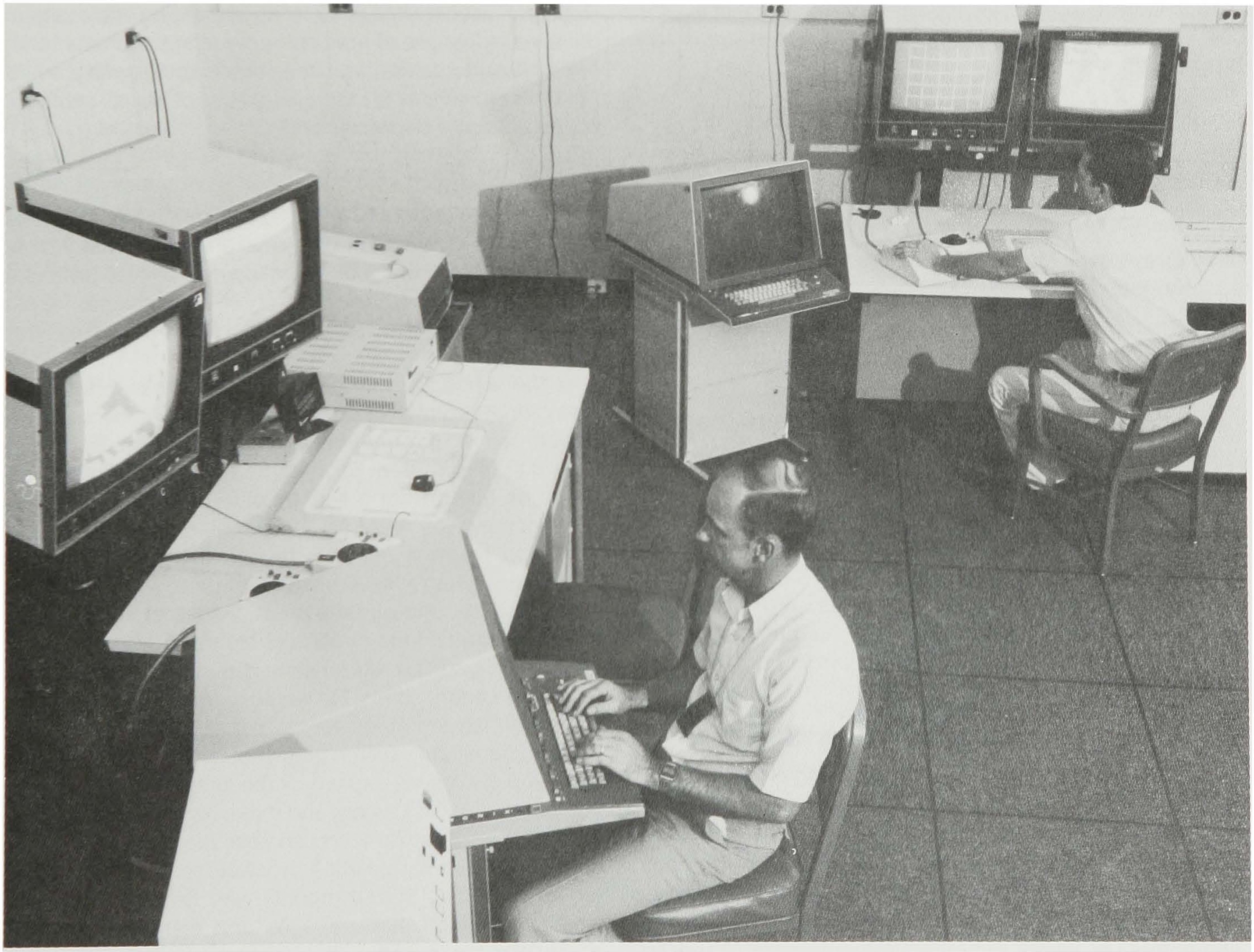
An image digitizing system supported the DIAL with a high-resolution scanner known as a microdensitometer, a recorder and magnetic tape units.

DIAL expanded

In 1982, the DIAL system was expanded to include what was described at the time as probably "the single largest digital image processing system built and delivered by a manufacturer."[4] COMTAL Corporation developed the system on contract with USAETL. It consisted of two work stations, each having two 512 by 512 pixel displays and one 1024 by 1024 display, each linked to a 4.2-Megabyte data base memory. The system had eight times the memory capacity and four times the speed of conventional 512 by 512 systems for image processing and used special hardware for geometric manipulation of images, including scaling between 0.2X and 3X, warping the coordinates of one image to match those of another, x-y axis translation and two-dimensional rotation of images. Other special hardware performed such functions as the addition of pseudocolor (color not captured in the original image), roaming within a data base, and a special close-up feature known as pixel replication zoom. The new system was linked at USAETL with a PDP 11/70 supermini and two Ampex parallel-transfer (high-speed) disks. This portion of the DIAL system was to become an entity in itself and served as an ungraded version of a fielded system called DEMONS (Demonstration System), which was developed and fielded by USAETL under the sponsorship of the Army Space Program Office (ASPO). The experience gained with this capability was later used to upgrade DEMONS.

In 1983, the DIAL mainframe computer was updated by the Control Data Corporation from a CDC 6400 to a CYBER 170/730. Plans were laid to add to the DIAL with an additional large-scale image processing system duplicating the experimental facilities at DMA known as the Remote Work Processing Facilities (RWPF). To that end, USAETL in 1983 acquired a VAX 11/785 32-bit supermini computer as its RWPF-clone control unit.[5]

The continual evolution of the multimillion-dollar DIAL, involving "bells and whistles you wouldn't believe" in the



USAETL scientists operate Digital Image Analysis Laboratory (DIAL) work stations.

words of one USAETL manager, provided a flexible, general-purpose tool for advancing the state of the art in image analysis and digital mapping and for special-purpose investigations of interest to a wide variety of customers.[6]

DIAL capabilities

DIAL could work with digitized imagery—photographs or maps transformed to digital signals on the microdensitometer or other production shop scanners—or digital images collected by various aerial or satellite-borne scanning systems. The imagery could be produced by radars or processed radar data as well as by electro-optical systems operating in the visible and infrared spectra. DIAL's image analysis capabilities included:

- Scrolling—a search technique that allows an interpreter to view an entire scene on the left screen of a pair of monitors while viewing portions of the scene at full resolution on the right screen.
- Magnification—allowing portions of an image to be seen in fine detail.
- Rapid Access—allowing an operator to call up any stored image in a matter of seconds.
- Colored Terrain Elevation—showing what color codes are assigned to different elevations, and in color contour mapping, which contour lines are color-coded.
- Transfer Functions—allowing an operator to alter an image on one screen of a pair of displays and display the altered image on the other screen.
- Gray-Level Mapping—allowing an operator to alter brightness and contrast.
- Photographic Negatives—permitting the transformation of a positive digital image into a negative digital image.
- Mosaicking—piecing together many small images to create a single, large one.
- Change Detection—allowing an operator to rapidly flicker two similar images on a screen in order to detect any changes in the scene.
- Warping—geometrically altering or warping a digital image for analytical purposes. For instance, geometrically distorted radar imagery could be compared to geometrically correct photographic imagery by means of warping[7].

Some unusual uses for DIAL

The DIAL was used during the 1979-1983 period to assist in criminal investigations and medical research as well as for laboratory experiments and developmental work on software for digital photogrammetry, feature extraction, cartographic displays and imagery analysis for intelligence applications. The Drug Enforcement Administration of the Department of Justice requested help on a case of possible possession and transfer of drugs; the FBI sought assistance in fingerprint analysis and handwriting restoration. Both agencies were interested in the DIAL's capability for image restoration in which poor-quality photographs can be deblurred using digital image manipulation techniques.

The special congressional committee investigating the assassination of President John F. Kennedy and others made use of DIAL in 1979 to investigate films and photographs taken in Dallas, including the Zapruder film of the assassination, photographs of the Dallas school book depository building and of Lee Harvey Oswald holding a rifle in his backyard. The committee had assigned the Los Alamos Scientific Laboratory, the Aerospace Corporation and the University of Southern California to investigate these images. These organizations, in turn, sent the processed material, contained on 50 magnetic tapes, to USAETL for image display. Other non-military applications of DIAL have included analysis of digitized x-rays of metallic welds to locate and quantify weld defects and analysis of cloud images for weather research. The Department of Microwave Research at the Walter Reed Army Institute of Research sought DIAL assistance in creating and analyzing microwave images of medical research specimens, and a self-motiviated person from the private sector was provided DIAL time to investigate the alleged use of illegal, subliminal advertisements on television.[8]

2. Digital Photogrammetry

From the outset, DIAL was used to create digital routines for making precise real-world measurements from images. The first requirement in digital mapping was that computers should be able to perform three-dimensional spatial measurements required in topographic mapping from imagery.

In the analogue mapping process, these photogrammetric operations were performed on a precisely sized and scaled pair of photographs of a portion of the Earth. The essential requirement for mapping was that each photograph be taken from a slightly different point. The slight displacement of features, or parallax, created by this operation made it possible to see the subject in three dimensions using a stereoscopic viewer. In a largely manual procedure, a photogrammetrist would choose several corresponding points in each photograph which could be precisely located by reference-to-ground surveys and were known as control points. He would then line up these points using an instrument known as a stereoplotter to create a three-dimensional illusion of the scene, correct the view to eliminate distortions caused by the attitude of the mapping camera (tilt, tip and swing) and make painstaking measurements of distances (to establish absolute scale). This whole group of stereo-compilation procedures, known as orientation, produced stereo models with ground truths from which elevations, feature sizes and distances could be accurately measured.

First steps toward automation

During the 1950s and 1960s, USAETL and other laboratories developed computer programs to solve the complex and rigorous triangulation problems needed to substitute analytical (mathematical) methods of orientation for the manual, analogue methods using stereoplotters. The mapping R&D community also developed computer-controlled equipment to perform various photogrammetric tasks, including the creation of precisely scaled, distortion-free rectified photographs and the extraction of elevations by analytical methods. These machines, such as the UNAMACE, represented the state of the art in photogrammetric operations at DMA in the late 1970s and early 1980s. They were not, however, digital mapping systems as the term came to be understood. UNAMACE, for example, used an optical flying spot scanner to extract horizontal (x and y) coordinates from pairs of photographs and a computer to calculate elevations from this data. It was called a hybrid system employing both analogue and digital technologies. It was also a costly single-function machine, with no on-line editing capability.

UNAMACE errors were of two kinds. Electronic noise recorded along with digital elevation data created false elevations. Also, UNAMACE could get "lost." If this condition was not detected by the operator, the result would be a tape omitting or misdescribing significant terrain features. For example, a "lost" UNAMACE digital elevation data tape might show a plateau in place of high mountains.

One of the hopes for digital mapping was that an operator at a single computer work station might perform the work of a number of manual mapping specialists and single-function machines like UNAMACE, editing his work as he went along.

Digital stereo compilation

Among the earliest experiments performed on the DIAL when it became operational in 1976 were efforts to develop procedures for interactive stereo compilation on a computer-graphics system.[9] Rather than creating a visible stereo model, the computer was used to extract three-dimensional measurements from a pair of overlapping digital images using a statistical correlation technique. An operator at a two-display DIAL work station would call up an image on one screen and select a number of points on the image. Placing a cursor on each, he would ask the computer to find the matching point in the corresponding image (stereo-mate) on the other screen. The computer would extract a small patch of pixels from one image and find a statistical match on the other image. The horizontal coordinates of each point would be recorded, making it possible to orient the two images relative to each other. By entering the known horizontal coordinates and elevation of certain other points on the images (control points), the operator could direct the computer to calculate the absolute scale and location of the imagery. By extracting a very large number of pass points, the operator could create a data base of matching x and y coordinates from which the computer could calculate elevations by measuring the displacement caused by parallax.

The Digital Image Matching Program

Early experiments at USAETL examined different measures of correlation and different patch sizes and shapes for digital stereo compilation. Interactive editing was performed by displaying the digital images on a pair of CRTs so that an operator could verify the computer had, for example, selected the correct match points. Computer-generated elevation points could be superimposed in red and blue on the images and viewed through a pair of anaglyphic goggles (having one blue and one red lens) to verify their correctness in stereo vision. Two Computer Sciences Laboratory engineers, F. Raye Norvelle and Michael Crombie, both of the Information Sciences Division, wrote computer programs for the DIAL to evaluate the application of various correlation methods to stereo compilation. From these, Norvelle developed the Digital Image Matching Program (DIMP) software for extracting large numbers of matching points for later use in digital elevation modeling and editing; and Crombie (later assisted by James Miller) developed digital pass point mensuration software. In 1982, both programs were delivered to DMA and were used for further experimental computer mapping work on the Remote Work Processing Facility.

3. Synthetic Photographs

According to an article in the Spring 1980 *Tech-Tran*, a quarterly review of work at USAETL, "a large number of interesting products become possible when digital ground truth and corresponding registered elevation matrices are available." In addition to editing elevations, an analyst can extract the elevation for any point by placing a cursor on it and requesting the computer to supply the data. Also, he can select two points on the image shown on his screen and ask for an elevation profile between them, information which is useful for computing lines of sight and for calculating the difficulty of cross-country movement.[10]

"When applied to civil engineering," the *Tech-Tran* article continued, "the use of elevation data on an interactive system can, within seconds, solve cut-and-fill problems for road, railroad and airfield construction, and for reservoir planning projects. An image analyst can pinpoint any irregular area on the ground-truth image and the computer can quickly calculate the quantity of earth that must be filled in or removed."

A program developed on the DIAL by F. Raye Norvelle, in 1983, reorganizes the information in an overhead image so that it appears on the computer screen as if seen from any selected oblique angle. This perspective scene-

A DIAL oblique graphic.

generation software uses DIMP and pass-point measurement techniques to develop horizontal and vertical (x,y,z) coordinates for every pixel in a digitized stereo pair of photographs, then reconstructs the image as it would appear to a camera on the ground or to a helicopter pilot in low-level flight. The computer, in effect, creates a synthetic photograph of the image from the desired perspective. This photograph can then be used to train low-level pilots or ground troops for operations in unfamiliar terrain. It differs from perspective scene generation in that it fills in all visible detail, including bushes and trees, rather than providing only a fishnet perspective drawing of terrain forms.[11]

4. Digital Feature Extraction

As Lawrence Gambino, director of the Computer Sciences Laboratory, explained in an interview, computer graphics techniques offered several advantages for photo interpreters and feature analysts over working with photographs. One example mentioned by Gambino was the greater ease of a digital system for comparing old and new images of an area, where the new imagery might be distorted in some fashion. With photographs, the new imagery would have to be rectified and scaled to match the old map or image before a comparison could be made. With a computer graphics system, the computer could instantly rectify the new imagery and overlay it on the old. That capability was demonstrated for the first time at USAETL in 1972, Gambino reported. Another early success at the Computer Sciences Laboratory (CSL) was showing how a computer could alter the gray scale of a photograph at a photo interpreter's command in order to make it easier to identify objects in shadows, for example. With that procedure, Gambino said, imagery analysts could save two weeks or more of photo lab work to get just the results he sought.[12]

But the main focus of CSL work on digital feature extraction during the 1979-1983 period concerned using computers to do much of the feature extraction work, either automatically or interacting with an operator.[13]

The feature extraction bottleneck

In mapping from photographs, analysts extract from the imagery the features relevant to a map, such as forests, fields, built-up areas, roads, railroads, streams and other linear features, and—depending on scale—buildings, airfields, etc. The analysts first classify the features, then identify them and locate them on a manuscript. In a manual process, the manuscript was usually a clear plastic (mylar) overlay devoted to one type of feature, such as streams or roads. If the features were destined for the Digital Land Mass System (DLMS) digital data base, they were classified by their radar characteristics before being digitized as Digital Feature Analysis Data (DFAD). Feature extraction was a time-consuming and tedious process; indeed, it was a principle bottleneck in the production of DLMS data at DMA in the production of terrain analyses for the Army and in intelligence evaluation of photographs.

Feature extraction automation experiments

One of the major attractions of digital mapping was the possibility that a computer could be assigned much of this work. If it could be taught to recognize edges and other linear features, and to classify the images correctly, then it could identify the features from a geographic data base. With appropriate instructions, the computer could then extract the desired features and build a topographic data base, thereby automating the feature extraction process.

A series of experiments on the DIAL during the 1979-1983 period cast cold water on this possibility. Together with other work in the mapping community, these experiments solidified the growing conviction among mapping specialists that digital feature extraction required the constant attention of an operator who could guide the process and correct computer feature classification errors.

The role of this man in the loop might be amplified by providing him with a computerized expert system of diagnostic rules of thumb, perhaps using the emerging technology of artificial intelligence. But most computer experts at USAETL believed that a fully automatic feature extraction system was not even on the horizon in the mid-1980s.[14]

Many different approaches

Automatic digital feature extraction work involved a large number of different approaches to statistical pattern recognition. The objective was to convert digital image features such as points, edges, blobs, spectral data and texture into recognizable real-world features. This was done by matching and linking together related digital image features. The results were compared with other relevant data sets, such as parallax and a priori data given the computer on feature characteristics for roads, forests, fields, and other natural and man-made features to complete the classification. After more than three years of study, including a review of all available algorithms for pattern recognition, a team headed by Michael Crombie of the Information Sciences Division came to the conclusion that the purely mathematical approach to automatic feature extraction failed to produce reliable results. The work, in Crombie's words, clearly showed that "a purely algorithmic approach is inadequate." Dr. Robert D. Leighty, director of USAETL's Research Institute, agreed in a 1983 paper called, "Trends in Automated Analysis of Aerial Imagery." Statistical pattern recognition algorithms "when applied to real-world imagery, are still not sufficiently robust to justify development of automated equipment," Leighty said. "Image analysis is a very complex problem without simple solutions." A summary of the feature extraction work prepared for the USAETL historical files in 1983 concluded that "at this time there is little or no real understanding of the relation between image detail and natural and cultural detail at the gray-shade level."[15]

Future applications

While discouraging as a sole solution to automated feature extraction, the results of Crombie's feature-extraction experiments did provide a menu of pattern-recognition techniques which could be used to group and classify digital features. For example, a method for semi-automated extraction of terrain information on forested areas was delivered to DMA and adapted by USAETL engineers for applications on the Remote Work Processing Facility, a DMA computer graphics laboratory analogous to DIAL.

Crombie's team recommended that USAETL explore how these pattern-recognition techniques could best be linked together with other knowledge to facilitate interactive feature extraction. For example, statistical pattern recognition might be used to screen out ocean imagery and imagery with large cloud cover, and to make a "first cut" analysis of features. The results could then be processed under operator control through a deductive reasoning process built into the computer. Such processes, known as expert systems, codified deductive rules of thumb used by diagnostic experts in a particular field such as photo interpretation. Computer coding of such reasoning rules might require artificial intelligence programming. Given the involvement of scientists and engineers from many USAETL components in feature extraction research, the most probable future research strategy appeared likely to be an effort to establish one or two agency-wide teams to demonstrate what could be done by combining algorithms and expert knowledge in a single interactive system, perhaps using the artificial intelligence methods and photo interpreter's logic system already being explored by the Research Institute.

To specialists in the more traditional disciplines of analogue mapping using stereo pairs of photographs, the engineers in the Computer Sciences Laboratory at USAETL were sometimes known as the "pixel eaters." The amount of detail in a digital image depends on the relationship between a single picture element or pixel on a CRT and the amount of ground truth it represents. As the amount of ground represented by a single pixel increased, the ability to make fine distinctions decreased. Road outlines, for instance, become blurred and closely adjacent features merge into a single gray shade. To obtain fine detail in mapping, each pixel might have to represent as little as 10 microns of a 9 by 9 inch aerial photograph, meaning that a single digitized image of this photograph might contain more than 500 million pixels, requiring a minimum of more than four billion bits of computer data.

Compounding Confucious

Since the average English word, when digitized, requires 48 bits of computer data, the computer memory required to record this photograph could hold nearly 90 million words. That is, by comparison, about one and a half times the word length of the 28-volume 15th edition of the Encyclopaedia Britannica. Confucius, who said a picture was worth a mere thousand words, was truly conservative in his estimate.

In digital mapping, the encyclopedic rapidly became the astronomical. A stereo pair of digital images might contain over eight billion pixels. But a stereo pair represented only a fraction of the imagery required to map a single geographic area, and a single topographic map represented a small fraction of the areas of the Earth which DMA was required to map. Moreover, the topographic map represented only a part of the variety of information on any area which might be of interest to military users. Additional information on terrain features might be needed which DMA, in turn, was required to prepare and store. It was estimated by some engineers that a digital data base covering all DMA mapping, charting, and terrain-analysis operations and requirements could require a hundred million trillion bits of computer storage.[16]

However fanciful this huge estimate may have seemed, the amount of digital imagery and other data required to make even one map was large enough to pose major data management problems. During the period covered by this history, USAETL addressed this data management problem in a variety of ways.

5. High-Speed Computing

In 1976, USAETL acquired the STARAN associative array processor with DMA funds from the Goodyear Aerospace Corporation. STARAN was, in effect, an early supercomputer, capable of solving some problems as much as 60 times faster than the DIAL's mainframe computer. While the mainframe had a 60-bit serial processor, meaning that it could consider words of up to 60 bits in length one at a time, the STARAN processor could consider words of up to 1,024 bits. This was achieved by creating a processor consisting of 1,024 one-bit microchips arrayed in parallel. This array allowed STARAN to process a typical digital raster image much faster than the mainframe or any other standard serial computer. Digital images were collected in raster format, meaning an array of picture elements arranged row by row and column by column in a two-dimensional field. Visually, a raster image could be compared to a pointillist painting or to a half-tone photographic image in a newspaper. Any digital operation which addressed a raster image pixel by pixel—for classification, to change gray tones or to eliminate electronic noise—could be processed much faster on the STARAN than on a serial computer. For example, it was estimated that the computer time require to process an entire Landsat scene could be reduced from six hours and 26 minutes to 10 minutes by using STARAN.[17]

STARAN had another characteristic potentially useful in managing very large data bases: an associative memory. Lawrence Gambino explained this feature as follows. Suppose you had to find out if there was a computer scientist in a crowded theater. If you proceeded like an ordinary serial computer, you would have to ask each person in order, row by row, "Are you a computer scientist?" But STARAN would only need to say, "If there is a computer scientist in the house, please stand up." The associative memory feature would direct the computer to the place in the theater (i.e., computer memory) where the computer scientist was "stored," without having to check all the other information stored in the memory.[18]

DIAL experts performed a number of mapping experiments using STARAN. With assistance from Goodyear engineers, they wrote software for raster processing, raster-to-vector and vector-to-raster conversion (vectors were analogous to line drawings), converting contour elevation data to gridded elevation data (for drawing perspective maps), and for identifying, symbolizing and tagging map features such as roads and streams. In the process, the engineers used the software for automated cartography.[19]

But STARAN had serious limitations as a research tool and was clearly unsuited for production work. One drawback was the lack of a high-speed communications link with other computers. Without this capability, the effectiveness of various applications was not much better than performing them on the mainframe.

Another serious drawback was the lack of a high-order language capability for programming the STARAN. Unlike the other DIAL computers, STARAN lacked an internal system for translating programming languages such as FORTRAN into instructions which could be read by the machine. All programs for the equipment had to be written in the most basic computer code known as machine code, a procedure which was slow and error-prone. By 1983, USAETL had completed its STARAN experiments and was laying plans to dispose of the equipment. In the meantime, Goodyear proceeded with follow-on systems such as the Massively Parallel Processor (MPP) which was delivered to NASA for Landsat processing, and the Advanced Signal Processor (ASPRO), a one-cubic-foot derivative of STARAN, for the Air Force and Navy. ASPRO was also being investigated for its applicability in artificial intelligence for rapid processing of rules and rule-based systems. Thus, STARAN-type architecture continued to play a role in various government programs.

6. Data Structure Investigations

The way that spatial information is stored and processed in a computer affects both the speed of operation and the usefulness of the data to a mapping specialist. Beginning in 1978, Carl S. Huzzen, of the Computer Sciences Laboratory's Information Sciences Division, oversaw a series of "data structure investigations" designed to review the variety of approaches developed in industry and at universities for formatting and processing spatial data. As Huzzen described these investigations, the principal concern was with storing and processing multiple terrain analysis overlays. An analyst should be able to display selected features delineated by irregular outlines or polygons from a data base containing multiple overlays of such descriptions, and compute the area, perimeter length and proximity of such features.

Huzzen's studies covered variants on two basic approaches, raster data structures and vector data structures. Each had strengths and weaknesses. Raster data—the row-by-row, column-by-column arrangement of pixels described earlier—could show perimeters only as a series of unconnected dots in which diagonals had a jagged appearance. Vectors, or lines connecting two points, smoothed out the jagged edges and took less data to describe. But rasters could be processed faster than vectors because they could be handled in parallel (as with the STARAN), whereas vector data required serial processing.

The studies covered not only conventional raster and vector data structures, but also vector studies involving hexagonal structures and raster studies involving hierarchical, branching data structures using extremely small and variable size rasters. The latter were described in a USAETL report, "Application of Hierarchical Data Structures to Geographic Data Systems."[20]

7. Display Technology

A major constraint on the use of digital data bases for mapping and terrain analysis was the inability of the analyst to see more than a small fraction of the relevant data at a given time on a CRT.

The dimensions of each CRT defined how many separate picture elements or pixels that monitor could display at one time. A 512 by 512 monitor—the industry standard at the time DIAL was first assembled—could display a field measuring 512 pixels by 512 pixels, or a total of 262,144 pixels, containing a minimum of 2.1 million bits of computer data. But this represented only five ten-thousandths of the data contained in one mapping photograph digitized with a 10-micron spot size. The 1024 by 1024 pixel high-resolution monitors added to DIAL subsequently could display four times as much data at a time. But that still limited the analyst to detailed viewing of only a tiny portion of an image at any one time, making it hard to keep track of the overall picture.

On the other hand, if he "zoomed out" to capture a view of the general area on which he was working, the view rapidly became blurred on the relatively small computer screen. Thus, the computer mapping specialist was faced with a difficult trade-off between recognizing large-scale topographic features and examining detail. Among the various investigations of display technology conducted at USAETL during the 1979-1983 period, one in particular explored ways to use large-screen displays to aid in the digital mapping process. This effort, begun by the Mapping Developments Division in 1983, involved the study of the large-format, high-resolution, multicolor display properties of large, flat screens using stretched polyvinyldyne flouride film, a substance with unique piezoelectric properties.[21]

Other feature extraction developments

In addition to the projects described above, USAETL scientists and engineers carried out several other projects to improve feature extraction capabilities for mapping and terrain analysis. The Research Institute conducted experiments in the Computer-Assisted Photo Interpretation Research program using an analytical (computer-assisted) stereoplotter, and planned to develop a soft-copy (all digital) research tool for the same purpose. Other Research Institute projects affecting feature extraction included radar studies, photo interpreter logic and artificial intelligence. The Geographic Sciences Laboratory also conducted studies in automated terrain analysis as part of the Digital Topographic Support System development. And the Pershing II project developed a method for extracting radar reference scenes from DMA digital topographic data to guide the Pershing II missile. Two other projects dealing with improvements in the existing, nondigital production system at DMA, the Extended Area Exit Pupil work station and the stereo orthophoto experiments, are described in the next section.

Footnotes

1. Interview, authors with Lawrence A. Gambino, Fort Belvoir, Va., 10 October 1984.

2. Ibid.

3. *Tech-Tran*, Vol. 5, No. 2 (Spring 1980), p. 2; interview, authors with James Stilwell, Fort Belvoir, Va., 28 May 1985.

4. COMTAL Corporation Press Release, 15 December 1982, Altadena, Calif.

5. Stilwell interview.

6. Gambino interview.

7. "Digital Image Processing at the ETL Computer Sciences Laboratory," USAETL Fact Sheet (undated).

8. *Tech-Tran*, Vol. 5, No. 2 (Spring 1980), pp. 1, 3.

9. Ibid.

10. Ibid.

11. Interview, authors with F. Raye Norvelle, Fort Belvoir, Va., 13 August 1985.

12. Gambino interview.

13. During this period, DIAL was also used by a DMA team headed by Bruce K. Opitz in a series of digital mapping experiments designed to define the "state of the art" as a guide to future DMA development efforts. After completing this "Pilot Digital Operations" study for DMA in 1982, Opitz moved to USAETL, first as chief of the Mapping Developments Division, and later as director of the Geographic Sciences Laboratory.

14. Gambino interview.

15. Interview, authors with Michael A. Crombie, Fort Belvoir, Va., 22 August 1985; Dr. Robert D. Leighty, "Trends in Automated Analysis of Aerial Imagery," Research Institute, USAETL, in-house document, 1983.

16. Crombie interview.

17. *Tech-Tran*, Vol. 5, No. 2 (Spring 1980), p. 6.

18. Gambino interview.

19. *Current Research and Development*, 1982, p. 31. USAETL in-house document scheduled for publication every two years.

20. Ibid. The latter were described in a 1984 USAETL report, "Application of Hierarchical Data Structures to Geographic Data Systems."

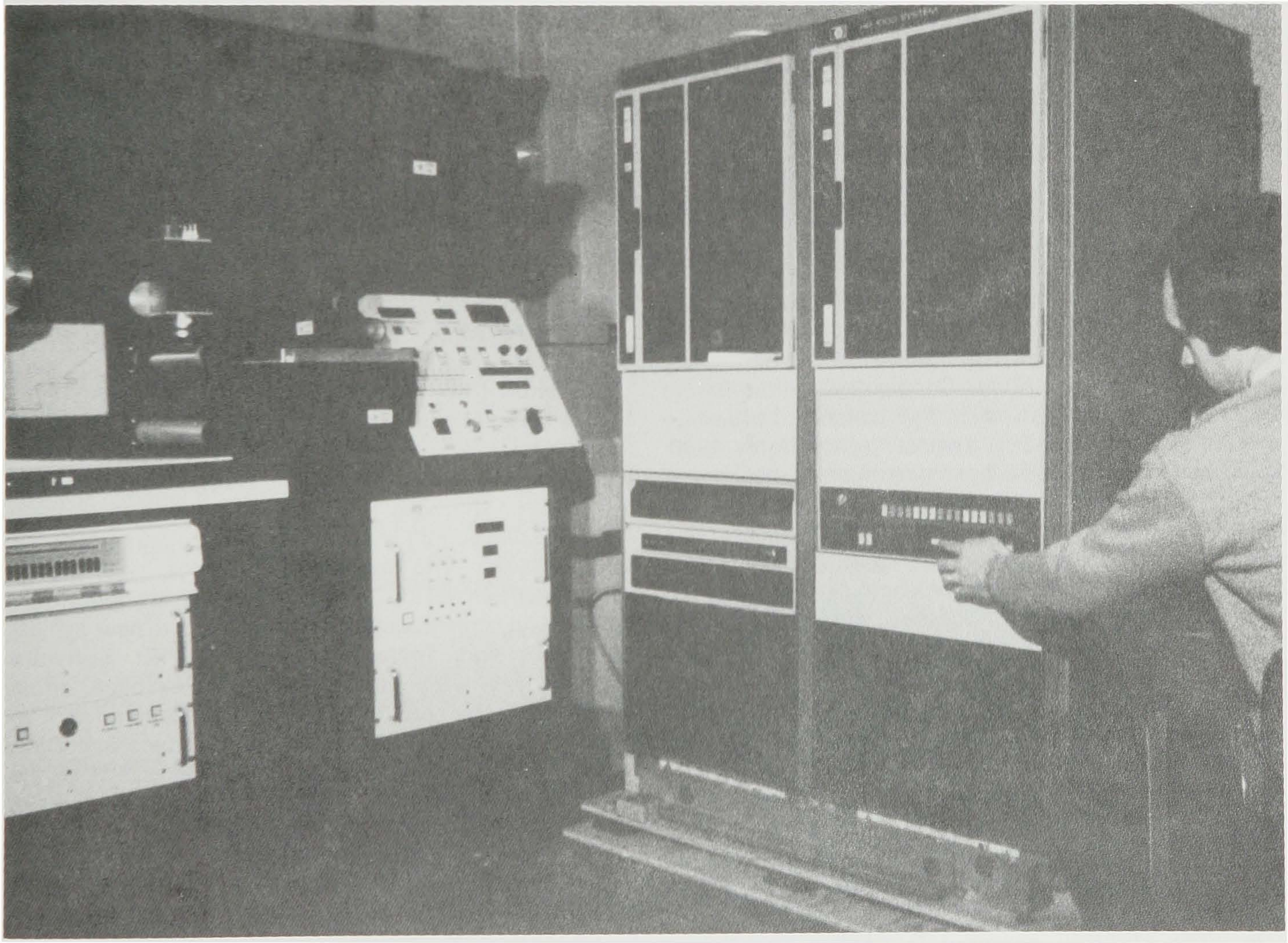
21. *Current Research and Development*, 1982, p. 34.

C. Other Compilation and Collection

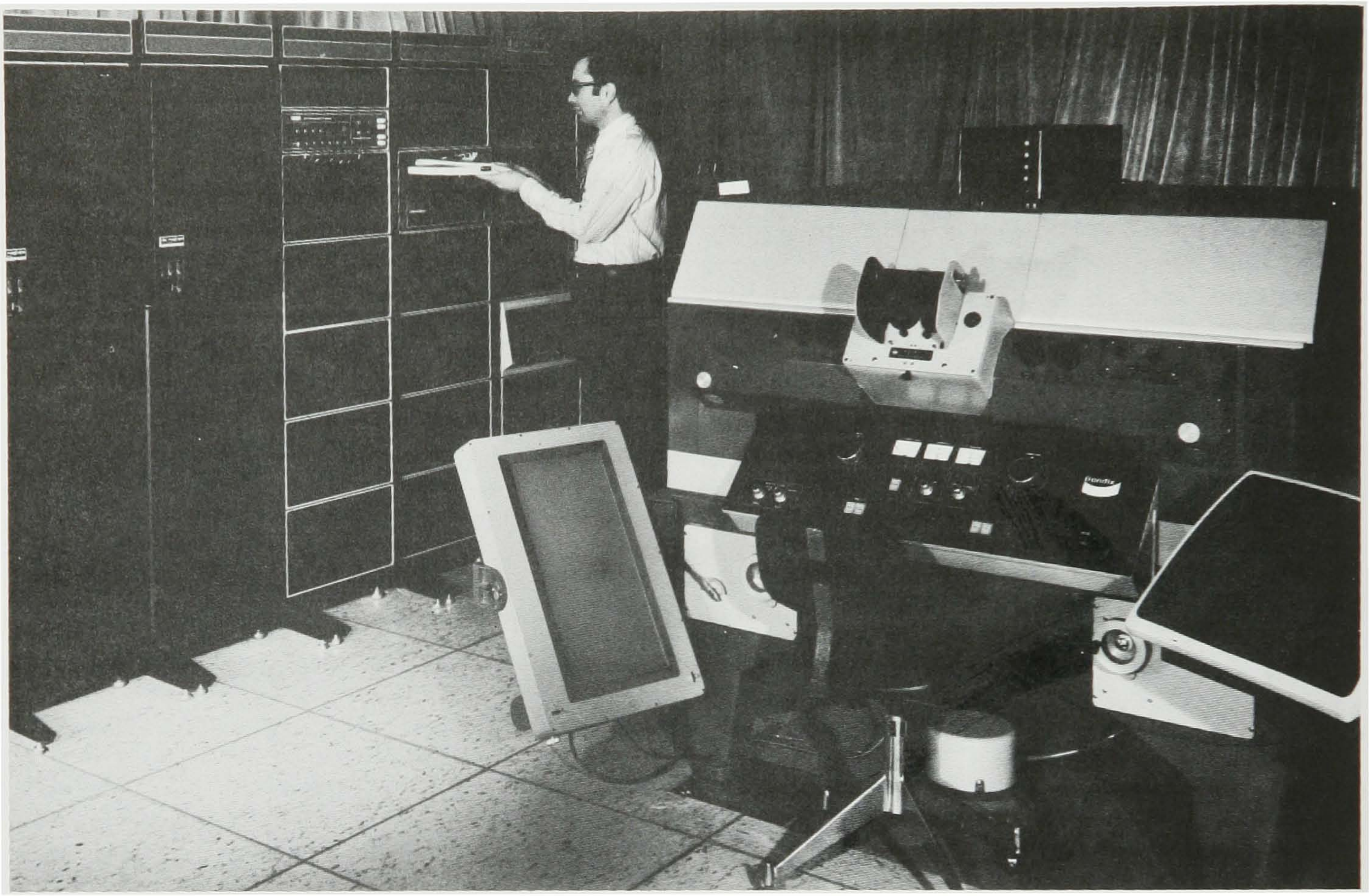
Image analysis lay at the heart of the analytical phase of map production and absorbed the bulk of USAETL funding and work hours devoted to research and development in this area. But the laboratories also addressed a variety of other problems in the preparatory phases of map production. These included ones dealing with the collection phase, such as automated evaluation of film to separate clear images from those with indistinct features or excessive cloud cover, and the orientation of cameras and sensors. In the compilation phase, projects included various printers designed to remove distortions from imagery, image digitizing systems and aids to gazetteer production. Many of these projects were of an experimental nature, resulting in prototypes which often demonstrated success but failed to find a place in the DMA production process. At least two—the Variable Geometry Laser Printer and the Photometric High Resolution Array Scanner (also employing laser technology)—could be classified as interesting, but unsuccessful.

1. Automated Evaluation of Filmed Imagery

The Optical Power Spectrum Analyzer (OPSA), delivered to the DMA Aerospace Center in 1982, automatically reviewed photographic film to select relatively cloud-free imagery with good image texture for use by production-line automated compilation equipment. OPSA was a production prototype based on the Recording Optical Spectrum



The Optical Power Spectrum Analyzer screens film for automatic compilation equipment.



The Replacement of Photographic Imagery Equipment (RPIE).

Analyzer equipment (ROSA) used as a research tool by the Research Institute. The Geographic Sciences Laboratory awarded the Eastman Kodak Company a contract for an OPSA prototype in April 1978. The completed prototype was delivered to USAETL for testing in January 1980. OPSA scanned film with a laser to record its optical power spectrum. This spectrum was then processed on a patented detector manufactured by RSI Inc., and converted to a digital signal. These digital data were analyzed on a Hewlett-Packard Model 1000 minicomputer and recorded on a magnetic tape. As processed, the data gave the horizontal coordinates (x and y) delineating cloud-covered areas and other adverse areas with insufficient image contrast and texture. In addition to screening film for automatic compilation equipment, the OPSA could be used to identify areas needing additional collection efforts and for evaluating different collection systems.[1]

2. Printer Improvements for Updating Rectified Imagery

In 1979, USAETL delivered to DMA a package of hardware and software improvements for a specialized photographic editor and high-speed, high-resolution printer called the Replacement of Photographic Imagery Equipment (RPIE). RPIE, manufactured for USAETL by Bendix Research Laboratories, was originally delivered to the Defense Mapping Agency (DMA) in 1976.[2] Because of its outstanding printing speed and clarity of detail (it used a five-micron spot size), RPIE was mainly used as a printer. In 1978, DMA sought improvements in the printer's optics and software. The magnification range was greatly increased (from 0.9 - 2.7× to 0.36 - 5.4×), the optics were modified to improve relief shading, and a new symbol generator was installed on the RPIE. Software improvements were installed to correct for offset errors caused by the printer's servo mechanism and to accommodate the new optics and symbol generator. DMA originally requested additional software to give RPIE the ability to piece together mosaics of photographs, but decided in 1980 that the mosaicking capability was not needed, and that part of the project was terminated.[3]

3. Variable Geometry Laser Printer

The projects described above, OPSA and RPIE, were what were called engineering development projects, designated in the Department of Defense budget as Program 6.4 activities. Engineering development projects tended to represent relatively risk-free technology. More adventurous or more risky development was generally found at what was known as budget program level 6.2 (exploratory development).[4]

The Variable Geometry Laser Printer (VGLP) was a 6.2 project of the Mapping Developments Division of the Topographic Developments Laboratory. Exploratory development projects were inherently risky propositions full of unknowns. The purpose of these projects was to discover these problem areas of technology and, where possible, to solve them. Inevitably, some problems would resist solution and these exploratory developments would come to an end without having demonstrated a success. The VGLP was such a story.

Work on the VGLP at USAETL began in 1978 and came to an end in 1983, when the prototype equipment was retrieved from the contractor. USAETL halted the project after insufficient progress was made. The VGLP represented a pioneering attempt to print map-quality (distortion-free) images directly from digital impulses transmitted to Earth from sensor-equipped reconnaissance satellites such as the NASA Landsat System. Before the Landsat data could be printed as map quality images, it had to be put through extensive computer processing designed to remove distortions caused by the variable positioning of the satellite in relation to Earth. In effect, the computer processing modeled the path of the satellite in relation to Earth and corrected the sensor data for variations in the satellite's "tilt, tip and swing." The VGLP was designed to by-pass this separate computer processing stage. Instead, by creating a printer capable of altering the point (pixel) size, position and density, USAETL's engineers hoped to produce a machine capable of rectifying satellite sensor data and printing its images on film in one continuous operation. In the VGLP project title, "variable geometry" referred to the design objective of a printing device capable of using variable pixel size, position and density to follow complex printing paths to remove spatial distortions from satellite data. "Laser" referred to the method to be used in printing the pixels on film.

A pioneering effort

In concept, tapes containing raw sensor data would be read into a minicomputer, reformatted for printing in raster format and transmitted to the printer system, which operated under the control of a PDP 11/23 microcomputer. The PDP 11/23 would extract horizontal coordinate data (x and y axes) and feed it to a Random Access Beam Positioner. Meanwhile, the sensor data would be converted to laser impulses and fed through an acousto-optical deflector to vary pixel size, position and density. The laser beam would then be projected via the beam positioner onto film.

The VGLP, from the outset, was considered a high-risk pioneering effort. "There was no printer anywhere that could vary geometry as we wanted," explained project engineer Ernest M. Stiffler.[5] The risk involved was reflected both in the small numbers of responses from commercial firms to USAETL's requests for proposals to carry out the development and in the subsequent difficulties experienced by the contractor which USAETL eventually selected in 1980. "The contractor really wasn't familiar with the problems involved in the VGLP," said one USAETL engineer, explaining why the development contract was allowed to lapse in 1982. Despite the problems, USAETL's Commander and Director Colonel Edward K. Wintz, expressed the view that work on the VGLP would probably have been continued if DMA had continued to express an interest in the project. However, DMA's plan to convert to an all digital production system by the 1990s meant it was no longer interested in funding projects related to mapping from hard-copy imagery of the type that would have been printed by the VGLP

4. Real-Time Attitude Estimation

From 1979 to 1981, Lawrence Gambino, under a USAETL contract with the Virginia Polytechnic Institute and State University, developed and refined the concept for a method to determine, with high accuracy, the attitude of space vehicles in real time. Before imagery from these vehicles could be used for spatial data analysis—a prerequisite for mapping and targeting—analysts had to know the angle from which the imagery was originally taken. The effort was in keeping with the real-time reporting ability of new collection systems, such as Landsat and later-generation spectral scanners. These offered direct transmission of digital imagery and other spectrum data to Earth for immediate processing. In a 1985 interview, Gambino said that a simplified version of the Real-Time Attitude Estimation project was being considered as a candidate experiment for a NASA space shuttle flight.[6]

5. Systems for Converting Printed Images to Digital Files

The rising demand for digital topographic data during the 1970s caused DMA to seek improved methods for converting filmed imagery, paper maps and mylar map overlays to digital form. USAETL engineers from the Mapping Developments Division worked on two such methods during the 1979-1983 period: the Photometric High-Resolution Array Scanner (PHIRAS) and the Advanced Image Digitizing System. Both projects were terminated before completion. USAETL engineers also developed and delivered to DMA, in 1983, a methodology for evaluating the accuracy of a variety of high-resolution image scanners. The test plan considered various performance characteristics such as geometrical accuracy, linearity of gray-scale response, modulation transfer function and output resolution.[7]

Available image digitizing systems in the late 1970s were of two types. Raster scanners, in which a photograph or other image was rapidly scanned in a series of fine lines, digitized imagery pixel by pixel. They offered speed, but had relatively poor resolution. Vector digitizing systems required an operator to trace points and lines in an image with the aid of a pointer or "mouse." These were highly time-consuming: it could take a single operator more than a month to digitize a standard map sheet. DMA wanted a system which would rapidly create digital image files out of old maps and new imagery. A digital graphics system, offering greater speed and flexibility than existing manual cartographic methods, would employ these data in maintaining and updating maps and digital topographic data files.[8]

A "breadboard" scanner

The Photometric High-Resolution Array Scanner combined high-resolution optics and a high-speed laser scanning system with computer control and processing. A "breadboard" (laboratory) high-speed laser scanner was developed and assembled at USAETL during the late 1970s. In 1980, a contract was awarded to the Ampex Corporation to develop a prototype scanner system for delivery to DMA for production use. The contractor failed to meet the development milestones and the contract was terminated in 1982.[9]

The Photometric High-Resolution Array Scanner represented an attempt to develop a single experimental machine using a new laser technology for scanning. While this project was still underway, DMA, in 1981, asked USAETL to conduct a design competition for another advanced-design, linear-array scanner, using the proven technology of light-gathering, solid-state cells known as charge-coupled devices (CCDs).

The Advanced Image Digitizing System, as this equipment was called, was designed to be integrated with other digital imagery processing systems then under development for DMA and was intended to become production-line equipment. If it had been produced, it would have been the first high-speed, high-volume image scanner capable of digitizing photographic imagery at high resolution and with high photometric and geometric accuracy. A two-contract design phase was to be followed by a single development contract based on the winning design. A reorganization at DMA transferred oversight of the project to the newly created Special Projects Office of Exploitation Modernization, resulting in a seven-month delay in sending out requests for proposals to industry. Two companies (Perkin-Elmer of Danbury, Conn., and Itek Optical Systems of Lexington, Mass.) were selected for the competitive design phase in May 1983, and delivered their designs to USAETL in late 1983. However, DMA, anticipating a shift in collection technology from photographic cameras to multispectral scanners producing digital images, decided not to proceed with the development project at that point.[10]

6. Geographic Names Input Station

Place names and locations were identified during the analytical or compilation phase of mapping at DMA from a Foreign Place Names File stored on over five million index cards. These cards were also used as source material for the periodic publication of gazetteers containing the name, description and location of geographic features. As an aid to the eventual automation of the Foreign Names Place File and of gazetteer production, USAETL, between 1979 and 1983, oversaw the development of a Geographic Names Input Station. This preproduction, prototype equipment consisted of a minicomputer and other hardware and software specially designed for compiling, displaying and printing transliterated foreign place names containing special symbols and diacritical marks.

The Geographic Names Input Station was intended for use as a DMA research tool for developing specifications for a digital filing system for foreign place names and locations which would contain all of the information in the Foreign Place Names File. It was also intended for use in developing requirements for future name data entry systems and evaluating problems of standardizing diacritical marks and other special symbols.

The hardware and software, assembled at the Electromagnetic Compatibility Analysis Center by the Research Institute of the Illinois Institute of Technology, was delivered to USAETL in 1981. It consisted of a Plessey minicomputer, an ECD intelligent terminal with disk drives, a Florida data printer and a Houston Instruments digitizing table. The terminal keyboard contained two keypads containing all the diacritical marks and special symbols required by DMA's Foreign Place Names File. The terminal displayed text with the diacritical marks in proper positions, while the data printer provided correct hard-copy text. The digitizing table was used by an operator to extract correct geographic or Universal Transverse Mercator coordinates for each named feature from existing maps. The equipment was delivered to DMA/HTC for testing in October 1982, and was subsequently used to create data files for a specialized gazetteer. These files were processed by a phototypesetter to produce a printed document. Responsibility for subsequent development work for this DMA project was transferred, in 1983, from USAETL to the Naval Oceanographic Research and Development Activity at St. Louis, Mo. (it was the Navy counterpart to USAETL and the Air Force's Rome Air Development Center for mapping R&D supporting the Defense Mapping Agency).[11]

Footnotes

1. *Current Research and Development*, 1982, p. 17. USAETL in-house document scheduled to be published every two years.

2. RPIE took digitized files made from previous, correctly calibrated imagery with distortions removed and updated them with new, uncorrected imagery, using a computer to match the new images to the old base. It then printed distortion-free "orthophotographs" from the updated imagery.

3. Installation historical files. Consists largely of unpaginated reports submitted yearly by USAETL elements and retained in the Cude Building at Fort Belvoir, Va.

4. The number 6 in these designations stands for Program 6, Research and Development, of the Department of Defense Program Budget. Program 6 provides most of the funds required to operate USAETL. At USAETL, these funds are divided into four main categories: 6.1 is basic research, 6.2 is exploratory development, 6.3 is advanced development, and 6.4 is engineering development.

5. Interview, authors with Ernest M. Stiffler, Fort Belvoir, Va., 24 April 1985.

6. Interview, authors with Lawrence A. Gambino, Fort Belvoir, Va., 23 May 1985.

7. Installation files, Topographic Developments Laboratory, Mapping Developments Division (TDL-MDD), Historical Summary, 1983 (unpaginated).

8. Interview, authors with Maurits Roos, Fort Belvoir, Va., 12 September 1985; *Current Research and Development*, 1982, p. 7.

9. Installation Files, TDL-MDD, Historical Summary, 1982.

10. Interview, authors with Maurits Roos, Fort Belvoir, Va., 12 September 1985.

11. Interview, authors with Douglas R. Caldwell, Fort Belvoir, Va., 4 September 1985.

D. Digital Topographic Data Processing

The creation of digital topographic products from digital or digitized imagery raised issues new to map production in the areas of quality control and organization or formatting of digital data.

1. Post Processing: The Quality Control Problem

To control the quality of digital topographic data and realize the benefits which these data offered in many applications, DMA was forced to introduce a new stage into the traditional mapmaking process. This consisted of a series of computer processing steps to correct errors in the digital data and to store the data in formats which could be used by cartographers as well as by the new customers who wanted digital topographic data for applications ranging from flight simulators to weapon guidance systems. These activities generally were known as post-processing operations. The major products of post processing in the early 1980s were the data bases known as Digital Terrain Elevation Data (DTED) and Digital Feature Analysis Data (DFAD). A number of other digital data bases were either in production or planned.

Quality control in the digital realm

A major quality control problem in the production of digital topographic data arose from the key difference between the digital and manuscript or analog methods of recording spatial and feature information. The map manuscript recorded the information graphically according to well-established conventions. Elevations, for example, were typically denoted by contour lines (although other visual conventions were sometimes used), roads by solid lines of certain colors and thicknesses, streams by blue lines and so on. With a lithographed map, the experienced map reader could find what he was looking for at a glance. If the mapmaker's pen slipped slightly, the error might be insignificant to the human eye. If he made gross mistakes and put a forest where a lake should have been, or overlayed the Mississippi River on the Rockies, a simple visual inspection would often suffice to detect the error.

Digital topographic data recorded the same information as a series of invisible magnetic patterns on tapes or magnetic disks. To be meaningful, these patterns had to be arranged in one of a number of spatial data formats. To a computer, electronic "noise" created by errant impulses in the recording system was as significant as correctly recorded information. When imbedded in a spatial data format, this noise could create spurious mountains and valleys. In addition, automated data recording systems such as the UNAMACE could become "lost" when extracting information from photographs, leading to the creation of false topographic files. Even microscopic flaws in a map manuscript could, when digitized, cause a computer to create a false topographic data base. Editing these files to remove errors presented a number of specific technical problems addressed by USAETL scientists, engineers and cartographers.

2. The Elevation Data Edit Terminal

The production of DTED at the Defense Mapping Agency (DMA) required, among other steps, the removal of those inaccuracies that inevitably occurred in compiling digital terrain elevations from stereoscopic images due to "noise" interference and operator error. The routine developed during the 1970s at the DMA production centers (the Aerospace Center in St. Louis, Mo., and the Hydrographic/Topographic Center in Brookmont, Md.) was to look for gross errors in a terrain profile drawn by a plotter from the compiled digital elevation data. This editing process was both less exact and slower than desired. The elevation data could not be checked directly against the original stereo image from which it was compiled, and any gross distortion detected by examination of the terrain profile drawing could only be corrected by repeating the compilation process.

In 1978, DMA asked USAETL's Mapping Developments Division (MDD) to oversee the development of production equipment which would allow an operator to overlay a matrix of elevation points on a stereoscopic image and make necessary changes in the elevation data by direct editing of the computer file. Major improvements in post-processing accuracy and speed were expected.

An anaglyphic approach

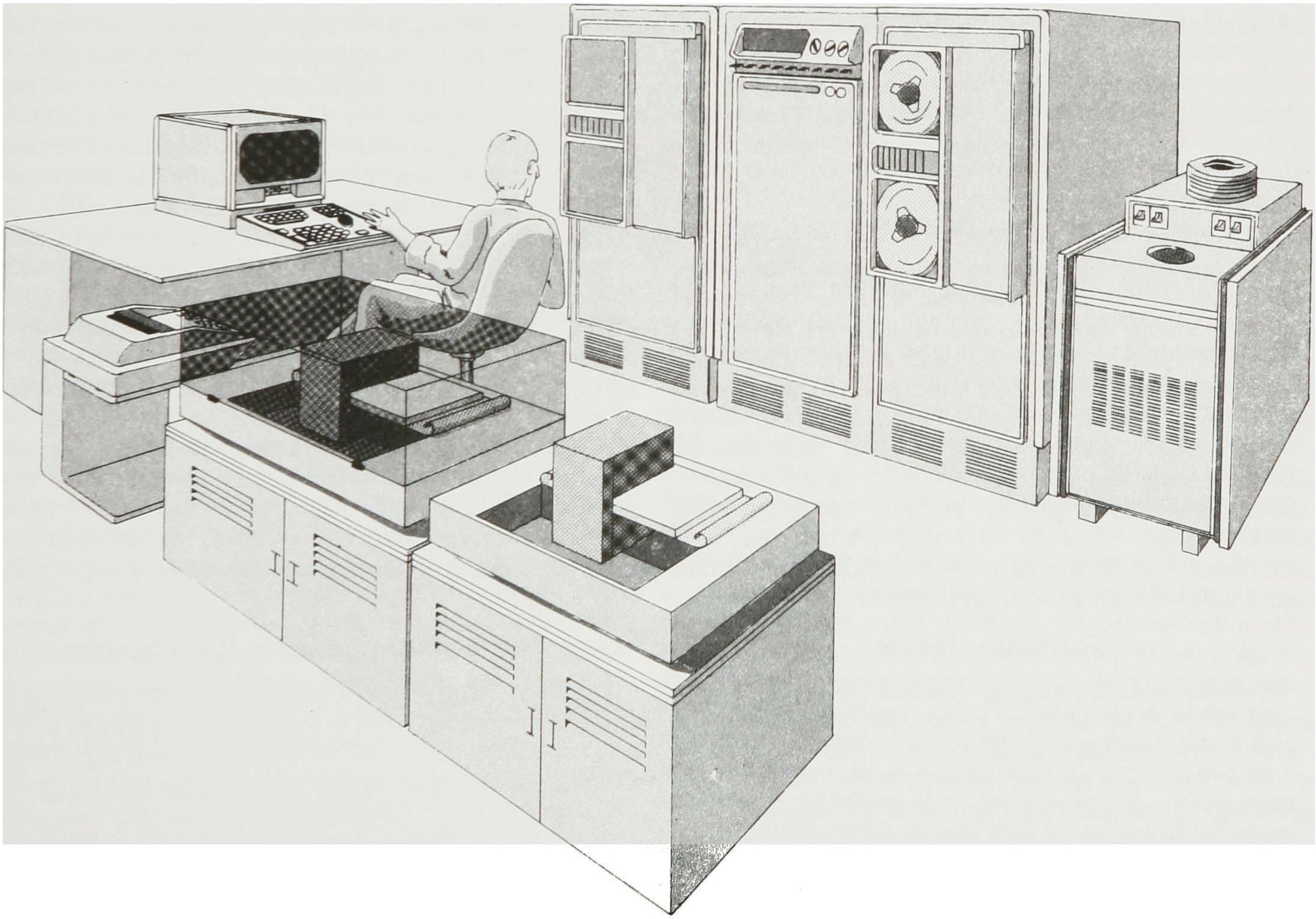
The technique selected by MDD project engineers for creating the required 3-D overlay of elevation matrix points was known as the anaglyphic method of stereoscopy. The anaglyphic method uses a single CRT display. Two images of the subject, each representing a slightly different point of view, are generated by video equipment and displayed simultaneously on the screen, one overlaid on the other. One image is shown in red, the other in green (usually cyan, or blue-green). An operator views the image through special goggles having one red lens and one green lens. The 3-D effect is created because each of the two superimposed images is visible to only one of the operator's eyes.

The EDET system

To use the Elevation Data Edit Terminal (EDET) system, stereo pairs of mapping photography were inserted into two video scanners employing a flying-spot scanning technique and photo-multiplying tubes. Each scanner created a video image of one photograph, one in blue and the other in green. These images were then superimposed on a CRT display. At the same time, digital elevation data which had been compiled on magnetic tape from the same photographs (by UNAMACE or other automated compilation equipment) were fed by a computer into the same CRT, appearing as superimposed red and green dots. When the operator donned his anaglyphic goggles, the images in the CRT appeared in three dimensions. The operator could then determine if the elevation points were on the surface of the land. By manipulating controls on the EDET console, he could raise or lower points as required to correct the elevations and could record the corrected data on the original magnetic tape. A Data-General ECLIPSE super-minicomputer handled the data and instructions for EDET.

Developmental history of EDET

Following DMA's 1978 request, Mapping Developments Division engineers defined the requirements for the EDET system, in 1979, issued requests to industry for proposals and evaluated the responses. In February 1980, a contract was awarded to DBA Systems Inc., of Melbourne, Fla. A series of developmental problems delayed delivery of the two prototype systems to DMA by more than a year, from January 1982 to May 1983. DMA tests then determined that the image resolution of the EDET's CRT display was not good enough for production work and sidelined the two machines. USAETL arranged to have one machine—the one delivered to the Aerospace Center in St. Louis—transferred to USAETL. There, MDD engineers continued to improve various aspects of the equipment, eventually achieving adequate resolution for production purposes. All changes implemented on the prototype at USAETL were also installed on the EDET system at the



Artist's concept of the Elevation Data Edit Terminal (EDET).

Hydrographic/Topographic Center in Brookmont.

Randall W. Nagle, project engineer for EDET at USAETL beginning in January 1984, anticipated further improvements in the equipment in the form of new, non-anaglyphic, soft-copy stereoscopic techniques. He also foresaw the use of EDET equipment for editing superpositioned digital feature data (as well as elevation data).[1]

3. Data Formatting and Translation Problems

An equally demanding set of problems arose from the need to translate between the various formats in which digital data was recorded.

A paper map user could not readily convert its topographic information to a new format so that he could, for example, gain a perspective view of terrain or rapidly compute the correct aim for a weapon. The flexibility of digital topographic data, as compared to paper maps, depended on the ability of a computer to accept spatial data in one format and rapidly translate it to another according to specific instructions in computer software. With the appropriate reformatting, digital topographic data could be manipulated to produce: CRT displays or plotted charts resembling traditional maps, simulated 3-D perspective views, or aiming data for missile and artillery targeting systems. The formats were determined largely by the method used to record digital data. The most common were the raster format, the elevations matrix and the vector format.

Formats: Rasters

The raster method "painted" the surface of an image with a very large number of very small "picture elements" or pixels. Raster recording techniques were used by a number of systems supporting DMA production of digital topographic data. These included digital image collection systems such as the National Aeronautics and Space Administration's satellite-borne Landsat Multi-Spectral Scanner; raster scanning systems such as the proposed Advanced Image Digitizing System, designed under USAETL supervision for digitizing photographs; and commercial scanners used by DMA to digitize paper maps and graphics, such as the SCITEX color scanner.

Formats: Vector

Whereas raster techniques "painted" the surface of an image in point-list fashion, vector-recording techniques "drew" lines and points, leaving out information on the detail in the open spaces between them. Vectors were produced by manually tracing lines and points on a map manuscript or overlay using a digitizing table and a pointer. Typical uses of vector-recording techniques at DMA were for tracing contour lines from a contour overlay sheet in order to create a digital record of elevations and recording feature analysis data— such as roads, rivers, lakes, forests and buildings.

Formats: matrices or grids

The matrix data format was generated by the UNAMACE and other automated compilation systems for extracting and recording elevation data from photographs, and was also used as the standard DMA format for storing digital elevation data such as DTED. It consisted of a dense grid of points, each recording the horizontal and vertical coordinates of a point on the Earth's surface. UNAMACE created an elevation matrix by spot-scanning in a raster mode. That is, reading across stereo pairs of images in a series of closely spaced scan lines and recording elevations at specified intervals. Other DTED were created by digitizing map contour manuscripts either in a raster or vector mode, going through a raster-to-vector conversion if necessary, and then converting from contour data to grid data. The DTED matrix was sometimes, though probably inexactly, referred to as raster-type data.

The translation problem

Each recording technique had its advantages and disadvantages. For example, raster data provided point-by-point image and elevation data, but required voluminous computer files which frequently had to be compressed by various compaction techniques designed to remove redundant or unimportant detail, and required additional processing to label features.[2] Vector data were compact. Labels or "tags" could be inserted as the operator traced lines, but they lacked visual detail and were very time-consuming. Typically, both kinds of data were required in compiling digital topographic data files, leading to a need for software to translate between rasters and vectors. An additional formatting problem involved the conversion of one form of elevation data to another. For example, an elevation grid could be used to store a detailed description of terrain or to create a perspective view using 3-D cartographic software, while contour lines would be used to depict elevations in an overhead or "orthogonal" view of the terrain. In order to use the same data base for both perspective and overhead views, it was necessary to have software capable of translating from contours to grids and vice versa.[3]

The post-processing bottleneck

Demand for digital topographic data covering large areas of the world required DMA to convert large quantities of new and existing map manuscripts and overlays to digital form. DMA's first approach was to use a digital tracing device (the Digital Graphics Recorder) to create vectors. Elevations and feature descriptors were recorded by operators as they traced the lines. Because DMA thought this process was too slow (it could take one person a full month to digitize the contour overlay for a single map sheet). DMA then acquired a raster-scanning system known as the Broomall Scan Graphics Automated Graphic Digitizing System. While this system produced large amounts of digital cartographic data in a relatively short time, it required additional data processing to convert the raster files to vector format and to record elevations and feature labels. The new process was described in a USAETL study as "entirely too labor-intensive," creating "significant bottlenecks" in digital topographic data production. The procedures, including source manuscript preparation, raster-to-vector conversion, error detection and correction, and feature "tagging" or identification, were "particularly time-consuming and error-prone." The subsequent acquisition by DMA in the early 1980s of the SCITEX Response-250 color scanner and graphics processing system alleviated some—but not all—of the production headaches. For example, the raster scanner of the new system, like all available commercial color scanners at the time, was too small to accept hydrographic charts without folding, introducing the possibility of digitizing errors and gaps at the folds.[4]

Raster-to-vector conversion

DMA sponsored a number of USAETL research efforts to overcome this production bottleneck. Several studies between 1976 and 1983 focused on improved software for raster-to-vector conversions. USAETL also sponsored a comprehensive evaluation of DMA's requirements for converting analog maps to digital cartographic files, work which was getting underway at the conclusion of the 1979-1983 period under the supervision of Douglas Caldwell of the Mapping Developments Division's Automated Cartography Branch.

The major focus of USAETL's research on improving the raster-to-vector process was on speeding up the data processing required for converting voluminous raster files to vector format and eliminating errors in the data. Microscopic flaws could lead to major vectorizing errors, and electronic noise and distortions in the digitizing process can lead to additional errors. An early USAETL study was performed on the STARAN associative array processor of the Digital Image Analysis Laboratory. The STARAN, an early supercomputer, processed raster data in parallel, giving it a significant speed advantage over normal serial computers. The 1976 study found that the STARAN was about four times faster than a standard mainframe computer for raster-to-vector conversions.[5] However, the STARAN, a limited production system, was not considered suitable for DMA production use.

Minicomputer raster-to-vector study

A second major USAETL study of raster-vector conversion, conducted by Caldwell, involved writing software for raster-to-vector conversion on a minicomputer. Minicomputers developed during the 1970s offered many advantages over the large mainframes then being used in digital mapping. They were less costly, almost as fast and much easier to maintain. Furthermore, when ruggedized, minicomputers could be housed in vans and used to support mobile combat forces in a variety of ways for interactive processing of intelligence and mapping data. "Minis brought interactivity to distributed systems," Caldwell said in a 1985 interview. However, minis generally had less internal memory and less powerful data-processing units than mainframes. Efficient minicomputer processing of raster data generally required software to selectively edit the data to remove its characteristic redundancy, as well as other software procedures for breaking down large data-processing tasks into more manageable tasks. (Raster redundancy occurred because each pixel represented, at most, a scarcely visible dot in the image when graphic data were recorded in raster form. Thus, the description of a uniform large area in an image might require hundreds or thousands of essentially similar pixels. By creating a simplified descriptor for such areas— known as polygons— software engineers could dramatically condense the amount of computer memory required to store an image.)

The chief feature of the "Mini Raster-to-Vector Conversion" study was a set of algorithms that operated on raster data condensed or "compacted" by a technique known as runlength encoding. In the process of converting these condensed rasters to vectors, the computer memory was required to keep track of only two scan lines of data at a time—a small fraction of the total raster file. Unattached line ends, line intersections and other key vector forms were automatically tagged. These tags were then reviewed by the software to automatically identify and correct errors.[6]

Contour-to-grid conversion

Elevation data processing systems at DMA had to be compatible with contour (vector) data and elevation matrix data, as well as convert the scale and density of the matrix data from one grid to another of different spacing. Between 1979 and 1983, USAETL scientist Rosalene Holecheck of the Automated Cartography Branch oversaw the development of software to accomplish these and related tasks. The software was prepared by Zycor Inc., to meet DMA specifications. It included four specialized algorithms for terrain elevation data modeling. Terrain elevation data, or matrix data, consisted of arrays of numbers corresponding to terrain elevations measured at the nodes of a regularly spaced rectangular grid imposed over an area of the Earth's surface. The algorithms were designed to perform interpolation tasks for: converting contour lines digitized from 1:50,000-scale maps and other sources to a regularly spaced grid where the grid spacing was often much closer than the contour interval; converting a regular grid of elevations into contour data at any map scale; converting one elevation grid to another with different spacing; and smoothing and generalizing an elevation grid to permit accurate contouring at scales much smaller than

1:50,000. The software was delivered to USAETL for testing in 1982 on USAETL minicomputers, algorithms were further optimized to improve speed, and the software was installed by Holecheck in 1983 at the DMA Hydrographic/Topographic Center on a new, interactive data processing system known as the Terrain Elevation System-Elevation Matrix Processing System (TES-EMPS). Work on the project, known at USAETL as Software for Automated Cartography, continued in 1984.[7]

This project, also known as Algorithms for Digital Terrain Modeling and Minicomputer Software for Terrain Elevation Data Modeling, generated several reports. Two which bear mention were "An Algorithm for Feathering Digital Terrain Elevation Models Using Filtering Techniques" and "Optimization of Cartographic Software." A key issue in the work was the degree of accuracy that could be achieved by different mathematical modeling techniques (algorithms) in interpolating a terrain grid from contour data and going the other way in contouring from gridded data while changing the scale of the presentation. In order to evaluate possible alternatives more precisely, USAETL launched an on-going study of evaluation methodologies for terrain modeling algorithms and also contracted, in 1983, with Dr. Steven Grotzinger of George Mason University for a study of the " Contour-to-Grid Problem."[8]

Bias detection software

In a related project, USAETL's Automated Cartography Branch developed and delivered to DMA specialized post-processing software to detect errors known as "bias." These occurred when digital terrain data for adjacent areas of the Earth were joined together in one data file. Data collection for a digital terrain data base typically covered an area defined by one degree of longitude and one degree of latitude. This was known as a one-degree cell. Bias consisted of small differences in the alignment of the digital terrain models of two adjacent cells. Unless detected and corrected, the bias would lead to gross errors within the digital terrain data base.

Other post-processing software

Interfacing—getting one machine to talk to another, or merging two different kinds of data files—represented another digital data processing problem for DMA. In the post-processing area, USAETL undertook at least two projects concerned with interfacing. One, known as Carto Validation and Plotting, resulted in a contract with Measurement Concept Corporation of Rome, N.Y., in September 1983. This project was to develop software for converting from the standard linear format used by DMA's new TES-EMPS topographic data processing system to the standard interchange format (SIF) used by other DMA production equipment such as the Intergraph computer graphics system and the SCITEX. Software was also developed to translate between the Automated Mapping System software used by a number of U.S. government domestic mapping agencies and the Intergraph standard interchange format software. Yet another interfacing project, known as Terrain Editing Capability and Software Merging, produced software capable of creating a single, interactively editable file combining digital feature data and digital elevation data from DMA DFAD and DTED data bases. This software was originally developed for the USAETL Research Institute's CAPIR, an interactive image analysis system, in order to check the accuracy of DMA data used in Pershing II targeting. The software was later delivered to DMA where it was to be used for converting existing inventories of DMA DFAD to the Standard Linear Format.[9]

A closely related interfacing problem concerned communication between computers and various output devices used in cartography, especially different designs of automated plotters. MDD engineers developed device-independent graphic software to address this problem.

From distinct mapping stages to a continuous process

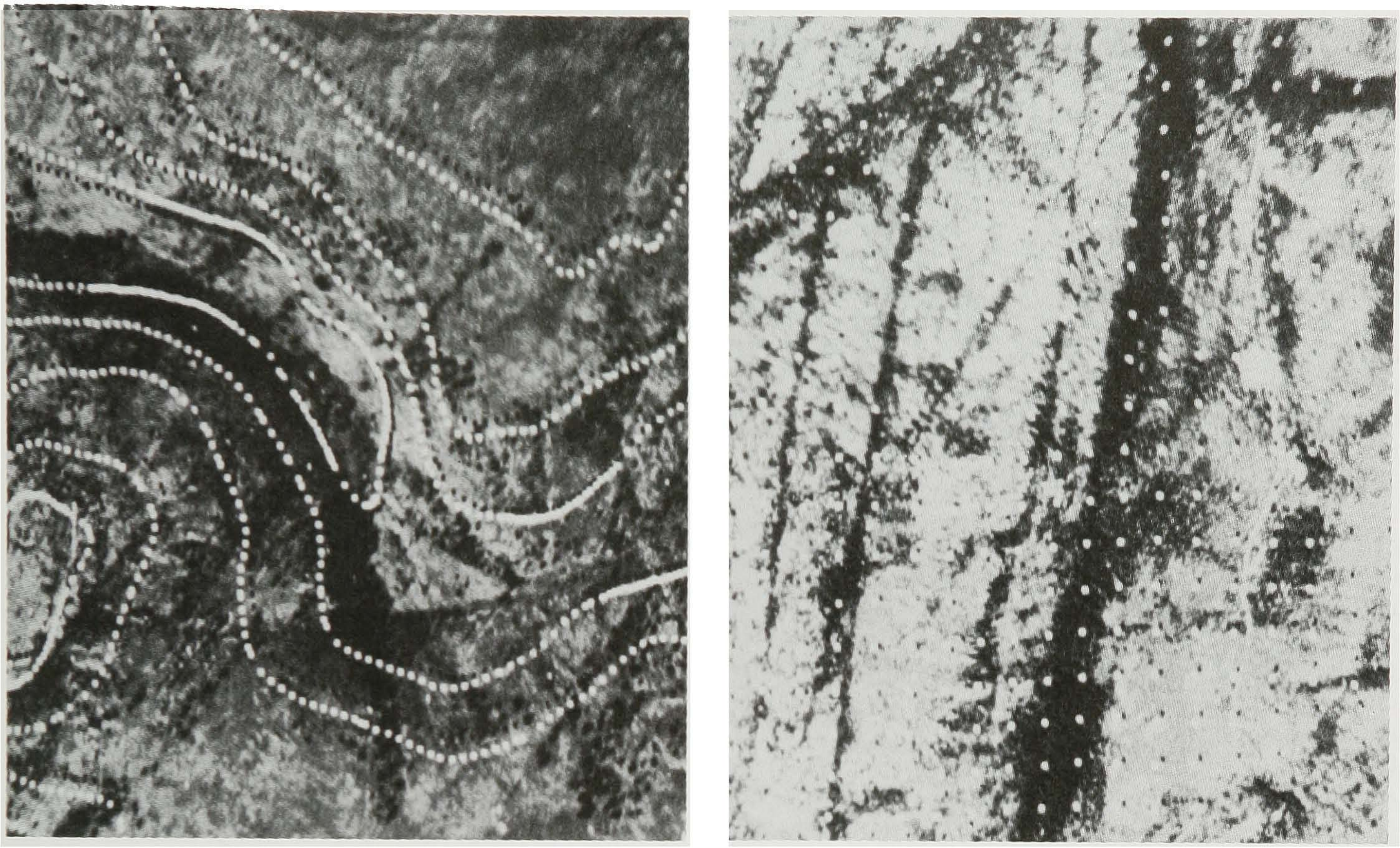
The close relationship between interface software for post processing and for other stages of topographic production was an example of an emerging fact about digital mapping. The ability to perform multiple tasks at a single computer work station, given appropriate software, often made it possible to blur the clear boundaries between phases of map production which had existed in the analog realm of lithography. These boundaries, for example, made a clear distinction between compilation—the analytical phase of mapping—and cartography, in which map elements were symbolized and synthesized. Another example of this trend toward merging distinct operations into one continuous process, here included under post processing, was provided by a experimental software known as the Topographic Finishing Station.

4. The Topographic Finishing Station

USAETL engineers undertook one important effort to bypass most of the data formatting problems in a series of experiments designed to demonstrate an ability to create contour overlays from raster data without going through such time-consuming steps as raster scanning and raster-vector conversion. These overlays, it was shown, could be checked against a digital stereo image of terrain, edited to remove distortions, and then sent to an output device such as a plotter or platemaker to create map overlays or lithographic plates. The experiments were used to develop specifications for a soft-copy Topographic Finishing Station for possible DMA production use.

Using DIAL's anaglyphic system

The Topographic Finishing Station (TFS) represented an



Topographic Finishing Station cathode ray tube outputs which use overlapping blue and red images to portray digital elevation data in stereo.

application of anaglyphic stereo superpositioning technique to a quality control and production problem. The exploratory development effort was carried out during the 1979-1983 period on the Digital Image Analysis Laboratory's computer graphics system by USAETL engineer Barry Holecheck, then assigned to MDD. The TFS was similar to the EDET in using anaglyphic soft-copy stereoscopy for interactive editing of digital files. But the differences between the two projects were illustrative of the divergent technological trends in DMA production during the late 1970s and early 1980s. EDET was designed to support the production of Digital Terrain Elevation Data from hard-copy photographs to produce a magnetic tape recording of elevation data. The TFS looked ahead to a time when DTED and other digital topographic data would be processed entirely in soft-copy—that is in digital form.

A shortcut in digital mapping

The Topographic Finishing Station converted DTED by computer processing from a raster-like matrix or grid of points to contour lines, also in raster format. These contour lines could then be superpositioned in stereo imagery on a CRT, using anaglyphic techniques, and corrected by an operator. Unlike EDET, TFS was essentially a software system, although two possible hardware configurations were examined in a contract report by the Illinois Institute of Technology carried out at the Defense Department's Electromagnetic Compatibility Analysis Center at Annapolis, Md. Also, unlike EDET, TFS was not funded by DMA, but was an in-house effort at USAETL designed to demonstrate to DMA how shortcuts in digital data processing, interactive editing and lithographic plate-making could speed digital map production. The effort involved a number of software experiments on the Digital Image Analysis Laboratory (DIAL) to create contours directly from matrix DTED files. This technique made it possible to bypass such steps as drafting contour overlays from hard-copy photographs, scanning the contour overlays with a vector digitizer or raster scanner, and processing the data with raster-to-vector or vector-to-raster conversion software and procedures.

A successful demonstration

In 1982, Holecheck demonstrated that raster contour data could not only be interactively edited on DIAL, but also directly output to any plotter or similar device supported by the device-independent graphics software recently developed by other USAETL engineers.[10] A contour plot tape was produced on the DIAL and taken directly to the Digital Laser Platemaker, another USAETL development, where a lithographic press plate was made.[11] Thus, the TFS project demonstrated a capability to go directly from unedited DTED files to a finished press plate in one compact series of operations, successfully merging the post-processing, cartographic and press-preparation phases of the production process. DMA, however, decided not to pursue this particular anaglyphic approach to digital contour mapping, and the project was terminated.

5. Work with West Point

An ongoing program at USAETL involved technology transfer to the United States Military Academy (USMA) at West Point. Richard Clark, succeeded by Larry Cook in 1981, directed the USMA technology support work unit during this period. The idea was for USAETL scientists to work with interested students to mutual benefit. In this case the focus was on software for digital elevation data processing and its possibilities.

The West Point program had two components. Under the leadership of Howard Carr, then head of the Mapping Developments Division of TDL, USAETL supplied funds and technical advice to establish an up-to-date computer graphics laboratory at West Point in 1979. At that time, "all they had there were a few programmable hand-held calculators," Carr said.[12]

Thus, USAETL undertook a program whereby in the spring term of their junior year, one or two cadets were selected to join USAETL's program. Using funds from the Office of the Chief of Engineers, USAETL gave the students funding to allow a month's work at USAETL, writing computer graphics software and learning the links between different types of terrain information displays.[13]

More than good will

Douglas Caldwell cited "good will" as a prime motivator of the USMA program, but pointed to other benefits as well. In 1980, for example, Cadet David Jones developed software at USAETL for the Tektronix 4014 Graphics Terminal with the capability to produce four displays on a single screen (line of sight, radar tracking, and profile and oblique views). In addition to producing this helpful work, the cadet received academic credit for his efforts. It was a program in which "both participants benefit."[16] (See experimental map graphics and illustration.)

Mutual satisfaction with the USMA Technology Support Program led to new ideas for expanding the effort. Toward the close of the 1979-1983 period, plans were made to fashion a second work unit dealing with topographic tactical decision graphics. In addition, plans were germinating at West Point's geography department to work in ADA—the Department of Defense's approved computer language—making it the first geography faculty to do so. Thus, USAETL's parallel software with West Point would be maintained. Software for doing 3-D displays would be converted to run in ADA, and the use of microcomputers for generating terrain graphics would be looked into extensively.

Though a small item on USAETL's agenda, USMA technology support was continued yearly with a significant beneficial effect for USAETL and the academy.

Footnotes

1. Installation files, Topographic Developments Laboratory, Mapping Developments Division (TDL-MDD), Historical Summary, 1979-1983; interview, authors with Randall Nagel, Fort Belvoir, Va., 16 May 1985.
2. For a discussion of compaction research at USAETL in the 1970s and early 1980s, see "Polynomial Terrain Modeling" in Dr. Edward C. Ezell's *ETL History Update, 1969-1978*, 1979, pp. 42-43.
3. Interview, authors with Douglas Caldwell, Fort Belvoir, Va., 10 September 1985.
4. "DMA Raster-to-Vector Analysis," (Battelle, Columbus Laboratories, USAETL Report No. 4), 30 November 1984, pp. 1, 16.
5. Ibid., p. E-1.
6. Ibid., p. E-3.
7. Installation Files, TDL-MDD, Historical Summary, 1979-1983; interview, authors with Rosalene Holecheck, Fort Belvoir, Va., 9 September 1985.
8. Installation files, TDL-MDD, *Historical Summary*, 1983.
9. Ibid.; interviews, authors with Douglas Caldwell, Fort Belvoir, Va., 4 and 10 September 1985.
10. Installation files, TDL-MDD, *Historical Summary*, 1982.
11. Ibid.; interview, authors with Barry Holecheck, Fort Belvoir, Va., 10 May 1985.
12. Interview, authors with Howard Carr, Fort Belvoir, Va., 12 September 1985.
13. Interview, authors with Douglas Caldwell, Fort Belvoir, Va., 6 May 1985.
14. Ibid.

E. Cartography

If geodesy and photogrammetry were the sciences of precomputer mapping, cartography was the art. Whether the mapmaker's spatial information was based on Eratosthenes' observations of the sun in about 250 B.C. from the bottom of an Egyptian well, or as today, from the observation of satellite orbits, he still had to draw the map. This entails making the classic decisions of the cartographer: what to show and how to show it.

1. Plotting Techniques: Drawing the Map

As recently as the last century, maps were often the work of one cartographer. The accompanying map of the Gettysburg battlefield was the work of Sgt. (later Maj.) E.B. Cope of the Union Army, who prepared it from sketches and measurements he made on horseback. When mapmaking became industrialized with the advent of lithography, and field sketches gave way to aerial photographs, the day of the single talented artisan came to an end. Today's printed maps are the product of many hands. But cartographers still make the decisions on what to show and how to show it. And, until recently, they often scribed the overlays required by the multicolored lithographic map.

The birth of automated cartography

Like any art, cartography had its tedious and exacting aspects. Cartographers had to rule grid lines to show coordinates, plot feature outlines and contours, insert place names and symbols, and color the map—work that could take months in an all-manual process for making a topographic map. The electronics revolution, including computers and cathode ray tubes, began to have an impact on the more tedious aspects of this ancient art as early as the late 1950s. A contract awarded in 1960 by USAETL's predecessor, GIMRADA, to the Gerber Scientific Instrument Corp., led to the development of an Automatic Point Reading, Plotting and Grid Ruling Machine using digital data. This became the forerunner of modern digital plotters used in a wide variety of cartographic and industrial drafting tasks.[1]

New plotting techniques

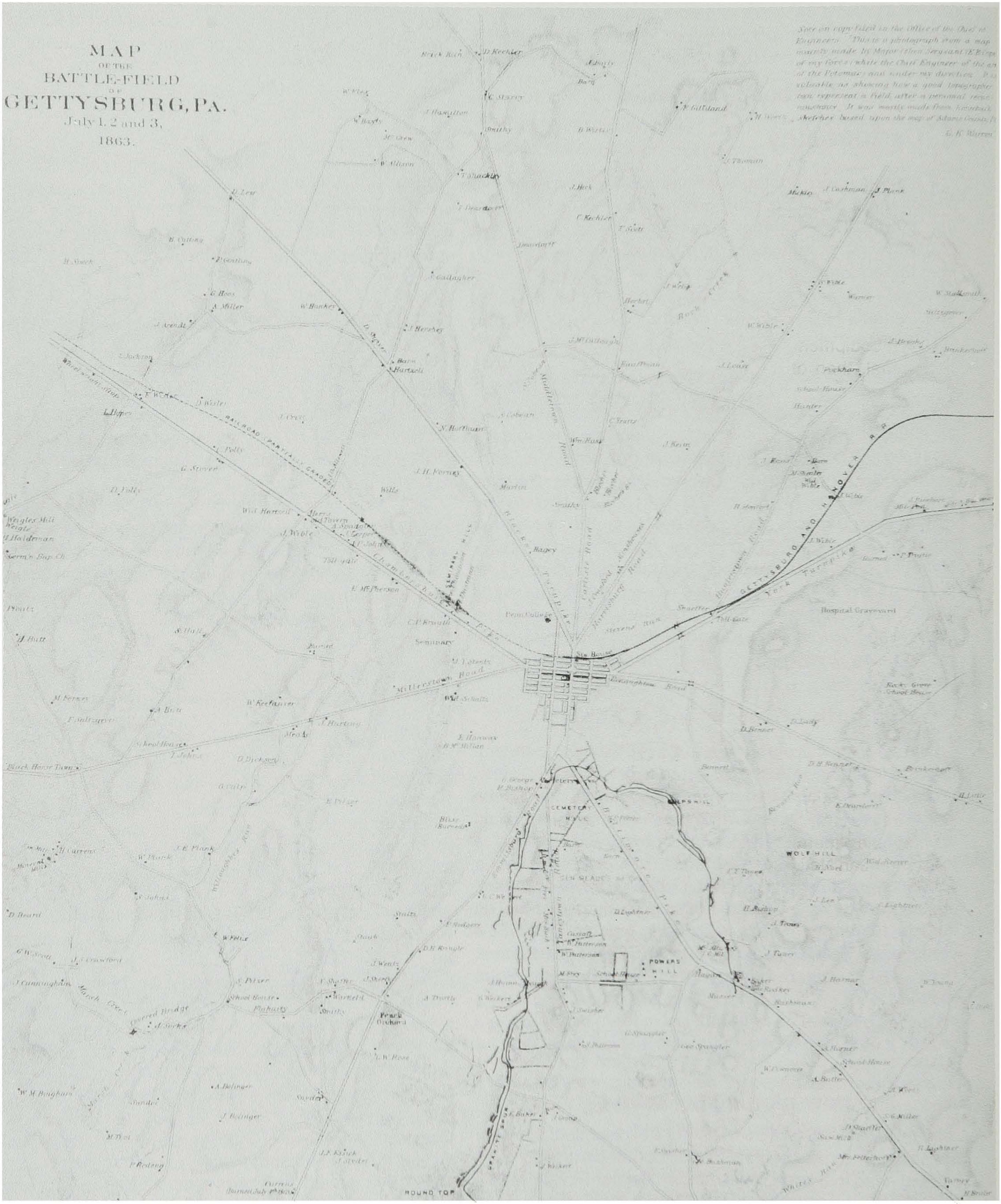
In the 1970s, USAETL's Mapping Developments Division attached an experimental, minicomputer-controlled CRT plotting head to a large scale modern Gerber Plotter, Model 1232, to demonstrate new technologies for placing names and symbols on maps and for automated production of flight charts. These plotting heads, faster than the standard photohead mounted on the Gerber plotter, recorded images directly onto color film "separates," which could then be used to make press plates. Film separates were an intermediate production stage between manuscript overlays and lithographic press plates. The CRT printheads could place letters and symbols of desired size and type at any desired axis on film mounted on the plotter, using a format which rotated a 51mm-square raster display within the 127mm-diameter display tube.

During the same period, USAETL adapted Electron Beam Recording (EBR) technology to map and chart production. The minicomputer controlled EBR system also recorded images directly to film, but compared to the CRT, EBR heads could plot larger images (up to 127mm by 203mm) in either raster of vector format.

The Mapping Development Division engineers also developed the Type Placement Composition System, a combination of specialized software and computers to provide digital instructions on type and symbol size, font, and location to the CRT and EBR plotting systems for automatic placement of map names, symbols and text on the film.[2]

DMA production applications

These developments led to orders from DMA for three CRT printhead systems, two EBR systems and a type composition system for production work. USAETL oversaw the engineering development of these orders by Image Graphics Inc. Final delivery and acceptance of the CRT printheads were accomplished in 1980. They were installed on Gerber and Concord Precision flatbed plotters at the DMA Aerospace Center and the DMA Hydrographic/Topographic Center. One EBR, without the raster plot option, was placed at the Aerospace Center, in 1979, as part of an Automated Air Information Processing System producing, among other products, Flight Information Publication (FLIP) Charts used by pilots for quick reference to navigation information. A second EBR system, including the raster option and additional software for on-line data processing, data extraction, image enhancement, image generation and variable scaling, went to the Hydrographic/Topographic Center in 1980. A Type Composition Console (TCC) was delivered to the Aerospace Center in 1979 and subsequently was modified during the 1981-1983 period to improve its efficiency and provide software interfacing among the TCC, CRT and EBR systems at the Aerospace Center.



Sgt. E.B. Cope's map of the Gettysburg battlefield done from sketches made on horseback.

2. Device-Independent Graphics Software

DMA map and chart production lines incorporated a number of different plotter designs and other hard-copy output systems. Interfacing computer-graphic software with these output devices typically required writing specially tailored instructions for each different type of device. Software tailored to specific output devices lacked flexibility and was subject to device-based obsolescence: as new equipment was introduced, old software had to be discarded and new software developed. Given the rapid pace of innovation in computers and output devices, the inflexibility of device-dependent graphics software could impose a high cost on modernization.

DMA asked USAETL to come up with "Device-Independent Graphics Software" (DIGS) routines, adapted to DMA equipment. The project was assigned to Richard Rosenthal, then of the Automated Cartography Branch. Rosenthal adapted commercial software (the DI-3000 package produced by Precision Visuals Inc.) to create a library of packages capable of running on several different systems at USAETL and DMA. These packages included routines compatible with Calcomp, Versatec, DeAnza, Tektronix and Gerber plotters. In 1983, USAETL delivered a Calcomp/Metafile DIGS package to the Hydrographic/Topographic Center for installation on a Univac mainframe and a second package for installation on a VAX super-mini used at HTC to edit Digital Feature Analysis Data (DFAD). A commercial DIGS package was procured for use on DMA's experimental computer-graphics installation known as the Remote Work Processing Facility Upgrade. Another DIGS package was procured and installed on USAETL's VAX-11/750 and linked to experimental 3-D perspective software. This package was employed in developing software for the Terrain Analyst Work Station (TAWS) to be used by the Army's Digital Topographic Support System. Resources Planning Associates Inc., was given a contract to examine issues relevant to the design of a raster-compatible "metafile" system for use at DMA, based on the American National Standards Institute's Virtual Device Metafile proposed standard. (A "virtual device" is a computer with essentially unlimited memory created by the linkage of the processing unit to large-volume magnetic disk files; a "metafile" is a standard device-independent display and record-keeping format.)[3]

3. The Bird's-Eye View and Other Map Art

Advanced plotters and type composition and placement systems relieved cartographers of much of the tedious drafting tasks associated with map production. But they were only the beginning of a burst of invention which, over the decades of the 1960s and 1970s, moved from relieving the cartographer of tedious, mechanical tasks to giving him the freedom to generate new kinds of map graphics and even to automating key decisions which had previously fallen into the realm of cartographic or artistic license. As Doug Caldwell wrote in 1982, "Cartographic license, the freedom to adjust, add or omit map features within allowable limits, means that the appearance of a map is dependent upon the cartographer who produces it."[4]

Early mapmakers, having limited factual detail on the unexplored continents and seas, often filled in blank spaces with fanciful designs, such as drawing elephants in unexplored jungle areas.

As geographic and other scientific knowledge became more complete, the fanciful aspect of cartographic license disappeared. But cartographers still faced the problems of what to show and how to show it. Among these problems were the questions of point of view and of compromise between recognizable detail and scale. Standardization of map information systems required the evolution of strict conventions governing the solutions of these problems. The bird's-eye view of the Earth's surface as seen from directly overhead became the standard map projections for example. Other conventions governed the design, scale and placement of feature symbols.

New artistic possibilities

Cartographic research at USAETL during the 1979-1983 period focused on ways in which computer technology could free cartographers from the relatively rigid artistic conventions required by the traditional map. Doug Caldwell noted in his 1982 article that:

> When the traditional mapmaking process merged with the computer revolution, a new area of research, automated cartography, was spawned. Early work was directed toward the objective and mechanical aspects of map production. Digitizers collected locational information and plotters produced printed maps. Recent research, however, goes beyond such objective procedures. Now, the subjective process of mapmaking, the realm of 'cartographic license,' is being explored.[5]

Experimental Map Graphics

Early cartographers solved the point-of-view problem by the refinement of the orthographic map, a convention which displayed an area as seen from directly overhead in a bird's-eye view (right angle to the surface). This flattened view of the world, though, had its limitations. Even when the convention of topographic contours was developed to show altitudes, it took a skilled map reader to readily translate between the map and his ground-level view of terrain. According to George Simcox of USAETL's Program and Resources Office, it had been estimated that in the 1980s, one U.S. Army officer in five could read a topographic map.[6] Various shading techniques were devised by 19th-century mapmakers to make variations in altitude—depictions of relief — more apparent to the user, as in Sgt. Cope's map. But shading was slow and costly work; mass-produced maps generally did not have shading.

In 1976, USAETL's Mapping Developments Division began a series of experiments with map design which used the speed and flexibility of computer graphics to create more easily readable maps. Early experiments were designed to create shading by digital techniques in order to produce overlays which would add this shading to conventional topographic (contour) maps. Subsequent work focused on new graphic techniques, displaying terrain in three dimensions.

3-D terrain views

Computer processing made it possible to create 3-D terrain views from any conceivable perspective in a very short time. These could be used to compute lines of sight, low-level flight paths, areas masked from radar coverage, and other information essential both to military commanders in the field and to construction engineers. A skilled cartographer could draw a 3-D map from one point of view, if given weeks or months to deliver the product. But a computer could generate such a view from any angle in a matter of minutes. Thus, computers introduced the practical possibility of making, as needed, map graphics tailored to a particular operational task at a particular time and place.

Experimental map-graphics work at USAETL developed along several different lines, serving the different needs of DMA production, other USAETL demonstration and development projects, and training for West Point cadet interns at USAETL. It involved activities treated elsewhere in this history, including the Field Exploitation of Elevation Data (FEED) demonstration, the Digital Topographic Support System (DTSS) and its associated computer work stations, and the video-disc demonstration.

Experimental oblique and perspective views

In the mid-1970s, DMA asked USAETL to help it fulfill an Army request for perspective views of potential battlegrounds in Europe. DMA wanted software routines which could create 3-D maps from the Digital Terrain Elevation Data (DTED) and Digital Feature Analysis Data (DFAD) files of the Digital Land Mass System (DLMS), using a vector format. In developing this software, USAETL engineers created routines for showing both oblique and perspective views. USAETL also decided to demonstrate to the mapping community how this software and other USAETL work could be used to create map graphics showing terrain relief in three dimensions.

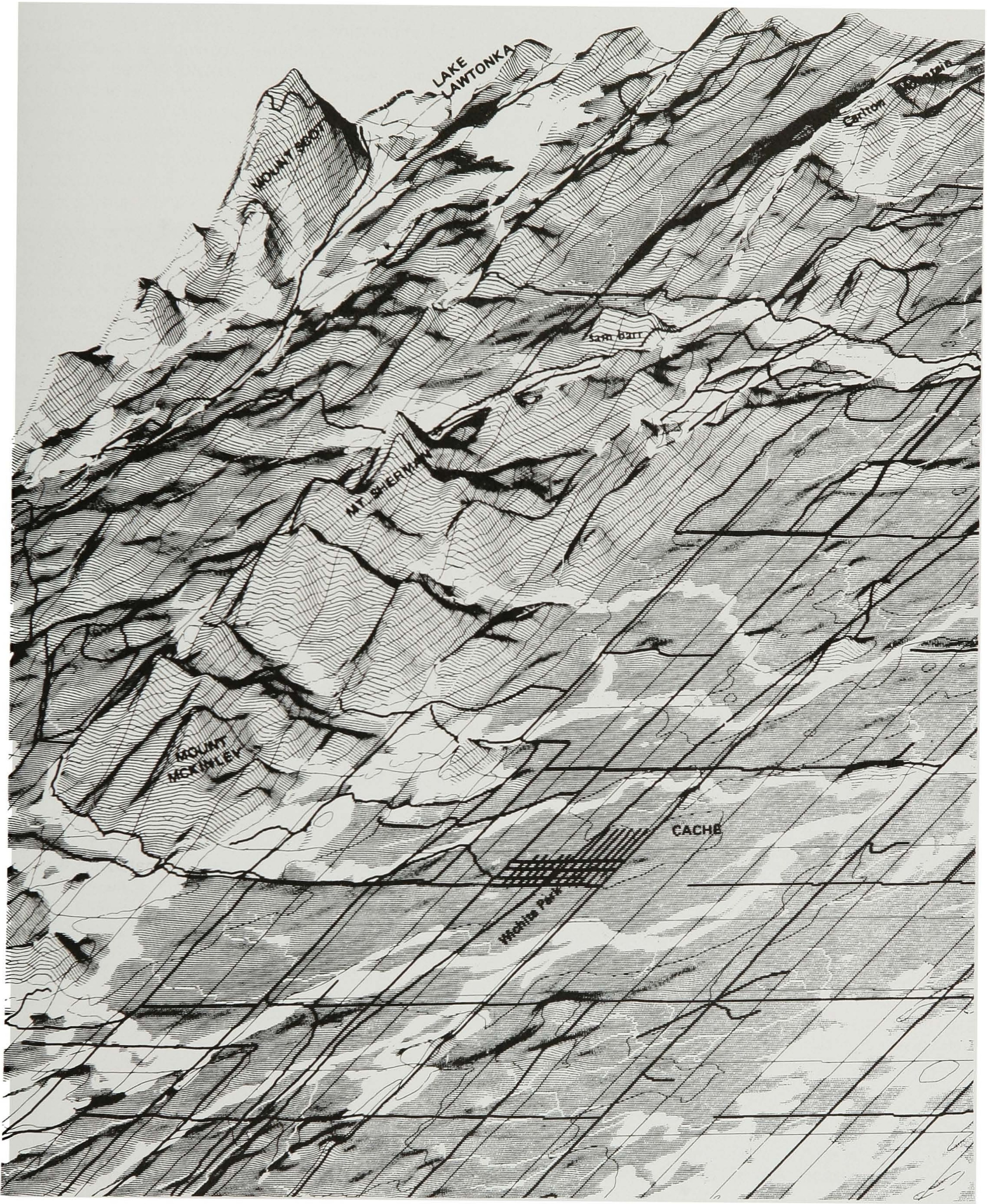
USAETL already had on hand a detailed digital topographic data base on the area around Cache, Okla., on the Fort Sill Military Reservation. Also, James Jancaitis of the Automated Cartography Branch had developed a data-compression technique known as polynomial terrain modeling, and had created a polynomial terrain model of the Cache area.[7] In 1977, the Automated Cartography Branch used these tools to create the accompanying oblique view of Cache (see page 77), which was printed and distributed at the annual convention of the American Society of Photogrammetry—American Conference on Surveying and Mapping, along with a standard topographic map of Cache also prepared by the Automated Cartography Branch in 1972. The oblique view was prepared in vector format on the DIAL mainframe computer and plotted on the Gerber 1232 plotter. Color overlays were manually prepared. The branch and project chief was Howard Carr, Jancaitis was project engineer and mathematician, William Randy Moore was responsible for system analysis and program development, Joseph Honablew carried out the data-base acquisition, wrote the processing software and did the cartography, and Peter Jacob provided programming support.[8]

In 1980, the Automated Cartography Branch produced another view of Cache, the perspective map, shown on page 78, using software developed by USAETL engineers.[9]

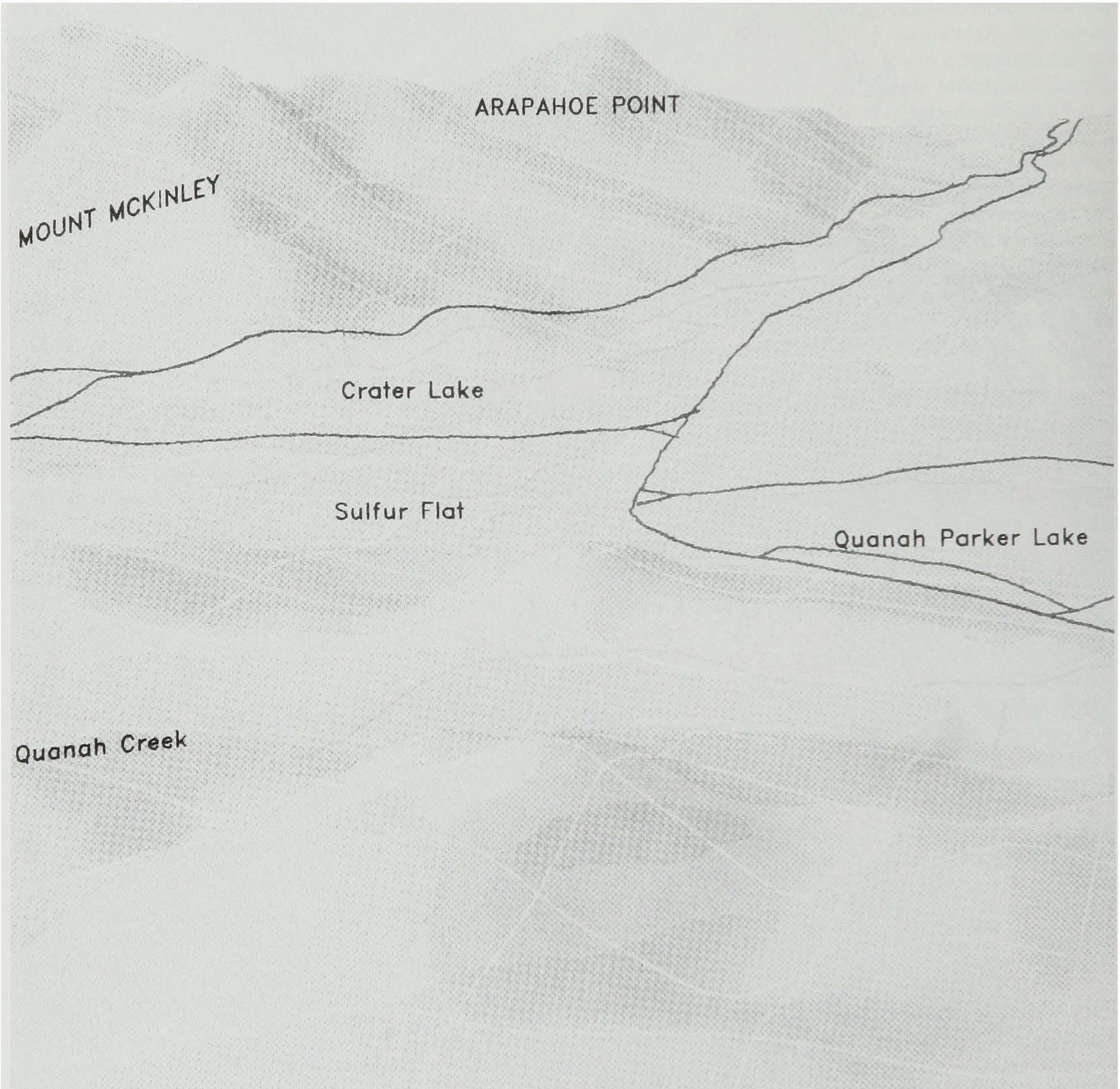
At that time, Automated Cartography Branch engineers also initiated a contract with the Research Institute of the Illinois Institute of Technology at the Electromagnetic Compatibility Analysis Center to develop production software from the experimental USAETL perspective software. The production software for DMA produced annotated perspective line plots from DLMS data. This software, delivered in 1981 and 1982, was installed on DMA's Univac 1108 production mainframe computers. The same software was used by Automated Cartography engineers to produce the annotated perspective view of San Francisco shown on page 79.[10]

Working with West Point

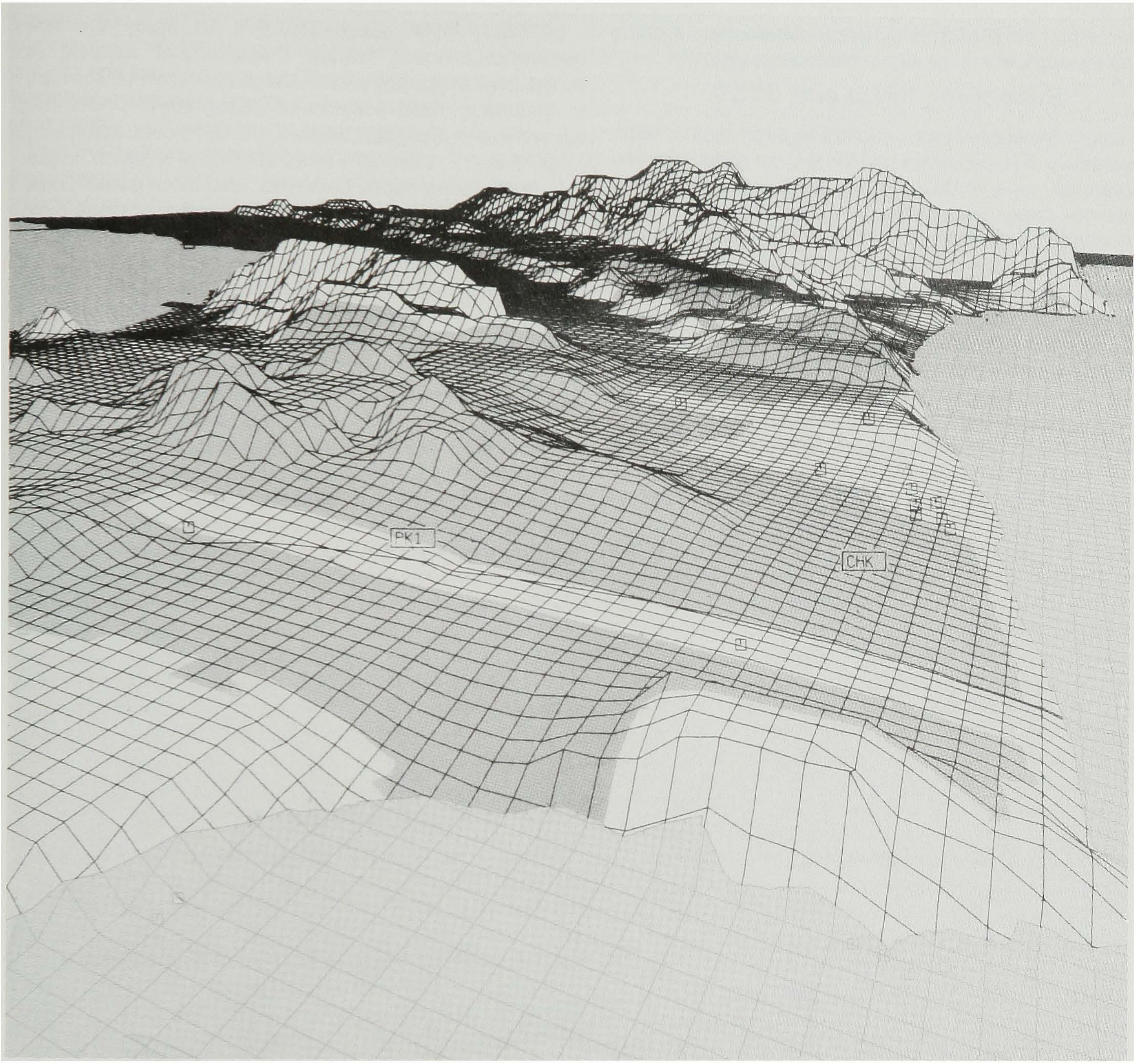
Meanwhile, in a related development, West Point cadets selected for a special summer training program in computer-graphics work at the Automated Cartography Branch began work to convert this software and the cartographic data base from vector to raster format for application on USAETL's DeAnza color graphics display system, where 3-D views could be shown with analytical hill shading. The original DeAnza work employed the Cache data base and specialized polynomial terrain modeling (vector) software developed at USAETL. The West Point cadets, working at USAETL, developed new raster software to read digital terrain matrix data (DTED Level 1) from DMA and output it in modified form to a disk file for employment with experimental map software. In the summer of 1983, a software contract was awarded to modify USAETL's shaded perspective image generation software so that it could employ data using this new raster format instead of the polynomial terrain data. Using this modified software, a data base was developed for the Fulda Gap area of West



Oblique map of Cache, Okla.



Perspective view of Cache, Okla.



Perspective view of San Francisco, Calif.

Germany, and a set of color, 3-D views were generated on the DeAnza. These views were then recorded on video disc and, along with similar recordings of the Cache area, became part of USAETL's on-going demonstration of the mapping applications of video-disc technology.[11]

Supporting FEED and DTSS

Another simultaneous development effort by the same group of USAETL engineers and West Point cadets created software to superimpose aircraft flight paths and radar coverage zones on oblique, perspective and plan (orthogonal) views of terrain as an aid to planning low-level flight paths in hostile territory. The software generated four views: oblique with aircraft flight path superimposed, plan with radar units sited and aircraft flight path superimposed, plan showing the interaction of the radar coverage and flight path, and a profile plot of the flight path with respect to the terrain. A subsequent task added a cruise-missile route analysis display which combined oblique and plan views of annotated terrain and provided real-time simulation of terrain-masking effect on radar sweeps. Finally, software was written to adapt these programs to the DeAnza color system in raster format, and to provide four simultaneous displays or "windows" on a single display screen, in this case, the high-resolution Tektronix 4014 display associated with the DeAnza. Software was completed to create 360-degree continuous panoramic scene generation from elevation data. Hard-copy color graphics were produced by means of a color CRT camera.[12]

A vector format version of this and other perspective view software was selected for incorporation in the FEED demonstration project and both raster and vector software were delivered to the Geographic Sciences Laboratory at USAETL to serve in the development of the (DTSS).[13]

Thus, the experimental map graphics program at USAETL served diverse needs, and at the same time demonstrated to audiences in the mapping community and the Army in the field the flexibility and improved map comprehension made possible by the new art of computer graphics.

Line generalization and feature displacement

The problem of compromising scale and detail represented another application of the art of cartography. Significant features could not always be shown in exact scale or in their exact locations due to the limitations of map size and scale. So over the years, a series of cartographic rules evolved which stipulated how outlines were to be generalized and which adjacent features were to be displaced for clarity in presentation. Interpreting these rules, drafting the appropriate lines and placing the feature symbols were major tasks for cartographers whether working on manuscripts for lithographic maps or manipulating computer graphics on a CRT display. According to a USAETL publication, line generalization and feature displacement required "the skills of a trained cartographer, one familiar both with the 'look of the land' and the limitations of the graphic arts."[14]

In 1981, DMA asked USAETL to study the line generalization and feature displacement aspects of subjective cartography and to design experimental software to automate these aspects of cartography. Under the supervision of Douglas Caldwell, USAETL contracted with ZYCOR Inc., to conduct a three-stage investigation. In the first task, researchers observed and interviewed DMA cartographers to investigate the decision processes they used in exercising cartographic license in generalizing lines and displacing features, and surveyed DMA requirements for automated software. A second task required a general survey of existing techniques for automating line generalization and feature displacement. Finally, recommendations were made for automating these cartographic activities at DMA. The final report, delivered to USAETL in 1983, identified seven methods of generalization which might be appropriate for use in map production: angle detection, mathematical fitting, epsilon filtering, low-pass filtering, tolerance bands, point relaxation and digital elevation matrix smoothing. Researchers reported that available algorithms for automatic feature displacement were not sufficiently developed to allow their use in map production. But techniques employed in automated circuit design did appear to offer a potential solution in the long term. Beginning in 1984, Caldwell initiated tests of the line-generalization algorithms to determine their usefulness in digital map production and to help develop specifications for line-generalization software.[15]

4. Editing Digital Cartographic Data

DMA had an ongoing need to develop editing systems for the evolving digital cartographic process. This account has already addressed both hardware and software systems developed at USAETL to perform editing during the preprocessing stage of digital terrain-data compilation, including the Elevation Data Edit Terminal (EDET), the Topographic Finishing Station (TFS), various raster-to-vector and contour-to-grid procedures, and the Geographic Names Input Station. Other interactive, computer-graphic work stations in use at DMA in the early 1980s included the TES-EMPS, an Intergraph system for editing Digital Terrain Elevation Data and Digital Feature Analysis Data (DFAD) in terrain matrix and vector formats, and the SCITEX color raster processing system. The key to this variety of editing stations was the wide variety of source data for digital cartography. EDET, for example, checked the accuracy of elevation matrix data automatically compiled from photographs; TFS was aimed at the quality control of elevation matrices and contours compiled from digital imagery; the TES-EMPS accepted input from automatic compilation equipment, digital-image processing equipment, tag entry systems for names and alphanumeric symbols and both raster scanners and vector-type digitizing systems; the SCITEX was used to update and modify existing color maps by putting them through a raster scanner and then editing the files to change names (e.g. from other geographic names systems to the DMA format), cartographic symbols (e.g. primary roads) and colors.

To make a hard-copy map from these digital files required the creation of a series of digital overlays, each containing one class of data, such as contours, roads, drainage, and polygons of different color for lakes, fields, forests, cities, etc. In the 1970s, USAETL developed the Digital Input/Output Display Equipment (DIODE) editing station for DMA to address some of these concerns.[16] But DIODE hardware was rapidly overtaken by commercial graphics work stations, such as the Intergraph. Moreover, neither DIODE nor any of the commercially available editing systems were equipped with software that could perform final device-independent edits of digital files created for cartographic (hard-copy) production. These files could be of three kinds. They might contain only centerline data consisting of feature traces and elevations as a digital counterpart to a manuscript draft of a map. They might also contain the fully symbolized map data, with appropriate distinctions between primary and secondary roads, etc. Or, they might contain only raster (pixel) data specifying gray shades or color. These files were designed for output to a hard-copy device, such as a plotter, or to a digital data base for later use. Before they were output for printing or storage, the files required editing by a cartographer who could check the accuracy of the topographic data, the correctness of the labels, the symbols and the gray shades or color scheme, and the congruency of the different overlays.

The DMA Aerospace Center asked USAETL, in 1978, to create an edit station which could perform these cartographic editing tasks on color map separations. The equipment was to be designed to draw on data formatted in a variety of ways, including DTED and DFAD, as well

Digital Input/Output Display Equipment (DIODE).

The Advance Edit System (AES) equipment.

as data for the CRT printhead, Gerber photohead and color raster plotters, and data from the Graphics Line Symbolization System and the Broomall Scan Graphic Automatic Graphic Digitizing System (AGDS). The latter is to include both vector and tag data.[17]

The Advanced Edit System (AES) project was assigned to John Garlow of the Automated Cartography Branch in 1979, and the equipment and associated software was delivered to the Aerospace Center in 1982 for testing and eventual integration into the production of maps and charts.[18]

AES hardware capabilities

The off-the-shelf hardware of the AES included an Intergraph interactive graphics system with both vector and color raster work stations, supported by a PDP 11/70 minicomputer, on-line storage and an Intergraph Disc Data Scanner. The PDP 11/70 was equipped with 256 kilobytes of random access memory, a cache memory and a 64-bit floating point processor. The on-line storage units were two 300-megabyte disk drives, each with a removable disk pack and rapid data-transfer capability (1.209 million bits per second). The Data Disk Scanner (DDS) was a direct memory access device "capable of searching millions of words of disk memory, at maximum disk-rotational speeds, to locate any desired set of display vectors or elements without burdening the central processing unit (CPU—the PDP 11/70) with [the task of] reading and comparing each element with desired values. . . . Data may be retrieved 10 to 30 times faster with a DDS than under CPU control only."[19]

This hardware made it possible for an operator to call up on the screen any combination of digital files representing map overlays (e.g. contour lines, drainage, roads and miscellaneous features) and display them simultaneously at a nearly 1:1 relative scale relationship with the intended output, including line weights, spacing and positions. For fine detail work, the system had a 60:1 zoom capability and the color raster work station an additional capability for enlarging (by a factor of eight) and moving a definable window on the screen.[20] Thus, an operator could check a series of files of digital overlays for overlapping lines and other graphic errors and make the necessary corrections in each file.

A multifaceted "interface"

The distinctive feature of the AES was software written by Sonicraft Inc., of Chicago. This software converted data from a variety of DMA formats to the Intergraph standard interchange format system for interactive editing, and then converted the data back to the desired formats for final printing or storage. It gave the AES a multifaceted capability to tie together or "interface" different DMA digital data production and output systems.

As delivered to the Aerospace Center in 1982, the software could handle input from the Graphics Line

Symbolization System (GLSS) as formatted for a Gerber plotter, modified (raster format) GLSS data for a raster plotter, modified GLSS data for the CRT Printhead, tag and vector data from the Broomall system (AGDS), and Digital Land Mass Simulation (DLMS) data in both DTED and DFAD formats. All of these data could be edited and then reformatted as GLSS data, DLMS data or plotter data for either the CRT Printhead or the Raster Plotter Systems. A contract modification was approved in September 1983 to add the ability to input and output text on the AES for the Gerber 4477 plotter and the CRT Printhead. Other potential routines for the AES included input and output for CALCOMP, XYNETICS and ZETA plotters as well as both older and newer model Gerber plotters. Thus, the AES offered DMA the capability for editing a wide variety of files in a wide variety of formats to create cartographic data bases for many different hard-copy products.

Footnotes

1. John T. Pennington, *History of U.S. Army Engineer Topographic Laboratories 1920-1970*, Fort Belvoir, Va., USAETL, 1973, pp. 242-244; Dr. Edward C. Ezell, *ETL History Update 1968-1978*, Fort Belvoir, Va., USAETL, 1979, pp. 23-24.
2. Ezell, pp. 24-26, 30-31.
3. Installation files, Topographic Developments Laboratory, Mapping Developments Division (TDL-MDD), Historical Summary, 1979-1983; Resource Planning Associates, "Study of Raster Metafile Formats," USAETL Report 0363, January 1975, pp. 1-5.
4. "Experts Study Subjective Thought," *Tech-Tran*, Vol. 7, No. 4 (Fall 1982), p. 1. Quarterly technology transfer newsletter published by USAETL.
5. Ibid.
6. Interview, authors with George Simcox, Fort Belvoir, Va., 16 October 1984.
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8. Installation files, TDL-MDD, Historical Summary, 1979-1983.
9. Ibid.
10. Ibid.
11. Ibid.
12. Ibid.
13. Ibid.
14. *Current Research and Development*, 1985, (draft), p. 15. USAETL in-house document scheduled to be published every two years.
15. Instation files, TDL-MDD, Historical Summary, 1981-1983; interview, authors with Douglas Caldwell, Fort Belvoir, Va., 10 September 1985.
16. Ezell, pp. 32-36.
17. Kenneth Karow, " The Advanced Edit System," (Sonicraft Inc., USAETL-0295), January 1983, passim.
18. Installation files, TDL-MDD, Historical Summary, 1979-1983.
19. Karow, p. 5.
20. Ibid., pp. 8-9.

F. Preparation for Press and Printing

A cartographically correct digital file could not be simply handed over to the lithographic printing departments at DMA. Rather, yet another stage of interfacing and editing was required to prepare the files for output to computer-based reproduction systems—so-called hard-copy devices—and to create color proofs to guide the printers. In 1983, the Automated Compilation Branch of USAETL's Mapping Developments Division began work toward the development of an integrated prepress cartographic data processing system called the Digital Pre-Press System (DIPPSY). The project was envisioned as providing another link in the chain of processing stages proposed for making maps and charts from digital topographic data. It aimed at building an advanced development model of the hardware, software and firmware required by DIPPSY by 1987, under the direction of USAETL engineer David Scott.

1. The Digital Pre-Press System (DIPPSY)

The DIPPSY, which incorporated some earlier USAETL work on digital screening, half-toning and color proofing, started in connection with the Digital Laser Platemaker. But for the most part, new developmental work was required. DIPPSY was to include four modules:

1. Hardware and software for composing digital color separation files (for making map products) from digital cartographic files in formats required by DMA graphic arts production equipment.
2. An interactive color raster-graphics work station for reviewing and editing the automatically composed files.
3. Firmware—special routines embedded in computer circuits—for screening and half-toning the digitally composed map-product imagery.
4. Hardware and software for creating, from digital files, the color proofs used in printing to evaluate and correct the color separations which, when overlayed on each other, create the final color map. These proofs are also used by press operators as guides to toning and printing final map products. The "Large-Format, High-Resolution, Cartographic Multicolor Digital Data Proofing System," or more simply, the Digital Color Map Proofer, would create a softcopy (CRT) display from DIPPSY files for such editing and quality control uses.

The digital composition hardware and software represented the core of DIPPSY. As planned, it would automatically create raster files containing the appropriate map symbols and color shades and then transmit the data in compressed form to a hard-copy device for direct printing or for making color separates on film. This would be used for making lithographic press plates. The DIPPSY composing module would accept data from a variety of DMA cartographic files. For instance, it would be able to take vectorized data in the DMA Standard Linear Format (SLF) and text files, convert these into raster format, and compose the data to meet particular map product specifications. DIPPSY was planned to support the production of maps as large as 44 by 60 inches with a printed copy resolution of at least 1,000 lines-per-inch.

2. Hard-Copy Devices

During the period covered by this history, USAETL engineers worked on three developments for taking digital cartographic data and turning it into lithographic press plates or final map copy. These were the Digital Laser Platemaker, the Filmwriter and the Quick Response Multicolor Printer.

The Digital Laser Platemaker was an Advanced Development project to create prototype equipment which could make press plates directly from digital data. The technology was successfully demonstrated but DMA decided the equipment was not needed. A principal rationale for etching press plates with a laser was that this step bypassed the film preparation stage of then-current DMA production procedures. As the cost of silver halide film rose during the late 1970s, DMA expressed an interest in technology to reduce the time and cost for making lithographic press plates.

The Digital Laser Platemaker, begun in 1978, was USAETL's response. The development was carried out under contract with EOCOM, a California company considered a leader in the field of laser platemaking. The equipment exposed large format, 48 by 60 inch plates using a 15-watt Argon-Ion laser controlled by a minicomputer. The system offered the option of writing images to film for archival storage. Prototype equipment was delivered to USAETL in 1981 for testing.

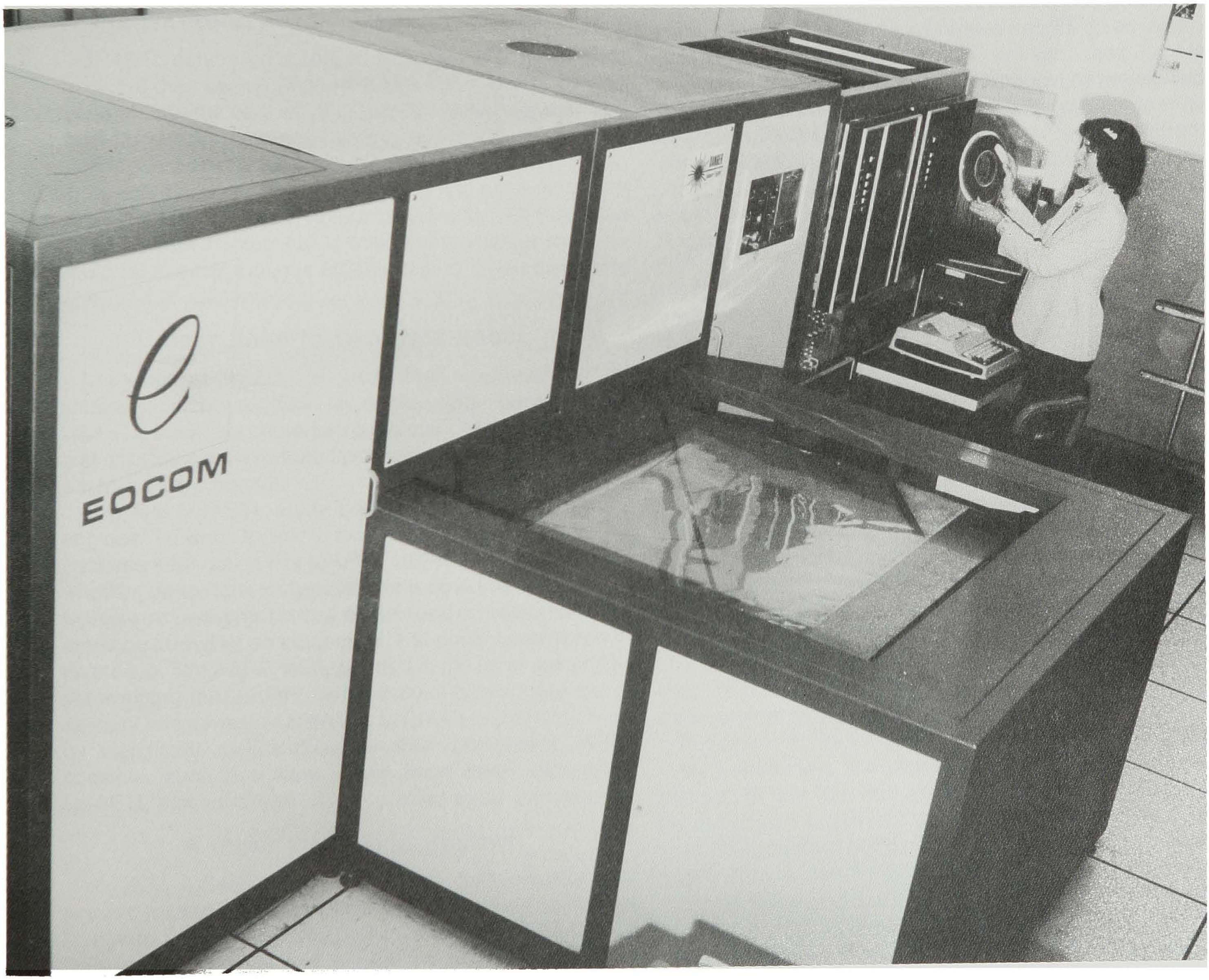
In 1983, the testing led to proposals for modifying the system, and a contract was awarded to Technology Applications Inc., to make changes to the semi-automatic mechanism which loaded plates or film into the platemaker for exposure. The project was cancelled by DMA in 1984, in large part because the cost of silver halide film fell, eliminating most of the savings expected from the production use of such equipment. The project resulted in one prototype, located at USAETL, a number of demonstration plates and a report, summarizing work on the project.[1] USAETL engineers planned to use the prototype equipment as a testbed for developing a high-speed, large-format filmwriting system, known as the Filmwriter.[2]

The Filmwriter project was initiated at the end of 1983, under the direction of David Scott, and was expected to result in a hard-copy device tied into the DIPPSY. Its purpose would be to write digital map and chart images on large-format lithographic film using data previously composed and formatted on DIPPSY. The imagery was expected to have a resolution of at least 1,800 lines-per-inch. The film would then be used to produce press plates.[3]

Large-Format Color Xerography was an alternative to lithographic presses, which were used by DMA for large volume production of maps and charts, to make small press runs. USAETL engineers working for the Army in the field on the Xerox Corporation's digital laser color printing equipment known as the Quick Response Multicolor Printer also conducted a study during the 1979-1983 period on the feasibility of producing a large-format QRMP for DMA use. Like the QRMP project itself, this study continued past the period covered by this report.[4]

3. Filmstrip Verification System

In yet another quality control project, USAETL began work, in 1983, on a Filmstrip Verificaton System for DMA. The equipment would allow enlargement and precise



The Digital Laser Platemaker.

measurement of DMA filmstrips, used as aircraft navigational aids, before they were shipped to users. These filmstrips provided to air crews were displayed on multipurpose CRTs aboard aircraft by means of electronic scanning devices. They contained extremely dense information: a typical 60-foot 35mm filmstrip might contain five different chart scales and cover 4.5 million square miles (an area greater than the continental United States) at a scale of 1:2,000,000 as well as 2 million square miles at a scale of 1:500,000. The Filmstrip Verification System would allow an operator to simulate on a computer console the positioning commands which drive the filmstrip display in the aircraft, enlarge the film image and allow precise measurement of film position. USAETL planned to deliver the production-ready system to DMA's Aerospace Center in early 1986.[5]

Footnotes

1. Interview, authors with David Scott, Fort Belvoir, Va., 10 September 1985.

2. Technology Application Incorporated, ''Digital Laser Platemaker Modifications,'' Fort Belvoir, Va., USAETL Report No. AD-A150190, December 1984.

3. Installation files, USAETL ''Lab of the Year'' submission (U.S. Army competition), 1984.

4. Ibid.

5. Ibid.

G. Distribution

After the Defense Mapping Agecy (DMA) prepares the digital data bases, maps and charts needed by the military services, it must distribute them to users. Paper maps and taped digital topographic data files, however, are bulky objects in the quantities needed by military users, their distribution is relatively slow, and they become outdated. During the period of this history update, USAETL engineers worked on several projects designed to speed distribution and reduce the bulk and weight of map collections.

1. Transmitting MC&G Data

USAETL continued its effort, in 1979-1983, to improve its digital data bases. Implied in this effort, however, was research into the best ways of providing user access. The most complete mapping, charting and geodetic (MC&G) data rendered in the best imaginable form is of no help to a lost soul halfway around the world if it is not sent to him or is sent to him too late. For just this reason, DMA tasked USAETL with finding out if telecommunication systems could be used to transmit MC&G data to DMA customers with greater efficiency.

User links to two data bases

Looking at ways to test the applicability of telecommunication links to digital data transmission, USAETL scientists chose two particular DMA data bases—both providing cases where improved user-data base linkup would be very helpful.

The first USAETL study began in 1979 under project engineer William Opalski to look into DMA's Automated Air Facilities Information File (AAFIF). USAETL wanted to know whether up-to-date air facilities data could be transmitted to users on their present-day equipment, on equipment that could be added or on equipment that could be adapted to do the job. The AAFIF study pointed to the latter possibility, determining that AAFIF users could only put together an efficient telecommunication link to DMA's digital data base by significant modifications to their computers. While possible, such a system would have been expensive. USAETL's second user linkup proved more promising.

A more promising system

In 1982, USAETL's work on data transmission was pointed toward a second DMA data base, the Automated Notice to Mariners (ANMS). The Transmission of MC&G Data work unit had already completed a study, contracted to the Electromagnetic Compatibility Analysis Center (ECAC) in Annapolis, Md. ECAC had recommended a pilot program to demonstrate electronic transmission of MC&G data in the ANMS—with a more promising prognosis than in ECAC's look at the AAFIF system. USAETL saw ways to improve the ANMS by improving its electronic linkup, thereby demonstrating the possibilities for electronic transmission of MC&G data.

The DMA Hydrographic/Topographic Center (HTC) established the ANMS to publish a monthly notice to mariners using collected navigation hazard and warning data. The Notice to Mariners was published, and eventually a computer system was set up through which authorized users could call in, give a password and be given data to update their navigation charts. In the case of the publication, such information could obviously arrive too late; in the case of the automated notice, the linkup could be a problem for a boat halfway around the world. USAETL scientists, led by project engineer John Garlow, noted that phoning DMA with multiple satellites and ground stations would work, but would also be an expensive way to do things.[1]

A remote station

USAETL had contracted its ANMS work to ECAC with the result that users, in 1982, could use the public phone system (including AUTOVON) and TWX/Telex lines to obtain up-to-date navigation information. A link to the Department of Defense AUTODIN system was also established to serve Navy ships with access to the fleet satellite communications system. The distance problem, however, remained unsolved. Having just one source of data, at the Hydrographic/Topographic Center, was sure to be a bottleneck. The pilot system envisioned back in 1979-1980 had included the need for shorter and cheaper telecommunication. USAETL scientists concluded that a remote station, or a series of them, could be designed to share the dissemination load while shrinking distance and cost. Such stations, located wherever needed, would demonstrate timely transmission of MC&G data.

At the end of 1983, USAETL was planning to turn its pilot system study into one pilot-remote station. Studies were planned to find who and where the potential users would be and what equipment these users had on the receiving end. Phase One included looking at the transfer of ANMS software to a remote station. The final stage would be reached when and if DMA decided to build and set up a system of such stations, called the Remote Automated Notice to Mariners Data Base Distribution System.

On USAETL's side, the ANMS effort was largely a

Researchers prepare special software to show the planning applications of the video disc system.

demonstration of the feasibility of transmitting mapping, charting and geodetic data; the gain to mariners was an added benefit. USAETL scientists were already turning to the question of transmitting graphics along with text. Text, such as that handled by ANMS, had been in John Garlow's view "the easy task."[2]

Graphic data distribution studies

From the outset of the ANMS study, USAETL and DMA looked to transmit as much as possible of the data available in text form in the monthly Notice to Mariners. That publication, in turn, typically contained "chartlets," little black-and-white graphics depicting complex changes that should be made to an existing chart. USAETL wanted to study the possibilities for transmitting these chartlets to users, allowing them to paste a facsimile directly onto their charts. USAETL was again looking at the transmission of MC&G data, but this time in graphic form.

Thus, at the close of 1983, USAETL's Mapping Developments Division was expanding its electronic transmission of MC&G to include graphics, but the exact direction of the research was undecided. DMA was interested in transmitting graphics, but perhaps on a more complex level than the little black-and-white chartlets. Studies into full-size (24- by 30-inch) color graphics and the attendant communications were a possibility, with USAETL continuing its central R&D role in the area.

2. Mapping Applications of Video Disc Technology

In late 1982, Mapping Developments Division engineers began an exploration of the uses of video discs for distributing and storing map graphics. These applications were of potential interest both to DMA, by providing a compact medium for distributing maps, and to the Army in the field, by providing both a compact medium for storing and distributing map graphics and a convenient means of accessing map files in the field. As a USAETL Fact Sheet on this project noted, "Although video discs hold large quantities of data, they take up relatively little storage space. A series of discs, for example, can hold as many maps as a bulky filing cabinet. Video discs also ensure easy access to information; data can be located and displayed on a television monitor in a matter of seconds."[3]

There was yet another potential military benefit to be realized from the development of mapping quality video discs, especially when linked with a microcomputer which could present additional graphic and text information overlayed on the video map. The compactness and low cost of the video disc playing equipment and microcomputer controller offered the possibility of distributing such systems widely within the ground combat forces. It might be possible to package such a hybrid video/digital graphics system in two or three suitcases. The microcomputer with video disc player offered the promise of extension to lower echelons, closer to the actual battlefield, giving the commander the means for battle planning.[4]

Many potential users

Finally, USAETL engineers anticipated many civil applications for the same technology. To quote from the same fact sheet, "an interactive video map system featuring city and county data would, for example, provide a flexible planning tool for local governments. Data on street plans, building layouts, zoning, utility and sewage networks, population distribution and transportation routes would be available at the touch of a button. Planners could generate graphic overlays to plot future development or compare alternative growth strategies."[5]

The approach taken by USAETL to video-disc mapping paralleled the combination of research and show-and-tell used in other USAETL projects such as the Field Exploitation of Elevation Data van.[6] By assembling a demonstration model and representative video discs, USAETL engineers could generate interest beyond the laboratories in the project while testing the shortcomings of off-the-shelf technology and draw up plans for needed improvements. A library of video disc maps and related planning material was collected both for demonstration purposes and for evaluating the resolution of video graphics as applied to mapping. Daniel Costanzo of the Automated Cartography Branch of Mapping Developments Division directed this project.[7]

The map video processing system

In 1983, following an initial survey of the available technology, USAETL acquired from On-Line Systems Inc., a test-bed map video processing system featuring a laser-optical video-disc player interfaced with an eight-bit microcomputer. Both were connected to a television monitor offering touch-screen control and computer-graphic overlay capability. USAETL engineers wrote software for the system to permit touchscreen controls for rapid panning of images and zoom enlargements, simultaneous registration of maps and aerial photographs of the same terrain, and the ability to overlay graphics and text on a video image.[8] Software developed elsewhere at USAETL for generating three-dimensional perspective views from digital terrain data was adapted to work with a microcomputer-controlled data base.[9]

In 1982, USAETL worked with the U.S. Army Engineer Water Resources Support Center and the U.S. Geological Survey to produce an experimental cartographic video disc. The imagery on the disc included Landsat images, aerial photographs, maps and charts of Cache, Okla., including USAETL's experimental maps. A subsequent video disc, created in 1983, recorded cartographic and other data on the Columbia River basin, other regions of the U.S., parts of the Middle East and the Fulda Gap area of West Germany. The latter included experimental color perspective views generated by West Point cadets working with USAETL equipment, as well as military symbols, allied and Warsaw Pact order-of-battle data, and other information needed for the situation maps and doctrinal templates (military planning overlays) required for Intelligence Preparation of the Battlefield work.[10]

Continuing studies

During 1983, USAETL engineers used this hardware, software and disc library to conduct demonstrations at USAETL and at various conferences. A graphics design study was undertaken on contract with Dr. Judy Olson to determine how best to place standard map products on video discs and how to design future map products to take maximum advantage of video-disc technology. A microcomputer-controlled image digitizer was acquired for study in connection with the system. Among the problems encountered in USAETL's video-disc research were the relatively poor resolution of commercial video recording technology and the orientation problem created by the inability of a standard size CRT to display more than a small fraction of a large map in a readable scale at any one time.

Planned work for the future included an investigation of an experimental hybrid disc capable of storing both video (analog) signals, and digital imagery and data.[11]

Footnotes

1. Interview, authors with John Garlow, Fort Belvoir, Va., 8 October 1984.
2. Ibid.
3. Installation files, Topographic Developments Laboratory, Mapping Developments Division (TDL-MDD), "Video Disc," in-house document (unpaginated).
4. For an account of the evolution of DTSS development at USAETL, see p. 14.
5. "Video Disc", (unpaginated).
6. See "FEED: The Virtues of Digital Elevation Data," p. 3.
7. Installation files, TDL-MDD, Historical Summary, 1983
8. Installation files, USAETL "Laboratory of the Year" submission (U.S. Army competition), 1984, p. 18.
9. Installation files, TDL-MDD, Historical Summary, 1983.
10. "New Demo Planned," *Tech-Tran*, Vol. 9, No. 2 (Spring 1984), p. 3. Quarterly technology transfer newsletter published by USAETL.
11. Installation files, TDL-MDD, Historical Summary, 1983.

V. Special Projects

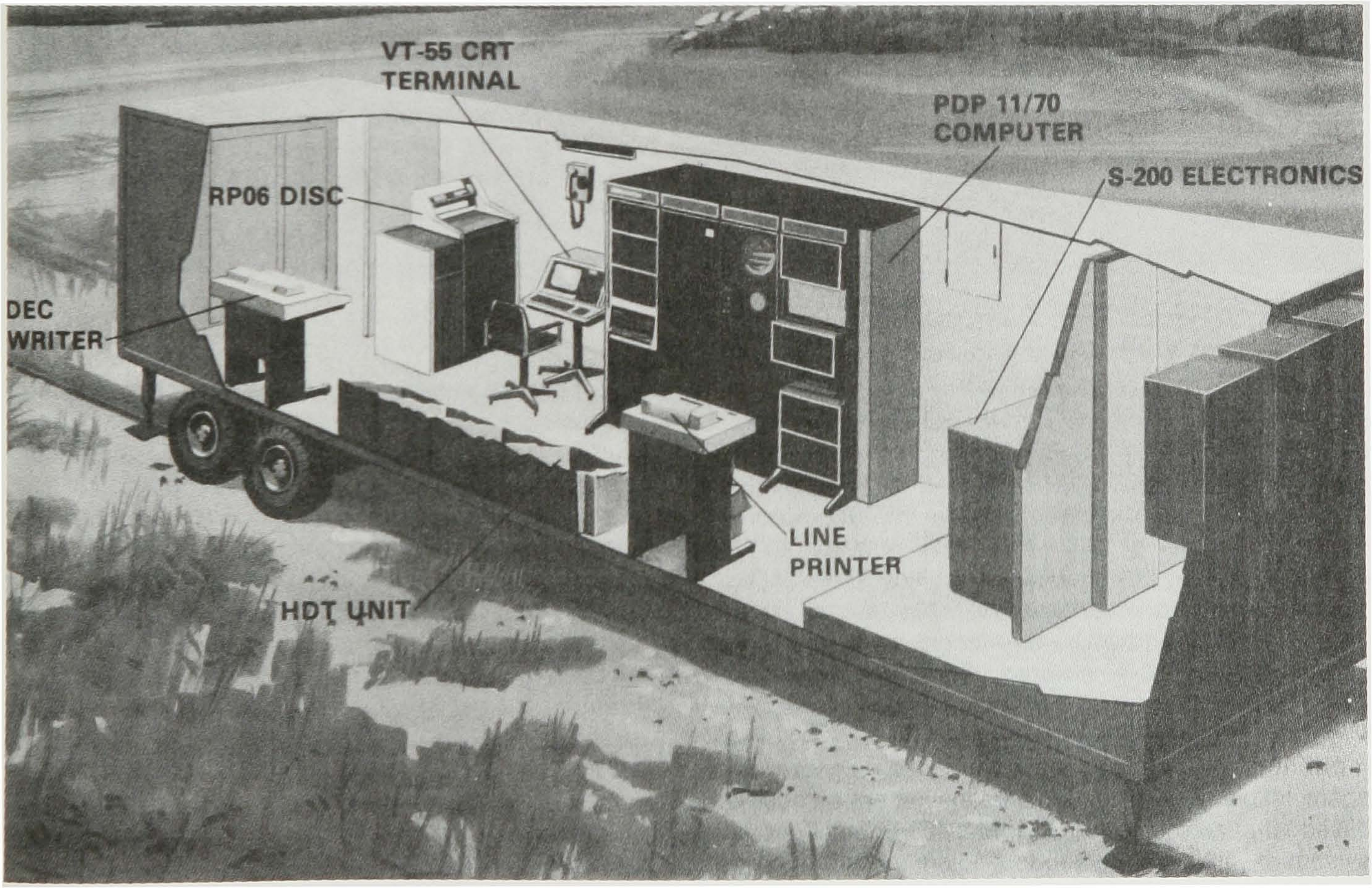
A. Digital Image Analysis in Support of the Tactical Commander

By far the most successful of the many show-and-tell projects carried out at USAETL between 1979 and 1983 was the version of the Digital Image Analysis Laboratory (DIAL) in a van known as DEMONS (for Demonstration System). For the first time, DEMONS allowed the Army in the field to analyze digital images of an enemy's second echelon positions in near real time. Working in near real time, Army operators use DEMONS to identify targets, provide their coordinates to field commanders and keep a running digital record of an enemy's moves.

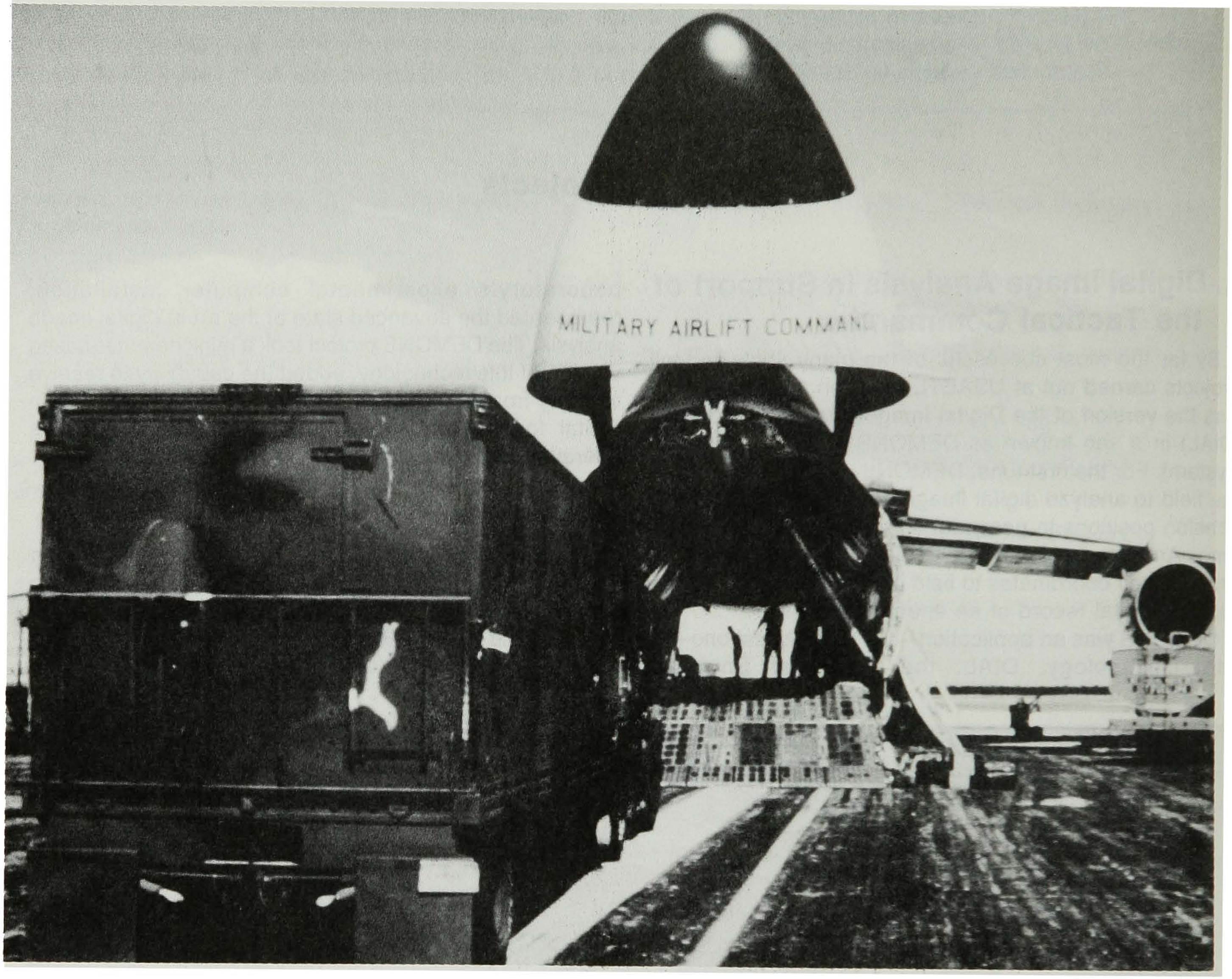
DEMONS was an application—the first tactical one—of DIAL technology. DIAL, the Computer Sciences Laboratory's experimental computer installation, represented the advanced state of the art in digital image analysis. The DEMONS project took a minicomputer-based version of this technology, added the capability to receive imagery from tactical aircraft, and placed this imagery in digital form in the hands of Army image interpreters operating in the tactical battlefield.

A critical link

The DEMONS prototype demonstrated a critical link in the new "see deep, strike deep" technology being developed to support the Army's new fighting doctrine known as the AirLand Battle. The significance of DEMONS rested on two parallel developments, then concurrently



Artist's concept of the DEMONS van in the field.



The DEMONS van en route to participate in an exercise in Europe.

underway in the Defense Department, which promised to radically alter the way future battles would be fought. The Army planned to field a variety of new rocket systems for attacking enemy positions at distances far beyond the traditional limits of the Army battle area. These weapons extended the reach of an Army Corps from the 20-30 kilometers provided by conventional artillery to distances of 100 kilometers and more. Packed with hundreds of small, terminally guided warheads, they could be used in all weather to attack mobile-armored enemy formations and supply columns waiting to reinforce the battle—a mission that previously could be carried out only by fighter and bomber aircraft and usually only in clear weather. Simultaneously, new, all-weather sensors were being installed in tactical aircraft with real-time data links to ground receivers. DEMONS technology helped link these capabilities together to provide an integrated means of finding, identifying and locating mobile targets deep in the enemy rear, scores of kilometers behind the forward battle line, without risking manned aircraft and pilots in this dangerous mission. DEMONS also represented one of the first prototypes of a possible new family of computerized Army battle management systems; a later version was planned for inclusion in the Army's projected All-Source Analysis System. Together with the new deep-strike rocket systems and new sensors, these new data-processing capabilities promised to redefine the time-space geometry of the battlefield.[1]

DEMONS configuration and field testing

The DEMONS system, as first assembled, used the same equipment as the DIAL high-speed work station, namely, a PDP 11/70 minicomputer, two high-density magnetic tape decks and a COMTAL S-200 display system with two

512 by 512 pixel displays and one 1024 by 1024 high-resolution display. This equipment was installed in two vans. DEMONS software was based on DIAL software developed at USAETL. As the DIAL high-speed work station evolved, parallel changes were made in the DEMONS vans. The major equipment upgrade involved the installation of the COMTAL Vision One/20 system, developed for USAETL in 1982. Further improvements were planned, including the replacement of the PDP 11/70 with a VAX minicomputer.

The DEMONS was assembled in 1979. In October of that year, it was used in a demonstration which included the capability of displaying and manipulating digital imagery received over a communications link. In 1980, the system was modified to interface with the Army's Battlefield Enhancement of Target Acquisition (BETA) system. Thus modified, the vans were flown to Germany in October 1980 as part of the annual REFORGER (Reinforcement of Forces in Germany) exercise, and participated in the subsequent SHOCKWAVE experiment, demonstrating the capability to provide rapid intelligence information.

DEMONS was next assigned to the Digital Imagery Test Bed (DITB) supporting the XVIII Airborne Corps at Fort Bragg, N.C. From there, it participated in the 1981 BOLD EAGLE exercise at Eglin Air Force Base, Fla., returning to Fort Bragg in 1982 after installation of the Vision One/20 system by DBA Systems Inc., Melbourne, Fla. In 1983, the equipment was modified by the installation of a Voice Recognition Module. This allowed the operator, an Army image interpreter, to keep his eyes on the cathode ray tube screen while using his voice to control image operations (such as scrolling, magnification, warping, etc.) and to input data into the computer. The DEMONS was used at Fort Bragg by the 525th Military Intelligence Group, 1st Battalion and 17th Military Intelligence Detachment to produce battlefield information to train operators.

First of many

For USAETL, DEMONS represented the first of many related projects. The several successful demonstrations of DEMONS rapidly produced an expanded USAETL program in support of the Army Space Program Office (ASPO). This expanded program included the engineering development of classified equipment and software to provide a fieldable digital-image-analysis work station capable of receiving and processing imagery and other data collected by new battlefield sensors. A related project for ASPO, the Advanced Synthetic Aperture Radar System (ASARS) Interface Device, got underway at the end of 1983. As described in the USAETL Laboratory of the Year 1984 submission, this device "will allow Army field intelligence systems to exploit Air Force radar data from the TR-1 aircraft program." The TR-1 was a tactical intelligence collection platform based on the high-flying Lockheed U-2 aircraft. USAETL's work on this program represented "a major cooperative effort between the Army and Air Force—one which will significantly strengthen the Army's tactical intelligence capabilities."[2]

Footnotes

1. During the late 1970s, Army strategists came to believe that the combination of a forward defense and well-timed strikes against enemy reinforcements moving toward battle gave the best assurance of reducing the long-standing odds against a successful conventional defense of NATO's Central Region (the West German border). This view was subsequently given voice in the AirLand Battle doctrine declared in the 1982 edition of Army Field Manual 100-5, "Operations." The new doctrine stated (in the words of a team of authors at the National War College) that the Army commander must fight two battles "simultaneously and in close coordination: the forward battle against committed units, and a deep battle against uncommitted forces both to delay and disrupt their commitment to the forward battle and to create opportunities for subsequent maneuver against them." The new doctrine, by reasserting the responsibility of the ground commander for fighting a battle extending both in length (along the front) and in depth (to the enemy's rear), effectively redefined and greatly enlarged the battlefield. Boyd D. Sutton, John R. Landry, Malcom B. Armstrong, Howell M. Estes III and Wesley K. Clark, "Deep Attack Concepts and the Defense of Central Europe," *Survival*, The International Institute for Stategic Studies, March/April 1984, pp. 53, 70.

2. See Installation files, "Laboratory of the Year" reports (U.S. Army competition), 1979-1984, passim.

B. Reference Scene Generation for the Pershing II

In December 1983, the Army acquired the first of a planned new generation of robotic weapons systems resulting from the completion of 10 years of high-priority research and development by USAETL engineers. The project resulted in the deployment of the first operational Pershing II (PII) missiles in West Germany. For USAETL, the success of the PII project ended an intense effort to meet demanding program deadlines—an effort that was acknowledged by the Army and the Defense Mapping Agency in achievement awards for two PII project engineers, Anthony Stoll and Donald J. Skala. The wider significance of the USAETL effort can be gauged by the fact that President Carter, in 1980, assigned the nation's highest defense priority—DX—to the Pershing II project (a distinction it shared with the XM-1 tank and the M-X missile).[1]

A breakthrough in accuracy

The PII's rapidly retargetable terminal guidance, the first for a ballistic missile, gave it unprecedented accuracy. This gain in accuracy shrank the average aiming error by a factor of at least 10, giving the PII real improvement over its medium-range predecessors. The PII's remarkable accuracy was produced by providing the missile's guidance computer with a digital radar simulation of the target and a line radar picture of the ground. The computer matched the radar picture and the radar simulation and issued steering instructions to the missile's flight controls. USAETL's Topographic Developments Laboratory reported in 1983 that the Pershing II's "technique of missile guidance is a major breakthrough in topographic technology and promises to lead to other equally sophisticated gains in the field."[2]

The thinking missile

Like artillery shells and "dumb" bombs, most ballistic missiles are prisoners of inertia. Once fired, they follow a mathematically prescribed path from launch to target, with an accuracy largely dependent on the aerodynamic design of the weapon and on the shooter's knowledge of where he is, where the target is and the compass direction or azimuth from shooter to target. Even when the shooter knows where he is in relation to the target, missiles can be pushed off course by small variations in launch speed and atmospheric buffeting; to correct for these midflight errors, modern ballistic missiles employ inertial guidance systems which can adjust the flight path to bring the missile back on its intended ballistic course. But inertial guidance cannot correct for mistakes made by mapmakers or missile crews. For this reason, mobile missiles tend to be less accurate than fixed missiles. The launch points of mobile missiles, unless preplanned, cannot be located to the same degree of accuracy, because precise survey is a time-consuming task.

Pershing II, a "smart" mobile missile, is designed to overcome the limitations of its type. Inertially guided at launch, in the last few seconds of flight it is under the control of a computer which correlates a digital radar simulation stored in its memory with images "seen" by a radar in the nose cone, calculates the course adjustments needed to bring the missile warhead to within a few dozen feet of the precise center of the target, and issues appropriate commands to rocket engines which steer the descending missile. PII's "brain" checks and corrects the missile's course many times in the last few seconds of flight before impact. Thus, PII becomes for a few seconds of flight a thinking robot.

The operational benefits of such terminal guidance are numerous. The missile launchers can be moved from location to location without degrading accuracy. Its operators can "shoot and scoot," increasing their chances of survival. PII accuracy could offer, for the first time, the practical choice of using a conventional warhead for certain targets. In the PII, these benefits flow from the use of the map-reading capability in the missile's guidance system.

Machine-readable maps in a map-reading machine

The "thinking" robot that guides the PII missile during its terminal flight consists, in part, of a map-reading, image-correlating machine that is in reality a specially designed computer routine and a machine-readable map or, more accurately, a sequence of such maps. The maps which guide this robot are known as reference scenes. These reference scenes are digital representations of landforms and buildings as they would appear to a radar of the type installed in the Pershing II. USAETL's Special Projects Division, between 1979 and 1983, developed and oversaw the production of the reference scene system, which represented, among other things, the first use of digital topographic data in a weapon.

Evolution of reference scene technology

The technology behind both the map-reading machine and the machine-readable maps was developed in the course of efforts undertaken at USAETL and elsewhere in the 1950s, 1960s and 1970s to create mapmaking machines. Through these efforts, USAETL engineers were directly involved in the evolution of three key PII technologies—image correlation by machines, radar mapping and digital topographic data processing.

A blending of USAETL accomplishments

Like many other USAETL developments for the Army in the field during the period covered in this history, USAETL's Pershing II work can be seen as an outgrowth of its earlier efforts to automate aspects of analytical photogrammetry, map compilation and cartographic drafting—all aspects of base-plant map production. The PII project at USAETL supplied a prime example of the cross-fertilization accomplishments of combining topographic research and development efforts for the Army in the field and the Defense Mapping Agency under the same roof.

The feasibility of electronic image correlation was demonstrated in a 1964 prototype instrument which automated analytical photogrammetric tasks involving the accurate and rapid marking, measuring and recording of photo image coordinates.[3] The same technique was incorporated in the various automatic map compilation development projects that evolved into the Universal Automatic Map Compilation Equipment (UNAMACE). Indeed, the development of computer-controlled electronic image correlation was generally recognized as one of the major accomplishments of the laboratories during the 1960s.[4] During the same period, USAETL sponsored the development of a further refinement of electronic image matching, the use of digitized imagery. This research was part of an effort to develop an all-digital automatic map compiler.[5] The use of digital data in map production, as well as in its emerging tactical applications, can be seen as a development growing out of the early, successful use of digital terrain data to control a prototype automatic map plotting machine produced for the laboratories in 1960 by the Gerber Scientific Instrument Co.[6] The UNAMACE, designed to extract elevations from photography and convert these elevations into digital signals in order to drive an automatic plotting device for mapmaking, was readily converted to a production source for Digital Terrain Elevation Data (DTED) of the sort used in the PII guidance system, FIREFINDER and other weapons systems. Finally, when radar systems became capable (during the 1960s) of producing geometrically precise imagery, the laboratories began a series of studies of radar mapping which provided needed expertise in the design of PII reference scenes.[7]

USAETL's role in the PII program

By the late 1960s, the technology of electronic image correlation and of radar mapping had matured sufficiently for application to "smart" weapons projects. The Army decided to apply these tools in the terminal guidance of the Pershing II missile, a theater-range weapon. In 1973, the Army asked DMA to produce the needed topographic data and USAETL to make the machine-readable maps. DMA, in turn, directed USAETL to develop the Pershing II data base specifications. To carry out this sensitive work, USAETL's commander formed the Special Projects Group, a team of specialists drawn from several parts of the organization, headed by Mel Crowell.

Reference scene generation research

By 1978, USAETL and DMA mapmakers developed the following process. First, they used the UNAMACE to produce DTED and orthophotographs of a target and its surrounding area, working from aerial photography. Orthophotographs adjust the viewing angle so that the viewer's eye is at right angles to the terrain. Next the the orthophotos are compiled into a mosaic map of the target area. An analyst then selects features on the landscape that can be "seen" by a radar scanner, assigns radar recognition values (reflectivity values) to these features, and converts the results to digital planimetric data on a digitizing table. The resulting data base is known as Digital Feature Analysis Data (DFAD). Next, a computer combines files containing elevation data (DTED) and planimetric data (DFAD) into a merged file stored on computer tape.

From analog to digital

Until 1978, the Army had planned to use an electronic image correlator in the Pershing II. This correlator required graphic reference scenes contained on film. These were created by computer from the merged digital topographic data tapes. In that year, the Pershing program manager decided to scrap the analog image correlator and its filmed reference scenes. Instead, the Pershing II was to acquire an all-digital control system. Beginning in 1978, USAETL was asked to accelerate its effort on the PII. The Army Missile Command, which was in charge of the Pershing II program, asked USAETL to develop and oversee the production of four key elements of the digital control system. The first element was the digital radar simulation or target map stored in the missile's computer "brain." The second element consisted of computer equipment and data processing routines to create such target maps or "reference scenes;" this equipment was called the Pershing Reference Scene System (PRESS). The third element was a specialized digital topographic data base adapted to the needs of the Pershing II guidance system; this was named the Pershing II Operational Data Base (PIIODB). It was drawn from DMA's Digital Land Mass Simulation (DLMS) data base, consisting of DTED and DFAD files originally developed to support low-level flight radar image simulators for B-52 bomber crews. The fourth element was a mobile, van-mounted, field-hardened computer facility for creating additional reference scenes in the field; this was named the Reference Scene Generation Facility (RSGF). The RSGF, an engineering development project, was prototype equipment that could be sent into the field where soldiers could use it to retarget the PII quickly.

Defining the product

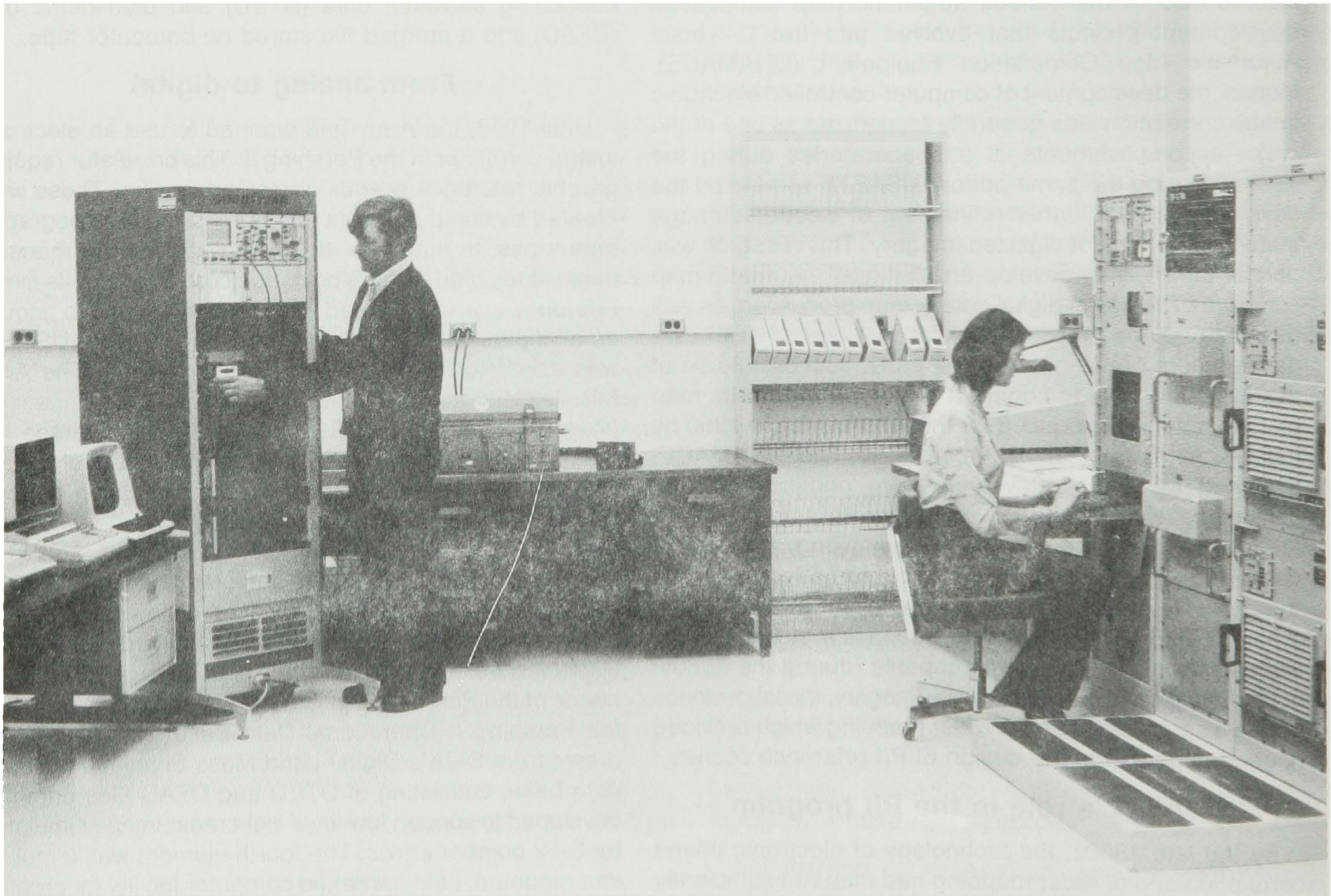
Pershing II soon became USAETL's top priority project. In 1978, the Special Projects Group, then under James Skidmore, conducted "an intensive investigation of off-the-shelf hardware devices capable of meeting the PII requirements."[8] Following this review, project engineer Jack Bondurant oversaw the preliminary design of the Reference Scene Generation Facility and the Pershing Reference Scene System equipment. The latter would be used at DMA for producing the PII Operational Data Base as well as for making target reference scenes. The Pershing II team next turned to the preparation of detailed contract specifications for the RSGF, PRESS and the PIIODB. A contract for $13.8 million was awarded to Goodyear Aerospace Corp., of Akron, Ohio, in August 1979. The contract called for the engineering development of the RSGF and PRESS equipment and software, and the production of one PRESS equipment set and five RSGFs.

Managing the project

Through this contract, USAETL assumed responsibility within the overall PII program for all aspects of the development of the reference scene equipment, including "system design and fabrication, hardware, software, configuration control, training, publications, provisioning and engineering support."[9] It was, Bondurant said, an unusual document in the experience of USAETL's engineers, who had "not done too many contracts like that."[10]

With the signing of the contract, the PII work at USAETL gathered even more momentum. The PRESS was delivered in November 1980, on schedule and within cost. The Special Projects Group was expanded in the same year and upgraded to a division of the Topographic Developments Laboratory, with two subordinate groups. John Pattie became division chief. Jack Bondurant directed the Equipment Development and Test Group while Donald Skala became head of the Design and Software Group. Total employment grew to a peak of 20 engineers.[11]

Much of the ensuing work consisted of developing the



USAETL scientists operate the labs' version of the Pershing II Reference Scene Generation Facility (RSGF).

PII data base and compacting the information it contained. The PII operational plan called for equipping each Reference Scene Generation Facility with a library of disks containing digital topographic data for the current operational area, drawn from the DLMS data base at DMA. Cramped quarters in the truck-mounted field housing of the RSGF limited the amount of closet space available for storing digital topographic tapes of the PII operational area. Bondurant described the problem as one of "fitting 180 cubic feet of equipment and data base into 150 cubic feet of space."[12] The solution lay, in part, in designing a more compact notation for digital data—analogous to the use of scientific notation for compressing long numbers (e.g., $10^{-12} = 0.000000000001$), and in extracting from the DLMS data base only those details that would be significant to the PII's radar. Bondurant's group reduced the volume of required data to a twelfth of its original size making it possible to store all the digital maps of the PII operational area on 14 80-megabyte disk packs, a library small enough to fit into the available space in the RSGF shelter. The compacting work was carried out at Goodyear Aerospace Corp., and tested at USAETL on the first laboratory model of the RSGF, delivered in 1981.[13]

Testing and training for field deployment

In 1982, four more RSGF systems, all truck-mounted for field deployment, were delivered to the PII prime contractor, Martin Marietta Corp., for testing and training. In a laboratory test at USAETL in 1982, soldiers from the Army Field Artillery School at Fort Sill, Okla., made reference scenes after only two days of training in the operation of the RSGF. These scenes were subsequently used in flight tests of the PII terminal guidance system. The PII development effort reached a climax in 1983 under the pressure to meet a political commitment for deployment in Europe by December. During that year, the RSGFs completed and passed all Army environment and engineering tests as well as all troop operational tests. At year's end, two RSGFs were deployed to Germany as ground support equipment for the newly deployed PII missile system.[14]

Awards

Project Engineer Anthony Stoll was presented the 1981 Army Research and Development Achievement Award for his work in monitoring the complex contract with Goodyear Aerospace for the production of the RSGF, PRESS and PIIODB. In the same year, Design and Software Branch Chief Donald Skala received both the Defense Mapping Agency's annual Research and Development Award and the USAETL Commander's Leadership Award for his work on the PII project. David Thacker received the USAETL Commander's Award in 1983 for his efforts on PII. Other personnel who made key contributions to the success of the project included Clyde Berndsen, Louis Wisniewski, Richard Marth and Bruce Zimmerman.[15]

Footnotes

1. Installation files, Topographic Developments Laboratory, Special Products Division (TDL-SPD), Historical Summary, 1978-1983.
2. Ibid.
3. John Pennington, *History of U.S. Army Engineer Topographic Laboratories (1920-1970)*, USAETL Report No. ETL-SR-74-1, p. 192.
4. Ibid., p. 206.
5. Ibid., pp. 198, 211-212.
6. Ibid., p. 243.
7. Ibid., p. 212.
8. Installation files, TDL-SPD, Historical Summary, 1980.
9. Installation files, TDL-SPD, Historical Summary, 1978-1983.
10. Interview, authors with Andrew Bondurant, Fort Belvoir, Va., 25 January 1985.
11. Interview, authors with John Pattie, Fort Belvoir, Va., 10 November 1984.
12. "PII Guidance System to be Tested," *Tech-Tran*, Vol. 7, No. 1 (Winter 1982), p. 8. Quarterly technology transfer newsletter published by USAETL.
13. Installation files, TDL-SPD, Historical Summary, 1978-1983.
14. Ibid.
15. Ibid.

VI. Major Research Institute Activities and Related Work

A. A New Center for Artificial Intelligence at USAETL

Certainly a major change at USAETL in the years 1979-1983 was the creation of the Center for Artificial Intelligence (CAI) within the Research Institute. The CAI replaced the Center for Coherent Optics, but assimilated and retrained many of the same personnel.

Artificial Intelligence (AI) is an area of computer science in which computers do tasks in a manner resembling human thought. This area of research held the attention of USAETL's Dr. Robert Leighty long before the creation of CAI. With research in geodesy undergoing a steady de-emphasis, particularly following the USAETL Organizational Study of 1978, new research efforts in feature extraction were pointing to AI as a valuable tool for the future.

With the hiring of Anne Werkheiser as AI team leader, AI came into sharp focus as a serious USAETL initiative. The emergence of AI research at USAETL was a big part of the 1979-1983 picture.

Coherent optics and beyond

CAI's antecedent, the Center for Coherent Optics, did research into the uses of lasers and automated terrain feature extraction. In 1979, the research was reoriented from working on "only the optical power spectrum."[1] The center carried out research in Hybrid Optical/Digital Image Processing, Laser Beam Recorder Technology, Voice Interactive Systems Technology, Computer-Assisted Photo Interpretation Research (CAPIR) and Holographic Recording Materials. With the founding of the Center for Artificial Intelligence, all but the last work effort continued, and new units were created dealing with Artificial Intelligence Research and a Robotic Reconnaissance Vehicle Demonstration.

Whether the research framework was Coherent Optics or Artificial Intelligence, its continuing focus was feature extraction—researching new ways to gain terrain information with speed and accuracy—providing the commanders with timely tactical background data. Thus, USAETL tried a variety of approaches.

Pattern recognition

The automated extraction of information from aerial imagery was an early goal of the Research Institute (RI). In the 1970s, efforts focused on image processing. Statistical Pattern Recognition (SPR) for image data have evolved from mathematical decision theory and communication theory. Optimists in R&D at the time had thought that hardware improvements might, over time, enable scientists to process digitally coded information according to numerical patterns.[2] The hardware they anticipated was the class of very high speed "number crunchers" known as supercomputers that began to evolve in the 1970s. But RI scientists ran into unforeseen problems with pattern discrimination. By 1979, the pattern recognition specialists had more doubts than results.

Despite vast improvements in hardware in the years up to and following 1978, RI researchers working in pattern recognition could "claim little progress in operational image analysis."[3] George Lukes, a scientist at the Research Institute, flatly stated that "the general application of statistical pattern recognition" to automated aerial imagery had been "over-ambitious."[4] Dr. Robert Leighty, tracking the "Trends in Automated Analysis of Aerial Imagery," saw little immediate use for SPR.

> SPR algorithms, when applied to real world imagery, are still not sufficiently robust to justify development of automated production equipment. Except for the simplest of patterns, our methods of applying algorithms in a brute-force manner is inefficient and often the cause of poor performance.[5]

The 1978 Leighty white paper

Accordingly, in 1978, Dr. Leighty produced an in-house white paper at USAETL urging the laboratory to de-emphasize SPR and move into AI in its feature extraction research. Lab-wide feature extraction work throughout the USAETL facility, with each group pursuing its own requirements for help from SPR, had produced little progress beyond an algorithm for cloud screening. It was now time for AI to be the focus of the feature extraction effort, becoming (in Lawrence Gambino's words) "the only game in town" for automated image analysis at USAETL in the early to mid-1980s.[6]

Although feature extraction was the application which led Dr. Leighty to push RI into the field of artificial intelligence research, AI was a technique with many potential military uses. Its distinctive characteristic was the application of specialized contextual knowledge to guide a computer through a complex process of search, evaluation and choice. Thus, an early academic test-bed for AI research was the the creation of computer programs for automatic chess playing. In the case of feature extraction, USAETL scientists talked of AI adding image understanding to conventional pattern recognition methods.

From pattern recognition to image understanding

To a computer, a digital image consisted of millions of tiny gray dots or pixels, generally read one by one. To extract these features, the computer proceeded somewhat like a child with a connect-the-dots puzzle, adding the prior step of numbering all of the dots according to their gray shade and texture. Statistical pattern recognition algorithms looked for all of the dots of a similar value and made decisions based on whether they formed lines or other patterns. Unlike a child, the ordinary SPR software lacked knowledge of context, so it did not know how to interpret incomplete or ambiguous clues (known technically as "saddle points," where a line changes direction; and "fuzzy sets," data giving inconclusive answers). Thus, the lines it drew might or might not delineate actual features.

Whereas a child might see a familiar pattern emerging from the connected dots which would aid him in completing the puzzle, the computer would go blindly on drawing uncomprehended and often incomprehensible patterns. According to Dan Edwards of the Research Institute's CAPIR project, SPR failed to work correctly more than half of the time.

The goal of image understanding AI research was to supply the computer with additional clues so that it would not only "see" a railroad going through a tunnel, but also make certain specific deductions from the image, much as a photo interpreter would.

Levels of image understanding

Clearly, there are different levels of image understanding, a fact which led to some misunderstanding of Leighty's objectives. To some computer scientists at USAETL, AI simply meant a set of rules and body of knowledge which led a computer, given certain information, to reach deductive conclusions. In feature extraction, for example, some practitioners talked as though AI was little more than pattern recognition at a higher level of generalization.

A basic SPR algorithm might identify the edge of a polygon defined by the predominance of a certain shade of gray; but the computer would require additional instructions and references to interpret this pattern as a field, forest, lake boundary, stream or road. For example, the computer might be programmed with additional algorithms to ask certain questions about the shape of the edge and the configuration of adjacent patterns, consult a dictionary of shapes, shades and textures, and select a list of possible answers. These added steps were not conceptually different from existing approaches to pattern recognition.

To Leighty, AI meant more—specifically the use of detailed contextual knowledge programmed into the computer to enable it to take the reasoning process several steps further. The computer could extract improbable answers and identify probable ones, thinking ahead to the next stage of analysis, while at each stage providing a clear explanation of its reasoning. To be sure, AI in the 1980s worked best on subjects with low concept to detail ratio. But while the computer's ability to see a railroad enter a tunnel and draw the appropriate conclusion might be an achievement unlikely in the 20th century, it remained a Research Institute goal.

A need for special skills

In this more ambitious definition, AI drew on specialized programming languages, such as Lisp. On the principle that a programming language should be suited to the problems it addressed, most programming languages such as FORTRAN and PASCAL had been designed for large scale engineering, scientific and statistical "number-crunching" or numeric processing. Lisp and similar languages used symbols to represent concepts and were more adaptable to AI requirements. Specialized symbol-processing hardware, such as Lisp machines, were developed to ease the time-consuming process of writing AI software. Lisp machines, for example, executed Lisp programs very quickly, had a "user-friendly" programming environment (a set of housekeeping functions which relieved programmers of much tedious detail work), and provided high-quality, easy-to-use graphics. Needless to say, the specialized software and hardware technology demanded by AI research required specialized researchers.

It was one thing for Dr. Leighty to call for intense work in the area of Artificial Intelligence, quite another to find the scientists to do it. In the early to mid-1970s it had been hard to find work in AI. By the mid-1980s, those skilled in the field were "priced out of the market."[7] George Lukes of USAETL's Research Institute observed in 1983 that the element holding back progress in the AI area was "neither interesting ideas nor research facilities" but the "lack of sufficient qualified personnel."[8]

A retraining effort

Dr. Leighty and team leader Anne Werkheiser assumed the academic administrator's task of directing a re-education of personnel. USAETL's coherent optics specialists—scientists trained to deal with lasers, lenses and SPR algorithms—began retraining toward AI work. Some took short courses; others began long-term training. Making use of universities, equipment vendors and software, coherent optics personnel went to school in "many different ways."[9] Werkheiser stated that it took longer than anyone had thought to train personnel in Lisp program language and AI techniques.[10] Yet the training was, she added, "a necessary bag of tools for a class of problems" and would continue.

An R&D plan for the Army: 1982

Dr. Leighty was not alone in seeing an increasing role for AI. In 1981, the Army asked USAETL to survey the potential military applications of AI/Robotics. The Research Institute and the Center for Artificial Intelligence contracted with Stanford Research Institute (SRI) to produce a report. SRI, a pioneering institution in AI, produced a 324-page report in August 1982 identifying "100 specific concepts for AI/Robotics combat/combat-support systems."[11] Given the large number of concepts, 10 broad categories of applications were identified:

- Human/Equipment Interface Aids
- Planning and Monitoring Aids
- Expert Advisors
- Data Assimilation and Access Aids
- Handling Support Systems
- Support Systems
- Situations Assessments Systems
- System Controllers
- Weapons
- Information Collectors

The report took an example from each category and gave it further study (e.g., Handling Support Systems led to the study of a tank ammunition handler).[12] Four of the 10 categories even provided examples of systems that could be developed with existing technology. The importance of the report was not in the realization of its many possible applications, rather, in Dr. Leighty's words, "it got people thinking."[13]

A Center for Artificial Intelligence

At the same time USAETL's R&D plan for the Army was emerging, concrete plans were underway to put AI research on the fast track at USAETL. On 4 March 1982, the Center for Artificial Intelligence officially replaced the Center for Coherent Optics. In 1983, the center acquired an in-house artificial intelligence test bed much like the one used by the Defense Advanced Research Projects Agency (DARPA) to study image understanding—an effort involving the best university computer science and AI groups searching for machine vision capabilities. DARPA had moved toward application areas—one of them cartography—and put together a test-bed facility at SRI. Thus, USAETL's new Center for Artificial Intelligence became a major participant in DARPA's effort.

At the same time the Army was also turning to AI, not only for R&D plans, but for functioning demonstrators. Both the Army and DARPA displayed an "increasing interest in autonomous vehicles for military applications."[14] Such vehicles depended on developments in AI, particularly in an offshoot of image understanding known as Route Selection: teaching a robot sufficient field craft to find its way across obstacle-strewn terrain. Thus, these vehicles were a major focus of concentration for the Center for Artificial Intelligence in the years following its founding, in early 1982. Indeed, Dr. Leighty already speculated in 1982 that the robotics effort might "threaten the work load balance of the center."[15] Soon Bruce Zimmerman was detailed to handle one of the two vehicular projects outside the center.

The military was seeking new applications for decision-making technology on the battlefield. USAETL, with its long experience with smart machines and mapping, was on the leading edge of this new and important technology.

The technology triad

USAETL scientists in this period often lumped three particular areas of USAETL's competence together as the technology triad. The triad was made up of USAETL's knowledge of Digital Terrain Data Bases, work in stereo vision, and pioneering work in inertial navigation systems for land vehicles. All three areas had an importance for evolving AI/Robotics technology. A "smart" robotic vehicle, for example, would need digital terrain information to preplan its route, and need stereo vision to navigate that route and deal with contingencies. It could do neither without an inertial guidance system to let it know where it was. When the call for AI/Robotic work arose, USAETL was ready.

An AI/Robotics steering committee

The Army's Artificial Intelligence/Robotics program began in May 1981, when Dr. Frank Verderame, Office of the Deputy Chief of Staff for Research, Development and Acquisition, asked USAETL to develop the R&D plan cited earlier.[16] Soon thereafter the Army formed an Artificial Intelligence/Robotics steering committee to coordinate research and development programs. After study, the committee identified 22 "mission-essential, technically feasible, high-priority applications" for artificial intelligence.[17] These, in turn, were examined and reduced to five research demonstrators. Army agencies would develop these five for demonstration in the near term, either as independent systems or parts of other projects. The demonstrators were envisioned as battlefield vehicles, ammunition handlers, maintenance tutors, artificial intelligence for tank commanders and medical aids.

Of the five demonstrators, the battlefield vehicle received the highest rating. USAETL, with its background in map-reading machines, was an obvious choice to aid in the project. The extensive retraining of personnel from coherent optics and other areas to artificial intelligence was building an AI foundation at USAETL. The laboratories was to play a major role in developing both this demonstrator and future, more sophisticated, autonomous systems.

Smart machines on the ground

The "intelligence" given the Pershing II missile by USAETL provided working proof that digital terrain information had useful navigational applications. USAETL's Digital Terrain Data study showed the applications of such data would only grow with the years. At the beginning of these applications were machines using digital terrain data to maneuver on the battlefield.

The demand for smart, robotic machines in surface battle was born of two wishes of the commander. First, if possible, the commander always wanted to multiply his forces—particularly if outnumbered from the start. Robotic machines could help, doing many tasks better than a human. Second, a smart machine could do tasks too dangerous for soldiers.

Short- and long-term approaches to robotics

The push for "machine intelligence" on the battlefield was evidenced by the fact that during this historical period USAETL was busy on not one, but two distinct, yet related, efforts to put robotic capability on the battlefield. The first, for the Army, involved providing terrain navigation for a tele-operated vehicle. The second, for DARPA, involved research toward a fully autonomous land vehicle. The two projects were alike in making use of USAETL's digital terrain data navigation experience, but the projects had different goals set in different time frames.

The Army program, which came to be called the Terrain Analysis Demonstrator, attempted to put together, in the near-term, a remotely controlled vehicle that can "take on the terrain with the same ease as a similarly constructed manned vehicle."[18] Dr. Robert Leighty and those working with him had the task of furnishing the planned vehicle with a terrain navigation subsystem. The idea was to start in the real world, on a battlefield, and make a machine that could work its way through obstacles, with an operator running it remotely from out of sight. Initially, this would be a remote-controlled rather than an autonomous land vehicle (ALV).

The DARPA idea, on the other hand, began with a theoretical ALV on an empty parking lot. USAETL's scientists continued work toward increasing the vehicle's capabilities, from eluding the parking lot pylons through many steps to eventual mixed road and open terrain navigation. The focus was not on the actual ALV itself, but on "developing the technologies needed to support autonomous vehicle operations."[19]

Short term: An Army platform

In response to the Department of the Army request for the development of artificial intelligence/robotics systems, USAETL began to investigate the area of terrain navigation and unmanned vehicle operations in 1981. The Army and USAETL sought to "demonstrate the capability to plan and conduct robotic vehicle operations using current technologies in a tele-operated mode."[20] The Army envisioned robotic platforms carrying, for example, reconnaissance/surveillance sensors, equipment for nuclear, biological or chemical detection or decontamination, or they might simply carry conventional weapons. Such intelligent machines could help the Army meet the challenge of the AirLand Battle doctrine and the AirLand Battle 2000 concept.

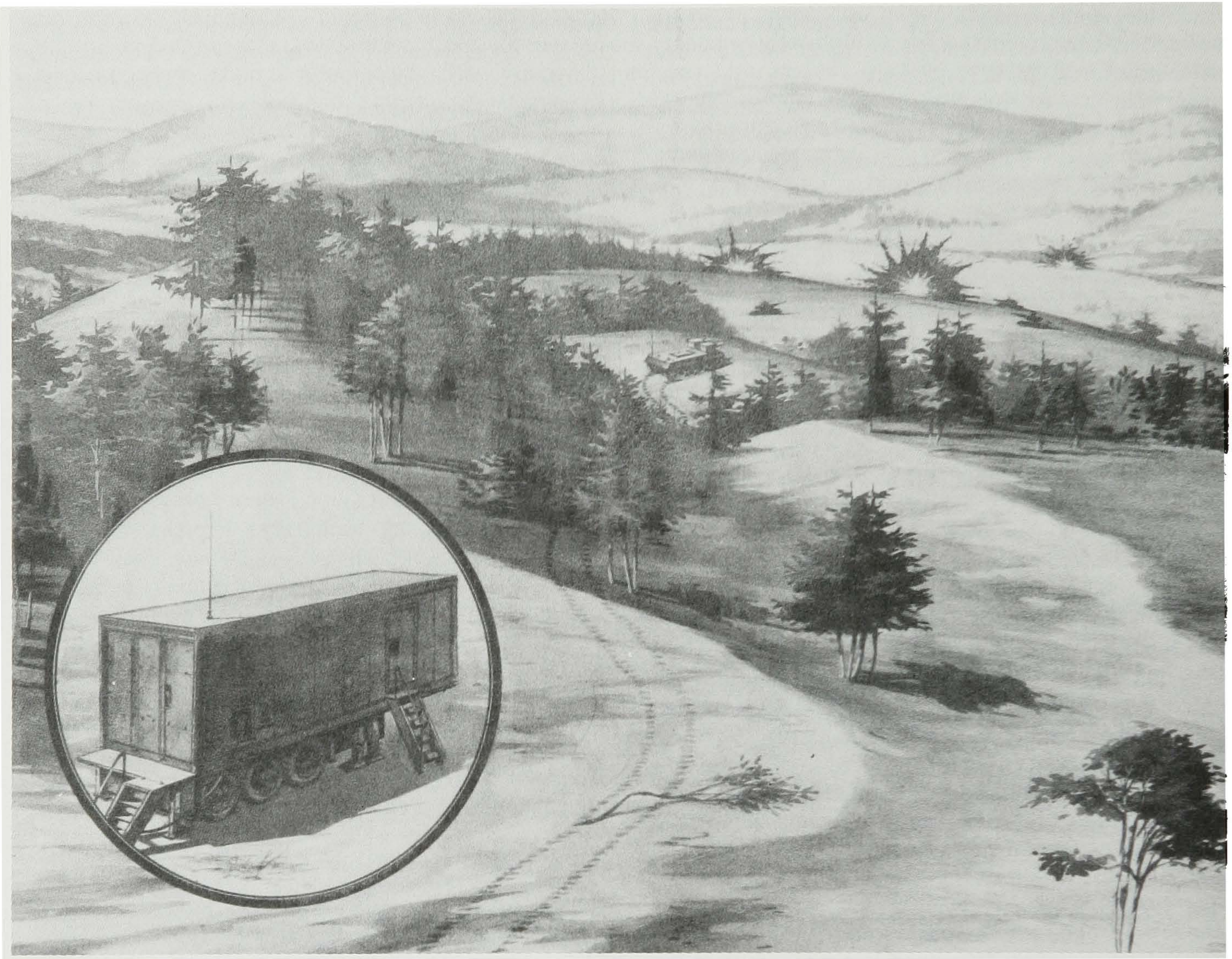
USAETL had received an AI/Robotics contract report (the SRI report[21]) in 1981, and was ready to provide the demonstratable technology the Army demanded.[22] The U.S. Army Materiel Command the the U.S. Army Training and Doctrine Command wanted some AI/Robotics work to show results in the near term. USAETL provided an initial concept plan for a Terrain Analysis Demonstrator in June 1982. Some overlap with a U.S. Army Human Engineering Laboratory (HEL) plan for a reconnaissance vehicle, however, led the two laboratories to submit a combined plan on 19 September 1982. The resulting Robotic Reconnaissance Vehicle with Terrain Analysis, left USAETL with responsibility for the heart of the project: the hardware/software development. HEL worked on the man-to-machine interface, the demonstration scenarios and conducting the eventual demonstrations.

A move to GSL and toward TACOM

After January 1983, USAETL maintained informal contact with the U.S. Army Tank-Automotive Command (TACOM), which, with the Armor Center, represented the eventual users of the evolving technology. Dr. Leighty's USAETL AI/Robotics committee also brought USAETL development labs into the vehicle project, because the demonstrator was more than just a Research Institute abstract study and involved, in any case, all three areas of USAETL's "technology triad" (Digital Terrain Data Base, Stereo Vision, Inertial System). In August 1983, the vehicle work was moved to the Intelligent Systems Group in GSL under Bruce Zimmerman, and plans were made to transfer overall responsibility for the project to TACOM under its Tactical Robotic Systems Program. USAETL (and HEL) were to remain on the management team, however, and retain the same development tasks. The Robotic Reconnaissance Vehicle with Terrain Analysis, would now be simply the Robotic Vehicle Demonstrator.

Tactical Robotic Systems: Phase 1

The Tactical Robotic Systems program began with a man-in-the-loop operating the demonstrator remotely on the same terrain as a similar manned vehicle. The development



Artist's concept of Army robotic vehicles on the battlefield.

plan would gradually reduce the role of the operator to fewer and fewer control functions, as the project progressed, drawing from new technology (perhaps from the DARPA long-term autonomous vehicle project) without restricting terrain capabilities. Leighty and Zimmerman pinpointed the advantage of this approach:

> With this approach, the Army can spin off fieldable robotic systems with designated payloads at any time, rather than waiting until the end of the program.[23]

As technologies developed, control functions were to move from off-board processing to the increasingly powerful on-board processing. In the first phase of the program, the demonstrator was to perform battlefield reconnaissance missions. It was to carry a modular payload of reconnaissance sensors separate from the vehicle control system's mobility sensors. The vehicle itself was to be tracked (a M113 or M551 without its turret), led about by USAETL's navigational subsystem while the operator and command control remained safely in the distance and out of sight.

The navigation subsystem

USAETL's navigation subsystem made use of in-house equipment to produce the terrain data base for the test area in the demonstration. USAETL personnel worked toward high-resolution, on-line digital maps with detailed information about the topography, hydrology, vegetation, soil types, lines of communication and concealment factors. With this information at hand, the computer graphic display combined mobility sensors (such as stereo vision to give three-dimensional maneuver information) and a position navigation device (such as USAETL's Position and Azimuth

Determining System (PADS) inertial unit) to maintain a constant geographic reference. Thus, the machine could tell where it was and where it could go.

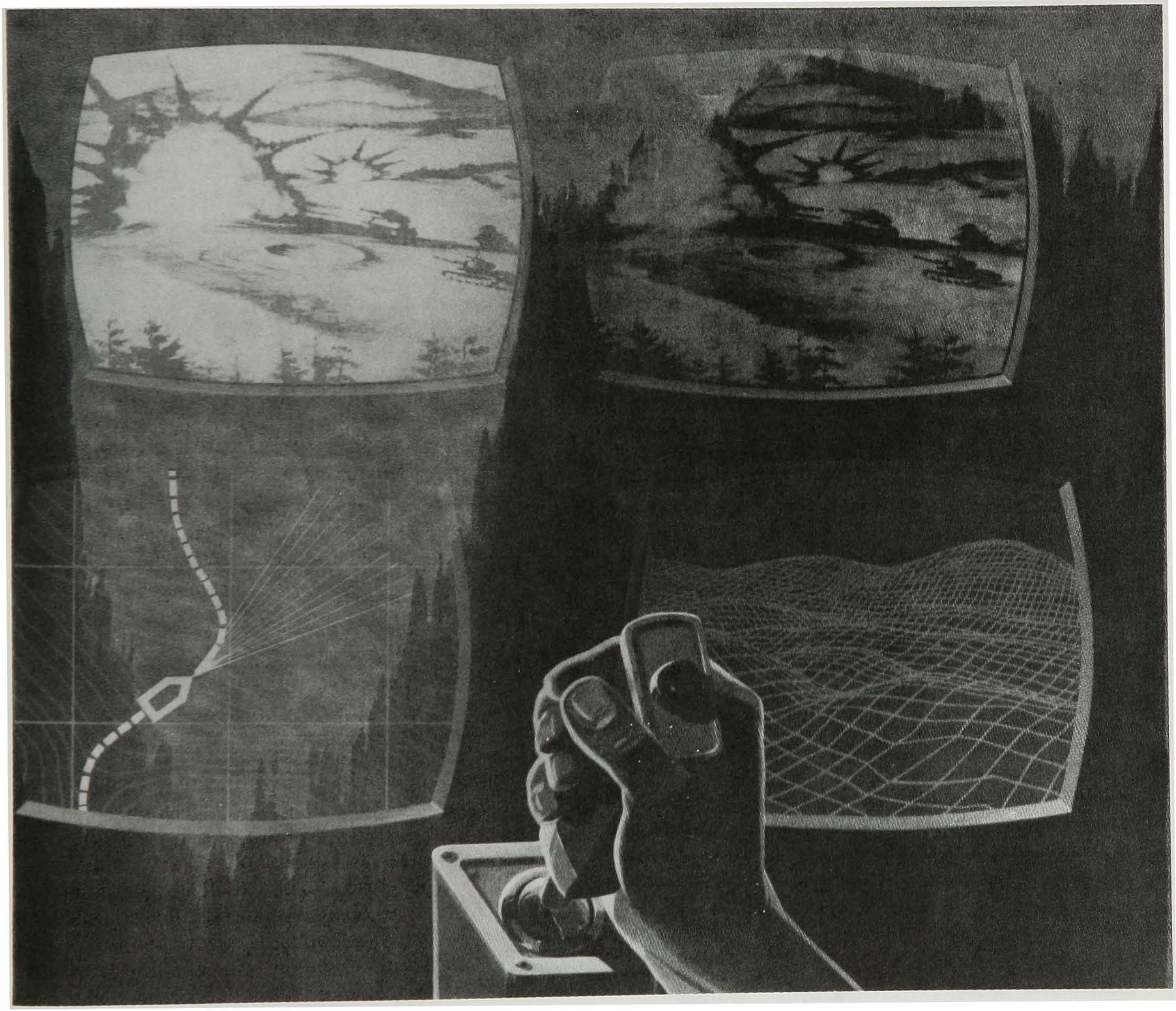
The unit was designed to be self-contained and unjammable (like PADS), and to provide all six components of vehicle position. The subsystem developers also included a thermal sensor designed to deal with darkness and poor visibility operations, and computer generated decision-making aids, to go along with the digital information about the area.

A preplanned route

The commander, working from static mapping data (where is the most concealed vantage point giving the best view?) and dynamic tactical information (where is the enemy and where is he going?), could pick the vehicle's destination. Using the terrain data base information and intelligence reports, the operator turned to the global-level route planner to choose the best route—weighing a combination of minimum distance, fuel consumption and time, with maximum concealment and survivability. This information took the form of a digital overlay on the digital map of the area. En route, a blinking cursor overlay kept the vehicle on this preplanned course. In the event of unplanned contingencies (i.e., an absent bridge), the operator just asked the system for another route and started over.

A first step

Leighty and Zimmerman stressed an important aspect



Artist's concept of a robotic vehicle operator's view of the terrain.

Autonomous Land Vehicle (ALV) prototype.

of the control systems design that allowed the system to operate for brief intervals without direct human intervention.[24] This aspect was "indispensable" as a "first step toward semiautonomous operation" if a communication link were broken, but it was also a critical first step toward the on-going effort to develop a truly autonomous land vehicle. USAETL was participating in the DARPA-funded Autonomous Land Vehicle program as well, but the robotic vehicle demonstrator subsystem's "design elements" were considered "essential for the evolutionary follow-on developments toward autonomy."[25] Indeed, the Tactical Robotics Systems Program was designed to use the same computer hardware as the DARPA work so that algorithms developed by DARPA could be tested and implemented in the Army system as follow-on work progressed.

DARPA's Autonomous Land Vehicle

To the unfamiliar, the Army's terrain analysis demonstrator-robotic vehicle demonstrator tele-operated vehicle seemed to overlap DARPA'S work toward an autonomous land vehicle. While complementary, the projects were very different.

> While DARPA's demonstrator will gain terrain maneuverability over time, the Army's demonstrator, which starts with complex maneuver capabilities, will eventually gain autonomy. The Army program emphasizes today's technology while DARPA's implements tomorrow's.[26]

New technologies for DARPA

The ALV was part of DARPA's Strategic Computing Program, which was a new initiative designed to cultivate recent advances in artificial intelligence, computer science and microelectronics. The aim was to create a new generation of "machine intelligent" technology for the military. The program's technology base includes advanced computing technologies, expert systems, voice recognition, natural language understanding and microelectronics. More specifically, in USAETL's case, DARPA was interested in an eventual ALV demonstrator to pull together new capabilities from the technology base, rather than push available capabilities at the user.[27] In 1983, USAETL's Research Institute became DARPA's technology and contracting agent for work on both the autonomous vehicle and related image understanding work. Work commenced with scientists at the University of Maryland's Computer Vision Laboratory and at the Martin Marietta Corp., the system integrator.

Growing capabilities

The technology and system integration research and development for the ALV were awarded to a contractor and a team of subcontractors. The aim was not necessarily vehicle development, but rather a "broadly applicable autonomous navigation technology base."[28] The scientists and engineers scheduled annual demonstrations for the years 1985 to 1990. The fully autonomous system was to maneuver over increasingly difficult terrain as the technology developed. New capabilities were to be incorporated into the ALV year by year.

- 1985: Road Following
- 1986: Obstacle Avoidance
- 1987: Cross-Country Route Planning
- 1988: Road Network Route Planning and Obstacle Avoidance
- 1989: Cross-Country Traverse with Landmark Recognition
- 1990: Mixed Road and Open Terrain

Support from image understanding

The development of the ALV was planned to draw support from several areas of image understanding research: road-following research to develop a vision system, parallel algorithm research for faster computer vision processing, and knowledge-based vision research for the required vision capabilities. Obstacle recognition and evaluation, and methods to plan circumnavigation paths were also to be studied.

Clinton Kelly at the Strategic Computing Program spoke of ultimately allowing the ALV to adapt to its environment and its mission using "some of the intelligence we associate with animals." Not only to go from point A to point B, but "also to detect when it is being sensed by something hostile, to evade, to hide and lie in wait and, at an opportune moment, to deploy a weapon."[29]

The AI/Robotics future

USAETL, providing the only direct line between the Army demonstrator teleoperated vehicle and the ALV, was performing a central role in AI/Robotics at the close of this period (1979-1983). Dr. Robert Leighty, active in both projects, had a unique overview of the future of the two USAETL projects.

Dr. Leighty asserted that completely autonomous military vehicles were "probably not" going to be a standard issue system "in this century." Conversely, he thought it possible that the Army's demonstrator, in its latter stages, might implement technology developed from DARPA's ALV and image understanding effort, thereby moving the Army vehicle systems "in that direction."[30] He added it was too early to predict the possible application for such autonomous systems, but, pointing to weapons platforms, reconnaissance systems and hazardous area uses, he predicted confidently that the future would "see unmanned vehicles in useful Army roles."[31]

Much of the Center for Artificial Intelligence's work had application to its vehicle research, but robotics was not always the primary focus. Basic research in AI, making use of the Stanford Research Institute-developed test bed at USAETL, promised results with wider applications.

Image understanding

The acquisition of USAETL's in-house artificial intelligence test bed in 1983 marked the laboratory's turn toward image-understanding research, DARPA's term for a marriage of artificial intelligence and statistical pattern recognition. Dr. Leighty had spoken earlier of a growing consensus that such an AI-SPR blending was required for automated image analysis.[32]

The image understanding test bed originally consisted of a VAX/780 computer and associated image understanding devices, a video processor and an optical film scanner. The operating system was VMS with EUNICE — a LINIX emulator that provided most UNIX capabilities in addition to the standard VMS capabilities. The software included the large image-understanding package developed by a consortium of universities (integrated by the Stanford Research Institute (SRI). SRI also installed the hardware/software at USAETL in 1983. The test-bed hardware set was later expanded to include a number of Lisp processors connected to the VAX, and USAETL scientists began writing and acquiring a library of Lisp programs to supplement the original image-understanding software package from SRI, most of which had been programmed in the language called C.

The test bed resembled the one DARPA's own SRI-developed, but it remained to be seen if either effort could, in AI team leader Werkheiser's words, "get the SPR and AI people talking the same languages."[33] Plans were undertaken at the close of the 1979-1983 period to set the AI researchers to work in four specific areas.

1. Synthetic Scene Generation: researchers sought to

move a "mouse" around in a scene while asking terrain-related questions

2. Terrain Transition: scientists sought short-cuts to detect change, eliminating the necessity to rebuild terrain data from the beginning.
3. Dynamic Scene Analysis: CAI researchers sought ways to teach machines to recognize and estimate velocity.
4. Battlefield Planning.

The Center For Artificial Intelligence (CAI) also closed the period 1979-1983 eager to demonstrate the applicability of AI to the Intelligence Preparation of the Battlefield (IPB). USAETL began a cooperative effort with the Army Intelligence and Communications School, and an Expert System development got underway. USAETL awarded two contracts in software for the procurement of some of the development. Throughout 1983, the center undertook training of personnel in the development of AI software using terrain data bases for IPB. Developing expert systems to support training of terrain and intelligence analysts was the goal.

An AI overview

CAI closed the 1979-1983 period in a cautiously optimistic spirit.[34] On one hand, AI was on the cutting edge of new technologies and of great interest to the defense community. On the other hand, some cautioned against unrealistic expectations for future results.

Dr. Leighty, speaking at the close of the period, saw useful applications for AI down the road. As the AI/Robotics initiatives of the Army and DARPA indicated, the push toward AI was well underway in 1983, and USAETL's Research Institute, as the laboratory's basic research element, was deeply involved through its new Center for Artificial Intelligence.

Footnotes

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33. Werkheiser interview.
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B. Deriving Information from Remotely Sensed Imagery

USAETL had played a role in developing a technology whereby maps and map-like products could be made better and faster. In addition, when rendered digitally, terrain products could be made to show things impossible to depict by conventional mapping methods. All such advances, however, presume that the terrain information is there in the first place. All terrain information products, from the most yellowed map to the prettiest three-dimensional color graphic, require an adequate base of information. Yet in many military situations, getting that information could be a problem.

Jeffrey Messmore, USAETL's procedural guide specialist, observed that the process of extracting features was proving, a "tough nut to automate." It was all the harder then, to extract features from imagery derived from a distance. Yet in many cases, remote sensing was the only available source of terrain information. What sort of data base could one expect from remotely sensed imagery? The Center for Remote Sensing (CRS) sought to answer this question, and to improve upon the answer in time.

A widened focus

In 1970, the Photographic Interpretation Research Division of the U.S. Army Cold Regions Research and Engineering Laboratory transferred to the Geographic Sciences Laboratory in USAETL. In 1974, it became the Center for Remote Sensing. The focus of CRS included studies of air-photo interpretation in general and related remote sensing technology. CRS sought to expand what could realistically be known by means of remote sensing. CRS also performed research into new remote sensing techniques that might supplement existing technology.

Needed: A co-op of specialists

By nature, photo interpretation required an interdisciplinary approach. The Army asked "how much can we know from the air?"[1] The many bits of information in the answer required as many specialists to interpret them. The fact that in the center's case, the imagery was remotely derived, which made it a "difficult problem taking a great deal of skill" to produce what the Army wanted, even "in just a crude way."[2] The wider focus of CRS required a wide cooperative of specialists.

Seeing through a tremendous filter

Dr. Jack Rinker, team leader of CRS, continued the work of Robert Frost at USAETL into remote sensing techniques. Likening the difficulty of sensing remotely to "seeing through a tremendous filter," Dr. Rinker sought new ways to determine, from afar, an area's composition, properties, use and probable response to stress. All these items were of direct and practical use to military and engineering planners who might have no other source of data for their operations.

The most frequently used instruments in the years 1979-1983 remained stereo aerial photography, radar and Landsat. Imagery coming from these three sources provided information by means of three methods of extraction: manual, interactive and automatic. CRS sought to improve techniques for all of these methods while continuing research into less perfected sources of imagery, such as infrared, thermal and passive microwave. This work (along with a radiation background study and photo interpretation logic and feature extraction work) was the heart of the center's effort from 1979-1983.

Photo analysis: Skilled execution of a simple concept

The three-fold principle of photo analysis at CRS continued to be defined by USAETL's pioneer imagery analyst Robert Frost. Frost's unpublished notes, in USAETL's Installation Files, can be distilled as follows:

1. An air photo is composed of pattern elements that indicate conditions, materials and events.
2. Like materials and conditions, given a like environment, yield like patterns; conversely, unlike materials and conditions yield unlike patterns.
3. The information gained will mirror the competence of the analyst.

Dr. Rinker stressed that while the concept of photo analysis is simple, "skill, experience, judgment and knowledge" are needed to implement it.[3] Accordingly, CRS worked on many fronts to find ways to ease the job of sorting out terrain components from the patterns they display in different types of imagery. During the years 1979-1983, CRS entered cooperative studies in this area with the U.S. Geological Survey, DMA's Inter-American Geodetic Survey, the Naval Research Laboratory and the National Aeronautics and Space Administration (NASA). Among the research aims were supporting the preparation of geographic data bases and tactical decision aids, and providing a basis for selecting subsurface waste disposal sites and making other terrain related decisions. The Army showed particular interest in identifying terrain conditions, locating potential ground water sources, and evaluating dust potential, cross-country movement and mobility.

Indicators of terrain conditions

During the years 1979-1983, USAETL looked into a variety of pattern relations to see what they might tell the analyst. Among the pattern relations studied were:

- Landform, soil type and dust potential in subhumid areas
- Landform, soil texture and vegetation type in subhumid areas
- Surface conditions in subhumid regions (including vegetation and soil) and radar back scatter
- Fracture patterns and subsurface conditions in temperate zones
- Geological structure, vegetation cover and radar patterns in tropical areas
- Tropical closed tree canopy configuration and ground conditions using aerial photographs and radar imagery.

Usable pattern relations found

Some of the above studies pointed USAETL scientists to usable relations between many of the factors examined. Landform, soil texture and vegetation type, for example, proved so closely linked that, knowing one, USAETL scientists were able to predict the other two. The CRS also found a direct connection between some vegetation; specific soil depth, type and surface irregularities (coppice dunes); and established relations between landform, grain size and fracture patterns for some igneous and metamorphic rock. Proven pattern relations provided USAETL scientists with keys to terrain identities (rocks, soil type, vegetation), terrain conditions and characteristics (dust potential, instability, canopy closure), and potential uses (waste disposal, ground water, engineering materials).

Spectrophotometric, chemical and special techniques

While the center's Judy Ehlen, for example, worked to perfect interpretation of geology from air photos, others were at work sizing up wholly different sources of terrain information from afar.

USAETL scientists sought to perfect spectral measurement techniques that could help the Army identify terrain materials and conditions, detect camouflage and establish terrain signatures. Spectral work also helped in the classification of multispectral imagery and the preparation of data bases.

Under the direction of Dr. Rinker, USAETL scientists Bob Satterwhite, Ponder Henley and Dr. John Eastes examined natural and man-made materials, paying close attention to their reflectance, absorptance, luminescence and radiance characterisitcs.

Cooperative efforts

As already observed, such remote sensing studies required interdisciplinary work by people of many talents. Recognizing this, USAETL combined its in-house efforts with cooperative work done with scientists on the outside. CRS worked with the Camouflage Research Branch of the Belvoir Research and Development Center, U.S. Army Foreign Science and Technology Center, NASA, U.S. Geological Survey and Naval Research Laboratory.

Reading canopy by laser profilometer

The joint effort with the Naval Research Laboratory was one of the center's major looks at special techniques. In this case, a jointly developed modified laser profilometer was tested over the Great Dismal Swamp (Virginia/North Carolina). Scientists recorded its effectiveness in measuring vegetation structure in relation to microwave radiance. This effort, on-going at the end of this period, sought to give the Army a way to see through canopy and assess its density.

On-going research: significant results

Much of the work CRS does, as with the laser profilometer, is basic research. But, the results of this research can be applied in new directions. The following are some of those results.

- Camouflage Detection: CRS researchers detected a disparity between man-made materials and some backgrounds with regard to luminescence.
- Terrain Identification/Data Base Preparation: CRS scientists collected spectral signatures for subhumid terrain surfaces, allowing easier remote identification of such conditions.
- Natural Surface Factors: Studies were made measuring the influence of weathering, lichen cover and desert varnish on spectral reflectances of natural surfaces. CRS demonstrated how these factors alter reflectance values, and how any development of terrain signatures must take such factors into account.
- Predicting the Presence of Groundwater: In the never-ending search for clues to finding groundwater, researchers established usable relations between water absorption band characteristics and vegetation stress.
- Digital Classification: CRS developed an improved basis for the digital classification of subhumid Landsat scenes. This effort reflected the center's desire to move remote sensing into interactive and automatic modes.

Digital dilemmas

In seeking to classify subhumid Landsat scenes digitally, CRS participated in USAETL's overall effort to digitize and (where possible) automate the map-related labors being studied and improved. Like other sources supplying terrain information, remote sensing work would benefit from automated techniques to help reduce tedium and speed information to commanders and planners. The results, however, of such effort at CRS in the years 1979-1983 were mixed.

Dr. Rinker and his fellow scientists, interviewed at the close of this period, expressed some doubts about the potential for automating their work. The center's work into digital analysis of Landsat data had run into some problems, forcing the researchers to get back to basics in digital classification.[4] Dr. Rinker cited particular problems with desert varnish and confusion caused by lichen cover. Machines could not make the correct distinctions on their own.

Automated vs. interactive methods

Dr. Rinker and his fellow researchers succeeded during this period in improving remote sensing techniques with interactive (man-in-the-loop) systems "constantly being developed."[5] Fully automated procedures, on the other hand, had been unsuccessful in Dr. Rinker's view. He flatly stated that such procedures are "of little practical use and are not likely to be improved in the forseeable future."[6]

Dr. Rinker tempered this judgment, however, with the observation that the center's work into interactive systems in this period showed that the analyst, aided (rather than replaced) by the machine, "had far less restrictions than do automatic procedures."[7] Indeed, he predicted that interactive techniques based upon digital classification of spectral data would "probably improve significantly in the future as satellites with more and narrower spectral band passes are launched."[8] Digital work by CRS provided ways to help the analyst, but no way to replace him.

Radiation backgrounds

CRS paid particular attention to radiation backgrounds research in the period 1979-1983, building on their early research efforts in the late 1950s. At that time, they had established the first instrumented field site for developing and evaluating infrared thermal remote sensing techniques. Scientists now were seeking to measure the infrared and microwave radiation characteristics of different terrain surfaces and man-made materials. They also examined how temperature, emissivity, time, season and weather affect these measurements.[9]

Again, USAETL was probing ways to provide the Army with remote sensing techniques—in this case to identify soils, and determine soil moisture and terrain surface characteristics. Researchers in this area also looked for improvements to thermal modeling, camouflage detection and matching, image analysis and feature extraction.

An instrumented test site

In 1976, CRS began putting together an instrumented site at USAETL to aid in thermal investigations. By 1979, CRS scientists Alan Krusinger and Dr. Ambrose Poulin had the site in full operation, testing various thermal relations that might provide information when remotely detected.

Reading thermal signatures

Because materials heat and cool at different rates, they theoretically could be distinguished from afar. USAETL's test bed addressed the many complications that arose in turning such theoretical reading of thermal signatures into fact. Thermal signatures varied daily as well as seasonally. A small pond for example, appeared hotter than its background early at night, the same as its background some time later and cooler than its background late at night. In general, surface radiation patterns proved to be greatly influenced by events from below (thermal conductivity) and above (wind, rain, changes in air pressure, incoming radiation and haze). Sorting out these factors and relations was the job facing USAETL's test-site scientists.

Tests and measurements at the site

Scientists used USAETL's instrumented test site to study the affects of time, season and weather on the thermal signatures of bare soil, different types of ground cover, and of the thermal contrast between a large truck and different backgrounds. They also tested various materials and targets against different backgrounds.

Measurements made at the site included dew point temperature, precipitation, air temperature, soil temperature and soil moisture profiles, incoming and outgoing radiation, and wind speed and direction. USAETL scientists used this information to build a standard data set for developing mathematical models for time-varying thermal signatures. Scientists also used these data to predict the times and conditions for maximum or minimum thermal contrast between a target and its background.

Early testing in 1979 and 1980 sought to relate soil moisture to radiometric temperature with "mixed success."[10] An in-house effort followed relating the radiometric temperature of fir trees to air temperature and background. As a result, research into backgrounds was increased ending in "highly successful" work on seasonal changes and their effect on backgrounds at the close of the period 1979-1983. CRS was able to identify some of the meteorological and ground characteristics associated with thermal contrasts occurring at different times and seasons. Scientists established that long-wave radiation was the most important piece of information in predicting thermal contrast.

Field studies down South

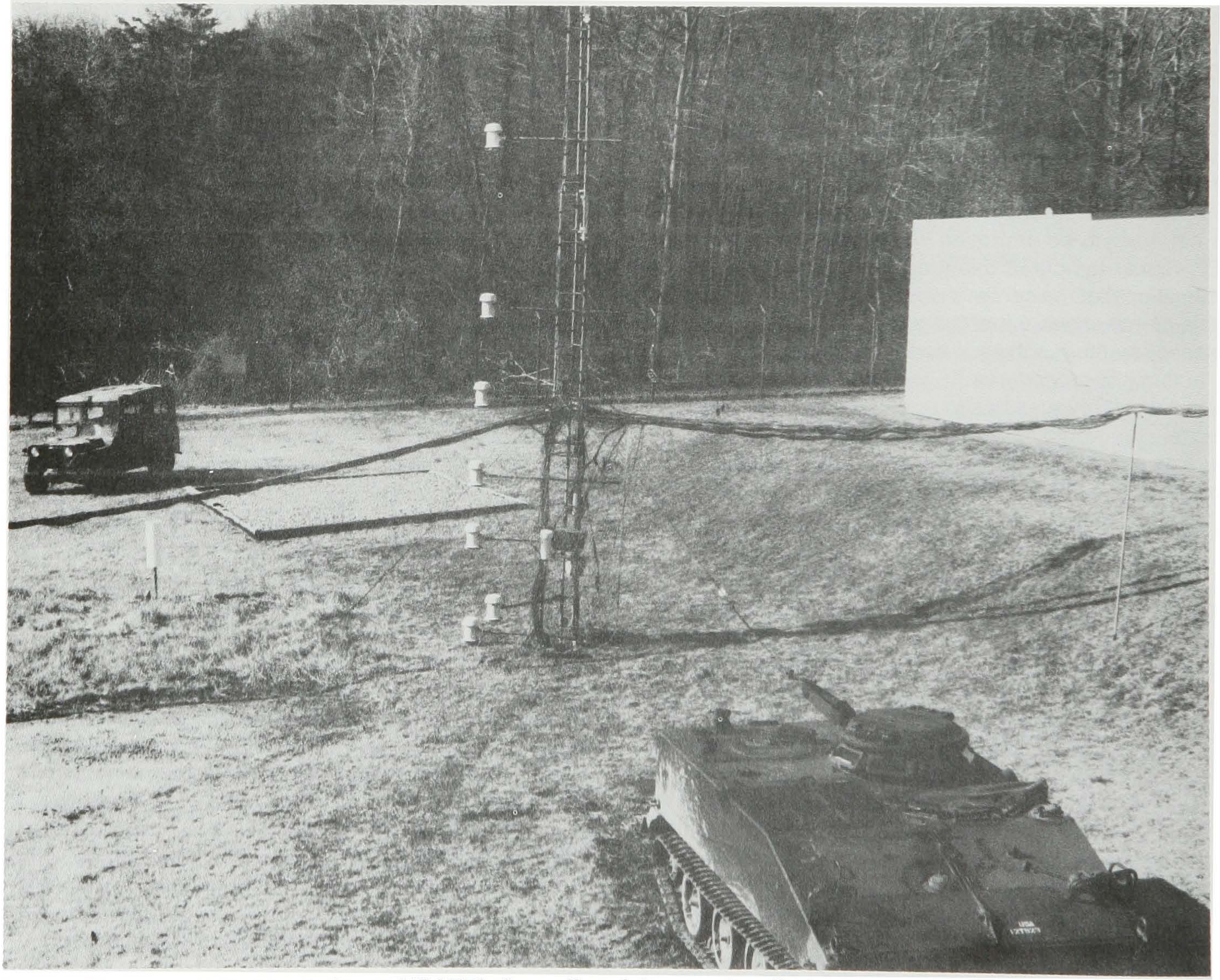
While scientists Krusinger and Poulin managed the test bed at home, Rinker and Henley did research in the field to evaluate airborne microwave remote sensing techniques. Working with the U.S. Geological Survey and the U.S. Fish and Wildlife Service at the Great Dismal Swamp and Merchants Millpond, researchers used ground truth information on soils, moisture, vegetation and weather to study airborne microwave measurements and establish relations that provide a basis for predicting terrain characteristics. Results pointed to a possible relation between microwave brightness and vegetation type, providing a basis for understanding why certain targets were easily confused.

Photo interpretation and feature extraction

Dr. Rinker led an on-going effort to "translate the results of research into knowledge-based systems."[11] To that end, CRS put the results of much of its research effort into document form. Throughout this period, CRS assembled materials to support terrain analysis work, data base preparation, and camouflage matching and detection. Thus, a basis was provided for developing image keys, digital classification techniques and knowledge-based systems.

Summary sheets

In order to help the Army and other agencies gather and interpret terrain information, CRS undertook the preparation of single-sheet summaries for photo interpretation. These sheets identified specific air photo patterns that are indirect indicators of terrain conditions and materials. Topics addressed included rock, soil and vegetation type; potential for dust generation; effects of surface irregularities on mobility and cross-country movement; areas of instability;



The CRS' instrumented test site at USAETL for soil-moisture and radiation-background experiments.

and location of engineering materials. At the close of 1983, CRS had completed 70 air-photo indicator sheets. Scientists had also prepared a series of spectral data sheets linking measurements of reflection, luminescence and radiation to specific terrain identities, conditions and camouflage signatures.

Knowledge-based systems

In addition to the summary sheets, CRS researchers also developed a knowledge-based example of a photo interpretation routine, and soil and vegetation classification systems based on photo patterns. They also reviewed 20 published land-cover/land-use classification systems. Dr. Rinker and Phyllis Corl worked toward an interim report recounting these efforts, scheduled for issue in mid-1984.[12]

Krusinger noted that much of CRS work falls "between basic and applied research."[13] Summary sheets and knowledge-based models did not, however, find application without conscious efforts by USAETL to transfer this technology elsewhere. Similarly, at the close of the 1979-1983 period, plans were underway for a workshop on "desertification" in conjunction with the Geological Survey.

Though remote indeed—in the sense of being both highly research-oriented and far removed from its MGI source—CRS had results during this period with direct applications to technology transfer, data base preparation (Digital Land Mass Simulation, Tactical Terrain Product Data Base, MGI) and establishing knowledge-based systems for use in interactive methods of analysis. Thus, George Lukes of USAETL could refer in 1983 to a "revolution in the diversity and performance of remote sensing acquisition systems."[14]

Footnotes

1. Interview, authors with Dr. Jack Rinker, Fort Belvoir, Va., 20 September 1984.
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12. Rinker and Corl, "Air Photo Analysis," p. 6.
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C. CAPIR: Computer-Assisted Photo Interpretation Research

At the beginning of the period 1979-1983, terrain analysts faced a classic supply and demand problem. The demand for digital cartographic products was mushrooming faster than existing image analysis methods could supply them. Within its Research Institute, USAETL looked for ways to improve techniques for creating and managing digital map data to aid in streamlining existing manual photo-interpretation techniques.

Bridging a gap

USAETL's George Lukes observed, in 1981, that it was "obvious that a substantial gap existed" between "current manual image analysis procedures and the requirements to provide large volumes of digital cartographic data."[1] The growing, unfilled demand derived in part of the successes witnessed in synthetic reference scene generation for geographic data bases (e.g., Pershing II), was leading to "new and expanding responsibilities for the mapping community."[2] At the same time a revolution in the diversity and performance of remote sensing acquisition systems had taken place based on electronic sensors recording image data digitally. More information was pouring in and more people wanted it, but the exacting chore of putting it into usable form was still left to the terrain analyst, plodding along with tried and true labor-intensive, manual procedures.

Photo to map

The Defense Mapping Agency (DMA) was asked how long it took to turn a photograph into a useful map. The agency estimated 800 man hours to go from photo to hard copy on a single standard 1:50,000 map. To make the map machine-readable (to digitize it) required an additional 800-1600 hours of skilled effort. Commanders do not typically have the luxury of such production schedules, and they can only hope the required terrain data are already on file. The files, however, must be built, maintained and updated. The production loop of the past required many trained people to do very tedious work lasting many hours.[3]

Long- and short-term help

At the start of the 1979-1983 period, work was underway to ease the production logjam. Within the Research Institute, scientists experimented with everything from high-risk, automated feature extraction techniques of the future to short-term interactive aids for the terrain analyst. The work proceeded on many levels, with predictably mixed results.[4]

Tools for the terrain analyst

In 1979-1983, George Lukes did a study of ways to support the human specialist with hardware and software to help information extraction from stereoscope aerial photography. The goal was to make the specialized work simple, fast and more accurate. The immediate target was the near-range and mid-range priority areas of DMA and digital spatial data users. USAETL scientists were working to develop and demonstrate improved procedures to produce, intensify, manage and exploit digital cartographic data files.

Reworking a Fish & Wildlife Service system

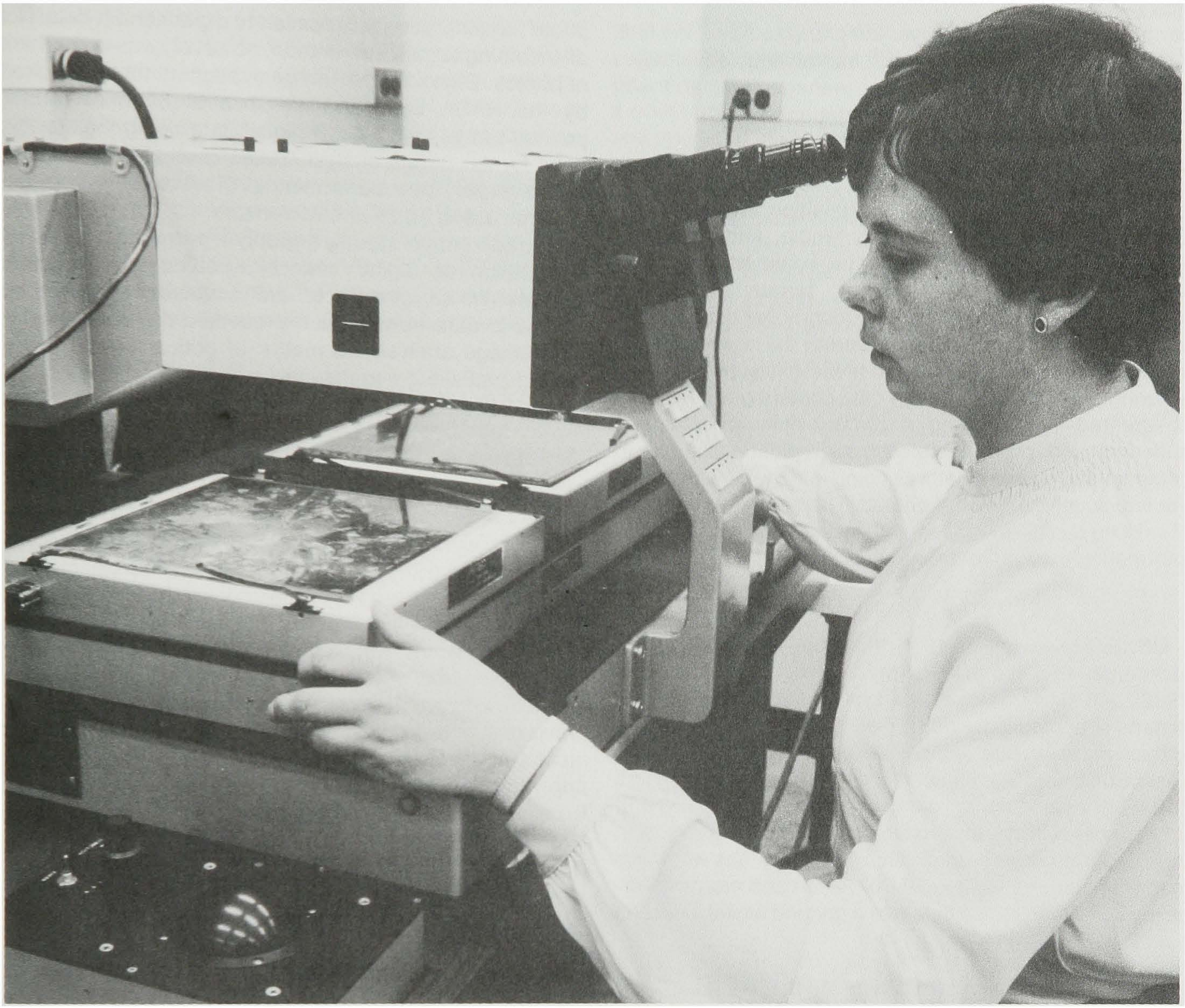
The Fish and Wildlife Service's Wetland Analytical Mapping System or WAMS had been developed in 1979 by Autometric Inc. The system attracted the attention of USAETL researchers looking for immediate off-the-shelf help. Lukes looked at their software to see if addition and adaptation could make a similar system work for USAETL's purposes. Working on Army independent research funds, Lukes concluded that a high-precision measuring instrument such as the APPS-IV analytical plotter could be tied to existing software to develop a useful Computer-Assisted Photo Interpretation (CAPIR) system.[5]

The concepts behind CAPIR

Writing in 1981, Lukes cited the "desired, but mutually exclusive, goals of quantity and quality production with minimized cost."[6] As a step toward that goal, USAETL scientists sought to provide some kind of working link between the aerial photograph, the photo interpreter and his digital products. The design of a research facility to do this was guided by three basic concepts:[7]

The first was direct data entry by the human specialist to digital files in an interactive system. The system would facilitate encoding and storing spatial data (in addition to supporting interactive prompting, option selection, graphic data display, editing and extensive data validation procedures—to cut down error).

The second concept was the use of a computer-interfaced stereoscope to be the direct-data entry device. Point, linear and areal features would be entered directly, in three-dimensional coordinates. USAETL would take advantage of some of its own developmental analytical plotters to perform real-time calculations of ground coordinates.



A scientist prepares to view stereopairs on the Computer-Assisted Photo Interpretation Research (CAPIR) system.

The third concept was direct stereo superpositioning of computer-generated graphics providing feedback to the photo interpreter. The interpreter would see "graphics representing encoded data" displayed directly in the stereo model before his eyes. This would be a crucial modification to the CAPIR concept.

Concepts into realities: 1981-1982

Turning Lukes' concepts into working realities required some borrowing, some adapting and some real invention.[8] The year 1980 was spent "pulling things off the shelf," including the assimilation of two large application programs, the Analytical Mapping System (AMS) and the Map Overlay and Statistics System (MOSS) from the Fish and Wildlife Service. AMS was a digital mapping system providing spatial data capture. MOSS was an interactive spatial analysis software system that stored and operated on data produced by AMS or some other external source. This software provided one starting point and Lukes' photo-interpreter's savvy provided the other.

The invention of stereo superposition: 1982

Linking the photo interpreter with the computer remained a goal of CAPIR. Thus, Lukes and Dr. Robert Leighty looked for ways to lend a greater precision to the conveniences offered by CAPIR. Specifically, they worked out a method to float the emerging topographic picture right into the CAPIR operator's view, super-positioning digital cartographic data directly over the photo source. This first, accomplished in February 1982, had obvious advantages for compilation, verification and management, and won Lukes and Leighty a government patent award.

The capabilities of CAPIR

With the addition of the superposition capability, the CAPIR system was conceptually whole, and entered a period of refinement. The operator could now examine stereoscopic imagery and enter terrain information (expressed in three-dimensional geographic coordinates) into a data base. He would then display the newly digitized information in the working stereo model (via superposition), allowing the analyst to see the data content graphically as he created it. By seeing a contour line, for example, superimposed on the stereo-model picture, he could compare at a glance what was going into the data files with the line suggested by the photos. The editing or verifying of existing data files now required just comparing the stored information with up-to-date photographs.

Demonstration of CAPIR

USAETL scientists used CAPIR during this period to test techniques to solve military and civil works problems. In 1982, Dan Edwards used the system to fashion a three-dimensional data base of the Fort Belvoir area from high-altitude mapping photographs provided by NASA. In 1983, Laslo Greczy, GSL, conducted a demonstration of CAPIR's civil work uses such as dam monitoring and analysis of urban areas. Greczy also examined CAPIR's future role in the Terrain Analysis Work Station (TAWS). Plans were also made to experiment using CAPIR to sort and merge three-dimensional planimetric data into a gridded digital elevation model.

Technology transfer and CAPIR

From the start, USAETL attempted to show the advantages of CAPIR. The generation of reference scenes for the Pershing II missile had been a USAETL area of effort, and CAPIR was used to verify such scenes. Outside USAETL, the Fish and Wildlife Service also acquired a CAPIR facility, and, in 1982, pushed to map duck habitats. The Defense Mapping Agency initiated a series of procurement programs to place CAPIR capabilities in base-plant production.

At the close of the 1979-1983 period, CAPIR continued to be a major focus for feature extraction research. Scientists were hoping to improve the system's man/machine interface by various means, including the integration of computer voice recognition and synthesis technology.

A soft-copy work station

CAPIR began its life dealing with the "standard frame photo" which it sought to convert to digital terrain data. Not all incoming terrain information, however, was in the form of photos. Digital terrain imagery, such as that generated by the NASA Landsat Multi-Spectral Scanner (MSS), pointed to the possibility of digital data being the starting point for the terrain analyst. Lukes cited a "revolution in the diversity and performance of remote acquisition systems based on electronic sensors. . . ." Such systems recorded image data digitally—permitting diverse exploitation of digital imagery. Soft-copy exploitation facilities linked directly to the acquisition system by electronic data transmission presented the possibility of rapid image analysis—a matter of critical concern to a harried battlefield commander.

CAPIR enhancements

Extending the existing CAPIR software to support a soft-copy work station was a major goal at the end of the 1979-1983 period. CAPIR specialists looked forward to an integrated work station granting man and machine access to the same digital data and to improved management of secondary collateral sources (textbooks, sketches, etc.). In addition, the existing CAPIR software was undergoing a series of enhancements to provide added capabilities and facilitate on-line photo interpretation. In 1983, specific efforts included support of global digitizing projects, provisions for multiple attributes/descriptors and integrated input/output device options. These enhancements were to apply to both hard-copy and soft-copy image exploitation. Researchers also were planning to introduce synthetic aperture radar models into CAPIR's geographic information system.

A link to artificial intelligence

At the close of the historical period, plans were underway to relocate CAPIR within the Research Institute from the Center for Artificial Intelligence to the Center for Physical Sciences. Lukes was preparing to go on extended training abroad, with CAPIR falling under the direction of Dan Edwards. Plans still called for CAPIR's extensive use in investigating image-understanding techniques. The long-range goals of the artificial intelligence specialists called for the introducton of expert system modules into the CAPIR environment.

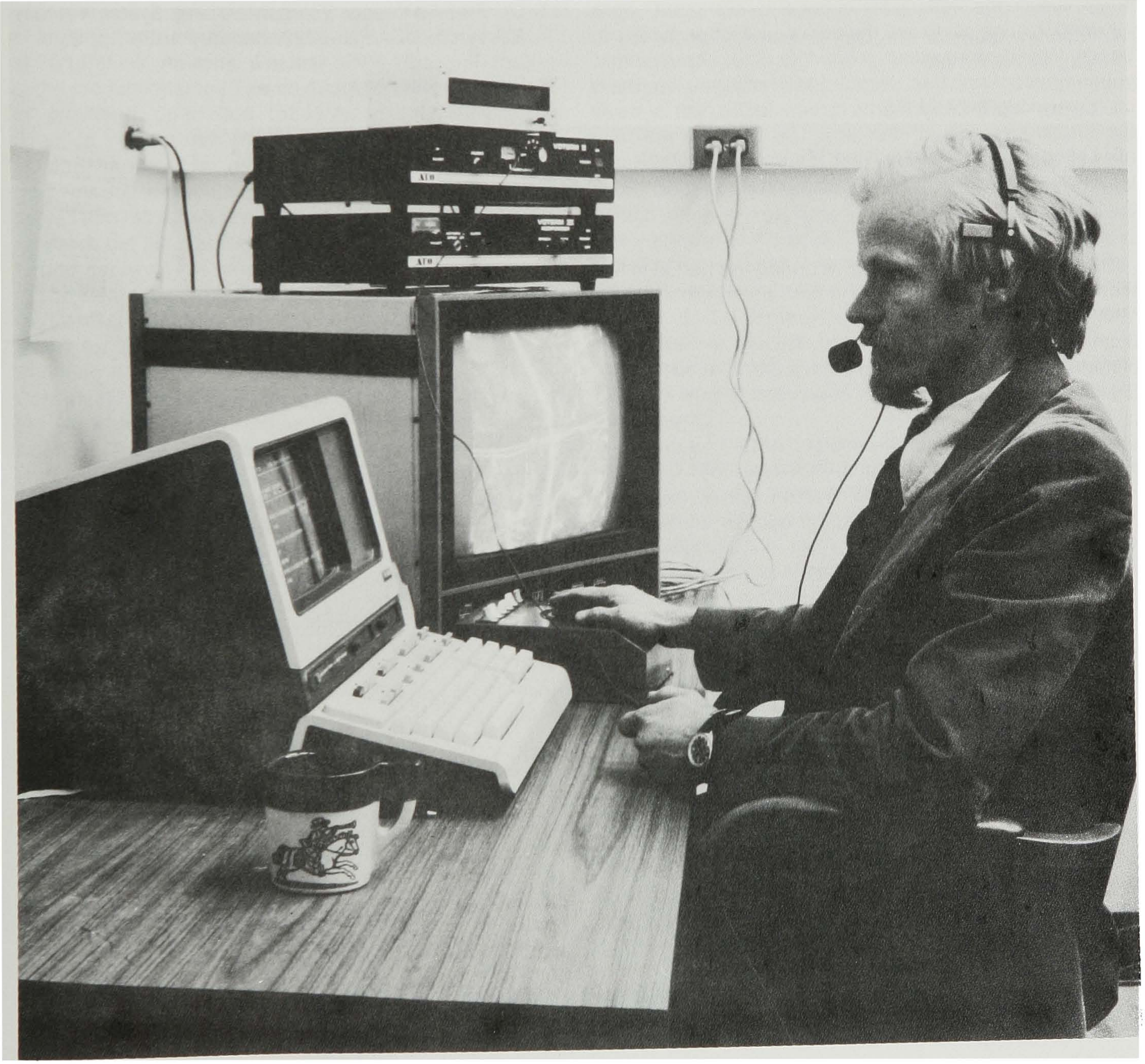
Voice recognition and CAPIR

Dr. Tice DeYoung at the Center for Artificial Intelligence had an abiding interest in Voice Interactive Systems Technology (VIST) and how this research might apply to CAPIR. In 1982, a voice data entry capability was added to the CAPIR system (and work began on installing a voice recognizer on the DEMONS (Demonstration System) as well).[9] Though a small project, done part-time and usually involving only one researcher, it was still considered significant.[10]

The CAPIR operator, eyes flush to the stereoscope, could direct cursor movement by voice (e.g., "slow, right"). Voice recognition, both as applied to CAPIR and other projects, continued in-lab through the end of the period. Plans were made to investigate limited connected speech recognition and stored speech synthesis.

Such work showed that "even with very crude, low-cost equipment, VIST could be useful."[11] During this period, Dr. DeYoung worked with Voice Recognition Modules and phonetic voice synthesis devices (VOTRAX and VOTALK). Following testing on a Hewlett Packard 1000 series minicomputer, several demonstration programs were written and a USAETL report published (ETL-0349).

The contributions of the CAPIR program in the 1979-1983 time frame include reducing the time involved in turning a photo into a map, and providing a new tool to capture and manage high-quality digital map data. CAPIR made it possible to return much of the work to the craftsman—a return to the best cartographic traditions. Future efforts will focus on transferring more of the work of photo interpretation from man to machine. While, in Edwards' judgement, no "black box" is on the horizon capable of doing terrain analysis automatically, CAPIR developments provide a solid foundation for incremental improvements.[12]



A USAETL scientist operates the voice recognition system.

Footnotes

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3. George Lukes, "Soft-Copy Terrain Analysis," 1983 (draft), p. 1. In installation files, Research Institute, Center for Artificial Intelligence (RI-CAI), 1983.

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Summary: A Common Thread

It is doubtful that even the great Baron Gottfried von Leibnitz, the "last man to know everything," could have mastered or understood the many directions of USAETL research and development. Yet there is a common thread of inquiry that runs between the laboratories of USAETL at Fort Belvoir. All work, whether at the Research Institute or the product-oriented Terrain Analysis Center, was related to providing up-to-date topographic information. The direction of research may have differed, along with its ultimate applications, and very often its timetable, but the goal was still information related to topography. Still, if the overall aim remained unchanged, the emphasis within that research did not. During the years 1979-1983, the inquiry turned decisively in new directions.

The clearest evidence of this is found in the creation of the Center for Artificial Intelligence, as well as the new uses found for Digital Topographic Data (among which the Pershing II "smart" missile is merely the most visible). Conversely, emphasis on theoretical geodesy lessened, as did work done at the request of the Defense Mapping Agency. These changes were reflected, in turn, by a concentration of USAETL's scientists and engineers in space-related activities and exploitation of digital terrain data, in addition to the traditional topographic support to the Army. Tackling new areas of inquiry meant new technology as well, a fact underlined by USAETL debating expansion of its physical facility in 1983.

We have seen that, throughout these changes, USAETL retained its special character. Research and development continued, with inter-laboratory cross-fertilization of ideas encouraged. We have seen that some initiatives led to dead ends, some led in positive directions, and some led in directions entirely unforeseen at the start. Not surprisingly, with technology transfer so much a part of the laboratories' mandate, spin-offs from USAETL research were common. Even in the civilian arena, USAETL work had impact.

At the close of the 1979-1983 period, only the broad outlines of USAETL's future research and development could be seen. More work for the Army Space Program Office, more concentration on Digital Topographic Data applications, developing products to provide timely topographic information for the Army—that much was clear. But the exploratory nature of USAETL work meant that the results of this R&D could only be guessed. It bears remembering that no one working 15 years earlier to streamline the map-making process could have foreseen his work finding application in a smart missile such as the Pershing II.

Similarly, the real significance of USAETL work during the 1979-1983 period will probably not be known for some years yet. In the interim, USAETL will continue its R&D efforts and do its best to spread the fruits of its labors. Much of the laboratories' work will baffle laymen, but there is certainly a tradition of achievement in the years 1979-1983 to bank on.

History of the U.S. Army Engineer Topographic Laboratories

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A note on primary sources: USAETL maintains an installation file at Fort Belvoir in the Cude building. This installation file is made up of "Annual Historical Summaries" provided by the individual laboratories. These reports are not sequentially numbered and are unpaginated. "Lab of the Year" reports are also found here, as are back issue of *Tech-Tran*, USAETL's quarterly newsletter for technology transfer. USAETL also produced a number of one-page information sheets on specific projects, some of which can only be indentified by title (e.g., "FEED").

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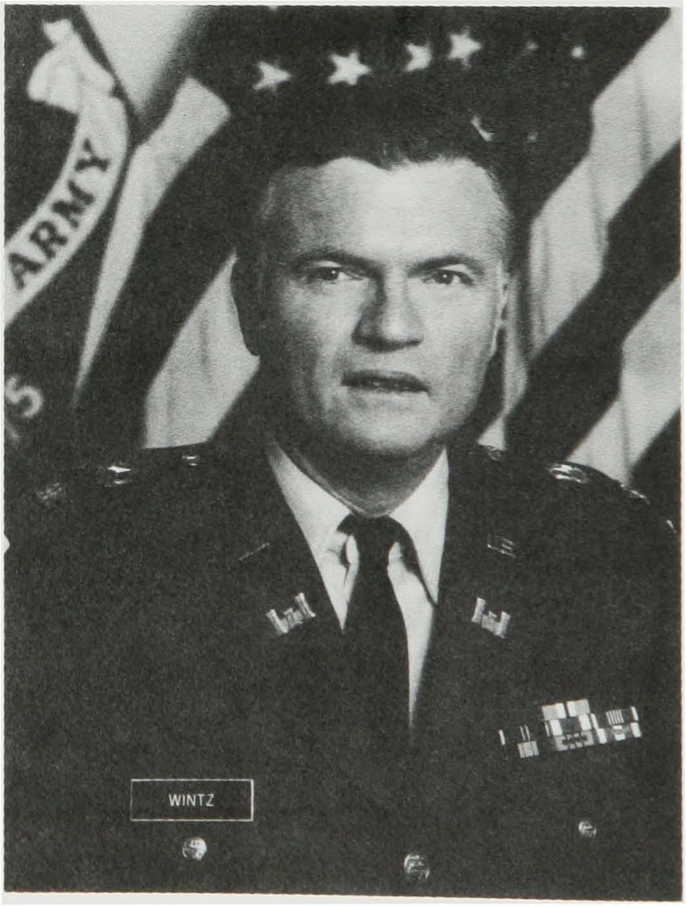
Appendices

A. U.S. Army Engineer Topographic Laboratories' Leaders, 1979-1983

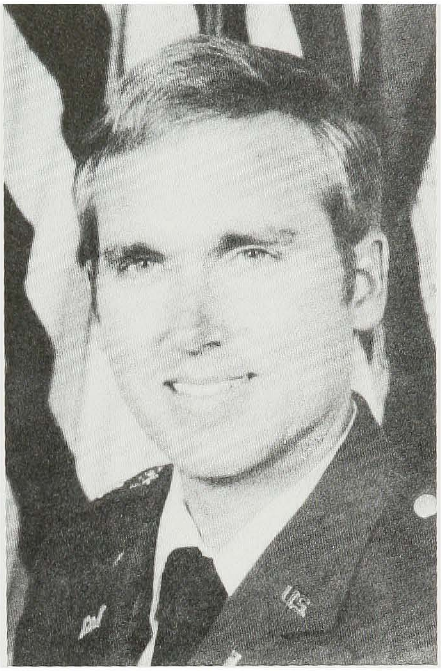
Commander & Director
Col. Daniel L. Lycan
15 Sep 78-31 Jul 81



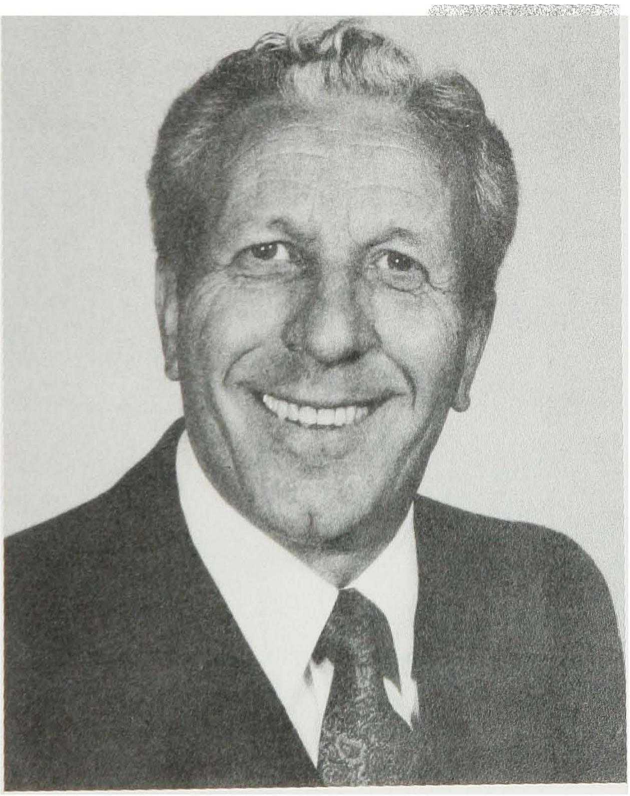
Commander & Director
Col. Edward K. Wintz
1 Aug 81-present

Dep. Commander & Director
Lt. Col. Douglas V. Myers
1 Mar 79-18 Dec 80

Dep. Commander & Director
Lt. Col. David G. Weise
19 Dec 80-18 Jun 82



Dep. Commander & Director
Maj. Mark M. Schnabel
19 June 82-present



Technical Director
Robert P. Macchia
1 Jul 73-present

B. Organizational Charts, 1979-1983

The multitude of laboratories, divisions and work groups at USAETL makes tracking institutional changes a nightmare. The nature of laboratory R&D assures that changes will be many; so many that listing them all would fill this volume to the exclusion of everything else. The authors have chosen instead to mention the most significant changes, and to include this information in the course of treating the work itself. For further clarification purposes, however, the following dated organizational charts of USAETL are provided.

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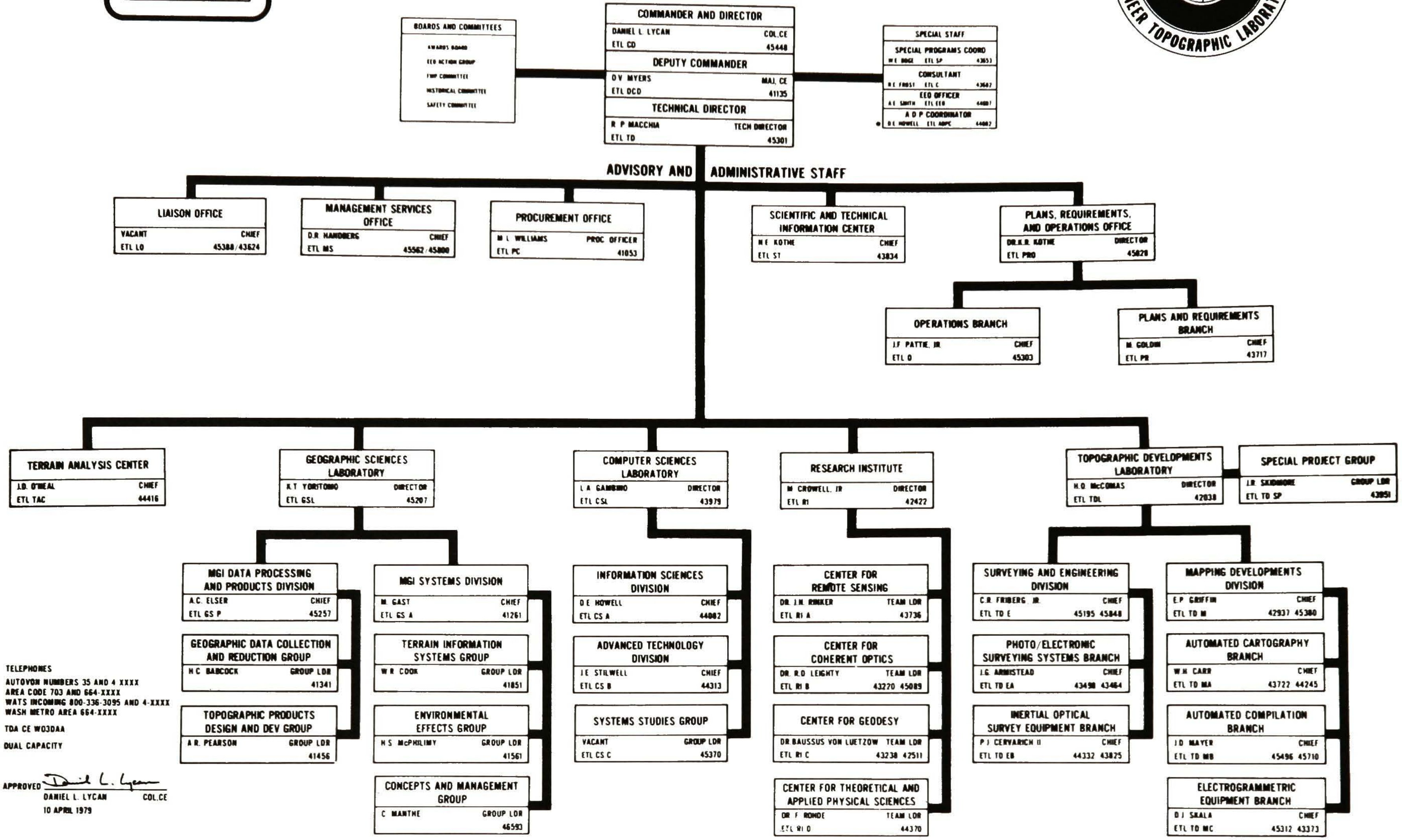

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  - FWP COMMITTEE
  - HISTORICAL COMMITTEE
  - SAFETY COMMITTEE
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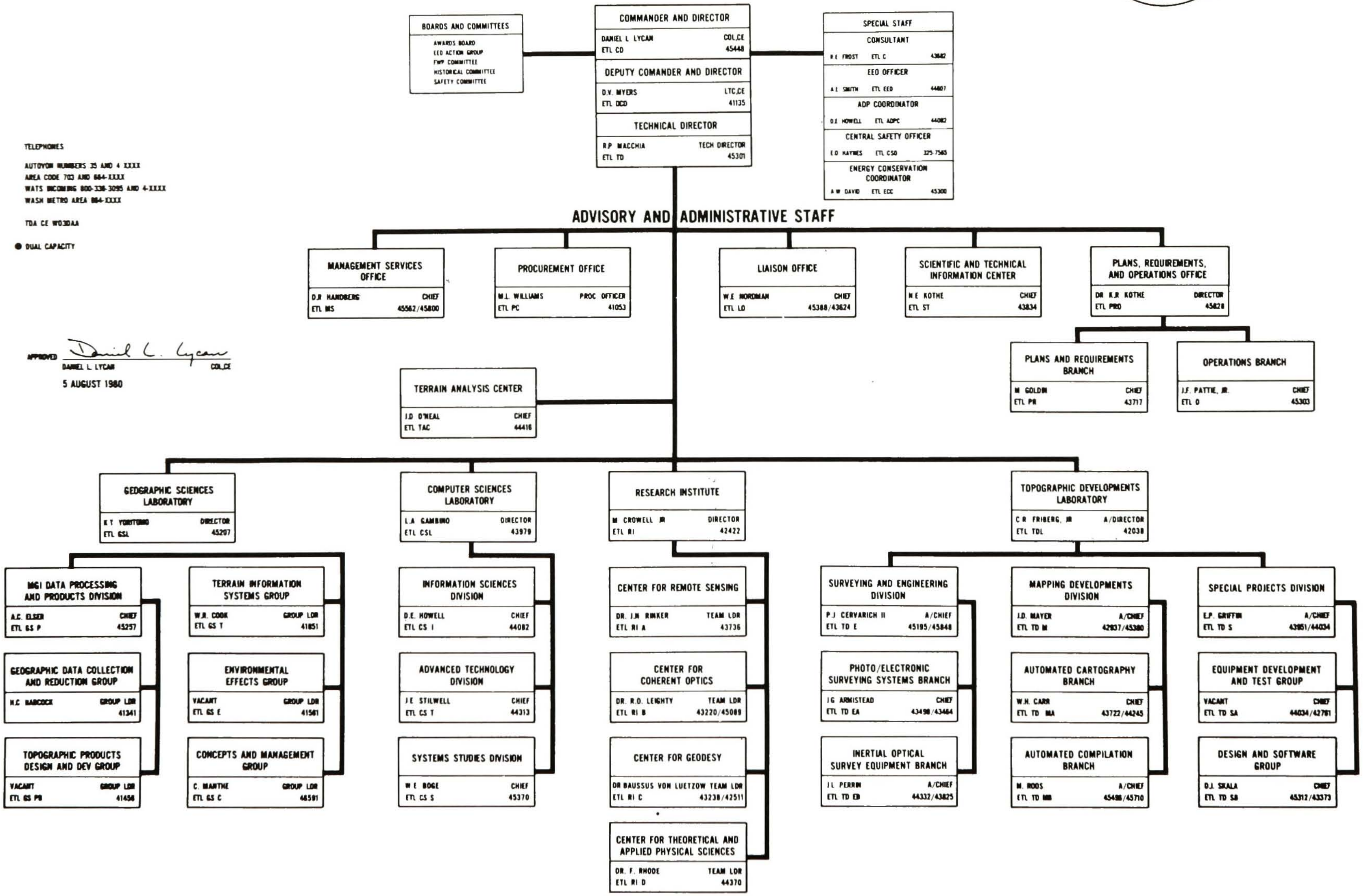

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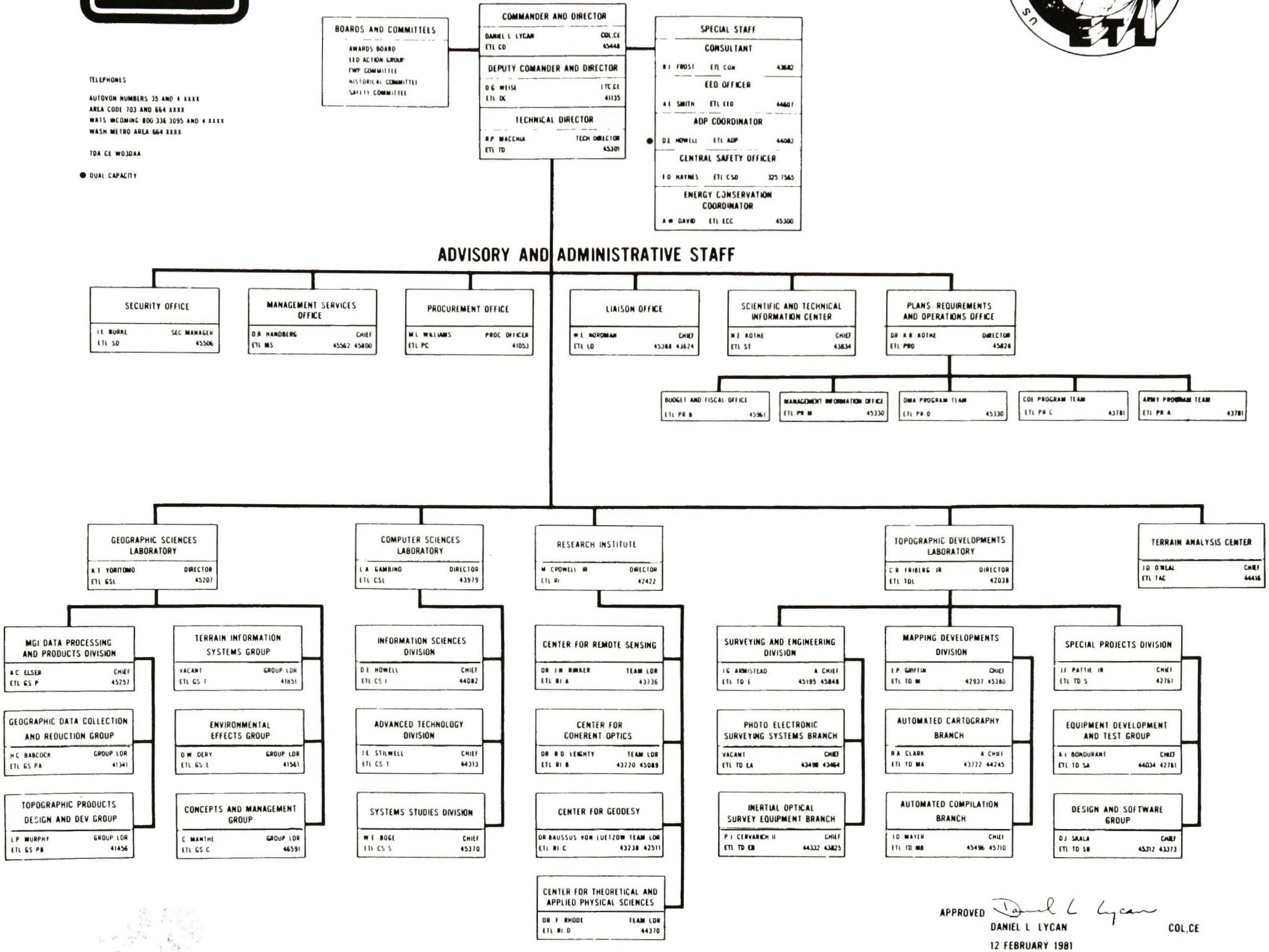

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12 FEBRUARY 1981

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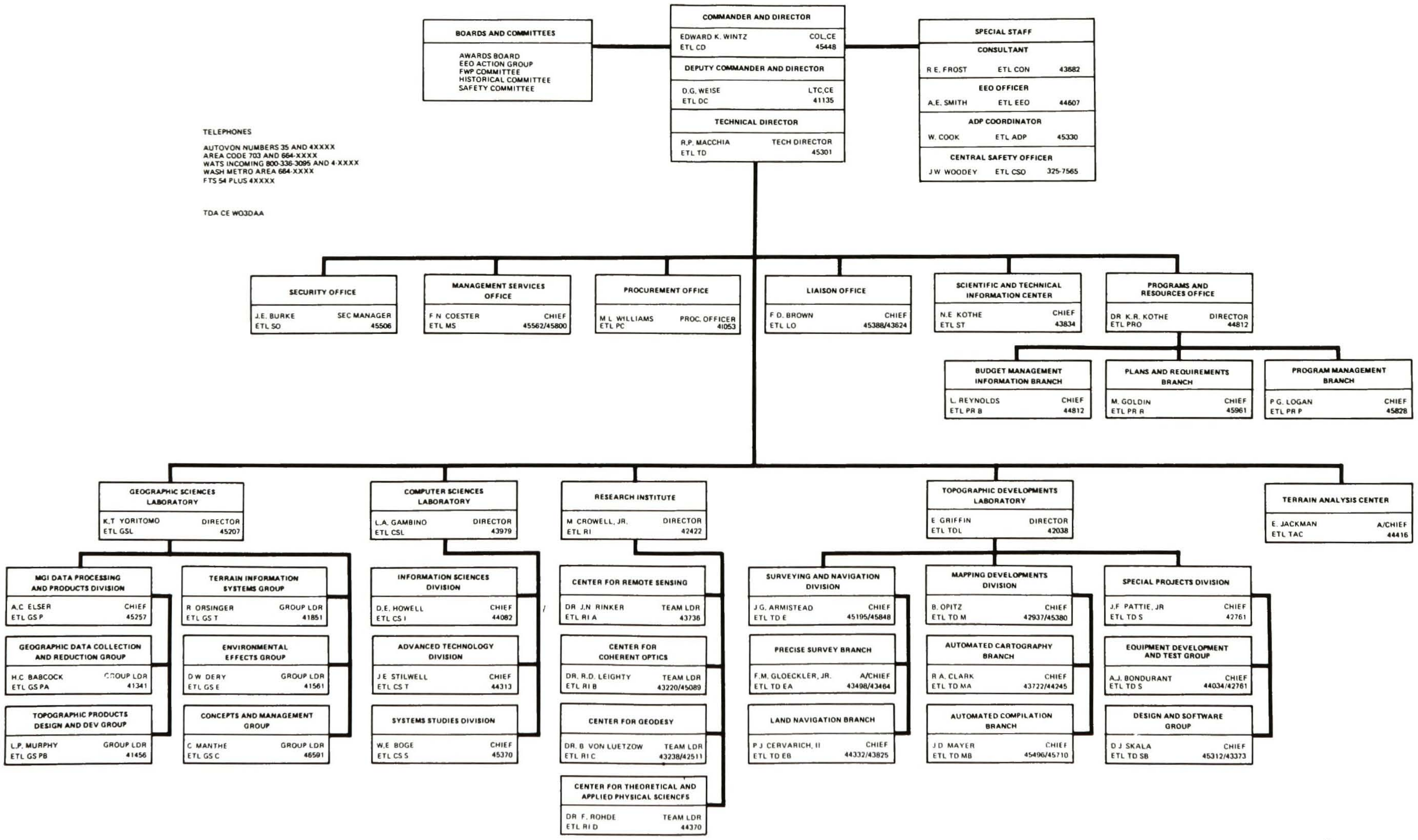

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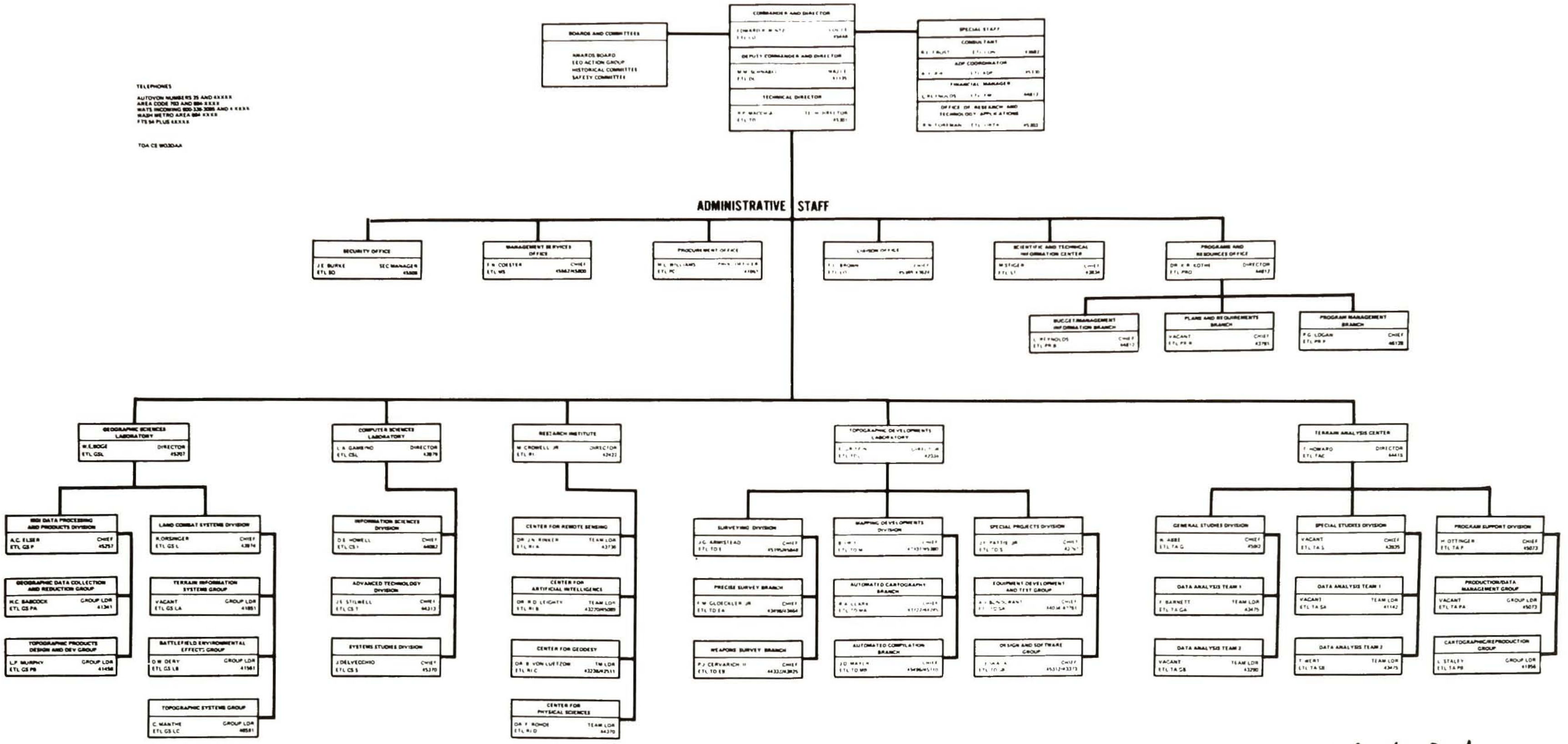

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28 JANUARY 1983

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C. Acronyms

It is fair to say that both the Army and the scientific community share a fondness for acronymns. At USAETL, where the two communities are one, reports can easily turn into alphabet soup for the layman. Every effort has been made in this history to minimize the confusion caused by this "economy." Nevertheless, the following list of acronyms is provided for the uninitiated and the understandably confused.

AAFIF	Automated Air Facilities Information File
ACSI	Assistant Chief of Staff for Intelligence
AES	Advanced Edit System
AGDS	Automatic Graphic Digitizing System
AI	Artificial Intelligence
ALBE	AirLand Battlefield Environment
AMC	U.S. Army Materiel Command
AMS	Army Map Service or Analytical Mapping System
ANMS	Automated Notice to Mariners
APPS	Analytical Photogrammetric Positioning System
ARTBASS	Army Training Battle Simulation System
ARTINS	Army Terrain Information System
ASAR	Advanced Synthetic Aperture Radar System
ASAS	All-Source Analysis System
ASPO	Army Space Program Office
ASPRO	Advanced Signal Processor
BEEG	Battlefield Environmental Effects Group (USAETL)
BEES	Battlefield Environmental Effects Software
BETA	Battlefield Enhancement of Target Acquisition
CAI	Center for Artificial Intelligence (USAETL)
CAPIR	Computer-Assisted Photo Interpretation Research
CCD	Charged-Coupled Device
CIG	Computer Image Generation
CPU	central processing unit
CRS	Center for Remote Sensing (USAETL)
CRT	cathode ray tube
CSL	Computer Sciences Laboratory (USAETL)
CVHRS	Combat Vehicle Heading Reference System
DARCOM	U.S. Army Materiel Development and Readiness Command
DARPA	Defense Advanced Research Projects Agency
DDS	Data Disk Scanner
DEDDF	Digital Elevation Data Dubbing Facility
DEMONS	Demonstration System
DFAD	Digital Feature Analysis Data
DIA	Defense Intelligence Agency
DIAL	Digital Image Analysis Laboratory
DIGS	Device-Independent Graphic Software
DIODE	Digital Input/Output Display Equipment
DIMP	Digital Image Matching Program
DIPPSY	Digital Pre-Press System
DITB	Digital Imagery Test Bed
DLMS	Digital Land Mass System
DMA	Defense Mapping Agency
DMA/HTC	DMA Hydrographic/Topographic Center
DME	distance measuring equipment
DMS	Defense Mapping School
DOD	Department of Defense
DRU	dynamic reference unit
DTAS	Digital Terrain Analysis Station
DTD	digital topographic data
DTED	Digital Terrain Elevation Data
DTSS	Digital Topographic Support System
EBR	Electron Beam Recording
ECAC	Electromagnetic Compatibility Analysis Center
EDET	Elevation Data Editing Terminal

EDGE	Environmental Design Guidance and Evaluation Software
FASE	Forward Area Survey Equipment
FEED	Field Exploitation of Elevation Data
FISTV	Fire Support Team Vehicle
FORSCOM	U.S. Army Forces Command
GIMRADA	U.S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency
GLSS	Graphic Line Symbolization System
GPS	Global Positioning System
GSL	Geographic Sciences Laboratory (USAETL)
HEL	U.S. Army Human Engineering Laboratory
HTC	Hydrographic/Topographic Center
IPB	Intelligence Preparation of the Battlefield
IPS	Inertial Positioning System
MAPS	Modular Azimuth Position System
MC&G	Mapping, Charting and Geodesy
MDD	Mapping Development Division (USAETL)
MERADCOM	U.S. Army Mobility Research and Development Command
MGI	Military Geographic Intelligence
MOSS	Map Overlay and Statistics System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
OACSI	Office of the Army's Assistant Chief of Staff for Intelligence
OPSA	Optical Power Spectrum Analyzer
PADS	Position and Azimuth Determining System
PHIRAS	Photometric High-Resolution Array Scanner
PII	Pershing II Guidance Missile
PIIODB	Pershing II Operational Data Base
QRMP	Quick Response Multicolor Printer
RAPS	Raster Plotter Systems
REFORGER	Reinforcement of Forces in Germany
RGSS	Rapid Geodetic Survey System
RI	Research Institute (USAETL)
ROSA	Recording Optical Spectrum Analyzer
RPIE	Replacement of Photographic Imagery Equipment
RS	Remote Sensing
RSGF	Reference Scene Generation Facility
SIF	standard interchange format
SLF	standard linear format
SPR	Statistical Pattern Recognition
SRI	Stanford Research Institute
SRU	static reference unit
TAC	Terrain Analysis Center (USAETL)
TACOM	U.S. Army Tank-Automotive Command
TACFIRE	Tactical Fire Direction System
TACIES	Tactical Image Exploitation System
TAWS	Terrain Analyst Work Station
TCC	Type Composition Console
TDL	Topographic Developments Laboratory (USAETL)
TEAS	Terrain Environmental Analysis System
TES-EMPS	Terrain Elevation System-Elevation Matrix Processing System
TFS	Topographic Finishing Station
TISG	Terrain Information Systems Group (USAETL)
TRADOC	U.S. Army Training and Doctrine Command
TSS	Topographic Support System
UNAMACE	Universal Automatic Map Compilation Equipment
USACE	U.S. Army Corps of Engineers
USAETL	U.S. Army Engineer Topographic Laboratories
USMA	U.S. Military Academy
UTM	Universal Transverse Mercator
VGLP	Variable Geometry Laser Printer
VIST	Voice Interactive Systems Technology
ZUPTS	Zero Velocity Updates

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