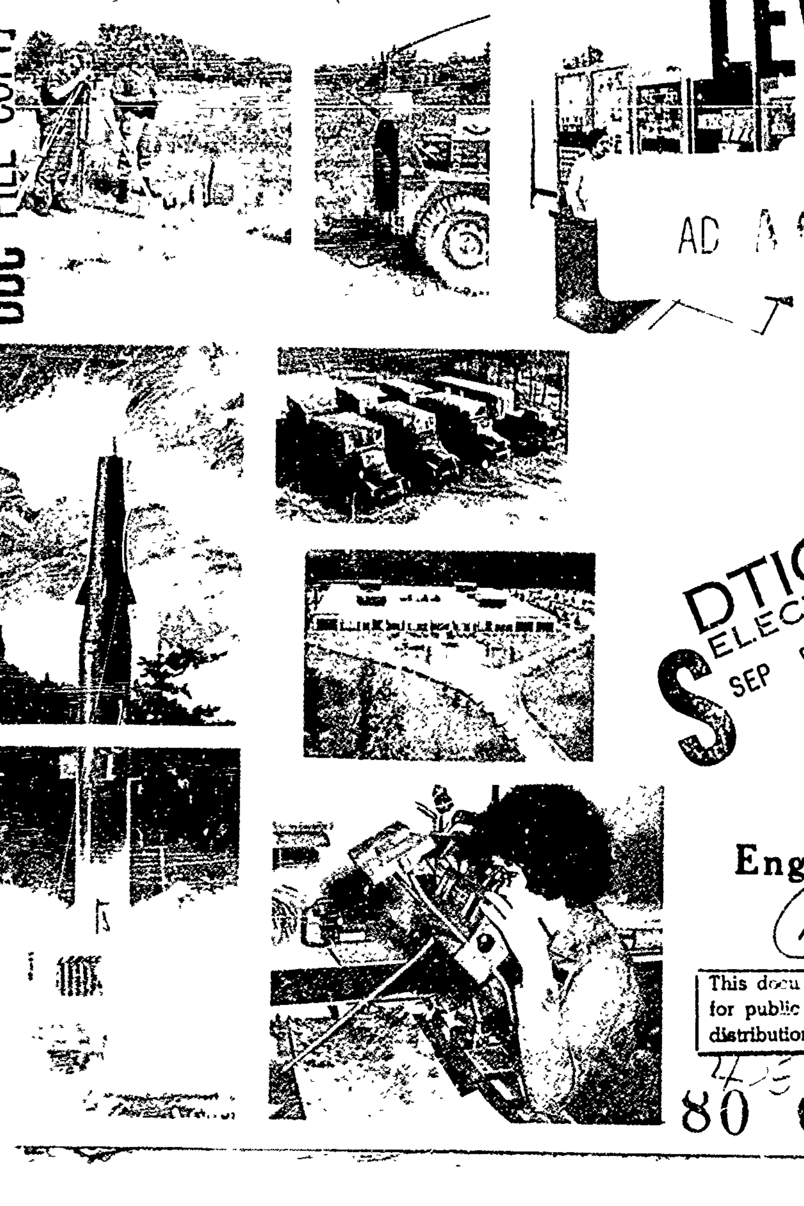

ETL HISTORY UPDATE

1968-1978

BY

Edward C. Ezell

FOR THE

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

FEBRUARY 1979

PREFACE

This history of research and development activities at the Engineer Topographic Laboratories (ETL) during the decade 1968-1978 has been prepared in part to satisfy the Corps of Engineers requirement for periodic updates of the histories of its field organizations. In 1973, ETL published John T. Pennington's *History of U.S. Army Engineer Topographic Laboratories (1920-1970)*, ETL-SR-74-1. This document will cover the years 1968-1978, the period ETL has been known by that title. Our goal, in addition to meeting official requirements, has been to describe some of the major accomplishments of this small, but highly active agency.

For the past 10 years, the men and women of ETL have been involved in an electronic and computer-based technological revolution. Although the technology has become harder for the layman, military and civilian alike, to understand, it has provided — and promises to provide in the future — the U.S. Army with better systems to meet its needs for topographic maps, terrain information, surveying, and the like.

This historical update is designed to increase public understanding of the unclassified research and development programs at the Engineer Topographic Laboratories.

Edward C. Ezell
Fort Belvoir
February 1979

ACKNOWLEDGMENTS

Official history can be written only with the cooperation of many people. At ETL, everyone — the Commander/Director, his Deputy, the Technical Director, the Laboratory Directors, and their subordinates — assisted the historian in compiling the material that follows. It is difficult to single out specific people, because all were helpful. Still, some special thanks are in order to the staff of the Liaison Office, especially to Boyd Poush, Darlene Brown, and Barbara Jayne. Other particularly helpful individuals include Kenneth R. Kothe, Natalie Kothe, Donald R. Handberg, Marvin Gast, and W. Howard Carr.

THE AUTHOR

Edward C. Ezell was born in 1939 in Indianapolis and holds a Ph.D. in the history of technology from Case Institute of Technology. After teaching for several years at the university level, Ezell began writing history full time on a contract basis with U.S. Government agencies. With his wife, Linda Neuman, he authored *The Partnership: A History of the Apollo Soyuz Test Project* for the National Aeronautics and Space Administration. A history of NASA's exploration of Mars was recently readied for publication. Dr. Ezell is also a frequent contributor to *National Defense* and *International Defense Review* and edited the most recent edition of *Small Arms of the World*.

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THE NATURE OF TOPOGRAPHIC SUPPORT

"The Army's primary objective is to win the land battle — to fight and win in battles, large or small, against whatever foe, wherever we may be sent to war. Land battle takes place amid the variances of the ground and the works of man upon it. Relief, surface conditions, drainage, vegetation, highways, cities, and farms — these and countless other features of the earth's surface profoundly affect combat. The effectiveness of the combat arms application of firepower is heavily reliant on topographic products and services.

". . . the primary objective of topographic support within the Army . . . is *to absolutely insure that timely, accurate, and sufficient knowledge of the battlefield terrain supports each commander throughout his planning and conduct of combat operations. . . .*"

* * * *

"If a target can be seen it can be destroyed!"

* * * *

"We expect to fight outmanned and outgunned. Aggressors choose time and place so that terrain may be unfamiliar to us. Short time to react."

* * * *

"We must quickly exploit possible terrain advantages to concentrate combat power."

* * * *

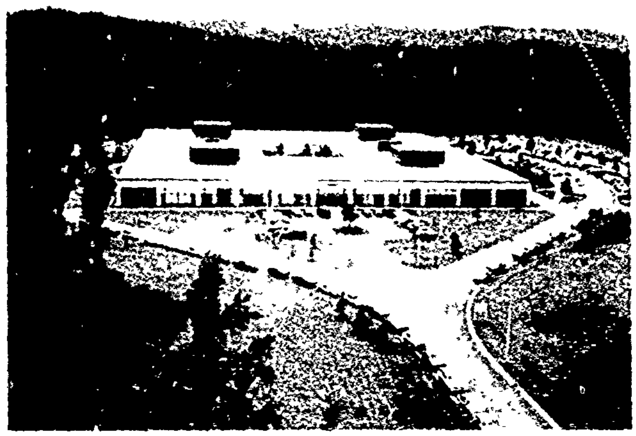
"Topographic support must prepare for winning the first battle."

* * * *

Source: Excerpts from U.S. Army Field Manual 21-32, "Topographic Support," 1 April 1978 (draft).

In the beginning

The Army Service Equipment Section Bldg., McCook Field, Ohio, circa 1920. All research on equipment for aerial photography, aerial mapping, flight clothing, and aircraft instruments was conducted in this building.



Since 1974

The William C. Cude Bldg. (2592) on the North Post of Fort Belvoir, Virginia, is the present home of the U.S. Army Engineer Topographic Laboratories.

Col. Daniel L. Lycan
Commander and Director

Lt. Col. Douglas V. Myers
Deputy Commander and Director

Robert P. Macchia
Technical Director

I
INTRODUCTION

The Engineer Topographic Laboratories (ETL) at Fort Belvoir, Virginia, is the U.S. Army 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. ETL is a field operating activity of the Corps of Engineers. In addition to the Corps, ETL performs work for two other major clients -- the Defense Mapping Agency (DMA), and the Army Materiel Development and Readiness Command (DARCOM). Specialists at the Engineer Topographic Laboratories have developed systems for DMA that permit the more rapid compilation and drafting of maps at base printing plants with greater accuracy and at a lower cost. In conjunction with DARCOM, ETL has created high-precision positioning systems for the Field Artillery, target positioning equipment for tactical missile units, and improved systems for reproducing maps portraying specific military geographic information needed by the Field Army. The equipment developed by ETL gives topographic units the capability to provide Army field commanders with timely, high-quality topographic information. In order to review the accomplishments at ETL during the decade 1968-1978, a brief look at its earlier history and developments in the discipline of topography is required.

II

ORIGINS AND ORGANIZATIONAL DEVELOPMENT 1917-1968

For centuries, military commanders have stressed the need for better maps and more precise topographic information, so that they could determine the relative positions of their own troops, enemy forces, and important terrain features. Until the first decade of the 20th century, surveying for topographic maps was done on the actual site with plane table, transit, and steel tape. Maps used in combat were generally based on information gathered long before the opening of hostilities, and tactical commanders were generally hampered by outdated and incomplete maps that gave either false or misleading information. History illuminates many examples of battles lost due to a lack of adequate maps, but the problems faced by the Imperial Russian Army during the Manchurian campaign of the Russo-Japanese War, 1904-1905, clearly illustrate the consequences for commanders who do not understand the terrain in which their troops are operating. In October 1904, hard-pressed by an effective Japanese offensive, Lieutenant General Baron G. K. Stackelberg, commanding the First and Third Siberian Corps, was told to counterattack through extremely rough and mountainous terrain. Fearful of losing control of his own troops and worried by the possibility of a flanking attack by the Japanese, Stackleberg told his commander Alexei Nicolaievitch Kuropatkin:

> The maps in my possession show nothing but a blank space along my line of march and only one road running from east to west. From the map the country would appear to be as flat as a pancake, but in reality it is extremely hilly and hardly passable for field artillery . . . I await further instructions. If there are any maps of this part of the country in possession of the general staff, I request that I may be provided with one.[1]

Urgent telegrams to St. Petersburg for surveyors and draftsmen could not solve the immediate need for military geographic information.

In the United States, James Warren Bagley, a topographic engineer with the U.S. Geological Survey, introduced an improved panoramic film camera* in the Alaska Territory in 1910 as an adjunct to traditional methods for large area surveys. Later, in March 1917, under the sponsorship of the National Advisory Committee for Aeronautics, the Geological Survey, the Army, and the Navy, Bagley extended the use of the camera to aerial photography for the collection of information used in the compilation of maps. While the tri-lens camera that he developed and used in France after the American entry into the first world war did not add significantly to the high-quality, large-scale (1:20,000) battle maps produced during that relatively static conflict, it did indicate the possibilities for developing new technologies for producing better maps and gathering military geographic information.[2]

Following World War I, the Corps of Engineers of the United States Army assumed the responsibility for two important components of map-making research and development — hardware for gathering and processing topographic data, and equipment for more expeditiously reproducing maps in the field. Bagley supervised the Engineer Detachment, working closely with the Army Air Service (later Army Air Corps) at McCook Field (later Wright Field) at Dayton, Ohio, in the development of a series of successively more satisfactory aerial cameras. He also assisted the 29th Engineer Battalion at Fort Humphreys (later Fort Belvoir), Virginia, in its early efforts to make usable field maps from aerial photographs. The area from Quantico in the south to Fort Humphreys in the north was photographed over and over again in the 1920s and 1930s as the engineers perfected techniques for rendering photographic information into maps.

The creation of the Engineer Board in January 1933 marked the beginning of formalization of topographic research and

*The panorama camera was first used in Alaska by C W Wright and F. E. Wright of the U S. Geological Survey in 1904. It was improved by C W. Wright in 1907.

development. Among other responsibilities, the Board supervised the mapmaking equipment being developed by the Army Corps of Engineers' Engineer Detachment. After the first world war, map reproduction had been assigned to the Engineer Reproduction Plant at Fort Humphreys, and in 1940 a research group was formed at the Virginia plant to investigate new techniques and equipment for the duplication and printing of maps.

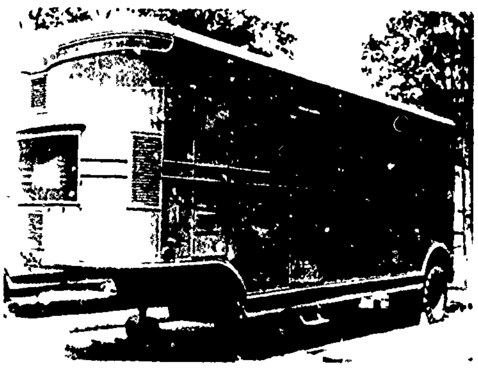
To take advantage of new facilities being built at Fort Belvoir and to concentrate the personnel working on mapping research and development projects, the Engineer Detachment moved from Ohio to Virginia in 1942. Only a small detachment, the Aerial Photographic Branch, remained at Wright Field to maintain the necessary liaison with the Army Air Forces. On 19 February 1943, the Engineer Detachment ended 23 years of essentially independent existence and became an integrated part of the Engineer Board.

During World War II, topographic maps for the field armies were produced in one of two ways: they were either compiled and published at the Army Map Service* base printing plants in the U.S. or were updated and reproduced in the theater of operations by a Topographic Battalion using the facilities of a Mobile Map Reproduction Train (on equipment that was developed at Ft. Belvoir). After limited experience with a reproduction train that consisted of eight semi-trailers, the Engineer Board developed an improved train, the equipment for which was housed in seven van-type trucks. The first of these more mobile trains was delivered in January 1943. By the end of the war, the Army Map Service employed 3,500 specialists to compile data and draft maps. Together, the U.S. base plants and the Topographic Battalions printed and distributed more than 500 million maps by 1945.

Numerous lessons were learned from the World War II experience. As necessary as maps were, the mapping process was time-consuming and required large numbers of personnel in base plants and in the field. Operations at the base plants were often too far removed from the theater of operations to ensure commanders that they would receive maps when they needed them. And map reproduction in the field was fraught with problems. While the Mobile Map Reproduction Train could reproduce maps with dimensions up to 560 x 710 millimeters, the mapmakers needed a cumbersome collection of equipment, for example, large camera units and equally large lithographic printing presses, plus such ancillary equipment as electric generators, water purification units, and maintenance equipment.[3] Also, even though the Mobile Map Reproduction Train was with the Army in the field, map data compilation and the cartographic drafting of maps were still time-consuming processes. Timely response to the field commanders' needs was not always possible. As a consequence, many tactical planners resorted to makeshift substitutes in order to understand the terrain facing their forces. Perhaps the best example was General George S. Patton's claim that he planned the movements of his Third Army using a 1:100,000 scale Michelin tourist road map of Europe he had acquired before the war. He said it gave him all he wanted — "rail-roads, road nets and rivers, and all that you have to know about terrain in general." He left it to his staff to wrestle with details on the larger-scale maps (1:50,000 and 1:20,000). In addition, Patton prided himself on a general knowledge of the terrain, having personally reconnoitered it 32 years earlier in 1912. He believed that with the aid of Freeman's *Norman Conquest* he could find routes suitable for his tanks, because, wherever William the Conqueror had gone nine centuries before, the going was bound to be good. William had obviously followed the watersheds. These routes, Patton argued, would be negotiable by his tanks in wet weather, if the Germans resorted to demolishing major bridges and erecting makeshift road blocks.[4]

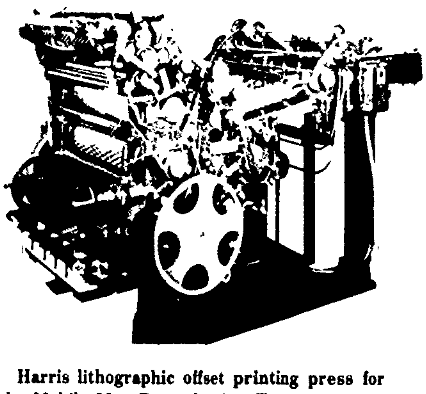
With the passage of three decades, the demands for up-to-date topographic information have increased. Lt. Col. William T. Sockhausen, who has served as Deputy Commander of the Engineer Topographic Laboratories, pointed out that

*A brief chronology of key dates for the U.S. Army's map reproduction facilities includes Central Map Reproduction Plant, 1909-1919 (Washington Barracks), Engineer Reproduction Plant, 1919-1942 (Ft. Humphreys [Ft. Belvoir]); Army Map Service, 1942-1968 (Brookmont, MD). The following organizations succeeded the Army Map Service at the Brookmont site: Army Topographic Command (TOPOCOM), 1968-1972, Defense Mapping Agency — Topographic Center, 1972-1978, and Defense Mapping Agency — Hydrographic/Topographic Center, 1978-present



A 1941 Fruehauf 10-ton semitrailer for the Map Reproduction Train printing press.

World War II vintage Engineer Mobile Map Reproduction Train.



Harris lithographic offset printing press for the Mobile Map Reproduction Train.

topographic units during the second world war were always making maps and continually trying to catch up with their reproduction orders. Unfortunately, many a commander never used these maps to their fullest, since too few of his staff were technically qualified to extract all the information that the standard topographic map could provide. "Today we are trying to give the man in the field simpler products on which all the analysis has already been done by specially trained personnel, often aided by the computer," Stockhausen said. In the future, a tactical commander or his staff will not have to be topographic geniuses. A series of symbols will tell them whether their tanks and troops can traverse a particular type of terrain. "The maps tell the commander go or no-go."[5] In like manner, contemporary surveying technology — called point positioning systems — provides UTM* grid coordinates without requiring large teams of specialized personnel running about with transits or other traditional, time-consuming forms of surveying equipment.

These new systems are ETL products that are either currently under development or have led to products recently issued to the Army. Most of the new techniques have evolved since 1963, a period of technological revolution and organizational change for the Army's topographic community. The dominant aspect of this new era is the introduction of electronic systems, especially those assisted by digital computers, that complete complex tasks much more efficiently than manual methods. A brief summary of the organizational history will help provide the background necessary to understand the emergence of ETL and its technological accomplishments of the past decade.

Following World War II, the Mapping Branch of the Engineer Board was elevated in status to become a technical department with four branches — Ground Control, Photo and Lithographic, Photogrammetric, and Aerial Photographic. This organizational structure remained essentially intact until 1951, when the department was renamed the Topographic Engineering Department, part of the Engineer Research and Development Laboratories, the new title given the Engineer Board in 1947. The 1951 reorganization reflected the greater authority and responsibility assigned the Corps of Engineers for developing materials for cartographic drafting and reproduction within the Department of Defense.

In 1956, the Surveying Branch of the Topographic Engineering Department was reorganized and designated the Survey and Geodesy Branch. Geodesy is the science that deals mathematically with the size and shape of the Earth and its external gravity field, with surveys of such precision that the overall size and shape of the planet must be taken into consideration. The Army mapmakers needed to know more about the exact nature of the Earth's shape, since new technology permitted more precise surveys that would result in even more accurate maps. The Survey and Geodesy Branch included four sections — Electronic Survey, Air and Ground Techniques, Geodetic and Astronomic, and Application Engineering.

The development of ground survey electronic equipment, managed since 1947 by the Signal Corps, was assigned to the Corps of Engineers, which in turn placed it under the authority of the Topographic Engineering Department. Also during the mid-1950s, the development of airborne radar and other electronic equipment to supplement photographic images for mapping applications took on a new impetus. Advances in electronics, which resulted from the Department of Defense's missile activities and the need for much more accurate launch point and target point information, increased demands for more sophisticated mapping equipment.

The department's Map Compilation Branch was also reorganized in 1956, reflecting new technological advances in that area. And the emergence of automated mapping as a field of research led to the creation of an Analytical and Automatic Mapping Section. In 1957, an Application Engineering Section was added to each of the technical branches to manage development projects from the engineer phase through the service test phase and standardization. A Topographic Systems Branch was formed in 1959 to systematize the solutions to topographic mapping problems and to permit more basic research for future and longer-range development programs. The Map Reproduction

*A military grid system based upon the Universal Transverse Mercator projection, applied to maps of the earth's surface extending to 84° N and 80° S latitudes.

Branch became a section of the topographic group, along with Systems Analysis, responsible for topographic mapping and position determination systems; and Research, responsible for basic and applied research for new surveying, geodesy, mapping position determination, cartographic and map reproduction principles and techniques.

By late 1959, the staff of the Topographic Engineering Department (107 members) was nearly double the number of personnel assigned similar tasks during World War II. Despite this growth, there was ample evidence that even more specialists would be needed in the near future. Advances in two specific technological areas had created a revolution in the fields of geodetic data collection and map production — missiles and satellites, which helped collect better and larger quantities of geodetic information; and digital computers and other automated devices, which aided in the compilation and reduction of the data obtained.

Since the second world war, the majority of Army research and development related to mapping and geodesy had been concentrated on combat mapping and surveying for tactical units. The missile, satellite, and computer era brought new requirements. Department of Defense and Department of the Army agencies now needed global and strategic maps and geodetic systems. After considerable internal discussion, the Army and the Corps and Engineers agreed that a separate agency within the Corps was required to manage these larger, more complex demands. The result was the creation on 1 August 1960 of the U.S. Army Engineer Geodesy, Intelligence, and Mapping Research and Development Agency (GIMRADA), at Fort Belvoir, under the direct command of the Chief of Engineers. GIMRADA was assigned all topographic engineering research and development then being performed by the Topographic Engineering Department, in addition to research and development in the fields of geodesy, terrain intelligence, and mapping being performed by the technical developments staff of the Army Map Service. GIMRADA was organized into six operating divisions — Research and Analysis, Intelligence, Strategic Systems, Photogrammetry, Surveying and Geodesy, and Graphics.

In 1962, a GIMRADA reorganization followed in the wake of the creation of the Army Materiel Command (AMC, later the U.S. Army Materiel Development and Readiness Command, DARCOM). AMC was created in August 1962 to combine the research, development, and logistics functions of five of the Army's seven technical services. To avoid duplication, overlap, and confusion between the Corps of Engineers and AMC, the two organizations agreed that the Chief of Engineers would retain primary responsibility for research and development of mapping and geodetic equipment, systems, and techniques in support of global systems and for operational mapping and geodesy, while AMC would oversee research and development necessary to provide mapping and surveying equipment for the field armies. GIMRADA would conduct the research and development necessary to provide AMC with the technical data required for initial materiel specifications with the Command's assistance.[6] This organization remained in force until 1965 without significant alterations.

The 1965 reorganization reflected a cyclical change. As Robert P. Macchia, ETL Technical Director noted, the Topographic Department of the Engineer Research and Development Laboratories, and later GIMRADA, emphasized development rather than conceptual research. Looking back over the decades, Macchia believes that one can see definite shifts in emphasis from research to development and back to research. By the early 1960s, most of the product-improvement and development projects of the 1950s were drawing to a close. Together with the new fields opened by missiles, satellites, and computers, the completion of those earlier projects led to the need for a new era of conceptualization. Beginning in 1963, there had been a substantial increase in funds and manpower directed toward research. The creation of a Technical Plans and Systems Analysis Division within the Development Laboratories at GIMRADA (figure 1) formalized, among other things, the search for automated mapping systems. One of the major developments to emerge from this era was the Universal Automatic Map Compilation Equipment (UNAMACE), which, as described below, revolutionized the production of maps at the Army Map Service.[7] Early in 1967, to carry out the engineering of UNAMACE and other Advanced Development projects, the Topographic Engineering Division

U.S. ARMY ENGINEER GEODESY INTELLIGENCE AND MAPPING RESEARCH AND DEVELOPMENT AGENCY
FORT BELVOIR, VIRGINIA

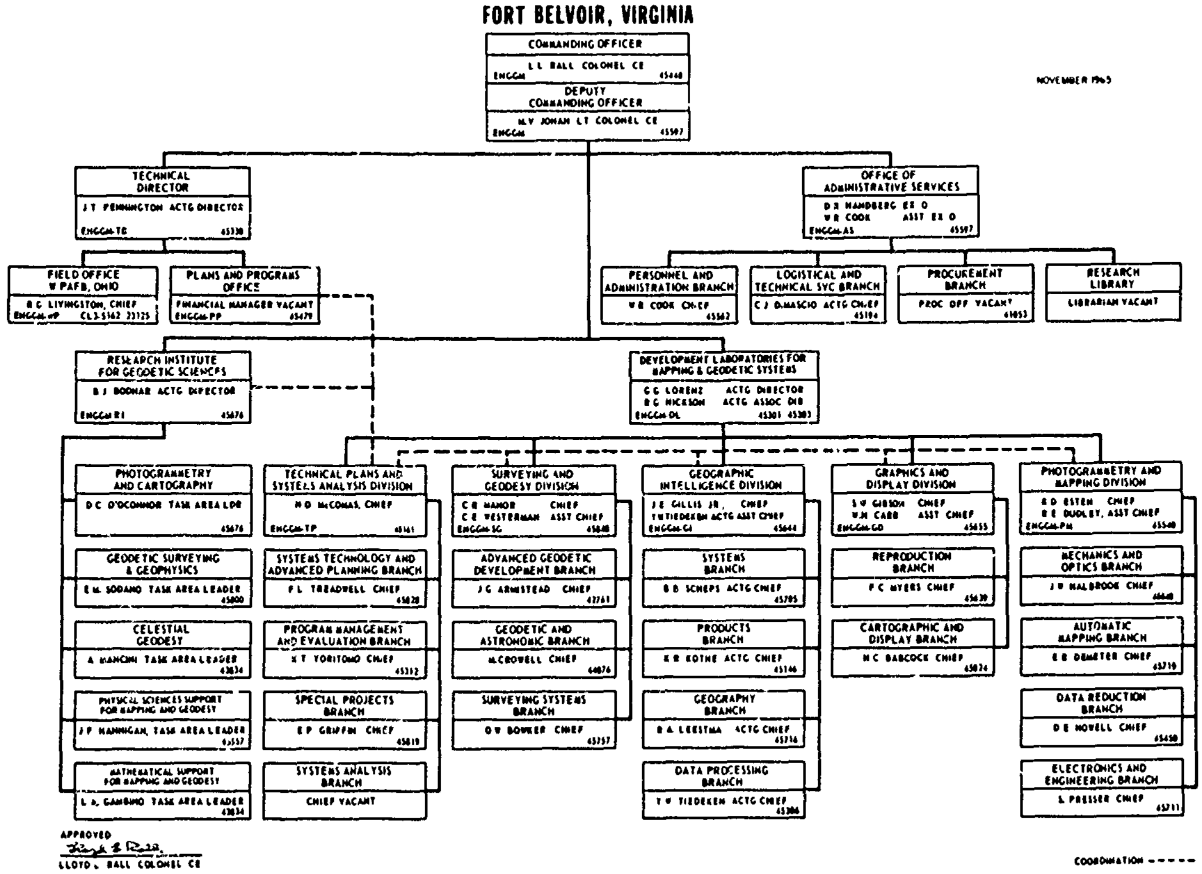


Figure 1

USAEGIMRADA

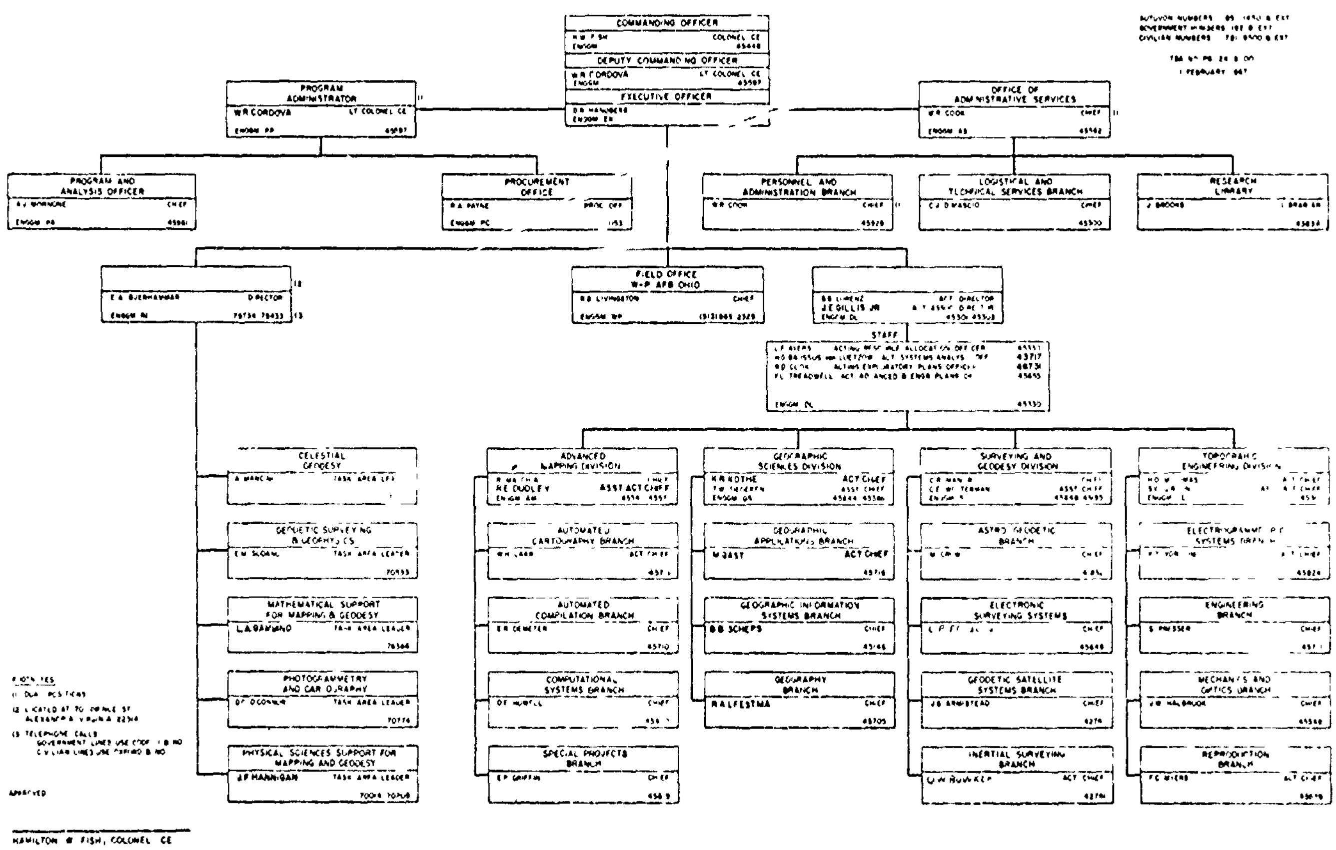


Figure 2

replaced the Technical Plans and Systems Analysis Division (figure 2). This name change indicated that the emphasis of GIMRADA's work had made another of those periodic shifts; this time the pendulum had swung from conceptual work to the actual engineering of hardware to be used by the map production centers and troops in the field.

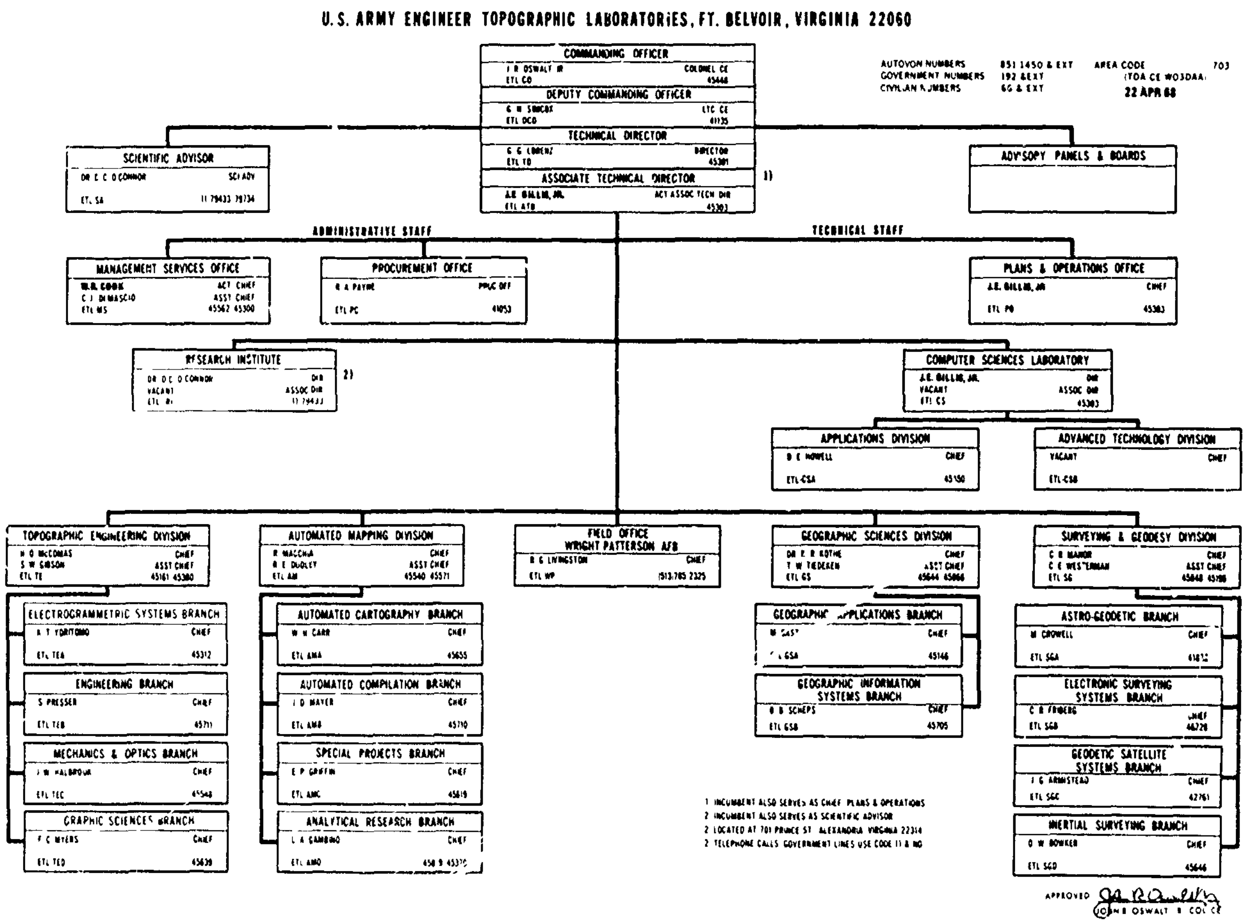
In July 1967 another important change took place. GIMRADA became the U.S. Army Engineer Topographic Laboratories (ETL).[8] With the name change came another reorganization, a major part of which was the modification of ETL's mission statement. The "research and development of equipment, procedure and techniques in the specific field of geodesy, engineer intelligence and mapping application both to troop and to base plant operations" was only part of the agency's function. ETL had taken on the task of fully describing, portraying, and measuring the ground on which the Army might operate. To help meet this mission, a Computer Sciences Laboratory was established to work on research and development projects oriented toward the solution of topographic science problems using mathematical modeling, computer technology, and systems analysis. The computer lab also provided computer support (both hardware and software) to all other elements of the Laboratories. Another indication of the technological changes in the wind was the alteration of the Advanced Mapping Division's name to the *Automated* Mapping Division. Whatever the future would bring the Engineer Topographic Laboratories, it was clear that the computer would have a definitive role. The Office, Chief of Engineers (OCE), established a revised ETL organization with a modified mission in May 1968 (figure 3).[9]

For a few years, ETL served as a subordinate command of the U.S. Army Topographic Command (TOPOCOM), but with the formation of the Defense Mapping Agency (DMA) in 1972, ETL was once again directly assigned under the OCE. With the addition of a number of elements from other laboratories, ETL was organizationally consoliated, but physically scattered. Some elements were located in trailers in the Mobility Equipment Research and Development Command compound. Two elements worked out of DMA Topographic Center, and the ETL Research Institute (RI) had facilities in downtown Alexandria, Va. ETL finally came together as a cohesive organization in 1974, when all elements moved into a new building on the North Post at Fort Belvoir.

At the end of Fiscal Year 1978, the William C. Cude Building and two annexes still housed all of ETL. The 1974 consolidation into one site was a real improvement; verbal communications increased, and the exchange of ideas was enhanced.

ETL had three research and development missions at this time. The mapping mission was primarily performed in support of the DMA and topographic units in the field Army. Point positioning was primarily for the Artillery in response to both surveying and target acquisition requirements. At the end of 1978, this area of research and development was expanding to include land navigation. In the area of military geographic information, ETL personnel were working to improve the terrain analysis capability in support of the field Army. On the operational side, the Terrain Analysis Center (TAC) was performing studies and producing graphic products to fill the gap between the strategic topographic support provided by Department of Defense agencies and the tactical support given the field Army by engineer terrain detachments.

ETL was the only defense laboratory that addressed the full range from basic research to engineering development in the topographic sciences. At the end of the engineering development cycle, adopted equipment was placed into operation within the DMA, or was procured by MERADCOM or other DARCOM laboratories for fielding within the Army. In defining requirements, ETL managers worked closely with DMA, DARCOM Headquarters, and a number of Training and Doctrine Command (TRADOC) schools. ETL operated with a lean headquarters element, consisting of the commander and director, deputy commander and director, and technical director. The commander and director was Col. Daniel L. Lycan. His deputy was Lt. Col. William T. Stockhausen, and the Technical Director was Robert P. Macchia. Each of the five subordinate laboratories was directed by a senior level civilian. Working under the headquarters staff, the laboratory directors carried out their distinctive programs on a largely decentralized basis. The total authorized manpower level was 305, including 16 military personnel. Seventy-six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DEPUTY COMMANDING OFFICER
LTC CE
ETL DCO 41135
TECHNICAL DIRECTOR
DIRECTOR
ETL TD 45301
ASSOCIATE TECHNICAL DIRECTOR
A.E. GILLIS, JR. ACT ASSOC TECH DIR
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GOVERNMENT NUMBERS 192 & EXT
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ADVISORY PANELS & BOARDS
ADMINISTRATIVE STAFF
TECHNICAL STAFF
MANAGEMENT SERVICES OFFICE
ACT CHIEF
ASST CHIEF
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ETL CS 45303
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CHIEF
ETL-CSA 45150
ADVANCED TECHNOLOGY DIVISION
VACANT CHIEF
ETL-CSB
TOPOGRAPHIC ENGINEERING DIVISION
CHIEF
ASST CHIEF
ETL TE 45161 45380
AUTOMATED MAPPING DIVISION
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ETL AM 45540 45571
FIELD OFFICE
WRIGHT PATTERSON AFB
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GEOGRAPHIC SCIENCES DIVISION
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ETL GS 45644 45866
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INERTIAL SURVEYING BRANCH
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APPROVED
JOHN R OSWALT JR COL CE

Figure 3

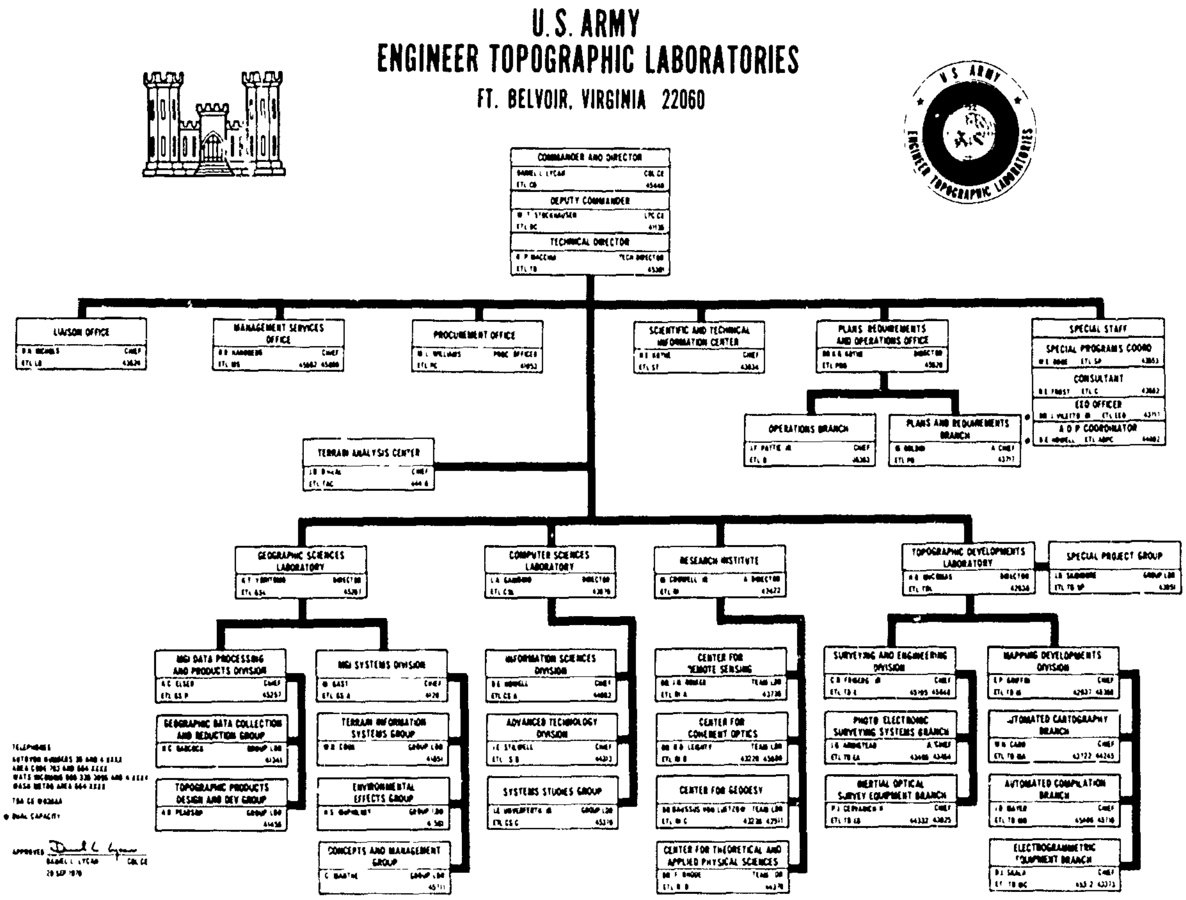

U.S. ARMY
ENGINEER TOPOGRAPHIC LABORATORIES
FT. BELVOIR, VIRGINIA 22060
COMMANDER AND DIRECTOR
DEPUTY COMMANDER
TECHNICAL DIRECTOR
LIAISON OFFICE
MANAGEMENT SERVICES OFFICE
PROCUREMENT OFFICE
SCIENTIFIC AND TECHNICAL INFORMATION CENTER
PLANS REQUIREMENTS AND OPERATIONS OFFICE
SPECIAL STAFF
SPECIAL PROGRAMS COORD
CONSULTANT
EEO OFFICER
A D P COORDINATOR
OPERATIONS BRANCH
PLANS AND REQUIREMENTS BRANCH
TERRAIN ANALYSIS CENTER
GEOGRAPHIC SCIENCES LABORATORY
COMPUTER SCIENCES LABORATORY
RESEARCH INSTITUTE
TOPOGRAPHIC DEVELOPMENTS LABORATORY
SPECIAL PROJECT GROUP
TERRAIN INFORMATION SYSTEMS GROUP
ENVIRONMENTAL EFFECTS GROUP
CONCEPTS AND MANAGEMENT GROUP
GEOGRAPHIC DATA COLLECTION AND REDUCTION GROUP
TOPOGRAPHIC PRODUCTS DESIGN AND DEV GROUP
INFORMATION SCIENCES DIVISION
ADVANCED TECHNOLOGY DIVISION
SYSTEMS STUDIES GROUP
CENTER FOR COHERENT OPTICS
CENTER FOR GEODESY
CENTER FOR THEORETICAL AND APPLIED PHYSICAL SCIENCES
SURVEYING AND ENGINEERING DIVISION
PHOTO ELECTRONIC SURVEYING SYSTEMS BRANCH
INERTIAL OPTICAL SURVEY EQUIPMENT BRANCH
MAPPING DEVELOPMENTS DIVISION
AUTOMATED COMPILATION BRANCH
ELECTROGRAMMETRIC EQUIPMENT BRANCH

Figure 4

percent of these people were directly involved in the scientific and technical work of the organization (figure 4).

Of the five laboratories, the Topographic Developments Laboratory (TDL) was the largest. This laboratory was concerned primarily with hardware development in support of the field Army, and DMA. TDL formulated the concepts and design of systems, and performed research and development work in mapping and point positioning. The Geographic Sciences Laboratory (GSL) had the main mission of research and development in support of terrain analysis, including the development of techniques, equipment and systems for the collection, storage, analysis and presentation of military geographic information. This laboratory was also responsible for creating the technological base of information on climatic effects on materiel and structures and aided in the establishment of operational doctrine in this regard. The Computer Sciences Laboratory was involved with the advanced application of computers for mapping purposes. CSL also provided consulting and support services to other ETL elements in the areas of mathematical modeling, simulation, and computer applications.

In general, it was the Research Institute (RI) that performed basic research at ETL. The RI work force was also involved with applied theoretical research. Emphasis was placed upon four areas: remote sensing, coherent optics, geodesy, and applied physics. RI maintained close ties with colleges and universities. As a research project progressed into the exploratory and advanced development stages, the project would be transferred into other laboratries. The Terrain Analysis Center (TAC), on the other hand, handled ETL's operational mission; i.e., the production of terrain analysis products.

At the end of fiscal year 1978, 29 percent of the budget was devoted to technology base research for DARCOM, OCE and DMA. For advanced engineering and development, 25 percent of the total budget came from DARCOM, and 26 percent came from DMA. The remaining funds consisted of reimbursable monies from other agencies such as the Navy, Air Force, and civil works activities within the Corps of Engineers.

The following chapter summarizes some of the major ETL activities for the years 1968 to 1978.

III

MAJOR ACCOMPLISHMENTS, 1968-1978

A. New Systems for the Topographic Production Center

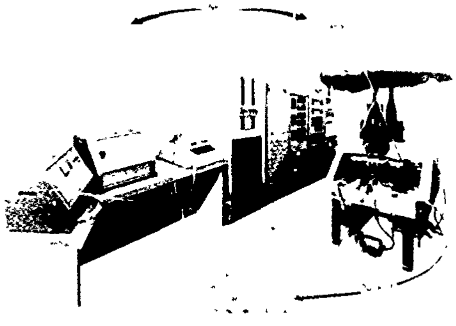
The production of accurate and current topographic maps for use by military combat forces depends upon the extraction of information from aerial photographs according to the established principles of photogrammetry. Reconstituting terrain data from aerial photographs and printing multicolor topographic products requires extremely precise measurement of images in the photographs. This complex mapmaking process involves photographic processing, stereoscopic plotting, cartographic drafting for symbolization/color separation, and, finally, printing of multicolor topographic maps. These time-consuming operations are expensive, because the mapmaking process requires highly skilled technicians and cartographers to operate and maintain the equipment. Until ETL specialists began to develop automatic equipment to supplement and supplant older procedures, mapmakers had to use mechanical devices (stereoviewers, stereo-projectors, and the like) to determine elevation information and to draft terrain features. To achieve a significant reduction in the time required and the money expended in map production, TDL's Mapping Developments Division (and its predecessors) has been involved in a number of research and development programs directed toward the automation of compilation, symbolizing, cartographic drafting, editing, and color separating. In addition, a capability is being developed to produce topographic products from data acquired during poor weather and illumination conditions when standard photographic systems could not produce useful images.

Since the beginning of the automation process in the early 1960s, the work has been divided into two broad categories, compilation and cartography. Compilation is the extraction of elevation and other data from aerial photographs using photogrammetric instruments. Cartography is the drafting of that information (contour lines, ground cover, waterways, man-made structures, etc.) onto a map manuscript and the subsequent preparation of color separations, so that the finished product can be printed. The first step in the automation process was to develop electro-mechanical systems that could reduce man-hours spent on the compilation process.

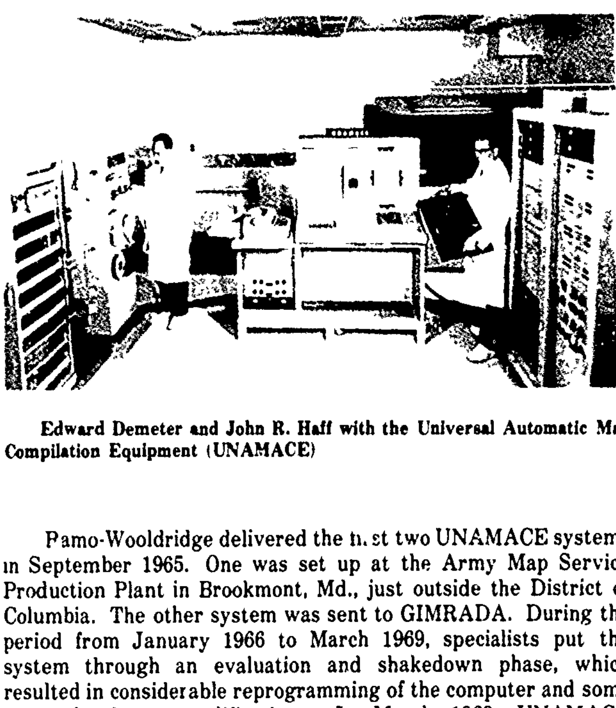
1. Universal Automatic Map Compilation Equipment (UNAMACE)

As a consequence of the work done in the 1930s and 1940s by ETL's predecessor organizations, the United States Army evolved sophisticated aerial equipment for the collection of photographic imagery used to make topographic maps. By the 1950s, these airborne systems enabled information to be gathered quickly — so quickly that the manual extraction and translation of this information into a form suitable for drafting maps could not keep up with data collection. This bottleneck led to research for automating the data compilation process. Perhaps the most time-consuming task was the manual extraction of elevation data from successive stereo pairs of aerial photographs. In the 1950s, several steps were taken to develop mechanical analogs for the measuring done by an individual viewing a stereo pair through an optical instrument. These mechanical systems required highly uniform photography to produce satisfactory end-products. As a result, work was begun on the development of a computer-controlled instrument that could digest a wide variety of imagery. Out of this need emerged one of ETL's most successful products — the Universal Automatic Map Compilation Equipment (UNAMACE).

UNAMACE provides for the automatic scanning of a pair of stereo photographs in very tiny increments with a flying spot scanner and for the translation of the resulting electronic impulses into elevation data used to draft map contour lines. Investigatory work on an Automatic Map Compilation device was conducted by the Ramo-Wooldridge Corp., Canoga Park, Calif., (later Bunker-Ramo Corp.) in 1960. Prototype equipment was delivered to GIMRADA in December 1963. This initial development was so successful that in February 1963, before the prototype Automatic Map Compilation System had been delivered, GIMRADA contracted with Ramo-Wooldridge for the development of UNAMACE. The Universal Automatic Map Compilation equipment in its original configuration consisted of a digital computer-controlled electronic measuring and image correlation system that automaticaly obtained terrain altitude data from input aerial photographs and output orthographically correct photographs, line-drop contour printouts, and magnetic tapes containing profile elevation information in electronically digitized format. Among the major elements of UNAMACE are four identical 230 x 460-mm. precision comparator tables (two dedicated to scanning the stereo input photographs, and two used for printing the orthophotographs and the contour printouts). A TRW-133 digital computer with associated equipment controls the automatic operation of the system; a console provides the capability to monitor and manually operate the system; and a tape recorder stores the extracted elevation information. UNAMACE differs from the earlier experimental Automatic Map Compilation System in that it is more suited for use in a production facility, and it does its work with greater accuracy and speed.



AUTOMATIC MAP COMPILATION SYSTEM



Edward Demeter and John R. Haff with the Universal Automatic Map Compilation Equipment (UNAMACE)

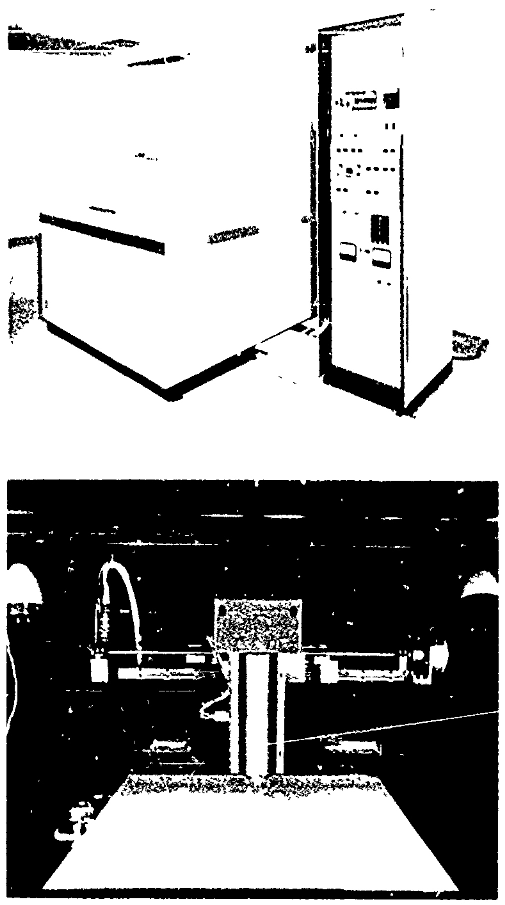
Ramo-Wooldridge delivered the first two UNAMACE systems in September 1965. One was set up at the Army Map Service Production Plant in Brookmont, Md., just outside the District of Columbia. The other system was sent to GIMRADA. During the period from January 1966 to March 1969, specialists put the system through an evaluation and shakedown phase, which resulted in considerable reprogramming of the computer and some minor hardware modifications. In March 1969, UNAMACE became a fully integrated element in the production of maps. With this equipment, information from photographs can be extracted in hours, compared to the days, and sometimes weeks, it takes trained individuals to do the same work.

In actual use, UNAMACE obtains its data from two overlapping aerial photographs that have been printed on large transparent film sheets (stereo diapositives). This equipment is extremely useful because it can operate with a wide range of photo formats and camera focal lengths. It can also compile map information from highly distorted photo imagery, such as convergent or panoramic photographs. In addition to the film diapositives, UNAMACE operators provide the computer with information about the geometric relationship between the two photographs and the ground and mathematical data that tells the computer what to do with the information it receives. UNAMACE produces orthophotographs and contours that have the Universal Transverse Mercator (UTM) grid ticks added for control and registration of the two outputs. Simultaneously, x, y, z coordinates (east-west, north-south, elevation) are stored on magnetic tape.[10]

Adoption of UNAMACE was only the first step in automating the process of compiling map data. Over the past 10 years, ETL specialists in what is currently called the Automated Compilation Branch, Mapping Developments Division, TDL, have produced several new pieces of equipment, which, when used with UNAMACE, speed up the compilation process.

2. High Resolution Orthophoto Output Table (HIROOT)

The High Resolution Orthophoto Output Table (HIROOT), developed under contract to ETL by the Link Division of Singer-General Precision, Sunnyvale, Calif., was another development associated with UNAMACE. This equipment was designed to replace the original orthophoto output table with a system that was larger in size and had finer photographic resolution. HIROOT produces a 610 x 760-mm. printout compared with the 230 x 460-mm. UNAMACE orthophotos. UNAMACE resolution is 40 lines per millimeter, while HIROOT produces 70 lines per millimeter The HIROOT orthophotos provide a 25-percent improvement over those from UNAMACE tables, especially in the area of identifying and plotting natural and man-made features (the planimetric elements) on the terrain. Also, the HIROOT print size is the same as that of the standard 1:50,000 map sheet. Delivered in 1970, HIROOT was being brought into the production cycle at the Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC) in 1978.[11]



Exterior (top) and interior (bottom) views of the High Resolution Orthophoto Output Table (HIROOT)

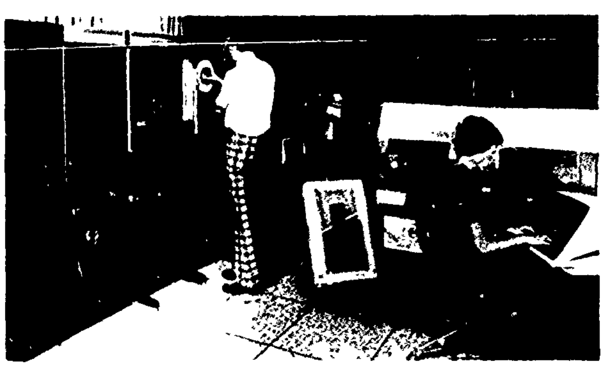
3. Replacement of Photographic Imagery Equipment (RPIE)

A new piece of hardware called Replacement of Photographic Imagery Equipment (RPIE) was developed for two specific purposes, but is presently being used for another task at DMAHTC. In technical terms, RPIE, which was developed under contract by the Bendix Research Laboratories Division of the Bendix Corp., Southfield, Mich., is a high-resolution, high-speed, large-format image restitution system. RPIE enables the Hydrographic/Topographic Center personnel to take new photographic imagery that has been converted into digital form (digitized), by the computer and substitute that new information for old information (also in digital form), to produce an updated orthophoto map. By using the computer to substitute new data for old data, a new photo map is produced quickly without going through the entire compilation process.

As John D. Mayer, Chief of the Automated Compilation Branch, pointed out, there are times when the map compilation specialists at DMAHTC have photographs with limited geometrical distortion but relatively poor resolution. The converse is often true as well. High resolution photographs that provide a clear picture of terrain features and man-made objects, are limited by poor geometry. RPIE enables specialists to get the basic relief of the topography from the photos with good geometry and then use the imagery from the high resolution photographs to indicate the planimetric elements on the terrain. The result is a high-quality orthophoto.

Mayer also noted that RPIE has proven to be beneficial in unexpected ways. Since becoming an operational system at DMATC in 1976, RPIE has seen minimal use for the two original purposes for which it was developed. Instead, it is used as an off-line orthophoto printer in conjunction with UNAMACE. Previously, UNAMACE produced orthophotos on-line. As the flying-spot scanner extracted information from the input photography and as that information was processed by the computer, an orthophoto image would be created on the output table. After UNAMACE had been in use for a time at DMATC,

Contractor personnel demonstrate Replacement of Photographic Imagery Equipment (RPIE) hardware.



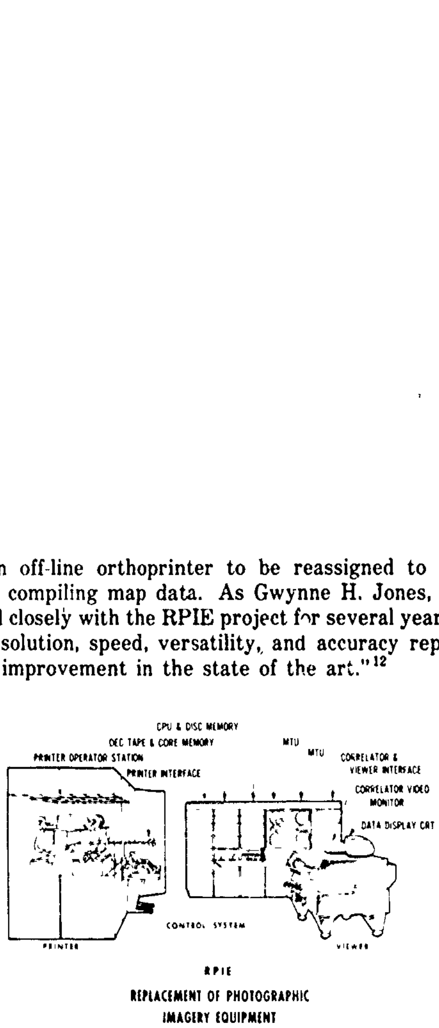
the line-drop output table was replaced by a piece of equipment that transferred the digitized information to a magnetic tape. The x, y, z data on the tape were run through RPIE to generate an orthophoto. RPIE gave the production center still greater speed and better quality outputs and permitted rectification of original photographs and enlargement of the orthophoto images. Compared to current orthophoto production equipment, the output resolution is higher, while the orthophoto printing rate is more than six times faster.

The three major subsystems of RPIE are the control, the viewer, and the printer. The control system consists of a Digital Equipment Corporation PDP-11/45 computer and the electronics required to link it with the printer and viewer. The computer includes a 49,152-word, random-access core memory management, 1.2 million-word disk, real-time clock, floating-point arithmetic unit, card reader, line printer, cathode ray tube (CRT) terminal, teletype, and two 9-track magnetic tape units.

The viewer unit is an AS-11B-1, manufactured by Ottico Meccanica Italiana (OMI) of Rome and modified for use with 230 x 460-mm. photo carriages and manual roll-film handling on the input stage. Much of the operator's interface with RPIE is through the CRT terminal, which is part of the viewer control system.

The printer is the critical portion of RPIE, because it represents a major breakthrough in the speed, accuracy, and versatility of production. This unit includes a laser light source, a 250 x 500-mm. X-Y input table, optics, and a 500 x 1,000-mm. output drum mounted on a 3-ton granite base. As the input photography is incrementally scanned, digitized information is transferred by the high-resolution optical system to the output film plane. While the system dynamically corrects the image for rotation and magnification, the operator can control various aspects of the final orthophoto by communicating with the computer via the teletype. The printer unit is installed in a clean-room environment, part of which is a darkroom containing the output drum.

Since it produced higher resolution (in excess of 100 lines) per millimeter, compared to 70 lines per millimeter for HIROOT), RPIE permitted one of the UNAMACE systems that was being used as an off-line orthoprinter to be reassigned to its basic function of compiling map data. As Gwynne H. Jones, Jr., who has worked closely with the RPIE project for several years, noted, RPIE's "resolution, speed, versatility, and accuracy represent a significant improvement in the state of the art."[12]



Replacement of Photographic Imagery Equipment (RPIE)

4. 3X Enlarging Printer

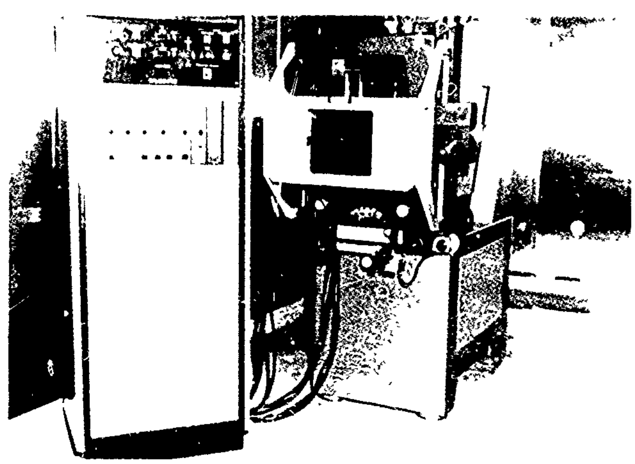
In response to a request from the Army Map Service in the 1960s for fixed ratio, precision enlarging printers, GIMRADA contracted with two industrial firms to develop and build three different units.

Watson Electronic and Engineering Co. of Arlington, Va., developed two of these enlarger printers; one enlarged 70 x 70-mm. negatives 4.0 times, the other enlarged the same negatives 3.3 times. The 4.0X enlarger was delivered to the Army Map Service in 1965.

The 3.3X unit was not perfected due to difficulties in locating a lens that would meet the resolution requirements of the Map Service. This latter project was terminated in the fall of 1969.[13]

The third fixed ratio, precision enlarger was developed by the Hoppmann Corp. of Springfield, Va. This unit, which produced prints twice the size of the negative (2.0X), was tested in 1969 at the Army Map Service and subsequently put into production use at that center.

Later, the Army Map Service requested the development of a 3.0X enlarging printer that would enlarge 76 x 152-mm. positives, primarily on film. These enlargements are used with equipment such as UNAMACE to exploit the information contained in geometric quality aerial photographs more fully than could be done if the original unenlarged negative were used. Delivered to DMATC in 1972, the 3X Enlarger Printer supplies input positives that provide an alternate capability in the map compilation process.[14]



3X Enlarging Printer

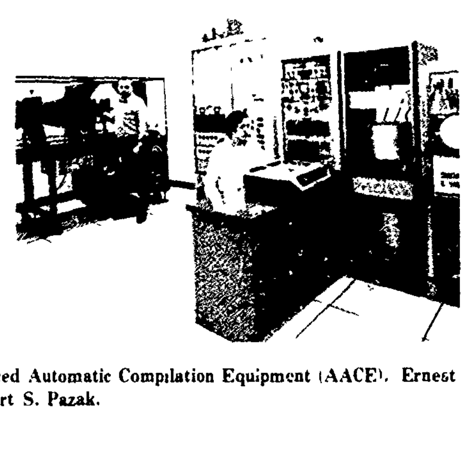
5. Advanced Automatic Compilation Equipment (AACE)

Begun as an in-house development project at ETL in 1968 and originally called the Advanced Automatic Compilation System, AACE ("System" was changed to "Equipment") was designed to be an improvement on UNAMACE. As John Mayer wrote:

> We knew the UNAMACE worked well; however, as with all prototypes, it had some inherent limitations. First, it was costly and we felt the system could be greatly simplified. Second, although the dynamic response of the system to rapid changes in relief was very good (the scan-search pattern is essentially inertia free), it was relatively inflexible or hardware bound in terms of what might ultimately be accomplished with the system, particularly in terms of speed and flexibility (for instance, automatic stream or contour following). Third, rapid advances were being made in computer technology, both in reduced costs and increased capability, and it was easy to see that this would be the greatest area of improvement (many of the UNAMACE improvements or modifications were software oriented). And finally, we felt the equipment must be tailored to people. This meant giving the operator the option of intervening while making the system as automatic as possible and providing the maintenance people with a highly reliable nearly maintenance-free system [15]

The Advanced Automatic Compilation Equipment embodies a calibrated, all-electronic scanning system in place of the conventional mechanical X-Y plotting tables used with UNAMACE. Basic design goals were greater speed and flexibility of operations, significant reduction in size and weight, and lower cost compared with UNAMACE. The normal mechanical X-Y motion of the diapositive carriers was replaced by a moving electrical beam (raster scanner) system that could be positioned under computer control anywhere over a 229 x 457-mm. area on a large (559-mm.) CRT. Each scanning system (of which there are two to produce a stereo image) consisted of the CRT, a 2:1 reduction lens, a glass plate diapositive, a collector lens, and a photomultiplier tube (PMT). The CRT produces the point sources of light, which are reduced by the reduction lens and, in turn, modulated by the imagery on the diapositive and then collected and measured by the PMT. The modulated light received by the PMT is converted into x, y, z coordinate data, which are recorded on magnetic tape. As with UNAMACE, the recorded information can be used to drive a plotter for the production of contours on an orthophoto printer.

While the AACE has shown considerable promise since the first demonstration model (brassboard) was completed in November 1973, it remains essentially a research tool at ETL. Perhaps the main reason DMAHTC has not rushed to adopt AACE is the basic utility of UNAMACE. That older system, especially as augmented by new ETL equipment, works very well.[16] As long as UNAMACE continues to meet DMAHTC needs, new systems such as AACE will be hard to sell. Development of AACE is still an important accomplishment because it advanced the state of the art. When DMAHTC is ready to update its equipment, work on systems such as the AACE and its successors will make the task easier.



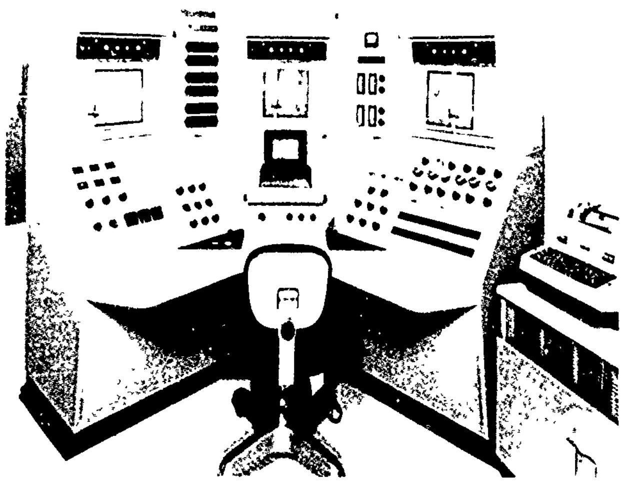
Advanced Automatic Compilation Equipment (AACE). Ernest M Stiffler and Robert S. Pazak.

6. Automatic Reseau Measuring Equipment (ARME)

In addition to automatic compilation equipment, the Automated Compilation Branch of the Mapping Developments Division has produced several pieces of hardware that help automate the marking and measuring of points on photo imagery. One of the major problem areas in analytical photogrammetric procedures has been the accurate and rapid marking, measuring, and recording of coordinates on aerial photographs. GIMRADA, in the early 1960s, worked on this problem with several companies. Two of the basic instruments developed were the Automatic Point Transfer Instrument (Link Division of Singer-General Precision) and the Variscale Stereo Point Marking Instrument (Bausch and Lomb, Inc., Rochester, N.Y.).[17] The Automatic Point Transfer Instrument proved to be too difficult to maintain and was withdrawn from service at DMATC. The Variscale Stereo Point Marking Instrument was later supplanted by the Micromark Instrument.

Point marking and point measuring instruments were designed to work together to feed information into a computer program called MUSAT (Multiple Station Analytical Triangulation Program), which in turn, after determining the orientation of all of these photographs in space, would feed these parameters into the UNAMACE. Micromark identifies and marks corresponding images (images of the same object from different vantage points) on each photograph of a stereo pair. The Automatic Reseau Measuring Equipment (ARME) accurately measures the photographs. Together, these instruments provide geometric data, so UNAMACE can automatically extract information from the photographic images.

The Automatic Reseau Measuring Equipment, put into use at DMATC in February 1975, is a special computer-controlled comparator, which measures (by automatic, semiautomatic, or manual means) stars, reseaus, and marked points on photographs. Two definitions are in order. First, a comparator is a precision optical instrument used to determine the rectangular coordinates of a point with respect to another point on any plane surface, such

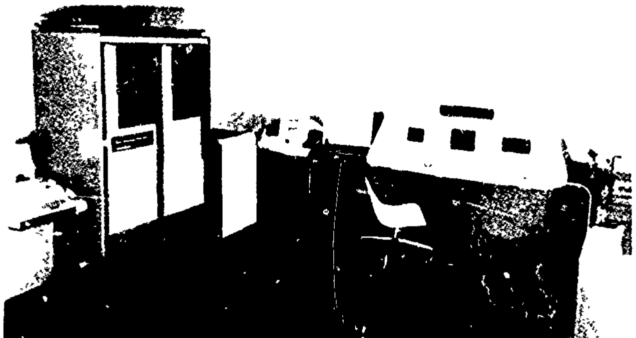


Automatic Point Transfer Instrument

as a photographic plate. Second, a reseau is nothing more than a series of small crosses etched on the stage plate of the aerial camera (about 10 micrometers in width and 2 millimeters long). ARME, developed by DBA Systems, Inc., Melbourne, Fla., can measure the coordinates of a terrain feature or a point by measuring its location in relation to four surrounding reseaus. In preparing photographic imagery for use in UNAMACE, it is necessary to control the metric quality of the image during processing. Often prints utilized in the compilation process are three or four times removed from the original image. ARME determines whether the print is geometrically faithful to the original negative. This equipment is a particularly significant development, because it measures reseaus against the heterogeneous background of a photograph. Many pieces of equipment can make such measurements on homogeneous backgrounds, but ARME can make these determinations on the extremely variable images produced by aerial cameras.

ARME consists of a modified 254 x 483-mm. monocomparator, an operator console, and a Varian 620/107 computer. In addition, there is the following ancillary equipment: a 32,000-word memory, 491,000-word disk file, two magnetic tape units, a printer-plotter, a card punch reader, and a teletype terminal. Special aids for the operator include a point locator to orient the scanned image area in relation to the whole photograph, an image monitor to view the photograph at 120X magnification, and a system monitor to view all communications with the computer.[18]

UNAMACE, ARME and RPIE, used together, have thoroughly altered the compilation of map data at the Hydrographic/Topographic Center. During the past 10 years, map compilation has shifted from a time-consuming manual task to an automated process. The compilation revolution has had several effects on the Hydrographic/Topographic Center. The number of people and the nature of their work have changed. But as ETL Technical Director Robert Macchia noted, the most important difference is that, with the ETL-developed systems, the cost and time required for producing maps can be reduced by 50 percent.[19]



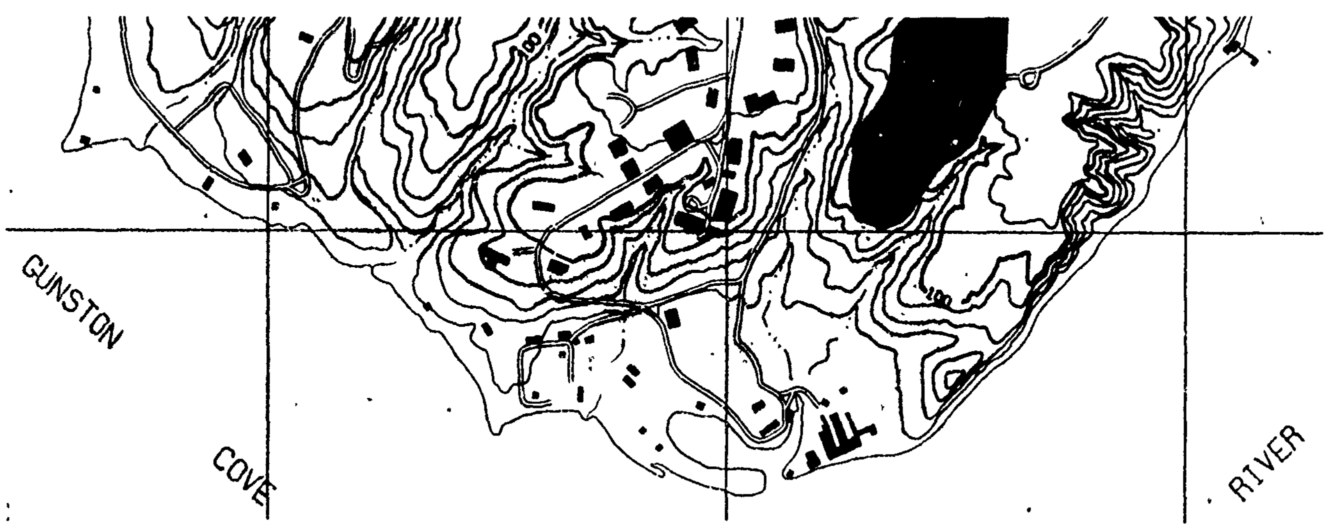
Automatic Reseau Measuring Equipment (ARME)

7. Semi-automated Cartography System (SACARTS)

All the work on systems that speed up the extraction of map data has improved the compilation process, but at the same time it has emphasized the need for automating the cartographic processes related to drafting and identifying features on topographic maps. Kent Yoritomo, formerly chief of the Plans Requirements and Operations Office and now Director of the Geographic Sciences Laboratory, noted that much of the time required in map production is associated with the cartographic aspects. Traditionally this has been a very labor intensive activity staffed by skilled draftsmen who prided themselves in the artistic nature of their work. Yoritomo reported, "First we recognized the great difficulty of automating the cartographic process. When we first came up with the concept of automatic cartographic systems, we realized that we were taking a purely human function and trying to have a machine do that same work. We also realized that the machine could not do it as simply as [when] the complex compilation process had been automated." Howard Carr, chief of the Automated Cartography Branch in the Mapping Developments Division, supervised much of the work in this area, and according to Yoritomo, "Carr broke the cartographic process down into small, discrete phases; contouring, lines of communications, and other symbology. His people developed techniques and equipment for each step. They made an assemblage of equipment, some of which is automatic and some of which is human-aided. In the end, the whole cartographic process is quicker."[20]

Howard Carr described the advantages of automated cartography. In the past, all features to be printed on a map in one color were usually combined into one color separation, which was then used to prepare a press-plate for reproduction. "A standard topographic map has five colors. The black features are representative of what man has made. Brown identifies ground contour information. Blue information is water, and vegetation is marked in green. Red helps to identify and classify man made changes or additions to the terrain." Cartographic color separations were prepared for many years by pen-and-ink drafting, which eventually evolved into scribing lines on paint-coated plastic

Fort Belvoir, Va. 1:12,500 Experimental Map



Produced by the Automated Cartography Branch, Engineer Topographic Laboratories, COL John R. Oswalt, Commanding.

NOTE This map was produced under a test environment and is not intended to meet mapping standards. Its sole purpose is to demonstrate capabilities and problems of automated cartography.

Data was compiled and simultaneously digitized on a Kelsh plotter equipped with a Foster digitizer and an incremental magnetic tape unit, at a model scale of 1 2,500. Digitizing resolution was .005 inch. Seventeen individual models, compiled separately, were scaled and joined by the computer. All symbolization was generated by the computer, however, no mathematical line smoothing or curve fitting was performed. Software was prepared in house, for the XDS 930 computer.

Data was output in color separated form on a CalComp 702 plotter, at publication scale, using a ballpoint pen. Because of the fixed line weight of the pen, output at a smaller scale was impracticable. (Use of an output plotter specifically designed for cartographic work would eliminate this problem as well as providing smoother line work) Output copy was photographed for production of litho plates Less than 1/2 hour of manual edit was performed on the output copy.

Total time required for cartographic processing, including computer time, plotting, and edit, was approximately 3 1/2 hours. This does not include photogrammetric compilation time which averaged approximately 6 hours per model.

This map produced, circa 1968, to demonstrate the potential for automating the cartographic process. While not as precise and aesthetic as hand drafted maps, this product clearly indicated that automation was possible and not just an impractical dream.

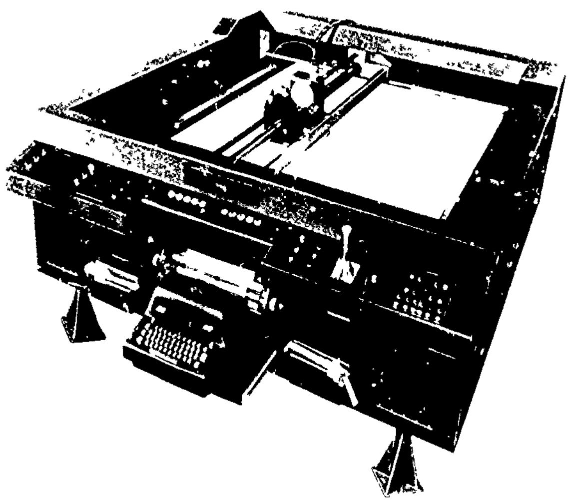
sheets. "This technique," Carr reported, "is itself giving way to the digitizing of cartographic features by manually operated digitizers that trace lines or by automatic line-scanning devices." Digital techniques offer several advantages in that the digitized line data can be processed in digital computers, performing tasks that are repetitive, tedious, and very demanding with respect to accuracy and graphic quality. The computer performs symbolization by converting centerline data into railroads, streams, roads, and the many unit symbols (such as houses, schools, mines, and road signs) that appear on a map. It can also scale the data as required and perform transformations to fit the map data from one form of map projection to another. During the past 10 years, the job of the Automated Cartography Branch has been to develop equipment, systems, techniques, and computer software that will reduce the hundreds of cartographic drafting man-hours required to make a map. Concurrent with these efforts is the development of new uses for cartographic data in digital form in solving terrain-related problems.[21]

From the Automated Cartography Branch's work has emerged the Semi-Automated Cartography System (SACARTS), comprised of both hardware and software elements. SACARTS was the result of studies conducted by the Army Map Service/GIMRADA Committee on Semi-Automatic Cartography in 1966-1967, with a formal development plan established on 1 August 1968. The objective for this project was the production of a system that would provide at least a 50 percent improvement in the production rate for standard 1:250,000 or larger scale military maps and provide digital map data for other map-related uses. The basic concept of cartographic automation involved digitizing the map manuscript, manipulating the data with a digital computer, and providing final output in symbolized and fine-drafted format through an automatic X-Y digital plotter. Primary inputs to the SACRATS will include orthophotographs and elevation data as produced by UNAMACE. Several different techniques are being explored to permit conversion of planimetric data from the orthophotograph into a digital format. These include the use of manual X-Y digitizers or the raster scanning of a color-coded draft manuscript map. After digitizing, the data will be edited by an interactive CRT device, which will enable the operators to view a screen and communicate with the computer about changes they desire to make. Subsequent computer processing will produce a magnetic tape suitable for driving an output plotter, which may be of the flatbed X-Y line drawing type or the raster-scanning-drum-type. UNAMACE elevation data will be converted to contour line format by computer, edited, and output in the same manner as planimetric data.

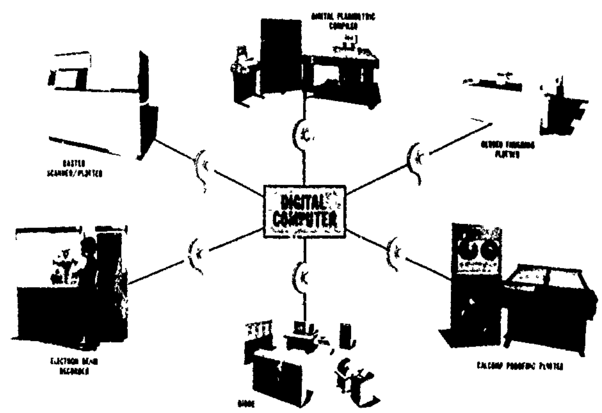
8. Gerber Flatbed Plotter

One of ETL's earliest automated developments was the creation of a digital plotter, which has had worldwide impact on mapping technology. One of the recommendations of studies made in the late 1950s on improving or automating cartographic operations called for the development of an instrument to rule grids and to plot points. Examination of existing commercial plotters revealed that none had the required accuracy, speed, and reliability. The specifications established for such a plotter called for a machine that would automatically plot or read control point information and generate precision map grids. The instrument should have the ability to plot and identify points, either automatically with input from punched paper tape or semi-automatically with input from a keyboard. Grid lines would be scribed on coated plastic sheets or inked on suitable drafting materials. Coordinate information to generate grid lines could be inserted by either the paper tape or keyboard. If the instrument was used as a point reader, the operator could position the carriage over a particular location using a joystick control and read the X, Y coordinates of that point on the digital display, obtaining a punched paper tape or typewritten record of the point or points as located.

Development of this machine was carried out under contract to GIMRADA by the Gerber Scientific Instrument Co., of Hartford, Conn., (February to October 1960). The resulting machine was an entirely new concept in plotter design. It was one of the first to embody all-digital logic and a new type of mechanical drive with precision ball screws. With the elimination of amplifiers servo systems, and cable or steel band drives, the inherent problems that had plagued analog plotters were eliminated.

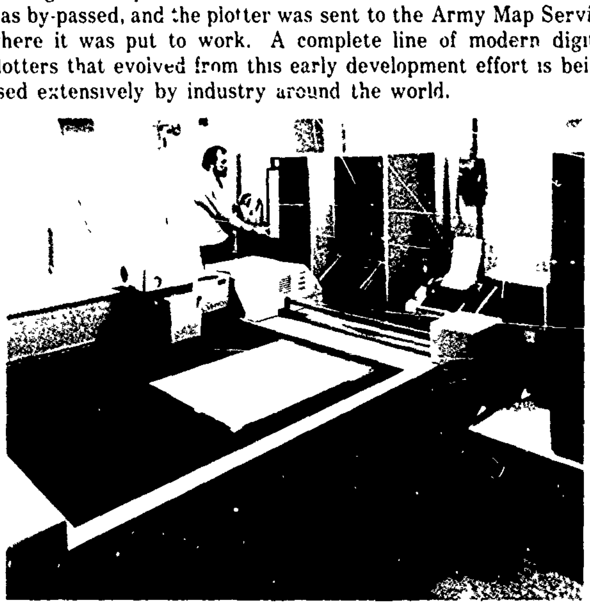


Early Gerber Plotter, circa 1960.



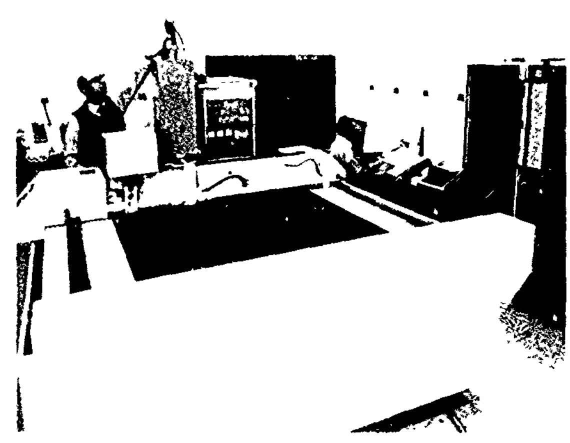
USAETL Experimental Cartographic Facility.

After a nine-month evaluation of the Gerber plotter, GIMRADA personnel decided that it was equal in accuracy to manual plotters (coordinatographs) and that it was capable of a much greater speed than manual instruments. The service test was by-passed, and the plotter was sent to the Army Map Service where it was put to work. A complete line of modern digital plotters that evolved from this early development effort is being used extensively by industry around the world.

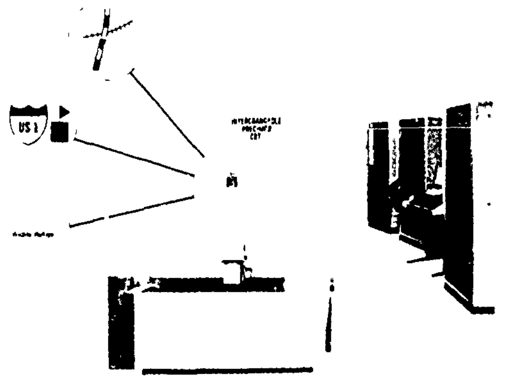


Bruce Zimmerman with Model 1232 Gerber Plotter without CRT printhead, circa 1974.

Currently at ETL, a later generation Gerber Plotter, Model 1232, is being used as a laboratory support system for SACARTS. Model 1232 is designed for very high-quality plotting of digital cartographic data. The standard plotter consists of a flatbed table with an X-Y carriage assembly driven by precision lead screws, with an overall accuracy of better than +0.02286 millimeter, a repeatability of +0.0127 millimeters, and a resolution of 0.00254 millimeter. The carriage assembly supports a 24-aperture station photohead that projects light from a mercury-xenon lamp directly onto photographic film placed on the table surface. Lines as small as 0.0508 millimeter wide and as large as 0.9144 millimeter wide can be drawn. Special symbols may be drawn or flash-exposed. The entire system is controlled by an on-line Hewlett-Packard mini-computer with 8,000-word core memory, magnetic tape, paper tape, and teletype input. The plotter is equipped with a newly developed K-mirror prism that provides for orientation of the light beam as projected onto the film. Multiple line apertures plot parallel lines on a single pass of the plotter, and rectangular apertures produce square-ended lines. Special symbols may be flash-exposed at a specified orientation. Under a current development project, a CRT printhead has been mounted on the carriage assembly in addition to the standard photohead. To maintain plotter independence, the CRT is controlled by its own mini-computer with a magnetic tape and disk file interfaced to the Hewlett-Packard minicomputer.



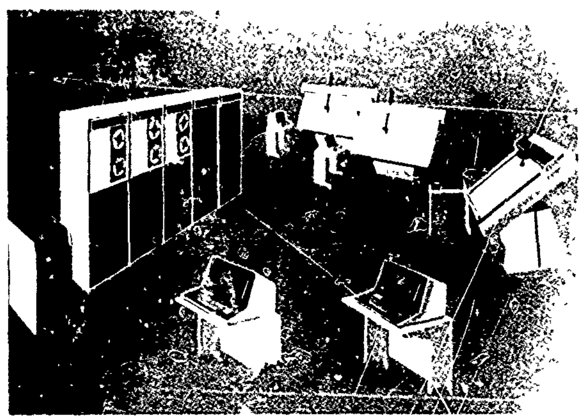
Joseph Goodwald and Walter Simpson at the Model 1232 Gerber Plotter with experimental CRT printhead attached.



Cathode Ray Tube (CRT) Printhead for placing type and symbols on maps.

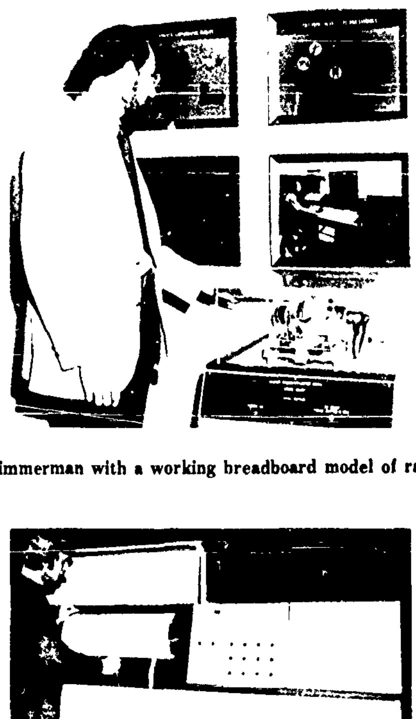
With the addition of the minicomputer-controlled CRT plothead, the plotter can produce alphanumeric data, unit symbols, and pages* of line symbology. When the 127-mm. diameter cathode ray tube is stepped over the plotter, the image on the CRT is optically projected at a one-to-one scale onto light sensitive film. When the plotter is combined with the Type Placement Composition System (TPCS), the result is a powerful photocomposition and automated drafting system. The TPCS uses either manual digitizers or an optical scanner to place coordinate data and other descriptions of map names and symbols onto magnetic tape. The taped data feed the minicomputer for the CRT printhead. Precision graphics, as large as the table of the plotter (1.22 x 1.52 meters), can be plotted at high data rates. Tests indicated that all the names for a typical 1:50,000 scale map (572 x 737 millimeters) can be positioned and exposed onto film in about 10 minutes. Production versions of the CRT printhead on the Gerber plotter have been developed for the three DMA mapping centers (Topographic, Hydrographic, and Aerospace).[22]

In the late 1960s, ETL specialists in conjunction with IBM of Kingston, N.Y., began development of a large (610 x 762-mm.) raster drum scanner/plotter. This device takes as its input a cartographic manuscript coded in colored pencil. The manuscript is mounted on the drum, and the imagery is digitized by an axially moving photocell scanning head, as the drum rotates at approximately 192 revolutions per minute. This scanner/plotter, using a reflected light and optical system to scan the image, can produce resolutions of 0.0254, 0.0508, and 0.1016 millimeter. After computer processing the scanned data, a linear array of eight light emitting diodes (LEDs) plots magnetic tape data onto high speed film at the same resolution as scanned. The raster drum scanner/plotter has been used to scan map color separation negatives and replot them from magnetic tapes with very high quality. Maps printed from the replotted negatives were indistinguishable from maps printed from original hand-drafted inputs.

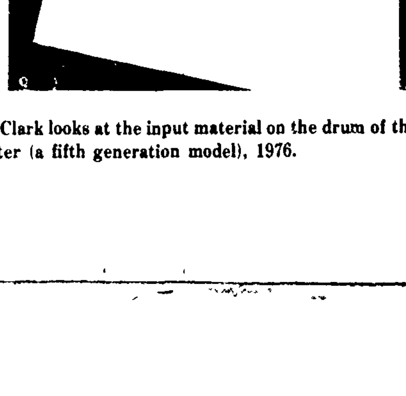


Type Placement Composition System (TPCS).

*A page represents a rectangular block of data drawn on the face of a CRT and may be 50 x 76 millimeters on a 127-millimeter diameter CRT.

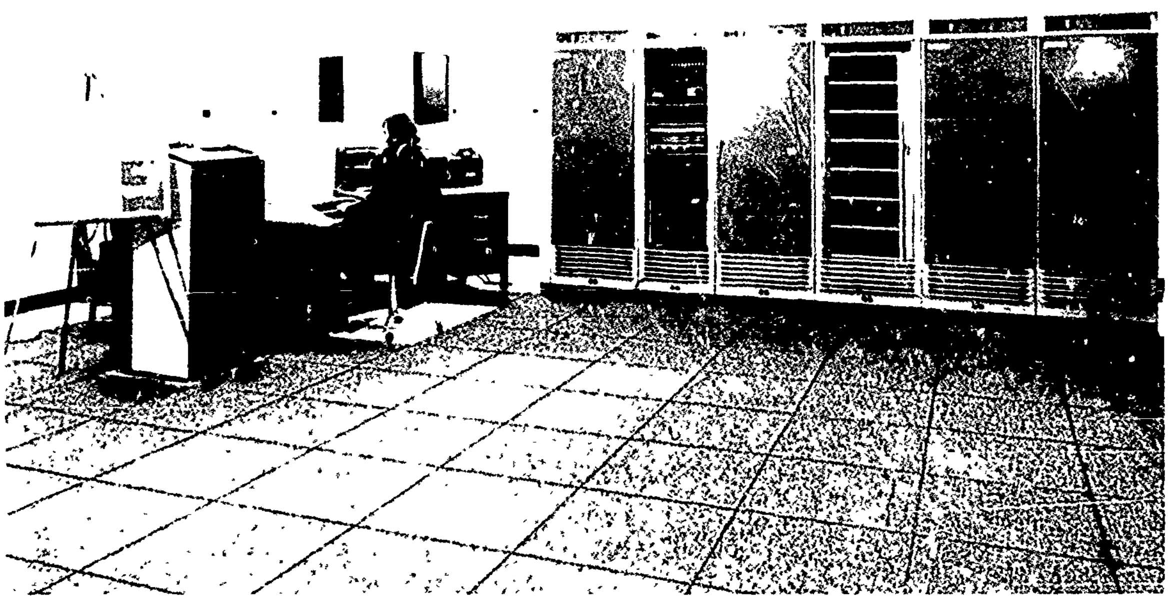


Bruce Zimmerman with a working breadboard model of raster scanner plotter.



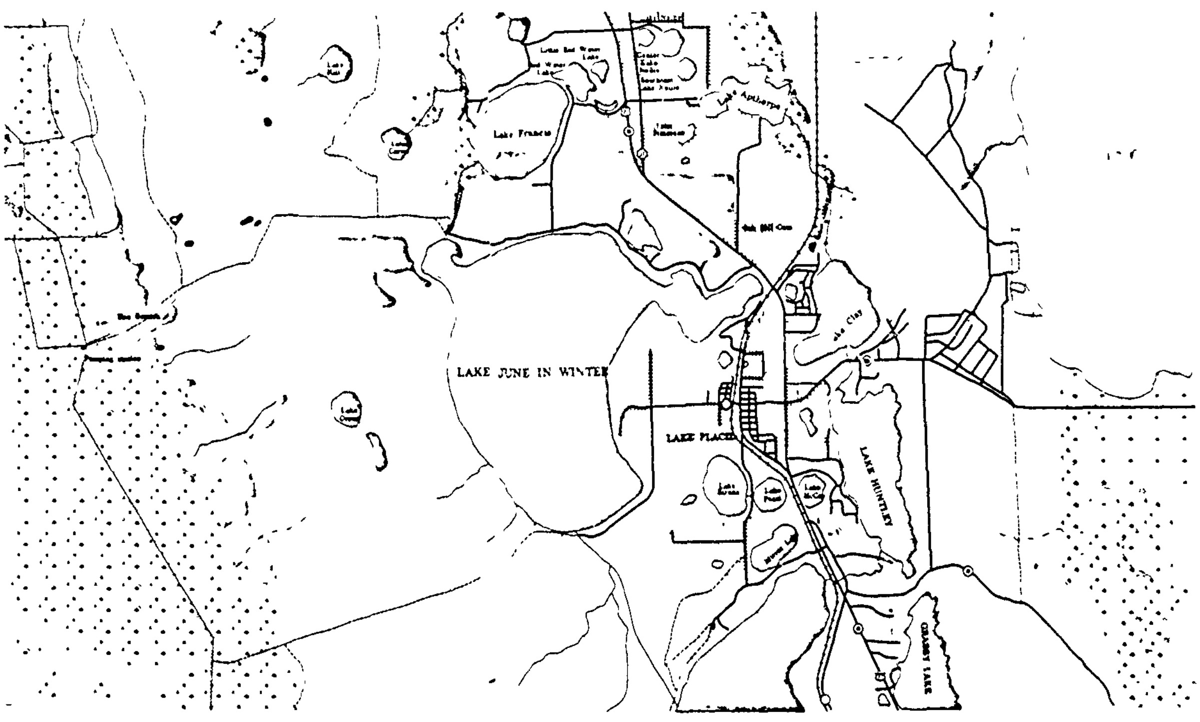
Richard Clark looks at the input material on the drum of the raster drum scanner/plotter (a fifth generation model), 1976.

Work with this cartographic scanner/plotter has given the ETL specialists considerable experience in handling raster-scanned information in computers and outputting processed images onto films that can be contact printed onto pressplates for final reproduction. The raster drum scanner/plotters developed by the Rome Air Development Center have been delivered to DMA Topographic and Aerospace Centers, where they are being tested prior to being made on a production basis. Meanwhile, the Automated Cartography people are working on the computer software, so that the STARAN Associative Array Processor can manipulate the output. Their aim is to produce a device that would skip the intermediate film storage step and allow the production center to go directly from digital data to a pressplate. This equipment will also be capable of facsimile scanning "pasteups," or hand-prepared materials, while simultaneously exposing a pressplate. Close attention has been given to the interface of this equipment with commercial telecommunication, microwave, and satellite communication links in a mode similar to that being used by the newspaper media. At the final session of a trade convention in Las Vegas, "Horizon '76: Systems to Satellites," advanced communications technology was demonstrated by means of impressive, on-site satellite transmission, courtesy of Dow-Jones & Co. This *Wall Street Journal* demonstration included the live transmission of a newspaper page from Chicopee, Mass., to a receiving antenna outside the convention center via a "Westar" satellite. The newspapers have had considerable success in scanning and transmitting full-page images by satellite, not only between points within the United States but also from the U.S. to other continents. The major differences between the newspaper and mapping/charting requirements are size of images and the precision and resolution of data points. The mapping and charting equipment will be sized to handle images up to about 1.22 x 1.52 meters with a precision of image placement approximately 0.0254 millimeters. Newspapers are generally 432 x 559 millimeters, and the technicians are not as concerned with spot placement precision as the mappers and chartmakers who must register five or more colors.[23] Automated Cartography Branch personnel have examined several digitizers for planimetric data.



The STARAN Association Array Processor, Goodyear Aerospace Corp. It can process digital data, such as that produced by the raster data from drum scanners, for automated cartography applications. STARAN can process the same intermittent stream of data in 78 seconds that an IBM 360-40 can process in 3 hours.

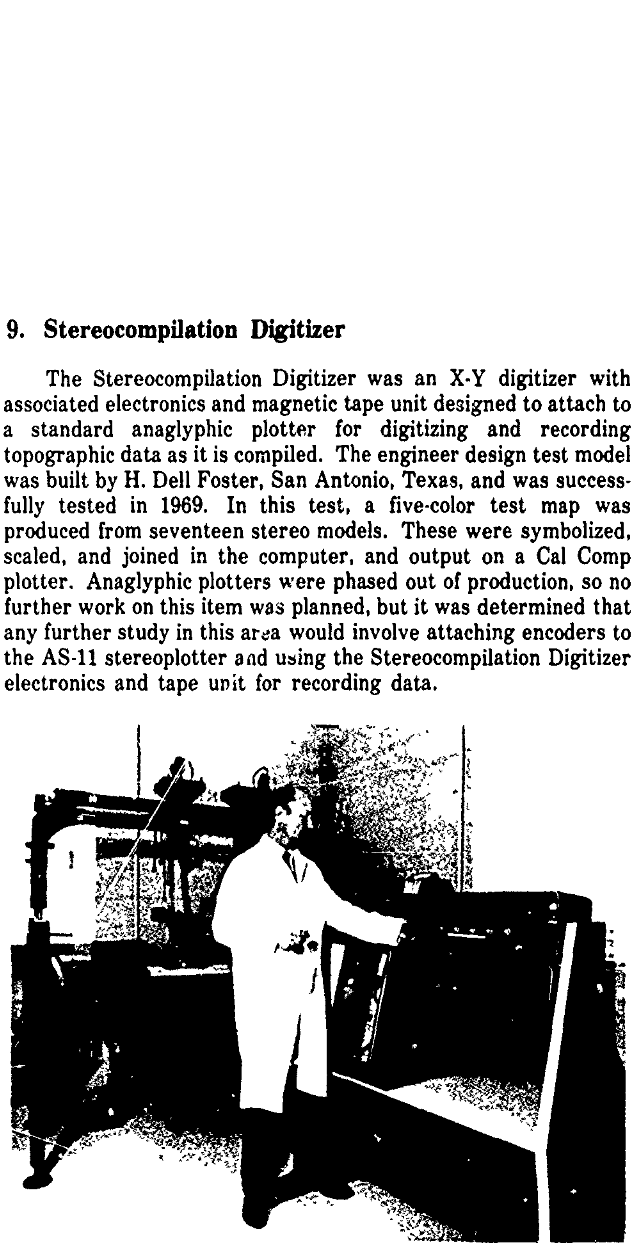
Lake Istokpoga, Fla., 1:50,000 Experimental Map



This map was produced to demonstrate the capabilities in 1976 for raster processing of map data.

9. Stereocompilation Digitizer

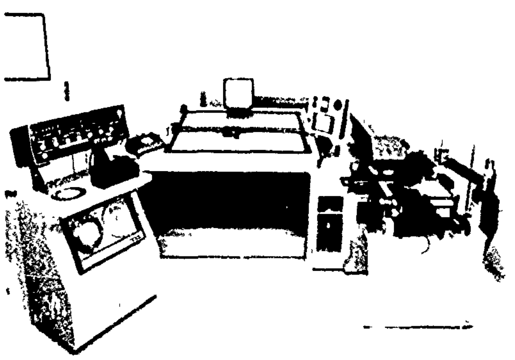
The Stereocompilation Digitizer was an X-Y digitizer with associated electronics and magnetic tape unit designed to attach to a standard anaglyphic plotter for digitizing and recording topographic data as it is compiled. The engineer design test model was built by H. Dell Foster, San Antonio, Texas, and was successfully tested in 1969. In this test, a five-color test map was produced from seventeen stereo models. These were symbolized, scaled, and joined in the computer, and output on a Cal Comp plotter. Anaglyphic plotters were phased out of production, so no further work on this item was planned, but it was determined that any further study in this area would involve attaching encoders to the AS-11 stereoplotter and using the Stereocompilation Digitizer electronics and tape unit for recording data.



Joseph Goodwald with Stereocompilation Digitizer equipment.

10. Digital Planimetric Compiler

The Digital Planimetric Compiler (DPC) is another piece of equipment that has been developed during the past decade by the Automated Cartography Branch. This X-Y digitizer with appropriate electronics and a magnetic tape unit was designed to be used over a light table for compiling planimetric data from orthophotographic mosaics. As this project was carried out in an extremely cost-conscious environment, all possible steps were taken to keep testing to a minimum. The engineer design test model, built by Optomechanisms, Inc., Plainview, N.Y., included an H. Dell Foster digitizer and an auxiliary stereoscope and rear projection viewer mounted on the table. Based on engineer design tests, the specialists elected to disassociate the optical equipment from the digitizing equipment. The Engineering Test/Service Test model equipment was built by Dimensional Systems, Inc., Waltham, Mass., with the computer program written by another contractor. As developed, DPC consists of five standard Bendix Datagrid digitizers linked to a PDP-11 minicomputer and magnetic tape unit. The work surface is backlighted so that film transparencies can be used as the primary compilation source. A "floating" console containing five thumbwheel switches is provided to enable the operator to input feature tag data. The tracing cursor is designed to leave a mark as features are traced so that the cartographer can easily monitor his progress. Control software has been developed to buffer the digitizer data and output the information on magnetic tape in fixed length records. Output is in Binary Coded Decimal (BCD) format. Incremental vector codes are used to describe linear data, with a vector produced every 0.127 millimeter of cursor movement. The Digital Planimetric Compiler has been successfully employed at DMAHTC for several years.[24]



Digital Planimetric Compiler (above) uses three encoders like the one below to read the x and y coordinates and the angle of orientation of manually selected topographic features on aerial photos.

11. Microfilming

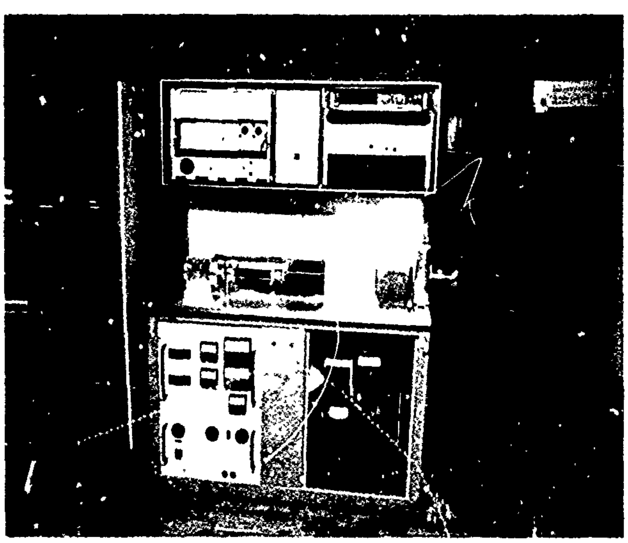
Since 1963, the ETL team has been involved in developing various electro-optical devices for producing, storing, retrieving, and using micromaps; that is, microfilmed copies of topographic maps. ETL employees developed a precision camera for use by DMATC that can produce micromaps ranging in size from 35 millimeters to 203 x 254 millimeters.

12. Electron Beam Recorder

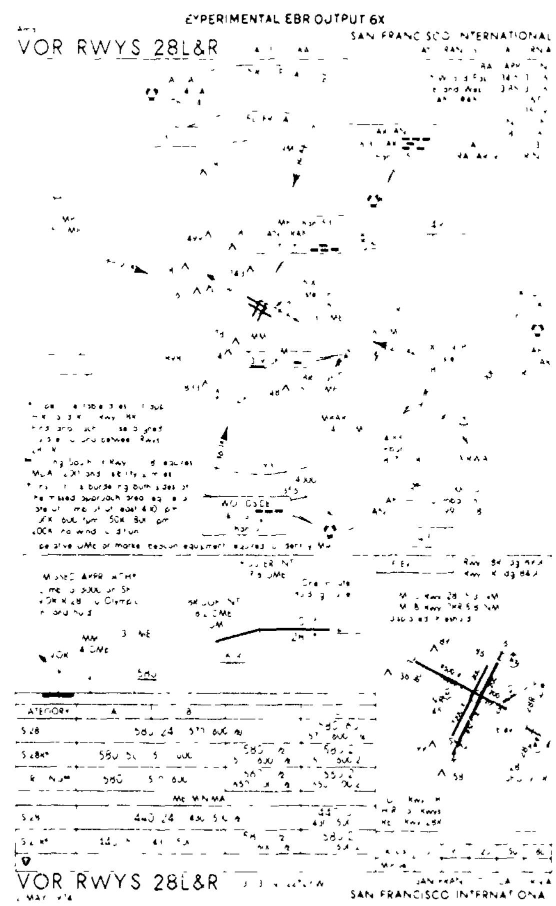
During the last two decades, a number of companies have developed electron beam film recorders to produce master recordings for a variety of applications — television recordings, computer output microfilms (COM), aerial reconnaissance imagery, satellite pnotography, and the like. An electron beam recorder (EBR) converts electrical signals into images on electron sensitive film. It is similar in concept to a cathode ray tube recorder in which the lens and phosphor have been removed and the recording film has been substituted. A typical EBR consists of a high resolution eletron gun, an electromagnetic system for focusing, deflecting, and controlling the electron beam, a film transport mechanism, a fully automatic vacuum system, and ancillary electronic equipment.

Building upon National Aeronautics and Space Administration (NASA) experiences with EBRs in reproducing ERTS/LANDSAT satellite imagery, ETL began to explore the feasibility of applying EBR technology to cartographic processes. The initial work, carried out under contract by CBS Laboratories in 1972, utilized an EBR prototype system developed for the NASA Earth Resources Technology Program. Subsequently, a number of CBS employees who had been working on EBR technology formed a new company called Image Graphics, Inc., with which ETL contracted in FY 1975 for an engineering development model EBR. The equipment was delivered in FY 1976. Extensive testing of this hardware led to the creation of a pre-production model Cartographic Electron Beam Recording System, which was installed at DMAHTC during the last quarter of 1978. The earlier development model system was updated to match the preproduction system.

An electron beam recorder was also developed for use in the Automated Air Information Production System. This Image Graphics EBR was installed during June 1978 at the Defense Mapping Agency Aerospace Center in St. Louis, Mo., for the direct production of FLIP (Flight Information Publication) charts.[25]



Cartographic EBR built by Image Graphics, delivered to ETL in 1976.



Flight Information Publication Chart produced with an electron beam recorder.

13. Digital Input/Output Display Equipment (DIODE)

A large computer interactive system suitable for editing precise cartographic digital data was delivered to DMATC on 15 January 1976. This system, called Digital Input/Output Display Equipment (DIODE), was described by Wesley H. Shepherd, DIODE project engineer.

General Approach. One technique for editing in the Automated Cartography System could be a manual process in which the final color separation negatives are retouched by manual opaquing and rescribing. Much of the advantage of automatically drafting the final separations would be negated by such an approach. A single compilation error, a bad tag for example, would cause havoc in a manual post-editing scheme, perhaps requiring hours and hours of rescribing. Further, when completed the digital data would be useless for storage and future use, and/or for data base use for other than map production. Discrepancies and errors in the data would not have been corrected.

A second technique available for editing is to re-digitize those features and points requiring modification on the off-line digitizers, and merge these new data with the correct portions of the original data. Problems associated with this technique are the amount of processing time required and the amount of final plotting required. To develop effectively a system of this sort would require nearly as much software development as for an on-line interactive edit system. The file structure required would not drastically differ from that required by on-line interactive system. However, the versatility of the editing capability would be severely limited, and the off-line re-digitizing process would require several iterations of final processing plotting before a usable product results. In terms of throughput, processing time on the large scale CPU (Central Processing Unit), and final plotting time, a strictly off-line, re-digitizing scheme would severely reduce the economy of the Automated Cartography System.

The interactive editing equipment provides the desired editing capability in the Automated Cartography System. The human operator directs the retouching operations, but is not burdened with rescribing. He re-digitizes the changes and missing data, but does not wait for another "final" processing run on the large CPU, nor for another off-line "final" plot to see what he did. Reiterate he may, but with real-time response where the results are instantly displayed simply as lines or in final symbolized form on the CRT displays. The digital data are updated, corrected and merged with the original data in real time as the changes are made. Off-line processing on the large CPU is kept to a minimum as is the off-line final color-separation plotting on the precision plotters.

[The figure below] depicts the system data flow with editing in the Automated Cartography System. The digitizing process converts the source data to digital form with all the tags and descriptive data required. Digitizing here refers to all the manual and automatic equipments and includes some intermediate processing routines, such as ConPlot from UNAMACE data, that produce line or feature data in digital form.

Processing the source data to form an orderly and structured format is an important and necessary step not only for editing, but for storage and for ease of access for the final color-separation processing. The source data are more or less randomly ordered during initial digitizing. Preprocessing re-structures and reorders these data into a sectionalized file structure suitable for editing and for efficient final color-separation processing and plotting. Transformation to the final map form may be accomplished during the preprocessing step. This operation also includes as much of the "automatic editing" as is possible without the help of human interpretations and decisions. Separately digitized features are connected to form continuous lines where positional and tag data

DEFINITION OF EDITING IN SACARTS

Editing =

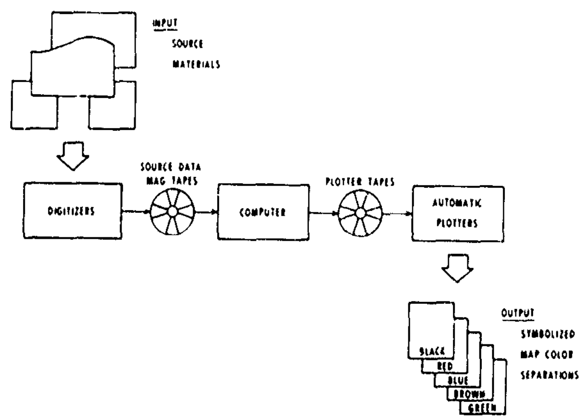
(All Normal Editing for Map Production)

+

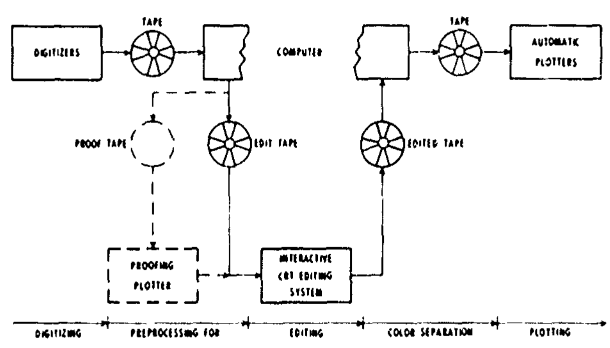
(Host of New Errors Introduced by the Automated Techniques)

Proofing	Erroneous TAGS of Features
Corrections	Erroneous (HONABLEW) Lines
Grids/Projection	Disjointed Line Segments
Marginal Data	Missing Data/Features
Control	Tape Errors
Etc.	Processing Errors
	Software Errors
	Software Limitations
	(Others ???)

AUTOMATED CARTOGRAPHY SYSTEM



An overall concept for the automated cartography system.



Automated Cartography System with Interactive Editing.

allow. Loose ends and potential trouble spots may be located, indexed, and listed during this preprocessing on the large CPU. Finally, a proof plotter tape for editing may be generated during, or just after, the preprocessing action.

Editing includes correcting, changing, modifying, etc., the digital data via the subject interactive editing equipment. Selected data are displayed on the CRT displays either as centerline data or as symbolized features. Program operations are directed by the operator via the keyboards, light pen, etc. Positional data required during editing are entered with the tablet or light pen. New data are digitized on the tablet as required. Data files are updated during editing in real time so that when editing is completed the data are ready for storage in a data base or for final color-separation processing to produce the final map color-separation negatives.

It is significant to note that all the digital data from all the digitizers are converted to a common format and file structure during preprocessing and any or all the data may be output on any of the system plotters, regardless of the source. Thus, data originated on the drum scanner may be plotted in final form on the flatbed plotters — or similarly, data compiled on the manual digitizers may be plotted on the drum plotter.

Further, it is significant to note that the large central processor is used for the large batch jobs of preprocessing and for final color-separation processing, whereas the interactive editing is off-line from the large CPU. Thus, the jobs requiring a large amount of processing are done on the large efficient central processor and the relatively slow "smaller" jobs of editing are done on-line with the small CPU.[26]

In November 1970, ETL awarded contracts to Bendix Corp., and Adage, Inc., for off the-shelf equipment to add to an existing controller for the development and testing of an interactive CRT display for digital map editing. The hardware delivered to ETL in March 1971 included an Advanced Remote Display System 100B storage tube CRT display terminal and keyboard, a 762 x 914-mm. Bendix Datagrid, and the hardware interfaces necessary for linkup with the existing Xerox Corporation SDS-930 computer. All the computer programs needed were developed by the Automated Cartography Branch and the Computer Sciences Laboratory (CSL) at ETL.

Based upon information gathered in tests made with a minimum-cost DIODE prototype system, ETL awarded a contract to Lundy Electronics and System, Inc., in June 1972 for the development of a more refined system, which would then be subjected to engineering tests. The hardware delivered to Ft. Belvoir in December 1975 included extra equipment necessary for laboratory tests. DIODE components required for production use included:[27]

DIODE SYSTEM HARDWARE PRODUCTION CONFIGURATION

A. CONTROLLER

1. PDP-11/45-CA & CPU & ASR 33
2. KT11-C Memory Segmentation
3. FB11-B Floating Point Processor
4. KW11-P Real-time Clock
5. MM11-SP Core Memory, 124K Words
6. Misc. Interface Equipment

B. STANDARD PERIPHERALS

1. RP11C/RP03 Disk, 20M Words
2. TM11-A/2 of TU10 Tapes

C. INTERACTIVE TABLET

1. 914 x 1219-mm Backlighted Datagrid
2. Bi-direction CPU Interface
3. Electronics for Stream Digitizing

D. REFRESH CRT DISPLAY

1. Lundy System 32/300
2. 16K Word Refresh Memory
3. Character Generator

E. STORAGE CRT DISPLAY

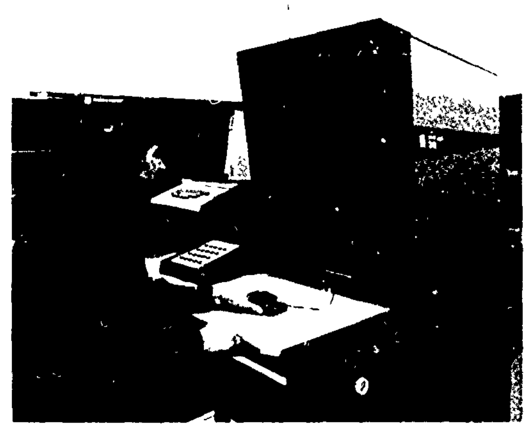
1. Tektronix 4014-1

F. FUNCTION KEYBOARD

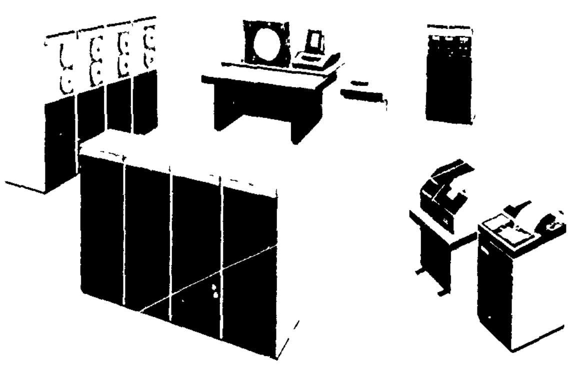
G. SPECIAL INTERFACES

H. SYSTEM SOFTWARE

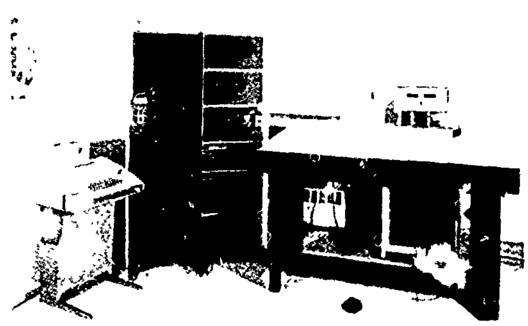
1. RSX-11/D, V6B



Wesley H. Shepherd at the Lundy System 32/300 Refresh CRT Display.



Digital I/O Display Equipment (DIODE)



Backlighted Bendix Datagrid used with DIODE.

In addition to the system sent to the DMATC in 1976, a second DIODE was delivered to the Hydrographic Center in 1978. When tests of both systems were conducted in 1978, several hardware and software anomalies still faced the designers. However, a third interactive system is under consideration for the Aerospace Center. Howard Carr explained: "We are interested in display technology that is more advanced than that used in the two previous systems. We are constantly searching for new interactive imaging systems that are more reliable, cheaper, faster, larger, etc., and are interested in all new and unique optical and/or electronic display devices such as the emerging gas discharge panels, solid state panels, electrostatic panels with Schjieren optics, etc."[28] The specifications for the DMAAC interactive system were drafted during the summer of 1978.

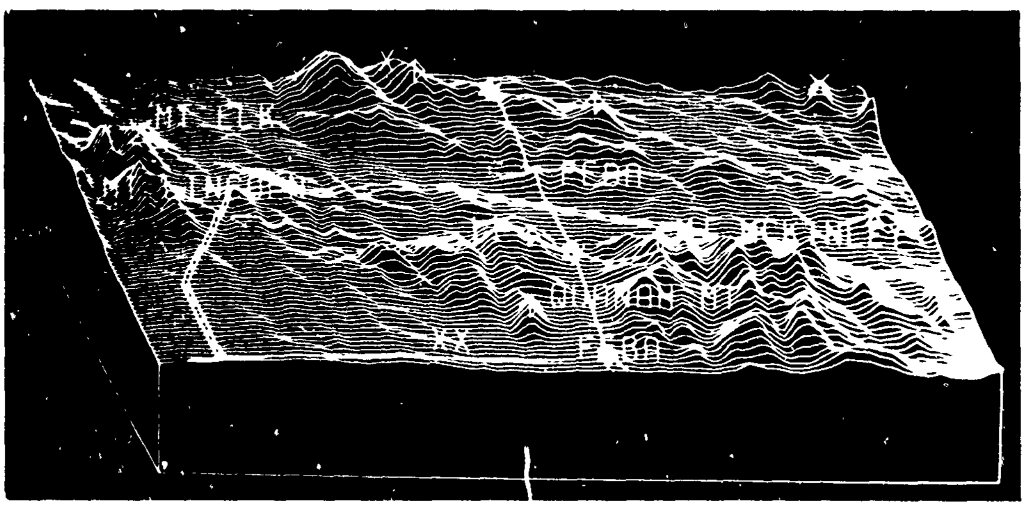
14. From Automated Mapmaking to "Auto Carto"

In discussing the accomplishments of the Automated Cartography Branch, Howard Carr reflected upon a change that has taken place since the early 1970s. "Within the past five years," the Branch has become more involved in "the development of computer software and direct user interaction with the digital data." During the past twelve years, there have been two major transitions. When the Automated Cartography Branch was established, computer hardware for automating cartographic drafting was just being developed. "When we started, the goal as we perceived it, and as our mission stated, was to automate the drafting of maps." But as they went further and further toward their goal of automating the cartographic processes, Carr and his colleagues realized that there were other ways to utilize the digital data they were generating. As Carr tells the story, "This digital data could very well be applied to producing new products, as well as to driving the drafting machines. So we began the transition from making topographic maps to new products that might substitute for maps, or to systems that would enable men in the field to interact directly with this data in terms of computer interactive systems." Carr predicted that the shift to these systems would be a major area of research and development for at least the next 5 to 10 years.

Among the substitutes for paper copies of maps are CRT displays that enable a battlefield commander or his staff to work at a computer terminal and, while looking at a large screen, determine the location of troops and other pertinent data. Carr, speaking about the future, pointed out that the tactical commander will be able to have "this information directly from the computer and display it on the CRT terminal with respect to topographic features." The form might be similar to a map overlay, or the commander might wish to call up a three-dimensional cross-section view as seen from a command post or the front lines of his forces. In either case, "we are using map data to show him exactly where he is, ostensibly in real time." This direct use of data allows him to overlay his force structures, the position of his forces, or the position of enemy forces and to combine these data with other key terrain information (soil and vegetation characteristics, tree cover, waterways, lines of communication) to determine, for example, whether infantry and tanks could traverse the terrain. Instead of permanent overprinted maps or laboriously drafted overlays, the commander of the future will be able to display as much or as little information as he wishes. "By being selective in this way, he can avoid being deluged with extraneous information which may tend to mask out what he is interested in." There are applications for this in the interactive graphic CRT display system in the Corps of Engineers civil works program as well.[29] The Army Terrain Information System (ARTINS), described later, might also exploit the direct use of data systems currently being developed by the Automated Cartography Branch.

James R. Jancaitis points to three-dimensional terrain display on a CRT display screen.

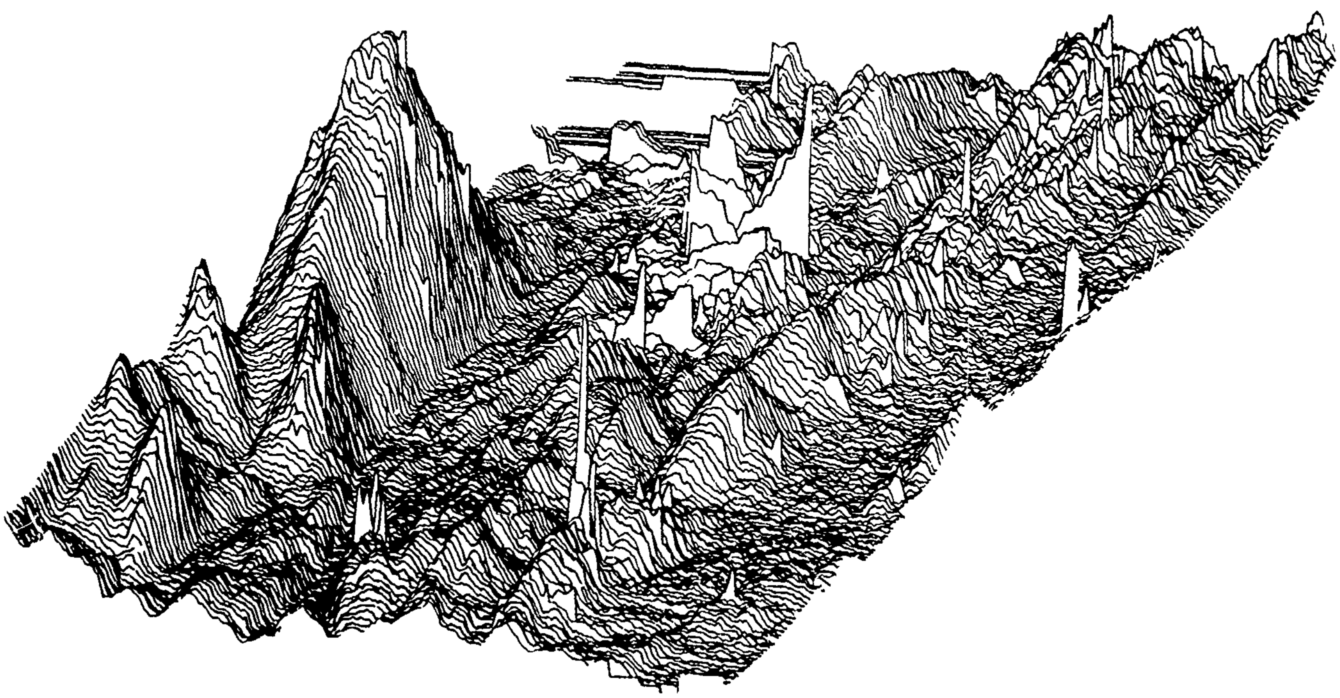
Enlargement of same terrain display. Future battlefield commanders may have such terrain information available in the field as part of a system such as ARTINS.



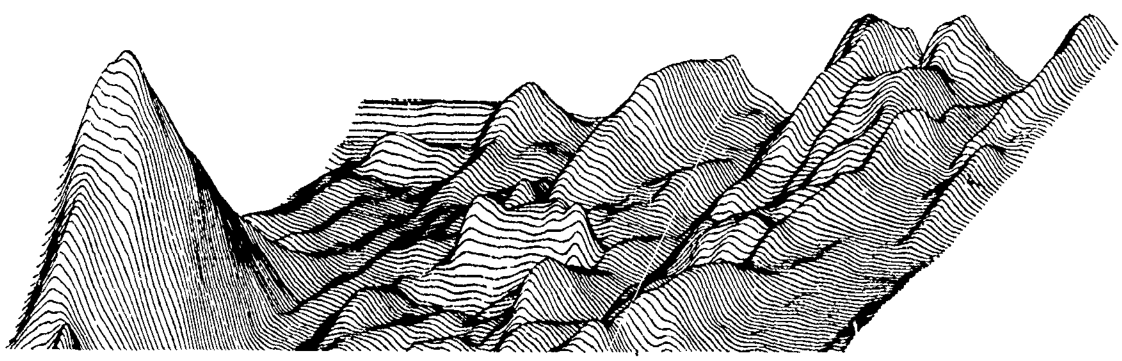
These pictures are a by-product of contract work performed for USAETL by Dr. John Junkins and James Jancaitis, University of Virginia, contract No. DAAK0272C0256. The primary contract goal was the conversion of digital terrain profile data into terrain contours as properly fitted to planimetric and hydrographic data. These pictures are presented here in order to show how the data set can be used to portray oblique views of the ground.

Compiled Jan 1974 by the Automated Cartography Branch, R. A. Clark Project Engineer, Col. JOHN E. WAGNER, COMMANDING.

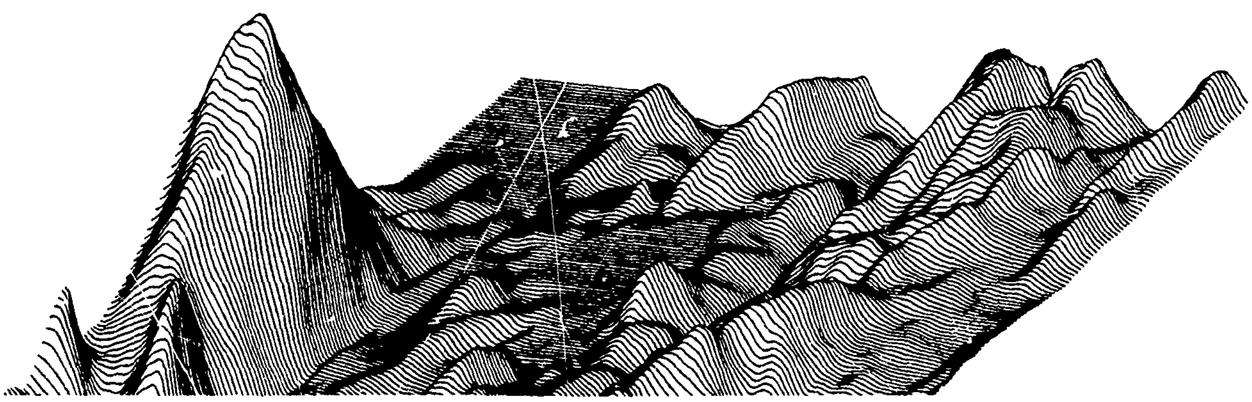
Before joining ETL, James Jancaitis worked with his colleagues at the University of Virginia on the conversion of digital UNAMACE data into three-dimensional representations of terrain.



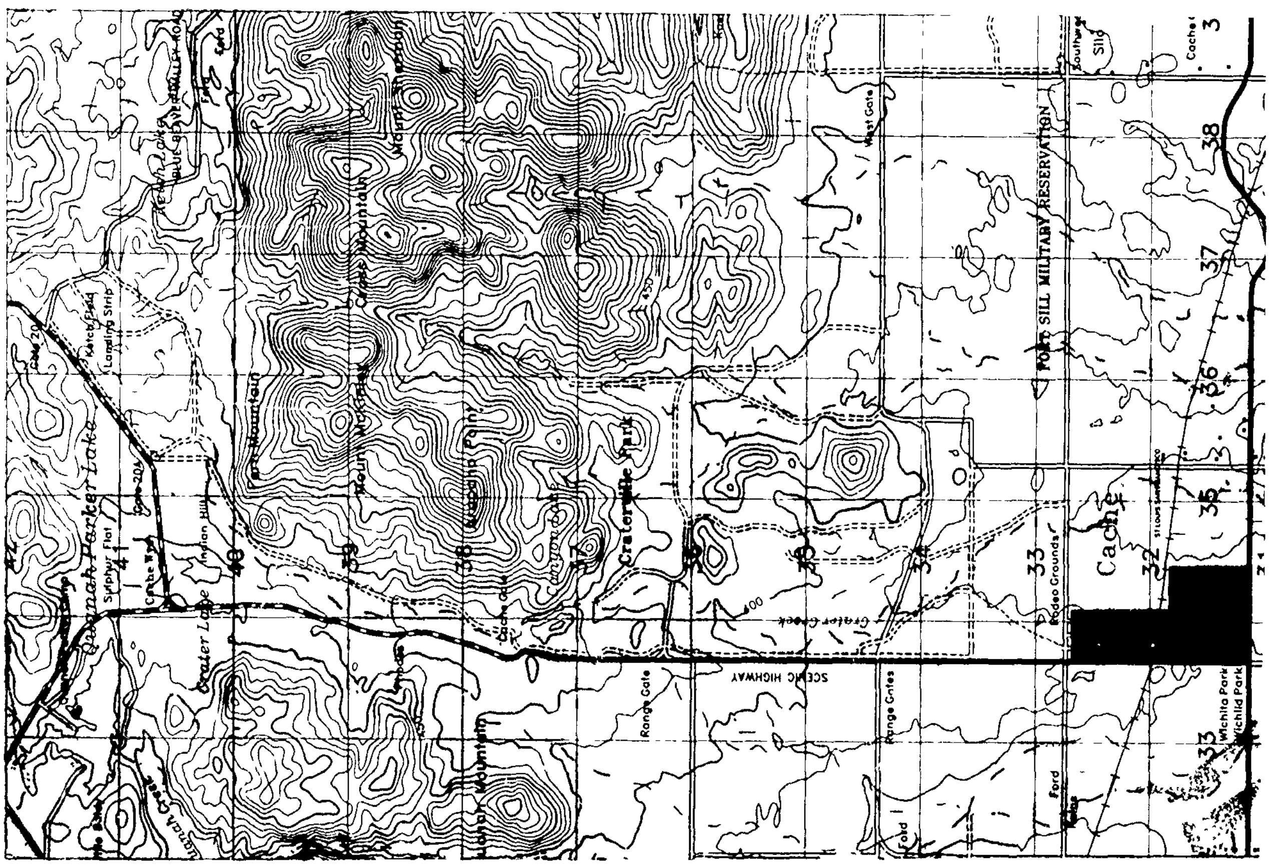
Raw UNAMACE profile data; view looking toward north east.



Smoothed profiles, noise and spikes, eliminated. Profile anomalies remain in water.



Profile anomalies removed from open water.



Standard topographic map treatment prepared by Automated Cartography Branch in 1972.

Two Views of Cache, Okla.

PREPARED BY THE AUTOMATED CARTOGRAPHY BRANCH

Chief	Howard Carr
Project Engineer, Mathematician	J. R. Jancaitis
System Analysis and Program Development	Wm. Randy Moore
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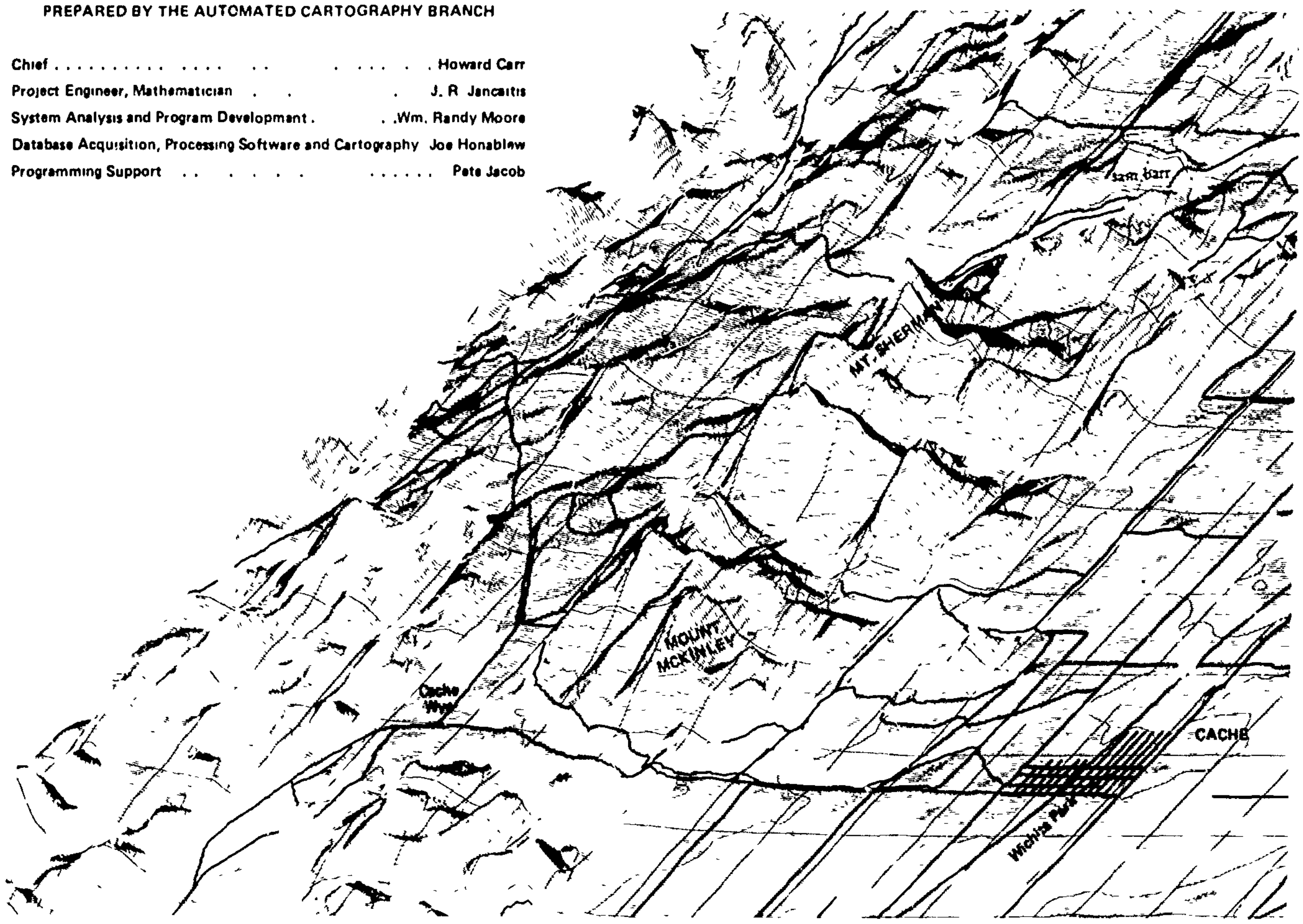


Experimental three-dimensional map produced by Automated Cartography Branch in 1977.

15. Polynomial Terrain Modeling

As with so much contemporary technology, the research and development work of the Mapping Developments Division has just begun to tap the wellspring of the computer and its related systems. Advances in this area are continually unfolding. A final example from the activities of the Automated Cartography Branch will illustrate this point. James R. Jancaitis has devised a way to compress bulky digital terrain data into a new compact, versatile computer format — the polynomial terrain model. Jancaitis evolved his polynomial modeling techniques from work he had done on converting digital terrain data into computer-generated contour lines. Polynomials provided an efficient answer to the contour question, and Jancaitis recognized the ability of polynomials to solve other problems, such as excessive bulk storage requirements, slow retrieval, and limited computer capacity for exploitation.

Polynomial terrain modeling is a powerful tool that makes it possible for the first time to store digital terrain data for the entire continental United States at a mapping scale of about 1:100,000 on a single 80-megabyte magnetic disk. The data compression power of polynomial modeling is so great that one tape or disk can hold 160 times as much information in compressed polynomial form as in the form of raw digital elevation data. Polynomial modeling alone accounts for an 80:1 data compaction ratio, compared to the digital terrain matrix format commonly used today. Since polynomials are also amenable to conventional errorless data compaction techniques, the compaction ratio can be improved even further. The high compaction and access efficiency attainable with polynomial coefficients now make minicomputer processing of elevation data a practical possibility. This development could open the door to field applications using mobile computers and prove to be a key to the effectiveness of the Army Terrain Information System.

The digital terrain matrix is a format for storing the vertical coordinates of a dense grid of equally spaced points on the Earth's surface. Using the new polynomial matrix, a computer can store an abstract mathematical model of terrain data instead of the huge mass of data for which the model stands. The polynomial model is represented by a matrix whose intersections are polynomial coefficients. Each element of the polynomial matrix covers a square of the Earth's surface and represents numerous digital terrain matrices. The elevation and location of a central point of the square are economically encoded in a polynomial equation that has the ability to "predict" the elevations of points elsewhere in the square, since the equation expresses the topology of a continuous surface area.

In the past, work with digital terrain matrices has required large, expensive computation and storage facilities in order to accommodate geographic areas large enough to be useful for practical purposes. Handling digital terrain matrices also requires excessive retrieval time. These format problems have been a barrier to expanded applications of digitized elevation data. The increased storage capacity and speedier processing that have resulted from using the polynomial model are only part of the story. Polynomials lend themselves to a wide variety of retrieval routines and can be used for a great number of applications.

In three months, a research team in ETL's Automated Cartography Branch developed applications software to exercise a polynomial data base of the Cache, Oklahoma, 1:50,000 topographic map sheet. Normally represented by over two million 16-bit elevation values, the Cache area was reduced to only 12,000 polynomials of 32 bits each on the minicomputer disc. The team has been testing the model on ETL's PDP 11/45 minicomputer system with good results. The evaluation of the polynomial data base continues as various computer routines are devised and tested for special purposes. Displayed almost instantly on a cathode ray tube or printed quickly by an automatic plotter, these digital map graphics portray the terrain from every conceivable angle.

The advantages of this technology have led to the adoption of the polynomial model by the Air Force Avionics Laboratory, which has selected the ETL polynomial terrain model format as the basis for an Airborne Electronic Terrain Map and Display System. Other anticipated uses for this concept have led the Strategic Air Command to ask the Defense Mapping Agency to explore application of polynomial terrain modeling to one of their experimental systems.[30]

The dynamics of current electronic and computer technology indicate that the cartographic revolution has only just begun. Each new technological breakthrough opens the way for many additional changes in cartographic processes, but as with many research and development programs, the individuals working in the field of computerized cartography have found that educating the consumer is one of their major tasks. By the time production centers have adjusted to a new and different approach to making maps, a still newer process is suggested by the ETL research team. However, during the next decade, the production methods for mapmaking will be modified even further. As with most technological revolutions, the people who keep up with the advances are the ones who will enjoy the excitement of the experience and the rewards of a product fabricated in the most efficient and accurate manner.

B. Improved Systems for the Field Army

Besides developing new equipment for map production centers, The Engineer Topographic Laboratories have been seeking ways of meeting the needs of field commanders for updated topographic information. Given the contemporary military possibility of a U.S. force facing a numerically superior enemy with a larger number of guns, combat commanders will want accurate, current terrain data delivered to them expeditiously. In an effort to provide better equipment for the field production of topographic products (maps and other types of displays), ETL specialists have conducted two major projects — the Topographic Support System (TSS) and the Army Terrain Information System (ARTINS). A review of how these projects came about and the manner in which they can aid the field commander, will provide another insight into the evolution of the ETL's mission over the past decade.

By the end of World War II, the United States Army, through equipment developed for and deployed with the topographic battalions, could carry out map compilation, cartography and reproduction functions in the field. In the post-1945 era, the Army continued to rely upon World War II vintage equipment housed in the Mobile Map Reproduction Train. There was limited interest in upgrading this materiel, since most parties believed that the Army Map Service production centers could meet the field Army's basic needs for maps. Exercise Red Arrow conducted by the U.S. Army Continental Army Command in June 1956 produced evidence to the contrary. One crucial aspect of the Red Arrow exercise was a target location test that employed a detachment from an engineer topographic company. At the conclusion of the exercise, the topographic detachment reported that a more systematic approach to target location in the form of a complete and high speed field mapping capability was badly needed. Maps produced in peacetime often did not reflect changes that were crucial in war — troop movements, field obstacle construction, aerial or artillery bombardments. It was believed at the time that field commanders needed standard format maps with this latest information reliably displayed. Indeed, successively updated maps might be required as a campaign progressed. Clearly, a Michelin road map would not suffice.

1. Rapid Combat Mapping System (RACOMS)

Between 1956 and 1963, GIMRADA awarded several contracts for examining a field system that would permit the rapid update of maps under combat conditions. These studies included the Semi-Automatic Topographic Data Reduction and Presentation System for the 1965-1975 decade, and the potentially more flexible and mobile Rapid Topographic Data Reduction System. The latter would have permitted the production of maps by combining ground survey and aerial photograph information.[31]

In October 1963, the Army issued an Operational Support Requirement for the creation of a Rapid Combat Mapping System (RACOMS). The Department of Defense, Director of Defense Research and Engineering (ODDR&E) assumed direction of the RACOMS project the following spring and a Tri-Service Project

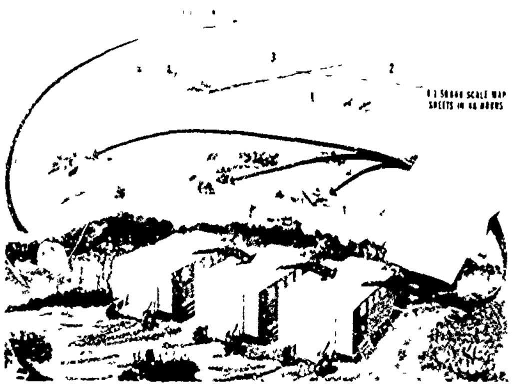
Management Office under the command of Col. Hamilton W. Fish* in the Office of the Chief of Engineers was established. RACOMS was the result of needs expressed by organizations such as the U.S. Army Strike Command, which might need a completely self-contained combat mapping system. Experience had indicated that such very mobile units often were sent to areas for which there was only limited military geographic information in map form. The Air Force and Navy were included in the RACOMS undertaking, because their aircraft would be involved in collecting the photographic and radar imagery used in compiling the maps. An authorizing document was prepared by the U.S. Army Combat Developments Command in August 1966 for a Field Army Rapid Combat Mapping System. No sooner had RACOMS been formalized and a number of research and development contracts awarded, than serious questions began to be raised about the technical feasibility and conceptual wisdom of the project. Developments in data gathering technology were rapidly beginning to outdate the proposed systems for RACOMS.

As initially planned, RACOMS would have consisted of eight mobile shelters or modules with expansible sides. These shelters could be airlifted by a C-130 aircraft. Inside the shelters, there would be an assemblage of standard cartographic equipment and off-the-shelf commercial components that would enable RACOMS to produce four 1:50,000 scale orthophotomaps with some cartographic delineation of elevations, man-made features, and the like within the first 48 hours, and two additional sheets every succeeding 24 hours based upon data acquired by an All-Weather Radar Mapping System.[32] Engineer design tests of RACOMS were conducted from June 1968 through January 1970, but, according to the Army Materiel Command much of the computer-operated equipment in the RACOMS modules could not be maintained in the field. Its cost, projected obsolescence in such a short time, and technological complexity spelled out termination.[33] However, the decision not to adopt RACOMS did not eliminate the battlefield commanders' need for timely topographic information.

*Colonel Fish was later the Commanding Officer of GIMRADA, 10 January 1966 to 31 July 1967.

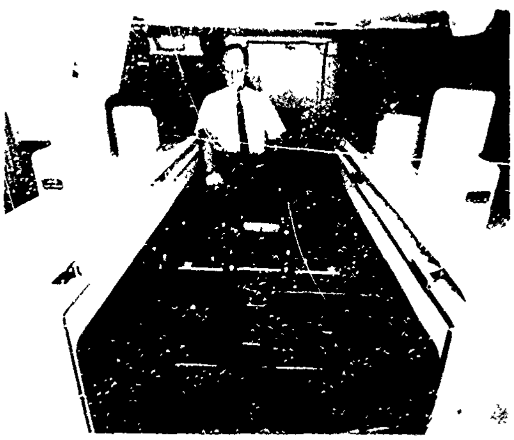
In the mid-1960s, concurrent with the RACOMS program, several investigations were conducted to evaluate mapping, charting, and geodesy requirements of the Army. In 1965 the Engineer Agency of the Combat Developments Command funded a GIMRADA Intelligence Division study to determine terrain intelligence requirements of the field army in support of work being done to develop the Command and Control Intelligence System-70 (CCIS-70). This system, which was renamed the Automated Data System Within the Army in the Field (ADSAF), would hopefully provide military commanders with a broad spectrum of intelligence and related information stored in easily accessible computer systems. IBM was selected to study the terrain intelligence aspects of CCIS-70/ADSA, and two important reports came out of their examination — "Operational Mapping Concept Study" and "Terrain Intelligence Input to the Tactical Operations System (TOS) of the Automated Data System within the Army in the Field (ADSAF)." The operational study, completed in August 1966, identified new commercial equipment that could be used in place of the older hardware in the Map Reproduction Train. The second study, dated July 1967, concluded that the volume of terrain information to be digested and analyzed would require automation of any field system, especially if it were to be effectively integrated with the ADSAF automated command and control system. These conclusions were approved in principle by the Combat Developments Command and forwarded to the Assistant Chief of Staff for Intelligence, who also approved, in concept, the automation of military geographic information for the field army.

Meanwhile, during the fall of 1967, an Ad Hoc Group of the Army Science Advisory Panel, chaired by Willis M. Hawkins, Vice President for Science and Engineering at Lockheed Aircraft Corp. and former Assistant Secretary of the Army for Research and Development, had been convened to examine several of GIMRADA's research and development projects as they related to Army requirements. Among the several recommendations of the Hawkins Committee was the suggestion that an Army Chief of Staff memorandum be drafted that would direct the Combat Developments Command to re-examine the needs of troops in the field for automated military geographic information, surveying,

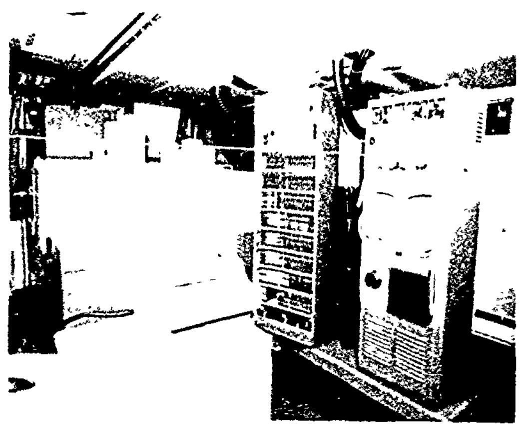


Artist's concept of the Rapid Combat Mapping System.

RACOMS modules undergoing tests at GIMRADA's compound at Fort Belvoir. Note the large power generators needed to provide energy for the various RACOMS systems.



John Denier with Automatic Photomapper showing positioning of input and output scanning for copying stereo glass-plate diapositives and exposing orthophoto negatives, circa 1966.



Automatic Photomappers a complex, portable, rugged system intended for use in RACOMS, was a field version of UNAMACE.

and topographic mapping. Such a study should determine the extent to which these activities should be combined and establish new requirements (official statements of need) for equipment to replace that being currently used.

2. Geographic Intelligence and Topographic Support System (GIANT)

This second Combat Developments Command study, done under contract by the North American Rockwell Corp. (now Rockwell International), was known by its accronym -- GIANT (Operations Research in Support of an Improved Geographic Intelligence and Topographic Support System for the Army in the Field). The statement of work called for:

> *Nature and Scope.* This study must provide a comprehensive and realistic appraisal of all theater requirements for survey, mapping and related topographic functions supporting the Army in the field as the basis for identifying the most efficient system for providing topographic (mapping and surveying) support in the 1970-1985 time frame. A parallel or integrated system for providing military geographic intelligence support to the army in the field in the same time frame will be identified, described and evaluated. The scope of this project includes all in-theater aspects of Geographic Intelligence and Topographic (GIANT) Support and is separate and distinct from CONUS [Continental United States] support, specificlly CONUS operations of the Army Map service (AMS). However, AMS operations and plans will be studied so that the interrelationship of theater and CONUS operations can be fully described. The identification of the optimum GIANT support system will include detailed quantitative statements of organizations, equipment and techniques required to provide this support. The study will be accomplished in two phases: the first phase end product will provide an interim report covering the period 1970-1975, and the second phase final study will cover the period 1975-1985. . . .[34]

In April 1970, the study results were released in a three-volume document, "Operations Research in Support of an Improved Topographic Support System for the Army in the Field, GIANT-75." As noted in the statement of work, GIANT-75 has two objectives: (1) "identify Army-in-the-Field users of topographic and military geographic information and determine their specific requirements" and, (2) "identify, describe, and evaluate the most efficient method for organizing, equipping, and operating an in-theater geographic intelligence and topographic (GIANT-75) system in support of the Army-in-the-Field during the 1970-1975 time frame." To satisfy the first objective, researchers were dispatched to survey the field users. Headquarters and troop unit staffs and unit personnel and commanders in overseas and CONUS locations were interviewed to determine user requirements:

REQUIRED PRODUCTS

GENERAL PURPOSE TOPOGRAPHIC PRODUCTS

1:25,000	Class B
1:50,000	Class A
1:100,000	Class A
1:250,000	Joint Operations Graphic — Ground (JOG-G)
1:12,500	Military City Map

SPECIAL PURPOSE TOPOGRAPHIC PRODUCTS

Large Scale Site Map (1:5,000 line)
Large Scale Photo Mosaics
Semi-controlled (unrectified)
Controlled (rectified)
1:25,000 Orthophotomap
(Contours desired)

1:50,000 SCALE

Vegetation
Drainage

Trafficability [identical to cross-country movement graphics for Armor, Infantry, etc.]
Lines of Communication
Cover and Concealment
Air Movement Data
Sensor Emplacement
Surface Materials
Amphibious Operations

1:25,000 SCALE

Nearshore Oceanography
Deadspace/Coverage/Slope

User response time (the time from when the user requests topographic products or data to the time he receives them) ranged from 48 hours to immediately (real-time). The number of different map products likely to be required was estimated based upon needs of a theoretical force operating in central Europe (one theater army, one field army, three corps, and 12 divisions) operating in an area of conflict approximately 1,150,000 square kilometers with an Army area of interest of 450,000 square kilometers. By analyzing the requirements and comparing them to existing capabilities, investigators concluded that existing topographic capabilities were inadequate. The second objective as directed toward identifying a possible system to meet the user requirements.

Although existing topographic units could not satisfy projected user requirements, there was still a possibility that some other organization could. The logical alternative was for a Continental United States (CONUS) base plant facility, such as the U.S. Army Topographic Command, to provide the products and services and transport the data to the field. The GIANT 75 study examined this scheme, but found it impractical. The remoteness of the CONUS facility from the battlefield precluded the capability of providing the user with his requirements in the necessary response times.

Again the study shifted back to the topographic units. It recognized that a topographic unit located in proximity to the user had the potential for rapid response. However, without creating a disproportionately large topographic support crew, the required topographic products could not be generated from basic raw input photographs and collateral intelligence. The mapping processes of surveying, photomapping, and reproduction, as well as storage and distribution, had to be streamlined. A data base produced in CONUS could serve as the basis for the generation of other topographic products and product revision, or for reproduction as required. (The Topographic Support System (TSS) that evolved from GIANT-75 and the subsequent Required Operational Capability (ROC) was predicated on the use of this data base.) In December 1971, the Army Vice Chief of Staff approved the GIANT-75 report in concept. The Office Chief of Engineers prepared the "Initial Draft Proposed Materiel Need" for the development of a Field Army Mapping and Terrain Information System (FAMTIS) in January 1972. FAMTIS was directed toward creating a system that would provide "military maps and allied data on an on-call basis" to the user in the field. It stressed the need for a "mobile mapping system" previously identified in GIANT. The U.S. Army Topographic Command assigned ETL the task of preparing an implementation plan.[35]

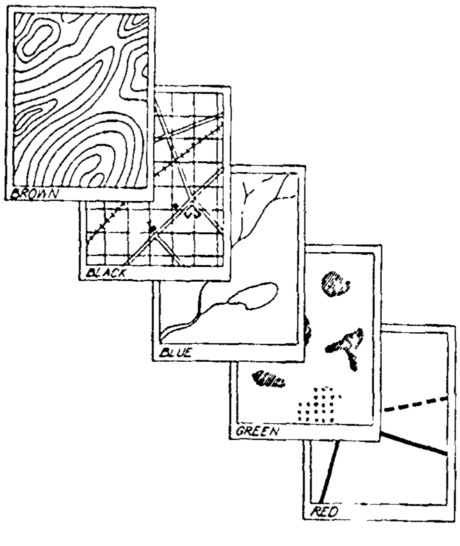
Meanwhile, several important changes in Army policy and organization had occurred. First, the Initial Draft Proposed Materiel Need, Engineering Document, was altered in format and given a new name — Draft Proposed Required Operational Capability (DPROC). More significant to the future of FAMTIS and related projects was the disestablishment of both the U.S. Army Continental Army Command (CONARC) and the U.S. Army Combat Developments Command (CDC), which resulted in the creation of two new commands — the U.S. Army Forces Command (FORSCOM) and the U.S. Army Training and Doctrine Command (TRADOC). The establishment of FORSCOM/TRADOC came about for many reasons: partly because of a periodic need for reorganization and partly because the U.S. Army was entering "an era of transition from combat status to peacetime operations, a time for contraction of the manpower base, and an era of economy in operations throughout the military departments."[36]

When the Combat Developments Command was discontinued on 1 July 1973, TRADOC was the consumer organization responsible for deciding what the requirements of the field army were for topographic and other support equipment. During this transitional period, the Field Army Mapping and Terrain Information System was also renamed; it was designated the Topographic Support System, 75-80 (TSS). Because of the various shifts and reorganizations, three and a half years passed between delivery of the GIANT-75 report and the 31 January 1974 delivery of the initial TSS Draft Proposed Required Operational Capability. Changes in Army Materiel Command (AMC) procedures delayed the approval of this document until September 1975. Two months later, the Department of the Army approved the Required Operational Capability (ROC) document, and TRADOC and AMC implemented the ROC in January 1976.[37]

3. Topographic Support System (TSS)

The Topographic Support System Required Operational Capability officially defined the need for a Topographic Support System.[38] At this time, plans called for having TSS in the field by the final quarter of fiscal year 1978. Cornelius Manthe, TSS project manager provided the following description of TSS. The Topographic Support System must be versatile, flexible, mobile, modular, evolutionary, and capable of producing products and services in a timely manner. Conceptually, there are some significant differences between TSS as envisioned and the topographic units currently in the field. TSS will include the military geographic information (MGI) function that is now only inadequately carried out by the engineer terrain detachments. And TSS will only revise and enhance general purpose maps produced by the Defense Mapping Agency; unlike the approach taken in RACOMS, no original compilation or cartography will be undertaken by topographic units. The enhancement will, by the addition of special detailed information, convert a general purpose topographic map into a special purpose graphic tailored to the particular needs of the commander in the field.

The primary components of the TSS are its four data bases. The first, designated the Thematic Graphic Data Base, is composed of a general purpose subset and a special purpose subset. The general purpose subset consists of color separation negatives generated during the normal mapping process, which are used to produce the map pressplate. General purpose topographic products can be produced effectively in the field, if the general purpose subset is on hand. The special purpose subset consists of current overlays designed to show MGI elements, such as detailed information on soils, vegetation, lines of communication, and drainage features. Special purpose elements are constructed as overlaps to 1:50,000 background graphics. TSS will have a field capability to produce special purpose elements.



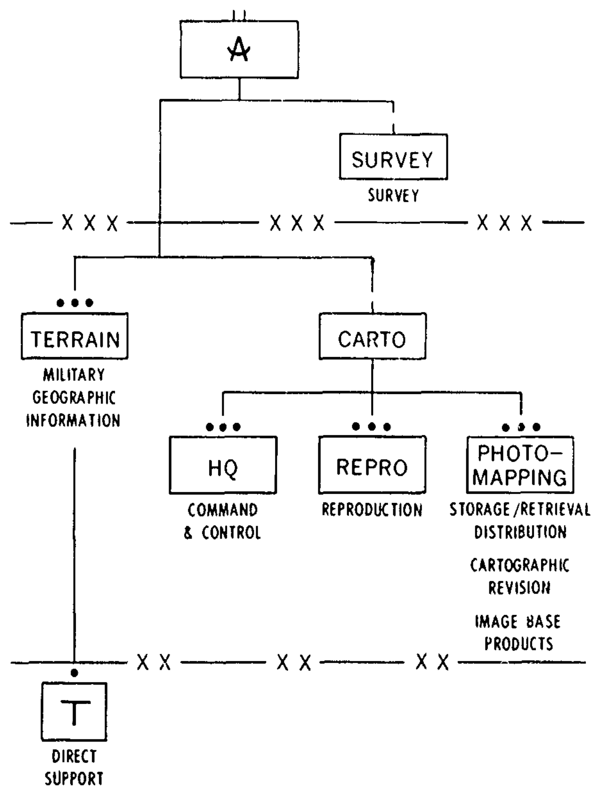
The five basic color separations generated during the normal mapping process.

The second data base will provde raw military geographic information. This will be a library of periodicals, reports, charts, and tabies containing general terrain information that has not been converted to special purpose formats. The third data base, for point positioning, will consist of orthophotographs that will aid in weapons targeting. This data base will be used with the Analytical Photogrammetric Positioning System to be described later. The fourth data base (imagistic) will comprise aerial photographs that provide up-to-date information.

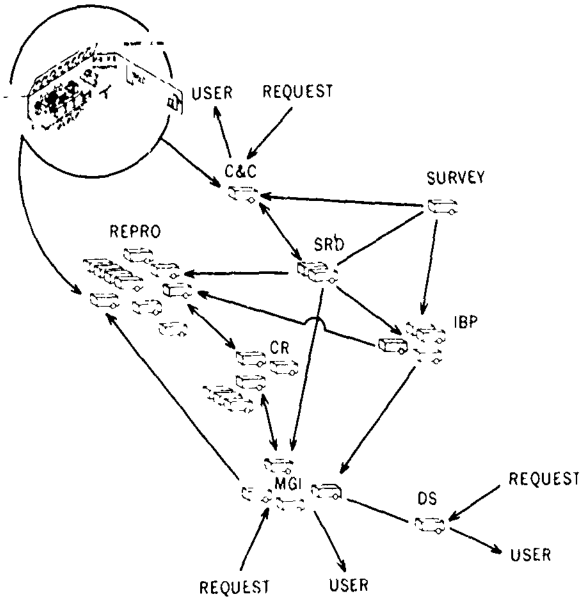
As a combat support system, TSS will consist of seven functional subsystems, each of which will comprise one or more modules. All except one of the modules will be housed in a standard 9 x 2.4 x 2.4-m military container mounted on a semi-trailer chassis. The module for direct support will be a smaller van-type unit mounted on a 2½-ton truck. The seven TSS subsystems are Command and Control; Storage, Retrieval, and Distribution; Reproduction; Cartographic Revision; Survey; Military Geographic Information; and Image Base Products.

The Command and Control (C&C) Subsystem handles the administrative and operational control of the TSS. It houses the engineer topographic staff which plans production to satisfy user requests, assigns work to other subsystems, monitors project status, and performs the quality control function for the system. The Storage and Retrieval Module stores the data bases to be used by one or more of the functional subsystems. In addition to maintaining the thematic graphic data base, it maintains a photographic data base and distributes all the TSS products.

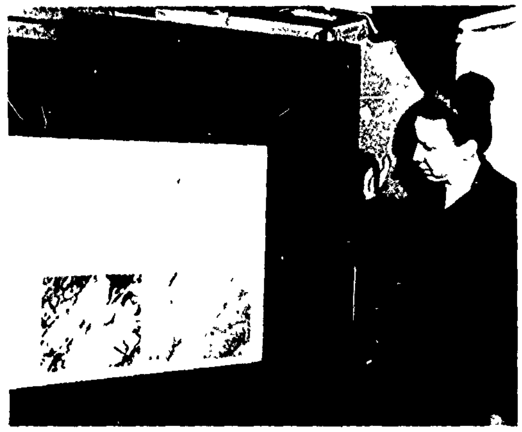
The topographic products of the TSS are reproduced in the Reproduction Subsystem. It consists of six modules: Camera, Map Layout, Plate Processing, Photomechanical, Press, and Finishing. The Camera Module produces color-separation negatives and has a 2.5X photographic reduction or enlargement capability. The Layout Module is the final preparation unit for the reproducibles. The Plate Processing Module prepares the lithographic plates, and the Photomechanical Module develops proofs for editing and processes manuscript images on plastic scribing materials or blueprints. Copies of the products are reproduced by the Press Module, which can accommodate materials in black and white or color, ranging in size from 254 x 356 millimeters to 584 x 737 millimeters. The Finishing Module performs the final steps of trimming, folding, binding, and packaging the products for distribution. Need for bulk storage has been eliminated, as only the minimum requirements are reproduced.



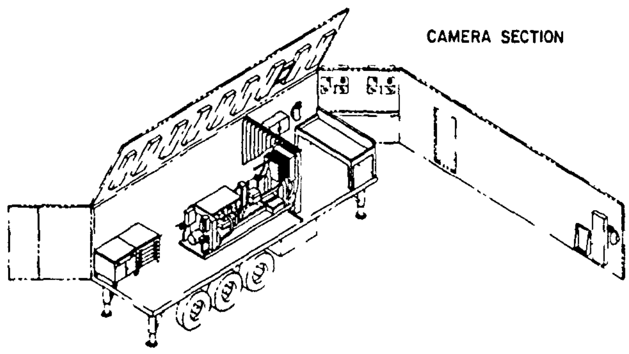
TSS Organization



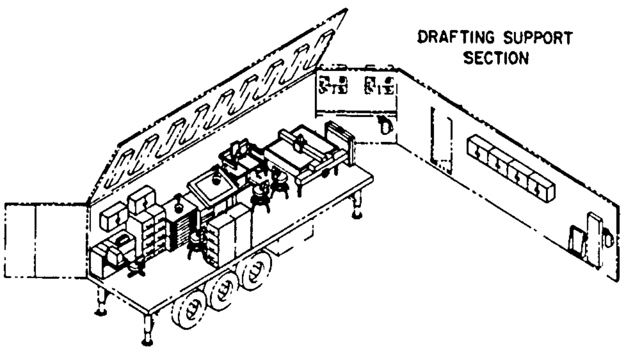
TSS Schematic



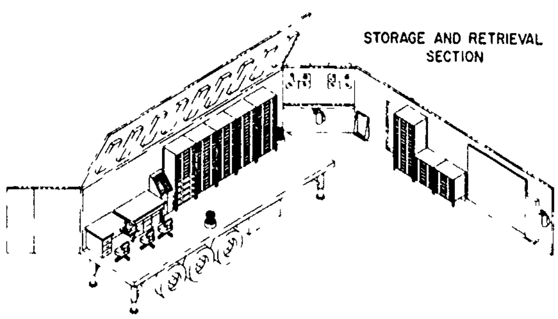
Army specialist checks alignment of map prior to making negative for reproduction.



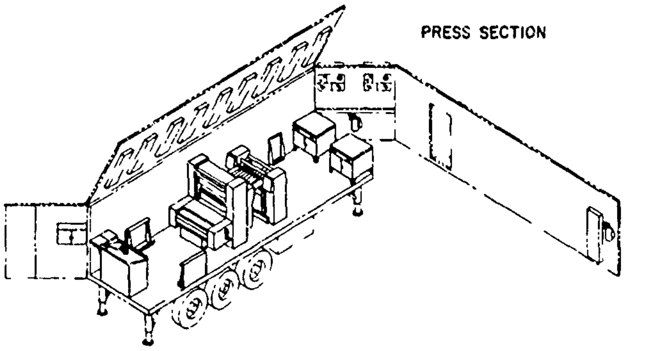
Camera Section of the Topographic Support System Reproduction Subsystem.



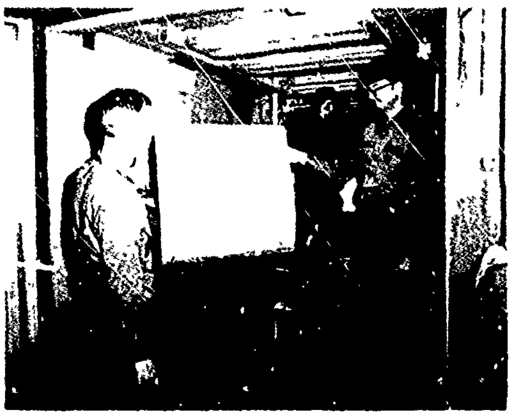
Drafting Support Section of Topographic Support System Cartographic Revision Subsystem.



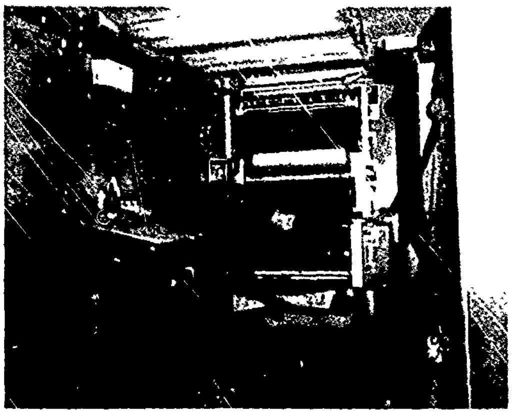
Storage and Retrieval Section of the Topographic Support System Image Base Products Subsystem.



Press Section of the Topographic Support System Reproduction Subsystem.



Topographic technicians display the pressplate which will be used to print a map.



Military lithographer takes a printed map out of the press.

In the Cartographic Revision Subsystem, reproducibles to annotate or update standard topographic products are prepared. Also in this subsystem, nonstandard products prepared on other systems can be prepared. The subsystem consists of a Compilation Module and a Drafting Module. In the Compilation Module, new information is obtained from basic source materials. Inside the Drafting Module grids, projections, plotted control sheets, and finished drawings are prepared in support of the other TSS susbystems.

The Image Base Products Subsystem, equipped with some of the latest, most expensive commercial products in the field, gives operators the capability to generate photomaps, to rectify cartographic and panoramic photographs, and to fabricate mosaics. The subsystem's three modules represent a significant increase in the quality of photographic-based topographic products.

The Surveying Subsystem is a radical departure from the traditional view of field surveyors equipped with stadia rods, levels, and theodolites. New equipment, such as the Analytical Photogrammetric Positioning System (APPS) and Lightweight Gyro Azimuth Surveying Instrument (SIAGL) that provide map control and artillery survey data, are being developed for topographic survey tasks. The subsystem consists of two modules, the Maintenance and Storage Module and the APPS Module. The Maintenance and Storage Module contains the parts, tools, test equipment, and work space for upkeep of the field surveying equipment. The APPS Module houses that piece of equipment and the Point Positioning Data Base it requires. A two-way radio allows contact with field surveying parties and transmission of data via Doppler signals.

The Military Geographic Information Subsystem has a terrain analysis capability that is used to provide current information to the Cartographic Revision Subsystem and to produce terrain intelligence to support unique user requests. Five modules comprise this subsystem — Collection, Analysis, Information, Synthesis, and Direct Support. The Direct Support Module, a truck mounted van deployed with each division in the corps area, provides terrain intelligence to division elements. It has an organic communication link to the collection module, and its analysis and cartographic capability will be able to produce quick-response rought copies as required. The Direct Support Module is the lowest level at which TSS will directly interface with intelligence and combat staffs.[39]

Once the mission and nature of the Topographic Support System had been determined, there were other problems that demanded attention. The first concern was the speedy delivery of TSS to the topographic units in the field. Having operated for a number of years without modern equipment, nearly everyone associated with the engineer topographic battalions acknowledged the fact that these units needed an updated system immediately.[40] But by January 1977, the demands on the limited number of dollars in the Department of the Army budget were forcing funding cutbacks in many development projects. As TSS Project Manager Manthe recounts, "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 Capability (IOC) date was still scheduled for the last quarter of fiscal year 1980." Manthe and his colleagues at ETL were given the task of finding a way of fielding TSS on time, but without spending any money in FY 1977 and 1978. The plan the ETL team devised to expedite creation of TSS without spending any funds was a significant departure from normal research, development, and procurement procedures.

The TSS had been redesignated a Non-Development Item (NDI) in the final Required Operation Capability document, rather than an Engineering Development phase of a research and development project. Instead of developing new hardware, as in the case of RACOMS, the Topographic Support System was to be built using off-the shelf military and commercial items. Acquiring equipment this way would speed up delivery of TSS to the field, but it could also cause problems. Each separate commercial item not previously type classified would have to be evaluated to see that it met military specifications and determine whether sufficient reliability, availability, and maintainability (RAM) data could be acquired, so that the materiel could be adopted. Once a decision had been made about the type of equipment needed for the Topographic Support System, Manthe and his colleagues designed the system, selected items to do all the required tasks, and prepared the necessary equipment lists and drawings. A series of Integrated Equipment Evaluation Team meetings were scheduled to review the proposed component lists and the design configurations of the modules, and Manthe's specialists conducted two market surveys to determine whether the required items were available and collected RAM data for each. All the information they collected and evaluated will be submitted to the U.S. Army Mobility Equipment Research and Development Command (MERADCOM) acting on behalf of the U.S. Army Materiel Development and Readiness Command (DARCOM; which replaced AMC on 23 January 1976), which will seek to approve type classification at a special In-Process Review. The In-Process Review, scheduled for the first quarter of fiscal year 1979, will insure that the various elements of the Topographic Support System are acceptable and ready for standardization. If the review goes as planned, the first contract will be awarded to procure TSS modules for the active topographic units in Europe plus some modules for training purposes at the Defense Mapping School. Acceptance Tests for this materiel are scheduled for the last half of fiscal year 1980. After all the modules are accepted, the system will be shipped to selected topographic units for follow-on evaluation. It is anticipated that TSS modules will actually be issued during the second quarter of fiscal year 1981.

TSS PROCUREMENT PLANS

FY79	45 modules for Europe	$ 19.2 million
FY80	no procurement	0.0
FY81	81 modules	23.9
FY82	81 modules	24.0
FY83	72 modules	19.3
	317 modules	$ 86.4 million

Procurement of the 3,500 items that make up TSS will be a big task, but MERADCOM and ETL personnel are confident that the job will be done on time, if the necessary funding is made available during the 1980s.[41]

Looking at the creation of the Topographic Support System, we find different perceptions of the accomplishment, but everyone agreed that new equipment was badly needed and overdue. Some ETL staff members, notably individuals in the laboratories, were frustrated by how long it took to get the requirements for an updated field topographic system approved. Robert Macchia, ETL technical director, offered his view. The lengthy time involved was part of a system of checks and balances, and the great cost of research and development made such a check-and-balance approach essential. Too many pieces of hardware have been developed at a substantial cost only to go nowhere, Macchia suggested. Equally significant, there are more requirements than there are dollars to pay for solutions. Macchia believed that his specialists in the laboratories had to be advocates of their projects, and, being creative people, they also had to suffer frustrations as they justified and rejustified their work. If the team at ETL sells this project, and, if it survives type classification, Macchia was reasonably certain, the wider defense community will recognize the value of this important work.[42]

Colonel Stockhausen viewed TSS from the vantage point of a career Engineer officer with experience in the topographic battalion. To Stockhausen, TSS was important because it represented a change in topographic doctrine. "Currently, doctrine is very similar to World War II doctrine. You are assuming that the topo units are going to make maps. Those days are gone. The individuals in the field are going to be making terrain analysis products — military geographic information products — which provide the analysis for the commander and give him a product from which he can make an informed decision." Technologically, TSS does not push the frontiers as far as might be possible, but the new equipment and the new doctrine with its emphasis on military geographic information for the commander will cause great changes in the lives of the people who work in the topo battalions. UNAMACE, RPIE, ARME, and the other equipment developed for DMATC changed the working world at that production center. TSS will also bring changes in the field. Skills will have to change, as well.[43]

Introduction of the Topographic Support System will be just the first step toward improving the capabilities of the topographic battalions. As TSS Project Manager Manthe pointed out, the new system was to be versatile, flexible, mobile, modular, evolutionary, and responsive. To extend this versatility, flexibility, and responsiveness, ETL will continue to develop new equipment that can be phased into the TSS modules in the future. One of the plans for improving TSS calls for the automation of the military geographic information aspect of the system through the introduction of an Army Terrain Information System (ARTINS).

4. Army Terrain Information System (ARTINS)

The Army Terrain Information System project is in the early stages of advanced development. During this stage, the concepts for such a system are validated, and cost effectiveness, and operational effectiveness are evaluated. A breadboard experimental system is required to explore various concepts. Applications programs are being developed to test the use of math models and a multipurpose data base.

The goals of the Army Terrain Information System team are the development and employment of a highly automated system that will satisfy the terrain intelligence needs of all field army elements. Fully operational, the system would embody automated processing, production, storage, retrieval, dissemination, and updating of terrain intelligence. The present concept calls for the deployment of ARTINS at the echelon above corps, with non-automated data provided to corps and division.

Data sources for ARTINS will be diverse. As presently conceived, a facility in the U.S. would provide data base materials for field updating, with military intelligence units, battlefield sensors, and aerial imagery providing additional information. Data reduction would be accomplished by both automated and manual processes, including mensuration techniques, photointerpretation, mathematical computations, and the application of engineering and other professional skills.

ARTINS promises to be an improvement over the initial MGI subsystem of TSS, because ARTINS would provide combat planners with more rapid responses to their questions. Plans call for the ARTINS computer data base to be continuously updated so that such information as recent bomb damage to bridges and the impact of an overnight rainfall on the fordability of a river would be readily available for display in graphic form on a computer-driven terminal. ARTINS would provide analysis of the impact of the terrain in a specified area on cross-country movement, fields of fire, line of sight, cover and concealment, and the like. Specific information, such as the velocity, width, and bank conditions of a river, would also be accessible from the ARTINS data bank.

The ARTINS digital data base is separated into two categories: areal data and feature data. The surface upon which all other terrain data are superimposed is represented digitally by elevation data. Areal data includes items such as vegetation and soils; feature data considers such things as bridges, roads, railroads, and pipelines.[44] Areal data include those terrain characteristics that can be digitized into a grid cell format. Areal data are organized into logical storage blocks comprising a fixed number of grid cells, or pixels, arranged in a square array.

Unlike terrain characteristics, feature data will not exist everywhere and cannot be organized into logical storage blocks.

> Rather, these data are stored in various files characterized by different record lengths. The data describing each specific feature are keyed to the appropriate ground location and orientation by means of stored coordinate values. In this way, the feature data can be readily overlayed onto the areal data. In the case of linear features, this is achieved by storing the coordinate values of starting and ending points of each line segment.
>
> a. *Linear Feature Characteristics.* The coordinates of the starting and ending points for each line segment will be stored for all types of linear feature data. Other feature-dependent characteristics will also be digitally encoded.
>
> b. *Point Feature Characteristics.* The coordinates of a point location are stored for each point feature. Other feature-dependent characteristics (include items such as bridge load classification and airfield status.)[45]

Several new Army tactical systems with an automatic data processing capability will require terrain information, if they are to be used to their fullest extent. These systems include:

SYSTEM	DESCRIPTION
Tactical Operations System (TOS)	A command and control system that will permit corps and division commanders to assimilate various forms of intelligence data to keep informed about the position of friendly and enemy forces. Those sources will include sensor, photographic, and radar inputs. Digital terrain information will permit the plotting by time and position of the information received from other systems, so that the data can be plotted in relation to the UTM grid system.
Missile Minder	An air defense system in which automation will be used to control firing batteries more effectively. Follow-on improvements to the system will include radar and communications planning functions.
Firefinder	System for locating firing enemy artillery pieces and mortars. Locations of the enemy artillery are determined by computer processing of the projective trajectories by the radar units, which can track multiple projectiles simultaneously. Detected artillery positions are relayed to TACFIRE (a Field Artillery direction system) for counterfire operations.
Patriot	A high-to-medium-altitude air defense system. Mobile, quick reaction, all-weather. Designed to conduct multiple simultaneous engagements against high-performance maneuvering targets and to have a high single-shot kill probability.

As this advanced equipment takes its place in the Army's inventory, a system such as ARTINS will be in demand by Army field forces. While various ETL organizations have been working on technological elements for ARTINS (e.g., much of the more recent work of the Automated Cartography Branch has direct application to ARTINS), progress on the system itself has been slow.

In the mid-1960s, an IBM study recommended the creation of an automated Engineer Terrain Information System as a subsystem of the computerized Tactical Operations System, but further consideration of this automated operation was held in abeyance while the GIANT study was executed. Once work began on creating a Topographic Support System using off-the-shelf equipment, work was also initiated within the Geographic Applications Branch of the Geographic Sciences Division on what was called the Army Terrain Information System, a name that indicated its importance to the entire Army.[46]

ARTINS CHRONOLOGY

YEAR	ACTION	BUDGET
FY 1971 —	ARTINS approved by the Department of the Army (DA). A Small Development Requirement (SDR) to provide new equipment and personnel structure for the Engineer Terrain Detachments (TDs). TDs in Vietnam provided with a listing equipment available to them under the special provisions of the ENSURE program.	$ 23,500
FY 1972 —	Outlined development schedule, made funding estimates and established liaison with Army automatic data processing (ADP) community regarding ARTINS. In response to changing Army procedures for R&D documents the SDR was revised to be a Qualitative Materiel Requirement (QMR) which was later changed to a	$ 4,400

Materiel Need (MN) and still later to a ROC.

FY 1973 — Funding for ARTINS advanced development was received. ARTINS listed as DA Project 862. An ADP General Functional Statements Requirement document for ARTINS was circulated throughout DA. The Combined Arms Combat Developments Activity (CACDA) of TRADOC circulated the ARTINS draft ROC through all DA channels. CACDA official proponent for ARTINS. $ 120,000

FY 1974 — By early 1974 the staffing of the ROC was completed. While it had been approved at all TRADOC levels, Major McAlister, deputy chief of staff, Combat Developments, TRADOC, requested a new survey of users to determine their needs for terrain information so that the automated system could be designed around their requirements. $ 200,000

FY 1975 — ETL began a comprehensive survey which lasted nearly the whole fiscal year. During FY 75 ETL did assist Engineer School in final development of new organization for the topo battalion and did work on design concepts for MGI modules of TSS. Due to absence of an approved ROC, the funds for Project 862 were dropped from the DA R&D program. $ 171,000

FY 1976 and FY 7T* — Another change in DA requirements documentation led to substitution of a Letter of Agreement (LOA) for a ROC. Almost all of this 15-month period involved ETL working with CACDA and the Engineer School on preparation of the LOA. Engineer School replaced CACDA as official proponent of ARTINS. During FY 7T Project 862 (ARTINS) was once again funded. $ 317,000

FY 1977 — The LOA was approved. A conceptual system design study was carried out and work on several aspects of the ARTINS hardware and software was begun. $ 516,000

FY 1978 — Software development began in earnest. Draft Type A Specification for the advanced development system was prepared. Considerable effort was expended on the procurement of a computer system for use in validating concepts and developing techniques and capabilities. $1,200,000

As one 1977 ETL document noted, the Geographic Sciences Laboratory was "involved with efforts to get an automated MGI capability into the field for more than 11 years." For five years, ETL assisted Department of the Army organizations that were sponsoring studies. Of the last six years, FY 1971-1977, ETL spent five years preparing, staffing, and assisting others with requirements documents but only one year actually doing ARTINS system planning. During the six years of direct ETL participation, about 17 man-years and $1,000,000 were expended, "almost all to achieve an approved requirements document."[47]

When the Army Terrain Information System became an approved research and development project, the MGI Systems Group and other branches of the Geographic Sciences Laboratory became involved in the complex world of tactical automated data

*Shift to new FY beginning on 1 October instead of 1 July led to creation of a transition period called FY 7T.

processing. The key to the success of ARTINS will be the extent to which its terrain information can be used to support other tactical systems — TOS, PATRIOT, FIREFINDER, and others. To help ensure such "interoperability," ETL personnel have been working with several of these other project teams and with the Project Manager for Army Tactical Data Systems.[48]

Money to pursue active development of ARTINS in fiscal year 1979 was not allocated by the Department of the Army. In late 1978, ETL personnel were still engaged in basic systems related research and development, but work on hardware for ARTINS field testing will have to wait until the Army community decides how ARTINS fits into other programs, what priority it deserves, and how much money the project should be allocated. When the Army answers these questions, the team at ETL will be ready to apply their technological skills to the preparation of an Army Terrain Information System.

C. New Systems for Surveying and Land Navigation

A new term — point positioning — has gained frequent use among topographers during the past decade. "Point positioning," rather than the more familiar "surveying," indicates yet another technological shift wrought by new instruments created by the Engineer Topographic Laboratories and its contractors. Traditionally, if a person has known where he was in relationship to a basic survey control point, the only way that person could extend his knowledge to unknown points was by laborious cross-country surveys with an optical device (transit, theodolite, etc.) and careful notation of coordinates on a topographic map. Surveying meant either triangulation or trilateration. During the 1950s and early 1960s, a series of increasingly sophisticated electronic instruments was created by ETL's predecessor organizations to speed up the surveying process and to reduce the number of people required to conduct such operations.[49] In time, the collection of data became less and less direct, and less and less like traditional surveying, but the end result was the same. One knew where he was relative to his base control point, but he had located the position of his new point by using new technological approaches to the problem. Since this activity could no longer, strictly speaking, be called surveying, it came to be called point positioning. In discussing point positioning, Carl R. Friberg, Jr., chief of the Surveying and Engineering Division at ETL, described three systems that reflect the new approaches to an old problem: (1) SIAGL,* the lightweight, automatic, electrically damped, pendulous, gyroscopic surveying instrument; (2) the Position and Azimuth Determining System (PADS); and (3) the Analytical Photogrammetric Positioning System (APPS).

1. Surveying Instrument: Azimuth, Gyro, Lightweight (SIAGL)

During the post-World War II period, considerable work was done in the United States on perfecting inertial devices for navigation systems in aircraft and missiles. It was not until 1956, however, that the Engineer Research and Development Laboratory (ERDL) investigated the possibility of using gyroscopic devices for azimuth determination for artillery surveys. Such gyroscopic devices are based on the north-seeking tendency of the gyroscope. German scientists had been studying instruments of this nature as early as 1921 and had demonstrated the feasibility of achieving survey accuracy sufficient for artillery surveying and weapons orientation.

In the late 1950s, the Autonetics Division of North American Aviation (now Rockwell International Corp.) developed and demonstrated a gyroscopic azimuth-determining device called Autonetics Baseline Equipment (ABLE). In June 1958, the Frankford Arsenal of the Ordnance Corps awarded a contract to Autonetics for a military model of this equipment. When the responsibility for the development of all gyroscopic orientation devices except those involved in the Pershing missile was assigned to the Corps of Engineers, the contract for ABLE was

*This unusual acronym is based on the military nomenclature surveying Instrument: Azimuth, Gyro, Lightweight.

transferred to ERDL. The first test equipment was delivered there in November 1958. With only limited engineer tests at Fort Belvoir and limited service testing by the Artillery Board at Fort Sill, Okla., it was determined that ABLE satisfied an urgent requirement for such a device. It was type classified under the title "Surveying Instrument: Azimuth, Gyro, Artillery" in October 1959. This equipment weighed approximately 91 kilograms and gave an accuracy of 30 seconds (1 sigma) at 35° latitude and 1 minute (1 sigma) at 65° latitude. Unfortunately, it was difficult to operate, sensitive to vibration produced by gun fire and vehicular traffic, and had to be sheltered from winds exceeding 8 kilometers per hour to achieve reliable field performance. Because of the instrument's large size and weight, lack of portability, and other operational difficulties experienced in field use, requirements were established for lightweight gyroscopic equipment. Development began in 1960.

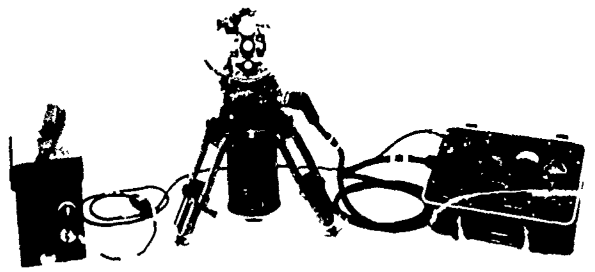
Based on the need for a lightweight device for azimuth determination as a subsystem of the Long Range Survey System, a contract was negotiated with Lear Siegler, Inc., Astronics Division, for the study, design, and fabrication of a prototype model of a Lightweight Gyroscopic Theodolite. The design parameters for this instrument were:

Weight	— 20.4 kilograms w/tripod and case (less power source)
Observing Time	— 20 minutes between 52°C and -17°C 30 minutes between -17°C and -54°C
Warm-up Time	— None
Accuracy	— .212 mil standard deviation Cosine 0 (0 = latitude of operation)
Operating Temperature Range	— 52°C to -54°C
Magnetic Fields	— 3 gauss
Reliability	— 500 hours mean time between failures

The test instrument delivered by the Astronics Division of Lear Siegler in March 1962 consisted of a theodolite mounted on a gyroscopic reference unit, a combined electronic control unit and carrying case , and a tripod. It was powered by internal batteries and weighed 14.23 kilograms. After 20 minutes operation time, it gave azimuth accuracies of 0.38 mil (standard deviation). With favorable engineering tests, the instrument met the requirements for short-range weapons orientation and, on correction of some minor deficiencies, it would be suitable for field use. In June 1963, a fixed-price contract was awarded to Lear Siegler for three engineer/expanded service test models correcting the deficiencies noted in the prototype model tests. One of these instruments was delivered to GIMRADA in August 1964 for compatibility tests with an instrument shelter developed in-house that would permit accurate instrument operation in high winds. In March 1965, two instruments were delivered to Aberdeen Proving Ground, Md., for engineer tests, and one was sent to the Artillery Board at Fort Sill.[51]

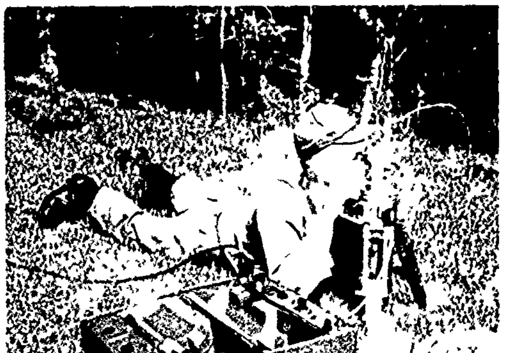
On 25 March 1965, a Qualitative Materiel Requirement document was approved by the Combat Developments Command authorizing testing. Unfortunately, the instruments did not pass all the tests, but the test cycle did demonstrate system suitability for field use. Lear Siegler was awarded a contract in 1966 to correct the problems, but the modifications proved to be unsuccessful. In attempts to improve the units, earlier design provisions were disturbed, which created additional technical problems. While the contractor made numerous changes to overcome the difficulties, the modified instruments failed to meet the requirements at ETL in 1967, and after prolonged periods of testing the ETL engineers recommended a complete overhaul of the test instruments prior to further evaluations. After a delay of more than a year, ETL was directed by the Army Materiel Command in February 1969 to continue development of new myroscopic units. A new contract was awarded to Lear Siegler on 30 June for the fabrication of four models and for complete research and analysis of past problem areas.

Creation of the Surveying Instrument: Azimuth, Gyro, Lightweight (SIAGL) was a major advancement in the surveying instrument field With an instrument that weighed approximately 18 kilograms (excluding batteries) that could be operated by one man under all weather conditions, day or night, very precise surveying accuracy could be maintained. According to Carl Friberg, SIAGL will determine north to an accuracy of .2 mil, or about 40 seconds of arc. This instrument will be used for laying in artillery pieces and for field survey. By early 1978, the first Lear Siegler SIAGL instruments procured by the Mobility Equipment Research and Development Command (MERADCOM) were being issued to Field Artillery units.*[53]



Surveying Instrument: Azimuth, Gyro, Lightweight (SIAGL)

In September 1970, the fabrication phase of the development was completed and acceptance testing started. After a successful high-latitude test at Fort Greeley, Alaska, however, testing was suspended due to excessive equipment failures. While the contractor was working on these problems, ETL recommended that a critical review and update of the materiel requirements be made considering the user's realistic requirements balanced with the performance expected from state-of-the-art gyro equipment to preclude unnecessary damage to the test articles and further delay in development. Acceptance testing resumed in January 1971. Four instruments were delivered in March; three of these went to the Test and Evaluation Command (TECOM), and one was sent to Germany for evaluation by U.S. Army topographic personnel and the Pershing Missile Command. Tests and type classification were accomplished in 1972 after almost 12 years of development.[52]



Using SIAGL.

*Lear Siegler is commercially marketing SIAGL as "Automatic Lightweight Inertial Northseeking Equipment" (ALINE)

2. Position and Azimuth Determining System (PADS)

The Position and Azimuth Determining System (PADS) was developed by applying inertial guidance technology used for many years in aircraft and spacecraft navigation to the land navigation and survey requirements of the Field Artillery. Clarence W. Kitchens, Sr., branch chief in charge of PADS development until his retirement in 1975, has described PADS in the following manner:

> The Positon and Azimuth Determining System is a vehicular mounted, velocity-aided inertial navigational system designed and developed by Litton Systems Guidance and Control Systems Division for the . . . Engineer Topographic Laboratories . . . to meet the Field Artillery survey requirements in the area of tactical weapons location. PADS is designed to extend survey control from a known position to stations/positions throughout an artillery division area where survey control is needed. With the advent of sophisticated surveillance techniques, advanced target acquisition capability, and the ability to air drop artillery teams and equipment, the Field Artillery is, and will continue to be, a highly mobile group. Increased range of artillery weapons further aggravates the surveying problem by placing additional importance on weapon directional orientation as well as positioning. 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 of tactical operation.
>
> PADS is a technological breakthrough and a radical departure from conventional survey techniques. PADS represents a new concept in surveying and navigation systems utilizing proven equipment and techniques. Designed for simple mounting in most Army vehicles, PADS is capable of providing accurate measurement of position, elevation and azimuth, while completing detailed land survey missions in a fraction of the time required by conventional methods. This can be accomplished while the vehicle is moving at a safe road speed over any terrain. The system is completely independent of both weather and visibility restrictions. Once calibrated, PADS functions automatically and continuously computes precise survey data.[54]

The exploratory development of inertial survey equipment by the Corps of Engineers began in 1958, when the responsibility for the development of the Artillery Survey System was transferred to the Engineers from the Ordnance Corps. The requirements at that time called for methods and equipment that would establish in 45 minutes 12 to 14 survey control stations in a division area to an accuracy of 1:3,000 with respect to survey control, together with elevation accuracy to +5 meters and azimuth accuracy to +20 seconds of arc. Of all the approaches investigated, including techniques such as flare triangulation, electronic hyperbolic systems, and simultaneous electronic ranging to an airborne station, only the inertial technique showed genuine potential.

In June 1959 a contract was awarded to General Electric for a study and preliminary design of an inertial system suitable for artillery surveys. The study, completed in three months, concluded that an inertial system employing data correction techniques was theoretically capable of performing the artillery surveys. In January 1960 General Electric was given a contract for the final design and fabrication of prototype equipment.

Initially, the system concept was based upon a traverse closure technique requiring the use of a separate general-purpose computer. Position readout was to have been in terms of geographic coordinates to simplify computer requirements. In July 1960, however, the user requested that the system design be changed to permit data correction en route (open traverse survey) and position readout in Universal Transverse Mercator grid coordinates. This change was incorporated into the system design. The prototype system designed for use in either a ground vehicle or a helicopter was not completed for system test until December 1962. It was tested by General Electric project personnel at Philadelphia and Valley Forge, Pa., and Burlington, Vt., under the supervision of GIMRADA during December 1962 to April 1963. The system was delivered to GIMRADA on 16 April 1963.[55] Tests of the prototype system demonstrated that it was feasible to perform surveys of one-hour duration to an en route accuracy of about 25 meters mean radial distance. The prototype was not suitable for engineering tests, because the computer subsystem was too sensitive to vibration and shock under dynamic conditions.[56]

On 24 April 1963, an in-process review was held to determine the direction of future development effort in the use of inertial techniques for surveying. At this review, GIMRADA was directed to terminate, by 30 June 1963, the task on inertial survey equipment pending the approval of a Qualitative Materiel Requirement by the Combat Developments Command. Work was resumed, however, with the implementation of further studies on the application of inertial techniques to surveying in 1965. These studies finally led to the implementation of the development program for the Position and Azimuth Determining System. On 20 December 1965, a contract was awarded to the Guidance and Control Division, Litton Systems, Inc., to study the application of inertial techniques to surveying. These investigations, aimed at a feasible approach for performing artillery surveys of six hours duration at latitudes as high as 75°, determined that while a pure inertial system would not meet all the goals, a vehicle-mounted system would be feasible with such aids as a laser velocimeter and continuous Kalma filtering using high-grade inertial gyros and accelerometers.[57]

True inertial systems consist of a level, gyroscopically stabilized platform with accelerometers attached that sense and measure motion when non-gravitational forces cause changes in the heading and speed of the vehicle that is transporting the platform. Application of Newton's laws of motion allows integration of the measured accelerations to obtain the vehicles velocity and position. Because they can operate without external references in hostile and remote environments, inertial navigation systems have proven very attractive for military applications.

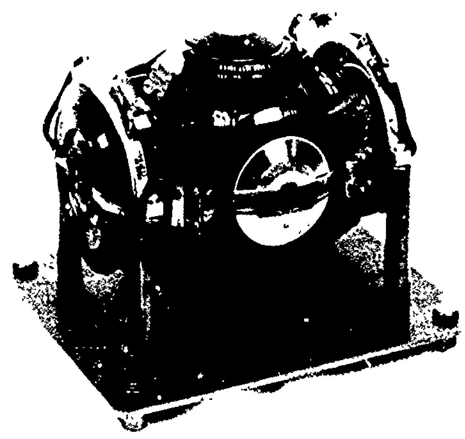
Carl Friberg noted that the inertial platform has accelerometers to measure motion forward-backward, right-left, and up-down. The motions they measure can be converted into x, y, z coordinates indicating movement north-south, east-west, and elevation. Through the computer, these coordinates can be displayed on the vehicle's dashboard. The heart of PADS is a modified version of the U.S. Navy AN/ASH-95 Carrier Aircraft Inertial Navigation System mounted on an M151A2 jeep. "Once you accept what a platform is and what it does," Friberg commented, "it is no different from an aircraft platform. The platform is not modified for land use; only the accompanying systems are adapted for use in a motor vehicle." In an aircraft or on a ship, if you want to update your navigation system, some external navigational system is used to correct any errors that have crept into the platform due to the effects of gravity and other external forces. "Whereas an aircraft cannot be stopped when an update of the inertial platform is required, a jeep can. We then take a look at the accelerometers. Two of them should be reading zero (forward-backward and left-right). The up-down accelerometer will be giving a reading because it is sensing gravity. However, due to platform drift (relative to the surface of the Earth), the other sensors will show some apparent acceleration due to gravity's pull on the drifted platform. This error can be corrected by either actually aligning the platform or compensating for the drift through the computer. This zero velocity update takes about 20 seconds. It is fully automatic. Stop the vehicle. Pull on the hand brake. Wait 20 seconds, and drive off again."[58]

From December 1967 to June 1968 additional studies were made under contract by Litton Systems to establish a higher level of confidence in the feasibility and practicability of the land configuration of the Position and Azimuth Determining System through inertial instrument testing, systems simulation, and laser velocimeter analysis and tests. The final technical report submitted by Litton Systems in December 1968 established the fundamental conclusion that PADS, as initially conceived, provided a practicable survey system that could meet the field artillery survey requirements. The Army recommended that an experimental prototype model of the vehicle-mounted PADS be designed, built, and tested in consonance with the conclusions of the study.[59] Supplementary studies conducted by Litton Systems during 1969 helped to select the better of two proposed configurations.[60]

The basic system proposed as a result of these studies included an inertial platform to provide the coordinate reference frame and measure vehicle acceleration. A laser velocimeter was to find the inertial velocity error and provide vertical velocity measurement. Calculations to determine present position and azimuth from the measured data given by the inertial platform and the laser velocimeter were to be performed in the computer, which would also update the system parameters during the mission by Kalman filtering techniques. The azimuth transfer device was to be a conventional theodolite affixed to the inertial platform.*

A requirements document for a Position and Azimuth Determining System was approved on 21 January 1969. ETL awarded a contract to Litton Systems on 3 February 1971 for the development and fabrication of a prototype system. The prototype PADS was designed to operate in a free inertial mode with the option of using two different types of velocity aids — laser velocimeter and odometer, or periodic velocity stops to define the navigation errors. The system components consisted of a modified carrier aircraft inertial navigation system (CAINS), AN/ASN-92, with an inertial measurement unit (IMU), a data processing unit (DPU), a control and display unit (CDU), and a power supply unit (PSU). A theodolite was added to permit azimuth transfer. These elements form the heart of the system and once initialized, provide a precise measurement of distance traveled, maintain a locally level, north-pointing coordinates reference, and display present position in Universal Transverse Mercator coordinates, elevation in meters, and azimuth in mils to the operator whenever the vehicle is stopped. These functions are accomplished using a sophisticated computer program that provides accurate navigation and survey data. By determining the remaining inertial draft errors with precise velocity reference information, Litton was able to take the giant step from an aircraft navigator operating with a kilometer-per-hour error to a land surveyor operating with a meter-per-hour error. The precise velocities are obtained in three ways: (1) an extremely accurate zero-velocity reference accomplished by bringing the vehicle to a complete stop, (2) a laser velocimeter, and (3) a precise odometer unit measuring distance traveled in short periods of time.

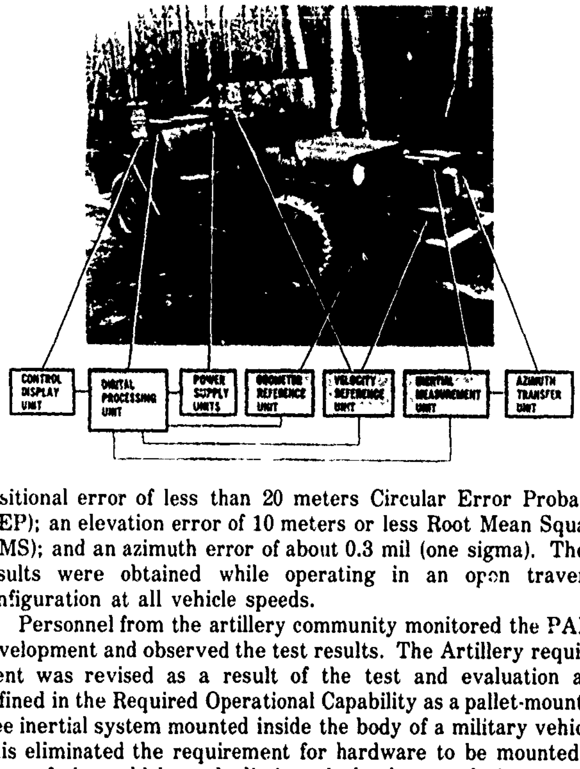
PADS design allows virtually everything to be accomplished by the computer. The operator sets the system mode switch to "calibrate" and enters the initial survey parameters. The system stores this information and automatically performs a one-hour self-alignment and calibration routine without operator intervention. When the system indicates that calibration is complete, the operator sets the system mode switch to "navigate" and drives to the initial survey control point, where he inserts the coordinates



Heart of the Position and Azimuth Determining System (PADS), the inertial measurement unit (IMU).

*When an azimuth reference is desired, it is obtained by using a theodolite and suitable target. The theodolite is set up over the survey point, leveled, and the distance from the porro prism to the theodolite and the horizontal angle between the azimuth reference and the porro prism measured and entered into the computer through the unit keyboard. The computer automaticaly calculates and displays the azimuth angle of the reference from true north.

ARMY'S PROTOTYPE
POSITION AND AZIMUTH DETERMINING SYSTEM



and elevation directly through the control and display unit. The azimuth determined by self-alignment can be used directly and is already in the computer, or it can be transferred in optically using a theodolite and porro prism mounted adjacent to and aligned with the azimuth gyro in the inertial measuring unit. The horizontal angle between the azimuth reference marker and the porro prism and the distance between the theodolite and porro prism are entered through the control and display unit keyboard. The computer automatically adjusts the inertial system to remove any gyrocompassing error. This complete azimuth update requires 10 to 12 minutes including setup time.

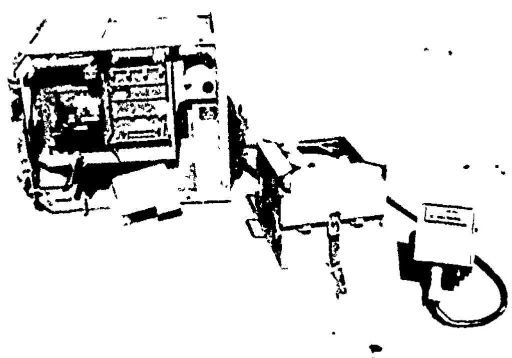
The system is now ready to survey. The driver can operate the vehicle at any safe speed, over any terrain, day or night. His only requirement is to stop (zero-velocity update) for approximately 20 seconds, whenever he sees a yellow warning light on the remote indicator or hears a warning buzzer. When he stops the vehicle, the computer automatically updates system errors. Frequency of stops can be every 10 minutes, if no velocity aids are used, or as long as one hour if the laser velocimeter is providing velocity information.

Field tests on the prototype PADS were conducted successfully by the contractor and observed by ETL between 22 August and 25 November 1972 in California. Engineer design tests were performed by ETL between 5 January and 15 August 1973. Five test courses exhibiting various terrain and road conditions were used to field test PADS in Northern Virginia. Upon completion of these field trials, the system was shipped to Hampton, Iowa, for testing over straight north-to-south and east-to-west test courses exhibiting large gravity anomalies and deflections. This test was necessary to determine whether large variations in gravity significantly affect positional accuracies. The test program demonstrated the feasibility and practicability of PADS for rapidly and accurately establishing and extending survey control to new positions. Large gravity anomalies did not degrade test results. Distance traveled during both series of tests varies from 48 to 421 kilometers during a six-hour survey mission; the elevation changes varied by approximately 500 meters. The overall accuracy obtained from extensive testing showed that the system could accomplish a six-hour survey mission with a positional error of less than 20 meters Circular Error Probable (CEP); an elevation error of 10 meters or less Root Mean Square (RMS); and an azimuth error of about 0.3 mil (one sigma). These results were obtained while operating in an open traverse configuration at all vehicle speeds.

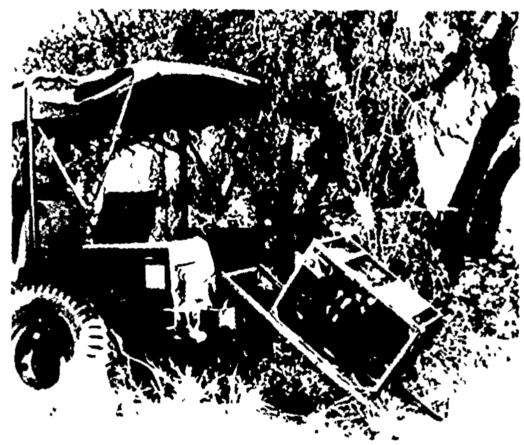
Personnel from the artillery community monitored the PADS development and observed the test results. The Artillery requirement was revised as a result of the test and evaluation and defined in the Required Operational Capability as a pallet-mounted free inertial system mounted inside the body of a military vehicle. This eliminated the requirement for hardware to be mounted in front of the vehicle and eliminated the laser velocimeter and odometer reference unit from the system. The mission period was relaxed to the time it takes to complete a 48-km survey with known survey control data available at the starting point or at both the starting and terminal points. The latter condition allows survey data adjustment throughout the mission, resulting in greater overall accuracy. The accuracies required during this survey are now 10-20 meters CEP in horizontal position; 5-10 meters RMS in elevation; and 0.3-1.0 mil (one sigma) in azimuth.

Flight testing of PADS aboard a CH-47 helicopter was conducted at the Naval Air Station, Lakehurst, N.J. on 24 July 1973. The vehicle mounted system was secured aboard the helicopter and operating from battery power performed a series of six 10-minute flights with the helicopter landing after each flight for a one-minute zero velocity update. A second series of flights was also performed to determine the feasibility of hovering the helicoper to obtain zero velocity updates. Additional helicopter testing of the PADS was performed at Fort Sill, Okla., during the first week of September 1973. These tests demonstrated the feasibility of operating the PADS in an aircraft.

In September 1973 ETL returned the Position and Azimuth Determining System to Litton Systems, so that the desired design changes could be made. Two variations of a new PADS were evolved. For the artillery, a palletized version of PADS was created that could be mounted in any M151A2 jeep or the light observation helicopter (OH-58A). This change in design permits the system to be used more flexibly, and it reduces the identifiability of a PADS jeep. Since the initial cost of these systems will be about $160,000 each for an initial lot of 125, the Army wanted to avoid easy detection and destruction of the PADS.[61]



PADS equipment.

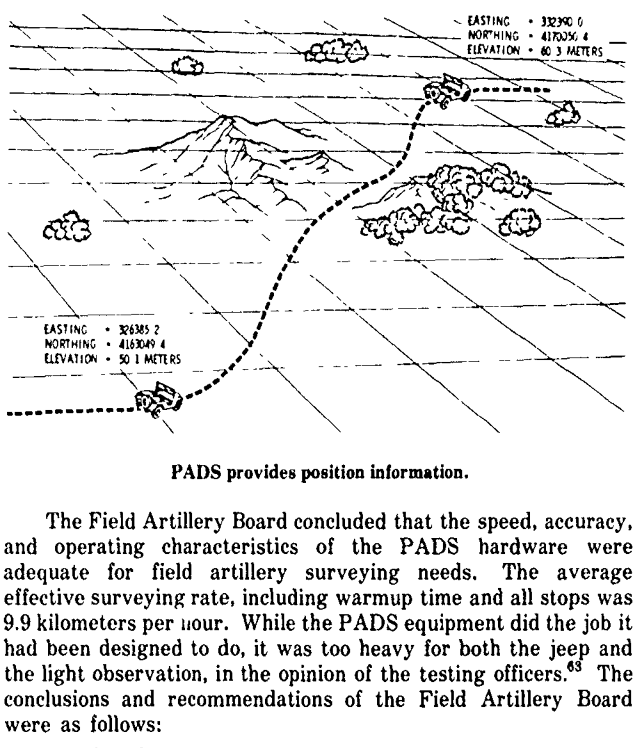


PADS CHRONOLOGY

24 September 1973	U.S. Army Training and Doctrine Command (TRADOC) submitted a proposed required operational capability (ROC) for PADS.
14 January 1974	ROC approved by the Department of the Army (DA).
15 February 1974	TRADOC provided U.S. Army Field Artillery School (USAFAS) with the PADS ROC.

10 March 1974	U.S. Army Mobility Equipment Research and Development Center provided the U.S. Army Troop Support Command (TROSCOM) with the provisional qualitative and quantitative personnel requirements information for PADS.
25 September 1974	PADS concept formulation in-process review (IPR) completed by correspondence with the recommendation that the project enter full-scale development phase.
4 October 1974	IPR recommendations approved by Acting Commander, TROSCOM.
17 June 1975	Contract DAAG53-75-C-0200 awarded to Litton Systems, Inc., for design, fabrication, and testing of five engineering development prototypes, support equipment, and documentation.
28 May 1976	Headquarters, TRADOC, directed the U.S. Army Field Artillery Board (USAFABD) to conduct an operational test (OT) of PADS.[62]

After nearly a year of preparation, the Army Field Artillery Board conducted the Operational Test II of the PADS hardware at Fort Sill between April and August 1977. The system was tested in both the ground and air-mobile modes of operation using two-man survey parties organized in accordance with the table of organization and equipment for a headquarters battery of an armored/mechanized infantry division direct support field artillery battalion. These survey parties used the test items to determine positions for firing batteries, countermortar radar, and target area survey control points. A typical mission involved determining the Universal Transverse Mercator coordinates, altitude, and grid azimuth of six points. The system was transported either in a jeep, a light observation helicopter, or a cargo helicopter with the jeep inside. During each mission, the test PADS traveled about 30-40 kilometers; for jeep-mounted missions, about 47 percent of this distance was over secondary roads, about 32 percent cross-country, and about 21 percent on primary roads. The total mission duration ranged from 2.5 to 6.8 hours. A total of 105 missions was conducted. All light observation helicopter missions were flown on one course. The truck and truck-cargo helicopter missions were run on 30 different courses.



PADS provides position information.

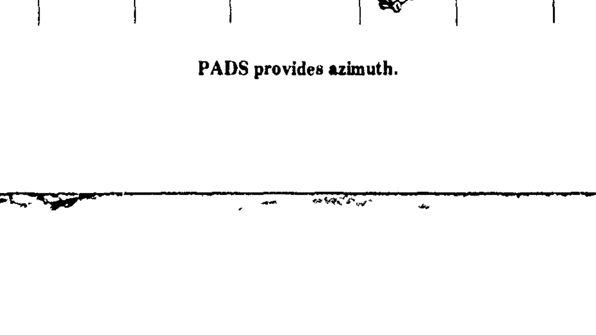
The Field Artillery Board concluded that the speed, accuracy, and operating characteristics of the PADS hardware were adequate for field artillery surveying needs. The average effective surveying rate, including warmup time and all stops was 9.9 kilometers per hour. While the PADS equipment did the job it had been designed to do, it was too heavy for both the jeep and the light observation, in the opinion of the testing officers.[63] The conclusions and recommendations of the Field Artillery Board were as follows:

> CONCLUSIONS: The Position and Azimuth Determining System (PADS), AN/USQ-70 merits continued development.

a. Its accuracy, except for azimuth transfers when mounted in the light observation helicopter, meets the needs of the field artillery. Its speed reduces the time required for a survey mission by 84 percent of that required by a conventional field artillery survey party while using only one-third the manpower.

b. The problems of PADS are primarily in the area of reliability and maintainability. Many of the causes of failure should be easily remedied; for example, water leakage, vertical accelerometer failure, and azimuth errors. Improved manuals and revision of the integrated logistics support system should allow PADS to meet its maintainability criteria.

c. Over a large number of samples, human error is virtually constant, but the human-machine interaction can be modified to yield a system less vulnerable to human error. The use of the theodolite in either the distant aiming point or known close point methods of azimuth transfer exposes the system to operator error, while the use of the two position method of transferring azimuths will virtually eliminate the human error factor from mission reliability.



PADS provides azimuth.

d. The mobility of PADS is reduced by the survey party being authorized more equipment than an M151 truck [jeep] can carry.

e. The overweight condition of the primary and battery pallets is a serious matter and can lead to personnel injury and vehicle damage. An extra man is needed to lift the primary pallet, but for no other reason. Lifting is an infrequent requirement and the parent organization can detail a man to assist the crew during loading and unloading of the primary pallet. The battery pallet's handles can be modified to allow a four-hand lift. The M151 truck is overloaded by the system, but the truck can be fitted with an overload kit which will increase its cross country load limit.

4. RECOMMENDATIONS:

a. That the PADS be continued in development and returned for retest.

b. That the shortcomings be corrected and, along with the suggested improvements, be incorporated into the PADS design.

c. That the operator be required to transfer azimuths by the two position azimuth transfer method.

d. That the survey party be authorized a trailer to carry authorized equipment.

e. That the draft equipment publications be revised to show that three men are needed to lift the primary pallet.

f. That the battery pallet be fitted with handles that will allow both crew members to use two hands when lifting the pallet.

g. That the PADS vehicle be an M151A2 truck equipped with overload springs.[64]

Based upon these Field Artillery Board test results and recommendations, the ETL team returned the PADS equipment to Litton Systems for modification. The improved hardware was delivered to ETL by the contractor early in 1978. An Operational Test IIA was conducted by the Field Artillery Board between

March and July. At the same time, Aberdeen Proving Ground completed the Development Test II that was suspended in the summer of 1977. Based upon the results of these evaluations, an in-process review will be held to make recommendatons concerning the type classification of PADS as a standard item.[65]

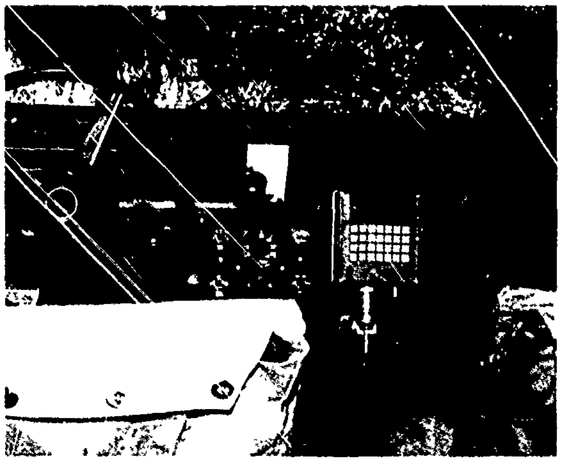
The Defense Mapping Agency also examined PADS to determine whether the inertial survey system could be adapted to its needs. ETL awarded a contract to Litton on 1 March 1974 to procure one Inertial Positioning System (IPS) for DMA to use in its field survey mission. IPS consist of the basic PADS components rack-mounted in a four-wheel-drive truck. The system operates in the free inertial mode with five-minute travel periods followed by 20-second stops for zero-velocity updates. The survey requirement is to start and terminate at survey control points where position, elevation, and azimuth data are available and the maximum distance is 30 miles. The accuracies required by this system are 5 meters CEP in horizontal position; 2.0 meters (one sigma) in elevation; and 20 arc seconds (one sigma) in azimuth.

Operator uses theodolite to measure starting azimuth which will be entered into PADS computer memory.

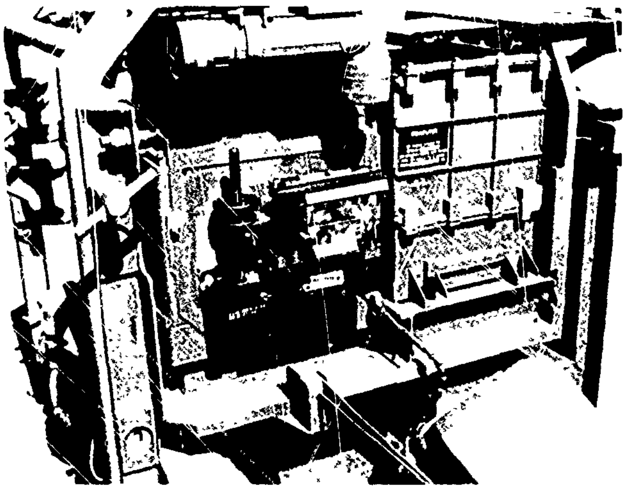
Operator leveling porro prism.

Litton markets a commercial version of IPS under the trade name Auto-Surveyor. IPS and Auto-Surveyor were used in field surveys in the Portland, Ore., and Huntington, W. Va., Army engineer districts during 1976-1978. Results were excellent. District surveyors found that they needed to modify some of their traditional surveying techniques to make full use of this faster technology. As one surveyor phrased it, "At this stage we still don't know everything it can do, but one thing is certain, we're trading in our buggy whips."[66]

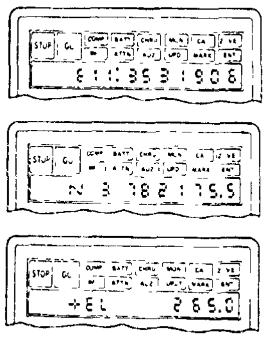
ETL obtained its own inertial survey system early in 1978. While its hardware and capabilities are basically the same as the IPS, a newer computer program, the Rapid Geodetic Survey System (RGSS), will permit ETL Research Institute personnel to measure the total geodetic environment on the ground, for example, three-dimensional positions, free air gravity anomalies, and gravity deflections of the vertical. It is anticipated that research with the RGSS will produce data that will benefit both the cartographers at DMA and the surveyors at the Corps of Engineers.[67]



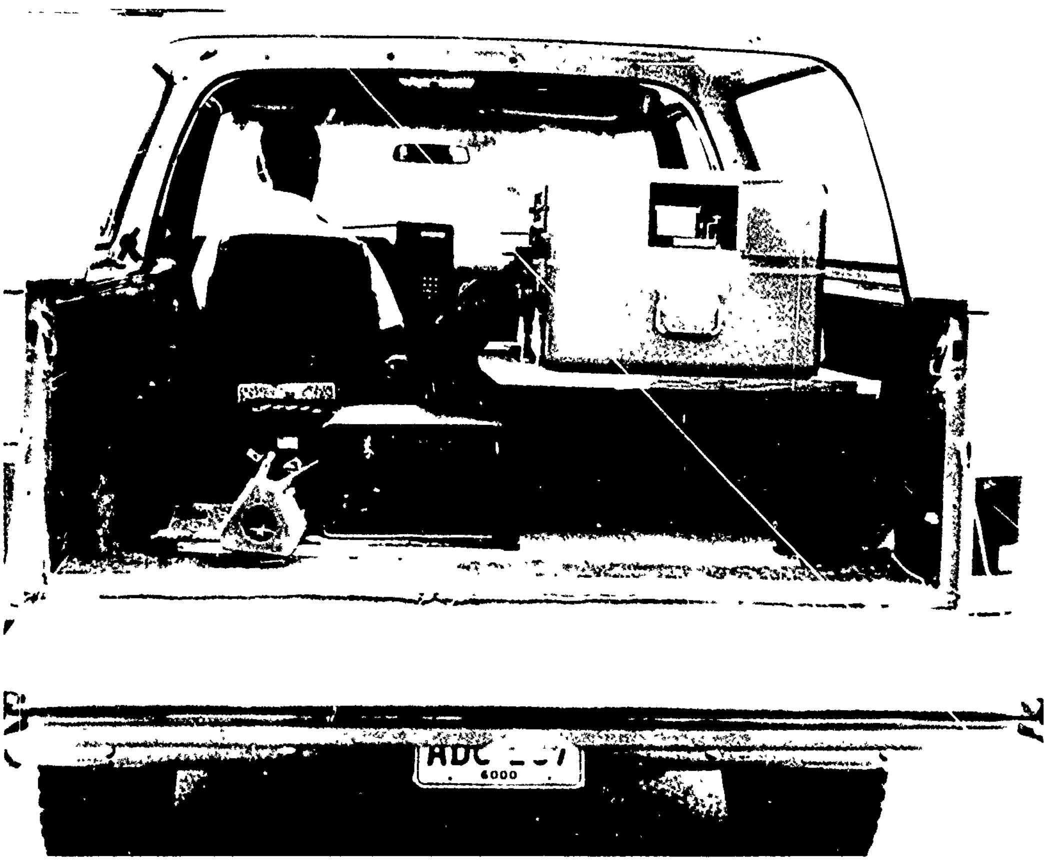
Control Display Unit mounted on dashboard of M151A2 jeep.



Close-up of PADS primary pallet. Inertial measurement unit on left, 32,000-word computer on right.



Example readout on Control Display Unit. Top display reads UTM Zone 11, East 353190.6. Middle display reads North 3782175.5. Bottom reads Elevation 265 meters.



Truck-mounted Inertial Positioning System (IPS), commercially marketed by Litton Industries as the Auto-Surveyor.

3. Analytical Photogrammetric Positioning System (APPS)

Development of the Analytical Photogrammetric Positioning System (APPS) is a research and development success story of which the ETL team is justly proud. As with PADS, many research and development projects take years to mature. Technological and organizational problems must be overcome, before a new or improved piece of equipment is introduced to the field. APPS was a happy exception to this rule. ETL engineers, led by Franklin R. Norvelle, were able to build upon existing knowledge and produce a required system in twenty months.

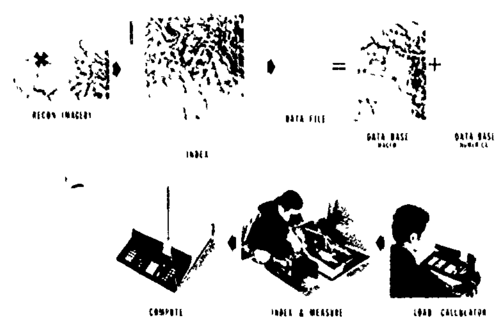
The problem addressed in the creation of APPS was the same as that posed for the other similar systems. John G. Armistead of the ETL Surveying and Engineering Division described the problem in a report.

> Basically, the Field Army needs detailed knowledge of the terrain throughout the battlefield area, plus the location of all friendly and enemy units with an accuracy of 20 meters or better in horizontal and vertical coordinates. The Army needs this information in near real time, day or night, and in all kinds of weather and terrain. The equipment must not require highly skilled operators and must be rugged enough to withstand transport and normal field use. Historically, these needs have been met by the use of line maps and by conventional survey operations. Line maps, however, often do not show enough terrain or culture detail to enable the user to locate a point with the required accuracy, and conventional survey operations are often too slow and weather-dependent.
>
> Photogrammetry provides an approach which overcomes some of these limitations if the equipment can be made rugged enough and simple enough for field use. For example, the photographs used in photogrammetry provide compact storage of a great mass of terrain and cultural information not available in line maps. Obviously, these photographs can be prepared much faster and cheaper than line maps. Photogrammetric techniques enable the determination of horizontal and vertical coordinates with greater accuracy than line maps and, of vital importance, provide the ability to determine the coordinates of points that would be difficult or impossible to determine by conventional surveys because of terrain, enemy action, or weather conditions. It should be understood, however, that the present concept for use of photogrammetry is to complement, rather than replace, line maps or conventional surveys. Perhaps some replacement will occur after the users gain more experience and confidence in the use of photogrammetric equipment and techniques in the field.[68]

Development of APPS actually began in 1968, when ETL engineers started investigating the feasibility of using photogrammetric techniques in military survey and mapping operations. The inital attempt to exploit photogrammetry involved an analog photogrammetric approach (rather than an analytical approach) which was based upon the use of a three-projector stereoplotter than generated an optical, three-dimensional stereomodel of the terrain. An electronic measuring device was used in conjunction with a mini-computer to provide faster, more accurate determinations of position and elevation.

A system based upon this concept called the Photogrammetric Facility (PF) was procured by ETL in 1970. Although the PF provided the necessary information and demonstrated the feasibility of the concept, the equipment was not suited for the field, because it was too large, too heavy, and required too much time and skill to operate. The Lance Missile Program Office personnel were also looking for a reasonably simple, rugged piece of equipment that could help them locate the position of targets for this tactical missile system. To answer both groups' needs, an analytical concept was developed during the summer and fall of 1971 to provide the simplest possible operation by relatively unskilled military personnel in the field. Six prototype Photogrammetric Positioning Systems were fabricated in-house by ETL in 1972-1973. Four of these systems were delivered to DMA, the Navy, and to engineer troops for evaluation. Two systems were subjected to Military Potential Tests at Fort Huachuca, Ariz., in 1972. APPS passes these tests with one deficiency, which was corrected, and the system was type classified awarded for 12 systems, which were delivered and deployed in September and October 1973.

APPS consists of two main components: a data base previously prepared by the DMA Topographic Center, and off-the-shelf hardware that has been modified and integrated by ETL to form a complete system. Looking at these components in more detail, a fairly typical data base would contain four items — approximately 100 cartographic photos, previously measured and marked by the Topographic Center; a photomosaic covering the general area of interest; numerical data for each photo stored on a magnetic tape cassette, including photo identification number, camera position, elevation, and orientation at the time of exposure, camera calibration, and refraction; and the data base handbook with a general description of the data base plus any special information or procedures required for the operator. The tape cassette also stores a program for the calculator so that it can perform all data reduction and printouts, a capability developed at ETL.



Major elements of Analytical Photogrammetric Positioning System (APPS).

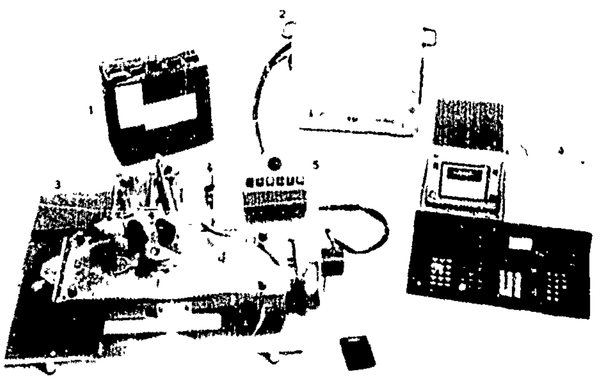
The photographs used in APPS are 229 x 229-mm. prints, each of which covers an area approximately 24 x 24 kilometers at a scale of 1:100,000. The test photography covered a total area of 80 x 210 kilometers over the White Sands Missile Range. The photos were measured by the Topographic Center using conventional photogrammetric triangulation and block adjustment techniques. All photo control and pass-point measurements were made with Mann monocomparators, and all data reduction was performed with the MUSAT III computer program developed by ETL. Six circles on each photo designate index points whose photo coordinates are known and are stored on the tape cassette. Multiple symbols designate checkpoints whose geographic coordinates are also known; these checkpoints provide a self-checking capability t verify that the equipment is operating property.

The second main component of APPS is the hardware, which consists of three off-the-shelf items plus an interface unit developed by ETL. The off-the-shelf items are a Hewlett-Packard 9810A calculator with tape cassette memory unit, a Bendix Datagrid, and a Zeimm Stereotope. The 9810A is a programmable calculator, which uses the program stored on the tape cassette to control the sequence of operation and to perform all data processing and printouts. The entire memory capacity of the calculator is used for the APPS program and data reduction.

The Stereotope was originally designed for map compilation but is used in APPS primarily as a stereoviewer. ETL modified the Stereotope somewhat by mounting a shaft angle encoder on the right-hand end of the Stereotope photocarriage and connecting it to the X-parallax mechanism. The encoder automatically transmits X-parallax data through the interface unit to the calculator for computation of elevation. The Stereotope baseplate is located on the Datagrid cursor, which is mounted on the Stereotope photocarriage. All X, Y movements of the carriage are continuously detected and measured by the Datagrid, and signals from the Datagrid are also automatically fed through the interface to the calculator.

The interface unit was developed by ETL to help the calculator, Datagrid, and shaft angle encoder interact as a system.

The operator controls the system through the control console and the calculator keyboard. APPS weighs 109 kilograms and is transported in three cases that weigh an additional 109 kilograms. The system can be set up on top of a standard size desk.



APPS Components

1. data base 2. interface unit 3. mensuration unit 4. computation unit 5. operator control unit.

A typical APPS operation proceeds as follows:

a. A target or other point of interest is identified or marked on reconnaissance photos or other stimulus material such as infrared and side-looking radar images.

b. The area of immediate interest in the stimulus material is visually located on the photomoasic of the entire area covered by the data base. Reference numbers on the mosaic identify the photos which provide stereo coverage of the area of immediate interest.

c. The operator obtains the desired photos from the data base file and mounts them on the Stereotope photocarriage. The orientation of the photos on the carriage need not be precise. The target is identified on the photos by visual comparison with the stimulus material.

d. The operator pushes keys on the calculator keyboard to load the program from the tape cassette into the calculator. This requires less than 30 seconds and need not be repeated unless the system is shut down.

e. The operator then moves the photocarriage over against mechanical stops on the left hand side of the Stereotope baseplate and pushes a button to signal the calculator to read the X, Y measurements from the Datagrid. This establishes in the calculator the origin or point of reference for the system. The identification number for the stereo pair is now entered in the calculator keyboard by the operator. The calculator automatically locates the data stored on the tape cassette for that stereo pair and loads the data into the calculator memory.

Army specialist using the APPS.

f. The operator views the left photo monoscopically with the Stereotope, centers over an index point, and signals the calculator to read the X, Y measurements from the Datagrid. This is repeated for each of four index points on the left photo plus four index points on the right photo. The calculator computes a transformation that converts Datagrid measurements into photo coordinates.

g. As previously indicated, the system is designed to be self-checking. Viewing both photos through the Stereotope, the operator centers over a checkpoint while adjusting the X-parallax and Y-parallax controls to obtain the necessary stereoscopic relationship between the photos and signals the calculator to read the X, Y measurements from the Datagrid plus the Z (elevation) measurement from the shaft angle encoder. The calculator then uses the data from the tape cassette and the X, Y, Z measurements to solve for the position and elevation of the checkpoint. The calculator automatically compares the computed values with the known values for the checkpoint. If these values agree within 10 meters, the self-check is satisfactory and the calculator signals the operator to continue. If the difference is more than 10 meters, the program automatically goes back to the previous step and the operator repeats the index point measurements. If the difference is still excessive, the equipment is probably malfunctioning.

h. Assuming normal operation, the operator can now determine the position and elevation of any point in the area of overlap between the two photos. To determine the coordinates of the target point previously identified from stimulus materials, the operator enters the assigned identification number for the point in the keyboard, views both photos through the Stereotope, and centers over the point while adjusting the X-parallax and Y-parallax controls. The operator then signals the calculator and within 10 seconds, the UTM coordinates and elevation in meters are printed out automatically together with the point identification number and UTM zone number. If the point lies within 50 km of the edge of a UTM zone, the coordinates for both UTM zones are printed out. These data may be stored on the tape cassette or may be transmitted via teletypewriter to the user. The whole operational procedure can be completed in less than 5 minutes.[69]

The APPS equipment can be unpacked, set up, and checked for proper operation and the first position determined in less than 15 minutes. The system costs approximately $50,000 complete with organizational spares and transport cases. The White Sands Missile Range data base cost approximately $1,000 per stereo model and required approximately four months to prepare, after the photography was obtained. Once established, the data base should be usable for five to ten years before major updating is required. Copies of a data base cost approximately $70 per stereomodel. Tests of the system run by ETL and the Defense Mapping Agency have demonstrated that it provides point positioning accuracy comparable to conventional ground surveys.

APPS has several uses. In the fall of 1978, the U.S. Army Field Artillery Board completed the second phase of the operational testing of the Photolocator System. When fielded, this system will be used by the division artillery survey platoon headquarters to generate survey control points where stereo photographic data exist. Housed in a shelter mounted on a 2.5-ton truck, the Photolocator System consists of several ancillary pieces of hardware that support the APPS. The editor of *Field Artillery Journal* in reporting on this new equipment commented: "The Photolocator System should provide immediate and accurate starting survey control for division survey operations in virtually any location in the world where tactical forces deploy."

In addition to use by the Field Artillery, the U.S. Army plans to use APPS in the Topographic Support System (TSS) as a means for determining the position and elevation of friendly units and enemy targets. The Navy evaluated APPS for use in airstrike exercises, and APPS-determined coordinates for offset aiming points and targets were compared with coordinates determined from maps and hydrographic charts. The bombing accuracy, or miss distance, for aiming points and targets was approximately 150 meters, when map coordinates were used as compared to miss distances of less tha 50 meters when APPS coordinates were used. In one case, the chart coordinates for a target differed from APPS coordinates by 2,600 meters. The miss distance was 600 meters when chart coordinates were used and about 50 meters with APPS coordinates. The target, an anchored ship, had evidently been moved after the charts were made — demonstrating the potential use of APPS to check map and chart accuracy. The Navy, after additional tests with APPS on an aircraft carrier as an aid for planning and conducting air strikes against land targets, decided to procure additional APPS for all aircraft carriers.

The DMA Aerospace Center has evaluated the system's ability to provide coordinates for targets and other points for Air Force weapon systems. The evalution report indicated that APPS provided very satisfactory performance, and the Air Force has procured additional APPS to support its missions. The Defense Mapping School and the Corps of Engineers are also evaluating the use of APPS to establish survey control by locating landmarks (such as crossroads) that can be found and occupied by survey personnel in the field. These APPS-determined points could be used as survey control points from which short local surveys could be run to a nearby artillery battery or other user. The Defense Mapping School plans to use a large-scale base (approximately 1:10,000) to establish ground control accuracy to one or two meters, which would hopefully be sufficient for preliminary construction and engineer topographic surveys. In several instances, APPS has uncovered errors in conventional surveys — demonstrating the potential for using APPS to check survey field work. ETL is continuing efforts to further develop APPS to give it more accuracy and greater flexibility.[70]

IV

A LOOK INTO THE FUTURE

Early in 1979, Colonel Daniel L. Lycan, Commander and Director of the Engineer Topographic Laboratories since mid-September, discussed current and future activities at the Laboratories:

> Looking forward to the next decade, I am certain that the rapid technological changes seen during the past ten years will continue. While this makes it difficult for us to predict the exact shape and form of the U.S. Army in the future, I am confident that the talented personnel who have created ETL's research and technology base will answer any challenge which the Corps of Engineers may be called upon to meet in the areas of topographic and geodetic systems. We have built a team in the spirit of the Corps motto — *Essayons* — "Let us try." We are not only willing to try new technological ideas in meeting the requirements of the U.S. Army, but we have proven that we can make sophisticated technological systems work for our customers.

A few examples will provide the reader with a better understanding of projects currently underway at ETL. There are three major areas of work at ETL: (1) geodesy and point positioning, (2) mapping, and (3) military geographic information.

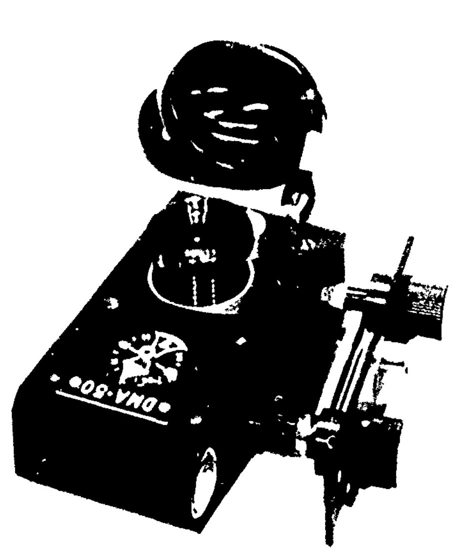
Specialists at ETL exploring low-cost land navigation and positioning equipment for combat vehicles. Building upon the knowledge gained with inertial navigation systems such as PADS, IPS, and RGSS, ETL has begun to address a need discovered after the 1973 war in the Middle East. Soviet armored fighting vehicles in that conflict had a navigational capability beyond that in American tanks. The Forward Area Survey Equipment (FASE) project was one of the first steps taken to meet this need. The goal of this project is to provide a vehicle positioning system for a unit cost of less than $20,000. In Fiscal Year 1977, contracts were awarded for two competing approaches to the development of such a system, with evaluation and tests scheduled for 1978.

The Army Program Manager for Navigation and Control Systems assigned ETL lead lab responsibility for the Combat Vehicle Heading Reference System with the task of developing "a simple, low-cost heading reference system for combat vehicles." Such a device would allow tanks to maneuver in a closed-hatch mode and during periods of poor visibility. One of the more immediately applicable systems includes a magnetic compass on the outside of the tank for update, a readout device for the driver, a directional gyro heading reference unit, and a readout device for the tank commander.

The Miniaturized Gyrocompass represents another application of gyro technology. ETL engineers are attempting to reduce the size of the north-seeking gyroscope. Field Artillery forward observers require a low-cost, lightweight, quick-reaction instrument for azimuth determination without dependence on magnetism. A feasibility model of the Miniaturized Gyrocompass was delivered FY 1978.

In another battlefield-related system, ETL specialists are examining the feasibility of joining the Analytical Photogrammetric Positioning System with reconnaissance systems, such as the remotely piloted vehicles and artillery-launched TV systems. This new project, the Near-Real-Time Exploitation Facility, is concerned with the exploitation of battlefield imagery obtained from remotely piloted vehicles. These radio-controlled big brothers of model airplanes can carry a TV camera that will transmit "live" images of the battlefield to the exploitation facility. There the picture appears on a TV screen. The interpreter identifies a target, and the picture is transferred to another TV screen mounted above an Analytical Photogrammetric Positioning System. With this system, the operator transfers the target into the data base and, following prescribed procedures, obtains the target position in about three minutes to an accuracy of 20 meters. This equipment has been installed in a van, and ETL engineers are continuing to examine its capabilities.

ETL is also working with an Escape and Evasion Viewer, which was designed for use by Strategic Air Command pilots or personnel sent on long range intrusion missions. This piece of equipment will contain microfilm of all the maps a pilot would have to carry if downed in enemy territory. The light-tight viewer is so designed that its internal illumination will not leak out to disclose the pilot's position at night. A similar device is currently being developed for Army application.



Hand-held Escape and Evasion Viewer

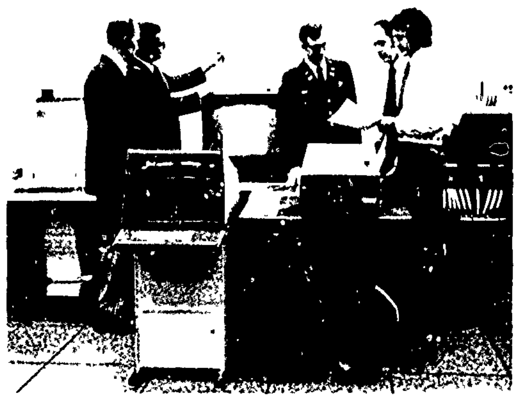
Also in the point positioning area of research at ETL, there is the Pershing II project. The Pershing II is a "smart missile" with a terminal guidance system for homing on pre selected targets. This is accomplished by the correlation of previously prepared computer-generated reference scenes of the target area with the actual radar imagery produced by the onboard forward looking radar. ETL's responsibilities include (1) developing equipment for producing reference scenes for targets of opportunity in the field, (2) defining the data base from which these scenes can be constructed, and (3) developing hardware for DMA to produce reference scenes for the pre-selected targets.

In the field of new mapping products and processes, the people at ETL are still working to further reduce the costs of producing maps. A major activity in this area is the automation of the extraction of map features from remote sensor information. Success in this enterprise would eventually speed the classification and portrayal of these features. This is still a slow manual task. Research concerned with speeding up feature extraction is being conducted on ETL's Digital Image Analysis Laboratory (DIAL) computers. One of DIAL's subsystems is the STARAN Parallel Processor, which performs mathematical operations in parallel rather than in sequence, significantly speeding up processing. DIAL's Real-Time Image Processing Station consists of a mini-computer, a command terminal, and display devices.

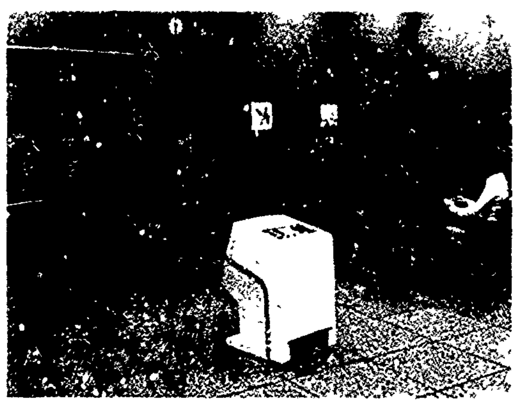
ETL's Research Institute is involved with the field of coherent optics. In an effort to automate the map compilation process more fully, the Institute has worked for a number of years to determine how successfully terrain features could be automatically recognized using hybrid coherent optical digital systems. One result of the specialists' research is the Recording Optical Spectrum Analyzer (ROSA), which uses a laser beam to analyze images. One application of this concept is in rapid assessment of large volumes of aerial photographs to delineate cloud cover and predict image quality. Work in this field will improve utilization of the vast aerial photo inventory.

The third aspect of ETL's program is military geographic information. While almost all work done at ETL has impact in this area, the Geographic Sciences Laboratory is specifically responsible for developing techniques for collecting, storing, and displaying geographic information which is needed for military operations. Besides the Topographic Support System (TSS) and Army Terrain Information System described in Chapter III, the lab has recently begun to compile a set of manuals for use by terrain analysts in the classroom and in the field.

One lesson of the 1973 Middle East War was that the U.S. Army had very limited capabilities for production of terrain



Pershing II Team, A. H. Faulds, C. E. Berndsen, T. Cooney, R. E. Saxe, and D. J. Skala.



Janet Vandecar operates display console for DIAL system.

information. The Defense Intelligence Agency could not help solve this problem due to personnel cuts, so the Chief of Engineers got the mission. The result was the formation in 1975 of the Terrain Analysis Center (TAC), an operational rather than R&D element of ETL. The co-location of this center with the research elements of ETL is designed to facilitate close interaction between the user and developer. Terrain analyses are performed by TAC in response to worldwide requirements of a broad range of Army elements. The terrain analysis program assigned to TAC and included in the Department of Army Consolidated Topographic Support Program, is validated and prioritized by the Assistant Chief of Staff for Intelligence and funded by the Chief of Engineers. Funding levels for Fiscal Year 1979 through Fiscal Year 1981 have been programmed at approximately $2 million annually. Representatives of DMA, recently assigned DOD program management of the terrain analysis program, have indicated that they expect that the program will grow over the next five to ten years.

* * * *

In a sentence, the role of the Engineer Topographic Laboratories can be summarized as follows: "Our work is dedicated to supporting the soldier by improving his effectiveness and survivability on the battlefield."[71]

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VI

APPENDICES

A

RESEARCH INSTITUTE

When GIMRADA was established in August 1960, there was virtually no basic research program within the Army for topographic mapping or geodesy. Three contracts existed for exploratory research:

Franklin Institute, Philadelphia	Investigations relating to mapping, geodesy, and position determination.
Research Divison, NewYork University	Instrumentation for satellites and related craft for surveying, mapping, and target location.
Midwest Research Institute Kansas City, Missouri	Investigations of effects of natural phenomena on surveying, mapping, and target-locating systems.

With the creation of GIMRADA, a research and analysis division was formed to allow the growth of an in-house basic research team. This division encouraged its scientists to pioneer research that was of interest to GIMRADA and, when necessary, contract with universities in the U.S. and Europe for other useful studies. Pennington summarized the work of these men in his early history of ETL.[1] By the end of the 1960s, the personnel of what is now called the Research Institute had become involved in a wide range of subjects, from support of the SECOR (Sequential Collation of Range) satellite project to explorations of laser holography.

During the November 1965 reorganization of GIMRADA, the Research Institute for Geodetic Systems was created. This change reflected the impact of the satellite era on the science of geodesy, which in turn was having its own effects upon the manner in which surveying and related tasks were accomplished. In 1968, the institute's title was shortened to Research Institute, reflecting the wider variety of questions the organization was addressing. The evolving foci of the Research Institute can be appreciated by following its changing subdivisions:

1967	1974-1978
Mathematical Support	Center for Remote Sensing
Astro Geodesy Geography Optics	Center for Coherent Optics
Electronics Geometrical Geodesy	Center for Geodesy
Photogrammetry Satellite Geodesy	Center for Theoretical and Applied Physical Sciences

In the summer of 1978, Col. Philip R. Hoge approved the "phase-down" of the geodesy program at ETL. This shift in emphasis was yet another example of the phenomena noted by Technical Director Macchia: as problems are solved or new areas for exploitation appear, a research and development agency must be ready, even eager, to make changes. Most of the current research activities at the Research Institute reflect new fields of investigation that have emerged in just the past decade.

In the spring of 1978, Armando Mancini, Director of the Research Institute, talked about the activities of his organization. He pointed out that his center chiefs act as interdisciplinary science team leaders of government, contractor, and university personnel. Robert D. Leighty directs the activities in the Center for Coherent Optics. Leighty is particularly interested in pursuing research in areas that will assist with the operation of UNAMACE and other map compilation projects. Research in coherent optics includes investigations to further improve such systems and increase their degree of automation.[2] Current fields of interest include pattern recognition, automated photogrammetry, optical memory systems, holographic terrain displays, and a number of related subjects. As with all basic research, it is difficult to predict which avenues of investigation will be profitable, but Leighty and his people are exploring a variety of approaches to improve the map compilation process.

Baussus von Luetzow, Team Leader of the Center for Geodesy, and his colleagues are currently beginning to apply the knowledge gained during the past two decades in the field of geodesy to more practical tasks, such as surveying. As their work leads to applied research, the geodetic emphasis of the Research Institute activities will be reduced.

Jack N. Rinker, Remote Sensing Team Leader, is also trying to develop new techniques that will assist the mapmakers. His people would like to be able to do by machine the type of feature identification tasks presently being done by photointerpreters. According to Mancini, it is too early to determine if they will be successful, but their work should be valuable to users of field systems such as ARTINS and production center equipment such as UNAMACE.

In the Center for Theoretical and Applied Physical Sciences, Frederick W. Rohde and his team are involved in a series of basic studies, including research supporting the Department of Defense Global Positioning System, which will provide world-wide navigational information for Army, Navy, and Air Force systems.

During the summer of 1978, Melvin Crowell, Jr., Chief of the Systems Concept and Definition Division, Topographic Developments Laboratory, became director of the Research Institute. His appointment would suggest that the growing emphasis on support of topographic development in basis research will continue. All of the Research Institute's current work reinforces the significance of investigations into advanced electronics and computer-based technology for future topographic systems in the U.S. Army.[3]

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B

COMPUTER SCIENCES LABORATORY

The Computer Sciences Laboratory (CSL) was a byproduct of the revolution wrought by the growing role of electronic and computer technology in topographic systems research. CSL, from its establishment in 1968, has consisted of two divisions, Applications and Advanced Technology. The Applications Division has served as the computer center for the rest of ETL, supporting projects throughout the agency. The Advanced Technology Division has pursued research into a variety of topographic problems that involve mathematical modeling and systems analysis.

In the summer of 1969 Lawrence A. Gambino moved from the Analytical Research Branch of the Automated Mapping Division to become director of the Computer Sciences Laboratory and for three years doubled as chief of the Advanced Technology Division. Gambino, who has been working on problems associated with analytical photogrammetry, has been a pioneer in the field of digital photogrammetry. After nearly a decade of work, Gambino and his division chiefs, Dale E. Howell (Applications) and James E. Stilwell (Advanced Technology), are beginning to see important payoffs from their research.

The Digital Image Analysis Laboratory (DIAL) is one of the major accomplishments of CSL. DIAL, which is being used for research in mapping and photointerpretation techniques is a mixture of computer hardware and computer program software. There are three hardware subsystems — a sequential computer, the STARAN parallel processor, and a real-time processing and display subsystem. In conjunction with these, an image digitizing system provides a part of the data base. This latter system includes a scanner, recorder, and magnetic tape units.

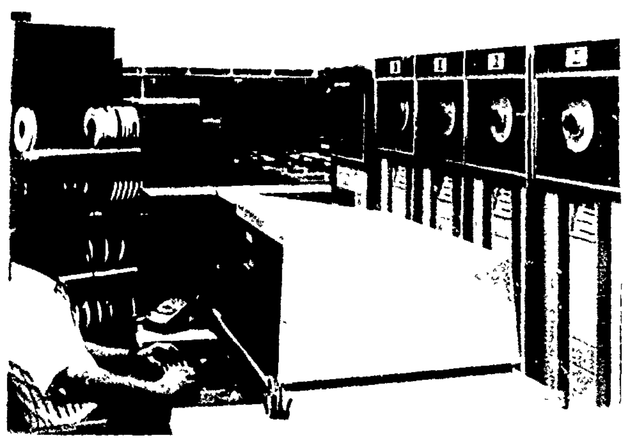
Photographic imagery is converted into digital form through a digitizing system. A photographic transparency is placed in the scanner, and information in digital form is extracted and collected on low-speed magnetic tapes. This data is subsequently transferred to a magnetic disk pack where it becomes part of the stored imagery data base.

The sequential computer is utilized because of its extensive memory capacity, which includes three disk packs and four magnetic tape units. The STARAN array processor, which performs mathematical operations in parallel rather than in sequence, allows many tasks to be performed much faster than on a conventional computer. On this processor, it is possible to perform mathematical operations on 1,024 bits simultaneously. A channel coupler provides the interface between the parallel processor and the sequential computer, sending imagery and commands back and forth. Data rates between the processor and computer are 4.8 million bits per second.

The real-time image processing subsystem consists of a minicomputer, a command terminal, and two display screens. This system is driven by an operator, who types in commands at the terminal. Many of the digital image processing operations are the result of local interaction between the minicomputer and the display screens. Other operations involve concurrent interaction between the central processor and minicomputer.

DIAL's capabilities include: SCROLLING, a search technique that allows an interpreter to view the entire scene on the left screen while viewing portions of the scene at full resolution on the right screen; MAGNIFICATION, where portions of a digital image can be magnified to see fine detail; RAPID ACCESS, during which an interpreter can see any stored imagery in a matter of seconds; COLORED TERRAIN ELEVATION, which color codes different elevations; COLOR CONTOUR MAPPING, which color codes contours; TRANSFER FUNCTIONS, a techniques that allows the alteration of details of an image on the left screen to be shown on the right screen; GRAY-LEVEL MAPPING, the manipulation of the brightness level and contrast function; PRODUCTION OF NEGATIVE IMAGES, a simple process to transform a positive digital image to a negative; MOSAICS, piecing together many small images to create a single large one; CHANGE DETECTION, a flickering technique that can show where change has occurred between two scenes; and WARPING, geometrically altering or warping a digital image.

By augmenting DIAL with additional equipment, CSL will create the Experimental Digital Interactive Facility (EDIF), an improved system with new mass storage capacities, which will be of interest to the DMA Hydrographic Topographic Center. Both DIAL and EDIF are being developed to further reduce the need for manpower in the mapping process.[1]



Peter Jacob at input console for the Computer Sciences Laboratory CDC 6400 Computer.

1. Interview, Dale E. Howell and James E. Stilwell-Edward C. Ezell, 13 Apr 78; M. A. Crombie and L. A. Gambino "Digital Stereo Photogrammetry," paper, Congress of the International Federation of Surveyors, Stockholm, Jun 77, and L. A. Gambino and B. L. Schrock, "An Experimental Digital Interactive Facility," *Computer* (Aug 77): 22-28.

C

TERRAIN ANALYSIS CENTER

The Terrain Analysis Center (TAC) is unique among ETL's subdivisions in that it is an operational organization housed by a research and development facility. Traditionally, terrain analysis refers to the process of evaluating geographic areas to determine the effects of natural and man-made features weather, and climate on military operations. For example, during World War II, allied forces, relied heavily on beach and coastal information for the Normandy invasion. Forces advancing across western Europe benefitted from a steady flow of information about the conditions of highways and other lines of communication. In the Pacific theater of war, planners utilized data about weather, terrain, and man-made facilities such as airfields to aid in planning combat operations there.

In the years immediately following World War II, the Army did not place great emphasis upon terrain analysis. Military geographic information (MGI) was collected and disseminated by engineer terrain detachments assigned to corps and higher levels. Terrain detachments were provided basic analytical data by a large geographic information production organization, the Department of Engineer Intelligence of the Army Map Service, which employed nearly 1,000 people. This production organization was transferred to the Defense Intelligence Agency, when it was formed in 1963. During the 1960s, most of the terrain detachments were deactivated, and today there are only three active and three reserve units.

After 1963, the Chief of Engineers continued to have responsibility for military geographic information, but he did not have an organization to do the work from 1963 to 1975. A small number or personnel from the old Department of Engineer Intelligence became involved in the Agency for International Development Resources Inventory Center (AID-RIC), which began operations on 1 October 1963 within the Corps of Engineers. AID personnel discovered that many of the skills employed in the development of military terrain analysis and many of their intelligence reports could also be adapted to the needs of economic development planners. James D. O'Neal, chief of the Terrain Analysis Center and one of the organizers of AID RIC, noted that information about soil, vegetation, water resources, and the like is formatted in a particular way for a military commander, but the same basic data can also be used for economic development projects, especially for taking inventories of an area's resources. AID-RIC did studies called General Inventories of Physical Resources in eight Latin American countries during the first two years of its existence. These studies were in great demand, and O'Neal and his thirty workers had more work than they could handle.

About two years after the creation of AID-RIC, the organization's name was changed to the Engineer Resource Inventory Center (ERIC). By 1965-1966, ERIC was receiving study requests from several Southeast Asian countries, and the center put together an enormous atlas of resource material for the lower Mekong region — Thailand, Laos, Cambodia, and South Vietnam. This study was sponsored to AID, but under the auspices of the United Nations Economic Commission for Asia and the Far East. O'Neal recalled that ERIC personnel had the distinction of being the only Americans working with the Cambodians, since there were no formal relations between Cambodia and the U.S. at that time. ERIC went through another name change in 1966, becoming the Engineer Agency for Resources Inventories (EARI). The workload shifted dramatically to Southeast Asia in both civilian projects and classified studies undertaken for the Defense Department's Advanced Research Projects Agency.

The Nixon administration changed the U.S. policy toward foreign assistance from bilateral programs through AID to multilateral assistance through international lending institutions such as the World Bank. With this shift, the type of support provided by EARI was no longer considered essential. Seeing this change, O'Neal and his associates began to cast about for other kinds of work, including some military projects for ETL. The Chief of Engineers also involved EARI in Corps of Engineers civil works projects in the U.S. As a result of the National Environmental Policy Act of 1969, the Corps district engineers had to file environmental impact statements for all their projects, and the prototype study done by EARI in this area was an Environmental Resources Inventory for the Lower Mississippi River Valley region of southern Louisiana. During the late 1960s and early 1970s. EARI did this kind of work for the district engineers, The Department of Health, Education, and Welfare, the Department of Housing and Urban Development, and the Environmental Protection Agency on a remibursable basis. There were no budgeted funds to support the organization. As a consequence, O'Neal and EARI Chief Robert L. Thomson spent much of their time on the road promoting new work for EARI among various government agencies. They never missed a payroll, but according to O'Neal it was often touch and go.

O'Neal's efforts to establish within the Office of the Chief of Engineers a more reliable method for funding for EARI failed, and by the spring of 1975 it was decided by OCE that the civil works resources inventory studies would not be enough to keep the group operating. EARI was abolished 1 July 1975, and O'Neal with a cadre of fourteen people was assigned to the newly created Terrain Analysis Center, which was housed in the ETL facility at Fort Belvoir. For accounting purposes, EARI had been assigned to ETL in 1972, but its staff had not moved to Fort Belvoir. They had been housed at the DMA Topographic Center facilities at Brookmont, Md.

With the establishment of TAC, O'Neal and his colleagues turned again to basic military terrain analysis work, primarily for the Army's assistant chief of staff of intelligence. TAC would fill a gap in the Army's production of terrain information, the gap between the global, strategic analyses done by the Defense Intelligence Agency and the localized tactical analyses of terrain detachments in the field. From 1963 until 1975, when TAC was formed, there was no organization — no person — addressing the departmental level terrain analysis requirements of the Army. The talents of the people at EARI represented the only reservoir of terrain analysis capabilities. Much of EARI's work for AID had found its way into the hands of the intelligence community, because it was the best comprehensive research available. The Middle East Yom Kippur War of 1973 stimulated the Army's interest in military geographic intelligence, formation, however, and the Training and Doctrine Command, the Forces Command, and other Army Organizations established heavy requirements for terrain analysis training and potential operations studies. TAC suddently had more work than they had manpower to handle. By mid-1978, O'Neal had requests for work equaling 260 man-years for the next five calendar years. To carry out these tasks, he would need fifty people, but he only had a staff of thirty. Any way he figured it, O'Neal said, he and his colleagues were going to be very busy during those five years as they worked to provide terrain intelligence to their customers.[1]

TAC Team Leader Ernest Jackman (foreground) checks factor map for public works support project with PFC Debra J. Meloche and Terrain Analyst Thomas F. Wert III.

1. Interview, James D. O'Neal Edward C. Ezell, 8 Mar 78.

D

CHRONOLOGY OF KEY DATES RELATING TO THE HISTORY OF THE ENGINEER TOPOGRAPHIC LABORATORIES

I. REPRODUCTION SYSTEMS

1919-1942	Engineer Reproduction Plant in charge of map publication.
Sep 1940	Research Section established in the Reproduction Division of the Engineer Reproduction Plant to investigate new techniques and equipment for the duplication and printing of maps.
1942	Engineer Reproduction Plant moves to Brookmont, Md.; and becomes the Army Map Service.

II. DATA GATHERING SYSTEMS

Apr 1920	Major James W. Bagley, CE, assigned to cooperate with Army Air Service in tests of aerial photography systems for topographic mapping.
1920-1942	Engineer Detachment (originally called the Aerial Mapping Detachment), McCook Field (later Wright Field), Dayton, Ohio, carries out majority of photogrammetric research and development.
26 Jan 1933	Engineer Board at Fort Belvoir, Va., granted authority for technical supervision of R&D projects conducted by Engineer Detachment.
30 Jun 1941	Mapping Section of Engineer Board raised to status of Mapping Branch.
ca. 1 Jul 1942	Mapping Branch placed in Technical Division I of Engineer Board.
19 Feb 1943	Engineer Detachment and majority of personnel transfers to Fort Belvoir, becoming part of Engineer Board. Only Aerial Photographic Branch remains at Wright Field.
1 Apr 1946	Mapping Branch raised to status of Technical Department V of the Engineer Board, with four branches — Ground Control, Photo and Lithographic, Photogrammetric, and Aerial Photographic.
1947	Engineer Board reorganized and designated Engineer Research and Development Laboratory (ERDL).
1951	Technical Department V became Topographic Engineering Department of ERDL. Branches renamed: Ground Control becomes Surveying; Photogrammetric becomes Map Compilation; Photo and Lithographic becomes Map Reproduction; Aerial Photographic not changed.
1956	Surveying Branch becomes Surveying and Geodesy Branch. Signal Corps Ground Survey Electronic Equipment activities terminated and responsibilities transferred to Surveying and Geodesy Branch. Map Compilation Branch reorganized to become Analytical and Automatic Mapping Section. Cartography Section made part of Map Reproduction Branch.
1959	Topographic Systems Branch formed in recognition of the need for a systematic approach to topographic mapping problems. Map Reproduction Branch becomes a section of this new branch. This begins separation of basic research activities from development activities.
1 Aug 1960	GIMRADA created. U.S. Army Engineer Geodesy, Intelligence, and Mapping Research and Development Laboratories for the first

time an independent field activity under direction of Office of the Chief of Engineers. GIMRADA organized into six operating divisions under a military director, a civilian assistant director, a civilian technical director, and a military executive officer. GIMRADA's mission statement reads: "The U.S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency (GIMRADA) is a Class II activity under the Chief of Engineers. It is the principal field agency of the Corps of Engineers for the accomplishment of research and development of equipment, procedures, and techniques in the specific fields of geodesy, engineer intelligence, and mapping for application both to troop and baseplant operation. The Chief of Engineers may assign work to this agency under research and development projects utilizing either RDT&E funds or other appropriate funds." The agency's six operating divisions are given the following functions: "Research and Analysis — This division will conduct basic and applied research in various scientific disciplines as required for new principles and techniques pertinent to surveying geodesy, mapping, position determination, targeting, cartographic drafting, information display and dissemination, and map reproduction to meet both tactical and strategic requirements for geodetic and mapping data. Intelligence — This division will conduct research, development, design, and tests of new and improved methods, techniques, equipment, and systems in support of engineer combat and strategic intelligence in acquisition, processing, analysis, evaluation, presentation, dissemination, storage, retrieval, and updating of engineer intelligence data and information. Strategic Systems — This division will conduct applied research, development, design, and testing of topographic mapping systems involving aircraft, missile, or satellite-borne data acquisition and ground-base data reduction subsystems; responsibilities include feasibility studies and tests to establish system concepts and component requirements, system engineering, system investigation, and systems/components compatability; will also provide assistance to the Director in the management of topographic systems developments. Photogrammetry — This division will conduct applied research, development, design, and testing of photogrammetric data reduction systems, equipment, and techniques for topographic mapping, control, and position determination in support of Army weapons and general military applications, plus provide computer and statistical support for the agency. Surveying and Geodesy — This division will conduct applied research, development, design, and testing of surveying and geodetic systems and related geodetic control requirements including satellite tracking equipment for geodetic purposes, for military mapping, and for combat operations. Graphics — This division will conduct applied research, development, design, and testing of cartographic, map reproduction and display systems, equipment, and techniques including terrain modeling and othe related requirements for the collection, preparation, dissemination, and display of topographic information."

1 Nov 1965 GIMRADA reorganization results in separation of basic research from development projects through the creation of the Research

Institute for Geodetic Systems and the Development Laboratories for Mapping and Geodetic Systems. The latter had five divisions — Technical Plans and Systems Analysis; Surveying and Geodesy; Geographic Intelligence; Graphics and Display; and Photogrammetry and Mapping.

1965-1971 Organizational changes:
GIMRADA, 1965
- Surveying & Geodesy Div.
- Geographic Intelligence Div.
- Graphics Intelligence Div.
- Photogrammetry & Mapping Div.

GIMRADA, 1967
- Surveying & Geodesy Div.
- Geographic Sciences Div.
- Advanced Mapping Div.
- Topographic Engineering Div.

ETL, 1968
- Surveying & Geodesy Div.
- Georgraphic Sciences Div.
- Automated Mapping Div.
- Topographic Engineering Div.

ETL, 1971
- Topographic Developments Lab.
- Geographic Sciences Lab.
- Topographic Developments Lab.
- Topographic Developments Lab.
- Computer Sciences Lab.

27 Jul 1967 Name changed from GIMRADA to U.S. Army Engineer Topographic Laboratories (ETL).

7 May 1968 Office of the Chief of Engineers approves revised organizational structure. Modified mission statement reads in part: ETL "is the principal field activity of the Army for accomplishing research and development of equipment, procedures, and techniques applicable to the topographic sciences to include mapping, geodesy, and military geographic information."

1 Sep 1968 U.S. Army Topographic Command (TOPOCOM) established as a Class II activity under the Chief of Engineers. ETL was subordinate to TOPOCOM, as were the Army Map Service (renamed U.S. Army Engineer Topographic Production Center) and the field topographic units (gathered under the U.S. Army Engineer Topographic Troop Command).

Jun 1970 Photographic Interpretation Research Division transferred from U.S. Army Cold Regions Research and Development Laboratory to ETL.

May 1971 Earth Sciences Laboratory transferred from U.S. Army Natick Laboratories to ETL.

Oct. 1971 ETL divisions reorganized — Surveying & Geodesy, Advanced Mapping, and Topographic Engineering merged into Topographic Developments Laboratory, with the following divisions: Systems Concept and Definition; Mapping Developments; and Surveying and Engineering. Geographic Sciences Division became the Geographic Sciences Laboratory, with the following divisions: Geographic Information Systems; Earth Sciences (formerly Earth Sciences Laboratory); and Photographic Interpretation Research.

1 Jan 1972 Defense Mapping Agency created. DMA incorporates TOPOCOM's Topographic Production Center, which becomes the DMA Topographic Center; chart production, nautical information, and distribution functions of the Naval Oceanographic Center assumed by DMA Hydrographic Center; Air Force Aeronautical Chart and Information Center becomes DMA Aerospace Center. ETL became a Class II activity reporting to OCE.

15 Aug 1972	Engineer Agency for Resource Inventories (EARI), Brookmont, Md., attached to ETL.
11 Oct 1973	Earth Sciences Division of the Georgraphic Sciences Laboratory abolished; Geographic Applications Division formed.
20 May 1974	Effective this date, ETL reports to the Chief of Engineers through Research and Development Office at OCE.
Sep 1974	After years of tenancy within MERADCOM's compound at the southern tip of Fort Belvoir, ETL moves into its new 9,200-square-meter building named after William C. Cude. Several groups such as the Research Institute are brought under the same roof with the rest of the ETL team. Cude Building is located on the North Post of Fort Belvoir.
28 Sep 1974	Photographic Interpretation Research Division in Geographic Sciences Laboratory abolished; Center for Remote Sensing established in Research Institute.
7 Apr 1975	Engineer Agency For Resources Inventories abolished; 14 employees transferred to ETL facility becoming the core of the Terrain Analysis Center (TAC).
15 Mar 1977	In the Geographic Sciences Laboratory, the Geographic Information Systems Division was redesignated the Data Processing and Products Division, and the Geographic Applications Division was redesignated the Data Applications and Systems Division.

E

COMMANDERS

ETL, 1966-1978

Commanding Officer
Col. Hamilton W. Fish
10 Jan. 66-31 Jul 67

Commanding Officer
Col. E. G. Anderson, Jr.
1 Aug 67-30 Jun 68

Commanding Officer
Col. John R. Oswalt, Jr.
1 Jul 68-31 Jul 71

Commander & Director
Col. John E. Wagner
1 Aug 71-15 Mar 74

Commander & Director
Lt. Col. Alfred B. Devereaux
15 Mar 74-26 May 75

Commander & Director
Col. Maurice K. Kurtz, Jr.
27 May 75-27 Jul 77

Commander & Director
Col. Phillip R. Hoge
28 Jul 77-20 Jul 78

Commander & Director
Lt. Col. William T. Stockhausen
21 Jul 78-14 Sep 78

Commander & Director
Col. Daniel L. Lycan
15 Sep 78-present

DEPUTY COMMANDERS

1966-1978

Deputy Commander
Lt. Col. William R. Cordova
Jun 66-Dec 67

Deputy Commander
Col. Colin M. Carter
Dec 67 (2 wks.)

Deputy Commander
Maj. William H. Revell
2 Jan 68-Feb 68

Deputy Commander
Maj. Alan L. Laubscher
Mar 68-Jun 68

Deputy Commander
Lt. Col. George N. Simcox
10 Jul 68-30 Apr 73

Deputy Commander
Lt. Col. Alfred B. Devereaux
1 May 73-14 Mar 74

Deputy Commander
Maj. Jack S. Chase
17 Apr 74-30 Mar 75

Deputy Commander
Lt. Col William T. Stockhausen
31 Mar 75-20 Feb 79

Deputy Commander & Director
Lt. Col. Douglas V. Myers
21 Feb 78-present

TECHNICAL DIRECTORS

1966-1978

Technical Director
Gilbert G. Lorenz
29 Jul 66-30 Jun 73

Technical Director
Robert P. Macchia
1 Jul 73-present

F

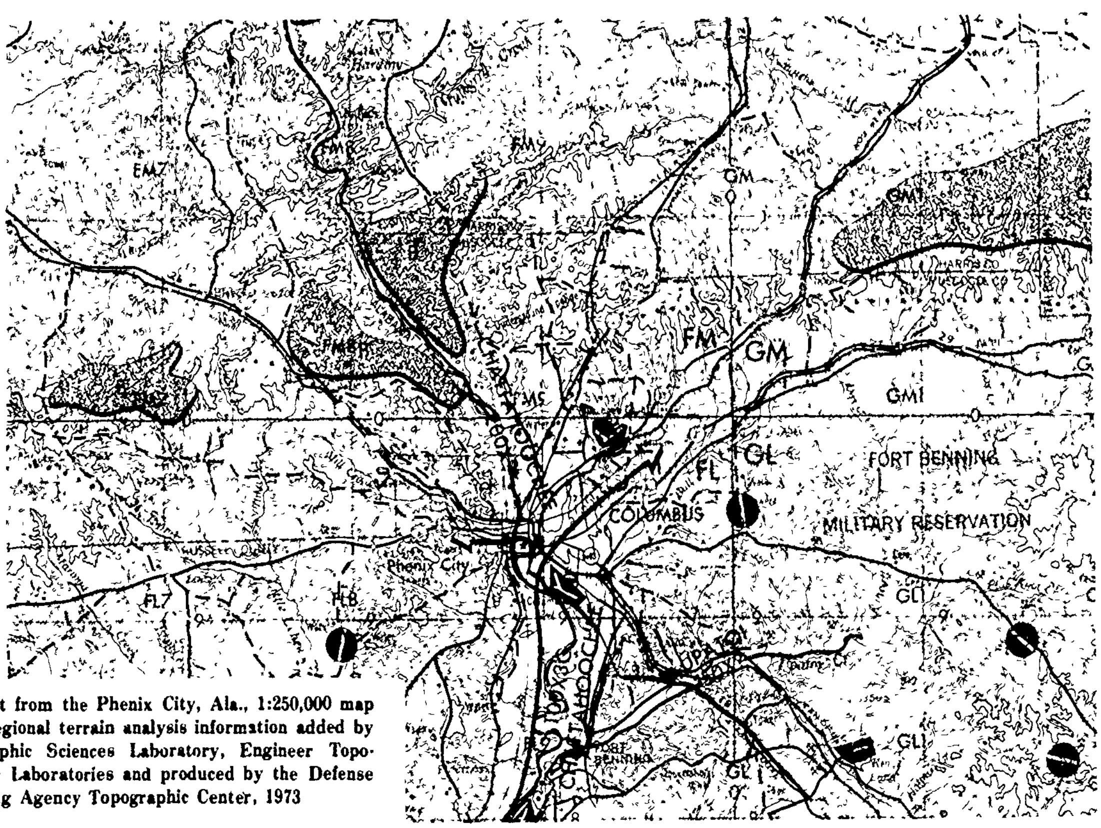
GLOSSARY OF ACRONYMS AND ABBREVIATIONS

AACE	Advanced Automatic Compilation Equipment
ADP	Automatic Data Processing
ADSAF	Automated Data System with the Army in the Field
AMC	Army Materiel Command
APPS	Analytical Photogrammetric Positioning System
ARME	Automatic Reseau Measuring Equipment
ARTINS	Army Terrain Information System
CACDA	Combined Arms Combat Development Activity
CONARC	U.S. Army Continental Army Command
CONUS	Continental United States
CRT	Cathode Ray Tube
CV-HRS	Combat Vehicle Heading Reference System
DA	Department of the Army
DARCOM	U.S. Army Materiel Development and Readiness Command
DARPA	Defense Advanced Research Projects Agency
DIA	Defense Intelligence Agency
DIAL	Digital Image Analysis Laboratory
DIODE	Digital Input/Output Display Equipment
DMA	Defense Mapping Agency
DMAAC	Defense Mapping Agency Aerospace Center
DMAHC	Defense Mapping Agency Hydrographic Center
DMATC	Defense Mapping Agency Topographic Center
DMAHTC	Defense Mapping Agency Hydrographic/Topographic Center
DPC	Digital Planimetric Compiler
DPROC	Draft Proposed Required Operational Capability
DT	Development Test
EBR	Electron Beam Recorder
EDT	Engineer Design Tests
ENTIS	Engineer Terrain Intelligence System
ERDL	Engineer Research and Development Laboratory
ET	Engineering Test
ETL	U.S. Army Engineer Topographic Laboratories
FAMTIS	Field Army Mapping and Terrain Information System
FASE	Forward Area Survey Equipment
FLIP	Flight Information Publication Chart
FORSCOM	U.S. Army Forces Command
GIANT	Operations Research in Support of an Improved Geographic Intelligence and Topographic Support System for the Army in the Field
GIMRADA	U.S. Army Engineer Geodesy, Intelligence, and Mapping Research and Development Agency
HIROOT	High Resolution Orthophoto Output Table
IOC	Initial Operational Capability
IPR	In-process review
LOA	Letter of Agreement
MC&G	Mapping, Charting, and Geodesy
MERADCOM	U.S. Army Mobility Equipment Research and Development Command
MERDC	U.S. Army Mobility Equipment Research and Development Center
MGI	Military geographic information
MUSAT	Multiple Station Analytical Triangulation Program
OCE	Office, Chief of Engineers
ODDR&E	Office, Director of Defense Research and Engineering
OT	Operational Test
PADS	Position and Azimuth Determining System
PMT	Photomultiplier tube
QMR	Qualitative Materiel Requirement
RACOMS	Rapid Combat Mapping System
ROC	Required Operational Capability

ROSA	Recording Optical Spectrum Analyzer
RPIE	Replacement of Photographic Imagery Equipment
RPV	Remotely Piloted Vehicle
SACARTS	Semi-Automated Cartography System
SDR	Small Development Requirement
SIAGL	Surveying Instrument: Azimuth, Gyro, Lightweight
ST	Service Test
TAC	Terrain Analysis Center
TECOM	U.S. Army Test and Evaluation Command
TOE	Table of Equipment and Organization
TOPOCOM	U.S. Army Topographic Command
TOS	Tactical Operations System
TPCS	Type Placement Composition System
TRADOC	U.S. Army Training and Doctrine Command
TROSCOM	U.S. Army Troop Support Command
TSS	Topographic Support System
UNAMACE	Universal Automatic Map Compilation Equipment
USAFABD	U.S. Army Field Artillery Board
USAFAS	U.S. Army Field Artillery School
USASTRICOM	U.S. Army Strike Command
UTM	Universal Transverse Mercator

G

SAMPLES OF EXPERIMENTAL MAPS
PRODUCED BY ETL, 1968-1978



Excerpt from the Phenix City, Ala., 1:250,000 map with regional terrain analysis information added by Geographic Sciences Laboratory, Engineer Topographic Laboratories and produced by the Defense Mapping Agency Topographic Center, 1973

MAP UNIT REGION	TERRAIN SUITABILITY FOR OPERATIONS				
	TERRAIN DESCRIPTION	AIR STRIP CONSTRUCTION	HELICOPTER LANDING ZONES	PARACHUTE DROP ZONES	TRACKED VEHICULAR MOVEMENT
1	Piedmont Plateau: Varies in topography from scattered, fairly smooth, rolling areas with steep eroded slopes to severely dissected deeply gullied, hilly areas with outcrops of rock. Streams flow through V-shaped valleys with rocky beds. Soils shallow, but fairly well drained. Predominately forest covered	Fair to Poor. Most sites require tree clearing operations	Fair. Many sites require tree clearing operations	Poor. Forested area with numerous steep slopes.	Poor. Steep slopes and trees restrict movement.
2	Coastal Plain. Rolling to moderately hilly topography with relatively gentle slopes of unconsolidated horizontal beds of sands, silts and clays. Relatively broad, flat, terraced stream bottoms. Soils deep, and well drained except along streams. Vegetative cover conditions vary from predominately forest to areas 30-50% cleared or under cultivation.	Fair. Many sites with good approaches and good drainage	Good to Fair. Some areas require tree clearing operations.	Fair. Many extensive areas have scarcity of large cleared sites	Fair to Poor. Trees restrict movement in many areas
3	Chattahoochee River Valley. Broad, flat, and terraced topography. Alluvial soils, generally well drained except in low areas and bordering streams. Predominately cleared or cultivated.	Good to Fair. Many sites with good drainage and approaches.	Good. Many cleared level sites with good drainage	Good. Many large cleared areas.	Good to Fair. Relatively level and free of natural barriers except for streams
4	Flint River Valley. Broad, flat, terraced river valley. Drainage varies from good to poor. Extensive swamp in northern portion. Forest covered.	Poor. Most sites require clearing operations and some areas have poor drainage.	Poor. Tree clearing operations required	Poor. Forest covered.	Poor. Trees restrict movement

Note: SOLID symbols indicate area is generally suitable for this type of operation
DOTTED symbols indicate area has only fair suitability for this type of operation
NO symbol indicates area is not suitable for this type of operation

MOVEMENT

Major Natural Corridors for Ground Movement

Major Natural Barriers to Ground Movement

A. Forest covered mountain ridges or elongated hills with steep slopes and rock outcrops
B. Severely dissected, deeply gullied, hilly terrain with steep slopes and V-shaped valleys. Forest covered
C. Forest covered swampy area

LANDING FACILITIES

Runway Pattern with Field Limits

Runway Pattern with Field Limits Unknown

Field with Unknown Characteristics

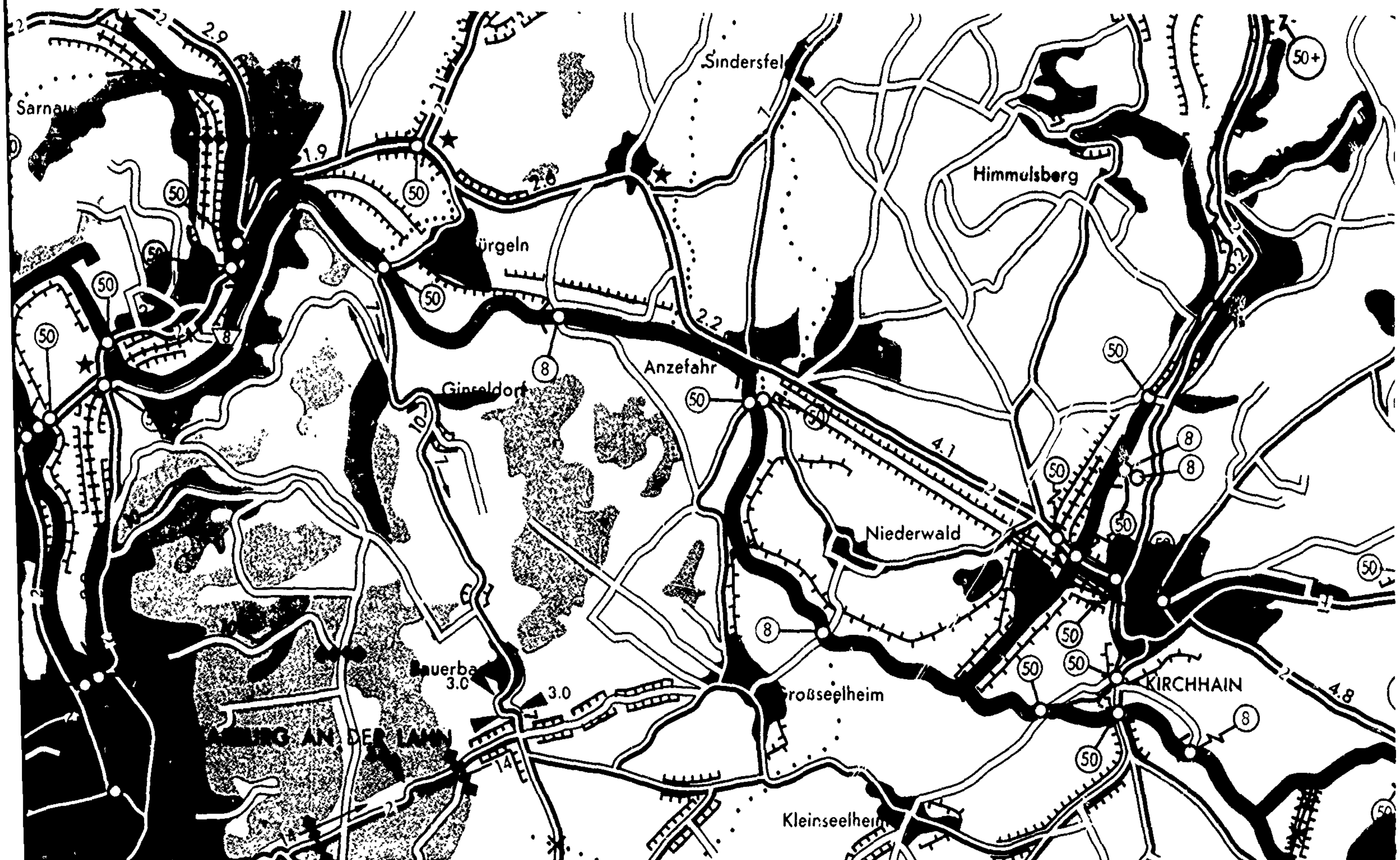
Legend for regional terrain analysis overprinted on the Phenix City, Ala., 1:250,000 map.

Excerpted material from experimental cross-country movement map developed by Geographic Sciences Laboratory, ETL, 1972.

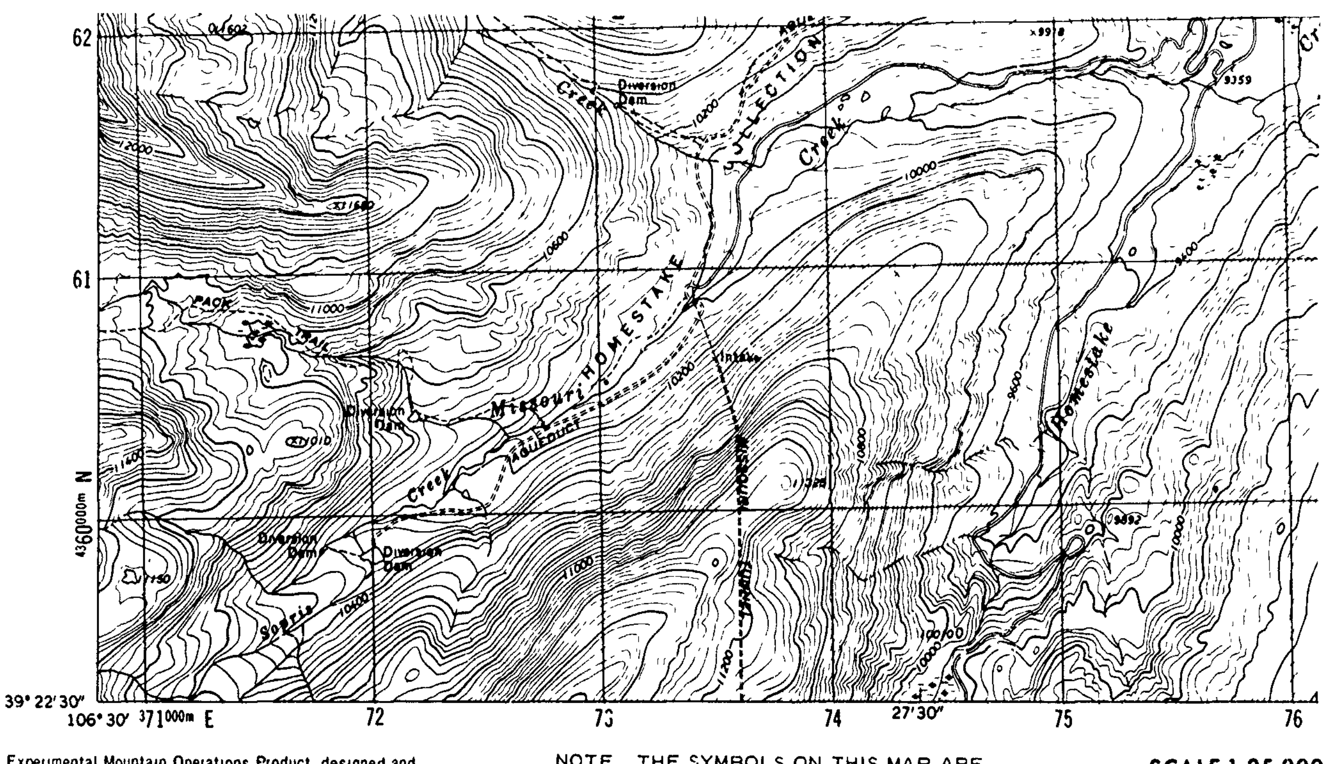
ESTIMATED MAXIMUM CROSS COUNTRY SPEEDS IN MPH

Map Unit	M-151 Jeep	M-35 2½ ton	M-113 APC	M-60 Tank	Foot Soldier
	24–29	18–20	16–17	12–14	3.5–4
	12–18	9–13	8–11	7–10	2.5–3
	3–6	4–5	3–4	2–3	2
	←PASSAGE BLOCKED→				3
	←PASSAGE BLOCKED→				
	Built-up Area (Travel off roads not evaluated)				

SPEED PREDICTIONS DO NOT INCLUDE TIME REQUIRED TO CROSS STREAMS


Anzefahr
Niederwald
Großseelheim
KIRCHHAIN

EXPERIMENTAL GRAPHICS



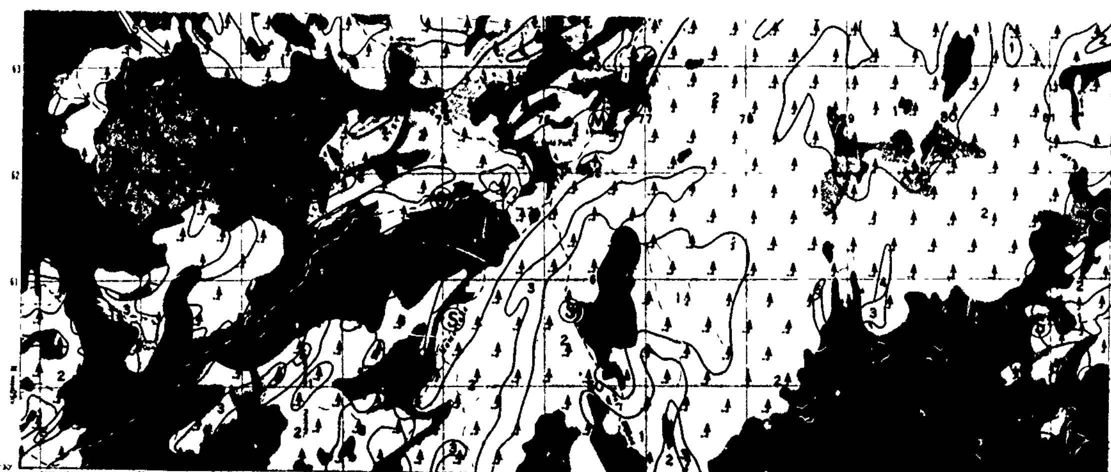
Experimental Mountain Operations Product, designed and produced by the U. S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA 22060

NOTE THE SYMBOLS ON THIS MAP ARE NOT STANDARD MILITARY TOPOGRAPHIC SYMBOLS.

SCALE 1:25,000

The above excerpt was taken from a standard U. S. Geological Survey topographic map. On the reverse of this map, ETL specialists added four special purpose Mountain Operations Graphics to make the terrain more comprehensible to troops operating in the area. Similar special purpose graphics could be developed for actual combat theaters if they were required and if previous planning was undertaken.

Mount Holy Cross, Colo.



CONCEALMENT/ FOREST CANOPY CLOSURE

- 70–100 percent closure
- 40–70 percent closure
- 10–40 percent closure
- Less than 10% closure
- 40–70% in summer, 0–10% in winter

VEGETATION TYPES

- Dominantly coniferous forest
- Dominantly deciduous forest
- Brushland
- Meadowland
- Swampland
- Barren ground and rock

SLOPE vs. MOBILITY (dry, firm surface)

1. 0-14° (25%) Suitable for all field movement
2. 14-24° (45%) Too steep for wheels, slow for tanks
3. 24-31° (60%) Difficult for tanks, avoid if sandy or wet
4. 31-45° (100%) M-29 Weasel, pack animals, & foot troops
5. Over 45° Suitable for technically proficient mountaineers

Zones 3 & 4 subject to avalanching

DRAINAGE

(fictionalized data)

- Less than 5m wide
- 5–10m wide
- Wider than 10m
- Intermittant stream
- (S) Shallow, less than 0.6m. deep
- (M) Medium, 0.6 – 1.2m deep
- (D) Deep, over 1.2m. deep
- Lake or pond
- Underground aqueduct

These graphics provide selected information which indicates the ease or difficulty of conducting mountain operations in the area. Each of the map type graphics covers the same area shown on the reverse side.