ERDC/GSL TR-01-20

Geotechnical and Structures Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Expedient Airfield Construction Using the Computer-Aided Earthmoving System

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October 2001

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Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Contents

Preface

The purpose of this report is to provide an assessment of Caterpillar®, Inc.'s Computer-Aided Earthmoving System (CAES) for use by the military in expedient airfield construction. This report provides data for the following:

a. Determining the military's existing airfield construction capabilities.

b. Assessing advanced technology for enhancement of interim force construction equipment.

c. Development of rapid airfield construction and repair methods.

d. Providing solutions for achieving the Army's responsiveness objectives.

Users of information from this report include the U.S. Military Engineer Units charged with expedient airfield construction, the U.S. Army Maneuver Support Battle Lab (MSBL), U.S. Army Engineer School, U.S. Army Force Projection Battle Lab Support Element, U.S. Army Deployment Modernization Office, U.S. Army Force Projection Center of Excellence, U.S. Army Force Projection Program Manager, U.S. Transportation Command, U.S. Army Corps of Engineers, Airfield Commanders, U.S. Army Aeronautical Services Agency, U.S. Air Force Civil Engineer Support Agency, U.S. Air Force Air Mobility Command, and agencies assigned operations planning responsibilities. Information concerning military equipment inventory, readiness, and operations shall not be released outside U.S. Government agencies.

The project described in this report is part of the Enhanced Construction Productivity component of the Joint Rapid Airfield Construction (JRAC) program currently sponsored by Headquarters, U.S. Army Corps of Engineers, CECW-EWS, Washington, DC. Funding for this investigation was jointly provided by Headquarters, U.S. Army Corps of Engineers, CECW-EWS, Kingman Bldg, Room 321, 7701 Telegraph Road, Alexandria, VA 22315, and the MSBL, Fort Leonard Wood, Missouri.

This publication was prepared by personnel from the U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (GSL), Vicksburg, MS. The findings and recommendations presented in this report are based upon the test and analysis of the CAES technology at Fort Bragg, North Carolina. The required field testing was conducted from March to

April 2001. The research team consisted of Messrs. Jeb S. Tingle and Travis A. Mann, Airfields and Pavements Branch (APB), GSL. SFC Frank Kissel, MSBL, supervised the data collection. SFC Robert Butcher, Maneuver Center Directorate of Combat Development, and Mr. Ernest Haney, Test and Evaluation Coordination Office, provided valuable technical support. Messrs. Tingle and Mann prepared this publication under the supervision of Dr. Gary Anderton, Acting Chief, APB, and Dr. Michael J. O'Connor, Director, GSL. Dr. Bryant Mather was Director Emeritus, GSL.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL John W. Morris III, EN, was Commander and Executive Director.

Recommended changes for improving this publication in content and/or format should be submitted on DA Form 2028 (Recommended Changes to Publications and Blank Forms) and forwarded to Headquarters, U.S. Army Corps of Engineers, ATTN: CECW-EWS, Kingman Bldg, Room 321, 7701 Telegraph Road, Alexandria, VA 22315.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic yards	0.7646	cubic meters
feet	0.3048	meters
horsepower (550 foot-pounds force per second)	745.7	watts
inches	25.4	millimeters
miles (U.S. statute)	1.6094	kilometers per hour
pounds (mass)	0.4536	kilograms
pounds (force) per square inch	0.0068948	megapascals
square feet	0.0929	square meters

Executive Summary

Personnel of the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, conducted an experiment designed to evaluate Caterpillar®, Inc.'s Computer-Aided Earthmoving System (CAES) for improving contingency airfield construction. Two identical assault landing zone (ALZ) sections were constructed side-by-side at Fort Bragg, North Carolina, by a light equipment platoon of the 37th Engineer Battalion from 26 March to 6 April 2001. One ALZ section was constructed using the CAES technology, and the other ALZ section was constructed using current horizontal construction methods. The two construction methods were compared in terms of earthmoving productivity, time requirements, manpower requirements, situational awareness, and accuracy.

The following conclusions were derived from the experiment and subsequent analysis of data:

a. The CAES construction method moved approximately 5.4 percent more earth in a 20-hr period based upon the volume estimates reported by the CAES Office project management system for the CAES and Non-CAES ALZ sections.

b. The CAES construction method reduced the time required for preconstruction activities and restaking by 28.2 hr, from 49.5 to 21.3 hr, because of the use of a digital design and the elimination of grade stakes.

c. The CAES construction method reduced the manpower requirements by 54 percent or 140 man-hours based upon the omission of two noncommissioned officer (NCO) ground guides and a dedicated five-man survey team.

d. The CAES technology provided a vertical accuracy within 2.3 in. and a horizontal accuracy within 9.6 in. in this experiment compared to geodimeter measurements. These levels of accuracy indicate that the CAES technology may be appropriate for final grade construction during contingency operations, but not the final grade construction of permanent facilities.

e. The CAES technology provided increased situational awareness regarding the location and activities of fielded equipment, a high-resolution picture of the existing grade, instantaneous productivity reports, and a consolidated picture of the entire project.

f. The CAES technology also increased the ability of the engineer unit to operate at night. Although the users preferred the use of equipment lights, they demonstrated the ability to operate without lights using only the CAES equipment.

g. The CAES equipment should not significantly affect rapid deployment transport procedures and may permit the immediate initiation of earthwork during rapid deployment operations.

h. The construction unit indicated that the CAES technology was easy to learn and understand. The CAES Office component was the most difficult to achieve user proficiency, and additional training was requested.

i. The CAES equipment had minimal impact upon standard preventive maintenance checks and service (PMCS) activities compared to current equipment maintenance requirements.

The results of the experiment were used to compare the CAES construction method to current construction techniques. The CAES equipment provides soldiers with an improved earthmoving capability compared to current horizontal construction methods. The CAES equipment improved the earthmoving productivity, reduced the time required for various construction activities, reduced the manpower requirements, and increased the construction officer's situational awareness. Sufficient vertical and horizontal accuracy was demonstrated to justify use during all earthmoving activities, and particularly appropriate for contingency operations. Additional details concerning the CAES equipment and the results of the experiment are contained in Chapters 2 and 3 of this report. Conclusions and recommendations are presented in Chapter 4.

1 Introduction

Background

The ability to quickly and efficiently transport soldiers and equipment close to the theater of operations is essential to the modern military's force projection capabilities. The U.S. Military's power projection policy requires that future force projection capabilities meet or exceed the following deployment objectives: one Interim Brigade Combat Team (IBCT) within 96 hr, one Division within 120 hr, and five Divisions within 30 days. Current sealift capabilities provide little assistance in meeting the first two of these objectives, which leaves strategic airlift as the primary means of transporting the IBCT and the first Division to the battlefield. Unfortunately, in many areas of the world, these airfields are denied, severely deteriorated, or simply do not exist. Currently, light/ medium engineer units do not have the capability to rapidly upgrade or construct contingency airfields within the future force projection timeline as defined above.

In light of this shortfall, a new program has been initiated entitled "Joint Rapid Airfield Construction," or JRAC. The primary objectives of this program are to (a) optimize site selection, (b) enhance airfield construction productivity, and (c) incorporate advances in rapid soil stabilization. The JRAC program will serve as the vehicle by which military engineers are provided with new tools and methods that will ultimately allow them to construct and/or upgrade contingency airfields to support future force projection operations. This effort will also drastically reduce the logistical footprint required to build contingency airfields by minimizing material and equipment quantities required for construction.

Purpose

The purpose of this report is to provide an assessment of the Computer-Aided Earthmoving System (CAES) of Caterpillar®, Inc. for use by the military in expedient airfield construction. This report provides data for the following:

a. Determining the military's existing airfield construction capabilities.

b. Assessing advanced technology for enhancement of interim force construction equipment.

c. Development of rapid airfield construction and repair methods.

d. Providing solutions for achieving the Army's responsiveness objectives.

The research initiated in this investigation represents the first phase of a comprehensive program designed to improve the construction productivity of rapid deployment engineer units. The results of the overall program will serve to improve the manner in which engineer units plan, design, and construct contingency airfields. The objectives of the enhanced construction productivity component of JRAC include: (a) developing an accelerated design, planning, and approval process, (b) developing a rapid earthmoving capability, (c) instituting effective quality control, and (d) increasing overall efficiency. The purpose of the experiment described in this report was to provide an initial evaluation of the CAES technology while assessing many aspects of the existing construction process that might benefit from this type of technology.

Scope

This investigation was limited to the construction of two 610-ft[1] sections of a simulated assault landing zone (ALZ). One ALZ section was constructed using the CAES equipment, and the second ALZ section was constructed without the CAES equipment as a control experiment. The two ALZ sections were essentially identical in design with similar cut and fill requirements. During the construction of the two ALZ sections, the following items were documented: time requirements for construction activities, volume of earth moved, the accuracy of the CAES system, manpower requirements, reporting requirements, and operator appraisals. This report presents a comparison of the requirements for the control experiment using current construction methodologies to the requirements of construction using the CAES equipment. The results published in this report will serve as the foundation for future experiments that will work to refine the needs and capabilities of military engineers in order to provide them with the tools necessary to accomplish their mission of building and maintaining in-theater airfields.

[1] A table for converting Non-SI units of measurement to SI units is presented on page ix.

2 Test Site and Equipment

Test Site

The ALZ sections were constructed in an abandoned borrow pit across from the Ammunition Supply Point (ASP) on the Fort Bragg reservation. A topographic survey of the site was conducted prior to the experiment using a Trimble® global positioning system (GPS) backpack surveying kit to determine the baseline condition of the site. The test site was relatively flat with a gentle slope extending from the southwest end to the northeast end. The test site area was approximately 242,000 ft^2 or 5.6 acres. The north end of each ALZ section included a small apron and was denoted as a cut section. The fill sections for each ALZ were located on the south end of the test site.

Detailed soil test information for the test site was unavailable. However, visual observations indicated a diverse mixture of soil types within the test area. The soil types generally ranged from a relatively clean, poorly-graded sand (SP) in isolated pockets to a high-plasticity clay (CH). The predominant soil type within the test area was a clayey sand (SC) material. Various soil colors, including pink and gray clays, indicated the presence of organics and/or contaminants. The inconsistent soil type was not ideal for evaluating the productivity of the earthmoving equipment; however, the variability of soil types was similar for both ALZs.

Computer-Aided Earthmoving System

The CAES equipment was developed by Caterpillar, Inc.®, for use in the mining industry. The equipment was developed to monitor excavation activities on large mining projects and has achieved some measure of commercial success. The CAES equipment consisted of three distinct components: the reference (base) station, the machine hardware, and the CAES Office management system. The interaction between the components of the CAES network is illustrated in Figure 1. The reference station consisted of a real-time kinematic (RTK) GPS antenna mounted on a 4- by 4-in. post set in the ground at a known location. The known location was established using a Trimble® GPS Backpack to determine the northing, easting, and elevation of the reference station point. The reference station also included a 900-MHz radio antenna for establishing local communications between the reference station, each piece of construction equipment, and the CAES Office. It was powered using a 12-volt battery supplemented by the use of a solar power cell. The final component of the reference station assembly was the computer receiver which collects the GPS data from the GPS satellites, establishes a correction factor for the known reference station, and continuously transmits corrections to each piece of construction equipment. The reference station setup is shown in Photo 1. The estimated purchase price for six complete CAES units, including installation, training, and field support, is approximately $465,000. This cost may change as product supply increases, commercial demand increases, or competitive systems emerge.

The second component of the CAES equipment is the actual hardware placed on each piece of construction equipment. The machine hardware consisted of four items: a GPS antenna, a 900-MHz radio antenna, a signal converter, and a hardened 386 microcomputer with display. The GPS antenna was mounted on the cab of the Deployable Universal Combat Earthmover (DEUCE) and immediately behind the hopper of the 613B scraper. The radio antenna was mounted immediately behind the cab of both vehicles. The signal converter was mounted beneath the seat of the DEUCE and beneath the steering column of the 613B scraper. The computer processor/display was mounted in the upper right corner of each cab using custom-crafted mounting brackets. Each piece of equipment was mounted using temporary mounts and no effort was made to properly integrate the CAES equipment within the design of either piece of equipment to reduce maintenance requirements. Achieving optimum mounting and wiring of the CAES system was beyond the scope of this project. The GPS antenna was used to collect location data from the GPS satellites. The radio antenna was used to receive corrections from the reference station and exchange information with the CAES Office. The signal converter manipulated the GPS signal for input into the computer software. The processor/display was used to display project information including design, cut locations, fill locations, depths of cut/fill, current location, current grade, etc. Photos 2 and 3 show parts of the CAES machine hardware mounted on a DEUCE and 613B scraper, respectively.

The final component of the CAES technology was the CAES Office project management system. The CAES Office was composed of a hardened laptop, management software, and a 900-MHz radio antenna. The project officer uses the management software to transmit designs, receive GPS data, perform diagnostic checks, and provide real-time project status with visualization of cut/ fill locations. The CAES Office project management system permitted real-time observation of construction equipment location, cut/fill requirements, volumes of earth moved, and equipment status. The CAES Office system is capable of monitoring up to 30 project vehicles at any one time.

It should be noted that a fourth component of the CAES equipment existed in the form of a desktop computer loaded with the CAES Office project management system. The desktop computer was available for providing real-time project monitoring in offsite locations through an analog modem connection. This component of the system was not used in this project but certainly has application to military construction of expedient airfields.

Construction Equipment

The CAES equipment was installed on three DEUCEs and three 613B scrapers during this experiment. These machines were used for the construction of both ALZs. Only two DEUCEs and two 613B scrapers were used at any one time to maintain an extra DEUCE and scraper in reserve. This precaution was taken to limit the effect of maintenance and downtime on the experiment. Precisely controlling the number of machines operating during the construction phase was essential in accurately comparing the CAES system to the control experiment.

The DEUCE is a 35,500-lb air-droppable bulldozer manufactured by Caterpillar, Inc.®, designed to replace the D5 bulldozer for light engineer forces. The DEUCE has three key features including dual operating modes for earthmoving and self-deployment, a six-way blade for difficult cuts, and an electronically controlled engine/transmission combination. In the earthmoving mode, the DEUCE uses a standard powershift transmission powered by 185 hp with an operating speed of 7 mph. In the self-deployment mode, the DEUCE uses a six-speed fully automatic transmission powered by 265 hp with a maximum speed of 33 mph. The dual operating mode feature of the DEUCE permits self-deployment between construction sites without a dedicated transporter. The DEUCE also has rubber tracks to prevent damage to conventional pavements and applies a ground pressure of 9.2 psi. The DEUCE has a modular cab for removal during low-velocity airdrops. The DEUCE is 110 in. tall with the cab and 90 in. tall without the cab. The DEUCE is 257 in. long and 116 in. wide in the self-deploy mode. Other features include a climate-controlled cab, ergonomic operator controls, and an onboard diagnostic system.

The 613B scraper is an elevating scraper manufactured by Caterpillar, Inc.® with an 11-yd^3 capacity. The 33,620-lb 613B scraper is 103.3 in. wide, 424.4 in. long, and 93.6 in. tall. The 613B scraper is powered by a four-stroke diesel engine generating 150 hp at 2,200 rpm. The transmission is a powershift, torque converter drive with four speeds forward and two speeds in reverse. The maximum operating speed of the front-axle-driven 613B is 25.5 mph. The 613B scraper has articulated steering with a minimum turning radius of 29.3 ft. The hydraulically controlled elevator can be operated in forward or reverse, and the soil is ejected by a sliding floor and dozer-type ejector. The 613B scraper may also be airdropped and is the primary earthmoving equipment for light engineer units.

3 Experiment and Results

General Design

It is important to note the differences in ALZ airfield construction between a peacetime (training) mission and an actual (contingency) mission. In order to train for their wartime mission, units have been constructing training ALZ airfields for years. The peacetime construction of these airfields is a very lengthy process with significant time and effort associated with the design, planning, and approval process. This process has been delayed even more in recent years because of limited financial resources, increased environmental awareness, and more stringent geometric and structural strength requirements. Based upon the new force projection timelines, the design, planning, and approval process will have to be completed in as little as 1 to 2 days, while maintaining the same high standards in geometry and foundation strength. The transition of the military's assets from a forward-deployment strategy to a force-projection strategy will require new methods of contingency airfield construction and additional unit training.

Several of the tasks associated with the planning, design, and approval process were not considered in this experiment because the time and effort required would not change as a result of the addition of the CAES technology. The following tasks were assumed to be equal for both the CAES and Non-CAES construction methods and were excluded from the analysis:

a. Determining the airfield requirements.

b. Site selection.

c. Collecting the initial topographic data.

d. Generating the actual airfield design.

e. Soliciting design approval.

Although difficult to measure, CAES has the potential to affect the initial topography, design, and planning tasks listed above. If the initial topography was obtained using low-resolution satellite images, etc., the CAES could then be used to increase the topographic resolution and assist in refining the design as construction progresses. This capability only requires an initial design to begin earthwork, and a final design is generated as the resolution improves.

The experiment was designed to compare the construction methodology using the CAES equipment to current construction techniques. Two ALZ sections were designed to simulate segments of a C-17-capable runway. Each runway segment was 90 ft wide with 10-ft shoulders. Each ALZ section was 610 ft long with a small apron area on the north end measuring 60 ft wide by 100 ft long. In addition to these design features, a ditch was designed along the outside edge of each ALZ section. The ditches were included in the design to evaluate the system for a variety of earthwork operations. The two ALZ sections were designed as mirror images to each other using the available area within the confines of the test site. The ALZ sections were designed to have similar cut/fill requirements. Each runway section design required approximately 10,000 yd^3 of total cut and fill for completion. Each ALZ section was designed to have approximately 25 percent more cut than fill to account for waste. Figure 2 presents a plan view representation of the two ALZ designs, and Figure 3 illustrates a 3-dimensional (3-D) visualization of both ALZ sections within the test site. Photo 4 shows the condition of the test site prior to construction.

The 37th Engineer Battalion's personnel was provided with 3 weeks of training using the CAES equipment by Caterpillar, Inc.®, representatives from 26 February through 15 March 2001. The first 5 days of training consisted of classroom instruction and initial field instruction followed by 10 days of actual hands-on training. The training was designed to familiarize the equipment operators with the CAES technology but was not sufficient to ensure proficiency. The last 2 weeks of the period were to train computer personnel and supervisors to use the CAES Office project management system.

CAES Construction Method

The approach to ALZ construction using the CAES equipment greatly differs from traditional horizontal construction methods in many aspects. Because of the limited scope of the experiment, every potential aspect of the CAES product could not be examined in detail; however, possible uninvestigated advantages or disadvantages from the system are discussed throughout this report.

The CAES ALZ section was constructed from 26 March to 2 April 2001, using the CAES product. Monday, 26 March, was used to verify the initial topographic conditions of each site using both the CAES and conventional surveying methods. Earthwork for the CAES ALZ section began on 27 March and was completed on 2 April. No work was accomplished 29 March through 1 April because of rain. Site conditions remained generally the same with the exception of 2 April when conditions were somewhat wet following a weekend rain event. Significant time was spent on 2 April using DEUCEs to push the scrapers because of the muddy conditions.

The CAES experiment can be divided into three phases: preconstruction, construction, and reporting. Each of these phases will be described in detail regarding the key activities and data collected. A comparison of the CAES experiment to the Non-CAES control experiment will be made following the description of the Non-CAES experiment.

Preconstruction

As previously mentioned, many of the tasks that would normally be performed during the design, planning, and approval processes were not considered for this experiment. However, a modified task list was created specifically for the construction of each runway section to quantify the differences in time, effort, and manpower requirements between the two different methodologies. The methodology developed for the implementation of the CAES equipment during this experiment was relatively simple. Once the design is complete, there are only four tasks that must be completed:

a. Reference station setup.

b. File conversion from *.dxf and *.tin to *.cat.

c. Design files sent to machines via radio network.

d. Construction planning.

For the task of setting up the reference station, only the time and effort to place it into operation were considered, and the assumption was made that the survey control for the site had already been established. Survey control was established by arbitrarily placing a stake in the ground and assigning it a northing, easting, and elevation using a Trimble® GPS Backpack survey kit. Survey control was established in the same manner for both construction methodologies. The same survey control points were used for the construction of both runway sections.

The file conversion required for this method consists of exporting a *.dxf and a *.tin file from Terramodel® and importing the file into the Caterpillar system as a *.cat file. The file must then be loaded on the field laptop computer with CAES Office and sent through the radio network to each individual machine working on the site. Once the files have been uploaded to the machine's onboard computer screen, earthwork can begin.

The construction planning tasks include all activities by the constructing unit to plan the deployment of their personnel and equipment. The only timed event associated with construction planning was the actual operations order briefing conducted by the construction officer prior to the commencement of the earthwork.

Construction

The machine operators perform earthwork tasks with the CAES equipment by using their onboard display screens to determine the appropriate location for cut and fill. The operator either selects an area in which to work or is directed by the construction officer. Topographic data of the new elevation are recorded after each pass of the vehicle, and all files are updated accordingly. This information provides near real-time progress reports for use in command, and control of the project and can be viewed both by the other machines and the CAES Office laptop computer in the command center. This method provides the operators and supervisors with a computer-generated representation of cut/fill data. Thus, in theory, the CAES equipment provides the capability to accomplish grading work without the use of grade stakes. If some stakes are desired by the constructing unit in order to help define the shape of the project and limits of construction, then they could be placed with reasonable accuracy by using the GPS information shown on the onboard display.

The CAES ALZ section was constructed by employing the scrapers in a racetrack configuration in which the scrapers cut on the north end of the section and ejected the soil on the south end fill area. The DEUCEs were used primarily for the construction of the small apron area and the ditches. A depiction of the construction methodology used for the CAES section is shown in Figure 4. Photo 5 shows a scraper cutting on the north end of the CAES ALZ section. Photo 6 depicts a scraper dumping its load on the south end of the CAES ALZ section. Photo 7 illustrates a DEUCE working on the eastern ditch. Construction of this runway section was stopped at 20 hr of work, and it is estimated that the runway was 76 percent complete, based upon the total volumes of cut and fill. Approximately 74 percent of the required cut sections were complete, and 79 percent of the fill sections were complete, based on volumes. The time requirements for selected preconstruction, construction, and reporting events are summarized in Table 1. A summary of the daily earthwork productivity in terms of volumes of earth moved is shown in Table 2. A listing of manpower requirements for the construction process is shown in Table 3.

Reporting

An important consideration in any construction method is the degree of command and control provided to the construction officer and his/her ability to estimate completion percentages and remaining work. This is especially important during military operations in which time is often the controlling factor in many decisions. The CAES technology provided effective command and control through its CAES Office product. The construction officer views a real-time picture of the required cut/fill areas within the project site. This instantaneous picture of the project provided the construction officer with a significant tool for increasing situational awareness. During the construction of the CAES ALZ section, the construction officer noted inefficiencies and errors in the construction process, which were corrected by relaying updated instructions to the machine operators through a single noncommissioned officer (NCO) on the ground. Additionally, the CAES Office product was used to generate rapid estimates of the volumes of cut and fill performed. These instantaneous calculations provided the construction officer with the capability to rapidly report work progress and percent complete to higher echelons. Photo 8 shows the construction officer briefing a group of NCOs using the CAES Office technology.

Non-CAES (Control) Construction Method

The traditional approach to ALZ construction without the CAES equipment was used to construct the second ALZ section. Many of the components of this process have not previously been qualitatively or quantitatively assessed. The Non-CAES ALZ section was constructed during the period 3-5 April 2001. Site conditions remained generally the same with the exception of 3 April when intermittent precipitation occurred. The conditions for the construction of the Non-CAES ALZ were similar to those experienced during the CAES experiment except for the muddy conditions of 2 April. Thus, the muddy conditions during the CAES experiment probably resulted in some immeasurable loss of productivity. Photo 9 shows the soft site conditions on 2 April. The Non-CAES construction method was also divided into three phases: preconstruction, construction, and reporting.

Preconstruction

Using the traditional methods of airfield construction, the following tasks were performed:

a. Format and prepare the design for construction drawings.

b. Print construction drawings.

c. Format and select points required for site layout.

d. Site layout/staking.

e. Construction planning (operations order).

These small, yet critical, tasks ensure that the project is constructed according to the design. They are also significant because of the resources required to complete them. Computer hardware and software, as well as a plotter, are required for printing. A survey team with a geodimeter is required in order to layout the site with grade stakes. Soldiers must be proficient in computer-aided drawing (CAD) and surveying techniques to accurately and efficiently complete these tasks. This methodology introduces a high probability of costly and time-consuming errors.

Construction

Grade stakes were placed every 100 ft longitudinally with lateral offsets at points of major grade changes to effectively define the shape of the airfield. Photo 10 depicts several grade stakes that were used to establish cut/fill locations for the Non-CAES ALZ section. Considerable interaction between the surveyors and equipment supervisors was required to maintain the proper amount of grade stakes. For example, a large quantity of grade stakes placed on the ground will accurately define the shape of the runway; however, they may interfere with the equipment operator's ability to maneuver on the jobsite and cause many of them to be knocked down. Photo 11 shows a grade stake that was damaged during construction. On the other hand, too few grade stakes may not accurately define the shape of the runway, and inevitably result in misplacement of material or unsuitable geometry. Significant time to correct mistakes was required. A dedicated survey team was required to replace or add grade stakes. The survey team was also responsible for tracking the progress of the project by collecting periodic information on the amount of material cut or filled on the site. This required extensive survey work to determine the cross section elevations at different points on the project site.

The construction process using conventional construction techniques required one NCO to direct cutting operations on the north end of the ALZ section and one NCO to direct dumping operations on the south end of the ALZ. Photo 12 shows an NCO ground guide directing dumping operations during the Non-CAES ALZ construction. A third NCO was required to oversee both operations and to direct DEUCE activities pertaining to spreading the dumped material, shaping the ditches, and forming the small apron. The third NCO was also responsible for counting scraper loads as the basis for reporting volumes of earth moved and estimating project progress for conventional progress reporting. The Non-CAES methodology also used a racetrack technique for cutting material on the north end and dumping material on the south end. Photos 13 through 15 show general construction activities during the construction of the Non-CAES ALZ section. Figure 5 illustrates the deployment of construction equipment for the Non-CAES ALZ section. Site conditions remained generally the same with the exception of 3 April, when the site was moderately wet from rain that day and the preceding weekend. Although the site was somewhat wet, it caused very few problems and was not comparable to the muddy conditions encountered on the CAES ALZ section on 2 April.

Construction of this runway section was stopped at 20 hr of work, and it is estimated that the runway was 69 percent complete, based upon the total volumes of cut and fill. Approximately 63 percent of the required cut sections were complete, and 77 percent of the fill sections were complete, based on volumes. Tabulated results from both experiments are shown in tables at the end of this chapter. The time requirements for selected preconstruction, construction, and reporting events are summarized in Table 1. A summary of the daily earthwork productivity in terms of volumes of earth moved is shown in Table 2. A listing of manpower requirements for the construction process is shown in Table 3.

Reporting

The traditional method of achieving command and control of the construction project consisted of fully utilizing the military's rank structure. The construction officer issued directives to his NCOs, who then conveyed the instructions to the troops. Thus, command and control required increased manpower. NCOs were strategically located around the project site to direct the construction activities and monitor progress. During the construction of the Non-CAES runway section, some earth was moved to an improper location. After a short period, an NCO checked the grade stakes and began correcting the error. However, the mistake required increased engineering effort to correct the problem. One NCO was also responsible for counting scraper loads as the basis for reporting volumes of earth moved and estimating project progress. The construction officer's estimated progress in terms of volume of earth moved for the Non-CAES experiment were 6,700 yd^3, while the actual volume moved according to the CAES Office system was 6,517 yd^3. The average error of the total estimate was only 2.8 percent. However, the average error of the NCO's daily estimates was 17.5 percent since the errors included both overestimates and underestimates.

Night operations

A potential benefit of modifying existing construction equipment with the CAES technology is enhanced earthmoving capabilities at night. Under current construction methodologies, light engineer units only conduct night operations using the equipment lights with or without floodlight systems. Generally, operations with only the equipment lights are limited to special circumstances because of increased safety concerns. During the experiment, a DEUCE and a 613B Scraper were used to conduct selected operations at night on 28 March and 5 April, respectively. Each night operation experiment included the following operational modes: CAES with Night Vision Goggles (NVGs), CAES without NVGs, and CAES with lights. Each night operation used a simplistic design and did not interfere with the official demonstration. The DEUCE night operations were conducted in an area immediately to the East of the CAES ALZ section using a simplistic design. The scraper night operations were conducted on the Non-CAES ALZ section following the completion of the official earthmoving demonstration in order to provide adequate maneuver space.

The volumes of earth moved for the night operations are shown in Table 4 at the end of this chapter. The results of the night operations demonstrated an enhanced capability for conducting earthmoving operations at night. Both the DEUCE and the scraper were effective in performing earthwork. The scraper's productivity shown in Table 4 was greater than that of the DEUCE during these limited tests. Both pieces of equipment were more effective performing cut operations than fill operations. Two operators were used in each set of night operations, and the most experienced operator was more effective in both cases. Operator comments indicated that the preferred operating mode was CAES with lights, followed by CAES without NVGs, and then by CAES with NVGs.

The results of these limited tests indicate that the CAES equipment could be an effective tool for enhancing night earthwork operations. The CAES technology demonstrated the capability of operating without lights, which would significantly reduce light signatures during hours of limited visibility. One negative point is that of safety concerns. The location of other machinery and pedestrian traffic cannot be detected on the onboard display of each piece of equipment. The CAES Office component can see all construction vehicles. Theoretically, the CAES Office user could radio equipment operators to prevent potential collisions. Additional precautions could include sectionalizing the design into smaller designs with buffer zones between individual pieces of equipment and/or using "chem lights" to establish boundaries. Photos 16 and 17 show the night signature of the onboard CAES display and earthmoving operations through NVGs, respectively.

Productivity Analysis

Five criteria were used to compare the CAES construction methodology to the Non-CAES traditional horizontal construction methodology:

a. Time requirements.

b. Earthwork productivity (Volumes of earth moved).

c. Manpower requirements.

d. Situational awareness.

e. Accuracy of the system.

Time requirements

The time required to perform preconstruction, construction, and reporting activities was monitored for both the CAES and Non-CAES methodologies. Table 1 at the end of this chapter shows a comparison of the results, which indicates that the activities required for the construction of the Non-CAES section required 1,703 min (28.4 hr) longer than the activities required for CAES construction. Eighty-four percent (84 percent) of the time reduction was related to preconstruction activities. This large reduction in time requirements was primarily attributed to the omission of the need for printed copies of detailed design drawings.

Earthwork productivity

The second evaluation criterion was a comparison of the earthwork productivity in terms of volumes of earth moved. Table 2 at the end of this chapter tabulates the volumes of earth moved, based upon daily reports from the CAES Office system which compared the ground topography at the beginning of an analysis interval to the topography at the end of the analysis interval. As mentioned previously, the CAES experiment moved 76 percent of its design earth volume within the allotted 20 hr of operation. The Non-CAES experiment moved 69 percent of the design earth volume for the control ALZ section within the allotted 20-hr operation period as measured by the CAES software. Figure 6 provides a 3-D Terramodel® visualization of the both the design and completed grades of both ALZ sections. Photos 18 and 19 show the final condition of the CAES and Non-CAES ALZ sections, respectively. Since the actual design volumes were slightly different, the CAES methodology actually moved only 370 yd^3 more earth than did the traditional methodology, which is a 5.4-percent increase in productivity.

The average daily productivity rates for the CAES and Non-CAES experiments were 363 and 344 yd^3/hr. These rates are for each hour of operation using two DEUCEs and two 613B scrapers. Thus, a 19-yd^3/hr increase in productivity was achieved using the CAES equipment. Dividing the productivity rates by four provides an estimate of the hourly productivity for one piece of equipment. The CAES equipment resulted in a unit productivity of 91 yd^3/hr, while the Non-CAES methodology generated a unit productivity of 86 yd^3/hr. It is impossible to distinguish the unit productivity rates between the DEUCE and the Scraper from this experiment; however, these average hourly rates could be used to make educated assessments concerning the time required to move a given amount of material using mixed construction equipment.

Figure 7 shows a plot of the volumes of earth moved during each experiment in terms of volumes of cut and volumes of fill. Both experiments performed more cut than fill, as was expected. The CAES experiment moved more earth, but its rate decreased sharply during the final day of construction. Figure 8 shows a plot of the daily productivity for the CAES and Non-CAES experiments. Both experiments show reduced productivity as the project is nearing completion. The decrease in productivity for the CAES experiment on the third construction day may have been caused by the muddy conditions on 2 April. The loss in productivity may be the result of using the DEUCEs to push the scrapers through muddy sections of the ALZ. Photo 20 shows a DEUCE pushing a 613B scraper during the poor site conditions on 2 April. The Non-CAES experiment appears to provide more uniform productivity rates, while the CAES experiment demonstrated most of its productivity increase in the early stages of the project.

Manpower requirements

Table 3 at the end of this chapter shows the manpower requirements for both construction techniques. The table indicates that the CAES methodology requires two fewer NCOs on the ground than the Non-CAES traditional methodology. The table also indicates that the elimination of the requirement of a dedicated survey crew reduces the required surveying manpower by one NCO and four soldiers for the CAES methodology. Note that the reference station setup would best be accomplished using 51T (surveyor) support but was excluded from the manpower comparison since the task only took 5 min. Thus, the total reduction in manpower for the CAES experiment over the Non-CAES experiment was three NCOs and four soldiers. This reduction in manpower requirements translates into reduced engineer effort and logistics support.

Situational awareness

A comparison of the situational awareness of the construction officer using the CAES equipment versus traditional construction procedures was also made. The CAES equipment was effective in providing increased situational awareness by identifying the location of errors/gaps in the progress, thus enabling the construction officer to issue immediate directives for refocusing the engineer assets. The CAES equipment also reduced errors caused by the misplacement of survey stakes and improper readings of marked survey stakes. The CAES Office technology provided instantaneous progress updates and aided in determining the percent of project completion. These command and control benefits combined to provide increased situational awareness to the construction officer.

Accuracy

One of the benefits of the CAES equipment was the reduced manpower in terms of eliminating the need for a dedicated survey team. The elimination of the need for survey stakes also reduced the time required for the initial stakeout and restaking of the ALZ. A primary concern with relying upon CAES's GPS technology for controlling earthwork activities is the horizontal and vertical accuracy of the GPS network. The accuracy of the CAES GPS network was evaluated by placing two control points within the test site at known elevations using the geodimeter. The location and elevation of these control points were measured using the geodimeter, a Trimble® GPS backpack survey kit, the CAES unit on a DEUCE, and a laser leveling system. The laser leveling system only provided elevation data.

The results of these comparison tests are shown in Table 5, which indicates that the accuracy of the CAES network compared to the geodimeter was within 1.92 in. in the northing direction and 9.60 in. in the easting direction. The source of the discrepancy in the magnitude of error between the northing and easting measurements is unknown. Thus, a horizontal accuracy of 9.6 in. was achieved during this experiment but may be the result of a systematic and correctable error. A comparison of the vertical accuracy between the CAES GPS network and the geodimeter indicated that a vertical accuracy of "2.28 in. was achieved. These accuracy tolerances are sufficient for rough earthwork activities, and may be sufficient for construction of contingency airfields. Thus, utilization of the CAES technology may preclude the requirement for surveying for contingency airfield construction. Another interesting observation is that the accuracy of the Trimble® GPS Backpack was within approximately 0.84 in. of the geodimeter results.

User Issues

The following paragraphs summarize the pertinent user issues pertaining to unit description, training, operation, maintenance, and recommended modifications. The information provided attempts to summarize the responses of the users of the CAES equipment during the experiment as expressed in after action reports (AARs).

Unit description

Two separate units from the 37th Engineer Battalion were involved in the experiment, one light equipment platoon, and one survey team. The light equipment platoon's composition included one 1st Lieutenant, five NCOs, and seven equipment operators. Their average GT score was 110 with education levels ranging from a General Education Diploma (GED) to an Associates Degree. The NCOs had an average of 3 years of computer experience. The platoon's operating experience ranged from 1 to 15 months for the DEUCE with an average of approximately 1,230 operating hours per soldier. The platoon's operating experience with the 613B scraper ranged from 1 month to 11.5 years with an average of 2,250 hr per soldier. The seven-member survey team consisted of one specialist, five privates first class (PFCs), and one PV2. The unit's average education level was a high school diploma. All of the team's survey experience was military with a range of 6 months to 2 years and an average of 1.5 years experience per team member. The team's experience with Terramodel® ranged from 1 month to 2 years with an average of 7 months. The survey team's leadership was deployed at the time of the experiment, and the specialist was in command.

Training

The 37th Engineer Battalion's personnel were provided with 3 weeks of training using the CAES equipment by Caterpillar®, Inc., representatives from 26 February through 15 March 2001. The training consisted of 5 days of classroom training and initial field training followed by 10 days of actual hands-on training. The training was designed to familiarize the equipment operators with the CAES technology but was not sufficient to ensure proficiency. The last 2 weeks of the training period were also used to train computer personnel and supervisors to perform the file conversion process and use the CAES Office project management system.

The operator training primarily consisted of teaching the operators how to read and understand the display screens on the equipment. User comments indicated that the training was very good and the system was both easy to use and understand. The operators indicated that the system was useable at the PFC-rank level. The CAES Office training was deemed insufficient by the users who requested more hands-on training and instruction manuals. A basic knowledge of computers and software greatly assisted in understanding the project management software. This system was recommended at the NCO level and above. User comments centered upon increased CAES Office simplification, training, and the need for troubleshooting training.

The survey team's training with the CAES equipment consisted of both file conversion training from Terramodel to CAES-compatible software and the reference station setup. While the survey team indicated that the file conversion training was adequate, the training appeared to be insufficient during the actual timed event. The reference station setup training was effective, but most users indicated that the software component of the setup should be simplified.

Operations

Pertinent user comments regarding the actual use of the CAES equipment during the construction process were collected along with comparisons to the traditional construction methodology. The operators indicated that the CAES system improved their ability to make accurate cuts and avoid slope errors, improved the situational awareness of the entire engineer unit, and eliminated the concerns regarding damaging grade stakes. The users commented that it was easier for inexperienced operators to understand their roles and be productive. The users indicated that the CAES equipment did not significantly affect the preventive maintenance checks and service (PMCS) requirements for the construction equipment.

The operators indicated that boundary stakes were needed to mark the perimeter, identify steep cuts, and shape ditches. While the general comments indicated increased situational awareness, NCOs were concerned with the inability to instantly determine if cuts and fills were being performed in the right locations. It was noted that the design itself becomes the focus, and NCO site adjustments are almost eliminated. The operators also indicated that they generally did not like using NVGs when operating at night.

Maintenance

One user concern centered upon the maintenance requirements of the CAES equipment as compared to the normal maintenance concerns. During the experiment, approximately six unscheduled maintenance incidents were recorded concerning the earthmoving machines themselves. Only two of the six incidents were related to the CAES equipment. The CAES related incidents included the loss in tracking of a DEUCE and a pinched coaxial cable on a 613B scraper. The Non-CAES maintenance items included a serious hydraulic leak on a DEUCE, a hydraulic leak on a 613B scraper, an oil leak on a DEUCE, and locked brakes on a DEUCE. The CAES-related incidents were rectified in less than 1 hr, while the Non-CAES incidents took substantially longer and required transport to a manufacturer service center in the rear for repairs. In addition to the machine maintenance, three additional CAES-related maintenance issues were recorded concerning the operation of the reference station and the CAES Office system. The reference station was down for approximately 95 min, because it only observed five satellites while six are required for resolution. The coaxial cable to the CAES Office system was cut twice, once by inadvertently closing the door of the command center on the cable and once by a DEUCE. Overall, the maintenance issues concerning the CAES system were minor in comparison to typical maintenance issues associated with operating the earthmoving equipment. Several of the incidents could have been avoided if the system had been properly integrated into the equipment rather than temporarily mounted. Many of the users were impressed by the ability of the CAES display to withstand the intense roughness of operating inside a scraper cab.

Recommended modifications

Throughout the experiment, the equipment users provided feedback concerning potential modifications and improvements to the CAES equipment for military use. Recommended modifications to the machine hardware included these additions to the display: anti-glare shield; ability to quickly turn on/off; ability to track/locate other machines; onboard communications as a text line or radio; latitude and longitude rather than northing and easting; and a clock. Other modifications to hardware should include: integration of the system wiring, painting of the GPS receiver, improving real-time updates, and providing at least one hand-held microcomputer display for the on-the-ground NCO to observe. Recommendations concerning the reference station setup included the need for simplified setup process and ruggedized hardware. The recommendations regarding the CAES Office system included: ruggedizing the CAES Office unit, adding compaction module software (permit GPS monitoring of compaction), improving the productivity report to include individual machine performance and percent complete, adding text labels to the design, and adding a message system to transmit directives from the construction officer to an individual operator. It was noted that the repeater packages should be evaluated for large sites, and troubleshooting guides should be developed.

Non-CAES related recommendations include construction helmets with built-in communications and increased training in engineering activities. The night operations highlighted the need for onboard communications and the ability to track/locate other construction equipment locations.

Table 1
Event Times for CAES and Non-CAES Experiments

Event	Time, min	
	CAES	Non-CAES
Topographic Survey[1]	190	90
Airfield Design	Same	Same
Preconstruction		
Reference Station Setup	5	N/A
File Conversion from *.dxf and *.tin to *.cat	32	N/A
Upload Design from CAES Office to Machines	30	N/A
Develop Construction Drawings	N/A	960
Print 5 Sets Construction Drawings (10 pages/5 min. per page)	N/A	250
Select Stakeout Points	N/A	60
Upload Stakeout Points to Geodimeter	N/A	25
Initial Stakeout of Airfield Section	N/A	195
Operations Order	10	25
Subtotal:	*77*	*1,515*
Time Savings:	*-1,438*	*-*
Construction		
Actual Machine Operation (2 DEUCEs and 2 613B Scrapers)	1,200	1,200
Restaking (5 Separate Events)	N/A	255
Subtotal:	*1,200*	*1,455*
Time Savings:	*-255*	*-*
Reporting		
Estimate Volumes of Earth Moved	<5	15
Estimate Percent of Project Completion	<5	<5
Subtotal:	*10*	*20*
Time Savings:	*-10*	*-*
Total:	**1,287**	**2,990**
Time Savings:	**-1,703**	**-**

[1] Topographic survey method was assumed to be the same for either experiment and not included in the comparison of results. The CAES survey was completed using a 3-ft grid, and the geodimeter survey used a 50-ft grid.

Table 2
Volumes of Earth Moved

Date	Analysis Period	Operation Time hr	Daily Cut & Fill Estimates[1] Cut yd^3	Fill yd^3	Total Cut & Fill yd^3	Productivity yd^3/hr
CAES Section						
26-Mar-01	*Design*	*0.00*	*5,325*	*4,201*	*9,526*	-
27-Mar-01	Day 1	4.50	1,152	1,239	2,391	531.3
28-Mar-01	Day 2	6.25	1,487	1,014	2,501	400.2
2-Apr-01	Day 3	9.25	1,295	1,078	2,373	256.5
	Total:	20.00	3,934	3,331	7,265	363.25
Non-CAES Section						
2-Apr-01	*Design*	*0.00*	*5,838*	*132*	*9,970*	-
3-Apr-01	Day 1	8.00	1,630	1,336	2,966	370.8
4-Apr-01	Day 2	7.50	1,204	1,373	2,577	343.6
5-Apr-01	Day 3	4.50	865	487	1,352	300.4
	Total:	20.00	3,699	3,196	6,895	344.75

[1]Daily cut and fill estimates are based upon the "To Be Cut" and "To Be Filled" calculations generated by the CAES Office software. These estimates do not include earth moved outside of the surveyed test site (if any). Note: A yd^3 can be converted to a m^3 by multiplying by 0.765.

Table 3
Manpower Requirements for Demonstrations

Individual	Primary Task	Number Required CAES	Non-CAES
Construction Officer	Supervision	1	1
Noncommissioned Officer (NCO)	Supervision/Construction	1	3
Equipment Operators	Construction	4	4
51T Personnel	Design/Surveying/Soils	0	5
Man-Hour Requirements	-	120	260
Percent Reduction (%)	-	*54*	*0*

Table 4
CAES Night Operations of DEUCE and 613B Scraper

Date	Equipment	Operation Time min	Cut/Fill Estimates Cut yd^3	Fill yd^3	Productivity yd^3/hr
DEUCE Night Operations					
28-Mar-01	DEUCE Design	0	105	87	-
28-Mar-01	DEUCE Productivity	32	72	11	156
613B Scraper Night Operations					
5-Apr-01	Scraper Design	0	563	704	-
5-Apr-01	Scraper Productivity	120	324	138	231

Note: A yd^3 can be converted to m^3 by multiplying by 0.765.

Table 5
CAES Accuracy Measurements

Elevation Accuracy

Device	Elevations, ft Control Points 1	2
Geodimeter	277.56	277.81
Trimble® Laser Level	277.57	277.32
Trimble® GPS Backpack	277.5	277.74
CAES (DEUCE)	277.4	278
Difference b/w CAES & Geodimeter	0.16	-0.19
Difference in inches	1.92	-2.28

Geospatial Accuracy

Device	Location of Control Points, ft			
	1		2	
	N	E	N	E
Geodimeter	4805.13	9735.10	4818.86	9763.29
Trimble® GPS Backpack	4805.186	9735.120	4818.930	9763.335
CAES (DEUCE)	4805.0	9734.3	4818.7	9762.5
Difference b/w CAES & Geodimeter	0.13	0.80	0.16	0.79
Difference in inches	1.56	9.60	1.92	9.48

Note: Feet can be converted to meters by multiplying by 0.3048.
Inches can be converted to centimeters by multiplying by 2.54.

4 Conclusions and Recommendations

Conclusions

Two simulated ALZ sections were constructed side-by-side at Fort Bragg, North Carolina, during the period 26 March to 6 April 2001. A light equipment platoon, Company A, 37th Engineer Battalion, performed the construction of both ALZ sections, one employing the CAES technology and one using current horizontal construction procedures. The purpose of the experiment was to evaluate the CAES technology for use in military airfield construction. The following conclusions were derived from the experiment and subsequent analysis of data:

a. The CAES construction method moved approximately 5.4 percent more earth in a 20-hr period based upon the volume estimates reported by the CAES Office project management system for the CAES and Non-CAES ALZ sections. This difference may change if the project is allowed to approach final grade, which is traditionally a less productive construction period. This value may also be a function of the size of the project, since only a limited section of an ALZ was used in this experiment.

b. The CAES construction method reduced the time required for pre-construction activities and restaking from 49.5 to 21.3 hr. This 28.2-hr reduction resulted from the use of a digital design and the elimination of grade stakes. Note that the time saving associated with most of the pre-construction activities would not be affected by the size of the project, but the initial stakeout and restaking activities would increase proportional to the project size.

c. The CAES construction method reduced the manpower requirements by 54 percent or 140 man-hr based upon the omission of two NCO ground guides and a dedicated five-man survey team.

d. The CAES technology provided a vertical accuracy within 2.3 in. and a horizontal accuracy within 9.6 in. compared to geodimeter measurements for this experiment. Note that the horizontal accuracy was skewed in one direction, indicating the possibility of a correctable systematic error. These levels of accuracy indicate that the CAES technology may be appropriate for final grade construction during contingency operations, but not the final grade construction of permanent facilities. Thus, a survey team would be required for the final grade construction of permanent facilities.

e. The CAES technology provided increased situational awareness regarding the location and activities of fielded equipment, a high-resolution picture of the existing grade, instantaneous productivity reports, and a consolidated picture of the entire project.

f. The CAES technology also increased the ability of the engineer unit to operate at night. Although the users preferred the use of equipment lights, they demonstrated the ability to operate without lights using only the CAES equipment.

g. The CAES equipment should not significantly affect rapid deployment transport procedures and may permit the immediate initiation of earthwork during rapid deployment operations.

h. The construction unit indicated that the CAES technology was easy to learn and understand. The CAES Office component was the most difficult to achieve user proficiency, and additional training was requested. The CAES technology does require computer skills to operate. The users indicated that the machine hardware was useable at the PFC level, while the CAES Office component was useable at the NCO level.

i. The CAES equipment had minimal impact upon standard PMCS activities compared to current equipment maintenance requirements. The ability to rapidly switch from CAES to Non-CAES operations should minimize the impact of potential technology maintenance problems.

The results of the experiment were used to compare the CAES construction method to current construction techniques. The CAES equipment provides soldiers with an improved earthmoving capability compared to current horizontal construction methods. The CAES equipment improved the earthmoving productivity, reduced the time required for various construction activities, reduced the manpower requirements, and increased the construction officer's situational awareness. Sufficient vertical and horizontal accuracy was demonstrated to justify use during all earthmoving activities and particularly appropriate for contingency operations.

Recommendations

The following recommendations are based upon the results and conclusions of the experiment described in the previous text:

a. Since the CAES technology was the first commercially available product selected for evaluation during the JRAC program, alternative commercial technologies should be evaluated to determine the enhancement capabilities of other systems.

b. The CAES system should be evaluated during the construction of a full-size ALZ in order to fully identify benefits and limitations in an actual ALZ construction scenario.

c. The CAES system should be evaluated during a controlled night operations experiment versus conventional night operation procedures (flood lights) in which multiple pieces of equipment are used.

d. A benefit-to-cost analysis should be conducted to determine the cost effectiveness of procuring a system with similar productivity enhancements.

e. Compaction and earthwork are interrelated during the airfield construction process, and the potential benefits of a compaction module should be explored.

f. As noted during the experiment, the time requirements for various pre-construction activities were excessive. Many of these activities were considered identical for both the CAES and Non-CAES construction methods, so they were not evaluated in this experiment. Significant time reductions may be realized by evaluating enhancements to pre-construction activities.

g. During the construction of the ALZ sections, it became apparent that the training requirements for the 51T personnel were inadequate. Additional training activities should be planned for the 51T personnel to become proficient in soil testing, surveying, and drafting.

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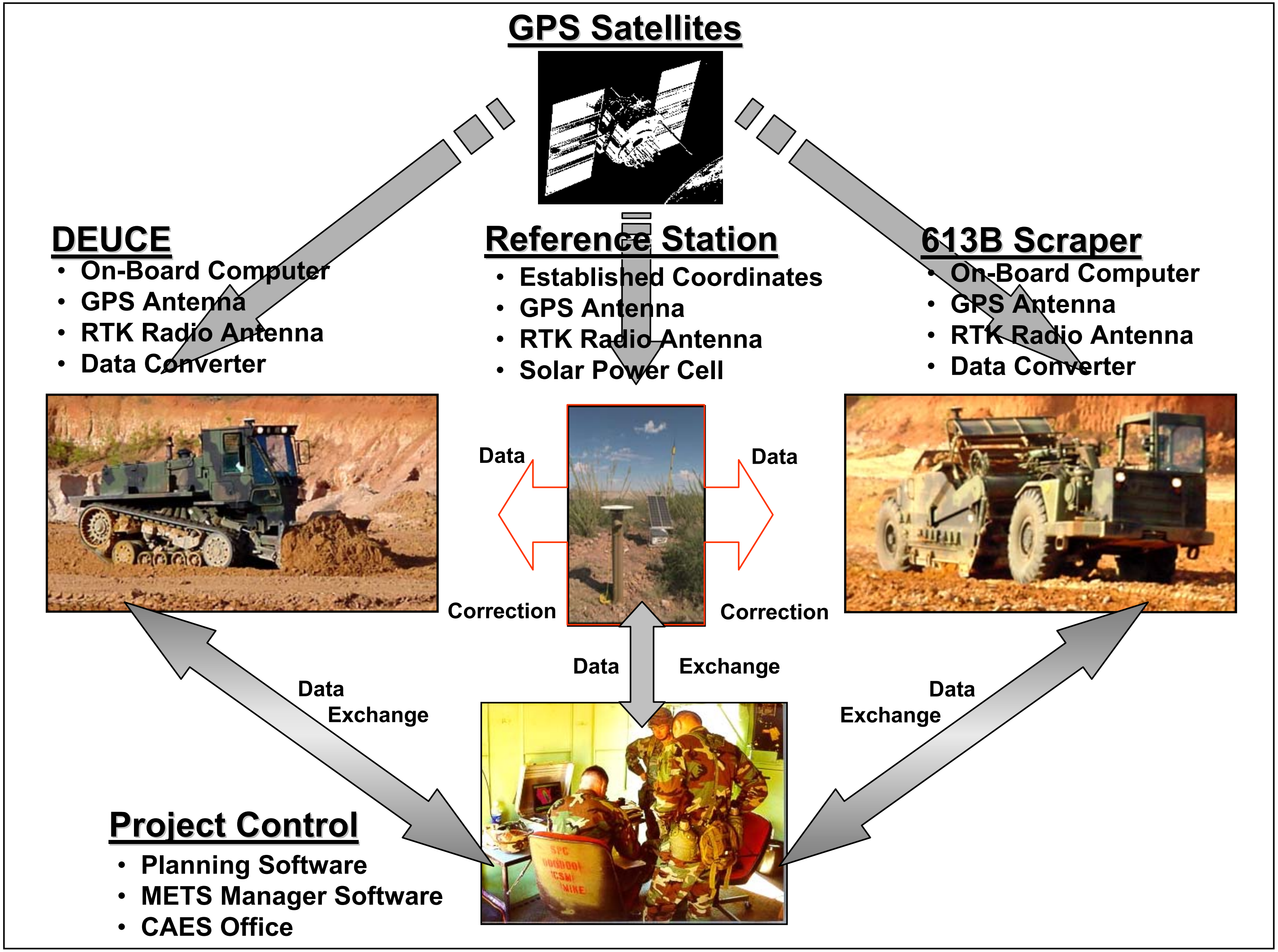

Figure 1. CAES network setup

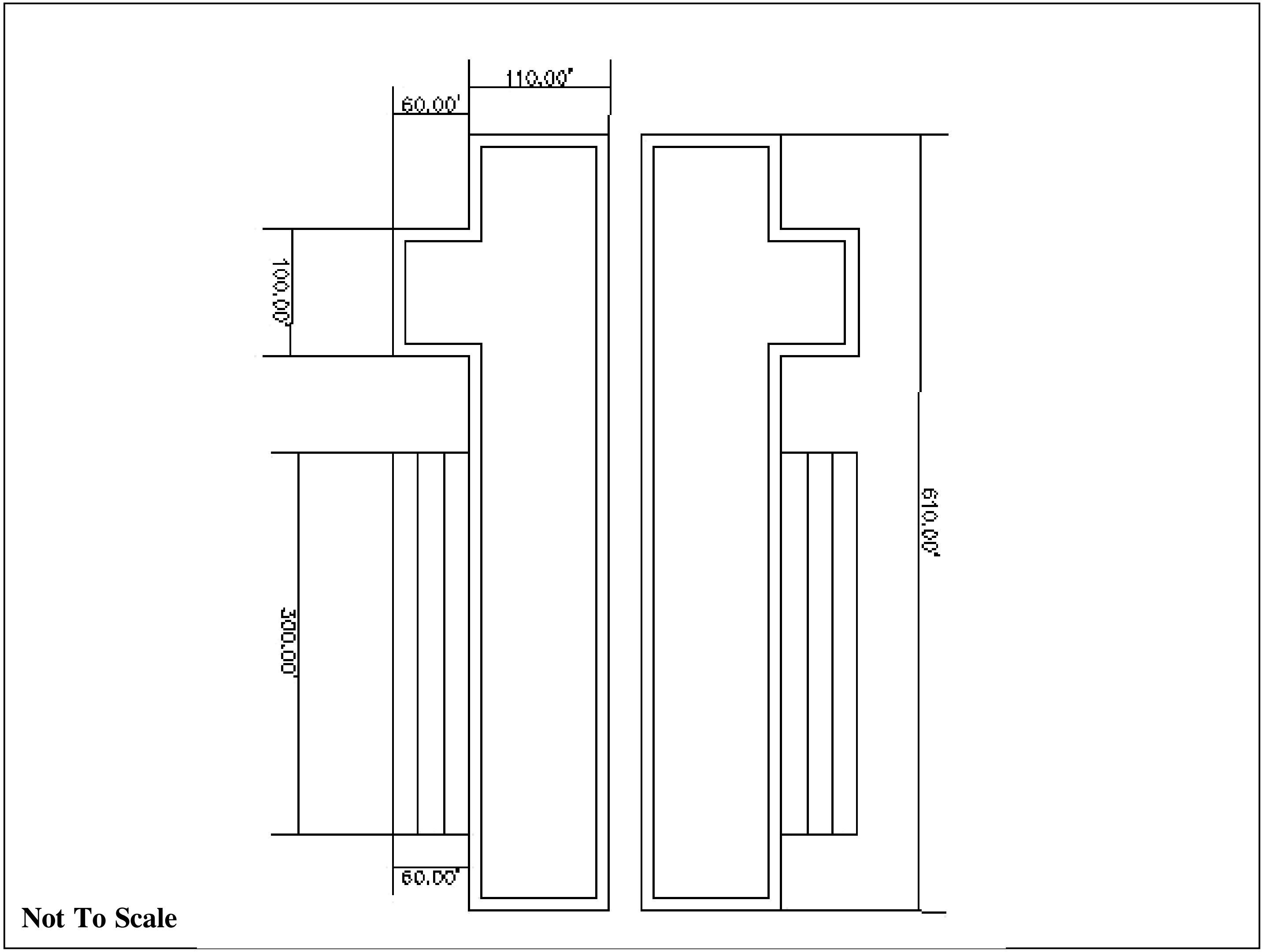

Figure 2. Plan view of geometric design of both ALZ sections

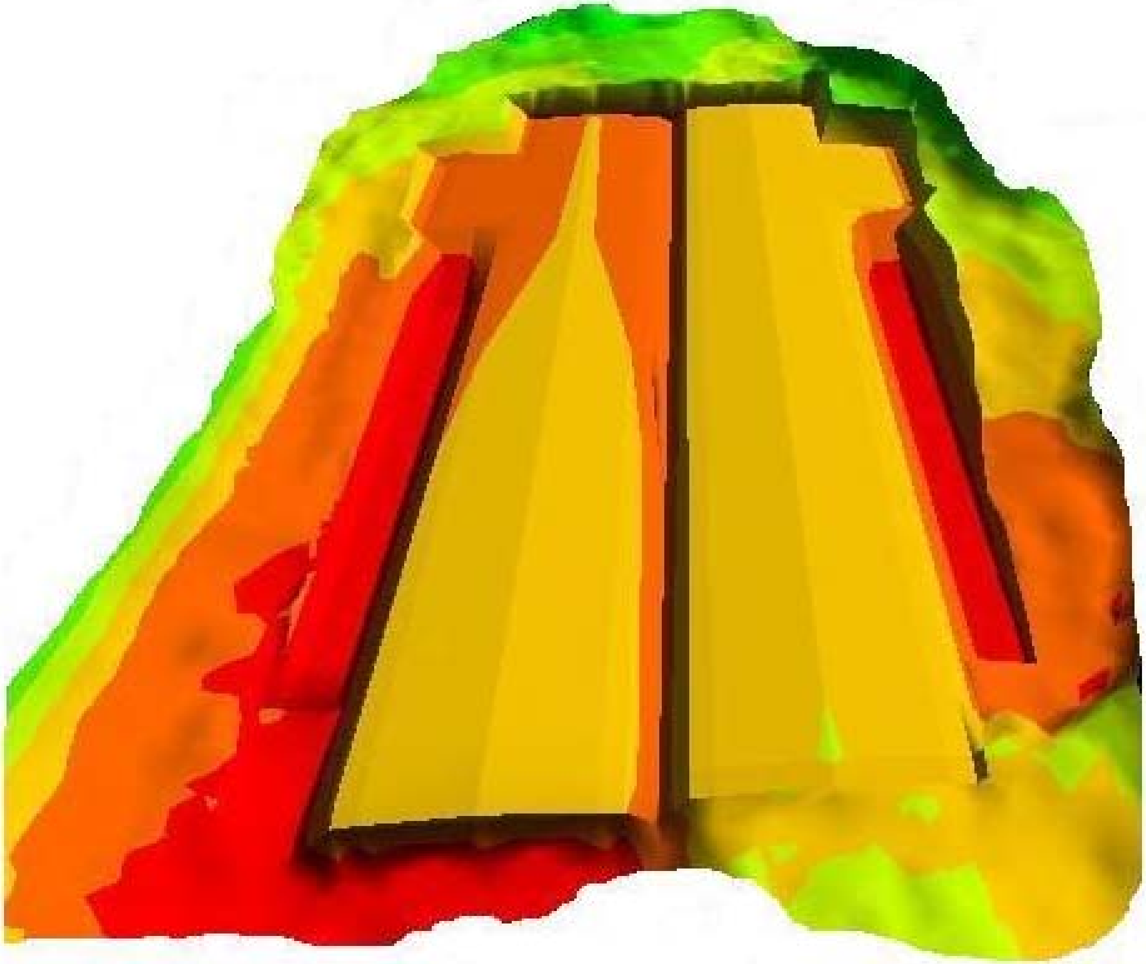

Figure 3. 3-D visualization of design surface for both ALZ sections

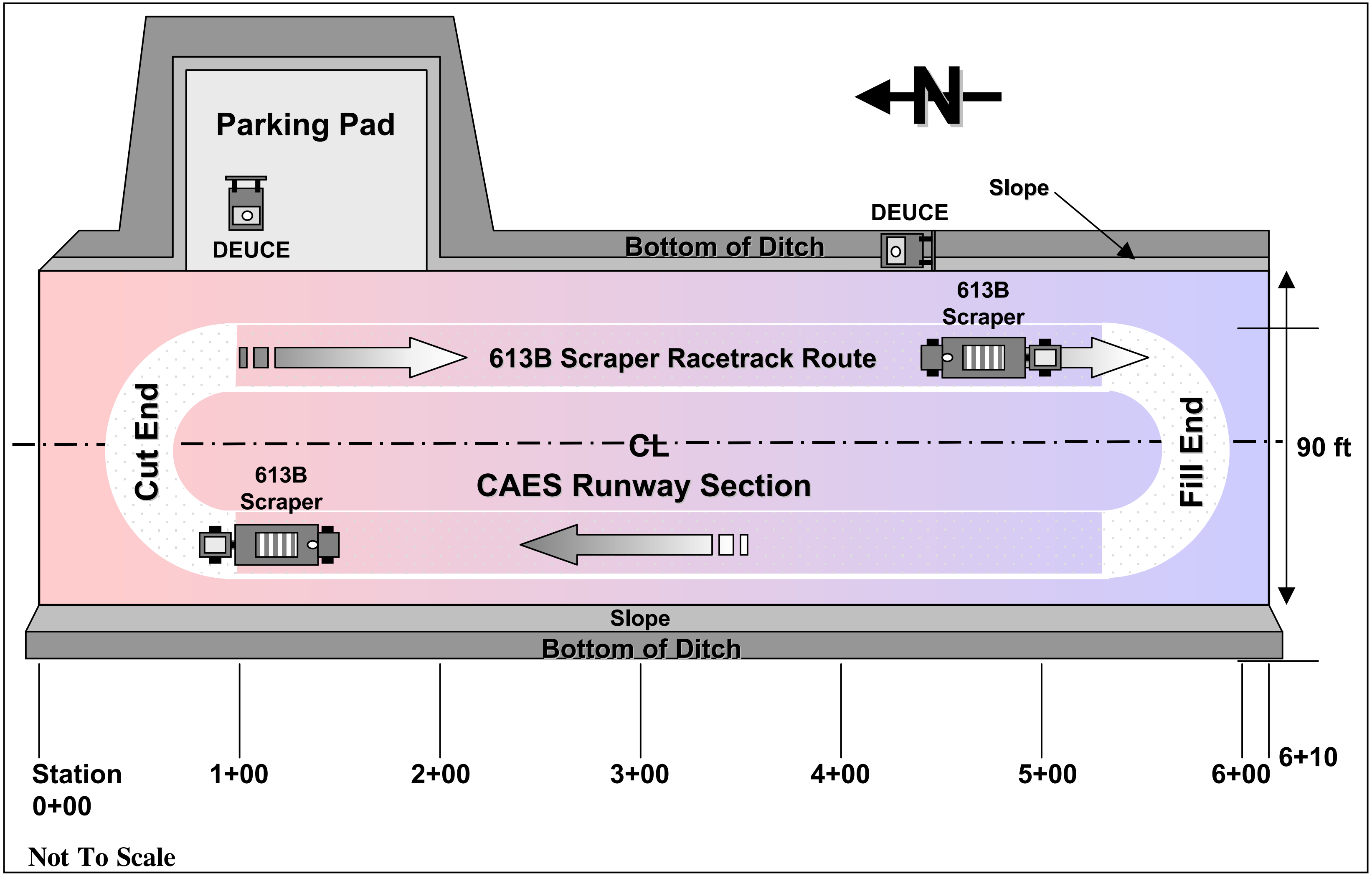

Figure 4. Construction deployment diagram for CAES section

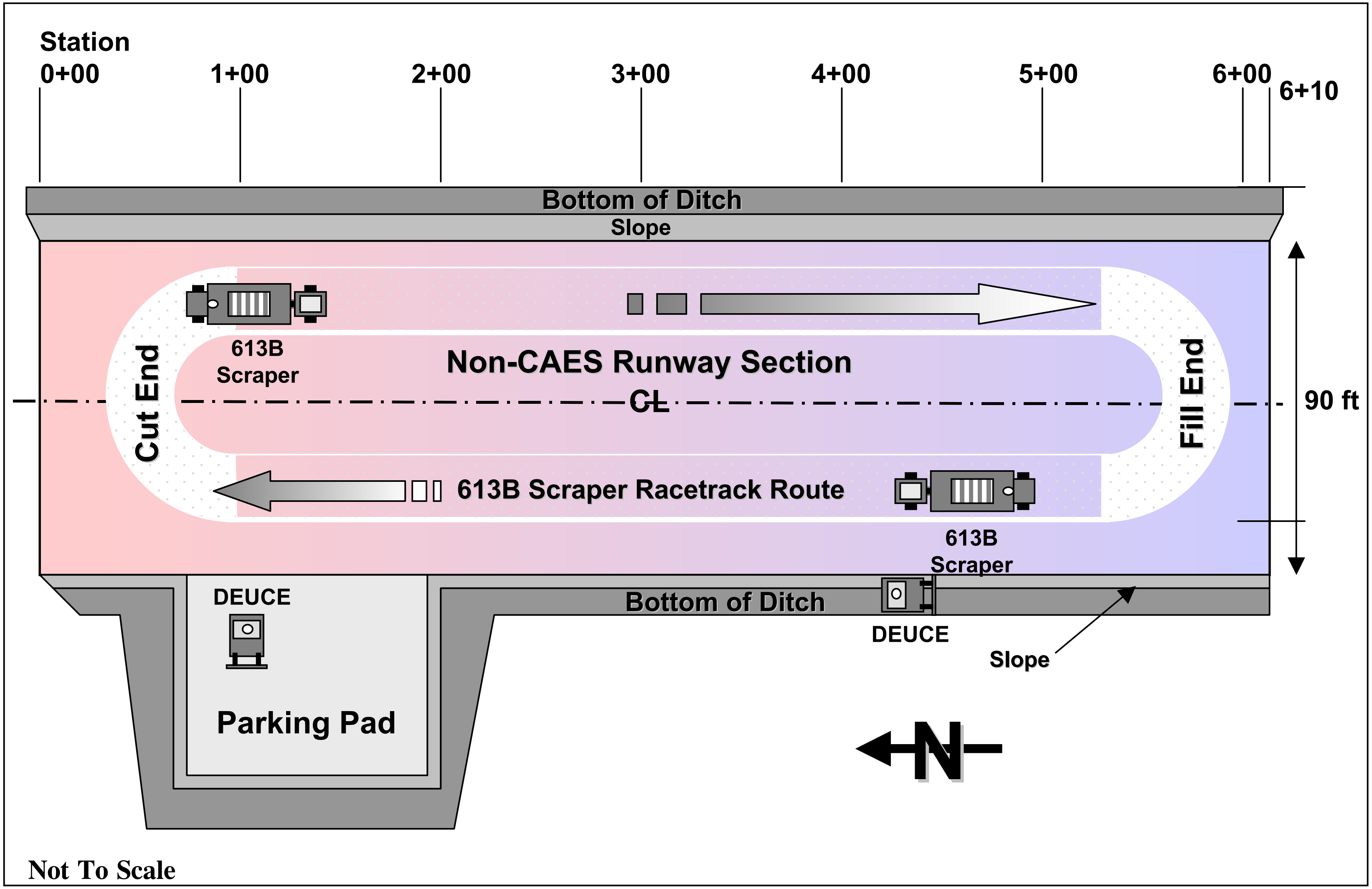

Figure 5. Construction deployment diagram for Non-CAES section

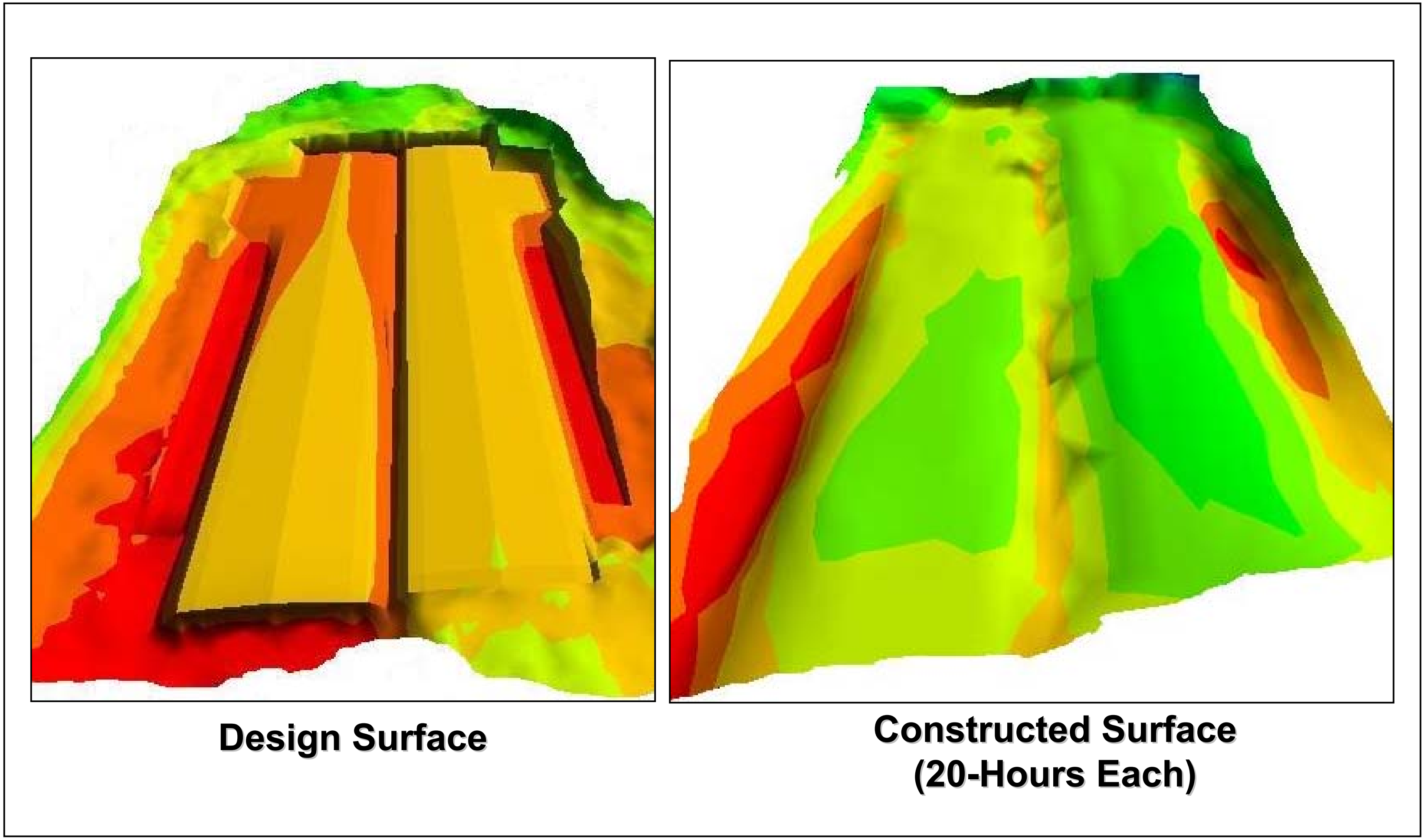

Figure 6. 3-D visualization comparison of design surface to constructed surface

Photo 1.   Reference station configuration

Photo 2.   CAES mounted on a DEUCE

Photo 3. CAES mounted on a 613B scraper

Photo 4. Condition of test site prior to experiment

Photo 5. 613B scrapers cutting on the north end of the CAES ALZ section

Photo 6. 613B scraper dumping on the south end of the CAES ALZ section

Photo 7. Deuce operating on the CAES ALZ section

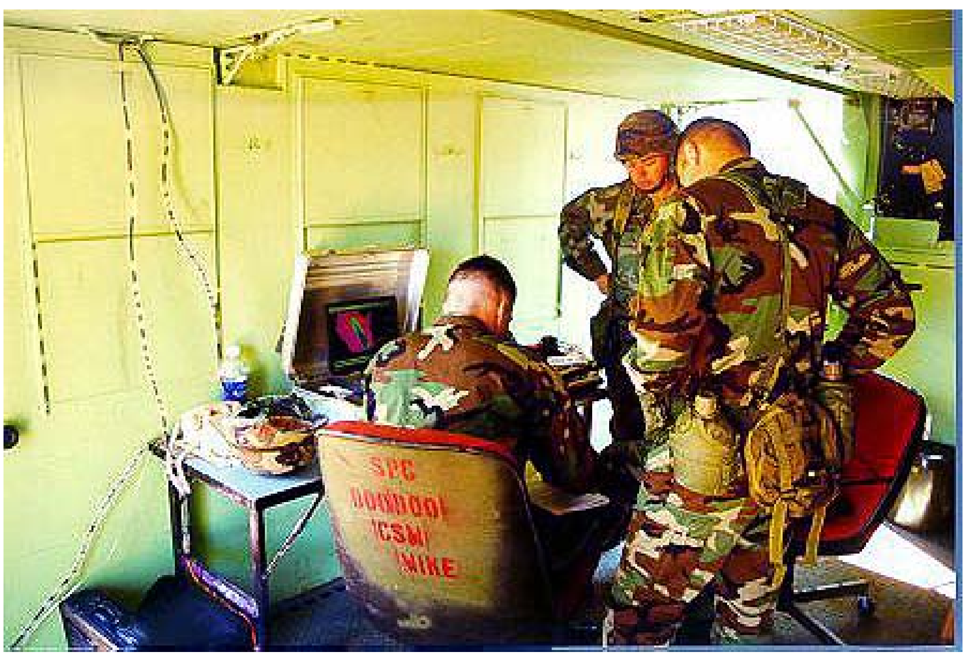

Photo 8. Construction officer briefing NCOs using CAES Office

Photo 9. Soft site conditions on April 2, 2001

Photo 10. Grade stakes marking cut/fill locations for Non-CAES ALZ section

Photo 11. Damaged grade stake on Non-CAES ALZ section

Photo 12. NCO ground guide directing dumping operations on Non-CAES ALZ section

Photo 13. Cutting operations during construction of the Non-CAES ALZ section

Photo 14. Ditch cutting operations on the Non-CAES ALZ section

Photo 15. Cutting and dumping operations on the Non-CAES ALZ section

Photo 16. 613B scraper night operations through NVGs

Photo 17.   613B scraper cutting during night operations

Photo 18.   Final constructed grade of CAES ALZ section after 20 hours

Photo 19. Final constructed grade of Non-CAES ALZ section after 20 hours

Photo 20. A DEUCE pushing a 613B scraper on 2 April

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
October 2001	Final report	

4. TITLE AND SUBTITLE

Expedient Airfield Construction Using the Computer-Aided Earthmoving System

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Jeb S. Tingle, Travis A. Mann

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center
Geotechnical and Structures Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/GSL TR-01-20

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Headquarters, U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution authorized to U.S. Government agencies and their contractors; critical technology; October 2001. Other requests for this document will be referred to Headquarters, U.S. Army Corps of Engineers (CECW-EW), Washington, DC 20314-1000.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The computer-aided earthmoving system (CAES) was tested during a demonstration project at Fort Bragg, North Carolina, from 25 March to 6 April 2001. The project was jointly developed by the U.S. Army Engineer Research and Development Center (ERDC) and the Maneuver Support Battle Lab (MSBL). Two 610-ft sections of a simulated C-17 assault landing zone (ALZ) were constructed side-by-side to the same specifications using two different methodologies. The CAES product was used to construct the first ALZ section using two 613B scrapers and two DEUCES. The control ALZ section was constructed with the same equipment and operators using current methodologies with the CAES product. The executing unit was the 37th Engineer Battalion of the 20th Engineer Brigade stationed at Fort Bragg, North Carolina. The results of the two test sections were compared to quantify the benefit/detriment of using the CAES equipment. Results of the evaluation are presented including: (a) a tabulation of the quantities of earth moved, (b) the accuracy results from comparison testing versus accepted technologies, (c) the manpower requirements for each method, (d) the time requirements for each method, and (e) the effects of the system on command and control of an airfield construction project. These results are used to perform an unbiased analysis of the CAES equipment for use by the military in expedient airfield construction. This project is the first phase of the enhanced construction capability component of the Joint Rapid Airfield Construction (JRAC) program.

15. SUBJECT TERMS

Airfield construction
CAES
Computer-aided earthmoving system
Earthmoving equipment
Enhanced earthmoving capability
Joint Rapid Airfield Construction

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		52	