

ESTCP Cost and Performance Report

(UX-3002)



Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range (1999 ESTCP Project)

April 2003



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TABLE OF CONTENTS

	Page
1.0 EXECUTIVE SUMMARY	1
1.1 BACKGROUND	1
1.2 OBJECTIVES OF THE DEMONSTRATION	1
1.3 REGULATORY DRIVERS	2
1.4 DEMONSTRATION RESULTS	2
1.5 STAKEHOLDERS/END-USER ISSUES	2
2.0 TECHNOLOGY DESCRIPTION	3
2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION (AIRBORNE MAGNETOMETER SYSTEM)	3
2.2 PROCESS DESCRIPTION	4
2.3 PREVIOUS TESTING OF THE TECHNOLOGY	5
2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY	5
3.0 DEMONSTRATION DESIGN	7
3.1 PERFORMANCE OBJECTIVES	7
3.2 SELECTION OF TEST SITES	7
3.3 TEST SITE HISTORY AND CHARACTERISTICS – CUNY TABLE	8
3.4 PHYSICAL SET-UP AND OPERATION	11
3.4.1 Overall Survey	11
3.4.2 Calibration Test Site	12
3.4.3 Physical Set-Up of Airborne Technology	12
3.5 SAMPLING PROCEDURES	13
4.0 PERFORMANCE ASSESSMENT	15
4.1 PERFORMANCE DATA	15
4.1.1 Overall Conclusions	16
4.1.2 Calibration Test Site Performance	16
4.1.3 Survey Site Performance	17
4.1.4 IDA Assessment of Performance and Conclusions	17
4.1.4.1 Analysis of ORNL HM3™ Data	17
4.1.4.2 Comparison with Ground-Based Geophysics	19
4.1.4.3 Conclusions	21
4.2 DATA ASSESSMENT	22
4.2.1 Airborne System Detection Parameters	22
4.2.2 Limitations and Considerations	23
4.3 TECHNOLOGY COMPARISON	23

TABLE OF CONTENTS (continued)

	Page
5.0 COST ASSESSMENT	25
5.1 COST REPORTING	25
5.1.2 Typical Airborne Survey Costs	26
5.1.3 Ground-Based Towed Array Technology Cost Comparison	28
5.1.4 Adjusted Cost Comparison	29
5.2 COST ANALYSIS	30
5.3 COST COMPARISON	31
6.0 IMPLEMENTATION ISSUES	33
6.1 COST OBSERVATIONS	33
6.2 PERFORMANCE OBSERVATIONS	33
6.3 SCALE-UP	33
6.4 OTHER SIGNIFICANT OBSERVATIONS	34
6.5 LESSONS LEARNED	34
6.6 END-USER ISSUES	34
6.7 APPROACHES TO REGULATORY COMPLIANCE AND ACCEPTANCE ..	35
7.0 REFERENCES	37
 APPENDIX A POINTS OF CONTACT	 A-1
APPENDIX B CALIBRATION SITE ORDNANCE, SIMULANTS, AND MISCELLANEOUS ITEMS	B-1

LIST OF FIGURES

	Page
Figure 1.	HM3™ Airborne Magnetometer Platform at Badlands Bombing Range 4
Figure 2.	HM3™ Airborne Magnetometer Platform at Badlands Bombing Range 4
Figure 3.	Aerial Image of the Cuny Table with Survey Areas 8
Figure 4.	Aerial Image of the Cuny Table Bombing Target (Site 1) 10
Figure 5.	Suspected Impact Area in the Stronghold Area of the Cuny Table 10
Figure 6.	Aerial Image of Suspected Target in Stronghold Area of the Cuny Table 11
Figure 7.	Analytical Signal Data from Site 1 (Cuny Table Bombing Target) 17
Figure 8.	BBR1 HM3™ Analytical Signal Distribution 19
Figure 9.	BBR2 HM3™ Analytical Signal Distribution 19
Figure 10.	Comparison of Theoretical and Measured Peak Responses at a Controlled Site 23
Figure 11.	Airborne Magnetometer Survey Cost 27
Figure 12.	Airborne Magnetometer Survey Cost per Acre 28

LIST OF TABLES

	Page
Table 1.	Survey Sites' Geographic Descriptions 11
Table 2.	Ground Follow-Up and Excavation Results 16
Table 3.	ORNL HM3™ Results as Rescored by IDA 18
Table 4.	BBR1 North MTADS Target Picks Not Excavated vs. HM3™ Target Picks . . 20
Table 5.	BBR1 South MTADS Target Picks vs. HM3™ Target Picks 20
Table 6.	BBR1 HM3™ Ground Truth from Excavated Targets vs. MTADS Targets Not Excavated 21
Table 7.	BBR2 HM3™ Ground Truth vs. MTADS Targets Not Excavated 21
Table 8.	Actual Total Demonstration Project Cost in FY99 USD 25
Table 9.	Cost Reporting for UXO Identification Technology at Demonstration Scale in FY99 USD 26
Table 10.	Representative Cost for UXO Ground-Based Identification Technology at Demonstration Scale in FY99 USD 29
Table 11.	Adjusted Costs for Airborne and Ground-Based Systems 30
Table 12.	Airborne Survey Efficiency Parameters 31
Table 13.	Comparison Between Airborne and Man-Portable Survey Costs 32

LIST OF ACRONYMS

AGL	above ground level
BBR	Badlands Bombing Range
BRAC	Base Realignment and Closure
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CTT	Closed, Transferred, and Transferring
DoD	Department of Defense
DOE	Department of Energy
EE/CA	Engineering Evaluation/Cost Assessment
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
FAC	Federal Acquisition Cost
FP	false positive
FUDS	Formerly Used Defense Sites
FY	Fiscal Year
GPS	Global Positioning System
Ha	hectares
HE	high explosive
HM3™	Helicopter-Mounted Magnetometer
IDA	Institute for Defense Analyses
ISMS	Integrated Safety Management System
MIPR	Military Interdepartmental Purchase Request
MTADS	Multi-Sensor Towed Array Detection System
NAD	North American Datum
NRL	Naval Research Laboratory
nT	nanotesla
OE	Ordnance and Explosives
ORNL	Oak Ridge National Laboratory
PC	personal computer
Pd	Probability of Detection

LIST OF ACRONYMS (continued)

QA	quality assurance
QC	quality control
rms	root mean square
STC	Supplementary Type Certificate
STOLS	Surface Towed Ordnance Locator System
USAESCH	U.S. Army Engineering and Support Center, Huntsville
USD	U.S. Dollars
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

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Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range, documenting the acquisition, processing, analysis, and interpretation of airborne remote sensing data for unexploded ordnance-related sites at the former Badlands Bombing Range, was prepared by the U.S. Army Corps of Engineers Engineering & Support Center, Huntsville (USAESCH), and the Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) under Military Interdepartmental Purchase Requests (MIPRs) W31RYO90696096 and W31RYO91270914. This work was prepared through funding provided by the Environmental Security Technology Certification Program Office, and serves, in part, to support engineering evaluation/cost assessment (EE/CA) activities at the former Badlands Bombing Range. Since the EE/CA work was unknown at the time of project planning, this particular benefit was entirely fortuitous. This project offers the opportunity to examine airborne methods for their applicability at DoD sites that contain unexploded ordnance and ordnance-related artifacts, such as waste burial sites, which present environmental and safety concerns for personnel.

We express our most sincere appreciation to Dr. Jeffrey Marqusee, Mr. Jeffrey Fairbanks, and Mr. Matthew Chambers of the Environmental Security Technology Certification Program Office for providing both support and funding for this project at the former Badlands Bombing Range. We also wish to thank Ms. Emma Featherman-Sam and the staff of the Badlands Bombing Range Project Office in Pine Ridge, South Dakota for their invaluable support to the project planning, reconnaissance, and data acquisition phases of this project. Our appreciation further extends to Dr. David Sparrow and Dr. Anne Andrews of the Institute for Defense Analyses (IDA) for their independent validation of the technical results, and Parsons Engineering Science for the ground follow-up, excavations, and EE/CA support.

Technical material contained in this report has been approved for public release.

1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

As a result of past military training and weapons-testing activities, an estimated 12 million hectares (approximately 30 million acres) of U.S. land is potentially contaminated with unexploded ordnance (UXO) and/or weapons testing-related artifacts. These contaminated areas include sites designated for base realignment and closure (BRAC) and Formerly Used Defense Sites (FUDS). Using current technologies, the costs associated with detection, identification, and mapping of this contamination could be several hundred million dollars. Current surface-based technologies have shown improvements in the ability to detect sub-surface UXO, but are unable to reliably discriminate UXO from other items that pose no risk. These approaches are generally labor intensive, slow, and expensive. Significant cost savings could be achieved if it is demonstrated that airborne methods can serve as an appropriate substitute for a portion of surface-based applications. Airborne magnetometers have not been used for UXO detection due to limitations in the physics and an inability to position the magnetic sensors in close proximity to the ground. Recent advances in airborne magnetic systems have enabled capabilities that are significantly improved over prior generation airborne systems. In addition to the aforementioned potential cost savings, an airborne approach will provide a safer operating environment for personnel performing UXO detection and mapping (stand-off versus direct ground contact), an ability to conduct surveys on difficult terrain or in locations not readily accessible from the surface, and a passive, non-intrusive approach by reducing or eliminating disturbance of indigenous plant and animal habitat.

The airborne system utilized for the project is based on airborne-quality cesium-vapor magnetometers mounted in the tips of three rigid 6-meter booms (one forward, two lateral) that are mounted to the airframe of a commercial helicopter. Ancillary equipment includes a real-time differentially corrected Global Positioning System (GPS) for navigation and data positioning as well as a laser altimeter. This configuration enables operation at a nominal flight altitude of 1 to 3 meters above the earth's surface. The survey methodology consists of parallel lines traversing the area of interest with the survey lines interleaved. Three traces of total magnetic field data were collected for each flight line providing a nominal survey (and data) line spacing of 3 meters with a flight line spacing of 9 meters. The survey process concludes with data processing, analysis, interpretation, and mapping using commercial software to generate digital images depicting locations and magnitudes of anomalies that may represent UXO.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objectives of the demonstration were; 1) to determine viability of an airborne magnetic system for the detection and mapping of UXO; and 2) to demonstrate an airborne system for footprint reduction applications to delineate areas of concern. The demonstration validated detection and characterization of ordnance and ordnance-related debris at previously ground-surveyed locations, at a large previously unsurveyed area, and at a controlled test site using airborne magnetometer technology. Through the use of the airborne system on both known and unknown sites, as well as at a thoroughly documented test site, this demonstration survey produced results that confirm this technology as both practical and cost-effective for detection and mapping of UXO, and wide-area surveillance associated with footprint reduction activities.

1.3 REGULATORY DRIVERS

No specific regulatory drivers influenced this technology demonstration. UXO-related activity is generally conducted under authority of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). A draft EPA policy related to UXO is currently under review. Regardless of a lack of specific regulatory drivers, many DoD sites and installations are aggressively pursuing innovative technologies to address footprint reduction and site characterization, which are areas of particular focus for this technology demonstration. In many cases, the prevailing concerns at these sites become a focus for the application of innovative technologies in advance of anticipated future regulatory drivers and mandates.

1.4 DEMONSTRATION RESULTS

To validate the detection capabilities of the system, a controlled test site (Calibration Site) was prepared and flown. Seeded items included engineering items, inert ordnance, and simulants that were selected to bracket the expected detection parameters of the system. The system succeeded in detecting all of the seeded items, which ranged in size from 6 to 65 lbs. at depths from 1 to 4.4 feet beneath the earth's surface. In addition to the Calibration Site, four additional known and unknown areas were surveyed totaling 287 acres. An objective of the project was to demonstrate that this technology could be used as a tool to aid in footprint reduction and to help delineate areas of concern for ordnance contamination. The technology exceeded expectations and actually identified individual items with a success rate ranging from 76% with 24% false positives to 100% with 0% false positives depending on the objective and evaluator. The IDA independent analysis suggests a different level of performance. The airborne system was compared to a performance baseline established by the Multi-Sensor Towed Array Detection System (MTADS), deployed by the Naval Research Laboratory, and detected approximately 50% of the individual ordnance targets detected by MTADS. Total projects costs for all work performed by the project team were \$220,229 in FY 1999 dollars.

1.5 STAKEHOLDERS/END-USER ISSUES

Issues related to this demonstration center on the appropriate use of the technology. Clearly, the airborne system is unable to detect all UXO items of potential interest. The technology is also constrained by the presence of tall vegetation and terrain that increases the distance between the system and the UXO items of interest, thereby limiting detection ability. It is also apparent that application of the technology to small survey areas will not be cost-effective due to the large cost associated with mobilization/demobilization and considerable helicopter costs. Users should consider both the intended UXO targets and survey area (size, terrain, and vegetation) before considering the use of airborne systems for UXO detection and mapping.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION (AIRBORNE MAGNETOMETER SYSTEM)

Many methods have been proposed for the detection and identification of UXO. Surface and airborne measurements of perturbations in the direction and/or strength of the earth's magnetic field can be used to locate underground ferromagnetic objects and structures. Although these methods have typically been used to characterize geologic features, they are also effective in locating ferrous man-made objects. While most methods require surface-deployed instrumentation (usually providing greater sensitivity), these methods generally have significantly higher acquisition costs (ranging from \$1,000 to \$10,000 per acre, depending on site conditions), are extremely time-consuming, and may present risks to personnel, equipment, and the environment.

With an estimated 12 million hectares (approximately 30 million acres) of U.S. land potentially contaminated with UXO and/or weapons testing-related artifacts, the costs associated with detection, identification, and appropriate clean-up of this contamination could be several hundred billion dollars. Significant cost savings could be achieved if airborne methods served as an appropriate substitute for a portion of ground-based methods. Airborne magnetometers have not been used for UXO detection due to limitations in the physics and an inability to position the magnetic sensors in close proximity to the ground. Recent advances in airborne magnetic systems have demonstrated capabilities that approach those of surface-based systems.

Both total field and directional (e.g. vertical component) magnetometers can be deployed in fixed wing aircraft, but such a deployment cannot support low altitudes and slow air speeds required for UXO-related applications. For helicopter surveys, the greatest sensitivity and shortest sample spacing are achieved with total field instruments employing optically pumped sensors, such as cesium vapor magnetometers.

Altitude, flight path spacing, sample interval along flight lines, background noise, and instrument noise levels determine the minimum target size that can be detected using airborne methods. Large UXO and UXO-related items may be detected to depths of several meters with airborne magnetic instruments. Surface magnetic measurements can be used in follow-up surveys to detect smaller objects.

In the Helicopter-Mounted Magnetometer (HM3™) system employed for this project (see Figures 1 and 2), cesium-vapor magnetometers were mounted in the tips of three rigid 6-meter booms (one forward, two lateral) mounted on the underside of the aircraft. This configuration enabled a nominal instrument altitude of 1 to 3 meters above the earth's surface. Survey lines were interleaved so that three traces of total magnetic field data were collected for each flight line, providing a nominal data profile spacing of 3 meters for flight line spacing of 9 meters. Noise effects were accommodated by using high sample rates with appropriate filters; by close monitoring of the pitch, roll, yaw, and flight path of the helicopter; and by correcting the data on the basis of compensation measurements. These compensation measurements determine the effects of orientation when the helicopter is the only significant source of magnetic interference. The acquisition process concluded with real time signal processing to remove noise.



Figures 1 and 2. HM3™ Airborne Magnetometer Platform at Badlands Bombing Range.

It is important to note that several substantial changes to the HM3™ deployment were implemented during this project. These changes included conducting the survey at particularly low altitudes (1 to 3 meters above ground level), and extending the data acquisition system sampling rate by five times what had been used for previous surveys (50 Hz versus 10 Hz).

2.2 PROCESS DESCRIPTION

A summary discussion is presented here with further detail provided in Sections 3 and 4. In summary, mobilization is conducted by ground transportation of the electronic equipment and personnel. The helicopter and aircrew are mobilized by air to the base of operations. The base is usually a local or regional airport with suitable security and fuel. The geophysical base stations for GPS and magnetics are established at known civil survey monuments. A processing center is set up in a local hotel room.

Installation is conducted by the aircraft mechanic according to Federal Aviation Administration (FAA) requirements, with support of the geophysical ground crew. This involves dismounting the tow hook arrangement and installing brackets at these and other hard points in the airframe. The booms, sensors and recording systems are subsequently attached to the bracket mounts.

Survey blocks are chosen and boundary coordinates determined. These are then entered into the onboard navigation system. Consideration is given to ambient magnetic fields, topography, vegetation, and survey efficiency when making the determination regarding coordinate entry. After installation, instruments are tested for functionality before and during an initial check flight. Calibration flights are then conducted to determine digital time lags and compensation coefficients required to correct the readings for the presence of the helicopter.

After calibration, surveying begins. The pilot and equipment operator are present in the aircraft during survey operations. The operator is responsible for updating and managing the navigation software as well as real-time quality control (QC) of the incoming geophysical data. Surveying continues on a line-by-line basis until the entire block is covered. Depending on the size of the survey area, multiple flights may be required.

At the end of each flight, data is downloaded to a personal computer (PC) for QC evaluation. This includes verification of data integrity and quality from all sensor sources. Data from the ground base station instruments for differential GPS and magnetic diurnal adjustments are integrated with the airborne data. The dataset is analyzed for completeness of areal coverage (no large gaps or non-surveyed areas) and for consistency of survey altitude throughout the survey block. Lines or areas of unacceptable or missing data are noted and resurveyed as appropriate.

Upon completion of the survey, the data is processed to correct for effects of digital time lag, selective availability in GPS, magnetic sensor dropouts, compensation for aerodynamic motion, magnetic diurnal fluctuations, array balancing, regional magnetic field, helicopter rotor noise, and positioning of individual magnetometers. Magnetic anomalies are analyzed to derive dig lists or other interpretive visual products (e.g., maps), depending on the application.

General and site-specific health and safety plans are generated for each survey project. Following the DOE Integrated Safety Management System (ISMS) process, plans then include provisions for general ground safety, using DoD models for UXO site safety. These models are further extended to encompass airborne operations and then add wholly new considerations for airborne operations in a UXO theater. The appropriate management at ORNL, the helicopter operator, and the project sponsor approve these health and safety plans.

A variety of skilled personnel are required to conduct this type of geophysical survey. The pilot must be trained in low level or “ground effect” flying. The geophysical console operator must be skilled in making real time decisions regarding data quality in order to conduct immediate re-flights. He must also be intimately familiar with the system in order to diagnose problems and effect any minor repairs in the field. The processing geophysicist must be familiar with airborne survey operations and data processing, in addition to analysis for UXO targets. All crew must be comfortable with safe operations in and around aircraft.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

This technology has evolved from traditional mineral exploration survey systems. While the fundamentals of magnetic surveying have not changed, the capabilities for mounting extremely high sensitivity magnetometers in such an inherently noisy platform were not successfully demonstrated until the mid-1990s. By 1997, the three-sensor HM3™ array was the most technologically advanced system, with noise reduction capabilities suitable for practical UXO detection.

In 1997, the HM3™ was tested at several different locations, including Canadian Forces Base Borden (Aerodat, Inc.), Jüterbog Tank Training Range (IABG, GmbH) and Edwards Air Force Base (ORNL). A two-sensor version was also flown at Eagle, Colorado (Ensco, Inc.) as part of the A-10 crash recovery effort, and in Indonesia as part of a mining exploration survey.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The primary advantage of this system is the capability to cover large areas of ground more quickly and cheaply than conventional ground-based surveys. The wider sensor spacing and higher altitudes found in airborne arrays showed good detectability for large UXO items. Detection of smaller items, however, is limited as a result of wider sensor spacing and higher altitudes. The airborne system

has an advantage in areas where ground access is limited or difficult due to surface conditions (swamp or marsh) or inherent danger (exposure to UXO or other contaminants). Areas with a sensitive ecological environment may also benefit from the less intrusive airborne technology.

At the time of this demonstration, no competing technologies to the HM3™ were known to exist for airborne magnetic surveys, although several new platforms have been proposed or are under construction. Most of these include identical sensor technologies with a higher sample rate and denser array of instruments in order to eliminate the requirement for interleaving lines.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Although airborne methods have historically been used to characterize geologic features, recent technological developments have led to an increase in sensitivity, making these methods reasonable for detection of many types of UXO. The analysis of magnetic data for the Cuny Table focused on identifying locations of surface and near surface UXO (and ordnance debris), and distinguishing between anomalies that occurred due to natural processes. Under the direction and guidance of USAESCH, ORNL and its team members acquired high-resolution magnetic data in support of the identification and mapping of surface and near surface UXO and ordnance debris within the Cuny Table. The mission flights required extremely low flight altitude, accurate flight line spacing, and high data acquisition speed. GPS and altitude information were also acquired. The following summaries describe each sensor platform, performance parameters for each sensor, and the utility of each data type in identifying UXO and ordnance debris.

The system was designed for the detection of small amounts of man-made ferrous metal (potentially as small as 10 kg to 20 kg), but also responds to larger, man-made magnetic objects or naturally occurring rocks and soils that are magnetic. Simultaneously, real-time differential global positioning system (GPS) data were acquired to geo-locate the magnetic data. The magnetometer system was mounted on a Bell 206L Long Ranger helicopter and flown at 3 to 5 meters above ground level (AGL). Flight line spacing was approximately 9 meters with an aircraft speed of 50 knots to 60 knots. The design of the magnetic sensor array enabled simultaneous acquisition of data along three lines. This unique acquisition procedure provided data at 3-meter line spacing with measurements at intervals of 0.75 meter to 1.0 meter along each line.

As discussed previously, the objectives of this project centered on demonstrating the usefulness of the technology as a tool to aid in footprint reduction, and to help delineate areas of concern for ordnance contamination. Sampling of anomalies of the appropriate sizes indicative of ordnance and explosives use verifies the application. The technology exceeded expectations and identified individual ordnance items including M38 practice bombs, 2.25-inch and 2.75-inch aerial gunnery rockets, as well as the locations and boundaries of waste burial sites.

3.2 SELECTION OF TEST SITES

The former Badlands Bombing Range, also known as the Pine Ridge Gunnery Range, is a formerly used defense site (FUDS) located within the Pine Ridge Indian Reservation in Shannon and Jackson counties, South Dakota. Totalling more than 339,000 acres, portions of the site are flat and devoted to farming and ranching. The remaining acreage are badlands that are gently rolling to nearly vertical in appearance, and have been formed due to the extensive rapid erosion of the soft fine-grained underlying sediments. The Badlands are primarily devoted to grazing, while a portion of the site is now part of the Badlands National Park.

With regard to historical ordnance, numerous areas exist across the entire site that were utilized for aerial gunnery, aerial bombardment, and surface-based gunnery activity. Historical records indicate use of the range began in the early 1940's and terminated in the mid-1970's. Groups that utilized the range include Rapid City Air Force Base (now Ellsworth AFB), the U.S. Army, and the South

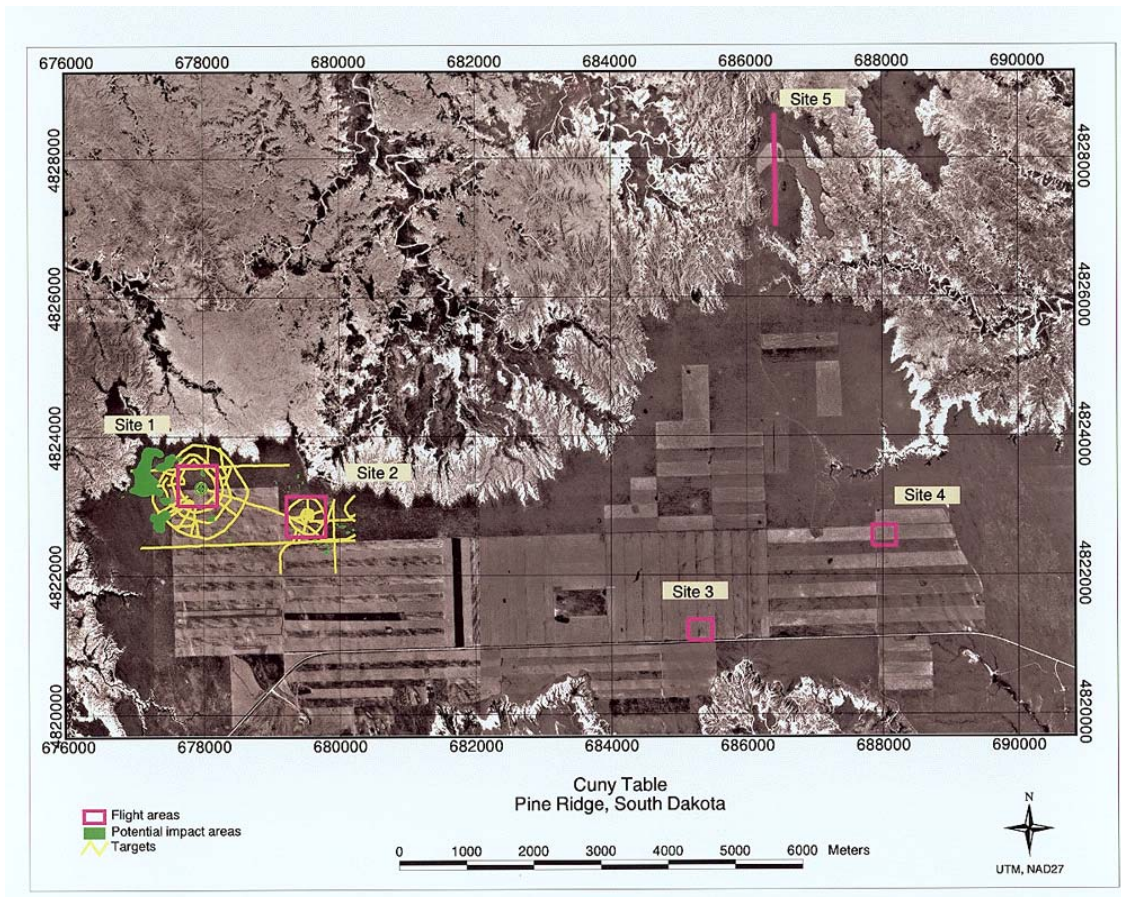


Figure 3. Aerial Image of the Cuny Table with Survey Areas (Denoted in red).

Dakota Army National Guard. Ordnance types found at the former Badlands Bombing Range include 75-mm high explosive (HE) projectiles, 105-mm and 155-mm HE and illumination projectiles, 8-inch HE projectiles, M38 practice bombs, M50 and M54 incendiary bombs, and 2.75-inch and 2.25-inch rockets.

This site was chosen for this technology demonstration because of favorable terrain and underlying geology, reasonable ordnance objectives (e.g. size, expected depth, composition, etc.), and the opportunity to integrate with ongoing EE/CA activities being conducted by the U.S. Army Corps of Engineers (i.e., leverage of field resources).

3.3 TEST SITE HISTORY AND CHARACTERISTICS – CUNY TABLE

Located in the northwestern portion of the Pine Ridge Indian Reservation is a large plateau known as Cuny Table. This area is approximately 10,000 acres in size with relatively flat topography. It has been used, and is currently being used, for farming and grazing of livestock. The Cuny Table is known to contain a number of aerial gunnery targets, aerial bombardment targets, and waste burial pits associated with the presence of ordnance and explosives. All six sites of interest for this project were located on the Cuny Table. The purpose of the survey was to acquire, process, and analyze geophysical data for suspected subsurface ordnance items, ordnance-related artifacts, and buried waste sites.

The survey areas were designated Sites 1-6. These sites are described below.

- Site 1, also known as the Cuny Table Bombing Target, is located on the western portion of Cuny Table that is unfenced and easily accessible. This site contains a target that is clearly visible (see Figure 4). Ordnance found at this site includes M38 practice bombs.
- Site 2, also known as the Aerial Gunnery Target, is also located on the western portion of Cuny Table that is unfenced and easily accessible. Ordnance found at this site includes both M38 practice bombs, and 2.75-inch rockets.
- Site 3, also known as Cuny Table Burial Pit, Section 15, is located on the south central portion of the Cuny Table that is fenced and easily accessible. The pit is located in a plowed field. No ordnance or ordnance debris of any type has been found in this field, and there are no obvious features that indicate that a target is present in this area.
- Site 4, also known as Cuny Table Burial Pit, Section 17, is located on the northeastern portion of the Cuny Table that is fenced and easily accessible. The pit is located in a plowed field. No ordnance or ordnance debris of any type has been found in this field, and there are no obvious features which indicate that a target is present in this area.
- Site 5, a newly discovered impact area, is located in the northern portion of the Cuny Table in an area known as the Stronghold Area (near the Stronghold Table, this area is a “peninsula” extending from the Cuny Table toward the Stronghold Table). This site, visible in both satellite and aerial imagery (see Figures 5 and 6), appears to contain a large target. It is remote, but accessible by road, and was found to contain ordnance debris at the surface as well as apparent impact craters.
- Site 6 is a small controlled test area with seeded items (also known as the Calibration Site). This area is located directly north of Site 4 and is described in Section 6.1.

Topography across Cuny Table was extremely flat. Trees, buildings, power lines and other obstacles are unobtrusive, and generally clustered together. Barbed wire livestock fences were the only obstacles encountered during data collection.

In total, 383 line-km of data was collected from all three sensors. The area surveyed was approximately 116 ha (approximately 287 acres). Data sample density on the ground was a function of the forward speed of the aircraft. Nominal spacing between lines was 3 meters.

At 50 Hz data recording rate and an average air speed of 20 m/s (approximately 45 mph), the spacing between sequential readings along a flight line was 0.4 meter.

No cultural features (e.g. buildings, power transmission lines, etc.) were present at this site that in any way interfered with detection and mapping of the suspect UXO items. Overall, the geologic features of this site were considered benign and conducive to the application of airborne geophysics.



Figure 4. Aerial Image of the Cuny Table Bombing Target (Site 1).



Figure 5. Suspected Impact Area in the Stronghold Area of the Cuny Table.



Figure 6. Aerial Image of Suspected Target in Stronghold Area of the Cuny Table. (This area is the same as depicted in figure 5.)

3.4 PHYSICAL SET-UP AND OPERATION

3.4.1 Overall Survey

The survey was completed during the period of June 9-13, 1999. Table 1 illustrates the survey sites and their respective parameters. A total of 14 survey missions were required to complete this project. Each mission recorded data in one or more digital files. Aircraft ground speed was maintained at approximately 20 m/s (approximately 45 mph) with a mean terrain clearance ranging from 1 to 3 meters consistent with the safety of the aircraft and crew.

Table 1. Survey Sites' Geographic Descriptions.

Site	Name	Coverage (in ha)	Coverage (in acres)	Line km
1	Cuny Table Bomb Target	37	91.5	137
2	Aerial Gunnery Target	37	91.5	122
3	Burial Pit, Section #15	12	30	37
4	Burial Pit, Section #17	12	30	35
5	Stronghold Area	17	42	49
6	Calibration Site	1	2.5	3

The survey aircraft was a Bell 206L Long Ranger helicopter. Operations were based out of Rapid City Regional Airport. The GPS and diurnal monitor base stations were established on Cuny Table near Site 1, the location of a known geodetic marker.

A comprehensive Operational Emergency Response Plan (Site-Specific Health and Safety Plan) was developed to address issues related to flight operations, safety, and emergency response. This plan was incorporated into an overall Mission Plan developed to manage field survey operations.

3.4.2 Calibration Test Site

A controlled calibration test site was established on Cuny Table specifically for this test. The site was developed in order to gain understanding regarding the limitations of the sensor technology, as well as signatures generated by each item suspected to exist with the former Badlands Bombing Range. Targets were chosen to bracket expected detection parameters, and all were known to the investigators. The logistics associated with the site include:

- establishing a survey grid of dimensions 100 meters in the north-south direction, and 45 meters in the east-west direction. Burial locations were staggered and placed at approximately 20-meter linear spacing between locations;
- establishing fiduciary data (i.e. dimensions, weights, descriptions) on all items to be buried, including photographs prior to burial. The ordnance, simulants, and miscellaneous items placed in the Calibration Site are listed in the Appendix;
- surveying the site prior to seeding using a Geometrics Model G-858 magnetic gradiometer to determine the background geology, soil conditions, and the presence/absence of any pre-existing ferrous “clutter;”
- excavating the burial sites using a commercial backhoe, and subsequently burying the objects of interest in the ground. Fiduciary data was recorded for each buried item including depth to the top of the item, burial orientation, azimuth, and inclination; and
- surveying the site after seeding, again using the Geometrics Model G-858 magnetic gradiometer, to determine ground-based geophysical signatures of each item for comparison to airborne geophysical data and for reacquisition of the items in the future.

3.4.3 Physical Set-Up of Airborne Technology

The HM3™ system is arranged with sensors at the end of each of three booms. The GPS antenna is mounted in the forward boom. The booms meet at the “hook.” The distance between the GPS antenna and the forward sensor is 1.2 meters; the distance from the GPS to the hook is 6.1 meters; and the distance from the hook to the lateral sensors is 6.1 meters. These numbers, plus the aircraft orientation, are required to calculate the position of each sensor.

The laser and radar altimeters were mounted beneath the helicopter, at roughly the same altitude as the sensors themselves.

Data was recorded digitally by a High-Sense Geophysics MiniMag™ data acquisition system in a proprietary data format. All raw data was recorded at a 50 Hz sample rate. Data was imported into a Geosoft format database for processing. All data processing was conducted using the Geosoft software suite.

The sensors used were Cesium vapor optically pumped magnetometers with sensitivity of 0.001 nanotesla (nT). A global positioning system was operated in real time differential mode to control aircraft navigation. The receiver antenna was mounted on the forward boom while a second system acted as the base station and radio transmitter.

During flight, magnetic data from the sensors is passed to the onboard console where the raw signal is processed into magnetic field strength. The data is filtered to remove high frequency noise associated with the helicopter; time stamped for correlation to other data streams, and recorded. Data is transcribed into a database post flight where additional processing is conducted.

Since the earth's magnetic field is in a constant state of flux, a base station sensor is established to monitor and record this variation every few seconds. With normal variations, the recorded data are subtracted directly from the airborne data on a point-by-point basis. The time stamps on the airborne and ground units are synchronized to GPS time.

The HM3™ system provides three tracks of total field data, but no measured gradient at low altitudes. The analytic signal is calculated from the final gridded total field data. There are several advantages to using the analytic signal. It is generally easier to interpret than total field data for small object detection. Total field measurements typically display a dipolar response to small, compact sources, meaning they have a positive and negative component. The actual source location is between two peaks and determined by magnetic latitude of the site and the properties of the source itself. Analytic signal is symmetric about the target, is always a positive value, and is independent of magnetic latitude. Generally, the analytic signal highlights the corners of source objects, but for small targets, these corners converge into a single peak.

Differential corrections to GPS information are completed in real time using a radio modem link from the base station. If this link is broken, no differential corrections are made to the data, and the raw GPS position is recorded. The status of this link is recorded in a separate data channel.

Much of the data was examined in the field ensuring sufficient quality for final processing. The adequacy of the compensation data, heading corrections, time lag, orientation calibration, and data format compatibility were all confirmed during data processing. During survey operations, flight lines were plotted to verify full coverage of the area. Missing lines, or areas where data was not captured, were rejected and reacquired. Data was also examined for high noise levels, data drop outs, loss of real time differential connection or other unacceptable conditions.

3.5 SAMPLING PROCEDURES

Sites 1 and 2 were previously mapped by Naval Research Laboratory (NRL) using the MTADS ground-based towed magnetometer system as part of a technology demonstration. During this demonstration, a significant number of anomalies were excavated to validate performance. Sites 3 and 4 were previously mapped by Geocenters, Inc. using the Surface Towed Ordnance Locator System (STOLS) ground-based towed magnetometer system for delineation of the limits of suspected disposal pits. These locations were chosen for this aerial survey since they were known to have existing subsurface anomalies for use in benchmarking system performance.

All target anomalies acquired with the airborne system at the six sites were stored in a Geosoft database. Each line in the database represented the survey site with the corresponding number. Individual targets were sorted by amplitude and numbered for identification. Maps of the target locations were made by plotting colored symbols with ID numbers. The colors corresponded to those used in the analytic signal map.

Target selection was refined manually by elimination of anomalies which appeared unlikely to be ordnance-related. These included obvious features such as fences, signposts, culverts, and other visible objects. Target signatures were also examined in the total field data to remove anomalies created by gridding. Of those remaining, a subset was selected for ground follow-up based on an analysis of the magnetic signatures. A full range of confidence levels was included in the follow-up selection, as shown by the signal strength. The purpose here was not to demonstrate the ability to detect large anomalies, but to clearly determine the capabilities of the system over a range of signal strengths.

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

Parsons Engineering Science, Inc. of Denver, Colorado, conducted ground follow-up on Sites 1 through 5. The Ordnance and Explosives (OE) crew was given anomaly locations and magnetic signature strengths. All targets were found within 1 meter of the specified coordinate.

For the purposes of calculating statistics on the excavations, any metallic source, whether ordnance or scrap, was considered a successful detection. This would be consistent with the use of this technology as a footprint reduction tool. Where reacquisition efforts found no response with hand held instruments, no hole was dug. These were considered false positive readings. On a few occasions reacquisition detected a source, but nothing was unearthed except magnetically active soils. These “hot” soils were not counted either for or against the statistical measurements.

Sites 1, 3 and 4 were tilled and replanted between the autumn airborne survey and the spring ground follow-up. This disturbance may have moved some of the shallow targets. The ground follow-up at these three sites (average OE related<64%, Dry>19%) had demonstrably poorer results than Sites 2 and 5 (OE related=100%, Dry=0%). A summary of these results is presented in Table 2.

Site 1 included a dig list of 49 anomalies with airborne responses ranging from 1.2-16.8nT/m (threshold cut-off 1.0 nT/m). Of these, 17 sites were investigated. Anomalies south of the fence bisecting the acquisition area could not be accessed on the ground. Results yielded 13 M38 practice bombs, including two with live spotting charges. The four other sites yielded one bomb fin, one “hot” soil response, and two false positives (OE related=82%, Dry=12%).

Site 2 included a dig list of 33 anomalies with airborne responses ranging from 1.8-35.4nT/m. Of these, 24 dig sites were investigated. Anomalies SW of another fence could not be accessed on the ground. Results yielded 16 M38 practice bombs, 5-2.25-inch rockets, one piece of bomb fragment, and two lengths of target tow wire (OE related=100%, Dry=0%).

Site 3 included a dig list of 13 anomalies, but none were investigated due to restricted land access.

Site 4 included a dig list of 11 anomalies with airborne responses ranging from 1.0-303.8nT/m. All dig sites were investigated. Results yielded one pit anomaly with more than 50 M38 practice bombs before digging was halted due to weather, an additional four M38 practice bombs, one large piece of bomb fragment identified as having come from a 5-inch rocket, two “hot” soil responses, and three false positives. Two of the false positives were two of the smallest anomalies reported (OE related=45%, Dry=27%).

Site 5 included a dig list of 117 anomalies with airborne responses ranging from 1.1-163.4nT/m. Of these, 30 dig sites were investigated. Results yielded 27 M38 practice bombs, one-2.25-inch rocket, and two pieces of bomb fragment (OE related=100%, Dry=0%).

Table 2. Ground Follow-Up and Excavation Results.

Area	Anoms	Dig Sites	M38	2.25-inch	Frag or Scrap	“Hot” Soils	No Contact	OE Related	Dry Holes
1	49	17	13	0	1 fin	1	2	82%*	12%*
2	33	24	16	5	3	0	0	100%	0%
3	13	0	NA	NA	NA	NA	NA	NA	NA
4	11	11	54	0	1	2	3	45%*	27%*
5	117	30	27	1	2	0	0	100%	0%
Total	223	82	60	6	7	3	5	89%	6%

*site had been plowed and planted between survey and reacquisition.

4.1.1 Overall Conclusions

The objective of the survey was to detect anomalous readings consistent with buried UXO and other hazards relating to military activities. The effects of local geology were minimal while topography was excellent with only minor obstacles. The data collected was examined in the field for quality assurance, and the acquisition phase was considered successful.

Overall, the demonstration was considered very successful. The detection capabilities of the system exceeded expectations both in terms of sensitivity to small objects, and in reacquisition location accuracy. It has demonstrated a safe, cost effective and environmentally friendly methodology appropriate to the site and to the demonstration objectives.

4.1.2 Calibration Test Site Performance

As discussed previously, a controlled Calibration Site was established on Cuny Table specifically for this demonstration. The site was developed in order to gain an understanding of the limitations of the sensor technology, as well as representative signatures generated by each item suspected to exist with the former Badlands Bombing Range. Targets were chosen to bracket expected detection parameters, and were known to the investigators.

As discussed previously, the Appendix contains a listing of the ordnance, simulants, and miscellaneous items placed at the Calibration Site. The airborne survey detected all twenty-five of the seeded items.

No false anomalies registered above 3nT/m, and only six legitimate targets registered below this level. The 3.0nT/m cut off effectively corresponds to a 4.5 kg target limit. The only exception to this is item 6009. This leaves an ambiguous range of responses between 1.3 and 3.0nT/m for targets less than 4.5 kg in weight. If a cut off value of 1.8nT/m is used, only two very small targets in unfavorable orientations remain undetected (6005 - a 2” Galvanized pipe w/end cap and 6022 - a 2.75” Rocket cylinder), with only four false anomalies. While this cut off is based on a priori knowledge, it nonetheless serves as the basis for a statistical evaluation of the detection probability of the system at this site.

For all targets at a 3.0nT/m threshold, the probability of detection (Pd) is 76% with 0% false positive. Pd is defined as the number of emplaced items detected divided by the total number

emplaced. Percent false positive is defined as the number of anomalies above the threshold that do not correspond to emplaced items divided by the total number of anomalies above threshold. At a 1.8nT/m threshold, the Pd is 92% with 15% false positives. Finally, at a 1.3nT/m threshold, the Pd is 100% with 31% false positives. For targets 10 lbs. and larger, the 3.0nT/m threshold represents a Pd of 95% with 0% false positive.

4.1.3 Survey Site Performance

The data from Sites 1 through 5 was processed according to the procedures outlined in Section 3. Figure 7 illustrates the results from the bombing target at Site 1, and is typical of the results obtained for the other survey sites. Note the symmetric and nearly circular distribution of magnetic hits around the center of the target typical of a bombing range. The east-west line through the center is a barbed wire fence with steel posts that border the edge of a road.

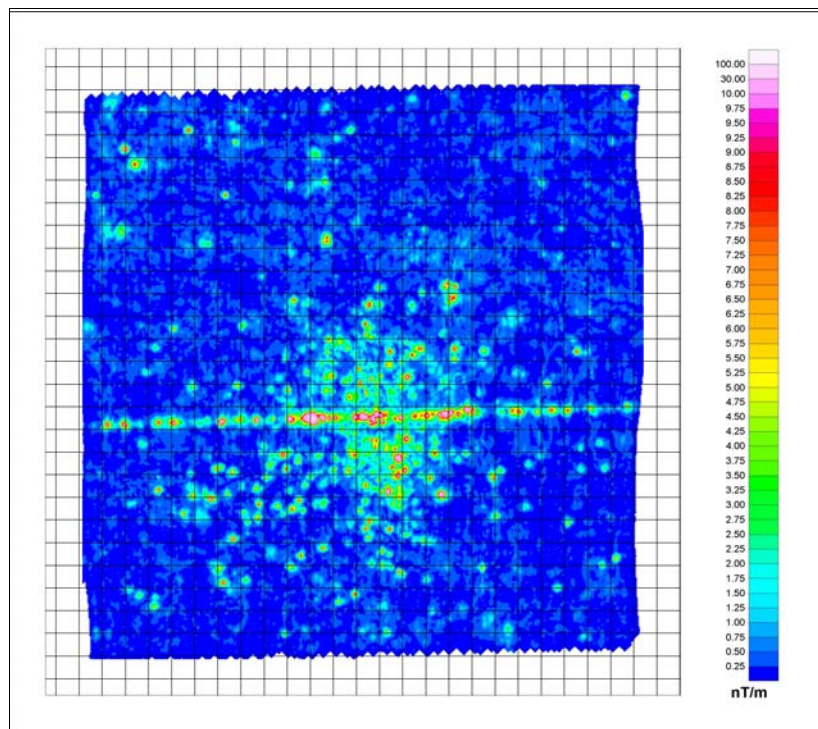


Figure 7. Analytical Signal Data from Site 1 (Cuny Table Bombing Target).

4.1.4 IDA Assessment of Performance and Conclusions

Section 4.1.4 was extracted from IDA report D-2615 “Review of Unexploded Ordnance Detection Demonstrations at the Badlands Bombing Range (BBR).”

4.1.4.1 Analysis of ORNL HM3™ Data

When originally scored by ORNL, all magnetic returns that were reacquired by ground-based sensors were regarded as successful hits, regardless of whether they represented intact ordnance,

ordnance-related scrap, or even hot soils. For the most part, this is reasonable (except perhaps for the inclusion of hot soils). Since the goal of the work was to characterize impact areas, any ordnance-related scrap could be considered a legitimate target. To generate dig lists, however, we are interested in finding intact ordnance, versus fins and rocket motors, which do not present a hazard. Finally, we also need to select a common terminology and scoring system to do the comparisons to MTADS performance. We opt for the scoring system shown in Table 3. Here, we eliminate the use of the term Pd in Reference 2, since the total number of ordnance items encountered is not known (Pd therefore cannot be determined), and replace it with percent ordnance (the fraction of digs that resulted in ordnance). The primary result of rescoring is that the percentage of targets corresponding to ordnance (referred to as Pd in Ref. 2) is lower, and the percentage of false positives is higher.

Table 3. ORNL HM3™ Results as Rescored by IDA.

Area	Anoms	Digs	M38	2.25-in.	Frag or Scrap	Hot Soils	No Contact	% Ord	% FP
1	49	17	13	0	1	1	2	76	24
2	33	24	16	4	4	0	0	83	17

We begin with a brief summary of the HM3™ data. The system records full-field magnetometer data, which is processed using the Geosoft tool to obtain what is referred to as an analytic signal, essentially a horizontal gradient. All decisions regarding target declarations were made by the ORNL team on the basis of the analytic signal. Initial target selection was done by amplitude thresholding on the analytic signal and selecting everything over 1.0 nT/m as a potential target. From this list, targets were selected for a dig list, which was then further downselected for actual digs. The number of dug targets was extremely limited and spanned the range of signal amplitudes (i.e., the dug targets do not represent all the strongest signals).

If the goal is to generate dig lists, it will be important to identify a discriminant to distinguish ordnance from clutter. In the case of the HM3™ data, the only parameter calculated in the original data analysis was analytic signal. Unfortunately, few targets were dug following the HM3™ survey. On BBR1, only 17 excavations were conducted, and all were in the part of the site north of fence line. Figure 8 shows distributions of analytic signal for ordnance and nonordnance ground truth. There is no potential to draw a line separating the two populations, which significantly overlap.

This finding is not surprising since it involved no more than creating an amplitude threshold. Depending on target size, depth, and sensor geometry, one expects the amplitudes to span the space.

The results for the analytic signal on BBR2 are similar. As shown in Figure 9, the ordnance and nonordnance (clutter) show almost total overlap in this parameter. The dug targets on BBR2 included only M-38 practice bombs and 2.25-in. rockets.

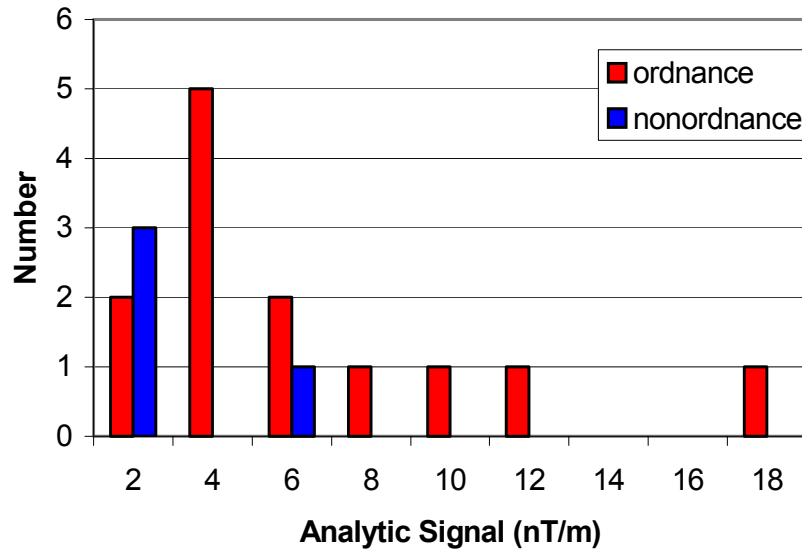


Figure 8. BBR1 HM3™ Analytical Signal Distribution.

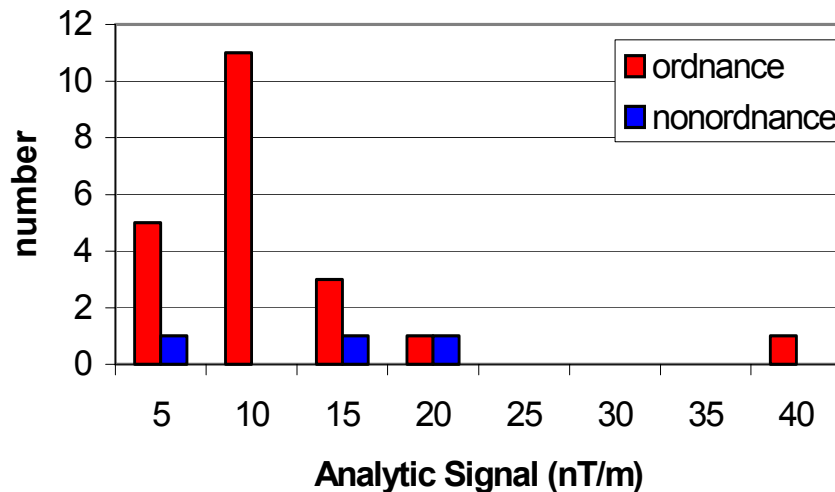


Figure 9. BBR2 HM3™ Analytical Signal Distribution.

4.1.4.2 Comparison with Ground-Based Geophysics

All performance comparisons in this document must be considered in the context of philosophies of target selection employed by two performers, which may skew results considerably. The MTADS target list on BBR1 includes the initial targets selected for the training set, as well as targets from the entire site selected based on the training set results. Target picks on the entire site were not weeded to select only large bombs, but to mirror the profile of the training set. On BBR2, the MTADS list concentrated on sampling smaller items. The HM3™ targets were selected using a simple amplitude threshold in the analytic signal data. Obvious nonordnance sources of anomalies, such as fences and posts, were manually removed from the dig lists.

Some MTADS target picks were dug prior to the HM3™ survey, so the MTADS target picks are divided into those that were dug and not dug. The MTADS targets not dug were separated into bomb-like and clutter-like based on the “size” threshold of 0.125 m (a discriminant found to retain 97% of the detected bombs). These locations were then examined for coincident target declarations in the HM3™ data. Table 4 shows the results for BBR1 North of the fence.

Of the 172 bomb-like targets MTADS detected, but not excavated, 95 were detected by the HM3™ (55 percent). Of the 173 clutter-like targets MTADS detected, but not excavated, only 13 (8 percent) were detected by the HM3™.

Table 5 shows the results for BBR1 south of the fence. The outcome is similar, with HM3™ detecting 45 percent of the bomb-like MTADS targets, and eight percent of the clutter-like MTADS targets.

Table 4. BBR1 North MTADS Target Picks Not Excavated vs. HM3™ Target Picks¹.

	MTADS	HM3™ Target	No HM3™ Target
Bomb-like (size >0.125)	172	95	77
Clutter-like (size <0.125)	173	13	160

¹ Based on a threshold of 1 nT/m in the analytic signal.

Table 5. BBR1 South MTADS Target Picks vs. HM3™ Target Picks.

	MTADS	HM3™ Target	No HM3™ Target
Bomb-like (size >0.125)	170	77	93
Clutter-like (size <0.125)	48	4	44

Table 6 compares the HM3™ dig results with the MTADS targets not dug for coincident detections. MTADS visited a smaller area than the HM3™. Ten of the eleven practice bombs found in the HM3™ ground truthing in the common area were detected and selected for the MTADS target list. The bomb that does not appear in the MTADS target list was in an area where the MTADS anomaly map showed a small patch of ground where no data was taken because of an obstacle to driving. With MTADS capable of a higher sample density, and making measurements at significantly closer standoff distance, it would be surprising for MTADS to miss anything found by HM3™. The MTADS did not select any targets at the locations where HM3™ ground truth resulted in no contacts or fins. At the location of the single “hot soil” reported by the HM3™, the MTADS reported a target which falls into the “clutter-like” category based on size discrimination.

Table 6. BBR1 HM3™ Ground Truth from Excavated Targets vs. MTADS Targets Not Excavated.

	HM3™	MTADS			
		Bomb-like	Clutter-like	No Detect	No Visit
M38	13	10	0	1	2
No Contact	2	0	0	2	0
Hot Soil	1	0	1	0	0
Fins	1	0	0	1	0

The same analysis was done on BBR2. We compared the HM3™ dug targets with the MTADS target picks that were not dug. The results are summarized in Table 7. Due to the lack of success in identifying a reliable discriminant in the MTADS data for BBR2, no attempt was made to differentiate MTADS picks into ordnance-like and nonordnance-like. Of 21 total ordnance items found in the HM3™ ground truthing, MTADS had the opportunity to detect 10, while the locations of the other 11 items were not visited in the MTADS survey. Of these 10 opportunities, MTADS reported target picks at nine. The missed item was a rocket.

Table 7. BBR2 HM3™ Ground Truth vs. MTADS Targets Not Excavated.

	HM3™	MTADS		
		Detect	No Detect	No Visit
M38	14	6	0	8
Rockets	5	1	1	3
Mixed	2	2	0	0
Clutter	3	0	1	2

4.1.4.3 Conclusions

First, it is important to note that the most appropriate use for these technologies may be in different missions. The HM3™ mounted on a helicopter was originally conceived as a footprint-reduction tool, where the main requirement was to detect enough ordnance or ordnance-related debris to identify areas that warrant more thorough examination. On the other hand, the MTADS' role is to produce dig lists of individual targets. As such, the ability to do discrimination is not equally important to the two systems. In fact, for the footprint-reduction mission, finding ordnance-related clutter may provide as important an indication of an impact area as finding intact ordnance.

The results of the HM3™, however, are very good, and it is tempting to ask how it would do in producing dig lists. This report looks at what is possible using the current data.

- On a homogeneous site, the Pd achieved by the HM3™ on individual targets is about 50 percent of that achieved by the MTADS.

- Only about 8 percent of the apparent clutter that appears in the MTADS dig lists is reported by the HM3™.
- Of 22 ordnance items detected and confirmed in the ground truth by HM3™, 20 were detected by MTADS. The cause of one missed detection is likely inaccessibility of the area by the vehicle.
- The helicopter-mounted HM3™ provides much faster production. We roughly estimate that the HM3™ survey rate would be about 10 times faster than the MTADS rate for a large site.
- Cost estimates prepared by the performers indicate that the per acre cost of the MTADS is about 2-3 times higher than that of the HM3™. These figures are very rough estimates and may not accurately reflect cost differences seen in operational surveys.

4.2 DATA ASSESSMENT

4.2.1 Airborne System Detection Parameters

In order to estimate the detection limits which support the previously discussed Pds for the airborne system at BBR, we performed some analysis based on a combination of theoretical calculations with measurements from the Calibration Site. This involved the following steps.

- Estimation of system noise levels.
- Calculation of dipole anomalies for a suite of target masses, and separation distances between the magnetometer and the target.
- Creation of a plot of anomaly strength versus target mass for selected separations.

Points representing the calculated peaks of dipole profiles (representing various ordnance items) and similar calculations for other masses were then plotted, and lines drawn connecting points for a selected height of the sensor above the target. These lines, which represent the expected peak amplitude for a particular UXO mass and height, are shown in Figure 8. The noise floor for the sensor array on the helicopter was estimated earlier as 0.6nT peak-to-peak, and is shown in red. From these calculations, we estimate that signal strength will be greater than rms noise for objects having masses greater than about 1 kg at 2 meters and about 2 kg at 3 meters.

It is important to note several important caveats regarding Figure 10. First of all, these estimates assume that the geometric and magnetic properties of the M38 are representative of all other ordnance that must be detected at BBR. In fact, several objects used at the test site have lower susceptibilities than the M38, or have remnant magnetization with detrimental effects on the sizes of their anomalies. Geometric properties (length/width ratio, diameter, orientation, etc.) of a particular piece of ordnance may reduce its peak anomaly. Finally, geologic conditions may force a much higher noise floor for some sites. All of these factors must be considered when determining whether this technology is appropriate for a particular site and UXO problem.

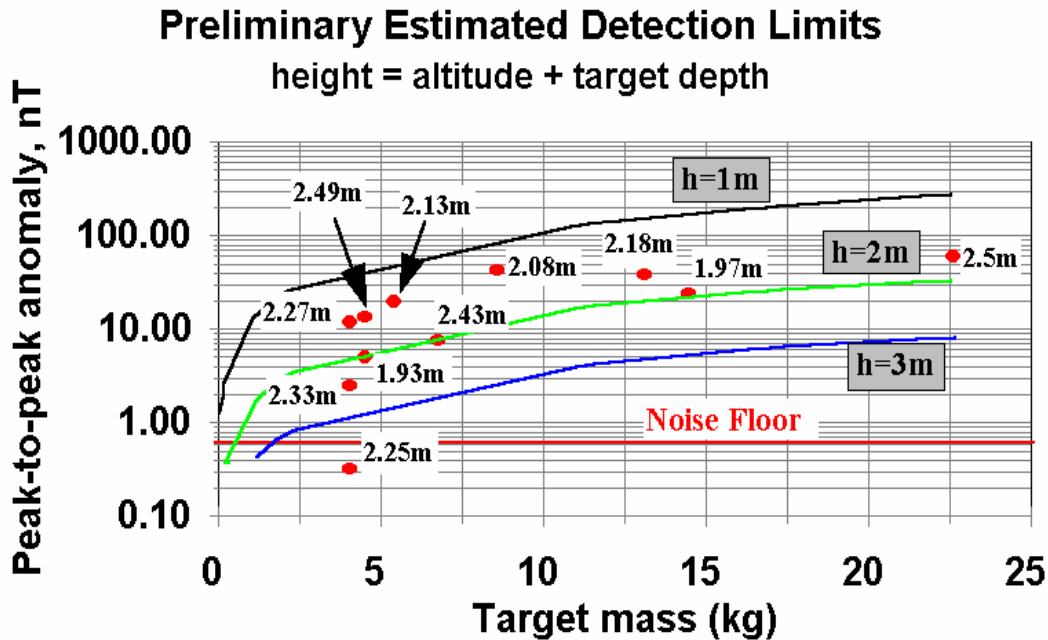


Figure 10. Comparison of Theoretical and Measured Peak Responses at a Controlled Site.

4.2.2 Limitations and Considerations

The basis underlying this survey is the use of magnetics as a surrogate for actual UXO detection. Considerable care and experience has gone into preparation, and conduct of this demonstration survey as well as the analysis and interpretation of those anomalies that are of particular interest to the sponsor. Virtually all UXO have a magnetic signature, and this survey has been designed to map those signatures. There are, however, a considerable number of items that also have magnetic signatures which are non-ordnance in nature. Care must be taken when using data from an airborne acquisition. An experienced geophysicist should be consulted regarding any processing, analysis, and interpretation of results from such a survey.

In a more generalized case, false positive anomalies are an inherent fact in UXO detection, often reaching 90% of all targets. An attempt has been made to reduce this number by careful processing and setting threshold limits on target selection. The users of this type of airborne-derived data should not become discouraged if the initial follow-up does not yield immediate results of previously undiscovered UXO.

4.3 TECHNOLOGY COMPARISON

The only comparison relevant to the airborne system is with a high production surface-based towed system such as MTADS, as opposed to a man-portable “mag-and-flag” approach. Previously discussed in subsection 4.1.4, the HM3™ compares both directly and favorably in a number of ways to the more detail-oriented MTADS approach. While each approach has specific applications, they can be directly compared in many areas including site coverage, detection limits, location accuracy, production rates, and costs associated with deployment and application. The aforementioned IDA report provides detailed information regarding this comparison.

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5.0 COST ASSESSMENT

5.1 COST REPORTING

The total cost of the airborne survey, including preparation of the test grid at the Calibration Site, was \$220,229. This represents a cost of \$765/acre. It must be noted that this was a research project, however, and not a production survey. Several areas were flown more than once, and all areas were relatively small by airborne survey standards. The inefficiencies of small areas and short lines can best be demonstrated by the percentage of airtime actually spent on line. The total project required 24 hours of helicopter airtime including mobilization and demobilization over nine days, but only 1.8 hours of that were actually spent collecting the data presented here (128 line km of flying at 20m/s). The remainder of the time was spent on turn-arounds at the end of lines, on ferry flights to and from the site, flights for refueling, on various calibration and experimental runs, and on re-flights of poorly acquired data. In addition, costs associated with the development and installation of the seeded items at the Calibration Site are included within the total cost for the project. The actual project demonstration costs are presented in Table 8.

Table 8. Actual Total Demonstration Project Cost in FY99 USD.

Task	Labor	Overhead	Subcontract	Total
Subcontract Placement	850	366		1,216
Magnetic Survey Mission Planning	3,100	1,333		4,433
Airborne Magnetic Data Acquisition			53,000	53,000
Airborne Magnetic Data Acquisition Oversight	6,400	2,752		9,152
Magnetic Data Post-Processing	6,800	2,924	18,020	27,744
Magnetic Data Analysis	10,200	4,386		14,586
MTADS Data Comparison	4,800	2,064		6,864
Data Integration and Analysis	15,700	6,749		22,449
Preparation of Products	4,700	2,021		6,721
Final Report	10,900	4,742		15,642
Travel	6,300	934		7,234
Project Management, Computer Support & Materials	17,700	7,656		25,356
Subtotal	87,450	35,927	71,020	194,397
Federal Acquisition Cost (DOE) (3% of Total)	2,624	1,078	2,130	5,832
Totals	90,074	37,005	73,150	220,229

The area surveyed during the demonstration that represents the closest to full production rates would be Site 5. It was completed in a single flight of approximately 40 minutes, with 13 minutes of the data presented in the analytic signal map. Projections for future sites based on the work here and previous projects indicate daily coverage rates of 200 acres/day at a cost of \$200/acre.

Table 9 represents costs associated with the airborne technology in a “real-world” implementation when operated at the scale of the demonstration. The scale of the demonstration for this cost profile is a 300-acre site, slightly larger than the original area surveyed during the actual demonstration. All costs represented in the table are costs that would be incurred only for a “production”

demonstration at a “real-world” site, and do not reflect any costs associated with the demonstration of an innovative technology. It is important to note that costs associated with excavation for ground-truthing and verification are not included in this cost profile.

Table 9. Cost Reporting for UXO Identification Technology at Demonstration Scale in FY99 USD.

Cost Category	Sub Category	Costs (\$)
FIXED COSTS		
1. Capital Costs	Mobilization/Demobilization	42,900
	Planning/Preparation/Health & Safety Plan (Mission Plan)	10,500
	Equipment	24,900
	Management Support	8,500
Subtotal		86,800
VARIABLE COSTS		
2. Operation & Maintenance	Operator Labor	13,600
	Labor for Data Processing, Analysis, and Interpretation	28,600
	Instrument Rental or Lease	5,500
	Helicopter Support Services	22,100
	Travel and Miscellaneous Materials	4,500
	Reporting	5,500
Subtotal		79,800
3. Other Technology-Specific Costs	Excavation for Ground-Truthing and Verification	Not Included
	Establish Calibration Site	Not Included
Subtotal		0
4. Miscellaneous Costs	DOE Federal Acquisition Cost (FAC)	5,000
TOTAL COSTS		
Total Technology Cost		171,600
Throughput Achievable (acres per hour)		30
Unit Cost per acre		572

Also of note, no one-time, demonstration-related costs associated with survey optimization, detailed Calibration Site analysis, non-routine analysis, or excessive re-flights over the survey areas to evaluate and/or refine the demonstration, are included in the costs outlined in the table.

5.1.2 Typical Airborne Survey Costs

Often, specific survey sites and parameters are unknown or ill-defined during the early stages of project planning when consideration is being given to which geophysical technology implementation is most applicable. With this in mind, a typical set of cost estimates were developed that could be utilized for project planning purposes. These cost estimates were based on early cost models for conducting similar airborne magnetometer surveys, as well as incorporating lessons learned and final project costs from similar past projects at Canadian Forces Base Borden, Jüterbog Tank Training

Range, and Edwards Air Force Base. While initial calculations of survey costs included a variable associated with geographic locale, it was determined that this variable was actually a constant (approximately) due to the offsetting of ORNL mobilization/demobilization costs, and the ferry time for a regional helicopter provider to mobilize/demobilize from the survey sites. In addition, the survey cost estimate models assume surveys are conducted over relatively large contiguous areas. Surveys conducted over areas less than 500 acres are not reflected in these cost models, and require a different estimation structure. Costs for reacquisition and intrusive sampling are also not included in the models.

These generic cost estimates include the following factors:

- Project management.
- Mobilization/demobilization of the applicable airborne technology.
- Data acquisition (including equipment and helicopter costs).
- Data processing, analysis, and interpretation.
- Reporting.
- Travel, materials, and miscellaneous expenses.
- Federal Acquisition Cost (3% congressionally-mandated administrative fee to DOE).
- 5% project contingency to account for weather, sensor change-out due to unanticipated failure, etc.

Figures 11 and 12 depict the cost estimate model for airborne magnetometer survey cost as a function of survey size in acres, and the cost estimate model for airborne magnetometer survey cost per acre as a function of survey size in acres, respectively.

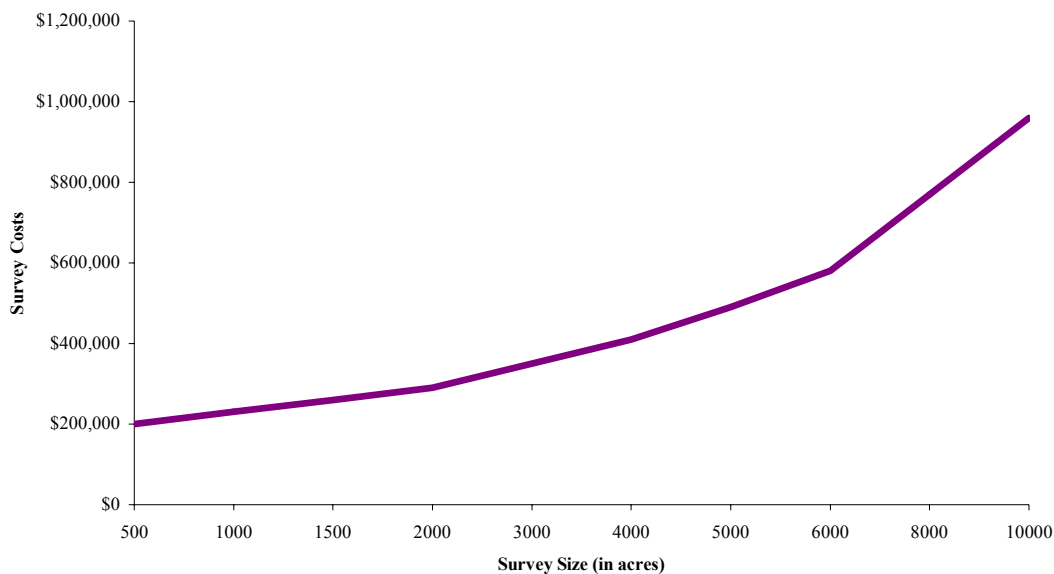


Figure 11. Airborne Magnetometer Survey Cost.

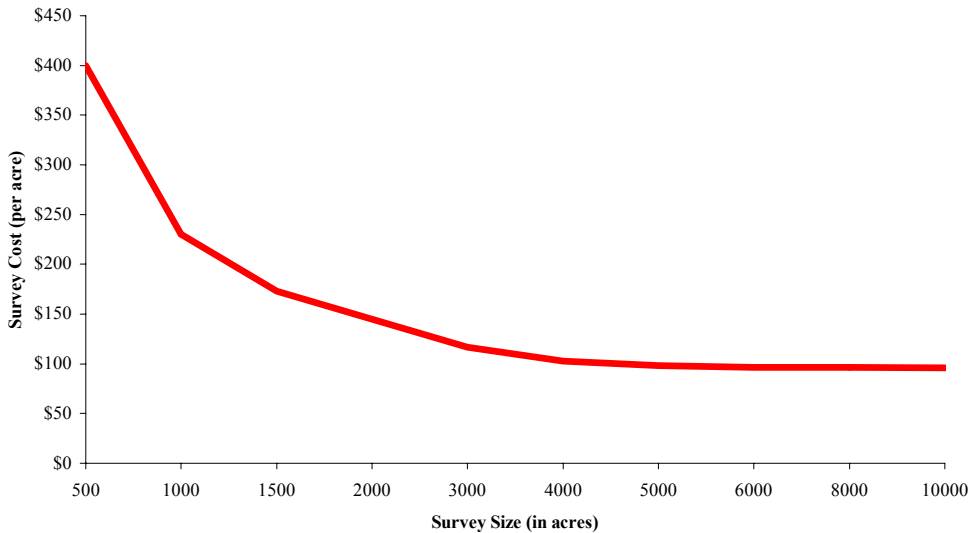


Figure 12. Airborne Magnetometer Survey Cost per Acre.

5.1.3 Ground-Based Towed Array Technology Cost Comparison

The cost comparison performed pertains to the use of a ground-based towed array of magnetometers similar to MTADS. This comparison was chosen for several reasons, including:

- MTADS was deployed at the same sites at BBR as the airborne technology (as reflected in the IDA report), which enables an easy comparison for broad-area search technology.
- USAESCH performed an assessment of costs associated with contractors that employ ground-based towed arrays for geophysical surveying at UXO sites.
- The extent of coverage possible with an airborne system renders comparisons to hand-held man-portable systems somewhat inappropriate.

Beginning with the cost comparison outlined in the IDA report, the following was extracted from the IDA report:

“For this demonstration, the MTADS total cost was \$377,296. If the excavation costs of \$169,096 and the reporting costs of \$24,000 are removed, the MTADS costs for the deployment, survey, and analysis parts of this demonstration were \$184,200. (Note that this does not separate out the costs of the EMI work.) The MTADS surveyed a total of more than 150 acres for a cost of \$1,222 per acre. For the HM3™, the total costs of this demonstration were \$220,000 to survey 287 acres, for a cost of \$766 per acre.”

According to the IDA report conclusions, “cost estimates prepared by the performers indicate that the per acre cost of the MTADS is about 2-3 times higher than those of the HM3™. These figures are very rough estimates and may not accurately reflect the cost differences seen in operational surveys.”

As mentioned, USAESCH performed an assessment of contractor costs associated with ground-based towed magnetometer arrays (similar to or the same as MTADS). Table 10 reflects the costs for a 287-acre survey, and includes all costs similar to the airborne survey illustrated in Table 9.

Table 10. Representative Cost for UXO Ground-Based Identification Technology at Demonstration Scale in FY99 USD.

Cost Category	Sub Category	Costs (\$)
FIXED COSTS		
1. Capital Costs	Mobilization/Demobilization	6,614
	Planning/Preparation/Health and Safety Plan (Mission Plan)	1,746
	Equipment	Included in Survey Cost
	Management Support	Included in Survey Cost
	Subtotal	8,360
VARIABLE COSTS		
2. Operation And Maintenance	Ground-Based Survey	129,650
	Labor for Data Processing, Analysis, and Interpretation	37,800
	Instrument Rental or Lease	Included in Survey Cost
	Travel and Miscellaneous Materials	26,060
	Reporting	4,230
	Subtotal	197,740
3. Other Technology-Specific Costs	Excavation for Ground-Truthing and Verification	Not Included
	Geophysical Prove-out	5,616
	Subtotal	5,616
4. Miscellaneous Costs	None Noted	0
TOTAL COSTS		
Total Technology Cost		211,716
Throughput Achievable (acres per hour)		3
Unit Cost per acre		735

5.1.4 Adjusted Cost Comparison

Costs have been shown for the actual HM3™ technology demonstration, a projected HM3™ deployment, the MTADS demonstration, and a competitive contractor ground-based towed array approach. These cost estimates are not directly comparable due to the added efforts of validation, exploratory and developmental data processing, and extensive detailed reporting. Both ORNL and NRL spent considerably more effort in data analysis than would have been necessary for a “production” deployment.

The actual costs illustrated in Table 8 associated with the HM3™ demonstration must be adjusted by eliminating the MTADS data comparison effort (\$6,864), as well as the cost associated with the Calibration Site set-up and ground-based geophysical mapping (\$11,400). Additionally, because of the nature of the developmental analysis and data processing, the associated costs are higher than would be expected for a commercial deployment. A reduction of \$20,000 from the ORNL processing renders these costs comparable to a commercial effort. Reporting and presentation requirements are also considerably more detailed for the demonstration. An additional cost

reduction (\$10,642) will bring these costs into relative alignment. These adjustments make the comparable cost \$171,323 for the HM3™ deployment (\$597 per acre).

For the costs associated with the MTADS demonstration deployment discussed in subsection 5.1.3, cost adjustments are required to enable direct comparison to the airborne costs. A cost addition is required for limited reporting, (\$5,000), while a cost reduction is required for data processing and analysis (\$20,000). These cost modifications applied to the total demonstration cost of \$184,200, yield an adjusted cost of \$169,200 for the 150-acre survey area (\$1,128 per acre).

The costs for the representative ground-based towed array illustrated in Table 10 are directly comparable to the adjusted cost scenarios described above. The cost for a competitively acquired ground-based towed array to survey 287 acres is \$211,716 (\$735 per acre). Table 11 provides a comparison of the technical approaches and their respective costs for deployment. As discussed previously, an airborne system deployment to a site consisting of less than 500 acres is not cost effective due to high mobilization/demobilization costs and technology set-up. Even discounting the potential economies of scale for a large area airborne survey, the adjusted costs provided in the table reflect airborne surveys to be approximately one-half the cost of the ground-based MTADS arrays and somewhat less than the commercial array.

Table 11. Adjusted Costs for Airborne and Ground-Based Systems.

Technical Approach	Total Cost	Acreage	Cost/Acre
HM3™ Demonstration	\$171,323	287	\$597
HM3™ Production	\$171,600	300	\$572
MTADS Demonstration	\$169,200	150	\$1,128
Commercial Array	\$211,716	287	\$735

5.2 COST ANALYSIS

The major cost driver for an airborne survey system is the cost of helicopter airtime. Data processing and analysis functions made up the bulk of the remaining costs. The costs associated with development of robust processing algorithms were a major factor in this particular survey. This is expected to diminish with each project as solutions to common problems are found. Mobilization is another major cost. Generally, this is a function of distance from the home base for the helicopter and equipment. Peripheral costs associated with this demonstration-validation project, such as ground truth and excavations were not considered in this part of the cost analysis.

The sensitivity of the overall cost to these drivers can be modeled under several different scenarios. Helicopter time on site is a factor of several variables. The first is the number and dimensions of the survey blocks. The greatest amount of non-survey time is spent in turns at the end of each line in preparation and alignment for the next line. Fewer and longer survey lines are therefore more efficient than numerous shorter ones.

The areas surveyed under this project demonstrate the efficiency of several different scenarios. The test grid is an example of a particularly small survey area (2.5 acres). On the other end of the scale,

Stronghold Table required only slightly more time to cover 42 acres - more than an order of magnitude increase in efficiency. The bombing targets (Cuny Table Bombing Target and Aerial Gunnery Target) required closer to six hours each, and covered 92 acres each. The relative efficiency of each of these scenarios is summarized in Table 12. The results show a nearly linear relationship between length of the survey line and the survey efficiency. These results will reach a plateau at a theoretical 185 acres/hour (ac/hr), which represents the maximum speed of the aircraft with zero time for turns.

Table 12. Airborne Survey Efficiency Parameters.

Site	Name	Coverage (in acres)	Airtime (in hours)	Efficiency (in ac/hr)	Line length (in km)
5	Stronghold Table Target	42	1.5	28	1.5
1	Cuny Table Bombing Target	92	6	15	0.8
2	Aerial Gunnery Target	92	6	15	0.8
3	Burial Pit, Section #15	30	4	7.5	0.4
4	Burial Pit, Section #17	30	4	7.5	0.4
6	Calibration Site	2.5	1	2.5	0.1

This means that lines longer than approximately 8-10 km do not gain additional efficiencies. One mitigating factor to this limit is a pilot performance issue. Longer lines typically require more frequent re-flights since it is more difficult to maintain precision flying over such long lines. In practice, a maximum line length of 5 km is advised.

The other major cost drivers were data processing and mobilization/demobilization. Processing and mobilization costs are generally linear with project size and transportation distance, respectively. Processing costs and data deliverable times will decrease with experience at multiple sites. Continued and consistent use of a static technology could potentially lead to overnight delivery times. Mobilization costs are unlikely to decrease with time. The use of a local helicopter and pilot may offer decreased mobilization costs, but risks significantly increased acquisition costs if the mechanic in charge of the installation is unfamiliar with the equipment, or if the pilot is uncomfortable with the level of precision flying that is required.

5.3 COST COMPARISON

As illustrated in subsection 5.1.3, comparing costs of fundamentally different technology approaches is both difficult and inconclusive. The previously discussed cost comparison provided a range of answers to the same question, namely, what are the costs of deploying each technology over the same size area under the same conditions? Table 13 provides yet another view of costs compared to ground-based surveying methods and technology.

Table 13. Comparison Between Airborne and Man-Portable Survey Costs.

Area (in Acres)	Airborne Cost (in \$/acre)	Airborne Total	Ground Cost (in \$/acre)	Ground Total	Savings
500	400	\$200,000	1,000	\$500,000	\$300,000
1,000	225	\$225,000	1,000	\$1,000,000	\$775,000
1,500	175	\$263,000	1,000	\$1,500,000	\$1,237,000
2,000	150	\$300,000	1,000	\$2,000,000	\$1,700,000

Based on several sources of information regarding the deployment of ground-based towed array systems on a UXO contaminated site, four scenarios are presented for the purpose of comparing airborne surveys to ground-based surveys. These sources of information are generally informal and include discussions both with industry and USAESCH staff experienced in the application of ground-based towed array surveying equipment and projects.

The scenarios described include sites of 500, 1,000, 1,500, and 2,000 acres of geographic extent, with respective costs of \$400, \$225, \$175, and \$150 per acre for the airborne survey portion of the cost comparison. These per acre values were taken directly from Figure 10. These comparisons between airborne and ground-based man-portable magnetometer surveys are summarized in Table 13. Neither the airborne nor the ground-based survey costs include the cost of excavation.

While both simplistic and generalized in nature, it is apparent that when the area of concern for potential UXO contamination becomes large, the costs for performing a ground-based man-portable survey become large as well when compared to the application of the airborne systems.

A number of factors must be considered when evaluating the appropriateness of the airborne technology and potential for substantial cost savings. While initially impressive, it is not possible to simply apply these types of cost savings across the entire DoD UXO program. Sites must be of sufficient geographic extent to warrant a deployment given the high costs associated with mobilization and demobilization. In addition, terrain, geology, and vegetation must also be considered for such a deployment. Extremely variable terrain and/or the presence of tall vegetation can greatly limit the use of the airborne technology. Finally, the UXO objective must be consistent with the detection limits and capabilities of the airborne system.

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

Costs were mostly within the original estimates. Data acquisition, processing and analysis tasks consumed nearly 60% of the funding. The presence of Parsons Engineering Science at the site reduced the cost of ground follow-up and excavation. This project was able to leverage mobilization costs to reduce the total expenditures. The site was geologically ideal, but logistically difficult. Refueling of the helicopter was done at the Rapid City Regional Airport. With a one-way flight time of nearly 30 minutes, this reduced the available onsite survey time to approximately 1.5-2 hours per flight. The ferry time between the airport and the survey site therefore represented a significant portion of the airtime. The possibility of refueling onsite in an environmentally acceptable setting will have to be investigated in the future.

Similar cost savings may be possible in the data processing and analysis tasks. As noted earlier, a considerable amount of time was devoted to developing or refining the processing methodology. The continued and consistent use of a static technology should reduce most of the processing procedures to a semi-automated technique. Under these conditions, rapid delivery of survey results should be possible in a production-oriented system.

6.2 PERFORMANCE OBSERVATIONS

The primary performance objectives were largely exceeded by this demonstration. Practical survey heights were lower than expected and the additional bandwidth in data recording allowed for much higher resolution of the seeded targets. The test grid was established with the objective of bracketing the detection capabilities of the system, and yet all seeded items were detected.

The objectives of this project were to demonstrate detection of ferrous targets, whether ordnance or non-ordnance. No attempt was made at classification, which made ground follow-up difficult to analyze with traditional UXO techniques (Pd and FP). The limited number of excavations compounded the difficulties, making statistically valid conclusions impossible. ORNL and IDA both conducted detection and discrimination analysis separately. In rough numbers, the digs resulted in about 80% ordnance with a 15% FP for the targets at this site.

6.3 SCALE-UP

Scale-up of operations could be conducted from either of two scenarios. The first scenario uses the current technology as is, with only minor modifications. The second scenario utilizes more comprehensive modifications to improve efficiency and resolution.

The current technology requires minor hardware and firmware modifications to improve aircraft and data positioning. Suitable training of geophysical personnel to handle the data processing will also be required, once the methodology has been refined to a more automated process. Given the current market conditions, equipment availability should not be an issue. A single operating system should be sufficient to handle all of the available work for the foreseeable future. At present, qualified personnel represents the most significant obstacle.

The second option incorporates more comprehensive modifications to the system in an effort to improve efficiency. Additional sensors in the array would eliminate the need for interleaving flight lines. This would improve data quality by reducing altitude variations and improving uniformity of coverage. It would also improve efficiency by reducing the number of survey lines required to cover a swath of ground, and reducing the number of re-flights required. In fact, later versions of the system have incorporated a number of major hardware modifications. These will be described in several follow-on reports. As with the first option, a single system should be sufficient to handle to current market demand, and the most significant obstacle is the shortage of qualified personnel. In addition, new processing techniques would have to be tested to handle the new data configuration.

6.4 OTHER SIGNIFICANT OBSERVATIONS

As mentioned previously, major factors in implementing or deploying the airborne system are topography and vegetation. Steep topographic variations make it difficult to achieve uniform altitude across the survey area. Most topographic features will be coherent between lines, which makes them easy to identify and will not be confused with ordnance signatures. The impact on data quality is that the average altitude will increase, making it more difficult to detect smaller objects.

Vegetation has a similar effect on data quality in that it necessitates an increase in survey altitude. Isolated pockets of vegetation or single trees can be handled in two ways. The first is to fly over them and create a small pocket of lower sensitivity data. The second is to fly around them and create a minor gap in data coverage. Continuous stretches of vegetation or forest should be avoided.

Geologic influence is another factor impacting the technology implementation. The difficulty of detecting ordnance in highly magnetic environments is well documented and impacts the airborne system as it would a ground system. The only solution to this problem would be to develop an airborne electromagnetic system.

6.5 LESSONS LEARNED

The primary benefit of this technology is in rapid reconnaissance of large open areas, commonly referred to as footprint reduction. Cost analysis shows that costs per acre decrease significantly with the size of the project, whereas ground surveys tend to have a fixed cost per acre. It would therefore be prudent to survey as large an area as possible with each mobilization, even if all of the data are not processed immediately.

6.6 END-USER ISSUES

End-users have been included in the project as often as possible. The USAESCH innovative technology director is the project Principal Investigator, the Oglala Sioux (land-owners) have been included in the project conception and preparation, and Parsons Engineering Science has conducted the ground truth in parallel to their own EE/CA activities. All of these parties have been supportive and encouraged by the survey results to date. In particular, the UXO technicians responsible for the excavations have expressed their admiration for the positioning accuracy of the results.

6.7 APPROACHES TO REGULATORY COMPLIANCE AND ACCEPTANCE

It is important to recognize the different aspects associated with the regulatory involvement in both the technology and the application of the technology to a UXO-contaminated site. With regard to the application of the technology, there are issues associated with regulatory drivers and involvement of both regulatory entities and other stakeholders that are relevant.

Although no specific regulatory drivers exist at this time for UXO-contaminated land, UXO clearance is generally conducted under CERCLA authority. Additionally, a draft EPA policy is currently under review. Regardless of a lack of specific regulatory drivers, many DoD sites and installations are aggressively pursuing innovative technologies to address footprint reduction and site characterization, areas of particular focus for this technology demonstration. In many cases, the prevailing concerns at these sites become a focus for the application of innovative technologies in advance of anticipated future regulatory drivers and mandates.

There are several types of sites where UXO contamination is an issue. These include Closed, Transferred, and Transferring (CTT) ranges, such as FUDS and BRAC sites, as well as sites on active and inactive ranges that are not scheduled for closure. Where sites are designated for civilian reuse, it is important that the UXO be removed to the extent possible, and that proper safeguards be established where there is any possibility that live ordnance might still be in place. It is also important that a permanent record be maintained to document all measurements that are made to support clearance activities. Advanced technology, such as the airborne system, is expected to contribute to the performance of these activities in terms of effectiveness as well as cost.

With regard to the technology itself, the only regulatory agency involved in the implementation of this technology is the Federal Aviation Administration (FAA). Since the boom mounting structure is bolted directly to the hard-points of the aircraft, this installation becomes a modification to the airframe that requires FAA approval. These approvals were obtained in the form of a Supplementary Type Certificate (STC). This certificate was obtained by the aeronautics engineer at the time of manufacture, and permits the installation of this equipment in any standard Bell B206L Long Ranger aircraft.

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7.0 REFERENCES

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APPENDIX A

POINTS OF CONTACT

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APPENDIX B

CALIBRATION SITE ORDNANCE, SIMULANTS, AND MISCELLANEOUS ITEMS

Item	Description	Weight (in lbs)	Length (in ft)	Width or Diameter (in ft)	Azimuth	Depth to Top of Item (in ft)
6001	2" Galvanized pipe w/end cap (rebar corner pin)	6	1.1	0.2	East-West	1.6
6002	3 ea. Rebar/rod sections	12	2.5	-	Random	1.85
6003	2" Galvanized pipe elbow	10	2.0	0.2	-	2.3
6004	Steel channel	15	1.75	0.25 x 0.25	-	2.1
6005	2" Galvanized pipe w/end cap	6	1.1	0.2	East-West	1.0
6006	2" Galvanized pipe with two cast floor flanges	10	1.2	0.2	East-West	1.3
6007	Empty (rebar corner pin)	-	-	-	-	-
6008	I-beam section	29	1.2	0.35	East-West	1.4
6009	Cast cylinder	25	0.85	0.4	-	1
6010	4 ea. Rebar/rod sections	9	2.5	-	Random	1.5
6011	I-beam section	10	0.3	0.67	-	2.1
6012	Rod	9	1.7	0.12	North-South	1.6
6013	100-lb. Bomb fragments	unknown	-	-	-	0.3-0.5
6014	100-lb. Bomb fragments	19	-	-	-	1.0-1.6
6015	250-lb. Bomb Simulant	50	5.3	1.2	North-South	4.4
6016	250-lb. Bomb Simulant	65	5.3	1.2	East-West	2.4
6017	100-lb. Bomb (intact)	50	4.0	0.65	North-South	3.1
6018	100-lb. Bomb fragments	32	2.2	0.8	North-South	1.3
6019	2.75" Rocket (nose section)	9	0.9	0.25	East-West	1.5
6020	100-lb. Bomb fragments (rebar corner pin)	unknown	-	-	-	0.3-0.5
6021	100-lb. Bomb fragments	unknown	-	-	-	0.3-0.5
6022	2.75" Rocket (cylinder)	9	0.75	0.25	East-West	2
6023	Steel T-Section Channel	9	1.05	0.25	-	2.4
6024	Cast Square Plate	55	1.1	1.4	-	3
6025	2 ea. 2.75" Rocket Simulants (rebar corner pin)	12	0.75	0.25	North-South East-West	1.3



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