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Airborne MTADS Demonstration at Aberdeen Proving Ground

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14. ABSTRACT

The second demonstration of the Airborne MTADS took place at Aberdeen Proving Ground in July 2002. Surveys were conducted on five sites containing different ordnance types and densities. Topographies varied from flat, mowed grasslands to trees and brush, wetlands, freshwater ponds, and marine offshore areas. Inert ordnance was seeded into three of the sites, including one area that had not previously been used as a range. Detection of the seed targets varied from very good on the airport site to near zero on a highly cluttered range. Detection of ordnance (81-mm and 105-mm) was difficult in the freshwater ponds, but straightforward in the offshore areas populated by larger targets. Surveying over water without fixed pontoons on the helicopter is limited to small ponds or rivers, or to very shallow water. Extensive, preexisting targets were dug on one of the highly cluttered ranges; more than 30% of the recovered targets were ordnance. The Airborne MTADS performance was measured against blind seeded targets. The Airborne MTADS production rate on these small sites was about 35 acres/hour.

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Acronyms

2-D	Two-dimensional
3-D	Three-dimensional
AEC	Army Environmental Center
agl	Above ground level
APG	Aberdeen Proving Ground
ATC	Aberdeen Test Center
BBR	Badlands Bombing Range
BRAC	Base Realignment And Closure
CEHNC	Army Corps of Engineers, Huntsville Center
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (commonly known as Superfund)
COG	Course over ground
CRADA	Cooperative Research and Development Agreement
CTT	Closed, Transferred or Transferring
DAQ	Data acquisition system
DAS	Data analysis system
DoD	Department of Defense
EM	Electromagnetic
EOD	Explosive Ordnance Detection
ESTCP	Environmental Security Technology Certification Program
FAR	False Alarm Rates [“ratio” is used herein, not “rates”]
FUDS	Formally used defense sites
GIS	Geographical Information System
GP	General Purpose
GPS	Global Positioning System
MTADS	Multi-sensor Towed Array Detection System
NRL	Naval Research Laboratory
OE	Ordnance and explosives
ORNL	Oak Ridge National Laboratory
P_d	Probability of Detection
QA	Quality assurance
QC	quality control
ROC	Receiver Operating Characteristic
RTK	Real-time kinematic
SERDP	Strategic Environmental Research & Development Program
USACE	US Army Corps of Engineers
UTM	Universal Transverse Mercator
UXO	Unexploded ordnance

Airborne MTADS Demonstration at Aberdeen Proving Ground

July 2002

1. Introduction

1.1 Background

1.1.1 The UXO Problem

Buried unexploded ordnance (UXO) is arguably the most serious and prevalent environmental problem currently facing Department of Defense facility managers. Not limited to active military bases and test ranges, these problems also occur at DoD sites that are currently dormant, and in areas adjacent to military ranges that belong to the civilian sector or are under control of other government agencies. The amount of land affected is generally agreed to be in excess of 10 million acres in the continental US. UXO mitigation and remediation requirements assume even more compelling proportions when the DoD lands involve Formerly Used Defense Sites (FUDS) or Base Realignment and Closure (BRAC) sites. These sites must be certified as suitable for their intended end use, depending on the pending disposition. Oversight and evaluation of these processes involve non-DoD agencies including the EPA; state, county, and local governments; and the civilian community.

1.1.2 Automated Geo-referenced Surveys

SERDP, ESTCP and the U.S. Army Environmental Center UXO Advanced Technology Demonstration Programs for nearly a decade have been addressing the need for more modern automated UXO detection and characterization technologies. These investments have resulted in the development, demonstration, and commercialization of automated site characterization technologies such as the Multi-sensor Towed Array Detection System *(MTADS)*.[1] The original *MTADS* system consists of a tow vehicle and two low-self-signature tow platforms: one for an eight-sensor magnetometer array, the other for a three-sensor time-domain electromagnetic (EM) pulsed induction array. *MTADS* uses GPS for navigation, recording sensor position locations, and survey guidance, and a sophisticated data analysis system. This system has demonstrated relatively rapid and efficient surveying of large sites, with commensurate economic benefits, for the full range of buried UXO targets at their maximum likely penetration depths. On ranges with relatively uncomplex use histories (i.e. ranges involving primarily the use of similar types of ordnance such as only air-deployed bombs and practice bombs, or only surface gun-fired projectiles, etc), routine UXO detection probabilities of greater than 95 percent are often achieved in areas without severe geological interferences. More importantly, these automated UXO site characterization systems are typically deployed with satellite-based GPS survey guidance and navigation support. Use of fully integrated GPS navigation systems allows sensor

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measurements to be (time and) location stamped so that the survey products are geo-referenced digital maps of the survey area in which buried target signals can be analyzed using physics-based fitting algorithms. The survey products are compatible with GIS mapping technologies. The survey products can thus be permanently archived, used for QA/QC evaluations, organized to support subsequent (or delayed) remediation activities, and used to evaluate or defend the performance of the system if legally challenged. A single vehicular-based automated survey system typically covers an area of 15-20 acres per day. In extended surveys the entire automated UXO site characterization activities, including the survey, target analysis, and preparation of reporting documents to support remediation activities can be delivered for $400-1000 per acre depending upon the size and complexity of the site. The *MTADS* technology was transitioned to the commercial sector (Blackhawk Geometrics, Inc.) by means of a CRADA and is currently being used to provide commercial UXO service activities to the DoD.[2] Other commercial UXO service providers have developed similar capabilities, which they are also marketing to the DoD for UXO site characterization studies.

This technology has provided a huge step forward in capability, efficiency, and economy for UXO site characterization. The Department of Defense,[3] the US Environmental Protection Agency (EPA), and the Army Corps of Engineers[4] have sanctioned this approach as the preferred technology, which should be used by default unless there are mitigating circumstances. While this has been declared the technology of choice, only a small fraction of the UXO site characterization activities are currently being carried out using the modern technology. There are purportedly four mitigating circumstances justifying the continued use of Mag and Flag approaches for UXO surveys. These include activities where sites are too small to justify use of vehicular systems, sites where forest canopies or limited sky visibility preclude the use of GPS, sites where the surface geology or topology is not suitable for vehicular surveys, and finally very large sites where the costs associated with vehicular (or Mag and Flag) surveys preclude any comprehensive action from being undertaken.

The first three of these limitations have been addressed by the Man-Portable *MTADS* adjuncts, which employ both GPS and acoustic navigation systems.[5,6] Under ESTCP Project 199811, NRL developed and demonstrated man-portable adjuncts to the vehicular-towed *MTADS* arrays: a man-portable magnetometer system (MMS) and a man-portable EM system (EMMS). Each system is implemented with either GPS or acoustic navigation to allow surveying in areas without sky view. The system hardware allows MMS and EMMS data to be combined with vehicular survey data, and a new data acquisition system for both the vehicular and the man-portable systems uses a modified data analysis system to seamlessly process all data sets. These man-portable adjuncts to the *MTADS* have also been transitioned to the commercial sector through a CRADA with Blackhawk Geometrics.[2] Variants of the NRL *MTADS* Man-Portable system hardware, as demonstrated for ESTCP, are generally available for use from several UXO service providers.

One significant limitation of the man-portable systems is that while they have relatively modest deployment and mobilization costs, they invariably are more expensive to operate (on a per acre basis) than the vehicular systems. Man-portable survey costs are typically similar to the costs of

Mag and Flag UXO survey products.[6] Even given this limitation they are preferable because they provide digitally referenced survey products.

1.1.3 The Airborne System

NRL, with the support of ESTCP Project 200031, adapted the vehicular *MTADS* magnetometry technology for deployment on an airborne platform.[7] The intent of this development is to provide a UXO site characterization capability for extended areas that are inappropriate for vehicular surveys. Because the sensors on an airborne platform must be deployed further from the ground surface than those on vehicular or man-portable systems, it was understood that detection sensitivity for single smaller UXO items would be compromised. It was a primary goal of the development, however, to retain as much detection sensitivity as possible for individual UXO targets.

Sites appropriate for airborne surveys include those with terrain that would be difficult to efficiently survey with a vehicular system and sites that are too extensive to economically evaluate with vehicular or other approaches. Some sites, particularly on active ranges, are cluttered with a variety of ordnance that makes clearance or even characterization activities potentially dangerous. There are many formerly used ranges dating from World War II (and earlier) that are located in areas involving tens or hundreds of thousands of acres with isolated bombing targets or impact ranges. Locations of many of these impact areas (or ordnance burial caches) are unknown or imprecisely located. Some of these areas are located on Native American reservations while others involve Closed, Transferred or Transferring (CTT) ranges. Therefore, the second primary objective of the development was that the final system must have production rates and production costs appropriate for deployment to explore very large sites that would be prohibitively expensive to survey by other techniques.

The first extended demonstration of the Airborne *MTADS* developed under ESTCP Project 200031 took place on a live ordnance range, the Impact Area of the Badlands Bombing Range on the Oglala Sioux Reservation near Interior, SD in September 2001.[8] During this demonstration a 10-acre site seeded with 25 inert projectiles (105-mm, 155-mm, and 8-inch) was flown to allow comparison of the system performance with that of the vehicular *MTADS*, which surveyed the same site. An additional 1600 acres were surveyed using the airborne system as part of continued clean-up efforts over the entire Impact Area. Analysis of the airborne data collected over the seeded site resulted in a total of 161 targets selected for digging including all of the seeded projectiles and one live, HE-filled, 155-mm projectile. We, therefore had to dig 6.2 holes for each recovered UXO target. A total of 1,193 targets were analyzed from the 1600-acre survey, resulting in 528 excavations and recovery of a total of 19 live UXO projectiles including eleven 155-mm and eight 8-inch projectiles.[8]

1.2 Official DoD Requirements Statement

The Navy Tri-Service Environmental Quality Research Development Test and Evaluation Strategic Plan[9] specifically addresses, under Thrust Requirements l.A.1 and 1.A.2, the requirements for improved detection, location and removal of UXO on land and under water. The index numbers associated with these requirements are 1.I.4.e and 1.III.2.f. The priority 1 rankings of these requirements indicate that they address existing statutory requirements, executive orders or significant health and safety issues. Specifically the requirements document states:

> *There are more than twenty million acres of bombing and target ranges under DOD control. Of particular concern for the Navy are the many underwater sites which have yet to be characterized. Each year a significant fraction (200,000-500,000 acres) of these spaces are returned to civilian (Private or Commercial) use. All these areas must be surveyed for buried ordnance and other hazardous materials, rendered certified and safe for the intended end use. This is an extremely labor intensive and expensive process, with costs often far exceeding the value of the land.... Improved technologies for locating, identifying and marking ordnance items must be developed to address all types of terrain, such as open fields, wooded areas, rugged inaccessible areas, and underwater sites.*[6]

1.3 Objectives of the ESTCP Demonstration

1.3.1 Development Objectives

The primary goals of the airborne *MTADS* Dem/Val program are enumerated below:

- Field an airborne magnetometer array capable of efficiently surveying and characterizing very large or inaccessible areas associated with DoD bombing and target ranges,
- The system should have the capability to characterize the presence of UXO associated with impact bull's eyes or buried ordnance caches, as well as individually detecting and characterizing larger buried UXO targets,
- The airborne survey system incorporates many of the successful developments associated with the vehicular *MTADS*, including sensors, satellite-based navigation, efficient data acquisition approaches, and the DAS suite of utilities for data manipulation and target analysis, and
- The system will create a permanent record in global coordinates of the positions of all targets, and GIS-compatible survey graphics products.

1.3.2 Demonstration Support and Coordination

Funding for this demonstration was provided by ESTCP, Project 200031. The Demonstration Test Plan, and this Demonstration Report document our activities for ESTCP. Our activities at APG were coordinated with George Robitaille of the Army Environmental Command (AEC) and Gary Rowe of Aberdeen Test Center (ATC). Our activities in the Demonstration at the APG took place in coordination with The Wide Area UXO Aerial Demonstration and Survey developed by AEC[10] with support by ESTCP Program 200103.

The *MTADS* airborne survey at the Impact Area of the BBR demonstrated the system production rates and costs on an extended area survey and evaluated the system detection and discrimination capabilities on a range used only for ground artillery training with relatively large (105-mm, 155-mm, and 8-in) projectiles. The second demonstration at APG was designed to evaluate the system performance on ranges with more complex use histories, in areas of high clutter, and in areas with a variety of terrain.[11]

1.3.3 APG Demonstration Objective

Multiple sites at APG were prepared to evaluate the performance of the NRL Airborne *MTADS* in comparison with the ACE/Huntsville-Oak Ridge airborne system (ESTCP Projects 200037 and 200101). The APG Test Plan[12] specified that each system would fly the same survey areas during the same demonstration period. Survey products from both the NRL and Oak Ridge surveys were submitted to both AEC and ESTCP/IDA for evaluation. Five survey ranges were prepared, in addition to a small Prove-Out-Area with known UXO challenges. In addition to existing UXO and clutter present on 4 of the 5 survey areas, additional seed targets were emplaced by ATC on 3 of the survey areas. Specific demonstration objectives include system performance evaluation for UXO detection and discrimination in response to the following challenges:

- Detection capability on a relatively low-clutter area seeded with small and medium sized UXO,
- Detection and discrimination capability on a mixed-use range with relatively flat terrain and low vegetation levels,
- Detection and discrimination capability on a very complex mixed-use range with areas of 2-meter high vegetation, transitions to shallow water, high levels of surface clutter and obstacles, and expectations of buried UXO caches,
- UXO detection capability in fresh-water ponds seeded with ordnance, and
- UXO detection capability on a marine projectile impact area with water depths of 0-2.5 meters.

1.4 Regulatory Issues

The regulatory issues affecting the UXO problem are most frequently associated with the BRAC and FUDS processes involving the transfer of DoD property to other agencies or to the civilian sector. When transfer of responsibility to other government agencies or to the civilian sector takes place, the DoD lands fall under the compliance requirements of the Superfund statutes. Section 2908 of the 1993 Public Law 103-160 requires adherence to CERCLA provisions. The basic issues center upon the assumption of liability for ordnance contamination on the previously DoD-controlled sites.

These regulatory considerations do not apply to active DoD facilities. However, even within sites such as APG, environmental concerns must be addressed because soil and ground water contamination by energetic residues and byproducts, and by heavy metals (Pb, Bi, As, Sb, U, etc.) associated with ordnance components, may migrate to underground aquifers and routinely, through run-off, reach other properties. Specifically at APG, extensive (on base) wetlands are used by migratory birds and other waterfowl and marine estuaries and bays beyond the APG boundaries (with known UXO contamination) are continuously harvested for finfish and shellfish by both private and commercial fishermen.

Conducting UXO geophysical surveys in shallow water wetlands and in shallow offshore areas is extremely difficult, expensive, and inefficient. The airborne *MTADS* provides a technology appropriate for addressing some of these challenges. This demonstration allowed us to evaluate how extensively it can be applied in terrains that cannot be traversed on foot, and in areas that are dangerous for routine ground activities. In addition, this demonstration provided data that can be used to demonstrate a statistical probability of success for the detection and characterization of isolated UXO targets, extended impact areas, and ordnance burial caches.

2. Technology Description

2.1 Background and Applications

2.1.1 System Specifications and Requirements

It was realized during our design modeling studies that using magnetometer arrays based upon helicopter platforms, the smallest military ordnance would not be detectable as individual targets. Extensive modeling calculations were carried out projecting target signatures as a function of altitude. Helicopter pilots were interviewed to determine the practical limitations for altitude, payload, platform design, and mission endurance capabilities that could be expected. We drafted and refined the specifications and requirements goals that became part of our original proposal and the Development Plan. Table 1 shows a summary of the design specifications that formed the requirements document incorporated into the Development Plan. We evaluated likely helicopter platforms and conducted both static and dynamic platform signature tests using magnetometers and candidate helicopters. Ultimately, based upon design, performance, and availability considerations, the Bell Long Ranger Series was chosen as the support platform. The Demonstration Report that we published following the BBR Impact Area Demonstration[8] describes in detail the system development including component and system integration and the series of shakedown studies conducted at the Airfield at Aberdeen Proving Ground. This description will not be repeated here.

2.1.2 Field Hardware

The airborne *MTADS* system hardware incorporates an array of seven total field magnetometers on a platform designed for mounting on any Model 206L series Bell Ranger helicopter. The *MTADS* magnetic sensors are Cs vapor full-field magnetometers (a variant of the Geometrics 822 sensor, designated as the Model 822A). The specially-selected magnetometers, which are airborne quality, were acceptance tested at the manufacturer's facility to verify sensitivity, sensor noise, heading error, dead zones, inter-sensor compatibility, and performance with the multi-sensor interface modules. The helicopter with the mounted magnetometer array is shown in Figures 1 and 2. All sensors are interfaced to a data acquisition computer (DAQ). The DAQ electronics are contained in a rack mounted in the rear starboard seat position in the helicopter, Figure 3. The interface to the helicopter power and power distribution system is also in the rack, as are readouts for all the sensor inputs. An operator in the rear port seat continually monitors the survey progress. In the 9-meter boom, the seven sensors are mounted with a 1.5-meter horizontal spacing. The time-dependence of the Earth's background field is measured by an eighth magnetometer deployed at a static site during survey operation.

The sensor positions over the surface of the Earth (latitude, longitude, and height above ellipsoid) are determined using satellite-based GPS navigation, employing the latest Real Time Kinematic (RTK) technology, which provides a real-time position update (at 20 Hz) with an accuracy in the horizontal plane of about 5 cm. Inaccuracies in the height above ellipsoid (HAE) typically are about twice those in the horizontal plane. GPS satellite clock time is used to time-stamp both position and sensor data information for later correlation.

Table 1. System Specifications and Requirements for the Airborne MTADS.

Survey Flight Duration	2 hours (including ferry/calibration time)
Survey Speed	10 - 20 m/sec
Lane Spacing	7 meters (nominal) *
Survey Area (Single Setup)	250 acres
Flights Per Day	3 (single pilot)
Detection Sensitivity	Isolated BDU-33 or 2.75-in Warheads
Sensor Sensitivity	0.01 nT
Sensor Data Rate	100 Hz
GPS Navigation Data Rate	20 Hz
GPS Sensor Position Accuracy	5 cm
Data Acquisition System (DAQ)	Compatible with *MTADS* vehicle DAQ
Data Analysis System (DAS)	Seamless integration with vehicle data

* Depending upon winds and pilot experience

Figure 1 – *MTADS* Airborne Survey hardware is shown being installed on a Bell Long Ranger at the Helicopter Transport Services Hanger.

Figure 2 – *MTADS* Airborne Survey on the Active Recovery Field. Note the 2-meter high vegetation that stretches from this point to the shoreline.

Dual GPS antennas (Trimble Zephyrs), deployed on the forward horizontal boom, in addition to providing the position over ground and the height above ellipsoid positions for sensor mapping, provide boom roll and yaw attitude information for sensor location corrections. A solid-state vertical gyro (Crossbow VG300CB) provides the pitch attitude correction and a high-speed digital 3-axis fluxgate sensor (Crossbow CXM539) provides three-axis information that can be used to derive aeromagnetic compensation corrections for the magnetometer sensor data.   Laser (Optech Sentinal, Model 3100DV) and radar (Terra, Model TRA350/TRI40) altimeters mounted on fixtures attached to the rear hardpoint on the helicopter provide separate independent altitude measurements to the DAQ computer. The dual altimeters were deployed because they provide complementary information when operating over water or vegetated surfaces.

As a result of studies conducted during the shakedown surveys and the large field survey at the BBR (see later discussion of target depth measurements and creation of DEMs), we decided to add additional altimeter measurement capability to the platform. Acoustic ranging sensors were purchased from EDP (SonaSwitch, Model Mini-A) and adapted for use as altimeters. Three downward-looking acoustic sensors were added to the system; one was mounted on each of the forward-pointing yellow nipples (Figure 1) on the sensor boom, and a third was mounted adjacent to the laser and radar altimeters. These sensors, reading at ~10 Hz, provide a much more comprehensive surface map, particularly when used in conjunction with the other altimeters.

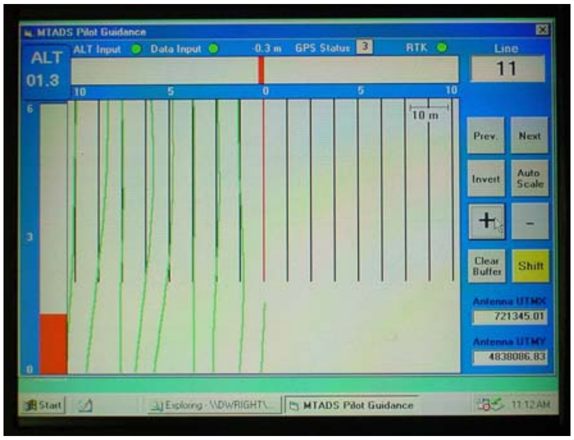
The helicopter pilot flies the survey using an onboard navigation guidance display developed specifically for this application. The navigation computer with its sunlight-readable screen is mounted to the right of the instrument panel, Figure 4, so that it is in the field of view of the pilot without obscuring his ability to visualize the whole forward boom and the field immediately ahead of the helicopter. The survey parameters are set up in the pilot display computer. The pilot display and the DAQ computers share the navigation and altimeter data.

The survey guidance display, Figure 5, provides left-right indicators, an altitude indicator, an automatic line number increment, an adjustment for lateral offset, a color-coded flight swath overlay, and the ability to zoom the presentation scale in or out on the display. The survey course-over-ground (COG) is plotted for the pilot in real time on the display, as are presentations showing the laser altimeter data and the GPS navigation fix quality. This allows the operator to respond to

Figure 3 – The DAQ console is shown mounted in the rear starboard seat position. Note the Trimble Model MS-750 units mounted on the side of the rack.

Figure 4 – Starboard side of the cockpit. The survey guidance display is shown mounted as it was used for the surveys.

both visual cues on the ground and to the survey guidance display. Following a survey, the pilot and the analyst could isolate and survey any missed areas before leaving the site. The experience gained in the shakedown exercises was sufficient to allow surveys to be conducted without the need for additional ground support personnel.



ALT 01.3

GPS Status 3

Line 11

Antenna UTMX 721345.01

Antenna UTMY 4838086.83

Figure 5 – Close-up of the pilot navigation display screen showing the pilot lining up on line 11 (red) of the survey grid.

The sensor boom and the internal components are fabricated using fiber and resin composite techniques. The fiber in the forward boom is Kevlar, because it is nonconducting. Internal gimbal and mounting structures in the forward boom are also nonmetallic. Securing screws and fasteners are brass, nylon, or non-magnetic stainless steel, depending upon tensile requirements. The lateral boom structure is fabricated using carbon composite materials and the interfaces for attaching the composite booms to the helicopter hard points are machined from aluminum.

The sensor boom, with internal ballast to approximate the sensors and sensor interfaces, was test flown at the manufacturer's facility. Minor adjustments were made and the system was test flown for flight certification in Canada.[13] Weight, balance, ballast, altitude and maximum speed restrictions were established and the system was type-certified for the Bell L-Ranger (Models 206-L, 206-L1, 206-L3, and 206-L4). The Canadian certification was submitted to the FAA in the US and was subsequently certified for US operation without modification.[14] The primary constraints on flight operation are a speed restriction to 65 knots and a restriction that there can be only one occupant in the front seats. The second passenger and the electronics rack are located directly at the center of gravity. Standard weight and balance calculations are done before beginning flights on each new aircraft. Typically, 50-75 lbs of ballast are required in the aft cargo hold to balance the forward sensor boom.

2.2 Data Preprocessing

Survey and navigation data recorded in the DAQ computer are transferred (using a ZIP disk or a notebook computer) to the Data Analysis System computer (DAS). The DAS software was developed specifically for the *MTADS* systems (vehicular, man-portable and airborne) as a stand-alone suite of programs written using IDL development tools, and graphical user interfaces (GUI's) working in a UNIX-based workstation environment. Over the past four years the *MTADS* DAS has been adapted to operate in a WINDOWS environment on a PC. Unless very large data sets are displayed, routine field notebook computers are suitable to display, process, and analyze survey data.

The first task of the analyst is inspection and processing of the data in preparation for target analysis. Initially, files are reviewed to determine sensor data quality. Necessary edits are carried out to remove spurious sensor readings, to clean up the navigation files, and to apply required sensor data filtering and smoothing operations. The navigation and sensor files are then processed together to establish a 3-dimensional coordinate location for each magnetometer sensor reading. Finally, the individual survey files are assembled into site survey maps (mapped data files). At this point target analysis can begin. Historically, these operations have been carried out using utilities associated with the *MTADS* DAS. We recently have begun adapting many of these operations and utilities to run from within the Oasis montaj software suite.[15] At this point all operations up to and including the creation of the mapped data files for target analysis can be carried out for airborne data using either montaj or the *MTADS* DAS.

2.2.1 Sensor Noise

The treatment of magnetometry data to correct for platform and motion induced signals, to a large extent, uses standard techniques. Some of these techniques have been developed and applied during the vehicular *MTADS* projects. These include the use of reference magnetometers to cancel diurnal field variations, a down-the-track demedian filter to cancel sensor baseline drift, sensor leveling subtractions to cancel sensor zero offset differences, and spatial data filtering to suppress geological effects and some platform-induced signal offsets.

2.2.2 Blade Noise

The largest platform-induced signal is usually that associated with the rotating blades. The noise is not primarily associated with the blades, themselves, but with the rotator hub assembly. These assemblies are “magnafluxed” during overhauls to inspect for stress or fatigue cracks. They are demagnetized before reinstallation, but the efficiency of this step varies widely. The rotor noise is primarily at 6.5 and 13 Hz because the helicopter is designed to operate at constant (6.5) rpm. The rotor rpm rate changes significantly only if the helicopter abruptly changes attitude or altitude, and quickly returns to the nominal value. There is also a 25 Hz noise spike that may result from boom vibrations, or vortex shedding. The effect is best visualized in a noise/frequency plot (power spectrum), as shown in Figure 6. The 6.5 Hz spike varies in intensity (from ~0.3 nT to >10nT, depending upon the helicopter. We have seen both extremes from the same machine before and after an overhaul. The 13 Hz signal reflects that the helicopter has two blades; each passes near each sensor once during a revolution of the rotator hub. The 25 Hz signal we believe is associated with a standing wave vibration of the forward sensor boom likely induced by vortex shedding or by higher frequency airframe vibrations. The 6.5 and 13 Hz interference signals seen by the outboard sensors are about a factor of two weaker than that seen by the center sensor. Our typical approach is to apply narrow notch filters at 6.5, 13 and 25 Hz to suppress the noise source to nearly zero for sensors 1, 2, 6, and 7. Sensors 3, 4, and 5 often have a just detectable remaining 6.5 Hz signal. All of these frequencies are significantly above the frequencies associated with UXO targets in field data. Applying the notch filters improves the appearance of the mapped data files and slightly improves the fit qualities for the lower intensity targets.

2.2.3 Platform Attitude Corrections

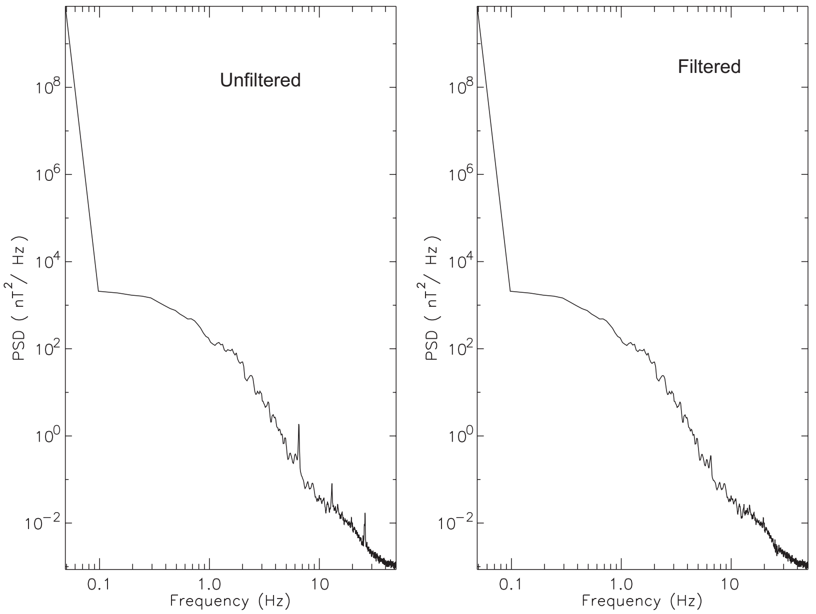


Figure 6 – A power spectrum (left Panel) is shown for sensor 6. One hour of data is included, which was taken during survey of the Active Recovery Field. The right panel shows the same data after notch filtering to remove blade and vortex shedding noise.

Traditionally, in airborne geophysical surveys and military airborne search applications, a technique called aeromagnetic compensation has been used to correct for platform attitude and orientation effects in magnetometry mapping surveys. This technique, primarily used in fixed-wing aircraft, uses commercially available sensor technologies and specially developed software algorithms to reduce the platform-induced magnetic noise to levels on the order of 0.01 nT. This approach has been used in the geophysical exploration community on both fixed-wing aircraft and helicopters. Depending on the techniques used, and the type of platform, the compensation has been demonstrated to reduce the platform and heading noise to 0.1-0.5 nT on some helicopter platforms. This is well below the typical geophysical noise levels measured in our vehicular surveys due to magnetic soils and rocks and sensor motions in the spatially varying Earth's field. The signal intensity from an individual ordnance item the size of a GP bomb (or a buried UXO cache) is a few to several hundred nT, even at several meters altitude. The ability to detect and characterize an isolated large target is therefore not a matter of signal strength or signal-to-noise ratio, but a matter of having a data sampling density high enough to identify the target as a target and to characterize its magnetic anomaly signature using the dipole-fitting routine. These issues were incorporated into the design of the horizontal sensor spacing in the array and the flying speed for the airborne platform.

NRL completed a development project with a subcontractor to adapt and apply existing aeromagnetic compensation software capabilities to the *MTADS* airborne system. The subcontractor owns the rights to this program, but unlimited use rights could be purchased. The use of the algorithm involves having the aircraft fly a set of high altitude closed-loop maneuvers involving extremes of attitude and orientation. From these data a set of attitude and orientation corrections are generated to compensate the attitude-dependent platform-induced signals. On all our shakedown flights and during the first demonstration at the BBR these data sets were taken; however, the platform attitude effects in the survey data have not warranted application of the algorithm. The urgency of the need to develop and apply these corrections has been mitigated by our success in application of the other *MTADS* data preprocessing techniques and filters enumerated above. The data taken during the airborne shakedown tests and during the BBR demonstration[8] have shown that the application of our normal preprocessing steps reduces the platform-induced noise to below 1 nT. Our existing aeromagnetic compensation routines reduce extreme attitude platform effects to slightly below 1 nT. However, to prove their value will require that we conduct surveys on areas that are geologically quiet on the sub-nT scale or that terrain effects require extreme attitude excursions during the survey process. While this is unlikely on most surveys over hard terrain, it is more likely that these corrections will be important in marine applications where a couple of meters of water intervene above the hard surface and the bottom sediments tend to be geologically more homogeneous.

2.2.4 Mapping Sensor Coordinates

The man-portable and vehicular sensor *MTADS* platforms are designed to maintain the sensors at a fixed height (25 cm) above the ground. The helicopter altitude varies considerably, depending upon the vegetation and the terrain. Therefore, the 2-dimensional ("Flat Earth") calculation algorithm used with the man-portable and vehicular analysis engines is inappropriate for use with the airborne data. For this reason the analysis algorithm was upgraded to a full 3-dimensional fitting routine. Each sensor reading is now mapped in 3 dimensions, an X-Y position (in Lat/Long or UTM coordinates) and an altitude (HAE) derived from the GPS data. The GPS sensor data streams are time-stamped by the GPS clock time that is accurate, as recorded, to the microsecond time scale. The computer clock correlates the GPS 'pulse per second signal' with the magnetometer trigger pulse. This is accurate at the millisecond time level. The sensor coordinates are determined by applying geometric corrections relative to the primary GPS antenna position. Platform attitude corrections are derived using the second GPS antenna (roll and yaw) and the fluxgate and inertial attitude sensors (all angles of rotation). Until after the first demonstration at the BBR, airborne target analyses were carried out using the sensor HAE and target tables were generated with target depths recorded in HAE. To determine the target depth below the ground surface, the surface HAE was subtracted from the target HAE. To accurately determine the surface HAE, it was measured at the time of target reacquisition. This is the approach used at the BBR demonstration.[8] It was decided that this approach was unacceptable for two reasons. First, the analyst during the target fitting process needs to have an estimate of the depth to assist his decision about classifying the target as UXO or scrap and to determine its UXO probability. Secondly, the additional step to measure the surface HAE in the field during reacquisition and to calculate the target burial depth is too complex an operation to be handled by UXO techs in the field and leads to loss (or mis-recording) of this information unless extreme care is taken during the process. For these reasons, modifications were made both to the DAS and to the altitude measurement process.

2.2.5 Digital Elevation Maps

In a 3-D survey such as those conducted with the *MTADS* airborne adjunct the physical dimensions of the array are large, and the sensor height above ground varies significantly during data acquisition. Furthermore, factors such as ground vegetation cover, reduced spatial sampling, and physical offsets of the altimeter data relative to the geophysical sensors compromise the accuracy with which we are able to measure geophysical sensor height above ground. Figure **7** schematically shows the important components of the altitude correction system.

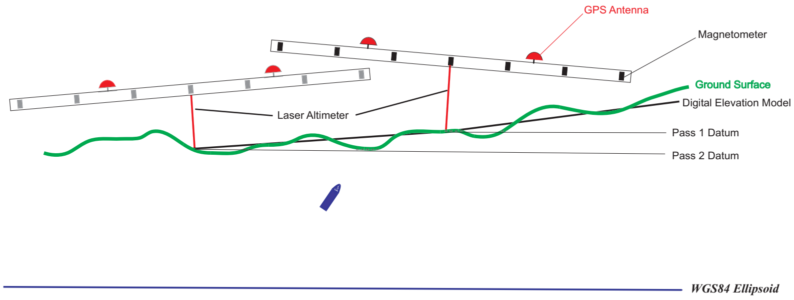


Figure 7 – Important components of the sensor boom involved in deriving the Digital Elevation Model.

To isolate these errors from the dipole fitting analysis we use the sensor HAE as the vertical reference, thereby ensuring a consistent coordinate system for both geophysical sensor input and target position output. While use of the height above ellipsoid ensures a consistent frame of reference for the fitting analysis, this measure is cumbersome for dig teams to use during the remediation process. Therefore, we modified the MTADS DAS to derive an estimated target depth below ground surface based upon the target's estimated HAE and a measure of the altitude from the laser altimeter. This provides an analysis aid to the analyst during target fitting. The (separately) positioned altimeter data are used to map the ground surface and derive a Digital Elevation Model (DEM) in the same coordinate system. The depth below ground for each target can then be refined by subtracting the target HAE from an interpolated (using the DEM) ground elevation HAE at the target's horizontal position. This step is currently done outside the DAS. In this manner, uncertainties with respect to the measurement of the ground surface is constrained to the depth below ground estimate, and does not compromise the validity of the feature information derived from the analysis routine itself.

The primary measure of aircraft height above ground level (agl) along the flight path is based upon the laser altimeter. However, using a single pass does not provide an accurate model of the ground surface under the outboard sensors because of terrain deviations lateral to the flight direction. This issue is addressed by generating a DEM of the survey area using all of the survey passes. This method effectively reduces error in our estimate of the ground surface elevation by interpolating measurements between passes, rather than assuming level ground and extrapolating from a single pass. The DEM (based upon four separate altimeter measurements, see below) is generated as a Geosoft[15] 'grid' file in which the survey area is broken down into a number of 'grid cells' each associated with a single value representing the interpolated ground elevation at that location. This format naturally imposes spatial filtering appropriate to the grid cell size and data sample density (when more than one sample falls within a grid cell the resulting value is an average of the samples). A grid cell size of 1.0 m^2 or less is typically used for the DEM to avoid undue filtering along the line. After the target horizontal location estimate is derived from the dipole fitting routine we extract the ground surface HAE from our DEM grid at that location (using the Geosoft 'grid sample' utility) and subtract it from the target HAE to derive an estimate of the target depth below ground.

To mitigate the sparseness of the laser altimeter data we added three acoustic altimeters to the system. Two are located on the forward boom, in line with the GPS antennae and the magnetometer sensors, reducing the impact of pitch measurement errors, and improving our lateral sample density. The third is located at the rear of the aircraft beside the laser altimeter to facilitate calibration and comparison of the acoustic altimeters relative to the laser altimeter. Figure 8 schematically shows the DEM derived using the additional elevation data. Unfortunately, the acoustic altimeters have a much larger footprint; thus they do not penetrate well through dense vegetation and give an inaccurate height above ground in significantly vegetated areas. The usefulness of the acoustic altimeters is limited to areas with limited vegetation cover. They work very well over water.

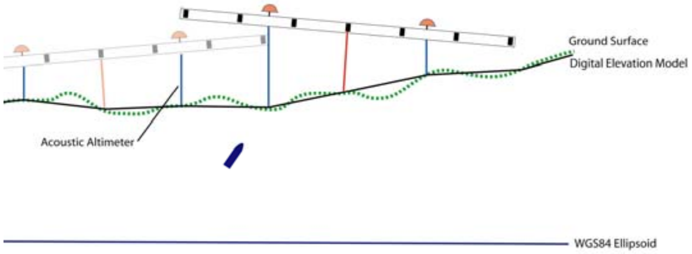
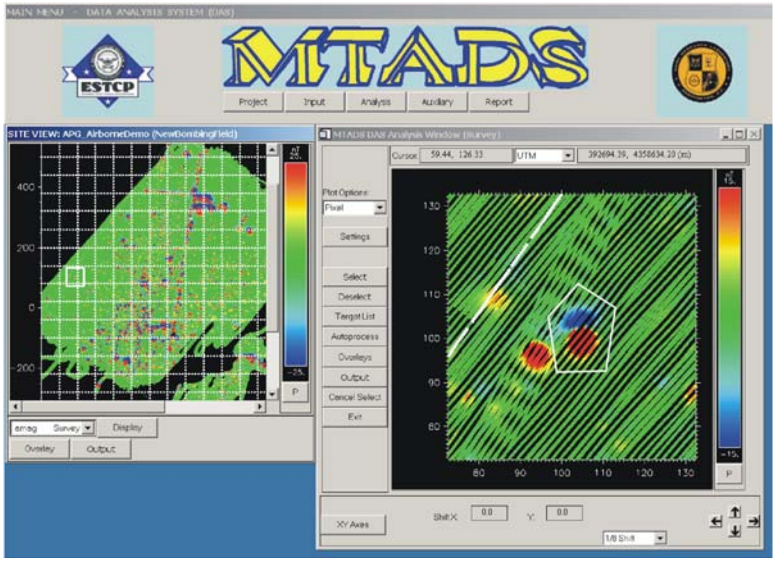


Figure 8 – Schematic of the sensor boom showing the GPS, laser, and acoustic altimeters used to derive the DEM.

2.3 Data Analysis

The DAS analysis GUI is written at multiple levels for both sophisticated and novice users. A novice user can perform data analysis using menu-driven tools and the background default analysis settings; see Figure 9. When a magnetic anomaly, such as one of those shown in Figure 9, is boxed for analysis using the computer mouse, the DAS selects the sensor data within the boxed area for consideration. Each sensor reading, with its HAE, is an input datum used in the 7-parameter iterative calculation to produce the best fit to a dipole approximation of the anomaly signature. Extensive training data sets (using inert ordnance) have been used to refine the algorithms to improve target analysis. In addition to position, depth, and size solutions, magnetic analyses provide dipole orientation and effective target caliber information and, using a "goodness of fit" analysis, provides guidance in the target fitting process, Figure 10. The

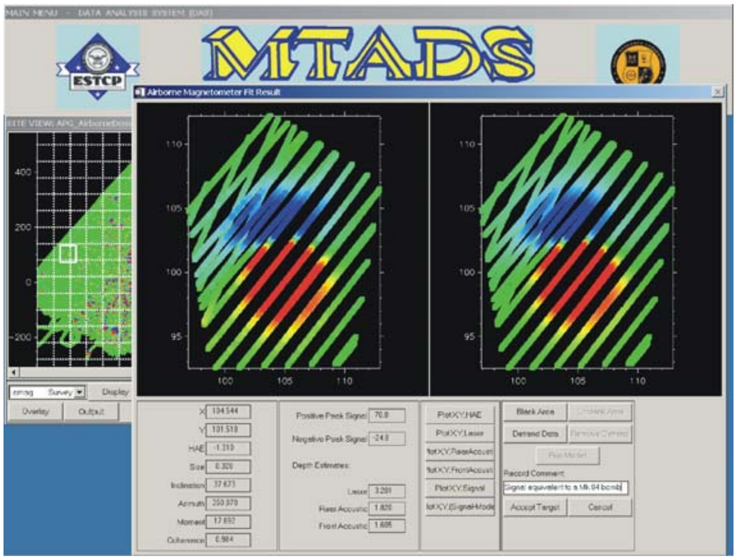


Cursor: 59.44, 126.33 UTM 392694.39, 4358634.20 (m)

Shift X 0.0 Y 0.0

Figure 9 – Site view and data analysis screens from the *MTADS* Data Analysis Program. A part of the Mine, Grenade, and Direct-Fire Weapon Survey is shown on the left. An individual target is boxed for analysis on the right.

range of expert options has been maintained and ported into the Windows-based DAS.



X 104.544
Y 101.518
HAE -1.310
Size 0.326
Inclination 37.671
Azimuth 350.970
Moment 17.692
Coherence 0.984

Positive Peak Signal 70.8
Negative Peak Signal -24.8
Depth Estimates:
Laser 3.281
Rear Acoustic 1.820
Front Acoustic 1.606

Record Comment
Signal equivalent to a Mk 84 bomb

Figure 10 – The target fit window from the *MTADS* DAS. Data from the target boxed in Figure 9 are shown on the left. The dipole model fit is shown on the right. Fit parameters are shown in the left and center columns. Advanced processing options are indicated on the right, where the analyst's comments are also recorded.

The DAS provides a range of graphical and numerical outputs to document the results of the target analysis process and to support remediation efforts. Visual images of selected parts of a survey in a variety of color and gray scale presentations can be created showing target data overlaid by landmark information and analysis results in bitmap (.tif) or editable (.ps) formats. Local, State Plane, or Global Coordinate system (UTM or Lat/Lon) presentations are selectable. The graphics are appropriate either for reports or to support target way pointing and remediation operations. Numerical target analysis results are prepared in tabular form in any desired combination of coordinate systems. These outputs are formatted for incorporation into reports or for import into spreadsheets that can be electronically loaded into the GPS navigation equipment to reacquire the targets in the field in preparation for remediation.

2.4 Aerial Photography

We were not allowed to take or use cameras on site at APG and the site managers were sensitive about the content of photographs and maps that were APG-generated products. Uncorrected, oblique, aerial photographs were provided as part of the test plan package by APG. These images provided general information about the site topography, surface vegetation, and ordnance surface clutter. Selected photos from this group are included in Section 3. To aid both in our data analysis and to enhance the graphical data products, we ordered from USGS digital orthophotoquads to include all 5 survey areas. These 1-m resolution (3.75 min) color images were available from 1994 data as electronic images and from 1998 images as paper prints. Examples of the images are also included in Section 3.

2.5 System Strengths, Advantages, and Weaknesses

2.5.1 Target Detection and Discrimination

The airborne system is not capable of detecting the smallest classes of buried UXO at depth (or on the surface). This was predicted in modeling studies, and verified during the shakedown flights. The measured magnetic anomaly target signatures are spatially spread out and diminished in intensity as the sensors move further above the ground. The extent of these effects, predicted by our modeling calculations, were generally borne out in our shakedown tests. The extent to which spreading target signatures interfere with each other and are obscured by geological features was carefully evaluated in the first airborne demonstration at the BBR. In that study, with relative large UXO targets sparsely distributed on the site, detection efficiency for individual UXO was equivalent between the airborne and vehicular arrays. Because of the lower data density and the more widely spread anomaly signatures, it proved more difficult to discriminate between UXO and clutter signatures from the airborne data than from the vehicular data. At that particular site about 40% more targets would have to be dug behind an airborne survey than the corresponding vehicular survey. The additional digging costs were more than offset by the much lower survey costs of the airborne system. The cost tradeoffs between digging more targets and reduced survey production costs are (and will always be) site specific, depending upon the types of UXO challenges, the relative density of targets, geological and topological conditions, and the size of the survey site.

In practice, the absolute (target size) limit of detection is determined by the background noise level, which is a combination of the geological noise, the density of metallic clutter noise in the field, and the platform-induced noise.

2.5.2 Airborne Technology Advantages

On large open ranges the vehicular *MTADS* is an efficient survey technology. A survey with the magnetometer array typically achieves a production rate of 20 acres per day while the EM array can typically survey 12-15 acres under similar conditions. When a site has vegetation cover or topography that precludes vehicular traffic, the man-portable adjunct *MTADS* can often be used. However, there are sites that cannot be traversed on foot, others that are dangerous, and still others that contain isolated bombing targets or impact ranges, located at best imprecisely, within tens or hundreds of thousands of acres. For these sites, the Airborne *MTADS* produces much more rapid and efficient surveying, with the commensurate economic benefits. On a large site, such as the Impact Area of the BBR surveyed during the first demonstration, the Airborne *MTADS* routinely completed 350-500 acres per day using a 3-man field crew.

The helicopter platform is designed to be flown at a low altitude (1-2 meters), with a horizontal sensor spacing of 1.5 meters, and a forward velocity of 10-20 meters per second. To achieve this, the sensors have been fixed to hard points on the helicopter. As seen in Figure 1, the sensor boom extends well in front of and is clearly and completely visible to the pilot. This is critically important for low altitude flights to allow the pilot to maintain minimal terrain clearance. With the sensor spacing of 1.5 meters, a data collection rate of 100 Hz, and a speed over ground of 20 m/sec, the data density is high enough to provide 30-50 data points over small targets (e.g. an 81-mm mortar) or several hundred data points for targets such as 155mm projectiles or GP bombs; this is more than sufficient to generate high confidence dipole signature fits for the individual UXO challenges.

2.6 Factors Influencing Cost and Performance

The largest single factor affecting the airborne *MTADS* survey cost and production rate is the cost of operating the helicopter on site. Typical charter costs are in the neighborhood of $2,000/day + $500/flight hour. There are typically 3 hour/day guaranteed minima. Time flying to the site from home base and time ferrying to and from the site morning and night are all charged at these rates. In addition, fuel costs in the field are typically $2.50/gal for Jet A with a truck rental of $400/day. Either a second pilot or an aircraft mechanic in the field adds $400-$500/day in cost. To these costs one must add the per diem rates for the pilot(s) and mechanic. The guiding principles are therefore to minimize ferry costs, maximize the survey hours flown each day, minimize the probability of wasted survey time (i.e. lost or unacceptable data), and use survey layout designs that maximize the length of survey lines and decrease the fraction of time spent in setup and off-site turns. The one-line corollary to these observations is that it is unlikely to be economical to undertake an airborne *MTADS* survey of less than several hundred acres. Mitigating circumstances are situations in which a UXO survey must be done over the water, in marshy wetlands, or in other areas where one can neither walk nor drive. In these situations performance issues may override cost issues.

To maximize productivity for the airborne *MTADS* survey of the target ranges at APG, the following conditions were implemented:

- Permission was obtained from Bell Helicopter to allow the helicopter to refuel with JP-8 (the military equivalent to Jet A). Refueling therefore took place at the Phillips Air Field, which required no additional ferry time. Refueling took place either between survey sites or when downloading survey data for ground analysis,
- The helicopter was chartered from Helicopter Transport Services from their FBO hanger at Martin State Airport (approximately 20 minutes flying time from APG). The platform and electronics were assembled and mounted on the helicopter at Martin State - spares were stationed on site to provide quick recovery, if necessary,
- One-hour missions were flown with data provided to analysts on the ground at the Airfield for prompt inspection to minimize time spent taking unacceptable data,
- All the impact range survey missions were set up in advance in the DAQ computers so that weather or logistics requirements (e.g. sharing survey ranges with the other demonstrators) allowed us to switch among survey sites by simply starting new survey files, and
- Surveys were planned to start at sunrise (or when morning ground fog allowed operations at both Martin State and APG) and end at sunset each day with short pilot rest breaks each hour and with a 45 minute break for lunch.

3. Demonstration Design

3.1 Performance Objectives

As stated in Section 1.3.3, the objectives of this demonstration were established and defined by APG in their Wide Area UXO Aerial Demonstration and Survey, as documented in their Demonstration Test Plan.[12] For the current round of demonstrations, the two aerial UXO survey systems under development by NRL and ACE-Huntsville/Oak Ridge were scheduled to conduct identical surveys of several survey sites including prepared ranges, active ranges, and dormant impact areas. Performance criteria emphasized the conduct of efficient aerial surveys, analysis of data, and preparation of data products including target reports ranking the analysis results and attempting to differentiate UXO from clutter. Three of the five sites were understood to contain inert seed targets with sizes ranging from 60mm mortars to 155mm projectiles. NRL's performance objectives and criteria (conforming with ESTCP guidance) are presented in tabular form in Table 2.

3.2 Test Sites

The five test sites chosen by APG include parts of four current or former impact ranges, and a prepared site at the Airfield, which is historically clear of UXO. At three of the sites (the Airfield, the Dewatering Ponds which were historically clear of UXO, and off-shore areas of the tidal Chesapeake encompassing an old impact area, known targets were seeded by ATC with inert ordnance from stores. Seed targets specified in the APG Test Plan[12] included 60- and 81-mm mortars; 2.75-in rocket warheads; and 105- and 155-mm projectiles. From the ground truth information provided following submission of the analysis results, no 2.75-in warheads or 155-mm projectiles were used as seed targets at the Airfield or the Active Recovery Field. The sites were designed to test the ability of the survey systems to deal with varying terrain, amounts of surface clutter, surface vegetation, and target densities. These ranges include a variety of land, marine, and freshwater terrains. The impact areas include ranges with a mixed-use history varying from antipersonnel ordnance to large GP bombs. Topology varies from flat and level, to rolling, with various areas covered by no vegetation, low-to-intermediate vegetation, to partial tree cover.

3.2.1 The Airfield

Two areas near the south end of Runway 35 were established as test areas. These are shown in Figure 11 as red boxes superimposed on the 1-meter resolution digital orthophotograph. The smaller area (east of the runway) was used to seed two targets of each ordnance type: coordinates were provided to the demonstrators. Targets were all buried horizontally at a depth of one target diameter. One target of each type was buried pointing North/South; the other was buried pointing East/West. The larger survey area south of Runway 35 was used to seed an unknown number of inert targets spanning the range of ordnance types. Ordnance were buried at distances from each other so that their signals would not interfere with each other. No targets were seeded

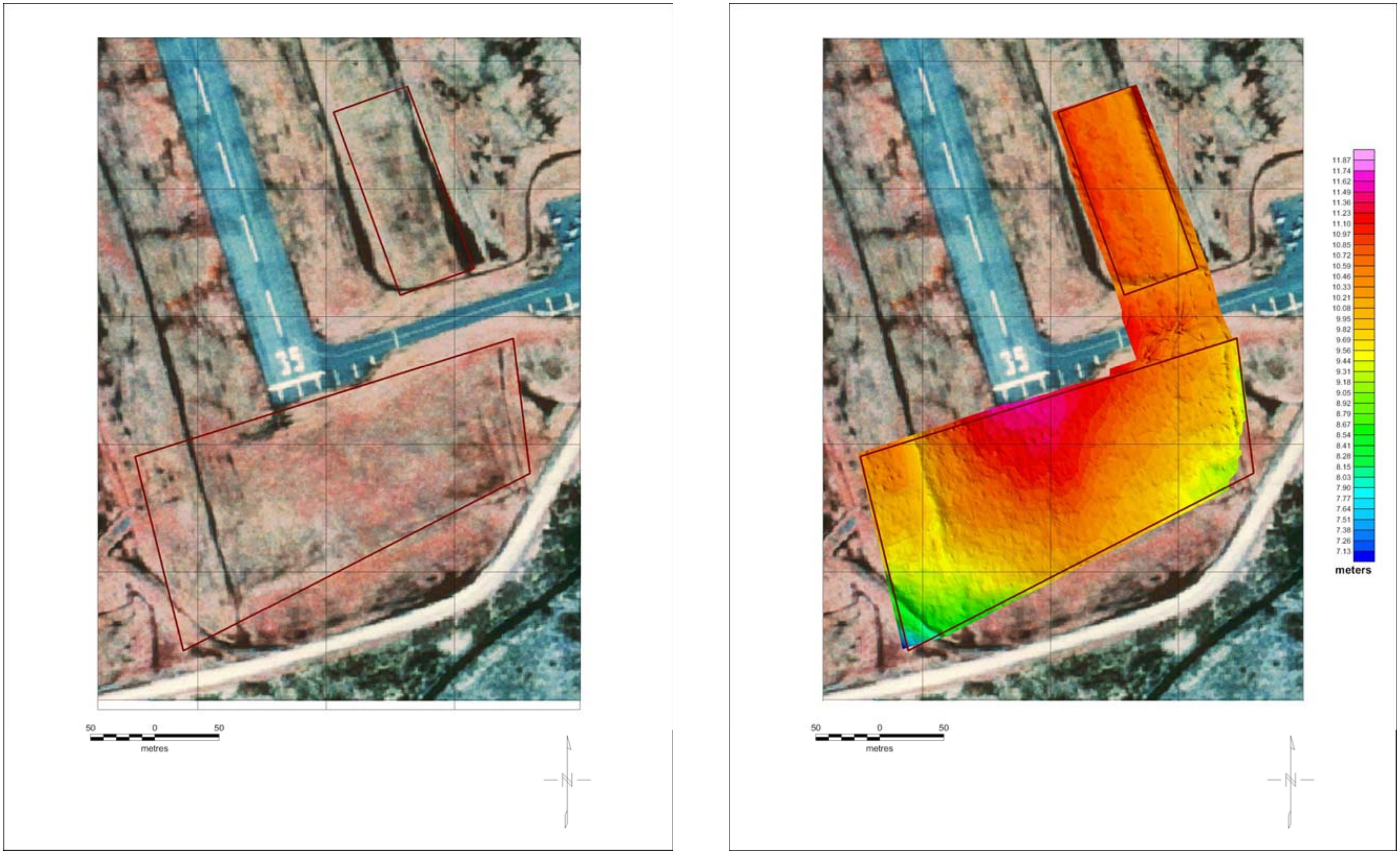


Figure 11 – Digital orthophoto of a portion of the Airfield near the end of Runway 35. The areas outlined by red rectangles are the designated survey areas. Calibration targets were installed east of the runway. The area south of the runway was the primary survey area. The panel on the right has the *MTADS* digital elevation map superimposed on both survey areas.

into any of the sites for this demonstration other than complete inert rounds. The rounds were unfuzed, but shipping lugs or dummy fuzes were installed in place of fuzes. The right side of Figure 11 shows the same aerial photograph with the Digital Elevation Model (DEM) map, generated from our survey, superimposed on the survey areas. The display, which is provided on a very fine scale shows that several of the surface scars in the photograph are reflected as depressions or ditches in the DEM. The disturbed area in the northwest corner of the demonstration site photo also appears as disturbed in the DEM; the disturbances resemble depressions or craters. These features will be discussed further in Section 4 of this report.

3.2.2 Dewatering Ponds

Much of the area of the dewatering ponds has been extensively reworked. Large amounts of fill have been added and the shallow freshwater ponds, shown in Figure 12, were created as part of a sediment control area when the UNDEX pond was being dug. Figure 13 shows the orthoquad aerial photo of the same area with the DEM map superimposed on the five ponds that were a part of this survey. The four small close-lying ponds in the southwest corner of the site were seeded with inert ordnance, as was the larger pond in the eastern half of the site. The inert seed targets were placed in the ponds, lying flush with the bottom. Water depths in the ponds were reported to be less than 2 meters. The banks of the larger pond were significantly elevated (~2 meters) above the water level and above the level of the surrounding area. Figure 14 shows the *MTADS*

Figure 12 – Oblique aerial photo of part of the dewatering ponds. The four small ponds in the foreground and the larger pond above were included in this survey.

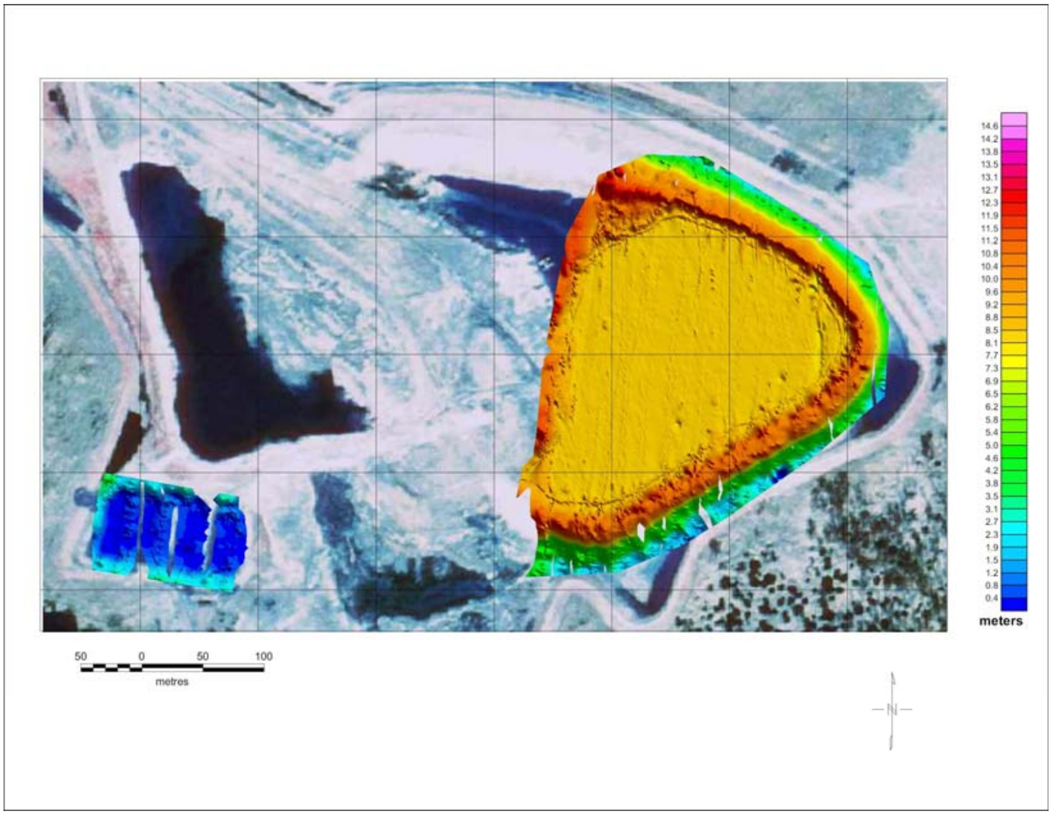


Figure 13 - Digital orthophoto of the dewatering ponds area with the *MTADS* DEM superimposed over the 5 survey ponds.

helicopter surveying over the larger pond. The banks of the smaller ponds, referred to as the finger ponds, were considerably more overgrown than is shown in Figure 12. Figure 15 shows the survey underway on one of the narrower of the finger ponds. The total area of the five ponds is 17.5 acres; our surveys covered about 20 acres including the shorelines.

Figure 14 – *MTADS* survey over the larger pond.

Figure 15 – *MTADS* survey over one of the finger ponds.

3.2.3 Active Recovery Field

The Active Recovery Field is a mixed-use impact range that has been used for many decades. Expected UXO covers the gamut from large experimental bombs to anti-personnel ordnance. The impact area includes both land and offshore areas, as shown in Figure 16. Over the years the shoreline has continued to erode; the current shoreline may be several hundred meters north of the shore at the time the range was created. This impact area currently serves as an active range while at the same time, it is being remediated. There are clusters of ordnance scattered at various points on the range, Figure 17. Ordnance and ordnance scrap from the current cleanup are being sorted and stockpiled on site, Figure 18. Figures 16 and 18 also show the presence of large steel blast shields, target mock-ups, heavy mechanical equipment, and geologically active bluestone revetments being used to stabilize the shoreline at various points.

Figure 16 – Aerial photo, looking approximately west to east, shows the Active Recovery Field. The Impact Area includes the cleared area and offshore areas that may extend for an additional several hundred meters.

All these features are apparent in the airborne survey. Figure 19 shows the *MTADS* airborne survey underway near the large oak tree shown near the shoreline in Figure 16. A digital orthophotograph is shown in Figure 20. Figure 21 shows the DEM overlay. Considering the image in Figure 16, the eastern border of the survey slightly overlaps the tree line near the shore (top of the photo). The survey extends westward, just encompassing the small pond near the center of the picture. The northern edge of the survey is just inside the tree line and the roads at the left edge of the photo, and extends to about 100 meters offshore on the south.

Table 2. Demonstration Performance Objectives

Type of Performance Objective	Primary Performance Criteria		Expected Performance	Actual Performance Result
Qualitative	Minimize Setup/Ferry Costs		Deploy from HTS, Refuel on Site	Accomplished
	Survey Marine/Fresh Water Sites		Successful survey in water <6 ft deep	Successful survey of ponds. Limited success in open water
Quantitative	Probability of Detection			
		Airfield	80-90% (depending on 60mm targs)	88% initial analysis 94% extended analysis
		Active Recovery Field	10%	7.8%
		Dewatering Ponds	90+%	32%
		Mine, Grenade, and Direct-Fire Weapon Range		No seeds, no UXO recovery
		Chesapeake Bay Tidal Area	70%	Seeded area not surveyed
	Target Location Accuracy		20 cm	~30 cm
	Percent Site Coverage			
		Airfield	100%	98%
		Active Recovery Field	95%	97%
		Dewatering Ponds	100%	95%
		Mine, Grenade, and Direct-Fire Weapon Range	75%	80%
		Chesapeake Bay Tidal Area	Unknown	~30%
	Survey Production Rate		30 acres/hour	40.6 acres/survey hour 22.7 acres/helo hour

The information in Table 2 relates our performance at the APG relative to our original system performance objectives, as stated in Table 1. The information is presented in terms of primary and secondary objectives taking into account the individual survey areas. The expected area coverage was based upon initial visual site analysis before the surveys began. We did not intend to survey areas that had significant tree cover. Our reported area coverage took into account additional missed areas resulting from our flying performance; or in the case of the offshore areas, limitations imposed by GPS coverage.

Expected detection probabilities reflected our assumption that we would not be able to detect the smallest seed ordnance, or perhaps the intermediate sized ordnance in deeper water. We did not expect to be able to detect seed ordnance on the Active Recovery Field. Our actual detection performance reported in the table is based upon only the seed targets as reported in the ground truth tables, which were provided well after our target declarations had been submitted to the program office.

Figure 17 – Clusters of ordnance exist on the surface at various points on the Active Recovery Field.

Figure 18 – Stockpiles of ordnance and scrap along the roads at the Active Recovery Field.

Figure 19 – *MTADS* Active Recovery Field airborne survey near the large tree at the shoreline.

3.2.4 Mine, Grenade, and Direct-Fire Weapon Range

The Mine, Grenade, and Direct-Fire Weapon Range has been a mixed-use range for many decades. It reportedly contains ordnance ranging in size from ICM sub-munitions to 500-lb bombs. Figure 22 shows an oblique aerial photo of this range. The area designated for this survey (73 hectares) includes land on both sides of the north/south road. The area west of the road is a currently used impact area that has recently installed gravel paths leading to target pads. The area on the other side of the road includes both open land and wooded areas and the rubble from remnants of older structures.

3.2.5 The Chesapeake Tidal Area

This range includes both on-and off-shore areas. It was primarily used as a projectile range with a record of more than 8,000 105-mm impacts. The original survey area included 11 hectares of marshland and 16 hectares offshore in the bay. Prior to beginning the demonstration the survey area was adjusted to include only offshore areas.

3.3 Test Site History/Characteristics

A description of the Impact Ranges and the prepared test sites at APG is provided in the Demonstration Test Plan[12] prepared by ATC.

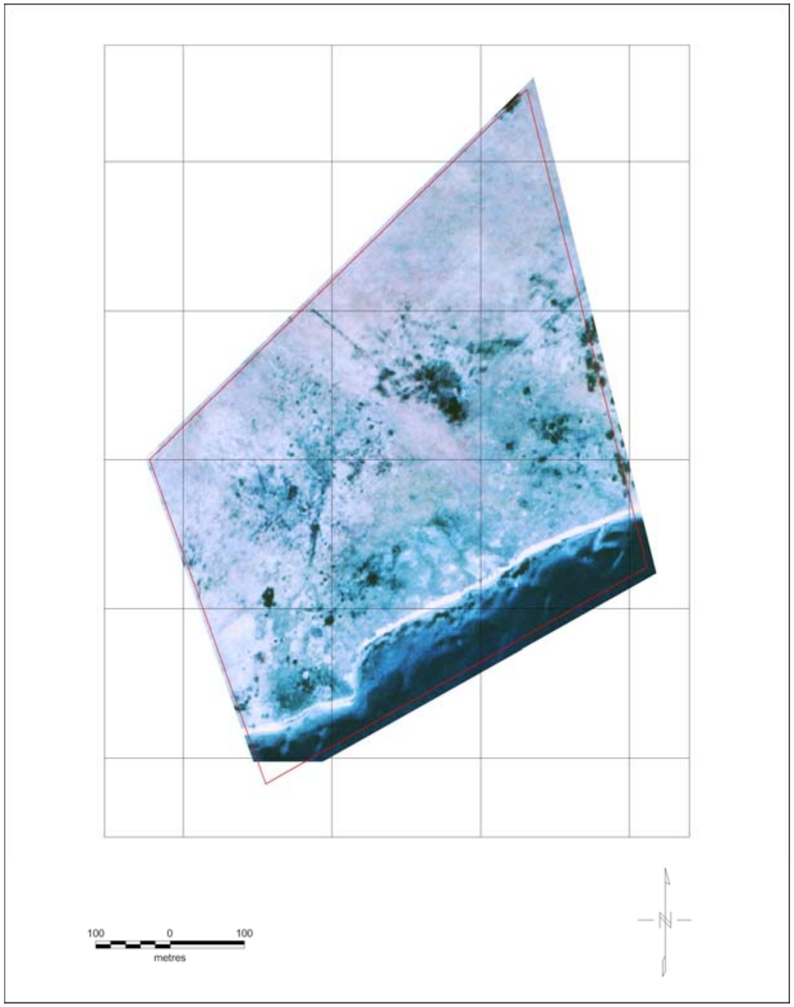


Figure 20 – Digital Orthophotograph of the part of the Active Recovery Field selected for survey.

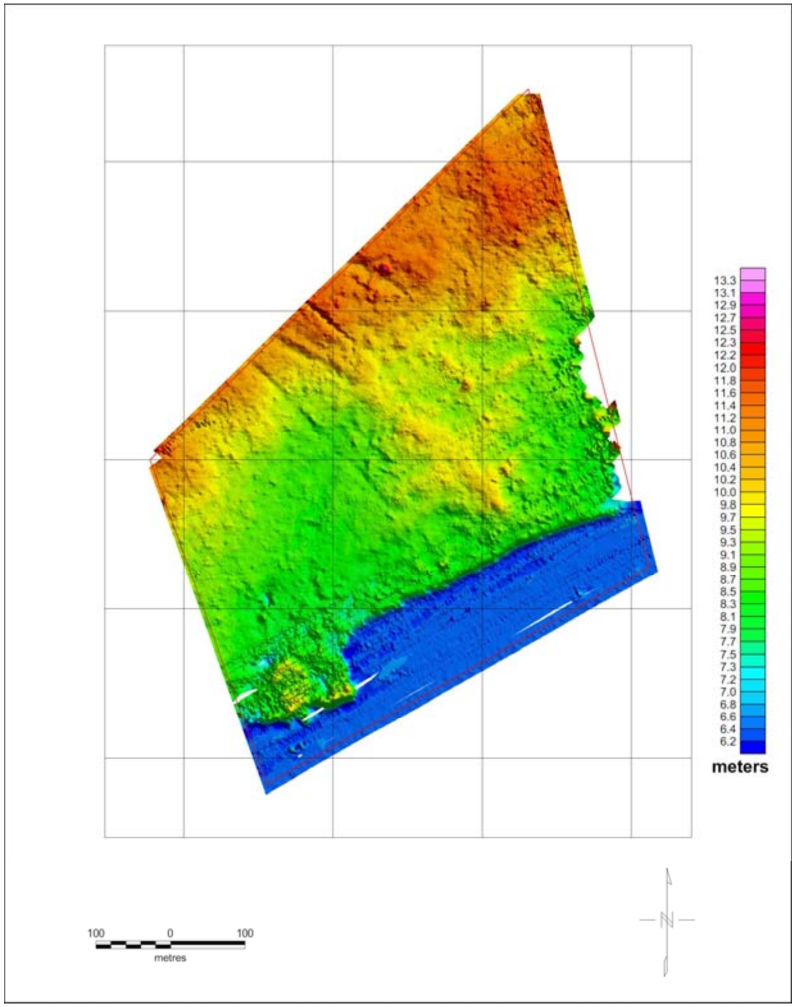


Figure 21 – Digital Elevation Model of the Active Recovery Field survey area taken from the *MTADS* airborne survey. Note the erosion of the shoreline compared to the DOQ in Figure 20.

Figure 22 – Aerial photo of the Mine, Grenade, and Direct-Fire Weapon Range shows the gravel roads leading to target pads.

4. Airborne *MTADS* Demonstration Surveys

4.1 Predemonstration Site Preparation

The APG Demonstration Test Plan defined the areas at the Airfield and at each of the Impact Ranges planned for airborne survey. The extent of each survey area was defined in the Test Plan, but perimeter coordinates of the surveys were not provided until the beginning of the on-site survey activities. NRL prepared, submitted, and acquired ESTCP approval of our Demonstration Test Plan prior to beginning operations on site. Following approval of the APG and NRL Test Plans, two modifications were made by APG in the designated survey areas. The scheduled survey of one of the offshore impact areas was cancelled. The survey of the other Chesapeake Bay Impact Area was cancelled as a joint activity for the NRL and the Oak Ridge systems. NRL agreed to conduct an offshore airborne survey of this Impact Area. This survey is described in more detail in Section 5 of this report.

APG prepared a seed target emplacement plan as part of their Demonstration Test Plan.[12] The demonstrators were told that calibration targets were emplaced at specified locations in a specified area at the Airfield. This area is subsequently referred to as the Calibration Target Area in this report. In addition, an unknown number of seed targets from the approved ordnance list were buried at Active Recovery Field and the Airfield Test Area. An unknown number of seed targets were emplaced in the fresh water ponds at the Dewatering Ponds Site and in the bay at the Chesapeake Bay Impact Area Range. In the latter two areas the seed targets were to be placed in the water, lying flat and flush with the bottom (not buried). The water depths in the dewatering ponds were specified as less than about 2 meters. The tidal water depths at the Chesapeake Bay Area were not specified. The demonstrators were not provided with sections of the APG Test Plan that contained seed target siting information.

4.2 Demonstration Plan

The Huntsville ACE/Oak Ridge demonstration team was scheduled to conduct airborne survey operations during the period 22-26 July. Because live-fire training on the APG ranges was of higher priority than the Airborne Survey Demonstrations, NRL volunteered to begin on-site survey operations on Saturday 27 July. Weekend use of the ranges for live-fire training is typically scheduled only to makeup missed weekday operations. Our actual onsite survey plans called for operations on 27, 28, and 29 July, with the 30th and 31st as possible makeup days. This required installation and testing to take place at the Martin State Hanger of Helicopter Transport Services (HTS) on 24-26 July. Special authorization was obtained from Bell Helicopter to allow the HTS helicopter to refuel with JP-8 at the Airfield. As this was the primary APG staging point for all survey operations, several hours of helicopter charter time were avoided ferrying back to Martin State Airport for Jet A fuel. The Airborne *MTADS* Flight Production Summary is provided in Table 3.

Table 3. Airborne *MTADS* Survey and Flight Production Summary

Date	**Survey/Activity**	**Survey File**	**Sortie**	**Hours**		
				Ferry (Pilot Log Hrs)	**Survey**	**Train/Test/Calibrate**
24-Jul	Equipment delivered to Martin State Hangar					
25-Jul	Pickup Security Badges At APG					
	Assemble Equipment At Martin State					
26-Jul	Install Equipment on Helicopter					
	Conduct Tests and Ground Runup					
27-Jul	Ferry to/from Airfield/ Pilot Orientation			0.88		1.60
	Cal site and Airfield	2208003	1	0.10		0.63
	Active Recovery Field	2208004	2	0.17	0.58	
	Active Recovery Field	2208005	2		0.52	
	Active Recovery Field	2208006	2	0.17	0.75	
28-Jul	Ferry to/from Airfield			0.77		
	Mine, Grenade, and Direct-Fire Weapon Range	2209002	3	0.12	0.80	
	Mine, Grenade, and Direct-Fire Weapon Range	2209003	3	0.12	0.80	
	Chesapeake Bay Impact Area	2209101	4	0.22	1.10	
	Mine, Grenade, and Direct-Fire Weapon Range	2209102	4	0.22	0.65	
	Mine, Grenade, and Direct-Fire Weapon Range	2209005	5	0.12	0.80	
29-Jul	Ferry to/from Airfield			0.74		
	Dewatering Ponds	2210001	6	0.11	0.98	
	Mine, Grenade, and Direct-Fire Weapon Range	2210002	6	0.11	0.87	
	Cal site (lower survey alt)	2210003	7	0.10	0.22	
	Airfield (lower survey alt)	2210004	7	0.10	0.55	
	High alt compensation flight	2210006	8			0.53
30-Jul	De-install/Packout					
		Sub-Totals		**4.02**	**8.62**	**2.77**
					Total	**15.41**

4.3 Survey Experimental Design

All NRL survey operations were coordinated from the Airfield. Space was made available in the Pilot's ready lounge for us to set up computers to monitor and evaluate data. At the beginning of each day the *MTADS*-equipped helicopter ferried from Martin State Airport to the Airfield. On 27 July, ~1.6 hours of flight time involved a pilot orientation flight with APG personnel to define flight approaches that were required to access each survey site while avoiding overflight of classified areas. Locations were established for placement of the reference magnetometer and first-order control points were identified to provide GPS correction information for each survey area. Survey coordinates were loaded into the pilot guidance and data acquisition computers and survey plans were developed for each site. A nominal survey line spacing of 7 meters was established. This was subject to revision if cross winds or other difficulties made complete area coverage difficult. A nominal survey speed of 20 m/s was established as the survey goal. The pilot was instructed to fly at the lowest altitude consistent with flight safety. Over water flight altitude was near the nominal 1.5 m height and the flight altitude at the Airfield was less than 1.5 m because of the benign terrain and the closely mowed surface.

Before beginning surveys for the record, about 0.6 hours were spent at the Airfield calibration area and the Airfield seed target area; these areas were flown to provide test and calibration data, and for pilot orientation. The data were not used for analysis. Survey data were taken in increments of about one hour as this file size is most conveniently processed. On each day of the demonstration surveying was delayed because of morning fog, either at APG or at the Martin State Airport. Because of the weather delay, the orientation flights, and the test and calibration flights, only the 100-acre Active Recovery Field survey was completed on 27 July. The remaining surveys were flown on 28 and 29 July [Mine, Grenade, and Direct-Fire Weapons Range, 130 acres; Dewatering Ponds, 20 acres; Chesapeake Bay Impact Area, 60 acres; and Airfield 15 acres] and the high altitude compensation flight data was taken on the way back to Martin State Airport at the end of the day on 29 July.

4.4 Data Processing

Survey data were inspected on site at the Airfield using notebook computers running the Windows version of the Airborne *MTADS* DAS. Separate project files were established for the Airfield surveys, the Active Recovery Field survey, and the surveys at the Dewatering Ponds, the Chesapeake Bay Impact Range, and the Mine, Grenade, and Direct-Fire Weapons Range. Individual sortie files were integrated into each of the survey projects. The only areas that were resurveyed during the demonstration were the calibration and seed target sites at the Airfield. The initial data taken at this site were considered preliminary, and were ultimately discarded. All data processing and target analysis took place off site, subsequent to the end of the fieldwork. Each data set was processed using the same approach and parameters.

Each data file was processed to remove data from aircraft turn-arounds (unless they occurred on the survey site and were the only data available at that location), and from well outside the survey boundaries. Sensor data were inspected and spurious data points were edited (clipped) from the file. A 500-point (5 second) demedian filter was applied separately to each sensor track. This suppressed zero-offset differences among the sensors, suppressed long-term sensor drift, heading offsets, and large-scale geology effects. A notch filter (at 6.45, 12.9 Hz) was applied to suppress blade- (rotor hub) induced noise and at 25.8 Hz to suppress platform vibration noise. The notch filter widths and roll-offs were adjusted and applied equally to all sensors. Values were chosen to null blade noise from the outboard two sensors at each end of the array. The center 3 sensors, which were closer to the blade footprint, retained some blade-based noise signal at a level that did not interfere with analysis of 60-mm targets.

4.4.1 Airfield Reanalysis

Subsequent to the initial submission of target analysis results, the ESTCP Program Office requested that we reanalyze the data from the Airfield site and pick all targets, regardless of size down to the noise-limited detection threshold. The data filtering that was initially used for this (and all other sites) was inappropriate for this analysis approach. After some experimentation to determine the best combination of filters to use, while simultaneously minimizing distortion of possible UXO target signatures, the Airfield data were re-filtered using a combination of a 6.45 Hz notch filter, a 6.5 Hz low pass filter, and the 500 point demedian filter. The notch filter was adjusted and separately applied to the signals for each sensor in the array. Figure 23 shows the results of the application of these filters on a clip of the Airfield data that contains the signals from a relatively strong (15 nT) and a relatively weak (1.5 nT) target at approximately 1713.3 s.

Figure 24 shows a comparison of the two different filter approaches. The analysis window on the left shows data as originally submitted, the window on the right shows the same data using the low pass filtering routine. It is apparent that at the nT level, this filtering routine effectively removes all blade-related noise from the data.

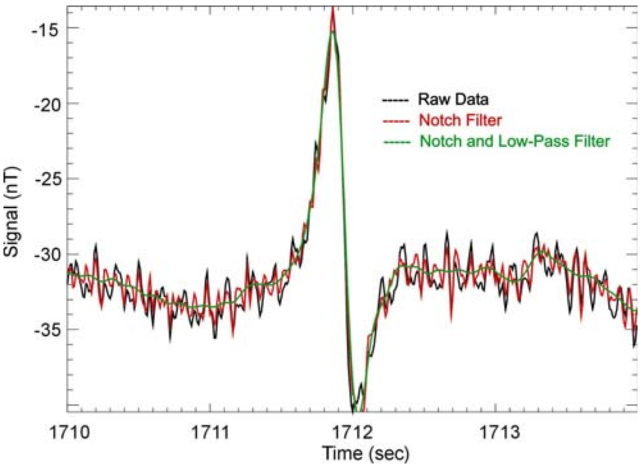


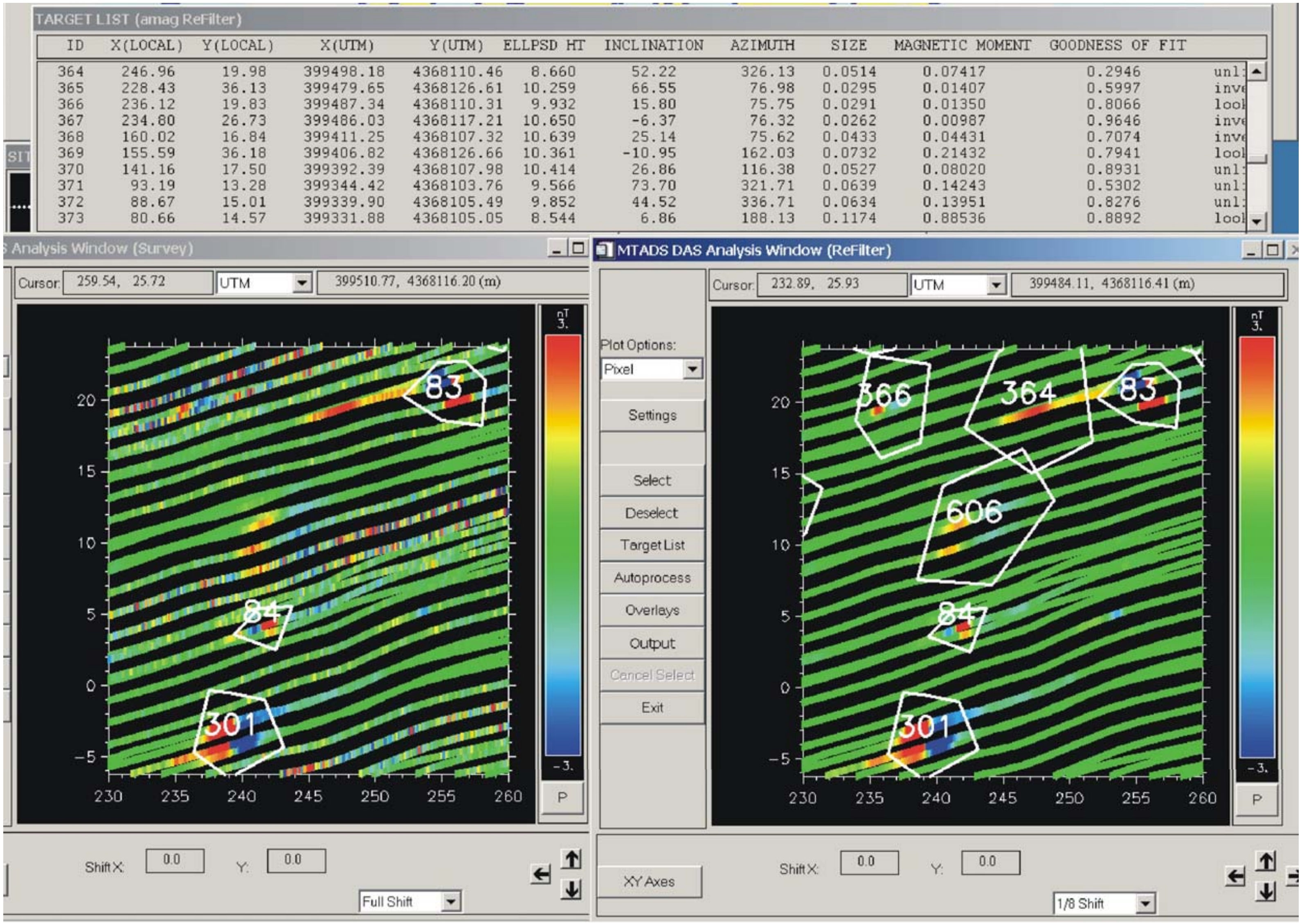
Figure 23 – A 4-second data clip for sensor 1 at the Airfield survey showing the effects of the filters used for reprocessing the data.

4.4.2 High Altitude Calibration Flight

As part of the demonstration at the APG, a high altitude compensation calibration flight was performed to assess the effect of aircraft attitude on the magnetometry data, and to allow for correction of these effects using aeromagnetic compensation techniques, if required. This flight consisted of a series of discrete, exaggerated pitch, roll, and yaw maneuvers while flying at high altitude. Making these measurements at high altitude allows us to isolate platform attitude and flight direction effects from geological and anthropological influences that dominate low altitude measurements. These maneuvers were repeated in each of the cardinal directions. To enable use of these data (via correlation with attitude measurements) for actual compensation, these maneuvers were exaggerated in amplitude and frequency, resulting in attitude variations significantly more severe and abrupt than those we would encounter during survey data acquisition. Figure 25 shows the results of one group of these pitch, roll, and yaw maneuvers. The greatest effect is observed on the middle sensor readings (mag 4) during roll maneuvers, although pitch variations have a similar effect, which is most pronounced for mag 1 in this sequence. In the top panel of Figure 26 we show a data clip taken during survey of the Airfield. The platform attitude excursions are much less severe than those generated during the high altitude calibration flight. The larger of the effects is in yaw, which is typically required to stay on course in a crosswind. In the lower panel of Figure 26 we see that application of the 500 point demedian filter to the platform attitude excursions effectively damps out platform attitude effects. Figure 27 shows in the left panel a histogram of the platform roll attitude during the entire Airfield survey. On the right the same information is provided following application of the 500-point demedian filter. We believe that the application of this simple filter effectively removes all attitude-related platform noise to the low altitude site indigenous noise limit. This conclusion applies except during the turn-arounds at the end of the survey lines, which are characterized by high pitch and roll attitudes. For the most part, data in turn-arounds have been edited from the processed survey data. Therefore, we have found it unnecessary to implement the aeromagnetic compensation routines that were developed for platform attitude corrections.

4.4.3 The Calibration Site

Ten inert ordnance items were buried in the Calibration Area. Figure 28 shows the *MTADS* magnetic anomaly image from the airborne survey. The areas boxed in white encompass the



TARGET LIST (amag ReFilter)

ID	X(LOCAL)	Y(LOCAL)	X(UTM)	Y(UTM)	ELLPSD HT	INCLINATION	AZIMUTH	SIZE	MAGNETIC MOMENT	GOODNESS OF FIT	
364	246.96	19.98	399498.18	4368110.46	8.660	52.22	326.13	0.0514	0.07417	0.2946	unl
365	228.43	36.13	399479.65	4368126.61	10.259	66.55	76.98	0.0295	0.01407	0.5997	inv
366	236.12	19.83	399487.34	4368110.31	9.932	15.80	75.75	0.0291	0.01350	0.8066	loo
367	234.80	26.73	399486.03	4368117.21	10.650	-6.37	76.32	0.0262	0.00987	0.9646	inv
368	160.02	16.84	399411.25	4368107.32	10.639	25.14	75.62	0.0433	0.04431	0.7074	inv
369	155.59	36.18	399406.82	4368126.66	10.361	-10.95	162.03	0.0732	0.21432	0.7941	loo
370	141.16	17.50	399392.39	4368107.98	10.414	26.86	116.38	0.0527	0.08020	0.8931	unl
371	93.19	13.28	399344.42	4368103.76	9.566	73.70	321.71	0.0639	0.14243	0.5302	unl
372	88.67	15.01	399339.90	4368105.49	9.852	44.52	336.71	0.0634	0.13951	0.8276	unl
373	80.66	14.57	399331.88	4368105.05	8.544	6.86	188.13	0.1174	0.88536	0.8892	loo

Analysis Window (Survey)

Cursor: 259.54, 25.72 UTM 399510.77, 4368116.20 (m)

Shift X: 0.0 Y: 0.0 Full Shift

MTADS DAS Analysis Window (ReFilter)

Plot Options: Pixel

Cursor: 232.89, 25.93 UTM 399484.11, 4368116.41 (m)

Shift X: 0.0 Y: 0.0 1/8 Shift

Figure 24 – *MTADS* analysis windows are shown for a section of the Airfield survey. On the left the data are shown as originally submitted. On the right data are shown following reprocessing using the low pass filter as described in the text.

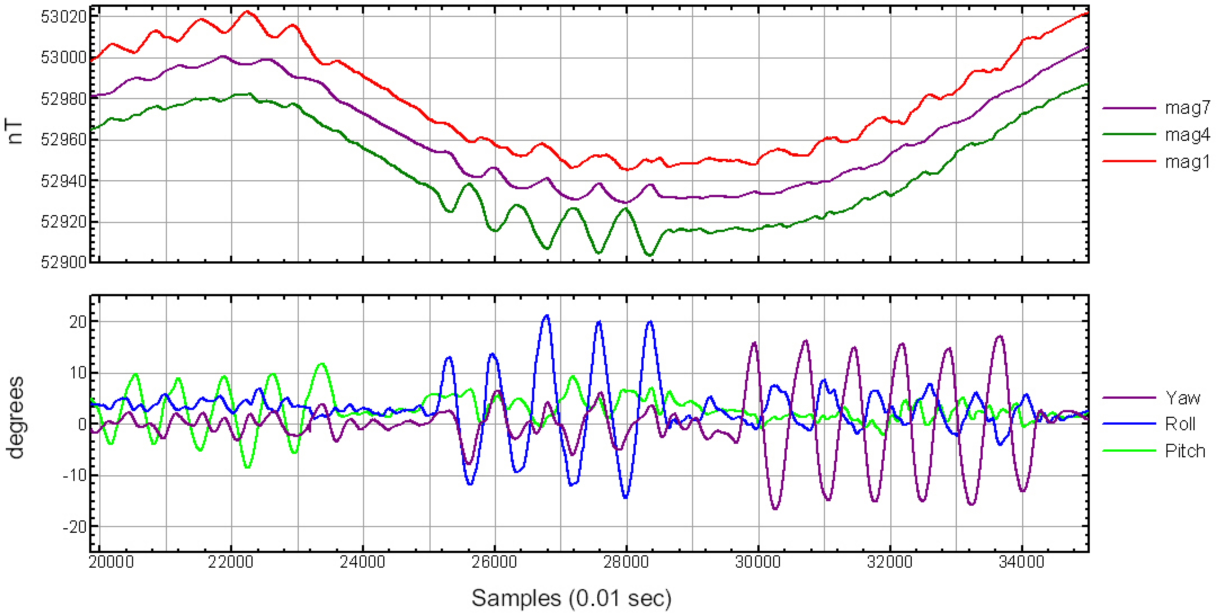


Figure 25 - The effects of platform attitude on the port (mag 1), middle (mag 4) and starboard (mag 7) sensors during pitch, roll, and yaw maneuvers at high altitude are shown.

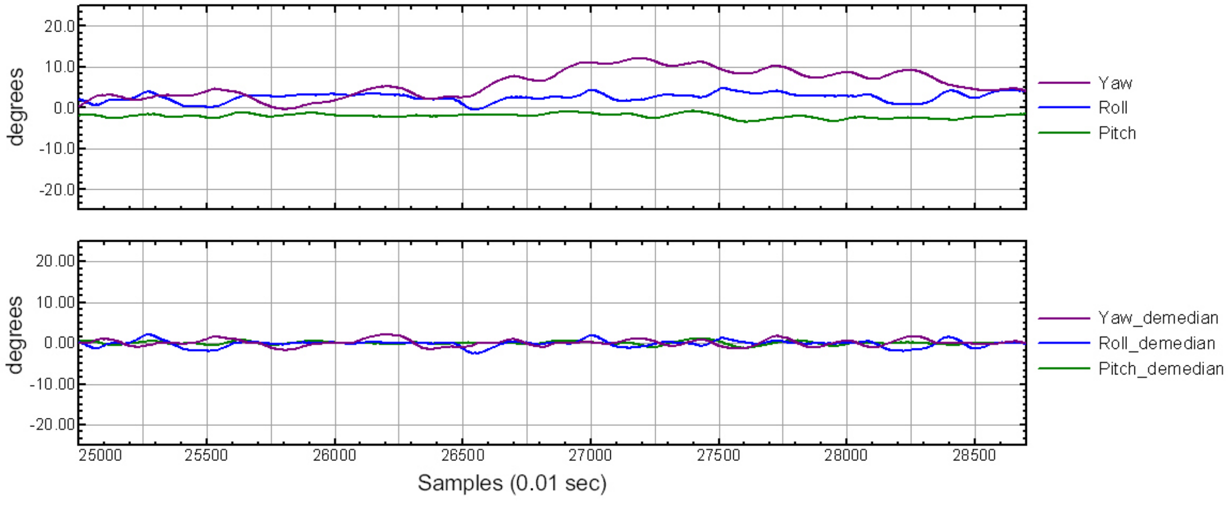


Figure 26. The upper panel shows typical aircraft attitude profiles during the Airfield survey. The lower panel shows the result of the application of a simple 500-point demedian filter to these data.

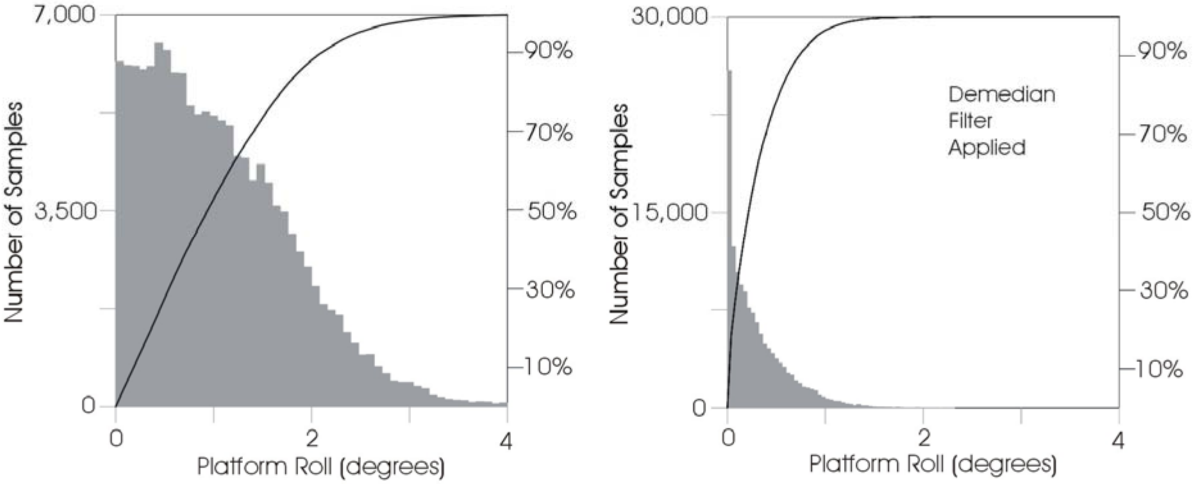


Figure 27 – This histogram presentation shows the helicopter platform roll data acquired during the entire Airfield survey. The data as acquired are shown in the left panel; the right panel shows the data following application of a 500-point demedian filter.

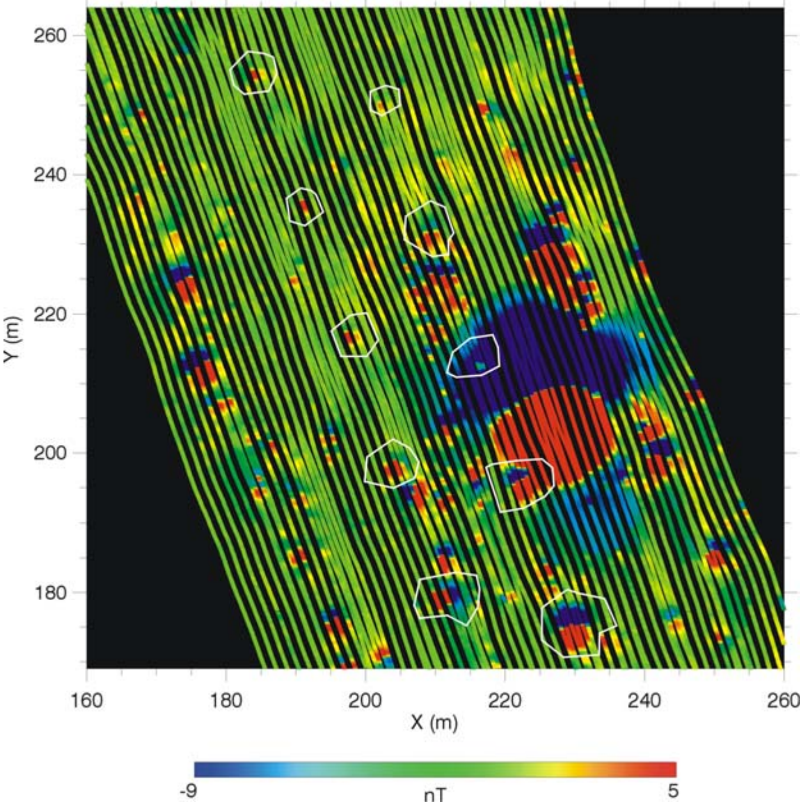


Figure 28 – Magnetic anomaly image from the airborne survey of the Calibration Site.

data selected for each of the individual target analyses. All targets were buried flat, at a depth of one target diameter. UXO include (top-to-bottom in Figure 28) 60-mm and 81-mm mortars, 2.75-in WHs, and 105-mm and 155-mm projectiles. The left line of targets was buried with their long axis pointing East/West. The line of targets on the right were buried oriented North/South. The image presentation is offset with a negative bias to allow the North/South pointing 2.75-in WH to be visualized within the intense negative lobe of the dipole signature of an unidentified deep object. The North/South-pointing 105-mm projectile is also partially obscured by the same deep object. All target positions analyze within 0.3 m of their reported positions. Positions of the two objects alluded to above were skewed by deconvoluting their signals from the more intense interfering signal. The predicted sizes of the objects are within the expected range from our target signature libraries. The 60- and 81-mm mortars lie very close to the realistic detection limit for the airborne system, particularly in areas with a significant clutter background. This area of the Airfield was assumed to be relatively clutter free.

5. Survey Results

5.1 The Airfield Survey

Target analysis operations were carried out using the *MTADS* DAS modified specifically for analysis of airborne data. The raw data were processed as described in Section 4.4. The initial target analysis at this site was designed upon the assumption that the smallest targets that were of interest were 60-mm mortars and the largest were 155-mm projectiles. As the survey image in Figure 29 shows, there are many magnetic anomalies on this site that are significantly larger than 155-mm projectiles. Buried utilities run roughly parallel to the east, south, and west survey boundaries. On the south the utility run lies beyond the limit of the survey, however both the east and west boundaries of the survey include the utility runs. Many of the larger signals associated with these facilities are unlikely to involve UXO. However, in the northwest corner of the site there is a significantly disturbed area in which the aerial photo and the DEM map both show features that resemble craters. The magnetic anomaly map shows significant magnetic signatures are associated with many of these features. In addition there are a few dozen isolated substantial target returns within the survey area that potentially could be large UXO. Therefore, the analysis reports both targets in the seed target size range, and others that are too large to be 155-mm projectiles.

The target list (included in the Target Report Appendix on CD) includes both small and large targets. The probability that an individual target in this list is one of the seed targets is ranked using the 6-category subjective analysis criteria established during the Jefferson Proving Ground Demonstrations. All large targets in the survey area are included in the target report even though many are clearly too large to be members of the class of seed targets. The column in the target report labeled “Probability as UXO Seed” evaluates the data on the basis of there being only 5 ordnance objects of interest on the site. A probability of 5 or 6 for a very large target indicates a very low probability of that object being a seed target; the probability of that object being a UXO larger than the class of seed targets might be significantly greater.

The target reports also contain columns labeled peak positive signal and peak negative signal. Values are entered for selected targets for which the target analysis fit converged. These data are not normally an output of the DAS target report. A utility was written to extract this information as it was requested specifically for this project.

The Airborne *MTADS* DAS analyzes for target vertical position as the height above ellipsoid (HAE). To get the depth below the surface the target HAE value must be subtracted from the HAE of the surface at the target location. For this project, this step takes place outside the *MTADS* DAS. The GPS sensors and acoustic, radar, and laser altimeters on the helicopter are all used to create a Digital Elevation Model (DEM) for the survey site, as described in Section 2.2.5. The fit target coordinates are used to extract the surface HAE from the DEM. This is differenced with the target fit HAE to extract the target depth, which is reported in the Target Report in the column labeled DEM Depth (m).

The first 318 targets in the Target Report were those included in the initial submission based upon 60-mm mortars being the smallest UXO of interest on the site. The data were reanalyzed to pick targets down to the system/site noise limit following reprocessing of the data as described above. Targets 319-618 resulted from the follow-up analysis.

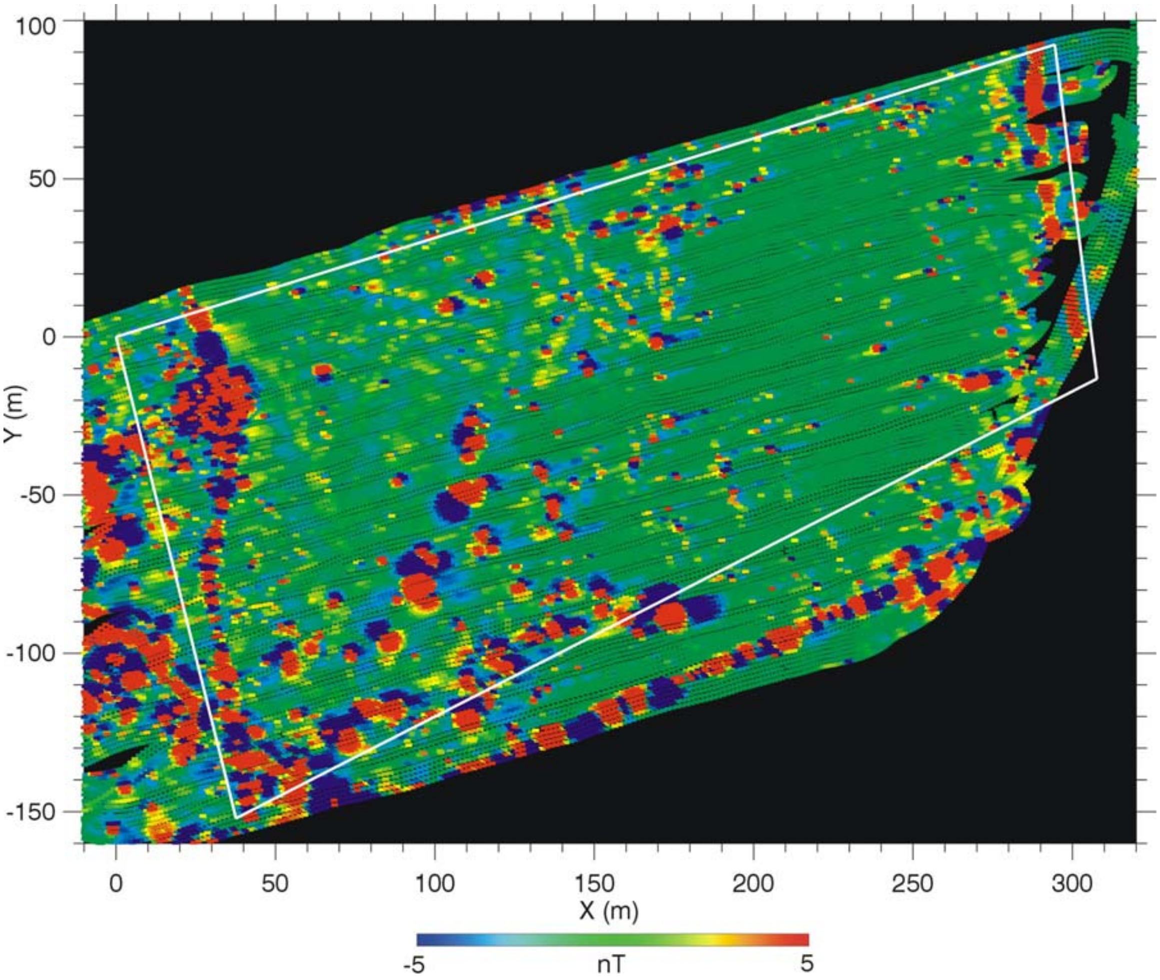


Figure 29 – Pixel Image Plot (sub-sampled) of the Airborne *MTADS* survey of the Airfield. The white border defines the limits of the survey. See Figure 11 for the DOQ and DEM presentations.

5.2 The Active Recovery Field Survey

The survey of the Active Recovery Field was completed as three consecutive files on 27 July. The area covered in this survey was ~100 acres. The magnetic anomaly image map is shown in Figure 30. This highly contaminated site (see Figures 17 and 18) is characterized by clusters of large and small ordnance, by stockpiles of recovered ordnance and scrap, an extremely dense ordnance deposit stretching for over 200 meters lying offshore in the bay parallel to the shoreline, by areas of dense six-foot tall vegetation, and by scattered steel blast shields and heavy equipment. Many of these features are apparent in Figure 30. It was within this context of signal returns many times larger than a signal generated by a 155-mm projectile that the data analysis was carried out. Where background levels allowed, targets were analyzed to the size level that would include 60-mm mortars. The target analysis of this survey required >100 hours of analysis time. The Target Report, included in the Appendix on CD, includes 2967 targets.

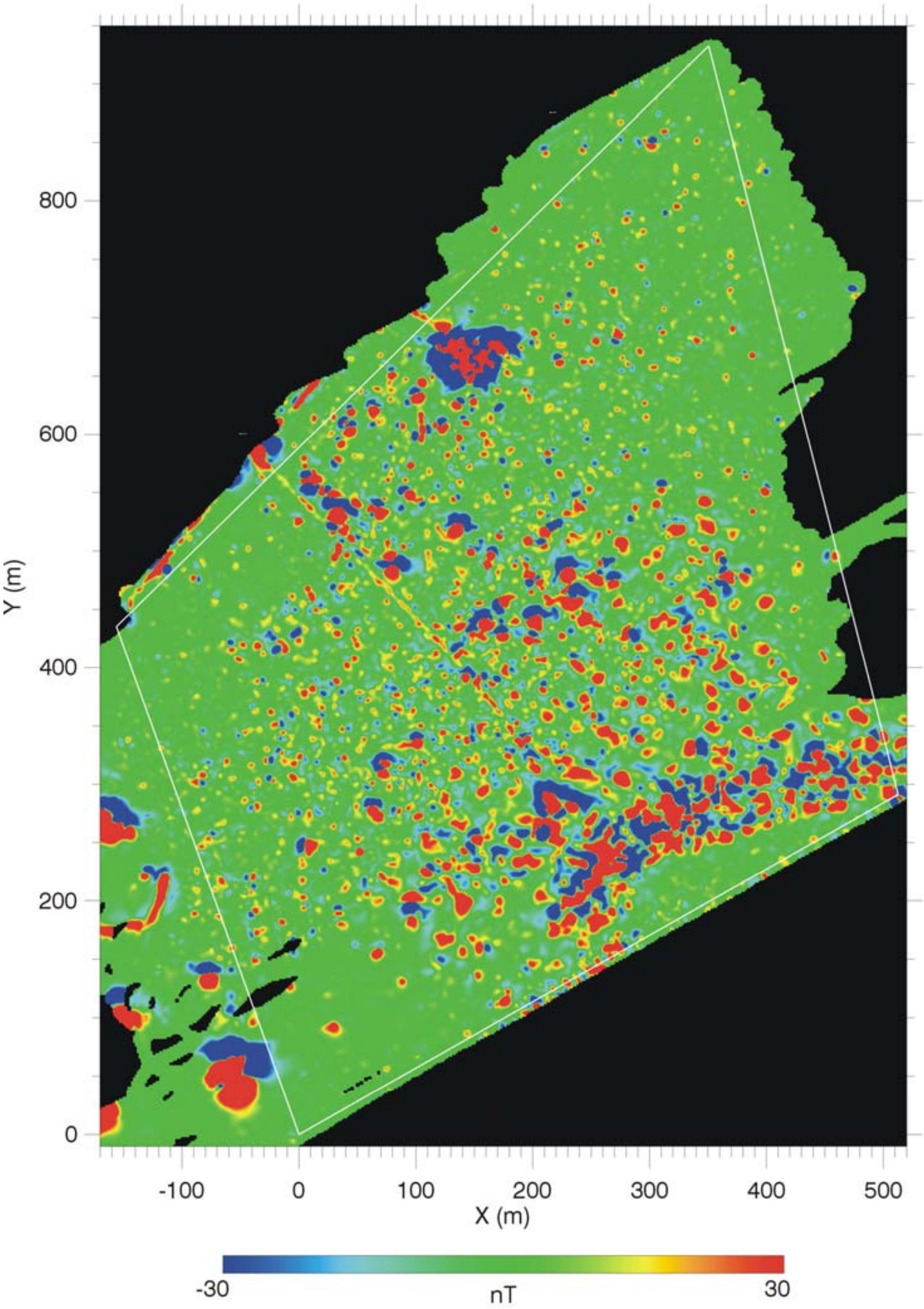


Figure 30 – Magnetic Anomaly Image (interpolated) of the Active Recovery Field. Note the cluster of surface ordnance at the top center, stockpiles of materials along the road, and the extended concentration of magnetic returns off shore.

5.3 The Dewatering Ponds

The entire survey area at the Dewatering Ponds Site consisted of 5 shallow water ponds. Figure 31 shows a plot of the four small ponds called the Finger Ponds. The image extends both north and south well beyond the ends of the ponds. There is a small missed survey area near the center of the south end of the western-most pond and a small missed area (due to data dropout) on the western edge of the second pond from the east. Figures 12 and 15 provide a perspective of the size and relative positions of the ponds.

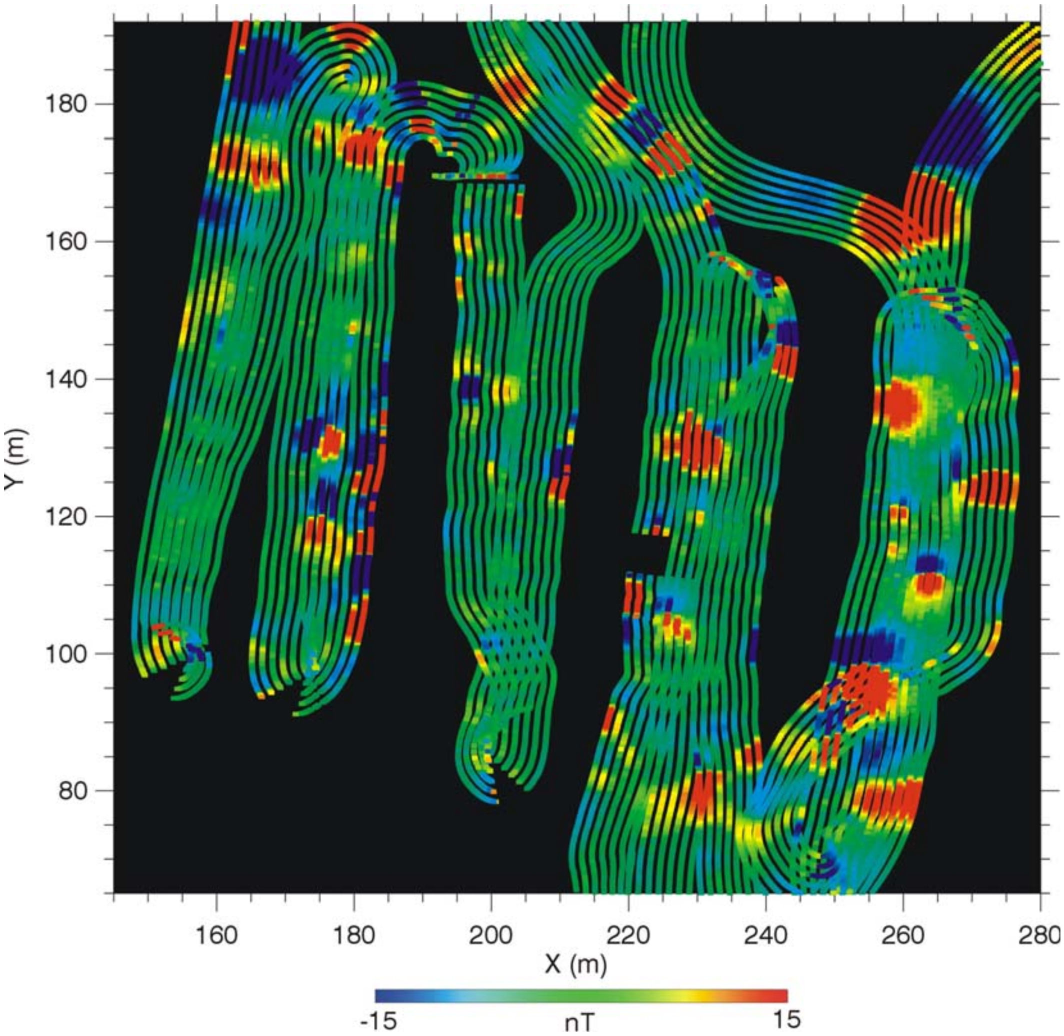


Figure 31 – Pixel image plot of the survey of the Finger Ponds at the Dewatering Ponds Site.

Figure 32 shows a magnetic anomaly image from the survey of the larger pond at the eastern edge of the Dewatering Ponds Site. Most of the more intense signals are from objects lying at or beyond the banks of the pond. A much finer scale is required to image the UXO lying on the bottom of the pond.

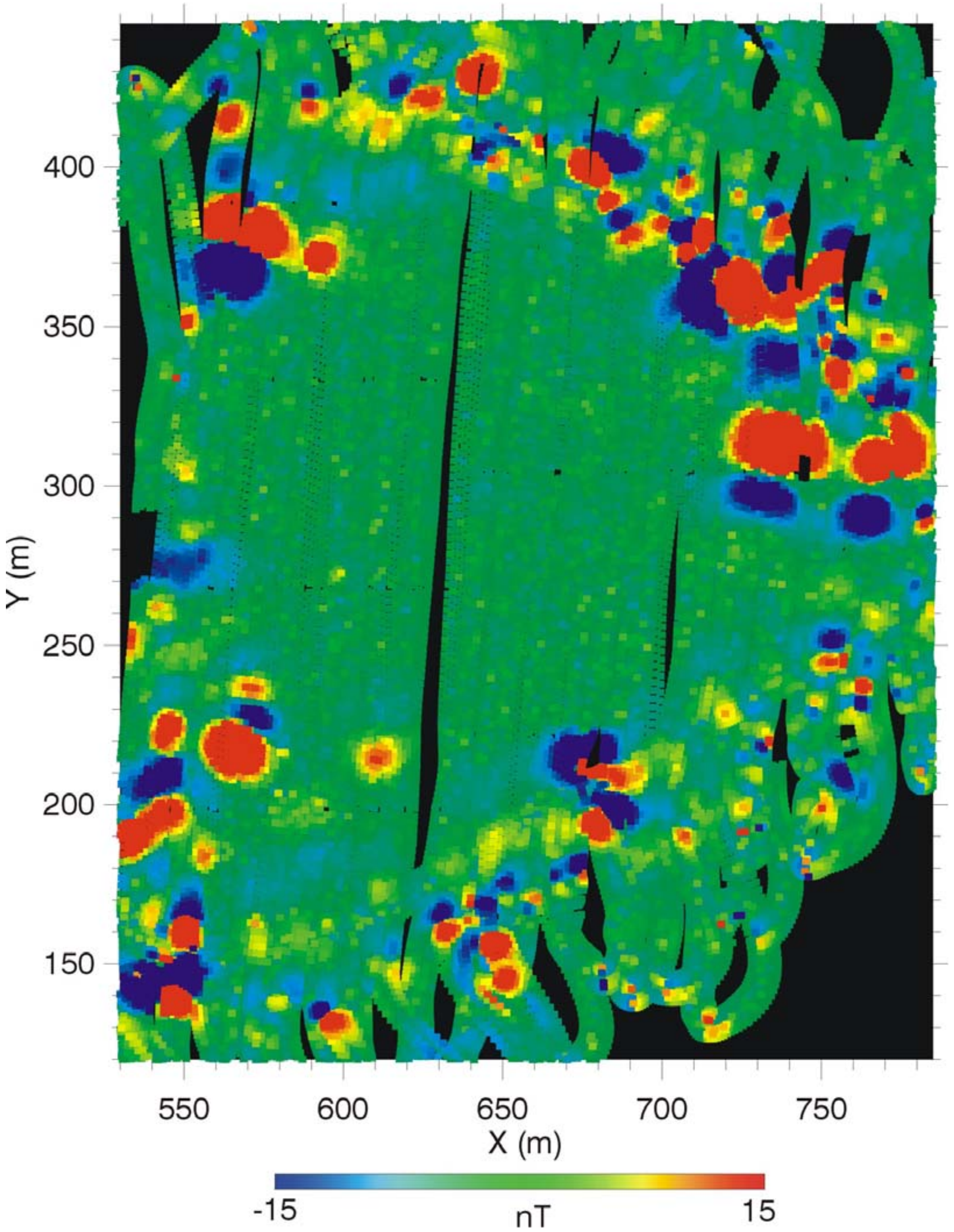


Figure 32 – Magnetic anomaly (subsampled, pixel) image from the survey of the larger pond at the Dewatering Ponds Site.

The Target Report in the Appendix on the CD contains 224 targets from the Dewatering Ponds. Only about 130 of the targets are small enough to be seed targets and many of these lie outside the pond areas. The larger targets and the targets beyond the pond shorelines are included in the Target Report because in the APG Demonstration Test Plan this survey area was claimed to be relatively free of clutter. These targets are provided so that they can be investigated if there is an interest in their identities.

5.4 The Mine, Grenade, and Direct-Fire Weapons Range

The Mine, Grenade, and Direct-Fire Weapons Range, shown in Figure 33, was the largest of the survey areas at 130 acres. A north/south paved road that is visible in the magnetic anomaly image bisects the survey. To the west of the road are a series of gravel roads leading to target pads. In Figure 22 these pads are shown as occupied by target structures. During the *MTADS* airborne survey the pads were not occupied. The blue stone used to construct the gravel roads and pads is very magnetically active. Figure 34 shows part of the upper road and the target pad. The anomalies, ranging in size from fuzes and antipersonnel ordnance to GP bombs, are shown scattered about the target. The large amount of missed area along the eastern side of the survey was the result of the tree cover in the area. The eastern most tip of the survey is dominated by high signal returns. Much of this area, observed during the survey, is characterized by construction rubble from earlier structures.

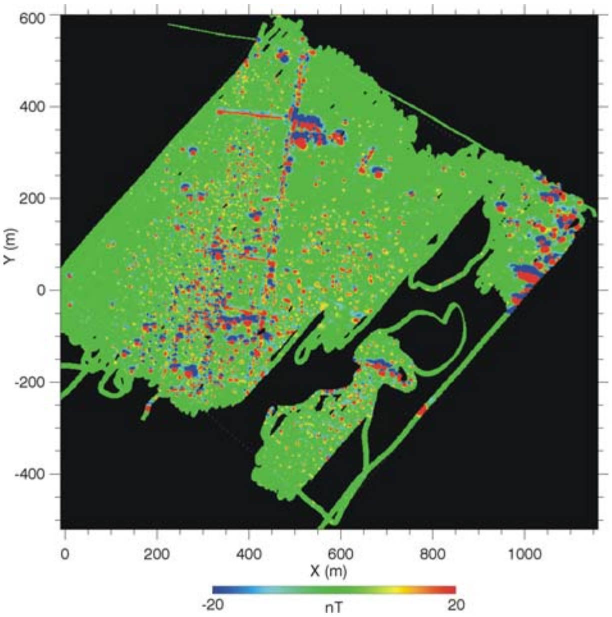


Figure 33 – *MTADS* survey image of the Mine, Grenade, and Direct-Fire Weapons Range.

Seed targets were not placed in this area. Therefore, the analysis was carried out assuming that the survey was in preparation for cleanup of a mixed-use range. The target report contains almost 3,400 targets. There are 8 areas that we considered to be too densely cluttered to successfully analyze. These are listed at the end of the target report. If these areas are designated for clearance, they should be surface cleaned and then surveyed using either the man-portable or the vehicular *MTADS* magnetometer arrays. The much higher density data would allow targets to be analyzed. Much of the remainder of the survey area could be effectively remediated (**<u>not cleared</u>**) using the airborne survey and analysis.

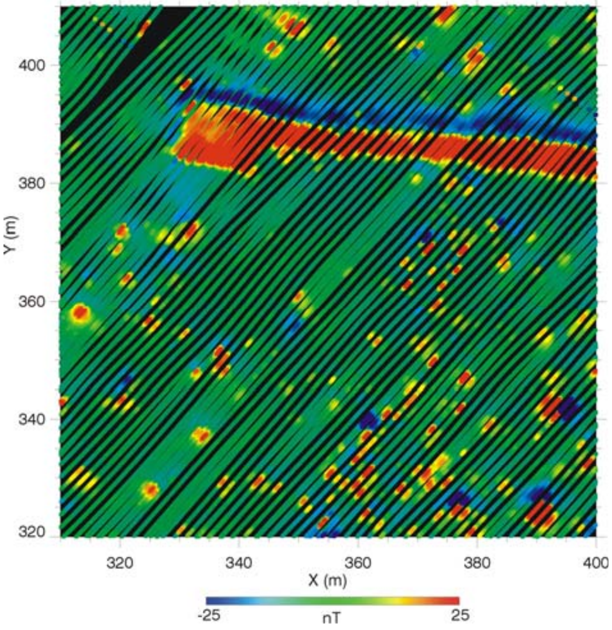


Figure 34 – Magnetic anomaly image of a portion of the Mine, Grenade, and Direct-Fire Weapons Range showing the target pad near the north corner of the survey in Figure 33.

To undertake a comprehensive UXO clearance of this range would require several clearances and resurveys. There is a substantial amount of both small ordnance and aluminum ordnance visible on the surface. The final survey therefore, should be done with an EM array. The EM array would also likely be able to defeat the high magnetometer return from the bluestone pads and roads. From an economic point of view, if this area were designated for clearance, it would be more economical to start over. One should first conduct a surface clearance, repeat the magnetometer survey, dig targets, then survey with an EM array and dig targets again.

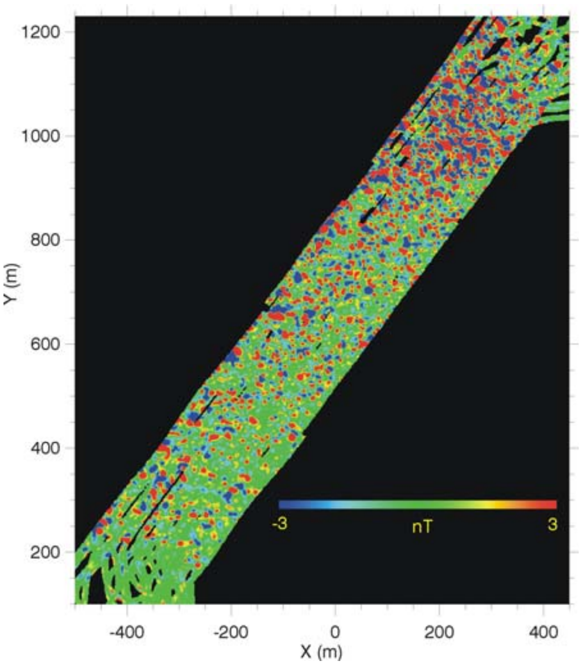


Figure 35 – Magnetic anomaly image (interpolated) of the Chesapeake Bay Impact Area survey.

5.5 The Chesapeake Bay Impact Area

An interpolated magnetic anomaly image of the Chesapeake Bay Impact Area survey is shown in Figure 35. The survey was ended well offshore because we lost signal from the GPS base station and there was not another station available within line-of-site for the helicopter to continue surveying closer to shore. The covered survey area includes about 60 acres of survey that provide a good estimation of the target density in the area.

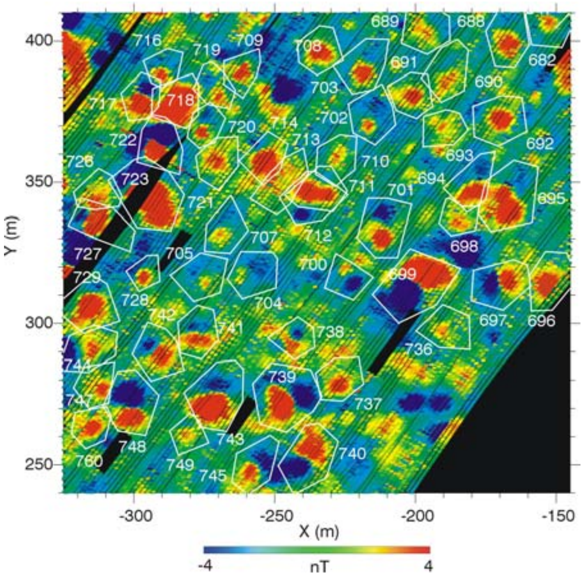


Figure 36 – Pixel image (subsampled) of an area near the south end of the Chesapeake Bay Impact Area survey showing individual target signatures.

The Target Report in the Appendix on CD contains 800 targets. The targets are much denser at the northeast end of the survey, although the entire survey area, as shown in Figure 36, reflects an impact area. Because of the significant standoff distance between the targets and the sensor boom, the target signatures spread and tend to overlap. Water depths are uncertain, but were likely in the range of 2.5-6 feet. From the shape of the anomaly signatures and the analyzed target depths, the water depths are probably shallower near the north end of the survey. The average analyzed target sizes are much larger than the 105-mm projectiles that were cited in the APG Test Plan as the likely dominant UXO. Because of the relatively large separation between the sensors and the targets buried in the sediment, larger targets are more visible in our analysis, and in some cases, multiple targets may make contributions to individual targets fits. It is our estimation that many, if not the majority of the targets in the target report are very large projectiles or GP bombs. This would be an ideal area to conduct an underwater survey with the Marine *MTADS* system. The comparison of the data sets would likely be very instructive.

6. Performance Assessment

6.1 Performance Criteria

These demonstration surveys were intended to evaluate the performance of the *MTADS* Airborne Survey System in a series of relatively small surveys at ordnance ranges and impact areas with various types, sizes and densities of ordnance and OE (and non-OE) clutter. Terrains on the survey sites vary from flat and level (grass-covered) to dense low vegetation, and even include areas with broken forest. Dry upland areas, low-lying wetlands, fresh water ponds, and shallow-water marine sites were included. Additionally, a prepared site was established using inert ordnance emplaced in a non-range area at the Airfield. Inert ordnance was also seeded among the existing ordnance, OE, and clutter at three other range survey areas. Performance goals were based upon detection of both the inert and live UXO challenges, and discrimination of the UXO from indigenous clutter on the sites. IDA personnel evaluated the results of the data analyses. Working with the ranked and prioritized target dig lists, the detection efficiency and location accuracies for the seed targets were analyzed.

To increase the value of the study IDA, working with personnel from APG/ATC and ESTCP, developed a selective dig list of additional targets for remediation. Carefully digging these targets will allow the survey performance to be evaluated against the live ordnance and clutter backgrounds at the Airfield and the Active Recovery Field. The Airfield results, combined with the seed target results, allow a more detailed evaluation of the ability to distinguish ordnance from non-ordnance targets. Finally, the results of the head-to-head relative performances of the *MTADS* and the Oak Ridge/Huntsville Airborne Survey systems under identical performance conditions can be evaluated. The extended study, including the additional dug targets and comparison of the performance of the two systems, will be treated in reports to be prepared by others. If these are available in time, the results can be incorporated into the Final Report and the Cost and Performance Report for ESTCP Project 200031.

6.1.1 The Airfield Seed Targets

Table 4 (the content was provided by IDA), shows the number and type of seed targets placed at the Airfield, and the *MTADS* detection results, assuming a 1 m and a 1.5 m detection halo. Table 5 is the ground truth for the seed targets at the Airfield.

Table 4. Seed Ordnance Emplaced and Reported at the Airfield *MTADS* Survey

Ordnance Type	Number Emplaced	Ordnance Found (1.0 m radius) Original Analysis	Ordnance Found (1.5 m radius) Original Analysis	Ordnance Found (1.0 m radius) Expanded Analysis	Ordnance Found (1.5 m radius) Expanded Analysis
60-mm	3	2	2	3	3
81-mm	21	14	14	16	18
105-mm	28	27	28	27	28

Table 5. Ground Truth for the Seed Targets at the Airfield

NRL ANALYSIS						GROUND TRUTH				
NRL ID	DEPTH (m)	INCL (deg)	AZI (deg)	MOMENT	Probability	IDA STRINGID	DEPTH (m)	INCL (deg)	AZI (deg)	Miss Dist (m)
572	0	0	0	0	6	PAF-60MM 2	0	45	90	0.68
258	0.13	73	332	0.1028	1	PAF-60MM 3	0	0	0	0.29
280	0.46	88	155	0.8497	2	PAF-60MM 4	0	75	90	0.24
229	0.14	36	331	0.0447	2	PAF-81MM 1	0.53	0	0	0.12
131	0.18	68	75	0.1165	2	PAF-81MM 2	0.53	45	90	0.46
246	0	42	177	0.0774	2	PAF-81MM 3	0.11	45	0	0.67
534	0.41	26	80	0.0615	4	PAF-81MM 4	0.53	0	90	0.18
180	0	80	42	0.1059	2	PAF-81MM 5	0.53	75	45	0.60
566					5	PAF-81MM 6	0.11	0	0	1.10
236					3	PAF-81MM 7	0.95	45	45	0.99
132	0.47	71	116	0.2875	1	PAF-81MM 8	0.11	75	90	0.06
226					2	PAF-81MM 9	0.53	75	0	0.27
136	0	84	18	0.2886	1	PAF-81MM 10	0.11	45	0	0.15
232					3	PAF-81MM 11	0.53	75	45	0.93
135	0.31	60	96	0.0891	1	PAF-81MM 12	0.53	75	90	0.21
						PAF-81MM 13	0.53	45	0	
238	0.21	48	306	0.0706	2	PAF-81MM 14	0.53	75	45	0.43
						PAF-81MM 16	0.53	0	45	
139	0.47	38	27	0.1665	1	PAF-81MM 17	0.53	75	45	0.14
198	0.2	74	90	0.0409	3	PAF-81MM 18	0.53	45	0	0.20
261	0.47	61	138	0.2772	1	PAF-81MM 20	0.11	75	45	0.40
569					5	PAF-81MM 21	0.53	45	90	1.28
						PAF-81MM 22	0.95	0	75	
590					5	PAF-81MM 26	0.95	45	0	0.90
245	0.45	15	324	0.4157	1	PAF-105MM 1	0.82	0	0	0.06
248	0.91	68	114	0.321	3	PAF-105MM 1A	0	0	0	1.09
89	0.6	79	111	1.9808	1	PAF-105MM 2	0.46	75	45	0.26
239	0.6	42	45	0.8355	1	PAF-105MM 3	0.82	45	45	0.29
130	0.58	67	97	1.3477	1	PAF-105MM 4	0.46	75	90	0.15
190	0.14	16	9	0.7448	1	PAF-105MM 5	0.09	0	0	0.05
227	2.36	35	91	6.2838	5	PAF-105MM 6	0.82	45	45	0.60
231	0.33	84	98	1.5426	1	PAF-105MM 7	0.09	75	90	0.24
228	0.54	78	59	1.3996	3	PAF-105MM 8	0.46	75	0	0.38
230	0.34	47	351	1.9145	1	PAF-105MM 9	0.09	45	0	0.03
240	0.53	67	358	1.4855	1	PAF-105MM 10	0.46	75	45	0.13
142	0.77	34	349	1.4633	1	PAF-105MM 11	0.46	0	0	0.15
243	0.28	33	3	0.7497	2	PAF-105MM 12	0.46	45	90	0.48
247	0.24	74	36	1.3588	1	PAF-105MM 13	0.09	45	0	0.20
137	0.04	82	250	0.3979	2	PAF-105MM 14	0.46	0	90	0.29
183	0.53	69	27	1.3491	3	PAF-105MM 15	0.46	75	45	0.06
199	0.22	73	35	0.2903	1	PAF-105MM 16	0.09	0	90	0.17
185	0.62	67	23	1.4913	1	PAF-105MM 17	0.46	45	0	0.37
187	0.48	81	47	1.194	1	PAF-105MM 18	0.46	75	45	0.29
196	0.32	47	17	1.0106	2	PAF-105MM 19	0.46	45	0	0.17
188	0.26	35	61	1.0456	3	PAF-105MM 21	0.09	45	90	0.11
195	0.61	53	17	1.1855	2	PAF-105MM 22	0.46	45	45	0.28
260	0.44	77	54	1.5276	1	PAF-105MM 24	0.09	75	45	0.30
279	0.63	87	251	1.2588	2	PAF-105MM 25	0.09	45	90	0.37
191	0.66	48	29	1.2854	1	PAF-105MM 26	0.82	75	0	0.19
282					5	PAF-105MM 29	0.09	45	90	0.19
284	0.09	27	16	0.3704	3	PAF-105MM 31	0.46	0	0	0.11
201	0.53	13	22	0.7641	1	PAF-105MM 36	0.46	0	45	0.05

Table 6, also from IDA, shows the cumulative detection probability (for all target sizes grouped together) as a function of UXO probability category assigned by the analyst.

Table 6. *MTADS* Detection Probability at the Airfield by Analyst Classification Category

UXO Likeliness	Cumulative P_D (1.0m radius)	Cumulative P_D (1.5m radius)
1	42.31%	42.31%
2	65.38%	65.38%
3	78.85%	80.77%
4	80.77%	82.69%
5	86.54%	92.31%
6	88.46%	94.23%

In the original analysis containing 308 targets, two of the three 60-mm and fourteen of the twenty-one 81-mm mortars were correctly reported. The 105-mm projectiles were all detected; one of the projectiles (NRL 248, StringID PAF-105mm 1A) was reported 10 cm beyond the 1.0 m detection halo. In the expanded analysis (610 total targets) the final 60-mm mortar was reported, as were four additional 81-mm mortars. In the expanded target report three 81-mm mortars were left undeclared. In each of these cases (NRL Target No's 572, 191, and 259) declarations were reported. These larger objects whose signatures masked the seed target obscured the missed seed target in each case.

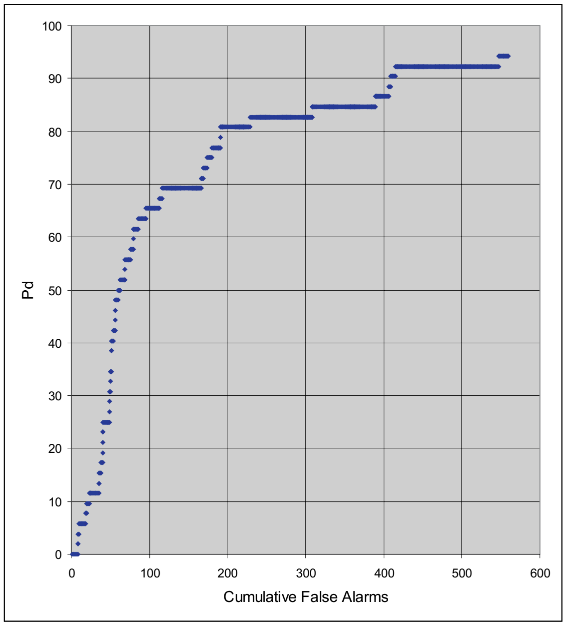


Figure 37 – ROC curve for the *MTADS* survey of the Airfield based upon the Target Report containing the expanded target analysis.

The information in our Target Report and the Ground Truth, provided by IDA, can be used to construct a pseudo ROC curve based upon the analyst's declarations in the Report. This ROC curve is shown in Figure 37 for the Airfield survey. The original analysis submitted 308 targets. This captured 44 of the 52 (or 85%) of the seed targets, including all of the 105mm projectiles. The false alarm rate for this analysis was then 6 digs for each recovered seed target. The expanded analysis included a total of 610 targets. The 302 additional targets submitted in the expanded analysis captured 5 additional seed targets. Only one of the 5 was a target with a fit that converged. The remaining 4 were unanalyzed items mechanically marked in dense clutter consisting primarily of large targets. Digging these targets might recover the additional 5 seed targets; however, it is debatable whether the analysis really isolated these seed targets. EOD personnel, digging targets in the field, unless they are specifically instructed to dig the flag, typically orient themselves with a metal detector to begin their operation. If the dig team felt their mission was to dig the large target (either specified by our dig list, or with guidance from their metal detector); once they recovered the large target they might, or might not, recover the nearby seed target. Digging all targets in the expanded target report would lead to a false alarm rate of 11.5 digs per recovered seed target. If all targets were dug, the final P_d is 94%, and three 81-mm projectiles are left in the field.

6.1.2 The Active Recovery Field Seed Targets

Sixty-four seed targets, including thirty-two 81-mm mortars and thirty-two 105-mm projectiles, were emplaced in the Active Recovery Field survey area. Table 7 summarizes the detection efficiency as a function of ordnance type and Table 8 provides the detection probability as a function of the analyst's classification category. The seed target detection efficiency at the Active Recovery Field was vanishingly small. The evaluation, which shows 5 correctly declared targets within a 1.5m radius, is misleading. Consideration of the survey data for these 5 targets shows that 3 of the 5 NRL declarations were accidental coincidences, resulting from analyzed objects that were much too large to be the implanted seed targets. The Active Recovery Field survey area is much too contaminated with very large ferrous objects to allow detection of the seed targets. The massive signatures of the very large objects effectively screen the returns from the much smaller seed targets.

Table 7. Seed Ordnance Emplaced and Reported at the Active Recovery Field MTADS Survey

Ordnance Type	Number Emplaced	Ordnance Found (1.0m radius)	Ordnance Found (1.5m radius)
81-mm	32	0	1
105-mm	32	4	4

Table 8. *MTADS* Seed Target Detection Probability at the Active Recovery Field by Classification Category

UXO Likeliness	Cumulative PD (1.0m radius)	Cumulative PD (1.5m radius)
1	3.13%	4.69%
2	4.69%	6.25%
3	4.69%	6.25%
4	6.25%	7.81%
5	6.25%	7.81%
6	6.25%	7.81%

To increase the value of the Active Recovery Field study, IDA worked with personnel from APG, ATC, and ESTCP to develop a selective dig list of additional targets for remediation. The MTADS and ORAGS target reports were sorted to establish common target picks. These were down-selected to targets that were relatively isolated from other interferences and to targets assigned relatively high UXO probabilities. The dig list prepared by IDA contained 291 targets. The ATC dig list was pared to 218 targets in the process of digging. Of the targets in the ATC list, 29 were not dug because they were offshore (or for other reasons), or the results were lost or were inconclusive. The final dig report is presented in Table 9. Recovery of these items (rather than the seed targets) provides a more meaningful evaluation of the MTADS and ORAGS surveys because they sample the inventory of targets that characterize the true UXO threat on this range. Of the 189 dug targets with a documented record, 91 were either intact UXO or substantial parts of UXO items. These items are highlighted in yellow in Table 9. This dig program resulted in slightly fewer than 2.1 digs per recovered UXO. Even though this was not a comprehensive, random sampling of the primary dig lists, the false alarm rate is very low.

Table 9. Active Recovery Field UXO dig results.

Dig List		Recovery Information			Δ (Dig vs Recovery)		Recovered Item(s)		
ATC Dig #	Depth (m)	Depth (m)	Dip (°)	Azimuth	Distance (m)	Depth (m)	Description	Weight (gms)	Dimensions (mm)
1	0.03	0.43	NA	NA	0.09	-0.40	Scrap from steel drum	3255	Not Recorded
2	0.56	0.46	NA	NA	0.08	0.10	Bar stock	1160	670 x 30 x 6
3	0.00	0.09	NA	NA	0.14	-0.09	Scrap iron	1025	180 x 50 x 30
4	0.00	0.18	NA	NA	0.13	-0.18	Wire	60	1070
5	0.16	0.17	NA	NA	0.08	-0.01	Welding rods	50	480
6	0.44	0.18	NA	NA	0.24	0.26	Scrap iron	8100	8315 x 12
7	0.39	0.09	NA	NA	0.47	0.30	Handle	95	245 x 30 x 3
8	1.50	1.37	NA	NA	0.05	0.13	1/2" Curled wire	490	3700 x 12 x 1
9	1.01	1.07	NA	NA	0.28	-0.06	Pipe & Ring	840	420 x 30
10	0.13	0.52	NA	NA	0.08	-0.39	Welding rods	5	240
11	0.22	0.12	NA	NA	0.16	0.10	Two inert mines (Volcano)	3420	120 dia x 65
12	0.16	0.00	NA	NA	0.02	0.16	Wie	15	910
13	0.00	0.14	NA	NA	0.16	-0.14	Spring	100	190 x 40
14	0.02	0.15	NA	NA	0.21	-0.13	Scrap iron	405	560
15	0.41	0.12	NA	NA	0.25	0.29	Wire	525	960
16	0.02	0.17	NA	NA	0.13	-0.15	Mower blade	1405	330 x 70 x 12
17	0.03	0.30	NA	NA	0.13	-0.27	Flat stock	160	115 x 30 x 5
18	0.43	0.21	NA	NA	0.06	0.22	Cable	830	1020
19	0.00	0.12	NA	NA	0.22	-0.12	Scrap	285	160 x 70
20	0.00				NA	NA	Fragments and stones (fragment cloud)	25 (frags only)	Not Recorded
21	1.34	1.37	15 NU	NE	0.52	-0.03	155-mm projectile. unfuzed fired	Not weighed	720 x 155 dia
22	2.01	1.52	25 NU	W	1.80	0.49	90-mm projectile., unfuzed fired	Not weighed	420 x 90 dia
23	1.30	0.13	0.00	SW	1.08	1.17	90-mm projectile., fuzed	Not weighed	356 x 90 dia
24	1.65	0.91	NA	NA	0.18	0.74	Household waste pile, metal pitcher, cups, wash buckets, misc. scrap metal	Not Recorded	Not Recorded
25	0.87	0.76	45 NU	ENE	0.31	0.11	8-inch projectile, unfuzed, fired	Not weighed	1050 x 200 dia
26	0.16	Lost	NA	NA	0.66	Lost	Fragment	2600	220 x 180 x 15
27	1.28	1.37	30 ND	SW	0.40	-0.10	90-mm AP round fired Lg piece of scrap metal	Not weighed 28780	300 x 90 dia 610 x 495 x 12
28	1.19	1.50	90 NU		0.41	-0.32	155-mm fired fuzed	Not weighed	840 x 155 dia
29	1.28	1.40	10 NU	E	1.18	-0.12	90-mm projectile., fuzed fired	Not weighed	390 x 90 dia
30	0.93	0.60	0	SW	0.43	0.33	240-mm projectile, fuzed, fired	Not weighed	Not Recorded
31	0.98	0.35	20 NU	S	0.46	0.63	120-mm projectile fuzed, fired	Not weighed	Not Recorded
32	2.14	1.52	NA	NA	1.18	0.62	projectile fragments	19670 total	Various
33	0.54						NOT RECOVERED		
34	0.99	0.76	NA	NA	0.33	0.23	Frag, base of 155	3060	65 x 165 dia
35	0.85	0.26	5 ND	SW	0.18	0.59	106-mm RAP round	Not weighed	400 x 106 dia
36	0.69						NOT RECOVERED		
37	0.33	0.30	NA	NA	0.90	0.03	Fragment cloud	Not weighed	Not Recorded
38	0.61	0.67	10 ND	NNW	0.18	-0.06	75-mm projectile, fuzed, fired	Not weighed	360 x 75 dia
39	0.75	Off shore in water, not recovered							
40	0.95						NOT RECOVERED		
41	0.53	0.46	NA	NA	0.30	0.07	Bomb fragment	25300	710 x 590 x 10
42	0.73		NA	NA	0.12	0.73	Fragments, unreliable recovery data, area disturbed by explosive testing after survey	110	Not Recorded

Dig List		Recovery Information			Δ (Dig vs Recovery)		Recovered Item(s)		
ATC Dig #	Depth (m)	Depth (m)	Dip (°)	Azimuth	Distance (m)	Depth (m)	Description	Weight (gms)	Dimensions (mm)
43	0.43	0.15	15	Lost	0.34	0.28	Railroad rail on end	Not recovered	
44	0.85	0.05	0	NA	0.31	0.80	Steel plate	490000 (est.)	1829 x 1829 x 19
45	0.86	0.2	0	NW	0.18	0.66	14-in fuzed projectile	Not weighed	1600 x 356
46	0.90		90 ND		0.41		155-mm projectile identified	Not recovered	
47	0.36	0.06	0	SSE	0.31	0.30	75-mm projectile, fuzed, fired	Not weighed	420 x 75
48	0.75	0.25	NA	NA	0.46	0.50	Small fragments	Lost	Lost
49	0.82	0.49	10 ND	NE	0.57	0.33	90-mm projectile, unfired, unfuzed	Not weighed	200 x 90 dia
50	0.25	0.1	0	W	0.94	0.15	155-mm M107 projectile, unfuzed unreliable recovery data, de-mil area	43800	630 x 155 dia
50 a	0.25	0	NA	NA	0.30	0.25	Fragment, unreliable recovery data, de-mil area	820	130 x 100 x 30
51	0.82	0.76	80 NU	N	0.36	0.06	120-mm projectile fuzed, fired	Not weighed	590 x 120 dia
52	0.66	0.31	85 NU	E	0.51	0.35	155-mm projectile. unfuzed fired	Not weighed	680 x 155 dia
53	0.41	0.46	NA	NA	0.49	-0.05	Fragments	4600 total	280 x 100 x 15 160 x 40 x 80
54	0.86	0	NA	NA	0.12	0.86	Scattered small fragments unreliable recovery data, in de-mil area	Not Recorded	Not Recorded
55	0.73	0.3	0	N	0.15	0.43	90-mm projectile	Not weighed	400 x 90 dia
56	0.90	0.91	85 NU	N	0.34	-0.01	155-mm projectile, fuzed, fired	Not weighed	660 x 155 dia
57	0.74	0.2	10 NU	W	0.28	0.54	120-mm projectile fuzed, fired	Not weighed	250 x 120
58	0.88	0.2	90	NA	0.28	0.68	Steel plate	5236000 (est.)	1829 x 1829 x 203
59	0.17	Off shore in water, not recovered							
60	0.40	0.16	0	SE	1.03	0.24	100-mm rocket, fired, unfuzed	Not weighed	1500 x 100 dia
61	-0.71	Off shore in water, not recovered							
62	0.21	Off shore in water, not recovered							
63	0.84	1.23	NA	NA	1.01	-0.40	Suspect Ammo Burial Pit below recovered Pipe and fragments	9100 4300	250 x 380 x 14 Various
64	0.73	Off shore in water, not recovered							
65	0.16	Off shore in water, not recovered							
66	0.90	0	0	NA	0.08	0.90	Steel core ground rod, approx 0.6 meters bent to ground surface ~1.2m in ground	270	1803 x 25
67	0.95	0.35	NA	NA	0.68	0.60	Fragment	3560	335 x 170 x 12
68	0.74	1.3	75 ND	Lost	0.11	-0.56	155-mm projectile, uncovered but not recovered		
69	0.64	0.61	0	NE	1.56	0.03	Large piece of angle iron	11000	740 x 90 x 18
70	0.52	0.64	75 NU	N	0.04	-0.12	Projectile fragment	16130	500 x 160 x 25
71	0.65	0.83	65 ND	WSW	0.34	-0.18	155-mm projectile, fuzed, fired	Not weighed	750 x 155 dia
72	0.46						NOT RECOVERED		
73	0.39	0.38	5 NU	ESE	0.74	0.01	8-in Projectile, fuzed, fired	Not weighed	870 x 240 dia
74	0.24	0.23	NA	NA	0.35	0.01	Fragment	3890	300 x 140 x 12
75a	0.92	0	NA	NA	1.47	0.92	Fragments	10100 total	390 x 180 x 10
75b	0.92	0.46	NA	NA	0.93	0.46			120 x 105 dia
75c	0.92	0.15	NA	NA	0.68	0.77			310 x 95 x 15
76	0.29	0.31	NA	NA	0.18	-0.02	Fragments	5800	300 x 120 x 40
77	0.67						NOT RECOVERED		
78	0.41	Lost	Lost	NNE	Lost	Lost	large frags (2)	Lost	Lost
79	0.46	0.31	70 NU	S	0.54	0.15	Fragment	7370	450 x 110 x 20
80	0.28	0	NA	NA	0.07	0.28	Large piece of fragment	12400	630 x 460 x 12
81	0.00	Surface	NA	NA	0.30	0.00	Small frags, unreliable recovery data, in de-mil area	Not recovered	Not Recorded

Dig List		**Recovery Information**			**Δ (Dig vs Recovery)**		**Recovered Item(s)**		
ATC Dig #	**Depth (m)**	**Depth (m)**	**Dip (°)**	**Azimuth**	**Distance (m)**	**Depth (m)**	**Description**	**Weight (gms)**	**Dimensions (mm)**
82	0.92		NA	NA	0.21	0.92	Large fragment Small fragment	6200 600	270 x 130 x 25 170 x 80 x 20
83	0.57	0.2	Not Recorded		0.40	0.37	2 metal rods	600 1200	620 x 12 dia 490 x 20 dia
84	0.69						Not recovered, in ground water		
85	0.73	0.76	NA	NA	1.31	-0.03	155-mm fragment	22320	310 x 20 x 155 dia
86	0.52	0.45	NA	NA	0.72	0.07	Scrap metal	640	300 x 40 x 15
87	0.61	0.2	10 NU	N	0.16	0.41	155-mm projectile, fuzed, fired		810 x 155 dia
88	0.39	0.38	NA	NA	0.65	0.01	Butterfly bomb	200	230 x 200 open
88a	0.39	0.31	NA	NA	0.48		Closing plug	300	30 x 60 dia
89	0.37	0.81	90		0.93	-0.44	155-mm projectile, fuzed, fired	Not weighed	625 x 155 dia
90	0.35	0.41	0	SSE	1.19	-0.06	155-mm projectile, fuzed, fired	Not weighed	840 x 155 dia
91	0.09	0.1	5 ND	N	0.47	-0.01	8-inch projectile, unfired (salute rd)	Not weighed	400 x 200 dia
92	0.69	0.61	NA	NA	0.16	0.08	Scrap metal	1240 total	230 x 30 x 20 150 x 15 x 15 100 x 20 x 25
93	0.92	0.1	NA	NA	0.35	0.82	Fragment	2020	225 x 125 x 12
94	0.76	0.43	20 ND	NW	1.61	0.33	155-mm projectile, fired, fuzed 3 Fragments Rod Fragments	Not weighed 3750 total	609 x 155 dia 510 x 30 120 x 45 x 30 220 x 100 x 40
95	0.58	0.31	NA	NA	0.20	0.27	155-mm fragment	21400	670 x 230 x various
96	0.73	0.61	15 NU	E	0.90	0.12	Projectile frag (90-mm) /w fuze	7500	400 x 180 x 40
97	0.10	0.15	NA	NA	0.85	-0.05	Fragment	5850	330 x 140 x 60
98	-0.01	0.76	10	Lost	0.45	-0.77	Large piece of 4" (102-mm) angle iron	Not recovered	12 mm thick, estimated 1.8 m long
99	0.68	0.15	85 NU	E	0.35	0.53	Fragment	Not recovered	60 x 150
100	0.66	0.46	20 NU	WSW	0.20	0.20	120-mm projectile fuzed, fired	Not weighed	527 x 120 dia
101	0.06						NOT RECOVERED		
102	0.50	0.61	75 NU	NNE	0.23	-0.11	90-mm Projectile, fuzed, fired	Not weighed	310 x 90 dia
103	0.97	0.91	0	SW	0.18	0.06	90-mm Projectile, fuzed, fired	Not weighed	310 x 90(dia)
103a	0.97	0.91	NA	NA	0.18	0.06	Cylinder Lifting eye	2850 590	200 x 90 dia 80 x 60 dia
104	0.18	0.15	NA	NA	0.51	0.03	Fragment	1670	150 x 120 x 12
105	0.61						NOT RECOVERED		
106	0.86	0.65	70 ND		0.45	0.21	155-mm projectile	Not weighed	610 x 155 dia
107	0.56	0.5			0.60	0.06	Fragments	3100	lost
108	-0.14	0.36	45 NU	N	0.53	-0.50	155-mm projectile, fuzed, fired	Not weighed	700 x 155 dia
109	0.68	0.46			0.44	0.22	Cylinder	5900	310 x 90 dia
110	0.37	0.05	NA	NA	0.18	0.32	Fragment	2030	45 x 150 dia
111	0.80	Off shore in water, not recovered							
112	0.27				0.25		Large, thin-wall (bomb?) frag, unable to recover	Not weighed	Not recovered
113	0.19	0.2	Not Recorded		0.22	-0.01	1/2 of 105-mm casing	5690	340 x 110 x 80
114	0.76						NOT RECOVERED		
115	0.42	0.46	Not Recorded		1.41	-0.04	1/2 of 90-mm casing	3800	310 x 130 x 30
116	0.42	0.31	NA	NA	0.12	0.11	Fragment	2830	210 maj dia x 40
117	0.46						NOT RECOVERED		
118	0.77	0.61	NA	NA	0.97	0.16	Fragment	4120	260 x 110 x 40
119	0.87	0.14	0	W	0.58	0.73	2.75 in rocket warhead fired, unfuzed	Not weighed	360 x 70 dia
120	0.48	Lost	Lost			Lost	Fragments		
121	0.83	0.45	NA	NA	0.55	0.38	Fragments	2320	Not Recorded

Dig List		Recovery Information			Δ (Dig vs Recovery)		Recovered Item(s)		
ATC Dig #	Depth (m)	Depth (m)	Dip (°)	Azimuth	Distance (m)	Depth (m)	Description	Weight (gms)	Dimensions (mm)
122	0.95	0.31	NA	NA	0.44	0.64	Fragment	2200 total	190 x 90 x 14 185 x 85 x 12
123	0.69	0.61	NA	NA	0.39	0.08	Unknown	8490	320 x 240 x 60
124	0.74	0.24	NA	NA	0.39	0.50	Fragment	5200	170 x 180 x 35
125	0.63	0.2	NA	NA	0.54	0.43	Fragments	640 total	90 x 60 x 12 50 x 45 x 30
126	0.63	0.61	Not Recorded		0.41	0.02	Fragments and rebar Rebar misplaced	frag 5400 Lost	260 x 130 x 35 Lost
127	0.95						NOT RECOVERED		
128	0.86	0.43	NA	NA	0.29	0.43	Fragment	3480	220 x 120 x 25
129	0.69						Large piece of tin	Not recovered	
130	0.36	0.3	NA	NA	0.34	0.06	Fragment	1400	310 x 80 x 10
131	0.72	0.6	NA	NA	0.29	0.12	Fragments	Not Recorded	Not Recorded
132	0.72						Small fragments were recovered near the surface. Schondstat indicated a deeper target. NOT Recovered		
133	0.53	0.45	NA	NA	0.51	0.08	Projectile fragment	4800	300 x 110 x 35
134	0.97	0.31	15 NU	SSW	0.24	0.66	5-inch projectile fired, unfuzed	Not weighed	510 x 127 dia
135	0.39	0.31	NA	NA	0.77	0.08	Steel Plate Ring	7900 700	480 x 240 x 25 100 dia
136	0.07	0.1	NA	NA	0.78	-0.03	Pipe & Ring	8340	Not Recorded
137	0.24	NA	NA	NA	0.30		Deep target	Not recovered	
138	0.10	0.21	0	E	0.31	-0.11	Rebar in concrete	Not Recorded	2 ea 32 dia. x 305
139	0.88	0.76	NA	NA	0.53	0.12	Fragments (low order detonation.)	15160 3450 6290 3070	550 x 250 x 25 360 x 120 x 15 240 x 160 x 20 340 x 90 x 25
140	0.55	0.46	5 ND	N	0.90	0.09	155-mm projectile, fired, unfuzed	Not weighed	625 x 155 dia
141	0.30	0	0	NE	0.02	0.30	175-mm projectile, unfuzed, fired	Not weighed	900 x 175 dia
142	0.89	0.91	NA	NA	0.73	-0.02	Projectile fragments	6350 total	360 x 120 x 30 (largest)
143	0.76	0.46	Not Recorded		0.03	0.30	Cylinder	3060	190 x 100 dia
144	0.79	0.61	NA	NA	0.68	0.18	Fragments WP projectile	Not weighed	Not Recorded
145	0.59	0.31	NA	NA	0.61	0.28	Steel fragment	1420	180 x 80 x 40
146	0.50	0.5	15 ND	SE	0.14	0.00	90-mm projectile, fuzed, fired	Not weighed	
147	0.14	0.2	5 ND	NE	0.48	-0.06	155-proj	Not weighed	
148	0.23	0.35	90 ND	Lost	0.38	-0.12	5-inch projectile, unfuzed, fired	Not weighed	550 x 125 dia
149	0.74	Off shore in water, not recovered							
150	0.97	0.3	NA	NA	0.44	0.67	Scrap metal	1250	590 x 60 x 7
150a	0.97	0.3	NA	NA	0.75	0.67	Fragment	1830	240 x 90 x 30
151	0.81	0.76	30 ND	NE	0.49	0.05	Rocket, unfuzed, fired Disk	9900 2200	390 x 105 dia 140(dia) x 50
152	0.44	0.36	NA	NA	0.55	0.08	Fragment	4600	220 x 160 x 5
153	0.36	0.12	NA	NA	0.21	0.24	Fragment	1000	270 x 150 x 8
154	0.87	0.61	45 D	NE	0.56	0.26	Thin walled cylinder	1830	300 x 100 dia x 7
155	0.92	0.1	NA	NA	0.95	0.82	Fragments	3800 400	270 x 110 x 20 130 x 50 x 30
156	0.70	0.62	0	SW	0.17	0.08	175-mm Projectile, fuzed, fired	Not weighed	990 x 175 dia
157	0.98	0.46	NU 15	ENE	0.33	0.52	155-mm projectile, unfuzed, fired	Not weighed	711 x 155 dia
157a	0.98	0.31	NU 15	ENE	0.62	0.67	155-mm projectile, unfuzed, fired	Not weighed	609 x 155 dia
158	0.72						NOT RECOVERED		
159	0.86	0.61	45	SE	0.61	0.25	Railroad spike	1300	360 x 30 x 30
160	0.62	0.46	10 NU	SW	0.47	0.16	155-mm projectile, fuzed, fired	Not weighed	625 x 155 dia
161	0.14	0.1	NA	NA	0.86	0.04	Fragment	4220 total	390 x 80 x 25

Dig List		Recovery Information			Δ (Dig vs Recovery)		Recovered Item(s)		
ATC Dig #	Depth (m)	Depth (m)	Dip (°)	Azimuth	Distance (m)	Depth (m)	Description	Weight (gms)	Dimensions (mm)
							Fragment Rotating band		110 x 80 x 5 105 x 65 x 5
162	0.12	0.33	10 NU	Lost	0.51	-0.21	8-inch projectile	~ 90900	813 x 203 dia
163	0.53	0.46	NA	NA	0.47	0.07	Small frags	325 total	110 x 50 x 20 50 x 20 x 20
164	0.47	0.46	50 NU	NE	0.25	0.01	90-mm projectile, fuzed, fired	Not weighed	382 x 90 dia
165	0.61	0	0	N	0.08	0.61	Fused 155-mm projectile	Not weighed	720 x 155 dia
166	0.78	0.2	NA	NA	0.99	0.58	Bomb fragments	9200	730 x 220 x 7
166a	0.78	Lost	NA	NA	0.77		Banding	Lost	Lost
167	0.15	Off shore in water, not recovered							
168	0.58	0.61	NA	NA	0.46	-0.03	Fragments (3)	Lost	Lost
169	0.56	Not recovered	NA	NA	0.46	0.00	25-mm cable, length unknown	Not recovered	Not recovered
170	0.57	0.15	NA	NA	0.47	0.42	Fragments	2950 total	320 x 80 x 35 150 x 55 x 20 65 x 35 x 10 155 x 30 x 8
171	0.72	0.61	NA	NA	0.81	0.11	Baseplates	3210 total	125 dia x 30 125 dia x 4
172	0.65	Off shore in water, not recovered							
173	0.77	Off shore in water, not recovered							
174	0.21	0.46	45 NU	S	0.12	-0.25	155-mm projectile. frag	17800	540 x 250 x 17
175	0.67	0.38			0.43	0.29	Bomb plug	1060	33 x 85 dia
176	0.43	0.85	5 NU	S	0.56	-0.42	75-mm projectile, fuzed, fired		360 x 75 dia
177	0.70	0.3	NA	NA	0.23	0.40	Fragment	560	80 x 60 x 40
178	0.36				0.12	0.36	Fragments from 90-mm projectile	6000 4100	330 x 120 x 80 300 x 110 x 30
179	0.59	0.2	NA	NA	0.36	0.39	Fragment		150 x 150 x 120
180	0.76						Deep target	Not recovered	
181	0.45	0.35	NA	NA	1.28	0.10	Fragment	725 total	100 x 80 x 20 60 x 40 x 12
182	0.08	0.99	90	NA	0.65	-0.91	Steel plate	13110	580 x 180 x 60
183	0.93	0.1	NA	NA	0.80	0.83	Fragment	1600	250 x 90 x 20
184	0.49	0.23	NA	NA	0.52	0.26	Fragment	900	130 x 80 x 15
185	-0.20	0.27	NA	NA	0.58	-0.47	Fragment	660	100 x 50 x 32
186	0.33	0.37	NA	NA	0.58	-0.04	Fragment	2200	320 x 80 x 20
187	0.53	0.25	NA	NA	0.22	0.28	Fragments	4620 total	260 x 100 x 60 170 x 70 x 15
188	0.46	0.24	NA	NA	0.18	0.22	Fragment	1100	100 x 70 x 30
189	0.96	0.31	NA	NA	0.76	0.65	Fragment	2150	320 x 90 x 20
190	0.36	0.24	Lost	Lost	0.57	0.12	105mm projectile, fired, fuzed	Not weighed	600 x 105 dia
191	0.42	0.31	NA	NA	0.86	0.11	Unknown	1960	150 x 220 x 10
192	0.00	0	5 ND	WSW	0.57	0.00	155-mm projectile, fuzed, fired	Not weighed	711 x 155 dia
193	0.47	Lost	NA	NA	0.45	Lost	155-mm base	11300	240 x 155 dia
194	0.32	0.35	NA	NA	0.19	-0.03	Fuze Fragments	1600 3200	120 x 90 (max dia) 190 x 100 x 70
195	0.48	Off shore in water, not recovered							
196	0.78	Off shore in water, not recovered							
197	0.73	1.2	NU 75	N	0.62	-0.47	155-mm projectile fuzed, fired	Not weighed	660 x 155 dia
198	0.14	0.46	NA	NA	0.70	-0.32	Fragments	4150 3800 600	300 x 120 x 30 290 x 150 x 20 90 x 60 x 25
199	0.34	0.31	NA	NA	0.51	0.03	Fragments	9760	270 x 130 x 70 140 x 90 x 25
200	0.65	0.61	NA	NA	0.62	0.04	Fragments	800 total	180 x 35 x 8 120 x 40 x 15 190 x 35 x 10
201	-0.47	0.46	90 NU		0.57	-0.93	1/2 casing 280-mm		680 x 280 dia

Dig List		Recovery Information			Δ (Dig vs Recovery)		Recovered Item(s)		
ATC Dig #	Depth (m)	Depth (m)	Dip (°)	Azimuth	Distance (m)	Depth (m)	Description	Weight (gms)	Dimensions (mm)
202	0.73	0.61	15 ND	SW	0.40	0.12	90-mm projectile	7400	270 x 90 dia
203	0.94	0.46	NA	NA	0.71	0.48	155-mm projectile base		240 x 155 dia
204	0.13	0.2	ND 15	S	0.24	-0.07	90-mm projectile casing, unfuzed	Not weighed	270 x 90 dia
205	0.34	0.46	NU 85	SW	0.67	-0.12	Low-order 90 or 105 mm projectile	11300	320 x 180 x 20
206	-0.23	Off shore in water, not recovered							
207	0.27	0.13	60 NU	E	0.19	0.14	105-mm fragment	4980	370 x 120 x 25
208	0.51	0.46	NA	NA	1.19	0.05	Fragment	2710	210 x 110 x 25
209	0.02	1	80 ND	ENE	0.44	-0.98	155-mm projectile fuzed, fired	Not weighed	660 x 155 dia
210	0.47	Off shore in water, not recovered							
211	0.34						Deep target	Not recovered	
212	0.49						NOT RECOVERED		
213	0.19	0.23	NA	NA	0.67	-0.04	Fragment	3220	30 x 155 dia
214	0.07	0.15	NA	NA	0.44	-0.08	Fragment	2600	210 x 120 x 35
215	0.50	Off shore in water, not recovered							
216	0.45	0.61	45 ND	NE		-0.16	155-mm projectile, fuzed, fired	Not weighed	390 x 155 dia
217	0.09	Off shore in water, not recovered							
218	-0.74	0.31	15 ND	SW	0.65	-1.05	165-mm projectile, fired, unfuzed	Not weighed	550 x 165 dia

6.1.3 The Dewatering Ponds Seed Targets

A total of 47 seed targets were emplaced in the five dewatering ponds, including 81-mm mortars and 105-mm and 155-mm projectiles. The edges of the ponds, particularly of the large pond, were heavily contaminated with large ferrous clutter items. The banks of the large pond were about 2 m above the water level, making it hard to survey at low altitude near the shoreline. The ponds were reported to be about 2 m deep. This has not been verified. Table 10, derived from the IDA report, shows the detection efficiency for the *MTADS* survey. The *MTADS* report contained 224 targets. It was noted in the NRL submission that about one half of the reported targets were outside the shorelines of the ponds or were much too large to be 155-mm projectiles. These targets were reported in case APG wishes to investigate them sometime in the future.

Table 10. *MTADS* Seed Target Detection Probability at the Dewatering Ponds by Classification Category

UXO Likeliness	Cumulative PD (1.0m radius)	Cumulative PD (1.5m radius)
1	19.15%	19.15%
2	25.53%	29.79%
3	27.66%	31.91%
4	27.66%	31.91%
5	27.66%	31.91%
6	27.66%	31.91%

The ground truth for the seed targets that were placed in the ponds is provided in Table 11. On the right in the table the *MTADS* assignments are given for those targets that were detected. The center column in the table provides analyst's comments resulting from re-imaging the targets in the ground truth list.

Table 11. Ground truth for the targets emplaced in the dewatering ponds.

Ground Truth						MTADS Assignment					
Location	**Target Number**	**Serial No.**	**Azi**	**Depth (m)**	**Rationalize Ground Truth With Survey Data**	**MTADS Target ID**	**HAE (m)**	**Depth DEM (m)**	**Size (m)**	**Fit Quality**	**Analyst Comments**
Large Pond	P-81MM 1	172	0	1.8	targ 114 is 1.5m east, overlaid with too many high passes						
	P-81MM 2	131	90	1.4	not picked, 3nT signal, lost in noise						
	P-81MM 3	127	45	1.4	no signal						
	P-81MM 4	170	0	1.8	lost to signal from huge targ 78						
	P-81MM 5	129	45	2.3	not picked, 4nT signal in 3nT noise						
	P-81MM 6	100	45	1.8	no signal						
	P-81MM 7	174	90	0.9	no signal						
	P-81MM 8	133	90	1.4	no signal						
	P-81MM 9	132	0	0.9	signal lost to targ 14 & 15						
	P-81MM 10	20	0	2.0	no signal						
	P-81MM 11	139	90	1.5	no signal						
	P-81MM 12	173	0	1.5	no signal						
	P-105MM 1	195	0	1.8	lost under target 115						
	P-105MM 2	178	90	0.9	target 247	247	7.01	1.45	0.096	0.73	105mm
	P-105MM 3	210	45	1.8	target in missed area						
	P-105MM 4	200	0	2.3	no signal						
	P-105MM 5	189	0	1.8	no signal						
	P-105MM 6	207	45	1.8	no signal						
	P-105MM 7	162	45	2.1	no signal						
	P-105MM 8	197	0	0.9	target 246						
	P-105MM 9	161	45	1.4	target 243, 2 m South because it was 2 targets	243	4.80	3.53	0.147	0.49	155mm
	P-105MM 10	145	45	0.6	target 241	241	7.77	0.59	0.091	0.62	105mm
	P-105MM 11	186	90	0.6	target 242	242	7.42	0.95	0.085	0.69	105mm
	P-105MM 12	172	90	1.2	I think targ 245 moved by 1.5 m	245	4.05	4.28	0.189	0.59	medium target, deep
	P-105MM 13	138	0	2.4	no signal						
	P-105MM 14	159	90	2.4	lost in huge negative anomaly						
	P-105MM 15	174	0	1.8	lost in noise						
	P-105MM 16	179	45	1.8							
	P-105MM 17	221	45	2.0	lost in noise						
	P-105MM 18	134	90	2.1	lost in noise						
	P-155MM 1	111	0	1.7	target 79, likely moved ~ 1m	79	6.44	1.89	0.122	0.70	155mm at 6 ft
	P-155MM 2	104	45	1.8	no signal, target moved?						
	P-155MM 3	105	90	0.9	target 14	14	6.62	1.75	0.142	0.67	155mm, with deep target below
	P-155MM 4	Lost	90	2.4	lost in target 78 signal						
Small Ponds	FP-81MM 1	169	45	0.5	surrounded by 203, 204, 205, not picked						
	FP-81MM 2	123	45	0.3	not picked, 4nT signal in 2nT noise						
	FP-81MM 3	136	90	0.5	lost under target 164						
	FP-81MM 4	180	0	0.2	lost under target 154, 155						
	FP-105MM 1	141	0	0.3	target 191, too big for 105mm ?	191	-1.39	1.79	0.172	0.72	difficult fit, 155mm
	FP-105MM 2	147	0	0.3	target 189, my coordinate may be wrong in table	189					part signature, wont fit
	FP-105MM 3	140	90	0.8	target 187	187	0.04	0.19	0.088	0.89	105mm/2.75in
	FP-105MM 4	198	45	0.3	target 202	202	0.10	0.17	0.102	0.83	105mm
	FP-105MM 5	193	45	0.3	target 166	166	0.03	0.35	0.113	0.93	105/155mm
	FP-105MM 6	171	0	0.3	target 168, shadowed by 167	167	-0.85	1.21	0.236	0.88	large deep taqrget
	FP-105MM 7	177	90	0.3	target 152	152	0.90	0.00	0.044	0.70	shallow target, 60/81mm
	FP-105MM 8	185	90	0.3	target 153	153	0.25	0.38	0.072	0.73	shallow, 81mm
	FP-155MM 1	106	45	0.6	target 186	186	-1.33	1.64	0.287	0.86	large target at 6 ft
	FP-155MM 2	109	0	0.6	target 164	164	-0.09	0.41	0.183	0.96	large shallow target, 155mm

The 81-mm mortars are uniformly undetectable. All of the 105-mm and 155-mm projectiles were detected in the small ponds; only a fraction were detectable in the large pond. Of the unreported targets in the large pond, most were missed because their signals were too small. One target (FP-105MM 2) was missed because it had the easting coordinate recorded incorrectly in the target report. A few of the targets were missed because their signals were buried by the very large signal returns from the edges of the large pond. In addition, it is possible that a few of the targets may have had their coordinates recorded incorrectly or that they were inadvertently moved. This is postulated because, in a few cases, appropriate signals were observed in somewhat displaced positions from the reported coordinates (e.g., P-105MM 12, P-155MM 1, P-155MM 2).

The helicopter altitude above the large and small ponds was very similar. It is likely that the majority of the targets were missed in the large pond because the water was deeper than in the smaller ponds.

7. Cost Assessment

7.1 Cost Reporting

There are several issues associated with the APG Airborne *MTADS* Demonstration that skew the compilation of information that would allow evaluation of typical operational costs for the Airborne *MTADS*. All preparatory site work was done by APG, including the definition of the survey areas, placement of targets, establishing GPS control points, and writing a detailed Test Plan that could be cribbed into the NRL Demo Test Plan. These costs are not reflected in the NRL demonstration.

Additionally, the demonstration site was close to the NRL home base and the helicopter charter FBO site. Helicopter ferry costs to the site, daily ferry costs, and refueling costs were minimal because of the short distances involved and the availability of fuel with free delivery to the helicopter when he landed on site. NRL people and contractors working on site during the demonstration returned home each night. There were minimal travel and no per diem costs associated with this demonstration. It was unnecessary to establish any logistics support on site. Data analysis took place post survey, and offices were provided on site at APG to support ground personnel during the demonstration to conduct data QC and preprocessing. This set of circumstances is unlikely to ever occur again in an airborne UXO survey.

The Airborne *MTADS* was designed as a wide area coverage survey system. The intent of the developers was to create a system that could be used to economically survey large areas to locate and isolate areas of UXO concern and to obtain target-specific information where target size allowed. The survey areas at this demonstration are the antithesis of the intent of the system designers. They are all small (the largest is only slightly over 100 acres); the longest survey lines (with the exception of the Chesapeake Bay survey) are about 500 meters and the average survey lane flown is probably half this.

The majority of the seed targets planted on the survey areas are at or below the designed detection limit of the airborne *MTADS*. Effectively all the objectives established by the demonstration designers are predicated with the goal of evaluating and grading the performance of the airborne systems to detect targets smaller than the system was intended to detect. It is only the unique characteristics of the airfield site that allowed these targets to be detected effectively on this specific site. The survey at the Active Recovery Field proved that it is not practical to detect from the air needles scattered in a junkyard. The average target size in this relatively saturated range is many times larger than the seed targets that were distributed about the area. The signature footprints of these very large targets overwhelmed the much smaller point source signals from the inert seed items. This survey once again confirmed that all UXO site characterization geophysics should begin with a comprehensive surface clearance.

The survey at the Mine, Grenade, and Direct-Fire Weapons Range was an interesting exercise and a well-conducted survey. Its value is completely compromised, however, by the fact that the results of the survey will not be validated by any recovery operations. The same is true (from the perspective of the performers) at the Chesapeake Bay Impact Area. The cost of analyzing targets on the Active Recovery Field, the Mine, Grenade, and Direct-Fire Weapons Range, and the Chesapeake Bay Impact Area surveys (nearly 7,000 targets) consumed the majority of the dollars devoted to the demonstration. It is debatable what was learned from these surveys that justifies this level of expenditure for target analysis.

On the positive side, these studies demonstrated that the Airborne *MTADS* can be effectively used to conduct UXO geophysics studies in wetlands, in shallow fresh water ponds, and in shallow water marine environments. It also demonstrated that, under near perfect survey conditions, the Airborne *MTADS* can efficiently detect targets as small as 81-mm mortars.

Production cost and performance data can be much better evaluated from other demonstrations, including the 2001 survey at the BBR[8], the 2002 revisit and survey at the BBR[16] and the airborne survey of Bombing Target S-1 on the Isleta Reservation.[17] These surveys average more than 1000 acres each, are at sites more typical of wide area UXO ranges, and have typically challenging logistics and ferry requirements. Very good cost data are available from each of these studies and will play an important part in developing the Cost and Performance Report.

7.2 Cost Tracking

Costs associated with this demonstration are documented in Table 12 below.

7.3 Cost Analysis

The actual survey area covered (after editing the data to near the specified site boundaries including a minor buffer) is ~330 acres. The actual flying hours used to create these survey files was 8.6. If we include the local and home base ferry times, the total helicopter flight hours were ~12.6. Survey production rates were then 38.4 acres/hour or 26.2 acres/hour based upon survey hours or helicopter charter hours. Mobilization, demobilization, calibration and training efforts are not included in this estimate. From Table 12 our survey costs (including Capital costs, and operating costs) including data processing, analysis, and reporting) are ~$181K or ~$550/acre. These costs do not include mobilization or demobilization costs, but do include some software development costs and some equipment repair costs. The production costs are dominated by target analysis costs, primarily at the Active Recovery Field and on the Mine, Grenade, and Direct-Fire Weapons Range. Included in these costs, but not specifically called out, are costs associated with developing and applying a new data processing strategy, the requested reanalysis of the Airfield data, and preparation of new interim report documents. These costs were ~$15K. Finally, an important component of the production costs on these projects is the preparation, approval, printing, and distribution costs associated with this report. Many of the specific costs cited above would not be typical of Airborne UXO survey production costs if the survey, analysis, and target tables were the primary deliverables.

Table 12. Airborne *MTADS* Survey Costs at APG

COST CATEGORY	Sub Category	Costs ($K)
START-UP COSTS	Site Characterization	0
	Mobilization/Setup Equipment Transport, Assembly, Helo Rental	5
	Demo Test Plan	6
CAPITAL COSTS	Capital Equipment	Not Costed
	Other Equipment (acoustic altimeters/mods)	18
	Modifications (Software)	20
	Repairs	15 (pass-through from other demos)
OPERATING COSTS	Equipment Lease/Rental	2
	Supervision	4
	Labor (during survey)	10
	Helo (post install)	18
	Travel	3
	Maintenance	2
	Consumables (fuel)	1
	Data Processing	3
	Data Analysis	40 (2 min/target)
	PAAF Reprocessing and Reanalysis	10
	Interim Reports	5
	Demonstration Report	25
DEMOBILIZATION	Dismantle	2
	Packout	2
	Transport	2
	Inventory Restock	2
Total Demonstration, Analysis, & Reporting		195

7.4 Cost Comparison

The objective for this section is to compare the demonstrated system's cost with the baseline alternative technologies. There are no directly comparable system technologies that are appropriate for direct comparison. There are no viable technologies for conducting wetlands or marine UXO surveys. The abilities of the airborne UXO search technology are unique at this point. Other technologies that could be contrasted for the dry land components of this demonstration include "Mag and Flag," variants of the GPS-based man-portable survey systems, and the vehicular towed arrays. These technologies are not really head-to-head competitive. Each is most appropriately used under specific site conditions, and with specific survey goals.

In general "Mag and Flag" production costs on small to intermediate surveys are generally costed at $1,000-3,000/acre depending upon the difficulty of the site conditions. The 'Mag and Flag" typically does not produce a digitally-mapped survey product. A version of a digitized product, using local coordinates and flag position estimates based upon the survey grid can be generated. It requires an additional person on site, and probably adds ~50% to the "Mag and Flag" survey cost.

A man-portable UXO survey using technologies similar to the *MTADS* systems, or the commercial variants would be costed at similar levels of $1,000-3000/acre. These data would be fully digital mapped data files; images, and target tables would be a standard output product.

Vehicular towed arrays used for UXO surveys are typically bid at $400-800/acre by commercial vendors. These rates include capital costs, depreciation, and repair allowances, but typically bring relatively low-cost and inexperienced personnel to the field. Mobilization/demobilization costs and local site logistics costs are not included in these figures. The rates depend upon the size of the survey, the site conditions, the density of targets that must be analyzed, and the complexity of the report product. These costs assume a dig list with global target coordinates as the only deliverable.

There are no commercial vendors bidding airborne UXO geophysics services. We estimate, based upon our production rates and costs, that ultimately the production costs for airborne UXO search services will likely range from $100-200/acre depending upon the site size and conditions. The airborne systems are appropriate for wide area searches (>500 acres, i.e. one survey day). Many sites will not be able to be completely characterized using the airborne system, however, if 100% coverage is required. Most sites will require some fill-in work by ground-based systems.

7.5 Implementation Issues

The end user of the Airborne *MTADS* technology is most likely to be one or more of the large A&E firms that do substantial amounts of UXO geophysics work. With some consulting cooperation with the original developers, the Airborne *MTADS* could be straightforwardly replicated for commercial applications. There have been serious inquiries from some groups about potential consulting help in establishing a commercial capability. The impediments are the substantial capital costs involved in putting a commercial system together, and uncertainties about the government establishing suitable venues for its use. If an RFP were to hit the street for a Wide Area UXO search (involving several thousand acres) it is likely that there would be multiple responders proposing to bring in airborne geophysics (similar to the Airborne *MTADS*) as a solution. It is our estimation that a large firm would want to see 25,000-50,000 acres in airborne UXO survey business as an incentive that would make it likely that they would be able to recover their investment costs.

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