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QUANTIFICATION OF UXO VARIABILITY FOR TARGET DISCRIMINATION

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SAIC Incorporated
1225 S. Clark St., Suite 800
Arlington, VA 22202

PRINCIPAL INVESTIGATOR
Jonathan Miller

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List of Acronyms

CV	Coefficient of Variation = (Standard Deviation / Mean)
DoD	Department of Defense
EM63	Geonics EM63 sensor
EMI	Electromagnetic Induction
EOD	Explosive Ordnance Disposal
FD	Frequency Domain
FFT	Fast Fourier Transform
GEM3	Geophex GEM3 sensor
IDL	Interactive Data Language by RSI (Research Systems Inc.)
MATLAB	Computing Language by MathWorks Inc.
MSE	Mean Squared Error
MTADS	Multi Sensor Towed Array Detection System
NRL	Navy Research Lab
ORDATA	Online UXO database at: http://maic.jmu.edu/ordata/Mission.asp
PDF	Probability Density Function
ROC	Receiver Operating Characteristic
SERDP	Strategic Environmental Research and Development Program
TD	Time Domain
UXO	Unexploded Ordnance

Executive Summary

Real UXO are often dented, bent, broken, or otherwise damaged. This produces variability in their EMI response and complicates the problem of UXO/clutter discrimination. The degree of consistency from one item to the next within a given class or sub-class of UXO is related to the peak theoretical performance of any discrimination scheme used to classify targets, and this represents a fundamental limit to the performance of all discrimination schemes. This project was aimed at quantifying the variability of real UXO and translating results into useful terms.

PROJECT APPROACH

We collected EMI data on 664 real UXO items from four DoD sites using two state-of-the-art sensors: GEM-3 (frequency-domain), and EM-63 (time-domain). For each UXO type we aimed to collect samples of sufficient size so that variability in the population could be quantified with reasonable accuracy. From 10 to 30 items was usually sufficient, as determined through Jackknife and Bootstrap re-sampling. Analysis was done by fitting each target individually using a joint time-domain - frequency-domain (TD-FD) model, and four physical parameters were derived from the fits: 1) magnitude A, 2) fundamental decay constant τ_f, 3) magnetic crossover time τ_{mag}, and 4) static dipole strength S. Mean and variance of these parameters were found for each UXO class, and all data was grouped and summarized for each class.

DATA COLLECTION

We took all practical steps to minimize measurement errors. These included careful alignment and positioning of the target on the test stand, running the sensor at close range to improve signal-to-noise ratio (SNR), frequent background shots, and calibration measurements at the beginning and end of every data file to check for sensor drift. Some error was inevitably introduced, notably in larger targets (4inch caliber and up) where differences in the spatial patterns of the primary fields of the two sensors produce complex effects which are especially marked at closer ranges. This leads to and inevitable trade off between SNR and signal distortion due to primary field taper, but we found this trade-off difficult to quantify in practice because the EM63 suffers a separate un-related distortion apparently due to non linear gain, documented in Appendix A. Field-taper effects are not known a-priori, and they vary from one target to the next, complicating assessment of the SNR / field-taper trade off. In retrospect, with the data analysis complete, we believe the sub-4inch caliber targets are well-characterized, but we could have

done better on the larger targets by measuring them at longer range, which would have reduced field-taper problems, at the expense of SNR.

CHECKING CONSISTENCY

We checked the consistency of our procedure by comparing recovered parameters from repeated shots on the same item taken on different days with different personnel running the test stand. This revealed a median coefficient of variation (CV) of 1.97% across all parameters and all target orientations. Measurement of response magnitude *A* had the best consistency with median CV of 1.40% across all orientations, and measurement of late-time fundamental decay time constant τ_f had the worst, with median CV of 4.00%. These values may be regarded as the inherent error level in our parameter estimation process.

EM63 CORRECTION

Comparison of analytic solutions to measurements on five metal spheres revealed complicated distortions in the EM-63 output, especially at low signal strengths. This motivated development of an empirical correction routine described in appendix A. The correction worked well on low and mid-range signal amplitudes, but produced undesired artifacts on strong signals, which were not seriously distorted in the first place. We therefore applied the correction to all targets and orientations except axial excitation of large, bulky targets where signal amplitudes were very high.

DATA VALIDATION

For virtually all small targets, we found good agreement between observed TD and FD signals. For large targets, (4 inch caliber and up), agreement was not as good, due, we believe, to the interaction of the larger target bodies with different spatial patterns of the primary fields emanating from the GEM3 and EM63 sensors. For a limited number of targets (5 items at Blossom Point), we also measured static dipole strength using the NRL MTADS magnetometer array. Magnetic remnance was evident in all 5 of these targets, and our attempts to remove it by averaging nose-up and nose-down results were only partially successful, due, we suspect, to the fact that magnetic remnance was not necessarily aligned with the principal axis. One of these targets had low remnance, and it exhibited particularly good agreement between the observed static moment and the low-frequency asymptote of the TD-FD model fit. These indicators suggest our procedures produced valid data.

MODEL REPRESENTATION

Physical parameters were derived by fitting a general TD-FD response model. This model consists of a linear combination of fundamental modes with time constants bounded between 1e-7 and 1e-1 (s). Each mode contributes a known response in both TD and FD, forming basis functions which may be weighted and summed so as to best-match observed TD & FD data simultaneously. The weights are found using least-squares minimization, under the constraint that negative weights are not allowed. This model guarantees physically realistic extrapolation beyond the measured range, and is flexible enough to produce good fits in the vast majority of cases.

EXPRESSING UXO VARIABILITY

Variability is expressed within each UXO class in terms of mean and variance of the four physical parameters mentioned above: 1) response magnitude *A* (liters), which relates to target size, 2) late-time fundamental decay time constant τ_f (s) which relates to conductivity and maximum diameter, 3) magnetic cross-over time τ_{mag} (s), which relates to quadrature peak, and 4) the static-field asymptote *S* (liters) which relates to target permeability and demagnetization factor.

SAMPLE SIZE

Observed mean and variance in our samples represent only estimators of the true mean and variance of the underlying distributions from which the samples were drawn. Confidence intervals (error bars) around our estimates were calculated using Jackknife and Bootstrap re-sampling plans. These error bars shrink with increasing sample size *n*, and our working goal was that the error bars should be less than one third (33%) of the estimate value. We aimed to collect enough UXO items in each category to satisfy this condition, usually 10 to 30 sufficed depending on the type, but availability was a problem in some cases.

RESULTS

Out of the 664 targets measured, 596 were assigned into groups for calculation of ensemble statistics. The remaining 68 targets were not included because they were "singletons" i.e. types for which only one example was found, or because equipment problems resulted in bad / missing data. Group membership was established by careful comparison of JPEG images of each target against images from the ORDATA online UXO database (http://maic.jmu.edu/ordata/Mission.asp). Positive identification was possible in the majority of cases. A total of 93 groups were analyzed, and results for each are found in Appendix D, including mean and standard deviation estimates with confidence intervals, and a quartile box-plot for each parameter and each orientation within each UXO group. On these summary sheets, confidence intervals above the desired value of 0.33 are printed in red. Fit summaries for each individual UXO are too numerous to be included as hard copy, so these are available in appendix E, which is a CD ROM disk. The disk also includes electronic versions of this report with all appendixes, jpeg images of all targets, and the entire raw data set in ascii format.

DISCUSSION

Variability is evident in all 93 groups. For certain UXO classes, physical parameters vary by a factor of 2 or more within the class, while for others, the range is much narrower. Across all targets, the fundamental time constant τ_f, appears to have wider variability than the other parameters, and the static field dipole strength "S" shows a high CV for aluminum targets, as expected since the true value must be zero for impermeable objects. Differences in fuze and tail fin configurations generally produced marked effects, except for targets with large ferrous bodies that dominate the signal. Presence of an intact rotating band on rifle-fired projectiles also produced marked effects including a general increase in the magnitude of axial responses (both nose-up and nose-down) and an increased discrepancy between nose-up and nose-down recovered parameters. In the theoretical case of spatially uniform excitation, nose-up and nose-down parameters should be nearly identical, but in the real-world case of non-uniform excitation, the

rotating band dominates nose-down orientation since the band is typically located toward the rear of the projectile. In effect, this contributes additional "variability" in target response due to target orientation.

1. Project Objective

This project was aimed at quantifying UXO variability by measuring a large number of real UXO and expressing variability in physically meaningful terms. Similar to navigation errors, modeling errors, and sensor noise, inherent UXO variability degrades discrimination performance, but unlike these other sources of error, it cannot be reduced through better engineering or better processing tools. The overall objective of this project is to promote improvement of discrimination algorithms by quantifying the inherent variability of UXO themselves. This information is useful for transitioning research results, which are often obtained under controlled test environments utilizing small numbers of representative samples, to complex and diverse real world settings.

2. Background

This project addresses the issue of discrimination of buried unexploded ordnance (UXO) from clutter in the context of environmental cleanup. In spite of the recent advances in UXO detection performance, false alarms due to clutter remain a serious problem. With traditional survey methods, the Army Corps of Engineers finds that 85-95% of all detected targets are not UXO. Since the cost of identifying and disposing of UXO in the United States using current technologies is estimated in the hundreds of billions of dollars, increases in performance efficiency due to reduced false alarm rates can result in substantial cost savings.

Successful discrimination between UXO and clutter depends on the existence of characteristic attributes associated with UXO that are consistent across all examples of an ordnance type and that distinguish them from clutter. However, real UXO are often dented, bent, broken, rusted-out, or otherwise damaged, causing variability in their EMI response and complicating the job of UXO/clutter discrimination. Although this variability may have an important impact on discrimination performance, it is generally not well understood, and has not been investigated systematically prior to this project.

Our efforts were leveraged by a previous SERDP project, UX-1121, which gave us experience developing models and parameter estimation procedures for EMI signals, as well as practical experience in test stand measurements and a substantial data set to work with. During this previous project, we discovered that physical deformations and alterations within a single UXO type can appreciably change its EMI response. As part of the final phase of UX-1121, we quantified variability for selected 60mm and 81mm UXO [1]; however, all of the 60mm and 81mm were excavated from a single site (Jefferson Proving Ground), and we only collected frequency-domain data. This current project expanded on that work by taking both time-domain and frequency-domain measurements, and including many more UXO items from four sites: Former Fort Ord CA, Fort McClellan, AL, Blossom Point MD, and Jefferson Proving Ground, IN.

2.1 Deriving Target Parameters from EMI Survey Data

The central idea behind EMI signal analysis is to process survey data so as to derive target parameters that are invariant with burial depth and target orientation. To the extent that these derived parameters reveal characteristic attributes of UXO that distinguish them from clutter, target discrimination may be performed. Data analysis can be approached as an inversion problem in which models that relate target attributes to observed signals are used. Such models can be derived analytically only in a few cases, e.g., the sphere [2], cylinder of infinite length oriented transverse to the primary field [3], and multiple conducting loops [3]. Numerical models can provide useful results for a variety of additional target types (e.g., bodies of revolution [4], and targets of arbitrary shape [5]), but are often not suitable for routine use due to long computation times.

Common to all these approaches is the concept of an induced dipole moment and corresponding magnetic polarizability tensor [6, 7, 8]. The dipole moment **m** induced in an object is a linear function of the primary field **H**. For a harmonic field oscillating at frequency **w**, the component of **m** are related to the components of **H** by

$$m_j = V\alpha_{jk} H_k \tag{1}$$

where the dimensionless coefficients $\mathbf{a}_{jk}(\mathbf{w})$ depend on the shape of the object, its material properties, and its orientation in the primary field, but not on its volume V. The coefficients are complex valued, reflecting the fact that there is a frequency dependent phase shift between the primary field and the induced or secondary field. The tensor $V\mathbf{a}_{jk}$ is called the magnetic polarizability tensor. For a pulsed induction sensor, the induced moment is a decaying function of time after the primary field cuts off. It is given by the convolution of the Fourier transform of $V\mathbf{a}_{jk}(\mathbf{w})$ with the primary field waveform

$$m_j(t) = V\int \hat{\alpha}_{jk}(t-u) H_k(u)\, du \tag{2}$$

where

$$\hat{\alpha}(t) = \int \alpha(\omega)\exp(-i\omega t)\, d\omega\,. \tag{3}$$

The EMI signal is then proportional to the rate of change of the flux through the receive coils due to the induced dipole moment, i.e., **∑m/∑**t.

For general sensor/target geometries, the EMI response is determined by calculating the primary field vector at the target location, calculating the induced dipole moment from (1) and (2) as appropriate, and then calculating the induced flux through the receive coil due to the induced dipole. For economy of notation, we can lump these manipulations into a Transmit/Receive matrix **TR** so that the output signal S(t) can be expressed as

$$S(t) = \frac{\partial}{\partial t}\mathrm{Tr}\{\mathrm{TR}\cdot\mathrm{B}(t)\}\,. \tag{4}$$

The trace operator Tr{} is the sum of the diagonal elements within the brackets. **B** represents the magnetic polarizability tensor. For a frequency domain sensor it is

$$\mathrm{B(t)} = V\begin{bmatrix} \alpha_{11}(\omega) & \alpha_{12}(\omega) & \alpha_{13}(\omega) \\ \alpha_{21}(\omega) & \alpha_{22}(\omega) & \alpha_{23}(\omega) \\ \alpha_{31}(\omega) & \alpha_{32}(\omega) & \alpha_{33}(\omega) \end{bmatrix}\exp(i\omega t)\,. \tag{5}$$

For a time domain sensor

$$\mathrm{B(t)} = V\begin{bmatrix} b_{11}(t) & b_{12}(t) & b_{13}(t) \\ b_{21}(t) & b_{22}(t) & b_{23}(t) \\ b_{31}(t) & b_{32}(t) & b_{33}(t) \end{bmatrix} \tag{6}$$

is an effective polarizability obtained from the convolution of the magnetic polarizability with the transmit waveform. It describes the decay of the induced dipole moment after the primary field cuts off. **B** is symmetric, and its eigenvalues (β_1**,** β_2**,** and β_3) correspond to the responses that are induced when the primary field is aligned in turn along each of the principal axes of the object. The **TR** matrix depends on the relative positions of the sensor and the target, the transmit and receive coil geometry, and various electronic parameters such as the number of turns, the transmit current, the receiver gain, etc. The advantage of writing the EMI signal in the form of (4) is that the space and time (frequency) dependencies are separated. **B** does not depend on the location of the target relative to the sensor, while TR depends only on where the target is, not what it is.

Within the magnetic polarizability tensor framework, the eigenvalues or response coefficients (β_1**,** β_2**,** and β_3) completely determine the target-dependent part of the EMI signal. The complete set of eigenvalues accounts for all of the information available for discriminating between different objects.

2.2 Example of Population Estimate Use

The following example, taken from a SERDP poster presented by Drs. Herb Nelson of NRL and Bruce Barrow of AETC, illustrates the underlying concept and highlights how population estimates for various UXO types will be transitioned into ancillary research and cleanup efforts.

> *"A four-acre portion of the L-Range at Blossom Point was used for this Demonstration. The area was surveyed using the MTADS magnetometer array once and the EM array in two orthogonal survey directions. We have focused our analysis on the 81mm mortars because there are enough of them to give reasonable statistics.*

We find the betas for the 81mm mortars to be distributed log-normally. We calculate a mean and sigma for each of the three betas. A 2-D representation of the 2-sigma ellipsoid for the three betas is shown plotted in Figure 1 over the beta values obtained from the individual targets. We can derive a Receiver Operating Characteristic (ROC) curve by increasing the size of this ellipsoid uniformly in each beta and counting the number ordnance item correctly identified and the number of false positives.

There are not enough examples of the other ordnance items to obtain reliable statistics. To obtain an ROC curve for the detection of all ordnance, we have used the distribution from the 81mm mortars to draw an ellipsoid centered on the beta values for each ordnance items. We grow all the ellipsoids simultaneously and determine P_d and P_{fa}."

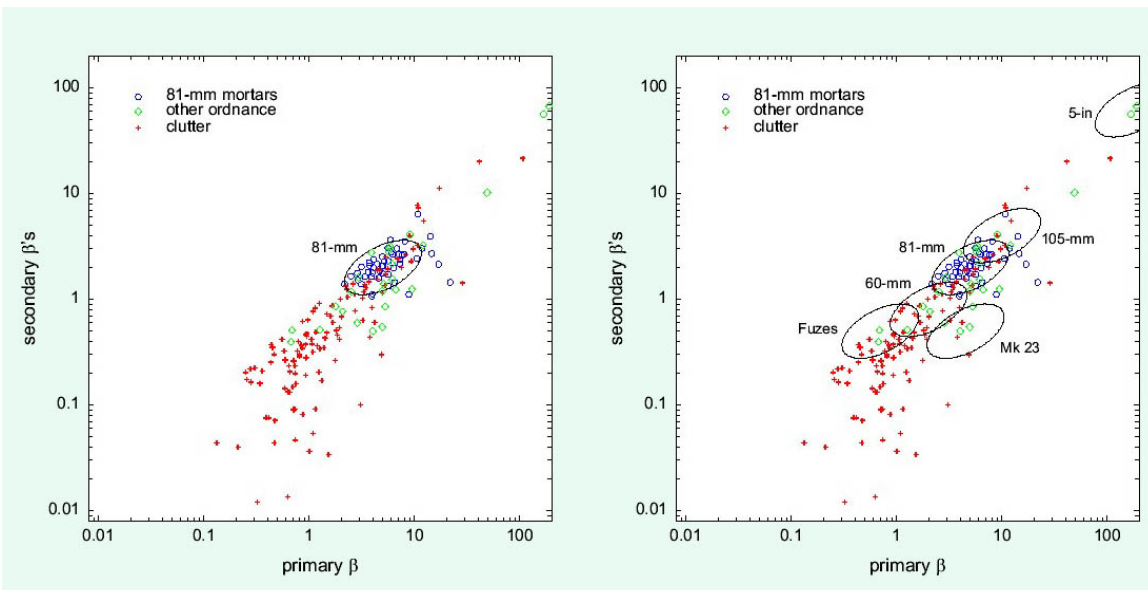


Figure 1. Left - 3**b** Analysis of the Blossom Point L-Range, 81mm Mortars Only. Right - 3**b** Analysis of the Blossom Point L-Range, all ordnance. Spreading of target parameters is evident (note ellipses to enclose values from given types). This spreading is caused in part by inherent variability of UXO.

Although this example includes errors in the data associated with field surveying, it illustrates several key concepts. First, derived target characteristics (response coefficients) from a given ordnance type tend to fall within certain parameter bounds. This is, in effect, the fundamental approach to discrimination using response model parameters. Second, because these target characteristics are intrinsically related to the target, they will not change with time. Thus, if we had statistics for the population of UXO types that are expected, the parameter bounds will provide a discriminating metric from year to year and potentially, also site to site. Third, because statistically sound estimates for the type populations were not available, the authors assumed that statistics derived for 81mm mortars were appropriate for all ordnance types present at Blossom Point. Given the lack of definitive data, this is a reasonable assumption. We can,

however, possibly improve the underlying model – and ultimately the ROC curves – if we understand the statistical distributions of the type-dependent response coefficients.

2.3 Examples of Damage Affecting UXO Response

EMI response changes when ordnance items are damaged. Figure 2 shows response of two 20mm projectiles obtained using the GEM-3 sensor. The data represent repeat measurements at two different

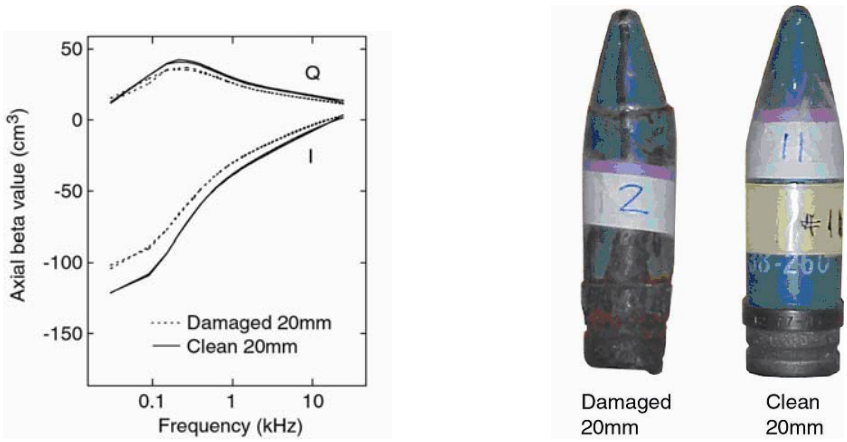


Figure 2. Axial response coefficients (β values) of these 20mm projectiles are somewhat different. β values were calculated twice for each projectile (note duplicate lines), based on data from different sensor heights (24cm and 36cm). Q → Quadrature, I → In phase.

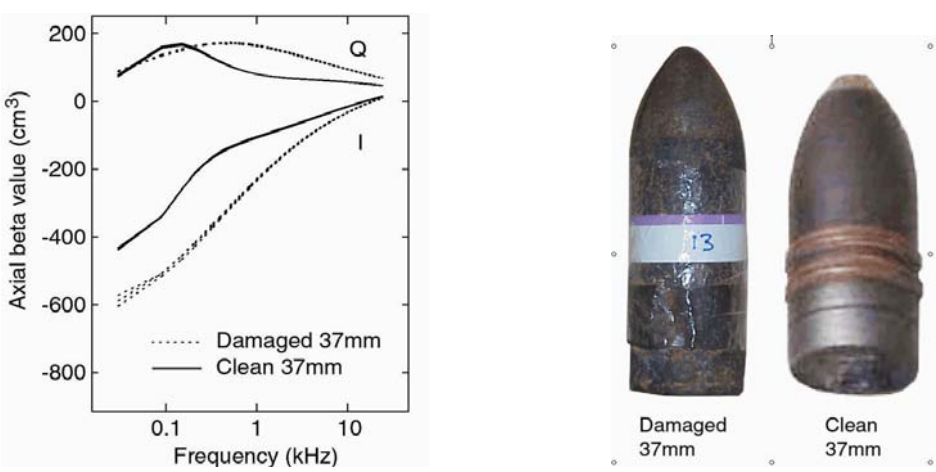


Figure 3. Axial β values of these 37mm projectiles are markedly different, due to loss of the rotating band on the damaged 37mm projectile. β values were calculated three times for each projectile (note the duplicate lines), based on data from different sensor heights (34cm to 50cm). Q → Quadrature, I → In phase.

sensor-to-target separations. Although the 'damaged' 20mm projectile is not significantly different than the 'clean' sample, the derived response coefficients are somewhat different and repeatable. Figure 3 presents similar data for two 37mm projectiles. In this case, the 'damaged' 37mm sample is slightly rusted and has lost its driving band. Note that the response coefficients are markedly different, illustrating the potential for high amounts of variability from one item to the next due to damage.

3. Project Tasks

3.1 Planned Tasks.

The goal of this project was to quantify UXO variability and express results in physically meaningful terms that are of interest in other research efforts. The technical approach to be used to attain the objectives consists of four major tasks, shown in Table 1.

1	Integration of time-domain models & procedures into the existing SERDP procedure libraries for frequency-domain models & procedures
2	Site selection and UXO target objectives
3	Controlled EMI measurements in air
4	Quantify variability

Table 1. The technical approach consists of four major parts.

In more detail, these tasks are:

- *Task 1.* Integrate existing time-domain models and procedures into the SERDP-related procedure libraries to complement our frequency-domain models for ordnance signatures. Specifically, the data handling and processing procedures for the EM-63 time-domain sensor to be used in these measurements will be integrated into the existing database.
- *Task 2.* Select sites that contain an adequate number of excavated UXO with different geologic settings. Determine the minimum number of UXO of each type required for statistical analysis.
- *Task 3.* Make controlled time-domain and frequency-domain measurements in air on these items.
- *Task* 4. Create the database containing all the measurements and perform parameter estimation to quantify inherent variability in seemingly identical items (viz., establish population estimates for critical parameters as a function of ordnance type).

In the process of executing this project, tasks 1 and 3 were completed fairly easily, but we encountered difficulty in task 2, and especially task 4.

3.2 Adjustment to Task 2: site visits.

We had initially intended to visit five DoD sites, but the process of making these arrangements proved to be more challenging than anticipated. The best places to find UXO are sites with ongoing remediation, but these operations typically have tightly controlled workflow and EOD teams are understandably

Jefferson Proving Ground, IN	143
Fort Ord, CA	202
Fort McClellan, AL	216
Blossom Point, MD	103
Total	664

Table 2. Summary of UXO by site.

focused on their mission and less disposed to make UXO available for test-stand measurements, even inert examples. However, with help from the SERDP program office and Huntsville, we were able to arrange visits to four DoD sites, and measured a total of 664 UXO targets, as summarized in tables 2 and 3.

3.2.1 Jefferson Proving Ground

Our first site was Jefferson Proving Ground, IN, where we processed 143 targets during the week of April 18, 2003. These targets covered a range of UXO types from 20mm to 155mm projectiles. All targets were fired rounds recovered from impact sites.

3.2.2 Fort Ord

We processed 202 targets at Fort Ord, CA, during the week of July 25, 2003. The targets covered a wide range of UXO types, but our effort at Fort Ord was focused on UXO types that we had not seen yet at other sites, and also on targets that showed varying degrees of corrosion. Certain UXO items were available in near-pristine condition and also in badly corroded/rusted condition. UXO at Fort Ord is stored in a former munitions assembly building in steel dumpsters, piled together with clutter items, frag and scrap recovered in cleanup operations. For most UXO types, finding a good representative sample required digging through the dumpsters. With EOD tech support from UXB International helping us, we found many interesting items this way, but in several cases, the number of examples was limited. In these cases we measured all that was available.

3.2.3 Fort McClellan

We went to Fort McClellan, AL, during the week of August 18, 2003, where we processed 216 UXO targets. With the help of EOD workers from Tetra Tech, we gained access to many hundreds of UXO items sealed in 55 gallon drums at a remote location. After indicating the targets we wanted, Tetra Tech staff certified them inert, tagged them and painted them blue, and made them available to

	Processed
20mm projectiles	27
25mm projectiles	4
37mm projectiles	46
40mm projectiles	24
57mm projectiles	5
60mm Mortars	50
75mm projectiles	14
76mm projectiles	0
81mm Mortars	79
90mm projectiles	14
105mm projectiles	5
155mm projectiles	21
2.36 inch rockets	30
3 inch Stokes	36
3.5 inch rockets	68
4 inch Stokes	35
4.2 inch mortars	2
hand grenades	40
rifle grenades	27
fuzes	73
flares	17
other	47
Total	664

Table 3. Summary of UXO by type.

us on our test stands.

3.2.4 Blossom Point

Measurements were taken at Blossom Point, MD, during the week of January 19, 2004. We collected measurements on 102 targets, including several types not seen before (e.g., 120mm mortars, 5-in rockets, and several kinds of fuzes). In addition to the standard set of EMI measurements with the GEM-3 and EM-63 instruments, we also collected carefully controlled magnetometer data on 6 selected targets using the *MTADS* towed magnetometer array in order to verify the extrapolation to DC that we use in our frequency-to-time-domain conversion routine.

3.3 Adjustment to Task 4: Data analysis.

Task 4 involved the use of a model to express EMI response in terms of features, or fitted parameters, which capture the information present in the signals. In order to permit analysis of variability via fitted parameters, the model must have the following properties:

1) It must be computationally inexpensive. Necessary since iteration is used in fitting.
2) It must match observed signals accurately. Necessary to capture available information.
3) It must be physically realistic. Necessary since extrapolation beyond data range must conform to analytical requirements.
4) It must produce stable and unique solutions. i.e. similar signals must produce similar fitted parameters, and visa versa.

Upon collecting data, we discovered properties (2) and (4) were not easily achieved. The initial plan was to use a response model developed under an earlier SERDP project (CU-1121), described in a white paper attached as appendix B. This model had performed well on a limited number of targets, however, we discovered it was insufficient for the wider range of targets measured in this project. A summary of our experience in modeling EMI data follows.

3.3.1 Approach 1 – the initial model.

1) Use an existing empirical model to fit both Time and Frequency domain data simultaneously.
2) Express variability through the moments of the fitted parameters.

This model failed to accurately match observed data in many cases, and it also suffered from instability and non-uniqueness. Sometimes parameters drifted off to infinity, and sometimes the same signal could be fit equally well with different sets of parameters. This made expression of variability through parameter fits impossible. In addition, several of the parameters were dimensionless “shape parameters” with no physical interpretation, making them less useful to other researchers. This approach was abandoned in favor of analysis using different means.

3.3.2 Approach 2 – the modified model.

1) Use modified model to fit both Time and Frequency domain data simultaneously.
2) Express variability through the moments of the fitted parameters.

The model was modified so that all parameters were bounded, and the parameter search algorithm was modified so that multiple non-unique solutions were always explored, and one region was chosen as "preferable" for all members of a UXO class. It was hoped that these steps would force fitted parameters to better reflect the variability of the UXO.

But this approach was also abandoned. The model still failed to fit certain targets accurately, the fitted parameters still had no physical interpretation, and in any case, the claim that UXO variability is accurately reflected by empirical parameters with no physical interpretation is suspect.

3.3.3 Approach 3 – use derived physical parameters.

1) Use a new model based on first principles to fit both TD and FD data simultaneously.
2) Express variability through the derived physical parameters, not through model parameters.

This was a much more robust approach. The model fits would serve only as a means to accurately determine physically meaningful parameters such as late-time exponential decay time constant, and variability would be expressed through those derived values, and not through the fitted model parameters themselves. This approach has two important advantages: (A) a simple, first-principles model may be employed which accurately matches nearly everything, and (B) the fitted parameters are only a tool for deriving the physical parameters which form the basis for expressing variability. As mentioned in the executive summary, these physical parameters are: : 1) response magnitude A (liters), which relates to target size, 2) late-time fundamental decay time constant τ_f (s) which relates to conductivity and maximum diameter, 3) magnetic cross-over time τ_{mag} (s), which relates to quadrature peak, and 4) the static-field asymptote S (liters) which relates to target permeability and demagnetization factor.

4. Project Accomplishments

4.1 Sensors

We used a Geonics EM-63 EMI sensor to perform all the time-domain measurements (figure 4) and a Geophex GEM-3 sensor for all the frequency-domain measurements (figure 5). The GEM-3 was purchased under an earlier SERDP Project (UX-1121) during which signal distortions in the GEM-3 had been investigated and successfully corrected. The EM-63 was purchased from Geonics in August 2002; shipment was received in September 2002. We assembled the unit and collected data on a 4-inch-diameter carbon steel sphere at a grassy park in Arlington and again at our Raleigh, NC, office. We also made a trip to Blossom Point, MD, to survey the emplaced targets there.

Figure 4. EM-63 sensor in the field.

Figure 5. The GEM-3 sensor in the field.

These tests showed that the EM-63 works largely as advertised, although we identified some problems. We tested the linearity of the gain by plotting normalized data from the same steel sphere at a range of signal strengths (target depths) and comparing it to the analytic solution for a sphere. The shapes of these response curves show good agreement with analytic solutions when signal strength is high, but non-linear gain effects were observed at low amplitudes.

4.2 EM63 Sensor Correction

Five metal spheres ranging in diameter from 1 to 4 inches, made of aluminum, bronze, and chrome steel, were measured with the EM63 and the GEM3 at various ranges. Fits to analytic solutions revealed that the EM63 produces a non-trivial distortion in output, especially at low signal strength. Based on these data, we developed an empirical correction which is described in detail in a white paper attached as appendix A. This correction worked well for weak and mid-range signal strengths, but not well for strong signals. We applied this correction to all targets, all orientations, except for nose-up and nose-down shots on the following large targets: Stokes mortars (both 3" and 4" calibers), 75mm, 90mm, 105mm, 155mm projectiles, and 5 inch rockets. These targets produce strong response in axial excitation so the EM63 correction was not needed, and it actually produced undesirable artifacts.

4.3 TD-FD Transformation

We next wrote a routine to transform time- and frequency-domain data back and forth numerically so that we could work with arbitrary response models and arbitrary excitation waveforms. Following standard practice, this routine uses Fast Fourier Transforms (FFT)s, convolutions, and time derivatives to convert the data, and we determined workable sampling intervals and bandwidths to deliver good comparisons against measured ranges of the GEM-3 and EM-63 sensors. We tested this

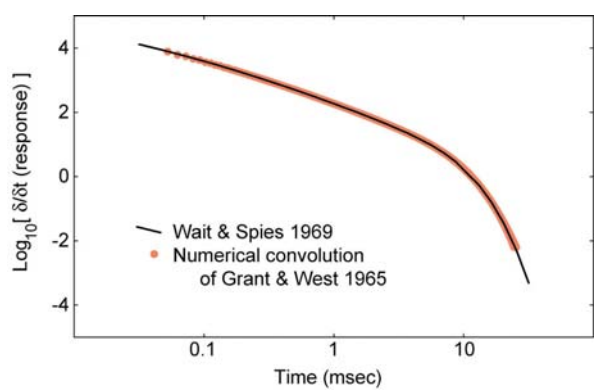


Figure 6. Validation of numerical conversions routine.

routine by converting the FD solution for a sphere [2] and comparing output against the TD solution for a sphere [3]. Figure 6 shows that things worked properly.

4.4 TD-FD Validation

Using the TD-FD transformation routine, we next compared GEM3 data (FD) against EM63 data (TD) for individual targets. This process required fitting an FD response model to the GEM3 data because the conversion process involves dense sampling beyond the measured range of the GEM3 in order to produce time-domain data that covers the measured range of the EM63. For this purpose, we used the FD response model that was developed under SERDP project: CU-1121, described below, and in appendix B. Figure 7 shows a good match to a tail-cone, boom, and fin assembly of an 81mm Illumination round (all non-ferrous), together with the TD conversion and match to (corrected) EM63 data. The successful match suggests that both sensors are produce reasonable results.

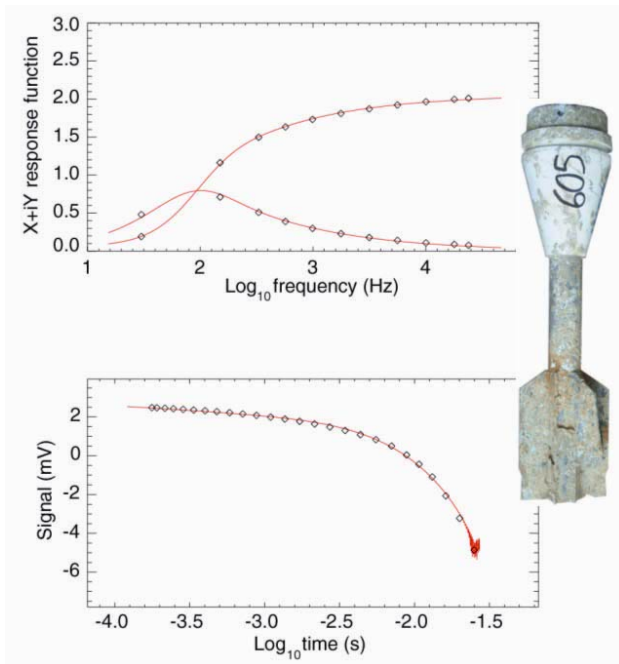


Figure 7. Validation of sensor data. Good agreement was seen by fitting a frequency- domain response model to GEM3 data, then converting that model over to time-domain and comparing against (corrected) EM63 data.

4.5 FD Response Model

This model was developed from the analytic solutions for permeable spheres, cylinders, and conducting loops. It provides exact matches to all those solutions through parameter adjustment, and also provides successful matches to a wide range of irregularly-shaped UXO, provided they have approximately uniform composition (homogeneous material properties). A brief description follows, and a detailed description is given in a white paper, attached as appendix B.

Frequency-domain EMI response of a metal target may be represented as a magnetic dipole ***m*** positioned at the center of the target, with magnitude and direction

$$\vec{\boldsymbol{m}}\, e^{i\omega t} = \overleftrightarrow{\boldsymbol{B}}\, \vec{\boldsymbol{H}}_O\, e^{i\omega t}, \tag{8}$$

where $\boldsymbol{H_o}$ is the primary field oscillating harmonically at frequency **w**, and ***B*** is a tensor which can be thought of as the constant of proportionality between $\boldsymbol{H_o}$ and ***m***. With a suitable rotation of coordinate

axes, $\boldsymbol{B}$ becomes diagonal, and the diagonal elements $\mathbf{b}_j$ (j = 1,2,3) correspond to the principal axes of the target. Each $\mathbf{b}_j$ is described by the formula:

$$\beta_j = A\left(\frac{f\,g-1}{f\,g+1}+S\right), \qquad g=\frac{\alpha^{2C}\,\mathrm{I}_{\nu+1}(\alpha)}{\mathrm{I}_{\nu}(\alpha)}, \qquad \alpha=\sqrt{i\,\omega\,\tau}\,, \tag{9}$$

where fitted parameters S, f, C, and $\boldsymbol{n}$ are dimensionless, while parameter A (the amplitude) has dimension of volume, and parameter $\boldsymbol{t}$ (the time constant) has dimension of time. The symbol $\mathrm{I}_{\mathbf{n}}(\mathbf{a})$ represents the Modified Bessel I function of order $\boldsymbol{n}$. All fitted parameters are real scalars.

4.6 Validation of Low-Frequency Asymptote

Following a suggestion made during an In-Progress-Report at the SERDP program office in 2003, we set out to measure static magnetic dipole moments to see if they matched low-frequency asymptotes produced by our FD model fits. We collected magnetometer data on six selected targets at Blossom Point, MD, during the week of January 19-23, 2004 using the MTADS towed magnetometer array. We also measured those same targets using the EM63 and the GEM3.

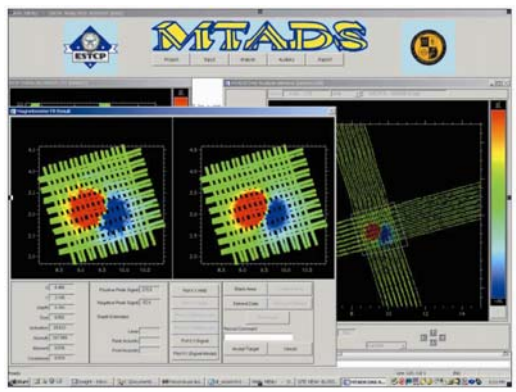


Figure 8. The MTADS DAS was used to recover magnetic moments from targets in the Blossom Point test pit.

Each target was measured in three orientations: nose up, nose down, and horizontal. In the case of magnetometer measurements, those orientations were carefully set with respect to the earth's field, which is aimed northwards but also plunges into the ground steeply at Blossom Point. The EM63 and GEM3 measurements were made as usual on a test stand, and the MTADS magnetometer measurements were made by positioning the target in a test pit and making passes over it with the MTADS mag array. Four passes were made for each target set-up: one each traveling North, South, East, and West. This served both to quantify the inherent measurement variability in the process, which turned out to be about 10%, and to expose any systematic error for data collection in any one direction (none was found). It also provided a bigger dataset from which to estimate magnetic moment. All six targets exhibited magnetic remnance, which made analysis difficult. Using the assumption that the remnance was predominantly aligned with the target principal axis, we were able to partially remove this effect by averaging the nose-up and nose-down results. Magnetic dipole values were calculated from

$$m = V\,A\,\mathrm{H}_0 \tag{7}$$

where *m* is the observed magnetic dipole moment (Amps m^2) provided by the MTADS data analysis system (figure 8), *V* is the target volume (m^3), *A* is the dimensionless response function (alpha value), and H_0 is the Earth's induction at Blossom Point (41.98 Amps/m).

Beta values were calculated from the active EMI data using the dipole model, with the point dipole located at a specific position inside the body of the target. This position differed from the "center" of the target (i.e. halfway along the target length), and was chosen such that the asymptotic limits for the nose-up and nose-down fitted models converged to the same value at low frequency. Figure 9 shows this position for one of the six test items.

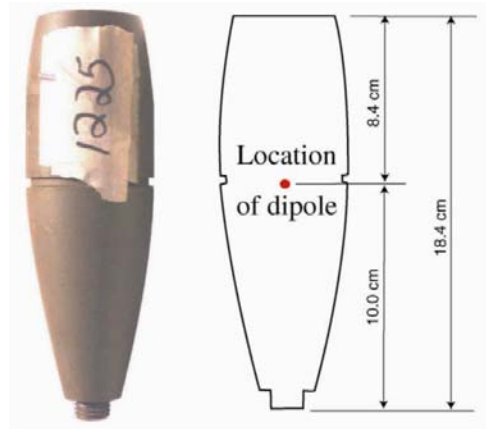


Figure 9. The location of the dipole to represent the target was chosen so that the low-frequency asymptotes for nose-up and nose-down orientations coincide.

Figure 10 shows good agreement between the fitted TD-FD model low-frequency asymptote and moments derived from the MTADS magnetometer array for axial response of the 60mm mortar test object shown in figure 9. Four values of magnetic moment are shown, (the green diamonds), representing the average of nose-up and nose-down orientations for each of the four directions (N,S,E,W) driven by the MTADS. Results from the other five targets were not as good, and we suspect this was due to magnetic remnance which was not aligned with the target principal axis.

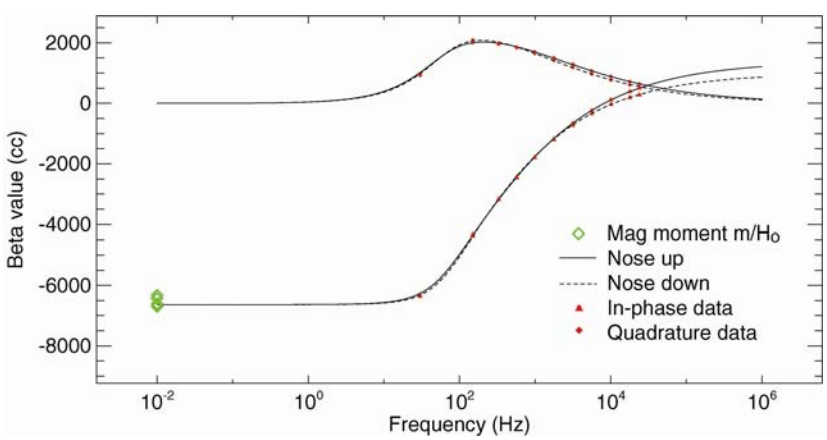


Figure 10. Good agreement was found between beta values calculated using equation 7 and the low-frequency asymptotes from the EMI response model of equation 9.

The graph shows values of *VA* (beta values), so it is not necessary to calculate the target volumes in order to make this comparison. The differences in the fitted curves for the nose-up and the nose-down orientations are caused by the non-uniform primary field that interacts with the target body, which is longitudinally asymmetric.

4.7 Sample size determination

Since this is a study of the statistics of UXO variability, it was critical to decide how many samples of each UXO type are required for adequate sampling of the variability. We performed a study of sample size that addressed this issue; the details are discussed in a white paper, attached as Appendix C.

The difficulty with estimating the required sample size for each type of UXO is that the variance of the parameters, which is not known *a-priori*, also affects the uncertainty in their estimated moments, making it impossible to calculate beforehand the sample size needed to achieve a desired uncertainty criterion. This problem may be approached in two ways. Under the *relative frequency* approach, assumptions regarding probability distributions are never permitted, so it is impossible to calculate uncertainty vs. sample size beforehand. Under this approach, uncertainty may only be calculated *a-posteriori* based on the observed measurements. In the *Bayesian* approach, intuitive and subjective assumptions may be used as a starting point to plan the experiment, and then these assumptions are updated through Bayes' Formula as experimental observations are obtained.

In the current project, we adopted a Bayesian-like approach, although we did not make use of Bayes' Formula itself. We determined the sample size using a-priori assumptions based on experience and judgment, and we calculated parameter estimates *a-posteriori* for each UXO class, along with associated uncertainties using Jackknife and Bootstrap re-sampling plans. These results allowed us to determine adequate sample size in order to meet our working goal: namely, sample size in each UXO class should be large enough that the coefficient of variability for each parameter was no more than 1/3 (i.e., error bars should be < 33%). This goal was affected by practical considerations in every case (e.g., UXO availability). If this criterion was not met with the existing sample of UXO, additional examples were sought until the criterion was satisfied.

4.8 Joint FD-TD response model

Physical parameters were derived through fitting a generalized TD-FD response model. This model consists of a linear combination of exponential modes, each of which contributes a known response in both TD and FD, forming basis functions which may be weighted and summed so as to best-match observed TD & FD data simultaneously. The weights are found using a least-squares minimization algorithm developed by Lawson and Hanson [9], which imposes the constraint that weights may not be negative.

The minimization algorithm is presented with a large group of basis functions from which to choose the best collection for matching data. Results show only about 5 to 8 basis functions are needed to find the least-squares match, and all others are automatically assigned zero weight by the minimization algorithm.

The group of basis functions presented to the minimization algorithm is determined in the following way: We start with 200 modes with time constants log-spaced from 1.e-7 to 1.e1 (s), and this set is then truncated based on data. Truncation is done differently on the upper (long time constant) end and lower (short time constant) end.

On the upper end, all time constants that are larger than the largest value evident in EM63 late decay data are excluded. This is determined by first fitting a single exponential mode to the last 5 “good” time gates in the EM63 record. These 5 data must have signal strength above 1.e-2 mV (the noise), and must also be monotonically decreasing, i.e. any rise in signal is interpreted as the start of bad data. The time constant that results from this fitting is the threshold used for truncating the upper (long time constant) end of the set of basis functions.

On the lower end, truncation is governed by the dynamic range of the sensors. The shortest time constant which can be detected was calculated from the highest frequency on the GEM3, and the earliest time gate on the EM63. This time constant depends on the configuration of the sensors, and for most data in this project, it was 3.16e-5 seconds. Any modes with shorter time constants cannot contribute to observed signals, and were truncated from the set for fitting. Unlike the modes truncated from the upper-end, however, those lower modes do physically exist in the target response, and they affect the shape of the FD curves as they approach their high frequency asymptotes. Even if we assumed some value for those modes, they do not affect estimation of the four derived physical parameters (magnitude A, fundamental decay constant τ_f, magnetic crossover time τ_{mag}, and static dipole strength S), however, they do affect the shape of the fitted TD-FD model, so, in order to give model fits a physically realistic appearance, we adopted the following simple form to determine weights for modes below the low threshold:

$$w_i = w_t \sqrt{\tau_i \tau_t} \ , \tag{10}$$

Where w_i is the weight on the i’th mode, w_t is the weight on the low threshold mode, and τ represents the mode time constant. Thus, any weight assigned to the threshold mode during the fitting process will automatically result in a collection of associated weights, governed by equation (10), to be applied to lower time scale modes. Again, this does not affect estimation of the four physical parameters under study, and is only used to create physically realistic model curves as they approach high-frequency asymptotes beyond the measured range of the GEM3.

To account for dissimilar gain factors and differences in measurement ranges between the two sensors, a single "gain ratio" must be found to adjust the relative magnitudes of the TD vs FD parts of the basis functions. This "gain ratio" is a scalar, and it is found through 1-D minimization, which requires iteration, but it is computationally inexpensive since only one variable is being searched. Processing time was about 25 seconds to fit one target using a Pentium workstation with 2GHz clock speed.

This model is flexible enough to produce good fits in the vast majority of cases, and it is based on the fundamental principle that EMI signals can always be represented as a sum of fundamental modes in both TD and FD. Figure 11 shows an example fit to a non-homogeneous target exhibiting a double peak in quadrature. This kind of target is impossible to fit accurately using our earlier models developed under CU-1121.

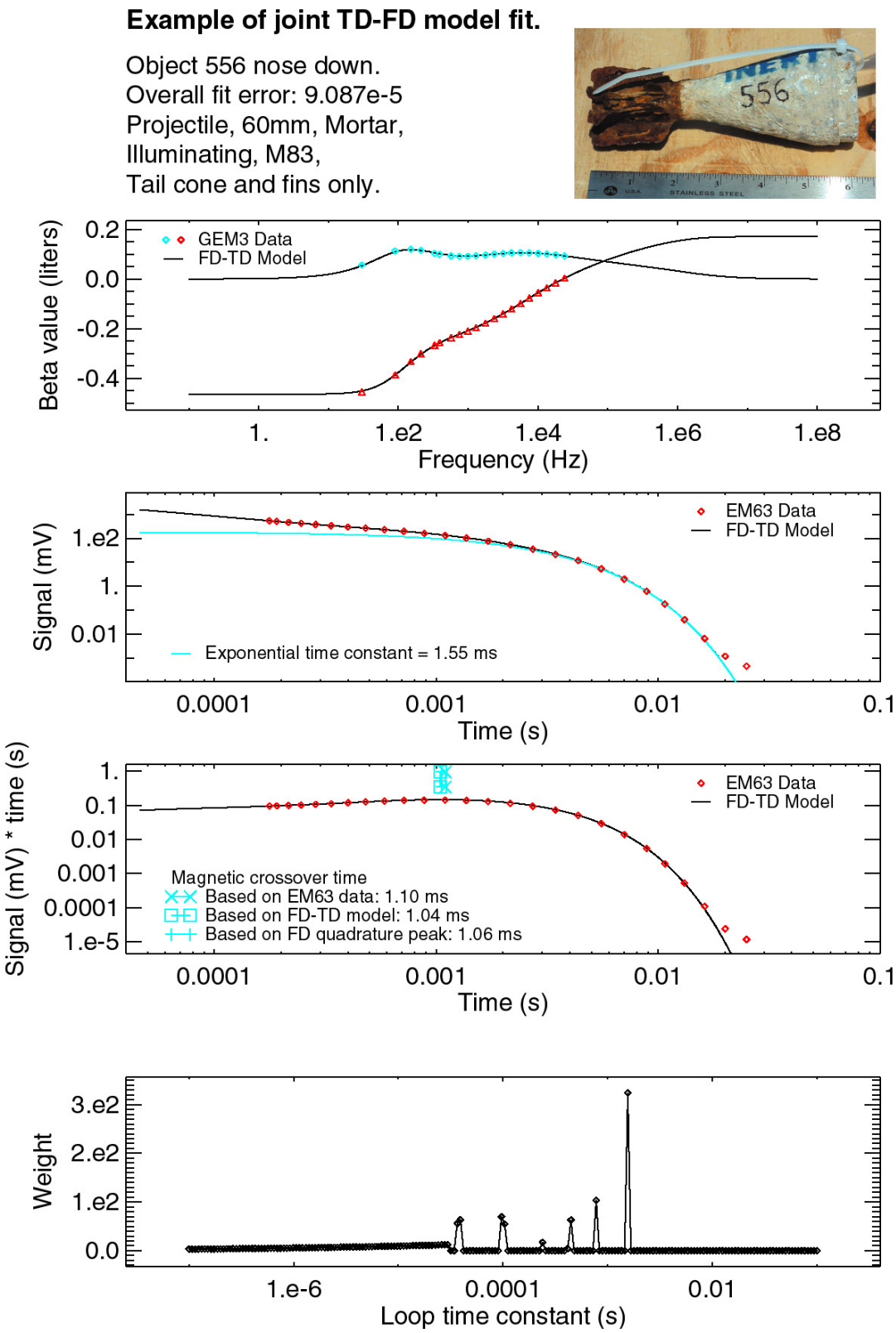


Figure 11. The joint TD-FD model fits a wide variety of EMI signals accurately, including this heterogeneous target with double-peaked quadrature.

4.9 Extracting physical parameters

Four physical parameters were derived from model fits to observed data.

4.9.1 Response magnitude *A* (liters)

This parameter was determined using GEM3 data only. This provided a uniform basis for evaluation, and avoided the problem of addressing non-uniform field effects which could produce conflicting values based on EM63 data. Magnitude was determined using equation (1), by calculating the transmitted primary field *H*, observing the dipole moment *m*, and solving for the response coefficient $V\alpha$. Note that this is a tensor, but since we're only measuring the targets' principal axes on the test stand, only one element of the tensor is interrogated. The reported value for response magnitude is the peak quadrature value in the fitted model.

4.9.2 Late-time fundamental decay time constant τ_f (s)

This parameter was determined from corrected EM63 data. First, any signals below 1.e-2 mV were considered noise, and since TD signals should only decay, any signals following a rise were also considered noise. After removing these data, the last five points of EM63 data were used to fit an exponential, and the resulting best-fit decay time constant is τ_f (s).

4.9.3 Magnetic crossover time τ_{mag} (s)

This parameter is the time at which the early-early decay regime characterized by $t^{-3/2}$ time dependency changes over to the late-early decay regime characterized by $t^{-1/2}$ time dependency [10]. We looked at three ways to evaluate this parameter from data: 1) multiply EM63 data by time and find the peak value. This approach was rejected because it couldn't predict values beyond the EM63 sampled range. 2) Calculate the reciprocal of $2\pi f_p$ where f_p is the frequency where the fitted TD-FD model reaches peak value in quadrature. We have seen empirically that this quantity is a good estimator of τ_{mag}, but this approach was also rejected in favor of a more direct method: 3) multiply the fitted TD model curve by time and find the peak value. This is the method by which we determined τ_{mag} (s).

4.9.4 Static-field asymptote S (liters)

This parameter was found by simply reporting the fitted *S* value which produces the best match between in-phase FD model points and in-phase FD data.

4.10 Goodness of Fits

A key challenge in this work is the problem of taking observed EMI signals measured at specific frequencies and time gates, and translating these data into quantities which are valid for any set of frequencies and time gates. This effort hinges on fitting models, and fitting them well. If a model fit is poor, then it cannot represent the information present in the original signals. We have therefore given considerable attention to goodness of fit. Figure 12 shows mean squared errors (MSE) for all the model fits performed in this study. The MSE value is overall fit error, representing the match of TD and FD signals to the joint TD-FD model. Five individual fits are shown in figures 13 through 17, corresponding

to the five diamonds in figure 12. These figures demonstrate a reasonable degree of fit accuracy for the majority of targets in the study.

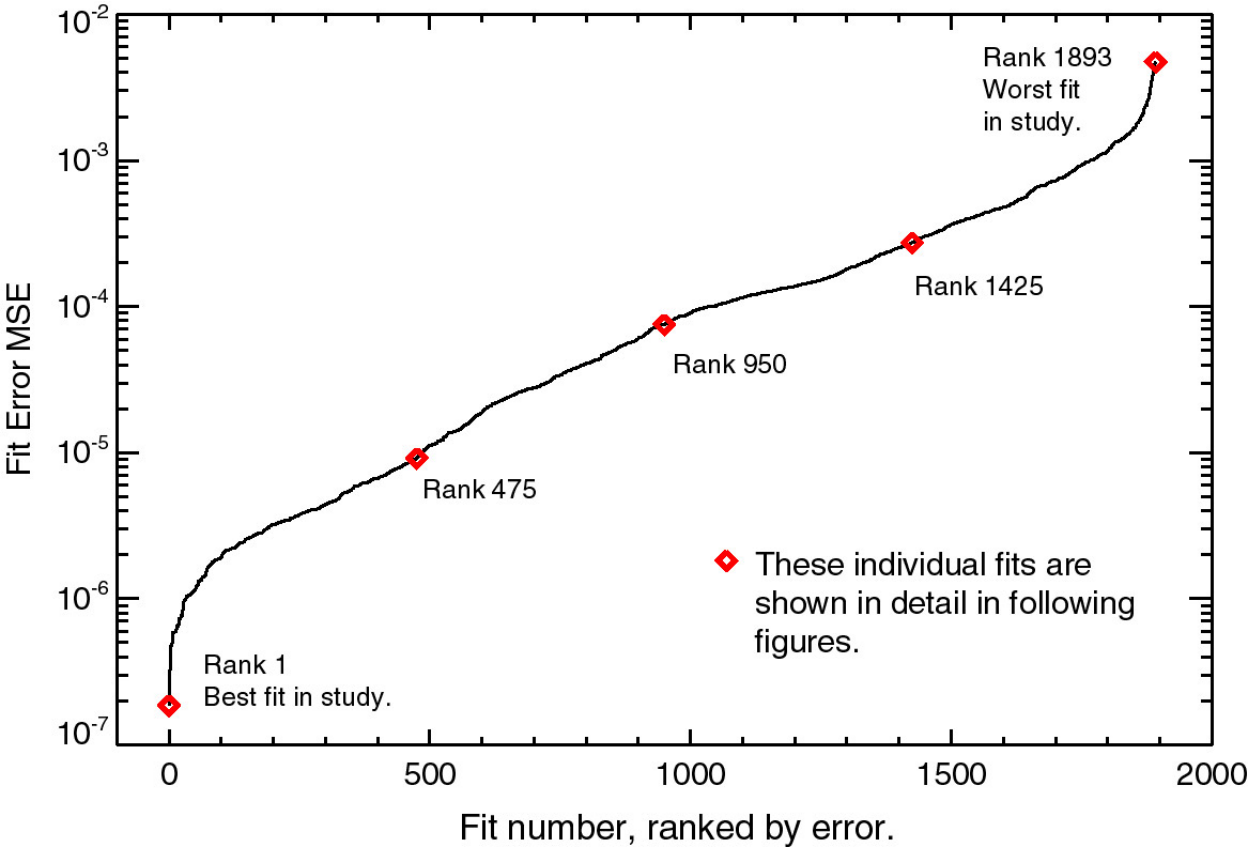


Figure 12. Mean Squared Error values for all the model fits in this study. The joint TD-FD model was fit to 1893 data sets (nose-up, horizontal, and nose-down for 631 targets), and MSE values were ranked for this graph. Five individual fits are shown in the following pages to illustrate goodness of fit values.

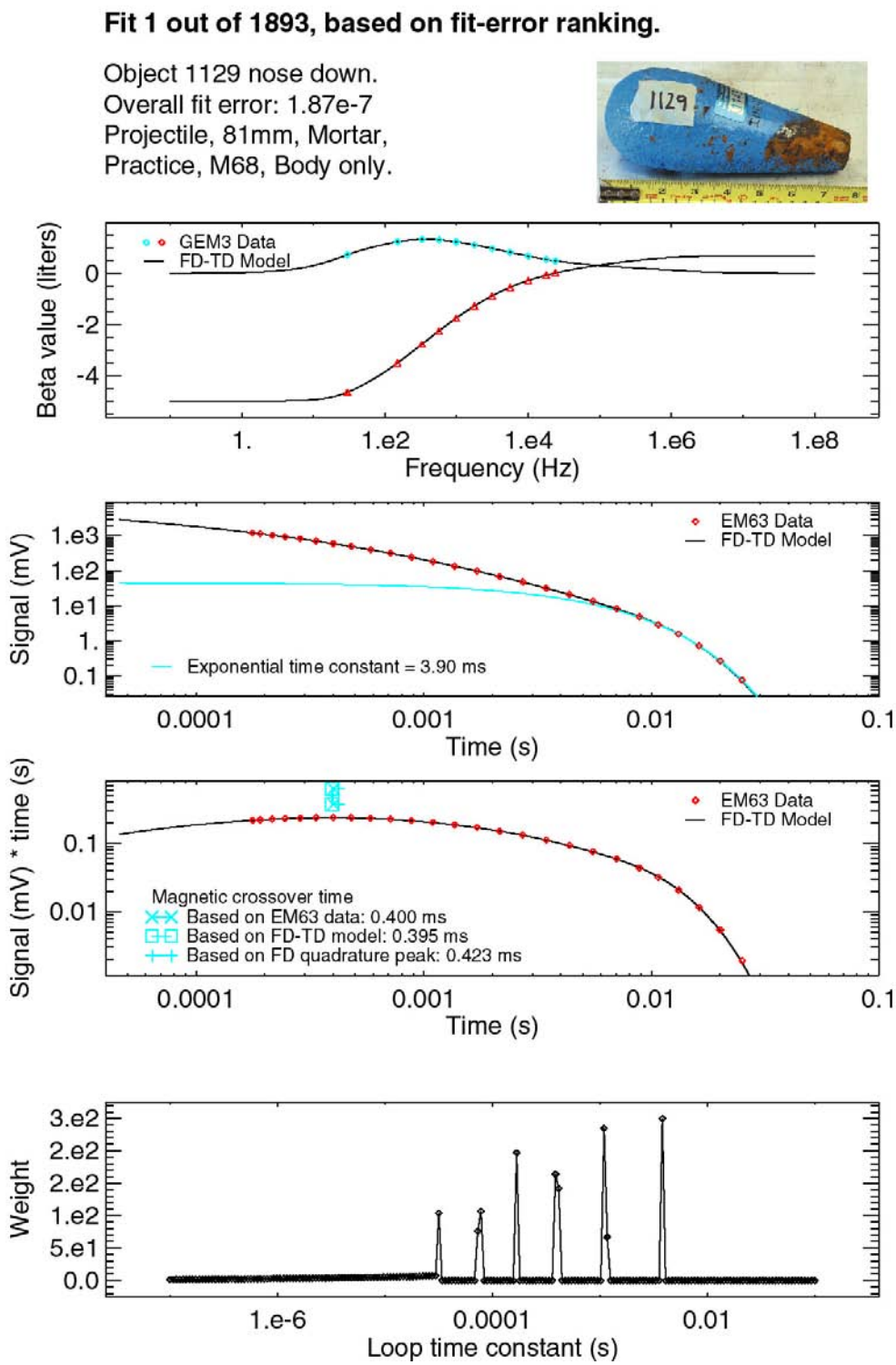


Figure 13. The rank 1 (best) fit.

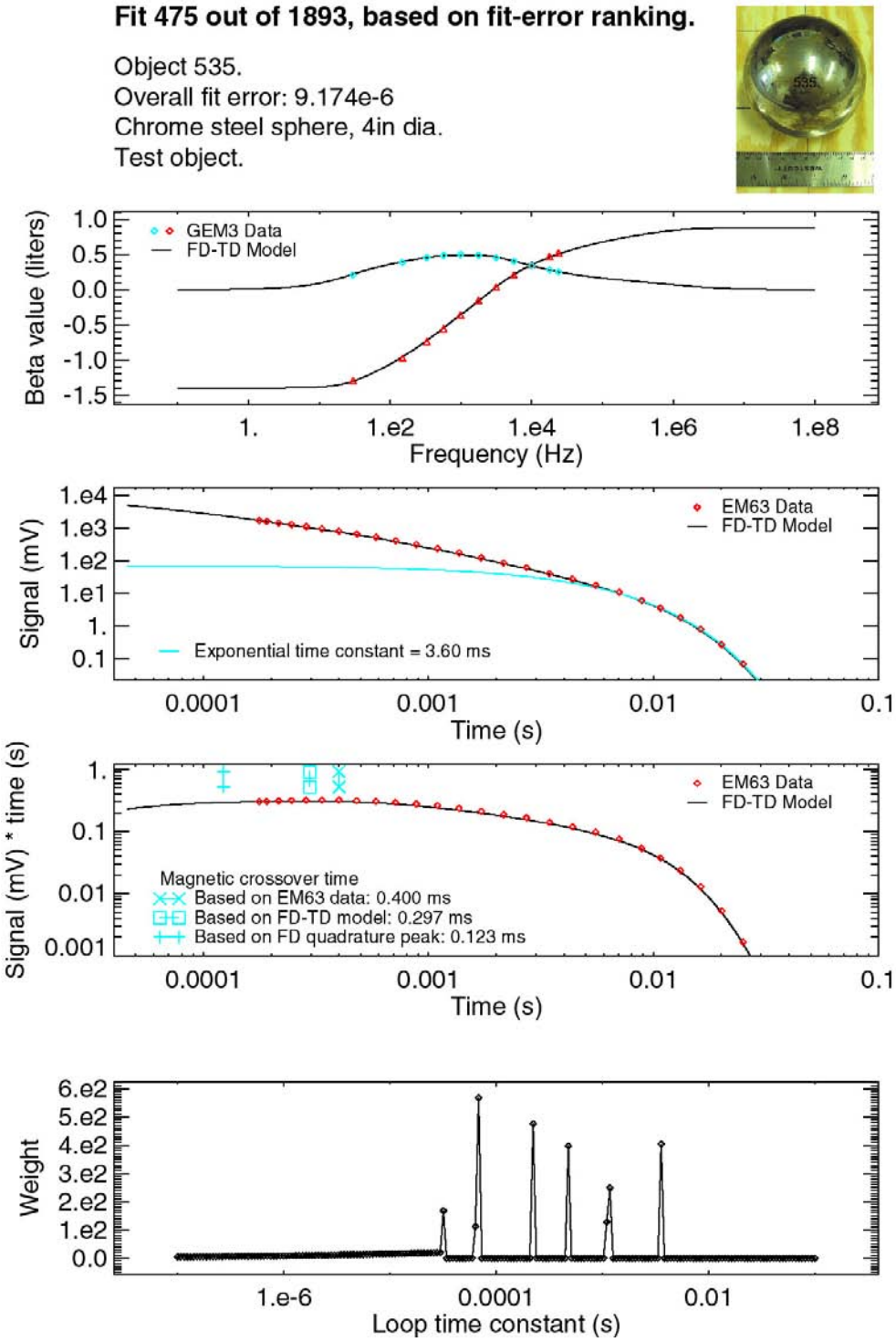


Figure 14. The 475th rank fit.

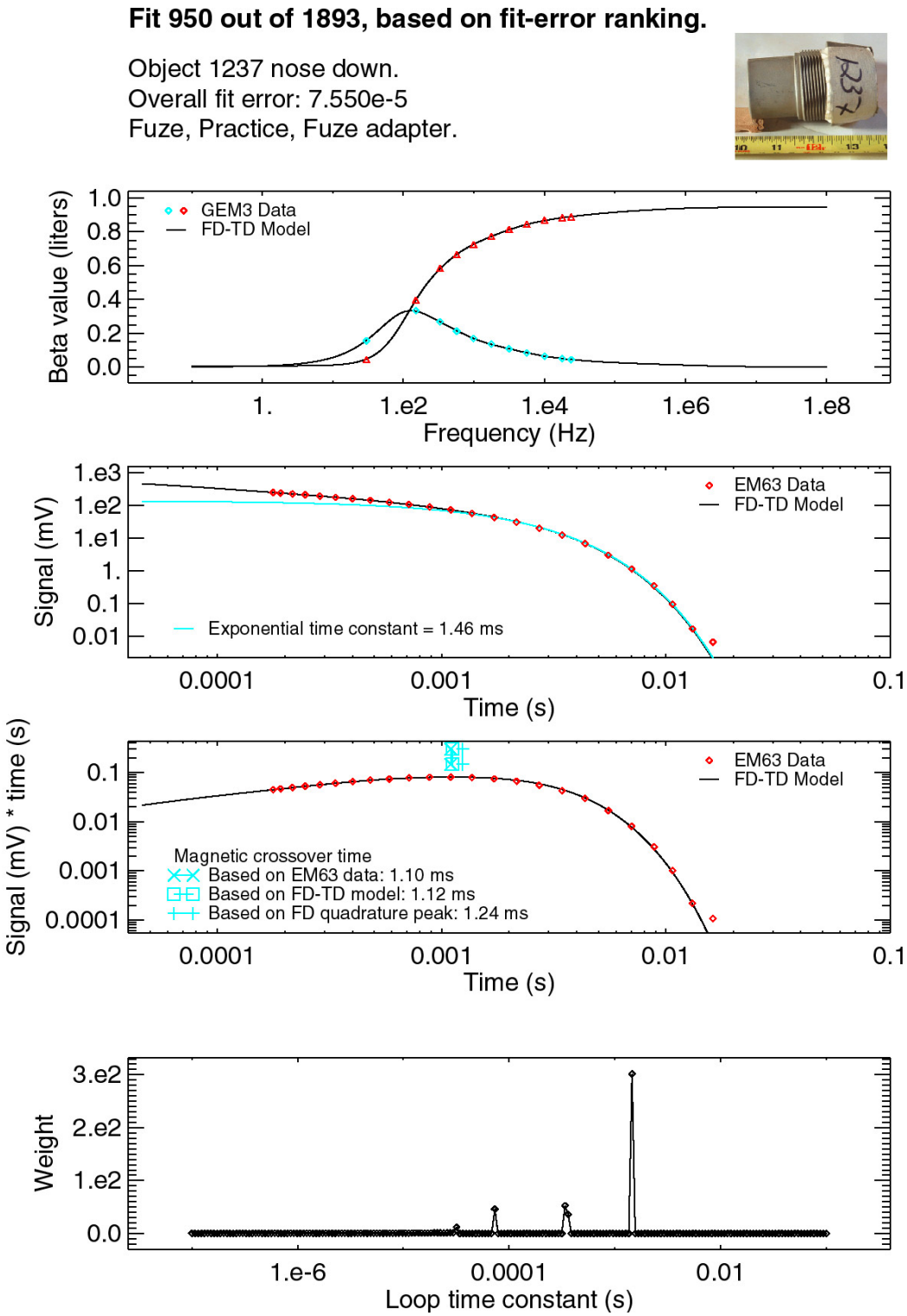


Figure 15. The 950th rank fit.

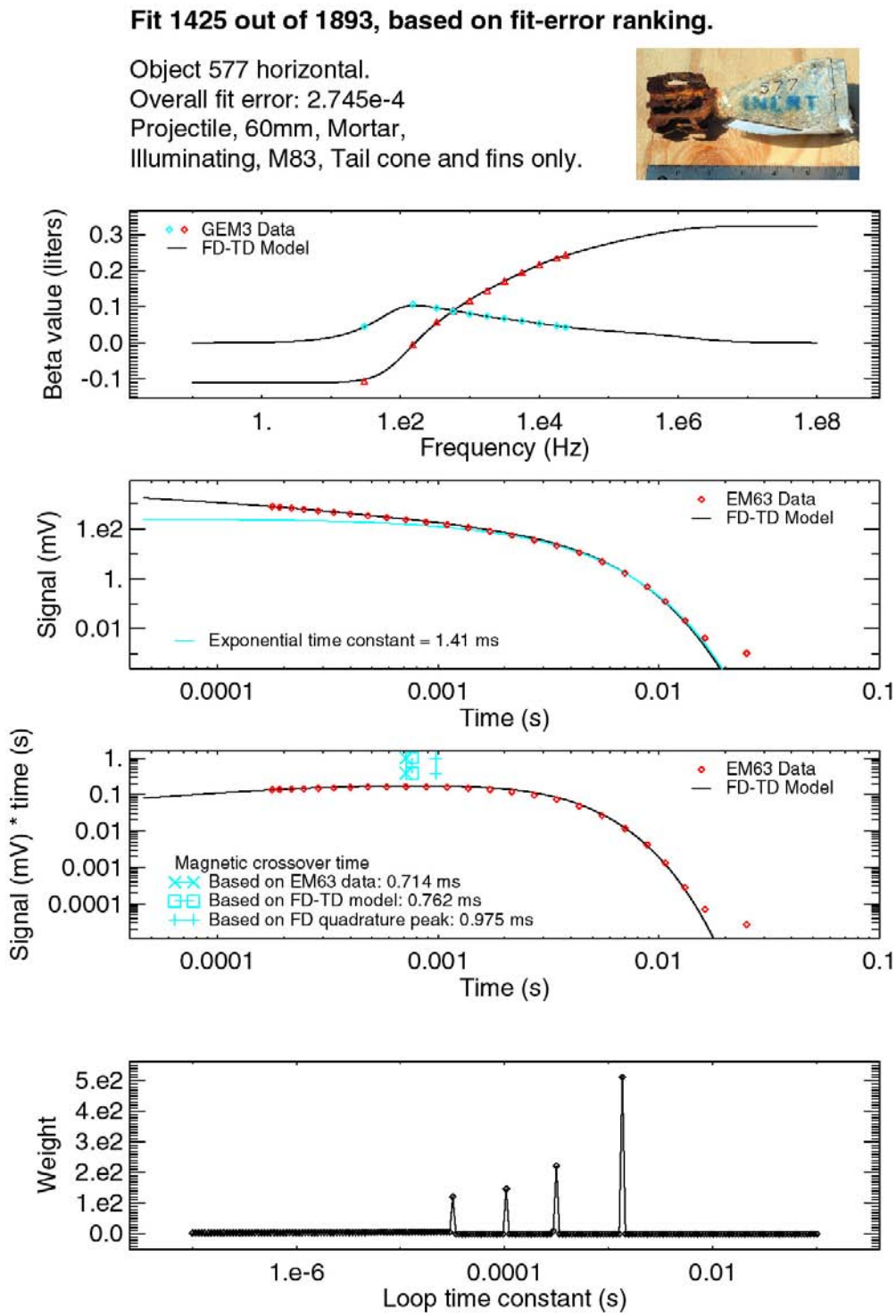


Figure 16. The 1425th rank fit.

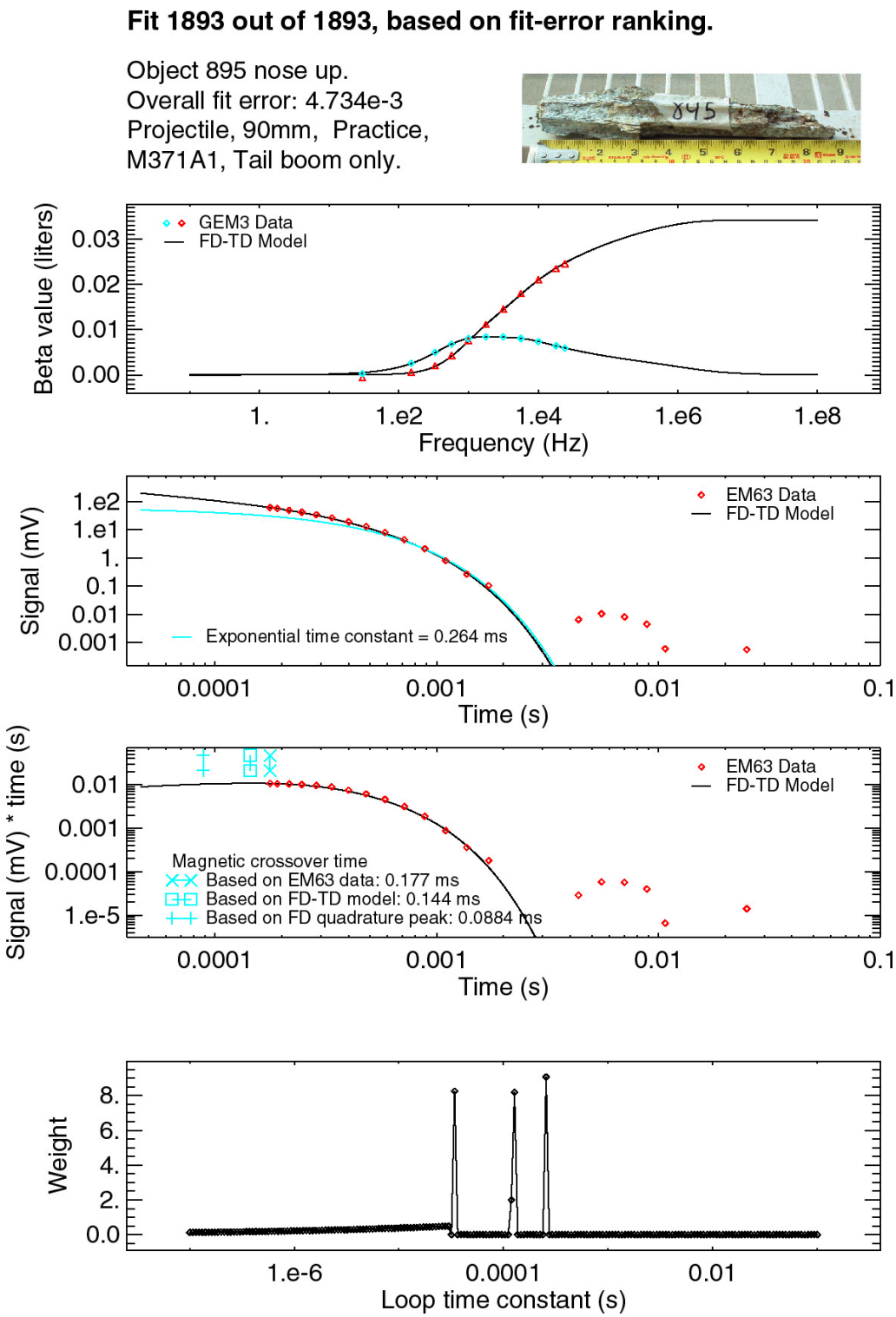


Figure 17. The rank 1893 (worst) fit.

5 Results

5.1 Groups

Out of the 664 targets measured, 596 were assigned into groups for calculation of ensemble statistics. The remaining 68 targets were not included in this exercise because they were "singletons" i.e. types for which only one example was found, or because equipment problems resulted in bad / missing data. A total of 93 groups were analyzed.

Individual targets were categorized into groups based on visual comparison of JPEG images of the target against images from the online UXO database ORDATA (http://maic.jmu.edu/ordata/Mission.asp). In the majority of cases, positive identification was possible. Together with written field notes, this process also resulted in precise information on the UXO nomenclature e.g. M301A3 81mm mortar rounds.

Some groups were divided into two or more sub-groups based on particular target attributes (e.g. presence or absence of rotating bands). These sub-divisions were based on examination of response data, field notes, and target images, but it is important to note that they are fundamentally subjective, and different choices of categorization would produce different results for variability. With that in mind, we used our best judgment and also provide the complete record of images, raw data, and grouped data for others to examine.

Two of the 596 targets were measured multiple times in order to calibrate the sensor and evaluate variability in our measurement process. Target 535, the calibration test sphere was measured 25 times for the purpose of sensor check and calibration against the analytic solutions. These data comprise group 0. Note that nose-up / horizontal / nose-down orientation is meaningless for this target, so the same data is simply repeated for all 3 orientations. Target 551, a 60mm mortar body was measured 5 times, forming group 1. These data were collected by different operators on different days in order to quantify the inherent variability in the process.

In addition, targets 528 through 534 (seven targets) were each included twice. These targets are actually the same item, a 60mm mortar, with different fuze / tail boom / fin configurations. Measurement of each configuration was included once as the lone member of a dedicated group (groups 2 through 8), and a second time as a member of group 9, which is aimed at quantifying variability due to fuze / tail boom / fin configurations only.

Table 4 shows a summary of the groups, and tables 5 and 6 show mean and standard deviations for recovered parameters.

Table 4

Group	Number of items in group	Description
0	25	Steel sphere, 4in dia, Chrome steel, Test object, Multiple shots on same target.
1	5	Projectile, 60mm, Mortar, Illuminating, M83, Nose and body only, Multiple shots on same target.
2	1	Projectile, 60mm, Mortar, HE, M49, No fuze.
3	1	Projectile, 60mm, Mortar, HE, M49, No fuze or fins.
4	1	Projectile, 60mm, Mortar, HE, M49, No fuze or fins or boom.
5	1	Projectile, 60mm, Mortar, HE, M49, No fuze or boom
6	1	Projectile, 60mm, Mortar, HE, M49, No boom
7	1	Projectile, 60mm, Mortar, HE, M49, No boom or fins
8	1	Projectile, 60mm, Mortar, HE, M49, No fins
9	7	Projectile, 60mm, Mortar, HE, M49, Same item with 7 different fuze/boom/fin configurations.
10	4	Projectile, 60mm, Mortar, Illuminating, M83, Nose and body only
11	3	Projectile, 60mm, Mortar, Illuminating, M83, Nose and body only, From Ft. McClellan.
12	17	Projectile, 60mm, Mortar, Illuminating, M83, Tail cone and fins only
13	5	Projectile, 81mm, Mortar, Illuminating, M301A1 & A2, Tail cone and fins only
14	5	Projectile, 81mm, Mortar, Illuminating, M301A3, Tail cone and fins only
15	15	Projectile, 81mm, Mortar, Illuminating, M301, Nose and body only
16	6	Projectile, 81mm, Mortar, Smoke, M819, Nose and body only
17	5	Projectile, 81mm, Mortar, Smoke, M819, Tail cone and fins only
18	5	Projectile, 81mm, Mortar, HE, M374, Tail cone and fins only
19	7	Projectile, 81mm, Mortar, Practice, M821, Body only
20	6	Projectile, 81mm, Mortar, Practice, M821, Body, boom, and fins.
21	2	Projectile, 155mm, Base ejection, No nose, Band intact
22	5	Projectile, 155mm, Base ejection, Band intact
23	9	Projectile, 81mm, Mortar, Smoke, M57, Tail cone and fins only
24	6	Projectile, 81mm, Mortar, Practice, M880, Body only
25	1	Projectile, 81mm, Mortar, Practice, M68, Body and fins
26	3	Projectile, 81mm, Mortar, Practice, M68, Body only, From Ft. McClellan
27	4	Projectile, 76mm, Practice, M496, Complete HEAT round
28	21	Projectile, 20mm, Practice, Highly deteriorated
29	4	Projectile, 60mm, Mortar, Smoke, M302, Body and fuze adapter only
30	3	Projectile, 60mm, Mortar, Practice, M69, From Ft. McClellan
31	2	Projectile, 60mm, Mortar, HE, M720, Un-filled body only.
32	6	Rocket, 3.5 inch, Practice, M29, Head only, Practice version of M28
33	8	Rocket, 3.5 inch, Practice, M29, Head and motor, Practice version of M28
34	4	Rocket, 3.5 inch, Practice, M29, Head and motor, Practice version of M28, From Ft. McClellan
35	10	Projectile, 3 inch, Mortar, Practice, Stokes, No fuze, From Ft. Ord
36	30	Projectile, 3 inch, Mortar, Practice, Stokes, No fuze, From Ft. McClellan
37	5	Rocket, 3.5 inch, Practice, M29, Motor only, Practice version of M28
38	4	Rocket, 5 inch, Practice
39	3	Grenade, Practice, MK II, Handle missing.

Table 4 - Continued		
40	10	Projectile, 4 inch, Mortar, Practice, Stokes, Body only
41	9	Projectile, 4 inch, Mortar, HE, Stokes, Remnance of low-order detonation
42	5	Projectile, 20mm, Practice, M99, Never fired, Band intact
43	10	Projectile, 37mm, Practice, Deteriorated, Band intact, From Ft. Ord
44	18	Projectile, 37mm, Practice, Deteriorated, Band intact, From Ft. McClellan
45	16	Projectile, 37mm, Practice, Deteriorated, Band missing, From Ft. McClellan
46	4	Projectile, 25mm, Practice, Band intact
47	9	Projectile, 40mm, Practice, M781
48	9	Projectile, 75mm, Shrapnel, Empty, Band intact
49	4	Projectile, 75mm, Shrapnel, Empty, Band intact, From Ft.McClellan
50	1	Projectile, 75mm, Shrapnel, Empty, Band missing, From Ft.McClellan
51	3	Projectile, 155mm, Shrapnel, Empty, Band intact
52	2	Projectile, 105mm, Empty, Band intact
53	2	Projectile, 105mm, Base ejection, Band intact
54	5	Projectile, 105mm, Illuminating
55	5	Grenade, Practice, M62, Fuze and handle missing., Practice version of M61
56	5	Grenade, Practice, MK II, Fake handle cast with body., From Ft. Ord.
57	6	Grenade, Practice, MK II, Fake handle cast with body., From Ft. McClellan.
58	10	Grenade, Practice, M69, Fuze and handle missing., Practice version of M67
59	9	Fuze, Practice, M1907
60	10	Fuze, Practice, MK VI, Used on Stokes Mortars.
61	11	Fuze, Practice, T-Bar
62	9	Fuze, Practice, M734, MO fuze.
63	2	Fuze, Practice, Simulated MT fuze.
64	9	Fuze, Practice, MT superquick A.
65	6	Fuze, Practice, MT superquick B.
66	3	Fuze, Practice, Fuze adapter.
67	8	Fuze, Practice, M745, PD fuze.
68	5	Fuze, Practice, M551, PD fuze.
69	11	Flare, M125, M126, M158, M159
70	5	Flare, M125, M126, M158, M159, Launcher tube only
71	10	Grenade, Rifle, Illuminating, M19
72	3	Grenade, Rifle, Practice, M11, Rear part of body
73	10	Grenade, Rifle, Practice, M11
74	2	Grenade, Rifle, Smoke, M22
75	7	Spent cartridge case, 40mm, M79
76	6	Spent cartridge case, 40mm
77	3	Grenade, Smoke, M18, From Ft. Ord.
78	5	Grenade, Smoke, M18, From Ft. McClellan
79	5	Projectile, 155mm, Shrapnel, Band intact., From Ft. Ord.
80	5	Projectile, 155mm, Shrapnel, Band intact., From Ft. McClellan
81	1	Projectile, 155mm, Shrapnel, Band intact., From Ft. McClellan, Full of lead balls.

Table 4 - Continued.		
82	3	Projectile, 155mm, Practice, Un-fired., Band intact.
83	4	Projectile, 120mm, Mortar, HE, M933, M934, Inert, un-fired.
84	1	Projectile, 90mm, Practice, M371A1, Tail boom and fins only
85	3	Projectile, 90mm, Practice, M371A1, Tail boom only
86	4	Projectile, 90mm, Shrapnel, Band intact.
87	8	Projectile, 81mm, Mortar, Practice, M43
88	31	Rocket, 2.36 inch, Practice, M7, Motor only., Practice version of M6.
89	7	Rocket, 2.36 inch, Practice, M7, Fuze body (adapter)., Practice version of M6.
90	30	Rocket, 2.36 inch, Practice, M7, Head and motor., Practice version of M6., From Ft. McClellan.
91	5	Flare, M48 or M2, Casing for M48 trip flare or M2 landmine.
92	5	Projectile, 57mm, Practice, Deteriorated, Band missing, From Ft. McClellan

Table 4. Summary of groups.

Table 5

	Amplitude parameter (liters)							S parameter (liters)					
	Nose Up		Horizontal		Nose Down			Nose Up		Horizontal		Nose Down	
Group	Mean	StdDev	Mean	StdDev	Mean	StdDev		Mean	StdDev	Mean	StdDev	Mean	StdDev
0	0.49	0.03	0.49	0.03	0.49	0.03		-1.4	0.087	-1.4	0.087	-1.4	0.087
1	0.63	9.40E-03	0.37	6.20E-03	1	0.015		-1.4	0.018	-0.68	0.011	-2.5	0.058
2	0.82	n/a	0.25	n/a	0.39	n/a		-2.8	n/a	-0.65	n/a	-1.6	n/a
3	0.59	n/a	0.2	n/a	0.33	n/a		-1.9	n/a	-0.48	n/a	-1	n/a
4	0.45	n/a	0.19	n/a	0.45	n/a		-1.5	n/a	-0.48	n/a	-1.5	n/a
5	0.91	n/a	0.24	n/a	0.82	n/a		-3.1	n/a	-0.65	n/a	-2.9	n/a
6	0.86	n/a	0.26	n/a	0.98	n/a		-2.6	n/a	-0.66	n/a	-3.4	n/a
7	0.42	n/a	0.22	n/a	0.49	n/a		-1.2	n/a	-0.5	n/a	-1.6	n/a
8	0.56	n/a	0.22	n/a	0.41	n/a		-1.6	n/a	-0.5	n/a	-1.2	n/a
9	0.66	0.2	0.23	0.027	0.55	0.25		-2.1	0.72	-0.56	0.087	-1.9	0.91
10	0.67	0.067	0.36	8.70E-03	1.2	0.21		-1.5	0.22	-0.66	3.50E-03	-2.8	0.36
11	0.73	0.052	0.36	0.013	1.1	0.19		-1.8	0.082	-0.73	0.07	-3.1	0.72
12	0.19	3.00E-03	0.099	4.80E-03	0.12	0.015		-0.085	7.30E-03	-0.096	0.016	-0.46	0.063
13	1.4	0.079	0.29	0.015	0.33	4.70E-03		-3.6	0.25	-0.6	0.041	-0.62	0.016
14	2.2	0.13	0.37	0.019	0.33	0.011		-6.2	0.4	-0.68	0.039	-0.66	0.04
15	1.7	0.18	0.88	0.067	3.3	0.69		-3.9	0.5	-1.8	0.19	-8.8	1.9
16	0.81	0.06	0.75	0.13	1.2	0.029		-0.12	0.067	-0.16	0.037	0.085	0.018
17	1	0.018	0.32	0.012	0.2	4.90E-03		0.1	5.00E-03	0.019	4.40E-03	-0.012	1.00E-03
18	2.1	0.35	0.37	0.037	0.41	0.024		-7.1	1.2	-0.79	0.085	-0.85	0.091
19	3.5	0.81	0.48	0.033	3.5	0.42		-11	3.9	-1.1	0.089	-12	2.3
20	3.9	0.87	0.46	7.60E-03	0.75	0.011		-14	3.2	-1.1	0.025	-2.2	0.02
21	48	n/a	7.9	n/a	61	n/a		-1.40E+02	n/a	-15	n/a	-1.50E+02	n/a
22	30	1.4	8.5	0.41	1.20E+02	2.1		-63	2.7	-15	0.76	-2.80E+02	7.2
23	1.8	0.52	0.33	0.044	0.32	0.039		-4.9	1.5	-0.65	0.034	-0.61	0.087
24	1.8	0.044	0.6	0.012	1.4	0.034		-6	0.13	-1.4	0.032	-4.6	0.11
25	2.8	n/a	0.52	n/a	2.7	n/a		-11	n/a	-1.4	n/a	-9.9	n/a
26	1.8	0.79	0.5	0.037	1.7	0.64		-6.9	3	-1.3	0.11	-6.4	2.3
27	7.2	0.37	0.69	0.013	1.4	0.082		-22	1	-1.7	0.029	-3.1	0.17
28	0.036	0.016	8.90E-03	1.90E-03	0.041	0.018		-0.13	0.054	-0.022	4.20E-03	-0.14	0.059
29	0.76	8.60E-03	0.19	7.80E-03	0.68	0.017		-2.2	0.03	-0.43	0.024	-2	0.051
30	0.87	0.029	0.21	0.015	0.75	0.043		-3.2	0.1	-0.55	0.045	-2.7	0.29
31	2.2	n/a	0.27	n/a	1.8	n/a		-6.9	n/a	-0.67	n/a	-5.8	n/a
32	2.6	0.25	0.68	0.069	2.4	0.82		-7.2	0.91	-1.6	0.22	-7.3	2.6
33	2.9	0.37	0.51	0.041	2	0.37		-9.4	1.6	-1.4	0.15	-5.8	1.5
34	8.4	1	0.71	0.019	4	0.57		-29	3.1	-1.9	0.067	-11	2.3
35	4.9	0.46	0.79	0.036	3.7	0.5		-15	2.7	-2.1	0.1	-11	2.2
36	5.9	0.68	1	0.049	5.8	0.8		-20	2.9	-2.6	0.091	-19	3
37	1.6	0.64	0.29	0.065	1.6	0.46		-4.2	2.4	-0.61	0.14	-4.3	1.7
38	11	0.65	4.4	0.16	8.1	0.38		-29	1.7	-9.7	0.4	-21	0.83

Table 5 - Continued

39	0.57	0.014	0.11	2.10E-03	0.79	0.011		-1.7	0.039	-0.27	4.80E-03	-2.5	0.038
40	7	1.3	1.4	0.22	5.3	0.56		-22	2.5	-3.4	0.5	-16	1.4
41	3.3	1.6	0.61	0.44	4.1	0.94		-11	4.2	-1.7	0.93	-14	2.8
42	0.2	2.40E-03	0.016	1.20E-03	0.32	2.50E-03		-0.62	6.20E-03	-0.037	2.60E-03	-0.91	6.20E-03
43	1.1	0.069	0.08	5.70E-03	1.3	0.1		-3.4	0.17	-0.21	0.013	-3.5	0.21
44	1	0.29	0.09	3.10E-03	1.2	0.35		-3.2	0.94	-0.23	7.70E-03	-3.1	0.95
45	0.86	0.27	0.086	0.01	0.96	0.3		-3.1	0.94	-0.22	0.022	-3.4	0.97
46	0.37	7.90E-03	0.048	1.10E-03	0.66	0.011		-1	0.014	-0.11	1.90E-03	-1.8	0.031
47	0.21	0.036	0.021	3.90E-03	0.21	0.042		-0.088	0.13	-5.60E-03	9.00E-03	-0.096	0.14
48	3.4	0.28	0.6	0.022	4.5	0.33		-11	0.74	-1.4	0.06	-11	0.7
49	1.9	0.057	0.67	5.90E-03	2.6	0.082		-6	0.22	-1.6	0.02	-6.3	0.28
50	1.9	n/a	0.63	n/a	2.1	n/a		-5	n/a	-1.4	n/a	-5.5	n/a
51	13	0.25	3.1	0.11	17	0.086		-33	1.1	-5.1	0.05	-32	0.34
52	5.3	n/a	1.5	n/a	9.7	n/a		-15	n/a	-3.3	n/a	-23	n/a
53	6.5	n/a	2.1	n/a	11	n/a		-19	n/a	-4.7	n/a	-26	n/a
54	4	0.67	1.7	0.014	8	0.44		-11	2	-4	0.059	-22	1.4
55	0.76	0.11	0.12	5.80E-03	0.82	0.041		-2.1	0.34	-0.29	4.70E-03	-2.3	0.083
56	0.98	0.036	0.13	4.80E-03	1	0.018		-3.2	0.14	-0.33	0.013	-3.3	0.069
57	0.15	7.70E-03	0.11	4.40E-03	0.18	0.014		-0.47	0.033	-0.27	0.011	-0.56	0.044
58	0.62	0.077	0.11	4.80E-03	0.67	0.028		-1.7	0.24	-0.3	0.02	-1.8	0.11
59	0.32	0.03	0.08	9.60E-03	0.4	0.046		-0.34	0.091	-0.23	0.046	-0.62	0.14
60	0.71	0.07	0.12	9.10E-03	0.8	0.062		-2	0.19	-0.33	0.019	-2.2	0.15
61	0.36	0.041	0.059	5.30E-03	0.38	0.054		-1.1	0.11	-0.19	0.016	-1.1	0.13
62	0.41	0.052	0.088	3.30E-03	0.47	0.11		-0.84	0.26	-0.25	6.00E-03	-1.1	0.35
63	0.97	n/a	0.094	n/a	1.2	n/a		-2.8	n/a	-0.14	n/a	-3.2	n/a
64	0.22	0.15	0.067	0.026	0.44	0.2		-0.53	0.42	-0.19	0.049	-1.1	0.58
65	0.18	0.02	0.046	8.60E-03	0.22	2.40E-03		-0.04	2.20E-03	-5.60E-03	1.20E-03	-0.037	2.40E-03
66	0.4	6.90E-03	0.088	9.60E-04	0.33	1.80E-03		0.016	3.90E-03	2.00E-03	1.80E-04	6.20E-03	2.50E-03
67	0.16	0.03	0.047	0.015	0.24	0.076		-0.14	0.13	-0.065	0.072	-0.24	0.32
68	0.084	0.02	0.016	6.80E-04	0.12	0.018		-0.027	6.20E-03	-6.90E-03	3.70E-04	-0.048	7.40E-03
69	0.26	0.076	0.093	0.023	0.14	0.045		-0.12	0.07	-0.044	0.014	-0.43	0.12
70	0.36	3.10E-03	0.24	2.00E-03	0.32	2.90E-03		-0.02	1.90E-03	-9.90E-03	2.50E-03	0.022	4.40E-03
71	0.42	0.034	0.12	4.20E-03	0.58	0.18		-0.26	0.053	-0.13	0.027	-1.6	0.46
72	0.27	0.077	0.097	6.80E-03	0.24	0.056		-0.87	0.24	-0.24	0.013	-0.78	0.19
73	0.79	0.27	0.14	0.016	0.6	0.14		-2.4	0.8	-0.33	0.038	-1.9	0.47
74	1.2	n/a	0.17	n/a	1	n/a		-3.4	n/a	-0.35	n/a	-3.3	n/a
75	0.22	4.20E-03	0.034	5.30E-04	0.21	6.50E-03		-0.077	4.50E-03	-0.033	6.10E-04	-0.1	2.70E-03
76	0.54	0.038	0.14	4.40E-03	0.59	0.069		-0.18	0.16	-0.011	8.00E-03	-0.14	0.17
77	0.35	0.24	0.1	0.079	0.52	0.3		-0.51	0.4	-0.17	0.072	-0.7	0.52
78	0.26	0.069	0.22	0.046	0.3	0.075		-0.39	0.12	-0.28	0.048	-0.44	0.14
79	12	0.18	3	0.052	17	0.37		-32	0.83	-5	0.14	-32	0.94
80	14	0.31	5.5	0.18	18	0.62		-37	2.4	-11	0.47	-37	2

Table 5 - Continued													
81	14	n/a	5.4	n/a	15	n/a		-38	n/a	-11	n/a	-42	n/a
82	6.5	1.6	7.1	0.07	17	1.9		-17	5.9	-14	1.4	-42	0.51
83	4.3	1.3	2.3	0.025	1.1	0.03		-10	2.8	-4.8	0.036	-2.2	0.04
84	0.092	n/a	0.13	n/a	0.17	n/a		-5.20E-04	n/a	-5.80E-03	n/a	-1.60E-03	n/a
85	0.037	0.039	0.048	0.024	0.05	0.022		4.20E-04	6.10E-04	-4.50E-04	3.40E-04	-3.50E-04	3.60E-04
86	4	0.34	1.3	0.058	5.3	0.26		-12	1	-3	0.17	-12	0.63
87	2.6	0.67	0.54	0.022	3.3	0.15		-7.6	2.1	-1.4	0.05	-11	0.26
88	1.5	0.12	0.13	7.30E-03	1.4	0.069		-4.4	0.44	-0.33	0.03	-4.1	0.25
89	0.31	0.088	0.029	8.30E-03	0.33	0.11		-1.2	0.33	-0.095	0.017	-1.2	0.41
90	1.4	0.17	0.33	0.036	1.5	0.22		-4.8	0.47	-0.9	0.1	-4.9	0.45
91	0.92	0.14	0.52	0.05	1	0.12		-2.4	0.37	-1.3	0.19	-2.8	0.3
92	1.8	0.088	0.26	0.045	2	0.49		-5.8	0.28	-0.65	0.12	-6.3	1.6

Table 5. Statistics for amplitude *A* and static dipole *S* parameters.

Table 6

	Magnetic crossover parameter (s)							Fundamental late-time decay constant (s)					
	Nose Up		Horizontal		Nose Down			Nose Up		Horizontal		Nose Down	
Group	Mean	StdDev	Mean	StdDev	Mean	StdDev		Mean	StdDev	Mean	StdDev	Mean	StdDev
0	0.23	0.015	0.23	0.015	0.23	0.015		4.1	0.19	4.1	0.19	4.1	0.19
1	0.41	6.70E-03	0.11	5.50E-03	0.33	7.00E-03		1.9	0.019	1.1	0.096	2.2	0.088
2	0.3	n/a	0.11	n/a	0.32	n/a		3.1	n/a	2.1	n/a	1.9	n/a
3	0.3	n/a	0.1	n/a	0.36	n/a		1.8	n/a	2.5	n/a	2.2	n/a
4	0.27	n/a	0.095	n/a	0.27	n/a		2.4	n/a	1.7	n/a	1.5	n/a
5	0.49	n/a	0.11	n/a	0.53	n/a		2.5	n/a	1.6	n/a	2.5	n/a
6	0.55	n/a	0.11	n/a	0.52	n/a		2.5	n/a	1.5	n/a	2.6	n/a
7	0.43	n/a	0.095	n/a	0.33	n/a		2.1	n/a	1.7	n/a	1.7	n/a
8	0.43	n/a	0.1	n/a	0.41	n/a		2	n/a	1.9	n/a	1.7	n/a
9	0.4	0.11	0.1	7.80E-03	0.39	0.099		2.3	0.41	1.8	0.36	2	0.44
10	0.4	0.027	0.11	5.90E-03	0.31	0.024		1.8	0.22	1.4	0.4	2.2	0.45
11	0.39	0.049	0.087	9.30E-03	0.31	0.052		2.6	0.83	2.8	0.67	2.5	0.46
12	1.4	0.13	0.93	0.11	1.2	0.12		1.6	0.053	1.5	0.059	1.7	0.067
13	0.43	0.023	0.22	6.70E-03	0.54	0.021		2.2	0.13	1.7	0.13	2	0.15
14	0.49	0.045	0.32	0.01	0.63	0.046		2.6	0.18	1.9	0.28	2.6	0.37
15	0.57	0.073	0.17	0.032	0.4	0.047		2.4	0.087	2.2	0.31	2.6	0.2
16	1.7	0.12	0.75	0.031	1.2	0.048		2.6	0.53	1.8	0.15	2.2	0.51
17	1.6	0.12	0.58	0.036	0.77	9.30E-03		1.7	0.042	1.6	0.027	1.8	0.067
18	0.37	0.037	0.28	0.018	0.6	0.16		2.6	0.096	2.3	0.12	2.5	0.086
19	0.41	0.16	0.11	0.074	0.39	0.16		3.3	0.6	2.9	0.65	3.3	0.55
20	0.29	0.023	0.09	0.014	0.36	0.01		3.7	0.043	3.3	0.072	3.5	0.095
21	1.3	n/a	0.33	n/a	1.6	n/a		10	n/a	3.7	n/a	11	n/a
22	3.7	0.2	0.35	0.023	1.6	0.092		9.8	0.52	3.6	0.22	11	0.74
23	0.42	0.069	0.26	0.058	0.53	0.078		2.1	0.36	1.7	0.23	2	0.39
24	0.31	0.02	0.094	2.50E-03	0.32	0.014		1.8	0.16	1.5	0.2	1.8	0.16
25	0.38	n/a	0.089	n/a	0.46	n/a		3.5	n/a	4.1	n/a	3.6	n/a
26	0.32	0.097	0.083	0.016	0.36	0.11		3.8	0.17	4.1	0.076	3.9	0.13
27	0.65	0.041	0.26	7.70E-03	1.1	0.029		3.7	0.013	3.2	0.021	3.3	0.03
28	0.36	0.19	0.071	9.10E-03	0.37	0.21		1.8	0.6	1.3	0.45	1.9	0.58
29	0.39	5.90E-03	0.13	5.90E-03	0.39	3.50E-03		3.4	0.075	3.1	0.083	3.2	0.066
30	0.39	9.30E-03	0.079	3.50E-03	0.43	3.50E-03		3.2	0.13	3.2	0.094	3.1	0.13
31	0.42	n/a	0.1	n/a	0.43	n/a		2.3	n/a	2.2	n/a	2.2	n/a
32	0.22	0.052	0.11	0.07	0.26	0.099		3	0.09	2.3	0.71	2.8	0.47
33	0.19	0.064	0.12	0.014	0.49	0.049		2.9	0.32	2.6	0.24	2.8	0.16
34	0.2	0.079	0.16	0.031	0.71	0.1		3	0.07	2.7	0.12	3	0.096
35	1.6	0.39	0.2	0.045	1.7	0.35		5.7	1.2	3.5	0.15	6.3	0.94
36	1.3	0.45	0.15	0.051	1.5	0.43		7.7	1.7	3.5	0.13	7.9	1.3
37	0.75	0.22	0.15	0.022	0.62	0.12		3	0.14	2.8	0.49	2.8	0.12
38	2.7	0.25	0.34	5.90E-03	4.2	1.1		9.6	0.41	3.8	1.60E-03	8.2	0.44

Table 6 - Continued

39	0.15	6.10E-03	0.077	0	0.14	3.50E-03		1	0.66	0.64	0.16	0.87	0.2
40	1.2	0.46	0.3	0.026	1.9	0.41		6.9	0.88	3.5	0.17	7.5	0.53
41	0.9	0.1	0.33	0.024	1.1	0.21		5.7	0.29	3.6	0.14	7.2	0.34
42	0.67	0.025	0.068	3.40E-03	0.7	0.031		2.7	0.21	2.9	0.33	2.8	0.18
43	0.97	0.19	0.12	0.013	0.92	0.18		3.6	0.12	3.9	0.38	3.7	0.11
44	1	0.041	0.13	6.60E-03	0.95	0.049		3.7	0.044	4	0.22	3.7	0.057
45	0.43	0.16	0.095	7.10E-03	0.42	0.14		3.7	0.23	3.9	0.43	3.7	0.22
46	0.64	0.066	0.1	0.01	0.62	0.057		1.9	0.16	2.1	0.061	2	0.15
47	1.2	0.84	0.49	0.17	1.2	0.84		1.3	0.82	0.58	0.22	1.2	0.85
48	1.5	0.25	0.23	0.018	4.2	0.94		6.1	0.61	3	0.23	6.2	0.63
49	1.5	0.28	0.23	0.028	3.2	0.37		5.3	0.43	3	0.16	5.5	0.46
50	0.52	n/a	0.26	n/a	0.54	n/a		3.2	n/a	2.9	n/a	3.5	n/a
51	1.4	0.064	0.38	0.013	13	0.22		12	0.37	2.7	0.076	14	0.14
52	2.4	n/a	0.31	n/a	5.9	n/a		11	n/a	3.5	n/a	11	n/a
53	2	n/a	0.28	n/a	5.1	n/a		12	n/a	3.6	n/a	11	n/a
54	1.7	0.11	0.27	0.012	1.8	0.12		5.4	0.5	3.3	0.11	4.6	0.93
55	0.096	0.01	0.069	2.70E-03	0.093	3.40E-03		0.76	0.21	0.59	0.27	1.7	2.5
56	0.18	0.014	0.086	3.40E-03	0.17	0.011		2.3	1.1	1.2	1.1	2	0.69
57	0.14	0.024	0.074	0.011	0.13	0.023		0.98	0.77	0.95	0.75	0.96	0.81
58	0.17	0.025	0.15	0.015	0.16	0.022		1.4	0.32	1.3	0.33	1.4	0.33
59	0.5	0.077	0.17	0.03	0.44	0.098		3	0.91	2.7	0.39	3	0.94
60	0.071	9.80E-03	0.067	5.20E-03	0.073	8.30E-03		1.1	0.26	1.1	0.36	1.2	0.37
61	0.17	0.016	0.13	9.50E-03	0.17	0.03		3.8	0.08	3.5	0.21	3.8	0.085
62	0.54	0.047	0.14	0.026	0.43	0.1		2.8	0.25	2.4	0.1	2.8	0.21
63	1.2	n/a	0.6	n/a	0.71	n/a		3	n/a	2.9	n/a	3	n/a
64	0.17	0.03	0.1	0.013	0.17	0.042		2	0.7	1.8	0.66	2	0.66
65	1.1	0.1	0.86	0.068	1.1	0.092		1.5	0.2	1.3	0.13	1.5	0.082
66	1.3	0.11	1.1	0.099	1.1	0.053		1.5	0.027	1.3	0.019	1.5	0.054
67	0.82	0.11	0.22	0.035	0.84	0.14		1.3	0.63	0.93	0.66	1.3	0.61
68	0.37	0.011	0.071	0	0.36	8.70E-03		0.46	0.026	0.57	0.082	0.49	0.051
69	0.19	0.19	0.18	0.051	0.13	0.046		1.3	0.15	0.36	0.14	2	0.93
70	0.34	0.011	0.39	0.014	0.43	0.019		1.7	0.11	1	0.32	1.6	0.17
71	0.4	0.052	0.44	0.065	0.2	0.12		1.3	0.42	0.63	0.13	2.7	0.81
72	0.13	0.047	0.048	3.50E-03	0.15	0.059		2.5	1.2	2.1	1.4	2.3	1.4
73	0.1	0.017	0.047	1.90E-03	0.13	0.037		3.3	0.16	3.2	0.91	3.3	0.13
74	0.1	n/a	0.067	n/a	0.2	n/a		3.6	n/a	3.4	n/a	3.6	n/a
75	0.16	6.90E-03	0.12	0.031	0.3	0.033		1.2	0.057	0.82	0.034	1.2	0.047
76	0.34	0.046	0.37	1.00E-02	0.47	0.095		1.1	0.11	0.66	0.051	1.1	0.12
77	0.068	0.029	0.046	0	0.048	3.50E-03		3.8	3.2	2.7	0.89	3	1.8
78	0.061	9.30E-03	0.047	2.70E-03	0.053	0.011		4.5	1.3	2.3	1.7	5.2	1.7
79	1.4	0.096	0.39	9.30E-03	14	0.34		13	0.68	2.7	0.075	15	0.48
80	1.7	0.36	0.38	0.029	13	0.7		12	0.3	3.5	0.073	14	0.73

Table 6 - Continued													
81	1.5	n/a	0.36	n/a	1.6	n/a		11	n/a	3.6	n/a	12	n/a
82	4.9	2	0.35	0.014	6.6	3.4		8.2	1.4	3.5	0.054	10	0.31
83	0.75	0.12	0.34	6.10E-03	1.7	0.051		3.3	0.33	3.5	0.057	3.7	5.10E-03
84	0.36	n/a	0.57	n/a	0.35	n/a		0.49	n/a	0.88	n/a	0.45	n/a
85	0.16	0.064	0.27	0.096	0.13	0.016		0.29	0.068	0.44	0.044	0.32	0.073
86	2	0.13	0.31	0.01	5.3	1.5		7.7	0.7	3.7	0.061	8.1	0.68
87	0.59	0.058	0.16	0.019	0.62	0.011		3.6	0.28	3.3	0.14	3.5	0.31
88	0.42	0.034	0.099	0.015	0.43	0.025		3.3	0.32	2.5	0.75	3.1	0.44
89	0.16	0.029	0.11	0.077	0.16	0.039		3.2	0.42	3.1	0.62	3.2	0.41
90	0.48	0.23	0.16	0.027	0.56	0.085		3.5	0.18	3.7	0.37	3.6	0.12
91	0.33	0.057	0.13	0.023	0.33	0.054		2.6	0.65	1.7	0.53	2.5	0.91
92	0.47	0.015	0.13	8.00E-03	0.46	0.038		3.3	0.085	4	0.043	3.2	0.085

Table 6. Statistics for magnetic crossover time and late-time fundamental decay time constant.

5.2 Check of measurement consistency

Group 1 represents five repeated measurement of target 551, a 60mm mortar body. To make this consistency check robust, these data were collected on different days with different personnel operating the test stand. If our procedures were perfect, variability in this group would be zero, but in practice some variability is evident due to errors creeping in.

The Coefficient of Variation (CV) is a measure of the dispersion of a distribution, defined as the ratio of the Standard Deviation to the Mean. If we look at all the data for this group, including all four parameters (A, S, τ_{mag}, and τ_f) and all three target orientations, we observe an overall median CV of 1.97%. Measurement of response magnitude A had the best consistency with median CV of 1.40% across all three target orientations. Masurement of late-time fundamental decay time constant τ_f had the worst, with median CV of 4.00%. These values may be regarded as the inherent error level in our parameter measurement process.

5.3 Variability due to fuze / tail boom / fin configuration

Group 9 represents 7 shots of the same 60mm mortar, with different fuze / tail boom / fin configurations. These data reveal substantial variability in recovered parameters, with CV values up to 45%. A full synopsis can be seen in the group report for group 9 in Appendix D.

5.4 Confidence intervals and Sample Size.

The observed mean and variance in our samples represent only estimators of the true mean and variance of the underlying distributions from which the samples were drawn. Confidence intervals (error bars)

around our estimates were calculated using Jackknife and Bootstrap re-sampling plans, discussed in detail in a white paper, included as Appendix C.

Jackknife and Bootstrap confidence intervals are presented along with estimated mean and standard deviation in the group reports. These confidence intervals shrink with increasing sample size *n*, and our working goal was that the error bars should be less than one third (33%) of the estimate value. We aimed to collect enough UXO items in each category to satisfy this condition, usually 10 to 30 sufficed depending on the type, but availability was a problem in some cases.

Jackknife and Bootstrap confidence intervals printed in red in the group reports in Appendix D indicate cases where the 33% working goal was not met. More UXO in these categories would have to be processed to increase accuracy of these estimated moments.

5.5 An example of non-obvious UXO differences

Group 63 is composed of two practice fuzes which were assumed to be of similar design based on visual inspection. Neither could be positively identified using the online ORDATA database, or any other source we had available. EMI data revealed however, that these two targets are very different: one is highly permeable and the other is essentially impermeable. Upon close inspection of the photographs, small differences can be seen which may serve as indicators for items of this kind. Figures 18 and 19 show nose-down response for these two targets.

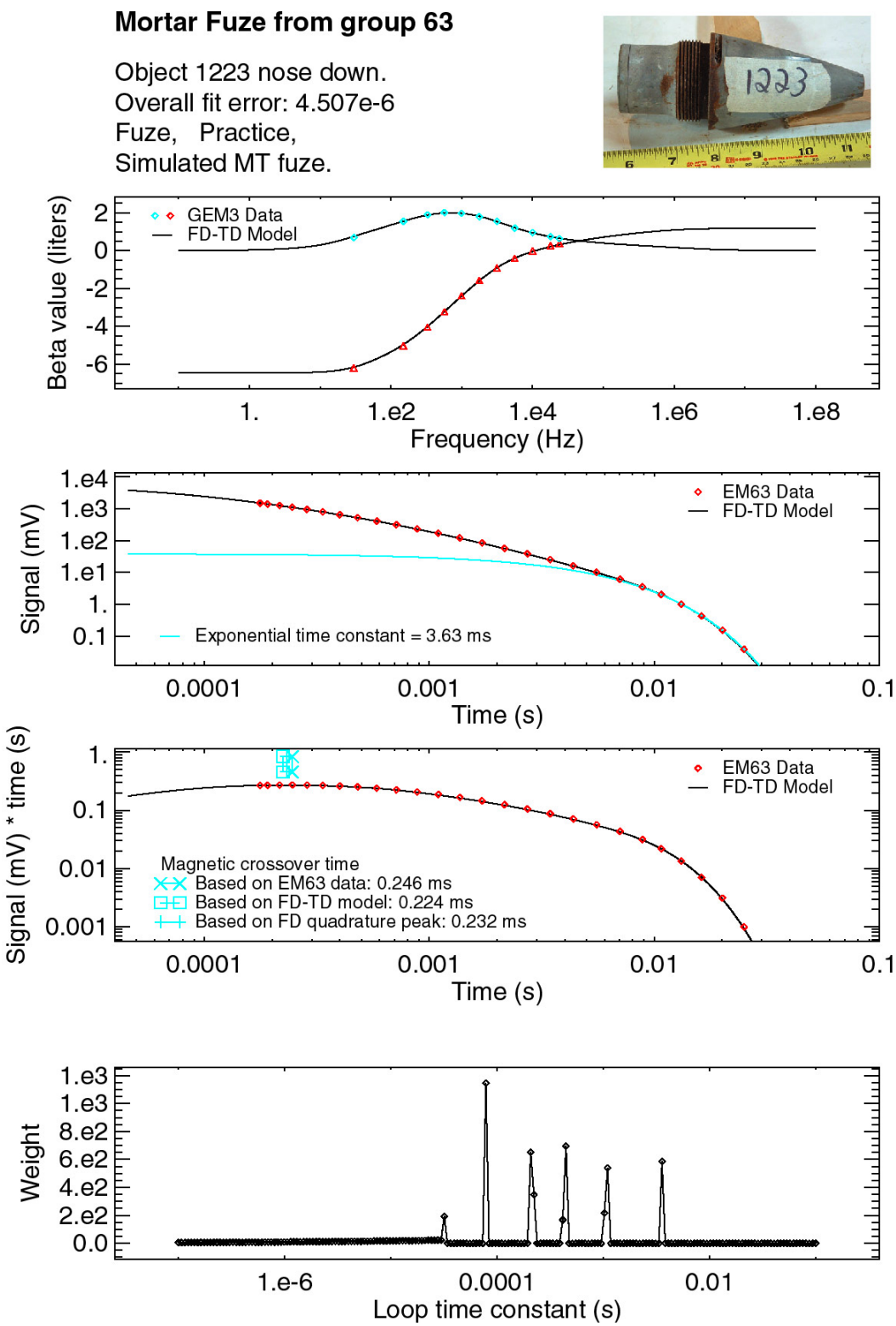


Figure 18. Target 1223 and 1224 appear visually to be similar but exhibit very different EMI signatures.

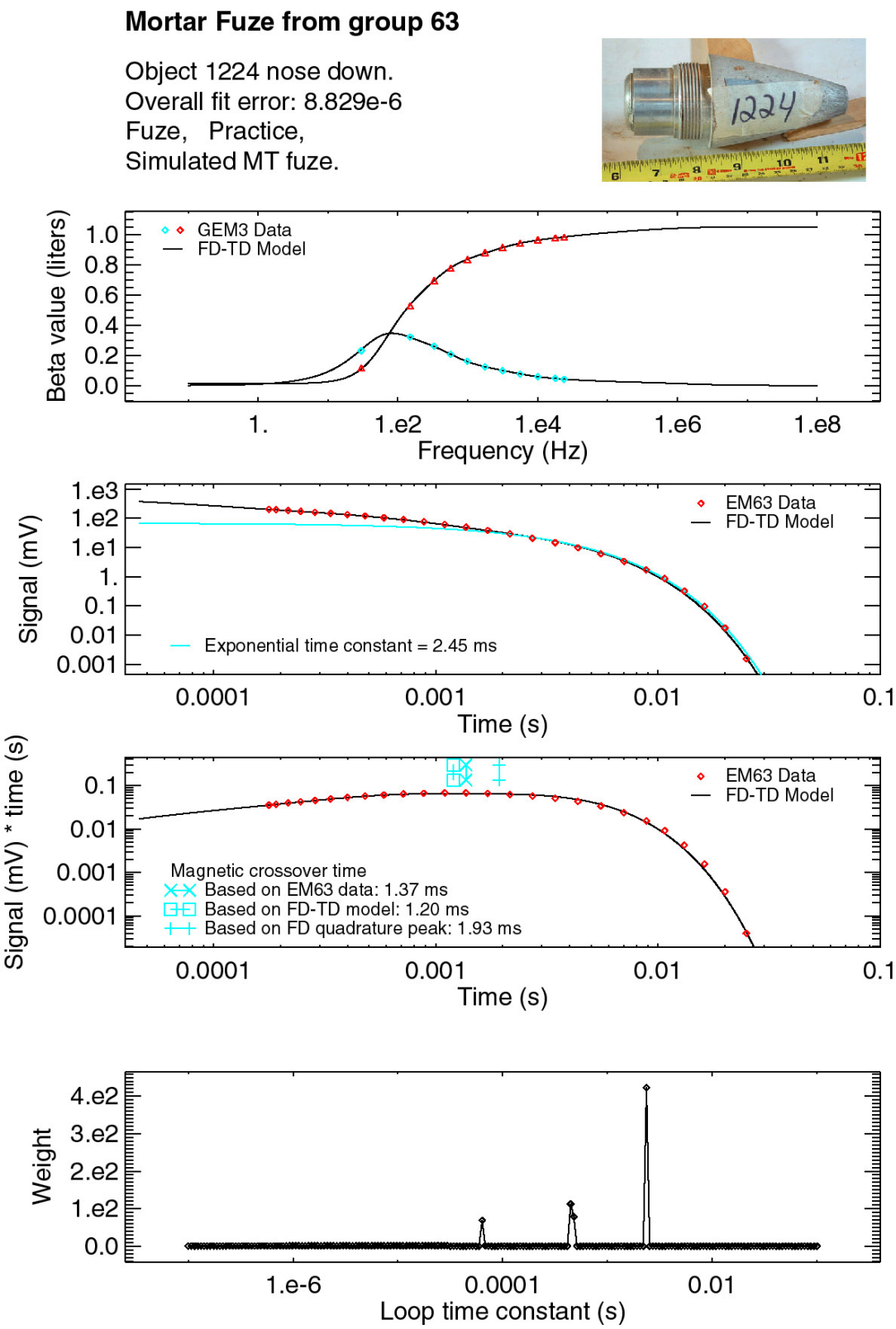


Figure 19. Target 1224 response, for comparison against target 1223.

5.6 Group results

Appendix D of this report contains results for all 93 groups in the study. Electronic versions of these reports are also included in Appendix E, the attached CD ROM.

5.7 Attached CD ROM.

Appendix E. is a CD ROM containing several folders. It includes all the raw data for this project, in comma-separated ascii format. It also includes JPEG images of each target, all the group reports, and all the individual fit reports for all targets in the study.

6. Conclusions

This project was fundamentally a pure data collection and analysis effort aimed at quantifying inherent variability in the EMI response of real UXO targets. The moments presented in tables 5 and 6, as well as the box-plots presented in appendix D represent the desired results, namely estimated means and standard deviations, including uncertainty estimates, for physical response parameters of UXO.

6.1 Representation of Variability

We initially expressed variability directly through moments of fitted model parameter values, but after collecting the bulk of the data we discovered that the fitting process sometimes led to regions in parameter space where dissimilar response curves could result from similar parameter values, or dissimilar parameter values could result in similar response curves. This caused instability in the fitting process and effectively invalidated our approach. As outlined in section 3.3, we therefore abandoned this approach, and ultimately went ahead with a different method in which physically meaningful parameters were derived from the model fits, and variability was expressed through those. The four physical parameters are described in section 4.9.

6.2 ROC Curves

We intended to define decision rules in multi-dimensional parameter space to encompass fitted parameter values of each UXO group, like the ellipsoids on p. 4. By varying the size of the decision rules we could generate Receiver Operating Characteristics (ROC) curves which would express the irreducible variability of the UXO – an upper bound on discrimination performance. Assessment of the best possible ROC curve hinges critically on the form of the surface in parameter space, e.g. an ellipsoid or rectangular prism, etc. This is a topic of ongoing research and sophisticated forms have been developed, application of which is beyond the scope of this project. In addition, ROC curves also depend critically on the distribution of non-UXO points in parameter space, which is unknown in this case. For these reasons, upper-bound ROC curves were not calculated. The reader is instead directed to tables 5 and 6, as well as the boxplots presented in appendix D to find our representation of the inherent variability of these targets.

6.3 Target Categorization

A key concern in this project was how to properly categorize targets so that each group represented a distinct class. In most cases the answer was clear, for example 60mm mortars clearly deserve a separate category from 20mm AP rounds, but the question of how far to go in defining sub-categories is an important one. For this, we relied on the data to reveal groupings. If observed parameters in a given group appeared to have bi-modal distribution, and this corresponded to some observable outward difference in the targets, then that group was a candidate for sub-division. Such is the case with groups 28 and 42. Both contain 20mm projectiles, but group 28 is highly deteriorated and group 42 is clean and new. The measured physical parameters are markedly different between these groups, and variability among the clean & new rounds is quite low, as expected.

6.4 Summary of Inherent Variability

Variability is evident in all 93 groups. For certain UXO classes, physical parameters vary by a factor of 2 or more within the class, while for others, the range is much narrower. Across all targets, the fundamental time constant τ_f, appears to have wider variability than the other parameters, and the static field dipole strength "S" shows a high coefficient of variation (CV = Stddev/mean) for aluminum targets, as expected since the mean must be close to zero. Differences in fuze and tail fin configurations generally produced marked effects, except for targets with large ferrous bodies that dominate the signal. Presence of an intact rotating band also produced marked effects including a general increase in the magnitude of axial responses (both nose-up and nose-down) and an increased discrepancy between nose-up and nose-down recovered parameters. In the theoretical case of spatially uniform excitation, nose-up and nose-down parameters should be nearly identical, but in the real-world case of non-uniform excitation, the rotating band dominates nose-down orientation since the band is typically located toward the rear of the projectile. In effect, this contributes additional "variability" in target response due to target orientation.

6.5 Transition to Other Investigators

This project was principally aimed at data collection and analysis, and the results are presented in their entirety, including, raw data, processed data, target images, fit results, and group statistics, in electronic format in the accompanying CD (Appendix E.).

7. References

[1] AETC, Incorporated, “Processing Techniques for Discrimination Between Buried UXO and Clutter using Multisensor Array Data,” SERDP Project UX-1121 Final Report, VA-3092-003-02-TR, April 2002.

[2] F. Grant and G. West, Interpretation theory in applied geophysics: McGraw-Hill Book Co., New York, NY, 1965.

[3] S. Ward and G. Hohmann, Electromagnetic Theory for Geophysical Applications, Electromagnetic Methods in Applied Geophysics, Society of Exploration Geophysicists, 1987.

[4] N. Geng, C. Baum, and L. Carin, “On the Low-Frequency Natural Response of Conducting and Permeable Targets,” IEEE Trans. Geoscience and Remote Sensing, vol. 37, No. 1, pp. 347-359, Jan. 1999.

[5] A. Sebak and L. Shafai, “Near-Zone Fields Scattered by Three-Dimensional Highly Conducting Permeable Objects in the Field of an Arbitrary Loop,” IEEE Trans. Geoscience and Remote Sensing, vol. 29, No. 1, pp. 9-15, Jan. 1991.

[6] L. D. Landau and E.M Lifshitz, Electrodynamics of Continuous Media, New York: Pergamon, 1960.

[7] T. Bell, B. Barrow, and J. Miller, “Subsurface Discrimination Using Electromagnetic Sensors,” IEEE Transactions on Geoscience and Remote Sensing, vol. 39, pp. 1286-1293, June 2001.

[8] C. E. Baum, Ed., Detection and Identification of Visually Obscured Targets, New York: Taylor & Francis, 1999.

[9] Lawson, C. L., Hanson, R. J. Solving Least Square Problems. Prentice Hall, Englewood Cliffs, NJ. 1974.

[10] Weichman, P. B. "Surface Modes and Multipower-Law Structure in the Early-Time Electromagnetic Response of Magnetic Targets." Physical Review Letters, v. 93 no. 2. July 2004.

Appendix A. EM63 Instrument Characterization

This white paper is submitted in response to an action item issued by the SERDP program office for project UX-1313 following the In-Progress Review of May 17, 2004.

1. Title: EM63 Instrument Characterization.

2. Background

The objective of SERDP project UX-1313 is to characterize and quantify the inherent variability in the electromagnetic induction (EMI) response of a wide variety of real UXO objects, and to understand the implications of these results on discrimination schemes. Our technical approach includes building a database of EMI measurements on a large number of UXO items using two sensors: the GEM-3 (frequency domain) and the EM-63 (time domain). These data provide the opportunity to characterize instrument behavior by comparing time-domain against frequency-domain, as well as comparing both against analytic models for the case of spheres and conducting loops.

3. Measurement Procedure

We strive to get clean measurements on each target, free of background signals, positioning errors, geologic interference, and sensor noise. Targets are measured in air on a test stand with the sensor aligned with a target principal axis, and with target range chosen to maximize signal-to-noise without saturating the sensor. The background measurements are collected before and after each target so that background signal can be interpolated and subtracted accurately. At the start and end of every data file, standard test items (spheres and loops) are measured to check sensor calibration. These data reveal a significant distortion in the output from our EM-63 instrument, and they provide the basis for the empirical correction presented in this paper.

Figure 1. The EM-63 sensor measures the axial response of a 3.5-inch rocket at Former Fort Ord, California.

4. Our EM-63

The EM-63 used in this project, serial number 63202, was purchased from Geonics in August 2002 and was received in September 2002. It consists of one 1x1 meter transmitter coil and three 0.5 x 0.5 meter receiver coils all centered on the same vertical axis and sharing the same x – y orientation for their sides. The bottom receiver coil is co-planar with the transmitter, and the other two are spaced vertically at uniform intervals. The bottom receiver records 26 time gates of data and the top receiver records one time gate. The middle receiver is the noise compensation coil, which is used to improve signal to noise of the upper and lower coils. Certain technical details of this sensor are considered proprietary by the manufacturer, such as transmit waveform and time gate intervals; however, we were able to obtain these data from Geonics without difficulty, with the agreement that we would not publish them.

5. Evidence of distorted signals

One of the standard test items that we measured at the beginning and end of every data file is a 4-inch diameter carbon steel sphere, known as target 535. This sphere was manufactured to high standards as a ball bearing for heavy industry, and we are comfortable assuming that it is essentially a perfect sphere with uniform material properties. Figure 2 shows the analytic model for conducting, permeable, spheres [1] fitted to GEM-3 data from target 535. As a check, the Dartmouth BOR code [2] was also used to numerically compute results, and all results agreed well. The fitted conductivity value was 1.75e6 mho/m, fitted permeability was 21.8, and both values lie within expected ranges for carbon steel [3]. This fit result from a single least-squares minimization over 26 data sets on the same target (Figure 3). These data were collected as part of our QA/QC procedure and include target ranges from 31cm to 56cm collected over a period of 7 months at four different sites. The fact that signals remain consistent under these circumstances indicates that extraneous variables were not a factor in the measurement process. It is possible that the GEM-3 sensor itself may have introduced systematic errors across all the data; any such error, however, would likely show up in separate comparisons of GEM-3 signals against analytic solutions for ferrite targets, conducting loops, and other types of spheres. To date, such an error has not been found. We conclude that our fitted parameters for conductivity and permeability of sphere 535 are accurate.

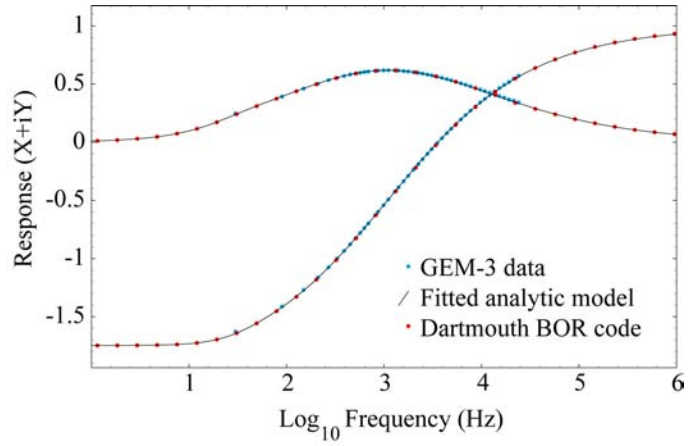


Figure 2. Response characteristics of the 4-inch diameter steel sphere (target 535) are well established.

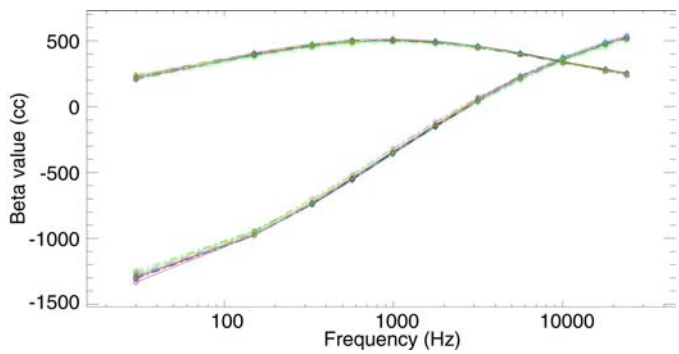


Figure 3. Consistency in measured response of sphere 535 at different ranges, sites, and conditions indicates that environmental variables were not a factor. Beta values, shown in this graph, also rely on target ranges, which varied from 31 to 56 cm.

Comparison with EM-63 time-domain data is done by numerical translation of GEM-3 results from the frequency domain to the time domain. Depending on desired time intervals and data density, frequency response must be sampled beyond the interval normally queried by the GEM-3. We rely on fitted analytic models such as that shown in Figure 2 to calculate response at arbitrary frequencies. Figure 4 shows comparison of EM-63 data against expected response. To make the comparison correctly, the particular excitation waveform produced by the EM-63 must be used. This waveform was provided to us by Geonics, and it was used to produce the *upper*

line in Figure 4, showing correction is needed at late time gates. The upper line also shows the data after using the empirical correction factors, discussed in the next section. The lower line is simply a check to demonstrate that our conversion routines are working correctly. It shows response of sphere 535 due to a step function waveform, along with the analytic solution [4] for this sphere in time-domain (both plotted one order of magnitude lower so that they can be seen clearly).

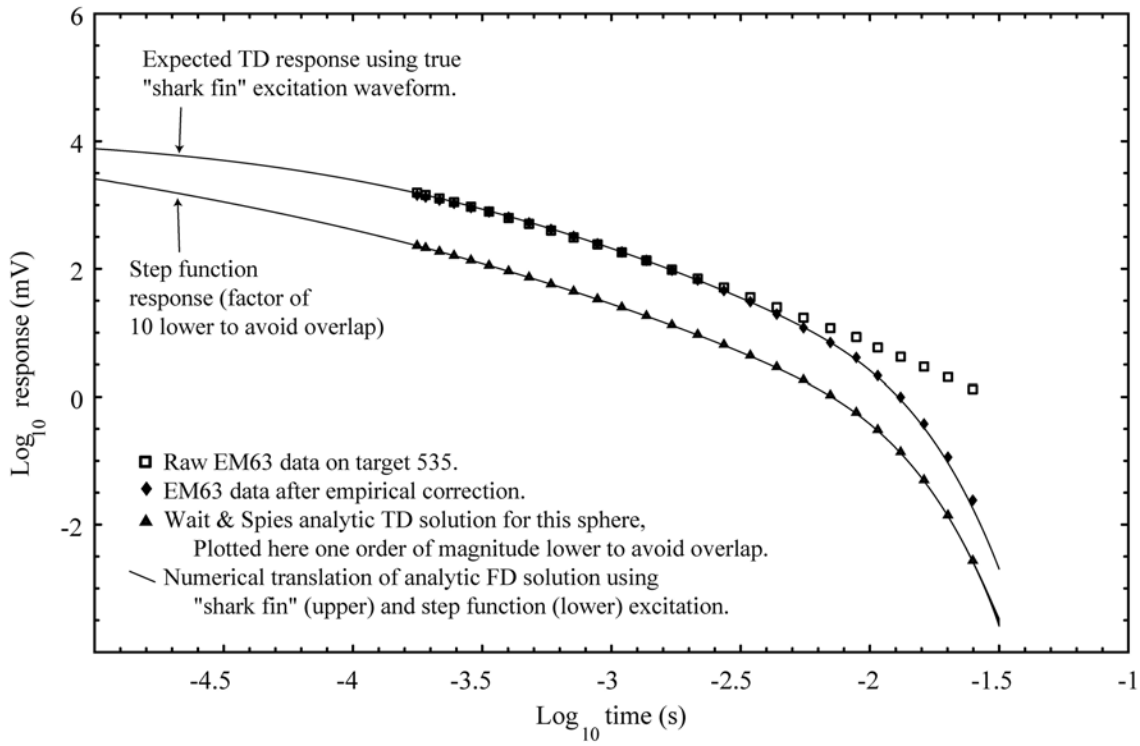


Figure 4. Time domain response of sphere 535. Raw data from the EM-63 on the upper line shows correction is needed at late time gates. The lower line shows a check of our FD-TD conversion routines: the analytic solution matches the calculated step-function response.

6. Development of Empirical Correction Factors

Using the same routines that produced Figure 4, apparent correction factors were calculated using data on five spheres and one conducting loop. In every case, expected time-domain response was based on frequency-domain data collected using the GEM-3. Table 1 is a summary of these targets. They were part of our QA/QC process at different times, in which calibration measurements were collected at the start and end of every data file. These data were collected at a variety of ranges to check distortion in different parts of

Target #	Description
22	4-inch diameter aluminum sphere
42	3-inch diameter chrome steel sphere
69	1-inch diameter stainless steel sphere
231	2.25-inch diameter bronze sphere
535	4-inch diameter chrome steel sphere
37	6.5-inch diameter wire coil

Table 1. The targets used to produce the empirical correction.

the dynamic range. The upper left graph in Figure 5 is an over-plot of apparent correction factors calculated from all these data, normalized to unity at the first time gate. The fact that these curves do not lie in a tight bundle indicates corrections do not depend simply on time gate. We found that desired correction factors can be better predicted when signal strength is used as an additional input, and our correction scheme relies on both time gate and signal strength. (Correction for instrument time delay was found to be 0.63 microseconds, which is negligible.)

The relationship between signal strength, time gate, and correction factor was investigated using a model. The model consists of a series of reference lines, one for each time gate. These lines relate signal strength (horizontal axis) to log of correction factor (vertical axis), and they are used to produce correction factors to be applied to each incoming signal on each particular time gate. The upper right hand graph of Figure 5 shows the reference line for gate 10 (red line), along with apparent desired correction factors based on targets in table 1.

The slope and intercept of each reference line is found separately for each time gate by least-squares minimization on apparent desired correction factors. Note that we are free to normalize however we wish. The upper-left graph in Figure 5 represents one possible normalization, corresponding to a reference line for gate 1 that has slope zero and intercept 1. By choosing a different slope and intercept at gate 1, apparent corrections at all the other gates will change, and the associated reference lines will change accordingly, since they are least-squares fitted to these data. The most appropriate normalization is found by performing a global minimization, in which the slope and intercept of the reference line at gate 1, which define the normalization, are treated as fitted parameters. With each iteration of the global minimization, a candidate normalization is considered, the apparent desired corrections are adjusted, and reference lines for each time gate are found through least-squares minimization. The objective function for the overall minimization is the sum of errors over all the gates. Results are shown in the lower two graphs in Figure 5, and a short piece of code that performs the correction written in IDL (Interactive Data Language) is attached as Appendix A.

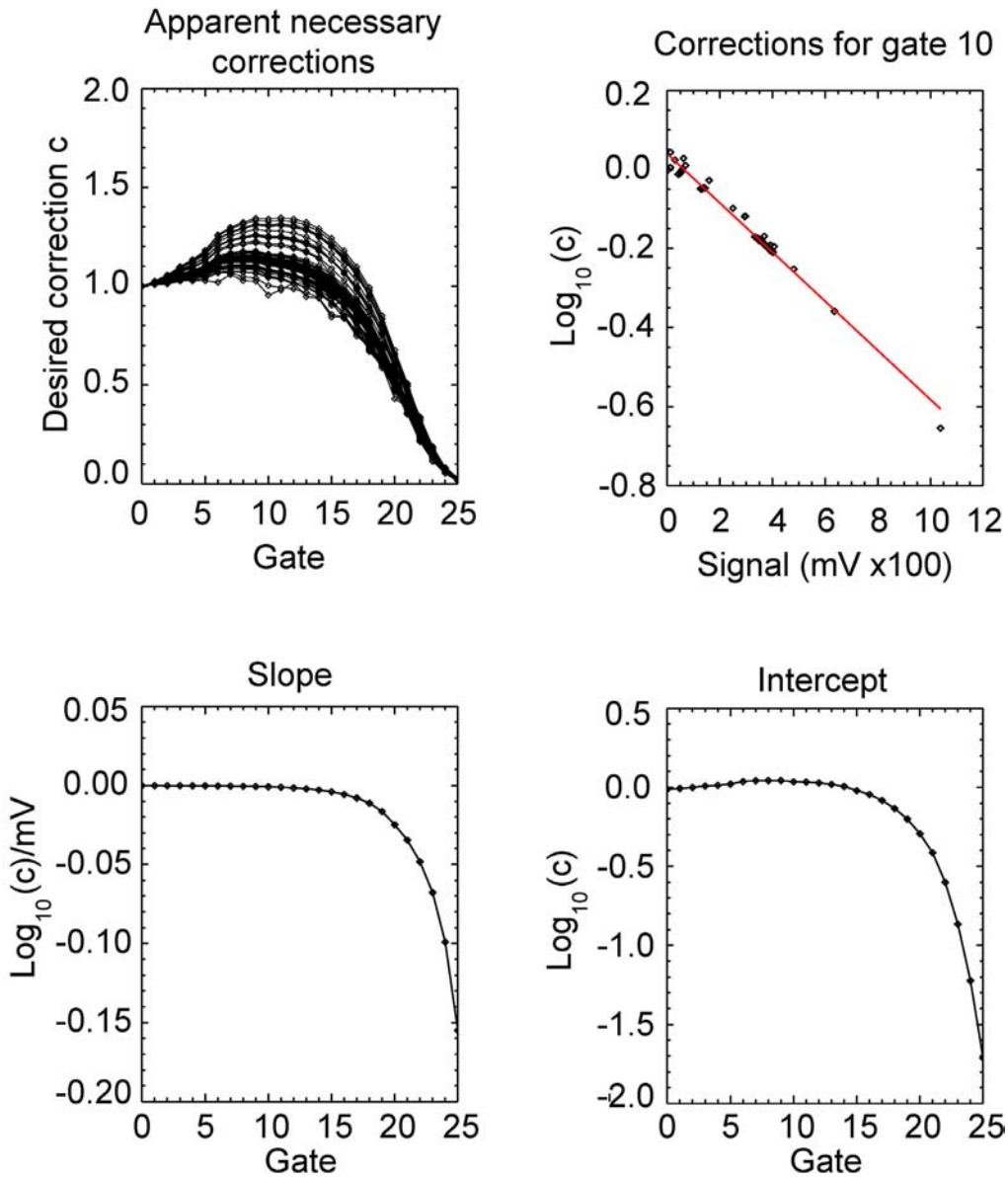


Figure 5. Top left: desired correction factors as a function of time gate for many different targets at many different distances; Top right: the corrections for time gate 10 as a function of signal amplitude after global minimization; Bottom curves: resultant slopes and intercepts determined for all time gates.

7. Communication of Correction Results to Other Investigators

We have exchanged data with Hunter Ware, who has collected data using a different EM-63 from ours. Hunter is concerned about dependence of EM-63 decay curve shape on target depth – it should be constant. We discussed our approach for correcting the EM-63 signals, and sent him the code in IDL that performs the correction. We also recently exchanged calibration results and we are loaning him one of our standard sphere targets (target #535) to determine if his instrument responds the same way ours does.

We transmitted the entire database to Scott MacInnes who is using it to guide generation of synthetic data. Scott bought a copy of IDL so that he can make use of the cleaned and corrected version of the dataset, which we store as an IDL save-set. He is successfully using these data and making progress.

Herb Nelson and Dan Steinhurst collected data on standard test spheres using the same EM-63 instrument that we use, and found that at short ranges, the shape of decay curve changes when the sphere is off-centerline versus directly below the sensor. When our correction is applied, the effect is still present. This is likely because our correction is based on sphere data collected farther from the sensor.

8. Conclusions

Our current empirical correction for the EM-63 is not completely satisfactory; the fit in Figure 4 at late time gates is still a little larger than the analytic solution, and for some other targets, good fits still cannot be found. We have investigated whether including more dependences than on signal amplitude and time gate number would improve results, but were unable to develop a consistent improved correction. We recognize that the characterization of the EM63 is imperfect, and will take that into account when analyzing the late time gate fits to data.

9. References

[1] Grant, F. and G. West, Interpretation theory in applied geophysics: McGraw-Hill Book Co., New York, NY, 1965.

[2] Shubitidze, F., K. O'Neill, Sun, K. and K.D. Paulsen, "Investigation of broadband electromagnetic induction scattering by highly conductive, permeable, arbitrarily shaped 3-D objects," IEEE Transactions on Geoscience and Remote Sensing, Vol 42, Issue 3, March 2004, p. 540-556.

[3] Weast, R. C. editor, Handbook of Chemistry and Physics, 56th edition: CRC Press, Cleveland OH, 1976.

[4] J.R.Wait, K.P.Spies, "Transient Magnetic Field of a Pulsed Electric Dipole in a Dissipative Medium", IEEE Trans. Antennas and Propagation, vol. AP-18, no. 5, pp. 714-716, September 1970.

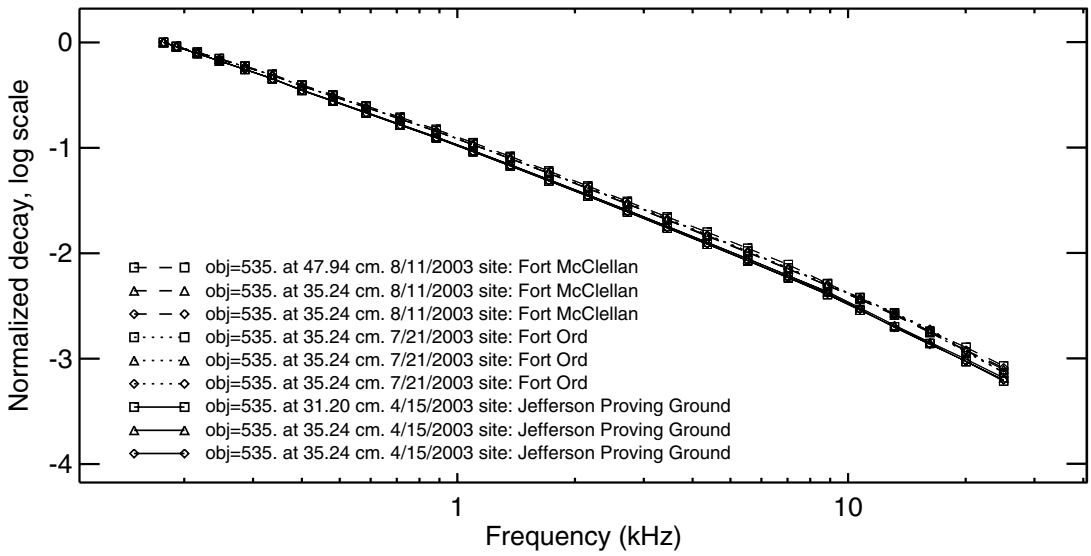
Appendix A. IDL Code for Determination of Correction Factors

```
pro correctEM63v3, inputData, outputData

;This routine applies an empirical correction to EM63 data.

;**** IMPORTANT ****
;Data must be in mV - which is the normal reported value from EM63 data files.

;slopes
c1 = [ -0.00012319066 , -0.00013404625 , -0.00015302852 , -0.00017675185 , -0.00020934104 $
       , -0.00025201343 , -0.00031743107 , -0.00039643308 , -0.00050319887 , -0.00064765414 $
       , -0.00083962396 , -0.0011274792 ,   -0.0015310127 ,   -0.0020987113 ,   -0.0029213163  $
       , -0.0039706805 ,   -0.0056575219 ,   -0.0078861811 ,   -0.011208033 ,    -0.016438056  $
       , -0.024864855 ,    -0.034595847 ,    -0.048287234 ,    -0.067787886 ,    -0.099105303  $
       , -0.15504639]

;intercepts
c2 = [ -0.013605141 ,  -0.0074949162 ,  -0.0011221539 ,  0.0079553535 ,  0.012161235  $
       ,  0.020366713 ,    0.036400575 ,    0.041823279 ,    0.042639443 ,    0.042695679   $
       ,  0.034981554 ,    0.032987948 ,    0.028031155 ,    0.018569659 ,    0.0056092566  $
       , -0.021102937 ,  -0.044521573 ,   -0.083331254 ,   -0.13392044 ,   -0.20099631   $
       , -0.29357261 ,   -0.41331247 ,    -0.60128803 ,    -0.86560418 ,   -1.2236113  $
       , -1.7120553]

factor = 10.d^(c1 * inputData + c2)
outputData = inputData * factor

end
```

ADDENDUM
To the white paper "EM-63 Instrument Characterization"

At the 2004 SERDP Symposium in Washington DC, I showed the white paper to Miro Bosnar, President of Geonics Inc, which manufactures the EM-63. We had a lengthy discussion and I described how we set up the EM-63 and made our measurements. Miro suggested that the discrepancies shown in the white paper might be due to stray coupling with nearby metal objects such as rebar in the concrete floor or metal in the roof.

The graph below shows this cannot be the cause. EM-63 measurements of our standard sphere, target 535, taken at 3 different sites shows consistent results. Any variation is small compared to the error shown in figure 4 of the white paper. At Jefferson Proving Ground we set up in a field with almost no nearby metal, at Fort Ord we set up inside a building with a metal roof and concrete walls & floor, and at Fort McClellan we set up in a wooden building with a concrete floor. See photos.



Jefferson Proving Ground

Fort Ord

Fort McClellan

Appendix B. EMI Signal Models

This white paper is submitted for project UX-1313.

1. Title: EMI Signal Models.

2. Background

SERDP project UX-1313 is aimed at characterizing variability in the electromagnetic induction (EMI) response for a wide variety of targets. This goal is facilitated through the use of models that capture EMI signal information and condense it into fitted parameters. The ideal model would have the following properties: (a) it would match all observed data perfectly, (b) it would produce physically realistic response at all points including asymptotes, (c) it would provide a unique parameter set for a given data set (avoiding non-unique solutions) and (d) it would require negligible computation effort so that data inversion is feasible. Given that EMI response is a complex physical process involving target shape and composition in non-obvious ways, it is surprising that simple analytic forms can do fairly well toward achieving (a) through (d). This white paper describes the simple analytic model we use in UX-1313.

3. An Observation

In this section we compare five known models and observe a pattern. Time- and frequency-domain versions exist for all five but here we look at frequency-domain only. For the case of a sphere with conductivity σ, relative permeability μ_r, and radius r, the exact response $S_s(\omega)$ in a uniform magnetic field [1] can be written

$$S_s(\omega) = A\left(\frac{g_s(\omega)-1}{g_s(\omega)+1} + s\right), \qquad g_s(\omega) = \frac{\alpha}{(\mu_r+2)}\frac{\mathrm{I}_{(2\frac{1}{2})}(\alpha)}{\mathrm{I}_{(1\frac{1}{2})}(\alpha)}, \tag{1}$$

where $\alpha = \sqrt{i\omega\tau}$, $\tau = \mu_r \mu_o \sigma r^2$ and $\mathrm{I}_{(\nu)}(z)$ is the Modified Bessel function of order ν. Appendix A1 is a *Mathematica* notebook showing this result, along with definitions for the constants A and s. Similarly, the exact response $S_c(\omega)$ of an infinite cylinder of radius r illuminated transversely by a uniform magnetic field [2] can be written

$$S_c(\omega) = A\left(\frac{g_c(\omega)-1}{g_c(\omega)+1} + s\right), \qquad g_c(\omega) = \frac{\alpha}{(\mu_r+1)}\frac{\mathrm{I}_{(2)}(\alpha)}{\mathrm{I}_{(1)}(\alpha)}, \tag{2}$$

where the constants A and s are defined differently but the time constant τ is as above. This is shown in appendix A2. For the case of a conducting loop with resistance R and self-inductance L, the exact response $S_d(\omega)$ in a uniform field can be can be written

$$S_d(\omega) = A\left(\frac{g_d(\omega)-1}{g_d(\omega)+1} + s\right), \qquad g_d(\omega) = \lim_{\nu\to\infty}\left(2\nu\alpha\frac{\mathrm{I}_{(\nu+1)}(\alpha)}{\mathrm{I}_{(\nu)}(\alpha)}\right). \tag{3}$$

Here, the time constant $\tau = L/R$ and the constants A and s are defined in appendix A3. This function is the building block for a model [3] recently developed at Duke University. Another recent model [4] from the University of British Columbia is designed to fit time-domain data empirically. When converted into frequency domain, (Appendix A4), it can be can be written

$$S_b(\omega) = A\left(\frac{g_b(\omega)-1}{g_b(\omega)+1} + s\right), \qquad g_b(\omega) = \frac{1}{\nu}\,\frac{\Gamma(\nu+1,w)}{\Gamma(\nu,w)}, \tag{4}$$

where the constants A, v, and s are defined in terms of the original model fit parameters a, b, and c. The term w is defined as $a(1/c + i\omega)$. Finally, a recent model [6] that works well on highly permeable targets with compact bodies is written

$$S_a(\omega) = A\left(\frac{g_a(\omega)-1}{g_a(\omega)+1} + s\right), \qquad g_a(\omega) = \sqrt{i\,\omega\,\tau}, \tag{5}$$

where, A, s, and τ are directly fitted parameters. We observe that all five of these models share the same basic form, shown at the beginning of each equation (1) through (5). We speculate that this form describes EMI response for a very wide range of targets and we examine it by investigating the relationship between phase angle & amplitude of $g(\omega)$ vs. In-phase (real) and quadrature (imaginary) parts of S. Appendix A5 shows derivation of this relationship and the resulting function surfaces are plotted in figure 1.

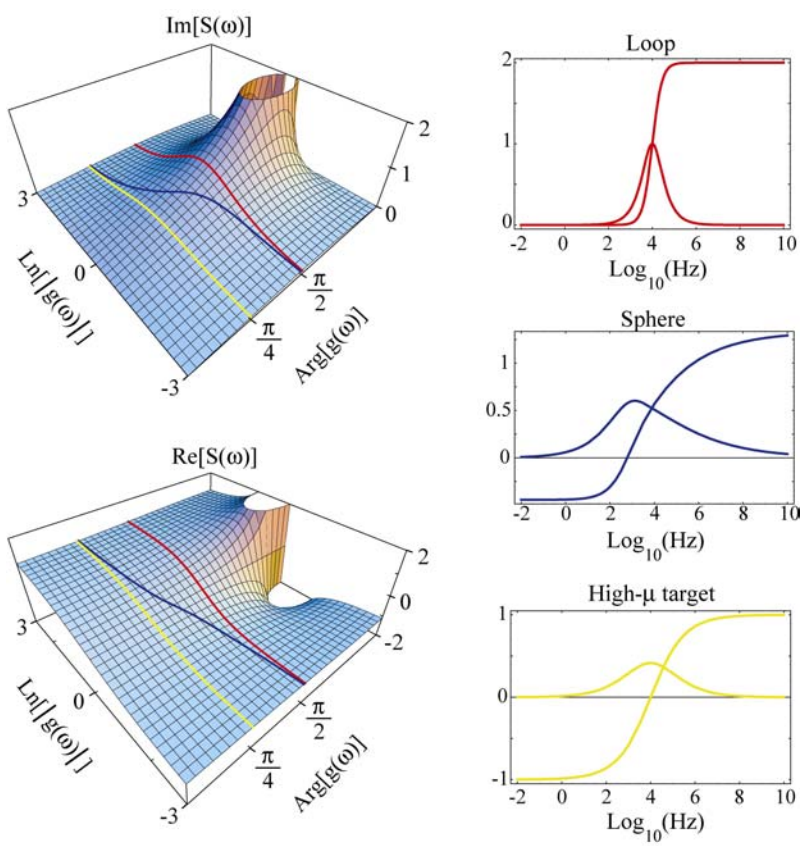


Figure 1. The relationship observed in equations (1) through (5) describes a unique surface on which EMI response curves lie. These surfaces are functionally defined in appendix A5.

4. Discussion

There are several observations to be made about this representation.

* At the low frequency limit $|g(\omega)|$ goes to zero in all but the UBC model. This ensures that the in-phase asymptote of S can go negative and the quadrature asymptote will be zero.

* At the high frequency limit, $|g(\omega)|$ goes to infinity in all five models, ensuring that the in-phase asymptote can go positive and the quadrature asymptote will be zero.

* The curve produced along a constant phase angle of $\pi/2$ corresponds to the loop response, and that of $\pi/4$ corresponds to the high-μ target response.

* In all three analytic solutions (the first three models above), $|g(\omega)|$ grows like ω as long as the phase angle is $\pi/2$. When g transitions to phase angle $\pi/4$ then $|g(\omega)|$ grows like Sqrt[ω].

* There is a characteristic pattern seen in the two analytic models for permeable targets: response begins along the π/2 phase angle, like a loop, then transitions at some point to π/4, like a hi-μ target. The point of transition is controlled solely by μ, and the shape of the transition curve is fixed but it occurs at different values of $|g(\omega)|$, depending on μ.

* The in-phase surface is above -1 for all phase angles < π/2. If the phase angle is greater than π/2 then negative-going dips will occur in the in-phase response just before the rise begins. This is non-physical and it is interesting that the analytic models never produce these artifacts because for them Arg($g(\omega)$) never rises higher than π/2.

* The peak in quadrature is guaranteed to occur when $|g(\omega)| = 1$, or slightly before. It may occur before depending on how rapidly Arg($g(\omega)$) is transitioning from π/2 to π/4.

5. Response Model

In this project we have had the opportunity to test many different variations of these models on a large dataset of EMI signals from real UXO. In general, simple forms of this kind do very well but problems arise, mainly of two kinds: targets that cannot be fit (poor model fidelity), and targets that can be fit more than one way (non-uniqueness). The former problem tends to get worse with fewer fitted parameters, and the latter tends to get worse with more fitted parameters. In negotiating this trade-off we have adopted the following:

$$S_m(\omega) = A\left(\frac{g_m(\omega)-1}{g_m(\omega)+1} + s\right), \qquad g_m(\omega) = \frac{b\,\alpha^{2c}\,\mathrm{I}_{(\nu)}(\alpha\,\nu)}{(1-b)\,\mathrm{I}_{(\nu-1)}(\alpha\,\nu)}, \qquad \nu = \frac{1-a}{a}. \tag{6}$$

This form matches that of the sphere and cylinder forms, and by virtue of the way ν is defined, we can arrive at the loop form by adjusting parameter a to zero. This is convenient because series expansions around $a = 0$ are computationally tractable. One important change in this form compared to the sphere and cylinder solutions is the inclusion of ν in the argument for the modified Bessel. This was done because without it, parameter τ and parameter b both expand beyond bounds on some targets. The effect of including with a new definition of b the function becomes identical to the original analytic forms. Another advantage is that fitted parameters a, b, and c are all bounded by 0 and 1. And parameter s is bounded by -1 and 1. This makes parameter searching easier since out-of-bounds values are easily discarded.

6. Conclusion

We show five known models in frequency domain format and observe a common form among them. This form is analyzed to discover the relationship between phase and amplitude of g, vs. real and imaginary parts of S. Results reveal some insight into the nature of these models. Benefiting from the experience of using different models to fit large amounts of UXO data, we adopted a model form drawn from the equations for spheres, cylinders, and conducting loops. Some modification was made in order to make the result computationally efficient.

9. References

[1] F. Grant and G. West, *Interpretation Theory in Applied Geopysics*. McGraw-Hill, New York, 1965.

[2] S. Ward and G. Hohmann, "Electromagnetic Theory for Geophysical Applications" in J. Benjamin and C. Cornell, *Probability, Statistics, and Decision for Civil Engineers*. McGraw-Hill Book Company, New York, 1970.

[3] L. Collins, Y. Zhang, J. Li, S. Tantum, and L. Carin, "Physics-based signal processing and sensor fusion for improved UXO detection," in *UXO/Countermind Forum*, Anaheim, CA May 1-5, 2000.

[4] L. R. Pasion and D. W. Oldenburg, "Locating and determining dimensionality of UXOs using time domain electromagnetic induction", in *Proc. Symp. Application of Geophysics to Engineering and Environmental Problems Conf.*, Oakland, CA, Mar 14-18, 1999 pp. 763-772

[5] M. Abramowitz and I Stegun, *Handbook of Mathematical Functions*. Dover, New York, 1972.

[6] J. Miller, T. Bell, J. Soukup and D. Keiswetter, "Simple Phenomenological Models for Wideband Frequency-Domain Electromagnetic Induction." IEEE Transactions on Geoscience and Remote Sensing, Vol. 39, No. 6, June 2001.

Appendix A1
Mathematica notebook showing equivalence of sphere response expressions.

The response function given by Grant & West [1] (p.495) for a sphere of permeability μ, conductivity σ, and radius r,

$$k = \sqrt{i\,\sigma\,\mu\,\omega};$$

$$\text{sphere} = \frac{(\mu_0\,(1 + k^2\,r^2) + 2\,\mu)\,\text{Sinh}[k\,r] - (2\,\mu + \mu_0)\,k\,r\,\text{Cosh}[k\,r]}{(\mu_0\,(1 + k^2\,r^2) - \mu)\,\text{Sinh}[k\,r] + (\mu - \mu_0)\,k\,r\,\text{Cosh}[k\,r]};$$

can be expressed differently using the Modified Bessel function:

$\mu_r = \mu / \mu_0;$ (* Relative permeability *)

$\nu = 3/2;$ (* A constant. ν fixed at 3/2 for spheres *)

$s = -\frac{\mu_r - 4}{3\,\mu_r};$ (* A constant. Bounded: -1/3 < s < 1 *)

$A = \frac{3\,\mu_r}{2\,\mu_r + 4};$ (* A constant. Bounded: 1/2 < A < 3/2 *)

$\alpha = \sqrt{i\,\omega\,\tau};$ (* Dimensionless *)

$\tau = \sigma\,\mu\,r^2;$ (* A characteristic time constant of the target *)

$$g = \frac{\alpha}{(\mu_r + 2)}\,\frac{\text{BesselI}[\nu + 1, \alpha]}{\text{BesselI}[\nu, \alpha]};$$

$$\text{FullSimplify}\left[\ \text{sphere} == A\left(\frac{g - 1}{g + 1} + s\right)\ \right]$$

True

Appendix A2
Mathematica notebook showing equivalence of cylinder response expressions.

The response function given by Ward & Hohmann [2] (p.263) for an infinite cylinder of permeability μ, conductivity σ, and radius r,

```
k = Sqrt[i σ μ ω];

cylinder = (μ0 (i k r BesselJ[0, i k r] - BesselJ[1, i k r]) - μ BesselJ[1, i k r]) / (μ0 (i k r BesselJ[0, i k r] - BesselJ[1, i k r]) + μ BesselJ[1, i k r]);
```

can be expressed differently using the Modified Bessel function:

```
μr = μ / μ0;            (* Relative permeability *)

ν = 1;                  (* A constant.  ν fixed at 1 for cylinders *)

s = 1/μr;               (* A constant.  Bounded: 0 < s < 1 *)

A = μr/(μr + 1);        (* A constant.  Bounded: 2/3 < A < 4/3 *)

α = Sqrt[i ω τ];        (* Dimensionless *)

τ = σ μ r^2;            (* A characteristic time constant of the target *)


g = α/(μr + 1) BesselI[ν + 1, α]/BesselI[ν, α];


FullSimplify[ cylinder == A ((g - 1)/(g + 1) + s) ]

True
```

Appendix A3
Mathematica notebook showing equivalence of loop response expressions.

The response function given by Grant & West [1] (p.488) for a loop of resistance R and self-inductance L,

```
β = ω L / R;
```

$$\text{loop} = \frac{\beta^2 + i\,\beta}{1 + \beta^2};$$

can be expressed differently using the Modified Bessel function with order ν at infinity. To show this, we need an asyptotic expansion of BesselI for large orders (Abramowitz and Stegun [5] p. 378):

$$\text{n}[z_] = \sqrt{1 + z^2} + \text{Log}\left[\left(\frac{z}{1 + \sqrt{1 + z^2}}\right)\right];$$

$$\text{BesselIapprox}[v_, w_] = \frac{1}{\sqrt{2\,\text{Pi}\,v}}\,\frac{\text{Exp}[v\,\text{n}[\frac{w}{v}]]}{\left(1 + (\frac{w}{v})^2\right)^{1/4}};$$

We now define the function using the asymptotic version and take the limit:

```
s = 1;
```

$$A = \frac{1}{2};$$

```
α = Sqrt[i ω τ];          (* Dimensionless *)

τ = L / R;                (* A characteristic time constant of the target *)
```

$$g = 2\,\nu\,\alpha\,\frac{\text{BesselIapprox}[\nu + 1, \alpha]}{\text{BesselIapprox}[\nu, \alpha]};$$

$$\text{FullSimplify}\left[\ \text{loop} == \text{Limit}\left[A\left(\frac{g - 1}{g + 1} + s\right), \nu \to \text{Infinity}\right]\ \right]$$

```
True
```

Appendix A4
Mathematica notebook showing equivalence of UBC response expressions.

common form UBC.nb

The time-domain model [4] given by Passion & Oldenburg

$$uTD = k\,(t + a)^{-b}\, e^{-t/c}\;;$$

when converted to the frequency domain through Fourier transform,

$$uFD = -\,\text{FullSimplify}\left[\int_0^\infty uTD\; e^{-i\,\omega\,t}\, dt,\ \{\,\omega > 0,\ a > 0,\ c > 0\}\right]$$

$$-a^{1-b}\, e^{a\left(\frac{1}{c}+i\,\omega\right)}\, k\, \text{ExpIntegralE}\left[b,\ a\left(\frac{1}{c} + i\,\omega\right)\right]$$

can be expressed differently using the incomplete Gamma function:

$$\nu = 1 - b;$$

$$w = a\left(\frac{1}{c} + i\,\omega\right);$$

$$A = \frac{-k}{2\,a^{b-1}\,\nu};$$

$$s = 1;$$

$$g = \frac{1}{-\nu}\,\frac{\text{Gamma}[\nu + 1,\ w]}{\text{Gamma}[\nu,\ w]};$$

$$\text{FullSimplify}\left[uFD == A\left(\frac{g-1}{g+1} - s\right)\ /.\ \text{Gamma}[\nu + 1,\ w] \to \nu\,\text{Gamma}[\nu,\ w] + e^{-w}\, w^{\nu}\right]$$

True

We made use of the recurrance relation: $\text{Gamma}[\nu + 1,\ w] = \nu\,\text{Gamma}[\nu,\ w] + e^{-w}\, w^{\nu}$. This relation is easily derived from Abramowitz & Stegun [5] equation 6.5.3 (p.260) and equation 6.5.22 (p.262).

Appendix A5
Mathematica notebook showing relationship between g(ω) and S(ω).

common form surfaces.nb

Mathematica's complex variable package is needed:

```
<< Algebra`ReIm`
```

Expressing the basic EMI response form using (r, θ) notation for g,

$$S = \frac{r\, e^{i\theta} - 1}{r\, e^{i\theta} + 1};$$

we solve for the in-phase and quadrature parts of S in terms of phase angle and amplitude of g:

```
imS = Simplify[Im[S], {Im[r] == 0, Im[θ] == 0}]
```

$$\frac{2\, r\, \mathrm{Sin}[\theta]}{1 + r^2 + 2\, r\, \mathrm{Cos}[\theta]}$$

```
reS = Simplify[Re[S], {Im[r] == 0, Im[θ] == 0}]
```

$$\frac{-1 + r^2}{1 + r^2 + 2\, r\, \mathrm{Cos}[\theta]}$$

The equations are simplified using the identity $r = e^{\ln(r)}$

```
quadrature = FullSimplify[imS /. r → e^lnr]
```

$$\frac{\mathrm{Sin}[\theta]}{\mathrm{Cos}[\theta] + \mathrm{Cosh}[\mathrm{lnr}]}$$

```
inPhase = FullSimplify[reS /. r → e^lnr]
```

$$\frac{\mathrm{Sinh}[\mathrm{lnr}]}{\mathrm{Cos}[\theta] + \mathrm{Cosh}[\mathrm{lnr}]}$$

Appendix C. Sample Size for Determining UXO Variability

This white paper is submitted in response an action item issued by the SERDP program office for project UX-1313 following the In-Progress Review of May 13, 2003. The action item was transmitted in a memorandum dated July 2, 2003, an excerpt of which is attached as an appendix.

1. Title: Sample Size for Determining UXO Variability.

2. Background

The objective of SERDP project UX-1313 is to characterize and quantify the inherent variability in the electromagnetic induction (EMI) response of a variety of real UXO objects, and to understand the implications of these results on discrimination schemes. Our technical approach includes building a database on a large number of UXO items and then estimating first and second order moments for parameters that govern their EMI response.

3. Sample Size

The sample size for each class of UXO affects the uncertainty in the estimated moments for that class. Unfortunately, the variance of the parameters, which is not known *a-priori*, also affects the uncertainty in their estimated moments [1], making it difficult to calculate beforehand the sample size needed to achieve a desired uncertainty criterion. This problem may be approached in two ways. Under the *relative frequency* or *frequentist* approach [2], assumptions regarding probability distributions are never permitted, so it is impossible to calculate uncertainty vs. sample size beforehand. Under this approach, uncertainty may only be calculated *a-posteriori* based on the observed measurements. In the *Bayesian* approach, intuitive and subjective assumptions may be used as a starting point to plan the experiment, and then these assumptions are updated as experimental observations come in. In the current project, we adopt a Bayesian-like approach, relying on experience to make assumptions on adequate sample sizes a-priori. During our visits to DoD sites, we do not have the opportunity to update our assumptions, so we're essentially using the frequentist approach until the site visit is over. Between site visits, we calculate uncertainties and update our assumptions based on evidence for each class of UXO. It is not practical to do this update explicitly using Bayes' theorem however, because derived parameters depend on the form of the model being used, and the models themselves are tailored to the observed data, hence the form of the model might be updated, making the process inordinately complex. Our basic approach is simply to iterate on data collection, uncertainty calculation, and then sample planning, until reasonable levels of uncertainty have been realized. Our working goal is for maximum uncertainty on any model parameter to be < 1/3 of the parameter value. This goal is subjective, and will be affected by practical considerations in every case.

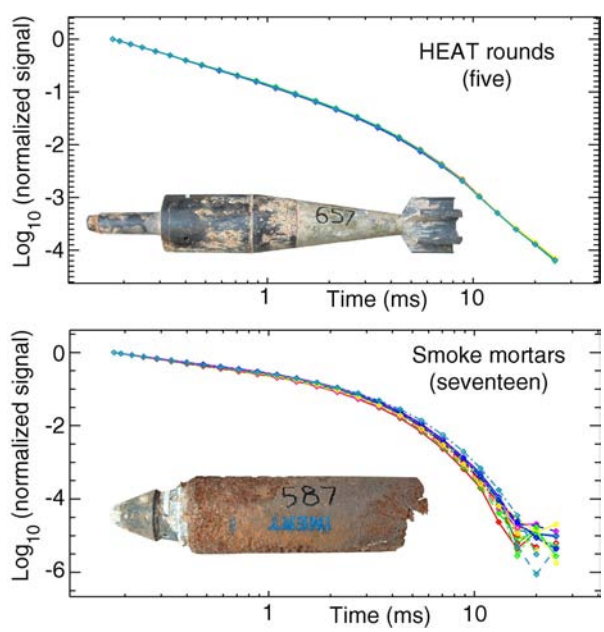


Figure 1. EM-63 signals from five HEAT rounds and seventeen smoke mortars. Sample size was based on a-priori assumptions of variability.

4. Practical Considerations

For each class of UXO at each site, we aim to collect a random sample from the native population, in such a way that the sample accurately reflects the underlying probability

distribution. Specifically, we want the *sample* mean and variance of each fitted parameter to be close to the *true* mean and variance of that parameter. Ideally, this can be accomplished by collecting *independent and identically distributed* (i.i.d.) realizations of the random variable. For real UXO, however, there are practical considerations that limit sample collection. First, availability is a concern. When only a few examples of a given UXO type are available, we simply use everything we can and continue to look for more at the next site. Another concern is the fact that UXO is rarely well mixed. At Fort McClellan for example, targets are stored in 55-gallon drums, each containing a distinct assortment, and we do not have the opportunity to mix it all together before pulling a random sample. Since we cannot expect to draw i.i.d. random samples, we have adopted a policy of collecting samples that reflect the full range of variability present; e.g., if bent UXO are found in the field, then bent UXO are included in the sample. This might skew our samples towards having too many "exotic" cases (we cannot know without mixing the entire population at the site), but it does, however, result in larger sample sizes for highly variable UXO, which is desirable. As described above, we also exercise judgment based on experience. For example, at Jefferson Proving Ground, we collected only five examples of HEAT rounds, because we predicted fairly homogeneous response, based on their condition and composition. By contrast, we predicted more variability in the smoke mortars so we measured seventeen of them. As shown in figure 1, our predictions were supported by the data.

5. Analysis Framework

The goal of this work is to describe the inherent variability in the UXO, and not variability from any other source, such as location error, sensor noise, or modeling error. We therefore take steps to ensure these sources are minimized. First, we control location errors by carefully aligning our test stand and periodically re-checking alignment during data collection. Second, we run the sensor at closest practicable range to the targets, so that sensor noise is insignificant compared to target signal. Lastly, we choose response models with two important properties: 1) they produces "noise-free" signals, as though recorded by a perfect sensor, and 2) they are able to match with very high fidelity the observed to ensure that modeling errors are minimized. The usual trade-off for these benefits is that relatively large numbers of fitted parameters (e.g. six) are required. We are content to work with six or more parameters, however, because the system is strongly over-determined and our parameter fitting routines have no difficulty achieving good fits.

A straightforward approach might be to model each sensor measurement (i.e., each voltage at each time gate or frequency) as a separate random variable, and then rely on the covariance matrix to preserve other necessary characteristics of the response. However, models of this kind will necessarily violate the Hilbert transform property in the frequency response of real targets [3] as well as the smoothness observed in real signals. In addition, we desire models that allow for extrapolation beyond the range of data, which is necessary for conversion between time domain and frequency domain. Therefore we need models that preserve physical characteristics and converge toward analytically correct asymptotes. Our approach is to use models developed under a previous SERDP project [4].

6. A Six-Parameter Model

Frequency-domain EMI response of a metal target may be represented as a magnetic dipole $\boldsymbol{m}$ positioned at the center of the target, with magnitude and direction

$$\vec{\boldsymbol{m}}\, e^{i\,\omega t} = \vec{\vec{\boldsymbol{B}}}\, \vec{\boldsymbol{H}}_O\, e^{i\,\omega t}, \qquad (1)$$

where $\boldsymbol{H_o}$ is the primary field oscillating harmonically at frequency $\mathbf{w}$, and $\boldsymbol{B}$ is a tensor which can be thought of as the constant of proportionality between $\boldsymbol{H_o}$ and $\boldsymbol{m}$. With a suitable rotation of coordinate axes, $\boldsymbol{B}$ becomes diagonal, and the diagonal elements $\mathbf{b}_j$ (j = 1,2,3) correspond to the principal axes of the target. Each $\mathbf{b}_j$ is described by the formula:

$$\beta_j = A\left(\frac{f\,g-1}{f\,g+1}+S\right), \qquad g=\frac{\alpha^{2C}\,\mathrm{I}_{\nu+1}(\alpha)}{\mathrm{I}_{\nu}(\alpha)}, \qquad \alpha=\sqrt{i\,\omega\tau}\,, \tag{2}$$

where fitted parameters *S, f, C,* and ν are dimensionless, while parameter *A* (the amplitude) has dimension of volume, and parameter τ (the time constant) has dimension of time. The symbol $\mathrm{I}_{\nu}(\alpha)$ represents the Modified Bessel I function of order ν. All fitted parameters are real scalars. This model is derived from analytic solutions for the conducting loop, for spheres of arbitrary permeability [5], and for infinite cylinders illuminated transversely, also with arbitrary permeability [6]. It provides exact matches to all of those analytic solutions through parameter adjustment, and also provides good matches to a wide range of irregularly-shaped UXO.

7. An Example: 20mm HE rounds.

We demonstrate the relationship between sample size and parameter uncertainty based on the data set for 20 mm HE rounds collected at Fort Ord in July of 2003. Twenty UXO of this type were measured and they exhibited relatively large variability in the nose-down orientation, due in part to the condition of the rotating bands. Some bands were intact, some were completely missing, and some, like the target in Figure 2, were partially broken. For the purpose of this example, we consider only the nose-down data, where the rotating band contribution is strongest. We fit all twenty UXO to the model (equations 1 & 2), and then analyzed the ensemble of fitted parameters to express the variability. Each parameter comes from some underlying distribution that is unknown, and the joint density function across all the parameters is also unknown. Our purpose is not to hypothesize the form of these distributions, but only to calculate first and second order moments, which may be defined no matter what the underlying forms are. Using the Jackknife and Bootstrap resampling plans, we then calculate confidence intervals around these estimates. These confidence intervals depend on sample size, and illustrate the relationship between sample size and parameter estimate uncertainty.

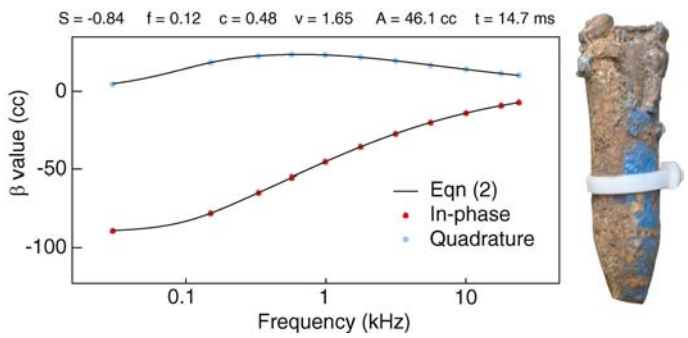


Figure 2. Nose-down EMI response of this 20 mm round from Fort Ord, CA, was fitted using Equation (2). UXO variability is expressed in terms of the model parameters *S,f,c,v,A,*and *t*.

8. Jackknife and Bootstrap Methods

The Jackknife and Bootstrap [7] are two ways of generating confidence intervals on any statistic calculated from a random sample. Let $\theta^{\mathrm{E}} = \theta^{\mathrm{E}}(X) = \theta^{\mathrm{E}}(X_1, X_2, \ldots, X_n)$ be an estimator of a true underlying parameter θ, calculated from the random sample $(X_1, X_2, \ldots, X_n)$ of the random variable *X*. The Jackknife estimate of standard deviation for this estimator is

$$\sigma_{\mathrm{JACK}} = \left(\frac{n-1}{n}\sum_{i=1}^{n}\left(\theta^{\mathrm{E}}(X_{j,j\neq i})-\theta^{\mathrm{E}\bullet}(X_{j,j\neq i})\right)^2\right)^{1/2}, \tag{3}$$

where $(X_{j,\ j \neq i})$ indicates that the ith point is deleted from the random sample, and the dot ∥ notation indicates averaging: $\theta^{E\bullet}$ = average of all the θ^{E} 's. Thus, the Jackknife operates on an exhaustive set of sub-samples, each having one less member than the total. The Bootstrap estimate is obtained by operating on random samples drawn *with replacement* from the observed values in the sample. Because of the replacement, you do not get back your original data set each time. You get sets in which a random fraction of the original points, typically ~ 1/e @ 37%, are replaced by duplicated original points. Let F be an empirical probability distribution function, putting probability mass $1/n$ on each X_i, and let $(X^*) = (X^*_1, X^*_2, \ldots, X^*_n)$ be an i.i.d. sample drawn from F. The estimator $\theta^{E}(X^*)$ for this sample is calculated, and the process is independently repeated B times, obtaining "bootstrap replications" of the estimator with each iteration. The bootstrap estimate of standard deviation for this estimator is

$$\sigma_{\mathrm{BOOT}} = \left(\frac{n}{n-1} \frac{1}{B-1} \sum_{i=1}^{B} \left(\theta^{\mathrm{E}}(X_i^*) - \theta^{\mathrm{E}\bullet}(X_i^*) \right)^2 \right)^{1/2} . \qquad (4)$$

Here again the dot ∥ notation indicates averaging: $\theta^{E\bullet}$ = average of the θ^{E} 's. Practitioners have found that setting B = 100 produces reasonably accurate results, and that is the value we use in the current calculations.

9. Results of the Example

The data set for 20mm HE rounds was analyzed and results are shown in appendix A. Estimated means and standard deviations for each of the six parameters are shown, along with Jackknife and Bootstrap confidence intervals on those estimates calculated from equations (3) and (4). To illustrate the effect of sample size, sub-samples of size n = 5, 10, and 15 were selected from the full sample of n = 20. Of the many thousands of possible sub-samples, three were selected for each n specifically to illustrate worst-case scenarios. They are shown in groups: the left-most in each group represents the sub-sample with the lowest bottom confidence interval. The center represents the widest confidence interval (maximum uncertainty), and the right-most represents the highest-value upper confidence interval. Figure 3 gives a diagrammatic explanation. These data show the trend of sample size with uncertainty, and in all cases the trends appear to approach asymptotes. Given an infinite data set, these asymptotes would represent the true parameters of the underlying distribution. Our apparent asymptotes are based on a finite data set, so It is incorrect to assume that these asymptotes represent the "true" parameters, however, we can expect the true values to fall within the error bars on the n = 20 estimate ~67% of the time. The graphs on the right hand side of appendix A show the associated standard deviation estimates, expressed as a percent of the n = 20 mean. The near-zero estimates for standard deviation at n = 5 and n = 10 reflect the fact that within our sample of 20, it is possible to find groups of 5 or 10 with very similar values. The low standard deviation for these sub-samples coincides with very small uncertainty (short error bars), and this is a reflection of the property discussed in section 3. Namely, that parameter uncertainty is directly affected by sample variance, which is not known a-priori, so calculating sample sizes beforehand for a

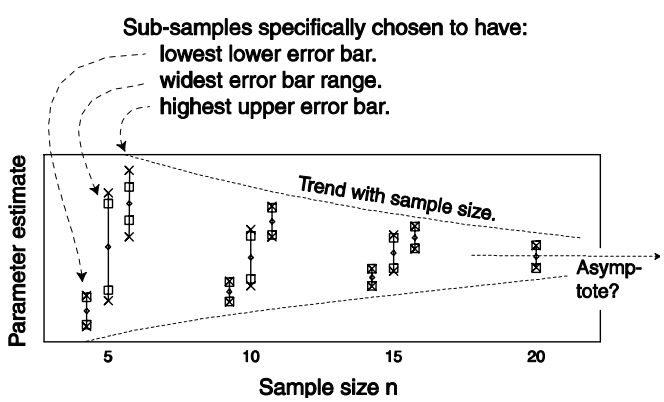


Figure 3. Explanation of the graphical presentation in appendix A.

specific uncertainty criterion is impossible without the use of subjective assumptions. Note that for this example, all the parameters' uncertainties are less than 1/3 their value, so our working goal is met for these 20mm. We plan to make this same analysis for all the different UXO types in our study. First and second order parameter estimates, along with confidence intervals for each, will be included in the final report.

10. Stochastic models of UXO

Estimates for first and second order parameter moments can be combined with assumptions regarding their underlying distributions to form stochastic models for UXO. These models produce EMI signals for randomly generated hypothetical UXO, which on average over many trials are guaranteed to match the observed first and second order properties in the UXO samples. This provides a way to generate any desired number of UXO for purposes of optimizing decision rules and testing discrimination schemes. A typical approach is to assume the parameters come from a Gaussian random process, so their joint probability density functions are all multivariate normal. In this case, the system is completely defined by the means and covariance matrix, which we estimate from the sample. To generate a random realization, the eigenvalues of the covariance matrix are used to define a rotation that establishes the random variables along principal axes. Independent random variables can then be drawn, one for each dimension, and the resulting point may then rotated back to the original coordinates. The coordinates are then inserted into the model (Equations 1 and 2), and the EMI response becomes available.

11. Conclusions

Sample size is an important consideration for this project. A-priori assumptions regarding underlying parameter variability must be made in order to determine appropriate sample sizes before measurements begin. We adopt a Bayesian-like approach that makes use of intuitive assumptions based on experience and judgement. Although we do not explicitly calculate sample sizes *a-priori* using Bayes' theorem due to modeling complications, we do calculate *a-posteriori* uncertainties after site visits to guide UXO selection at later sites. Subject to practical considerations, our working goal is to have uncertainty for each parameter fall below 1/3 of the parameter value. This criterion is met for the example data set of 20mm UXO from Fort Ord. The relationship between sample size and parameter uncertainty is illustrated using this example. Uncertainty trends downward with increasing sample size, however the apparent asymptote does not represent the true parameter value because we have only a finite sample. The true value may, however, be expected to fall within the error bars for the $n = 20$ sample estimate ~67% of the time. The results of this analysis can be combined with Gaussian random processes to form stochastic models for UXO. These may be used in Monte Carlo studies for assessing performance of arbitrary discrimination schemes.

References

[1] J. Benjamin and C. Cornell, *Probability, Statistics, and Decision for Civil Engineers*. McGraw-Hill Book Company, New York, 1970.

[2] A. Ang and W. Tang, *Probability Concepts in Engineering Planning and Design*. John Wiley & Sons Inc. New York, 1975.

[3] T. Bell, B. Barrow, J. Miller and D. Keiswetter, "Time and Frequency Domain Electromagnetic Induction Signatures of Unexploded Ordnance." *Subsurface Sensing Technologies and Applications,* Vol. 2, No. 3, July 2001.

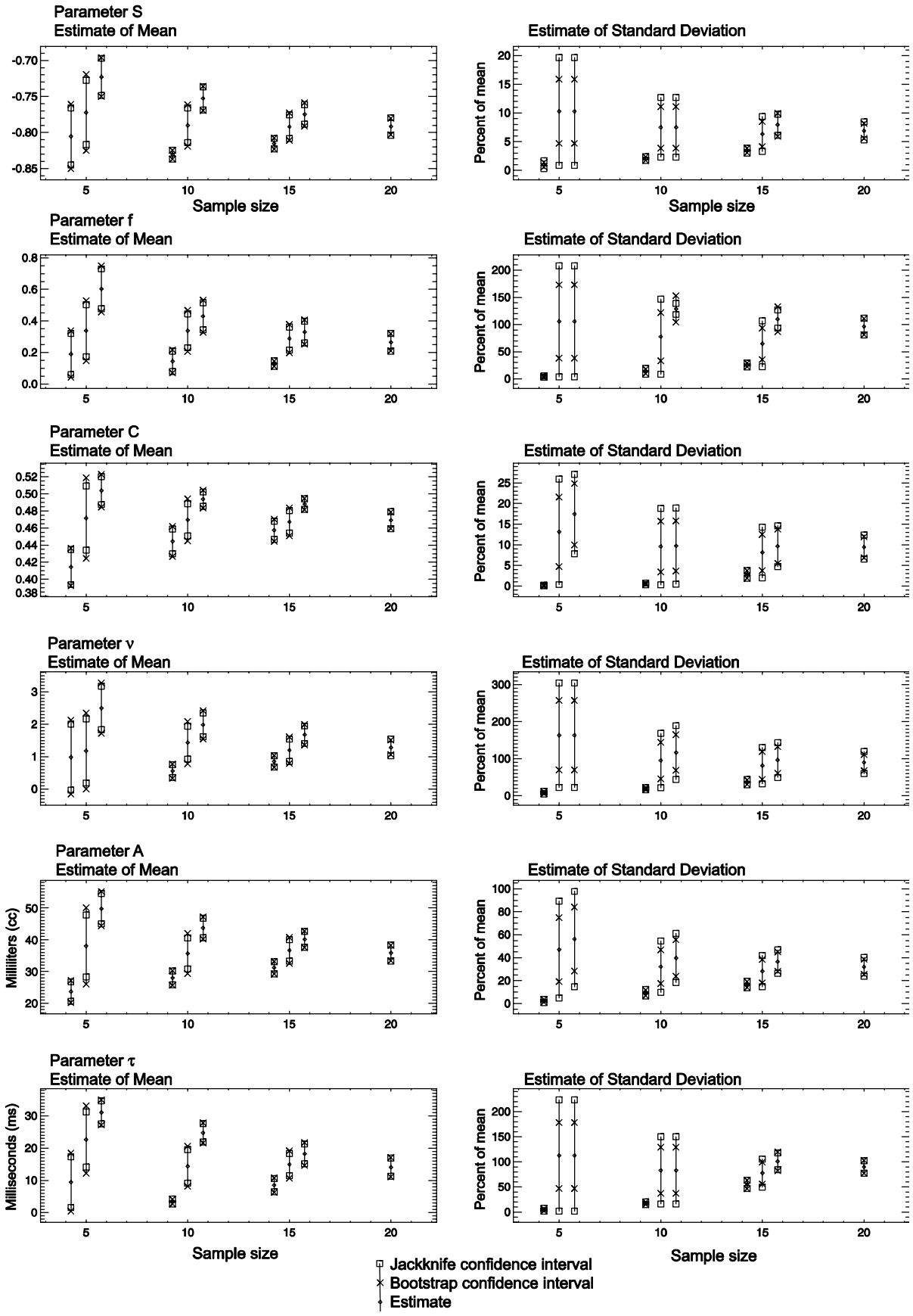
[4] J. Miller, T. Bell, J. Soukup and D. Keiswetter, "Simple Phenomenological Models for Wideband Frequency-Domain Electromagnetic Induction." IEEE Transactions on Geoscience and Remote Sensing, Vol. 39, No. 6, June 2001.

[5] F. Grant and G. West, *Interpretation Theory in Applied Geopysics*. McGraw-Hill, New York, 1965.

[6] S. Ward and G. Hohmann, "Electromagnetic Theory for Geophysical Applications" in *Electromagnetic Methods in Applied Geophysics*, Tulsa, OK, Society of Exploration Geophysicists, 1987.

[7] B. Efron, *The Jackknife, the Bootstrap and Other Resampling Plans*. Society for Industrial and Applied Mathematics, Philadelphia, 1982.

Appendix A. Estimated moments of model parameters for nose-down 20mm HE rounds.



Appendix B. Excerpt from the memorandum dated July 2, 2003 from the Executive Director, Strategic Environmental Research and Development Program.

"Prepare a white paper that better defines and justifies the methods used to determine adequate sample size for measurements. There exist standard quantitative statistical measures that would indicate what constitutes a sufficient sample set. Investigate the applicability of jackknife and bootstrap methods."

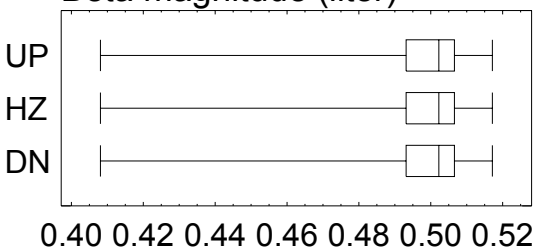
Appendix D. Group Summary Sheets

Group 0. Steel sphere, 4in dia, Chrome steel, Test object
Multiple shots on same target.
25 items in group.

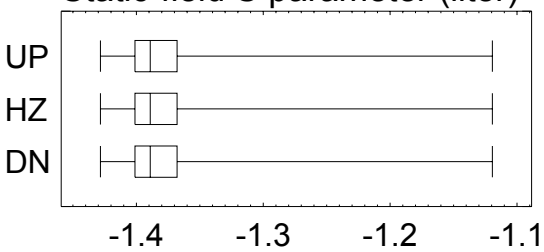
Item ID numbers:

535, 535, 535, 535, 535, 535, 535, 535, 535, 535, 535, 535, 535, 535, 535, 535

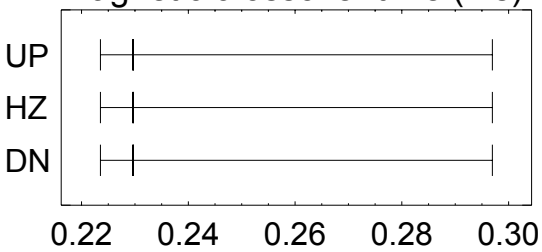
535, 535, 535, 535, 535, 535, 535, 535, 535



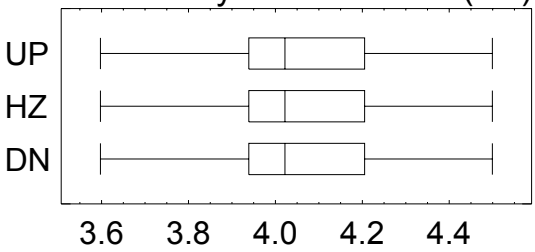
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.49	5.9e-3	6.3e-3	0.030	7.5e-3	7.5e-3
HZ	0.49	5.9e-3	6.5e-3	0.030	7.5e-3	7.8e-3
DN	0.49	5.9e-3	6.3e-3	0.030	7.5e-3	7.6e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.4	0.017	0.018	0.087	0.021	0.022
HZ	-1.4	0.017	0.018	0.087	0.021	0.022
DN	-1.4	0.017	0.018	0.087	0.021	0.021



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.23	2.9e-3	3.0e-3	0.015	8.6e-3	6.4e-3
HZ	0.23	2.9e-3	2.9e-3	0.015	8.6e-3	6.4e-3
DN	0.23	2.9e-3	3.0e-3	0.015	8.6e-3	6.6e-3

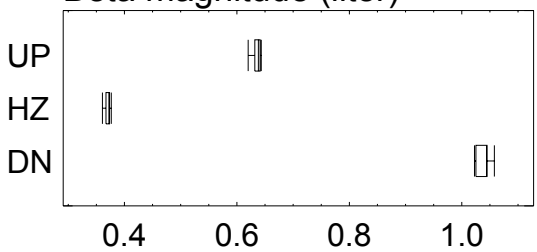


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	4.1	0.038	0.036	0.19	0.033	0.028
HZ	4.1	0.038	0.037	0.19	0.033	0.028
DN	4.1	0.038	0.036	0.19	0.033	0.027

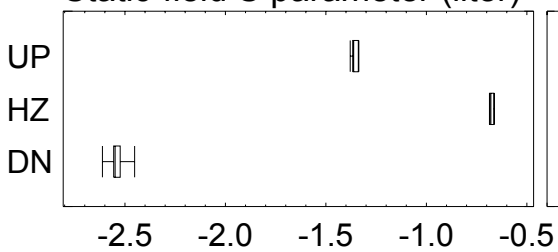
Group 1. Projectile, 60mm, Mortar, Illuminating, M83, Nose and body only
Multiple shots on same target.
5 items in group.

Item ID numbers:

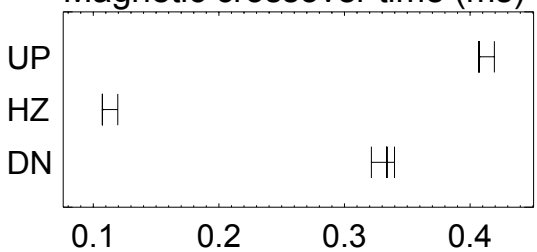
551, 551, 551, 551, 551



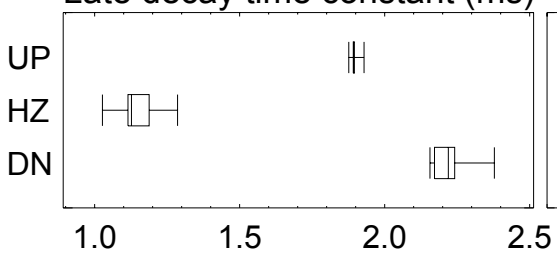
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.63	4.2e-3	4.4e-3	9.4e-3	4.3e-3	3.3e-3
HZ	0.37	2.8e-3	2.8e-3	6.2e-3	2.3e-3	1.8e-3
DN	1.0	6.6e-3	6.4e-3	0.015	3.7e-3	3.1e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.4	8.2e-3	8.4e-3	0.018	4.1e-3	3.9e-3
HZ	-0.68	5.1e-3	5.0e-3	0.011	2.0e-3	2.8e-3
DN	-2.5	0.026	0.024	0.058	0.025	0.018



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.41	3.0e-3	2.8e-3	6.7e-3	9.3e-4	2.3e-3
HZ	0.11	2.4e-3	2.6e-3	5.5e-3	2.3e-3	2.1e-3
DN	0.33	3.1e-3	3.2e-3	7.0e-3	2.4e-3	2.0e-3



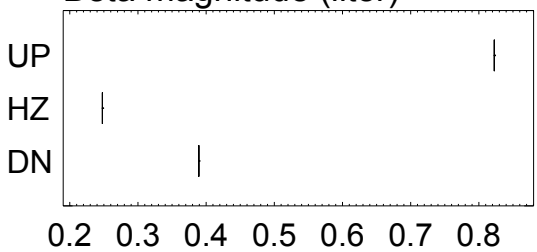
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.9	8.7e-3	8.0e-3	0.019	0.011	8.0e-3
HZ	1.1	0.043	0.042	0.096	0.037	0.027
DN	2.2	0.039	0.039	0.088	0.046	0.033

Group 2. Projectile, 60mm, Mortar, HE, M49, No fuze.

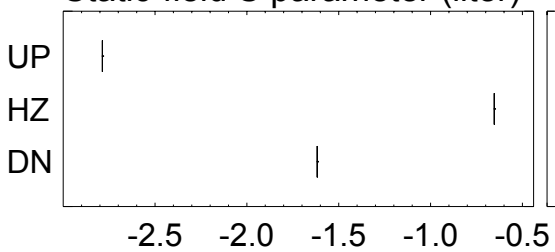
1 item in group.

Item ID number:

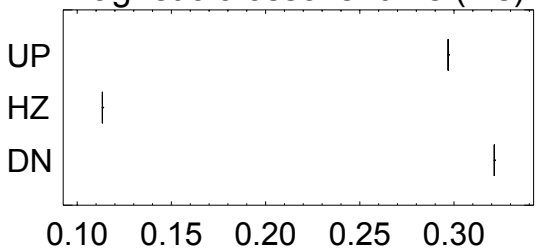
528



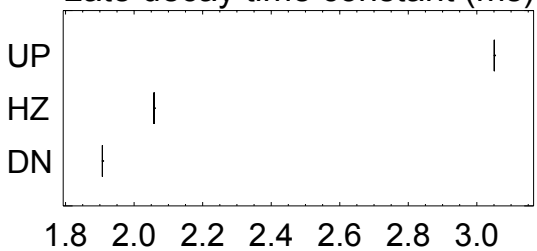
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.82	n/a	n/a	n/a	n/a	n/a
HZ	0.25	n/a	n/a	n/a	n/a	n/a
DN	0.39	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-2.8	n/a	n/a	n/a	n/a	n/a
HZ	-0.65	n/a	n/a	n/a	n/a	n/a
DN	-1.6	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.30	n/a	n/a	n/a	n/a	n/a
HZ	0.11	n/a	n/a	n/a	n/a	n/a
DN	0.32	n/a	n/a	n/a	n/a	n/a



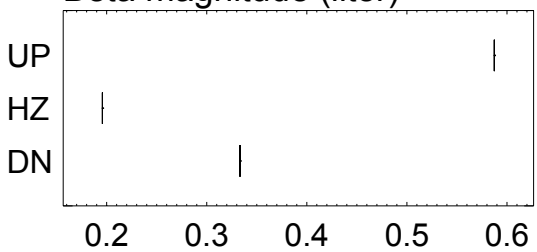
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.1	n/a	n/a	n/a	n/a	n/a
HZ	2.1	n/a	n/a	n/a	n/a	n/a
DN	1.9	n/a	n/a	n/a	n/a	n/a

Group 3. Projectile, 60mm, Mortar, HE, M49, No fuze or fins.

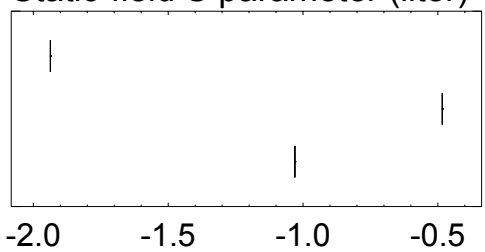
1 item in group.

Item ID number:

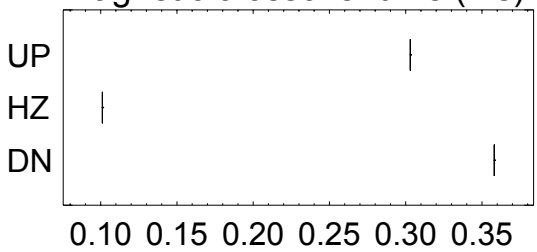
529



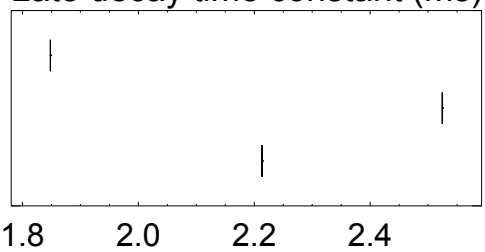
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.59	n/a	n/a	n/a	n/a	n/a
HZ	0.20	n/a	n/a	n/a	n/a	n/a
DN	0.33	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.9	n/a	n/a	n/a	n/a	n/a
HZ	-0.48	n/a	n/a	n/a	n/a	n/a
DN	-1.0	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.30	n/a	n/a	n/a	n/a	n/a
HZ	0.10	n/a	n/a	n/a	n/a	n/a
DN	0.36	n/a	n/a	n/a	n/a	n/a



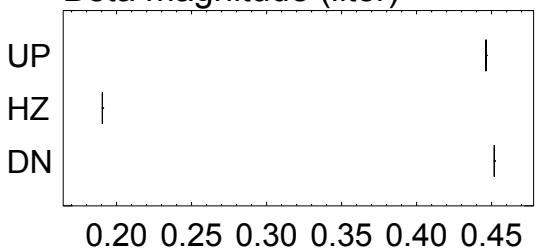
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.8	n/a	n/a	n/a	n/a	n/a
HZ	2.5	n/a	n/a	n/a	n/a	n/a
DN	2.2	n/a	n/a	n/a	n/a	n/a

Group 4. Projectile, 60mm, Mortar, HE, M49, No fuze or fins or boom.

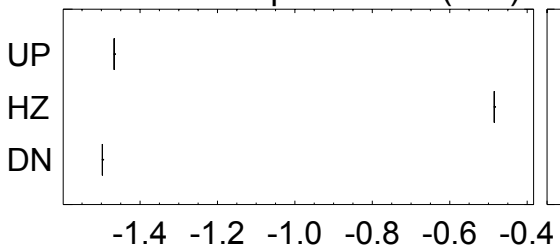
1 item in group.

Item ID number:

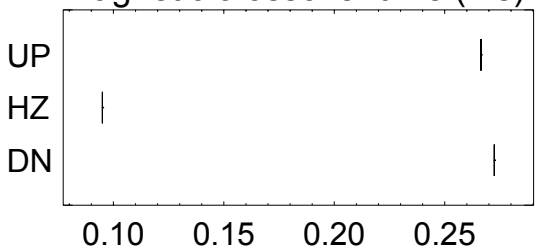
530



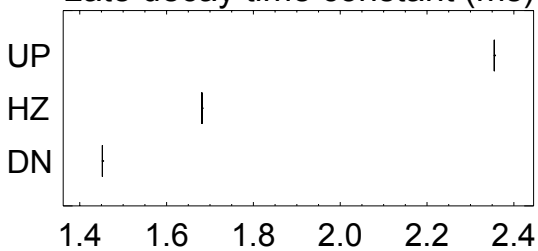
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.45	n/a	n/a	n/a	n/a	n/a
HZ	0.19	n/a	n/a	n/a	n/a	n/a
DN	0.45	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.5	n/a	n/a	n/a	n/a	n/a
HZ	-0.48	n/a	n/a	n/a	n/a	n/a
DN	-1.5	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.27	n/a	n/a	n/a	n/a	n/a
HZ	0.095	n/a	n/a	n/a	n/a	n/a
DN	0.27	n/a	n/a	n/a	n/a	n/a



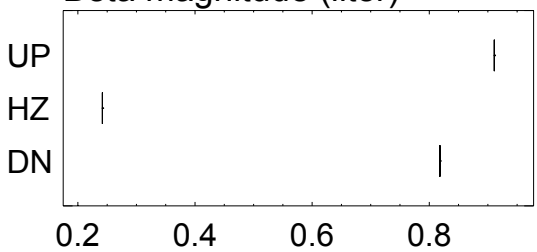
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.4	n/a	n/a	n/a	n/a	n/a
HZ	1.7	n/a	n/a	n/a	n/a	n/a
DN	1.5	n/a	n/a	n/a	n/a	n/a

Group 5. Projectile, 60mm, Mortar, HE, M49, No fuze or boom

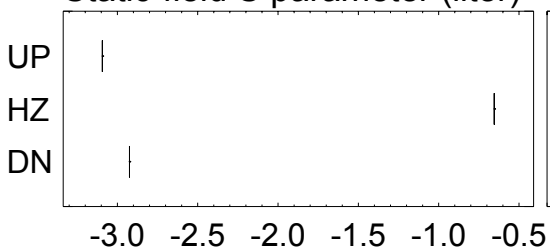
1 item in group.

Item ID number:

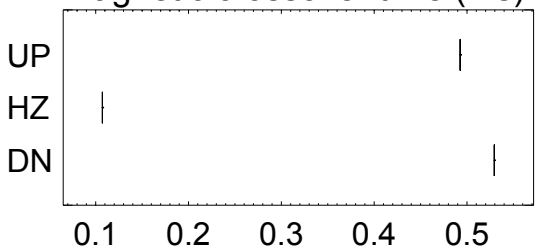
531



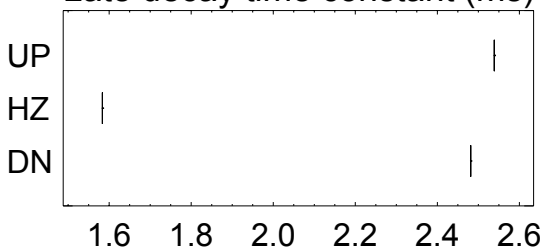
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.91	n/a	n/a	n/a	n/a	n/a
HZ	0.24	n/a	n/a	n/a	n/a	n/a
DN	0.82	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-3.1	n/a	n/a	n/a	n/a	n/a
HZ	-0.65	n/a	n/a	n/a	n/a	n/a
DN	-2.9	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.49	n/a	n/a	n/a	n/a	n/a
HZ	0.11	n/a	n/a	n/a	n/a	n/a
DN	0.53	n/a	n/a	n/a	n/a	n/a



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.5	n/a	n/a	n/a	n/a	n/a
HZ	1.6	n/a	n/a	n/a	n/a	n/a
DN	2.5	n/a	n/a	n/a	n/a	n/a

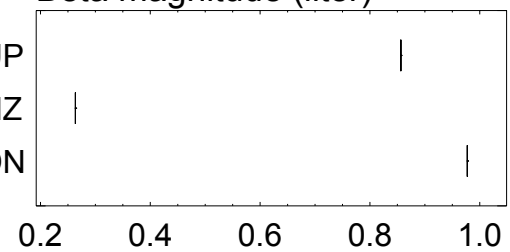
Group 6. Projectile, 60mm, Mortar, HE, M49, No boom

1 item in group.

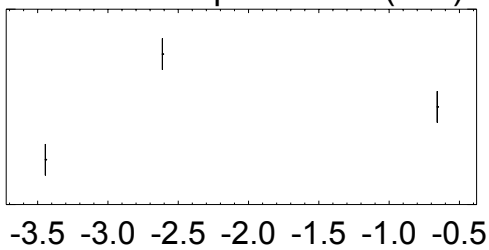
Item ID number:

532

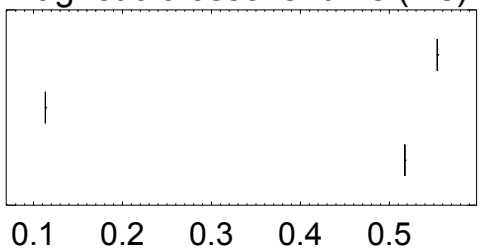
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.86	n/a	n/a	n/a	n/a	n/a
HZ	0.26	n/a	n/a	n/a	n/a	n/a
DN	0.98	n/a	n/a	n/a	n/a	n/a



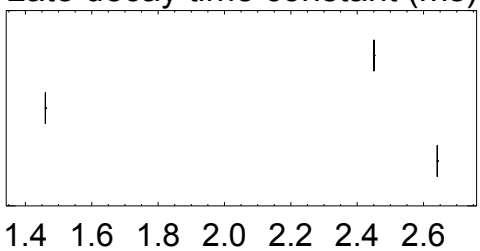
Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-2.6	n/a	n/a	n/a	n/a	n/a
HZ	-0.66	n/a	n/a	n/a	n/a	n/a
DN	-3.4	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.55	n/a	n/a	n/a	n/a	n/a
HZ	0.11	n/a	n/a	n/a	n/a	n/a
DN	0.52	n/a	n/a	n/a	n/a	n/a



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.5	n/a	n/a	n/a	n/a	n/a
HZ	1.5	n/a	n/a	n/a	n/a	n/a
DN	2.6	n/a	n/a	n/a	n/a	n/a

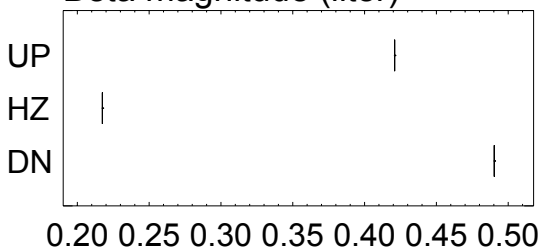


Group 7. Projectile, 60mm, Mortar, HE, M49, No boom or fins

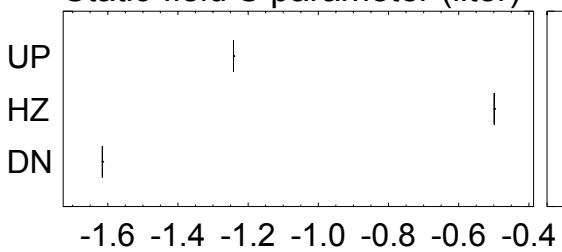
1 item in group.

Item ID number:

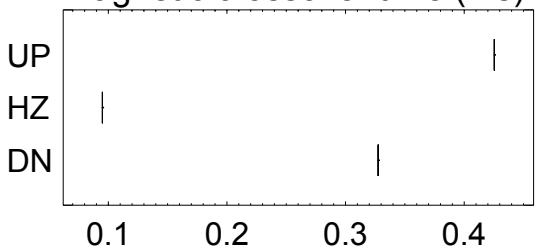
533



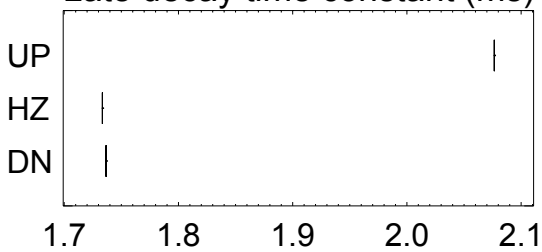
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.42	n/a	n/a	n/a	n/a	n/a
HZ	0.22	n/a	n/a	n/a	n/a	n/a
DN	0.49	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.2	n/a	n/a	n/a	n/a	n/a
HZ	-0.50	n/a	n/a	n/a	n/a	n/a
DN	-1.6	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.43	n/a	n/a	n/a	n/a	n/a
HZ	0.095	n/a	n/a	n/a	n/a	n/a
DN	0.33	n/a	n/a	n/a	n/a	n/a



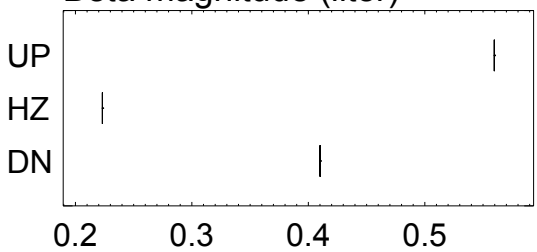
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.1	n/a	n/a	n/a	n/a	n/a
HZ	1.7	n/a	n/a	n/a	n/a	n/a
DN	1.7	n/a	n/a	n/a	n/a	n/a

Group 8. Projectile, 60mm, Mortar, HE, M49, No fins

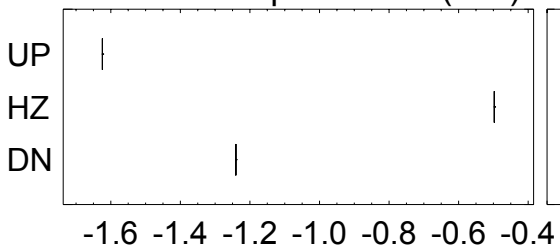
1 item in group.

Item ID number:

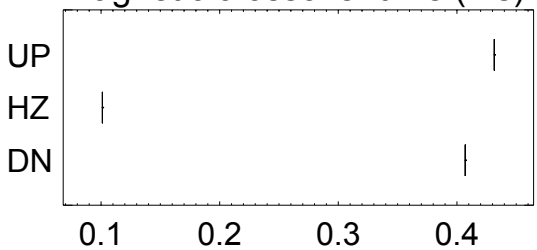
534



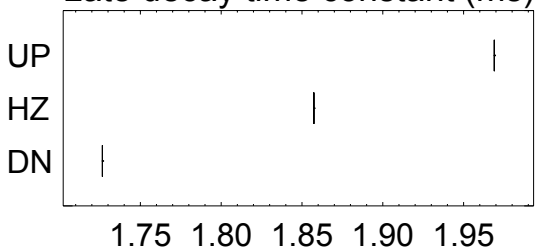
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.56	n/a	n/a	n/a	n/a	n/a
HZ	0.22	n/a	n/a	n/a	n/a	n/a
DN	0.41	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.6	n/a	n/a	n/a	n/a	n/a
HZ	-0.50	n/a	n/a	n/a	n/a	n/a
DN	-1.2	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.43	n/a	n/a	n/a	n/a	n/a
HZ	0.10	n/a	n/a	n/a	n/a	n/a
DN	0.41	n/a	n/a	n/a	n/a	n/a



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.0	n/a	n/a	n/a	n/a	n/a
HZ	1.9	n/a	n/a	n/a	n/a	n/a
DN	1.7	n/a	n/a	n/a	n/a	n/a

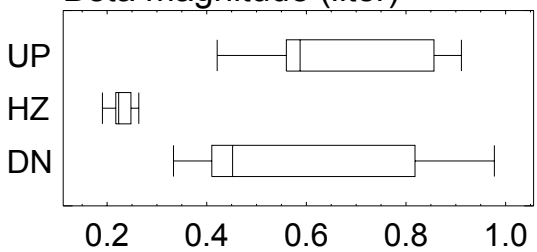
Group 9. Projectile, 60mm, Mortar, HE, M49, Same item with 7 different fuze/boom/fin configurations.

7 items in group.

Item ID numbers:

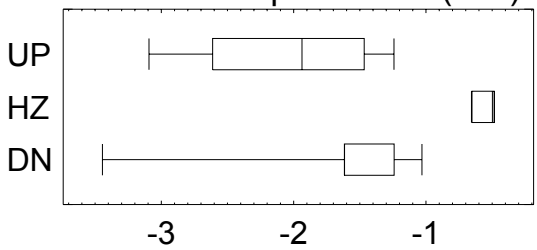
528, 529, 530, 531, 532, 533, 534

Beta magnitude (liter)



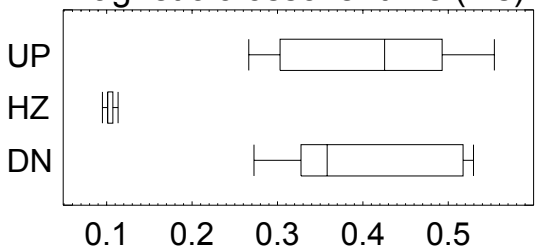
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.66	0.077	0.075	0.20	0.029	0.032
HZ	0.23	0.010	9.8e-3	0.027	5.7e-3	5.6e-3
DN	0.55	0.093	0.11	0.25	0.074	0.077

Static-field S parameter (liter)



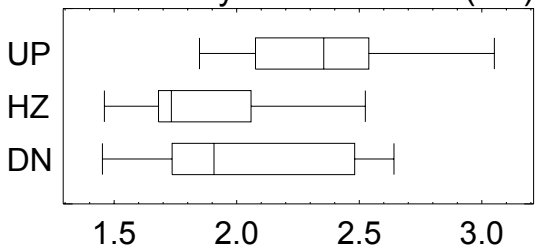
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-2.1	0.27	0.27	0.72	0.12	0.10
HZ	-0.56	0.033	0.031	0.087	6.6e-3	0.012
DN	-1.9	0.34	0.35	0.91	0.26	0.27

Magnetic crossover time (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.40	0.041	0.044	0.11	0.021	0.023
HZ	0.10	2.9e-3	3.0e-3	7.8e-3	1.4e-3	1.3e-3
DN	0.39	0.038	0.042	0.099	0.021	0.021

Late decay time constant (ms)



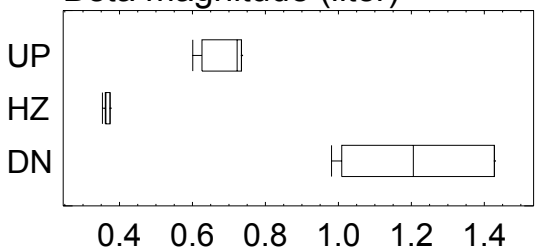
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.3	0.15	0.15	0.41	0.13	0.11
HZ	1.8	0.13	0.13	0.36	0.15	0.11
DN	2.0	0.16	0.18	0.44	0.091	0.092

Group 10. Projectile, 60mm, Mortar, Illuminating, M83, Nose and body only

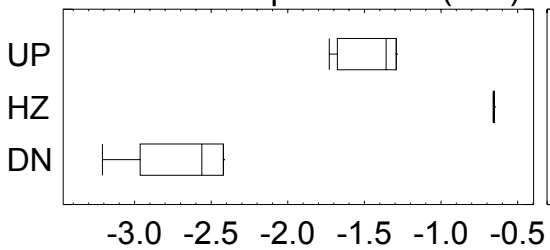
4 items in group.

Item ID numbers:

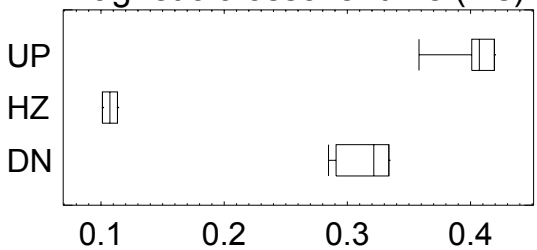
552, 553, 554, 555



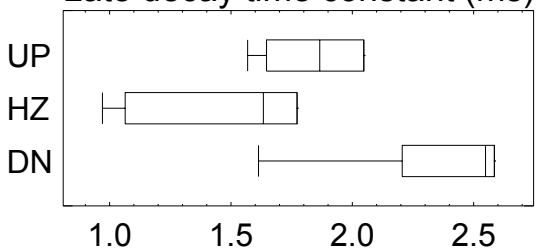
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.67	0.034	0.034	0.067	9.8e-3	0.023
HZ	0.36	4.4e-3	4.6e-3	8.7e-3	4.0e-3	3.2e-3
DN	1.2	0.10	0.11	0.21	0.083	0.072



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.5	0.11	0.11	0.22	0.030	0.068
HZ	-0.66	1.8e-3	1.8e-3	3.5e-3	1.8e-3	1.4e-3
DN	-2.8	0.18	0.18	0.36	0.098	0.12



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.40	0.013	0.014	0.027	0.016	0.012
HZ	0.11	2.9e-3	3.0e-3	5.9e-3	2.3e-3	2.4e-3
DN	0.31	0.012	0.013	0.024	4.8e-3	7.5e-3

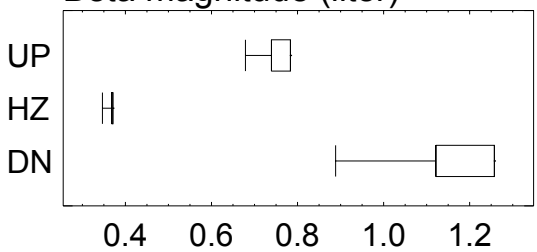


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.8	0.11	0.11	0.22	0.069	0.073
HZ	1.4	0.20	0.21	0.40	0.059	0.13
DN	2.2	0.23	0.22	0.45	0.23	0.18

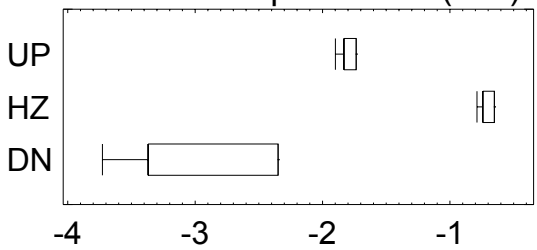
Group 11. Projectile, 60mm, Mortar, Illuminating, M83, Nose and body only
, From Ft. McClellan.
3 items in group.

Item ID numbers:

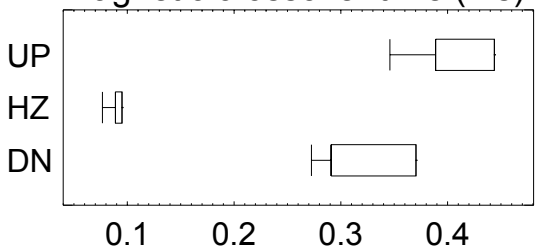
1108, 1109, 1110



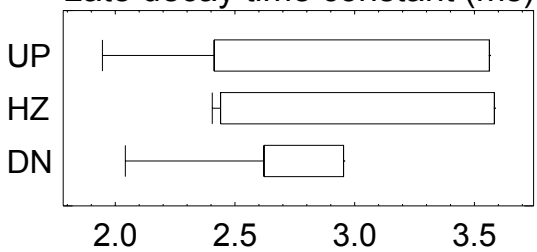
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.73	0.030	0.030	0.052	0.026	0.022
HZ	0.36	7.6e-3	8.0e-3	0.013	9.4e-3	7.3e-3
DN	1.1	0.11	0.12	0.19	0.096	0.079



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.8	0.047	0.044	0.082	0.040	0.034
HZ	-0.73	0.040	0.041	0.070	0.037	0.034
DN	-3.1	0.41	0.45	0.72	0.42	0.33



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.39	0.028	0.026	0.049	0.024	0.020
HZ	0.087	5.4e-3	5.4e-3	9.3e-3	5.0e-3	4.4e-3
DN	0.31	0.030	0.029	0.052	0.034	0.028



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.6	0.48	0.48	0.83	0.47	0.39
HZ	2.8	0.39	0.42	0.67	0.53	0.39
DN	2.5	0.27	0.27	0.46	0.24	0.20

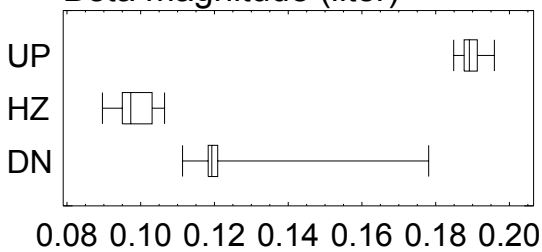
Group 12. Projectile, 60mm, Mortar, Illuminating, M83, Tail cone and fins only

17 items in group.

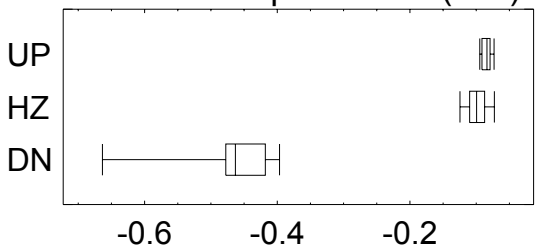
Item ID numbers:

556, 557, 558, 559, 560, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581

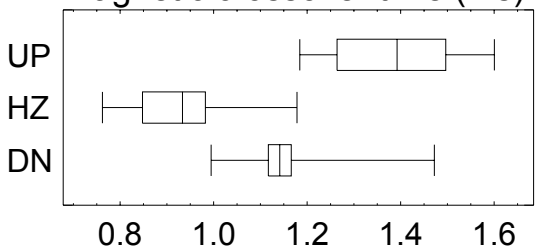
582



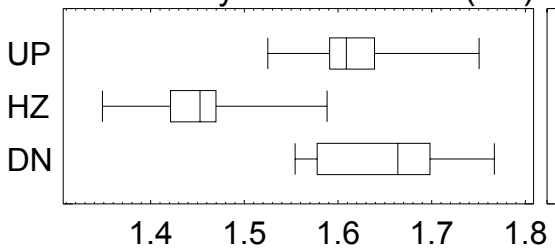
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.19	7.2e-4	8.3e-4	3.0e-3	5.4e-4	4.8e-4
HZ	0.099	1.2e-3	1.2e-3	4.8e-3	6.3e-4	5.7e-4
DN	0.12	3.6e-3	3.3e-3	0.015	0.011	7.6e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.085	1.8e-3	1.8e-3	7.3e-3	8.6e-4	7.3e-4
HZ	-0.096	3.9e-3	4.1e-3	0.016	1.9e-3	1.9e-3
DN	-0.46	0.015	0.015	0.063	0.027	0.020



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.4	0.032	0.034	0.13	0.014	0.013
HZ	0.93	0.028	0.025	0.11	0.020	0.018
DN	1.2	0.030	0.028	0.12	0.028	0.023



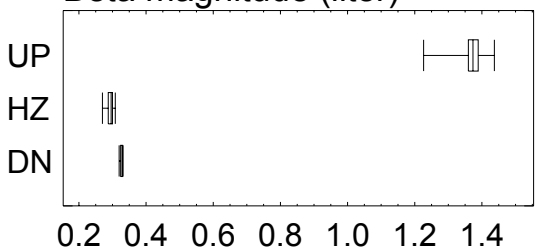
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.6	0.013	0.013	0.053	0.013	0.012
HZ	1.5	0.014	0.016	0.059	0.013	0.012
DN	1.7	0.016	0.018	0.067	8.9e-3	8.3e-3

Group 13. Projectile, 81mm, Mortar, Illuminating, M301A1 & A2, Tail cone and fins only

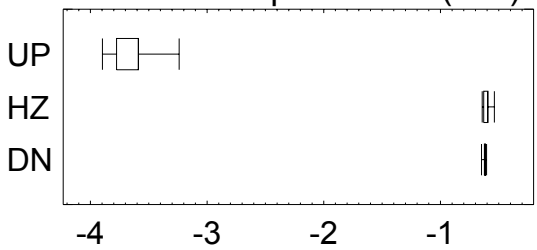
5 items in group.

Item ID numbers:

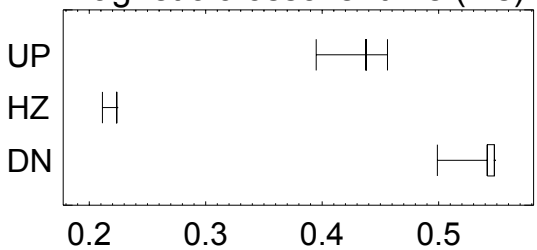
561, 562, 563, 564, 565



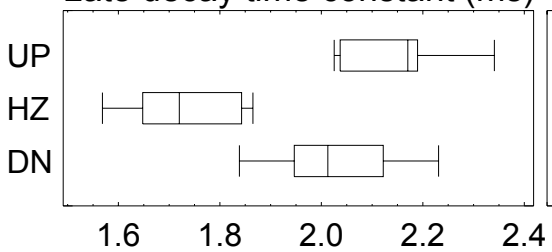
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.4	0.035	0.037	0.079	0.043	0.032
HZ	0.29	6.5e-3	6.8e-3	0.015	6.1e-3	5.2e-3
DN	0.33	2.1e-3	2.2e-3	4.7e-3	1.6e-3	1.5e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-3.6	0.11	0.10	0.25	0.10	0.085
HZ	-0.60	0.018	0.019	0.041	0.017	0.014
DN	-0.62	7.3e-3	6.9e-3	0.016	8.4e-3	6.3e-3



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.43	0.010	9.6e-3	0.023	8.9e-3	6.3e-3
HZ	0.22	3.0e-3	3.3e-3	6.7e-3	9.3e-4	1.8e-3
DN	0.54	9.3e-3	9.6e-3	0.021	0.016	0.011



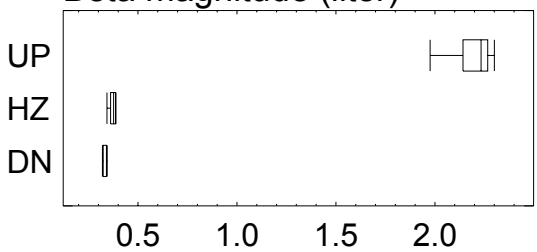
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.2	0.058	0.054	0.13	0.045	0.039
HZ	1.7	0.057	0.061	0.13	0.030	0.030
DN	2.0	0.068	0.068	0.15	0.047	0.042

Group 14. Projectile, 81mm, Mortar, Illuminating, M301A3, Tail cone and fins only

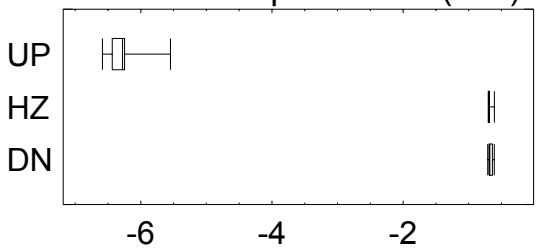
5 items in group.

Item ID numbers:

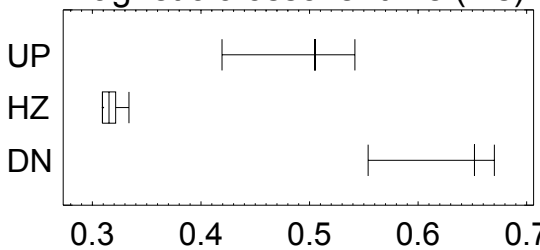
566, 567, 568, 569, 570



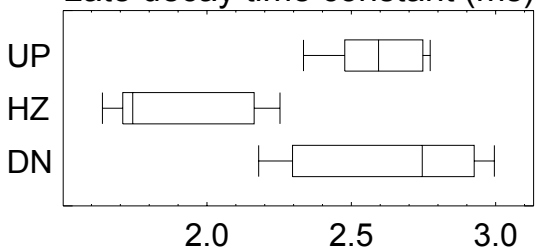
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.2	0.058	0.061	0.13	0.060	0.046
HZ	0.37	8.5e-3	9.1e-3	0.019	6.6e-3	5.7e-3
DN	0.33	4.9e-3	5.4e-3	0.011	2.2e-3	2.5e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-6.2	0.18	0.20	0.40	0.23	0.17
HZ	-0.68	0.018	0.020	0.039	0.030	0.021
DN	-0.66	0.018	0.019	0.040	0.012	0.011



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.49	0.020	0.021	0.045	0.024	0.017
HZ	0.32	4.6e-3	4.6e-3	0.010	4.3e-3	3.1e-3
DN	0.63	0.020	0.024	0.046	0.029	0.021



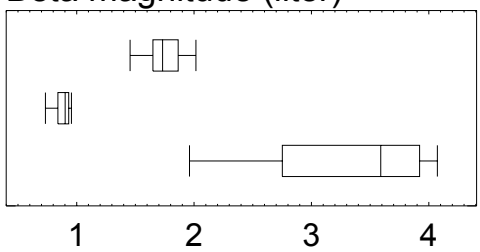
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.6	0.083	0.077	0.18	0.051	0.047
HZ	1.9	0.13	0.14	0.28	0.052	0.068
DN	2.6	0.17	0.17	0.37	0.069	0.10

Group 15. Projectile, 81mm, Mortar, Illuminating, M301, Nose and body only

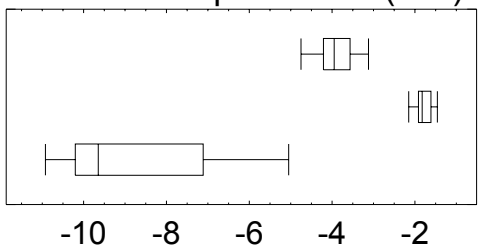
15 items in group.

Item ID numbers:

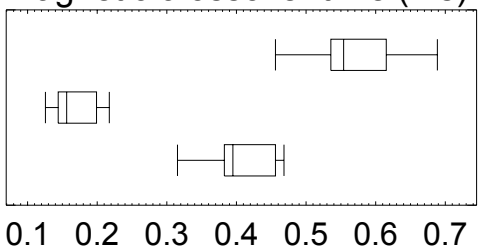
583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597



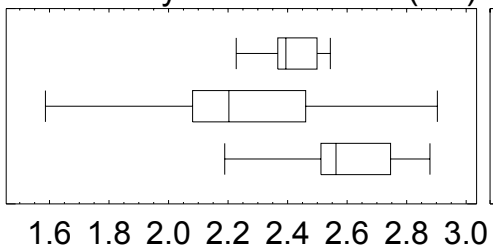
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.7	0.046	0.044	0.18	0.027	0.025
HZ	0.88	0.017	0.017	0.067	0.012	0.011
DN	3.3	0.18	0.18	0.69	0.096	0.10



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-3.9	0.13	0.14	0.50	0.073	0.065
HZ	-1.8	0.050	0.053	0.19	0.030	0.031
DN	-8.8	0.49	0.49	1.9	0.28	0.27



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.57	0.019	0.020	0.073	0.011	9.8e-3
HZ	0.17	8.2e-3	8.4e-3	0.032	3.6e-3	3.3e-3
DN	0.40	0.012	0.013	0.047	7.3e-3	6.9e-3



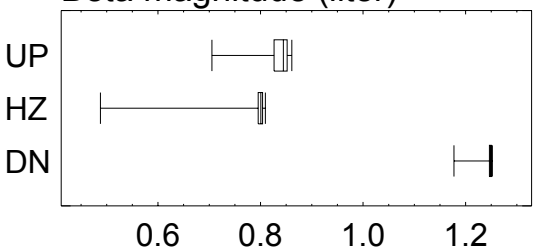
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.4	0.023	0.022	0.087	0.016	0.016
HZ	2.2	0.080	0.076	0.31	0.074	0.072
DN	2.6	0.051	0.051	0.20	0.034	0.029

Group 16. Projectile, 81mm, Mortar, Smoke, M819, Nose and body only

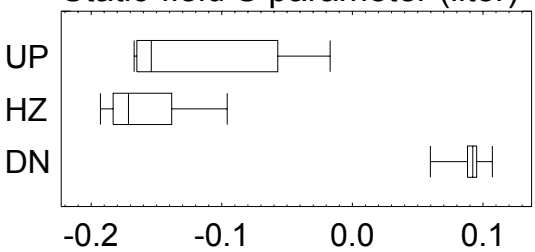
6 items in group.

Item ID numbers:

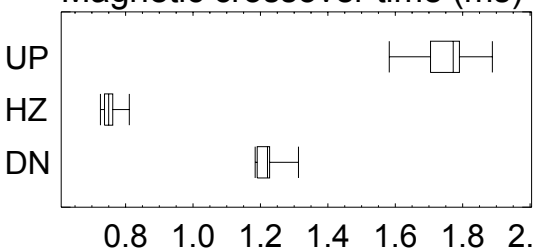
598, 599, 600, 601, 602, 1215



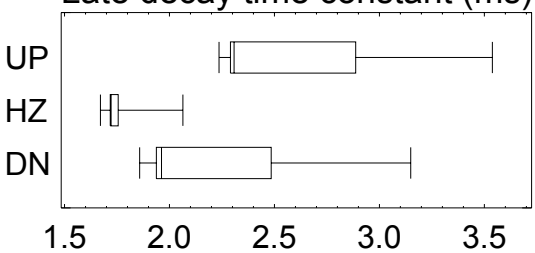
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.81	0.025	0.023	0.060	0.025	0.020
HZ	0.75	0.052	0.048	0.13	0.11	0.070
DN	1.2	0.012	0.012	0.029	0.023	0.014



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.12	0.027	0.026	0.067	0.019	0.021
HZ	-0.16	0.015	0.014	0.037	0.015	0.013
DN	0.085	7.3e-3	6.8e-3	0.018	4.6e-3	4.1e-3



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.7	0.049	0.046	0.12	0.029	0.023
HZ	0.75	0.013	0.013	0.031	0.016	0.012
DN	1.2	0.020	0.019	0.048	0.027	0.017



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.6	0.22	0.20	0.53	0.24	0.20
HZ	1.8	0.060	0.055	0.15	0.11	0.069
DN	2.2	0.21	0.21	0.51	0.24	0.18

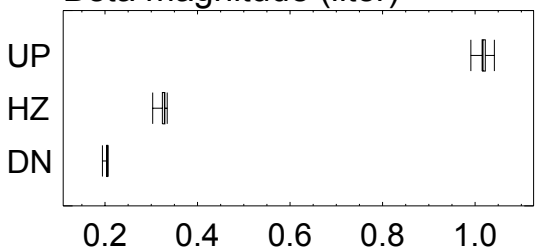
Group 17. Projectile, 81mm, Mortar, Smoke, M819, Tail cone and fins only

5 items in group.

Item ID numbers:

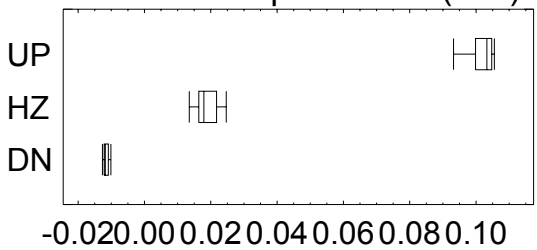
603, 604, 605, 606, 607

Beta magnitude (liter)



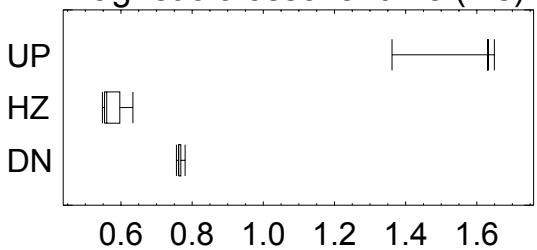
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.0	8.1e-3	7.8e-3	0.018	7.8e-3	6.7e-3
HZ	0.32	5.5e-3	6.0e-3	0.012	7.4e-3	5.2e-3
DN	0.20	2.2e-3	2.0e-3	4.9e-3	3.4e-3	2.2e-3

Static-field S parameter (liter)



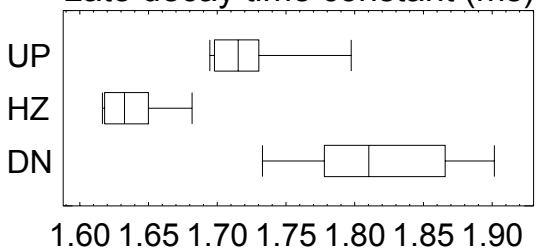
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.10	2.2e-3	2.3e-3	5.0e-3	2.4e-3	2.0e-3
HZ	0.019	2.0e-3	1.9e-3	4.4e-3	1.3e-3	1.2e-3
DN	-0.012	4.5e-4	4.8e-4	1.0e-3	3.1e-4	2.9e-4

Magnetic crossover time (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.6	0.054	0.046	0.12	0.094	0.064
HZ	0.58	0.016	0.018	0.036	0.014	0.013
DN	0.77	4.2e-3	4.1e-3	9.3e-3	4.3e-3	3.0e-3

Late decay time constant (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.7	0.019	0.018	0.042	0.024	0.016
HZ	1.6	0.012	0.012	0.027	0.011	8.8e-3
DN	1.8	0.030	0.030	0.067	0.019	0.018

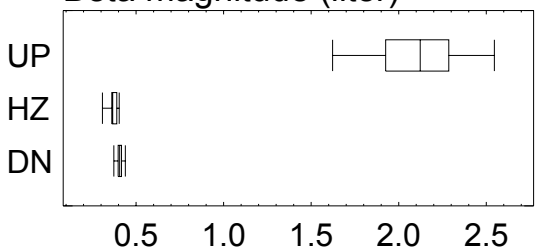
Group 18. Projectile, 81mm, Mortar, HE, M374, Tail cone and fins only

5 items in group.

Item ID numbers:

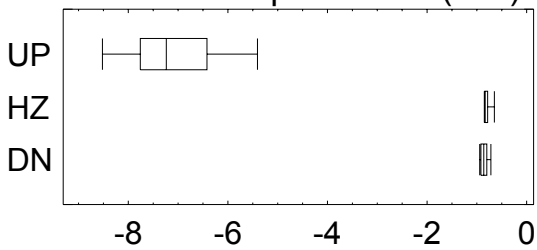
608, 609, 610, 611, 612

Beta magnitude (liter)



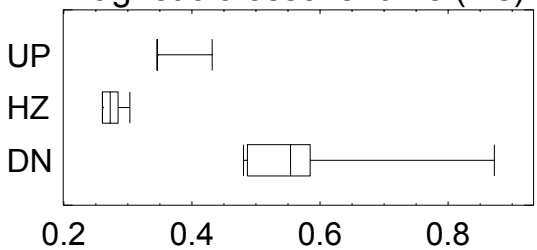
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.1	0.16	0.16	0.35	0.12	0.086
HZ	0.37	0.016	0.017	0.037	0.017	0.012
DN	0.41	0.011	0.012	0.024	9.1e-3	7.0e-3

Static-field S parameter (liter)



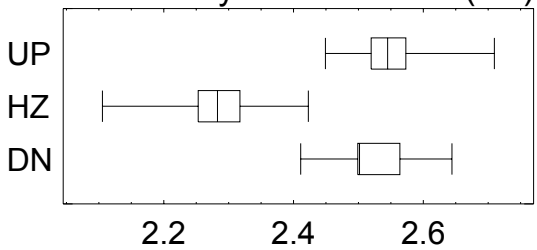
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-7.1	0.54	0.55	1.2	0.39	0.34
HZ	-0.79	0.038	0.040	0.085	0.051	0.035
DN	-0.85	0.041	0.043	0.091	0.029	0.028

Magnetic crossover time (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.37	0.017	0.019	0.037	0.028	0.020
HZ	0.28	8.1e-3	7.8e-3	0.018	6.5e-3	4.9e-3
DN	0.60	0.072	0.072	0.16	0.10	0.074

Late decay time constant (ms)



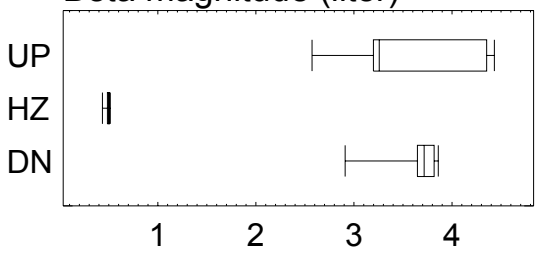
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.6	0.043	0.046	0.096	0.044	0.033
HZ	2.3	0.051	0.051	0.12	0.049	0.038
DN	2.5	0.039	0.044	0.086	0.032	0.025

Group 19. Projectile, 81mm, Mortar, Practice, M821, Body only

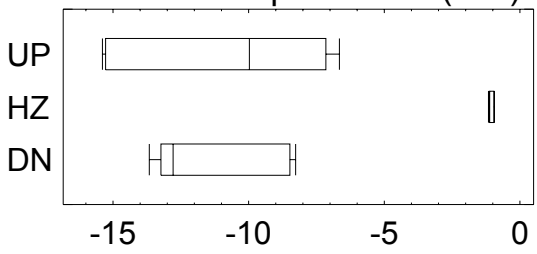
7 items in group.

Item ID numbers:

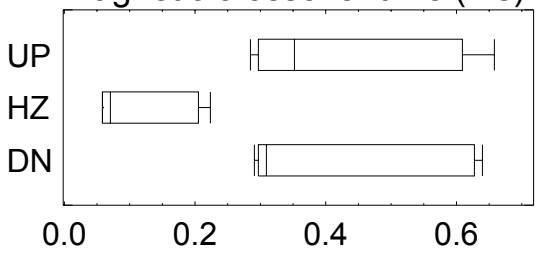
1202, 1203, 1204, 1205, 1206, 1213, 1214



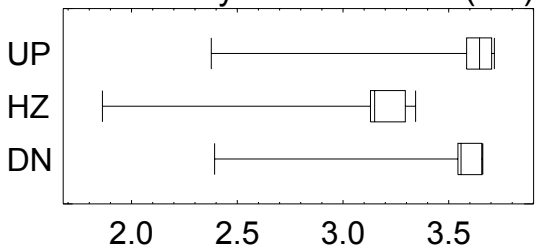
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.5	0.31	0.29	0.81	0.11	0.15
HZ	0.48	0.013	0.012	0.033	7.6e-3	8.4e-3
DN	3.5	0.16	0.14	0.42	0.099	0.12



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-11.	1.5	1.4	3.9	0.52	0.69
HZ	-1.1	0.034	0.030	0.089	0.020	0.023
DN	-12.	0.88	0.81	2.3	0.56	0.64



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.41	0.060	0.052	0.16	0.040	0.044
HZ	0.11	0.028	0.024	0.074	0.019	0.024
DN	0.39	0.062	0.055	0.16	0.040	0.053



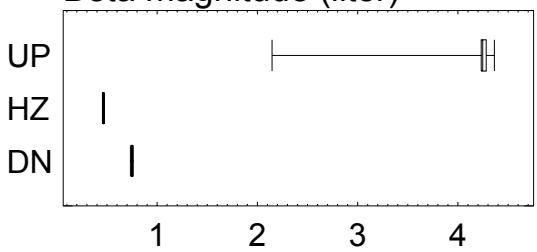
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.3	0.23	0.20	0.60	0.15	0.20
HZ	2.9	0.25	0.21	0.65	0.16	0.20
DN	3.3	0.21	0.18	0.55	0.15	0.18

Group 20. Projectile, 81mm, Mortar, Practice, M821, Body, boom, and fins.

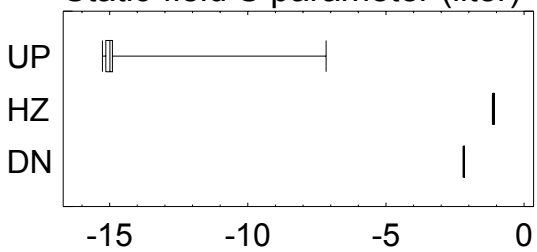
6 items in group.

Item ID numbers:

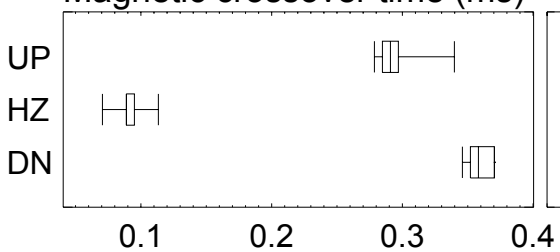
1207, 1208, 1209, 1210, 1211, 1212



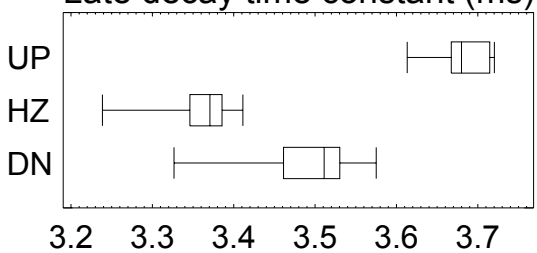
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.9	0.35	0.36	0.87	0.75	0.48
HZ	0.46	3.1e-3	3.1e-3	7.6e-3	2.3e-3	2.1e-3
DN	0.75	4.3e-3	4.7e-3	0.011	2.9e-3	2.3e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-14.	1.3	1.3	3.2	2.8	1.8
HZ	-1.1	0.010	0.010	0.025	8.3e-3	6.3e-3
DN	-2.2	8.4e-3	8.5e-3	0.020	5.0e-3	4.6e-3



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.29	9.4e-3	9.8e-3	0.023	0.014	9.9e-3
HZ	0.090	5.8e-3	5.0e-3	0.014	5.7e-3	4.7e-3
DN	0.36	4.2e-3	4.3e-3	0.010	2.1e-3	2.6e-3

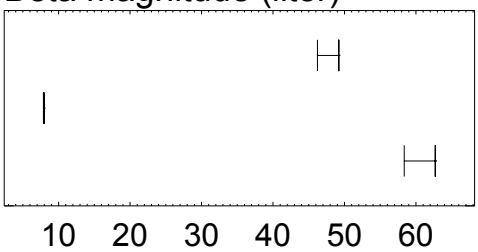


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.7	0.017	0.019	0.043	9.8e-3	0.011
HZ	3.3	0.029	0.031	0.072	0.015	0.019
DN	3.5	0.039	0.039	0.095	0.024	0.024

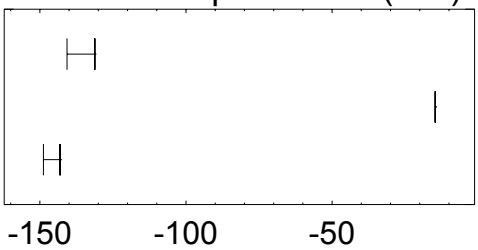
Group 21. Projectile, 155mm, Base ejection, No nose
Band intact.
2 items in group.

Item ID numbers:

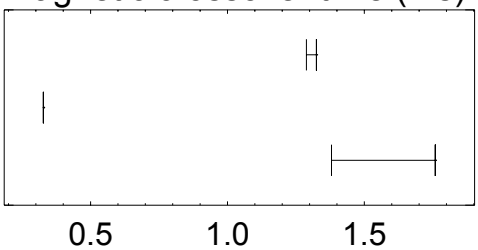
623, 624



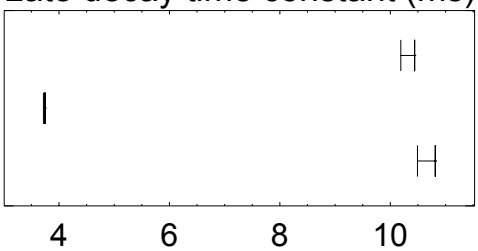
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	48.	n/a	n/a	n/a	n/a	n/a
HZ	7.9	n/a	n/a	n/a	n/a	n/a
DN	61.	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.4e+2	n/a	n/a	n/a	n/a	n/a
HZ	-15.	n/a	n/a	n/a	n/a	n/a
DN	-1.5e+2	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.3	n/a	n/a	n/a	n/a	n/a
HZ	0.33	n/a	n/a	n/a	n/a	n/a
DN	1.6	n/a	n/a	n/a	n/a	n/a

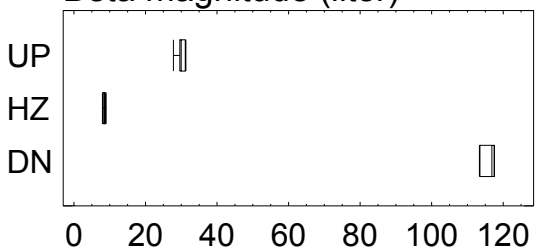


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	10.	n/a	n/a	n/a	n/a	n/a
HZ	3.7	n/a	n/a	n/a	n/a	n/a
DN	11.	n/a	n/a	n/a	n/a	n/a

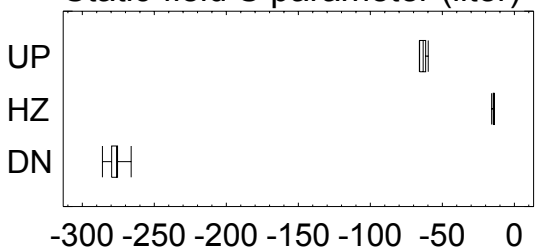
Group 22. Projectile, 155mm, Base ejection
Band intact.
5 items in group.

Item ID numbers:

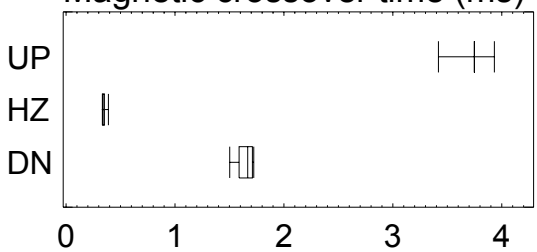
625, 626, 627, 628, 629



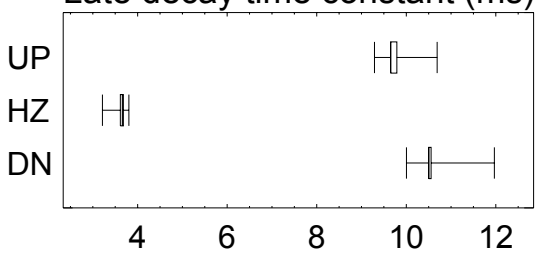
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	30.	0.63	0.63	1.4	0.57	0.44
HZ	8.5	0.18	0.19	0.41	0.12	0.11
DN	1.2e+2	0.96	1.0	2.1	0.31	0.57



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-63.	1.2	1.1	2.7	0.67	0.69
HZ	-15.	0.34	0.29	0.76	0.38	0.27
DN	-2.8e+2	3.2	3.3	7.2	3.0	2.2



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.7	0.088	0.088	0.20	0.064	0.056
HZ	0.35	0.010	8.7e-3	0.023	0.014	0.010
DN	1.6	0.041	0.045	0.092	0.032	0.029



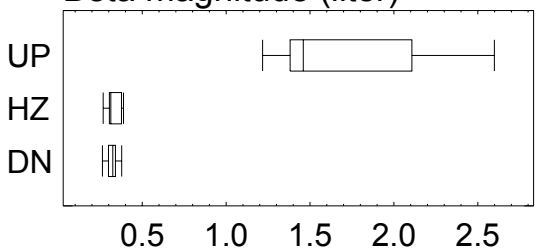
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	9.8	0.23	0.22	0.52	0.30	0.19
HZ	3.6	0.10	0.095	0.22	0.14	0.097
DN	11.	0.33	0.31	0.74	0.46	0.32

Group 23. Projectile, 81mm, Mortar, Smoke, M57, Tail cone and fins only

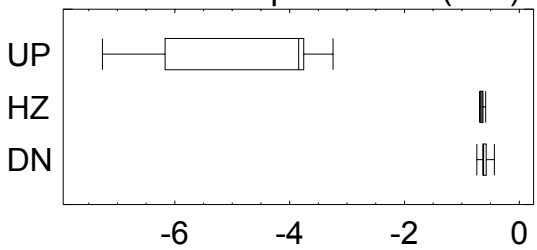
9 items in group.

Item ID numbers:

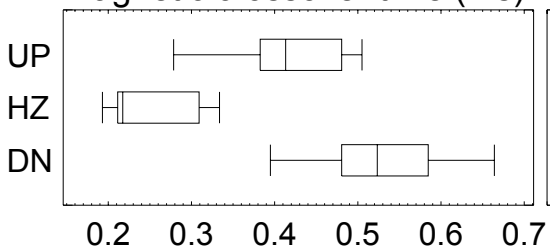
630, 631, 632, 633, 634, 635, 636, 637, 638



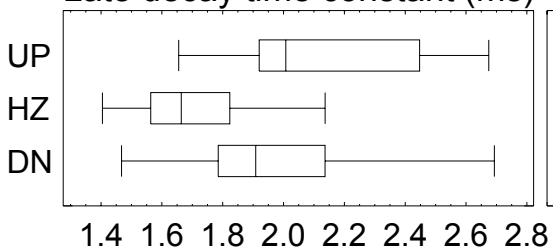
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.8	0.17	0.18	0.52	0.087	0.086
HZ	0.33	0.015	0.015	0.044	6.8e-3	6.7e-3
DN	0.32	0.013	0.013	0.039	8.2e-3	7.5e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-4.9	0.52	0.54	1.5	0.24	0.27
HZ	-0.65	0.011	0.013	0.034	1.0e-2	7.9e-3
DN	-0.61	0.029	0.031	0.087	0.030	0.025



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.42	0.023	0.024	0.069	0.021	0.017
HZ	0.26	0.019	0.019	0.058	5.8e-3	7.6e-3
DN	0.53	0.026	0.029	0.078	0.022	0.019



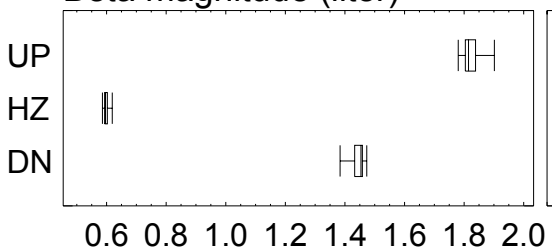
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.1	0.12	0.13	0.36	0.067	0.073
HZ	1.7	0.076	0.077	0.23	0.064	0.056
DN	2.0	0.13	0.14	0.39	0.097	0.097

Group 24. Projectile, 81mm, Mortar, Practice, M880, Body only

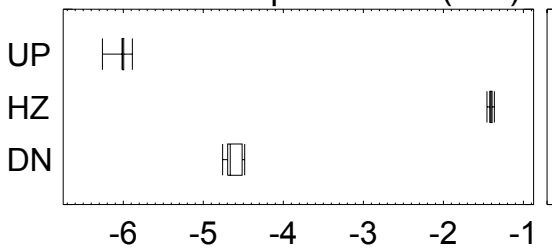
6 items in group.

Item ID numbers:

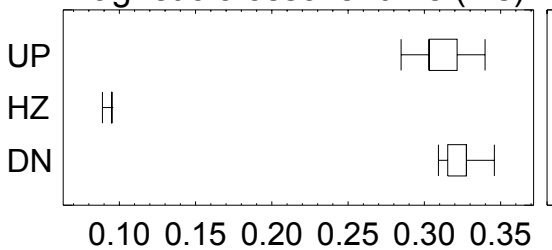
648, 649, 650, 651, 652, 653



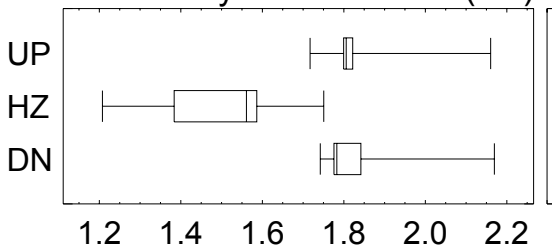
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.8	0.018	0.018	0.044	0.021	0.017
HZ	0.60	4.8e-3	4.7e-3	0.012	5.4e-3	4.1e-3
DN	1.4	0.014	0.015	0.034	9.2e-3	8.2e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-6.0	0.052	0.053	0.13	0.052	0.041
HZ	-1.4	0.013	0.014	0.032	0.011	8.3e-3
DN	-4.6	0.045	0.049	0.11	0.025	0.032



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.31	8.0e-3	7.7e-3	0.020	6.7e-3	5.5e-3
HZ	0.094	1.0e-3	1.1e-3	2.5e-3	2.3e-3	1.5e-3
DN	0.32	5.8e-3	5.6e-3	0.014	4.9e-3	4.1e-3



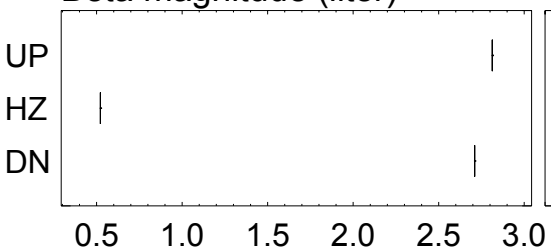
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.8	0.066	0.068	0.16	0.11	0.073
HZ	1.5	0.081	0.078	0.20	0.052	0.043
DN	1.8	0.066	0.065	0.16	0.12	0.082

Group 25. Projectile, 81mm, Mortar, Practice, M68, Body and fins

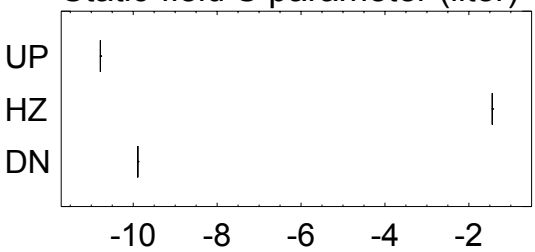
1 item in group.

Item ID number:

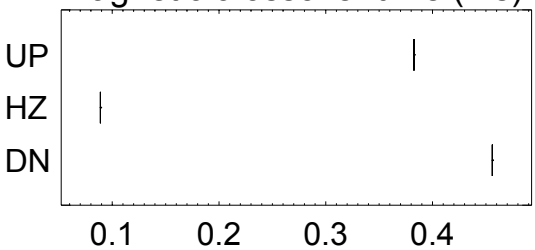
1127



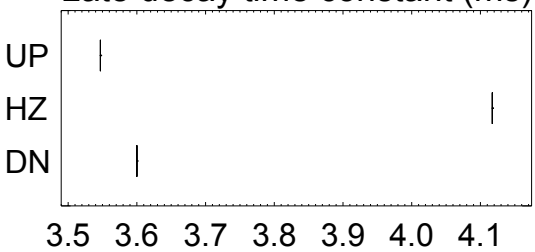
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.8	n/a	n/a	n/a	n/a	n/a
HZ	0.52	n/a	n/a	n/a	n/a	n/a
DN	2.7	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-11.	n/a	n/a	n/a	n/a	n/a
HZ	-1.4	n/a	n/a	n/a	n/a	n/a
DN	-9.9	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.38	n/a	n/a	n/a	n/a	n/a
HZ	0.089	n/a	n/a	n/a	n/a	n/a
DN	0.46	n/a	n/a	n/a	n/a	n/a

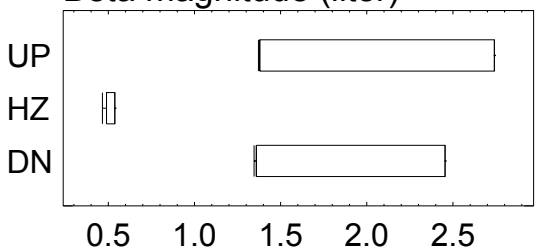


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.5	n/a	n/a	n/a	n/a	n/a
HZ	4.1	n/a	n/a	n/a	n/a	n/a
DN	3.6	n/a	n/a	n/a	n/a	n/a

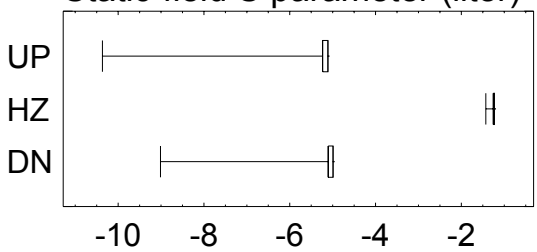
Group 26. Projectile, 81mm, Mortar, Practice, M68, Body only
, From Ft. McClellan.
3 items in group.

Item ID numbers:

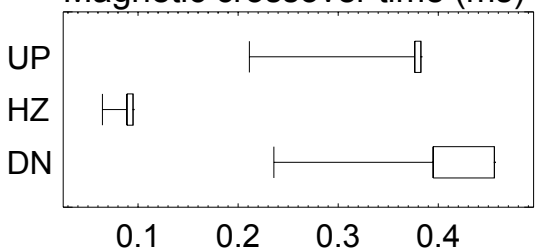
1128, 1129, 1131



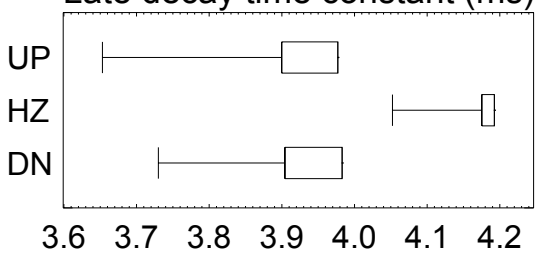
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.8	0.46	0.45	0.79	0.64	0.47
HZ	0.50	0.021	0.021	0.037	0.020	0.018
DN	1.7	0.37	0.34	0.64	0.51	0.37



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-6.9	1.7	1.7	3.0	2.4	1.8
HZ	-1.3	0.063	0.060	0.11	0.077	0.059
DN	-6.4	1.3	1.2	2.3	1.8	1.3



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.32	0.056	0.058	0.097	0.076	0.057
HZ	0.083	9.3e-3	9.9e-3	0.016	0.010	8.6e-3
DN	0.36	0.066	0.066	0.11	0.066	0.055



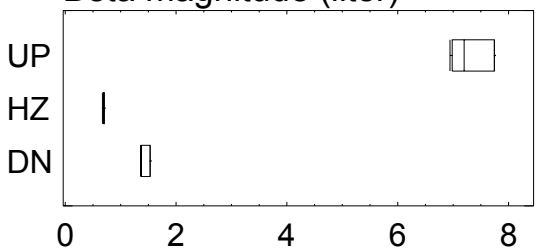
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.8	0.098	0.095	0.17	0.10	0.084
HZ	4.1	0.044	0.042	0.076	0.054	0.042
DN	3.9	0.075	0.071	0.13	0.071	0.060

Group 27. Projectile, 76mm, Practice, M496, Complete HEAT round

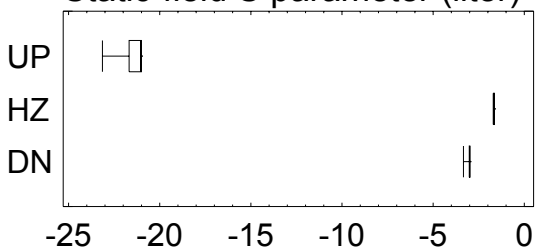
4 items in group.

Item ID numbers:

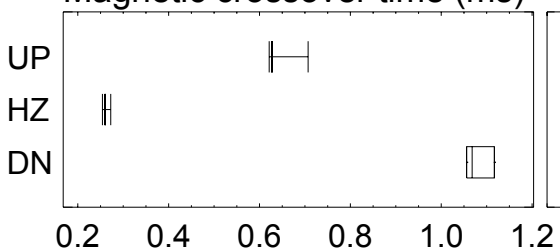
654, 656, 657, 658



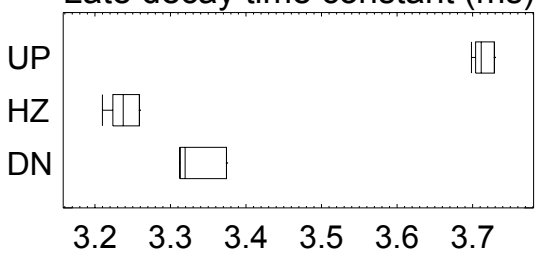
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	7.2	0.18	0.20	0.37	0.21	0.16
HZ	0.69	6.5e-3	6.3e-3	0.013	8.0e-3	5.8e-3
DN	1.4	0.041	0.039	0.082	0.066	0.043



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-22.	0.50	0.47	1.0	0.57	0.43
HZ	-1.7	0.015	0.016	0.029	6.8e-3	9.0e-3
DN	-3.1	0.084	0.090	0.17	0.13	0.083



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.65	0.020	0.022	0.041	0.033	0.021
HZ	0.26	3.9e-3	3.7e-3	7.7e-3	4.1e-3	3.2e-3
DN	1.1	0.015	0.014	0.029	0.020	0.013



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.7	6.6e-3	7.1e-3	0.013	6.5e-3	5.0e-3
HZ	3.2	0.010	0.011	0.021	8.3e-3	7.1e-3
DN	3.3	0.015	0.016	0.030	0.023	0.015

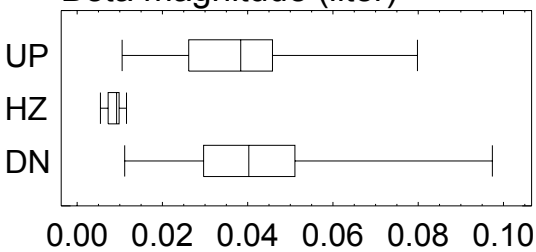
Group 28. Projectile, 20mm, Practice, Highly deteriorated

21 items in group.

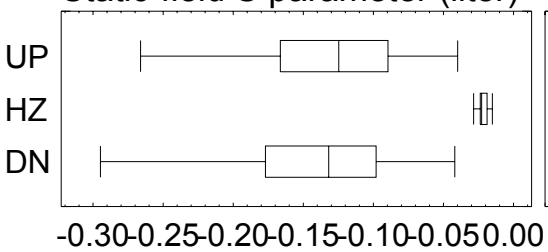
Item ID numbers:

659, 660, 661, 662, 663, 664, 665, 667, 668, 669, 670, 671, 672, 673, 674, 675

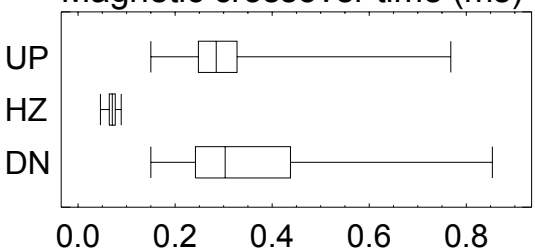
676, 677, 678, 679, 680



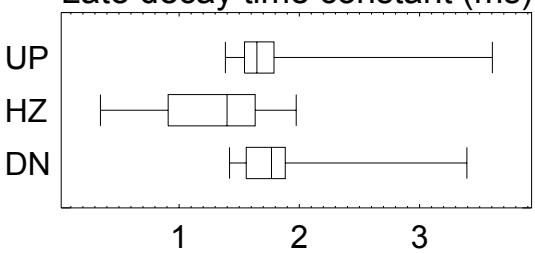
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.036	3.5e-3	3.3e-3	0.016	3.5e-3	2.9e-3
HZ	8.9e-3	4.1e-4	3.5e-4	1.9e-3	2.3e-4	2.3e-4
DN	0.041	4.0e-3	3.9e-3	0.018	5.1e-3	4.3e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.13	0.012	0.011	0.054	0.010	9.9e-3
HZ	-0.022	9.1e-4	7.9e-4	4.2e-3	5.0e-4	5.2e-4
DN	-0.14	0.013	0.012	0.059	0.012	0.012



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.36	0.043	0.045	0.19	0.034	0.032
HZ	0.071	2.0e-3	1.9e-3	9.1e-3	2.1e-3	1.7e-3
DN	0.37	0.046	0.048	0.21	0.039	0.042



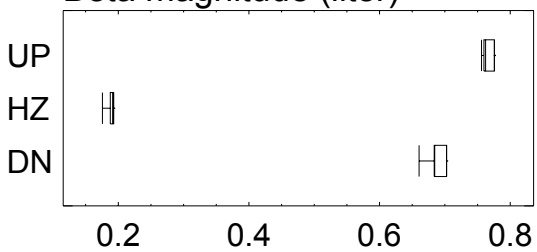
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.8	0.13	0.12	0.60	0.20	0.17
HZ	1.3	0.099	0.10	0.45	0.059	0.053
DN	1.9	0.13	0.14	0.58	0.13	0.12

Group 29. Projectile, 60mm, Mortar, Smoke, M302, Body and fuze adapter only

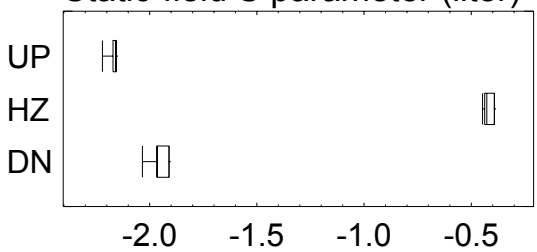
4 items in group.

Item ID numbers:

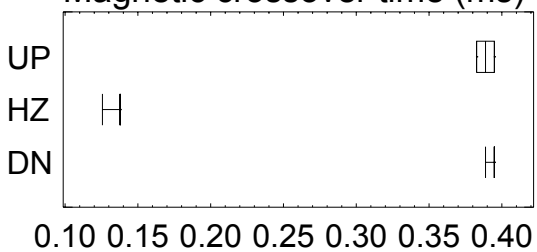
681, 682, 684, 685



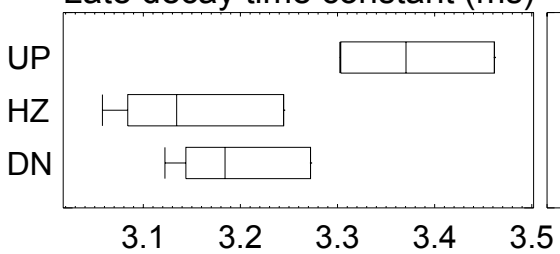
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.76	4.3e-3	4.5e-3	8.6e-3	5.1e-3	3.9e-3
HZ	0.19	3.9e-3	4.0e-3	7.8e-3	4.7e-3	3.4e-3
DN	0.68	8.6e-3	8.7e-3	0.017	7.9e-3	6.3e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-2.2	0.015	0.015	0.030	0.020	0.014
HZ	-0.43	0.012	0.012	0.024	0.013	0.010
DN	-2.0	0.025	0.026	0.051	0.023	0.021



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.39	2.9e-3	3.0e-3	5.9e-3	2.3e-3	2.2e-3
HZ	0.13	2.9e-3	2.9e-3	5.9e-3	2.3e-3	2.0e-3
DN	0.39	1.8e-3	1.8e-3	3.5e-3	0.0	1.1e-3

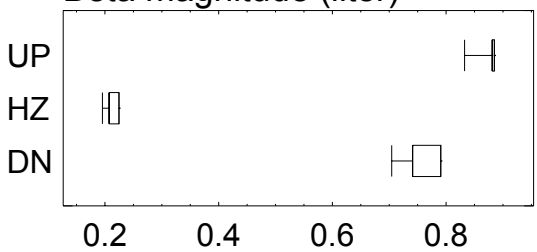


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.4	0.038	0.038	0.075	0.034	0.029
HZ	3.1	0.041	0.046	0.083	0.042	0.032
DN	3.2	0.033	0.037	0.066	0.033	0.027

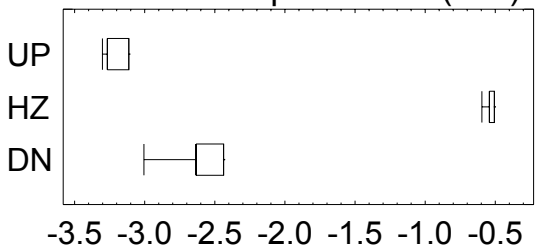
Group 30. Projectile, 60mm, Mortar, Practice, M69
, From Ft. McClellan.
3 items in group.

Item ID numbers:

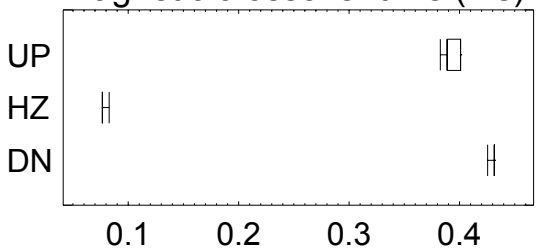
1103, 1104, 1107



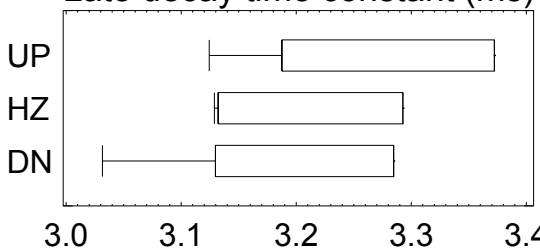
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.87	0.017	0.017	0.029	0.022	0.017
HZ	0.21	8.5e-3	8.8e-3	0.015	7.3e-3	7.0e-3
DN	0.75	0.025	0.028	0.043	0.021	0.019



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-3.2	0.058	0.059	0.10	0.065	0.052
HZ	-0.55	0.026	0.027	0.045	0.022	0.021
DN	-2.7	0.17	0.18	0.29	0.15	0.13



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.39	5.4e-3	5.5e-3	9.3e-3	5.0e-3	4.3e-3
HZ	0.079	2.0e-3	2.0e-3	3.5e-3	2.9e-3	2.0e-3
DN	0.43	2.0e-3	2.1e-3	3.5e-3	2.9e-3	2.0e-3



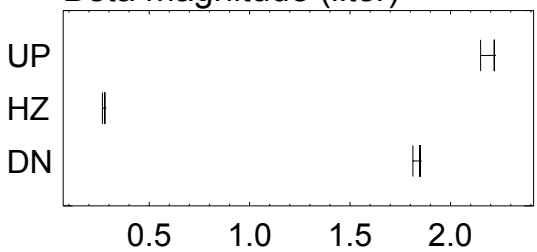
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.2	0.074	0.076	0.13	0.077	0.064
HZ	3.2	0.054	0.057	0.094	0.075	0.054
DN	3.1	0.074	0.081	0.13	0.064	0.056

Group 31. Projectile, 60mm, Mortar, HE, M720, Un-filled body only.

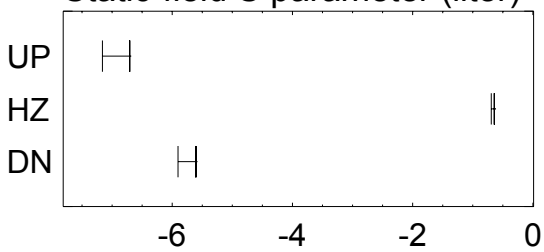
2 items in group.

Item ID numbers:

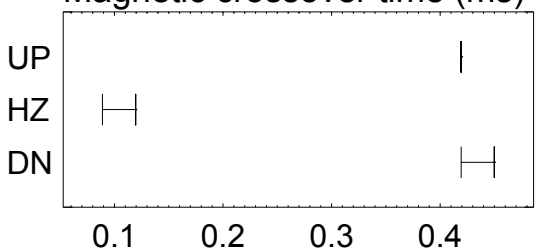
1225, 1232



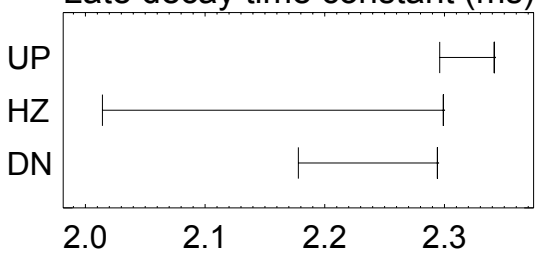
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.2	n/a	n/a	n/a	n/a	n/a
HZ	0.27	n/a	n/a	n/a	n/a	n/a
DN	1.8	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-6.9	n/a	n/a	n/a	n/a	n/a
HZ	-0.67	n/a	n/a	n/a	n/a	n/a
DN	-5.8	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.42	n/a	n/a	n/a	n/a	n/a
HZ	0.10	n/a	n/a	n/a	n/a	n/a
DN	0.43	n/a	n/a	n/a	n/a	n/a



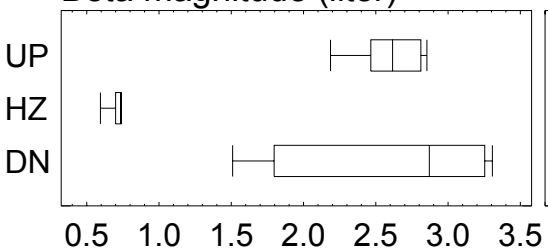
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.3	n/a	n/a	n/a	n/a	n/a
HZ	2.2	n/a	n/a	n/a	n/a	n/a
DN	2.2	n/a	n/a	n/a	n/a	n/a

Group 32. Rocket, 3.5 inch, Practice, M29, Head only
Practice version of M28.
6 items in group.

Item ID numbers:

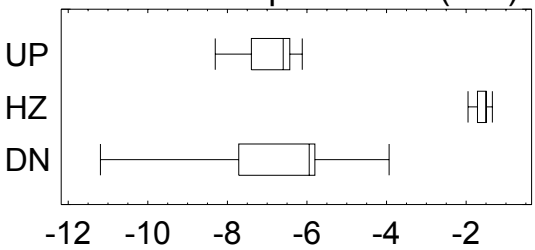
700, 701, 702, 703, 704, 705

Beta magnitude (liter)



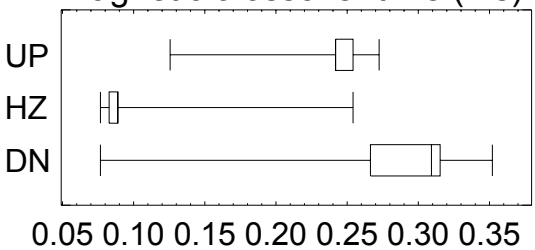
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.6	0.10	0.10	0.25	0.069	0.061
HZ	0.68	0.028	0.027	0.069	0.014	0.017
DN	2.4	0.34	0.35	0.82	0.092	0.18

Static-field S parameter (liter)



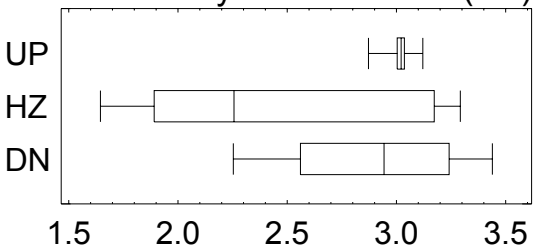
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-7.2	0.37	0.36	0.91	0.16	0.19
HZ	-1.6	0.091	0.090	0.22	0.061	0.055
DN	-7.3	1.1	1.1	2.6	0.78	0.72

Magnetic crossover time (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.22	0.021	0.022	0.052	0.029	0.021
HZ	0.11	0.029	0.031	0.070	0.059	0.038
DN	0.26	0.040	0.043	0.099	0.048	0.035

Late decay time constant (ms)

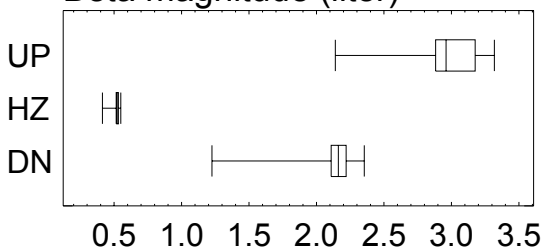


	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.0	0.037	0.036	0.090	0.025	0.023
HZ	2.3	0.29	0.28	0.71	0.14	0.17
DN	2.8	0.19	0.18	0.47	0.097	0.11

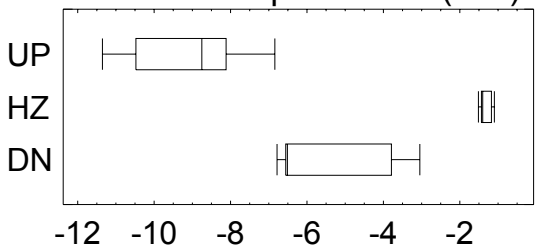
Group 33. Rocket, 3.5 inch, Practice, M29, Head and motor
Practice version of M28.
8 items in group.

Item ID numbers:

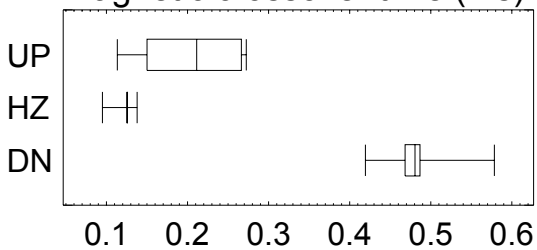
706, 707, 708, 709, 710, 711, 712, 713



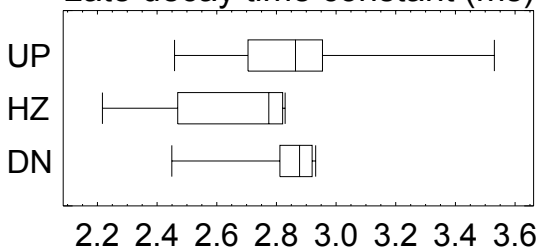
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.9	0.13	0.12	0.37	0.13	0.10
HZ	0.51	0.015	0.014	0.041	0.028	0.020
DN	2.0	0.13	0.13	0.37	0.17	0.13



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-9.4	0.57	0.51	1.6	0.32	0.30
HZ	-1.4	0.052	0.055	0.15	0.043	0.041
DN	-5.8	0.52	0.54	1.5	0.44	0.45



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.19	0.023	0.023	0.064	8.9e-3	0.010
HZ	0.12	5.0e-3	4.7e-3	0.014	4.5e-3	3.7e-3
DN	0.49	0.017	0.017	0.049	0.016	0.013

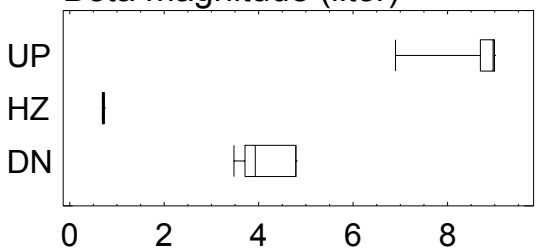


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.9	0.11	0.11	0.32	0.14	0.10
HZ	2.6	0.084	0.083	0.24	0.051	0.054
DN	2.8	0.056	0.056	0.16	0.083	0.064

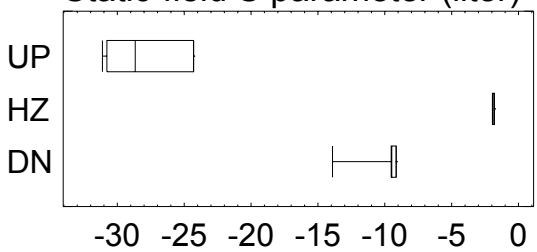
Group 34. Rocket, 3.5 inch, Practice, M29, Head and motor
Practice version of M28, From Ft. McClellan.
4 items in group.

Item ID numbers:

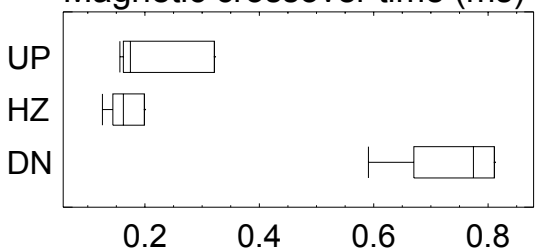
1136, 1137, 1138, 1139



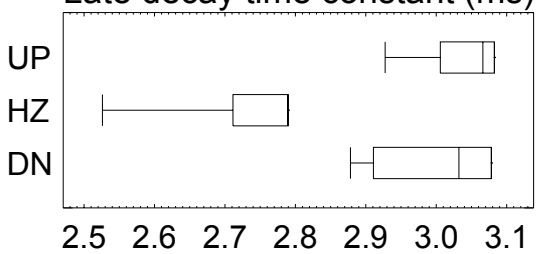
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	8.4	0.50	0.53	1.0	0.74	0.52
HZ	0.71	9.3e-3	9.7e-3	0.019	9.9e-4	5.8e-3
DN	4.0	0.29	0.30	0.57	0.32	0.22



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-29.	1.6	1.6	3.1	1.7	1.2
HZ	-1.9	0.033	0.036	0.067	0.045	0.033
DN	-11.	1.1	1.3	2.3	1.8	1.2



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.20	0.039	0.043	0.079	0.061	0.043
HZ	0.16	0.016	0.017	0.031	0.014	9.9e-3
DN	0.71	0.050	0.051	0.10	0.031	0.027

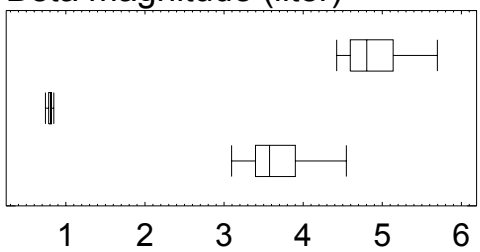


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.0	0.035	0.033	0.070	0.029	0.024
HZ	2.7	0.062	0.062	0.12	0.073	0.057
DN	3.0	0.048	0.049	0.096	0.020	0.033

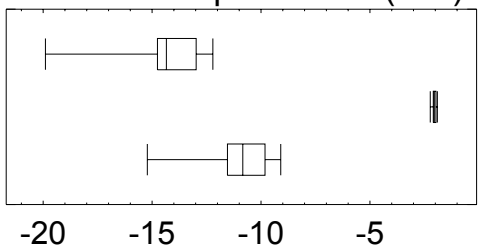
Group 35. Projectile, 3 inch, Mortar, Practice, Stokes, No fuze
From Ft. Ord.
10 items in group.

Item ID numbers:

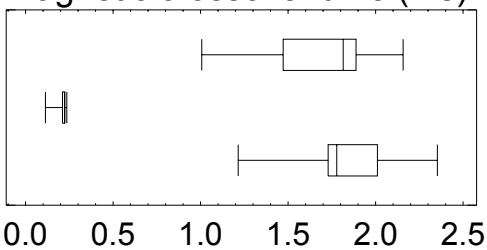
714, 715, 716, 717, 718, 719, 720, 721, 722, 723



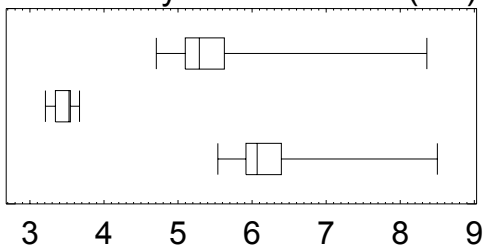
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	4.9	0.15	0.15	0.46	0.093	0.096
HZ	0.79	0.011	0.012	0.036	6.8e-3	6.3e-3
DN	3.7	0.16	0.16	0.50	0.10	0.098



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-15.	0.85	0.88	2.7	0.70	0.77
HZ	-2.1	0.032	0.033	0.10	0.022	0.020
DN	-11.	0.69	0.71	2.2	0.53	0.51



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.6	0.12	0.13	0.39	0.070	0.068
HZ	0.20	0.014	0.014	0.045	0.011	0.011
DN	1.7	0.11	0.12	0.35	0.075	0.072



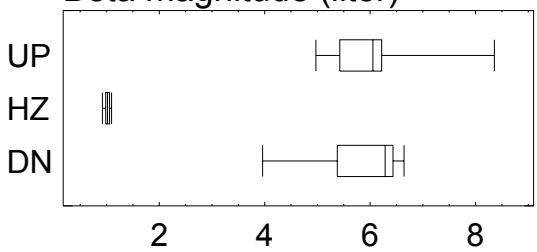
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	5.7	0.37	0.36	1.2	0.44	0.38
HZ	3.5	0.048	0.051	0.15	0.026	0.024
DN	6.3	0.30	0.29	0.94	0.35	0.31

Group 36. Projectile, 3 inch, Mortar, Practice, Stokes, No fuze
From Ft. McClellan.
30 items in group.

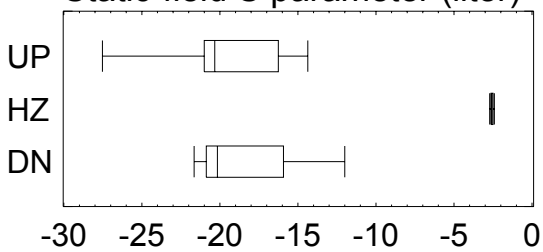
Item ID numbers:

950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965

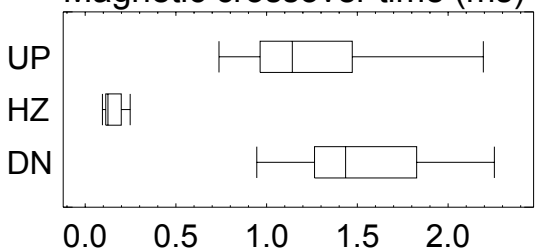
966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979



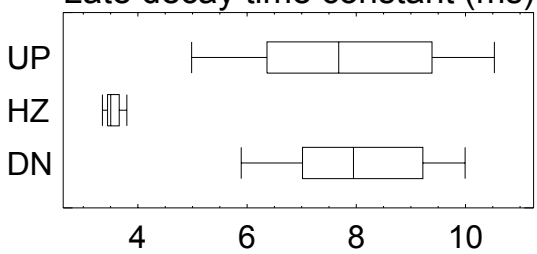
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	5.9	0.12	0.12	0.68	0.18	0.14
HZ	1.0	9.0e-3	8.7e-3	0.049	4.7e-3	4.6e-3
DN	5.8	0.15	0.14	0.80	0.11	0.10



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-20.	0.54	0.45	2.9	0.44	0.40
HZ	-2.6	0.017	0.015	0.091	8.4e-3	8.0e-3
DN	-19.	0.54	0.48	3.0	0.36	0.31



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.3	0.082	0.073	0.45	0.050	0.044
HZ	0.15	9.3e-3	8.5e-3	0.051	5.1e-3	4.5e-3
DN	1.5	0.079	0.075	0.43	0.039	0.033

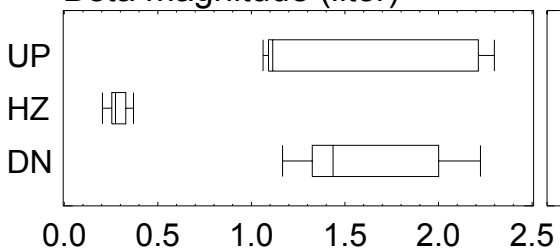


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	7.7	0.31	0.31	1.7	0.14	0.12
HZ	3.5	0.024	0.026	0.13	0.012	0.011
DN	7.9	0.24	0.25	1.3	0.10	0.087

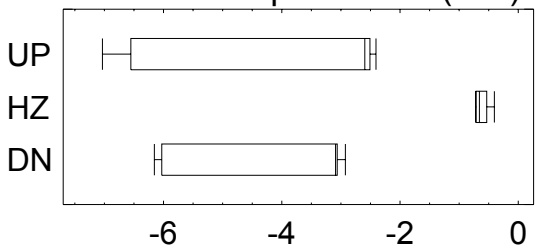
Group 37. Rocket, 3.5 inch, Practice, M29, Motor only
Practice version of M28.
5 items in group.

Item ID numbers:

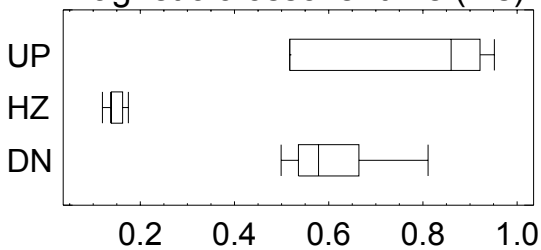
727, 728, 729, 730, 731



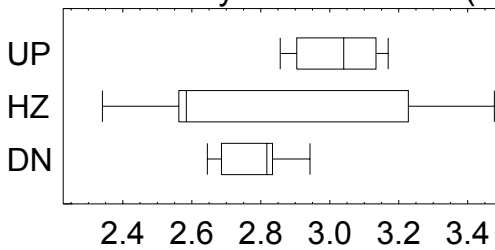
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.6	0.29	0.29	0.64	0.094	0.18
HZ	0.29	0.029	0.031	0.065	0.020	0.018
DN	1.6	0.20	0.19	0.46	0.10	0.14



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-4.2	1.1	1.1	2.4	0.37	0.78
HZ	-0.61	0.061	0.060	0.14	0.048	0.041
DN	-4.3	0.75	0.78	1.7	0.24	0.67



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.75	0.098	0.091	0.22	0.032	0.067
HZ	0.15	9.8e-3	9.9e-3	0.022	6.2e-3	5.6e-3
DN	0.62	0.056	0.059	0.12	0.052	0.041



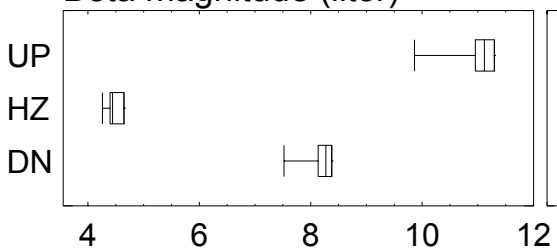
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.0	0.062	0.059	0.14	0.027	0.033
HZ	2.8	0.22	0.23	0.49	0.12	0.15
DN	2.8	0.054	0.058	0.12	0.034	0.031

Group 38. Rocket, 5 inch, Practice

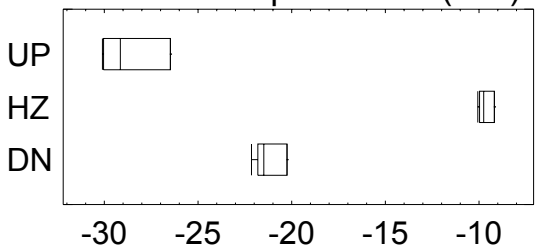
4 items in group.

Item ID numbers:

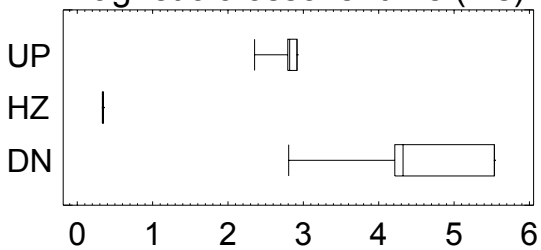
1296, 1297, 1298, 1299



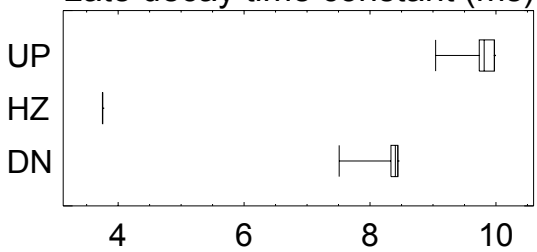
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	11.	0.32	0.33	0.65	0.43	0.31
HZ	4.4	0.080	0.077	0.16	0.074	0.053
DN	8.1	0.19	0.18	0.38	0.24	0.17



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-29.	0.85	0.83	1.7	1.1	0.74
HZ	-9.7	0.20	0.20	0.40	0.22	0.16
DN	-21.	0.41	0.44	0.83	0.47	0.34



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.7	0.13	0.13	0.25	0.17	0.12
HZ	0.34	2.9e-3	2.9e-3	5.9e-3	2.3e-3	1.8e-3
DN	4.2	0.56	0.54	1.1	0.50	0.39



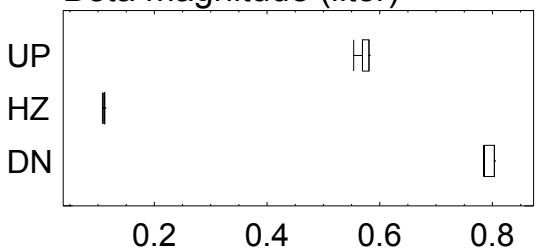
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	9.6	0.21	0.20	0.41	0.26	0.18
HZ	3.8	7.9e-4	7.4e-4	1.6e-3	7.1e-4	5.8e-4
DN	8.2	0.22	0.23	0.44	0.34	0.24

Group 39. Grenade, Practice, MK II, Handle missing.

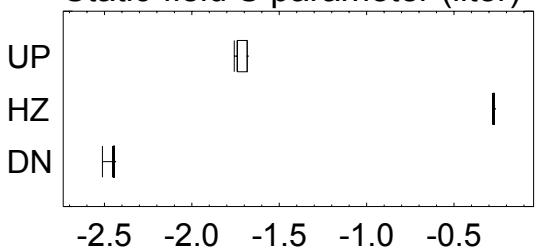
3 items in group.

Item ID numbers:

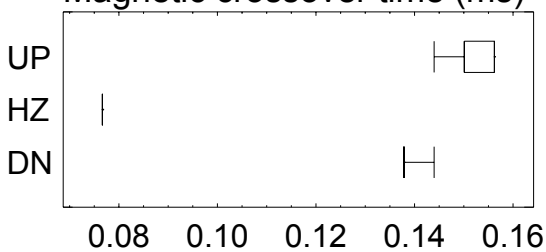
732, 733, 734



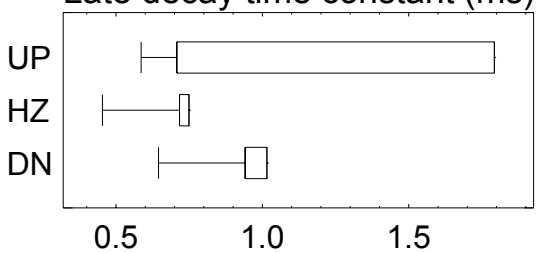
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.57	7.9e-3	6.9e-3	0.014	6.6e-3	5.6e-3
HZ	0.11	1.2e-3	1.1e-3	2.1e-3	1.3e-3	9.4e-4
DN	0.79	6.2e-3	6.2e-3	0.011	8.3e-3	6.1e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.7	0.022	0.020	0.039	0.024	0.018
HZ	-0.27	2.8e-3	2.6e-3	4.8e-3	3.8e-3	2.6e-3
DN	-2.5	0.022	0.021	0.038	0.027	0.020



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.15	3.5e-3	3.5e-3	6.1e-3	2.9e-3	2.5e-3
HZ	0.077	0.0	1.2e-16	0.0	0.0	0.0
DN	0.14	2.0e-3	2.0e-3	3.5e-3	2.9e-3	2.0e-3



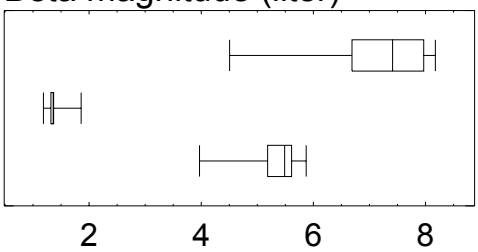
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.0	0.38	0.37	0.66	0.49	0.35
HZ	0.64	0.094	0.089	0.16	0.12	0.085
DN	0.87	0.11	0.12	0.20	0.13	0.10

Group 40. Projectile, 4 inch, Mortar, Practice, Stokes, Body only
ORDATA database online does not contain 4" stokes.
10 items in group.

Item ID numbers:

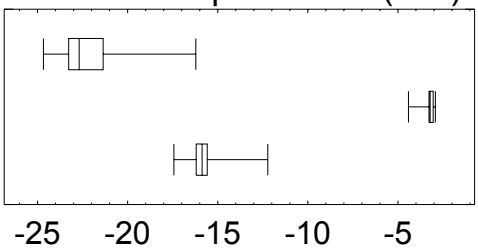
737, 738, 739, 740, 741, 742, 743, 744, 745, 746

Beta magnitude (liter)



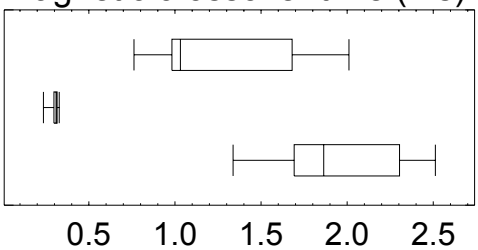
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	7.0	0.40	0.45	1.3	0.30	0.29
HZ	1.4	0.069	0.077	0.22	0.066	0.064
DN	5.3	0.18	0.17	0.56	0.21	0.18

Static-field S parameter (liter)



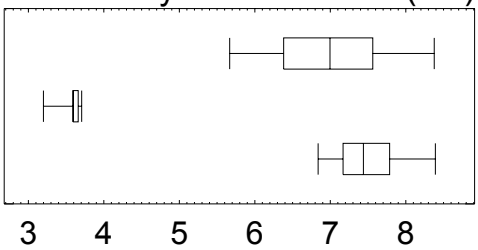
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-22.	0.81	0.80	2.5	1.0	0.80
HZ	-3.4	0.16	0.18	0.50	0.16	0.16
DN	-16.	0.45	0.48	1.4	0.73	0.53

Magnetic crossover time (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.2	0.14	0.15	0.46	0.085	0.085
HZ	0.30	8.2e-3	7.9e-3	0.026	0.013	9.3e-3
DN	1.9	0.13	0.14	0.41	0.067	0.063

Late decay time constant (ms)

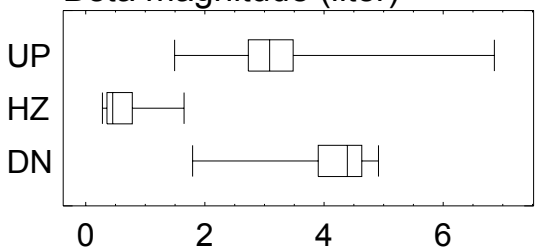


	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	6.9	0.28	0.29	0.88	0.16	0.14
HZ	3.5	0.053	0.051	0.17	0.046	0.038
DN	7.5	0.17	0.18	0.53	0.11	0.095

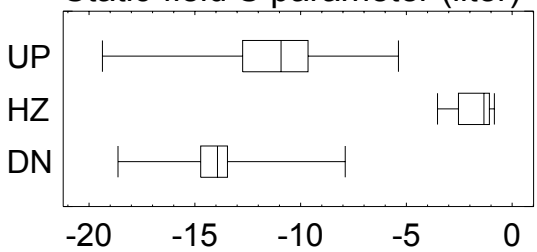
Group 41. Projectile, 4 inch, Mortar, HE, Stokes, Remnant of low-order detonation
ORDATA database online does not contain 4" stokes.
9 items in group.

Item ID numbers:

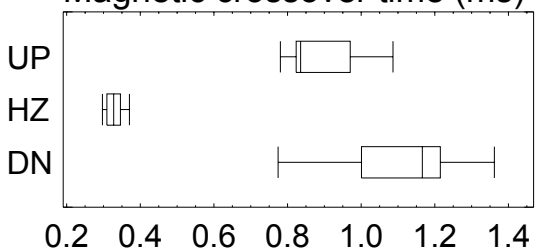
747, 748, 749, 750, 752, 753, 754, 755, 756



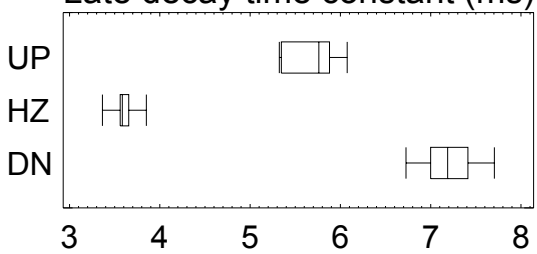
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.3	0.52	0.50	1.6	0.72	0.53
HZ	0.61	0.15	0.14	0.44	0.22	0.16
DN	4.1	0.31	0.36	0.94	0.52	0.35



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-11.	1.4	1.3	4.2	1.4	1.2
HZ	-1.7	0.31	0.30	0.93	0.25	0.23
DN	-14.	0.93	1.0	2.8	1.1	0.89



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.90	0.035	0.036	0.10	0.024	0.020
HZ	0.33	7.8e-3	8.4e-3	0.024	5.3e-3	4.7e-3
DN	1.1	0.070	0.070	0.21	0.042	0.046

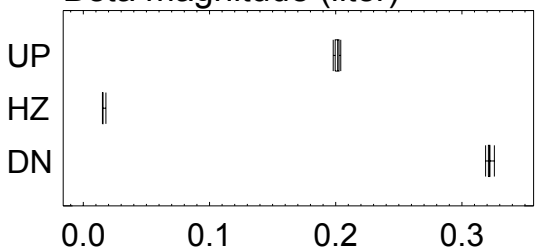


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	5.7	0.096	0.098	0.29	0.040	0.044
HZ	3.6	0.047	0.046	0.14	0.041	0.036
DN	7.2	0.11	0.12	0.34	0.068	0.062

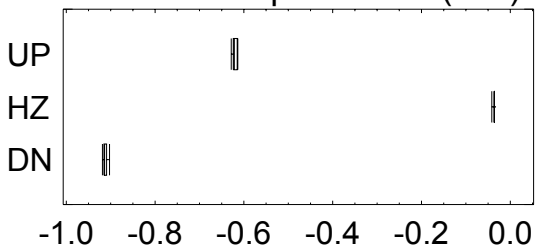
Group 42. Projectile, 20mm, Practice, M99, Never fired
Band intact.
5 items in group.

Item ID numbers:

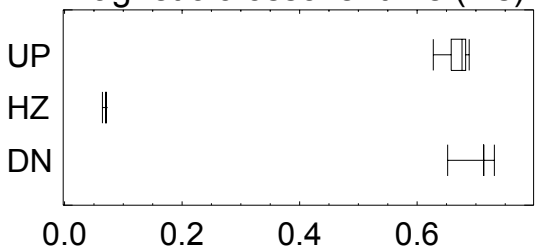
757, 758, 759, 760, 761



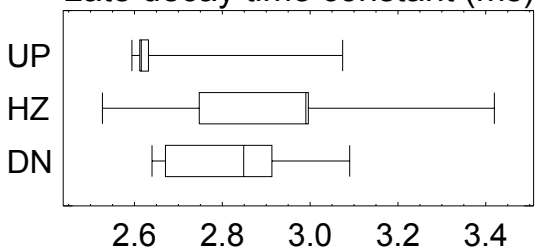
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.20	1.1e-3	1.0e-3	2.4e-3	6.8e-4	6.2e-4
HZ	0.016	5.2e-4	5.3e-4	1.2e-3	9.0e-4	5.9e-4
DN	0.32	1.1e-3	1.1e-3	2.5e-3	1.1e-3	8.3e-4



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.62	2.8e-3	2.7e-3	6.2e-3	1.6e-3	1.3e-3
HZ	-0.037	1.2e-3	1.1e-3	2.6e-3	2.2e-3	1.5e-3
DN	-0.91	2.8e-3	2.7e-3	6.2e-3	2.4e-3	1.7e-3



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.67	0.011	0.011	0.025	0.011	8.3e-3
HZ	0.068	1.5e-3	1.3e-3	3.4e-3	4.6e-4	1.1e-3
DN	0.70	0.014	0.012	0.031	0.013	0.011

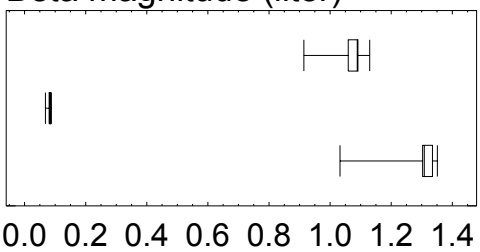


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.7	0.092	0.086	0.21	0.17	0.11
HZ	2.9	0.15	0.15	0.33	0.13	0.10
DN	2.8	0.083	0.084	0.18	0.057	0.046

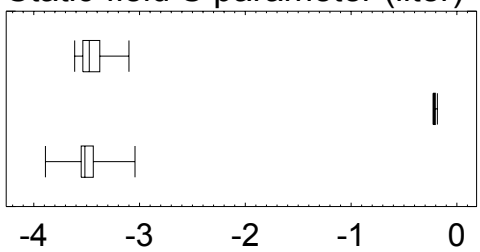
Group 43. Projectile, 37mm, Practice, Deteriorated
Band intact, From Ft. Ord.
10 items in group.

Item ID numbers:

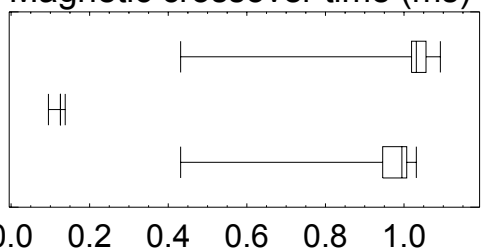
762, 763, 764, 765, 766, 767, 768, 782, 783, 784



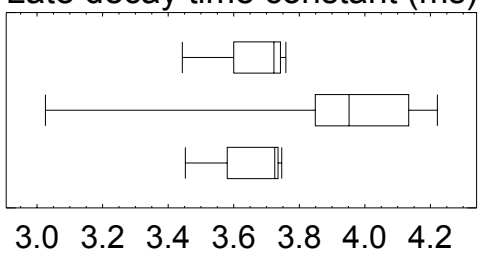
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.1	0.022	0.022	0.069	0.018	0.015
HZ	0.080	1.8e-3	1.7e-3	5.7e-3	1.8e-3	1.5e-3
DN	1.3	0.032	0.035	0.10	0.044	0.038



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-3.4	0.053	0.053	0.17	0.049	0.044
HZ	-0.21	4.0e-3	4.0e-3	0.013	3.9e-3	3.1e-3
DN	-3.5	0.067	0.068	0.21	0.078	0.061



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.97	0.061	0.073	0.19	0.14	0.096
HZ	0.12	4.0e-3	4.6e-3	0.013	5.0e-3	4.0e-3
DN	0.92	0.057	0.061	0.18	0.13	0.085



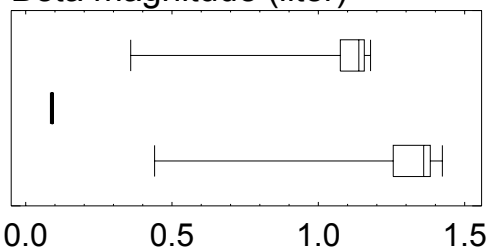
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.6	0.037	0.036	0.12	0.024	0.022
HZ	3.9	0.12	0.13	0.38	0.13	0.10
DN	3.7	0.033	0.034	0.11	0.022	0.022

Group 44. Projectile, 37mm, Practice, Deteriorated
Band intact, From Ft. McClellan.
18 items in group.

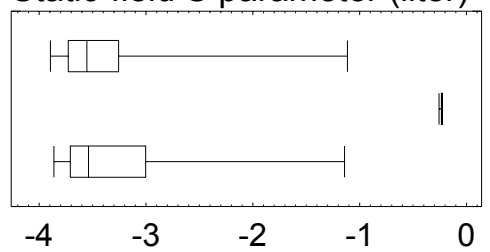
Item ID numbers:

980, 983, 984, 986, 987, 988, 989, 990, 991, 992, 998, 1000, 1001, 1003, 1007, 1008

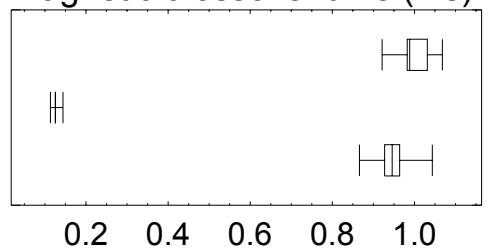
1009, 1056



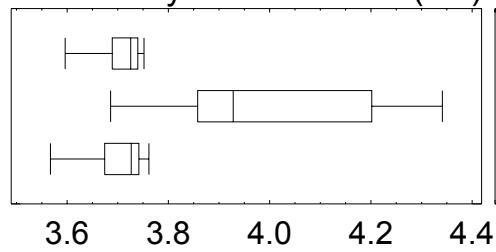
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.0	0.068	0.069	0.29	0.068	0.074
HZ	0.090	7.2e-4	7.6e-4	3.1e-3	4.3e-4	4.0e-4
DN	1.2	0.083	0.087	0.35	0.071	0.072



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-3.2	0.22	0.23	0.94	0.22	0.23
HZ	-0.23	1.8e-3	1.7e-3	7.7e-3	2.2e-3	1.9e-3
DN	-3.1	0.22	0.24	0.95	0.19	0.19



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.0	9.6e-3	9.2e-3	0.041	6.2e-3	6.1e-3
HZ	0.13	1.6e-3	1.6e-3	6.6e-3	1.8e-3	1.5e-3
DN	0.95	0.012	0.011	0.049	7.9e-3	7.7e-3

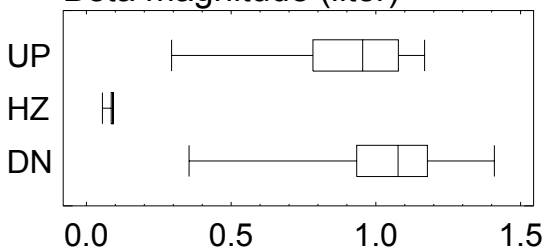


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.7	0.010	0.010	0.044	9.1e-3	8.5e-3
HZ	4.0	0.051	0.045	0.22	0.025	0.026
DN	3.7	0.013	0.012	0.057	0.010	0.011

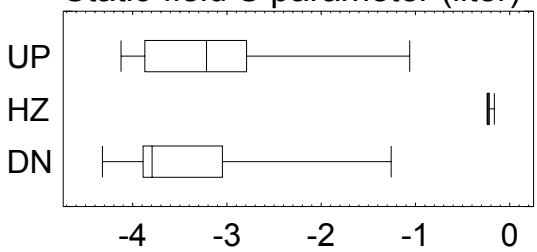
Group 45. Projectile, 37mm, Practice, Deteriorated
Band missing, From Ft. McClellan.
16 items in group.

Item ID numbers:

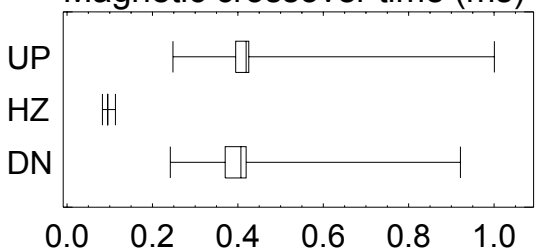
981, 982, 985, 993, 994, 995, 996, 997, 999, 1002, 1004, 1005, 1010, 1057, 1058, 1059



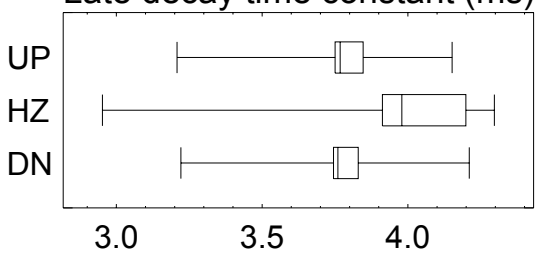
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.86	0.066	0.064	0.27	0.054	0.051
HZ	0.086	2.6e-3	2.8e-3	0.010	3.8e-3	3.3e-3
DN	0.96	0.074	0.076	0.30	0.060	0.054



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-3.1	0.23	0.27	0.94	0.20	0.19
HZ	-0.22	5.4e-3	5.3e-3	0.022	7.0e-3	6.1e-3
DN	-3.4	0.24	0.26	0.97	0.22	0.23



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.43	0.040	0.041	0.16	0.11	0.070
HZ	0.095	1.8e-3	1.9e-3	7.1e-3	1.9e-3	1.3e-3
DN	0.42	0.035	0.035	0.14	0.091	0.065

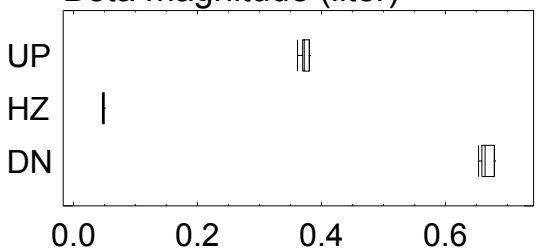


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.7	0.057	0.062	0.23	0.054	0.055
HZ	3.9	0.11	0.11	0.43	0.091	0.093
DN	3.7	0.056	0.059	0.22	0.058	0.058

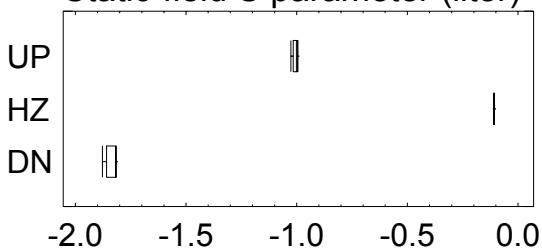
Group 46. Projectile, 25mm, Practice
Band intact.
4 items in group.

Item ID numbers:

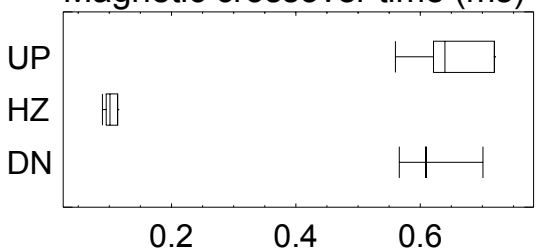
769, 770, 771, 772



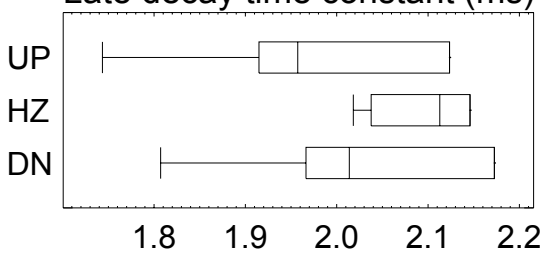
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.37	3.9e-3	4.0e-3	7.9e-3	3.4e-3	2.5e-3
HZ	0.048	5.3e-4	5.1e-4	1.1e-3	5.3e-4	4.1e-4
DN	0.66	5.5e-3	5.0e-3	0.011	5.6e-3	4.2e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.0	7.0e-3	6.0e-3	0.014	4.2e-3	4.1e-3
HZ	-0.11	9.6e-4	1.0e-3	1.9e-3	1.8e-4	6.1e-4
DN	-1.8	0.015	0.015	0.031	6.9e-3	0.010



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.64	0.033	0.031	0.066	0.029	0.024
HZ	0.10	5.2e-3	5.3e-3	0.010	4.6e-3	3.3e-3
DN	0.62	0.028	0.028	0.057	0.031	0.022



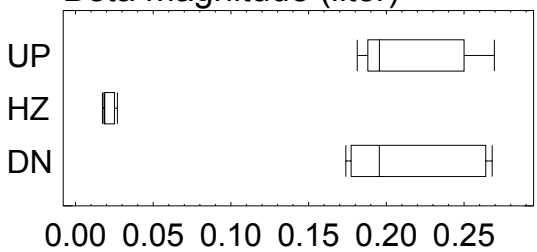
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.9	0.078	0.072	0.16	0.068	0.056
HZ	2.1	0.030	0.028	0.061	0.013	0.019
DN	2.0	0.075	0.073	0.15	0.065	0.049

Group 47. Projectile, 40mm, Practice, M781

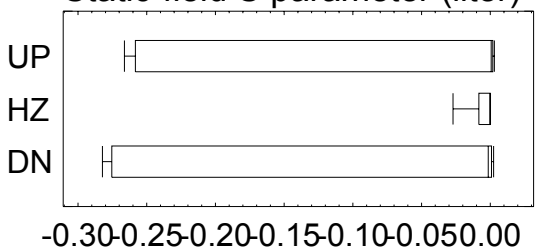
9 items in group.

Item ID numbers:

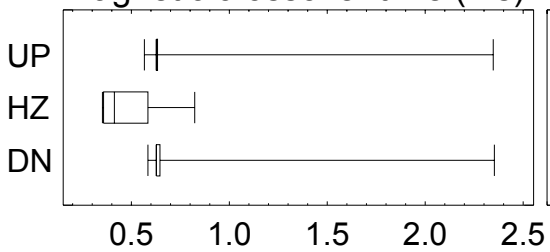
773, 774, 775, 776, 777, 778, 779, 780, 781



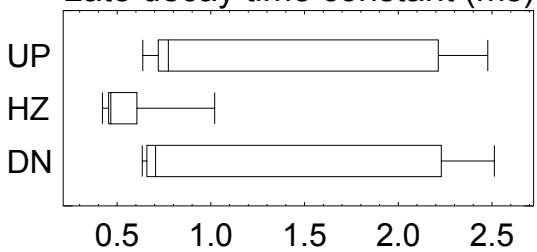
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.21	0.012	0.011	0.036	6.1e-3	7.9e-3
HZ	0.021	1.3e-3	1.2e-3	3.9e-3	5.0e-4	5.9e-4
DN	0.21	0.014	0.013	0.042	6.0e-3	8.0e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.088	0.043	0.044	0.13	0.019	0.023
HZ	-5.6e-3	3.0e-3	2.8e-3	9.0e-3	4.6e-3	3.6e-3
DN	-0.096	0.046	0.048	0.14	0.020	0.026



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.2	0.28	0.28	0.84	0.13	0.16
HZ	0.49	0.057	0.059	0.17	0.047	0.039
DN	1.2	0.28	0.27	0.84	0.13	0.12



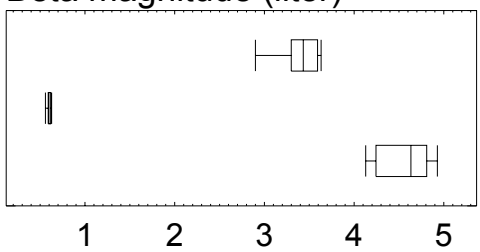
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.3	0.27	0.26	0.82	0.13	0.19
HZ	0.58	0.073	0.060	0.22	0.070	0.067
DN	1.2	0.28	0.26	0.85	0.13	0.20

Group 48. Projectile, 75mm, Shrapnel, Empty
Band intact.
9 items in group.

Item ID numbers:

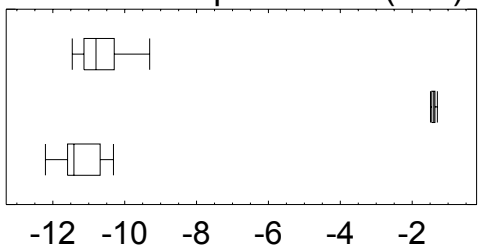
785, 786, 787, 788, 789, 790, 791, 792, 793

Beta magnitude (liter)



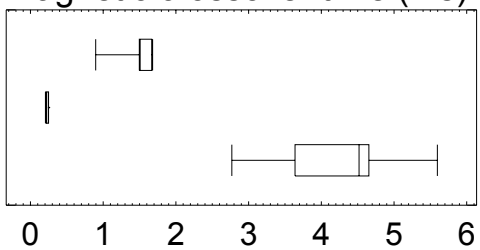
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.4	0.094	0.083	0.28	0.064	0.071
HZ	0.60	7.3e-3	7.6e-3	0.022	5.6e-3	5.0e-3
DN	4.5	0.11	0.11	0.33	0.035	0.045

Static-field S parameter (liter)



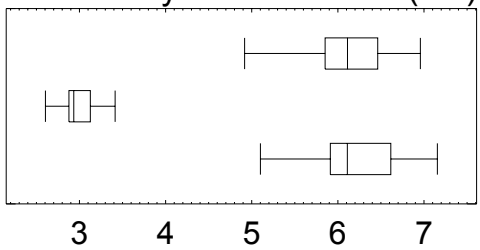
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-11.	0.25	0.22	0.74	0.18	0.17
HZ	-1.4	0.020	0.018	0.060	0.014	0.012
DN	-11.	0.23	0.22	0.70	0.12	0.12

Magnetic crossover time (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.5	0.085	0.076	0.25	0.11	0.086
HZ	0.23	6.1e-3	7.0e-3	0.018	2.0e-3	2.5e-3
DN	4.2	0.31	0.30	0.94	0.19	0.19

Late decay time constant (ms)

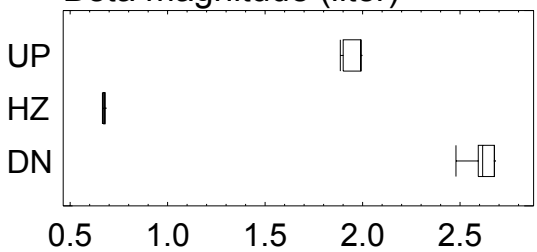


	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	6.1	0.20	0.20	0.61	0.18	0.15
HZ	3.0	0.077	0.077	0.23	0.068	0.061
DN	6.2	0.21	0.21	0.63	0.16	0.13

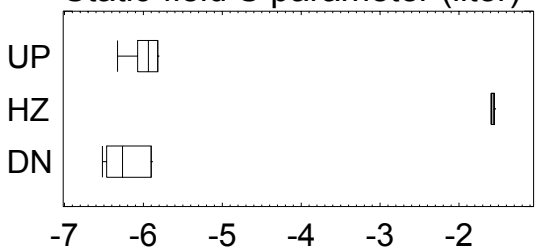
Group 49. Projectile, 75mm, Shrapnel, Empty
Band intact, From Ft.McClellan.
4 items in group.

Item ID numbers:

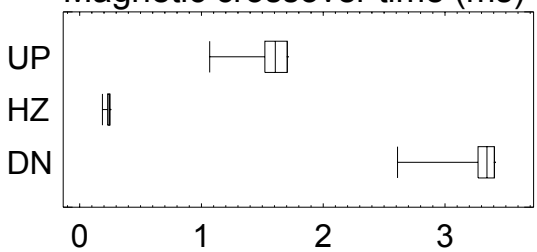
1122, 1123, 1124, 1126



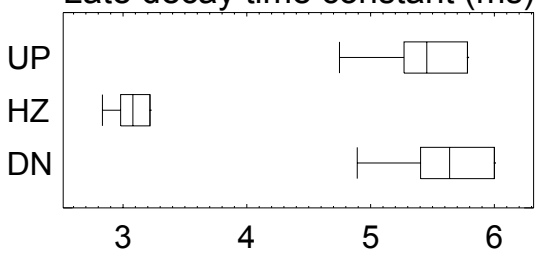
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.9	0.028	0.029	0.057	5.1e-3	0.018
HZ	0.67	2.9e-3	2.8e-3	5.9e-3	1.8e-3	1.8e-3
DN	2.6	0.041	0.039	0.082	0.041	0.030



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-6.0	0.11	0.11	0.22	0.096	0.081
HZ	-1.6	9.8e-3	0.010	0.020	5.8e-3	6.2e-3
DN	-6.3	0.14	0.14	0.28	0.14	0.10



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.5	0.14	0.14	0.28	0.17	0.11
HZ	0.23	0.014	0.013	0.028	0.017	0.011
DN	3.2	0.18	0.19	0.37	0.27	0.19

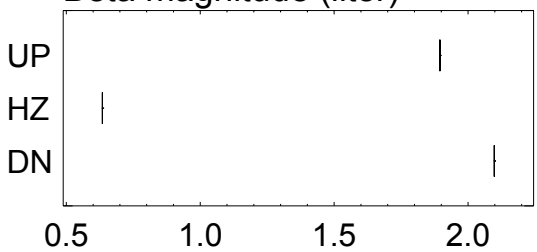


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	5.3	0.22	0.23	0.43	0.19	0.16
HZ	3.0	0.081	0.093	0.16	0.063	0.055
DN	5.5	0.23	0.22	0.46	0.20	0.16

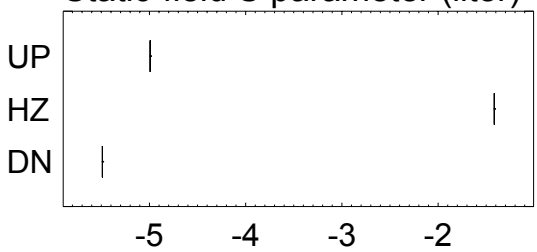
Group 50. Projectile, 75mm, Shrapnel, Empty
Band missing, From Ft.McClellan.
1 item in group.

Item ID number:

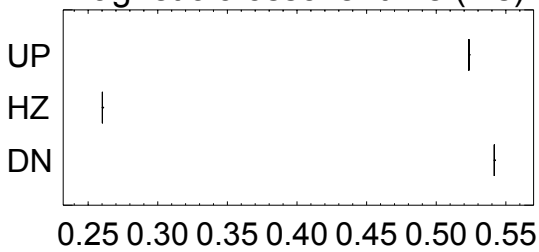
1125



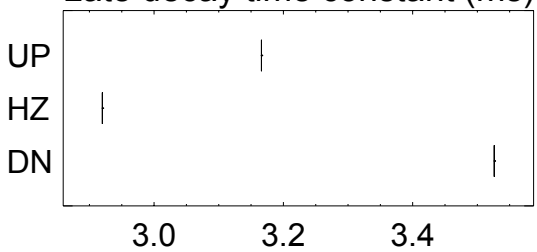
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.9	n/a	n/a	n/a	n/a	n/a
HZ	0.63	n/a	n/a	n/a	n/a	n/a
DN	2.1	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-5.0	n/a	n/a	n/a	n/a	n/a
HZ	-1.4	n/a	n/a	n/a	n/a	n/a
DN	-5.5	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.52	n/a	n/a	n/a	n/a	n/a
HZ	0.26	n/a	n/a	n/a	n/a	n/a
DN	0.54	n/a	n/a	n/a	n/a	n/a

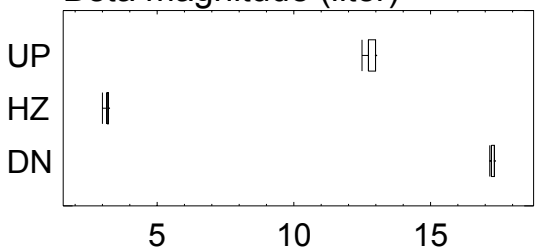


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.2	n/a	n/a	n/a	n/a	n/a
HZ	2.9	n/a	n/a	n/a	n/a	n/a
DN	3.5	n/a	n/a	n/a	n/a	n/a

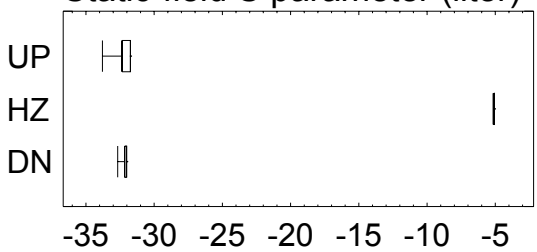
Group 51. Projectile, 155mm, Shrapnel, Empty
Band intact.
3 items in group.

Item ID numbers:

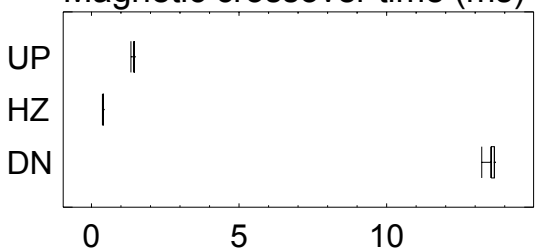
794, 795, 796



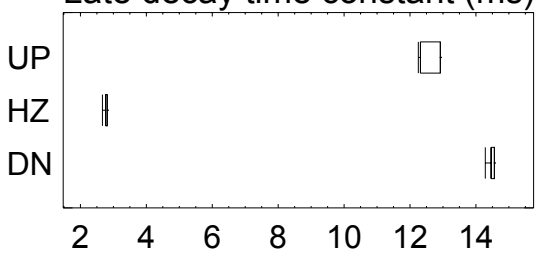
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	13.	0.14	0.14	0.25	0.12	0.11
HZ	3.1	0.066	0.058	0.11	0.068	0.049
DN	17.	0.050	0.048	0.086	0.045	0.037



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-33.	0.61	0.59	1.1	0.59	0.49
HZ	-5.1	0.029	0.030	0.050	0.025	0.019
DN	-32.	0.20	0.19	0.34	0.22	0.16



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.4	0.037	0.036	0.064	0.052	0.035
HZ	0.38	7.4e-3	6.7e-3	0.013	7.6e-3	5.7e-3
DN	13.	0.13	0.12	0.22	0.13	0.10

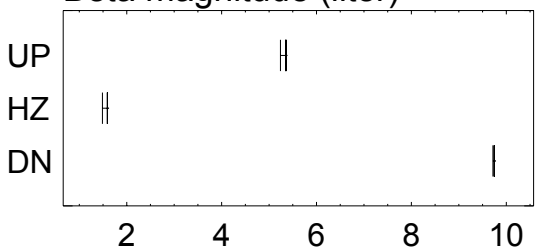


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	12.	0.21	0.20	0.37	0.27	0.20
HZ	2.7	0.044	0.041	0.076	0.041	0.035
DN	14.	0.081	0.078	0.14	0.072	0.060

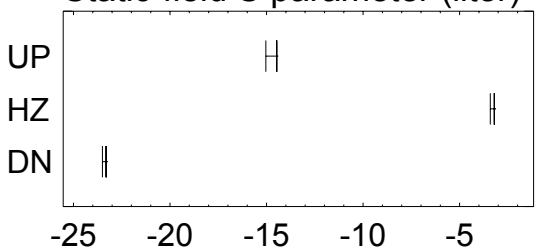
Group 52. Projectile, 105mm, Empty
Band intact.
2 items in group.

Item ID numbers:

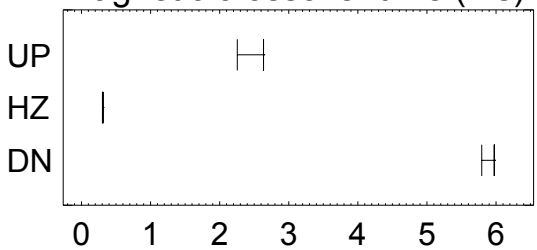
798, 799



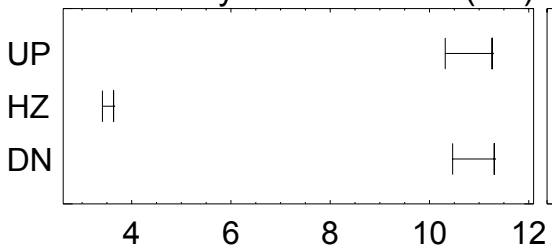
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	5.3	n/a	n/a	n/a	n/a	n/a
HZ	1.5	n/a	n/a	n/a	n/a	n/a
DN	9.7	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-15.	n/a	n/a	n/a	n/a	n/a
HZ	-3.3	n/a	n/a	n/a	n/a	n/a
DN	-23.	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.4	n/a	n/a	n/a	n/a	n/a
HZ	0.31	n/a	n/a	n/a	n/a	n/a
DN	5.9	n/a	n/a	n/a	n/a	n/a

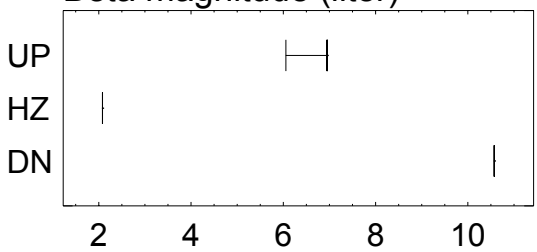


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	11.	n/a	n/a	n/a	n/a	n/a
HZ	3.5	n/a	n/a	n/a	n/a	n/a
DN	11.	n/a	n/a	n/a	n/a	n/a

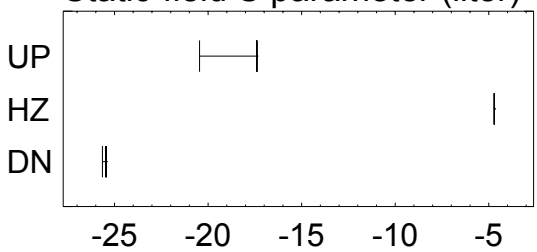
Group 53. Projectile, 105mm, Base ejection
Band intact.
2 items in group.

Item ID numbers:

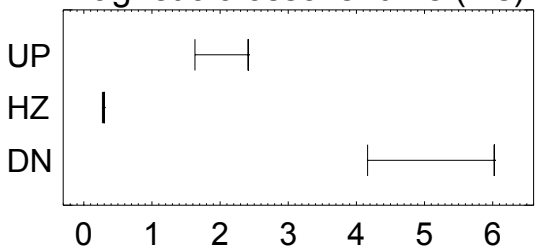
1301, 1302



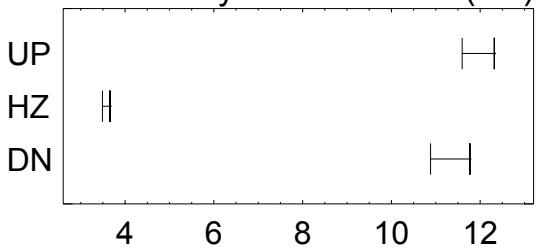
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	6.5	n/a	n/a	n/a	n/a	n/a
HZ	2.1	n/a	n/a	n/a	n/a	n/a
DN	11.	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-19.	n/a	n/a	n/a	n/a	n/a
HZ	-4.7	n/a	n/a	n/a	n/a	n/a
DN	-26.	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.0	n/a	n/a	n/a	n/a	n/a
HZ	0.28	n/a	n/a	n/a	n/a	n/a
DN	5.1	n/a	n/a	n/a	n/a	n/a



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	12.	n/a	n/a	n/a	n/a	n/a
HZ	3.6	n/a	n/a	n/a	n/a	n/a
DN	11.	n/a	n/a	n/a	n/a	n/a

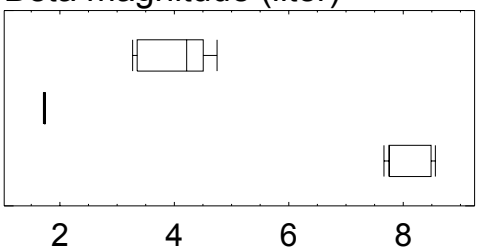
Group 54. Projectile, 105mm, Illuminating

5 items in group.

Item ID numbers:

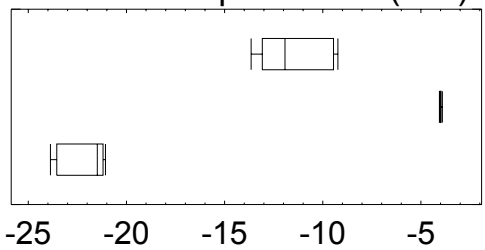
800, 801, 802, 886, 887

Beta magnitude (liter)



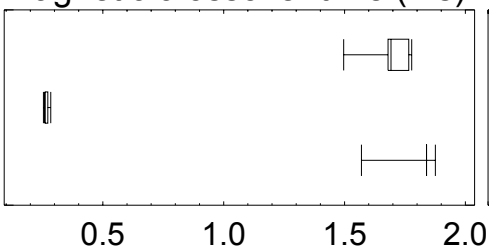
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	4.0	0.30	0.31	0.67	0.12	0.17
HZ	1.7	6.2e-3	5.9e-3	0.014	3.8e-3	3.5e-3
DN	8.0	0.20	0.19	0.44	0.068	0.12

Static-field S parameter (liter)



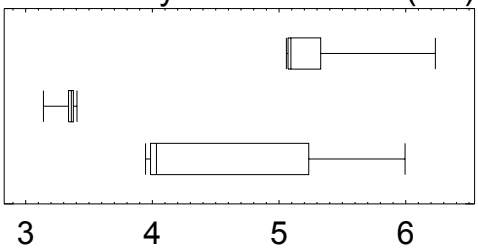
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-11.	0.91	0.94	2.0	0.35	0.46
HZ	-4.0	0.026	0.025	0.059	0.024	0.019
DN	-22.	0.61	0.61	1.4	0.22	0.31

Magnetic crossover time (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.7	0.050	0.047	0.11	0.060	0.044
HZ	0.27	5.5e-3	5.7e-3	0.012	4.6e-3	3.8e-3
DN	1.8	0.056	0.051	0.12	0.094	0.061

Late decay time constant (ms)

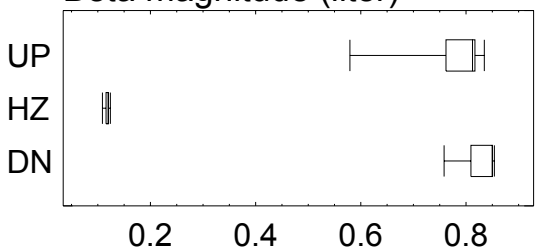


	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	5.4	0.22	0.24	0.50	0.34	0.23
HZ	3.3	0.047	0.043	0.11	0.072	0.047
DN	4.6	0.42	0.42	0.93	0.30	0.29

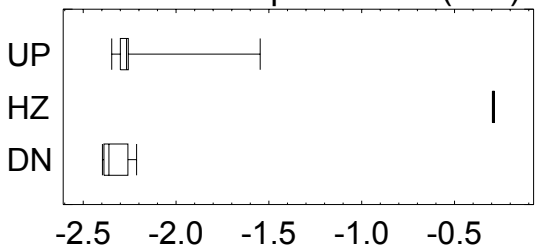
Group 55. Grenade, Practice, M62, Fuze and handle missing.
Practice version of M61.
5 items in group.

Item ID numbers:

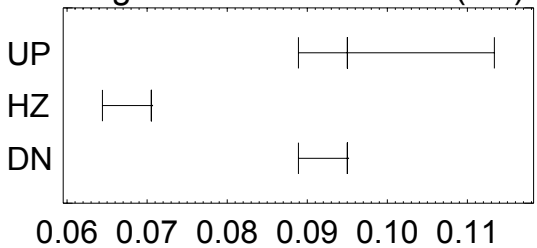
803, 804, 805, 875, 876



Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.76	0.047	0.047	0.11	0.068	0.050
HZ	0.12	2.6e-3	2.5e-3	5.8e-3	2.5e-3	2.0e-3
DN	0.82	0.018	0.018	0.041	0.019	0.015



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-2.1	0.15	0.14	0.34	0.27	0.18
HZ	-0.29	2.1e-3	2.0e-3	4.7e-3	1.0e-3	1.2e-3
DN	-2.3	0.037	0.037	0.083	0.020	0.022



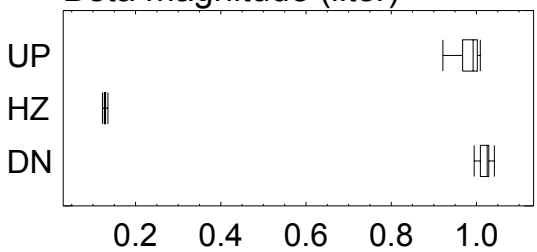
Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.096	4.5e-3	4.6e-3	0.010	6.1e-3	4.3e-3
HZ	0.069	1.2e-3	1.2e-3	2.7e-3	2.4e-3	1.6e-3
DN	0.093	1.5e-3	1.4e-3	3.4e-3	4.6e-4	8.9e-4

Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.76	0.095	0.093	0.21	0.080	0.063
HZ	0.59	0.12	0.12	0.27	0.19	0.13
DN	1.7	1.1	0.99	2.5	2.1	1.4

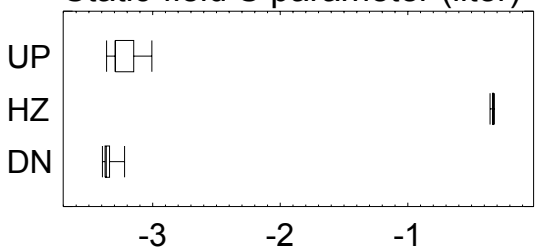
Group 56. Grenade, Practice, MK II, Fake handle cast with body.
, From Ft. Ord.
5 items in group.

Item ID numbers:

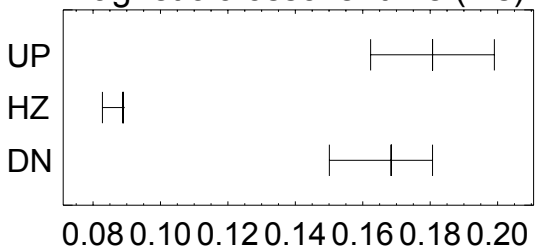
806, 807, 808, 809, 810



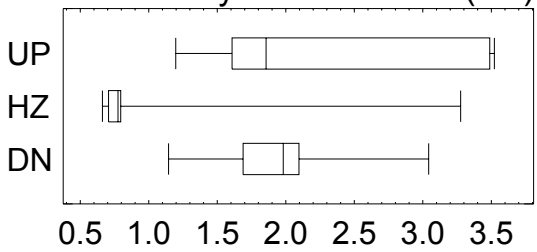
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.98	0.016	0.015	0.036	0.017	0.013
HZ	0.13	2.1e-3	2.1e-3	4.8e-3	2.0e-3	1.6e-3
DN	1.0	8.2e-3	7.9e-3	0.018	5.9e-3	5.1e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-3.2	0.064	0.061	0.14	0.053	0.047
HZ	-0.33	5.7e-3	5.5e-3	0.013	6.9e-3	5.2e-3
DN	-3.3	0.031	0.031	0.069	0.042	0.031



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.18	6.3e-3	6.3e-3	0.014	5.3e-3	4.3e-3
HZ	0.086	1.5e-3	1.5e-3	3.4e-3	4.6e-4	1.0e-3
DN	0.17	5.0e-3	5.5e-3	0.011	4.5e-3	3.5e-3

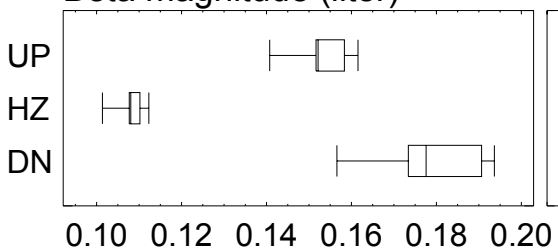


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.3	0.49	0.47	1.1	0.18	0.32
HZ	1.2	0.51	0.47	1.1	0.97	0.64
DN	2.0	0.31	0.31	0.69	0.30	0.23

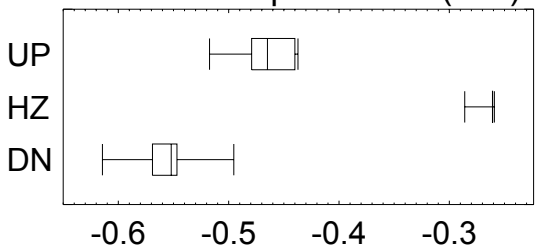
Group 57. Grenade, Practice, MK II, Fake handle cast with body.
, From Ft. McClellan.
6 items in group.

Item ID numbers:

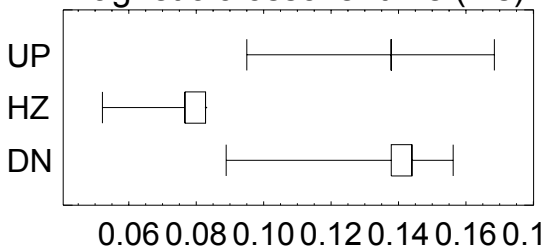
1092, 1093, 1094, 1095, 1096, 1097



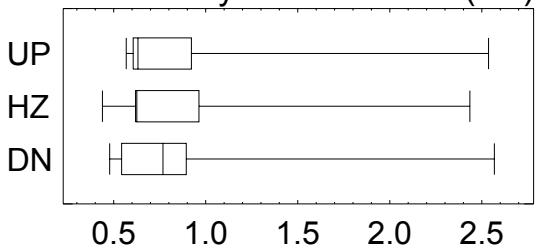
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.15	3.1e-3	2.9e-3	7.7e-3	2.0e-3	1.8e-3
HZ	0.11	1.8e-3	1.6e-3	4.4e-3	9.6e-4	1.0e-3
DN	0.18	5.5e-3	5.4e-3	0.014	4.1e-3	3.6e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.47	0.013	0.012	0.033	7.0e-3	7.9e-3
HZ	-0.27	4.6e-3	4.2e-3	0.011	3.6e-3	4.2e-3
DN	-0.56	0.018	0.018	0.044	0.014	0.012



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.14	9.7e-3	9.5e-3	0.024	0.011	9.1e-3
HZ	0.074	4.7e-3	4.7e-3	0.011	6.1e-3	4.4e-3
DN	0.13	9.6e-3	9.7e-3	0.023	0.015	0.011

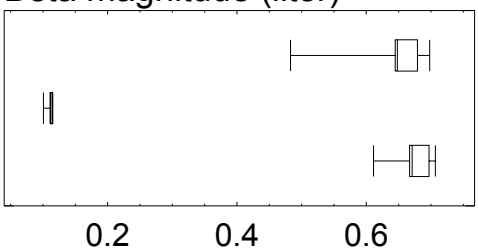


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.98	0.32	0.30	0.77	0.58	0.43
HZ	0.95	0.31	0.31	0.75	0.52	0.36
DN	0.96	0.33	0.30	0.81	0.58	0.39

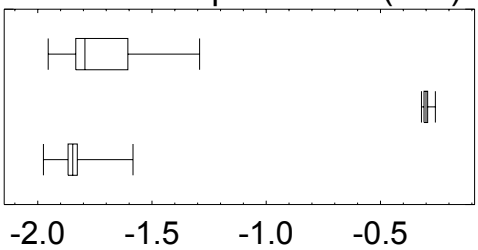
Group 58. Grenade, Practice, M69, Fuze and handle missing.
Practice version of M67.
10 items in group.

Item ID numbers:

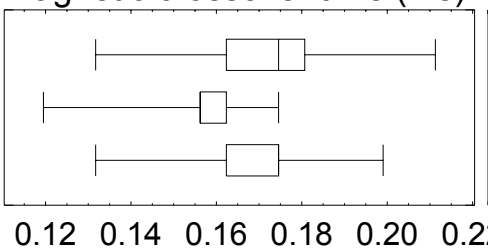
811, 812, 813, 814, 815, 816, 817, 819, 877, 878



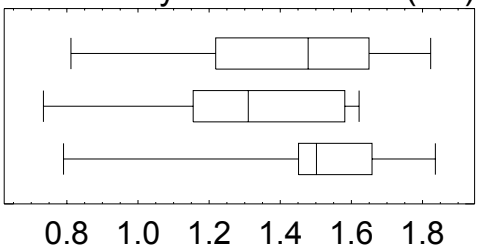
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.62	0.024	0.025	0.077	0.020	0.020
HZ	0.11	1.5e-3	1.6e-3	4.8e-3	1.3e-3	1.1e-3
DN	0.67	8.7e-3	8.3e-3	0.028	9.5e-3	6.8e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.7	0.076	0.072	0.24	0.054	0.059
HZ	-0.30	6.4e-3	6.8e-3	0.020	5.1e-3	4.6e-3
DN	-1.8	0.036	0.036	0.11	0.040	0.030



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.17	7.8e-3	8.3e-3	0.025	5.9e-3	5.8e-3
HZ	0.15	4.8e-3	4.8e-3	0.015	5.5e-3	4.5e-3
DN	0.16	7.1e-3	7.2e-3	0.022	4.0e-3	4.0e-3



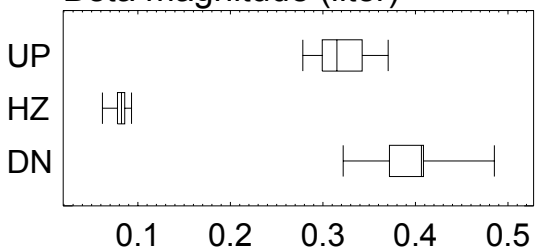
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.4	0.10	0.11	0.32	0.069	0.055
HZ	1.3	0.10	0.11	0.33	0.062	0.052
DN	1.4	0.10	0.11	0.33	0.084	0.063

Group 59. Fuze, Practice, M1907

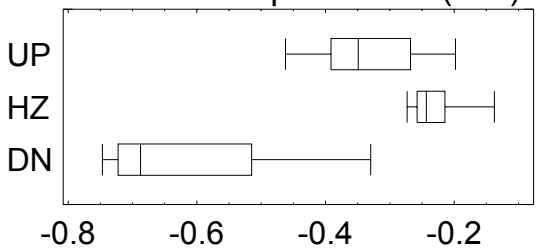
9 items in group.

Item ID numbers:

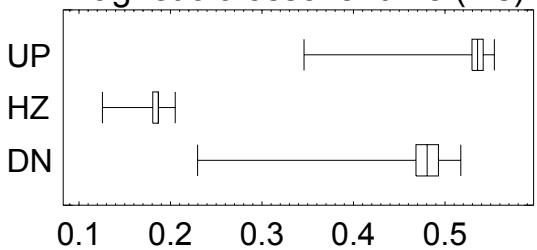
820, 821, 822, 823, 824, 825, 826, 827, 828



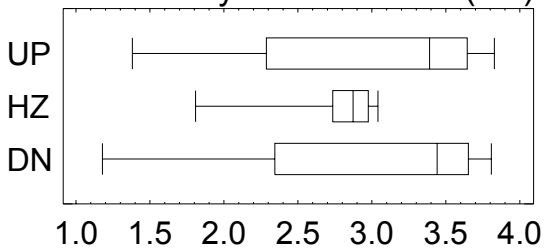
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.32	0.010	0.010	0.030	6.5e-3	6.4e-3
HZ	0.080	3.2e-3	3.2e-3	9.6e-3	2.7e-3	2.2e-3
DN	0.40	0.015	0.016	0.046	0.014	0.012



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.34	0.030	0.031	0.091	0.017	0.016
HZ	-0.23	0.015	0.016	0.046	0.013	0.011
DN	-0.62	0.047	0.048	0.14	0.043	0.032



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.50	0.026	0.026	0.077	0.025	0.024
HZ	0.17	9.9e-3	0.010	0.030	5.0e-3	5.1e-3
DN	0.44	0.033	0.036	0.098	0.037	0.030



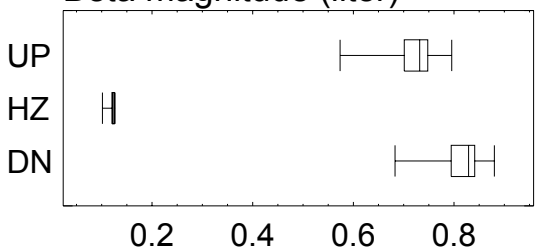
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.0	0.30	0.29	0.91	0.19	0.18
HZ	2.7	0.13	0.13	0.39	0.19	0.14
DN	3.0	0.31	0.31	0.94	0.24	0.21

Group 60. Fuze, Practice, MK VI, Used on Stokes Mortars.

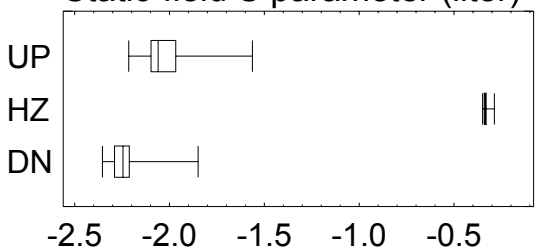
10 items in group.

Item ID numbers:

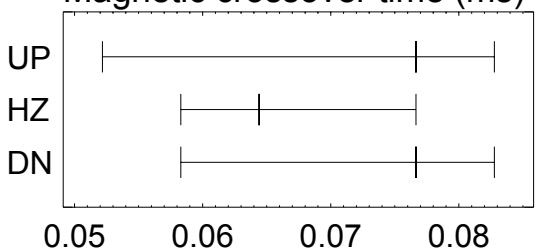
829, 830, 831, 832, 833, 834, 835, 836, 837, 838



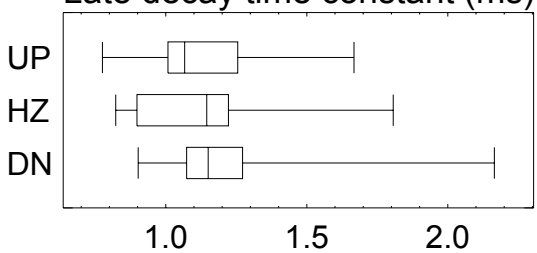
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.71	0.022	0.021	0.070	0.017	0.017
HZ	0.12	2.9e-3	2.7e-3	9.1e-3	2.1e-3	1.9e-3
DN	0.80	0.020	0.019	0.062	0.015	0.015



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-2.0	0.059	0.064	0.19	0.082	0.062
HZ	-0.33	5.9e-3	6.2e-3	0.019	7.8e-3	6.4e-3
DN	-2.2	0.046	0.049	0.15	0.069	0.055



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.071	3.1e-3	3.2e-3	9.8e-3	2.4e-3	2.1e-3
HZ	0.067	1.6e-3	1.8e-3	5.2e-3	1.3e-3	1.2e-3
DN	0.073	2.6e-3	2.8e-3	8.3e-3	1.7e-3	1.6e-3



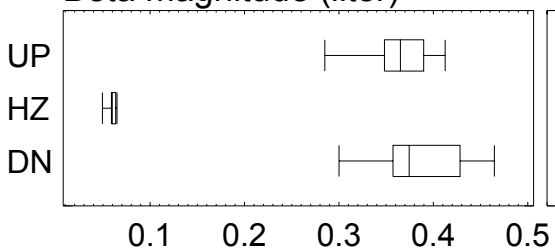
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.1	0.082	0.071	0.26	0.078	0.067
HZ	1.1	0.11	0.11	0.36	0.086	0.081
DN	1.2	0.12	0.11	0.37	0.19	0.15

Group 61. Fuze, Practice, T-Bar

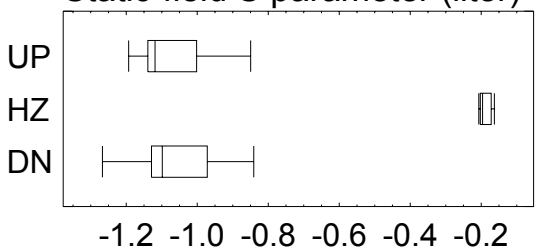
11 items in group.

Item ID numbers:

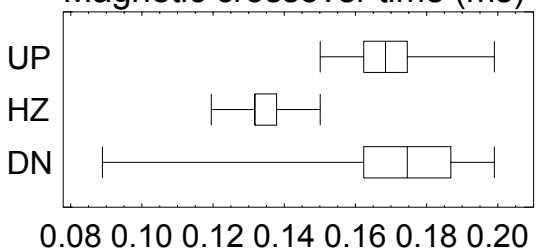
839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849



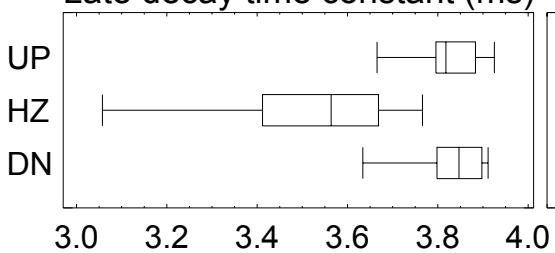
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.36	0.012	0.014	0.041	8.1e-3	7.3e-3
HZ	0.059	1.6e-3	1.7e-3	5.3e-3	1.0e-3	9.8e-4
DN	0.38	0.016	0.016	0.054	9.0e-3	8.2e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.1	0.033	0.034	0.11	0.027	0.024
HZ	-0.19	4.9e-3	4.8e-3	0.016	2.9e-3	3.0e-3
DN	-1.1	0.039	0.038	0.13	0.027	0.025



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.17	4.7e-3	4.8e-3	0.016	4.2e-3	3.6e-3
HZ	0.13	2.9e-3	2.8e-3	9.5e-3	2.0e-3	1.7e-3
DN	0.17	9.0e-3	9.1e-3	0.030	0.014	0.010



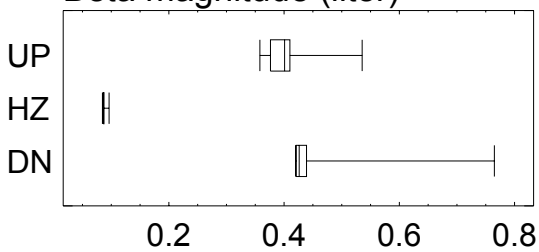
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.8	0.024	0.024	0.080	0.017	0.016
HZ	3.5	0.064	0.062	0.21	0.056	0.045
DN	3.8	0.026	0.024	0.085	0.025	0.022

Group 62. Fuze, Practice, M734, MO fuze.

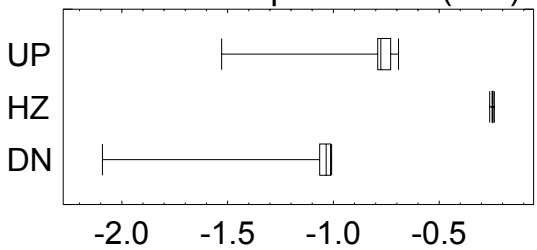
9 items in group.

Item ID numbers:

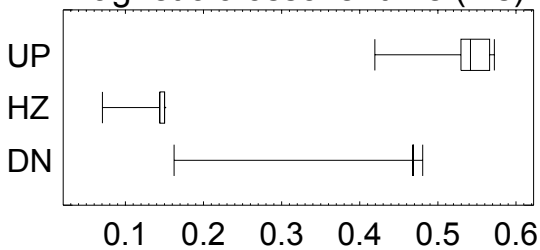
1222, 1239, 1240, 1241, 1242, 1243, 1244, 1245, 1246



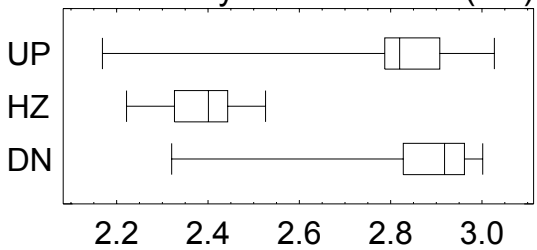
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.41	0.017	0.016	0.052	0.030	0.022
HZ	0.088	1.1e-3	1.0e-3	3.3e-3	2.3e-3	1.7e-3
DN	0.47	0.038	0.037	0.11	0.099	0.066



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.84	0.087	0.085	0.26	0.21	0.14
HZ	-0.25	2.0e-3	1.9e-3	6.0e-3	2.3e-3	1.8e-3
DN	-1.1	0.12	0.11	0.35	0.31	0.21



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.54	0.016	0.015	0.047	0.028	0.019
HZ	0.14	8.5e-3	8.3e-3	0.026	0.020	0.013
DN	0.43	0.034	0.032	0.10	0.083	0.055



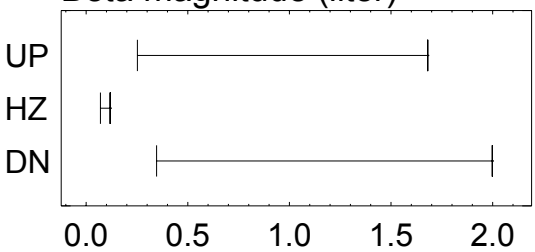
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.8	0.083	0.079	0.25	0.15	0.11
HZ	2.4	0.034	0.035	0.10	0.021	0.024
DN	2.8	0.070	0.069	0.21	0.12	0.089

Group 63. Fuze, Practice, Simulated MT fuze.

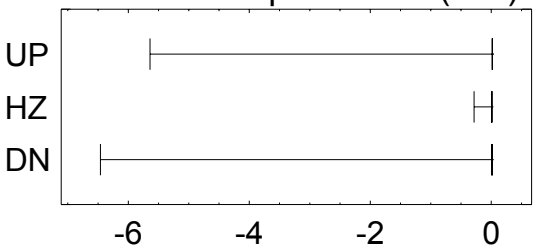
2 items in group.

Item ID numbers:

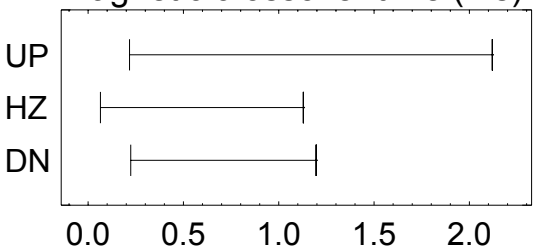
1223, 1224



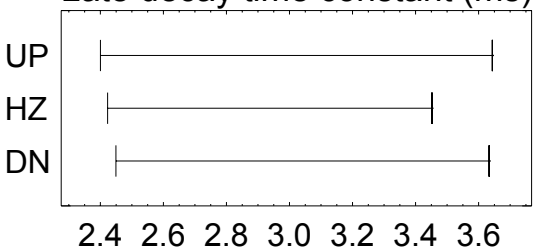
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.97	n/a	n/a	n/a	n/a	n/a
HZ	0.094	n/a	n/a	n/a	n/a	n/a
DN	1.2	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-2.8	n/a	n/a	n/a	n/a	n/a
HZ	-0.14	n/a	n/a	n/a	n/a	n/a
DN	-3.2	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.2	n/a	n/a	n/a	n/a	n/a
HZ	0.60	n/a	n/a	n/a	n/a	n/a
DN	0.71	n/a	n/a	n/a	n/a	n/a



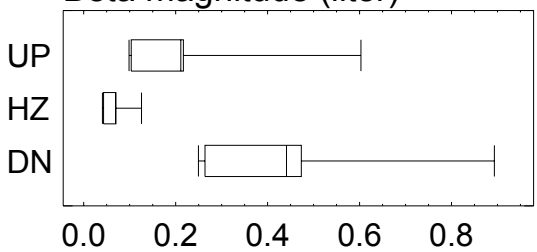
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.0	n/a	n/a	n/a	n/a	n/a
HZ	2.9	n/a	n/a	n/a	n/a	n/a
DN	3.0	n/a	n/a	n/a	n/a	n/a

Group 64. Fuze, Practice, MT superquick A.

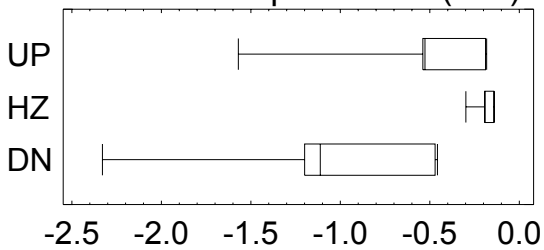
9 items in group.

Item ID numbers:

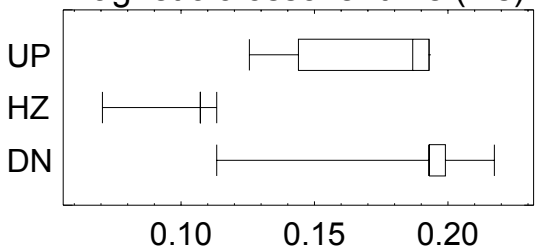
1235, 1247, 1248, 1249, 1250, 1251, 1252, 1253, 1254



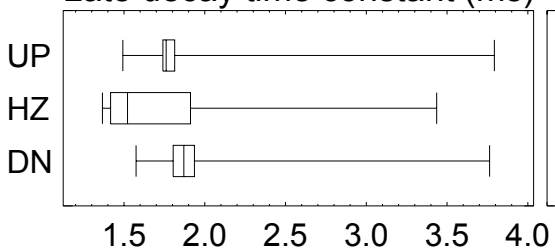
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.22	0.051	0.049	0.15	0.092	0.065
HZ	0.067	8.6e-3	7.8e-3	0.026	0.012	8.4e-3
DN	0.44	0.065	0.058	0.20	0.091	0.068



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.53	0.14	0.13	0.42	0.24	0.19
HZ	-0.19	0.016	0.015	0.049	0.022	0.019
DN	-1.1	0.19	0.18	0.58	0.23	0.18



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.17	0.010	0.011	0.030	5.4e-3	6.0e-3
HZ	0.10	4.2e-3	4.2e-3	0.013	8.3e-3	5.9e-3
DN	0.17	0.014	0.015	0.042	6.6e-3	8.0e-3



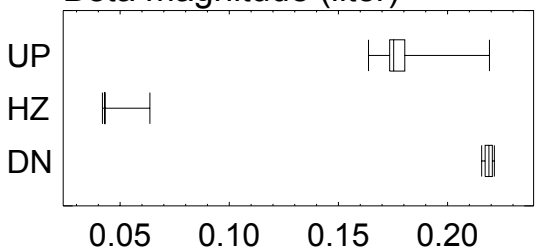
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.0	0.23	0.22	0.70	0.56	0.37
HZ	1.8	0.22	0.22	0.66	0.39	0.27
DN	2.0	0.22	0.21	0.66	0.51	0.34

Group 65. Fuze, Practice, MT superquick B.

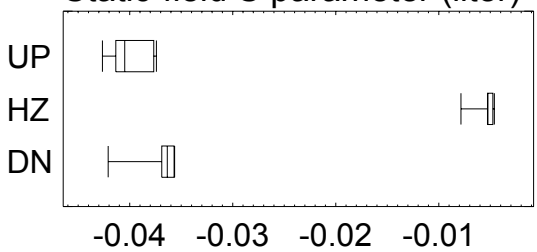
6 items in group.

Item ID numbers:

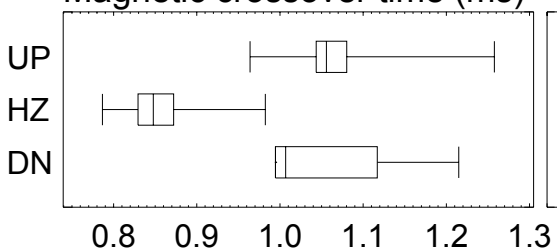
1271, 1272, 1273, 1274, 1275, 1276



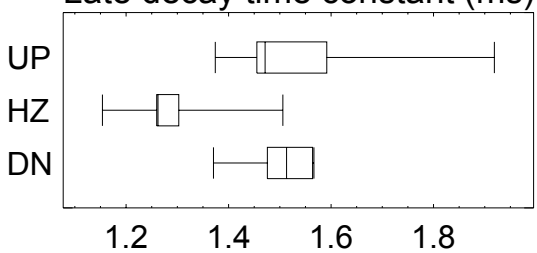
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.18	8.0e-3	8.1e-3	0.020	0.013	9.3e-3
HZ	0.046	3.5e-3	3.6e-3	8.6e-3	7.4e-3	5.0e-3
DN	0.22	9.9e-4	9.5e-4	2.4e-3	4.6e-4	5.2e-4



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.040	9.2e-4	9.0e-4	2.2e-3	4.4e-4	5.4e-4
HZ	-5.6e-3	4.8e-4	5.3e-4	1.2e-3	7.1e-4	5.1e-4
DN	-0.037	9.9e-4	8.9e-4	2.4e-3	1.5e-3	1.1e-3



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.1	0.042	0.039	0.10	0.054	0.039
HZ	0.86	0.028	0.027	0.068	0.035	0.025
DN	1.1	0.038	0.038	0.092	0.037	0.032



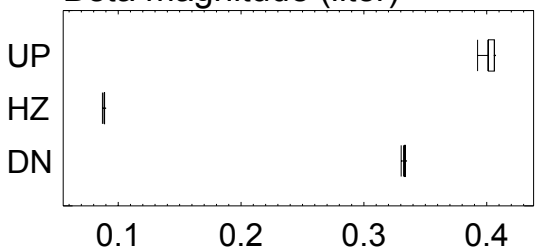
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.5	0.080	0.086	0.20	0.11	0.086
HZ	1.3	0.051	0.049	0.13	0.061	0.044
DN	1.5	0.033	0.033	0.082	0.017	0.018

Group 66. Fuze, Practice, Fuze adapter.

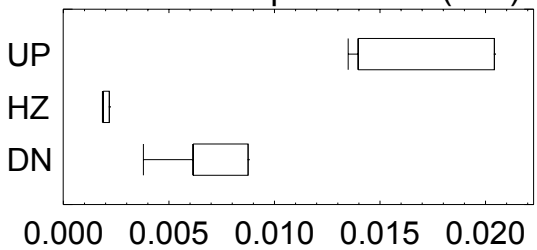
3 items in group.

Item ID numbers:

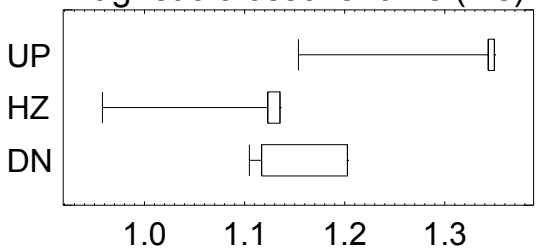
1236, 1237, 1238



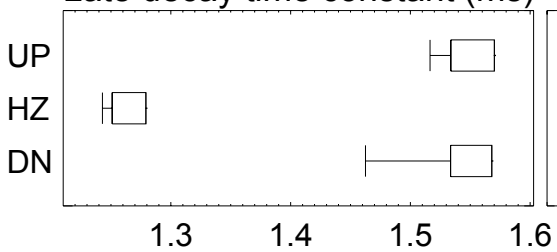
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.40	4.0e-3	4.3e-3	6.9e-3	3.5e-3	3.3e-3
HZ	0.088	5.5e-4	5.6e-4	9.6e-4	6.7e-4	4.8e-4
DN	0.33	1.0e-3	1.1e-3	1.8e-3	9.6e-4	8.3e-4



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.016	2.2e-3	2.3e-3	3.9e-3	2.9e-3	2.2e-3
HZ	2.0e-3	1.0e-4	1.0e-4	1.8e-4	1.3e-4	9.2e-5
DN	6.2e-3	1.4e-3	1.5e-3	2.5e-3	1.2e-3	1.1e-3



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.3	0.064	0.065	0.11	0.088	0.064
HZ	1.1	0.057	0.057	0.099	0.075	0.053
DN	1.1	0.031	0.031	0.053	0.038	0.029



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.5	0.016	0.017	0.027	0.015	0.013
HZ	1.3	0.011	0.011	0.019	0.012	9.0e-3
DN	1.5	0.031	0.032	0.054	0.029	0.026

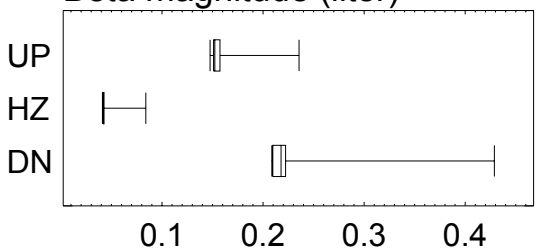
Group 67. Fuze, Practice, M745, PD fuze.

8 items in group.

Item ID numbers:

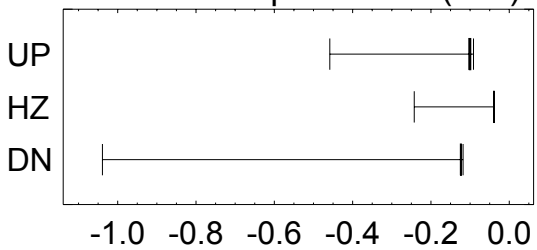
1263, 1264, 1265, 1266, 1267, 1268, 1269, 1270

Beta magnitude (liter)



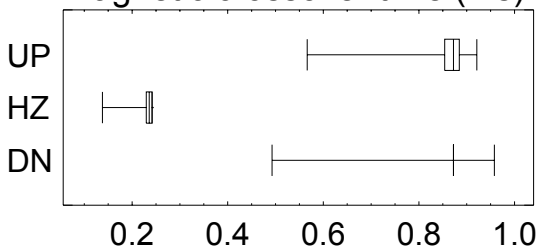
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.16	0.011	9.8e-3	0.030	0.025	0.017
HZ	0.047	5.3e-3	5.2e-3	0.015	0.014	8.8e-3
DN	0.24	0.027	0.027	0.076	0.067	0.043

Static-field S parameter (liter)



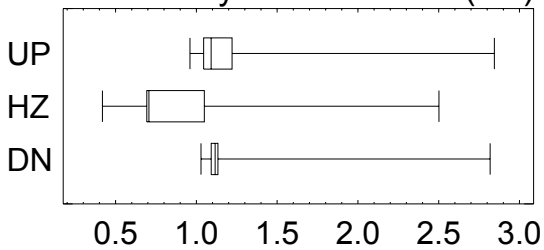
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.14	0.045	0.044	0.13	0.11	0.076
HZ	-0.065	0.025	0.023	0.072	0.067	0.043
DN	-0.24	0.11	0.11	0.32	0.30	0.20

Magnetic crossover time (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.82	0.039	0.042	0.11	0.068	0.047
HZ	0.22	0.012	0.013	0.035	0.026	0.018
DN	0.84	0.051	0.048	0.14	0.10	0.073

Late decay time constant (ms)



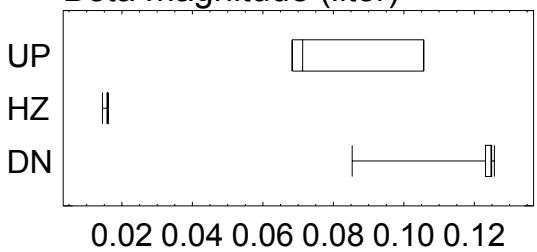
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.3	0.22	0.23	0.63	0.52	0.34
HZ	0.93	0.23	0.22	0.66	0.45	0.31
DN	1.3	0.22	0.22	0.61	0.54	0.36

Group 68. Fuze, Practice, M551, PD fuze.

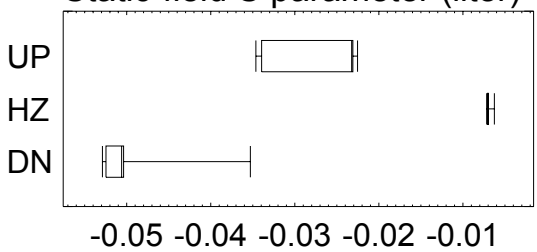
5 items in group.

Item ID numbers:

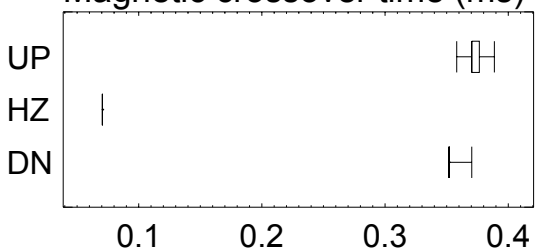
1280, 1281, 1282, 1283, 1284



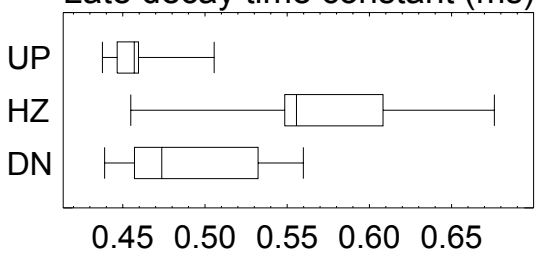
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.084	8.9e-3	9.2e-3	0.020	2.8e-3	6.2e-3
HZ	0.016	3.0e-4	3.0e-4	6.8e-4	4.8e-4	3.3e-4
DN	0.12	7.9e-3	7.8e-3	0.018	0.015	9.9e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.027	2.8e-3	3.0e-3	6.2e-3	9.0e-4	1.9e-3
HZ	-6.9e-3	1.6e-4	1.6e-4	3.7e-4	2.6e-4	1.8e-4
DN	-0.048	3.3e-3	3.4e-3	7.4e-3	5.6e-3	3.9e-3



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.37	5.0e-3	4.8e-3	0.011	4.5e-3	3.8e-3
HZ	0.071	0.0	1.1e-16	0.0	0.0	0.0
DN	0.36	3.9e-3	3.8e-3	8.7e-3	2.4e-3	2.8e-3



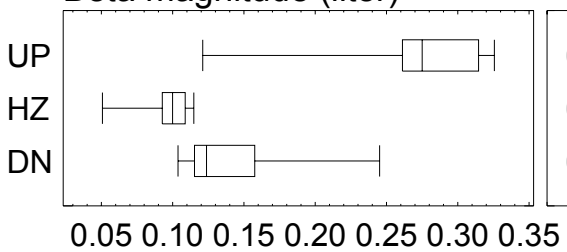
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.46	0.012	0.012	0.026	0.015	0.011
HZ	0.57	0.036	0.036	0.082	0.031	0.026
DN	0.49	0.023	0.023	0.051	0.012	0.014

Group 69. Flare, M125, M126, M158, M159

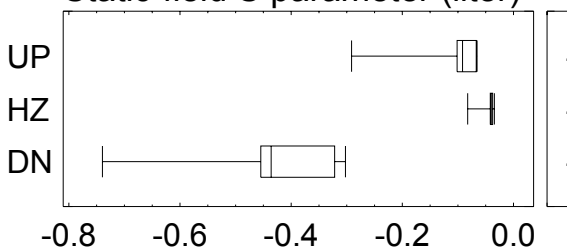
11 items in group.

Item ID numbers:

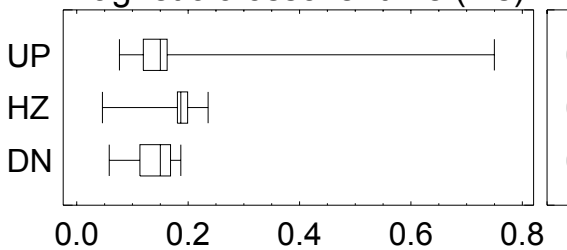
850, 851, 852, 853, 854, 855, 1067, 1068, 1069, 1070, 1071



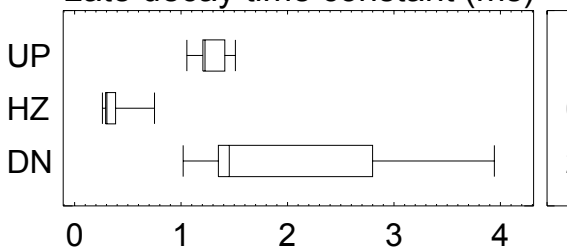
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.26	0.023	0.026	0.076	0.016	0.016
HZ	0.093	6.8e-3	7.3e-3	0.023	5.7e-3	5.8e-3
DN	0.14	0.014	0.014	0.045	0.014	0.012



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.12	0.021	0.020	0.070	0.028	0.019
HZ	-0.044	4.3e-3	4.1e-3	0.014	7.2e-3	5.4e-3
DN	-0.43	0.037	0.038	0.12	0.051	0.038



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.19	0.056	0.055	0.19	0.15	0.097
HZ	0.18	0.016	0.015	0.051	0.023	0.018
DN	0.13	0.014	0.014	0.046	8.5e-3	9.0e-3



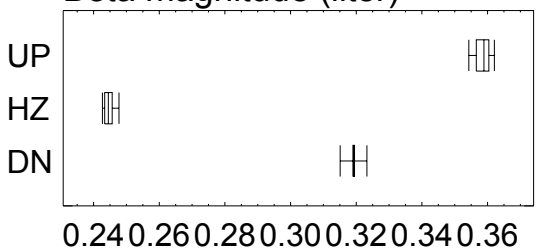
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.3	0.045	0.043	0.15	0.029	0.031
HZ	0.36	0.042	0.039	0.14	0.083	0.059
DN	2.0	0.28	0.28	0.93	0.23	0.18

Group 70. Flare, M125, M126, M158, M159, Launcher tube only

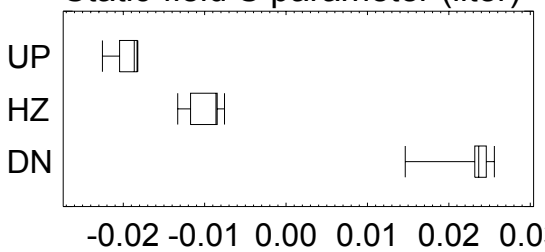
5 items in group.

Item ID numbers:

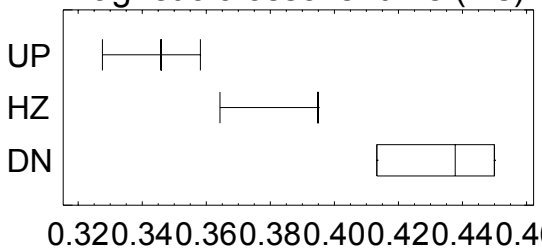
1062, 1063, 1064, 1065, 1066



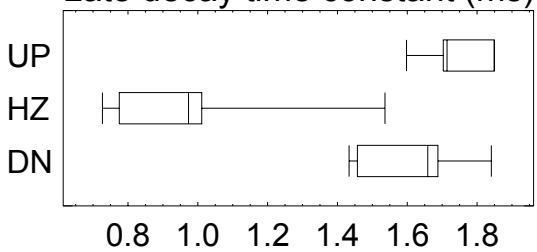
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.36	1.4e-3	1.4e-3	3.1e-3	9.2e-4	8.5e-4
HZ	0.24	8.9e-4	9.1e-4	2.0e-3	7.2e-4	5.7e-4
DN	0.32	1.3e-3	1.2e-3	2.9e-3	1.3e-3	1.0e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.020	8.4e-4	8.6e-4	1.9e-3	7.9e-4	6.0e-4
HZ	-9.9e-3	1.1e-3	1.1e-3	2.5e-3	6.6e-4	6.6e-4
DN	0.022	2.0e-3	2.0e-3	4.4e-3	3.1e-3	2.1e-3



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.34	5.0e-3	4.8e-3	0.011	4.5e-3	3.3e-3
HZ	0.39	6.3e-3	6.4e-3	0.014	4.7e-3	5.1e-3
DN	0.43	8.3e-3	8.5e-3	0.019	2.9e-3	4.9e-3



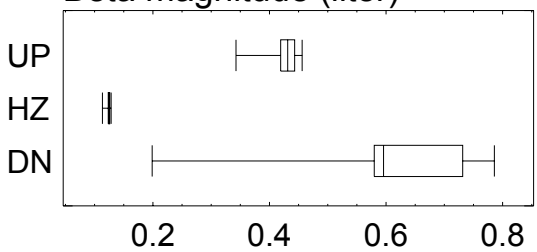
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.7	0.048	0.041	0.11	0.030	0.026
HZ	1.0	0.14	0.16	0.32	0.17	0.13
DN	1.6	0.076	0.075	0.17	0.046	0.043

Group 71. Grenade, Rifle, Illuminating, M19

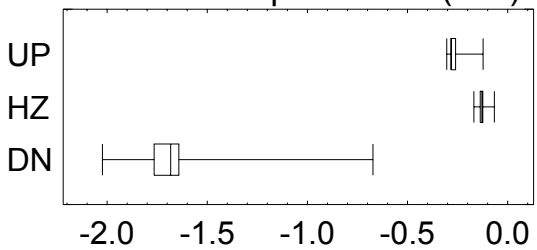
10 items in group.

Item ID numbers:

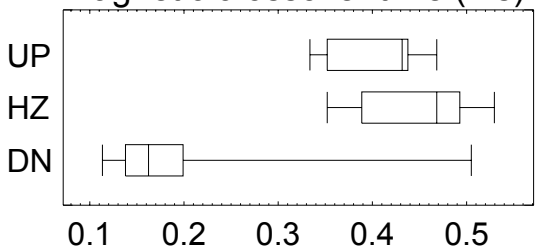
856, 857, 858, 859, 860, 861, 862, 863, 864, 865



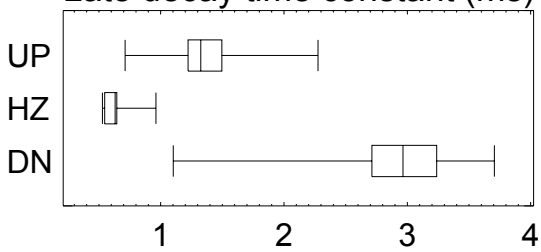
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.42	0.011	0.010	0.034	0.012	8.1e-3
HZ	0.12	1.3e-3	1.2e-3	4.2e-3	1.9e-3	1.3e-3
DN	0.58	0.057	0.065	0.18	0.054	0.044



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.26	0.017	0.016	0.053	0.032	0.023
HZ	-0.13	8.5e-3	8.1e-3	0.027	0.012	9.5e-3
DN	-1.6	0.14	0.14	0.46	0.14	0.13



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.40	0.016	0.017	0.052	6.0e-3	7.7e-3
HZ	0.44	0.021	0.020	0.065	8.7e-3	0.010
DN	0.20	0.037	0.039	0.12	0.067	0.052



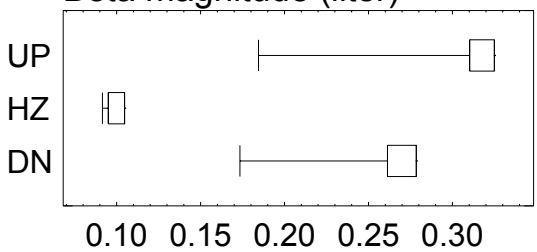
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.3	0.13	0.14	0.42	0.15	0.13
HZ	0.63	0.040	0.042	0.13	0.072	0.048
DN	2.7	0.26	0.26	0.81	0.21	0.19

Group 72. Grenade, Rifle, Practice, M11, Rear part of body

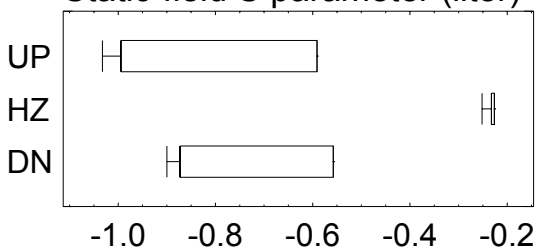
3 items in group.

Item ID numbers:

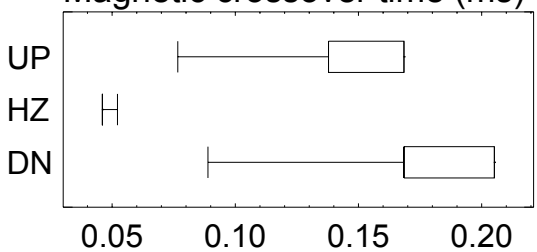
1072, 1073, 1074



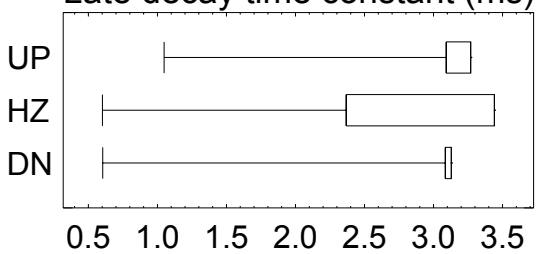
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.27	0.045	0.047	0.077	0.056	0.044
HZ	0.097	3.9e-3	3.9e-3	6.8e-3	4.0e-3	3.1e-3
DN	0.24	0.033	0.032	0.056	0.038	0.029



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.87	0.14	0.15	0.24	0.18	0.14
HZ	-0.24	7.7e-3	7.6e-3	0.013	8.1e-3	6.0e-3
DN	-0.78	0.11	0.11	0.19	0.14	0.10



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.13	0.027	0.028	0.047	0.025	0.023
HZ	0.048	2.0e-3	2.0e-3	3.5e-3	2.9e-3	2.0e-3
DN	0.15	0.034	0.035	0.059	0.033	0.026



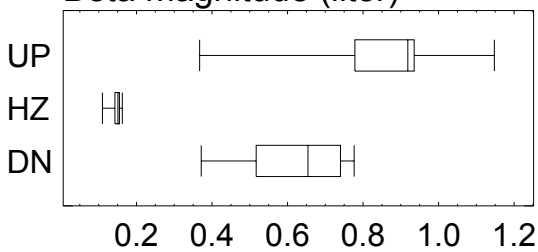
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.5	0.71	0.75	1.2	0.92	0.71
HZ	2.1	0.83	0.84	1.4	0.73	0.63
DN	2.3	0.83	0.82	1.4	1.2	0.84

Group 73. Grenade, Rifle, Practice, M11

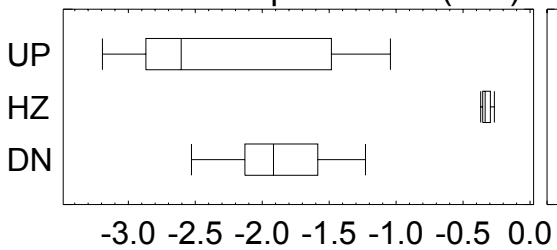
10 items in group.

Item ID numbers:

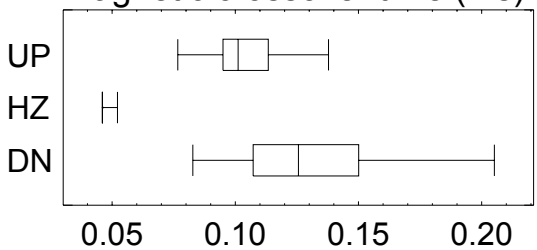
1075, 1076, 1078, 1079, 1080, 1081, 1082, 1083, 1084, 1085



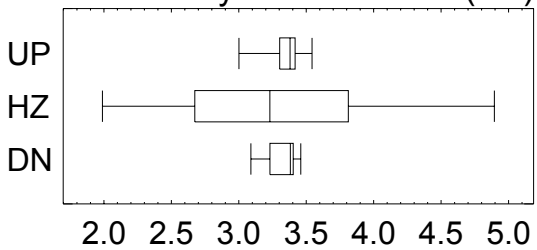
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.79	0.085	0.094	0.27	0.047	0.045
HZ	0.14	5.2e-3	5.3e-3	0.016	4.5e-3	4.0e-3
DN	0.60	0.046	0.046	0.14	0.023	0.023



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-2.4	0.25	0.28	0.80	0.15	0.14
HZ	-0.33	0.012	0.012	0.038	6.1e-3	6.1e-3
DN	-1.9	0.15	0.15	0.47	0.080	0.076



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.10	5.4e-3	5.4e-3	0.017	5.2e-3	4.5e-3
HZ	0.047	6.1e-4	6.0e-4	1.9e-3	1.8e-3	1.2e-3
DN	0.13	0.012	0.012	0.037	0.010	8.4e-3



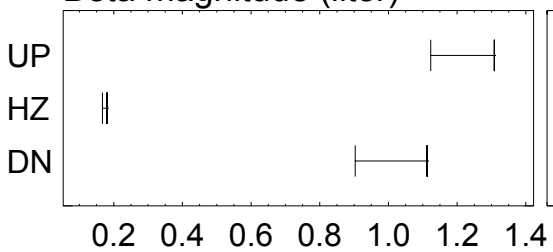
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.3	0.051	0.051	0.16	0.040	0.032
HZ	3.2	0.29	0.29	0.91	0.20	0.16
DN	3.3	0.043	0.041	0.13	0.021	0.022

Group 74. Grenade, Rifle, Smoke, M22

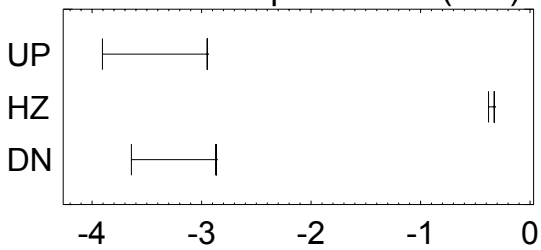
2 items in group.

Item ID numbers:

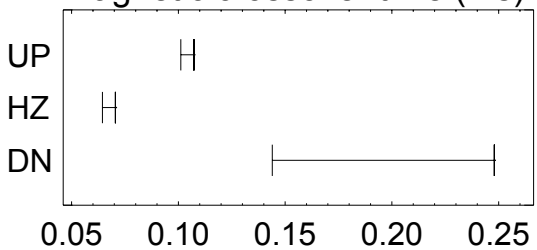
866, 867



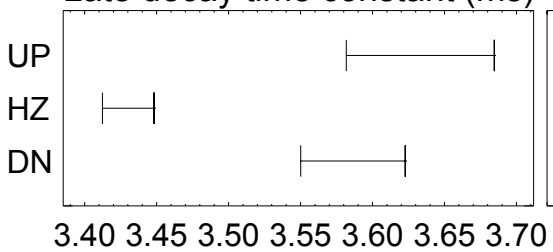
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.2	n/a	n/a	n/a	n/a	n/a
HZ	0.17	n/a	n/a	n/a	n/a	n/a
DN	1.0	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-3.4	n/a	n/a	n/a	n/a	n/a
HZ	-0.35	n/a	n/a	n/a	n/a	n/a
DN	-3.3	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.10	n/a	n/a	n/a	n/a	n/a
HZ	0.067	n/a	n/a	n/a	n/a	n/a
DN	0.20	n/a	n/a	n/a	n/a	n/a



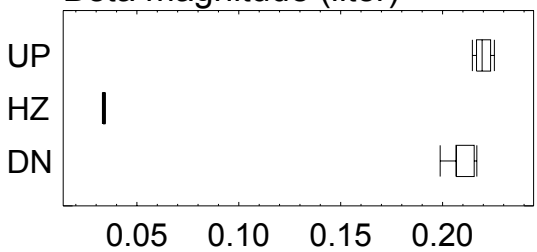
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.6	n/a	n/a	n/a	n/a	n/a
HZ	3.4	n/a	n/a	n/a	n/a	n/a
DN	3.6	n/a	n/a	n/a	n/a	n/a

Group 75. Spent cartridge case, 40mm, M79

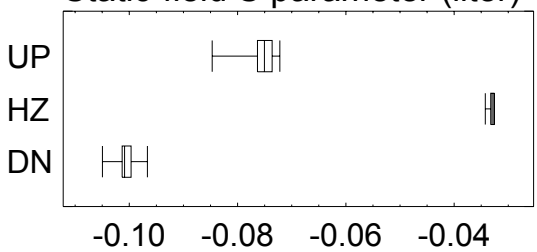
7 items in group.

Item ID numbers:

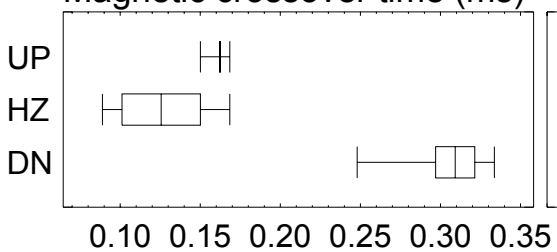
868, 869, 870, 871, 872, 873, 874



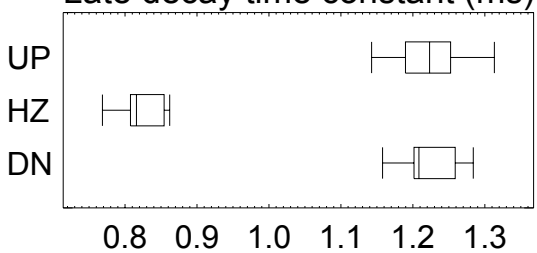
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.22	1.6e-3	1.5e-3	4.2e-3	9.2e-4	8.4e-4
HZ	0.034	2.0e-4	1.9e-4	5.3e-4	8.3e-5	9.8e-5
DN	0.21	2.5e-3	2.7e-3	6.5e-3	1.5e-3	1.6e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.077	1.7e-3	1.7e-3	4.5e-3	1.4e-3	1.3e-3
HZ	-0.033	2.3e-4	2.4e-4	6.1e-4	2.0e-4	1.5e-4
DN	-0.10	1.0e-3	9.4e-4	2.7e-3	8.2e-4	6.9e-4



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.16	2.6e-3	2.8e-3	6.9e-3	1.5e-3	1.6e-3
HZ	0.12	0.012	0.012	0.031	6.1e-3	6.9e-3
DN	0.30	0.012	0.013	0.033	7.7e-3	9.0e-3



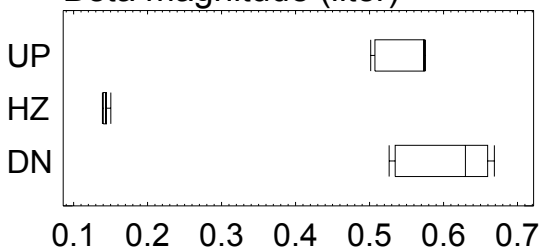
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.2	0.022	0.023	0.057	0.017	0.014
HZ	0.82	0.013	0.013	0.034	7.6e-3	7.2e-3
DN	1.2	0.018	0.018	0.047	0.012	0.012

Group 76. Spent cartridge case, 40mm

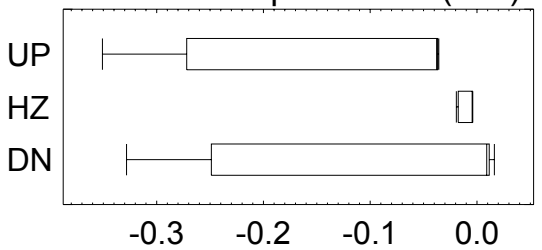
6 items in group.

Item ID numbers:

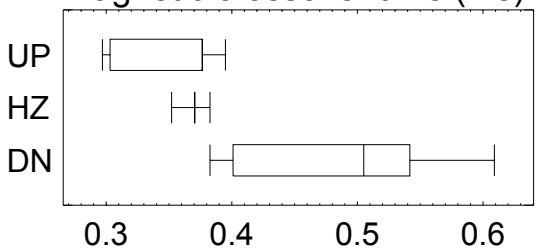
1255, 1256, 1257, 1258, 1259, 1260



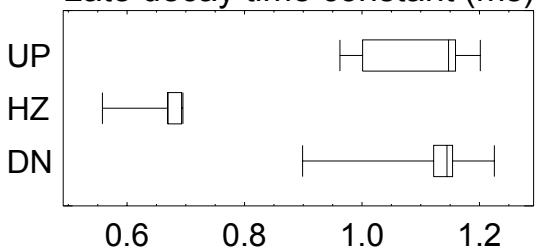
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.54	0.016	0.017	0.038	1.1e-3	8.3e-3
HZ	0.14	1.8e-3	1.9e-3	4.4e-3	1.8e-3	1.4e-3
DN	0.59	0.028	0.030	0.069	6.8e-3	0.013



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.18	0.065	0.070	0.16	0.014	0.034
HZ	-0.011	3.3e-3	3.5e-3	8.0e-3	3.5e-4	1.5e-3
DN	-0.14	0.071	0.076	0.17	0.014	0.032



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.34	0.019	0.020	0.046	4.3e-3	9.7e-3
HZ	0.37	4.1e-3	4.0e-3	1.0e-2	4.0e-3	3.2e-3
DN	0.47	0.039	0.039	0.095	0.021	0.022

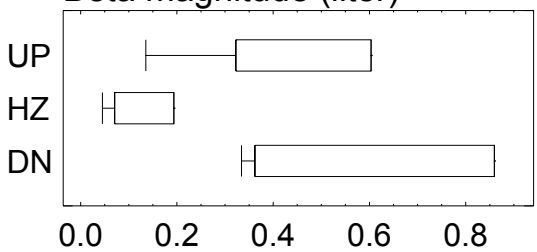


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.1	0.043	0.046	0.11	0.013	0.022
HZ	0.66	0.021	0.019	0.051	0.033	0.021
DN	1.1	0.048	0.048	0.12	0.042	0.035

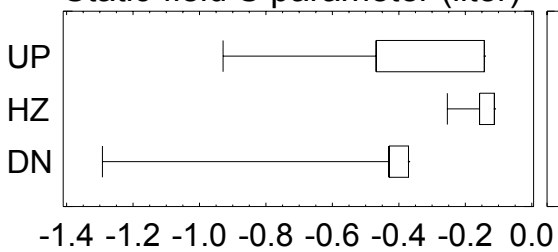
Group 77. Grenade, Smoke, M18
, From Ft. Ord.
3 items in group.

Item ID numbers:

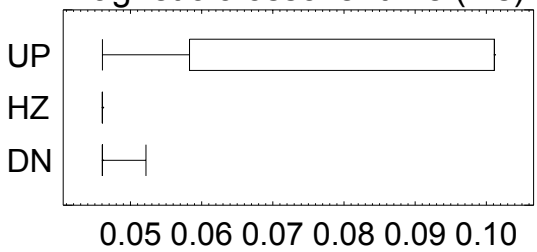
879, 880, 894



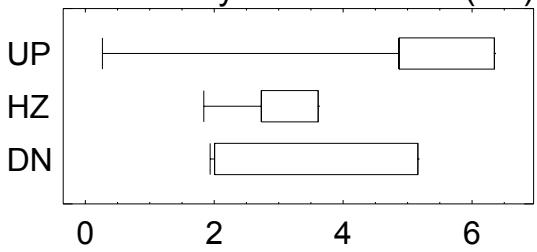
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.35	0.14	0.15	0.24	0.12	0.11
HZ	0.10	0.046	0.043	0.079	0.053	0.038
DN	0.52	0.17	0.16	0.30	0.23	0.16



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.51	0.23	0.25	0.40	0.19	0.19
HZ	-0.17	0.042	0.041	0.072	0.040	0.031
DN	-0.70	0.30	0.28	0.52	0.39	0.28



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.068	0.017	0.018	0.029	0.018	0.015
HZ	0.046	0.0	1.0e-16	0.0	0.0	0.0
DN	0.048	2.0e-3	2.0e-3	3.5e-3	2.9e-3	2.0e-3

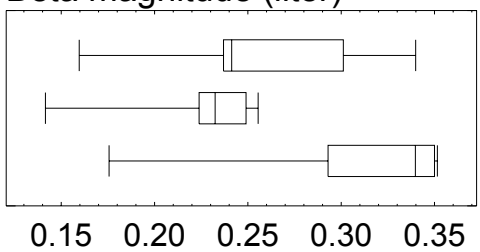


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.8	1.8	2.0	3.2	1.9	1.6
HZ	2.7	0.51	0.51	0.89	0.42	0.36
DN	3.0	1.1	1.0	1.8	1.5	1.0

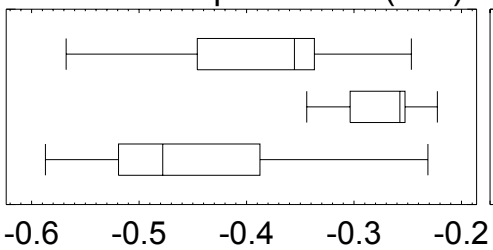
Group 78. Grenade, Smoke, M18
, From Ft. McClellan.
5 items in group.

Item ID numbers:

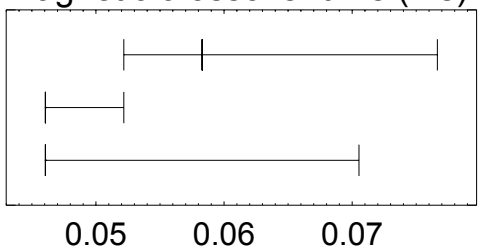
1098, 1099, 1100, 1101, 1102



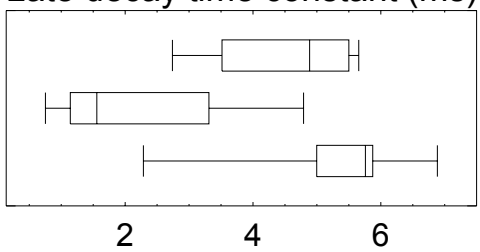
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.26	0.031	0.030	0.069	0.024	0.019
HZ	0.22	0.021	0.019	0.046	0.029	0.021
DN	0.30	0.033	0.030	0.075	0.044	0.031



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-0.39	0.054	0.052	0.12	0.045	0.038
HZ	-0.28	0.021	0.022	0.048	0.016	0.014
DN	-0.44	0.062	0.059	0.14	0.055	0.046



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.061	4.2e-3	4.4e-3	9.3e-3	5.9e-3	3.9e-3
HZ	0.047	1.2e-3	1.3e-3	2.7e-3	2.4e-3	1.6e-3
DN	0.053	4.9e-3	5.2e-3	0.011	4.6e-3	3.2e-3

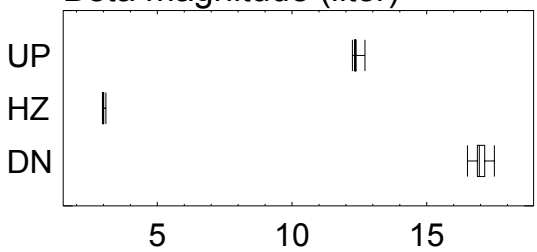


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	4.5	0.57	0.60	1.3	0.32	0.39
HZ	2.3	0.76	0.81	1.7	0.56	0.42
DN	5.2	0.78	0.83	1.7	0.93	0.66

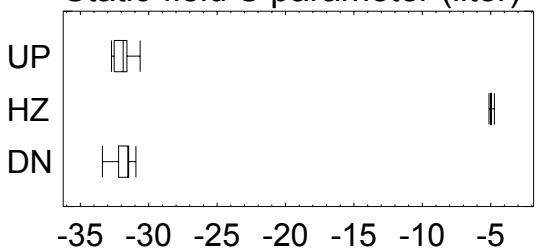
Group 79. Projectile, 155mm, Shrapnel
Band intact., From Ft. Ord.
5 items in group.

Item ID numbers:

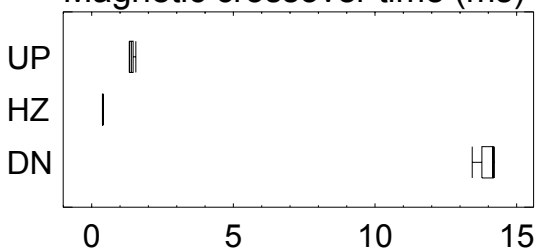
881, 882, 883, 884, 885



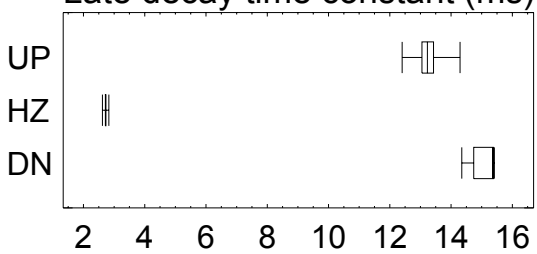
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	12.	0.080	0.077	0.18	0.11	0.080
HZ	3.0	0.023	0.024	0.052	0.028	0.020
DN	17.	0.16	0.16	0.37	0.14	0.11



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-32.	0.37	0.35	0.83	0.31	0.26
HZ	-5.0	0.064	0.062	0.14	0.067	0.053
DN	-32.	0.42	0.45	0.94	0.42	0.32



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.4	0.043	0.042	0.096	0.034	0.031
HZ	0.39	4.2e-3	4.2e-3	9.3e-3	4.3e-3	3.0e-3
DN	14.	0.15	0.16	0.34	0.13	0.14

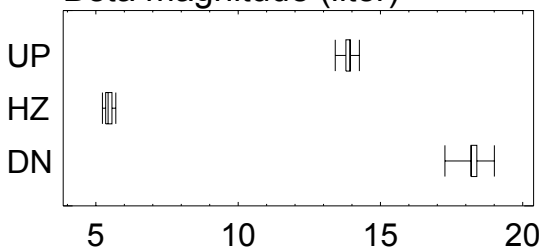


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	13.	0.31	0.32	0.68	0.29	0.20
HZ	2.7	0.033	0.033	0.075	0.033	0.026
DN	15.	0.21	0.22	0.48	0.15	0.19

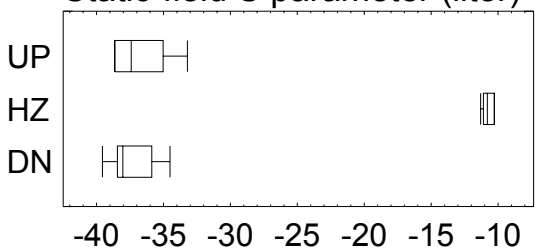
Group 80. Projectile, 155mm, Shrapnel
Band intact., From Ft. McClellan.
5 items in group.

Item ID numbers:

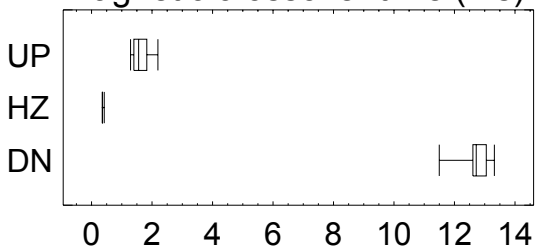
1086, 1087, 1088, 1089, 1090



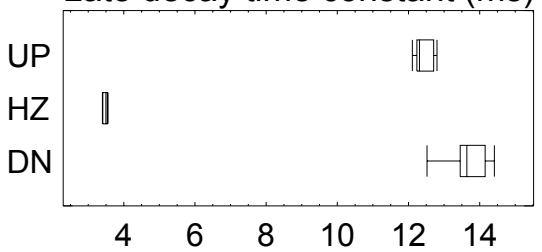
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	14.	0.14	0.13	0.31	0.13	0.095
HZ	5.5	0.082	0.086	0.18	0.056	0.052
DN	18.	0.28	0.29	0.62	0.28	0.21



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-37.	1.1	1.1	2.4	0.70	0.68
HZ	-11.	0.21	0.22	0.47	0.092	0.096
DN	-37.	0.92	0.88	2.0	0.58	0.53



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.7	0.16	0.17	0.36	0.13	0.10
HZ	0.38	0.013	0.014	0.029	7.6e-3	7.7e-3
DN	13.	0.31	0.29	0.70	0.36	0.26

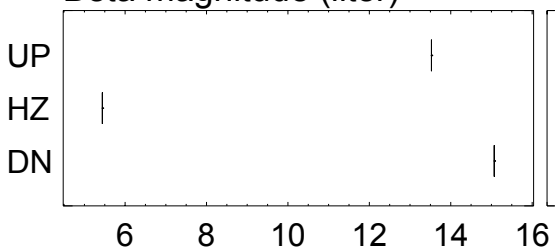


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	12.	0.14	0.14	0.30	0.060	0.079
HZ	3.5	0.033	0.031	0.073	0.013	0.017
DN	14.	0.33	0.32	0.73	0.30	0.25

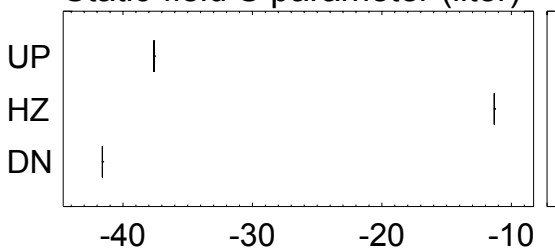
Group 81. Projectile, 155mm, Shrapnel
Band intact., From Ft. McClellan, Full of lead balls.
1 item in group.

Item ID number:

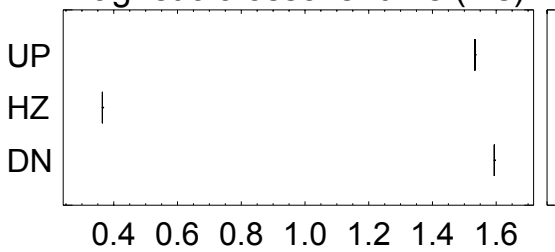
1091



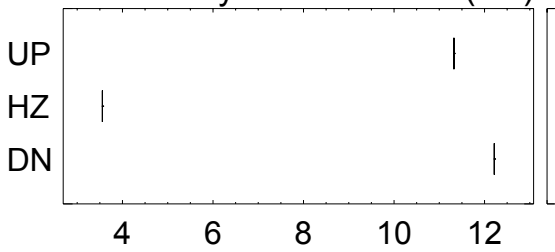
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	14.	n/a	n/a	n/a	n/a	n/a
HZ	5.4	n/a	n/a	n/a	n/a	n/a
DN	15.	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-38.	n/a	n/a	n/a	n/a	n/a
HZ	-11.	n/a	n/a	n/a	n/a	n/a
DN	-42.	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.5	n/a	n/a	n/a	n/a	n/a
HZ	0.36	n/a	n/a	n/a	n/a	n/a
DN	1.6	n/a	n/a	n/a	n/a	n/a

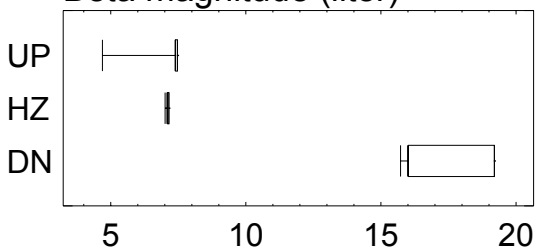


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	11.	n/a	n/a	n/a	n/a	n/a
HZ	3.6	n/a	n/a	n/a	n/a	n/a
DN	12.	n/a	n/a	n/a	n/a	n/a

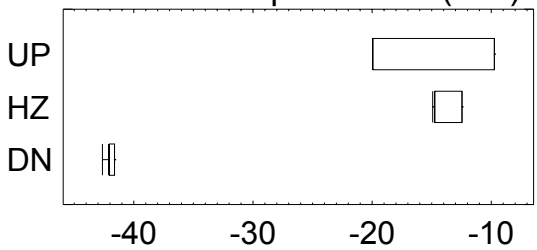
Group 82. Projectile, 155mm, Practice, Un-fired.
Band intact.
3 items in group.

Item ID numbers:

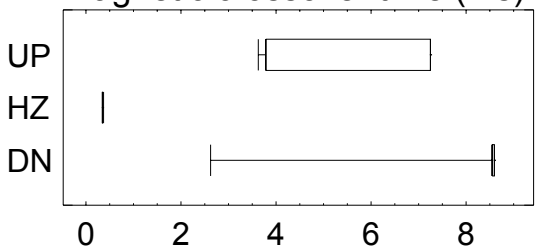
1288, 1289, 1290



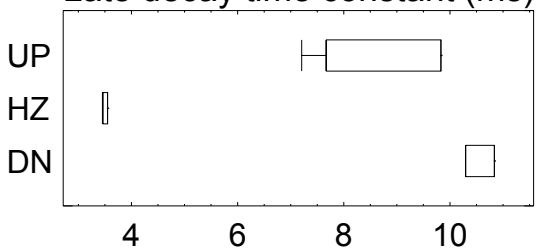
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	6.5	0.91	1.1	1.6	1.3	0.92
HZ	7.1	0.040	0.043	0.070	0.033	0.032
DN	17.	1.1	1.2	1.9	1.4	1.0



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-17.	3.4	3.9	5.9	4.8	3.4
HZ	-14.	0.79	0.86	1.4	1.0	0.75
DN	-42.	0.29	0.32	0.51	0.24	0.22



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	4.9	1.2	1.3	2.0	1.6	1.2
HZ	0.35	8.2e-3	8.9e-3	0.014	0.012	8.1e-3
DN	6.6	2.0	2.2	3.4	2.8	2.0



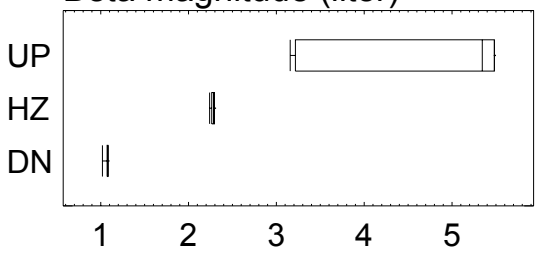
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	8.2	0.81	0.91	1.4	0.93	0.77
HZ	3.5	0.031	0.034	0.054	0.040	0.030
DN	10.	0.18	0.20	0.31	0.25	0.18

Group 83. Projectile, 120mm, Mortar, HE, M933, M934, Inert, un-fired.

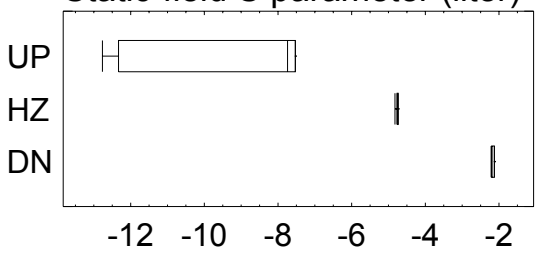
4 items in group.

Item ID numbers:

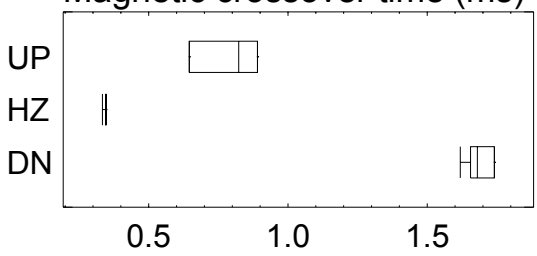
1291, 1292, 1293, 1294



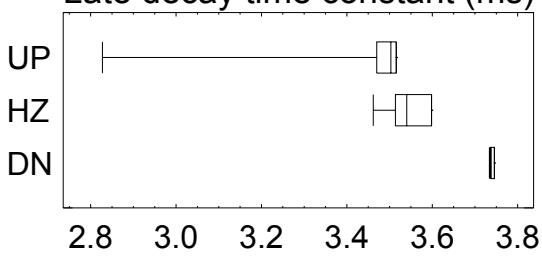
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	4.3	0.64	0.70	1.3	0.053	0.50
HZ	2.3	0.012	0.013	0.025	9.2e-3	9.2e-3
DN	1.1	0.015	0.016	0.030	0.022	0.015



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-10.	1.4	1.5	2.8	0.17	1.0
HZ	-4.8	0.018	0.020	0.036	0.020	0.015
DN	-2.2	0.020	0.021	0.040	0.026	0.018



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.75	0.062	0.065	0.12	0.024	0.045
HZ	0.34	3.1e-3	3.4e-3	6.1e-3	5.3e-3	3.5e-3
DN	1.7	0.026	0.029	0.051	0.023	0.019



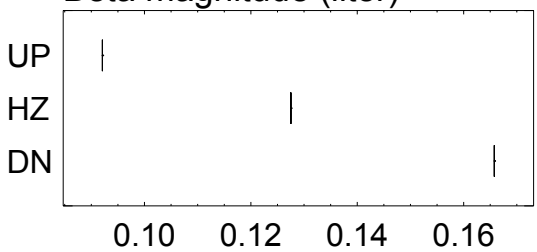
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.3	0.17	0.17	0.33	0.27	0.19
HZ	3.5	0.028	0.026	0.057	0.024	0.020
DN	3.7	2.6e-3	2.8e-3	5.1e-3	2.8e-3	2.2e-3

Group 84. Projectile, 90mm, Practice, M371A1, Tail boom and fins only

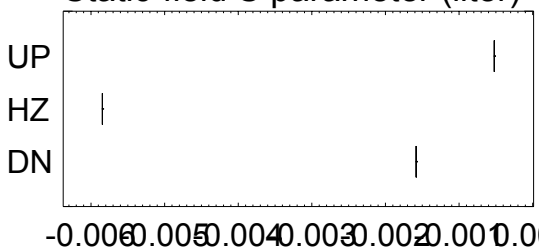
1 item in group.

Item ID number:

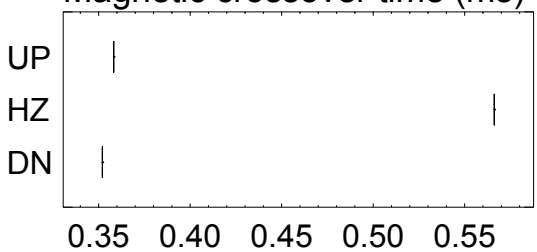
889



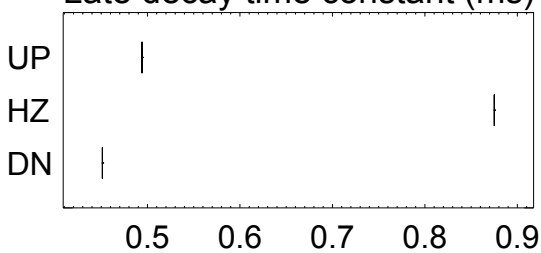
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.092	n/a	n/a	n/a	n/a	n/a
HZ	0.13	n/a	n/a	n/a	n/a	n/a
DN	0.17	n/a	n/a	n/a	n/a	n/a



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-5.2e-4	n/a	n/a	n/a	n/a	n/a
HZ	-5.8e-3	n/a	n/a	n/a	n/a	n/a
DN	-1.6e-3	n/a	n/a	n/a	n/a	n/a



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.36	n/a	n/a	n/a	n/a	n/a
HZ	0.57	n/a	n/a	n/a	n/a	n/a
DN	0.35	n/a	n/a	n/a	n/a	n/a



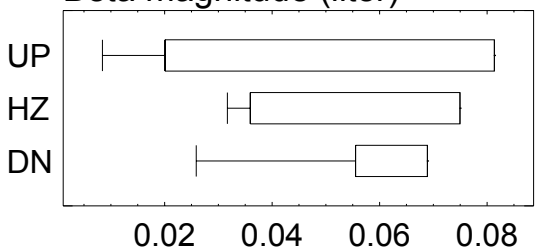
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.49	n/a	n/a	n/a	n/a	n/a
HZ	0.88	n/a	n/a	n/a	n/a	n/a
DN	0.45	n/a	n/a	n/a	n/a	n/a

Group 85. Projectile, 90mm, Practice, M371A1, Tail boom only

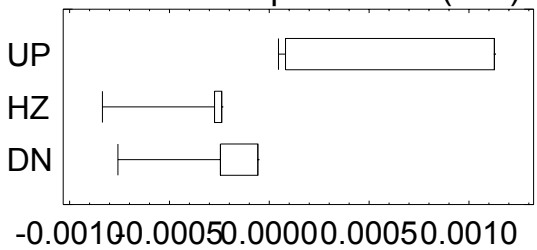
3 items in group.

Item ID numbers:

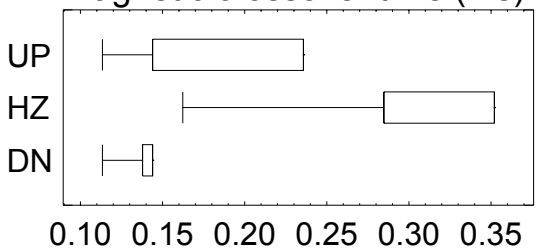
890, 891, 895



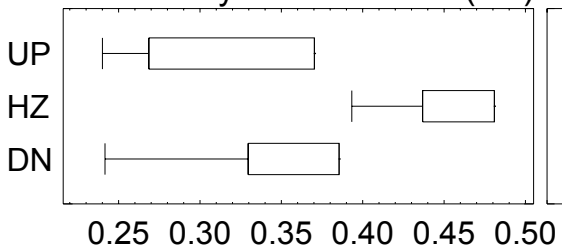
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.037	0.023	0.025	0.039	0.027	0.022
HZ	0.048	0.014	0.014	0.024	0.017	0.014
DN	0.050	0.013	0.011	0.022	0.012	0.010



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	4.2e-4	3.5e-4	3.9e-4	6.1e-4	4.9e-4	3.7e-4
HZ	-4.5e-4	1.9e-4	1.9e-4	3.4e-4	2.6e-4	2.0e-4
DN	-3.5e-4	2.1e-4	1.9e-4	3.6e-4	2.1e-4	1.8e-4



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.16	0.037	0.039	0.064	0.038	0.034
HZ	0.27	0.056	0.053	0.096	0.050	0.044
DN	0.13	9.3e-3	8.7e-3	0.016	0.010	8.5e-3

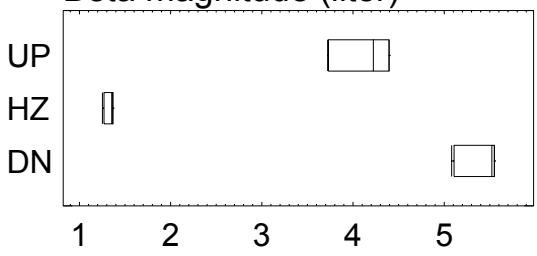


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.29	0.040	0.042	0.068	0.043	0.037
HZ	0.44	0.025	0.028	0.044	0.021	0.020
DN	0.32	0.042	0.045	0.073	0.036	0.035

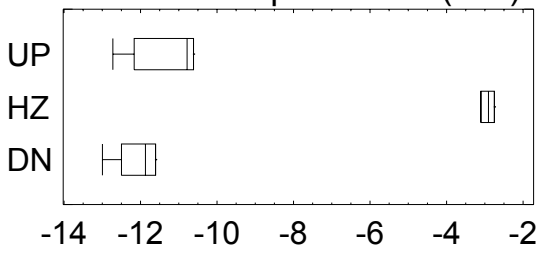
Group 86. Projectile, 90mm, Shrapnel
Band intact.
4 items in group.

Item ID numbers:

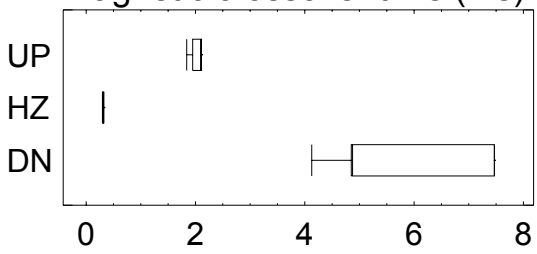
1132, 1133, 1134, 1135



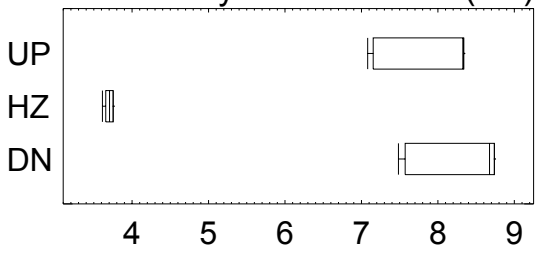
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	4.0	0.17	0.19	0.34	0.062	0.13
HZ	1.3	0.029	0.031	0.058	7.6e-3	0.022
DN	5.3	0.13	0.14	0.26	0.014	0.087



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-12.	0.52	0.55	1.0	0.21	0.35
HZ	-3.0	0.086	0.091	0.17	0.057	0.059
DN	-12.	0.31	0.35	0.63	0.19	0.22



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.0	0.064	0.064	0.13	0.040	0.045
HZ	0.31	5.2e-3	5.6e-3	0.010	4.6e-3	4.1e-3
DN	5.3	0.73	0.80	1.5	0.95	0.71



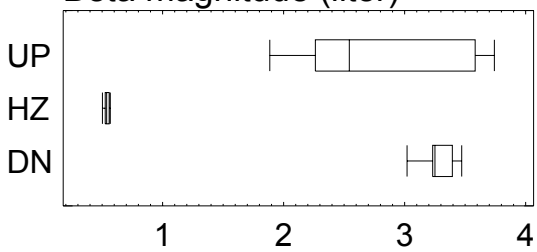
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	7.7	0.35	0.38	0.70	0.026	0.25
HZ	3.7	0.030	0.031	0.061	0.021	0.019
DN	8.1	0.34	0.37	0.68	0.038	0.27

Group 87. Projectile, 81mm, Mortar, Practice, M43

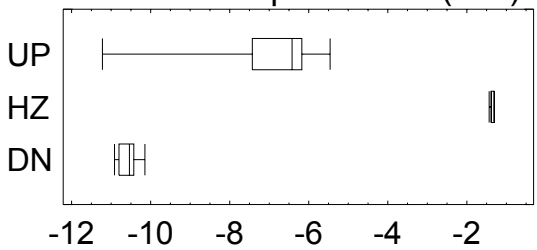
8 items in group.

Item ID numbers:

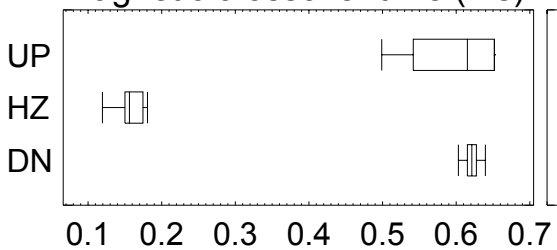
896, 897, 898, 899, 900, 901, 902, 903



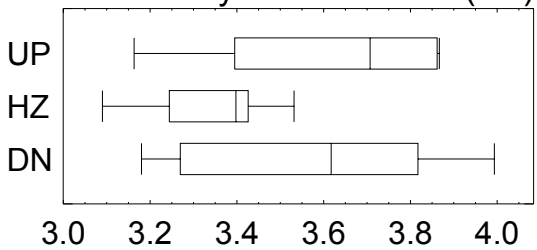
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.6	0.24	0.22	0.67	0.17	0.17
HZ	0.54	7.7e-3	8.0e-3	0.022	4.9e-3	4.6e-3
DN	3.3	0.053	0.057	0.15	0.036	0.036



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-7.6	0.76	0.73	2.1	0.54	0.57
HZ	-1.4	0.018	0.017	0.050	8.5e-3	8.9e-3
DN	-11.	0.092	0.098	0.26	0.067	0.060



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.59	0.020	0.020	0.058	0.011	9.6e-3
HZ	0.16	6.9e-3	6.7e-3	0.019	5.9e-3	4.8e-3
DN	0.62	3.9e-3	4.0e-3	0.011	3.3e-3	3.2e-3



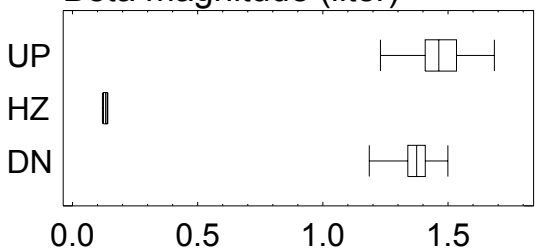
Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.6	0.098	0.095	0.28	0.043	0.041
HZ	3.3	0.051	0.049	0.14	0.034	0.027
DN	3.5	0.11	0.11	0.31	0.050	0.045

Group 88. Rocket, 2.36 inch, Practice, M7, Motor only.
Practice version of M6.
31 items in group.

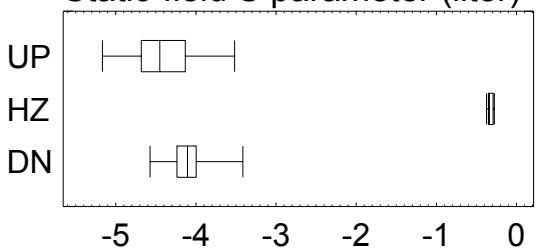
Item ID numbers:

1019, 1020, 1021, 1022, 1023, 1024, 1025, 1033, 1034, 1035, 1036, 1037, 1038, 1039, 1040, 1041

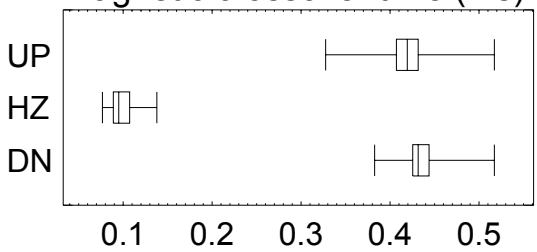
1042, 1043, 1044, 1045, 1046, 1047, 1048, 1049, 1050, 1051, 1052, 1053, 1054, 1060, 1061



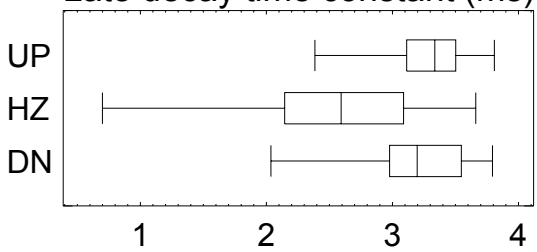
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.5	0.022	0.019	0.12	0.014	0.015
HZ	0.13	1.3e-3	1.3e-3	7.3e-3	5.1e-4	5.1e-4
DN	1.4	0.012	0.012	0.069	0.010	8.7e-3



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-4.4	0.079	0.068	0.44	0.048	0.047
HZ	-0.33	5.4e-3	5.6e-3	0.030	2.5e-3	2.7e-3
DN	-4.1	0.044	0.044	0.25	0.039	0.035



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.42	6.2e-3	6.1e-3	0.034	6.8e-3	5.5e-3
HZ	0.099	2.7e-3	2.8e-3	0.015	2.1e-3	2.1e-3
DN	0.43	4.4e-3	4.3e-3	0.025	5.7e-3	4.7e-3

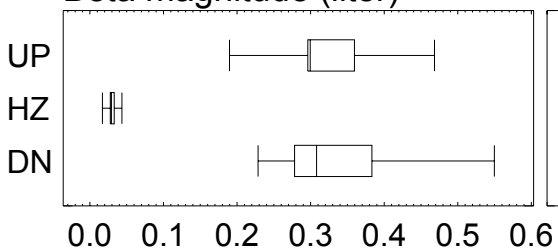


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.3	0.057	0.054	0.32	0.056	0.049
HZ	2.5	0.13	0.13	0.75	0.094	0.081
DN	3.1	0.079	0.087	0.44	0.059	0.058

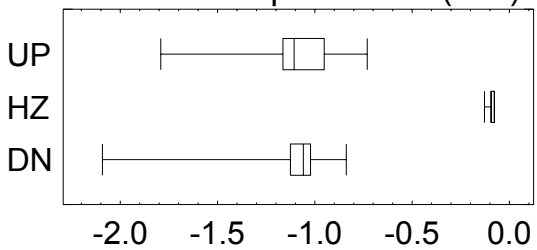
Group 89. Rocket, 2.36 inch, Practice, M7, Fuze body (adapter).
Practice version of M6.
7 items in group.

Item ID numbers:

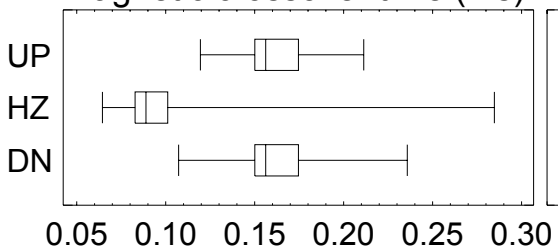
1026, 1027, 1028, 1029, 1030, 1031, 1032



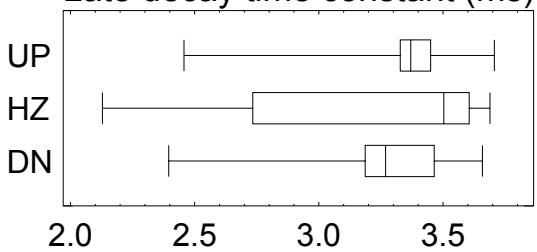
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.31	0.033	0.030	0.088	0.032	0.026
HZ	0.029	3.1e-3	2.9e-3	8.3e-3	2.9e-3	2.4e-3
DN	0.33	0.040	0.038	0.11	0.053	0.039



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-1.2	0.12	0.12	0.33	0.14	0.11
HZ	-0.095	6.5e-3	6.1e-3	0.017	7.3e-3	5.4e-3
DN	-1.2	0.16	0.15	0.41	0.24	0.17



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.16	0.011	0.012	0.029	0.010	9.1e-3
HZ	0.11	0.029	0.024	0.077	0.060	0.039
DN	0.16	0.015	0.014	0.039	0.016	0.014



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.2	0.16	0.15	0.42	0.15	0.12
HZ	3.1	0.23	0.23	0.62	0.14	0.14
DN	3.2	0.15	0.12	0.41	0.19	0.14

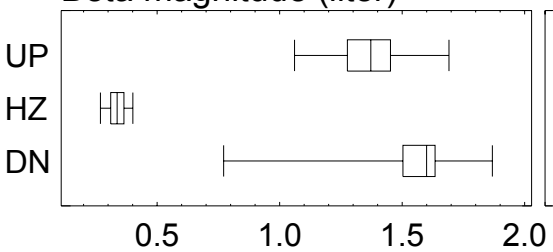
Group 90. Rocket, 2.36 inch, Practice, M7, Head and motor.
Practice version of M6., From Ft. McClellan.
30 items in group.

Item ID numbers:

1140, 1141, 1142, 1143, 1144, 1145, 1146, 1147, 1148, 1149, 1150, 1151, 1152, 1153, 1154, 1155

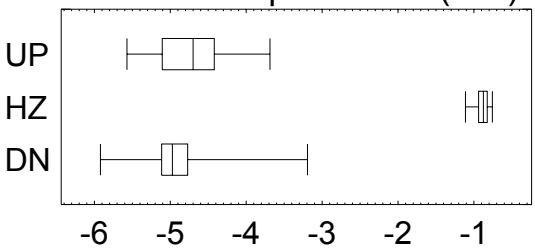
1156, 1157, 1158, 1159, 1160, 1161, 1162, 1163, 1164, 1165, 1166, 1167, 1168, 1169

Beta magnitude (liter)



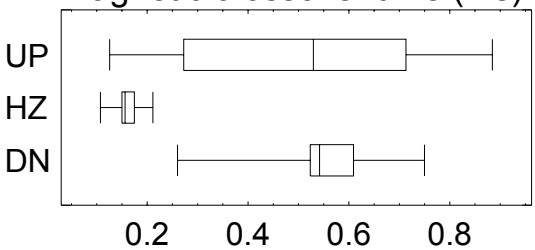
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.4	0.031	0.033	0.17	0.019	0.020
HZ	0.33	6.5e-3	7.1e-3	0.036	3.9e-3	3.8e-3
DN	1.5	0.039	0.040	0.22	0.057	0.054

Static-field S parameter (liter)



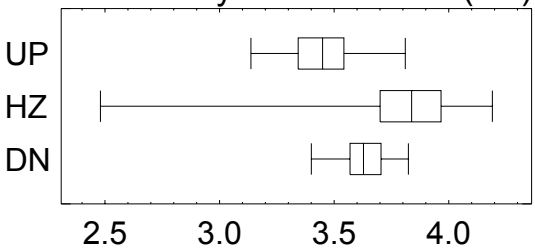
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-4.8	0.085	0.087	0.47	0.053	0.060
HZ	-0.90	0.018	0.017	0.10	0.012	0.011
DN	-4.9	0.082	0.073	0.45	0.14	0.12

Magnetic crossover time (ms)



	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.48	0.043	0.040	0.23	0.017	0.015
HZ	0.16	5.0e-3	5.6e-3	0.027	3.2e-3	3.2e-3
DN	0.56	0.015	0.016	0.085	0.022	0.018

Late decay time constant (ms)



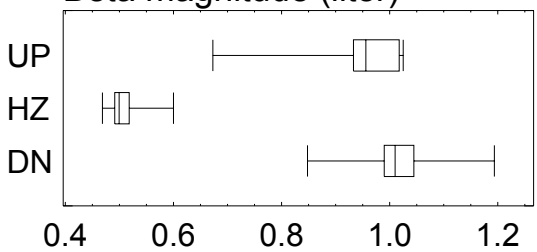
	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.5	0.033	0.035	0.18	0.022	0.020
HZ	3.7	0.067	0.068	0.37	0.099	0.090
DN	3.6	0.023	0.022	0.12	0.013	0.012

Group 91. Flare, M48 or M2, Casing for M48 trip flare or M2 landmine.

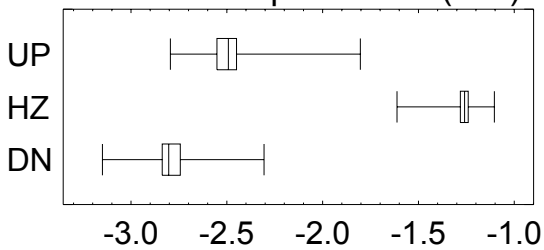
5 items in group.

Item ID numbers:

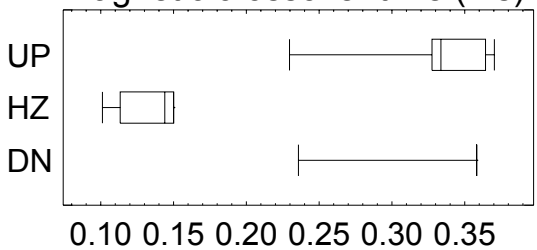
1112, 1113, 1114, 1115, 1116



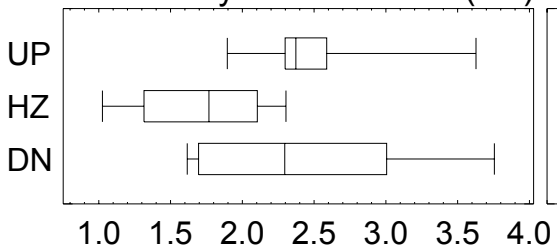
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.92	0.064	0.066	0.14	0.092	0.063
HZ	0.52	0.023	0.021	0.050	0.029	0.021
DN	1.0	0.055	0.051	0.12	0.052	0.043



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-2.4	0.16	0.17	0.37	0.21	0.15
HZ	-1.3	0.084	0.078	0.19	0.10	0.079
DN	-2.8	0.14	0.14	0.30	0.14	0.10



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.33	0.025	0.022	0.057	0.033	0.024
HZ	0.13	0.010	0.010	0.023	5.3e-3	6.5e-3
DN	0.33	0.024	0.024	0.054	0.043	0.030

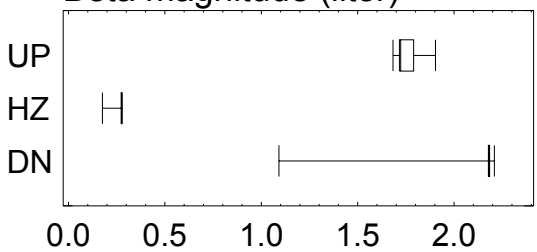


Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	2.6	0.29	0.32	0.65	0.35	0.25
HZ	1.7	0.24	0.22	0.53	0.13	0.12
DN	2.5	0.41	0.43	0.91	0.27	0.23

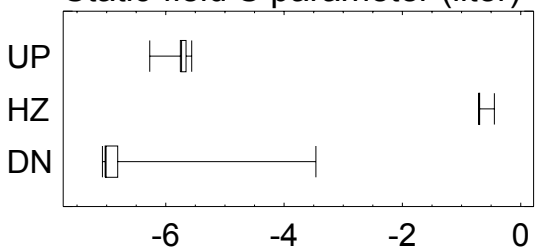
Group 92. Projectile, 57mm, Practice, Deteriorated
Band missing, From Ft. McClellan.
5 items in group.

Item ID numbers:

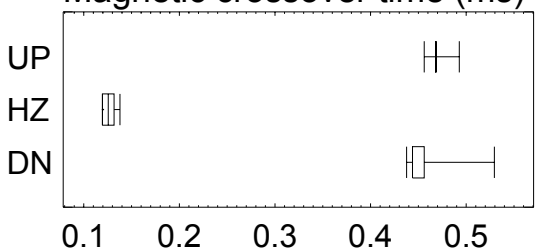
1117, 1118, 1119, 1120, 1121



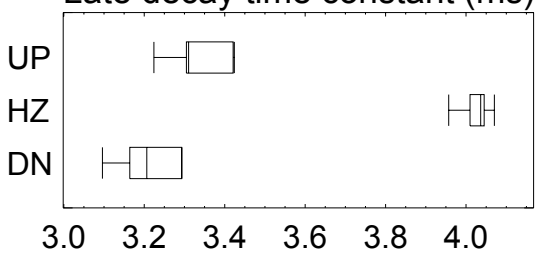
Beta magnitude (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	1.8	0.039	0.039	0.088	0.041	0.034
HZ	0.26	0.020	0.020	0.045	0.038	0.025
DN	2.0	0.22	0.23	0.49	0.43	0.29



Static-field S parameter (liter)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	-5.8	0.12	0.12	0.28	0.18	0.13
HZ	-0.65	0.052	0.055	0.12	0.097	0.065
DN	-6.3	0.70	0.76	1.6	1.3	0.88



Magnetic crossover time (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	0.47	6.7e-3	7.4e-3	0.015	7.6e-3	6.0e-3
HZ	0.13	3.6e-3	3.6e-3	8.0e-3	2.3e-3	2.4e-3
DN	0.46	0.017	0.018	0.038	0.028	0.019



Late decay time constant (ms)	Mean	Conf. intervals Jack	Conf. intervals Boot	StdDev	Conf. intervals Jack	Conf. intervals Boot
UP	3.3	0.038	0.038	0.085	0.023	0.025
HZ	4.0	0.019	0.022	0.043	0.019	0.015
DN	3.2	0.038	0.038	0.085	0.023	0.023

Appendix E. Data and Results