ARMY RESEARCH LABORATORY

XLCB: A New Closed-Bomb Data Acquisition and Reduction Program

by Barrie E. Homan and Arpad A. Juhasz

ARL-TR-2491 May 2001

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5066

ARL-TR-2491 **May 2001**

XLCB: A New Closed-Bomb Data Acquisition and Reduction Program

Barrie E. Homan and Arpad A. Juhasz
Weapons and Materials Research Directorate, ARL

Abstract

A new closed-bomb data acquisition and reduction program has been developed based on the Microsoft Excel 97 spreadsheet platform. With the addition of IOTech's Wavebook/512 data acquisition hardware, the voltage signal from the closed-bomb experiment is directly captured into the spreadsheet where burning rate (BR) calculations can be performed. Additionally, XLCB has the capability to generate pressure vs. time data based on given BRs, geometrical form, and propellant thermochemistry. A proposed summary sheet is included to better facilitate the exchange of information between interested parties in the propellant community. The Visual BASIC code used in this program was adapted from the FORTRAN algorithms in BRLCB with some additional improvements/modifications. The implementation of a user-friendly interface, the technique used to calculate the derivative, and the comparison of the normalized surface area and vivacity profile are some of the more dramatic changes. Multiple fits of the BR law ($A*P^n$) using different pressure regimes can be graphically chosen from either the BR vs. pressure graph or the vivacity graph.

Contents

INTENTIONALLY LEFT BLANK.

List of Figures

INTENTIONALLY LEFT BLANK.

1. Introduction

The intrinsic linear burning rate of a propellant is a pivotal parameter used in computer simulations to predict the interior ballistic behavior of guns. The closed bomb has found general acceptance as the method of choice for determining this linear burning rate (BR). The assumptions used to deduce the BR from experimental closed-bomb pressure-time histories are essentially the same as those used to produce the pressure in lumped-parameter interior ballistics simulations.

Various embodiments of the closed-bomb BR reduction technique have been used in the community [1–4]. A number of years ago, a program aimed at general usefulness was offered by the U.S. Army. The program, named BRLCB [5], was developed to provide the user the capability of reducing experimental pressure-time data to BRs for a wide range of multiperforated and layered grains as well as artificially synthesize closed-bomb pressure-time behavior for these propellants for use in predicting their behavior in closed bombs. BRLCB was written in FORTRAN as a character input-based program that would run under the then prevalent DOS environment. Different files were used to store the experimental data, reduction parameters, and output with the associated higher bookkeeping requirements. The linear quality of a character-based program makes it difficult to interactively control the reduction parameters and affects the ability to easily compare the results.

The current effort seeks to improve upon the general usefulness of the BRLCB program by recasting it in a Windows environment and addressing the scatter apparent in many of the derived BR data. In addition, the new version, labeled XLCB, seeks to follow up on recommendations made at a Joint Army-Navy-NASA-Air Force (JANNAF) workshop [6] by incorporating a feature intended to provide the user an "internal standard" method to assess the "goodness" or credibility of the BR data. Finally, a suggestion is included concerning the potential use of the Data Summary Output File structure from XLCB as a generalized format for BR data exchange in the JANNAF community.

2. XLCB Program Overview

XLCB is a closed-bomb data reduction program aimed at taking advantage of the interactive capabilities of the Windows environment and the computational and file manipulation capabilities offered by Microsoft's Excel spreadsheet program. Using an Excel template created for this purpose provides closed-bomb data file structuring. The template provides cells for storage of the experimental data as well as needed propellant identification, comments, and parameters used in the data reduction. A blank template file is provided for the user as part of the program software. The file structure is generally compatible with the Microsoft Office environment to facilitate the movement of data and graphics for the preparation of reports and presentations.

XLCB preserves most of the capabilities of its predecessor BRLCB [5], improving some aspects of the reduction while providing a user-friendly interface. The program has been designed to encompass all of the pertinent information on the propellant and experimental conditions into one file. A spreadsheet environment was chosen due to the large amount of data and parameters needed to reduce the data from a closed-bomb firing. Due to the universal availability of the Microsoft Excel spreadsheet program, XLCB was developed for this platform. Currently at the U.S. Army Research Laboratory (ARL), an acquisition system (see section 2.1) has been developed that permits data to be collected directly into the proper position in XLCB for reduction. However, the pressure vs. time data (strictly in ASCII format at this time) from other sources can also be imported into the spreadsheet. A snapshot of a portion of the new program spreadsheet is shown in Figure 1. The program was designed as an Excel add-in, which has the advantage of producing smaller data files and eases code maintainability. All of the functionality is accessed through the menu <XLCB> placed to the left of the default menu <Data>. The <CBDAC> menu item is a separate add-in that is used to control the data acquisition hardware installed at ARL. Because of this hardware dependence, the program is not part of the public release version of XLCB. However, the specifics of this code are available upon request.

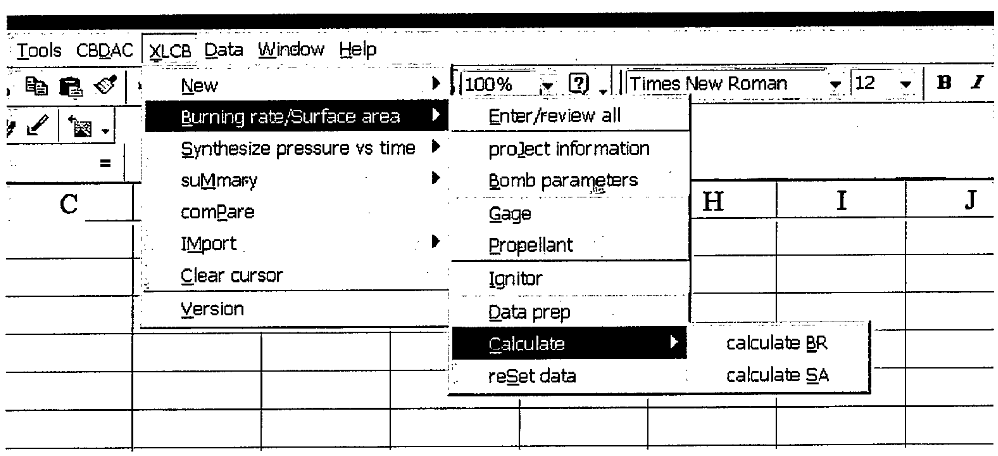


Figure 1. Screen capture of XLCB add-in menus.

The program comes with a user manual that explores the detailed operation of the program. Therefore, only a brief outline of some of the operational aspects follows. The <XLCB> menu is arranged such that the flow of operations that needs to be completed are in top to bottom order. Although all of the reduction/simulation parameters can be accessed directly from the entries in the spreadsheet, there are certain calculated parameter values that would not be correctly updated. Therefore, it is recommended that all parameter data be accessed through the menus. Experimental data needed as input to the reduction code is acquired directly into XLCB by the data acquisition system recently installed at ARL. For pre-existing data, XLCB supports two functions to import pressure vs. time data. The first method was implemented to import data gathered from the legacy Nicolet oscilloscope data-acquisition hardware system recently replaced. The other import function is more general and will import ASCII-format data files that have pressure and time in column form.

The final pressure-time data needs to conform to some basic rules for the reduction to be successful. The reduction assumes that at the first pressure point, all of the igniter has been consumed and all of the propellant has been uniformly ignited. Calculating the pressure due to the igniter and deleting all early points below this pressure approximates this requirement. The reduction also assumes that the last of the propellant has been consumed at the maximum pressure (P_{max}). As a consequence, all points after the occurrence of P_{max} need to be deleted. Both of these operations can be performed automatically by the selection of <Auto select pressure region of interest (ROI)> (Figure 2) accessed by selecting the <Data prep> menu item. Other optional procedures can also be performed from this form.

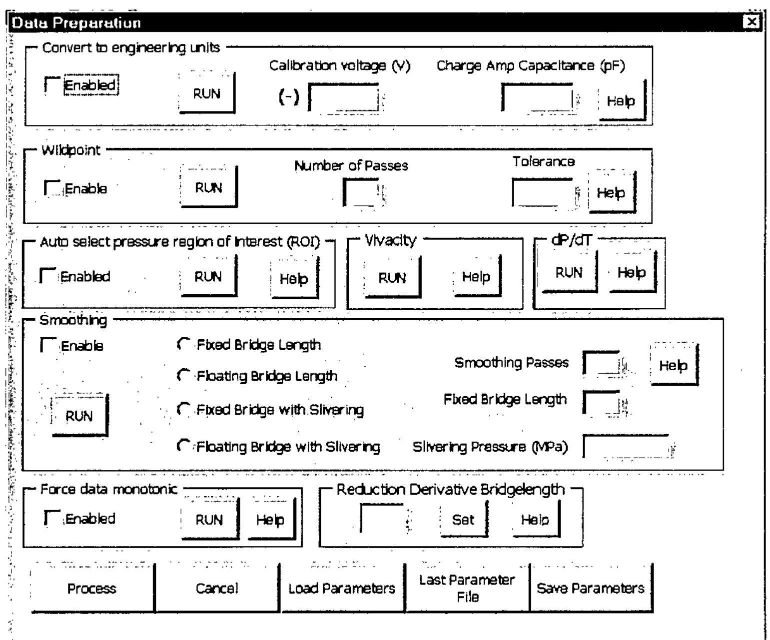


Figure 2. Screen capture of data preparation form.

Each tool can be run individually or as a set. The choices made can be saved in a file to be applied across many experiments. The <Convert to engineering units> tool is used when there is voltage-time data gathered directly from the pressure sensor/amplifier output. The <Wildpoint>, <Smoothing>, and <Force data monotonic> tools are optional procedures that attempt to minimize the effects of noise in the pressure signal. The Wildpoint filter will replace outlier points with a local average. Smoothing of the data is accomplished by fitting a number of nearest neighbors to a quadratic function. The point being smoothed is then replaced by the functional value at this point. The number of neighbors can either be chosen (fixed) or allowed to float depending on the nature of the curve at that point. If a floating bridge is chosen, then the program will select the largest bridge, less than 35, which will encompass a pressure change less than 10% of the maximum pressure. As will be discussed in section 2.2, the code will need to search for the instantaneous burn depth of the propellant. BRLCB and developmental incarnations of XLCB used, as a starting point, the previous calculated depth for this search. A pressure drop would then appear in the code as some amount of propellant becoming unburned, clearly not physical. A solution to this problem was to force the data to monotonically increase. After a new search routine that always starts at depth=0 (not burned) was implemented, this function became an optional feature to further minimize jitter effects and to maintain compatibility with previous data. The last parameter input on this form is the <Reduction Derivative Bridgelength>. This is a new mandatory parameter that is used when deriving the burning rate from the calculated depth profile and will be further discussed in the following section on BR reduction (section 2.2). Calculation of the vivacity and the quickness (dp/dt) are automatically executed when the BR procedure is complete. However, either calculation can be forced by selecting the <RUN> option in Figure 2.

2.1 Data Acquisition

To increase the working pressure range and system efficiency, a new data acquisition system has been installed for the micro-closed-bomb. The pressure-sensing element is a piezoelectric transducer from Kistler* capable of pressures up to 1,000 MPa. The charge from the sensor is converted to voltage and amplified by a Kistler model 5010B1 dual-mode charge amplifier. The voltage signal output is then captured and digitized by IOTech's Wavebook/512 multichannel analog-to-digital converter capable of 1 MHz (single channel with the addition of IOTech's WBK21 Industry Standard Architecture [ISA] card) data acquisition rate at 12-bit resolution.

The Wavebook has the advantage of being directly computer controlled with the ability to record vast amounts of data limited only by the capacity of the computer's memory and hard-disk space. However, the current Excel program limits the number of data points to 65,000. Routines have been written for Microsoft Excel

*Model 6213B.

that will interface the data acquisition hardware and computer and allow for the direct retrieval of the results into a spreadsheet compatible with the XLCB reduction software. As the reduction code calculates the BR based on the pressure-time history of the experiment, XLCB has the capability to convert the voltage-time trace output from the hardware to the form required. Two curves are acquired for each firing run: calibration and data. The calibration consists of a voltage step function supplied by a precision voltage reference* passed through a pushbutton switch to the amplifier's voltage input. The voltage measured after the amplifier compared to that of the known input gives the amplification factor of the acquisition system. This factor, together with the sensitivity of the pressure gauge, is used to produce the pressure-time trace.

2.2 BR Reduction

The current data reduction routine (XLCB) and its predecessor (BRLCB), calculates the mass of propellant that must have burned in order to produce the pressure seen in the bomb at a particular time. Ideally, the energy liberated during the combustion of the propellant will appear as the thermal energy of the resultant gas. However, the walls of the chamber provide a heat sink to the combustion products of the propellant. At a given time t, the energy balance in the chamber, is given by [5],

$$E^0 = E_s(t) + E_l(t), \tag{1}$$

where E^0 is the initial energy in the combustion chamber in the form of the chemical energy of the unburned propellant, and E_s and E_l denote the energy remaining in the solid and the energy liberated in the combustion process. This liberated energy is partitioned into the thermal energy of the resultant gas products E_g (manifesting itself as pressure) and an additional energy term, Q_w, representing the cumulative heat loss to the chamber walls:

$$E_l(t) = E_g(t) + Q_w(t). \tag{2}$$

The amount of heat lost will depend on the ratio of the bomb's surface area to volume, with the larger bomb expected to have the lower heat loss. Comparisons [7] between results of the 200-cm^3 and 25-cm^3 closed bombs have shown a discrepancy (~3%) in the calculated burning rate. In these tests, identical loading densities and reduction parameters were used. The heat loss treatment, being considered the most likely culprit, is a subject of further investigation. The treatment of heat loss is, unfortunately, not a trivial matter and several approaches have been attempted [2, 8]. Currently, the heat loss is assumed to be directly proportional to the experimental pressure

---

*Calibrators, Inc., Model DVC-8500.

$$Q_w(t) = Q_{max} \frac{P_{ch}}{P_{ch}^{max}}, \qquad (3)$$

where P_{ch} is the chamber pressure and Q_{max} represents the total heat loss at maximum pressure. The deduced burn depth will be greater as a result of the inclusion of heat loss for a given pressure. The effect would be an apparent upward shift in the resulting burning rate. The magnitude of Q_{max}, which will affect the extent of the burning rate curve shift, is derived from the maximum experimental value of pressure P_{ch}^{max}. Assuming all of the propellant is consumed by the time of maximum pressure, equations 1 and 2 state that the total heat loss, Q_{max}, is the difference between the initial energy E^0 and the thermal energy of the gas products:

$$Q_{\max} = E^0 - T_{ch}^{\max}(m_{ig}C_{v_{ig}} + m_a C_{v_a} + m_g C_{v_g}), \qquad (4)$$

where C_v is the heat capacity at constant volume, and m is the mass (*ig* = igniter, *a* = air, *g* = gas, *s* =solid propellant). The adiabatic temperature of the gas at maximum pressure T_{ch}^{max}, can be obtained (using the Noble-Abel equation of state) from

$$T_{ch}^{max} = P_{ch}^{max}\left(\frac{V_{ch} - b_{ig}m_{ig}^0 - b_a m_a^0 - b_s m_s^0}{\Re_{ig} m_{ig}^0 + \Re_a m_a^0 + \Re_s m_s^0}\right), \qquad (5)$$

where V_{ch} is the chamber volume, *b* is the covolume of the gas products, m_x^0 is again the mass of the ingredients initially in the chamber, and $\Re_x$ is the universal gas constant divided by the molecular weight of component *x*.

The Noble-Abel equation of state is also used to determine the amount of propellant that must have burned (mass fraction) to produce the experimentally measured pressure. A form function that relates the current dimensions of the propellant to the remaining solid mass is used to calculate the area of the propellant surface for each pressure-time point. For some geometries, the depth reached for a given mass burned is not in closed form and must be found by a numerical searching method. A new technique (Brent's method [9]) was implemented to increase the depth/area calculation throughput. The BR is then calculated using the derivative of the mass generated at each time step. Knowing the propellant density (ρ), the BR is then

$$BR = \frac{dM/dt}{\rho A_s}, \qquad (6)$$

where *M* is the mass generated, and A_s is the total propellant surface area provided in the form function.

BRLCB used a "finite-difference" method to perform the derivative of the solid propellant mass as a function of time. This technique is very sensitive to any jitter in the data. As a consequence, the calculated BR-pressure graph was subject to large-magnitude, high-frequency fluctuations that can hide more subtle features. To combat this problem, an algorithm based on the Savitzky-Golay derivative technique [9] was instituted in XLCB to perform this operation. This algorithm determines the derivative by least-squares fitting of a polynomial of degree n (quadratic in the current configuration) to m nearest neighbors where m+1 constitutes the chosen bridgelength. The mass generation rate dM/dt is simply the derivative of this fitted polynomial evaluated at the point in question. The results of the two different reduction programs, BRLCB and XLCB, are shown in Figure 3. The propellant used for this test was 7-Perf JA2* fired in the 200-cm^3 closed bomb. Except for the derivative treatment, both data sets were treated in a similar manner (i.e., the same preparation [smoothing, wildpoint, etc.] parameters were used). The Savitzky-Golay derivative technique [9] clearly minimizes the noise without removing any of the underlining BR trends. The differences in the noise level between the two data sets is due solely to the derivative method as the data was also reduced in a version of XLCB that employed the identical finite-difference method used in BRLCB. In this case, the data produced by the two programs were indistinguishable to 1–2 parts in 1,000.

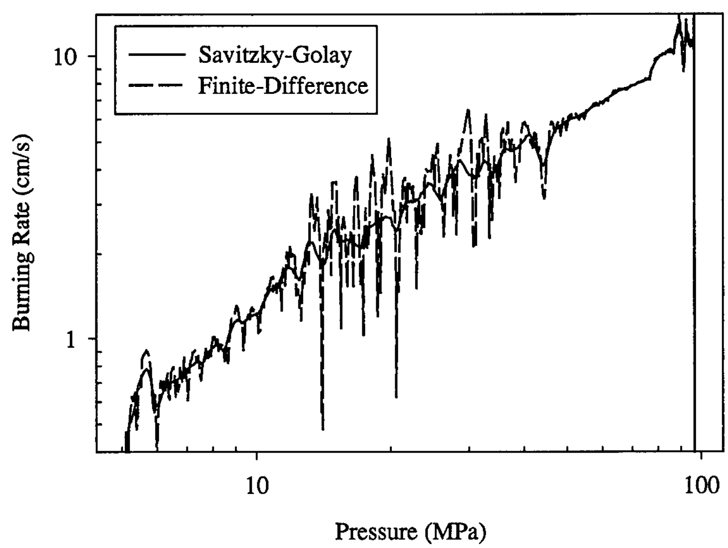


Figure 3. Effect of derivative method.

It has been suggested [10] that the vivacity, V, is a critical piece of information in the evaluation of the BR data. The vivacity as used in XLCB, is defined in reference [10] as

*A double-base, type-classified formulation.

$$V = \frac{dP/dt}{P \cdot P_{max}}, \quad (7)$$

where the pressures P and P_{max} are determined from the experimental data. Although a calculation option in BRLCB, the automatically calculated and plotted vivacity is used in XLCB as a confidence guide to the pressure regimes of the calculated burning rates. As an example, JA2 in a form of right-circular cylinders (cord-form factor) was fired in a 200-cm^3 bomb (0.34 loading density [LD]) resulting in the vivacity plot in Figure 4. Also plotted in Figure 4 is the calculated surface area normalized to the vivacity at 50% maximum pressure. As a measure of the geometrical progressively of the propellant, the normalized surface area as compared to the vivacity gives a good indication of where in the pressure range the assumptions used in the reduction are valid. In this case, the propellant has a regressive form function with a corresponding negative slope in both the vivacity and the surface area function.

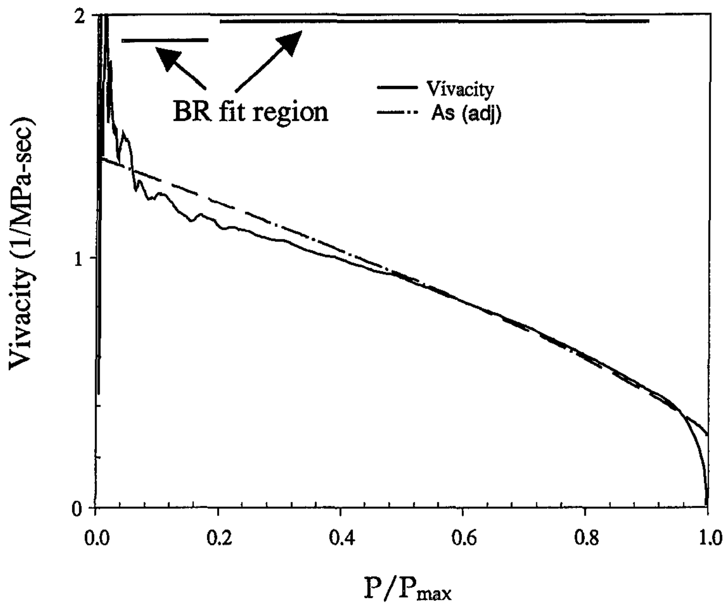


Figure 4. Comparison of vivacity and normalized surface area.

In contrast, the vivacity in Figure 5 is for a 7-perf granulation, JA2 propellant fired in a 200-cm^3 bomb. The vivacity and surface area both reflect the progressive nature of the 7-perf form function. However, both Figures 4 and 5 exhibit a clear mismatch at both the lowest and highest pressures. The mismatch at the lower pressures is probably due to flamespread during the ignition of the propellant charge. The high-pressure mismatch may indicate the point at which some of the propellant grains, ignited earlier in the ignition process, are burning out. Both conditions are contrary

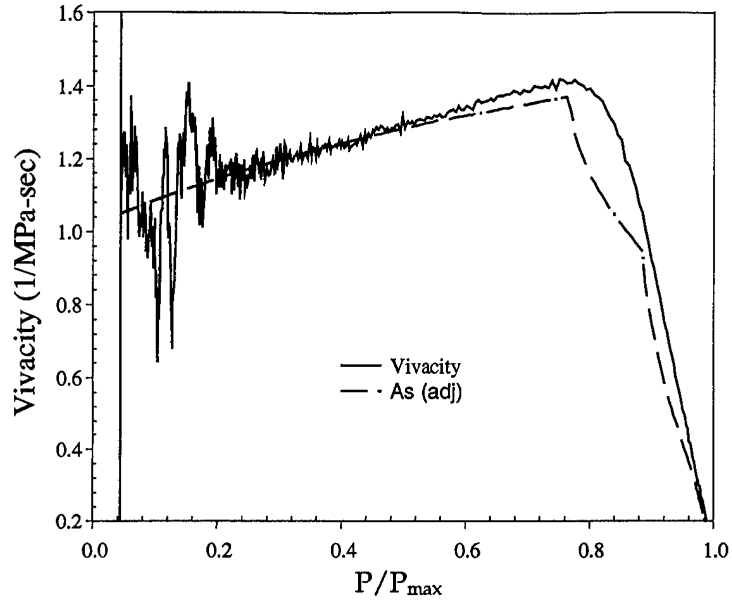


Figure 5. Vivacity of 7-perf geometry.

to the working assumptions of the reduction. The more subtle differences between the surface area and vivacity in the central pressure regime are not as straightforward to explain. Both experiments [11] and simulations [12] suggest that if the BR exponent is much greater than 1, then the vivacity will exhibit non-linear behavior. It is not known from the experiments whether the large exponent is real or the result of deviation from the assumed combustion conditions. The simulations, constrained to follow the assumptions, also demonstrate similar behavior. If flamespreading occurs at the lowest pressures, it is not known at what pressure the propellant becomes fully ignited and to what extent the assumption of the homogeneously burning and instantly ignited propellant bed is still valid. For propellants that are progressively neutral, the effect of flamespreading should be less apparent. For propellants with a strong surface-area dependence on the depth in the grain, this effect is more pronounced. In addition, there may be a chemical progressivity introduced into a "homogenous" propellant by the manufacturing process [13] that is not accounted for by the simple surface area progression. Greater mismatch between the surface area and the vivacity profiles is evident for the propellant shown in Figure 6. In this case, JA2 cord propellant was purposely damaged by partially cutting through half of the grains in the charge.

Using the vivacity as a guide, the coefficients of portions of the BR data are fitted to the familiar functional law

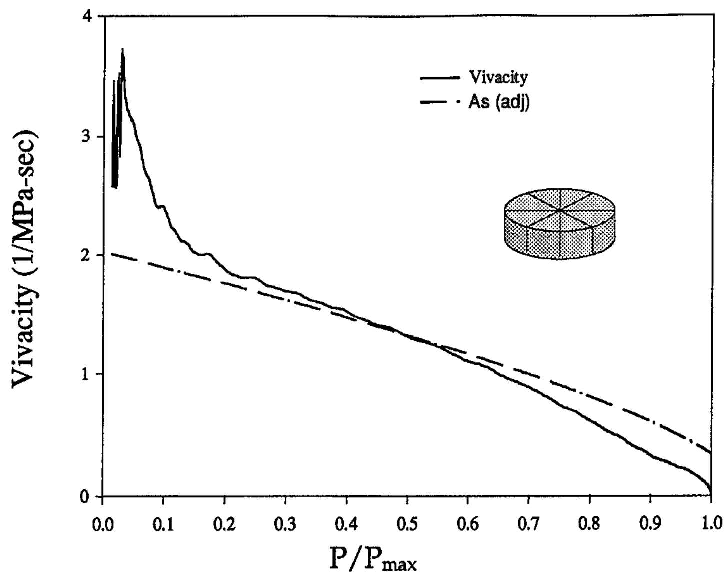


Figure 6. Vivacity of pre-cut grains.

$$BR = AP^n, \tag{8}$$

where the parameter A is the prefactor, P is the pressure, and the exponent n being dimensionless. Previously, the pressure regimes used in the calculation of equation 8 were either chosen prior to reduction or the data would need to be imported into another program. XLCB allows the choice of up to four different pressure regimes to be chosen for calculating the coefficients of equation 8. Two such pressure regimes were chosen with the results displayed graphically in Figure 7. The program is able to choose these regions graphically using the computer's mouse from either the BR or the vivacity curves. Alternatively, for precise control, the pressure regions may be numerically chosen as absolute or relative pressures.

Both the vivacity curves (Figure 4) and BR (Figure 7) are contained on one sheet of the Excel program to better facilitate the use of the vivacity in choosing the pressure regimes. The vivacity chart (Figure 4) includes two straight lines at the top of the graph that demarcates that portion of the vivacity curve that corresponds to the burning rate linear fits in Figure 7.

3. Pressure Simulation

The capability to simulate the pressure-time behavior of a propellant in a closed bomb has been preserved from BRLCB. Simulated pressure-time curves are useful

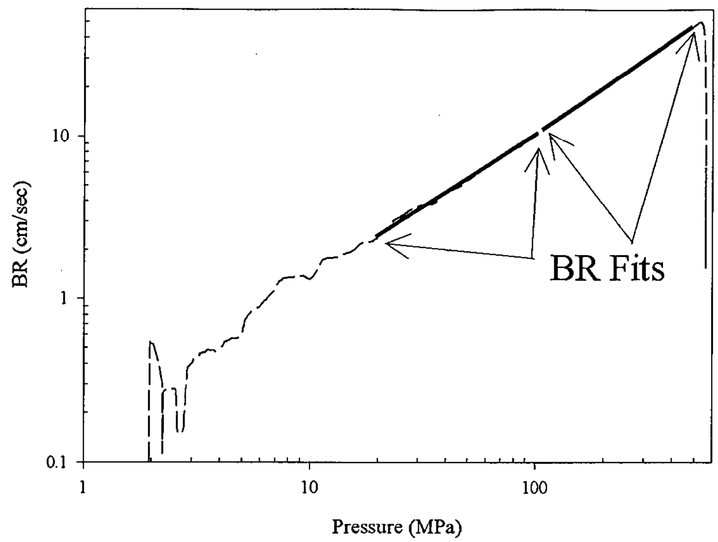


Figure 7. BR of JA2 with linear fits.

when attempting to understand the anomalous behavior of an existing propellant or helping to predict the performance of a notional charge. In addition to the propellant thermochemistry and geometry, the burning rate for the propellant must be supplied. This information can be in the form of a tabulated BR vs. pressure or the BR can be in functional form specified for each propellant layer. The output of the simulation is placed directly into the proper worksheet where a subsequent reduction can be performed.

3.1 XLCB Summary Sheet

To better facilitate the sharing of data among the propellant community, a proposed form of a BR summary is included with XLCB. The method for the presentation of results is similar to that developed earlier for the Naval Surface Warfare Center (NSWC) at Indian Head, MD [14]. XLCB, however, attempts to integrate the collection, processing, and presentation of the data into one program. The summary (Figure 8) contains the interpolated values of the BR at fixed multiples of 10 MPa in pressure. Using this method, the comparisons between different CB firings can be done at consistent pressures. Firing information, charge (propellant and igniter) information, propellant geometry, and thermochemistries are also presented in the summary. The summary also contains information for the calculation of the relative quickness, defined as

$$RQ \equiv \frac{1}{n}\sum_{i=1}^{n}\frac{\dot{P}_i^T}{\dot{P}_i^R}, \tag{9}$$

ARL-Ignition and Combustion Branch
Burning Rate Analysis

File	
Date of Firing	
Project	
POC	
Comments	

Charge Information

	Propellant	Ignitor			Propellant Geometry (cm)	
Type			Impetus (J/g)		Length	
Lot			Flame Temp (K)		Diameter	
Source			Density (g/cc)			
Mass (g)			Mol. Wt. (g/mole)			
Propellant Temp. (K)			CoVol. (cc/g)			
Bomb Volume (cc)			Gamma			
Bomb Temp. (K)					Type	
Heat Loss Fraction						

Propellant ThermoChemistry

Layer	Start/End	Impetus (J/g)	Flame Temp. (K)	Density (g/cc)	Mol. Wt.	CoVol (cc/g)	Gamma

Pressure (MPa)	BR (cm/s)	Pressure (MPa)	BR (cm/s)	Pressure (MPa)	BR (cm/s)	Pressure (MPa)	BR (cm/s)

	RQ File					
Maximum Pressure MPa	Description					
	Pressure (Rel)					
	dP/dT (MPa/sec)					

Figure 8. Example of summary sheet.

where $\dot{P}_i^T$ and $\dot{P}_i^R$ are the derivatives of the pressure at up to 5 time points for a test and reference experiment, respectively. The maximum pressure, P_{max}, is stored in the summary for later calculation of the relative force, defined as

$$RF \equiv \frac{P_{max}^T}{P_{max}^R}, \tag{10}$$

where P_{max}^T and P_{max}^R are the maximum pressure obtained for the test and reference shots.

An option to print this summary along with two other pages is provided. The second page includes both of the graphs presented in Figures 4 and 7. The final third page (Figure 9) provides the parameter information regarding the linear least-squares fit of BR vs. pressure described previously. This printed package provides the basic information about the propellant characteristics most important to the end user.

BURN RATE PARAMETERS							
Max. Pressure (Mpa)=		562.7216187					
Region	Start Press (Mpa)	End Press (Mpa)	Ps/Pmax	Pe/Pmax	a (cm/s)	n	r^2
1	112.046	505.3351	0.1991	0.898	0.1353	0.9458	0.9936
2	19.8816	99.8009	0.0353	0.1774	0.1911	0.8624	0.9854
3	-1	0	-0.0018	0	0	0	0
4	-1	0	-0.0018	0	0	0	0
Current region	2						

Figure 9. Screen capture of BR parameters page.

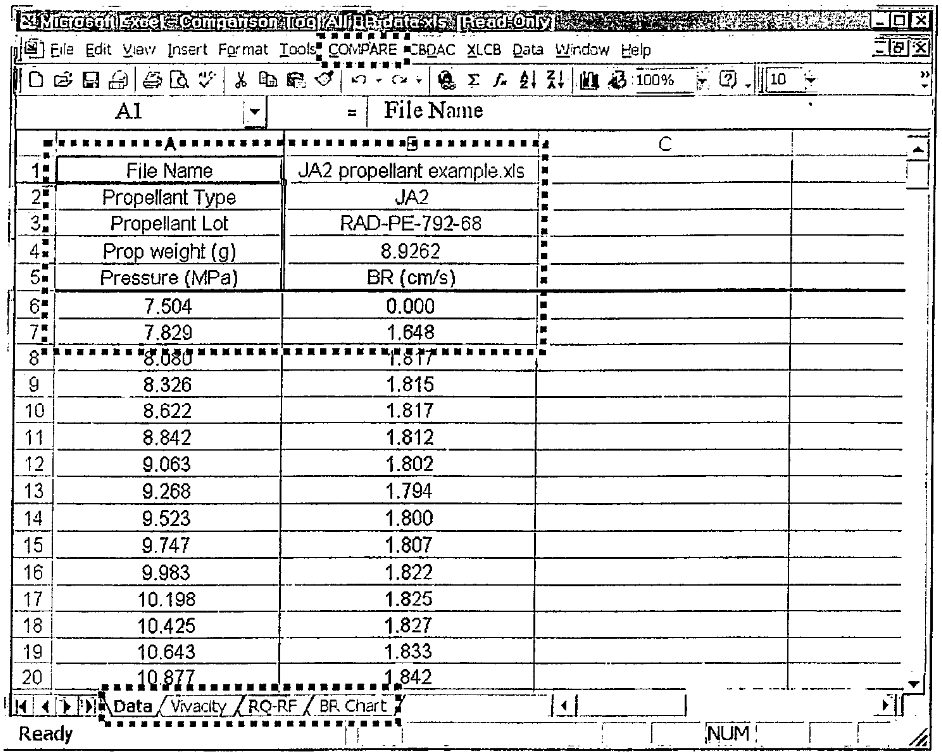
3.2 Comparison Tool

The XLCB-generated master file warehouses all the information concerning a single experiment. Once a series of related closed-bomb runs have been performed, it is often desirable to compare the results. In addition, multiple experiments are usually performed under the same conditions for statistical reasons. The BR and vivacity results from multiple experiments can be gathered together for analysis by using the companion spreadsheet template named "Comparison Tool." A screen capture of the main worksheet is shown in Figure 10 with three areas highlighted and labeled with roman numerals. Using the built-in tools (region I) data can be imported, averaged, the linear BR (equation 8) can be calculated, and the results of these operations plotted. Along with the average, the standard deviation is also calculated. Three types of information are imported from each selected master file (see Figure 10, region II). Both the BR as a function of pressure (region II) and the vivacity (region III) are extracted to the template. The ability to calculate the relative force (RF) and relative quickness (RQ) requires the information from

I

II

III



	A	B	C
1	File Name	JA2 propellant example.xls	
2	Propellant Type	JA2	
3	Propellant Lot	RAD-PE-792-68	
4	Prop weight (g)	8.9262	
5	Pressure (MPa)	BR (cm/s)	
6	7.504	0.000	
7	7.829	1.648	
8	8.080	1.817	
9	8.326	1.815	
10	8.622	1.817	
11	8.842	1.812	
12	9.063	1.802	
13	9.268	1.794	
14	9.523	1.800	
15	9.747	1.807	
16	9.983	1.822	
17	10.198	1.825	
18	10.425	1.827	
19	10.643	1.833	
20	10.877	1.842	

Figure 10. Comparison tool template.

multiple closed-bomb runs. The data required for the calculation is placed in the spreadsheet labeled RQRF (region III).

Using the comparison tool, the BR law (equation 8) can be applied to any of the plotted series. The graph produced by the Comparison Tool program is shown in Figure 11. The BR vs. pressure for both imported files along with the average is plotted. The linear fit (delimited by the arrows in the figure for clarification) of the average in the region between 50 and 500 MPa is also included on this graph.

4. Conclusions

A new closed-bomb reduction and pressure simulation software package has been developed with a much improved user interface. A new technique to calculate the derivative of the depth function has greatly reduced the appearance of high frequency noise in the BR vs. pressure graph without loss of information. A new format has been proposed that will ease the sharing of BR data among the community at large. Detailed user manuals for the described programs are available from the authors.

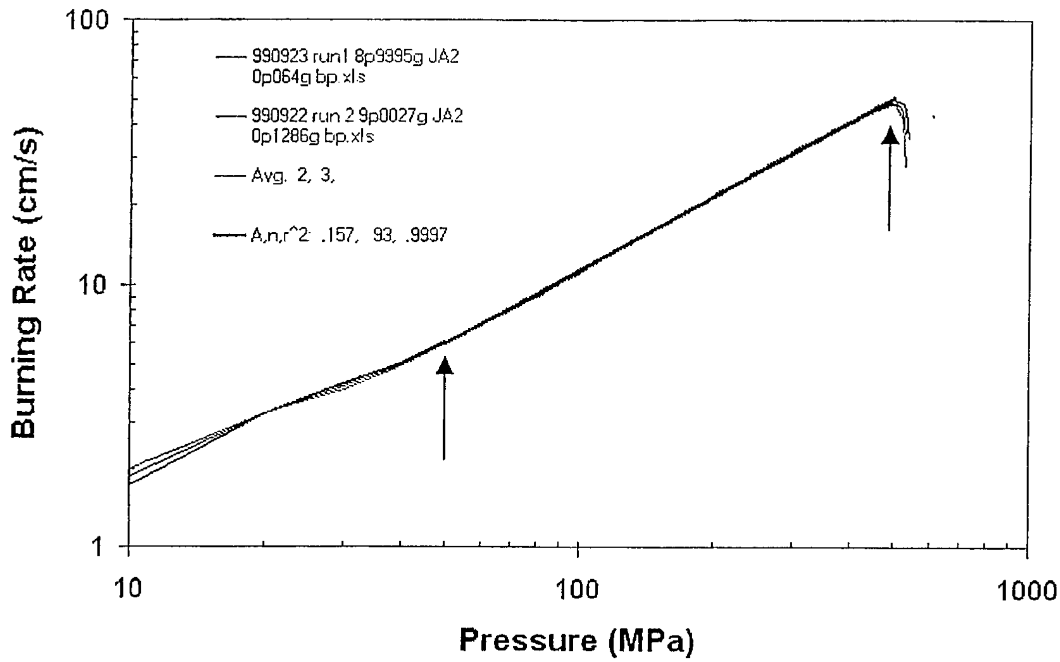


Figure 11. Comparison tool of two JA2 test runs with average and BR law fit.

INTENTIONALLY LEFT BLANK.

5. References

1. Celmins, A. "Solid Propellant Burning Rate Measurement in a Closed Bomb." BRL-1840, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1975.

2. Price, C., and A. A. Juhasz. "A Versatile User-Oriented Closed Bomb Data Reduction Program." BRL-2108, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1977.

3. Oberle, W. F., A. A. Juhasz, and T. M. Griffie. "A Simplified Computer Code for Reduction to Burning Rates of Closed Bomb Pressure-Time Data (MINICB)." BRL-TR-2841, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1987.

4. Robbins, F. W., and F. R. Lynn. "Analytic Solutions to the Closed Bomb." BRL-TR-2892, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1988.

5. Oberle, W. F., and D. E. Kooker. "BRLCB: A Closed-Chamber Data Analysis Program Part I–Theory and User's Manual." ARL-TR-36, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 1993.

6. Juhasz, A. A., W. Waesche, and R. Simmons. "Workshop Coordinators' Report of the JANNAF Solid CHON Propellant Burning Rate (BR) and Tailoring Workshop." ARL-TR-2197, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 2000.

7. Juhasz, A. A., C. D. Bullock, B. E. Homan, and D. Devynck. "Micro Closed Bomb for Characterizing the Burning of Propellants at Gun Pressures." Proceedings of the 36th JANNAF Subcommittee, 1999.

8. Tompkins, R. E., R. E. Bowman, and A. A. Juhasz. "A Study on the Effects of Variable Surface Area to Volume Ratio on Closed Bomb Burn Rates." BRL-TR-2685, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1986.

9. Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery. *Numerical Recipes in C.* Cambridge, MA: Cambridge University Press, 1992.

10. Klingaman, K. W., and J. K. Domen. "The Role of Vivacity in Closed Vessel Analysis." *Proceedings of the 31st JANNAF Subcommittee Meeting,* CPIA Pub. 609, vol. I, pp. 149–159, 1994.

11. Homan, B. E., D. Devynck, P. Kaste, R. Skaggs, D. Bullock, and A. Juhasz. "Burning Rates and Impact Sensitivities of BNMO/NMMO/Nitramine Energetic TPE Propellants." Proceedings of the 37th JANNAF Subcommittee Meeting, 2000.

12. Birk, A., D. Kooker, and P. Baker. "Model of Cavity Combustion Within and Energetic Solid: Application to Composition B." Proceedings of the 37th JANNAF Subcommittee Meeting, 2000.

13. Ritchie, S. J. "Closed Bomb Evaluation of the Burning Rate Gradient in Gun Propellants." *Proceedings of the 35th JANNAF Subcommittee Meeting*, CPIA Pub. 680, vol. I, pp. 15–21, 2000.

14. Eliott, K. C. Personal communication. Naval Surface Warfare Center, Indian Head, MD, October 1998.

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	OSD OUSD(A&T)/ODDR&E(R) DR R J TREW 3800 DEFENSE PENTAGON WASHINGTON DC 20301-3800
1	COMMANDING GENERAL US ARMY MATERIEL CMD AMCRDA TF 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	DARPA SPECIAL PROJECTS OFFICE J CARLINI 3701 N FAIRFAX DR ARLINGTON VA 22203-1714
1	US MILITARY ACADEMY MATH SCI CTR EXCELLENCE MADN MATH MAJ HUBER THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL D DR D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI AI R 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1197
	ABERDEEN PROVING GROUND
2	DIR USARL AMSRL CI LP (BLDG 305)

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CS AL TP 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CS AL TA 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	CHAIRMAN DOD EXPLOSIVES SAFETY BD HOFFMAND BLDG 1 RM 856 C 2461 EISENHOWER AVE ALEXANDRIA VA 22331-0600
2	COMMANDER NSWC IHD CODE 8530 CODE 6210 101 STRAUSS AVE INDIAN HEAD MD 20640-5035
1	HQS US ARMY MATERIEL CMD AMCICP AD M FISETTE 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	US ARMY BMDS CMD ADVANCED TECHNOLOGY CTR PO BOX 1500 HUNTSVILLE AL 35807-3801
1	PM CRUSADER SFAE ASM AF E PICATINNY ARSENAL NJ 07801-5000
1	PMO PEO ARMAMENTS TANK MAIN ARMAMENT SYS AMCPM TMA AT H YUEN PICATINNY ARSENAL NJ 07806-5000

NO. OF COPIES	ORGANIZATION
7	COMMANDER US ARMY ARDEC SMCAR AEE B S MOY T MANNING K KLINGAMAN A FEHSAL S EINSTEIN J RUTKOWSKI B BRODMAN PICATINNY ARSENAL NJ 07806-5000

ABERDEEN PROVING GROUND

NO. OF COPIES	ORGANIZATION
31	DIR USARL AMSRL WM BD W R ANDERSON R A BEYER A BIRK A L BRANT S W BUNTE C F CHABALOWSKI L M CHANG T P COFFEE J COLBURN P J CONROY R A FIFER B E FORCH B E HOMAN S L HOWARD P J KASTE A J KOTLAR C LEVERITT K L MCNESBY M MCQUAID M S MILLER T C MINOR A W MIZIOLEK J B MORRIS J A NEWBERRY M J NUSCA R A PESCE-RODRIGUEZ G P REEVES B M RICE R C SAUSA J A VANDERHOFF A W WILLIAMS

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 2001	Final, June 1999–June 2000

4. TITLE AND SUBTITLE
XLCB: A New Closed-Bomb Data Acquisition and Reduction Program

5. FUNDING NUMBERS
622618-H80

6. AUTHOR(S)
Barrie E. Homan and Arpad A. Juhasz

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-BD
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-2491

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

10.SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A new closed-bomb data acquisition and reduction program has been developed based on the Microsoft Excel 97 spreadsheet platform. With the addition of IOTech's Wavebook/512 data acquisition hardware, the voltage signal from the closed-bomb experiment is directly captured into the spreadsheet where burning rate (BR) calculations can be performed. Additionally, XLCB has the capability to generate pressure vs. time data based on given BRs, geometrical form, and propellant thermochemistry. A proposed summary sheet is included to better facilitate the exchange of information between interested parties in the propellant community. The Visual BASIC code used in this program was adapted from the FORTRAN algorithms in BRLCB with some additional improvements/modifications. The implementation of a user-friendly interface, the technique used to calculate the derivative, and the comparison of the normalized surface area and vivacity profile are some of the more dramatic changes. Multiple fits of the BR law ($A*P^n$) using different pressure regimes can be graphically chosen from either the BR vs. pressure graph or the vivacity graph.

14. SUBJECT TERMS
XLCB, closed bomb, data acquisition, BRLCB, burning rate

15. NUMBER OF PAGES
25

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. ARL Report Number/Author ARL-TR-2491 (Homan) ____________ Date of Report May 2001 ________

2. Date Report Received ______________________________

3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) ______________________________

____

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) ________

____

____

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. ______________________________

____

____

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) ______________________________

____

____

____

CURRENT ADDRESS

____
Organization

____
Name E-mail Name

____
Street or P.O. Box No.

____
City, State, Zip Code

7. If indicating a Change of Address or Address Correction, please provide the Current or Correct address above and the Old or Incorrect address below.

OLD ADDRESS

____
Organization

____
Name

____
Street or P.O. Box No.

____
City, State, Zip Code

(Remove this sheet, fold as indicated, tape closed, and mail.)

(DO NOT STAPLE)