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# A Graphical User Interface (GUI) for Automated Classification of Bradley Fighting Vehicle Shock Absorbers

by Patrick Sincebaugh, William Green,  
and Gerard Rinkus

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# **Army Research Laboratory**

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## **A Graphical User Interface (GUI) for Automated Classification of Bradley Fighting Vehicle Shock Absorbers**

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## **Abstract**

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In this report we describe a diagnostic system that is being utilized to evaluate the condition of armored vehicle shock absorbers. We begin by providing the motivation behind the development of the smart shock absorber test stand (SSATS). We then describe the theory required to evaluate the condition of shock absorbers. This theoretical discussion leads to a description of what real life data are acquired during a shock absorber test, and how it can be analyzed to determine the condition of a shock absorber. We then explain the design and capabilities of the SSATS graphical user interface (GUI), which includes the integration of a neural network classification scheme. We finish by discussing recent results of utilizing the system to test and evaluate Bradley armored vehicle shock absorbers.

## **Acknowledgments**

We would like to thank the U.S. Army Artificial Intelligence Center for continuing to support our development of AI-based systems. We would like to acknowledge Eric Olson and Judy Miller from RRAD for their assistance in providing logistical support and technical assistance pertaining to shock absorber testing. We would also like to thank Dick Suchter, formerly of the Paul Munroe Corporation, for his assistance in providing technical data pertaining to the hydraulic test stand used for this project.

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# 1. Introduction

The need to develop an improved testing methodology for armored vehicle shock absorbers was identified at the U.S. Red River Army Depot (RRAD). The Combat Vehicle Remanufacturing Facility at RRAD is responsible for the maintenance and overhauling of armored fighting vehicles (AFVs). These vehicles are completely disassembled upon arrival and the individual system components, such as the track and engine block, are diagnostically tested. The vehicles are then reassembled with components that have passed their individual tests. The reassembled vehicles are then performance tested by driving them around a test track for a specified amount of time and distance. If a vehicle meets or exceeds all of the performance criteria, it is released back into the field. There are various functional tests performed on individual system components. However, until the development of the smart shock absorber test stand (SSATS), there was no diagnostic test to evaluate the AFV shock absorbers. The decision to reinstall or discard shock absorbers was based on a nonscientific "touch test" performed after the vehicle was driven around the test track. This testing procedure was not reliable. Failure rates as high as 78% occurred in the field. These high failure rates led to rising expenses and downtime, creating the demand for a significantly better diagnostic testing capability for AFV shock absorbers. The U.S. Army Research Laboratory (ARL) developed and implemented the SSATS to meet this need.

## 2. Shock Absorber Theory

In order to cause a physical body moving with velocity ( $v$ ) to come to rest, a deceleration force ( $-a$ ) must be applied. Assuming a constant deceleration, the total distance ( $S$ ) that is traveled by the body is represented by equation (1),

$$S = v^2/2a, \tag{1}$$

where  $v$  is the initial velocity.

If the velocity that will be reduced to zero is in the vertical direction, then  $S$  is equal to the height traveled by the body ( $H$ ), while the acceleration is equal to the gravitational acceleration ( $g$ ). This yields equation (2),

$$H = v^2/2g. \quad (2)$$

Solving equations (1) and (2) yields

$$2aS = 2gH. \quad (3)$$

In the case of a shock absorber causing the deceleration of the vertical velocity of an armored vehicle, the deceleration is limited by gravitational forces and is defined as  $G = a/g$ . Using this value and solving equation (3) for the stopping distance  $S$  results in

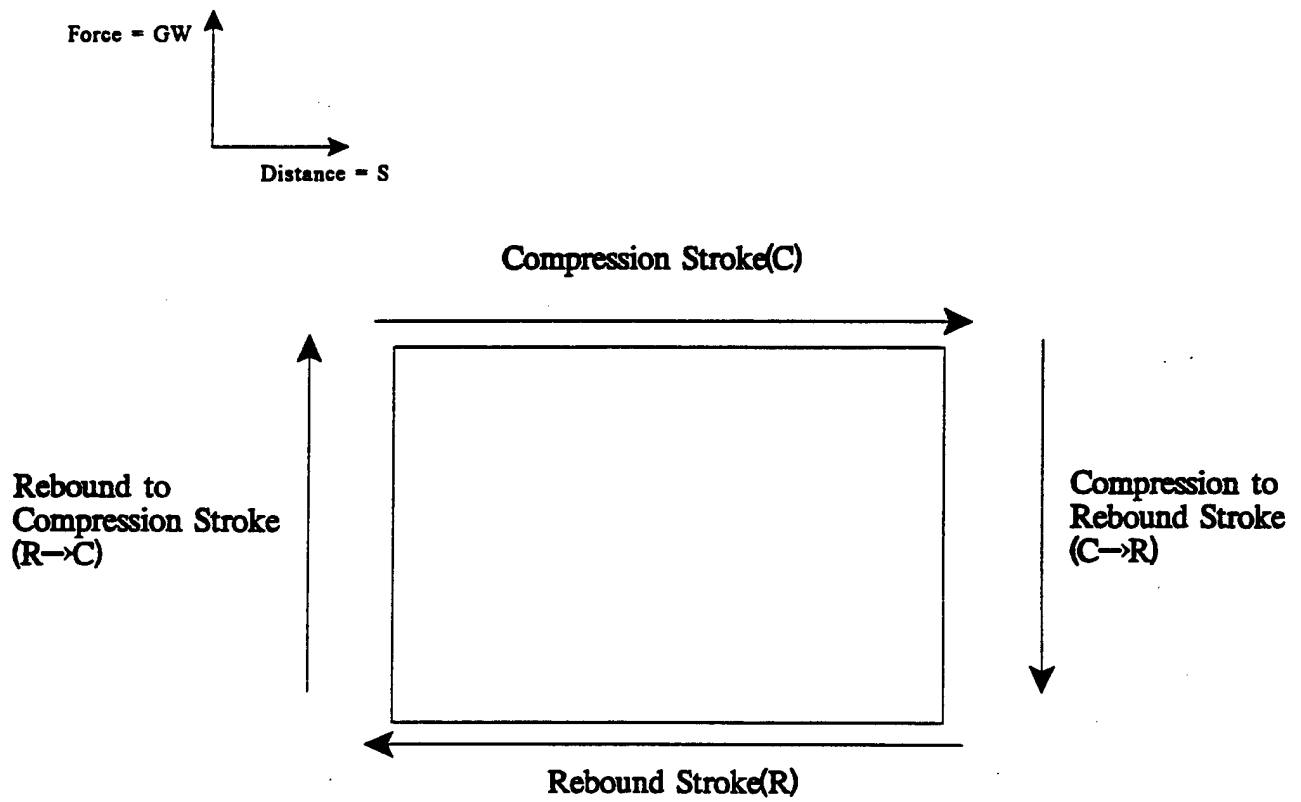
$$S = H/G. \quad (4)$$

The energy ( $E$ ) that is stored in a body of weight ( $W$ ) falling from height ( $H$ ) is defined by  $E = WH$ . Substituting the value of  $H$  from equation (4) yields,

$$E = GWS, \quad (5)$$

where  $GW$  is defined as the active force. For an ideal case, a constant force would result in the constant deceleration of the moving body. Figure 1 displays the force vs. displacement curve representing the ideal case (Harris and Crede 1988). The energy that is dissipated during the deceleration process is defined as the area under the curve of the force vs. displacement diagram.

The theory described previously can be applied to the problem of evaluating the capability of a shock absorber to dissipate energy created by the body of an armored vehicle moving in the vertical direction.



**Figure 1. Force vs. Displacement Diagram for an Ideal Shock Absorber.**

### **3. Shock Absorber Test Stand System Development**

**3.1 Hydraulic Test Stand.** A hydraulic test stand was developed to provide a diagnostic testing capability for AFV shock absorbers. The test stand consists of an electronic test console interfaced with a hydraulic power supply. Hydraulic fluid is supplied to a servo cylinder mounted on a load frame. A shock absorber is mounted vertically into the load frame and is subjected to a sinusoidal motion of 38 cycles per minute (CPM) (adjustable up to 290 CPM) at a 2- to 3-in stroke. Sensors are mounted to the test stand and the shock absorber under test in order to acquire data relating to the force on the shock absorber, the resulting displacement, temperature, and the cycle rate.

**3.2 Data Acquisition (DAQ) System.** A PC-based system was developed to automate the acquisition and analysis of data provided by the hydraulic test stand. Analog voltage signals representing the force applied to the shock absorber, the resulting displacement, the temperature of the shock absorber, and the frequency of oscillation are input to an analog to digital (A/D) converter board plugged into an expansion slot of an 80486 PC. The data signals are connected to the A/D board in a referenced single ended (RSE) configuration. Time is calculated using the sampling rate of the DAQ board, and the average velocity is calculated using the sampling rate and displacement data. The DAQ system was designed to acquire data at five testing frequencies: 38, 50, 100, 150, and 290 CPM. Table 1 depicts the parameters that were used to acquire approximately 100 data points for analysis.

The number of scans/cycle is based upon a DAQ scan rate of 500 Hz and the test frequency. The data bin divisor (DBD) is a number that was calculated to ensure that the number of scans between data points was within the limitations of the A/D conversion rate of the hardware being used. The parameters described previously were coded into the data acquisition software routine to ensure accurate data measurements.

**Table 1. Parameters Used to Calculate Number of Data Points**

Frequency	No. of Scans/Cycle	DBD	No. of Data Points
38	790	8	99
50	600	6	100
100	300	3	100
150	200	2	100
290	103	1	103

**3.3 Data Analysis.** A testing procedure for Bradley armored vehicle shock absorbers was developed with the assistance of the shock absorber original equipment manufacturer (OEM) and the quality assurance team at RRAD. The first test requirement specifies a nominal temperature range for the shock absorber being tested. A temperature value is acquired from a thermocouple connected to the shock absorber. The temperature reading is automatically compared by a software analysis routine to determine if it is within the required range. Force values representing the compressive load at midstroke, rebound load at midstroke, load at the first 10% of the compressive stroke, and the load at the first 10% of the rebound stroke are then acquired from load cell sensors. These load values are compared by the software analysis routine to predetermined specified force requirements. If the shock absorber fails the temperature range check, it is tested again at a proper temperature. If the shock absorber fails any portion of the force requirements test and passes the temperature range check, it is considered a faulted shock absorber and is further analyzed by a neural network classification scheme.

Based on the theory described in section 2, it was concluded that the condition of an AFV shock absorber could best be evaluated by analyzing the force vs. displacement diagram of the shock absorber. A testing procedure was developed to collect data as a shock absorber is oscillated at 38 CPM. Preliminary analysis of the data acquired from faulted Bradley armored vehicle shock absorbers shows that the condition can best be classified into four fault categories. These shock absorber fault types are the result of the presence of physical anomalies, such as a bent rod, leaky seal, damaged casing, etc. These categories are named Fault Types 1, 2, 3, and 4. Figure 2 shows

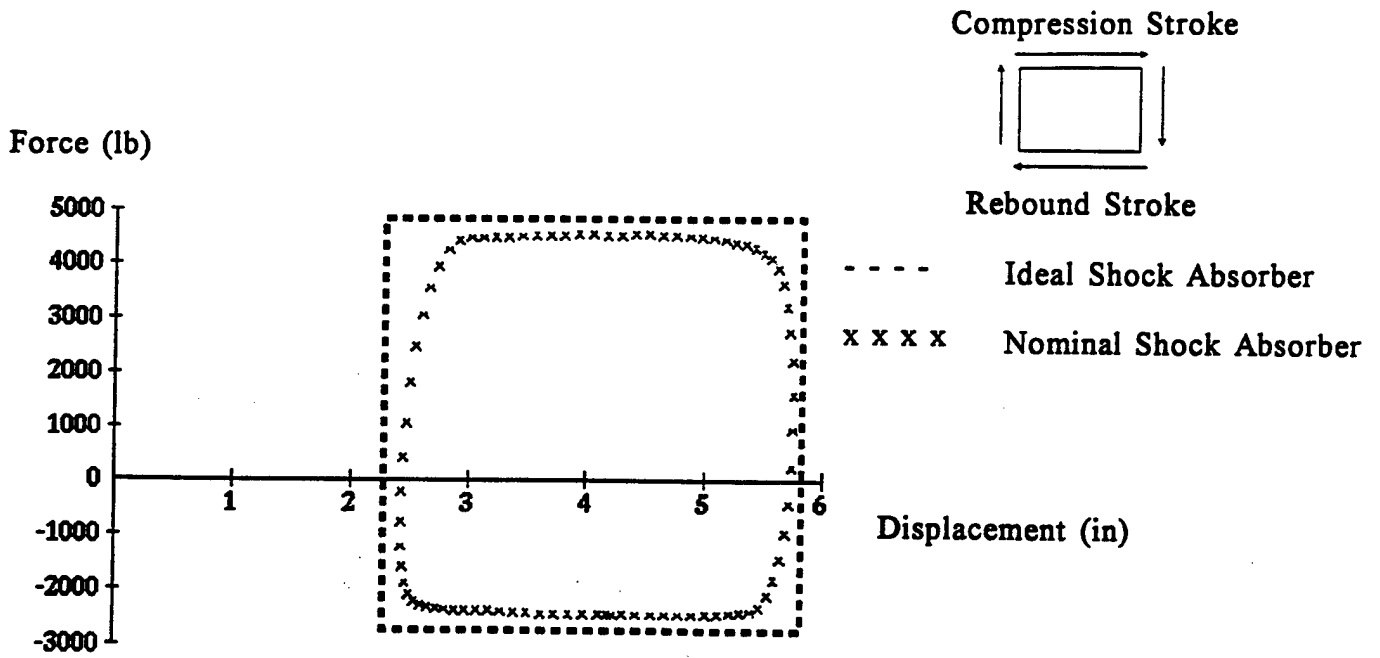


Figure 2. Force vs. Displacement Phase Diagrams for an Ideal and a Nominal BFV Shock Absorber.

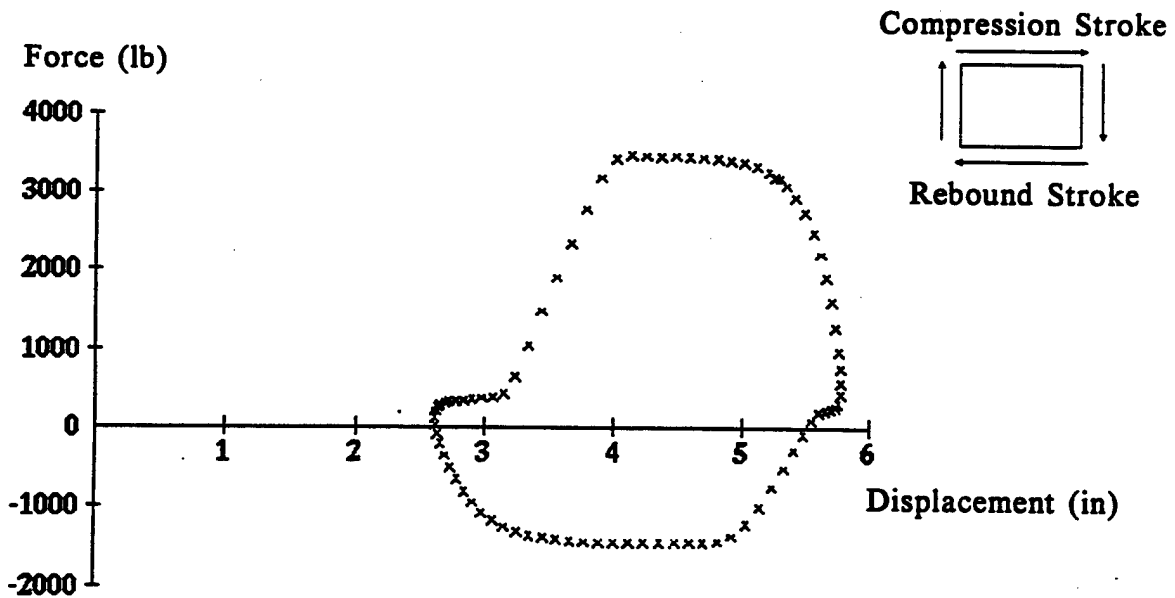


Figure 3. Typical Force vs. Displacement Diagram for a Type 1 Faulted BFV Shock Absorber.

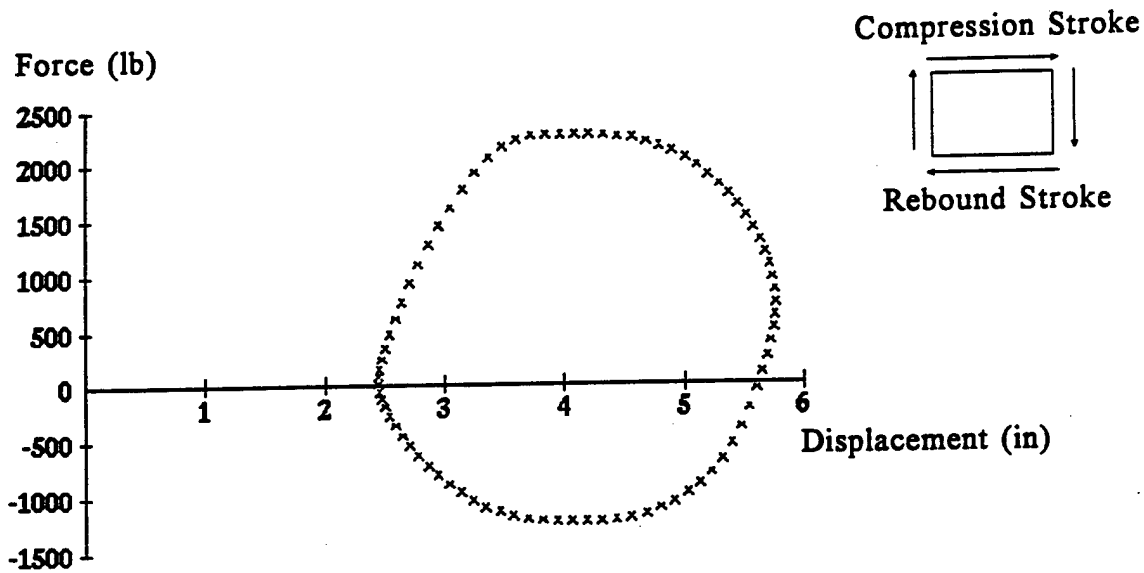


Figure 4. Typical Force vs. Displacement Diagram for a Type 2 Faulted BFV Shock Absorber.

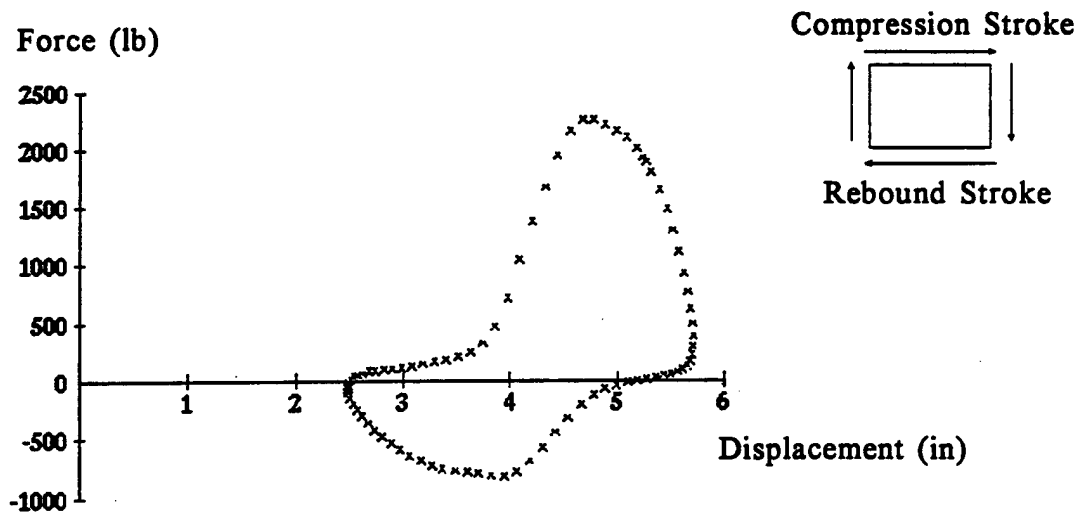


Figure 5. Typical Force vs. Displacement Diagram for a Type 3 Faulted BFV Shock Absorber.

the force vs. displacement diagram for a nominal shock absorber as compared to an ideal shock absorber. Figures 3, 4, and 5 are typical phase diagrams for Fault Types 1, 2, and 3. The Fault Type 4 category was defined to account for unique types of faults and for shock absorbers with a combination of Fault Types 1, 2, or 3.

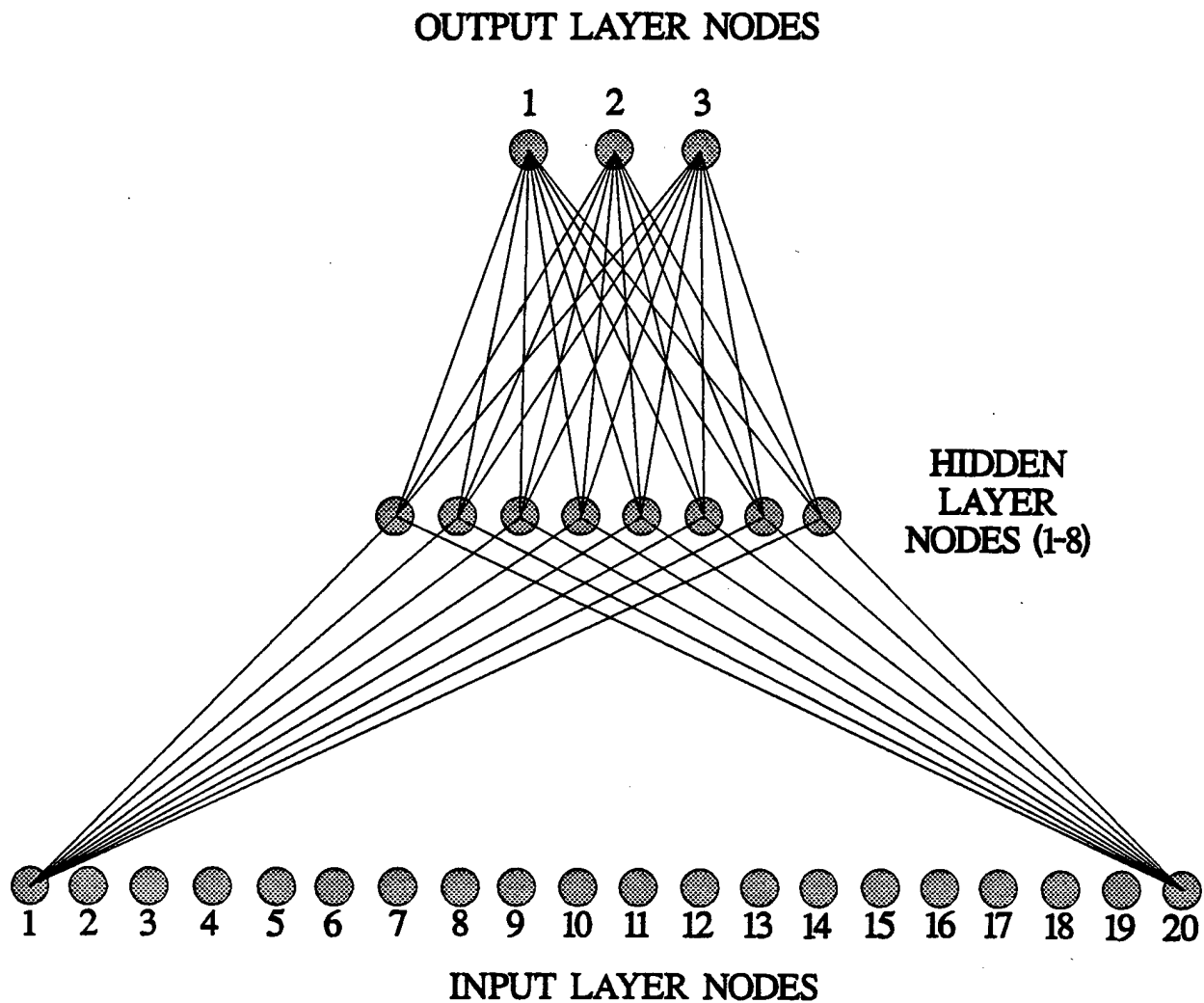
A fully connected, feed-forward backpropagation neural network was developed to classify the faulted condition of used Bradley armored vehicle shock absorbers. The network architecture consists of an input layer, one hidden layer, and an output layer as shown in Figure 6. The input layer comprises 20 input nodes. The hidden layer comprises eight nodes. The output layer comprises three nodes. Table 2 summarizes the output values and the corresponding fault classifications.

**Table 2. Output Nodes Classification**

Fault Type	Node 1	Node 2	Node 3
1	>0.85	<0.35	<0.35
2	<0.35	>0.85	<0.35
3	<0.35	<0.35	>0.85

If the network output does not meet any of the criteria outlined in Table 2, then the shock absorber is classified as Fault Type 4. Fault Type 4 can be a unique type of fault for which the network was not trained to recognize, or it could be any combination of Fault Types 1, 2, or 3. There is no corresponding output for a nominal shock absorber since the network is only implemented once the preliminary data analysis determines that the shock absorber is faulted.

A total of 84 Bradley armored vehicle shock absorbers were acquired from RRAD to train the neural network. Eight of the shock absorbers were new and were, therefore, classified as nominal. The condition of the new shock absorbers was verified by analyzing the force vs. displacement plots, temperature values, and load ranges acquired from the hydraulic test stand. The remaining 76 shock



\* The network connections from each of the INPUT LAYER NODES (2-19) to each of the HIDDEN LAYER NODES are not shown for purposes of visual clarity.

**Figure 6. Backpropagation Architecture Used to Classify Faulted BFV Shock Absorbers.**

absorbers were faulted. The faulted shock absorbers were categorized as either Fault Types 1, 2, or 3 by analyzing preliminary force vs. displacement plots acquired from the hydraulic test stand. Real data were then acquired and stored for each individual shock absorber. These data were then manipulated into the proper data representation format to train the backpropagation network. After experimenting with the various parameters, such as the learning rate, number of hidden layer nodes, etc., the network was successfully trained to classify the faulted Bradley armored vehicle shock absorbers.

Once the network was adequately trained, it was tested using shock absorbers of known condition. The network successfully classified 100% of the shock absorbers. The neural network was then converted to C code and integrated with the previously written testing software. This completed the development of the SSATS GUI.

## **4. The SSATS GUI**

The SSATS graphical interface is a software application that controls the acquisition, display, and analysis of shock absorber testing data in near real time. It also easily performs statistical process control (SPC) for product assurance and can retrieve for display archival data files. Figure 7 shows the hierarchical relationship between the windows that make up the interface. Appendix A shows each of these windows. Each window also has items that control processes in that window or access to other windows, including one or some combination of buttons, pull-down menus, variable numeric inputs, or scroll bars. Each window also has items that provide necessary information to the user, which include one or some combination of simple numeric and text indicators, green/red LED style indicators, histograms, or plots.

The main window at the top of the hierarchy provides access to the following:

- Shock absorber testing window (SATW): Used to test and classify shock absorbers.

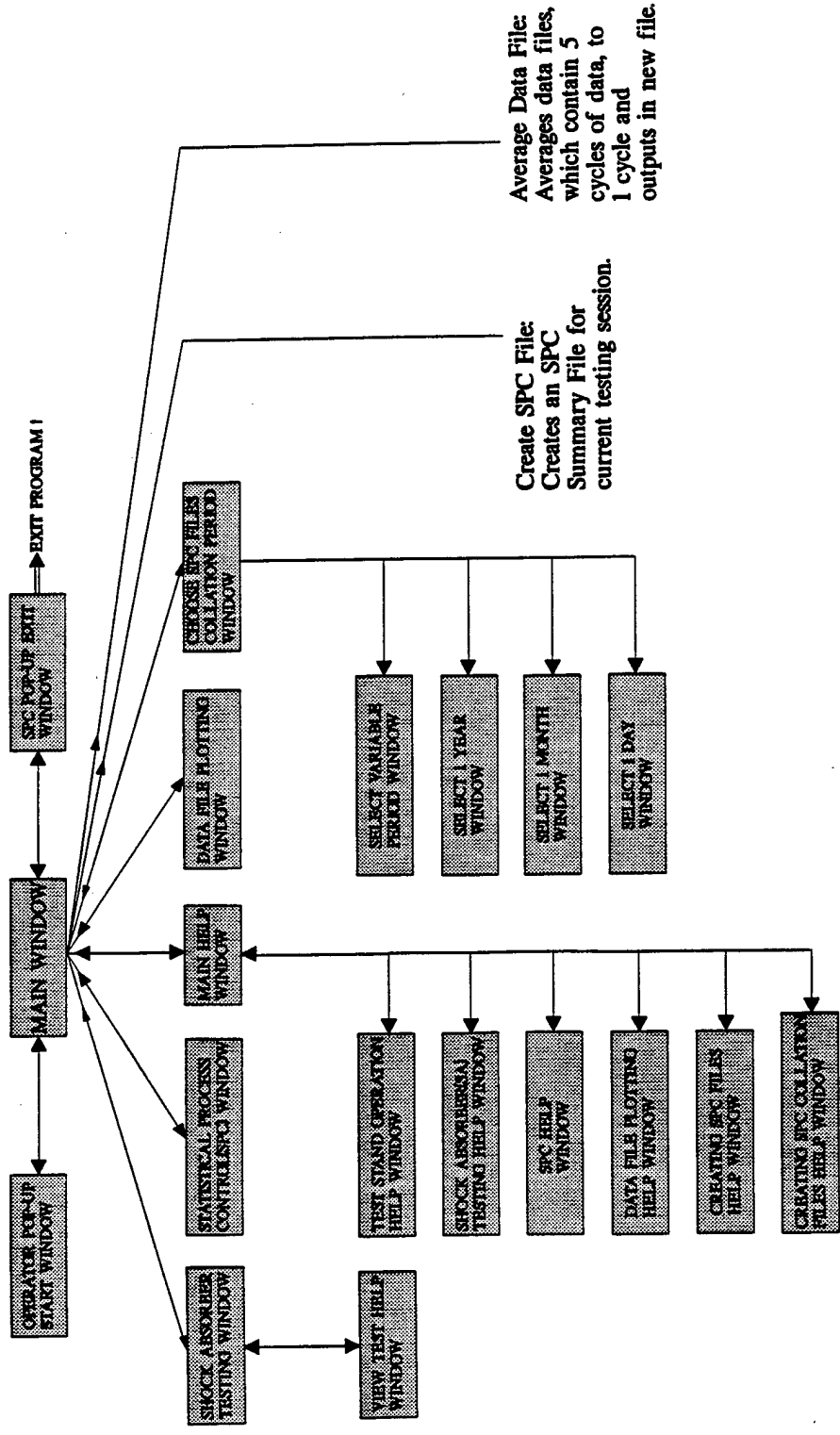


Figure 7. SSATS Interface Windows Hierarchy.

- SPC window (SPCW): Used to graphically view the statistical breakdown of classification data in the current testing session.
- Main help window (MHW): Used to read on-line information concerning all aspects of testing shock absorbers and using the graphical interface itself.
- Data file plotting window (DFPW): Used to retrieve and plot existing data files.
- Choose SPC files collation period window (CSFCPW): Used to summarize data from one or more SPC summary files into a single SPC collation file which inclusively covers the user -defined time period.

An SPC summary file can be created from the main window using the “create SPC file” button. These files contain the statistical breakdown of classification data in the current testing session. Figure 8 is an example of an SPC summary file, and Figure 9 is an example of an SPC collation file. Test data files always contain just over 5 cycles of data regardless of the testing frequency. Average test data files can be also created from the main window, in which 5 cycles are evenly weighted and averaged.

The SATW displays the load (L) vs. position (x) phase diagram, the load history plot, and the temperature history plot of the shock absorber under test while the test is in progress. The SATW also displays one cycle at a time and replaces it with the following cycle over the course of 5 cycles. The user individually sets the “save data” and “retest” buttons to yes or no, and makes a selection from the “number cycles of data” pull-down menu before beginning a test. The selection from the pull-down menu must accurately reflect the actual testing frequency. The retest capability is used to test the same shock absorber again, such as when the first test is done at an improper temperature. The “state of testing” indicator informs the user that a test is in progress.

Acquisition and display of test data begin immediately after the “start test” button is set to “on.” The shock absorber under test must be oscillating in the load frame of the test stand before data acquisition begins. After data acquisition for all cycles is complete and the data fully analyzed, which may require neural network classification, the “test result” indicator displays nominal, faulted-types 1, 2, 3, and 4, temperature failure—retest at 38 CPM or unknown—retest at 38 CPM.

**BRADLEY SHOCK ABSORBER TESTING SPC SUMMARY: Fri, Feb 17, 1995 - #1**  
**FILENAME: c:\braddata\02175scl.s38**

**# Shock Absorbers Tested: 20**  
**# Nominal Shock Absorbers: 15**  
**Percentage (%) Nominal Shock Absorbers: 75.0**  
**# Faulted Shock Absorbers: 5**  
**Percentage (%) Faulted Shock Absorbers: 25.0**

**# Faulted Shock Absorbers - Type 1: 3**  
**Percentage (%) Faulted - Type 1: 15.0**  
**# Faulted Shock Absorbers - Type 2: 1**  
**Percentage (%) Faulted - Type 2: 5.0**  
**# Faulted Shock Absorbers - Type 3: 1**  
**Percentage (%) Faulted - Type 3: 5.0**  
**# Faulted Shock Absorbers - Type 4: 0**  
**Percentage (%) Faulted - Type 4: 0.0**

**Figure 8. SPC Summary File.**

**SPC Collation File - all SPC data in 0295 collated.**  
**FILENAME: c:\braddata\025monsc.c38**

**# Shock Absorbers Tested: 80**  
**# Nominal Shock Absorbers: 35**  
**Percentage (%) Nominal Shock Absorbers: 43.8**  
**# Faulted Shock Absorbers: 45**  
**Percentage (%) Faulted Shock Absorbers: 56.2**

**# Faulted Shock Absorbers - Type 1: 3**  
**Percentage (%) Faulted - Type 1: 3.8**  
**# Faulted Shock Absorbers - Type 2: 11**  
**Percentage (%) Faulted - Type 2: 13.8**  
**# Faulted Shock Absorbers - Type 3: 21**  
**Percentage (%) Faulted - Type 3: 26.2**  
**# Faulted Shock Absorbers - Type 4: 10**  
**Percentage (%) Faulted - Type 4: 12.5**

**Figure 9. SPC Collation File for Any Single Month.**

“Temperature failure” indicates that testing was done at an improper temperature. “Unknown” indicates that testing was not done at a frequency of 38 CPM. Since the neural network was trained on data taken at 38 CPM, shock absorbers tested at other frequencies will not be classified. This requires another test at 38 CPM. However, data can still be acquired and stored at other frequencies. The SATW also individually shows if the testing temperature was within the proper range, if the shock absorber met the load requirements, and if the shock absorber should be rejected with the “temperature test failure,” “load test failure,” and the “reject shock LED” style indicators, respectively. The “view test help” button provides on-line help on usage of the SATW. The “exit test window” button returns the user to the main window.

The SPCW displays, numerically and graphically, the number of nominal and faulted shock absorbers and the number of each type of faulted shock absorber classified in the current testing session. This statistical description is updated each time a shock absorber is classified. This information is given in the SPC data listing and the “# nominal and # faulted shock absorbers” and “# Faulted Shock Absorbers - Types 1, 2, 3, 4” histograms. The SPCW can be accessed any time a test is not in progress.

The MHW displays several buttons which allow the user to view on-line help information on any one of six different topics, including operation of the test stand, testing procedure, SPC, plotting archived data files, creating SPC files, and collating SPC files. The MHW can be accessed any time a test is not in progress.

The DFPW displays two user-defined plots. Each plot is defined by making a selection from the pull-down menu above it, which includes L vs. x, L vs. v (velocity), v vs. x, L vs. t (time), and x vs. t. The user can interchange the x and y axis of either plot. Selection of the existing data file from which to generate the plots begins immediately after the “plot data file” button is set to “on.” The DFPW can be accessed any time a test is not in progress.

The CSFPCW displays a pull-down menu, SPC file collation period, from which to select the time period over which SPC summary files will be collated. The choices include any day, any

month, any year, or a variable period. In each case, the time period is then exactly defined by the user. In the case of a 1-yr collation, SPC collation files for each month of that year are further collated to minimize the number of files involved. The CSFCPW can also be accessed any time a test is not in progress.

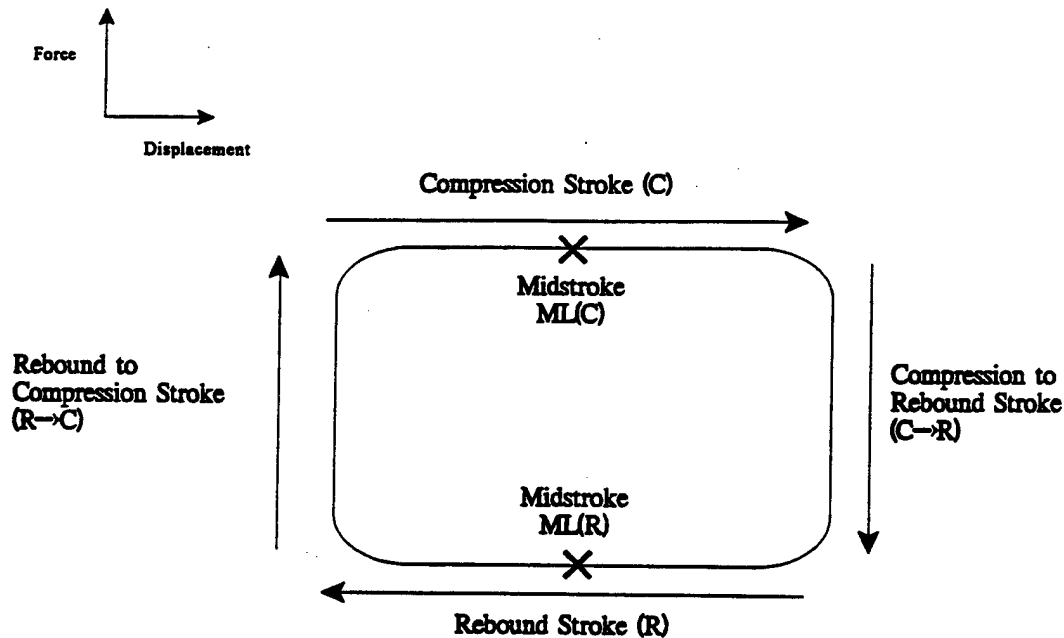
## 5. BFV Shock Absorber Test Results

The SSATS system tested and evaluated 57 BFV shock absorbers at RRAD over the period 7 August 1996 to 18 September 1996. Table 3 gives the load specifications, where ML(C), ML(R), DL(C), and DL(R) are the mid-stroke load in compression, mid-stroke load in rebound, damping load in compression, and damping load in rebound, respectively. Each damping load is defined to be the load after completing 10% of the stroke. The specifications were determined with the assistance of the shock absorber OEM and the quality assurance team at RRAD.

**Table 3. Load Specifications**

Type	Requirement
ML(C)	ML(C) > or = 2,310.0 lb ML(C) < or = 4,760.0 lb
ML(R)	ML(R) > or = 1,680.0 lb ML(R) < or = 2,310.0 lb
DL(C)	DL(C) > or = 1,155.0 lb
DL(R)	DL(R) > or = 840.0 lb

Figure 10 shows how the load (force) vs. position (displacement)-phase diagram of a shock absorber is divided into the compression stroke and rebound stroke. It also shows the location of ML(C) and ML(R). The average values of ML(C), ML(R), DL(C), and DL(R) were determined for each shock absorber and are listed in Appendix B. Names of data files in Appendix B are in "mmddyBn" format, in which "mm" denotes a two-digit month, "dd" denotes a 2-digit day, "y" denotes the last



**Figure 10. Midstroke Position of Compression Stroke.**

digit of a year, and “n” denotes a shock absorber test number. In this way, each shock absorber test is uniquely identified by day, month, year, and test number, which changes over the course of a day.

Only data from 55 of the 57 data files listed in Appendix B were considered, since the data for test nos. 09166B3 and 09176B2 were taken at a temperature out of the proper testing range. Using the load specifications given in Table 3, 12 out of the 55 shock absorbers, approximately 22%, were found to be nominal. The average values of ML(C), ML(R), DL(C), and DL(R) for nominal shock absorbers were 4,113.44 lb, 1,773.96 lb, 2,793.25 lb, and 1,324.65 lb, respectively. Most of the 43 faulted shock absorbers could be categorized as either failing one load requirement, which was always ML(R), or two or more load requirements, which usually included ML(R) and DL(R). This is shown in Appendix C. The average values of ML(C), ML(R), DL(C), and DL(R) for faulted shock absorbers that only failed ML(R) were 3,856.21 lb, 1,624.28 lb, 2,559.08 lb, and 1,091.66 lb, respectively. The average value of ML(R) in these cases is within approximately 3% of the specification. Decreasing the lower limit of the ML(R) specification by 5% (to 1,596 lb) would result in 37 nominal shock absorbers and 18 faulted shock absorbers, an increase of nominal shock absorbers of approximately 45%. The average values of ML(C), ML(R), DL(C), and DL(R) for

faulted shock absorbers that failed ML(R) and DL(R) were 3,314.35 lb, 1,397.70 lb, 1,889.95 lb, and 630.45 lb, respectively. The average values of ML(R) and DL(R) for these shock absorbers are significantly less than the values for shock absorbers only failing ML(R).

Figure 11 shows the load vs. position phase diagram for nominal shock absorber no. 08236B5. Figure 12 shows the load vs. position phase diagram for faulted shock absorber no. 08236B7, which only failed the ML(R) requirement. This shock absorber was classified as Faulted, Type 1. The phase diagrams of shock absorber nos. 08236B5 and 08236B7 have very similar shapes. Figure 13 shows the load vs. position phase diagram for shock absorber no. 09126B6, which failed ML(R) and DL(R) requirements. This shock absorber was classified as Faulted, Type 2. The phase diagram of no. 09126B6 is shaped similar to an oval. The phase diagrams for shock absorber nos. 08236B7 and 09126B6 are dissimilar. Figure 14 shows the load vs. position phase diagram for faulted shock absorber no. 09126B3, the single faulted shock absorber that only failed ML(R) and DL(C) requirements. This shock absorber was classified as Faulted, Type 1. Figure 15 shows the load vs. position phase diagram for faulted shock absorber no. 08076B3, which failed each requirement. This shock absorber was classified as Faulted, Type 2. Figure 16 shows the load vs. position phase diagram for the Type 4 shock absorber no. 08216B2. This shock absorber was similar enough to both Type 1 and Type 2 that it was not classified as either. The number of faulted shock absorbers classified as Type 1, Type 2, and Type 4 were 28, 12, and 3, respectively. No faulted shock absorbers were classified as Type 3. The classification of each faulted shock absorber is given in Appendix D.

## 6. Conclusions

The Materials Directorate\* (MD), ARL, has developed and implemented a SSATS based on an interactive GUI to evaluate the condition of armored vehicle shock absorbers. The GUI is a software

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\* Materials Directorate was transitioned to Materials Division within the Weapons & Materials Technology Directorate (WMRD).

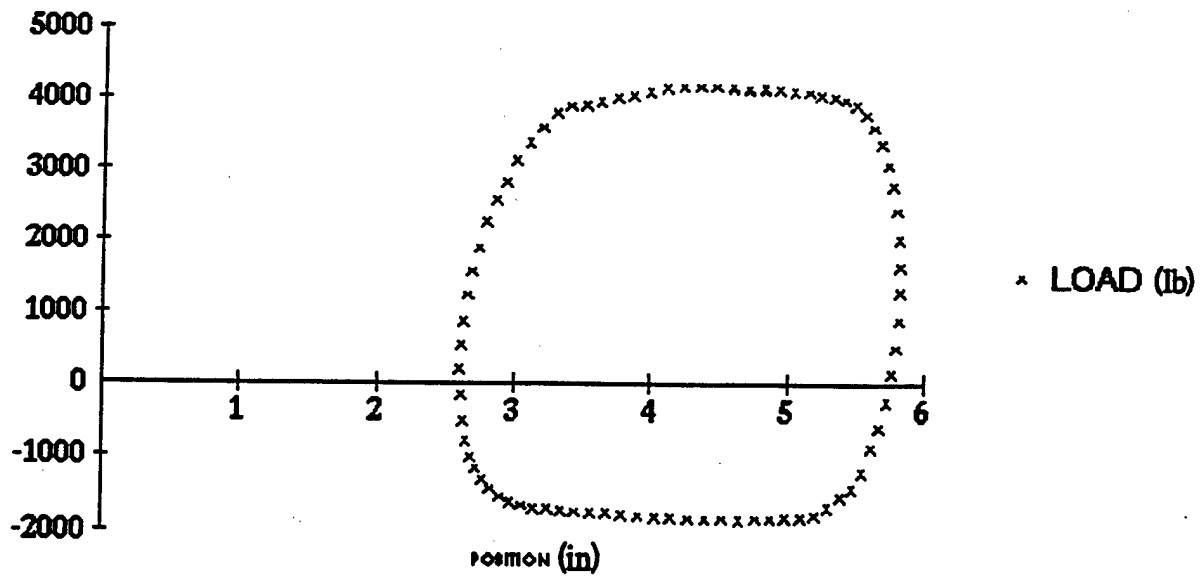


Figure 11. Load vs. Position Phase Diagram for Nominal Shock Absorber No. 08236B5.38.

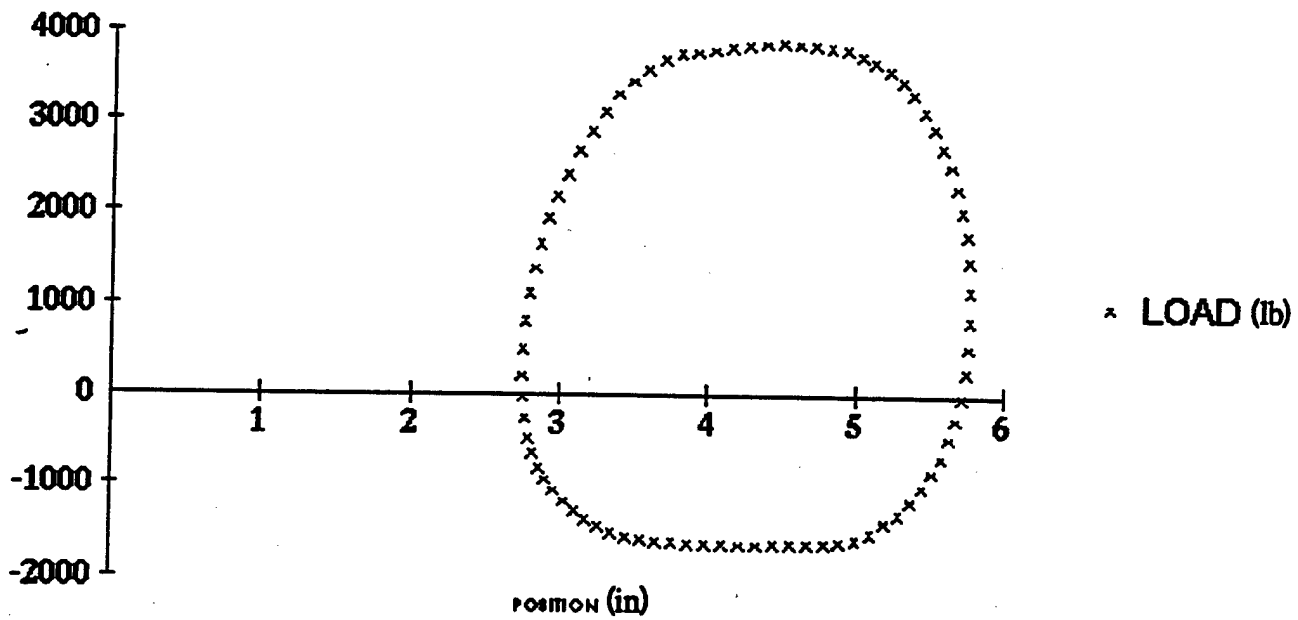


Figure 12. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 08236B7.38.

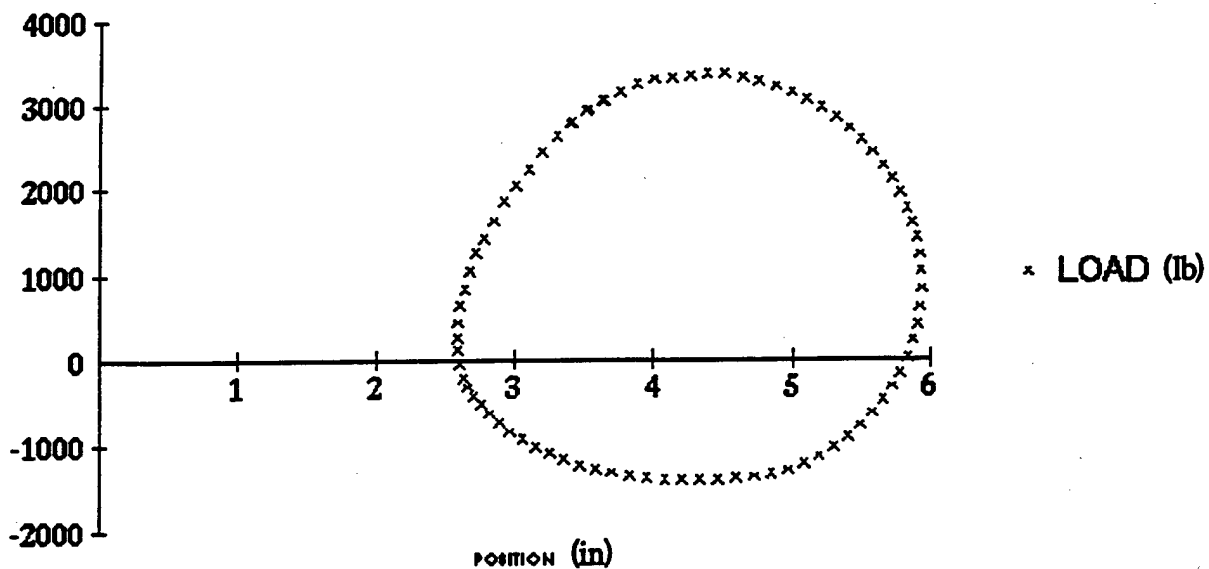


Figure 13. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 09126B6.38.

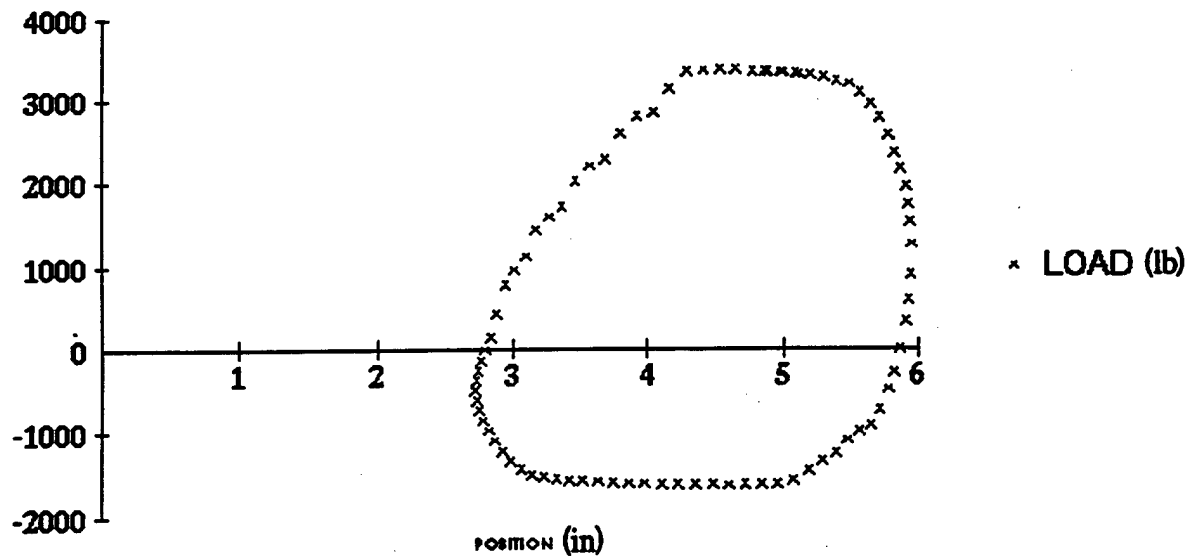


Figure 14. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 09126B3.38.

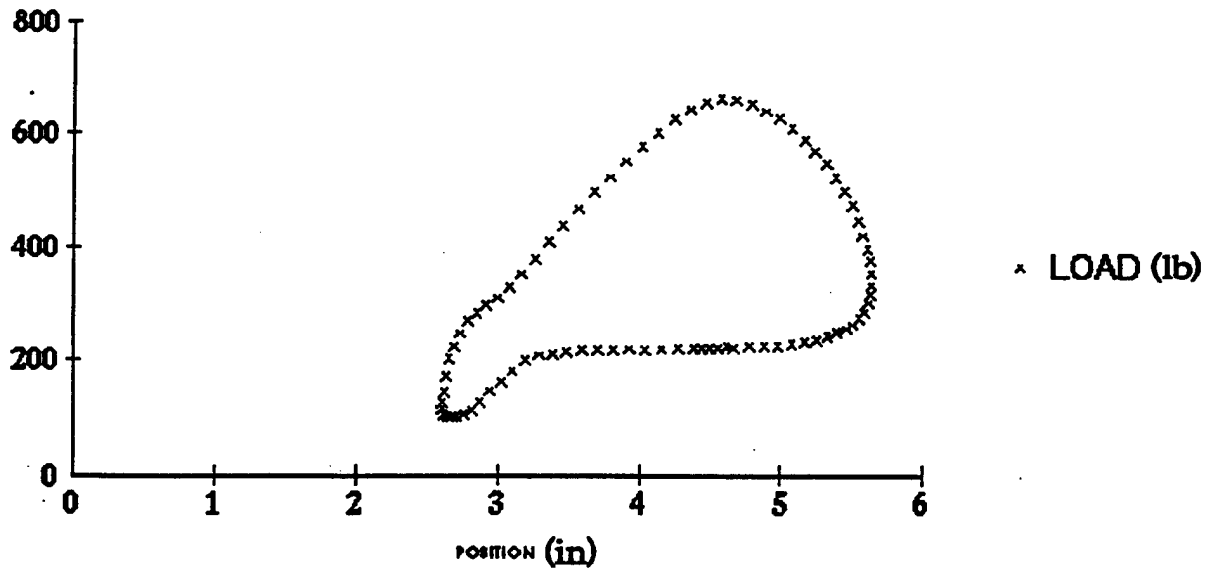


Figure 15. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 08076B3.38.

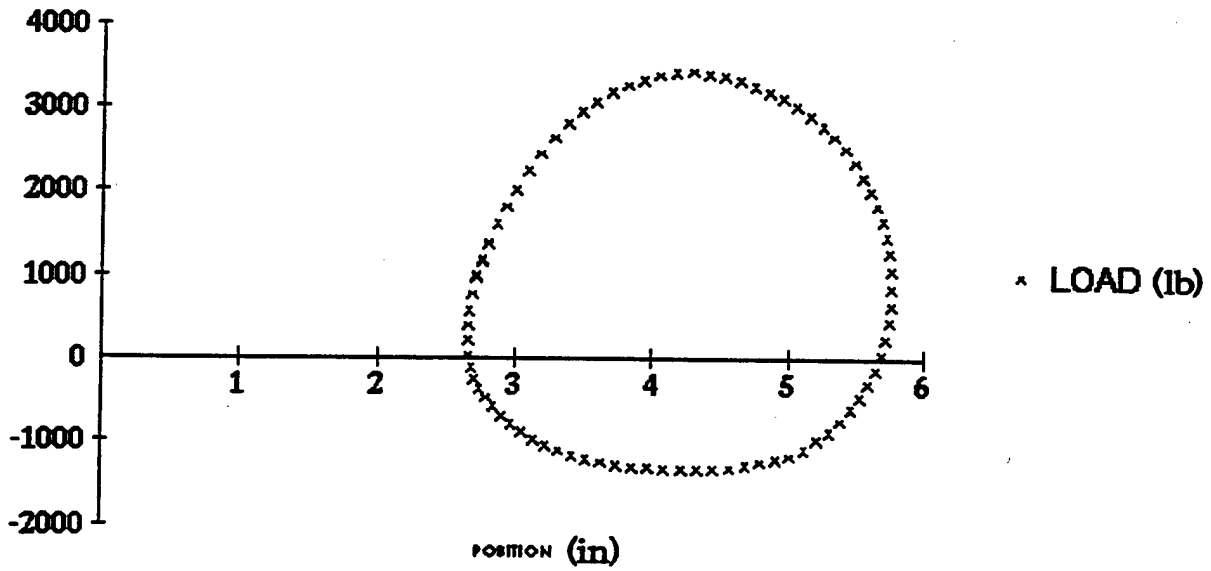


Figure 16. Load vs. Position Phase Diagram for Faulted Shock Absorber No. 08216B2.38.

application that controls acquisition, display, and analysis of testing data, performs SPC for product assurance, and plots archived data files. The shock absorber is mounted in a hydraulic test stand which oscillates the shock at a preset frequency. A DAQ system acquires data from sensors mounted to the test stand and the shock absorber. These data are analyzed in order to classify the shock absorber as nominal or faulted. If the shock absorber is classified as faulted, the data are further analyzed by a neural network based classification scheme. A fully connected feed-forward backpropagation network was successfully trained and tested to classify the faulted shock absorbers as either Fault Type 1, Fault Type 2, Fault Type 3, or Fault Type 4. These shock absorber fault characteristics are present due to physical anomalies, such as a bent rod, leaky seal, damaged casing, etc. Classifying the fault types and archiving the results enables the user to track the problems associated with the shock absorbers and to monitor any significant trends. For example, a high percentage of shock absorbers with leaky seals may represent a design problem which can be corrected by the manufacturer.

Once developed and tested, the SSATS system was transitioned to RRAD where it is being utilized to evaluate the condition of Bradley armored vehicle shock absorbers. The system was first implemented to evaluate shock absorbers that had been previously tested at RRAD by visual inspection and by a nonscientific "touch test." It was discovered that this nondiagnostic testing technique resulted in the misclassification of 40% of the shock absorbers.

The SSATS system tested and evaluated 57 shock absorbers at RRAD in August and September 1996. It was determined that 12 out of the 55 shock absorbers, approximately 22%, were nominal. It was also determined that 33 out of the 55 shock absorbers, or 60%, only failed the ML(R) load requirement. The shape of the load vs. position phase diagrams for these shock absorbers was very similar to the shape of the phase diagrams for nominal shock absorbers. In contrast, the shape of the phase diagrams for other faulted shock absorbers was dissimilar to those of nominal shock absorbers. The ML(R) specification could be considered for modification at this time. However, the ML(R) specification should remain significantly above the average ML(R) for shock absorbers that failed both ML(R) and DL(R). If the ML(R) requirement is decreased too drastically, this could result in poor shock absorbers being accepted for reuse.

The SSATS system provides an accurate functional testing capability for armored vehicle shock absorbers by implementing a neural network based classification scheme. The utilization of this system reduces vehicle downtime, resulting in an increase in combat readiness and a significant financial savings.

## 7. References

Harris, C. M., and C. E. Crede. *Shock and Vibration Control Handbook*, 3d ed., p. 395, 1988.

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**Appendix A:**  
**SSATS GUI Windows**

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# THE MAIN WINDOW

## MAIN WINDOW

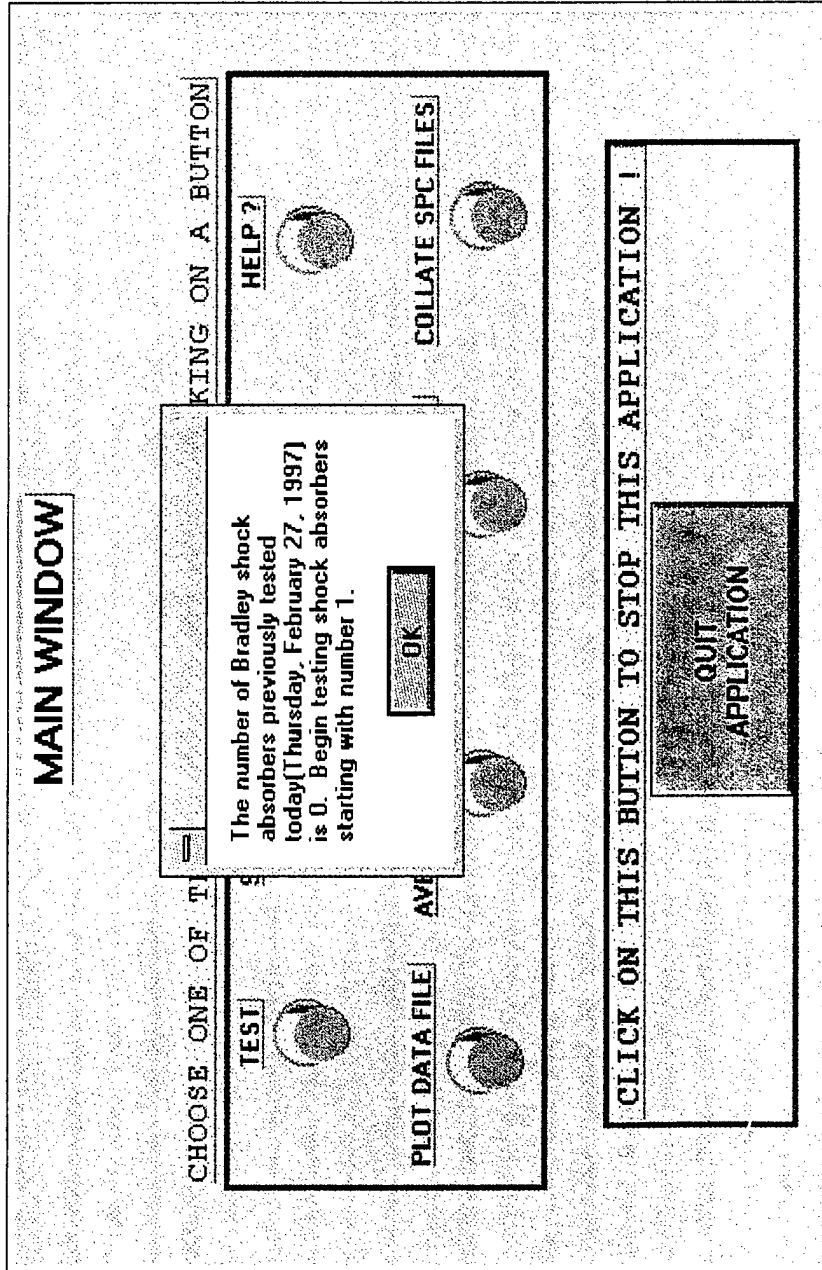
CHOOSE ONE OF THE CHOICES BELOW BY CLICKING ON A BUTTON

<input type="radio"/> TEST	<input type="radio"/> STATISTICAL PROCESS CONTROL(SPC)	<input type="radio"/> HELP ?
<input type="radio"/> PLOT DATA FILE	<input type="radio"/> AVERAGE DATA FILE	<input type="radio"/> CREATE SPC FILE
		<input type="radio"/> COLLATE SPC FILES

CLICK ON THIS BUTTON TO STOP THIS APPLICATION !

QUIT APPLICATION

# THE OPERATOR POP-UP START WINDOW



# THE SHOCK ABSORBER TESTING WINDOW

## SHOCK ABSORBER TESTING WINDOW

**Load (L) vs. Position (s)**

Y-axis: 7000.0, 6000.0, 4000.0, 2000.0, 0.0, -2000.0, -4000.0, -5000.0 [lbs]

X-axis: 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.5 [s]

**Load (K) vs. History**

Y-axis: 7000.0, 5000.0, 2500.0, 0.0, -2500.0, -5000.0 [lbs]

X-axis: 0, Time Index: 419

**Start Test**

**Exit Test Window**

**Save Data?**  YES  NO

**Retest?**  YES  NO

**View Test Help?**  YES  NO

**State of Testing**

Testing Complete

Prepare for Next Test

**Number Cycles of Data?**

5 @ 38 CPM

**Load Test Failure?**  YES  NO

**Temp Test Failure?**  YES  NO

**Reject Shock?**  YES  NO

**Frequency [CPM]** 38

**Test Result**

Faulted, Type 1

**Temperature (F) History**

500.0

400.0

300.0

200.0

100.0

0.0

0 Time Index: 419

## THE VIEW TEST HELP WINDOW

### VIEW TEST HELP WINDOW

#### **HOW TO USE THE SHOCK ABSORBER TESTING WINDOW:**

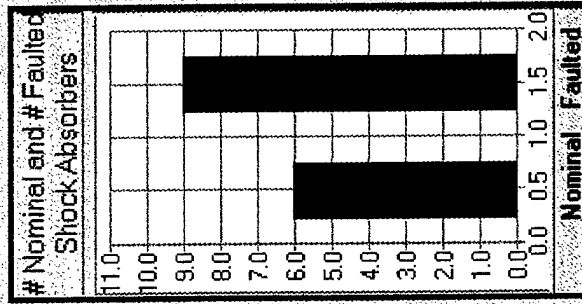
- Step 1** - Set the Save Data ? button by clicking on it with the left mouse button. The text below the Save Data ? button will indicate if data is or is not being saved.
- Step 2** - Set the Number Cycles of Data ? menu by first pressing and holding down the left mouse button after placing the mouse cursor over the downward pointing black triangle to the right of the menu. Then, while holding down the left mouse button, move the cursor such that it highlights a single menu choice. Let go of the mouse button.
- Step 3** - Set the Retest ? button by clicking on it with the left mouse button. Set it to NO if a new shock absorber is being tested; set it to YES if the same shock absorber is being retested.
- Step 4** - Click on the Start Test ! button to begin the acquisition of data. The acquisition will stop itself.
- Step 5** - Click on the Exit Test Window ! button to exit the SHOCK ABSORBER TESTING WINDOW and return to the MAIN WINDOW.

**CLICK ON THE BUTTON BELOW TO RETURN  
TO THE SHOCK ABSORBER TESTING WINDOW !**

**EXIT THIS  
WINDOW**

# THE STATISTICAL PROCESS CONTROL(SPC) WINDOW

## STATISTICAL PROCESS CONTROL(SPC) WINDOW



**Statistical Process Control Data**

# Nominal Shock Absorbers:

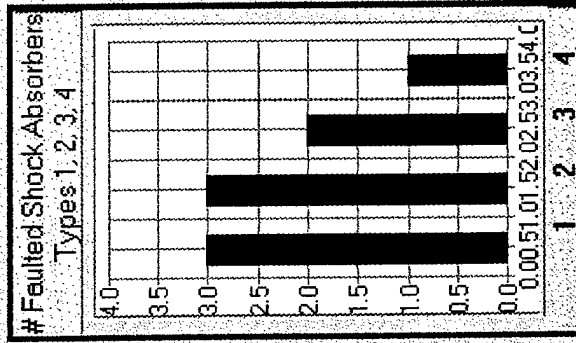
# Faulted Shock Absorbers:

# Faulted Shock Absorbers - Type 1:

# Faulted Shock Absorbers - Type 2:

# Faulted Shock Absorbers - Type 3:

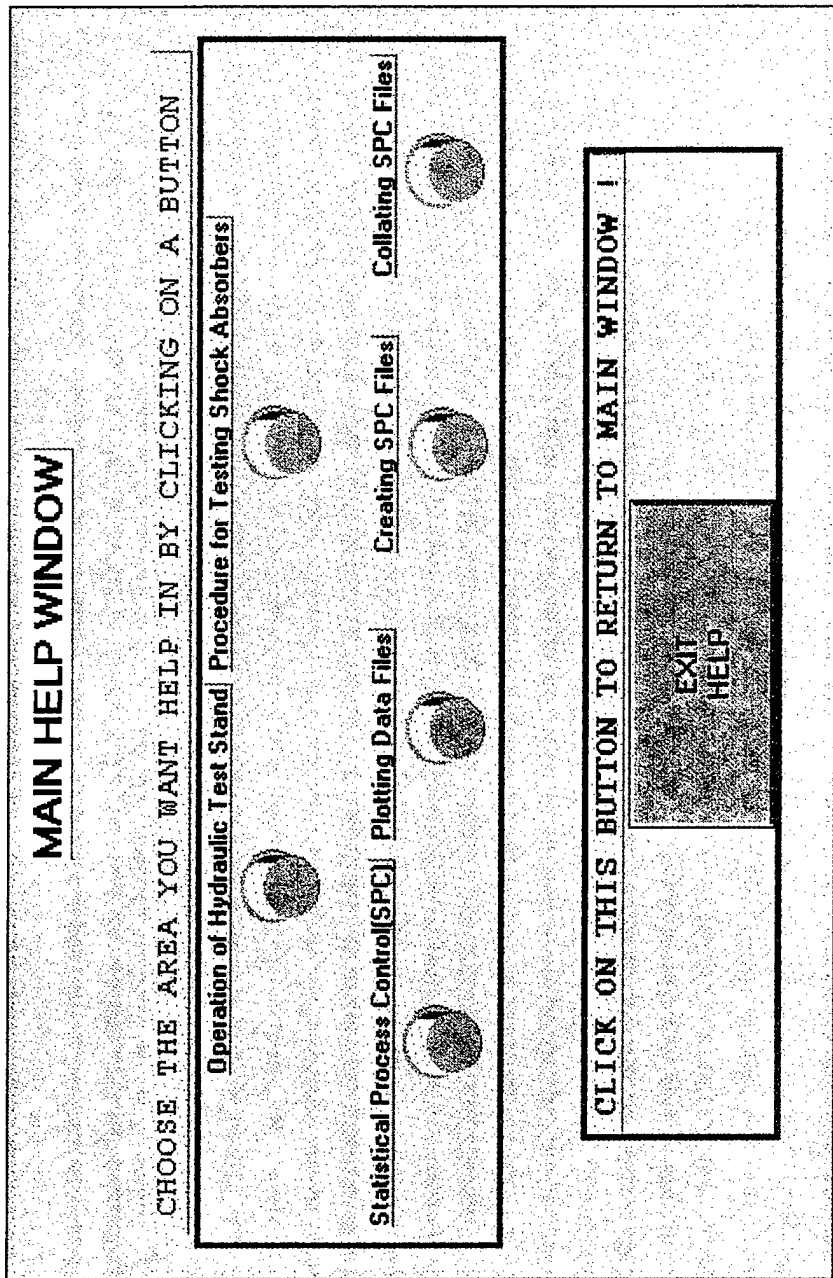
# Faulted Shock Absorbers - Type 4:



CLICK ON THIS BUTTON TO RETURN TO MAIN WINDOW!



# THE MAIN HELP WINDOW



# THE TEST STAND OPERATION HELP WINDOW

## TEST STAND OPERATION HELP WINDOW

### INFORMATION ON THIS WINDOW (TEST STAND OP HELP WINDOW)

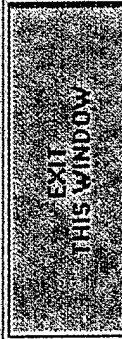
This help window is on how to pre-test and set-up the shock absorber test stand before any actual testing of shock absorbers can begin. This window also contains other general information.

### How to Pre-Test and Set-Up Shock Absorber Test Stand

- 1) Verify that main power to test stand is turned on.
- 2) On the test stand's electronic control console (ECC), set the Frequency Select switch to 38 cpm, adjust the Amplitude Control knob fully counter clockwise, set the Load Display Select switch to 0-10,000 lbs., set the Shock Absorber Select switch to 0, set the Pressure Select switch to BYPASS, and set the Position Display Select switch to MEAN.

NOTE: DO NOT start hydraulic power unit (HPU) at this time.

CLICK ON THIS BUTTON TO RETURN TO MAIN HELP WINDOW !



## THE SHOCK ABSORBER(SA) TESTING HELP WINDOW

### SHOCK ABSORBER(SA) TESTING HELP WINDOW

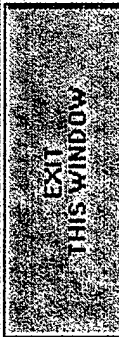
#### INFORMATION ON THIS WINDOW ((SA) TESTING HELP WINDOW)

This help window is on the procedure for testing shock absorbers to determine if they are nominal or faulted. Shock absorbers must be tested at the correct frequency and in the correct temperature range for a proper determination. The SHOCK ABSORBER TESTING WINDOW will automatically check to see if these criteria are met.

#### How To Properly Test Shock Absorbers

- 1) (See the TEST STAND OPERATION HELP WINDOW for proper pre-test and set-up of test stand unit which includes both the test stand itself and the electronic control console(ECC)).
- 2) Set Shock Absorber Select switch on ECC to 2 in order to test Bradley shock absorbers.  
Set Position Display Select switch on ECC to MEAN and verify that the Position Meter on the ECC reads approximately 4.25".
- 3) Install shock absorber:
  - a) Install lower shock absorber clevis pin. Install shock absorber with smaller diameter end down. Shock absorber can only be installed one way.

CLICK ON THIS BUTTON TO RETURN TO MAIN HELP WINDOW |



# THE SPC HELP WINDOW

## SPC HELP WINDOW

### INFORMATION ON THIS WINDOW (SPC HELP WINDOW)

This help window is on Statistical Process Control (SPC). SPC information includes two main categories of shock absorbers, which are nominal (passed mechanical testing) and faulted (failed mechanical testing), and four subcategories of the faulted shock absorbers, which are Type 1, Type 2, Type 3, and Type 4.

### How To View SPC Information

1) Click on the SPC button in the MAIN WINDOW to show the SPC WINDOW. The histogram on the left of the SPC WINDOW shows the number of shock absorbers that are currently categorized as nominal and the number that are currently categorized as faulted. The histogram on the right shows the number of shock absorbers in each of the four faulted categories. The number of shock absorbers in each category is listed between the two histograms.

CLICK ON THIS BUTTON TO RETURN TO MAIN HELP WINDOW

EXIT  
THIS WINDOW

# THE DATA FILE PLOTTING HELP WINDOW

## DATA FILE PLOTTING HELP WINDOW

### INFORMATION ON THIS WINDOW (DATA FILE PLOTTING HELP WINDOW)

This help window is on plotting existing data files. Any one of five different plots, including Load(L) vs. Position(x), Velocity(V) vs. Position(x), Load(L) vs. Velocity(V), Load(L) vs. Time(t), and Position(x) vs. Time(T), can be shown for the same data file. Two plots can be shown simultaneously.

### How To View Plots of Existing Data Files

- 1) Click on the **PLOT DATA FILE** button in the MAIN WINDOW to show the DATA FILE PLOTTING WINDOW (DFPW).
- 2) To the left side in the DFPW is **Plot.1(P1)**. Choose any one of five different plots to show in P1 by doing the following:
  - a) Locate the downward pointing black arrowhead below the text **Plot.1(P1) Choice**. Place the mouse cursor over the arrowhead. Press and keep down the left mouse button. Move the mouse in order to highlight a single plotting choice. Let go of the left mouse

CLICK ON THIS BUTTON TO RETURN TO MAIN HELP WINDOW !

EXIT  
THIS WINDOW

# THE CREATING SPC FILES HELP WINDOW

## CREATING SPC FILES HELP WINDOW

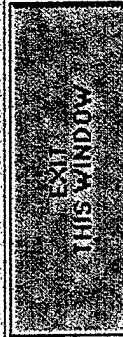
### INFORMATION ON THIS WINDOW (CREATING SPC FILES HELP WINDOW)

This help window is on creating SPC files. All SPC files follow a standard format. Each SPC file contains, in the following order, a header section, a section giving the breakdown between nominal and faulted shock absorbers, and a section giving the breakdown among only faulted shock absorbers.

### How To Create an SPC File

- 1) Click on the **CREATE SPC FILE** button in the MAIN WINDOW to produce a SPC Summary File (SPC File).
- 2) Immediately after production of the SPC file a small window will automatically pop up. This window will give the full file path of the SPC file just produced. The SPC file will contain the most recent information on number of nominal and faulted shock absorbers. Click on the "OK" in the pop up window to return to the MAIN

CLICK ON THIS BUTTON TO RETURN TO MAIN HELP WINDOW !



# THE CREATING SPC COLLATION FILES HELP WINDOW

## CREATING SPC COLLATION FILES HELP WINDOW

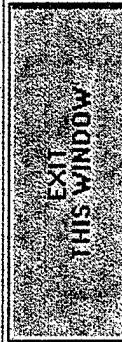
### INFORMATION ON THIS WINDOW

This help window describes the procedure for collating SPC files in each of four different ways. These include collating all SPC files created on a single day, in a single month, in a single year, or over a user-defined period.

### How To Create an SPC Collation File

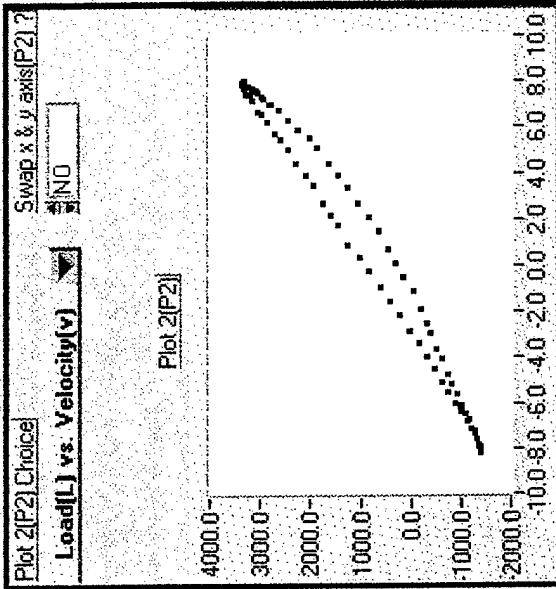
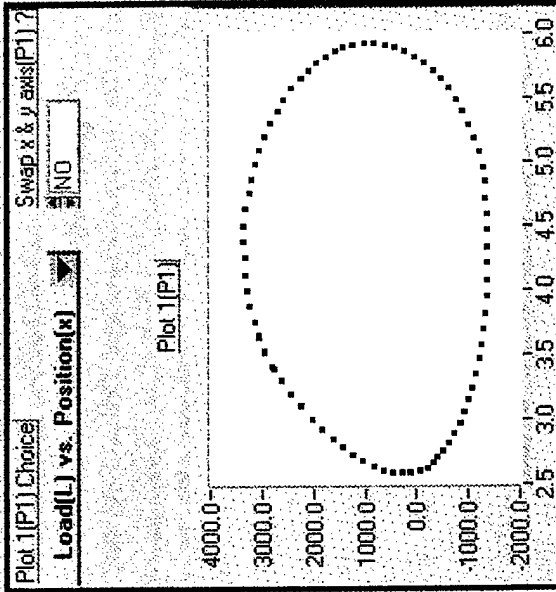
- 1) Click on the **COLLATE SPC FILES** button in the **MAIN WINDOW**. This brings up the **CHOOSE SPC FILES COLLATION PERIOD WINDOW**.
- 2) Choose Variable, 1 Day, 1 Month, or 1 Year from the SPC File Collation Period ? menu using the left mouse button. Verify the choice made in the Selection Made box and then click on the **DONE** button.
- 3) Depending on the choice made in 2) the **SELECT VARIABLE**.

**CLICK ON THIS BUTTON TO RETURN TO MAIN HELP WINDOW !**



# THE DATA FILE PLOTTING WINDOW

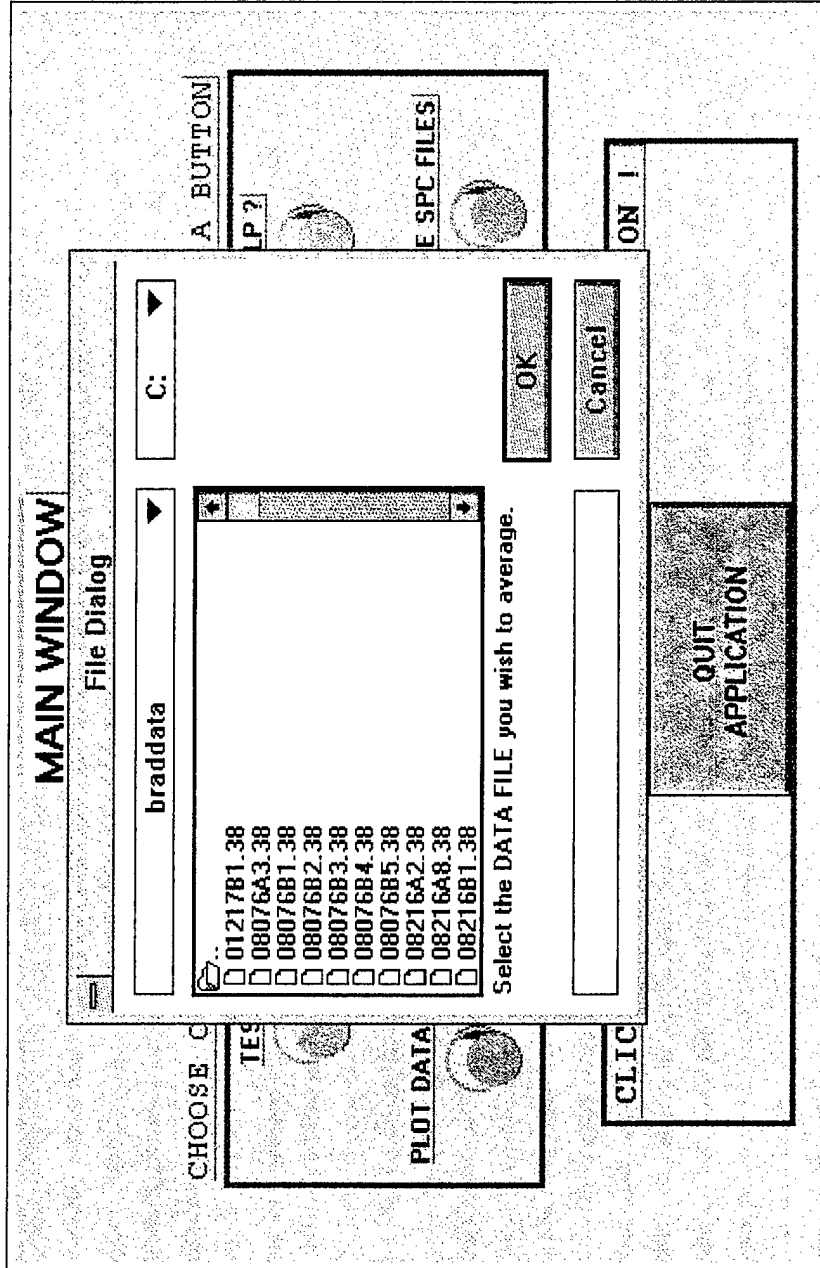
## DATA FILE PLOTTING WINDOW



Data File Path  
c:\braddata\0912686.38

Plot Data File | Exit This Window |

# THE AVERAGE DATA FILE POP-UP WINDOW



# THE CHOOSE SPC FILES COLLATION PERIOD WINDOW

## CHOOSE SPC FILES COLLATION PERIOD WINDOW

Select a period over which you want to collate SPC files below. Interpret the choices as follows: 1 Day - collate files created on the same day; 1 Month - collate files created in the same month; 1 Year - collate 1 Month files created in the same year; and Variable - collate files created between (inclusive) any two logical dates. Verify the period selected by looking at the Selection Made box and then click on the Done button below.

SPC File Collation Period ?  
Variable

Selection Made  
Variable

Click on this button to indicate done !  
DONE

# THE SELECT VARIABLE PERIOD WINDOW

## SELECT VARIABLE PERIOD WINDOW

Use the left mouse button to select the from and to (inclusive) dates defining the period over which to collate SPC files. Verify the dates by looking at the two sets of Selections Made boxes below and then click on the Done button below.

### FROM DATE (FD) ?

Day(FD) ?	Month(FD) ?	Year(FD) ?
1	January	1995

### TO DATE (TD) ?

Day(TD) ?	Month(TD) ?	Year(TD) ?
1	January	1995

### Selections Made - From Date

Day(FD)	Month(FD)	Year(FD)
1	January	1995

### Selections Made - To Date

Day(TD)	Month(TD)	Year(TD)
1	January	1995

Click on this button to indicate done !

DONE

## THE SELECT 1 DAY WINDOW

### SELECT 1 DAY WINDOW

Use the left mouse button to select the particular day in the particular month of the particular year to collect SPC files for. Verify the date by looking at the Selections Made boxes below and then click on the Done button below.

Day ?	Month ?	Year ?
1	January	1995

#### Selections Made

Day	Month	Year
1	January	1995

Click on this button to indicate done !

DONE

# THE SELECT 1 MONTH WINDOW

## SELECT 1 MONTH WINDOW

Use the left mouse button to select the particular month of the particular year to collate SPC files for. Verify the month and year by looking at the Selections Made boxes below and then click on the Done button below.

Month ?	Year ?
January	1995

### Selections Made

Month	Year
January	1995

Click on this button to indicate done !

DONE
------

# THE SELECT 1 YEAR WINDOW

## SELECT 1 YEAR WINDOW

Use the left mouse button to select the particular year to collate SPC files for. Verify the year by clicking at the Selection Made box below and then click on the Done button below.

Year ?  
1995

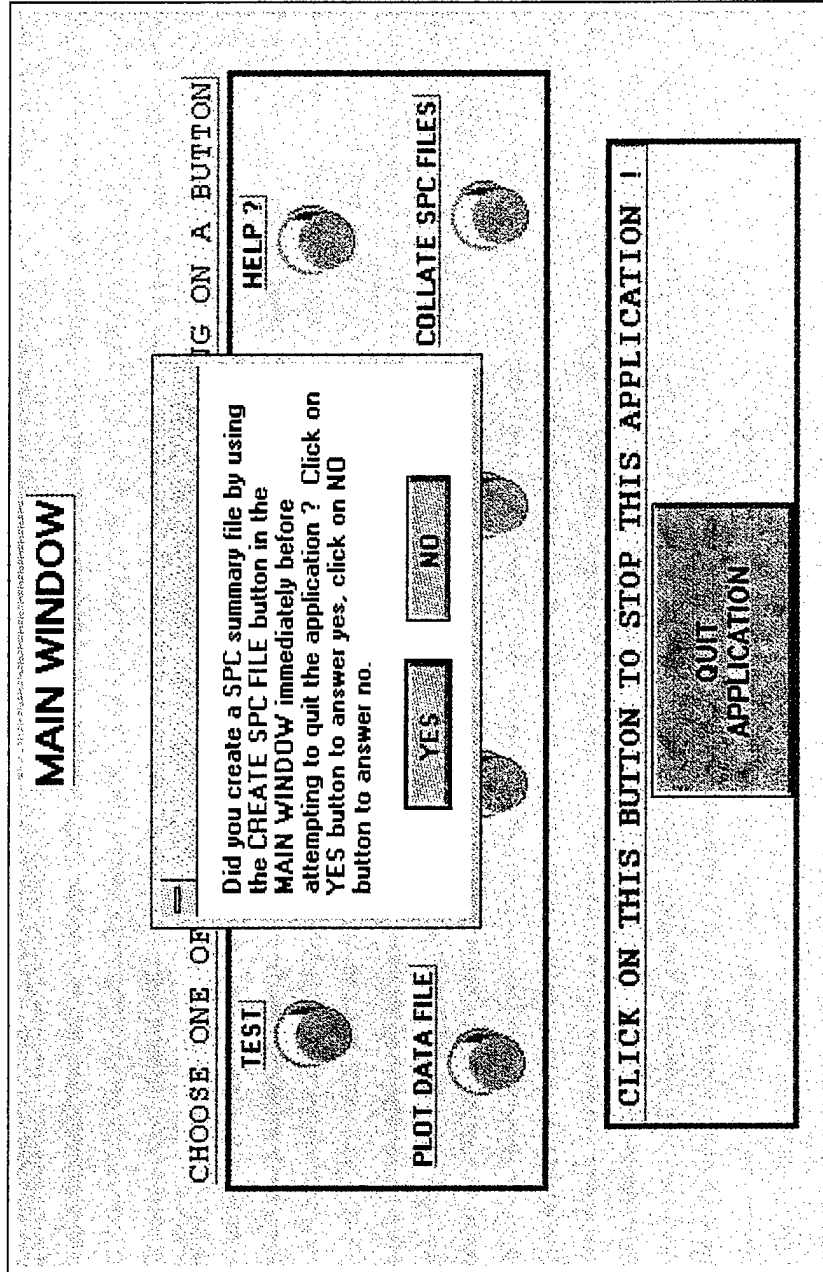
Selection Made

Year  
1995

Click on this button to indicate done !

DONE

# THE SPC POP-UP EXIT WINDOW



**Appendix B:**  
**Load Values**

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Shock Absorber	ML(C) (lb)	ML(R) (lb)	DL(C) (lb)	DL(R) (lb)
08076B1	4,072.27	1,584.07	3,052.92	1,181.31
08076B2	3,724.02	1,661.73	2,765.81	1,417.35
08076B3	589.90	219.63	296.18	241.61
08076B4	4,266.68	1,821.03	2,113.51	1,440.19
08076B5	4,208.92	1,828.55	2,302.00	1,480.47
08216B1	3,299.79	1,458.78	1,838.99	676.45
08216B2	3,386.02	1,319.16	1,900.45	630.78
08216B3	1,312.41	489.40	662.64	39.44
08216B4	3,800.34	1,595.17	2,554.16	1,192.75
08216B5	3,712.48	1,584.72	2,242.92	999.47
08216B6	4,111.43	1,542.53	2,741.77	971.23
08216B7	4,154.77	1,745.90	2,825.54	1,203.83
08216B8	4,069.69	1,618.87	2,700.60	960.31
08216B9	4,601.31	1,864.87	3,456.78	1,496.90
08216B10	4,238.15	1,809.19	3,239.38	1,495.59
08216B11	3,997.82	1,612.05	2,616.41	963.51
08216B12	4,013.38	1,751.12	2,758.00	1,200.16
08216B13	3,780.74	1,609.23	2,508.72	1,117.08
08216B14	4,096.91	1,542.53	2,986.09	1,248.02
08236B1	3,973.17	1,635.56	2,690.17	1,147.65
08236B2	4,075.77	1,631.17	2,782.38	1,133.34
08236B3	4,050.39	1,584.48	2,639.43	990.93
08236B4	3,986.68	1,584.85	2,900.84	1,189.36
08236B5	4,125.01	1,807.15	2,833.04	1,351.95
08236B6	4,127.13	1,686.16	2,915.53	1,157.27
08236B7	3,834.70	1,647.62	2,438.39	976.05

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## **Appendix C**

### **M(=Met) / F(=Failed) Values**

**INTENTIONALLY LEFT BLANK.**

Shock Absorber	ML(C)	ML(R)	DL(C)	DL(R)
08076B1	M	F	M	M
08076B2	M	F	M	M
08076B3	F	F	F	F
08076B4	M	M	M	M
08076B5	M	M	M	M
08216B1	M	F	M	F
08216B2	M	F	M	F
08216B3	F	F	F	F
08216B4	M	F	M	M
08216B5	M	F	M	M
08216B6	M	F	M	M
08216B7	M	M	M	M
08216B8	M	F	M	M
08216B9	M	M	M	M
08216B10	M	M	M	M
08216B11	M	F	M	M
08216B12	M	M	M	M
08216B13	M	F	M	M
08216B14	M	F	M	M
08236B1	M	F	M	M
08236B2	M	F	M	M
08236B3	M	F	M	M
08236B4	M	F	M	M
08236B5	M	M	M	M
08236B6	M	M	M	M
08236B7	M	F	M	M

Shock Absorber	ML(C)	ML(R)	DL(C)	DL(R)
08236B8	M	F	M	M
08236B9	M	F	M	M
08236B10	M	F	M	M
08236B11	M	F	M	M
08236B12	M	F	M	M
09126B1	M	F	M	M
09126B2	M	M	M	M
09126B3	M	F	F	M
09126B4	M	F	M	M
09126B5	M	F	M	M
09126B6	M	F	M	F
09126B7	M	F	M	M
09126B8	M	M	M	M
09126B9	M	F	M	F
09166B1	M	F	M	M
09166B2	M	F	M	F
09166B3		Invalid Test - Temperature Out of Range		
09166B4	M	F	M	F
09176B1	M	F	M	M
09176B2		Invalid Test - Temperature Out of Range		
09176B3	M	M	M	M
09186B1	M	F	M	F
09186B2	M	F	M	M
09186B3	M	F	M	M
09186B4	M	F	M	M
09186B5	M	F	M	M

Shock Absorber	ML(C)	ML(R)	DL(C)	DL(R)
09186B6	M	F	M	M
09186B7	M	F	M	M
09186B8	M	M	M	M
09186B9	M	F	M	M
09186B10	M	F	M	M

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**Appendix D:**  
**Faulted Classification Results**

**INTENTIONALLY LEFT BLANK.**

Shock Absorber	Type (1, 2, 3, or 4)
08076B1	1
08076B2	4
08076B3	2
08216B1	1
08216B2	4
08216B3	1
08216B4	1
08216B5	1
08216B6	1
08216B8	2
08216B11	2
08216B13	1
08216B14	1
08236B1	1
08236B2	4
08236B3	1
08236B4	2
08236B7	1
08236B8	2
08236B9	1
08236B10	2
08236B11	1
08236B12	1
09126B1	1
09126B3	1
09126B4	2

Shock Absorber	Type (1, 2, 3, or 4)
09126B5	2
09126B6	2
09126B7	1
09126B9	1
09166B1	1
09166B2	2
09166B4	2
09176B1	1
09186B1	1
09186B2	1
09186B3	1
09186B4	1
09186B5	1
09186B6	1
09186B7	1
09186B9	2
09186B10	1

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1	PRIN DPTY FOR TCHNLGY HQ US ARMY MATCOM AMCDCG T M FISETTE 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	PRIN DPTY FOR ACQUSTN HQS US ARMY MATCOM AMCDCG A D ADAMS 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	DPTY CG FOR RDE HQS US ARMY MATCOM AMCRD BG BEAUCHAMP 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001

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6. AUTHOR(S)  Patrick Sincebaugh, William Green, and Gerard Rinkus*				
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13. ABSTRACT (Maximum 200 words)  In this report we describe a diagnostic system that is being utilized to evaluate the condition of armored vehicle shock absorbers. We begin by providing the motivation behind the development of the smart shock absorber test stand (SSATS). We then describe the theory required to evaluate the condition of shock absorbers. This theoretical discussion leads to a description of what real life data are acquired during a shock absorber test, and how it can be analyzed to determine the condition of a shock absorber. We then explain the design and capabilities of the SSATS graphical user interface (GUI), which includes the integration of a neural network classification scheme. We finish by discussing recent results of utilizing the system to test and evaluate Bradley armored vehicle shock absorbers.				
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