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14. ABSTRACT

This TOP describes performance testing of explosive components employed in missile and rocket systems. Components such as safe and arm firing devices, initiators, linear shaped charges, exploding bridgewires, explosive transfer line assemblies, etc. are subjected to a series of environmental tests followed by a function or final performance test. The performance test verifies compliance to all requirements as specified by the missile or component specification. Data from these tests are used mainly for test and evaluation purposes but could be used to support aging surveillance assessment programs. Typically, 10% of the explosive component population or lot is selected for performance testing. Successful completion of testing will result in a shelf life of 5 years starting from the test completion date.

15. SUBJECT TERMS

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Resistance Measurement
Detonation Velocity
Penetration Measurement
Missile Ordnance
Flight Safety Components
Environmental Test
Climatic Testing
Aging Surveillance

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

Test Operations Procedure (TOP) 5-2-522 20 November 2007
DTIC AD No.

PERFORMANCE TESTING OF EXPLOSIVE COMPONENTS

1. SCOPE.

a. This TOP describes performance testing of explosive components employed in missile and rocket systems. Components such as safe and arm firing devices, initiators, linear shaped charges, exploding bridgewires, explosive transfer line assemblies, etc. are subjected to a series of environmental tests followed by a function or final performance test. The performance test

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verifies compliance to all requirements as specified by the missile or component specification. Data from these tests are used mainly for test and evaluation purposes but could be used to support aging surveillance assessment programs.

b. Typically, 10% of the explosive component population or lot is selected for performance testing. Successful completion of testing will result in a shelf life of 5 years starting from the test completion date.

c. This document provides guidance for test planning, execution, and reporting by DTC test centers. Test requirement formulation, test procedures, and test results are discussed in this TOP.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
Firing Test Cell	Selected to provide adequate protection for personnel and equipment suitable for function testing of explosive components.
Temperature Facility	To be able to condition the test item to the required temperatures and relative humidity from 5 to 95 percent. It is recommended that temperature chambers be able to condition ordnance from -54°C to 71°C.
Vibration Facility	Vibration equipment suitable for subjecting explosive components to extreme acceleration levels at temperature extremes.
Shock Test Facility	Shock test equipment suitable for subjecting explosive components to high g levels at temperature extremes.
Centrifuge Facility	Acceleration equipment suitable for subjecting explosive components to constant g-levels at temperature extremes.
Radiographic Facility	X-ray cameras and exposure processing equipment suitable for radiographic testing of explosive items.

2.2 Instrumentation.

Devices for Measuring	Measurement Uncertainty (2σ)
Temperature	0.7ºC
Humidity	As required
Acceleration	As required
Pressure	10 Pa
Initiation Time	As required
Penetration Depth	0.5 mm
Recording of Test Events	As required
Meteorological Conditions	As required
Electrical Performance	As required

2.3 Test Controls. Unless otherwise specified in an individual procedure, all tests shall be performed at the following atmospheric conditions.

Temperature	20 to 30°C (60 to 95°F)
Relative Humidity	30 to 90 percent
Pressure	Local ambient

2.4 Tolerance For Test Conditions. Unless otherwise specified, tolerances for test conditions shall be as follows:

a. Temperature. The temperature of the test section measurement system and the temperature gradient throughout this envelop, which is measured closed to the test item, shall be within ±2ºC (± 3.6ºF) of the test temperature.

b. Electrical. The input voltage and current of the power supply shall be within ± 1% of the actual firing test requirement.

2.5 Equipment Calibration.

a. All test equipment shall be calibrated in accordance with International Standards Organization (ISO) 10012-1[1][*] with calibration traceable to the National Institute of Standards and Technology. All calibration records shall be maintained on file and made available for inspection as required.

b. The accuracy of instruments and test equipment used to control or monitor the test parameters shall be verified prior to and following each test then calibrated in pre-determined intervals and shall meet the requirements of ISO 10012-1 to the satisfaction of the procuring activity.

3. REQUIRED TEST CONDITIONS.

3.1 Test Objectives and Approach. Functional testing verifies compliance to performance requirements as specified by the missile specification. The components are generally subjected to environmental tests, with inspections at various points in the test sequence to monitor component health. Function testing is performed after completion of all environments. Post-test assessment and visual inspections are performed to ensure that all ordnance devices initiated as required and all explosives were consumed in test.

3.2 Test Requirements.

a. A thorough environmental qualification test series will be performed on all critical ordnance components prior to functional test. Generally, the test series includes pre and post visual and radiographic inspection, pre and post electrical checks (insulation resistance, bridgewire resistance, and/or grid dip), temperature cycling, shock, and vibration tests. Additional tests may be required and can be determined from the missile specification requirements. In the absence of documentation, perform a review of the system's Life Cycle Environmental Profile (LCEP) to determine the necessary tests and appropriate test sequence. Further LCEP guidance may be found in STANAG 4370[2]. Further information regarding electrical tests can be found in MIL-STD-1576[3] and MIL-HDBK-1512[4].

b. Test Sequence. A typical environmental test series is shown in Figure 1.

c. Performance at Temperature. The unit is often function tested at the temperature extremes in order to determine the effect of temperature on the range of performance.

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[*] Superscript numbers correspond to those found in Appendix C, References.

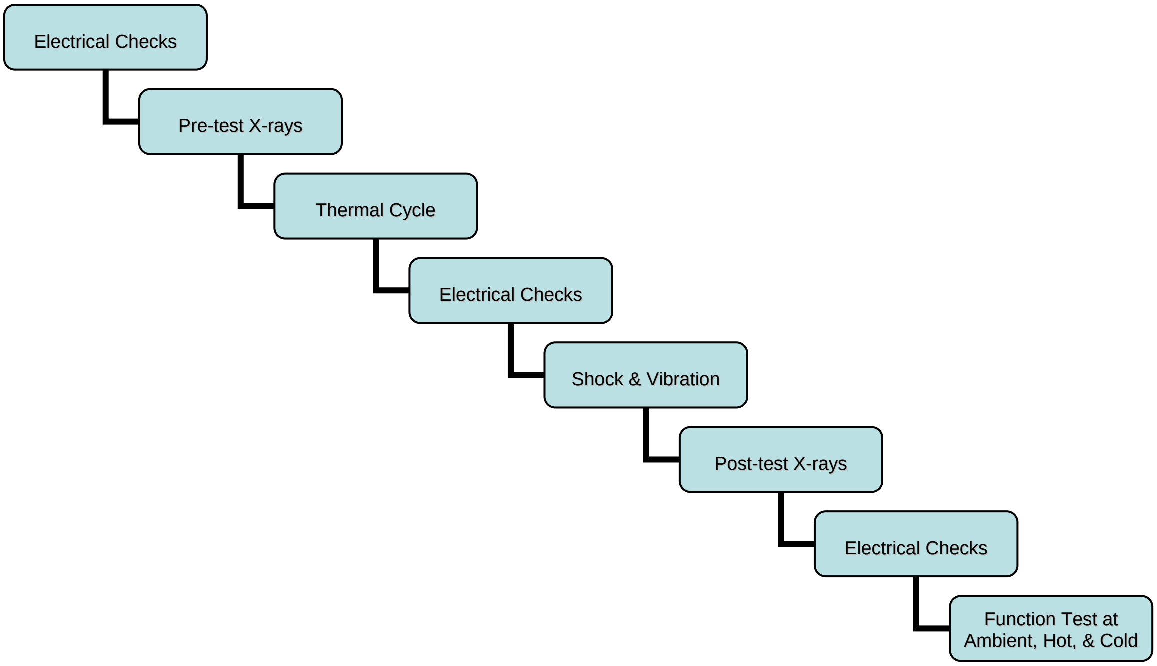


Figure 1. Typical Test Sequence

3.3 Test Components. Typical ordnance components being utilized in missile designs and subjected to these tests are: Explosive Bridgewires (EBWs) Detonators, Safe and Arm Firing Devices, Linear Shape Charges, Explosive Transfer Leads, Frangible Sectors, Gas Generators, Arm and Disarm Switches, Flexible Confined Detonating Cord Assemblies (FCDCA), etc.

3.4 Sample Size Requirements.

a. A typical test sample size is 10% of each selected lot. If the lot size is too small such that the number of assets would significantly deplete the stockpile, then select 20% of the lot for test.

b. If the component is made by two or more manufacturers, determine if it is necessary to test each manufacturer's unit. The number of assets in the inventory may determine which manufacturer's component is tested. Typically, a test sample size of 10% is selected from each lot and from each manufacturer.

3.5 Test Failure. The following conditions constitute a test item failure.

a. Non-fulfillment of safety requirements or the development of safety hazards.

b. Non-fulfillment of specific test item performance requirements.

c. Deviation from established environmental requirements.

3.6 Disposition of Material. Any item (s) that may contain explosive materials after completion of the tests will be released to Explosive Ordnance Disposal (EOD) personnel for disposal. All other materials will be recovered and disposed of in accordance with all local and state environmental regulations.

3.7 Safety Requirements.

a. Follow the local Safety Standing Operating Procedure (SSOP) when conducting operations with explosive components. Personnel involved in test operations shall be thoroughly aware of the hazards and take appropriate precautions to conduct operations in a safe manner.

b. Care will be taken to limit personnel exposure to a minimum number of personnel, for a minimum time, to a minimum amount of hazardous material consistent with safe and efficient operations. Access to the area will be restricted via locked gates and roadblocks. Ensure arming crew bunkers or barricades are available for test personnel and the required fire symbols are posted.

c. Any explosive item deemed too dangerous to handle or store will not be touched. The area will be cleared and the appropriate personnel will be notified for disposition instructions.

d. Test personnel shall utilize grounding strap (s), wrist stats and wrist stat tester (Semtronics Model 400 or equivalent) when handling the explosive components. Use appropriate low current instrumentation such as the Valhalla Model 4314AN Igniter Circuit Tester or equivalent when conducting Bridgewire resistance measurements.

4. TEST PROCEDURES.

4.1 General. The primary objective of this test is to ensure component performance is within system specification; i.e., successful ordnance operation during the function tests. The procedures below assume the explosive components have successfully passed all inspection, electrical, and environmental tests similar to those in the sequence of Figure 1.

4.2 Test Conduct.

a. Prior to testing, the ordnance component may need to be assembled per specification and configuration will be controlled by such specifications. Upon completion of final inspections, the units and the test fixture will be made ready for function testing in the ordnance bunker and /or detonation test bay. Instrumentation will be installed on the test fixtures (witness plate, pressure bomb, etc) as appropriate and operationally checked. Instrumentation and video recording systems will also be prepared and certified as being test ready. If the components are to be functioned at hot or cold temperatures, verify that the climatic chamber can achieve the required temperature condition.

b. Verify all electrical sources used to function the component provide adequate voltage and current. Wiring guidance may be found in Harper[5].

c. Temperature Conditioning. Functioning of the ordnance may be required to be performed at the weapon system operational temperatures (hot and cold). Place the ordnance inside the climatic chamber. Install the necessary temperature measuring device (thermocouples) on the test item and in the chamber. Verify operation of the chamber and the data acquisition equipment. Start temperature conditioning by raising the temperature to the high temperature limit within the required period of time, i.e. at the specified temperature rate of change. Hold the chamber temperature until stabilization occurs. Stabilization has occurred when the responding thermocouple of the test item is within 3ºC (5ºF) of the specified temperature extreme. Once stabilized, maintain conditioning for two hours prior to functioning the component. Repeat the above for the low temperature extreme components.

d. Function Test. Remove the explosive component from the climatic chamber and quickly install it into the test firing fixture. Note the firing should occur within a five minute time interval in order to maintain temperature conditions. Make any last minute instrumentation adjustments. When all non-essential personnel have evacuated the test cell, the arming crew installs the arming and firing line. The arming crew retreats to the firing location, ensures all personnel have evacuated the test cell and begins the test countdown. The instrumentation and video recorders are turned on at least 10 seconds prior to activating the firing command. Activate the fire command. The explosive component should function but if it doesn't, repeat the fire command several times. If it doesn't fire, the arming crew shall disconnect the firing line from the firing point and wait the prescribed time as defined in the SOP (usually 30 minutes) before returning to the test cell to investigate the cause of the no fire situation. Continue recording data in case of a delayed firing. If the component does fire, the arming crew shall again wait the prescribed time before returning to the test cell to inspect the area. If there is no hazardous debris or gases in the area, the all clear signal may be given and the test personnel can begin preparations to test the next component.

4.3 Data Acquisition Procedures.

a. Function Time Measurement. The function time, measured from current application to detonation, can be determined using a breakwire made from a one mm pencil lead mounted on the explosive component. A simulated breakwire voltage is applied from 1.5 VDC to zero VDC to accurately mark the detonation time. Another technique uses the firing current and an accelerometer installed on the exterior of the firing chamber to measure the function time. Both implements can be installed to provide redundant function time information. A typical function time measurement setup is shown in Figure 2. Note, the data acquisition system needs to have a sampling rate of at least 20,000 samples per second.

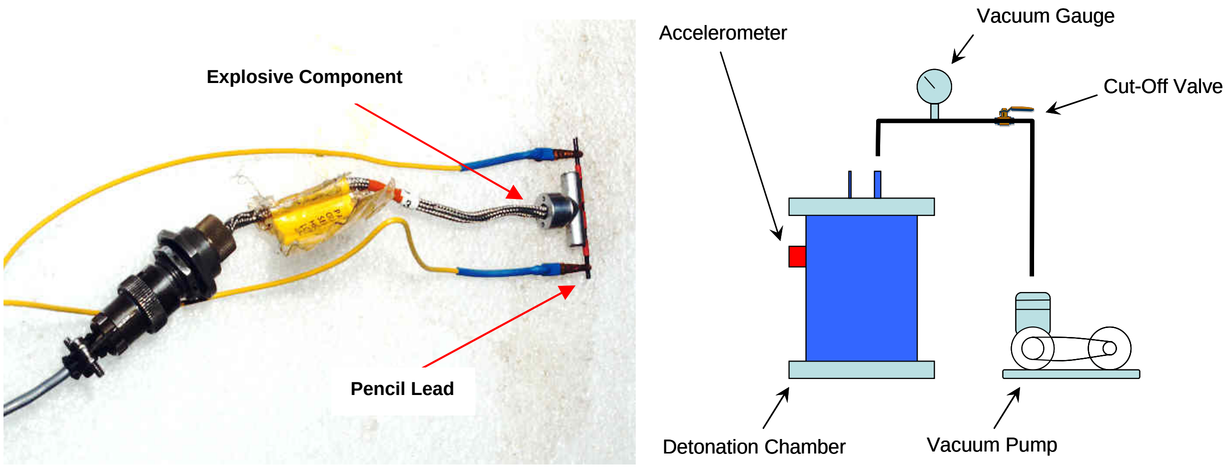


Figure 2. Breakwire and Accelerometer Installation Examples

b. Dent Block Depth of Penetration Measurement. The dent block depth of penetration can be measured using multiple dial indicators as shown in Figure 3. A typical depth of penetration is approximately 10 to 20 mils for small detonators such as EBWs, Delta-V initiators, and Pyrotechnic Valve initiators. The detonator, sleeve, and the dent block assembly are installed into the firing fixture which is designed to assure that the assembly remains in proper alignment. It is important that the firing end of the sleeve is flush against the dent block. If the firing end of the detonator extends too far, the detonator may be loosened in the sleeve to allow it to be flush. If the detonator does not extend far enough, the sleeves are too long and will have to be reworked. An example dent block fixture with witness plate test results is shown in Figure 4.

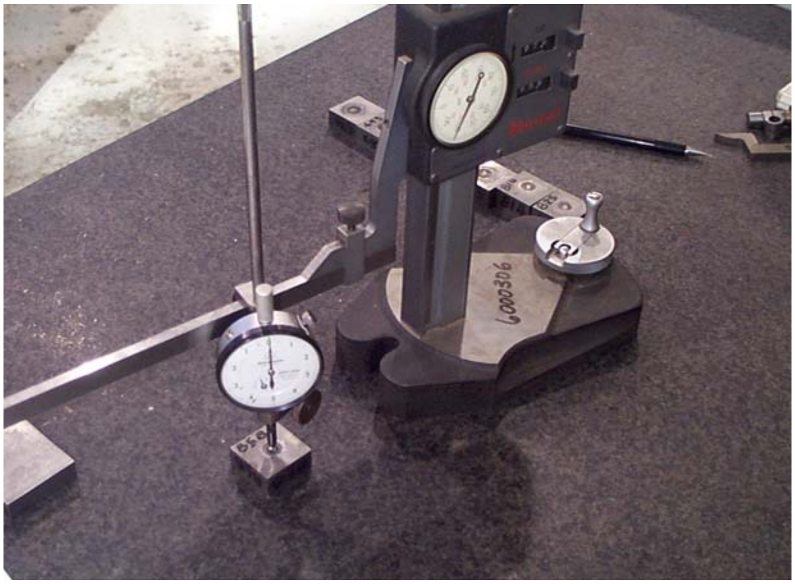


Figure 3. Dent Block Depth Measuring Device - Dial Indicators

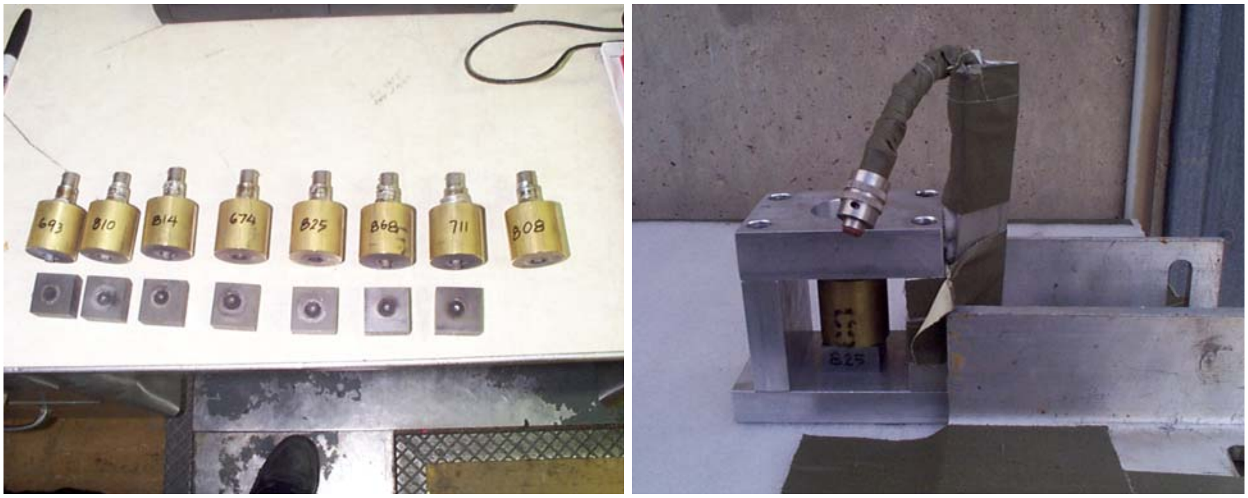


Figure 4. Dent Block Firing Fixture and Witness Plates

c. <u>Pressure Measurement.</u> The pressure generated by the ordnance system can be measured using an aluminum pressure bomb. In this application, the bomb is 10 cm in diameter and has a total free volume of 1442 ± 16 cm^3 (not including the volume displaced by igniter). The pressure bomb has two pressure transducer port provisions. An example pressure bomb is shown in the photographs of Figure 5. The igniter is coated with grease and screwed into the end of the bomb and is then initiated by applying a typical all-fire constant current. The chamber pressures are recorded using a data acquisition system having a sampling rate of 20,000 samples per second.

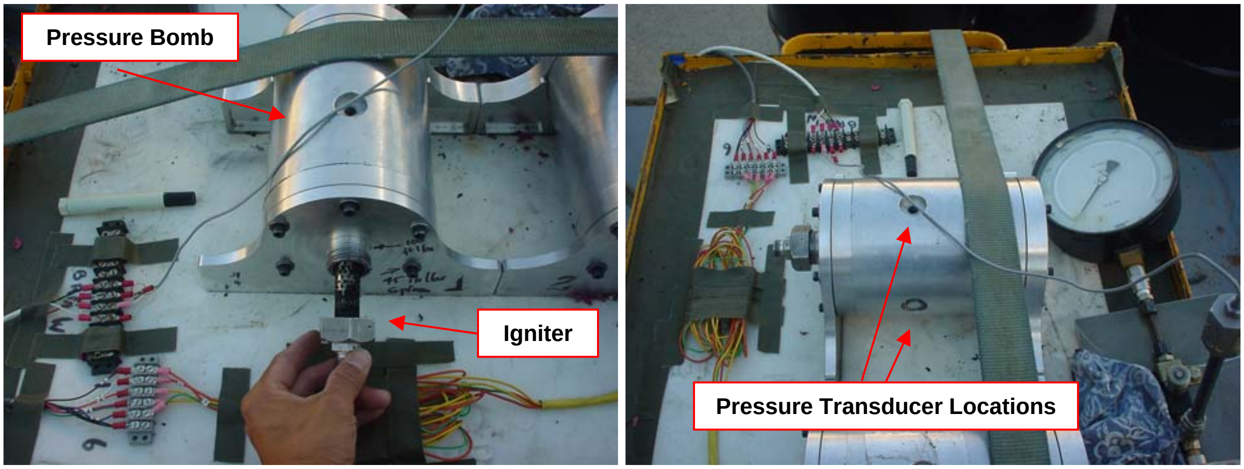


Figure 5. Pressure Bomb Installation

d. Linear Shape Charge (LSC) Penetration Measurement. The LSC depth of penetration can be measured using the steel or aluminum witness plates, as shown in Figure 6. The hardness of the witness plates must be known prior to the initiation and is usually specified in the component test specification. The LSC depth of penetration (Figure 7) is usually measured at four or more points (depending upon the length of the charge) in the cut using multiple dial indicators as shown in Figure 3.

e. Detonation Velocity Measurement. The velocity of detonation can be measured using two breakwires. Each wire is biased by a 1.5 V DC battery via a 100 Ω load at the input. Each of the breakwires are placed underneath the LSC and connected to the data acquisition system. The data acquisition system in this case must be capable of at least 50,000 samples per second. A typical example of this setup and test result is provided in Figure 8.

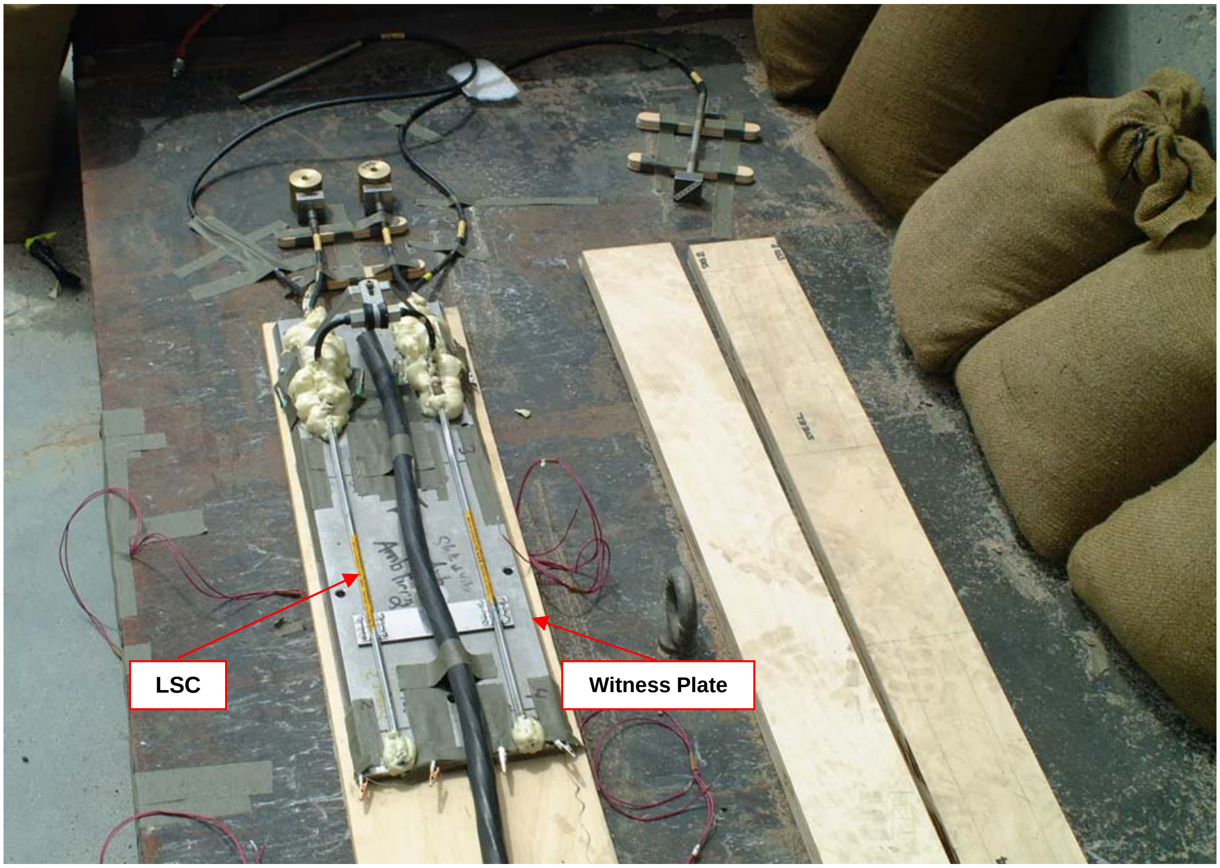


Figure 6. LSC Pre- Function Test Setup

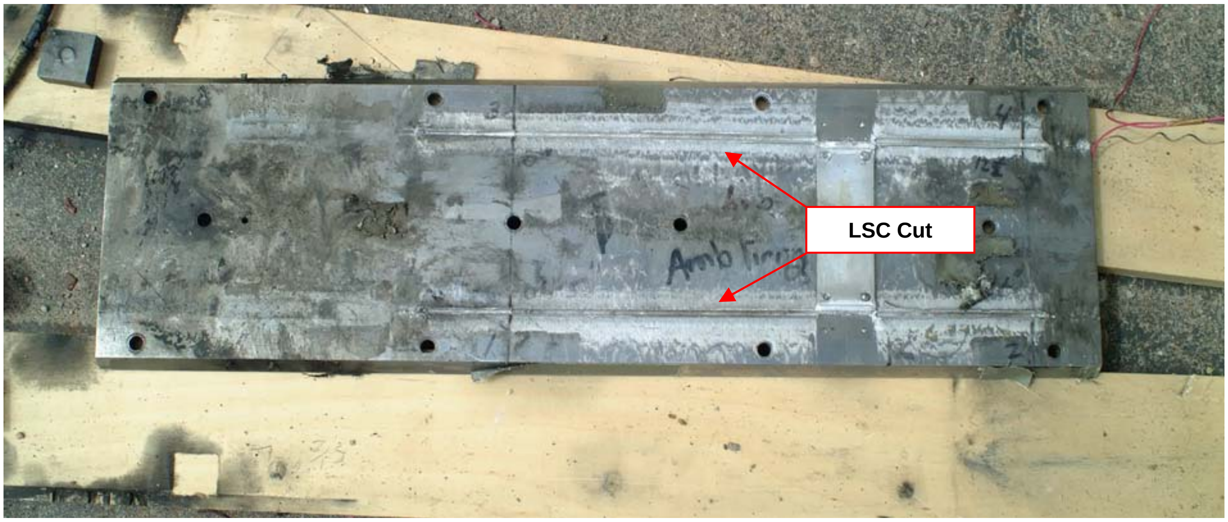


Figure 7. Witness Plate Post-Function Test Results

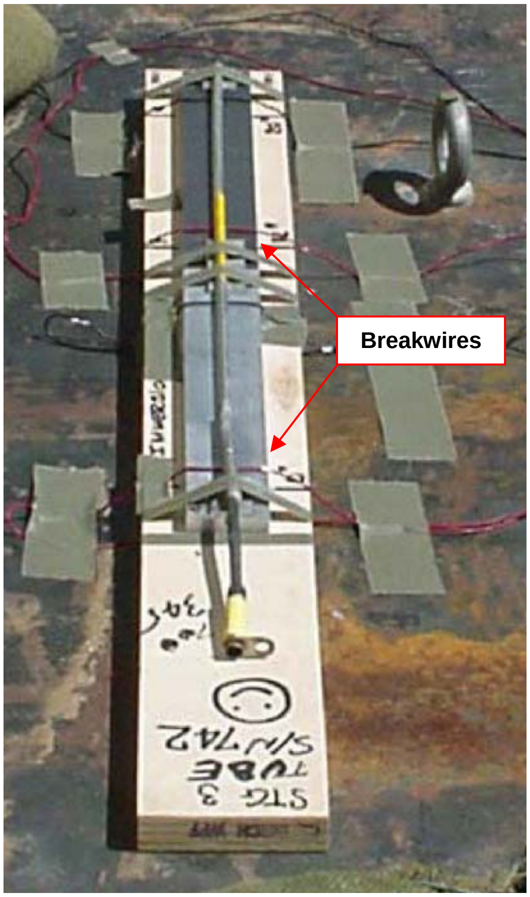


Figure 8. Typical Velocity of Detonation Setup

5. DATA REQUIRED.

a. Test item descriptions to include pre and post-test inspection and radiograph results.

b. Environmental test sequence and test specification parameters such as, temperature, humidity, acceleration, vibration levels, shock levels, altitude, test duration, etc.

c. Explosive component electrical parameters such as input voltage and current, bridgewire resistance, case insulation resistance, etc.

d. Test equipment descriptions.

e. Instrumentation locations.

f. Data recordings.

g. Acceleration, temperature, altitude, and humidity time histories (if applicable).

h. Detonation pressure versus time data.

i. Witness plate or dent block hardness values prior to the function test.

j. Witness plate results (depth of penetration).

k. Detonation velocity.

l. Descriptions of any failures, test item or equipment.

m. Test logs and documentary photographs/video of the test setups and performance test results.

6. PRESENTATION OF DATA.

Test data may be presented in the form of plots, checklists, or tables similar to those shown in Appendix B.

APPENDIX A. BACKGROUND

1. Components. All of the explosive components tested in this TOP are utilized as Flight Termination System (FTS) components and as such require very rigorous testing. The components are briefly described below.

a. Arm and Disarm Switch. The Arm and Disarm switch is used in the control of initiation circuits for stage separations, gas generators for stage liquid injection thrust vector/ roll control, and for stage thrust termination.

b. Frangible Sector. The Frangible Sectors are used in the Motor Thrust Termination (TT) ports to provide a means for both tactical and flight safety thrust termination. Upon command, four frangible sectors simultaneously fragment disabling the TT port snap rings. Due to the disabled snap rings, the internal pressure of the motor forces the TT closures open. Forward thrust is subsequently terminated.

c. Linear Shape Charge Assembly. The LSCA is comprised of an inert manifold and approximately 3 meters of two parallel leg/U–bend linear shape charge containing high explosives. Length of the assembly can vary depending upon the missile.

d. Explosive Bridgewire. The EBW detonator is currently being used as part of the FTS on target missile systems. The EBW consists of an EBW header assembly with a single gold bridgewire and a PETN bridgewire charge. There is a stainless steel detonator body which contains a transfer charge and a PETN output charge. When the detonator is installed, the output charge of the detonator is in close proximity to the ordinance device to be initiated.

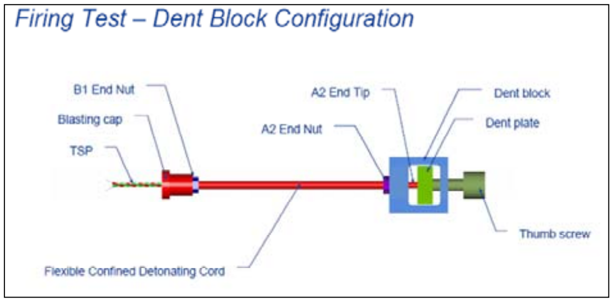
e. Altitude Control System Explosive Valve Squib. The Squib contains two roll thruster assemblies and one pitch and yaw thruster assembly. Gaseous nitrogen is stored in a pre-charged pressure vessel. The system is energized by an IEU command to a squib actuated valve in the supply line from the pressure vessel. The high pressure gas is directed to a regulator that drops the thruster inlet gas to its 2068 kN/m^2 (300 psi) operating pressure. The nitrogen cylinder is a Kevlar 49 wrapped aluminum liner. The squib actuated valve consists of a valve body having a male inlet port for mounting to a gas storage chamber. The valve is functioned to the open position by firing one or both of two squibs which in turn detonate a diazodinitrophenol booster charge forcing the ram and plug forward (toward the stored gas chamber), opening the passage to stored gas. A metal-to-metal interference fit ram (or piston) is installed behind the plug on the downstream side of the valve. This ram provides a seal between the valve flow passage and the explosive primer (or cartridge). The valve is functioned to the open position by firing of one or both of two standard Army electric squibs, which is turn detonate a diazodinitrophenol booster charge forcing the ram and plug forward (toward the stored gas chamber) opening the passage.

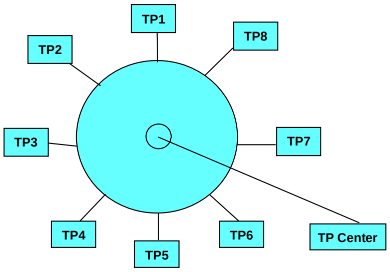
2. Performance. The explosive component performance after long term storage may deteriorate. Tests are conducted on production units to determine their reliability. The effects of aging, storage conditions, and other environmental conditions cause propellants to generally degrade over time due to chemical changes and thus, effecting performance of the explosive. Components may be stored in bunkers for several years to achieve aging or may be subjected to extended diurnal temperature cycling to accelerate aging. Other environmental tests are conducted to test the components ability to withstand fatigue and wear caused by transportation. Upon completion of the environmental tests, ballistic data is collected during performance tests and compared to the component specification and to any historical test data.

APPENDIX B. EXAMPLE CHECKLISTS AND DATA PLOTS

Table B-1. Dent Block Measurement Data Sheet

DENT BLOCK ID	WITNESS PLATE MATERIAL	LSC STAGE	PENETRATION DEPTH MEASUREMENT LOCATION & DEPTH (mm)									DEPTH OF PENETRATION (mm)		
			1	2	3	4	5	6	7	8	9	Maximum	Mean	Minimum
	1018 STEEL # 1													
	1018 STEEL # 2													
	2024 AL # 1													
	2024 AL # 2													
	1018 STEEL # 1													
	1018 STEEL # 2													
	2024 AL # 1													
	2024 AL # 2													
	1018 STEEL # 1													
	1018 STEEL # 2													
	2024 AL # 1													
	2024 AL # 2													
NOTE: Witness plates: Point 1 was measured at 51 mm from the edge, Points 2 to 9 were measured at 25 mm apart														





Block surface = zero depth

TP 1 = 90 deg (12 o'clock position) proceed
in counter clockwise direction

Dimensions are in mm

Serial Number	TP 1	TP 2	TP 3	TP 4	TP 5	TP 6	TP 7	TP 8	TP center
3	-1.270	-1.778	-1.524	-1.524	-1.778	-1.778	-1.778	-1.778	-3.302
7	-1.016	-1.270	-1.270	-1.270	-1.270	-1.270	-1.270	-1.270	-1.778
9	-1.270	1.270	-1.524	-1.270	-1.270	-1.270	-1.270	-1.270	-2.286
13	-1.524	-1.524	-1.524	-1.524	-1.524	-1.524	-1.524	-1.524	-2.032
81	-1.270	-1.524	-1.524	-1.524	-1.524	-1.524	-1.524	-1.270	-2.540
83	-1.016	-1.016	-1.016	-1.016	-1.016	-1.016	-1.016	-1.016	-1.270
93	-1.016	-0.762	-1.016	-1.016	-0.762	-0.762	-0.762	-0.762	-1.524
121	-1.524	-1.524	-1.778	-1.524	-1.778	-0.008	-2.032	-1.778	-3.048

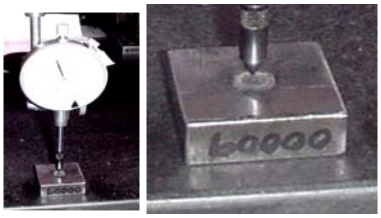


Figure B-1. Dent Depth Measurement Example

Table B-2. Detonation Velocity Measurement Sheet

DATE	LSC S/N	AODS STAGE	BREAKWIRE IDENTIFICATION	TIME (ms)	LENGTH (mm)	DELTA T (ms)	VELOCITY (km/sec)	VELOCITY (km/sec)		
								Maximum	Mean	Minimum

Table B-3. Performance Test Measurement Sheet

TEST ITEM											
TEST ENGINEER											
Test											
Equipment											
Item	**Lot**	**S/N**	**Pre-Test Resistance**		**Post-Test Resistance**		**Required Firing Current**	**Input Current**		**Actual Firing Current**	**Comments**
			Pin A-B	**Pin C-D**	**Pin A-B**	**Pin C-D**		**Pin A-B**	**Pin C-D**		
1											
2											
3											
4											
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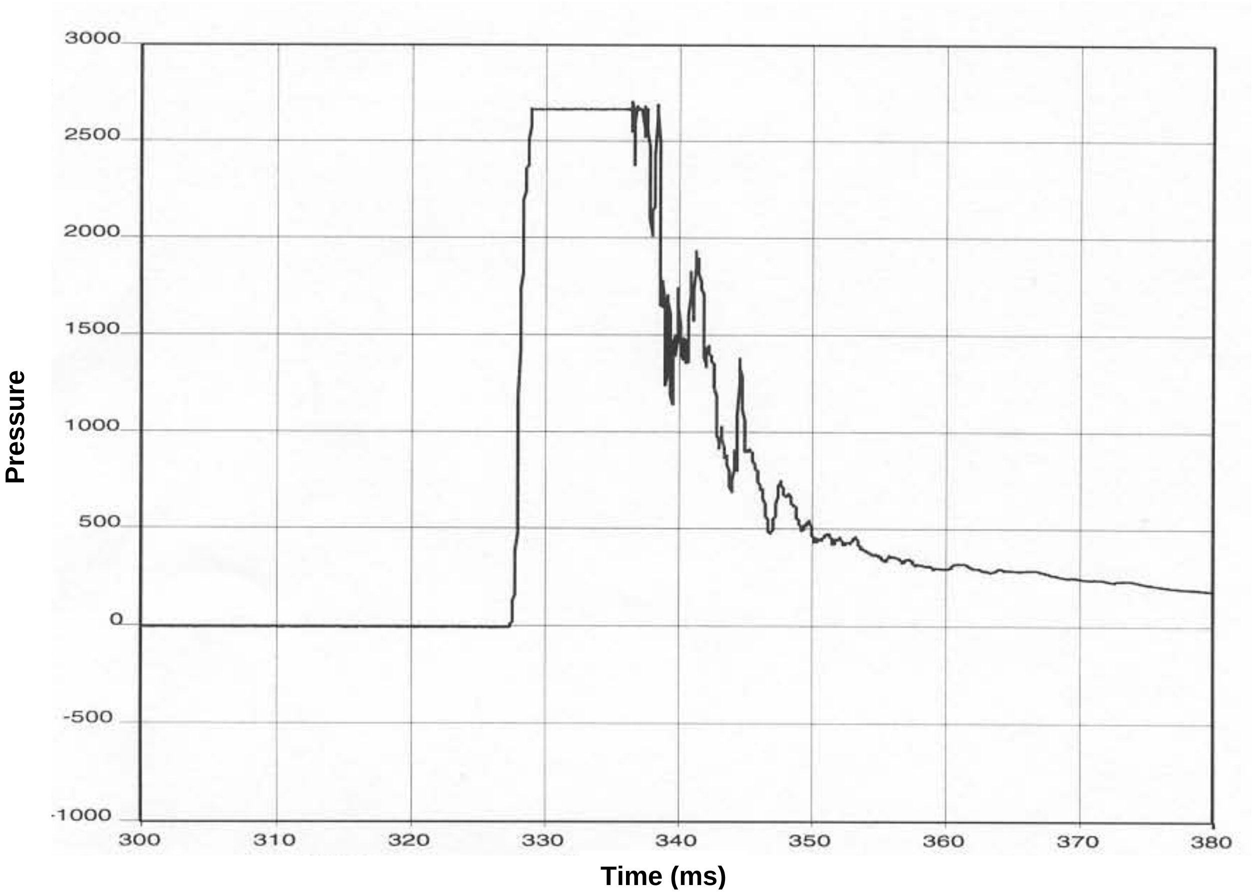

Figure B-2. Example EBW Pressure Time History

APPENDIX C. REFERENCES

1. ISO 10012-1 Quality Assurance Requirements for Measuring Equipment – Part 1: Metrological Confirmation System For Measuring Equipment, 7 January 1994.

2. STANAG 4370 Environmental Testing, AECTP 400, 18 May 2006.

3. MIL-STD-1576 Electroexplosive Subsystems, Safety Requirements and Test Methods for Space Systems, 31 July 1984.

4. MIL-HDBK-1512, Electroexplosive Subsystems, Electrically Initiated, Design Requirements and Test Methods, 30 September 1997.

5. Harper, C. A., Handbook of Wiring, Cabling, and Interconnecting for Electronics, McGraw-Hill Book Company, New York, NY, 1972.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the Technology Management Division (TEDT-TM-B), US Army Developmental Test Command, 314 Longs Corner Road, Aberdeen Proving Ground, Maryland 21005-5055. Technical information may be obtained from the preparing activity: US Army White Sands Missile Range, TEDT-WS-SV-A, White Sands Missile Range, NM 88002-5178. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.