

An Overview of the CAD/PAD Joint Program Office (JPO) Product Improvement Programs

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ABSTRACT: The Cartridge Actuated Device/Propellant Actuated Device (CAD/PAD) JPO supports the tri-service U.S. Department of Defense community by conducting a wide range of research, product development, and Product Improvement Programs (PIPs). New and enhanced CAD/PAD components are being developed to address the evolving requirements of the USN, USMC, USAF, USAA, NASA, and other specific system applications. This paper presents an overview of selected on-going CAD/PAD JPO programs. Specifically, this paper updates the progress achieved in the development of new energetic materials to be used in cartridge percussion primers, new technologies capable of proving precise timing between output events, and enhanced initiation technologies which can reliably ignite insensitive explosive compositions.

BACKGROUND: Cartridge Actuated Devices and Propellant Actuated Devices (CAD/PAD) are utilized for various applications throughout the U.S. military. A cartridge is defined as an energy source utilizing one or more energetic materials. A Cartridge Actuated Device (CAD) is defined as a device releasing cartridge energy to perform a work function. A Propellant Actuated Device (PAD) is defined as a rocket powered device releasing controlled propellant energy to perform a work function. Also, an Aircrew Escape Propulsion Systems (AEPS) is a "PAD" specifically designed for aircrew systems applications. For example, on the F/A-18E/F aircraft, there are over sixty-six (66) cartridges, CADs, and AEPS (Figure (1) on the next page). As shown, the F/A-18E/F utilizes a NACES (Navy Aircrew Common Ejection Seat) ejection seat to provide the pilot escape capability during an emergency situation.

Specifically, a cartridge is comprised of three basic sub-components:

- (1) an initiation stimulus,
- (2) a cartridge operation, and
- (3) the cartridge work performing action.

The CAD/PAD JPO and the CAD Research and Development/Production Improvement Program Branch (CAD R&D/PIP) are conducting a series of programs that support all three of these sub-component areas. This paper highlights on-going programs which implement new energetic materials into cartridge designs, enhance new commercially-off-the-shelf (COTS) technologies into cartridge designs, optimize manufacturing processes that ensure availability of these components to the fleet, and ensure that the final fielded cartridge designs provide the longest possible useful lifetime for the fleet applications. The primary objective of all of these programs is to improve cartridge CAD performance in the fleet at the lowest total ownership costs to the program managers.

INITIATION STIMULUS: Cartridges have various methods of being initiated when reacting to an external stimulus. Some of these initiation methods include: a percussion primer or primers, a bridgewire or bridgewires, exploding bridgewire, exploding foil, and laser energy pulse among others. Percussion primers provide the initiation stimulus for a large number of cartridges used in various U. S. military CAD/PAD applications.

An example of one of the less complex cartridges that utilizes a percussion primer is the CCU-61/A Impulse Cartridge (Figure (2) on next page). The CCU-61/A Impulse Cartridge was developed in the 1960's to provide capability to sever the drogue parachute riser lines on an aircraft ejection seat. This seat was originally installed on the USN/USMC OV-10 Bronco and remains in service today with the Broncos supporting California Department of Forestry. (Photo (1) on next page).

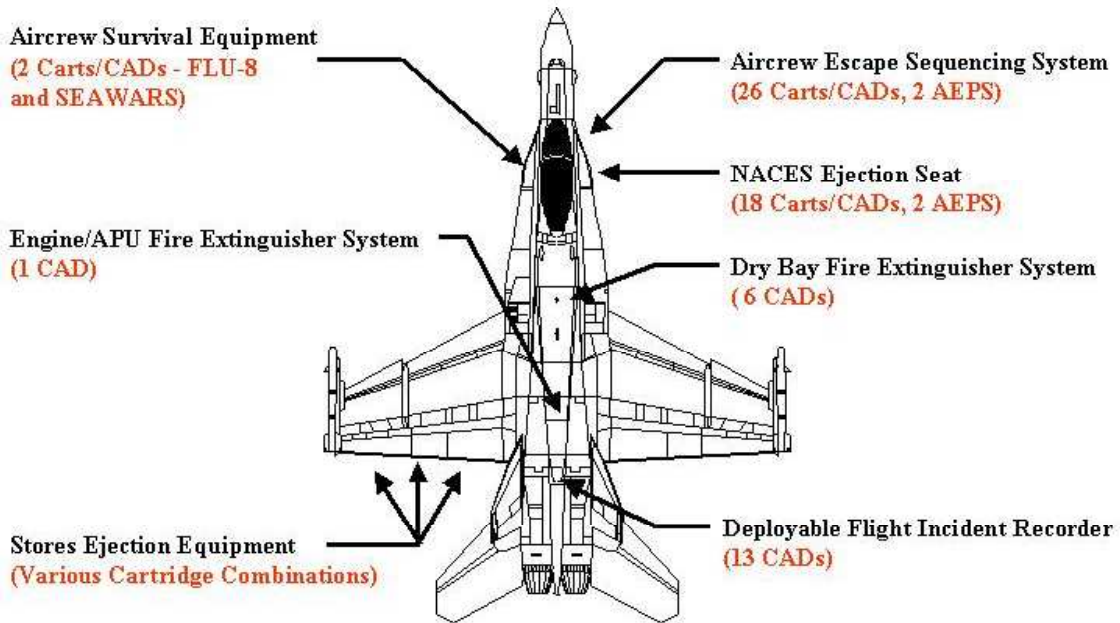


Figure 1: F/A-18 E/F CAD/PADs

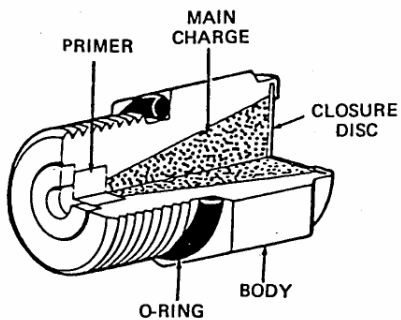


Figure 2: CCU-61/A Impulse Cartridge



Photo 1: OV-10 Bronco
California Department of Forestry

The CAD R&D/PIP Branch is conducting a program to reduce or eliminate toxic substances used in the production and subsequent fleet operations including percussion primer materials contained in this pyrotechnic cartridge. This Branch program supports a U. S. Executive Order (Number 12586 of Aug 93) which directs a reduction in the quantity of toxic materials discharged by federal agencies. A program was established, supported by the USN and by the CAD/PAD JPO, which establishes an objective of replacing the primary explosives lead azide and lead styphnate with materials that are environmentally benign, or at the very least, less toxic than lead. The CCU-61/A Impulse Cartridge utilizes a PVU-1/A Ignition Device (Percussion Primer) (Figure (3)). This device (primer) contains a lead styphnate charge and was selected as a viable sub-component replacement candidate.

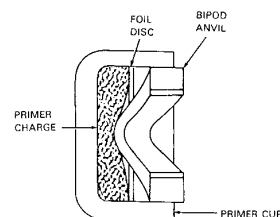


Figure 3: PVU-1/A Ignition Device

The PVU-1/A Ignition Device (Percussion Primer) contains the USN 5086 primer mix that is comprised of 26.0% Normal Lead Styphnate, 41.5% Barium Nitrate, 20.0% Antimony Sulfide, 10.5% Calcium Silicide (treated), and 2.0% Tetracene.

Working jointly with the U. S. Army Armament and Development Command (ARDEC) and with Los Alamos National Laboratories, the CAD R&D/PIP Branch investigated the use of Metastable Intermolecular Composite (MIC) compounds to replace the currently used USN 5086 mix for percussion primers. The MIC compounds were originally developed at Los Alamos and are a class of thermite materials consisting of nano-scale metallic fuels and metallic oxides. These compounds are characterized by relatively hot condensed phase products and are often considered to be gasless, although they do produce some pressure.

Based on the very positive initial investigations, both ARDEC and the CAD R&D/PIP Branch (working with USN production assets located at the Indian Head Division, Naval Surface Warfare Center) conducted programs to produce one selected MIC composition, Al/MoO₃ – Aluminum Molybdenum Trioxide. Other facilities and collaborators were identified to participate in the overall investigation and manufacturing phases of the program. These included the South Dakota School of Mines and Technology, Innovative Materials and Processes LLC of Rapid City, SD, and Energetic Materials Technology of Alexandria, VA. After a detailed effort, substantial amounts of Al/BiO₃ were manufactured, evaluated, and loaded into PVU-1/A Ignition Device (Percussion Primer) hardware. A series of functional tests were conducted on these primers, over the current temperature range of -65° F to 200° F (-54° C to 93° C), and the results achieved all established parameters. These primers were then loaded into impulse and delay cartridge hardware, including the CCU-61/A Impulse Cartridge, and again all the functional test parameters were achieved. Continuing investigations are underway to evaluate this material, and others that have been recently identified, capable of achieving the U. S. Executive Order direction to reduce toxic materials utilized by Federal Agencies. The CAD R&D/PIP Branch will continue to publish status reports on all of these energetic materials replacement programs.

CARTRIDGE OPERATION (TIME DELAY): In addition, as part of the overall escape system, delay cartridges are utilized to provide optimized timing for all required events. These escape system events include jettisoning (or fracturing) the canopy, providing the stimulus to ensure the pilot is properly positioned in the ejection seat, and providing the ballistic energy to propel the ejection seat away from the stricken aircraft. As an example, the WB55 Cartridge Actuated Initiator provides supplemental ballistic pressure to the escape system after a 0.3 second delay. This initiator is very similar to the MC50 Cartridge Actuated Initiator (Photo (2) and Figure (4)).



Photo 2: MC50 Cartridge Actuated Initiator

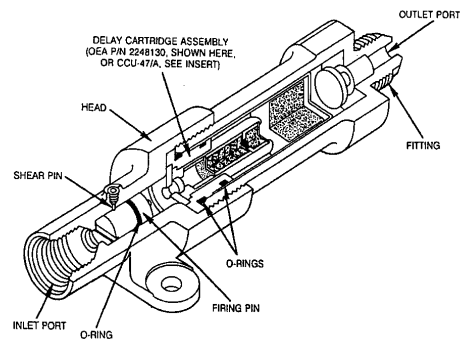


Figure 4: MC50 Cartridge Actuated Initiator Schematic

For this initiator, ballistic pressure is used as the stimulus to actuate a percussion primer. This primer, in turn, initiates a pyrotechnic column that provides the required 0.3 second time delay before initiating the output charge which provides ballistic pressure to the remainder of the system.

Currently, pyrotechnic cartridges provide the required time delays for a wide range of CAD/PAD systems. These cartridges contain energetic materials that burn in a column at a controlled rate and provide ballistic output after the required system delay has been achieved. These current cartridges fall into two basic categories: “pressed column” type cartridges and “small column insulated delay (SCID)” type cartridges. One example of the “pressed column” type cartridges is the CCU-40A/A (Figure (5)). This cartridge is used on the AV-8B aircraft and provides a 0.575 second delay prior to generating ballistic pressure to deploy the ejection seat parachutes (Photo (3)).

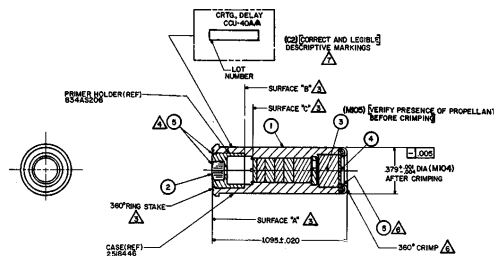


Figure 5: CCU-40A/A Delay Cartridge



Photo 3: USN AV-8B Aircraft

As shown, the CCU-40A/A delay cartridge is 1.095 inches long and 0.379 inches (2.78 centimeters and 0.963 centimeters) in diameter. Included in this cartridge are the percussion primer, the delay column, and the output charge that generates the required ballistic pressure for system operation. The CCU-40A/A Delay Cartridge is the smallest of the family of current U. S. Navy and U. S. Air Force delay cartridges or initiators. By maintaining the physical envelope of the CCU-40A/A cartridge, the selected technology can be rapidly implemented into larger cartridge or initiator applications. Thusly, maintaining this physical envelope,

while implementing an alternate electronic time delay technology, has been identified as the primary design challenge of this program. A critical secondary design challenge is the packaging of the sub-components that comprise the selected alternate technology.

Both of these current types of delay cartridges are expensive to produce, provide imprecise delay times (a tolerance of 25% for the “pressed column” type cartridges and a tolerance of 8% for the SCID-type cartridges are considered acceptable over a standard aircraft environmental temperature range), and require change-out as often as every 18-months during the maintenance cycle for some aircraft applications. Implementing cartridges that replace the pyrotechnical delays with electronic technologies will provide a more precise delay for system applications and, through potentially longer installed lifetimes and reduced per cartridge procurement costs, will significantly reduce the life cycle cost of the cartridges. These cost savings are a direct benefit to both the U. S. Navy and U. S. Air Force aircraft fleets.

TIME DELAY PROGRAM HISTORY: The electronic time delay (or digital delay) cartridge concepts were originally evaluated by the U. S. Navy in the early 1990’s to determine if the current state-of-the-art for power supplies and electronic components available at that time could meet the physical size requirements of fleet delay cartridges. This evaluation revealed that significant technical advancements would be required to achieve the program objectives at that time.

Subsequently, technical advances have been achieved for power supplies and electronic components that have enabled current-off-the-shelf (COTS) or “close to” COTS sub-components to meet the physical size requirements. The present program is based on utilizing these technical advancements for military applications.

An electronic time delay (digital delay) cartridge is comprised of three key elements:

- (A) the power supply,
- (B) the electronic circuit, and
- (C) the interface between the electronic circuit and the energetic material used to generate the output ballistic signal.

Establishing and managing an electrical power budget for the new delay cartridge is one of the critical design concerns. Once this power budget is established, technical options and design trades can be evaluated for each sub-component. Maintaining an identical form, fit, and function as the current delay cartridges is the primary overall design concern.

TECHNICAL APPROACH: The CAD R&D/PIP Branch, after conducting an extensive technical review, selected Pacific Scientific – Energetic Materials Company of Hollister, CA to design, develop, and manufacture an electronic time delay cartridge for various CAD/PAD applications. Piezo-electric crystal technology is the basis for the Pacific Scientific approach to developing an electronic time delay cartridge. Piezo-electric crystals have been in widespread use for many years. These crystals convert mechanical energy to electrical energy (for example, by striking the crystal, a spark is generated for barbeque grill initiation). In addition, there are numerous COTS suppliers of various piezo-electric crystal compositions, sizes, energy conversion efficiencies, and costs.

The CAD R&D/PIP Branch and Pacific Scientific have established project goals for this joint effort. The primary goal is to develop a single electronics module capable of various delays ranging from 10 milliseconds to several minutes. The qualification program for this electronics module can then be applied to other delay applications with a minimum of additional functional testing. The useful lifetime (both the shelf and installed lifetimes) of the new cartridge will be maximized in regard to the electronics and to the energetic materials. The design will be producible utilizing sub-components available with short lead times. In addition, during the design phase, the manufacturing processes will be considered with design options available to optimize these processes. And, the design will contain significant margin which is demonstrated in the cartridge ruggedness and reliability. As these cartridges are used in various CAD/PAD applications, ensuring high reliability can ensure pilot's lives.

Pacific Scientific adopted the U. S. Government approach to developing an electronic time delay cartridge by focusing on each of the three critical elements: (1) the power supply, (2) the electronic circuit, and (3) the interface between the electronics and the energetic materials output

charge (Figure (6) and Photo (4)). Managing the electrical power budget for their selected design was established as a priority.

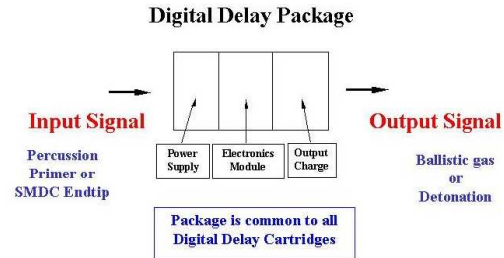


Figure 6: Cartridge Design Approach



Photo 4: Pacific Scientific Cartridge

A. Power Supply: As stated, piezo-electric crystal technology provides the stored energy supply for the Pacific Scientific cartridge design. Also as stated, the current U. S. Navy fleet CCU-40A/A delay cartridge utilizes a percussion primer to accept mechanical energy input and generate sufficient ballistic pressure or hot particles to initiate the pyrotechnic column. After a detailed engineering review, the question of whether a standard percussion primer could provide sufficient output to generate the required piezo-electric voltage to reliably initiate the output device was evaluated.

Percussion primers have been in use for over a hundred years. For ALL of these applications (commercial and military), the percussion primer accepts a mechanical energy input and generates an output that, in turn, reliably initiates another energetic material. For the proposed Pacific Scientific design, the output from the percussion primer provides all of the ballistic energy to stress the piezo-electric crystals and generate the necessary voltage. This is a new application for percussion primers.

The U. S. Navy has investigated percussion primers since their inception into military use. Developing and testing these primers has remained an important aspect for all military applications including those primers used with cartridges and CAD/PAD components. Evaluating the ballistic performance of the primer has been the topic of many technical papers². The typical ballistic outputs of these primers can be grouped into two categories: “boomers” and “poofers” (both are very technical terms). For previous applications, both ballistic outputs are acceptable as subsequent in-line energetic material can be reliably initiated with either output. However, for the Pacific Scientific design, the “boomer” primer output generated sufficient voltage from the piezo-electric crystals while the “poofer” primer output generated marginal voltages. Marginal voltage generated by the piezo-electric crystals directly affects overall cartridge performance. To eliminate this potential performance affect, a closure disk has been integrated over the primer to ensure adequate performance regardless of output type.

B. Delay Circuit: Pacific Scientific selected an Application Specific Integrated Circuit (ASIC) as the basis for their electronic delay module. As previously stated, Pacific Scientific established an overall power budget for the cartridge and the ASIC, which allowed the delay portion of the electronic circuit to be well within the established parameters. The government team participated in ASIC development and several critical design reviews. This process identified several enhancements that were implemented to ensure very precise delay times over the temperature range while requiring minimal electrical current. In addition, there was sufficient electrical power remaining in the budget to ensure reliable operation of the electrical circuit used to initiate the energetic material output charge.

C. Interface to Output Charge: Pacific Scientific selected the Reactive Semi-Conductor Bridge (RSCB) technology to interface between the electrical circuit and the energetic material output charge. Building on previous work patented by Sandia National Laboratories and others, Dr. Thomas Baginski, Auburn University (working with Quantic Industries, Inc., now Pacific Scientific – Hollister Operations) optimized a standard semi-conductor bridge design. This enhanced design, the RSCB,

generated additional output which reliably initiates various energetic materials even when a physical gap exists between the bridge and energetic materials. Pacific Scientific has preformed numerous functional tests which have demonstrated the capability of the RSCB to initiate energetic materials. In addition, these functional tests have included successful initiation of the energetic material across physical gaps on the order of 0.050 inches. This capability has greatly simplified the energetic material loading process against the RSCB and allowed this basic design to be implemented in other system applications.

Integrating the selected sub-components of each critical element has allowed Pacific Scientific to adopt a system approach to their design process. The final Pacific Scientific cartridge design meets all the current CCU-40A/A delay cartridge physical size and ballistic output requirements (Figure (7) and Photo (5)).

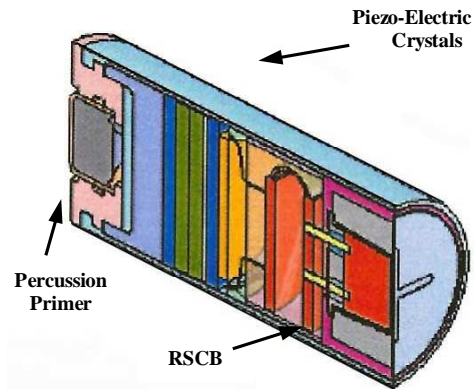


Figure 7: Pacific Scientific Delay Cartridge



Photo 5: Pacific Scientific Delay Cartridge Sectioned View

Pacific Scientific has conducted an extensive functional test program to develop their final cartridge design. These tests can be compiled into 4 testing groups: piezo-electric crystal evaluation, primer evaluation, cartridge proof-of-

concept, and energetic material evaluation (Table (1)). The results of these functional tests have contributed to the overall design.

Test Series	Qty.	Contribution
Piezo-electric crystal evaluation	Over 50	Specific crystal, thickness, and quantity identified
Primer Evaluation: Standard USG and Pacific Scientific primers	Over 100	“Boomer” and “Poofer” criteria identified, design modification adopted
Cartridge Proof of Concept	Over 15	Full-Up cartridges tested after temperature conditioning
Energetic Material Evaluation	Over 40	Identified optimal energetic materials

Table 1: Pacific Scientific Test Results

The integration of electronic sub-component assembly with energetic materials loading operations presented a range of issues to be addressed. To this end, Pacific Scientific conducted a manufacturing process review for their cartridge design. This review generated substantial modifications to the basic design in an effort to ease assembly procedures. In addition, several non-destructive test points were included in this process to verify the operation of selected sub-components after assembly.

Pacific Scientific also completed a technical drawing review for their cartridge design. The modifications, detailed during this drawing review, ensured that all metal sub-components could be readily fabricated and that all electronic sub-components would meet their respective requirements both pre- and post- assembly. Electronic sub-component obsolescence plans have also been adopted to ensure no major re-qualification efforts are required as the electronic sub-components continue to evolve.

Pacific Scientific has completed the Proof-of-Concept design phase for their electronic time delay cartridge design. The Design Verification Test phase is currently on going. The environmental and functional tests to be conducted during this program phase are detailed in MIL-C-83125 “General Design Specification for Cartridges used in Cartridge

Actuated/Propellant Actuated Devices”. These tests are designed to demonstrate the functional capability of the design through environmental and thermal exposures which reduces the risk to beginning the full-scale qualification effort (Table (2)). Minor design iterations have resulted in some schedule delays to this phase of the program; however, the CAD R&D/PIP Branch remains confident that Pacific Scientific design is capable of being qualified for use in various CAD/PAD applications.

Test Condition	Quantity
Six Foot Drop	6
Forty Foot Drop	1
Shock	8*
TSH&A	9*
Low Temperature	9*
Vibration	9*

* - Sequential Test Series

Note: Functional testing of these cartridges will be conducted at ambient, -65° F, and 200° F (-54° C to 93° C).

Table 2: Design Verification Test Series Pacific Scientific Delay Cartridge

SUPPLEMENTAL PROJECT: Based on the technical success achieved during the Pacific Scientific effort, the CAD/PAD JPO and the CAD R&D/PIP Branch established a second project to implement electronic time delay cartridges into fleet applications. An industry team of Special Devices, Inc. and Scot, Inc. was selected as the industry partners to design, develop, and evaluate an alternative electronic time delay cartridge. This team, working with the CAD R&D/PIP Branch, has selected differing piezo-electric technology sub-components and manufacturing processes as part of their effort to meet the CCU-40A/A Delay Cartridge physical size and cartridge functional requirements. This second project is currently in the Proof-of-Concept phase and the results of this effort will be reported in future publications.

CARTRIDGE WORK-PERFORMING ACTION:

The output from a cartridge performs the action as required by the system. One of these actions for a cartridge is to generate ballistic pressure. Some examples of how this ballistic pressure is used by a system include (a) providing the power to the inertial reel which properly positions a pilot in the ejection seat, (b) transferring this signal to the next in-line CAD/PAD, (c) initiating a rocket for canopy jettison or ejection seat operation, or (d)

releasing a weapon or store. Cartridge ballistic pressure also is used in cutters to sever cables, to function fire suppression systems, and to deploy various countermeasures. These actions only highlight some of ballistic pressure functions performed by cartridges in everyday fleet operations. The CAD R&D/PIP Branch is conducting programs to optimize the output performance of fleet cartridges to ensure that all of these operations are effectively achieved over the longest installed lifetime and at the lowest per cartridge cost possible.

On-going CAD/PAD JPO programs have re-established the IHDIV, NSWC as a supplier of the ammonium perchlorate (AP) propellant utilized in many fleet cartridges. In addition, supplementary projects have been conducted to investigate the physical and chemical properties of this propellant to ensure that it generates similar ballistic performance from lot to lot. For example, the CAD R&D/PIP Branch is conducting a project to provide positive dimensional control to 5808 ammonium perchlorate propellant. Controlling the specific physical characteristics greatly reduces final cartridge production and packaging issues.

The CAD/PAD JPO and the CAD R&D/PIP Branch are also conducting projects to optimize the sealing process for fleet cartridges. Enhancements to the time-honored “crimp and glue” type cartridge sealing technique are continually being investigated. Laser welding of cartridge closure disks has been implemented in a wide range of IHDIV as well as many commercially available cartridges. Laser welding (Photo (6)) ensures a hermetic seal to the cartridge closure and allows the installed (or useful) lifetime to be maximized to the fleet. In addition, the traditional non-destructive test methods (especially helium leak testing) have proven an effective tool to evaluate the hermeticity of this weld. A hermetic seal provides protection from fleet environments and, again, maximizes the useful (installed) lifetime of the cartridge.



Photo 6: Example of Cartridge Laser Welding

CONCLUSIONS: The CAD/PAD JPO and the CAD R&D/PIP Branch will continue to support efforts focused on enhancements and optimizations for all three cartridge sub-components: (1) the initiation stimulus, (2) the cartridge operation, and (3) the cartridge work performing action. Transitioning these new cartridge and CAD designs into fleet applications implements the technical modifications. Providing the end users within the USN, UMSC, USAF, USAA, and NASA the optimal cartridges and CADs, which reliably provide the required work action over the longest installed (or useful) lifetime and at the lowest cost, is the ultimate objective of the CAD/PAD JPO and of the CAD R&D/PIP Branch.

REFERENCES:

- ¹ - “Recent Accomplishments in MIC Primer Development at NSWC/Indian Head” – Dr. Peter Ostrowski, Energetic Materials Technology, Alexandria, VA, Mr. Magdy Bichay and Mr. Todd Allen of IHDIV, NSWC, Indian Head, MD and V.E. Sanders and S. F. Son of Los Alamos National Laboratory, Los Alamos, NM – 41st AIAA JPC (AIAA 2005-3514), July 2005
- ² - “Variables Affecting the Output of Low Brisance Percussion Primers” Frank J. Valenta, IHDIV, NSWC, 28th International Pyrotechnics Seminar, Adelaide, South Australia – November 2001