3 REVIEW OF PAPERS PRESENTED AT THE
5TH ELECTROEXPLOSIVE DEVICE SEMINAR 6

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REVIEW OF PAPERS PRESENTED AT THE 5TH ELECTROEXPLOSIVE DEVICE SYMPOSIUM

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Problems associated with the safe and reliable use of electroexplosive devices and associated components have stimulated valuable thinking in the design, development and subsequent usage of these units. At the recent 5th E.E.D. Symposium the results of a number of research and development programs were presented. As can be seen from the brief review to follow, the electroexplosive units discussed are obviously designed to meet certain operational and functional requirements, however prime consideration has been given to safety associated with the use of the devices. The first paper to be discussed reviews the development of a 15 second delay squib by the McCormick-Selph Company under contract to Douglas Aircraft Company and was presented at the Symposium by Mr. Sid Moses of Douglas.

The failure of a Delta Space Vehicle flight in August of 1965 was traced to malfunction of a delay squib which caused premature ignition of the third stage motor. The National Aeronautics and Space Administration, Goddard Space Flight Center (Goddard), decided to replace it with a new, high reliability device. Douglas Aircraft Company, Missile & Space Systems Division (Douglas) was contracted to prepare a specification for a new squib.

It wasdecided that the delay squib should be a single circuit device rather than the more conventional two circuit devices which have been popular. This was based on the conviction that the modern EED, having a flush bridgewire and a pressed prime, has virtually eliminated the broken bridgewire problem. With a single circuit EED, some weight saving could be achieved in the wiring system and possible circuit-to-circuit problems were eliminated.

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SQUIB CHARACTERISTICS

Goddard awarded a contract to McCormick-Selph of Hollister, California, for the development and qualification of this 15 second delay squib.

A schematic design is shown on figure 1. For this development, McCormick-Selph utilized two interesting proprietary materials: (1) The initiating explosive around the bridgewire is a high-temperature stable, non-conductive material. Both the material and its residue combustion products are non-conductive. (2) The delay column is a pyrotechnic, prepackaged in a lead tube, which is then drawn to a diameter of less than 0.1 inch, designated by McCormick-Selph as Small Column Insulated Delay (SCID). The SCID in the 15 second delay squib is completely gasless and has a deflagration rate of 14 seconds per foot. Based on the Development and Qualification Program, the squib has the following characteristics at 70°F.

A. When calculated at the 95 percent confidence level:
   1. At least 99.9 percent of the squibs have a five minute no fire of 1.72 amperes (approximately 2.1 watts) which exceeds the no-fire safety requirement of 1.0 ampere (1.0 watt).
   2. At least 99.9 percent of the squibs will have a delay of between 14.8 and 16.8 seconds.

B. When calculated at the 90 percent confidence level:
   1. At least 99.9 percent of the squibs require a minimum all-fire current of 3.47 amperes for a 20 ms pulse.
   2. The squib initiator has a demonstrated reliability of 99.36 percent when fired with a 4.0 ampere, 20 millisecond pulse based on 370 firings.

DEGRADATION TESTS

Test squibs were subjected to 25 applications of tests measuring insulation resistance, dielectric strength and electrostatic discharge. In addition, test squibs were subjected to a current of 20 milliamperes for a period of 24 hours representing a small leakage through the electrical circuit. None of these tests degraded the firing characteristics of the squib. Test squibs were subjected to 25 cycles of the 1.0 ampere no-fire current. After this test, the squibs functioned in a normal manner. In subsequent tests, two initiators were subjected to 52 cycles of the no-fire current for 2-1/2 minutes followed by a five minute cooling period. After this test the initiators were functioned at 4.0 amperes. The bridgewire burnout time of 2.6 milliseconds for the squibs tested is comparable to an average of 2.4 milliseconds for the 72 qualification firings. McCormick-Selph stored the delay squibs at 160°F for eight hours, 130°F for 72 hours and 112°F for 336 hours. The squibs were then fired in a 10cc pressure chamber and behaved in a normal manner.

ELECTROSTATIC PROTECTION

Because of a previous lethal accident caused by static electricity, extra precautions were taken in making this squib safe from electrostatic discharges (ESD). A review of ESD protection devices indicated to Goddard-Douglas that a preferential air gap between the electrical lead-in pins of the squib and the metal case appeared to offer the best protection available. This allows an electrostatic spark to jump across a small air gap without passing through the explosive primer material around the bridgewire. In the production squib, this air gap was controlled to break down between 1000 and 3500 volts dc. A preferential air gap is protection only if it can be determined that it is preferential. That is, the primer material around the bridgewire must be insulated so that breakdown does not occur through this material. With development squibs, breakdown of the primer cavity did not occur at 10,000 vdc providing a factor of safety of at least 3:1 over the maximum breakdown of the preferential gap.

RF SENSITIVITY

As part of the development program, 270 initiators were sent to Franklin Institute for RF sensitivity tests.

As an additional safeguard against RF, a Douglas lossy line (skin effect) filter is installed on the squib in the spacecraft. This filter is similar to one described by Warner and Klamt at the Second Hero Congress in 1963. It provides from 10 to 80 db protection over the frequency range from 0.1 to 10,000 MHz.

It appears that the time delay initiator developed under this program will offer an effective solution to the Delta programs operational requirements vehicle at the same time a high degree of safety is designed into the device.

The second paper to be discussed was presented by Mr. Louis J. Montesi of the Naval Ordnance Lab. and presents the results of further development work on a Water Arm-Air Safe Detonator originally developed by Stresau and Slie.

Safe Arm

Current Navy design practice for explosive trains is to interrupt the action of the sensitive explosives between the initiator and the input to the lead and/or booster. The explosive action is interruped to avoid accidents from unintentional initiation of the "sensitive" explosives in the train. This has previously been accomplished by interposition of barriers and/or by misalighment of the train components.

A second Navy requirement is that arming, or alignment of the displaced components, for example detonator to lead, be accomplished after launch. In underwater ordnance, such arming is usually accomplished by mechanical means, actuated by either water pressure or movement of the device through water.

A third Navy requirement is that any explosive used beyond the interrupter shall be no more sensitive than the Navy standard of tetryl.

An appealing approach to the development of systems which are to arm after water entry is to utilize the difference between the confining action of air and of water to control propagation of detonation. Stresau and Slie invented a "Water Confinement Arming Device" using the above differential confinement principle. This is a device which will propagate to detonation only when immersed in water. It does not depend on physical interruption of the column to prevent detonation propagation when in air. The detonator, as further refined by Stresau is shown in figure 2.

The unique feature of this design is that a lightly confined column of explosive is surrounded by an annular air cavity and, in turn, by a relatively heavy metal tube. The diameter of the column of explosive is chosen so that it is less than the failure diameter when the annular cavity is filled with air, and larger than its failure diameter when this same cavity is filled with water. This change in "failure diameter" is the result of the greater effectiveness of water as a confining medium. This effect is further increased by the reflected shock wave from the surrounding tube.

Stresau in his original assessment of safety and reliability used a "no dent criterion" for a detonator failure in air. That is, when his device was initiated in air, explosives could propagate to and through the base charge, but could not produce any measurable dent in a steel witness block used to measure base charge output. However this design when fired in air occassionally permitted complete burning of the base charge explosive.

The purpose of this report is to describe work at the Naval Ordnance Laboratory undertaken to further the development of an explosive device of this type.

a. Study feasibility of using higher density nitroguanidine to increase mechanical stability to vibrational forces.
b. Quench burning action when fired in air.
c. Verify confinement enhancement effect of steel jacket when in water.
d. Improve fabrication methods: shorter column, better plastic tubing material.
e. Make item capable of meeting usual surveillance conditions for explosive components, i.e. Mil-Std-304 temperature-humidity cycle.

A detailed report of the results of this investigation are given in Mr. Montesi's paper, however, a brief summary is as follows.

The first tests conducted were to determine the optimum charge density of the nitroguanidine transmission charge. It can be concluded from the results that the nitroguanidine transmission charge density should be less than 0.80 gm/cm and more than 0.35gm/cm for reliable initiation of the base charge in water. As regards safety, or chance initiation of the base charge in air, no high order initiation of the base charge occurred over the entire density range.

In addition to these tests the propagation velocity of nitroguanidine at various densities was measured underwater using a 35 mm smear camera. The propagation velocities of nitroguanidine were measured in two test configurations: with and without the outer metal confining sleeve. As earlier stated it was suspected that the shock wave underwater was reinforced by the reflected shock wave from this confining tube. The results of these tests although inconclusive appear to support this suspicion. It is also evident that the propagation velocity increases as the density of the nitroguanidine transmission charge increases.

Tests were conducted to determine the otpimum barrier thickness required for reliable detonation transfer in water. There were 54 out of 54 successful fires made with barriers ranging in thickness from 40 to 200 mils. Nineteen out of 19 fires were observed with a barrier thickness of 150 mils, a thickness nearly four times greater than the intended 40 mil design thickness.

The safety aspects of the WARAS Device tested in air were assessed using the VARICOMP test procedure. To prove that detonation will not propagate in air from nitroguanidine to the CH-6 base charge across the 40-mil thick aluminum more sensitive explosives--PETN and Calcium Stearate-RDX, (1.65/98.35) were substituted--for the CH-6 below the aluminum barrier. It should be noted that only the CH-6 in the base charge is changed.

As an additional conservatism all of the safety tests were conducted with a thinner barrier than is intended in the final design, i.e. 25 mils instead of 40 mils.

Three types of quenching were noted: (a) somewhere in the nitroguanidine column leaving some unburned nitroguanidine, (b) somewhere in the intermediate CH-6 charge above the aluminum barrier leaving some unburned CH-6, and (c) quenching at the barrier with all explosives above the barrier being consumed. Only when the latter outcome was observed was there any chance of initiating the VARICOMP explosive.

The safety and reliability aspects of the WARAS Detonator were deemed acceptable with a 40-mil thick aluminum barrier.

The device did not pass the temperature-humidity test, a concentrated effort in that direction is being made.

Leakage was traced to: (a) poor epoxy seals, (b) pin holes in the tube (it seems that it is possible to get pin holes in tubes of 2 mils wall thickness), (c) tube punctures during loading.

It appears essential to either increase the wall thickness of the tubing or have inspection techniques that will preclude the acceptance of tubing having pin holes or other leaks. Since damage to the tubes may occur during the loading process the use of thicker tubes is going to be investigated. The use of a thicker tube will necessitate a reconfirmation of the safety and reliability estimates already made.

An entirely different approach to the design of electroexplosive devices was given in a paper presented by Mr. D. J. Lewis of the Space Ordnance Systems Company.

LASER ENERGIZED EXPLOSIVE DEVICE

On the basis of several preliminary experiments utilizing a laser to initiate explosives, the Space Ordnance System Company decided to investigate laser-energized systems. The reasons were; if explosives could be initiated using coherent light as a source of energy and a means found to transmit it to various components (detonators, initiators, igniters, etc.), one could not only eliminate the RF, electrostatic, and EMI problems, but might possibly arrive at a system that was a great deal simpler in design.

The LEED system (Laser Energized Explosive Device) eliminates the use of all connecting metallic lines, bridgewires, spark gaps, ceramic headers, etc. The laser source creates an energy pulse which is transmitted via non-metallic, fiber optic conductors directly to the pyrotechnic compound to produce the required reaction. A schematic of this unit is shown in figure 3.

A simplified but informative explanation of the operation of lasers in general and the specific application of lasers and fiber optics to this concept is given in Mr. Lewis's paper.

The initiator used with the LEED system looks exactly like a normal EBW or hot bridgewire unit on the outside. It is however, extremely simple in design. All bridgewires, spark gaps, pins, ceramic headers, insulators, etc., have been eliminated and the device simply contains the explosive compound sealed in by means of a glass window. The glass itself is a high quality infrared transmitting glass with tapered conical shaped edges which recollimates the laser beam being received from the optical fiber and loads the window optimally. The windows are designed, and have been tested, to withstand up to 100,000 psi and allow the application of laser light on the explosive compound over a 0.01 in^2 area.

One of the most interesting features of the LEED system is the ease of connecting the optical fibers to the end-users: detonators, initiators, etc. The system does not require any special methods of optical fiber end-coating, grinding, or special geometry and the optical fiber ends can be cut and mated to the connector in simple fashion.

The connectors do not have to be water or moisture tight since these environments do not effect the transmission of energy from the donor to the receiving fiber.

The LEED system is completely insensitive to RF and electrostatic energies. The only physical connection to a detonator or initiator, or group of these devices, is the series of optical fibers. The coherent light moves, independently of these fields, to the explosive device and causes the pyrotechnic reaction. Since the optical fibers and the ordnance devices are immune to reaction of these fields, (they contain no electrical circuitry or are pure Faraday shields; radiation has no means by which it can produce effects), the system is completely safe and reliable.

Accidently setting off the LEED system by means of extraneous light sources is very nearly impossible for the following reasons:

a. High intensity non-coherent sources are very nearly non-existent. Tests with output energy as high as 5000 joules, using non-coherent sources, have been focused into the fibers and have not set off any reaction.

b. Due to the characteristics of the fiber optics, unless the energy it is transmitting is coherent, the phenomenon necessary for pyrotechnic reaction will not be present and since there is no naturally coherent sources, thehazard is eliminated.

c. The fiber is totally internally reflecting and, hence, is totally externally reflecting. Therefore no energy will be received by the fiber unless it is within the acceptance angle of the fiber which is below 9 degrees.

It can be seen that a very high intensity light (higher than the flux density of the surface of the sun) that is coherent, at the right frequency to transmit efficiently down the fiber, and within the acceptance angle of the fiber must be used.

The LEED system power supply is adaptable to the normal electrical systems used in aircraft, missiles and spacecraft. The system operates in a similar fashion to an EBW system.

A low voltage source, i.e., DC battery or 400 cycles AC, is used as input energy. This is then stepped up to a higher voltage and charged into a capacitor. The capacitor is then "dumped" into the optical pumping source, which may be a xenon flashlamp, to create the necessary population inversion in the ruby or neodymium rod. Basically, the system is a low voltage, to high voltage stepup, to energy storage, and then via an electrical switch, to the flashlamp.

Following further development this concept could offer an attractive solution to many of the operational and safety problems currently being experienced in missile systems.

An area of definite concern to users of electroexplosive devices is the Stability of RDX in shape charge since this is a system often used in conjunction with E.E.D.'s. The results of an interesting study in this regards were presented by Dr. N. J. Bowman and Mr. E. F. Knippenberg of the General Electric Company.

Within recent years flexible linear shaped charge (FLSC) has received widespread acceptance within the aerospace industry and is currently being used in a number of missile and spacecraft systems. Use of FLSC in missile stage separation applications offers several important design advantages. In particular, its use generally results in significantly lighter weight structures as compared to alternate systems.

FLSC contains a continuous core of high explosive encased in a thin metal sheath. Almost all FLSC manufactured and utilized to date consists of an RDX explosive core in a lead alloy sheath. Originally FLSC was fabricated with a cardiod cross-sectional shape. More recently a chevron shape has been employed, as it was found to give significantly improved cutting performance. While the chevron shape is optimum from an explosives performance standpoint, it is somewhat fragile from a mechanical point of view. In particular the thin metal sheath of this configuration has been found to be easily distorted by internal gas pressure generated during storage or testing at elevated temperatures. When subjected to increasing internal pressure, the chevron shape has been found to gradually deform into a shape approaching a triangle. With the loss of the chevron shape, the cutting ability drastically degrades.

In actual applications the shaped charge is provided with end-seals to prevent moisture from being absorbed into the RDX core since this can destroy the detonating properties of RDX. Thus, any chemical instabilities of the FLSC constituents, or of the end-seal materials, result in the generation of gases which will gradually distort the chevron shape and degrade its cutting properties. Therefore, it is essential that the ingredients and sealing materials used in the FLSC possess a high degree of chemical stability at elevated temperatures.

In order to study the variables involved in thermal stability of RDX, two samples of this explosive were obtained from the Canadian Arsenal Ltd. The first sample was designated as Type B indicating that it was made by the Bachman process which utilizes acetic anhydride as the nitration medium. This results in the formation of from 8 to 10% of HMX as a bi-product.

The second sample, normally referred to as Type A RDX, was made by the British process which uses only nitric acid and results in less than 1% of HMX being formed.

There were a wide variety of theories as to the cause of the instability found in shaped charge made from RDX. They can be divided into classes and each was studied experimentally and most of them eliminated. The general classes are as follows:

1. Sheath materials and/or moisture. The usual material for shaped charge sheath is antimonial lead but pure lead and aluminum have also been used. Moisture may enter into the reaction postulated between RDX and the sheath material.
2. Additives
3. Materials used in making adequate end-seals in shaped charge systems.
4. Impurities in the RDX.

The Bowman-Knippenberg study produced the following:

* 1. The lead-water-RDX interaction does lead to the evolution of gas, but at a very slow rate. The ballooning of shaped charge cannot be explained on the basis of this reaction alone. The following was also found:
    a. An increase in the percentage of lead (surface area of contact) causes an increase in the rate of gas evolution.
    b. An increase in the percentage of water leads to an increase in the rate of gas evolution.
2. Hydrogen, even if formed by the reaction of lead and water, does not react with RDX appreciably to form volatile amines.

3. The presence of aluminum of the type used in sheath materials, does not lead to evolution of gas. Aluminum is several times as strong as lead (tensile strength roughly ten times as high) and it was not possible to get ballooning even at 350°F as the end-seals consistently failed first. It is therefore concluded that, with aluminum sheathed shaped charge, ballooning will not occur until a high internal pressure has been gernerated. It is probable that the seals will fail before this necessary pressure is reached.
4. Any PbO formed by the reaction of water and lead does not act to accelerate the decomposition of RDX.
5. The presence of HMX has no effect on the stability of RDX.
6. Duponol (an antistatic agent) in the amounts usually present causes only a slight increase in gas evolution. Duponol in gross amounts is known to lead to thermal instability.
7. Rhodamine (a dye) in the amounts usually present in shaped charge does not affect thermal stability of RDX.
8. No fibers were found in the raw RDX upon microscopic examination of the two samples that were available. From this it has been concluded that raw RDX is thermally unstable even in the absence of fibers, although undoubtedly it is less stable if cellulose fibers are present (as has been reported).
9. M and P-100 (the epoxy resin presently used in Mark-6 shaped charge assemblies) will cause rapid gas evolution IF IT COMES IN CONTACT WITH THE RDX CORE. This may occur through faulty preparation of the assemblies. Vapor contact is to be avoided particularly with over catalyzed M and P-100 which will contain free TETA.
10. Other epoxys tested as replacements for the M and P include: Metagrip, CONAP, Armstrong C7 and Scotchcast No. 10. CONAP, even in direct contact with RDX, envolved only a small amount of gas. However, its physical properties (flexibility particularly) make it undesirable for use. The second best from a gas evolution standpoint was Scotchcast No. 10. It has acceptable physical properties and its use is recommended.

11. The largest part of the thermal instability of "raw" RDX comes from the impurities which it contains. There are at least 50 of them and it is impossible to identify any particular ones that are detrimental. The chances are that many of the possible impurities have poorer stability than the RDX itself. There are others, notably HMX, which are more stable.

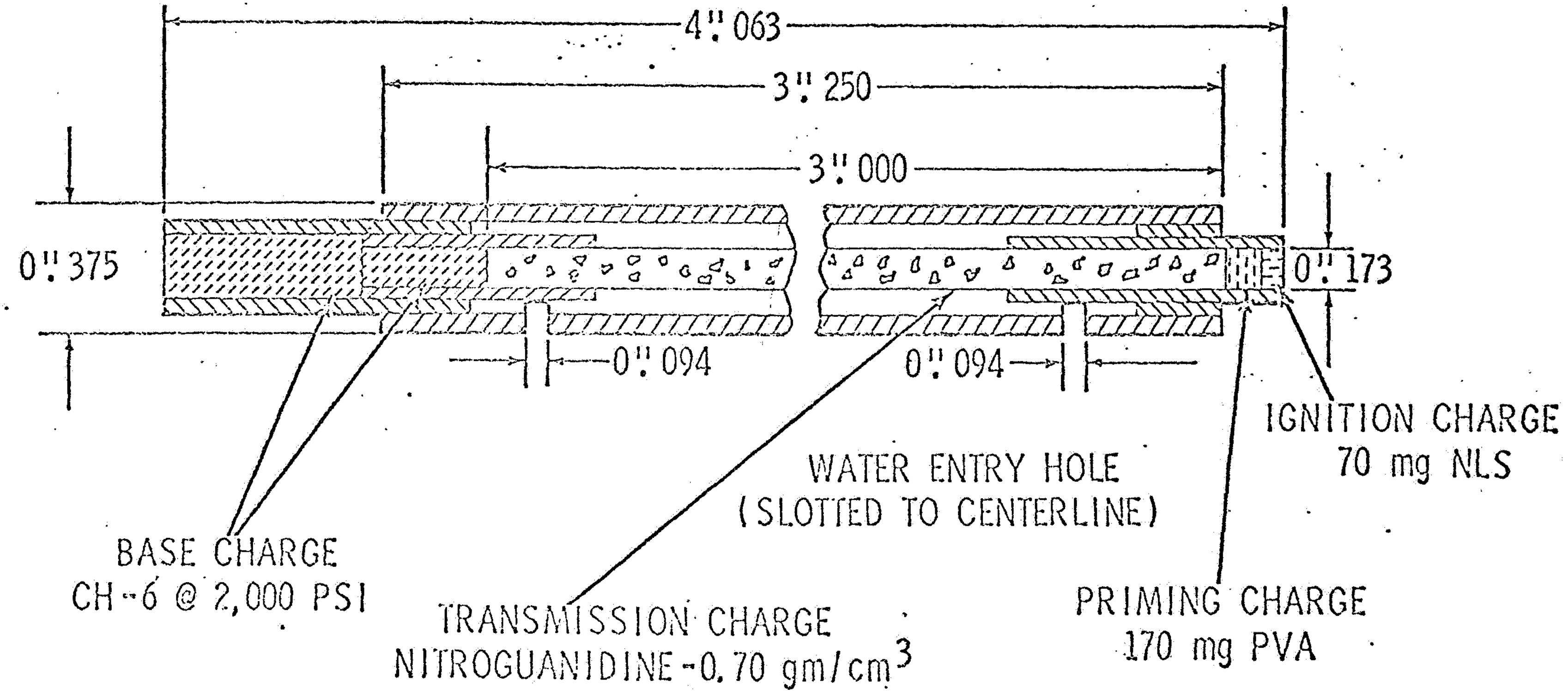
It has been shown, both by isoteniscope-gas evolution tests and forced ballooning tests on shaped charge itself, that these impurities can be removed by recrystallization from acetone. It is important to note that a TRUE RECRYSTALLIZATION is required using differential solubility and no water in any form. The term recrystallization is used in the explosives industry to include a variety of processes in which water is added while cooling or evaporating.

12. It is necessary to drythe RDX at elevated temperatures (65°C to 80°C) under reduced pressure with a stream of DRY air flowing over the surface or through it. This is required for two reasons. First calculations have shown that if the water content is above 0.2%, ballooning of the 15 grain, lead sheathed shaped charge may occur due to the vapor pressure of the water alone. Secondly, if this is not done the RDX may not be dried homogeneously and local concentrations of water several times the average value may be found.

13. By use of highly purified RDX, keeping the water content of the RDX below 0.2%, and using improved end-seal materials, shaped charge can be made that is stable indefinitely at temperatures to 240°F.

Fig. 2.

WATER CONFINEMENT ARMING DEVICE
(STRESAU TYPE K160)



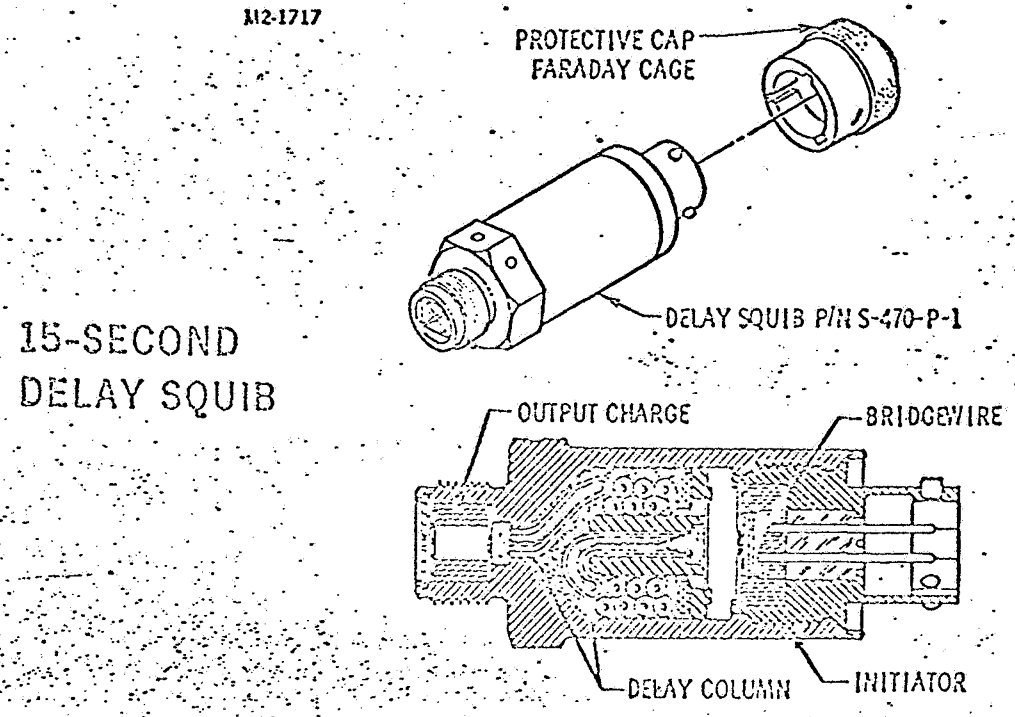


Figure 1. 15-Second Delay Squib

LASER ENERGIZED EXPLOSIVE DEVICE