



AMRA TN 65-06

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**MALFUNCTION OF IGNITERS IN
THE AMRA VARIABLE PARAMETER
ROCKET ENGINE**

TECHNICAL NOTE

by

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JULY 1965

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**MATERIALS ENGINEERING DIVISION
U. S. ARMY MATERIALS RESEARCH AGENCY
WATERTOWN, MASSACHUSETTS 02172**

Rocket materials

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ABSTRACT

Three firing tests on nozzles were rendered unsatisfactory due to malfunctioning of the pyrotechnic igniters. These igniters were off-the-shelf manufacturer's items. Failure of the igniters was manifested by the leakage of hot gases through the squib end of the igniter body case, followed by complete erosion of that element resulting in a deleterious decrease in chamber pressure and extension of burning time. Although the igniters were several years old, the manufacturer did not believe that aging was the problem. Subsequent examination of the igniters indicated the presence of corrosion of the electrical lead wire immediately adjacent to the ceramic seal enclosing the primer charge. In order to minimize further mishaps, the manufacturer replaced the primer charge unit in all of the igniters remaining on hand.

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INTRODUCTION

Concurrent with the development of rocket engines is the requirement for reliability of all component parts, since failure of a single element can seriously impair the objective of a test mission. For instance, a pyrotechnic igniter in a solid propellant engine should be designed and constructed such that it will fire in a reproducible manner even after adverse storage conditions for varying periods of time. However, mishaps do occasionally arise, as evidenced by the malfunctioning of pyrotechnic igniters, a manufacturer's standard item, during three experimental tests of nozzles in AMRA's Variable Parameter Rocket Engine, thereby rendering test data useless. An investigation was made to determine the cause of failure.

ROCKET TEST ENGINE

The Variable Parameter Rocket Engine is a unique solid propellant static device specifically developed to provide flexibility in the selection and control of experimental parameters for the rapid, systematic testing of rocket nozzle materials. This particular engine was designed on a modular basis with reusable components to provide ease and economy in assembly and operation.

The general configuration of the AMRA Variable Parameter Rocket Engine is shown in Figure 1, and represents a radical departure from conventional solid propellant motors. Since this static test engine and its operation have been described in greater detail in several earlier reports,* only a brief description will be included here. The solid propellant engine was designed on a modular basis to be capable of testing materials over the following range of operating conditions:

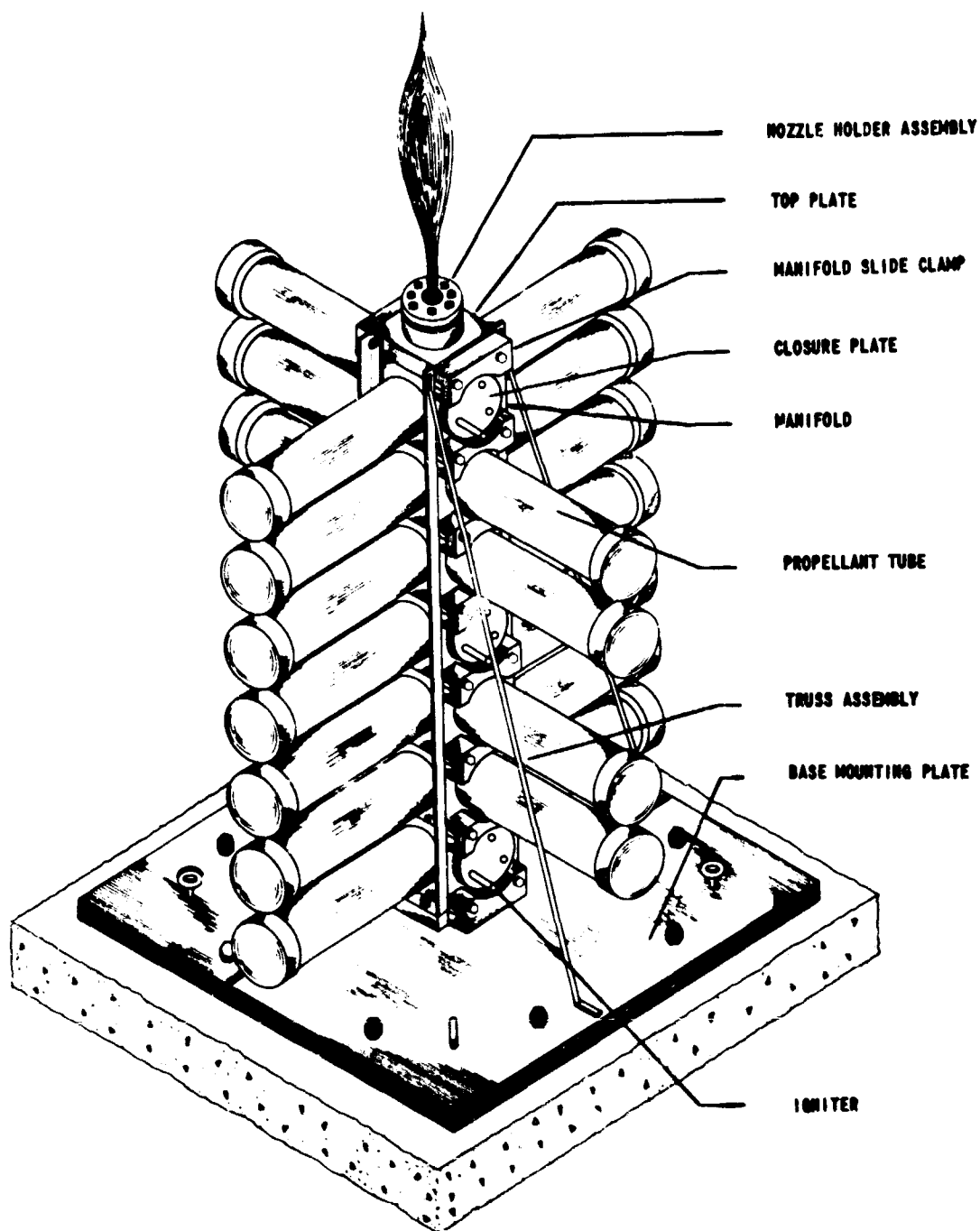
- a. chamber pressure: up to 1600 psi;
- b. burning time: up to 100 seconds;
- c. nozzle throat sizes: up to 1 inch.

Essentially, the engine consists of simple, interchangeable, reusable components which may be assembled into various configurations to produce the required operating conditions. As shown in Figure 1, it is installed to fire in a vertical position with a downward thrust towards the concrete pad. The basic engine consists of central cubic manifolds which serve as structural support elements, heat sink, and combustion chamber.

*ARTHUR D. LITTLE, INC. Variable Parameter Rocket Motor (U). DA-19-020-505-ORD-4537, WAL File No. 766.1/1, Final Report, 15 March 1960. Confidential Report.

LEVITT, A. P. The Variable Parameter Rocket Engine - A New Tool for Rocket Nozzle Materials Evaluation, U. S. Army Materials Research Agency, WAL TR 766.1/2, October 1960. Confidential Report.

WONG, A. K., and LEVITT, A. P. Rocket Nozzle Testing in a Solid Propellant Variable Parameter Rocket Engine. U. S. Army Materials Research Agency, AMRA TR 65-12, June 1965.



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Figure 1. VARIABLE PARAMETER ROCKET ENGINE ASSEMBLY

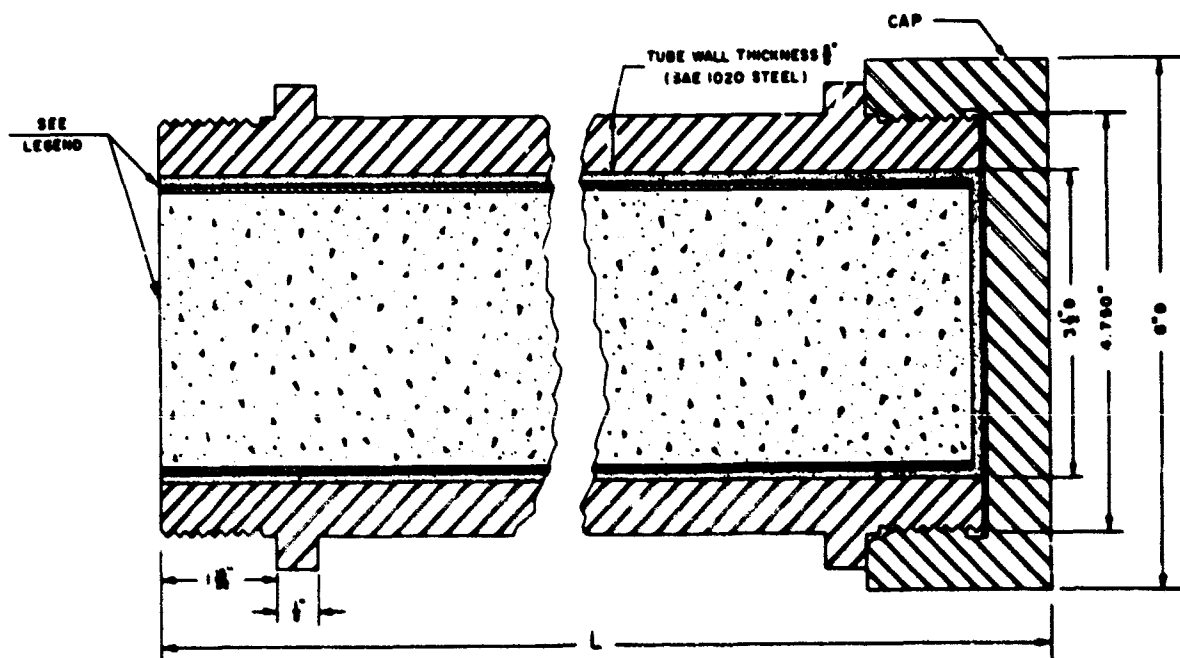
Metallic safety burst disks located in side closure plates in the manifold are used to minimize damage to the engine due to overpressure. Further, to accommodate minor transient overpressures commonly associated with the tests of nozzles of small diameters, a safety plenum chamber is sometimes utilized. This device is similar in size, shape, and installation to the reusable steel propellant tube except that it contains no propellant charge and is equipped with a precalibrated shear diaphragm.

A pressure transducer is used in conjunction with an oscilloscope and a Polaroid camera to measure and record pressure as a function of burning time. The pressure tap is located at the base of the engine.

The propellant used in this study was a nonaluminized 4700 F Thiokol polymer-ammonium perchlorate formulation procured in the form of solid cylinders approximately 3-3/8 inches in diameter and 57-1/2 inches long. These cylinders consisted of the extruded propellant grain 3-1/8 inches in diameter, surrounded by an inhibitor layer, and encased in a cardboard tube. The charge is simply cut to predetermined lengths with a hacksaw using appropriate safety precautions, and potted into the steel propellant tube with an epoxy compound. A cross section of a potted propellant charge is shown in Figure 2.

LEGEND

-  LAYER OF POTTING COMPOUND APPROX. 1/8" THICK.
-  CARDBOARD TUBE
-  INHIBITOR LAYER 1/8" THICK.
-  PROPELLANT GRAIN 3 1/8" DIA.



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Figure 2. VARIABLE PARAMETER ROCKET ENGINE - TYPICAL PROPELLANT TUBE

Ignition of the propellant is accomplished by means of squib-actuated pyrotechnic igniters, the general configuration of which is shown in Figure 3. These igniters were supplied by the manufacturer specifically for use with their propellant and are installed in the engine as the final step in the preparation of the test. One or more igniters may be required depending on the number of charges to be fired in a given test. The primer squib is electrically ignited by a hot wire and fires a hot flame jet into the combustion chamber, thereby igniting the propellant charges.

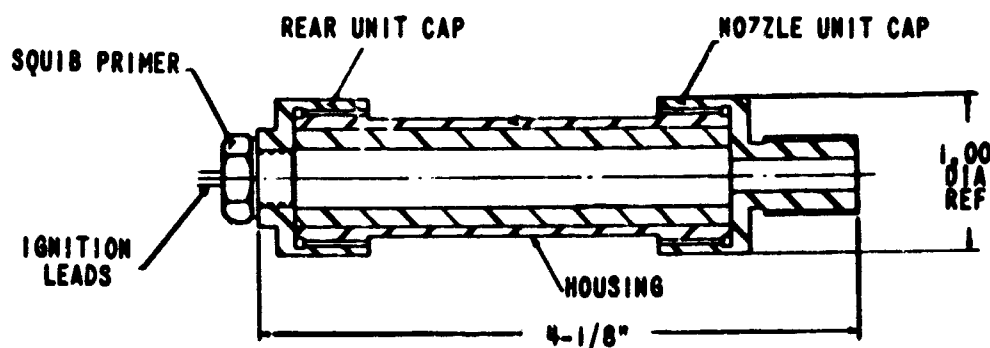


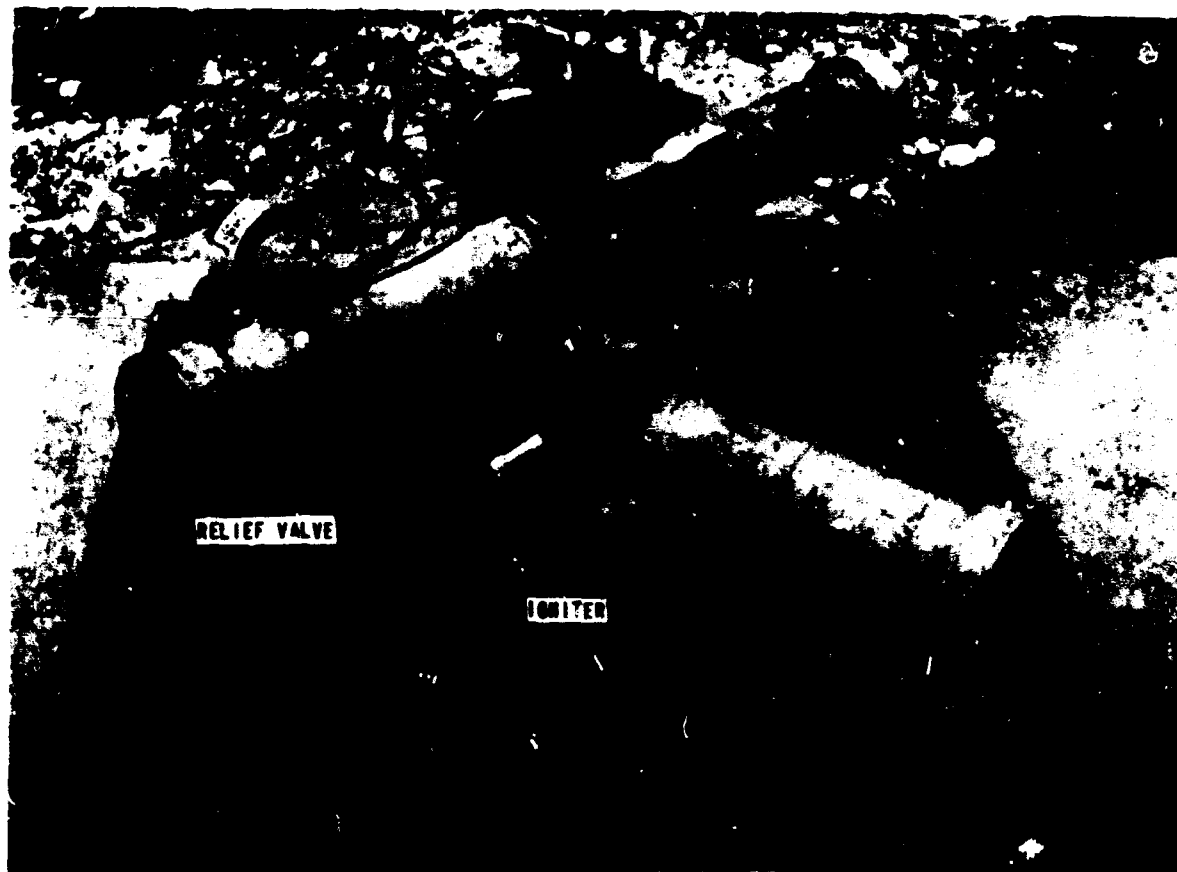
Figure 3. IGNITER ASSEMBLY

The igniter consists of an igniter-charge bonded to the wall of a cylindrical steel case. The nozzle end is threaded and screwed through a closure plate attached to the side wall of the combustion chamber. In the opposite end is a squib containing a primer charge, insulated pressure-sealed electrical connections and lead wires.

FIRING TEST

Prior to testing, the nozzles were cleaned, weighed, and measured. A nozzle was then inserted into a heavy steel holder and held in place by the nozzle retainer. The preloaded propellant tubes were screwed into the threaded side parts of the engine. Side plates were also screwed into the unused propellant tube side ports of the engine. The function of these plates was both to seal off unused openings in the manifold and to support the igniter and safety burst disk assembly. Colored motion pictures of the test and selective nozzle temperature measurements were also used as test controls.

Three static nozzle firing tests were scheduled at a chamber pressure of 730 psi for 15, 25, and 40 seconds. The nozzle inserts in these tests were graphite with a density of about 1.68. The throat diameter was 1/2 inch. Four propellant tubes and two manifolds were required for each test. The general appearance of the engine as it was assembled for all three firings is typified by the engine configuration used in the third test as shown in Figure 4. Prior to cutting and potting into the propellant tubes, the charges were radiographed to detect flaws. No defects were found. For each test, two loaded propellant tubes were assembled to each manifold directly opposite each other. At right angles to the loaded tubes, a closure plate was used to seal one threaded porthole while an igniter plate was used for the remaining porthole. The manifolds were



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Figure 4. VPRE ASSEMBLY - TEST 3

then coupled by means of side clamps and stacked two high. Silicone O-rings were used to seal off the hot gases. A total of 4 loaded propellant tubes, 2 igniters, and 2 diaphragm pressure relief valves designed to rupture at 2000 psi each were used in the first test. The second test was set up in the same manner except that only a single igniter was used. In the third and last test, a single igniter and a single pressure relief disk assembly were installed in the engine.

The assembly of the rocket engine and its many components was completely normal and unaccompanied by any major difficulties. Consequently, no firing problems were anticipated. The igniter, located in a closure plate in the lower manifold, is shown in Figure 4 immediately after installation but prior to the attachment of the electrical firing lines. Note that the igniter was positioned to fire in a direction at right angles to the lower pair of propellant tubes and not directly into the faces of the individual charges. The purpose of this was to promote uniform ignition of the burning surface areas to insure a controlled pressure rise during the pressure transient period.

Weather conditions were ideal for this series of tests. The day was fair, the sky intermittently cloudy, and the temperature 75 F. After

final inspection of the engine assembly for the first test, the electrical firing leads were attached to both igniters and the firing commenced in a normal manner. Subsequent examination of the pressure transient data indicated that the pressure following ignition rose to a maximum of approximately 630 psi in 1/2 second, leveled off on a plateau for 1-1/2 seconds, and began to decrease at the rate of about 35 psi per second. A copy of the pressure burning time trace is shown in Figure 5a. Here it may be observed that a pressure plate pulse occurred at the 14-second mark, which is attributable to the delayed activation of the second igniter. The rapid decrease in pressure after the 2-second mark is directly attributable to expulsion of the ceramic pressure seal and erosion of the igniter since this engine is of the constant burning surface area type and since examination revealed less than 1 percent increase in the throat diameter of the nozzle. The total burning time of the test was extended to approximately 28 seconds.

In view of the mishap in the first test, special precautions were taken to inspect the assemblies of the other two test engines. Furthermore, since review of the pressure-time curves indicated that one igniter was sufficient for smooth ignition, only one igniter was used in the latter tests.

Despite the care taken in the latter two tests, the same phenomena occurred. Figures 5b and 5c are copies of the pressure-burning time curves of tests No. 2 and 3 showing actual chamber pressure build-up after ignition to maximums of 710 and 870 psi, respectively, in less than one second. Pressure instability due to failure at the igniter seal was evident from a sharp decrease in chamber pressure. Subsequent post-firing examinations of the test nozzles revealed negligible throat erosion, indicating progressive failure of the igniter as the primary cause of pressure instability and regression.

Examination of the engines after each of the three tests disclosed the absence of the igniter and the presence of an erosion-ridden venthole in the side closure plate through which the hot gases issued. In the first test only one pyrotechnic igniter failed although two were installed. The appearance of the engine after the first two tests was similar. Figure 6 is a photograph taken after the second test. In both cases the engine remained intact except for the missing igniter and eroded orifice. Test No. 3 suffered a similar fate as shown by the photograph in Figure 7. Note that in all three cases the pressure relief assembly, calibrated to be activated at 2000 psi, was unharmed and remained intact. After each test, a search was made of the range area in order to recover the missing igniter.

INVESTIGATION

Recovery of the igniter used in the first test was made from an earth bank 30 feet away from the engine. After a normal test run, an igniter

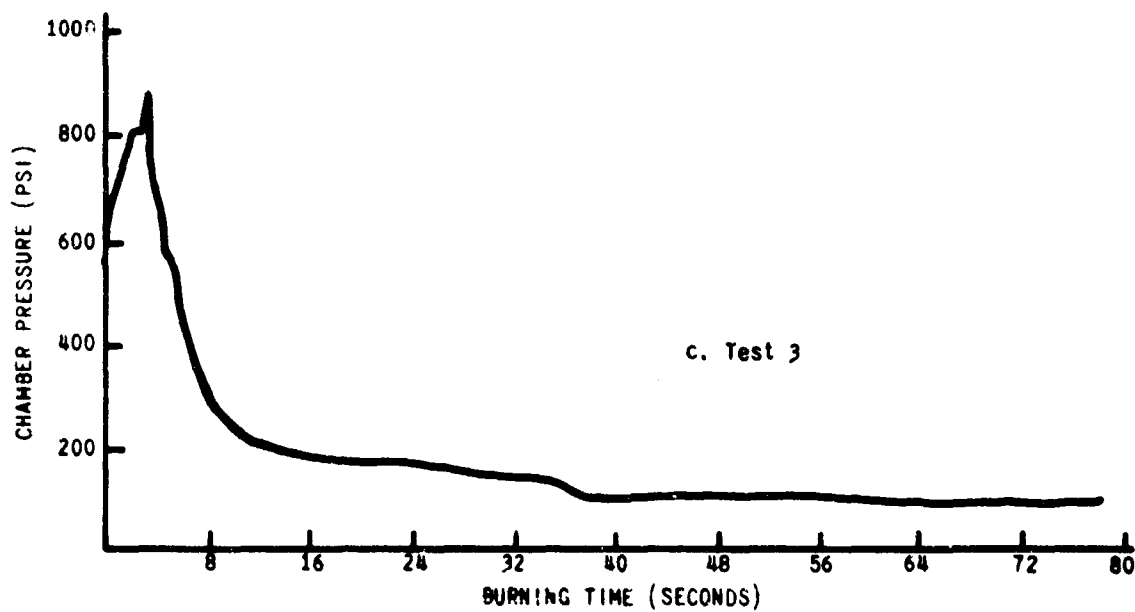
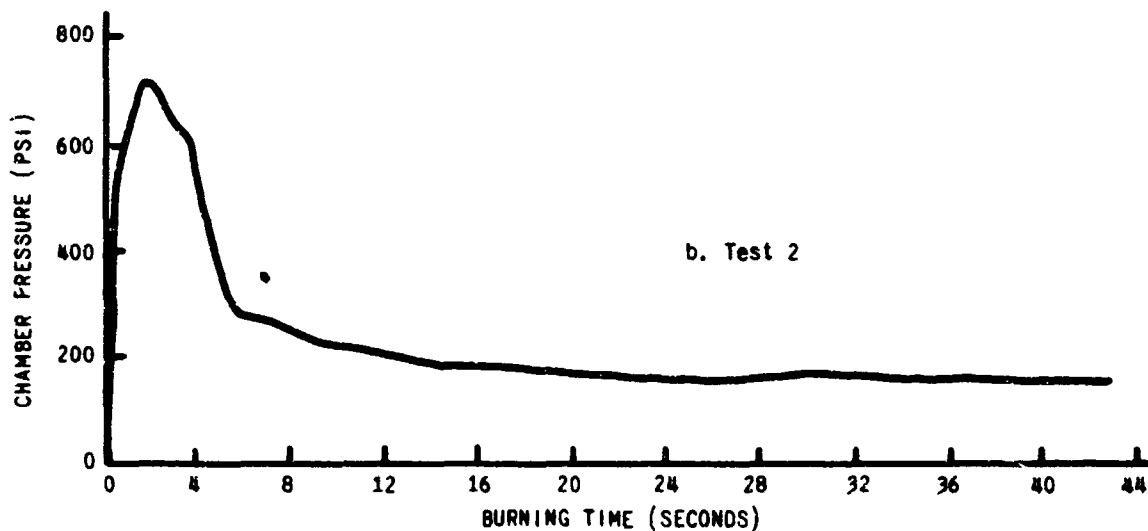
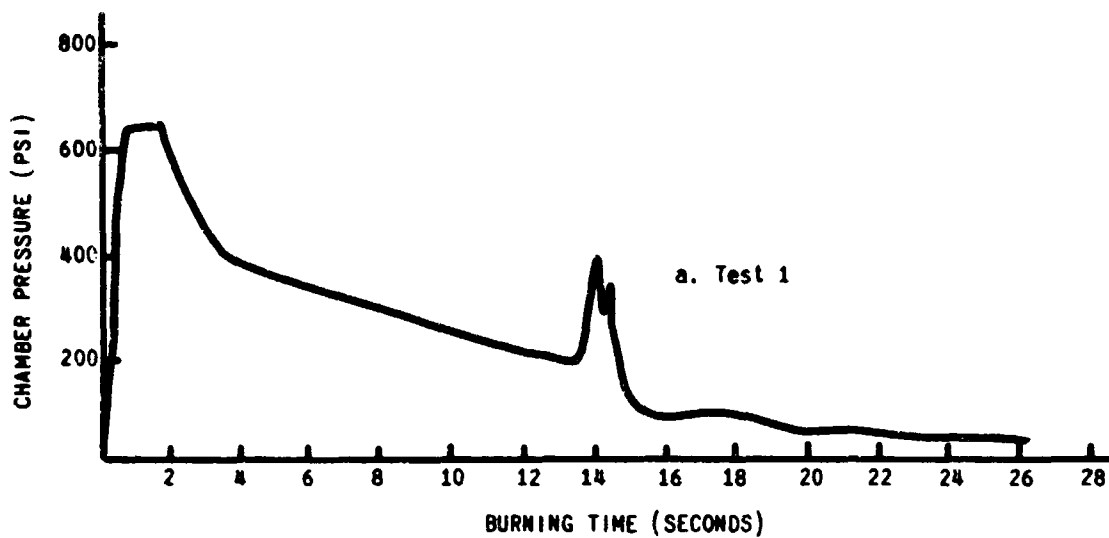
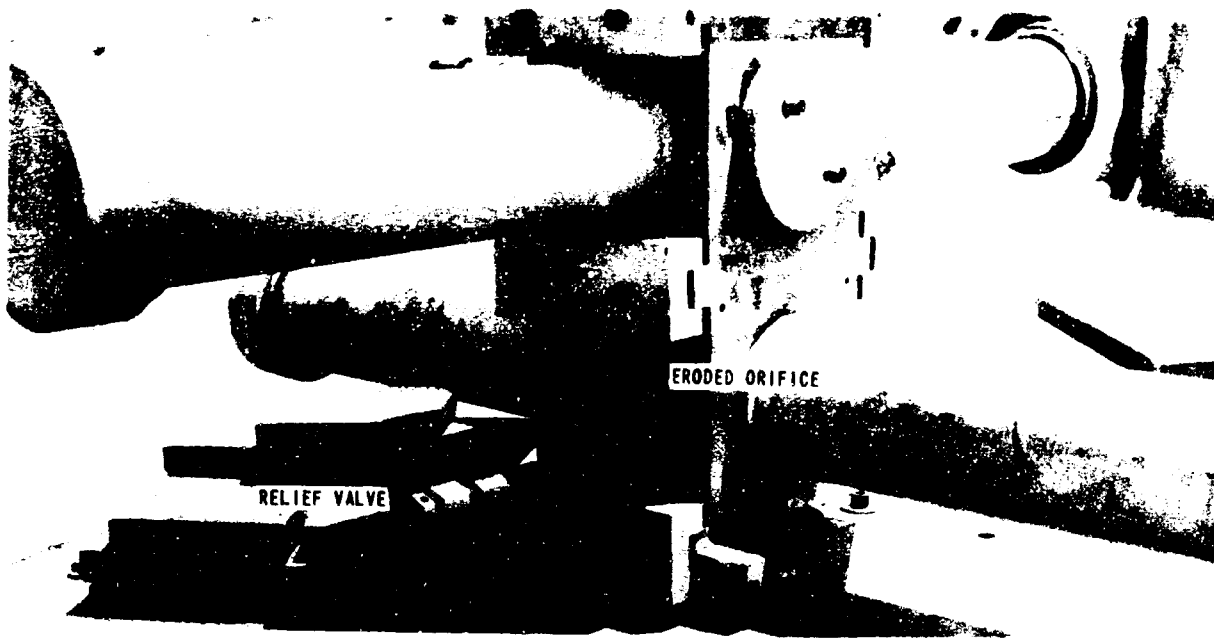
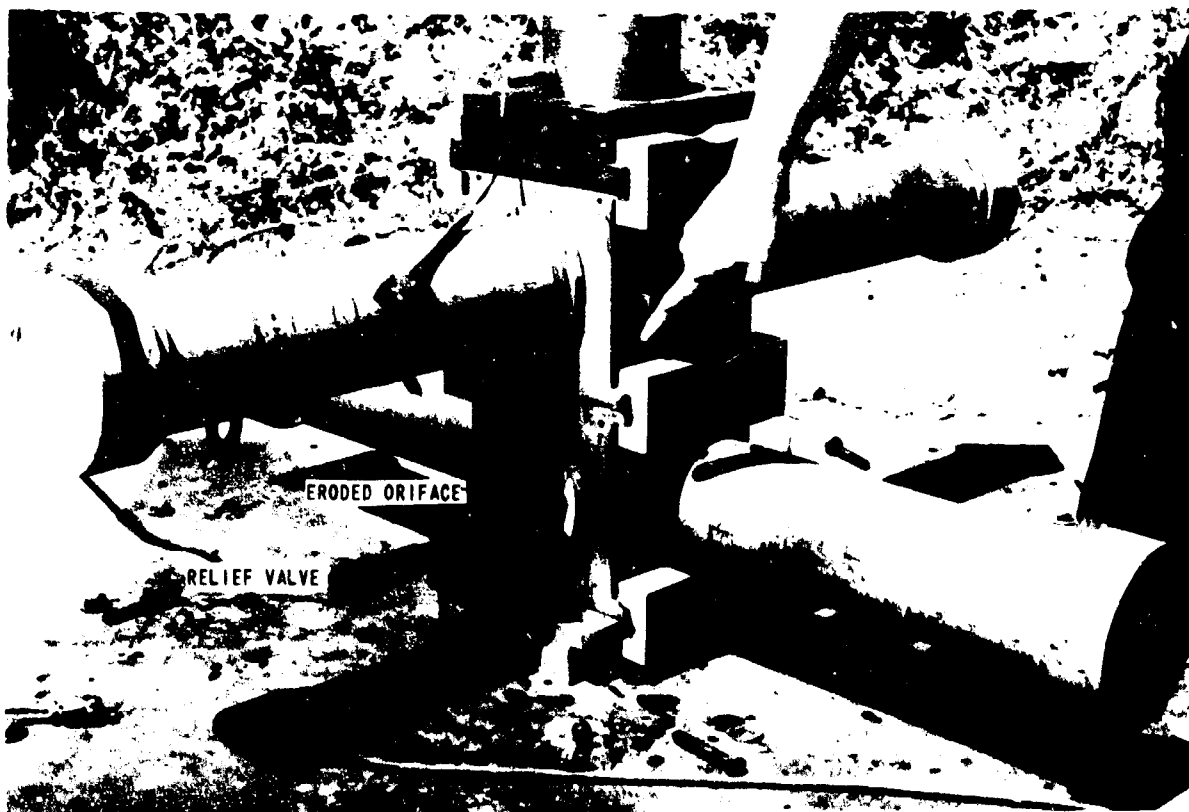


Figure 5. PRESSURE TRACINGS



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Figure 6. VPRE TEST 2, AFTER FIRING, CLOSEUP OF IGNITER MOUNTING PLATE



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Figure 7. VPRE TEST 3, IGNITER FAILURE

body can be removed intact from the engine. A satisfactory used igniter unit is shown in Figure 8. This igniter was one of the two utilized in test No. 1 and was easily removed from the side closure plate. Although the paint on the body was scorched, the steel body retained its physical

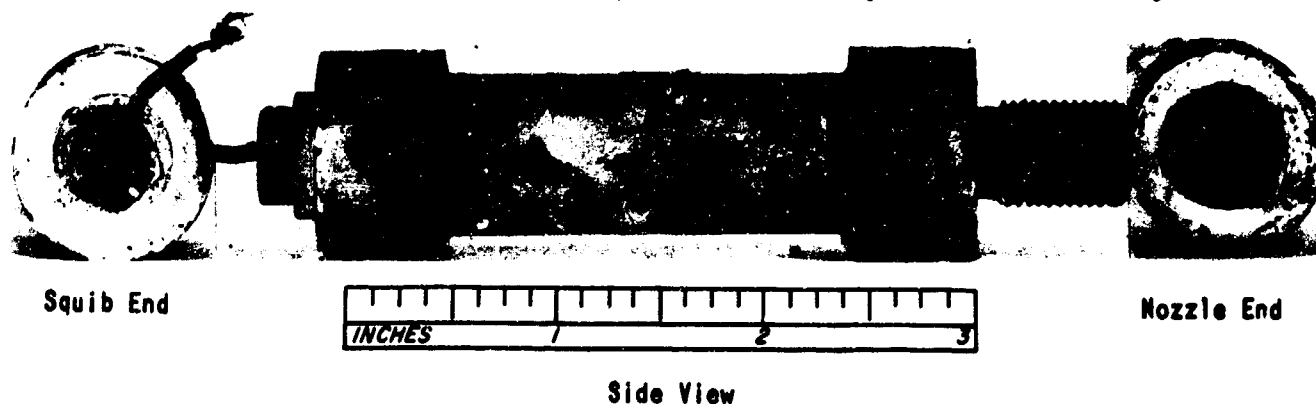


Figure 8. VPRE TEST 1, EXHAUSTED IGNITER

integrity. In contrast, the igniter body salvaged from the protective earth bank after the first test was blackened and scaled from overheating, its threaded nozzle section completely disintegrated, and its center body section almost eroded in half as shown in Figure 9. The igniters recovered from subsequent tests were similar in appearance except that the



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Figure 9. VPRE TEST 1, ERODED IGNITER

erosion progressed completely through the wall separating the squib end from the nozzle end. Figure 10 shows three views of the salvaged igniter fragments from test No. 2. Note in the view of the squib end that the ceramic seal and lead wires have been removed in entirety and the remaining orifice only slightly enlarged, while the nozzle end has become completely disintegrated. A comparison may be made of this figure with that of Figure 8 which shows the integral though exhausted pyrotechnic unit of the first test. It was speculated that in each test the igniter wires were forced out of the seal by the high pressure gases followed by the ceramic sealant itself. As the hot gases flowed out at high velocity through the squib end orifice, the center body section and the nozzle end overheated causing erosion of the center wall. This allowed an increase in the flow of gases, inducing complete erosion of the threaded nozzle section, as shown in Figure 10, and consequent ejection of the igniter body. As mentioned previously, the malfunction of the igniter contributed directly to the regression of chamber pressure and loss of test data.

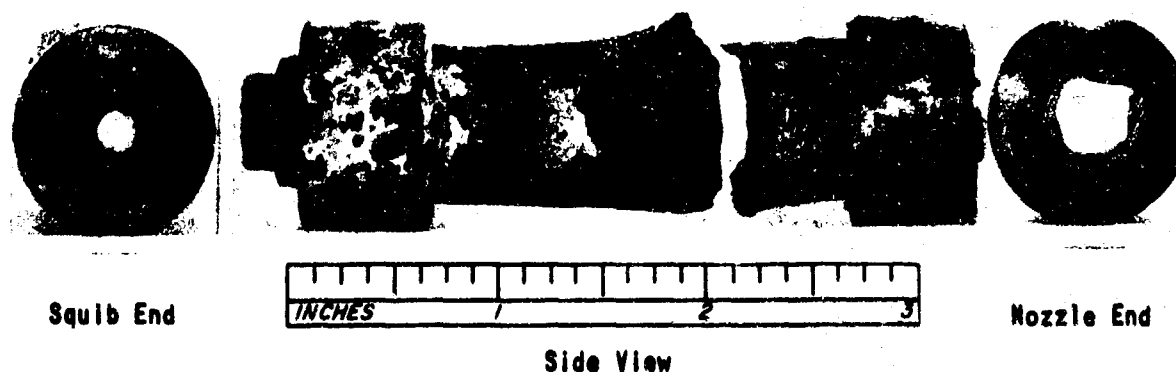


Figure 10. VPRE TEST 2. ERODED IGNITER

An investigation was initiated to determine the cause of failure. Review of 8-mm colored moving pictures taken during the tests verified that the source of failure was located at the squib end of the igniter. This phenomenon was manifested on the screen by the presence of a pinpoint red glow in the region of the intersection of the lead wire and glass seal within a second after ignition. The glow increased progressively in magnitude and was eventually replaced by hot gases issuing forth from the squib end. Concurrently, the body of the igniter also heated up to red heat and then to failure as the hot gases accelerated through its ruptured side. In due course the igniter nozzle eroded and the igniter unit was ejected from the engine while the hot gases continued to pour from the gaping orifice in the side of the engine.

The igniters used in this Variable Parameter Engine were nearly four years old and were stored in the original wooden containers. The containers were maintained in a protective propellant storage igloo. Approximately 30 units had been used previously without any difficulties whatsoever. Aging, per se, was not considered the problem although it may have been a contributing factor. Information from contractor personnel indicated that igniters of this type were standard for missile applications and have been used throughout the world under severe conditions without any known failures. In fact, the unit was designed to withstand pressures well in excess of the 600 to 800 psi pressures encountered in these tests.

Two units from the same shipment as those used in the tests were forwarded to the contractor for test inspection of both the igniter body and primer elements. One igniter was capped and static fired, achieving a chamber pressure of up to 2300 psi and a total burning time of 50 milliseconds without failure. Subsequently, the exhausted cylinder was hydrostatically tested. At a pressure of 4700 psi, leakage was observed between the threads on the housing. When a pressure of 6000 psi was achieved the test was discontinued without further incident. The shear strength of the primer unit and the structural strength of the steel housing were deemed satisfactory. A firing test in a rocket engine was set up for the evaluation of the second igniter. No failure occurred at 2100 psi during the total burning time of 1.1 seconds. In both cases, post-test examination of the squib end seal by contractor personnel revealed it to be sound and intact. Subsequent information from the contractor indicated

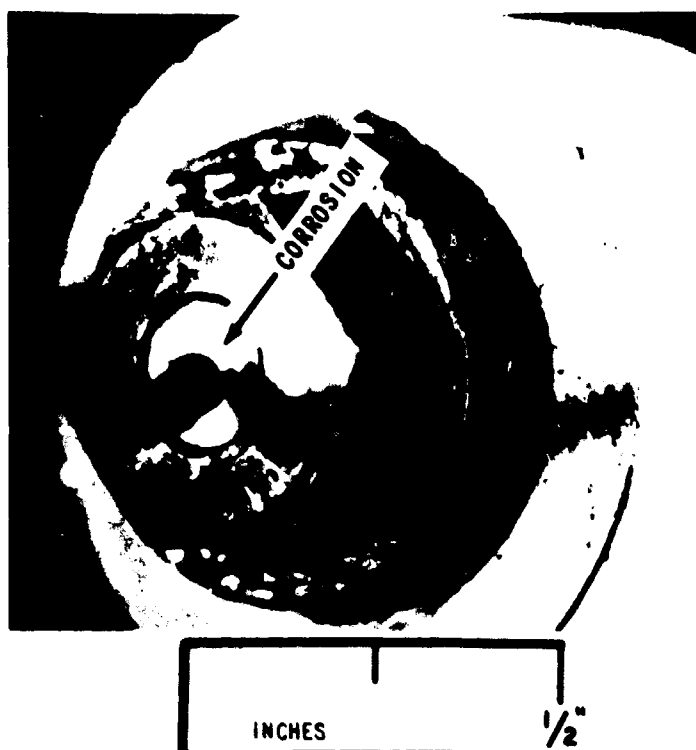
that the normal operating pressure of the igniters is about 1400 psi for an operating time of 130 milliseconds with a rise time of 25 milliseconds.

Additional AMRA tests on the igniters on hand included the firing of each of two igniters into a single manifold nozzle having a 1/2-inch throat diameter. The maximum chamber pressure generated was less than 50 psi. Again, no damage to the squib end seal or housing case was observed and the igniter behavior was satisfactory.

METALLOGRAPHIC STUDY

Other exploratory studies were also made. The remaining igniters from the same shipment were all radiographed but the results were considered to be negative since no internal flaws were detected.

Further examination, including visual inspection with a binocular microscope, disclosed a rust-colored layer on the surface of several igniter wires in the area immediately adjacent to the entrance of the wire into the ceramic seal. A representative photograph of this condition is shown by the enlarged end view of the igniter in Figure 11. The affected area is the thin dark band on the wire just below the polyvinylchloride insulation. The width of a typical band was approximately 1/32 inch and completely encircled the wire. In order to determine the extent and intensity of the attack, several exhausted squibs were sectioned, as shown in Figure 12. The



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Figure 11. PROPELLANT IGNITER, SQUIB END
DIAGONAL VIEW

wire embedded in the fused ceramic sealant was clean and shiny except in the regions of corrosion. Inspection revealed that the rust penetrated below the exterior surface of the sealant to a depth of about 1/32 inch as illustrated by the photograph. The igniter wire was removed for further study. Metallographic examination of the diametral cross section revealed a coarse grain structure as shown in Figure 13. Under higher magnification, the presence of a coating approximately 0.0002 inch was revealed. Figure 14 is a representative photomicrograph of the coated surfaces. X-ray diffraction analysis indicated the wire composition to be mainly iron possibly flash plated with an intermediate layer of copper, followed by a thin layer of tin. Inspection of the wire approaching the wire-sealant



Figure 12. CROSS-SECTION OF EXHAUSTED SQUID

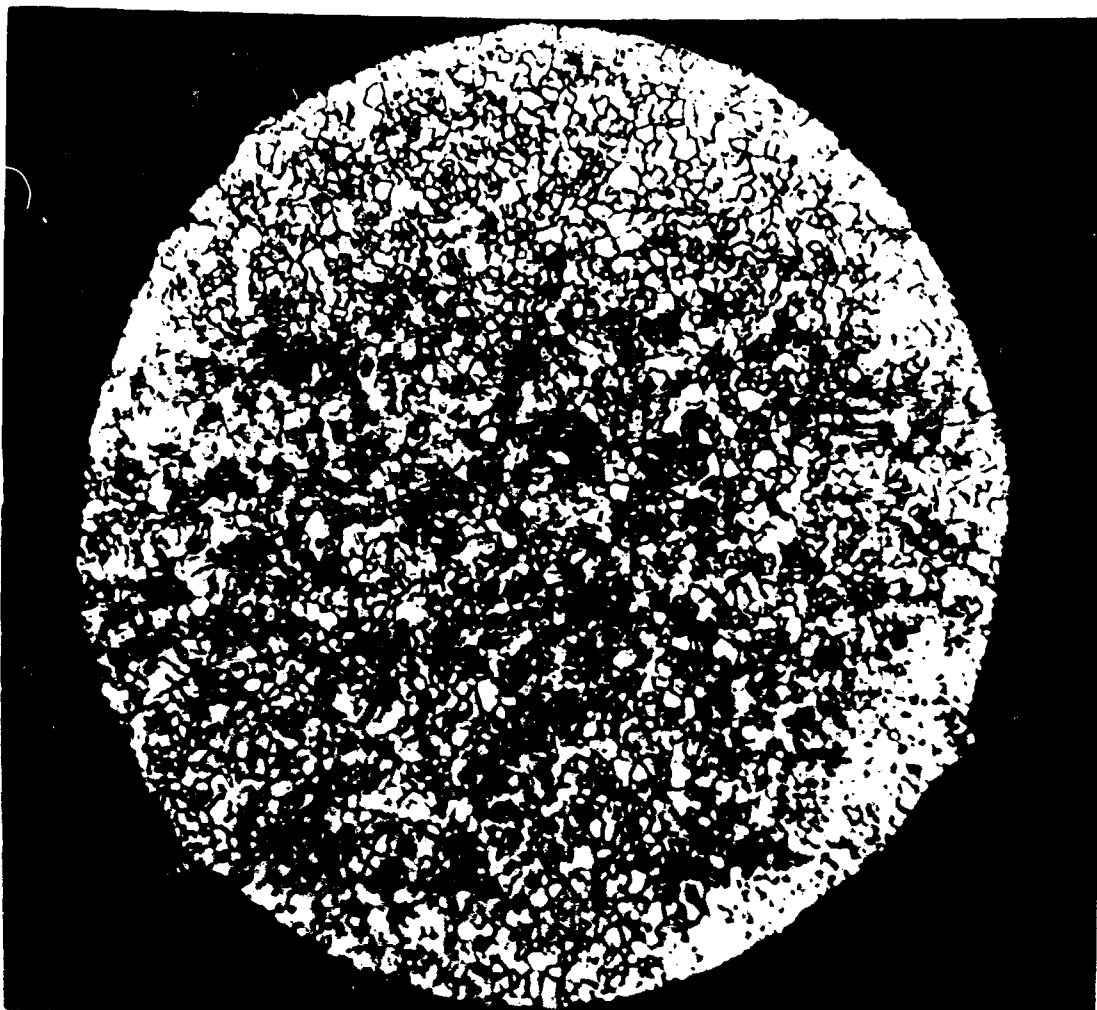


Figure 13. IGNITER WIRE - CROSS-SECTION. Mag. 150X

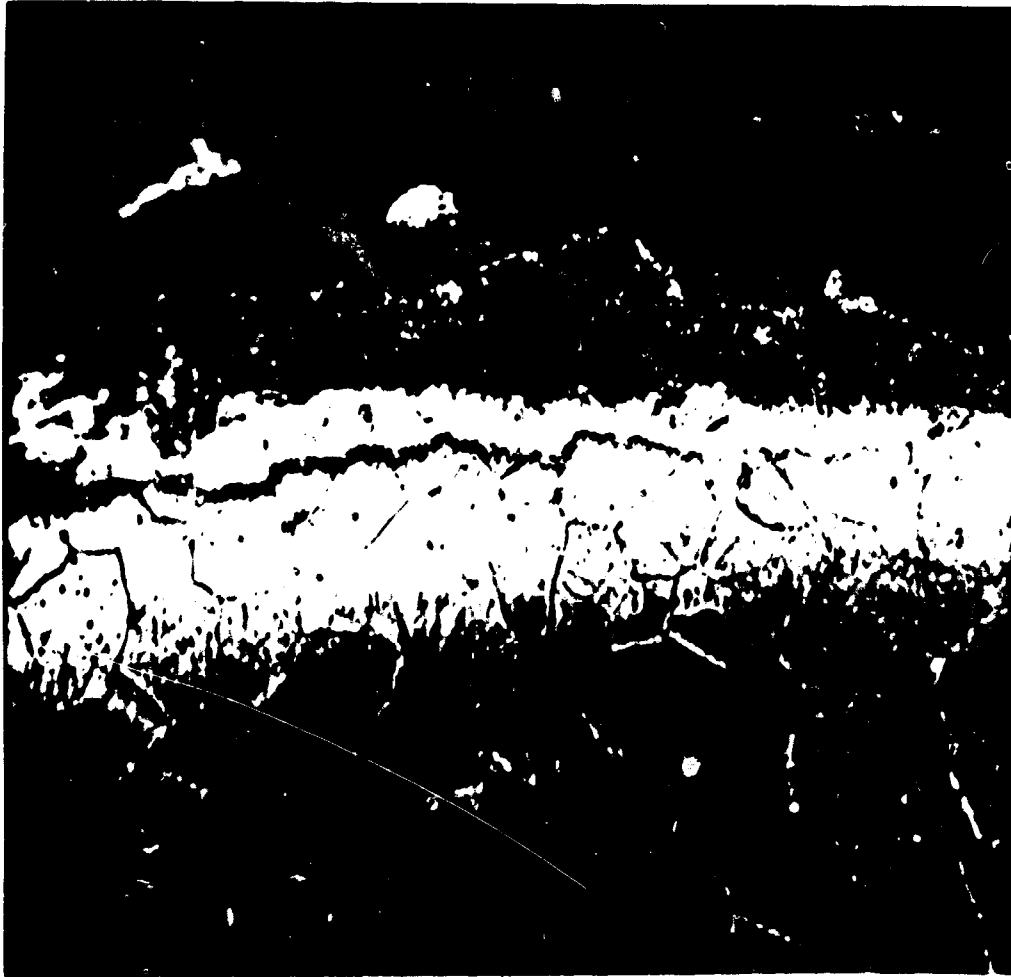


Figure 14. IGNITER WIRE - COPPER TIN COATING ON IRON WIRE. Mag. 1000X

intersection revealed a decreasing amount of coating material. The wire embedded in the sealant itself was not coated. Based on these observations, it is speculated that the assembly of the ignition wire to the squib consists of first fusing the wire into the ceramic sealant and secondly, applying a protective coating. The method utilized does not appear to provide sufficient coating to the full length of bare wire, thereby exposing vital areas to the corrupting environment. Examination of corroded areas disclosed the lack of a protective coating, as shown in Figure 15. However, the areas of greatest concentration of corrosion products on the wire were above the glassy sealant's external surface.

Although the investigation did not conclusively pinpoint the cause of failure, the microscopic and photographic studies did provide sufficient telltale evidence to mark the squib primer element as the suspect part. It was speculated that corrosion of the ignition lead wire, promoted by a combination of inadequate protection and corrosive atmosphere, initiated in an exterior area immediately adjacent to the surface of the pressure sealant and progressed into the glassy seal area to such a depth as to reduce the shear resistance between the wire and seal. Upon application

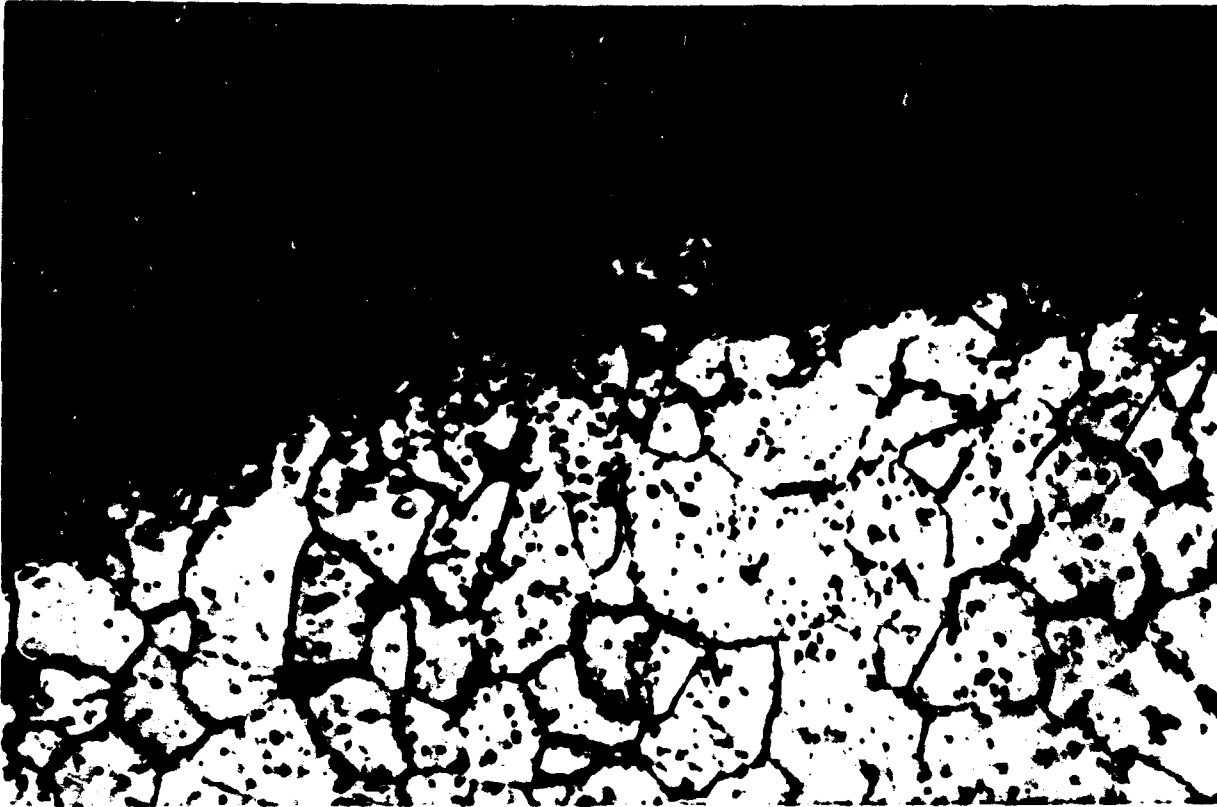


Figure 15. IGNITER WIRE - CORRODED AREA. Mag. 1000X

of pressure and heat, the wire was ejected, leaving a path for the hot gases to flow.

In lieu of further concrete evidence, the manufacturer's representative, while acknowledging no responsibility for the malfunction of the igniters, proposed to remedy the problem in the interest of improving functional reliability of the component, by replacing the primer squib element and protecting the lead wire at the junction of the pressure seal with a dab of asphalt cement. The proposal was accepted and the igniters on hand (approximately 60) were reconditioned at no cost to the government.

To check the reliability of the reconditioned igniters, three were selected at random for firing tests in a single manifold chamber with a 0.101-inch-diameter nozzle. The igniters behaved satisfactorily in all three tests, generating peak pressures varying from 190 to 200 psi and total burning times varying from 1.5 to 2.1 seconds. Over ten nozzle tests, using the reconditioned igniters, have been performed satisfactorily at chamber pressures up to 1600 psi. No further malfunctions are anticipated. However, it was recommended that manufacturing procedures in processing the squib primer element be reviewed and that missiles on stand-by basis currently using these igniters be inspected to avoid mishaps of the type experienced in the Variable Parameter Rocket Engine.

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